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Sigurd Anderson, Governor

STATE GEOLOGICAL SURVEY
E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

NO. 68

GEOLOGY

OF

HARDING COUNTY

by

Charles Laurence Baker

University of South Dakota
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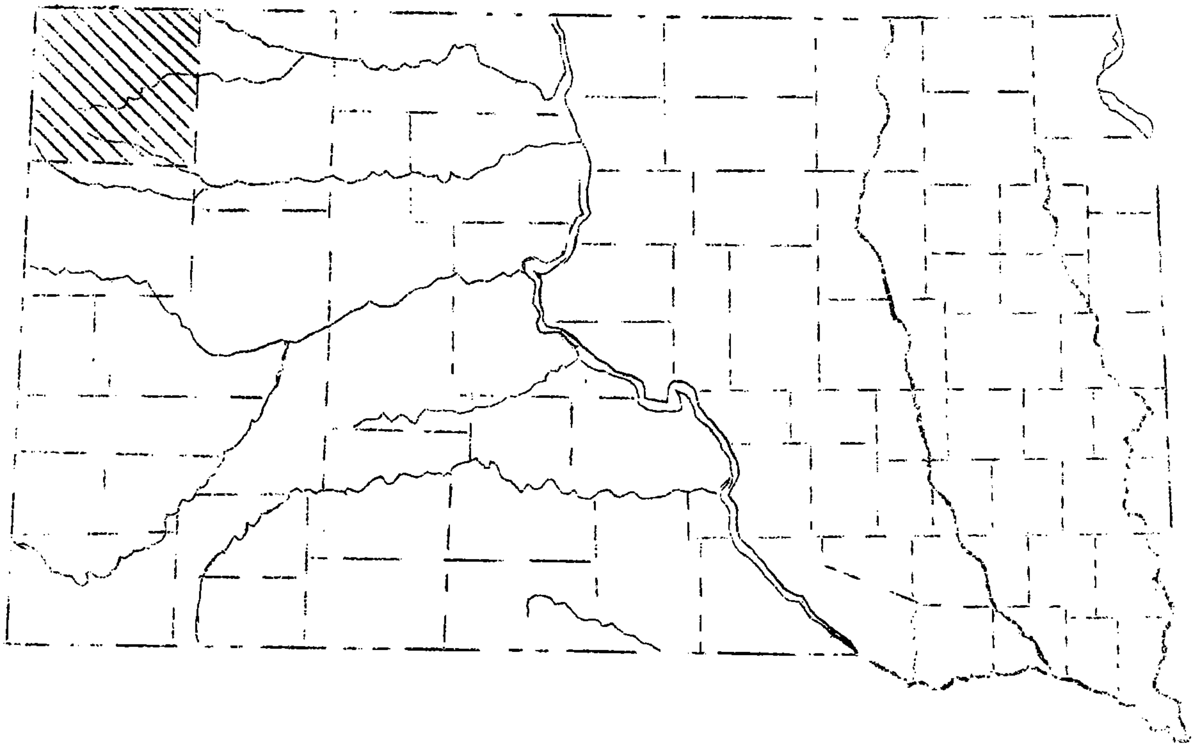

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GEOLOGY OF HARDING COUNTY

by

CHARLES LAURENCE BAKER

PREFACE

A United States Geological Survey field party consisting of Emerson M. Parks, Heath M. Robinson, Robert J. Riggs, P. E. Coaske and W. C. Van Emon discovered in 1911 the three upfolds, or anticlines, in western Harding County. The results of work on geology and lignite in the county were published in 1916. A contour map of the three upfolds, made by Gail F. Moulton and N. W. Bass, was published by the Federal Survey in January, 1922. To date no one of the three has been tested by a bore hole. Subsequently Moulton located the State Royalty 1 boring, drilled mainly by the John Deere Estate, 6 miles south of Camp Crook, in which Dr. J. R. Fanshawe, geologist stationed there during the boring, recorded some 16 shows of oil at different depths with 40 feet of oil saturation in the upper St. Peter sandstone from 7820 to 7860 feet depths. No test for production was made.

This report presents maps showing the southward visible extension of the Camp Crook line of uplift, the northern or visible part of the Slim Buttes upfold, the location of a third upfold crossing the North Fork of Moreau River, the discovery that both Hell Creek and Ludlow are mainly wind-laid deposits and the history of the development of the surface features, or landscape, of the county. The geology of the buried Paleozoic rocks, which, with the exception of the Pennsylvanian and Upper Cambrian, are thinning towards the Black Hills uplift, is considered and likewise the significance, as respects oil accumulation, of the wedging out and thinning of various rocks.

The geologic map of Harding County is generalized somewhat from that in Bulletin 627, U. S. Geological Survey, omitting some small outliers; the south tier of townships was mapped in part by the writer.

A belt of uplifted rocks extends northwestwards from the Laramie or Front Range of the Rockies, forming the Hartville uplift in central eastern Wyoming. Thence a single narrow uparch connects with the Black Hills in western South Dakota and the Bear Lodge uplift, adjacent in Wyoming. En echelon farther north is the Baker-Glendive or Cedar Creek upfold, stretching north-northwest from central Harding County, South Dakota, to about midway between the Yellowstone and Missouri rivers in eastern Montana. The long narrow Baker-Glendive arch is really an uplift in the largest sedimentary basin on the continent, the Dakota Basin or downwarp, the deepest part of which in South Dakota extends north-south through central Perkins County, at the north line of which the top of the Dakota sandstone lies about 1700 feet below sea level. At the west the Camp Crook anticline has a direction nearly north-south, a direction continued in two upfolds in other parts of the county, one near the east line. These have been mapped so far as feasible by the present writer. The two upfolds in the northwest quarter of the county are aligned north-northwest.

The great handicap in mapping geologic structure in South Dakota on the surface exposed Cretaceous rocks is almost ubiquitous slumping, caused more by the great content of bentonite than the lack of coherence of individual particles. Although a number of geologists have written on Harding County they have failed to recognize the bentonite but one of them, W. C. Toepelman, realized the nearly omnipresent slumping.

Because the surface outcropping deposits are incoherent and therefore not resistant to erosive forces and successive base levels limiting downward the erosion were low, a number of different peneplains or end stages of denudation developed during the Cenozoic, one during the Eocene, one between the Oligocene and deposition of the Mio-Pliocene volcanic ash, one by early Pleistocene and subsequently there have been three successive old age stages of erosion.

Owing also to lack of cohesion of the outcropping formations the present surface became covered very extensively by deposits made by the wind.

Harding County is the driest in the State, annual rainfall averaging 13.9 inches and varying from 4.33 to 24 inches at Camp Crook. It is also perhaps the coldest, with a record of 57 degrees below zero at Camp Crook. It has the lowest rainfall because it is the county farthest removed from the Gulf of Mexico, the source of the moisture, greatest in spring and early summer (May and June). Crop growing without irrigation is extremely hazardous but grazing of cattle and sheep, if not overdone and if sufficient acreage is used, can be successful though ordinarily livestock cannot be fattened for market.

The best soil in the county is the loessal sandy or silty loam derived from the Tongue River formation of the northeast quarter of the county.

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SURFACE FORMATIONS

The outcropping formations first will be described, the oldest first and the youngest last. Then will follow an account of the underground formations known from deep borings.

PIERRE BENTONITIC CLAY

The State Royalty No. 1 boring, in Sec. 35, T. 18 N., R. 1 E., began in the Pierre and reached its base at 2020 feet depth. This is nearly the entire thickness of the Pierre. The greatest thickness of the upper part exposed in the county is in the valley of the South Moreau River. A low arch along the North Fork of the Moreau in T. 15 N., R. 8 E., exposes a few feet of the uppermost part and the very top is exposed on Sand Creek near the Butte-Harding County boundary. At the latter place are limy brittle concretions containing Inoceramus and other marine fossils. A half mile farther up the creek there is a transition zone 20 feet thick, at the base of the overlying Fox Hills, of brownish weathering light grey carbonaceous silts with light grey porcellaneous textured limy concretions. At other places thin silts are interbedded with the clay. The usual Pierre is a somewhat greasy clay of cheesy texture, dark blue grey, largely bentonitic in composition, the bentonite being leached and hydrated volcanic ash. The largest area of exposure in the county, along the South Fork Moreau River, near the southwest corner, shows the clay as usual flowing down into a gently rolling or dimpled surface, stained in places rusty brown with iron oxide, the clay being impermeable, gypsiferous and alkaline and not absorbing water, having a sparse growth of wiry grass. The clay at the surface is waxy or gumbo-like, swelling and sticky when wet but spongy with numerous surface cracks and powdery when dry, easily removed by the wind when not protected by grass, possessing practically no resistance to abrasive forces. Locally the uppermost Pierre is carbonaceous, containing plant fragments.

FOX HILLS SAND

The type locality of the Fox Hills is in Dewey County, South Dakota, on the divide between the lower Cheyenne and Moreau rivers. There the formation is thickest and the State's formation richest in marine fossils. In Harding County the Fox Hills belongs to the Colgate facies which is probably non-marine and ranges from 20 to 75 feet in thickness. Marine fossils, if once existent, have been dissolved in the loose sand.

There can be little or no break in time between deposits of the Pierre and Fox Hills, because the upper Pierre and the Fox Hills are a single ammonite zone, that of Discoscaphites and Sphenodiscus. However, on North Fork Moreau River, in SW ¼ Sec. 16, T. 15 N., R. 8 E. there is channelling and erosion at the contact between the two. In the first meander bend upstream from the iron highway bridge there is about 50 feet thickness of Fox Hills exposed, with numerous clay balls and inclusions, much contorted fossil quicksand, some chunks of lignite, balls of marcasite (common in both Fox Hills and Hell Creek), with cross bedding. In the meander bend to the south large chunks of Pierre clay are included in the basal Fox Hills. In places also, besides transported fragments of lignite, there are thin carbonaceous and clayey seams. A section 65 feet thick without base or top in a south meander bend of Sand Creek about 3 miles southeast of the crossing of Highway 85 is fine angular grained buff sand, locally stained yellow brown with hydrous iron oxide, cross bedded, locally coherent in large lenses with rusty brown coated tubercular or warted, branching Halymenites major. When unoxidized the sand is light grey or else pepper and salt with a greenish hue. Just east of the NW corner Sec. 23, T. 15 N., R. 8 E., in the north meander bend of North Fork Moreau River, the Fox Hills is apparently only 20 feet thick and is tawny grey, fine grained and cross bedded with eroded plant fragments and large irregular indurations.

The Fox Hills sand consists of fine grained angular quartz, transparent feldspar, and chert varying from black through grey shades to cream, with some hornblende, biotite, chlorite (altered to vermiculite), muscovite and selenite. There is about an equal amount of bentonite in rounded fine grained waxy or greasy particles ranging in color from olive through yellow to cream. The dark chert and colorless quartz and feldspar give the pepper and salt appearance while the greenish hue is due to chlorite and bentonite. When dry and oxidized the surface is buff tawny to brown; the sand when moist is light grey.

The problematical Halymenites major Lesquereaux, originally considered diagnostic for the Fox Hills, is now known to range in age from Niobrara to Mid-Eocene. It was originally thought to be a marine alga and later to be a boring. In eastern Pennington County, South Dakota, the writer finds it to stand vertically in the strata, to range up to 4 inches in diameter with exterior tubercles or warts up to one inch in height, and concentric like an onion in cross section.

