SOUTH DAKOTA

STATE GEOLOGICAL SURVEY

E.P. Rothrock, State Geologist

Report of Investigations

No. 28

STRUCTURAL CONDITIONS IN HARDING COUNTY

By

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November, 1937

1946 Reprint

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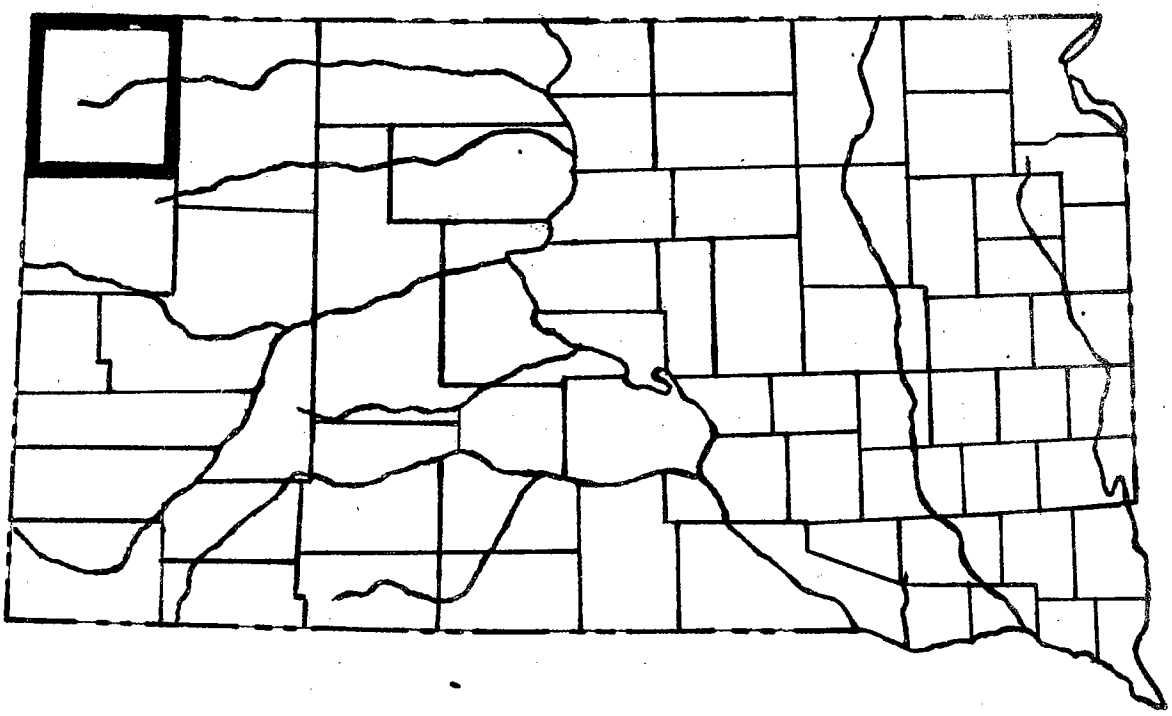
INDEX MAP



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By

E.P. Rothrock

INTRODUCTION

Due to the proximity of oil fields in Wyoming and Montana there has long been considerable interest in the possibility of finding petroleum or gas in Harding and Butte counties, South Dakota. An oil showing struck in the spring of 1936, fifteen miles north of the northwest corner of Harding county, increased this interest. In an attempt to obtain information which might encourage drilling in this state, therefore, a party from the State Geological Survey spent the summer of 1936 in Harding county. It was planned to make a reconnaissance of the entire county to disclose the main features of the geology and structure and to map the details of such areas as might give a hint as to the character of the minor folds. The short time available during the field season did not permit extensive detailing of the county, but it is hoped that the information contained herein will show its general structural features and point out areas favorable for further geologic prospecting and drilling.

The State Geologist was assisted in this survey by Dr. W.V. Searight, Associate Professor of Geology at the University of South Dakota, and much of the success in outlining the stratigraphy is the result of his careful work. The work of Garold Warner and John A. Trantina as geological assistants added much to the accuracy and speed with which the survey was carried on.

SUMMARY OF RESULTS

The bed rock of the region slopes in a northeasterly direction at a rate of about 25 to 30 feet to the mile. On this regional dip are superimposed two lines of folding trending roughly north and south. One line follows roughly the Little Missouri and the other lies in the vicinity of the northern Slim Buttes. The rocks lying at the surface belong to the Lance formation, and the survey revealed that the details of the Ludlow and Hell Creek members of this formation were more continuous than had been supposed. Certain coal zones and some sands could be

followed with much greater accuracy than previous descriptions of this formation had indicated.

Outcrops about the Black Hills and records of wells drilled in the vicinity show that about 7000 or 8000 feet of sedimentary strata underlie Harding county. Some of these carry oil in the states to the west. These data cannot guarantee the presence of oil in Harding county, but are sufficiently encouraging to warrant further prospecting.

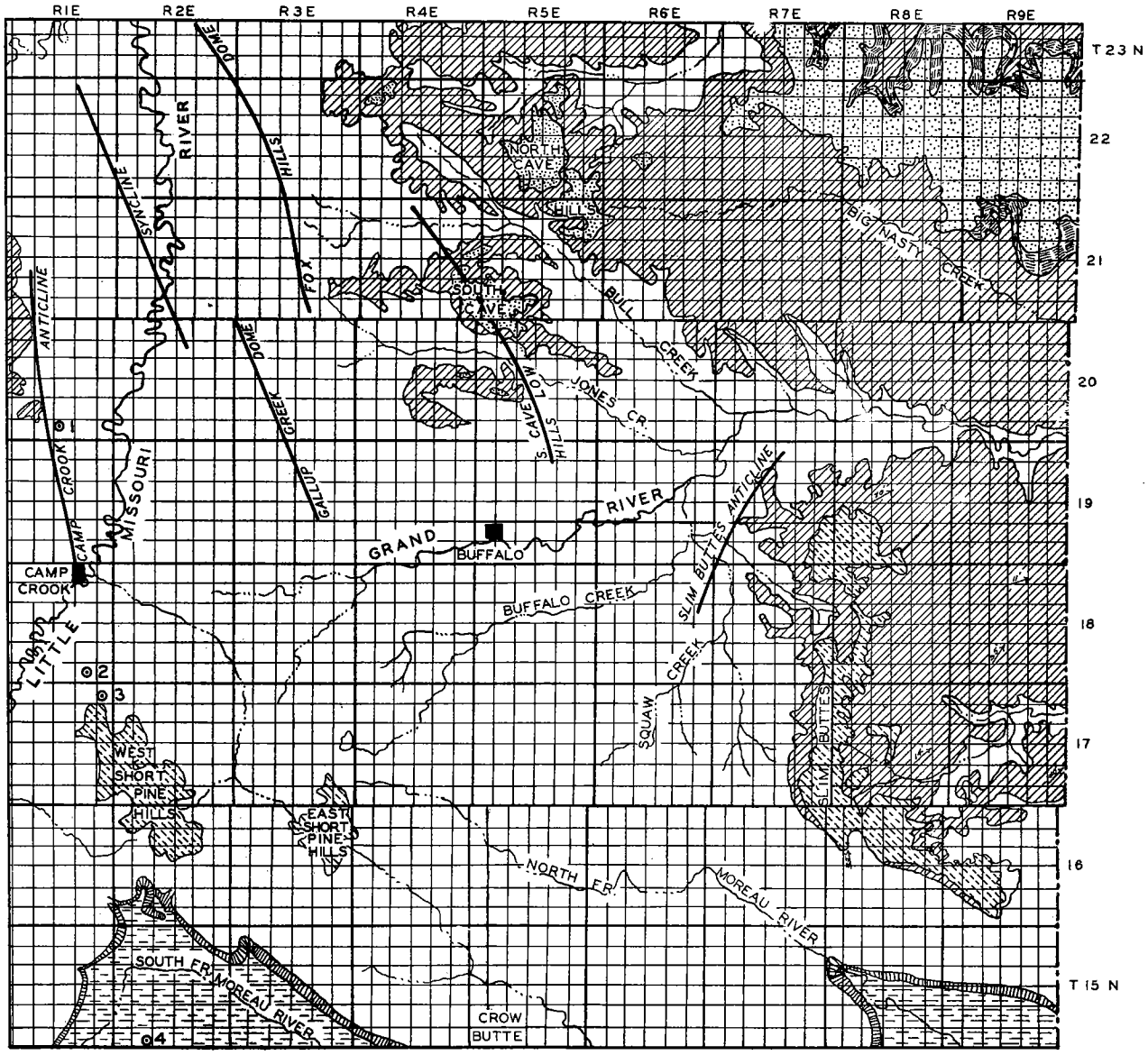
LOCATION, AREA, AND GEOGRAPHIC FACTORS

Harding county lies in the extreme northwestern corner of South Dakota. Its western side is the boundary between this state and Montana and its northern side is the boundary between this state and North Dakota. It is nearly square, having a length of 53 miles north and south and a width of 51 miles east and west. It occupies an area of approximately 2700 square miles.

Its western edge is drained by the Little Missouri which flows northward into the Yellowstone River in Montana. The rest of the county, however, is drained to the east by the Grand and Moreau Rivers which head in the divide at the eastern side of the Little Missouri valley. The tributaries of these two rivers drain fully four-fifths of the county. The main streams carry some water most of the time, although the flows are small after such dry years as those preceding 1936. Some of the larger tributaries also carry small streams which were flowing at the end of the dry summer of 1936. Clark, Fork and Bull Creeks were notable examples. Most of the streams, however, are intermittent and water for drilling will have to come from wells over most of the county. It is indeed fortunate, however, that shallow sands are everywhere available which can furnish good water in large quantities.

Transportation is easy, most of the county being served by good graded roads over which truck hauling can easily be done. A few state highways cross the county, U.S. Highway 85 giving access southward to Belle Fourche and northward to Bowman, Montana. State Highway No. 18 crosses the county east and west connecting Camp Crook and Buffalo with Mobridge and Aberdeen. No railroad crosses the county, but easy access to rail facilities of Belle Fourche and Bowman is provided by these excellent highways.

GEOLOGIC MAP
OF
HARDING COUNTY - - SOUTH DAKOTA



LEGEND

GEOLOGY

- WHITE RIVER BEDS
- FORT UNION FORMATION
- LANCE FORMATION
- LUDLOW CANNON-BALL MEMBER
- HELL CREEK MEMBER
- FOX HILLS FORMATION
- PIERRE FORMATION
- DIP IN FEET PER MILE

NOTE

GEOLOGY ADAPTED FROM U.S.G.S. BULL. 627

OIL TESTS

- ⊙1 HOLMAN NO. 1
- ⊙3 HARDING SCHOOL LAND NO. 1
- ⊙4 GOVERNMENT NO. 1
- ⊙2 STATE NO. 1

SCALE IN MILES

6 5 4 3 2 1 0 6 12

The Jump-Off, a rough region of canyons and buttes on the eastern side of the Little Missouri divide and the big buttes which are sprinkled over the county offer little hindrance to travel or haulage. The North and South Cave Hills and Table Mountain are large buttes lying in the northern end of the county which rise to heights of two or three hundred feet and are capped by thick layers of sandstone. In the southern half of the county lie the East and West Short Pine Hills and the picturesque Slim Buttes. These southern buttes are white topped due to Tertiary sediments which make the cap rock. They resemble the scenery of the White River Badlands but have the added beauty of evergreen trees to set off the whiteness of the rocks. None of these buttes are large enough to form a serious handicap to transportation. Even the largest, the Slim Buttes and South Cave Hills, offer little hindrance to travel since passes through which roads have been constructed cross them at fairly close intervals.