In the type locality of Fox Ridge in Dewey and Corson Counties marine ammonites and pelecypods, etc. are extremely abundant wherever the formation is locally indurated but absent from the loose sediments. Since in Harding County and to the north in southeastern North Dakota the sands are incoherent there is always the possibility that marine fossils were originally present and have been dissolved out by the underground water obtainable in the region.

The source of the Fox Hills is probably the shore lines and beaches of the Upper Cretaceous sea. At the end of Pierre clay deposition the marine basin either filled up to then exactly sea level or else either uplift of the basin or withdrawal of sea water owing to lowering of sea bottom elsewhere took place, permitting land streams and the wind to spread a thin sheet of sand over a bottom of bentonitic clay. Particles of the bentonite adhered to the harder sand grains and were carried along with them to the final resting place of the sediments, becoming rounded during transport.

HELL CREEK

The last deposit of Cretaceous age, containing the last of the dinosaurs, is the Hell Creek, here the representative of the entire Lance formations. Although heretofore stated to be sandstones and shales the Hell Creek, as well as the overlying lower Paleocene (Ludlow or Tullock), in reality is made up of loess, bentonite, loose volcanic ash and a few thin channels of fine grained sands of the same composition as the underlying Fox Hills. Aside from the channels the deposits were made by the wind. The Fox Hills grades up into Hell Creek into overlying Paleocene through transitions so gradual that definite contacts between are generally non-existent. The old name for the Hell Creek was the "sombre" beds they being dull shades of dark dull grey or drab with local rusty layers stained by hydrous iron oxide. There are a few thin brownish carbonaceous streaks and some thin lignites, the latter in the upper part. The thickness ranges up to about

425 feet. The Hell Creek outcrops in the lower, flatter plains and stream valleys of about three-fourths of the county where most of the surface is covered by wind-deposited loess and some sand ridges.

The great content of bentonite leads to the peculiar erosion remnants known as "mud buttes" or "elephant backs". These (Plate 1) resemble hay or straw stacks, steep-sided, bare of all vegetation except the gumbo lily, each surrounded at the base by a "moat or trench", sometimes undrained. The material has practically no resistance to wind, water or weather. Close to the badlands of young topography such as the "jump-off" amphitheatre at the head of South Fork Grand River drainage, these stacks are closely spaced but on the flat old age surfaces there may be fewer than one stack to the square mile. One of the most impressive erosion remnants is Crow Buttes, just west of Highway 85 close to the south line of the county.

The following description of the Hell Creek badlands is that of Charles J. Hares, (pages 6, 7), "Geology and Lignite Resources of the Marmarth Field, Southwestern North Dakota", Bull. 775, U. S. Geological Survey, 1928:

> "The noted badlands of North Dakota are found along Little Missouri River and its main tributaries, extending back from the river in places to a distance of 10 miles, in other places but a few miles. Through them the river meanders sluggishly, disappearing behind a group of hills, then coming into view only to disappear again behind more badland hills. These badlands are formed by the erosion of a former surface characterized by low relief, sluggish streams, and some monadnocks, which has been dissected by the streams until scarcely a flat-topped hill or ridge is left. The crests of the highest hills and ridges are at the same general level and merge with the more or less smooth surface of the rolling, grassy, and treeless upland, showing that at one time the upland was intact and covered the entire region but has been cut to pieces by the streams. All the larger streams in the badlands meander over flood plains, depositing detritus gathered in the upper parts of their courses when torrential rains wash down tremendous quantities of disintegrated material from the soft shale and sandstone. Small coulees are continuously being captured by larger ones that have greater tributary areas.

In the dissection of the region, which is composed of hard and soft rocks, hills of various and odd shapes are developed that, from some vantage point, appear as serrated ridges, pinnacles, domes, cones, pillars of shale capped by sandstone, bare slopes with scanty vegetation, valleys of sharp acclivity, and vertical cliffs. To attain the summits of some of these hills and cliffs it is necessary to travel up a valley and approach them from a higher level. If the imagination is unrestrained it pictures nature in the process of sculpturing these weird and grotesque figures. Here a hard lens of sandstone juts out from the side of a bare hill; there one protrudes into the air as a huge log or connects two hills with a natural bridge. All these varied and fascinating erosion forms are repeated over and over again, until distinct outlines are lost to view and the myriad forms fade into the horizon.

No little amount of roughness in some parts of the badlands is contributed by the reddish porcellanite-capped hills, which add a pleasing touch of color to the landscape. This cap of craggy, slag-like material protects the underlying rocks from rapid erosion. Here and there such a cap crowns a conical hill or belts a terraced bluff. This material is formed by burning of lignite beds. The badlands are difficult to traverse not because of their relief but because of their complete dissection, their precipitous slopes, the deep and in places vertical-walled gullies, and the almost endless repetition of angular features. The journey, if directed otherwise than along the drainage lines or divides, is one of continual ascent and descent and of heading by circuitous routes the numerous deep gullies and impassable box canyons of only a few feet in width. Such maneuvers are repeated over and over again as long as the journey remains in the rough land.

The growth of the badlands is interesting. In places the traveler may ride for some distance over a rolling grassy country and upon arriving at the crest of a divide or hill be confronted by abrupt downward slopes ("breaks") that merge into a chaos of badlands. As soon as the sod is broken good smooth country is rapidly transformed by erosion into an almost arid waste. Torrential rains falling on the bare soft rocks quickly run off, carrying tremendous quantities of mud and sandstone detritus.

In most places in the badlands there is very little soil and on many slopes none at all; consequently plants have only the slightest chance to get a foothold -- a condition favorable to rapid run-off and rapid erosion. All that seems necessary to start the process of forming badlands is a certain amount of relief, a semi-arid climate, a bare spot, soft rocks, and concentrated precipitation. When once started erosion continues until the profile of the valley is nearly flat. Here and there two or more badland areas may be working up the same valley. The younger ones may be caused by the deepening of the main stream or the giving away of a hard stratum of rock or, in very minor degree, even of tough sod."

The sediments contain many balls of marcasite and of iron carbonate concretions changed on the outcrop to shiny nearly black or brown hydrous iron oxide; again quoting from Hares, page 21 of above cited report for an apt description of these concretions and nodules:

"Ferruginous nodules and layers are characteristic features of the Hell Creek member of the Lance and are sparingly present in the Ludlow lignitic member of the Lance, but are, as a rule, rare in the Fort Union, though fairly numerous in the Sentinel Butte shale member. The nodules are of various queer shapes and sizes, some round, some flat, some cylindrical, and some branching much like the fossil plant <u>Halymenites</u> <u>major</u>. They also resemble this fossil in the surface markings and are sometimes wrongly identified as fossils. The ferruginous masses occur in some places as lenses or irregular masses, in others as layers, associated usually with cross-bedding, which incline as high as 15° and are thick enough to be incorrectly interpreted as indicating the true bedding of the strata. The colors of the weathered material are brownish yellow, brown, dark red, and nearly black. Much of the nearly black material has a shiny luster. When broken the dark oxidized coating on many specimens is only a veneer, or the whole interior may be completely altered. The dense, compact, and gray unaltered material is largely iron carbonate. The coating marks the progress of oxidation from impure iron carbonate to iron oxide. In weathering the coating often shows a structure resembling that of a tortoise shell, and commonly the exterior markings extend to the unoxidized part. Some specimens exhibit a columnar structure in the coating. The content of iron probably varies greatly, the darker nodules carrying the larger amount.

"Large numbers of these nodules accumulate at the foot of bare slopes, as the finer, lighter, and less resistant material washes or is blown away. They are contemporaneous in origin with the inclosing rocks, not due to secondary accumulation of the iron, as the material takes part in the cross-bedding and the nodules, so far as noticed, show no evidence of having grown and forced the laminae apart; however, no specimens were collected showing bedding planes."

The wavy lamination of loess and brownish carbonaceous loess is characteristic. The thin layers of unaltered ash are still loose and powdery, grey, weathering rusty. Fragmentary bones of dinosaurs and turtles are fairly common. Local induration of the silts (loess) and fine grained channel sands produce spherical and log-like "concretions". The bentonite exceeds in bulk the other sediments. It is sticky (coherent) and slippery when wet but spongy, pustular, much cracked and powdery at the surface when dry. There is considerable gypsum, sometimes in veinlets, the soil being alkaline and practically impervious to moisture; it is bettered somewhat by a considerable mixture of silt and fine sand transported by the wind from other sources.

LOWER PALEOCENE (LUDLOW OR TULLOCK)

This formation is separated from the underlying Hell Creek by a change in color from grey to tawny or yellow, which does not always take place at the same horizon, by the total absence of dinosaur fossils and by the content of workable lignite beds up to 25 feet in thickness, of the best quality found in the State. In places the base is a ripple marked, cross bedded, tawny, fine grained sand or silt overlying a bed of lignite. The Ludlow is from 300 to 350 feet thick. At the northeast corner of the county it grades into a marine formation, known as the Cannonball, of a Paleocene stage older than the Midway of the Gulf Coastal Plain. Most of the Ludlow is loess with its characteristic wavy lamination. It contains considerable selenite and a small percentage is partially indurated by limy cement in local lenses some of which are "concretionary". Aside from the lignite there are numerous brown loessial layers. The whole appears to be wind deposit much of which settled in shallow ponds, bogs and marshes with subtropical vegetation, sequoia and cypress trees being particularly abundant though yews, poplars, ginkos, soapberries and haws also occur as fossils.

The Ludlow outcrops in a broad belt extending from the central-north to near the southeast corner of the county.

That the Ludlow with its local thin, partly indurated beds is somewhat more resistent than the underlying Hell Creek is shown by scarped bluffs of the former approaching on the north side close to the South Fork Grand River in the southern part of T. 20 N., R. 8 E., the river lowlands widening to the west upstream on Hell Creek outcrop.

TONGUE RIVER

This is higher Paleocene (Fort Union) but only the lower 400 feet of the formation occurs in South Dakota, where it is limited to Harding and adjacent Perkins counties. It is more sandy than the Ludlow and begins, at least in north-central Harding County, with a thick fine-grained sand, poorly indurated with limy cement where it forms the thick caprock of the mesetiform Table Mountain, Eagles Nest Butte, North and South Cave Hills and outliers. Even here the rock is so soft as generally to crumble when rubbed between the fingers, with cavities where the sand is incoherent forming the recesses giving the name to the Cave Hills. Colors vary from light grey through tan and buff to brown, depending upon amount of oxidation of the contained iron salts. The sands are generally very fine grained and evenly thin bedded though a basal mudball conglomerate occurs in Eagles Nest Butte. Two beds of sands are present in North Cave Hills, the lower 75 to 100 feet thick and in places coarser than the overlying, locally cross bedded, yellow to brown, bedded, muscovitic and easily examined in the two roadgaps, the upper bed ranging up to 135 feet in thickness. A higher limy sandstone caps the Lodgepole Buttes, brownish yellow, massive and up to 100 feet thick. A fine grained local quartzite is found in place at the top of the Cave Hills, in Lodgepole and Anarchist buttes, and in the flat-topped hill northeast of the present-day Ludlow postoffice. Pieces of this, generally wind grooved and polished to a dull lustre, can be found on the surface in southern North Dakota and northern South Dakota as far east as Missouri River. Some is really a fine dull lustred chert ("tripolite") and often there are plant remains. Locally great piles of angular boulders of it rest upon the Hell Creek along both North and South forks Moreau River as well as on their stream terraces. Other locally indurated quartzites occur lower in Tongue River as well as in the basal somewhat conglomeratic Oligocene (strewing surfaces upon and at base of Crow Buttes) and in the top volcanic ash caprock of Mio-Pliocene age of southwestern Slim Buttes.

Much loose silicified wood of a number of kinds and colors rests upon the top of the caprock sandstone on the south rim of South Cave Hills and likewise on the slopes of Anarchist Butte. Most of the Tongue River petrified wood is glossy in lustre, differing therein from the dull surface of the sparse fragments in the Hell Creek. It is evident that most of the petrified wood found in basal Oligocene and in Pleistocene and recent gravels in South Dakota is derived from the Tongue River, once far more extensive in its distribution than at present. Workable lignite beds are rare in the Tongue River of South Dakota, perhaps none occurring in Harding County. Dicotyledonous plant leaves occur in Anarchist Butte, of poplar, banana, soapberry and fig.

The Tongue River outcrops are confined to Townships 20 to 23 N., Ranges 4 to 9 E., the silt and sand in Townships 22 and 23 N., Ranges 7 to 9 E., because of permeability and lack of alkalies, being the basis of the most productive soils in the county.

OLIGOCENE (WHITE RIVER)

The maximum thickness of the White River appears to be not much over 125 feet and that only in tilted landslide blocks formed before the deposition of the overlying flat-lying volcanic ash. It outcrops around the edges of the mesas known as hills or buttes, such as Slim Buttes and East and West Short Pine Hills and caps part of North and South Cave Hills and some other isolated buttes and ridges. To the southwest, in the Short Pine Hills, the Oligocene rests directly upon folded and bevelled Hell Creek. In Slim Buttes it rests mainly upon the Ludlow but on the southern side upon the Hell Creek. In South Cave Hills the Oligocene lies upon the caprock sandstone of the lower Tongue River. The folding and regional northeastward tilting of the upper Cretaceous and Paleocene formations occurred and erosion of these formations to a peneplain took place before the Oligocene was deposited. The Oligocene surface itself, including its tilted landslide blocks, was eroded to a peneplain before deposition of the overlying unaltered volcanic ash.

The Oligocene here is similar in content to that of the Big Badlands. Most of it is Chadron or basal with characteristic brown and yellow beds. The rest is the overlying Brule some of which is pinkish and prevailingly bentonitic. Vertebrate fossils confirm the lithologic determinations. The base is often a glistening glaring white conglomeratic sandstone with an ashy to bentonitic matrix. This contains small pebbles of quartz and microcline, angular fragments of multicolored chert, broken shards, and angular pieces of silicified wood derived from Tongue River. W. C. Toepelman (The University of Chicago Abstracts of Theses, Science Series, Volume IV, pages 229, 230) describes the White River on the east side of Slim Buttes as follows:

> "Because of the development in it of peculiar structural features, the White River is the most interesting formation of the section. It rests unconformably between the Ludlow member of the Lance and the Arikaree (?) formation of Miocene age. Normally it is practically horizontal in position, but in a few places is highly tilted. The horizontal outcrops consist of a basal portion of 15-20 feet of dazzling white sandstone, 15-25 feet of plastic, gray-to-maroon and purplish clay, and 20-30 feet of alternating gray-to-pink clay and sandstone. In the tilted areas the thickness is much greater, reaching 277 feet at a maximum. The lower 60-80 feet is identical with that indicated above. The alternating series of clay and sandstone may persist for 20-40 feet and is overlaid by a massive nodular pink sandstone and clay up to a maximum of 125 feet. The basal white sandstone and overlying clay are correlated with the Chadron formation (Titanothere beds), the alternating sandstones and clays and the massive pink sandstones with the Oreodon and Protoceras beds, respectively, of the Brule formation of the type White River section in southwestern South Dakota."

All the clays mentioned by Toepelman are bentonites. Occasionally a rounded quartz pebble is found lying on the surface in different parts of the county. It is apparently residual from the basal Oligocene. Undoubtedly, as proved by existing extent of outcrops, the Oligocene once covered the entire county, being mainly a wind deposit.

MIO-PLIOCENE VOLCANIC ASH

This formation is a felted aggregate of shards (splinters and flakes), plates, needles and fibres of volcanic dust or tuff (ash) admixed with which is some fine angular fragmental quartz particles of silt and fine grained sand size. In the south Slim Buttes there is a basal conglomerate and some thin stream channel deposits near the base of rounded limy nodules derived from the underlying White River Oligocene; the latter are whitish on the inside and have a light brown coating. Near the J. B. Ranch on the east side of south Slim Buttes, there is a green sand with seams of magnetite (black sand), the green matrix being a hydrous iron silicate. The ash formation rests unconformably upon a flat surface of eroded Oligocene and locally on pre-Oligocene. Most of it is light grey though where more consolidated it is light green with veinlets of glassy milky hyalite (a glassy chalcedony). There are a few thinly laminated pond deposits as well as the basal stream deposits; the remainder and much the greater part of the whole has settled from the air, with some cross bedding and banding but mostly structureless and nodular, apparently having accumulated rapidly as dust falls from explosive volcanoes. (Plate 2) Its thickness ranges up to 250 feet. It produces the caprock cliffs of East and West Short Pine Hills and Slim Buttes. Minerals present include quartz, feldspar, biotite, phlogopite, chlorite, epidote, augite and hornblende.

No indigenous fossils have been found in the formation in South Dakota but across the State line in Carter County, Montana, there has been found a late Miocene beaver. This gives a correlation with the Bijou formation outcropping along the Missouri River south of Chamberlain, also volcanic ash. The Rosebud (Arikaree) ash, overlying without break the Oligocene south of White River, appears to have been eroded from Harding County before the deposition of the Bijouan (Mio-Pliocene or Barstovian-Clarendonian). The volcanoes from which the Bijouan was derived are apparently those of the Absaroka Plateau on the east side of the Yellowstone Park basin, then as now the prevailing planetary winds bring westerly. The Bijouan extends as far east as Yankton and, conservatively estimated, must have averaged over 250 feet thick over an area of 100,000 square miles. The volcanic explosive products of the time, reduced to hard rock, would amount to at least 2,500 cubic miles.

BURIED ROCK FORMATIONS

Although three deep holes have been drilled in southwestern Harding County and one in north-central Perkins, relatively little is known about the underground rocks of the Mesozoic Group. The State Royalty hole five miles south of Camp Crook was cored continuously in the Paleozoic and hence we have better information from it concerning buried Paleozoic rocks than in any other boring in the State. The holes were drilled with the rotary drill, the cuttings being greatly contaminated by bentonitic clays from the Pierre, Fuson, Morrison and Sundance formations which when wetted by drilling water swell, slake, heave, and sluff off into the hole. Also whenever the flexible and elastic steel drill pipe bends, it reams off the sides of the uncased hole, the materials of which mix with those being cut by the bit at the bottom. We must search carefully for the first appearance going downwards of a new formation and, as often happens, this is merely a repetition of a kind of rock already penetrated higher up, hence there is confusion and uncertainty. The resistivity logs show where marked changes in electrical potentials occur but give little information on the real composition of the rocks.

MESOZOIC ROCKS

A shallow hole drilled in 1926 on the Fox Hills dome by cable tools give a better record but is only 1200 feet deep. This is situated in Sec. 7, T. 22 N., R. 3 E., and was drilled for the Montana-Dakota Utilities Company by the Grey Well Drilling Co. of Milwaukee, Wisconsin. The record, from study of the cuttings follows:

0 - 60 ft.	Hell Creek (Lance) sand, medium and angular grained, much biotite and phlogopite mica, kaolinized feldspar and black hornblende, some milky chert, sanidine, chlorite and serpentine, glassy plagioclase, ruby garnet, slender prismatic apatite, angular quartz.
60 - 90 ft.	Sand, as above, with clay.
90 - 100 ft.	Silt, olive drab, propylitized, wood fragments and lignite.
100 - 120 ft.	Sand, fine grained, clayey, grey, with some minerals as from 0 - 60 ft.

120 - 150 ft. Silt, as at 90 - 100 ft., darker, brownish, clayey, with jet fragments.

150 - 220 ft. Fox Hills sand, fine grained, much clay, much magnetite (black sand), a little serpentine, with bentonite matrix.

220 -1200 ft. Pierre clay, grey, bentonitic, silty from 220 to 310 ft., shell fragments from 420 feet downwards, light grey bentonite 570 - 580 and 620 - 630 ft.

The Shell J. T. Homme No. 1 boring, SE$\frac{1}{4}$, Sec. 13, T. 20 N., R. 12 E., Perkins County, is 1150 feet lower structurally on top the Pierre than the State Royalty boring five miles south of Camp Crook. However, owing to thinning of the Mesozoic rock section eastwards, the Shell hole is 982 feet lower structurally on top Dakota sandstone than the State Royalty and on top of the Spearfish red beds 715 feet lower, the interval between top Pierre and top Dakota having decreased eastwards 200 feet and between top Dakota and top Spearfish 267 feet.

Section, descending order, surface downwards, penetrated in State Royalty boring, five miles south of Camp Crook:

Age	Formation	Thickness	Kind and Nature of Rocks
Cretaceous	Pierre	2020	Clay, bentonitic, grey, marine, becoming more compact downwards, Eagle sandstone 1320 - 1365 ft. below top, Campanian.
	Niobrara	260	Marl, with small white chalky specks and clay, grey, marine, Senonian.
	Carlile	445	Shale, dark grey, marine, some sandstone 160 - 190 ft. below top, Turonian.
	Greenhorn	30	Limestone, clayey, light grey, marine with <u>Inoceramus</u> and <u>Globigerina</u>, Turonian.
	Graneros	510	Shale, dark blue grey, Cenomanian above, Albian below, marine.
	Mowry	135	Shale, dark grey, bituminous, volcanic ash, bentonite, some sand, silt and mudstone, fish scales.
	Newcastle (Muddy)	125	Sandstone and siltstone, light grey, probably some shale, dark grey, non-marine.
	Skull Creek (Thermopolis)	240	Shale and mudstone, dark blue grey, bentonite.
	Dakota	70	Sandstone, fine angular grains, light grey, with plant fragments and some clay, non-marine.
	Fuson	50	Clay and sandstone, varicolored, very bentonitic, zone of manganosiderite pellets, size of sand grains, at top, terrestrial.
	Lakota	70	Sandstone, coarse to fine, grey, some shale and mudstone, terrestrial, coarser at base.

State Royalty boring (continued)

Age	Formation	Thickness	Kind and Nature of Rocks
Jurassic	Morrison	30	Clay, varicolored, bentonitic, land laid.
	Sundance	620	Clay, siltstone, sandstone, with some limestone in lower part, all with specks of glauconite, light green grey and brown, lavender and purple, bentonitic, marine.
?	Spearfish	458	Siltstone, salmon, with anhydrite.
?	Minnekahta	42	Limestone, light grey, pink and brown, dense, fine grained, anhydrite at top.
?	Opeche	90	Siltstone, dark brick red, coarse sand at base.