OUTCROPPING FORMATIONS

The formations exposed at the surface in Harding county are classified geologically as belonging to the upper part of the Cretaceous and middle part of the Tertiary systems of rock. They represent deposits made by a retreating sea and by the floods of great rivers. They include not only the mud and sand washed into the sea and piled upon its beaches, but enormous thicknesses of sands and clays, many of them gumbo, which were washed by streams and wind over great flats left after this sea retreated and piled in swamps along great tidal flats. The youngest rocks in the region, those forming the tops of the buttes are remnants of the debris left from the carving of the Rocky Mountains, which had been spread over the plains in front of the mountains far east of Harding county. The sea, the winds, and the streams have thus conspired to lay a rather bewildering array of rocks layer upon layer and from this block of rocks the present surface of Harding county has been carved.

Dark gumbo shales carrying marine fossils and overlain by yellow fluffy sand represent the ocean's direct contribution to the rock layers now exposed in the county. The great series of dark gray, somber looking sands and clays which outcrop over most of the county represent the deposits laid down by wind and streams on the recently exposed ocean bottom after the sea had withdrawn. Coal beds in these rocks tell of the existence of swamps carrying abundant vegetation and the numerous fragments of bones of dinosaurs and shells of turtles which they contain are remnants of an extensive group of land-living, air-breathing

animals which wandered over these flats. The brilliant white rocks capping the Slim Buttes and Short Pine Hills are remnants of the stream deposits which were brought from the Rocky Mountains long after the swamps and dinosaurs had gone their ways. In these white beds we find the remains of mammals, which are typical of the White River beds of the Bad Lands. These are the forerunners of many of the animals with which we are now familiar.

These deposits can be considered as great blankets of rock which lay piled one upon another each covering the entire county before the streams cut the present surface. Each blanket was characterized by certain lithological characters and a certain fauna or group of animals whose bones are still to be found in it. The following table gives the names which are ordinarily applied to the blankets or formations as they are geologically termed.

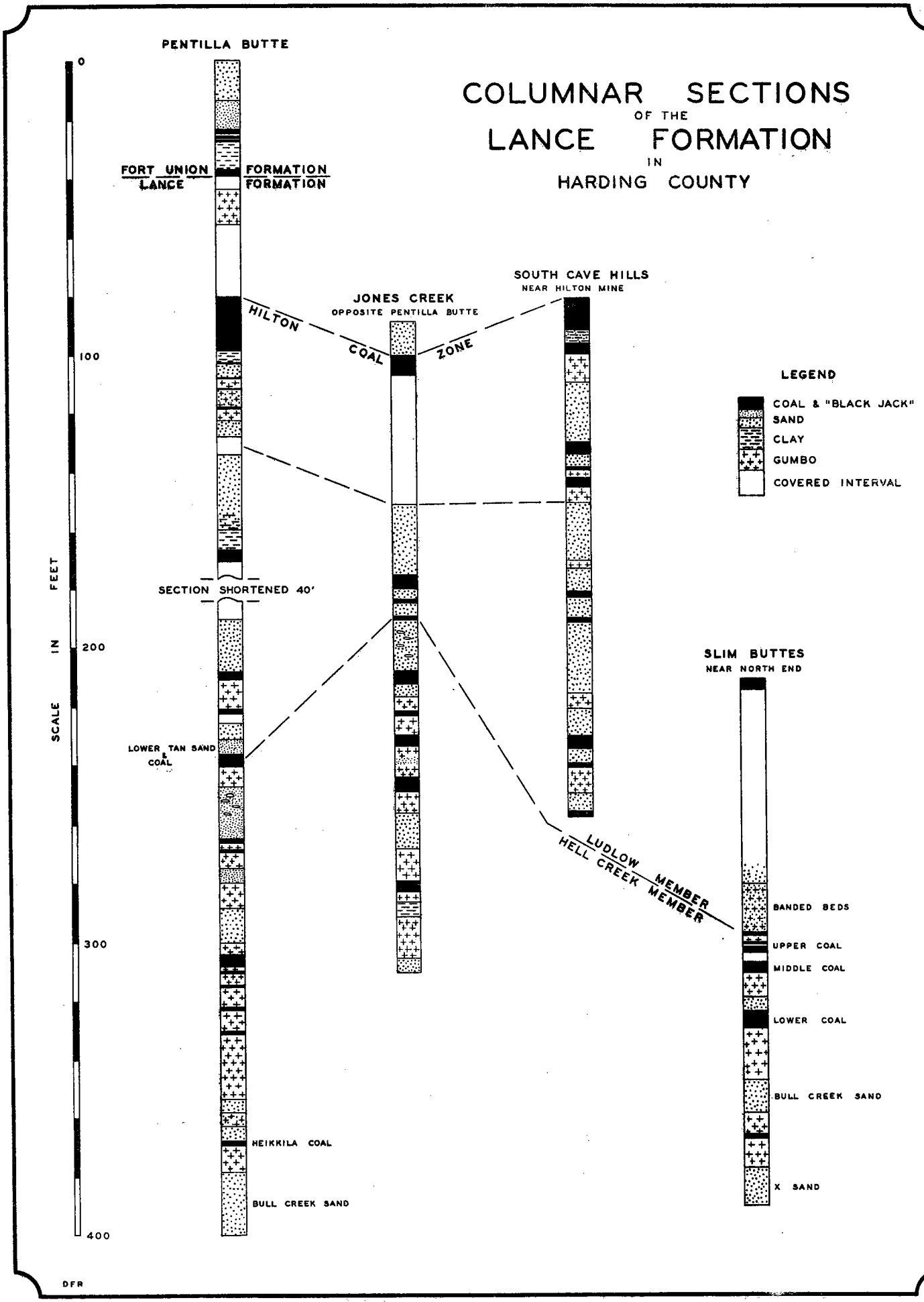

COLUMNAR SECTIONS
OF THE
LANCE FORMATION
IN
HARDING COUNTY
PENTILLA BUTTE
FORT UNION FORMATION
LANCE FORMATION
JONES CREEK
OPPOSITE PENTILLA BUTTE
SOUTH CAVE HILLS
NEAR HILTON MINE
HILTON COAL ZONE
SECTION SHORTENED 40'
LOWER TAN SAND & COAL
HEIKKILA COAL
BULL CREEK SAND
LUDLOW MEMBER
HELL CREEK MEMBER
SLIM BUTTES
NEAR NORTH END
BANDED BEDS
UPPER COAL
MIDDLE COAL
LOWER COAL
BULL CREEK SAND
X SAND
LEGEND
COAL & "BLACK JACK" SAND
CLAY
GUMBO
COVERED INTERVAL
SCALE IN FEET
0
100
200
300
400
DFR

TABLE OF FORMATIONS OUTCROPPING IN HARDING COUNTY

Origin	Age	Thickness	Formation	Members	Materials
Stream Deposits	Miocene			Arikaree	Sandstone
	Oligocene (White River Beds)		Brule Chadron		White sandstone and clay
Swamp & Coastal Plain Deposits	Eocene	30 ft.	Fort Union		Red buff sandstone
	Cretaceous	800 ft.	Lance	Ludlow	Yellow sandstone, clays and coal beds
				Hell Creek	"Somber beds" Grey gumbo-sands & clay with coal
Ocean Deposits		50 ft.	Fox Hills		Fluffy yellow sandstone
			Pierre		Dark grey to black shales

The following descriptions present the details of the formations for the benefit of those who care to investigate the stratigraphy of the county further:

THE PIERRE FORMATION

The southern boundary of Harding county lies just north of the large gumbo area in which the Pierre shale comes to the

surface. The outcrops of this formation extend northward into Harding county in two small areas. One occupies about two townships in the southwestern corner of the county while the other covers about the same area in the southeastern corner.

This is the oldest formation exposed in Harding county and is composed of a dark-colored shale which weathers to a very sticky gumbo. According to Dr. W.V. Searight, this represents the upper portion of the Pierre.[1] The fossils collected from it indicate a correlation with the Virgin Creek member of the Pierre in the Missouri valley. It is also possible that at least a portion of the underlying Mobridge member is also represented.

The section of the Pierre formation as measured by Dr. Searight is as follows:

Section of the Pierre Formation

S. line Section 29, T. 15 N., R. 2 E., ½ mile east of Gustave Road

	Feet
3. Sandstone, yellow, grey when fresh. Called and mapped Fox Hills on previous maps.....	30
2. Silt, buff, gray when fresh with 5 feet ferruginous zone at base. Ferruginous zone has rusty concretions at base. Lenses of slabby sandstone 20 and 28 feet above base.....	35
1. Gumbo clay, dark, contains Sage Creek fauna possibly 100 feet below top.....	100+

FOX HILLS FORMATION

Between the dark shales of the Pierre formation and the "somber" beds of the Hell Creek there outcrops along the south line of Harding county a thin band of light-colored sands. These have been assigned to the Fox Hills by previous workers in this region. The outcrops are usually on gentle, grass-covered slopes over which good exposures are very rare.

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1. Searight, W.V., South Dakota Geol. Survey, Report of Investigations No. 27, "The Lithological Stratigraphy of the Pierre Formation of the Missouri Valley in South Dakota," 1937, p. 35.

Along Highway 85, however, about 300 feet south of the county line and a mile south of Crow Butte, the road cuts display the following section:

Fox Hills Section

Exposed near the N.E. corner of Section 6, T. 14 N., R. 5 E., Butte County

		Feet
Hell Creek		
Fox Hills	Sandstone, very soft, yellow and even-grained (50-60 mesh). Differs from Hell Creek sand in that it lacks gumbo; is not the least bit sticky; runs through the fingers readily and is not tough when struck with a pick.....	23
	Gray clays with numerous sandy streaks.....	25
Pierre	Shales, blue and flaky.....	15

This is not a typical Fox Hills section though the sand and clay resembles that of typical Fox Hills lithologically. No fossils were collected from this outcrop, although a search for them was made. It is of interest to note that this section does not correspond to the typical Fox Hills farther eastward in South Dakota, especially at the type section at Fox Ridge, nor with the section given by Messrs. C.E. Dobbin and R.M. Larsen for the northern part of the Cedar Creek anticline between Baker and Glendive, Montana.[1] The formation in Harding county is much thinner, less than 50 feet, whereas that taken from the northern end of the Cedar Creek anticline is 148 feet. In the southern part of the Cedar Creek anticline the thickness diminished to about 100 feet which is about twice the thickness in Harding county. The prolific fauna which this formation carries from its type locality on the Fox Ridge as far west as Faith is entirely missing.

LANCE FORMATION

The Lance formation is of chief interest because it outcrops over all but a very small fraction of the county and map-

1. C.E. Dobbin and R.M. Larsen, Geologic Structure Contour Map of the northern half of the Cedar Creek anticline, Ballum Co., Montana, and Bauman Co., N. Dak., U.S. Geol. Survey, 1934.

ping structure from surface outcrops must be done by following beds in this formation. The Lance has been divided by Winchester into two members.[1] The lower member, which he calls the Hell Creek, is characterized by dark, gray colors which led early writers to designate it as the somber beds of the Lance. The upper division weathers to a yellowish color and in type sections appears much more sandy than the Hell Creek. This member he calls the Ludlow member after the old Ludlow post office which was located a mile south and a mile east of the present town of Ludlow in Harding county. The boundary between these members of the Hell Creek formation is not as sharp as might be desirable for structural purposes because so much of the identification has to depend on color and relative sandiness of the beds. Weathering produces a typical yellow color found in the type section of the Ludlow, in beds which are gray and appear like Hell Creek on first exposure. In other places yellow sand zones appear below dark, somber, gumbo zones. The use of certain coal bearing zones, however, has permitted an arbitrary line to be drawn between these two members which suffices for the purpose of this survey.

Hell Creek Member

The name "somber beds" used by earlier writers in describing these strata was well chosen, for it gives a good impression of the character of the Hell Creek beds. Dark, gray buttes rising above dark gray badlands gives an impression of color monotony which would be maddening were it not for the constant variety of topographic forms which this formation makes.

A second characteristic of these beds is the presence of gumbo. Buttes and badlands display bare slopes of sand and clays which stand nearly vertical. The material is slippery when wet, but when dry is so tough that it is with difficulty that a pick is driven into it. In a few places the sand becomes loose enough to blow during very dry times, but on most dry outcrops the pick bounces off or chips only small flakes. It is as though the sand grains were stuck together with stiff tar.

These gray gumbo sands especially serve to separate Hell Creek sands from the loose sands of the underlying Fox Hills and from the overlying yellow Ludlow and the red Fort Union beds. Those in which both the gray color and gumbo character are well developed are in the Hell Creek member of the formation.

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1. B.E. Winchester and others, "The lignite field of northwestern South Dakota," U.S. Geol. Survey, Bulletin 627, 1916, p. 14.

Bone fragments of Cretaceous reptiles are not uncommon in these beds. Their presence has led paleontologists to designate the Hell Creek as the "Ceratops beds." Both the horn-dinosaurs, triceratops, and the duck-bill dinosaur, trachydon, were noted during the reconnaissance, along with the fragments of many turtle shells.

The thickness of the Hell Creek is not easy to determine since no wells have been drilled through it and since there is no place in which both top and bottom of the member is exposed in any proximity. The difference in elevation between the top of the Fox Hills and what appears to be the base of the Ludlow on Crow Butte in the southern part of the county along Highway 85 is 312 feet. The distance between these two points is nearly a mile and therefore, the figure can be only approximate. Winchester[1] reports that 425 feet of Hell Creek was measured at the southern end of the Slim Buttes in T. 15 and 16 N., R. 8 E.

Ludlow Member

This member of the Lance is described as "interbedded, light-colored sandstones and shales of varying composition and lignite. The Ludlow member is distinguished from the underlying triceratops bearing a portion of the Lance by a generally lighter color and a greater amount of sandstone and lignite."[2]

Though a rather general statement and leaving much to be desired in the way of detail, the above is perhaps as good a statement as can be made of the general character of the member. Certain it is that there is a striking difference between the weathered outcrops of the Ludlow and those of the Hell Creek member. Near Ludlow this condition is very evident as it is a truly yellow country. The long, gentle slopes and shallow road cuts in this section all show yellow sandy beds. On the steep slopes of buttes like Table Mountain, however, where slopes and rapid erosion have made exposures on very steep cliffs, the somber gray color is evident far up into what should be yellow Ludlow beds. The lack of gumbo in these sands, however, is noticeable.

In all outcrops where weathering has had a chance to work for sufficient time, however, the light yellow or tan color be-

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1. D.E. Winchester, op. cit., p. 19.
2. Ibid., p. 20.

comes very evident. This is markedly different from the weathering of the gumbo bearing Hell Creek where top sands become a golden yellow but the dominant gray character remains unchanged.

As originally defined, an important character of the Ludlow member was the presence of lignite coal. In fact, it was originally designated as the "Ludlow-lignitic member," and in the description it was stated that "the Ludlow member is distinguished from the underlying triceratops-bearing portion of the Lance by a generally lighter color and a greater amount of sandstone and lignite."[1] Coal, therefore, is an important feature of this member.

Where most carefully studied, the coal appears as beds in dark, somber colored clay zones resembling very much the underlying Hell Creek. These zones are separated by distinct zones of light-colored sandstone. Three coal zones occur in the formation in the vicinity of Pentilla Butte and some of them can be traced over large areas. Individual coal beds are not so easily correlated because of thickening and thinning, but the persistence of these zones made possible the mapping of considerable areas and correlation across the wide valleys. Thus, while the stratigraphy is complicated in detail, certain broad and persistent features can be used as a basis for structural mapping.

A section at the Pentilla Butte and in the Badlands beneath them shows four coal zones. One at the top of the formation and separated from the overlying Fort Union by ten feet of sand was 47 feet thick and contained three thin coals. A second, separated from the upper zone by 25 feet of light yellow sandstone, was 28 feet thick and contained the thick Hilton coal seam. A third was separated from the Hilton zone by 21 feet of white or cream-colored sand. Thirty feet of this zone was exposed but the lower portion was lost in the covered slopes. Some tan-colored sands at the base of the slope marked the bottom of the yellow, sandy Ludlow member of the Lance, but below these sands lies a very persistent section of gray, gumbo beds and coal seams which mark the transition between the Hell Creek and the Ludlow. This zone was traced about the Cave Hills and into the Slim Butte region. It doubtless could have been followed further had time been available for the detailed work necessary.

Though it was not possible to obtain continuous sections of the Ludlow member at any one place it was possible to piece

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1. Winchester, op. cit., p. 20.

together sections from certain buttes and neighboring badlands at several places along Jones Creek and Bull Creek. The following successions were obtained in this manner:

Ludlow Succession on and near Pentilla Butte

Section 13 and 14, T. 20 N., R. 4 E.

	Feet
Fort Union	
Sandstone, Fort Union Cap rock, massive.....	60-70
Sand, maroon, weathering to purple cast.....	2
Sandstone, cream-colored, fine-grained.....	10
Coal, three thin coals separated by red clays....	3
Silt, red, sandy.....	10
Ludlow	
Coal.....	2
Clays, gray and sandy.....	5
Gumbo, dark gray.....	12
Sandstone.....	5
Coal.....	.15
Clay, gray.....	10
Sand, light-yellow, fine-grained, ledge maker of shelly sandstone about the middle.....	25
Hilton Coal Zone	
Coal.....	2
Clay.....	.5
Coal and blackjack, top 5 feet coal, interbedded streaks of coal and blackjack in lower 10 feet.....	15
Clay, brown, and some blackjack, limonite concretions on lower contact.....	5
Gumbo, gray.....	6.3
Blackjack.....	.1
Gumbo, dark gray.....	3
Coal.....	.1
Gumbo sand.....	2
Coal.....	.1
Gumbo, dark gray.....	3
Coal.....	.25
Clay, dark gray.....	4.3
Sand, fine-grained, buff-colored.....	6
Clays, brown.....	3
Coal.....	.2
Covered Interval.....	3
Sand, exposed at top. This is evidently the massive sand from below the Hilton zone in other sections.....	21.4

Clay, brown and shaly	5
Coal	.15
Clay, brown, showing considerable plant matter	2.3
Clay, yellow	5.3
Coal and blackjack	3
Covered interval	56
Sand, tan colored, designated as upper tan sand in mapping	20
Coal	2
Gumbo, dark gray with concretions which make white spots and whose crystals have the appearance of splintered log ends	10
Sand, tan colored medium-grained designated as lower tan sand	15
Coal	2

Hell Creek

Gumbo, dark gray	10
Sand, medium-grained, uniform, containing very large concretions; when fresh is gray but weathers to a golden yellow on exposure	21.6-42
Coal	1
Sand	.66
Coal	.5
Gumbo, dark gray	8
Sand, uniform, medium-grained, golden yellow; designated Bull Creek sand in mapping	12
Gumbo, dark gray, containing triceratops bones and limonite concretions	5
Lignite or blackjack with limonite concretions at base	3
Gumbo, dark gray	15
Coal and blackjack	1
Gumbo, dark gray	8
Lignite	.5
Gumbo, dark gray	25
Sand, yellow, gumbo sand	5
Gumbo sands alternating with gumbo	5
Gumbo sands, yellow	5
Lignite	1
Gumbo, dark gray	9
Gumbo sand, yellow, uniform medium-grained	22

The interesting parts of this section from the standpoint of this report are, first, the Hilton coal zone, which occurs

near the top of the Ludlow section, and the zone of gumbo with many coal seams just below the yellow sands which are considered the base of the Ludlow. Both of these zones are very persistent although the details change very rapidly In the section just given the sands in the upper part of the gumbo zone at the Ludlow-Hell Creek contact are very conspicuous.

At the Heikkila Coal mine six miles north of the section these sands have entirely disappeared and the following section occurs:

Section of Ludlow and Upper Hell Creek at Heikkila Coal Mine

S.W. ¼ Sec. 21, T. 21 N., R. 4 E.

Section by W.V. Searight

	Feet
Sandstone; massive cross-bedded, looses, friable; gray weathers buff, fine micaceous, lower three feet gumbolite; large sandstone concretions.....	17.1
Sand, one foot overlain by clay three to eight feet mottled with large patches of gray, yellow, brown and buff. Upper four to five feet coal and blackjack with bed of sandy clay one foot more or less thick at about the middle.....	7.9
Sands and silts, mostly sand below, with silt above. Possibly interbedded. Covered with gumbo crust. Upper four to five feet under blackjack appear mostly clay. Top three feet blackjack some coal blossom. Flattish clay, iron-stone concretions over these beds probably came from upper part.....	13.2
Sand, fine, loose, gray, covered with gumbo crust. Blossom six inches plus at the top over underclay one foot thick with very abundant rootlets.....	7.7
Sand, loose, gray, covered over with drab gumbo wash. (Not pronounced) Abundant rootlets under blackjack; 2½ feet more or less sandy blackjack with glance coal in upper part.....	7.3
Gumbo clays; lower three to four feet weathers very dark gray, upper lighter gray with buff cast; contains large gray, rough septarian concretions with very poor chopwood cone-in-cone. Calcite in septaria. Concretions to six feet across and two feet thick. One foot plus blossom at the top. Very fluffy with much brown iron powder.....	21.1
Clay, gray, weathers to medium gray gumbo. Coal one foot under 21 inches of blackjack at the top.....	3.7
Clay, drab gray, breaks down to gumbo, rootlets exceedingly abundant in upper one foot below blackjack. Upper six inches to one foot is flaky blackjack with abundant pressed plant remains.....	10

Clay and sand. Hard when fresh. Horizontally banded. Weathers light gray and buff and brown in horizontal bands with gumbo checked surface. Buff from a distance. Bed of clay iron-stone concretions two feet below the top..... 11.4

Heikkila Coal zone

Coal	1 foot, plus
Blackjack	3 to 6 inches
Limonitic Shale	3 feet, plus
Blackjack	1½ feet
Coal	1 foot, plus 8.6

Clay, silicious, light gray, very light in places, conspicuous bands on outcrops. Weathers to gumbo. Contains rootlets in places. Some semblance of bedding; really fine sand, in part at least, drab and fluffy, under light gray gumbo checked crusts. Apparently derived from sands similar to that below..... 5.5

Sandstone, fine, gray, micaceous, massive, cross-bedded. Contains spherical concretions consisting of limonitic shells filled with grey sandstone to two and one-half inches, some long and some compounds of spheres..... 27.7

The following sequence will illustrate the section in this area.