PALEOZOIC ROCKS

The nature of the Minnelusa and underlying formations are depicted on the correlation chart of two wells in Harding County, at the left, and at the right, the Shell Homme boring in N.E. Perkins County and the Carter Northern Pacific 1 on top the Baker-Glendive arch in Montana 8 miles north of the northwest corner of Harding County. In the two latter the same formations are found with substantially the same thicknesses. However, towards the Black Hills uplift in southwestern Harding County the formations thin and one, the limestone in the mid-Ordovician, disappears near the southwest corner of the county. Still farther south-east, before reaching the outcrops of the formations near Deadwood in the Black Hills, the Charles formation, present in southwest Harding County, disappears and the next underlying Whitewood dolomite has thinned to 50 feet, the entire thickness of the Paleozoic beneath the top of the Minnelusa being 1500 feet thick near Deadwood, more than 2200 feet (with base not known) beneath the Harding-Butte County line in Northern Ordnance Government 1 boring, 3870 feet thick in the trough of the Dakota downwarp or basin in the Shell Homme boring in Perkins County and 3980 feet thick on the Baker-Glendive uplift 8 miles north of the northwest corner of Harding County.

The base of the Minnelusa formation, of Pennsylvanian age, is a varicolored clayey laterite zone, left on the surface as an insoluble residue upon solution of the underlying limestone and dolomite; the prevailing color of the laterite is red, denoting its formation in a moist warm climate. The remainder of the Minnelusa is alternating interbedded dolomite, limestone, sandstone, and red claystone, with a little anhydrite.

The next underlying formation, the Charles, may be the basinward equivalent of the upper Madison, though it is not certain. It is characterized by three horizons of anhydrite, which is dense, fine grained and bluish; the lowest one is assumed to be the base of the formation. Most of the formation is limestone and dolomite.

The underlying Madison is interbedded limestone and dolomite though apparently mainly limestone in the trough of the Dakota Basin. It thins from 750 feet there to 500 feet on the Butte-Harding County line in Northern Ordnance Government 1 boring. Its base is the Englewood dolomitic sandstone or siltstone with locally coarse sand or small pebbles just above the unconformity at the bottom.

The next underlying dolomite formation has been referred by some to the Devonian and by some others to the Silurian. However, inasmuch as it resembles and occupies the position of the Ordovician Whitewood of Black Hills outcrops as well as the Stony Mountain of Manitoba it is herein referred to the Ordovician, either Middle or Upper, since the dolomite fossils if and when obtained from cores will probably be too poorly preserved to permit other than generic determinations, most the Black Hills genera being common to both Upper and Middle Ordovician.

The next underlying limestone, as the Charles likewise, does not outcrop in South Dakota but there appears to be substantial agreement that it belongs to the Trenton group, called the Red River in Manitoba and equivalent more or less to the Galena limestone of the tri-state lead district at the common corner of Illinois, Wisconsin and Iowa. It disappears southwards before reaching the Butte-Harding County line though perhaps not by unconformity (erosion) since it may be a wedge ending westward where limestone deposition ceased. Graptolites found in a core from the base of the limestone at depths 7,727-30 ft. in the State Royalty boring 6 miles south of Camp Crook occur in the lower Viola limestone of Oklahoma, which is lower Trenton age.

The next underlying formation, the Black River, is equivalent to the Glenwood of northeastern Iowa and southeastern Minnesota, the upper part of the Winnipeg formation of Manitoba. Fossils found in it on the outcrop in east Deadwood are of Black River age. It is mostly dull green very flaky, fissile and splintery shale, caving badly where water soaked, composed largely of bentonite, apparently the only potash bentonite yet known in the United States. It is generally sandy at top and base and contains small pellets or nodules of black phosphate; some of the shale is grey and brown. It is a widespread formation known from the California-Nevada boundary southeastward to the Rio Grande on the Mexican boundary and eastward to New York and Georgia; it being originally a volcanic dust or ash, the product of explosive volcanoes, carried eastwards and southwards by the higher prevailing planetary winds.

The underlying sandstone, generally white to buff, on the average with medium sized grains, more or less rounded, is distinctively and characteristically St. Peter--and different from all other sandstones of the Dakota region.

The lowermost Paleozoic formation, the Upper Cambrian or Deadwood, is characterized by the presence of grains of glauconite, in general a darker green than those in the Sundance, disseminated through sandstones, limestones, dolomites and shales; generally a basal sandstone, in places conglomeratic, rests upon the underlying crystalline pre-Cambrian.

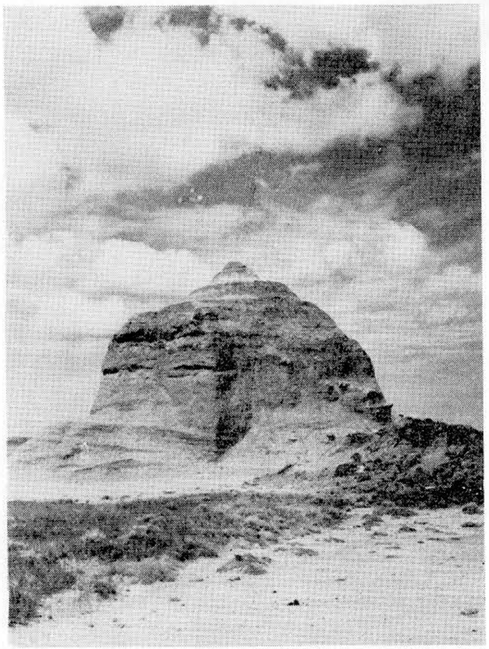
EXPLANATION OF PLATES

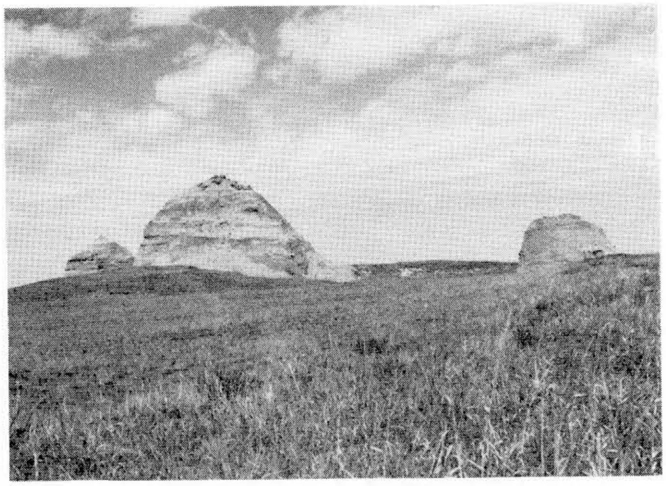
Plate 1, Erosion forms in Hell Creek loessial sediments
a. Upper left and right - Residuals or "stacks" surrounded by shallow trenches or moats. Easily slaking bentonitic clays readily removed by the wind.
b. Lower left and right - Badland topography in alternate dark and light grey bentonitic and loessial clays at foot of the "jumpoff", north of East Short Pine Hills. Gullies cut by cloudbursts in grass-covered pediment flats in foreground. Lack of intermediate debris slopes is characteristic of badlands denuded by winds.

Plate 2, Erosion scarp of Slim Buttes in volcanic ash. Two upper views are in vicinity of Cedar Pass, lowermost on west flank between J.B. and Reva gaps. Characteristic landslide topography of rotated blocks near bases of cliffs in the two lefthand views.

Plate 3, Short Pine Hills. Castellated cliffs produced by vertical fractures (joints) in volcanic ash at north margin East Short Pine Hills. Lower two are of west side West Short Pine Hills, middle one showing tilted and subsided block of White River Oligocene dropped against Hell Creek in ridge in background. Lower view has in the middle the axis of arch (anticline) in Hell Creek beds south of Camp Crook, looking north from middle of Sec. 14, T. 17 N., R. 1 E. Mesa is capped by volcanic ash. Two degree sloping alluvial fan at left of base of mesa.

PLATE I





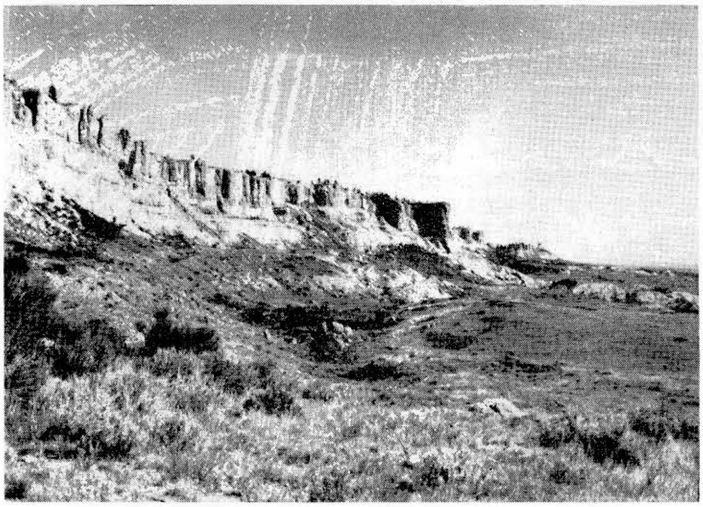
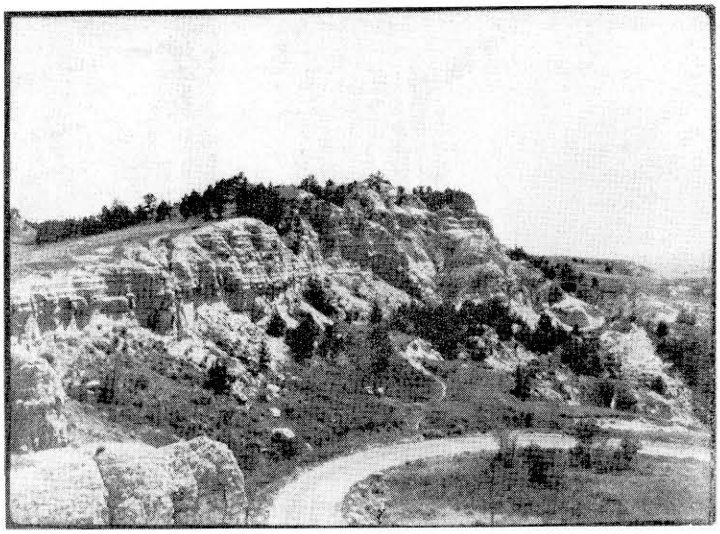