Section of Contact--Gumbo Zone. Northwest of Slim Buttes

Secs. 8 and 9, T. 19 N., R. 7 E.

		Feet
Coal.....		3
Sand and clay, sand yellow; this interval not detailed....		62
Sand; yellow-gray with shelly ledges.....		5
Lignitic shale, marks the base of the Ludlow.....		.3
Banded beds, alternating yellow sands and gray gumbo clay. Beds average one inch thick.....		15
Upper Coal zone		
Clay	2 feet	
Coal	1 foot	
Clay	2 feet	
Lignitic shale and blackjack	1 foot	
Coal	1½ feet	7.5
Sandy clay.....		5
Coal and blackjack, designated Middle Coal.....		3
Gumbo clay, dark gray; some sandy.....		9
Gumbo sand.....		5
Coal and blackjack		
Blackjack and coal	1 foot	
Clay, top is black fire clay	1½ feet	
Coal and blackjack (Lower coal)	1½-2 feet	4

	Feet
Gumbo, dark gray	20
Gumbo sand, yellow; designated Bull Creek sand in mapping	10
Coal	1
Gumbo, dark gray	7
Coal	1
Gumbo, dark gray	10
Gumbo sand, yellow; designated as sand x in mapping	15

The Ludlow member of the Lance can be measured in only a few places. Over most of the county the upper part has been eroded and where the Ludlow is typical the base is not exposed. The best sections appear to be those exposed on the slopes of the Cave Hills and neighboring buttes. At Pentilla Hill the total exposure of the Ludlow is 255 feet from the base of the Fort Union to the top of the lignite-bearing gumbo of the upper Hell Creek. This is its maximum in the detailed sections measured. Winchester, however, reports a maximum of 300-350 feet in the type locality east of the north Cave Hills.[1] His measured section at the south end of the north Cave Hills, however, shows but 175 feet of Ludlow between the Fort Union sandstone and the top of the Hell Creek. There appears to be some thinning of this member toward the north but sufficient sections were not available to give a picture of this character.

FORT UNION FORMATION

The Fort Union formation is of little importance in this investigation as it did not offer a horizon on which structural mapping could be carried on. It makes the cap-rock of the buttes in the northern part of the county, namely the north and south Cave Hills and the Table Mountain. It also covers an area of about four townships in the extreme northeastern corner of the county. Its most striking characteristic is the sandstone at its top which makes the butte caps and stands out as a sheer cliff 30 to 60 feet high. The sand is medium grained and in places is very calcareous, weathering into spongy masses and boulders which break down rapidly on weathering into a sandy talus.

Below the sand is a section of very fine sands and clays of rather striking colors: cream, lilac, chocolate, black are all used in describing these rocks. In most sections they are not visible since they are soft and easily covered by the over-

1. Winchester, op. cit., p. 20.

lying sands. A section taken on Anarchist Butte in Sec. 34, T. 22 N., R. 9 E., showed 38 feet of these highly colored beds under 88 feet of sandstone:[1]

Anarchist Butte Section

Sec. 34, T. 22 N., R. 9 E.

Section by Winchester

	Feet
Sandstone, brown, coarse, forming cap of hill	51.5
Shale, chocolate-colored, with coal smut	1
Sandstone, orange to cream-colored, fine-grained, with some limonite crusts	20
Sandstone, yellow to buff, fine-grained, with many limonite layers 4 or 5 inches in thickness; 8 feet above base is a more resistant layer which forms a shelf in many places	18
Shale, chocolate-colored, with some lignite	1.5
Clay, drab	4
Quartzite; under surface of layer rather stalactitic	1.5
Clay, lilac-colored	3
Shale, black, fissile	1
Shale, chocolate-colored, fissile	20
Lignite, weathered	1
Shale, chocolate-colored	5
Lignite, weathered	2
Shale, chocolate-colored	.5
Sandstone, yellow	
Total	130

On Pentilla Butte, 50 miles southwest of Anarchist Butte, these highly colored beds measured 23 feet.

Section east of Pentilla Butte

Sec. 14, T. 20 N., R. 4 E.

	Feet
Sandstone, buff, making cap rock of the butte. This is estimated	60-70
Sand, maroon, weathering to purplish color	1
Sandstone, light cream to buff	10
Coal interval. Three 6 inch beds of coal separated by red clay	3
Silt, red, sandy	10

1. Winchester, op. cit., p. 29.

At the south end of the south Cave Hills a heavy Fort Union cap rock is underlain by 20 feet of light gray sands and clays above a 6 inch coal seam. This probably corresponds to the lower section of the Fort Union as is described on Anarchist Buttes. No break in the sedimentation is evident between the Ludlow and the Fort Union, the distinction being made largely on the basis of color.

WHITE RIVER BEDS

The White River beds lie unconformably on the Ludlow and Fort Union in Harding county and form the white caps of the Slim Buttes and the East and West Short Pine Hills. They are also to be found in small patches on top of the Cave Hills lying on the Fort Union cap rock. Their gleaming white and gray rocks form a sharp contrast to the yellow and somber gray colors of the Lance formation which outcrops all about them. These beds correspond in age to the Oligocene beds of the White River badlands and carry a similar fauna. The sands and gumbo clays of the Chadron formation are easily recognized and above them lie the clays and sands of the Oreodon beds of the Brule formation. These beds have been described as follows:[1] "The formation in most places overlies the Ludlow and is sharply contrasted from it in color and texture as well as being separated by a distinct erosional unconformity. The average thickness in undisturbed outcrops hardly exceeds 60 feet. In these sections the formation consists of 10 to 20 feet of coarse, dazzling white sandstone with, at the base, numerous rounded feldspar crystals and pebbles up to three-fourths of an inch in diameter, overlain by three to eight feet of gray to olive green plastic clay and 20 to 40 feet of alternating gray, greenish, pinkish, and white clay, sandy clay and fine to coarse gray sand in beds from a few inches to two feet thick, all partially consolidated. At several places to the south of Reva Gap much thicker sections are exposed. In every case the beds are tilted at angles of from 6 to 30 degrees. The basal 60 feet correspond to the normal horizontal beds. The alternating clay and sand series may persist for an additional 20 to 60 feet and are overlain by massive pink nodular clays without distinct bedding planes. The maximum thickness the latter measured was nearly 60 feet in Sec. 32, T. 18 N., R. 8 E. In this outcrop a total section of about 150 feet occurs.

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1. W.C. Toepelman, South Dakota Geological and Natural History Survey, "The Possibilities of Oil in Eastern Harding County," p. 6.

"In several places, notably in the west half of T. 18 N., R. 8 E., the White River is absent and the Arikaree is in contact with the Ludlow.

"The basal sandstone and overlying green clay seem to represent the Titanothere beds; the alternating sands and clays, the Oreodon; and the upper part of the massive pink clays, the Protoceras beds of the type section along the White River. Fossils are, however, much less abundant in this region and no exact correlation can be made."

A section measured in the Slim Buttes and Short Pine Hills by Winchester[1] gave the following:

Sections of White River Beds

Slim Buttes, in Sec. 1, T. 17 N., R, 7 E.

	Feet
Clay, flesh-colored, plastic when wet.....	12
Sandstone, coarse to extremely coarse, calcareous grit; contains much quartz, many fresh feldspar crystals, some clay pebbles.....	62
Clay, sandy, banded; contains limonite concretions.....	66
	140

East Short Pine Hills, in Sec. 36, T. 17 N., R. 3 W.

	Feet
Clay, flesh-colored, calcareous; contains seams of chalcedony as much as three-fourths of an inch thick, and thick plates and irregular masses of siliceous concretions with chalcedony streaks; very plastic.....	60
Like overlying bed, but does not contain the siliceous plates.....	30
Sandstone, white, unconsolidated; coarse grit with plastic calcareous clay matrix; weathers into fluted forms.....	66
Unconformity	
	156

The unconformity at the base of the White River beds and their very limited distribution makes them useless for structural purposes.

1. Winchester, op. cit., p. 32.

ARIKAREE FORMATION

This formation is the youngest bed rock formation in Harding county and is found only on the tops of the Slim Buttes and Short Pine Hills. This very limited distribution makes it useless for the purposes of this report, but a description is given here to complete the stratigraphic picture.

The formation is composed of sands and clays sufficiently indurated to make very steep cliffs. It is impregnated with much volcanic ash which varies greatly in amount. One specimen from the Short Pine Hills carried so much ash that it was identified as a volcanic tuff by the petrographer to whom it was submitted.

The following description of the formation on the Slim Buttes is given by Toepelman:[1]

"The exact stratigraphic age of the uppermost beds in the section is open to more or less doubt. They were called the Loup Fork by Todd and referred to the Arikaree by Darton. There is, however, no faunal evidence to establish the age, the only fossils known being fragmentary water-born bones of White River species.

"Except at the base the formation is remarkably constant over the entire outcrop area. The thickness varies up to a maximum of 240 feet in the southwestern part of the region. The beds are disconformable upon the White River except in slump areas where the White River is truncated. Locally as in T. 18 N., R. 8 E., the latter is absent and the Ludlow is in direct contact with the Arikaree. The base of the latter is almost a plane and indicates a complete base level between Oligocene and Arikaree times.

"As indicated above, the basal portion is variable from place to place. In the southwestern part of T. 17 N., R. 8 E., the formation begins with 5 to 25 feet of coarse buff conglomerate made up of water-worn fragments of White River material; small pockets of almost perfectly laminated fine whitish sandstone are included in the conglomerate. In the middle of the same township (in the large butte north of Gill P.O.), no

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1. Toepelman, op. cit., p. 7.

trace of White River material is present in the 20 feet of greenish conglomeratic sandstone which marks the base. The material here consists wholly of quartz and other siliceous pellets in a coarse sand matrix. Lenses of finer soft, green, massive sandstone replace the coarser rock locally. To the north the base is less easily distinguished, except in a few places where several inches of green, gravelly sandstone occur. The separation between the Arikaree and the White River is then best made on the basis of lamination, which is absent in the latter but well developed in the former.