PLATE II



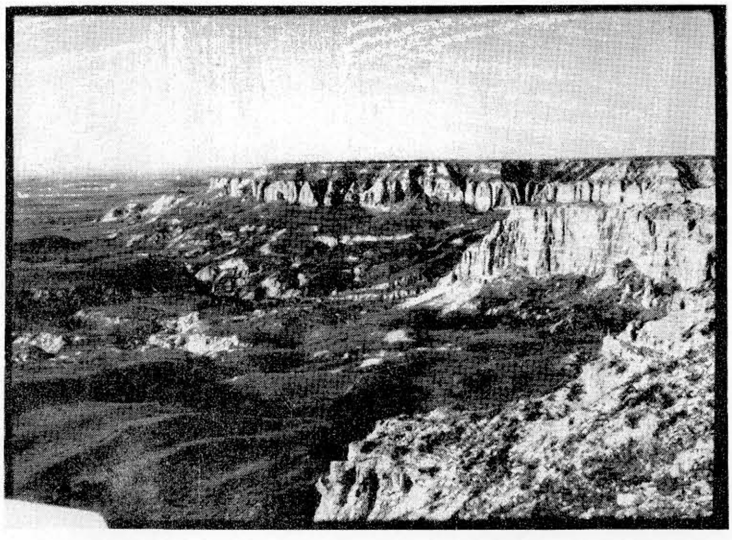
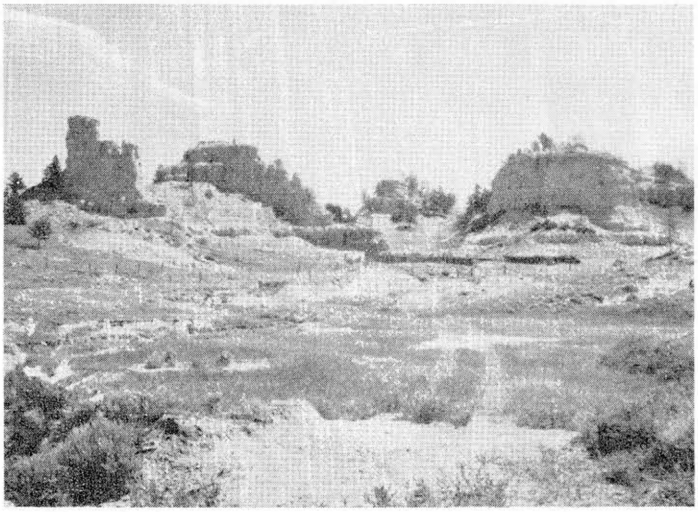
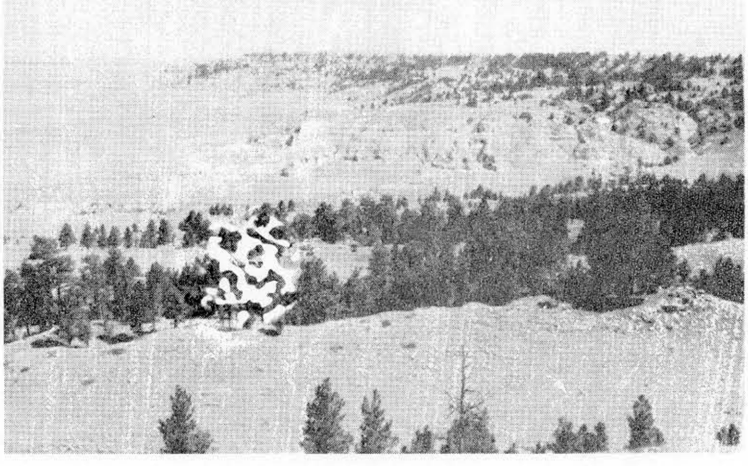


PLATE III





THE MAKING OF THE SURFACE

The lack of coherence of the surface outcropping formations is the main influence in the making of the surface features or topography of Harding County. The materials are easily carried away by the forces of wind, weather and water. Even a poorly coherent, locally partly cemented, rock stands out as a prominence while the force of gravity, exerted downwards, causes much slipping and sliding, flowage and slumping of fine and loose aggregates. Two factors, non-resistance and base-levels of erosion relatively high in altitude and thus not far below original upland surfaces, result in great rapidity in erosion, hence no surface feature in the county can be older than the Pleistocene or latest epoch of earth history. The wind, both as a destroyer and depositor, is much more effective here, where loose sediments prevail, than where rocks are coherent.

The higher older erosion levels persist as relics in the flat-topped steep sided mesas or tablelands, plateaus in miniature--the East and West Short Pine Hills--the Slim Buttes, the North and South Cave Hills, the Lodgepole Buttes and Table Mountain. The peneplain found on their tops may have been made when the drainage flowed north-northeast into Hudson's Bay, a course still maintained by Little Missouri River. As a consequence the mesa tops lower in going from southwest to northeast, though the surface on top Lodgepole Buttes may be later than on the others. The two Short Pine Hills still make the divide between the northward flowing Little Missouri and eastward flowing Grand and Moreau rivers, the last two having extended headward and westward capturing much of the former drainage. There is considerable possibility that the two Cave Hills and the Slim Buttes are remains of the west and east side divides of a former northward flowing stream. The former watershed between this stream and the Little Missouri perhaps continues north across Bowman County, North Dakota, through the Medicine Pole Hills (8 miles south of Rhame) and Post Office Butte (one mile northwest of Rhame) which are still on the divide between northward-flowing Little Missouri and eastward-flowing North Fork Grand rivers. The water level in North Fork Grand River north of Slim Buttes has an altitude of 2670 feet. Little Missouri River water level at North Dakota State Line is 2875 feet in altitude though the Little Missouri has the greater flow. The Little Missouri drainage, after leaving South Dakota has to flow about 375 miles to meet water flowing only 135 miles down Grand River, the two meeting on the Missouri at Mobridge. Accordingly, the Grand and Moreau drainages, by headward extension, gradually are capturing the Little Missouri system, the upper part of the latter having already been captured by the Belle Fourche. The narrowness, compared with the length north-south of Slim Buttes and the northward flowing course of Squaw Creek to the west, are favorable to the supposition of former north-flowing drainage.

Slim Buttes and the Short Pine Hills are capped with the volcanic ash, the surface being flat, except for some deflation hollows (wind blowouts), where not cut up by head ravines. South end of West Short Pine Hills has an altitude of 4019 feet matched by one of 4025 in ABarB Buttes across the line in Montana and equivalent to the average altitude of the erosion-bevelled outer Dakota-Lakota hogbacks of the Black Hills. South end East Short Pine Hills has an altitude of 3889 feet and west end North Slim Buttes 3624 feet. Table Mountain reaches 3607 feet and Lodgepole Buttes 3222. From the two latter and the Cave Hills the volcanic ash, undoubtedly once present, has been removed, its erosion probably continuing until Lower Pleistocene, judging from history elsewhere on the plains. It is, of course, quite possible that there has been considerable erosion of deposits once existing above the present surface of Short Pine Hills and Slim Buttes. In fact, the total removal of the volcanic ash in the north half of the county could scarcely have occurred without erosion in the highest part of the south half.

OLD AGE TOPOGRAPHY OF LITTLE MISSOURI RIVER BASIN

The Little Missouri River basin in most of Harding County is still in the old age stage though near the North Dakota line rejuvenation from the main Missouri since end of glaciation has worked headward initiating a new cycle, the latter having produced the badlands in North Dakota which reach upgrade to south of Marmarth. The Little Missouri channel, owing to the prevalence of torrential rains and cloudbursts, has cut steep banks about 20 feet high below the adjacent loess-covered flats. From the top of these banks there is a gentle rise in the surface westward to the Long Pine Hills, west of the Montana line, and eastward and southward to the base of the steep eroded and landslip slopes of the Short Pine Hills. The steepest slope grade, about 2°, or 200 ft. per mile, is close to the bases of the mesas (Pl. 3, Fig. 3). Drainage channels leading from the latter are sharply intrenched, by cloudburst action, below the general slope which ordinarily is covered with wind-deposited loess. Some sand dune and sand ridge areas occur east of the river near the north county line and reaching to the west foot of the

West Short Pine Hills in the southeast corner of T. 17 N., R. 1 E. Source of sand in both cases is probably exposures of Fox Hills sand farther northwest, now largely covered by loess.

The basin of Valley Creek, called Prospect Valley by General Custer in 1874, heads near Harding post-office and joins the Little Missouri near Camp Crook. Its surface is broad, low and flat to gently rolling. Its cover of loess and that of Little Missouri River basin would be good productive soil if sufficient moisture were available. An older erosion stage in Valley Creek basin is shown by a flat on east side of the West and west side of the East Short Pine Hills cut about 100 feet lower and separated by a scarp or abrupt incline from the summit flat.

OLD AGE VALLEY STAGE OF GRAND AND MOREAU RIVER BASINS

Like the Little Missouri an old age topography is developed upon the headwaters of the eastward flowing drainages, both being developed in a short time because of the non-resistance of outcropping Hell Creek and Ludlow formations. The "jump-off", an amphitheatre in a semi-circle at the head of South Fork Grand River drainage (Pl. 1) now encroaching on the higher Little Missouri River basin with steep-sided head gullies cutting back into a smooth surface, generally flattens out within a half mile into the old age plain of the South Fork. As will be seen from some of the pictures cloudbursts have trenched the lower flat. Disintegration of the Hell Creek is extremely rapid and much of the loosened material is swept away by the wind. In fact, it would be difficult to determine whether wind or water is the greater eroding agent. South of Buffalo and between Buffalo and Reva Gap there are rather extensive areas of wind-deposited dunes and ridges which occur also in the valley of North Fork Moreau River near the southeast corner of the county. Lower down, north of Slim Buttes, there is a terrace about 50 feet high along South Fork Grand River. All rivers and major creeks of these drainages, as well as the Little Missouri River, meander greatly because of full load of sediment. Loess virtually everywhere mantles the flattish old age surfaces; in places it is difficult to distinguish between the modern and the Hell Creek--Ludlow loesses. The general level of the old age surface in eastward-flowing drainage is about 200 feet below that on the Little Missouri. The surface appears to be the same as the 1800 feet in altitude old age pre-glacial erosion stage prevalent along Missouri River to the east. Along South Fork Grand River its level is more than 900 feet below the top of north Slim Buttes.

PROCESSES DESTROYING THE HIGH MESAS

In order to appreciate the rapidity in rate of destruction of the higher remnants of the ancient cover, it is necessary to emphasize over again the great lack of resistance caused by absence of consolidation and the slaking and crumbling propensities of the rock materials. These are matters which most geologists have been slow to realize and hence development of existing topography has been considered to have begun farther back in geologic time than is probable. Abundance of loose fine materials gives the wind a chance to abrade, gather up and transport in great amount, the wind being likewise in abundance, in fact, far more prevalent than rain. Consequently wind action is great relatively to that of water in motion. Importance of wind is shown, for example, by most tributaries of the east-flowing upper Moreau River flowing southeast, their courses being initiated and controlled by prevalent northwesterly winds which apparently also are the cause of the shifting of the South Fork Moreau River southwards, its south side tributaries being short as a consequence. Southeast-flowing tributaries of South Fork Grand River likewise are prevalent in north-central and northeast Harding County, the South Fork channel having shifted southwards until the greatest amount of relief within a short distance in the county is the 950 feet within five miles between the north rim of north Slim Buttes and the river channel to the north.

The volcanic ash capping the tablelands of the south half of the county is permeable to water both in its interstices and its numerous fractures. This is why the summit flats are covered with grass while the edges or bluffs support pines and the ravines thickets of deciduous trees, sufficient moisture being afforded by seepage. Numerous springs issue at the top of impermeable bentonitic layers in underlying Oligocene where present and where absent, in Ludlow or Hell Creek. The springs increase their flow shortly after the rains, indicating relative rapidity of percolation.

Part of the slumping or landslipping occurred before deposition of the volcanic ash in area where extensive removal of Oligocene deposits permitted bluffs, scarps, steep slopes and badlands to form wherever Oligocene remnants persisted. Much of this earlier slumping is found along the east side of Slim Buttes south of Reva Gap. Although this has been interpreted as giant cross-bedding, Toepelman has shown correctly that the areas of inclined strata are bounded on one or more sides by "faults" produced by rotation of blocks subsiding down steep slopes. For example, Ship Rock, the easternmost of the three castles, one mile southeast of Reva Gap, is a wedge-shaped block subsided between two fractures.