"The remaining thickness of the formation may be divided roughly into three parts, which are best developed again in T. 17. Immediately above the conglomerate are 80 to 90 feet of exceedingly fine-grained white to pinkish sandstone with very fine beds and laminae. The next 50 feet is more massive, gray to light green sandy shale and sandstone, with less perfect bedding and some cross-bedding on a small scale. These two divisions occur in most outcrops over the entire area covered by the Arikaree and only slight variations occur. The upper 100 feet in the thickest sections consists of predominantly gray to light green fine-grained thin bedded sandstone, with, near the top, several thin beds of almost pure white material resembling volcanic ash."

In the east Short Pine Hills the following section is described by E.M. Parks:[1]

Section of Arikaree on top East Short Pine Hills

Sec. 36, T. 17 N., R. 3 E.

	Feet
Sandstone, quartzitic, containing chloritic material; resists erosion to a marked degree; ranges in thickness from 2 to 5 feet.....	3.5
Sandstone, fine-grained, greenish white, calcareous; forms a steep cliff; weathered surface shows concretionary structure; typical specimens contain angular feldspar, biotite, quartz, epidote, calcite, and fragments of glass, together with chloritic material; called a rhyolite tuff by E.S. Larsen of the U.S. Geological Survey.....	140.0
Unconformity (?)	
	143.5

1. Winchester, op. cit., p. 35.

SUB-SURFACE FORMATIONS

The rock formations which would have to be penetrated in prospecting this county must be inferred, since few deep wells have been drilled within its borders and none of these have penetrated rocks below the Pierre formation. From measurements about the Black Hills, where the formations underlying Harding county outcrop, and from records of deep wells drilled outside the county, however, a sufficiently accurate picture of the formations can be obtained. At the northern end of the Black Hills about 40 miles south of the south boundary of Harding county the total thickness of sedimentary rocks is about 6100 feet. A deep well known as the Hunter No. 1, drilled by the Gypsy Company in Meade county about 20 miles north of Wall and 60 miles northeast of Harding county penetrated 5001 feet without reaching the bottom of the sediments. The "Marmath Well", N.P.R.R. No. 1, 15 miles north of the northeast corner of Harding county penetrated 8186 feet of sediment without reaching the pre-Cambrian. From these figures it is evident that between seven and eight hundred feet of sub-surface sediments are available for testing in Harding county. The sediments correspond, in the main, to those outcropping in the Black Hills, but as important differences occur within the formation, they will be discussed briefly here.

Pierre Formation

The Pierre formation in its outcrops and well logs averages about 1500 feet thick. There is no reason to doubt but that this thickness continues under Harding county. As it lies immediately beneath the thin Fox Hills sandstone it will be encountered within a few feet of the surface in any drilling. Its upper contact should lie between 100 and 700 feet from the surface, depending on the location in the county. It would be nearest the surface in the south and west portions of the county and farthest from it in the north and east portions. About the Black Hills it is described as "a monotonous succession of dark gray fissile, pure shale beds with many calcareous, iron-stained concretions, some of which are surrounded by a shell of cone-in-cone. In the upper portions of the formation the weathering of the concretions does not stain the shale materially, and it is almost dark gray or black. Near the bottom of the formation, however, where the shale is lighter in color, the iron stain causes a general yellowish appearance on the weathered surfaces. ...At a horizon at about 400 feet below the top of the formation there are lenses or porous, dull-gray limestone mostly from 3 to 6 feet in diameter, containing large numbers of Lucina occidentalis and other fossils. Most of these lenses project above

the general surface as steep, rounded hills which are known as 'Tepee Buttes.'"[1]

Well logs report the Pierre as a dark shale sometimes qualifying it as black, blue-black, or grey. On the outcrop most of it is sticky and is often classified as gumbo.

Two wedges of sand finger into the Pierre formation from the west in Montana. The upper one is known as the Judith River sandstone and the lower one, lying at the base of the Pierre, as the Eagle sandstone. These sands are important in eastern Montana as they produce gas in the Baker and Glendive fields. Both were present in the "Marmath" well (N.P.R.R. No. 1 in Montana) and were also reported in Harding county from a well drilled a few miles north of Camp Crook. In this last well the Judith River was reported as 990 feet and the top of the Eagle at 775 feet.

The increase in shaly material as the formation is traced eastward and the absence of these sands in the Black Hills outcrops and well logs to the east suggest that these sands pinch out either within the boundaries of Harding county or a short distance outside of it.

The Colorado Group

The Colorado Group as it is sometimes called, includes all the rocks below the Pierre and above the Dakota sandstone. In the outcrops about the Black Hills and eastward in South Dakota four separate formations are recognized in this group. As recorded by Darton[2] the Colorado includes the following formations:

Colorado Group

		Feet
Niobrara Formation	Chalk	150 to 200
Carlyle Formation	Shale, dark	600 to 800
Greenhorn Formation	Shelly limestone	25 to 35
Graneros Formation	Shale	1000
		1775 to 2035

1. N.H. Darton, U.S.G.S. Folio 164, p. 5.
2. N.H. Darton, "The Belle Fourche Folio," U.S.G.S. Folio No. 164.

In Montana the above divisions have disappeared and the Colorado group is described as "a marine shale with a thickness of 2200 feet." In wells in southeastern Montana about 2400 feet of shale can be assigned to the Colorado Group. About the middle of this interval is a zone of lime shells which probably represents the Greenhorn. No indications of the Niobrara chalk formation are reported. The Colorado Group in Harding county, therefore, should consist of the 1180 feet of shale corresponding to the Niobrara and Carlyle formations of the Black Hills and 150 feet of shale and shells which should contain the Greenhorn formation and about 1070 feet of shale representing the Graneros.

The Dakota-Kootenai Group

Under the Colorado shale lies a zone of sands which have been variously divided in different parts of the Great Plains. A classic section in the Black Hills has always recognized three divisions; the upper, called the Dakota sandstone, was assumed to be the base of the Cretaceous system and is reported as approximately 100 feet thick. Below this lies a zone of shale known as the Fuson formation, which separates the Dakota sandstone from the underlying Lakota. The Lakota and Fuson formations are usually assigned to the lower Cretaceous (Comanchean system).

In the Black Hills outcrops the upper sand, the Dakota, varies from 20 to 200 feet and usually shows a massive sandstone at the base with shelly sandstone on top.

The underlying Fuson is largely clay in most outcrops. Soft sandstones are common, however, as the following section indicates:

Section of Fuson Formation at Sturgis, South Dakota

		Feet
Sandstone, very fine-grained, soft, ash gray, some limonitic layers and nodules; bottom 0-2 feet buff and harder.....		35
Darker member		
Carbonaceous shale, some bits of coaly material.....	1 foot	
Clay, ash gray.....	2 feet	
Clay, brown, sticky; some limonitic concretions and slabs of selenite up to 3 or 4 inches across.....	14 feet	
Sandstone, ash white, shelly.....	2-3 feet	19

The Lakota formation shows from two to three separate sand members separated by shales. On the hill at Sturgis, South Dakota, the following section was exposed:

Section of Lakota Formation at Sturgis, South Dakota

		Feet
Sandstone, buff, massive, cross-bedded; occasional 2-4 inch light grey clay partings; looks like Dakota which lies above it. Makes big cliff.....		73
Shale, blue-black.....		16
Sandstone, soft, light creamy buff. 2-4 feet fine clean gravel at its base.....		28
Shale, brown, sticky, not blocky like the typical Morrison clays.....		45
Sandstone and shale zone		
Sandstone, massive, buff.....	5 feet	
Alternating beds of buff sandstone and grey flaky shale; beds about a foot thick.....	10 feet	
Sandstone, buff, massive.....	5 feet	20
		182

This group of sandy formations is continued into Montana where it is represented by the Kootenai formation. The Kootenai is described by Perryl as follows:

"Two massive gray sandstone members separated by red and green shale. Basal sandstone particularly massive, coarse-grained or conglomeratic, coarse, wide-spread and uniform." The thickness for southeastern Montana is given as 250 feet. In the "Marmarth" well a sand zone about 209 feet thick was encountered which evidently represents this Lakota group. It is evident, therefore, that about 200 feet of this sand zone may be expected in drilling in Harding county.

Morrison Sundance Group

The Jurassic system which underlies the Dakota-Lakota zone over most of the Great Plains should be encountered beneath Harding county. In the Black Hills it is represented by varigated shales containing some bright colored sandstone, lying

1. E.S. Perry, Ground Water in Eastern and Central Montana, Memoir 2, Montana Bureau of Mines and Geology, Table 1, 1931.

beneath the Lakota sandstone and assigned to the Morrison formation. These shales are underlain in turn by the white Unkpapa sandstone where it is present and where it is not, by the Sundance formation, a thick formation characterized by light sandstones, green shale zones, oyster beds and belemnites' fossils. In the northern Black Hills, exposures of these formations were measured in the vicinity of Whitewood, South Dakota.

Sections of Morrison, Unkpapa and Sundance Formations
Whitewood Hill, Whitewood, South Dakota

	Feet
Sandstone, buff, massive, base of Lakota Formation	
Morrison Formation:	
Shale, dark	4
Shale, ash gray	2
Clay, carbonaceous, nearly a coal seam	3
Sandstone, slabby, light grey to buff, some white	1.5
Shale, blue-black when fresh, weathers to a lighter grey	50
Shales, dark, with 8 massive buff limestone beds, 4 to 10 inches thick	25
Unkpapa Formation:	
Sandstone, soft, light red to creamy, occurring in patches between Rapid City and Whitewood. Not present in the Whitewood Hill section	0-100
Sundance Formation:	
Sandstone, shelly buff, with partings of dark sandy shale. Contact with Morrison marked by ½ foot flaky sandstone which changes abruptly to shales with buff limestone layers	10
Sandy shells; 4 inches limestone at top	8
Limestone, very fossiliferous	1
Shale, grey, blocky, mostly covered	15
Limestone, very fossiliferous	2
Sandstone, massive, buff	2
Limestone:	
Very fossiliferous 1.5 feet	
Shale, calcareous .5 feet	
Limestone, thin bedded, weathering into little blocks 2-3 inches across 1.5 feet	3
Sandstone, shelly with dark shale partings, top foot all shale	8.5

	Feet
Limestone, grey, dense, weathers white, no fossils	0.25
Sandstone, soft, shelly	1.75
Sandstone, buff, with shale partings, lower sand beds very thin but gradually increasing in thickness until 1.5 feet thick at top. Massive sandstone	5
Shells, sandstones, buff, shales, brown ¼ inch beds	2
Covered	2
Shales, brown, blocky, weather dirty grey	25
Sandstone, calcareous, very fine-grained and almost lamellar; breaks into thin slabs with a tough "felty" feel	2
Covered	10
Shale, poor outcrop	3
Sand, buff, soft	5
Shales, brown and dark grey	15
Covered	24
Sandstones, capped with very fossiliferous limestone	5
Covered	40
Sandstone, shelly, soft	11
Covered	11
Sandstone, buff, slabby, ripple-marked	6
Covered	48
Sandstone, buff	3
Covered, probably grey shale, basal member	3
	270

These formations are designated as the Morrison and Ellison formations. In Montana the Morrison is represented as being from 0 to 100 feet thick and composed of "varigated shales with beds of sandstone. They are present only in central and southern Montana."[1]

"Below the Morrison where it is present and below the Kootenai where the Morrison is absent, appears a series of marine Jurassic sediments 300-500 feet thick, known as the Ellison formation....the formation is composed of sandstone, shale, and limestone. The sandstones are more abundant toward the top, and dust-colored limestone toward the center."[2] Well logs in southeastern Montana indicate that the formations should underlie Harding county. The Morrison formation is, of course, proble-

1. Perry, op. cit., p. 50.
2. Ibid.

matical since it thickens and thins rather rapidly, but the Sundance formation seems to be quite continuous and should be 500 or 600 feet in thickness.

The Red Beds

Red beds belonging to the Permian and Triassic systems outcrop in the Black Hills and have a wide distribution over the Great Plains. In the Black Hills a thickness of some 900 feet is exposed; the section consists of the Permian Opeche red beds, about 100 feet thick, above which lies the dense Minnekahta limestone, 60 feet in thickness, and above this, 700 to 800 feet of red beds belonging to the Triassic Spearfish formation. This last formation is composed of red beds which correspond to the Chugwater red bed series of Montana and Wyoming.

All deep wells in western South Dakota have encountered red beds at the proper horizon. In deep wells in southeastern Montana a thickness of 1050 feet is reported. In these wells the interval is composed of red shales and sandstone with interbedded anhydrite and salt. Two thin limestones are reported, one near the top and one near the bottom of the red bed series but the information that is at present available is not sufficient to state definitely whether either of these could be correlated with the Minnekahta limestone of the Black Hills. It is possible that some of the red sands at the top of the series in these wells may belong to the Sundance formation since the lower sands of this formation in some places have a considerable thickness of red color.

Whatever the age of these beds they will be very useful to the driller in correlation. It is impossible to penetrate this zone without noticing the unmistakable color.

From the thicknesses in southeastern Montana and those in the northern Black Hills it is probable that 1500 feet of red beds may be encountered beneath Harding county.

The Pennsylvanian System

In the Black Hills and Wyoming the red beds are underlain by Pennsylvanian rocks which have given shows of oil. These rocks all belong to the Minnelusa formation in the Black Hills. In Wyoming they have been separated into two formations, the Ten Sleep and Amsden. The system apparently thins out northward and disappears somewhere in central Montana. In southern

Montana it is present and known as the Quadrant formation. From this distribution it is evident that these rocks will be encountered in drilling in Harding county and should be tested as they contain important reservoir rocks in which petroleum could accumulate.

In the northern Black Hills the upper portion of the Minnelusa formation consists of massive sandstone which occupies one-half of the total thickness. Beneath this lie alternating sandstone, shales, and limestone in beds 3 to 10 feet thick. The percentage of limestone increases towards the base and is marked in most places by a 25 foot bed of red shale. A typical northern Black Hills section is recorded by Darton in the Central Black Hills Folio:[1]

Section of Minnelusa Formation
Bear Butte Creek near Sturgis, South Dakota

	Feet
Local cherty bed	5-6
Sandstone, white, sugary, with quartz layers and veinlets; becomes more yellowish or coffee-colored, calcareous, and cross-bedded in the lower portion	188
Limestone, purplish, shaly; some soft massive beds	30
Sandstone, purplish, calcareous; fine-grained and white at base	27
Sandstone, alternating beds of yellow, salmon, purple and red; in some places cross-bedded and ripple-marked; partly calcareous and shaly	45
Limestone, grey, light purple, and drab, very fine-grained; calcite druses	5
Sandstone, fine, yellow-gray above, massive and purplish below	11
Limestone, pink, brown, and grey, rather gritty at top and bottom	22
Sandstone, fine, salmon-colored; cross-bedded and calcareous	4
Limestone bands, pink, purple, yellow, and brown, some spotted; shaly and hackly; rectangular joints	31
Sandstone, massive, salmon-colored, calcareous	10
Limestone, purple and brown	1.5
Sandstone, white; weathers red on surface	37

1. N.H. Darton, U.S.G.S. Folio 219, The Central Black Hills, p. 8.

	Feet
Shale, red, with thin limestone layers, rests on Pahasapa limestone.....	25 +
	450

The Quadrant formation in southern Montana is described by Perry.[1] "The Quadrant is composed of from 500 to 1000 feet of interbedded shales and sandstones with some limestones. Certain of the sandstones are quite porous and even friable (crumbly), and they make excellent water carriers."

In wells drilled in southeastern Montana the section is somewhat similar to that of the Black Hills, about 600-650 feet of rock can be assigned to the Pennsylvanian system. At the top lies about 100 feet of sandstone probably corresponding to the Ten Sleep of Wyoming and the top of the Minnelusa in the Black Hills. The lower part is described as interbedded dolomite and limestone with red and varigated shales. Anhydrite is reported in the lower part of the section, apparently in considerable abundance.

Anhydrite also appears as a prominent constituent of the Pennsylvanian formations encountered in the Hunter No. 1 well north of Wall, 50 miles southeast of Harding county. In this well 350 feet of alternating shales, sandstones and limestones with interbedded anhydrite were assigned to the formation. The heavy sandstone at the top is represented by only 20 feet of tight sand.

From this information it is reasonable to expect the Pennsylvanian system beneath Harding county to be about 500 or 600 feet thick with 50 to 100 feet of sand, probably water bearing, at the top of the section. Beneath this 450 to 500 feet should be a section of alternating sands, shales and thin limestones with anhydrite and possibly salt beds. The sands may make water trouble for the drillers since the general eastward slope of the formation should generate an artesian head.

The Massive Limestones

At the base of all sedimentary sections in this part of the Great Plains, there lies a great thickness of massive limestones. Most of these are Mississippian in age, though in many

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1. Perry, op. cit., p. 52.

outcrops thin Ordovician, Devonian, and Cambrian limestones appear. This holds true not only for the outcropping sections in Montana and Wyoming but also in the Black Hills and in all deep wells drilled in South Dakota, west of the Missouri River. A similar section, therefore, may be expected in drilling Harding county.

In the northern Black Hills these limestones are divided into the following formations:

System	Formation	Description	Depth
Mississippian	Pahasapa	Massive, light gray to dove-colored limestone	600 feet
	Englewood	Purple, very fossiliferous limestone	60 feet
Ordovician	Whitewood	Buff, massive, fossiliferous limestone	80-100 feet
		Total	740 feet

In eastern and central Montana the limestone series is reported as about 3000 feet thick and divided into the following formations:[1]

System	Formation	Description	Depth
Mississippian	Madison	Massive, grey or white crystalline limestone; shaly and sandy at base	1000 to 1500 feet
Devonian and Cambrian	Jefferson Gallatin Flathead	Mainly massive limestone, quartzite at base	2000 feet

Deep wells in Montana near Harding county report 900 feet of limestone without reaching the bottom of the section. Interbedded with these limes are some anhydrite beds and a number of shows of oil and gas have been reported. The Hunter No. 1 well, near Wall, South Dakota, showed 190 feet of massive limestone. It is probable, therefore, that between 800 and 1000 feet of limestone will be encountered in this position in Harding county.

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1. Perry, op. cit., Table 1.

Cambrian Formations

The lowest sedimentary rocks which may be encountered in this part of the Great Plains are sandy formations which lie on top of what drillers call "the granite." In the Black Hills this part of the section is represented by the Deadwood formation, a series of quartzitic sandstones and shales about 400 to 500 feet thick in the northern part of these mountains. This formation consists of upper and lower sandstone members which together make the bulk of the thickness. Between these sandstones is a zone of green shales and limestones. The Deadwood formation is also found in the Bighorn Mountains in Montana where it is very similar to the Deadwood of the Black Hills. In central and southern Montana a quartzite occupies a similar stratigraphic position and may be correlated with the Deadwood. These formations are not encouraging as oil reservoirs but will offer the last chance of finding this fuel if they occur beneath Harding county since they lie directly on the gneisses, schists, and granites of pre-Cambrian group of rocks. These last are known to the driller as "the granite" and offer no chance whatsoever of finding oil or gas.

STRUCTURE

The stresses which folded the Black Hills formed two major structures in western South Dakota, the Black Hills uplift and the Lemmon syncline. The Black Hills uplift included not only the mountains but a long fold trending northwestward through Wyoming which dies out in a series of low anticlines in southeastern Montana. A short distance east of these folds the orogeny was carried farther northward by a long, narrow anticline which extends from Harding county northwestward to Glendive, Montana. Its southern end lies en echelon with the northern end of the Black Hills folds. This large anticline has been called the Cedar Creek anticline by Calvert.[1] The important gas fields near Baker, Montana occur in it. The Cedar Creek anticline dies out in the extreme northwestern corner of Harding county along the Little Missouri River in a series of folds which have been described by the U.S. Geological Survey and are shown on the accompanying map.

East of the Black Hills and Cedar Creek fold lies a great trough which occupies nearly all of western South Dakota between the Black Hills uplift and the Missouri River. Its axis plunges

1. W.R. Calvert, U.S. Geological Survey, Bulletin 471, p. 201.

northwestward passing through the city of Philip in Haakon county and the city of Lemmon in Perkins county,[1] and into North Dakota. For this reason it has been called the Lemmon syncline or Lemmon Basin.[2] This trough determines the regional dip of the area here considered since it lies high on the western flank of the great syncline. The minor details of the structure were superimposed on the regional structure by variations in the stresses attendant upon the general movement.