Wherever any incoherent material, be it ash, loess, sand, gravel or bentonite, becomes saturated with water it is lubricated and will flow if a sufficient pressure differential from higher to lower level exists. In any declivity along the surface between the material and either air or water the weight of the stuff above presses both downwards and outwards and if strength or coherency be exceeded, movement down slope must occur, either of individual particles or of larger or smaller aggregates of particles. The net result is slumping, sliding, heaving or flowage until lodgment is attained. Where sizeable blocks move as a unit down a slope they break loose from the unmoved part along a surface concave outward and upward, the mass rotating as it moves until the outer upper front end of the mass is projected upwards leaving a depression on the surface or sag directly in front and below the surface of breakage. At certain places, such as the west front of Slim Buttes south of J. B. Gap and the southern broader part of East Short Pine Hills (seen well in the aerial photographs) long narrow slivers of slump blocks exist, movement having occurred on several curved concave upward planes, thus:

Fractures in the volcanic ash are nearly vertical (perpendicular to its flat upper surface) as will be seen in Plate 2. Masses break loose, since they have no side support, and either fall, or lean outwards at their tops in columns or walls until they finally topple over, breaking into pieces when they hit the ground below. Such unstable masses occur at present at the northwest corner of north Slim Buttes, also at the southeast corner about a mile northeast of Reva Gap and at the southwest corner of West Short Pine Hills. The greatest amount of downward sliding occurs when the total amount of steep declivity is greater and also where the greatest amount of moisture is retained; these chance to be north-facing slopes of north Slim Buttes and the great piles of slide rocks on the north sides of North Cave Hills and Table Mountain. In Sec. 20, T. 19 N., R. 18 E., at the north foot of the steep declivity of the north flank of north Slim Buttes a tilted block of Oligocene 500 feet wide, a half mile long and 125 feet thick is lodged in the bottom of a narrow valley. The nearest Oligocene in its original position lies at an altitude

200 feet higher and 3/4 of a mile to the south. In the southwesternmost spur of West Short Pine Hills, near NE corner Sec. 35, T. 17 N., R. 1 E., as shown in Plate 3, a southward-tilted block of Oligocene, in the saddle between the spur to the west and the main mesa to the east, is dropped down below the Hell Creek to the west along an eastward dipping fracture, while higher to the east, the west edge of the main mesa is walled by castellated volcanic ash.

The backward recession of the bounding cliffs of the mesas is quite a rapid process but it would not be except for the incoherence of the fallen and sliding material which must be disintegrated into small pieces and removed at a rapid rate by wind and water in motion, else a low slope would form covered with slide and fallen material protecting the table-land edges from further recession.

Rock falls and slides take place every year upon melting of winter snow and during or after heavy rainfalls. Mudflows are rather common in the bentonitic and loessial Hell Creek, which in places subsides bodily on spurs between ravines along well marked fractures though more generally it is too incoherent to move in a large solid mass.

There are places in the Ludlow outcrop where more indurated fine sand slabs have subsided at various angles up to the vertical or where on interravine spurs the plate has subsided to greater extent increasingly lower down the slope, lifting in the process the edge of the non-subsiding part.

WORK OF THE WIND

It should be apparent that in places where rocks are mainly loose or relatively incoherent aggregates, where moisture supply is so sparse that ground surface is bare or sparsely covered with vegetation and where in winter there is a combination of dryness and relative strong wind intensity, the ground being too dry to freeze, much material is swept away by the winds to accumulate wherever it lodges in place where vegetal or other cover or protection from wind prevents it from being again picked up and transported. Also, it is easy to see that a winnowing effect goes on, the fine silt or dust-sized particles being carried farther and in weaker air currents than particles from the size of sand upwards. We have spoken of the widespread loess cover in Harding County, to be attributed largely to grass cover in untilled areas in years of rain and snowfall adequate for growth of grasses, sage brush, or creeping prickly pear cactus. In drier years the surface is less protected by vegetation and then deflation (wind erosion) takes place where eolation (wind deposition) occurred in times more propitious.

Nevertheless, even in times favorable for the growth of grasses deflation hollows or "blowouts" are scattered throughout the county from highest table land to lowest valley. In such water accumulates after heavy rain or melting of thick snow, provided the soil is not too permeable to prevent total loss by seepage of the water. Wind and sun evaporate such shallow pools. There is also a great deal of shallow wind etching of the surface other than the undrained blowouts, and this is prevalent wherever the prickly pear grows. Likewise, as already noted, less consolidated parts of such poorly coherent sandstones as the thick basal Tongue River in the Cave Hills are scooped out by the winds leaving alcoves, recesses and small grottos or caverns. Many "hoodoo" or monument isolated pinnacles or columns are left where winds have swept away less coherent surroundings.

TERRACES AND GRAVELS

There is an extensive terrace along Little Missouri River in North Dakota where the rejuvenated river has intrenched its course just north of Harding County. The gravels are igneous and metamorphic rocks which may have come altogether from basal White River Oligocene deposits or a part of which were derived in Pliocene or Pleistocene times from erosion of pre-Cambrian rocks in either the Black Hills or Bighorn Mountains. It is unlikely that they came from the Black Hills unless at a former time Spearfish Creek drained into the Little Missouri, since no tributary of the present Little Missouri nor of the Belle Fourche upstream from its elbow of capture of the former Little Missouri reaches back as far as the pre-Cambrian exposures of the Black Hills. The highest places in Powder River Basin west of the Black Hills are the Pumpkin Buttes covered in their summit flats by igneous and metamorphic boulders and pebbles, the remnant of a former high depositional plain built up by streams from the Bighorn Mountains of Wyoming. In Harding county the loess cover lies deep over the Little Missouri Basin but is doubtless underlain in the lower flood plain area by the sheet of gravel exposed in the terraces in Bowman County, North Dakota.

The gravel found in terraces in Grand and Moreau river drainages in Harding County consists only of hydrous iron oxide concretions from Hell Creek and Fort Union Paleocene formations, of silicified wood mainly from the Tongue River, and of the fine grained quartzite or chert ("tripolite"), also of the Tongue River. These gravels, after removal of overlying loess covers, have been used for roads in some pits east of the Buffalo-Bowman highway along Bull Creek, the main tributary of South Fork Grand River. In these gravel pits occur disintegrated fragments of fossil tusks of either mastodon or elephant.

Pediment slopes outward and downward from the foot of the cliffs of south side West Short Pine Hills and north side East Short Pine Hills, composed of light colored debris of Oligocene and overlying volcanic ash, mantled by loess, have been dissected by intrenchment of ravines and gullies at heads of South and North Forks of Moreau River. The same dissected pediment evidently is the one on the north side of north Slim Buttes where the trenching seems to belong to the same erosion substage as that cutting the present flood plain fifty feet below the terrace along South Fork Grand River to the north.

A terrace and intrenched meanders along North Fork Moreau River in the vicinity of Govert post office, extends down stream, the terrace having been traced to the junction of the two forks of the river. This is the terrace whose surface as well as that south on the adjoining uplands is strewn with angular wind-abraded blocks of the Tongue River chert or quartzite residual from that formation which formerly covered the area.

STRUCTURE

Determination of structure of surface rocks in Harding County is possible only where exposures are good and then only where the rocks have not flowed nor settled. Dips or inclinations of surface rocks have to be consistent both in amount and direction. These three essentials rule out of consideration a large part of the county.

As stated before, three arches (anticlines) were found in the northwest quarter of the County by Emerson Parks and others and later contoured by Moulton and Bass. The western of these upfolds, named the Camp Crook anticline, was mapped as closing, or ending, to the south in the vicinity of the town of Camp Crook. However, loess covers nearly all bedrock in Townships 18 and 19 N., R. 1 E., and the writer has been able to map the axis of an upfold, apparently the southward continuation of the Camp Crook anticline, from Sec. 11, T. 17 N., R. 1 E. to Sec. 36 in the same township, south of which it again becomes covered by loess capping the rock pediment of Fortyeightmile Creek. The east flank is covered by the Cenozoic of West Short Pine Hills; the west flank is steep and near the axis the west dip averages about 6½ degrees. Since the base of the Fox Hills lies only a short distance beneath the surface, core drilling will easily and relatively cheaply define the necessary details of the structure. The same applies to the structure found in the central eastern half of the county which may be called the Slim Buttes anticline, though deeper drilling will be necessary to reach the base of the Fox Hills beneath the Cenozoic cover of the Slim Buttes.

On page 91 of "The Lignite Field of Northwestern South Dakota", Bulletin 627 of the U. S. Geological Survey, 1916, under description of T. 20 N., R. 7 E. there is the following statement: "In general the rocks show a very slight northeasterly dip, but there seems to be a gentle anticline trending north in the northeastern part of the township, which gives in Sec. 22 a distinct local northwest dip of more than three degrees." Also, Rothrock and Searight in 1936 mapped an area of northwest dips diagonally across T. 19 N., R. 7 E. Work by the writer in 1951 found the two to be parts of an extensive arch whose ridge or top axis extends southwards across the east part of Townships 19 and 20 N., R. 7 E., in which the axial plunge is to the north. Apparently the axis continues south under the Cenozoic cover of Slim Buttes and may be the same structure as found by the writer in the northwest quarter of T. 15 N., R. 8 E., where the top of the Pierre clay is exposed beneath the Fox Hills sand along the valley of North Fork Moreau River.

Maps of both these arches are included in this report. There appears to be another arch, mainly in Butte County, the west dip on which is found on the Pierre-Fox Hills contact along Sand Creek in Sec. 31, T. 15 N., R. 6 E. A south-southwest dip of 6 degrees in NW$\frac{1}{4}$, sec. 9, T. 18 N., R. 8 E., which flattens to the southeast, may be near the south plunging end of the Slim Buttes uplift but since it is on a ridge sloping downwards from the south scarp of North Slim Buttes it is not free from suspicion that it may be a landslip.

The top of the upfold on North Fork Moreau River is near the middle of the east half of Sec. 17, T. 15 N., R. 8 E., the top of the Pierre clay falling 90 feet southeastward in about 4 3/4 miles downstream from that point.

Square top Butte, near south line Sec. 26, T. 21 N., R. 27 E., capped by basal Tongue River sandstone, shows an abrupt westward dip near its west end; it is the farthest north the top of the upfold can be seen on the surface. Dips to north and east indicate the fold here plunges northward. The contours on the map in Sec. 1 and 12, T. 20 N., R. 7 E., and 6, 7 and 8, in T. 20 N., R. 8 E. are at 10 feet intervals, the others shown having a 25 feet interval. The top of the upfold can be easily seen also in Sec. 14, T. 20 N., R. 7 E. and in S$\frac{1}{2}$, Sec. 21, T. 19 N., R. 7 E. Aside from the dips and contours shown on the map no other exposures affording good structural data are visible. The same statement is true for the other two maps.

DISCUSSION OF OIL PROSPECTS

We know at present in Harding County four upfolds (arches or anticlines) in the rocks favorable for accumulation of oil and a thickness of rocks beneath them averaging 8000 feet containing permeable zones in which oil or gas can accumulate. It is known also that in the State Royalty boring 6 miles south of Camp Crook the geologist on the boring determined shows of oil or gas at more than a dozen different depths, two of which were in the Newcastle and Lakota sands and the others scattered through Paleozoic rocks from 5500 to 7860 feet depths. The St. Peter sandstone at depths of 7820 to 7860 was saturated with oil but no test for production was made there or at any higher horizon. In default of such actual testing it is impossible for anyone to be certain whether or not profitable production could have been attained in the Camp Crook boring. Likewise it is a disputed point at present whether any oil field in the State of South Dakota can be profitable if found, because the State's population is very sparse, consumption of petroleum products or natural gas being relatively very small and cost of transport to adequate markets being great.

Oil, like gold, has a habit of being "where you find it" but nevertheless no one has succeeded yet in overcoming the law of gravity. That law means that if underground water in the rocks is free to move now or has been free to move in past times from places of intake to places of discharge oil and gas, lighter than the water, can accumulate only under trapped or stagnant conditions at levels in rocks above which waters move. Spaces within the rocks above such levels will fill with oil or gas, provided such are present. If no water is present in the rocks oil will run down grade and accumulate in the bottoms of troughs or downfolds. In some cases such as organic or inorganic "reefs" in either limestone or dolomite or equally permeable rocks in lens-shaped bodies oil or gas may accumulate with or without any water being present. But in most cases the great accumulator of oil or gas is underground water under artesian (hydrostatic) pressure, and that is precisely why upfolds (anticlines or domes), sealed up and therefore impermeable fractures ("faults") in rocks, so-called "wedge-edge" or "stratigraphic traps"--essentially merely decrease to zero in permeability upslope in underground rocks--and various kinds of permeable "reefs" are sought for in oil prospecting.

Nature is ever wasteful of resources. Dr. G. M. Lees, commenting on the Persian Gulf region, judged capable of producing from 5 to 10 times as much oil as the entire United States, remarks that "The mountain belt of Iraq and Persia is really a gigantic oil graveyard. Much of its oil escaped millions of years ago, and the oil now remaining underground is probably only a small fraction of the one-time total". In California, Mexico, South America and Indonesia, where oil production is obtained from rocks of later geologic times, from Cretaceous to Pliocene, the story is the same--much more oil lost through fracturing and erosion than remains in existing rocks.

There has been more time for wastage of oil from Paleozoic rocks than from those of later Mesozoic or Cenozoic age. Fundamentally this is the main reason why Paleozoic rocks have not been so productive as the younger. Paleozoic oil production occurs in the main where those rocks remain little disturbed from their original position and in two regions, namely, the great interior lowland basins of the United States and Canada and the platform area of lowlands of European Russia, with some possibilities as yet untested in broad lowland, little faulted basins of northwest Australia and the western flank of the great Parana Basin of southern South America.

Possibilities for oil production in South Dakota exist in the Sundance of the Jurassic and the Newcastle-Dakota-Lakota group of sands in middle and lower Cretaceous as well as in all members of Paleozoic rocks. Paleozoic possibilities merit further consideration. Though there is little doubt some Paleozoic production should be had it is premature to assess its ultimate possibilities. We limit further discussion to "wedge-edges" or "stratigraphic traps", the other kinds of structural control of accumulation being simple and well understood.

One kind of stratigraphic trap exists down the slope (or dip) from a seepage where solidifying of oil residue at the surface has afforded a seal for oil-bearing rocks. This type does not exist in South Dakota, where there are virtually no surface seepages. The most productive of all stratigraphic traps is where an advancing or transgressing impermeable formation covers entirely a permeable zone which thereafter becomes oil-bearing. Unfortunately, this is quite rare, only two really important examples being known, namely, the east Texas and east shore Lake Maracaibo, Venezuela, oil fields, both of which rank among the world's greatest producers.

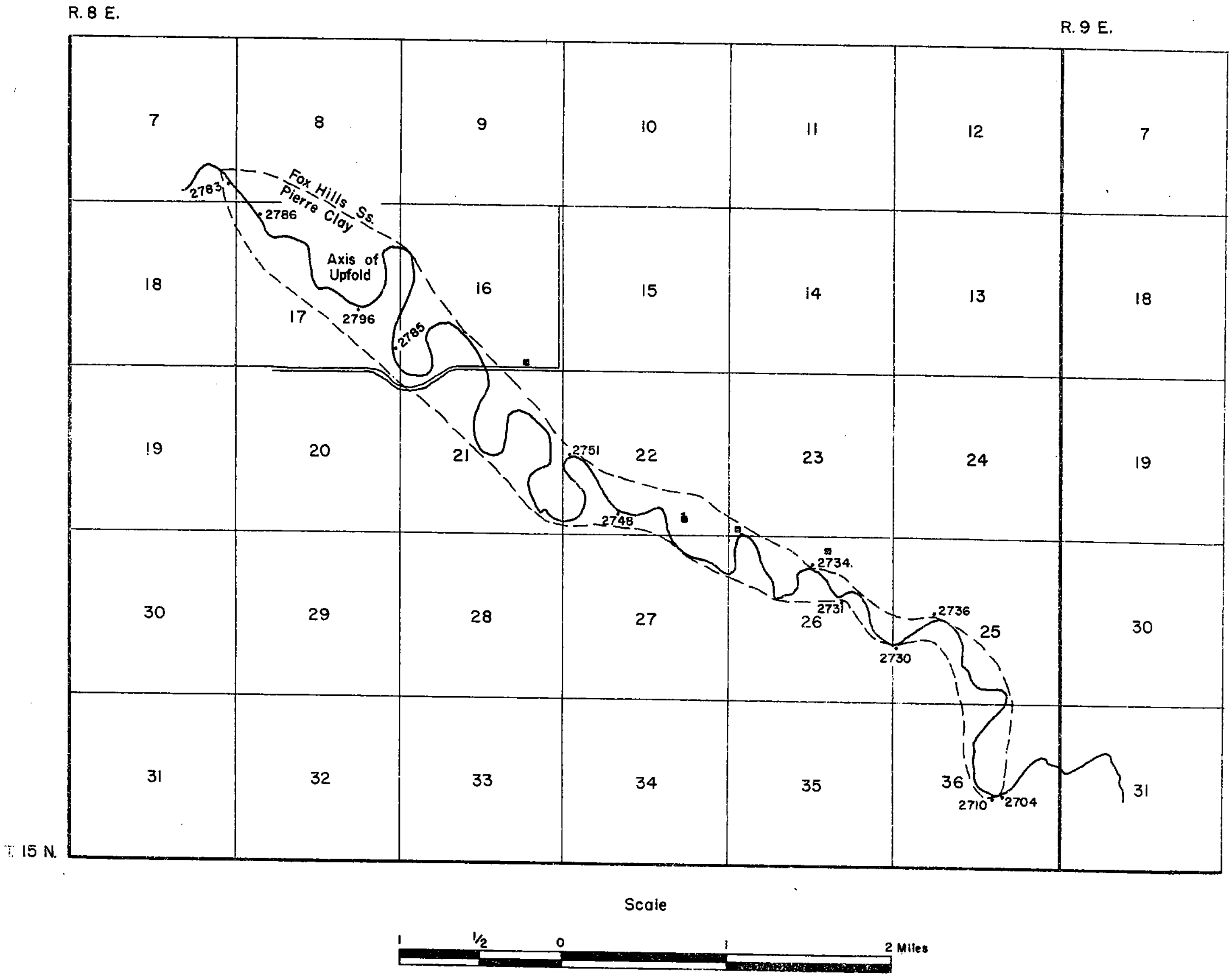
Thickness of Paleozoic beneath the base of the red beds, increases from south to north in western South Dakota from 820 feet on the Chadron uplift in Shannon County to nearly 3900 feet in the Shell Homme boring in the Dakota Basin in northwest Perkins County. Since the Paleozoic is thicker in the trough of the Dakota Basin than over the Sioux quartzite or Black Hills uplifts it is evident that, relatively speaking, either the uplifts were rising or else the basin was sinking during that era or else the one rose while the other sank; the final result would be the same.

Thicknesses from top of Minnelusa downwards to top of St. Peter in the Harding and Perkins County and the Little Beaver Dome, southern Baker-Glendive arch, borings are as follows: 3120 in Shell Homme 1, in Dakota Basin; 3370 in Carter N. P. 1, Little Beaver Dome of Baker-Glendive arch; 2500 in State Royalty 1, Camp Crook arch southern extension; 2150 in Northern Ordnance 1, Butte-Harding county line and 1140 in outcrop near Deadwood, in Black Hills. These figures apparently indicate that the Baker-Glendive arch is solely a Cenozoic (Laramide or Cordilleran) structure while the Camp Crook arch as well as the Black Hills are uplifts whose beginnings go back to pre-Cambrian.

The only really impermeable caprock shale in the Paleozoic succession is the Black River (Decorah-Platteville) bentonitic and chloritic green shale overlying the St. Peter sandstone which may account for the 40 feet thick oil saturation in that sandstone on top of the structurally favorable Camp Crook arch. Nevertheless, permeability is, like most things, a relative term; some limestones and dolomites or in fact, any dense, completely cemented rocks may be impermeable and we find in certain horizons in this particular Paleozoic succession clayey limestones and shaly dolomites which are likely impermeable. For example, there was oil in the Carter N. P. No. 1 well on the Baker-Glendive arch in the top of the Ordovician limestone just below a green clayey dolomite whose base is at 8300 feet depth. The dense fine grained bluish anhydrite of the "Charles" likewise affords an impermeable cap in the same boring and two adjacent Montana-Dakota Utilities Co. wells, oil occurring in the limestone just beneath and having been produced for 15 years in the latter two wells. Most of the oil shows found in borings in the two arches are in the Ordovician, but oil horizons occur also in the "Charles" and Madison.