Regional Dip

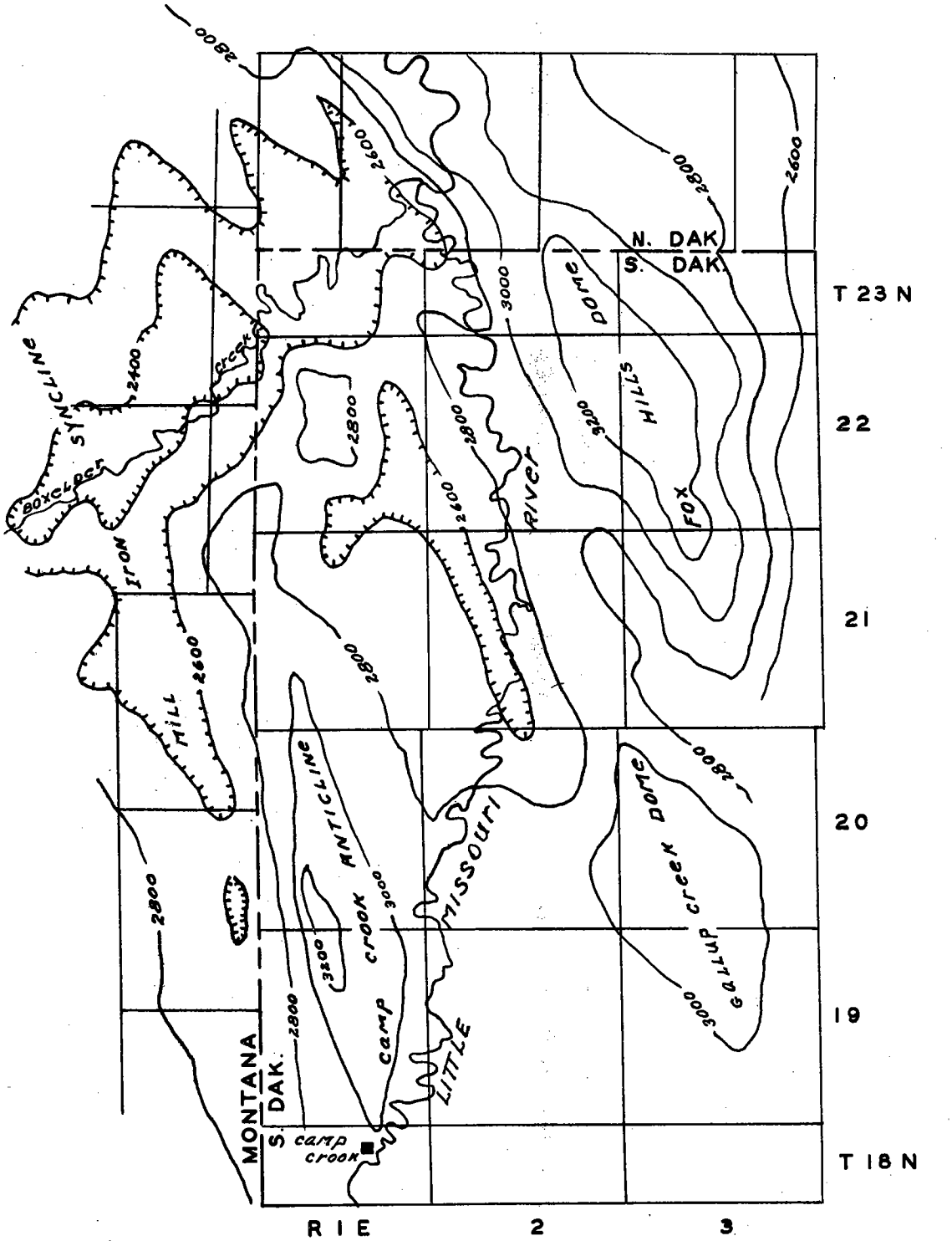
The regional dip of this area is toward the northeast. Elevations taken on the base of the Ludlow at Crow Butte in the southern end of the county, near Buffalo, at the Jump Off near the Little Missouri, and in the Slim Buttes gives a general dip which is almost directly northeast and averages between 30 and 40 feet per mile. North of Buffalo the dip turns farther east until it is mapped by Winchester as going directly east in the northern part of the county.[3] There is a difference in elevation of nearly 400 feet between the base of the Ludlow on Lizzy's Butte, southwest of the Cave Hills, and at the north end of the Slim Butte 30 miles directly east. There is an average dip of 25 feet a mile in the country east of the Slim Buttes,[4] and as high as 65 feet to the mile are reported by Winchester and Toepelman.

Little Missouri Folds

In the Little Missouri valley folds have been superimposed on this northeast dip which were of sufficient prominence to map in at least two locations. One set consisting of three large folds which appeared to be the end of the Cedar Creek anticline has been mapped by the U.S. Geological Survey.[5] These three elongated domes lie near the Little Missouri, the Camp Crook anticline being the southernmost. It lies immediately west of the Little Missouri River; its southern end is in the vicinity

1. E.P. Rothrock and W.R. Robinson, S. Dak. Geological Survey, Report of Investigations No. 26, Structure map.
2. Winchester, op. cit., p. 36.
3. Ibid., p. 37.
4. W.C. Toepelman, S. Dak. Geological and Natural History Survey, Circular 12, p. 9.
5. G.F. Moulton and N.W. Bass, U.S.G.S. Memorandum for the Press, "Oil and Gas Prospects in the Cedar Anticline and Vicinity, in Montana, N. Dak., and S. Dak.," Jan. 11, 1922.

STRUCTURES NEAR THE LITTLE MISSOURI RIVER



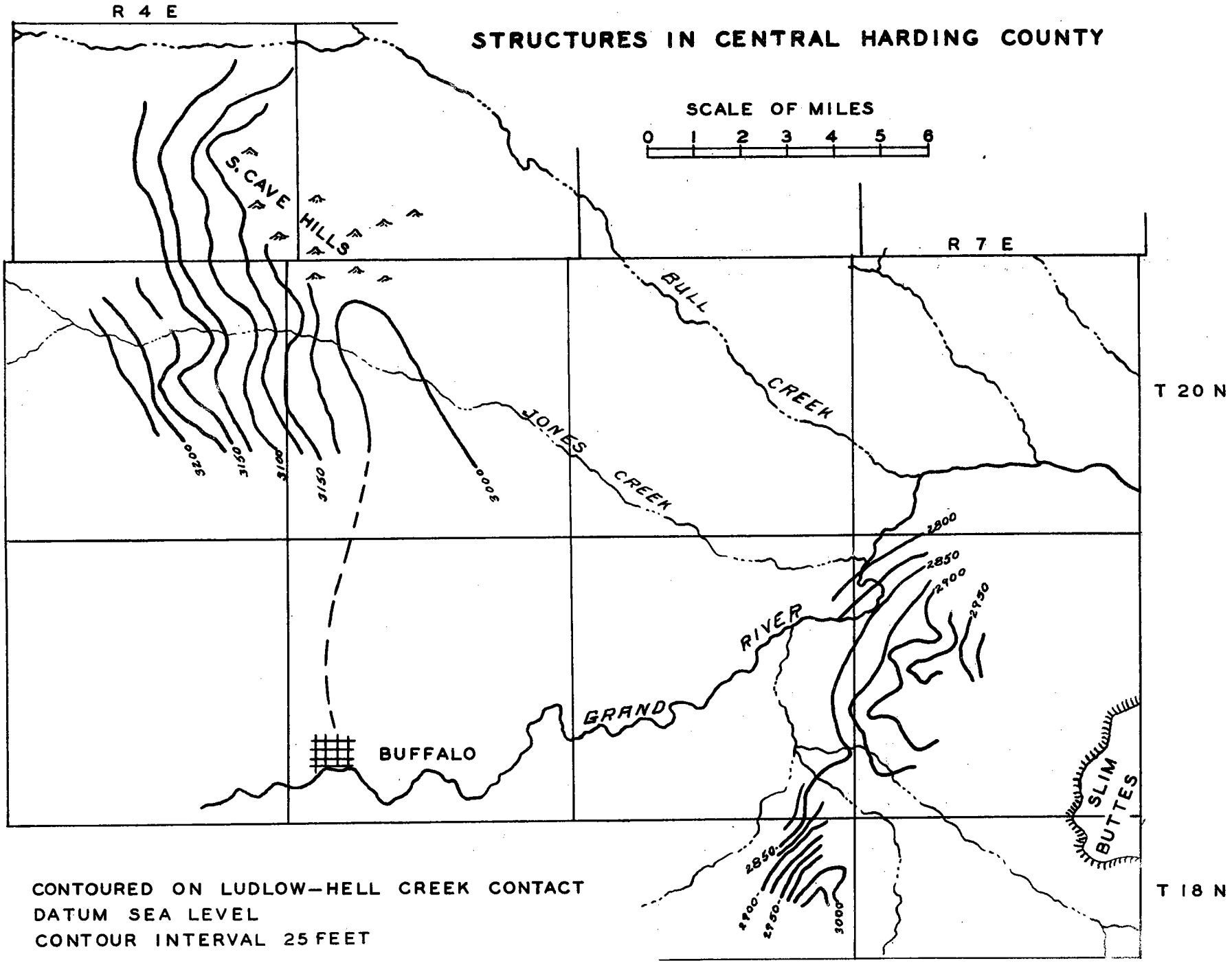
FROM U.S. GEOLOGICAL SURVEY PRESS NOTICE 3762

CONTOURS ON TOP OF PIERRE FORMATION
DATUM SEA LEVEL
CONTOUR INTERVAL 200'

DEPRESSION CONTOURS

SCALE OF MILES

0 6 12


STRUCTURES IN CENTRAL HARDING COUNTY
SCALE OF MILES
0 1 2 3 4 5 6
R 4 E
R 7 E
T 20 N
T 18 N
S. CAVE HILLS
BULL CREEK
JONES CREEK
RIVER
GRAND
BUFFALO
SLIM BUTTES
3200
3150
3100
3050
3000
2800
2850
2900
2950
3000
CONTOURED ON LUDLOW—HELL CREEK CONTACT
DATUM SEA LEVEL
CONTOUR INTERVAL 25 FEET

of Camp Crook from which place it extends northward for 14 or 15 miles. Its highest point is 6 miles north of Camp Crook about which a closure of 200 feet has been mapped.

East of the Cedar Creek anticline is the crest of a low dome which the U.S. Geological Survey designated as the Gallup Creek dome. As mapped it is about 10 miles long and 5 miles wide. Its southern end lies in the wide valley of the Grand River where outcrops were not available. It appears to have a closure of 100 feet or more.

The largest of these folds is the terminal fold of the Cedar Creek anticline proper. It has been designated the Fox Hills dome and lies west of the Little Missouri River extending from the state line about 20 degrees east of south for a distance of about 14 miles. The slope has been mapped on the east, south and west sides. The least closure is on the north, along the crest of the anticline and is indicated as 100-200 feet.

The Slim Buttes Fold

A second line of folds lies immediately west of the Slim Buttes, where a series of low folds of smaller magnitude appear, trending almost due north and south. Westward dips varying up to one and one-half degrees were followed from the Antelope preserve northward past the bend of the Grand River. It was not possible to map the structures on this line of folding in detail, but the reverse (west) dips were mapped for a distance of 12 miles and indicated a series of small low folds or domes along the larger flexure. Clark Fork and the north flowing section of the Grand River appear to lie in the bottom of the syncline west of the flexure. The Grand River cuts across it just below its junction with Bull Creek. It was not possible to carry detailed mapping across the Grand River but reverse dips of about the same magnitude as those south of the river are plainly visible. North of the valley it is probable, therefore, that the folding could be followed for some distance northward.

OIL AND GAS POSSIBILITIES

Harding county is still wildcat territory. Two wells have been drilled as oil tests, but only reached the basal sand of the Pierre formation and gave no indication of oil or gas. The fact that the formations which carry gas at Baker, Montana and oil in the Marmarth well, 16 miles north of our state line are

known to underlie Harding county makes the structures in this county interesting prospects. There is no way to ascertain whether oil pools lie in this county, however, without test drilling in the most probable locations. Such locations so far as now known would be along the tops of the structures which have been described above. These will have to be the only guides until further exploration shall extend them into regions which this investigation could not map in detail.

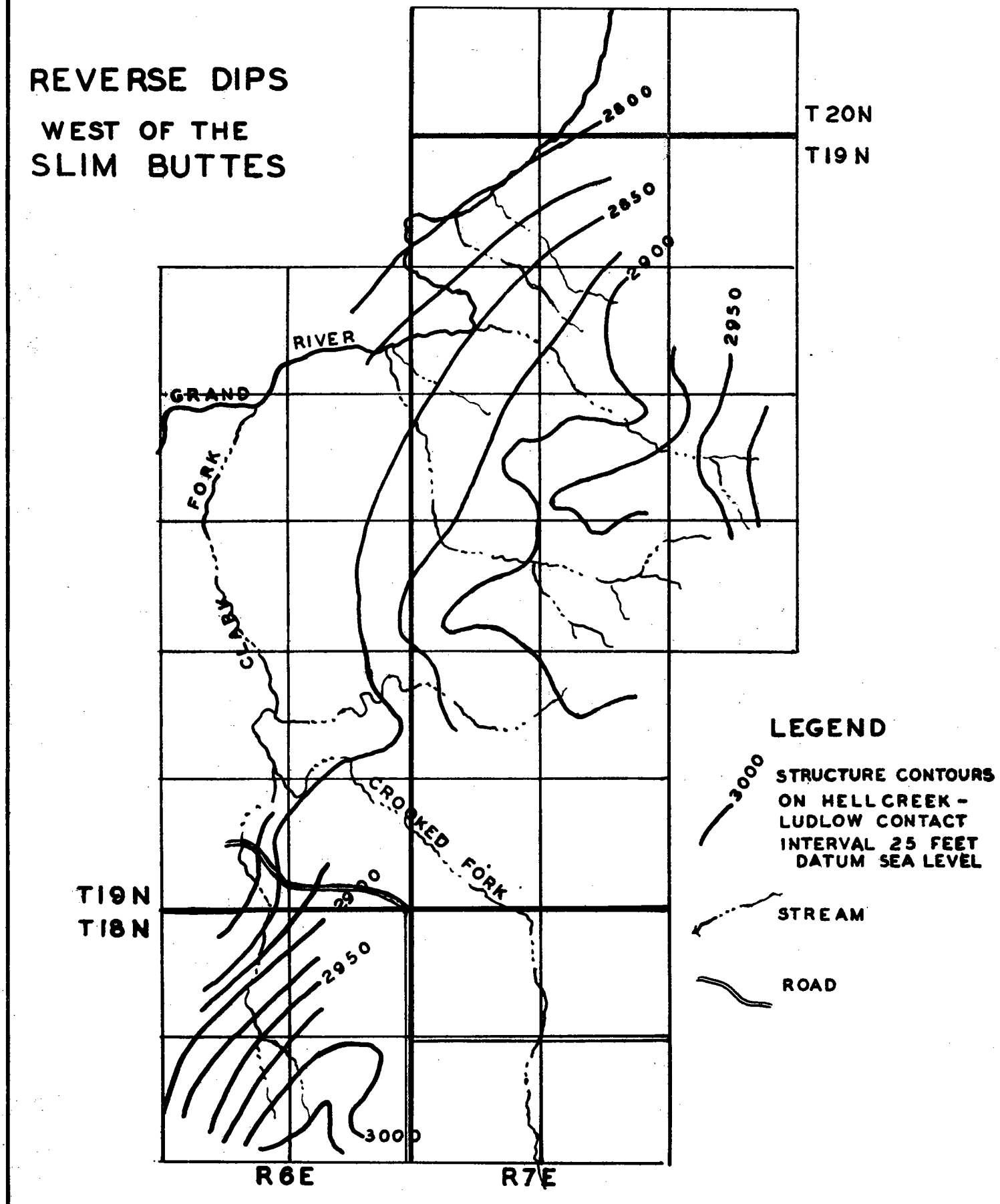
The shallow horizons do not appear to be favorable from the little drilling that has been done. The Dakota and Lakota sandstones are full of water but have given shows of gas and oil elsewhere. The Graneros and Carlyle sands (Big Muddy and Wall Creek sands) which produce in Wyoming near the Black Hills are either absent or dry. The prospector, therefore, will have to hunt for oil in the deeper sands of the Pennsylvanian and in the limes of the Mississippian system.

The Marmarth well reported a considerable thickness of near shore and lagoon deposits in the Pennsylvanian sections which do not appear in outcrops of the same system about the Black Hills. A section of similar deposits was also reported in the well drilled 20 miles north of Wall, South Dakota, by the Gypsy Oil Company. It is possible, therefore, that the same lagoon conditions obtaining in the Pennsylvanian system in these two wells, continues across Harding county. This has been considered by some oil operators as a favorable indication.

Tests to the Dakota group of sandstones would have to be drilled to depths of about 3500 feet. The possibilities of the Sundance and associated sands would be tested at about 3800 feet. The sands of the Pennsylvanian probably would be encountered at about 5500 feet and seem to offer the best possibilities from the information now available. Limestones of the Mississippian underlying the Pennsylvanian shore deposits probably offer the last chance for production in this region as the older Paleozoic systems are either thin or lacking in all available outcrops in this portion of the Great Plains.

WATER

Water is not a serious problem in Harding county. The larger rivers carry water much of the time and shallow wells can produce water at most places in the county. Even in the driest part of the summer of 1936, water was flowing in the Grand River,


REVERSE DIPS
WEST OF THE
SLIM BUTTES
T 20N
T 19 N
T19N
T18N
R6E
R7E
2800
2850
2900
2950
3000
RIVER
GRAND
FORK
CLARK
CROOKED FORK
LEGEND
3000
STRUCTURE CONTOURS
ON HELL CREEK -
LUDLOW CONTACT
INTERVAL 25 FEET
DATUM SEA LEVEL
STREAM
ROAD

Clark Fork and the Little Missouri. The sandy Ludlow member of the Lance gives water which carries a higher percentage of the salts than the underlying Hell Creek. In fact, it is possible to separate the two by the alkaline taste of water from Ludlow wells. The underlying Hell Creek furnishes an excellent quality of very fresh water, which, so far as known, contains no objectionable solid either for drinking or for use in boilers. In the southern half of the county, the Hell Creek area, 200 to 400 feet of this member will furnish water sands at various horizons. In the northern half of the county the Ludlow member is largely sandy. The Ludlow sands will furnish water to depths of 200 feet, which with the underlying Hell Creek offers about 600 to 800 feet of water sands immediately below the surface.

The thin sand formation known as the Fox Hills, immediately below the Hell Creek member of the Lance, gives an excellent quality of water. It is not known just how extensive this sand is but it is assumed to underlie the entire county.

Below the sands just mentioned lie several thousand feet of impervious shale which would not furnish water for drilling purposes.

ERRATA

Geologic map legend should read:

Oil Tests

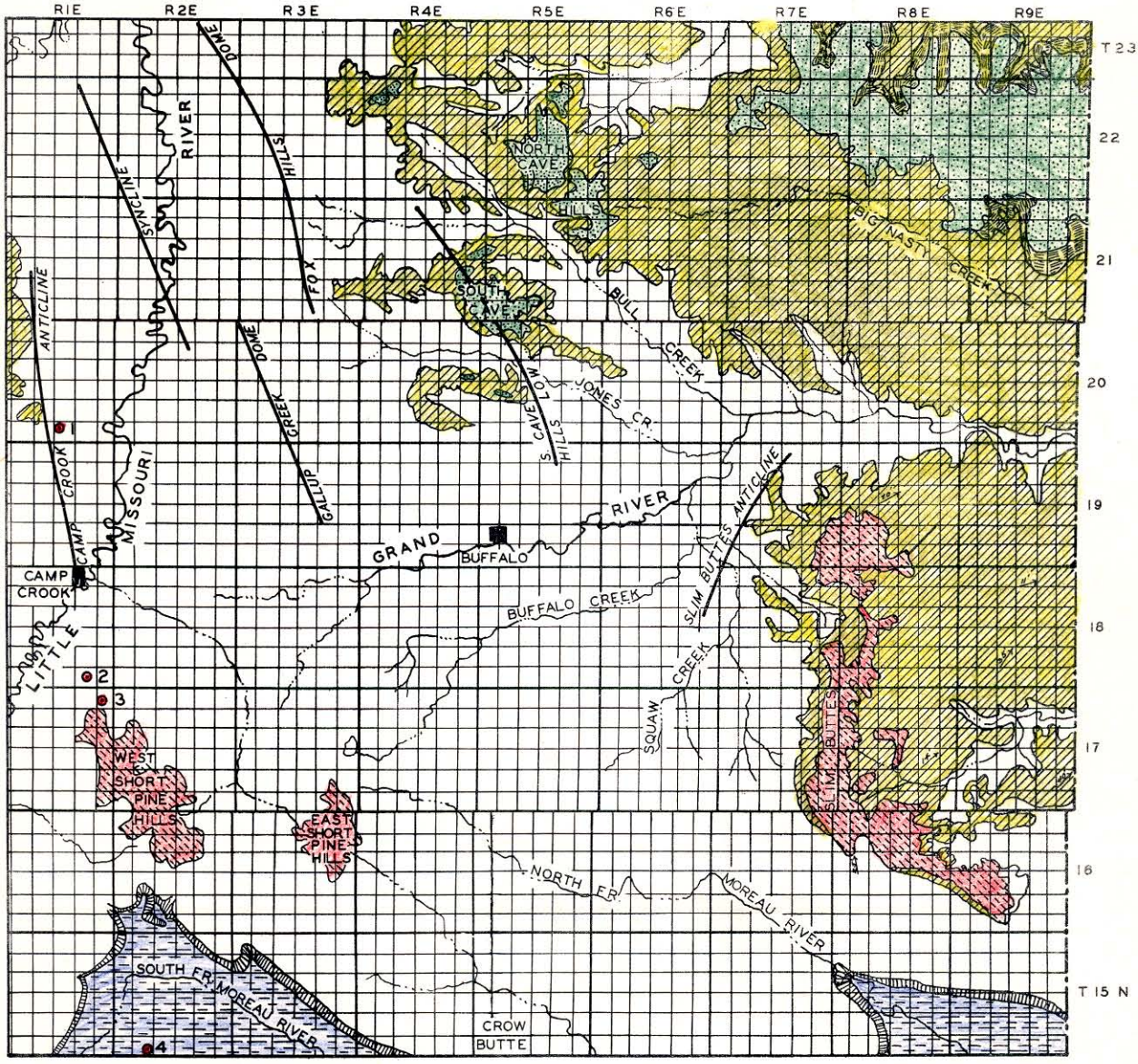
⊙1 Holman No. 1

⊙2 State No. 1

⊙3 Harding School Land No. 1

⊙4 Government No. 1

GEOLOGIC MAP
OF
HARDING COUNTY - - SOUTH DAKOTA



LEGEND

GEOLOGY

- WHITE RIVER BEDS
- FORT UNION FORMATION
- LANCE FORMATION
- LUDLOW CANNON-BALL MEMBER
- HELL CREEK MEMBER
- FOX HILLS FORMATION
- PIERRE FORMATION
- DIP IN FEET PER MILE

NOTE

GEOLOGY ADAPTED FROM U.S.G.S. BULL. 627

OIL TESTS

- 1 HOLMAN NO. 1
- 3 HARDING SCHOOL LAND NO. 1
- 4 GOVERNMENT NO. 1
- 2 STATE NO. 1

SCALE IN MILES

6 5 4 3 2 1 0 6 12