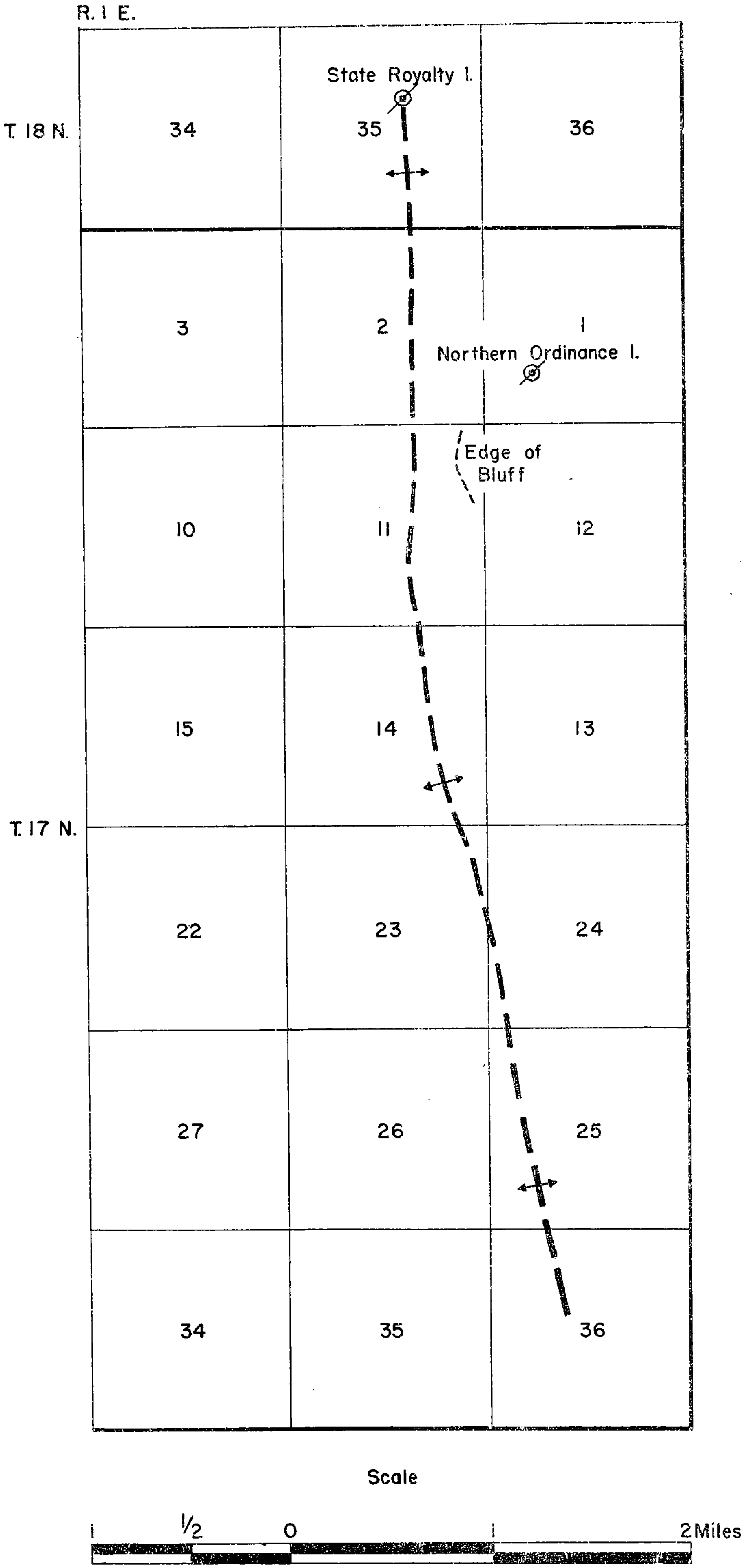
The "Charles" and the Minnelusa, both with impermeable caprocks, cover entirely the underlying rocks. Such places as where the middle limestone of the Ordovician wedges out on the axis of the Camp Crook anticline somewhere south of the State Royalty boring, may afford a favorable trap for oil.

Although 3 different oil intervals occur in Montana-Dakota Utilities and Carter Northern Pacific No. 1 wells on top the Baker-Glendive arch and they are but some two miles apart only one of the zones is common to them, namely the one just beneath the middle "Charles" anhydrite. The situation is characteristic of oil accumulation in limestone and dolomite where local permeability or fracturing determines the occurrence. It is obvious that correct prospecting should be done in dry holes (those not filled with water or drilling mud) with cable tools, else productive horizons may be overlooked quite readily.



Anticline crossing North Fork Moreau River, T. 15 N., R. 8 E. South East Harding County South Dakota.

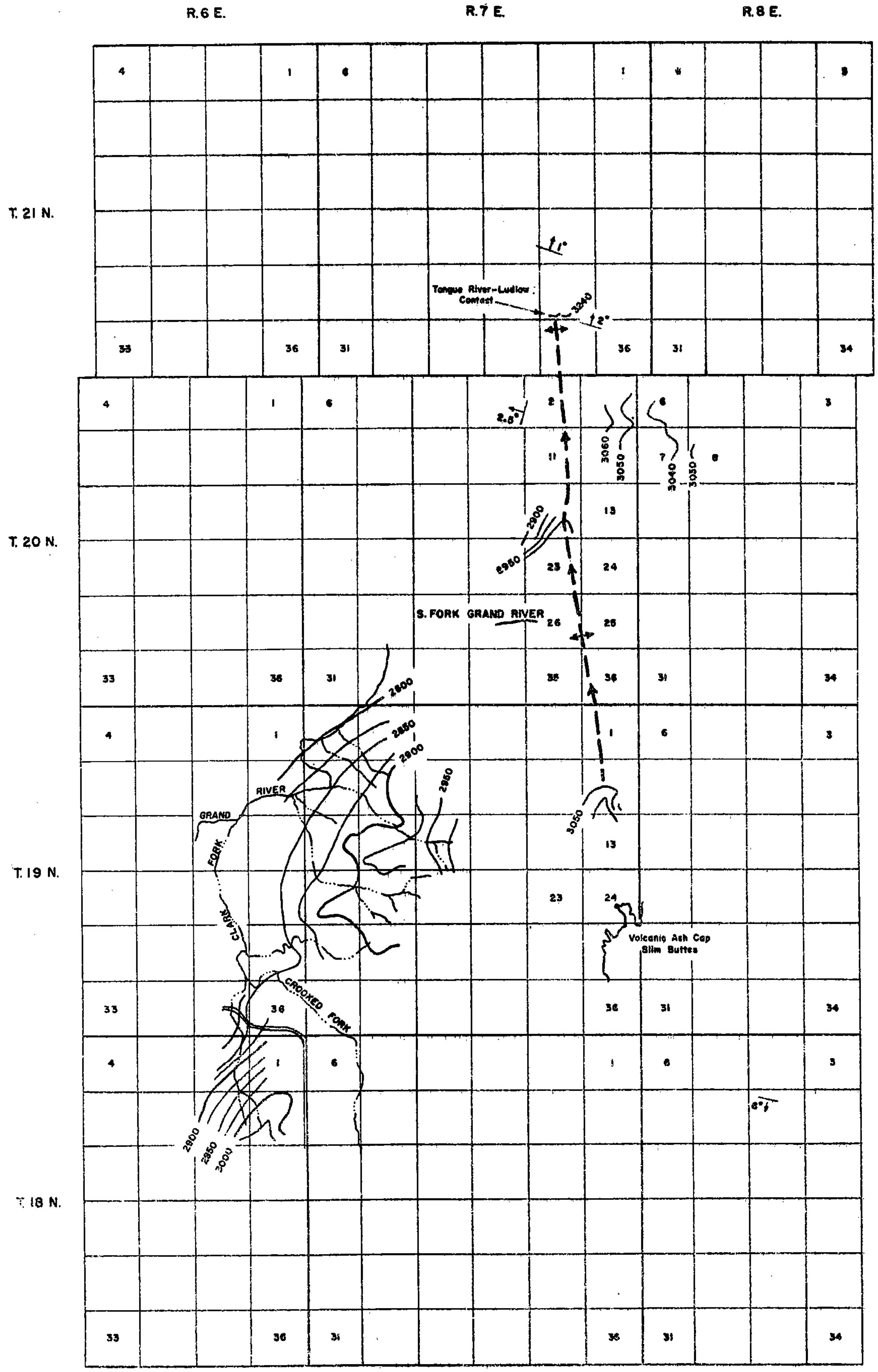
Plane table altitudes based upon barometric datum of 2700 feet.



Anticlinal axis south of Camp Crook.

Axis of Anticline

Abandoned boring



STRUCTURE MAP OF NORTH END SLIM BUTTES ANTICLINE, HARDING COUNTY, SOUTH DAKOTA

25 Foot structure contours on Cretaceous-Paleocene contact except on higher sandstone near NW corner of T. 20 N., R. 8 E..

Axis of anticline

Arrow in direction of dip of rocks.

Scale

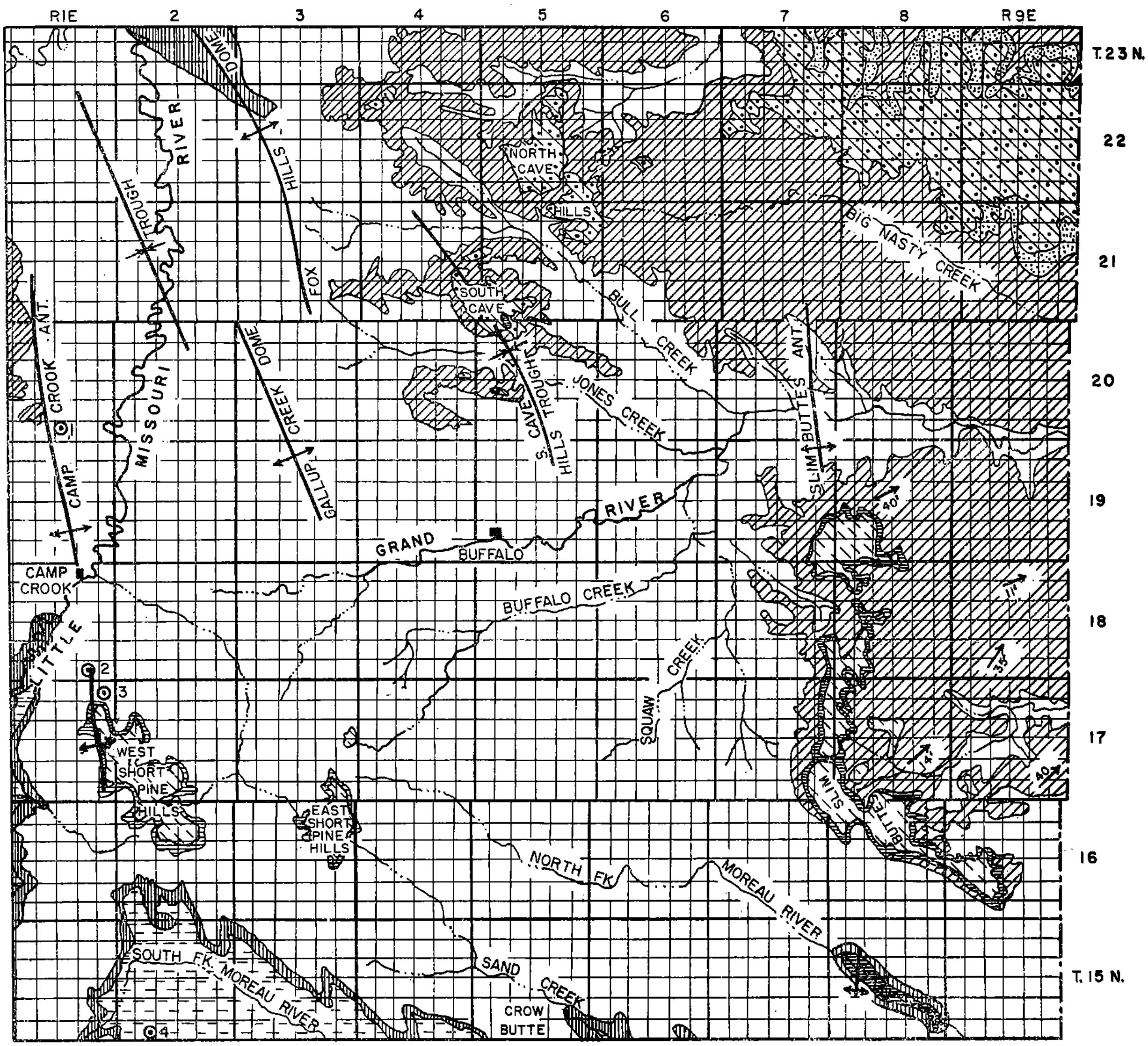
Miles

1 0 1 2 3

GEOLOGIC MAP

OF

HARDING COUNTY SOUTH DAKOTA



LEGEND

GEOLOGY

- Volcanic Ash (Upper Miocene)
- White River Formation (Oligocene)
- Fort Union Formation
- Ludlow-Cannonball Member
- Hell Creek (Lance) Formation
- 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
2 State No. 1
3 Harding School Land No. 1
4 Government No. 1

SCALE IN MILES

6 3 0 6 12