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STATE OF SOUTH DAKOTA
George T. Mickelson, Governor

STATE GEOLOGICAL SURVEY
E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

No. 64

THE PENNINGTON-HAAKON COUNTY CENTRAL BOUNDARY AREA WITH GENERAL DISCUSSION OF ITS SURROUNDINGS

by

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Vermillion, South Dakota
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WITH GENERAL DISCUSSION OF ITS SURROUNDINGS

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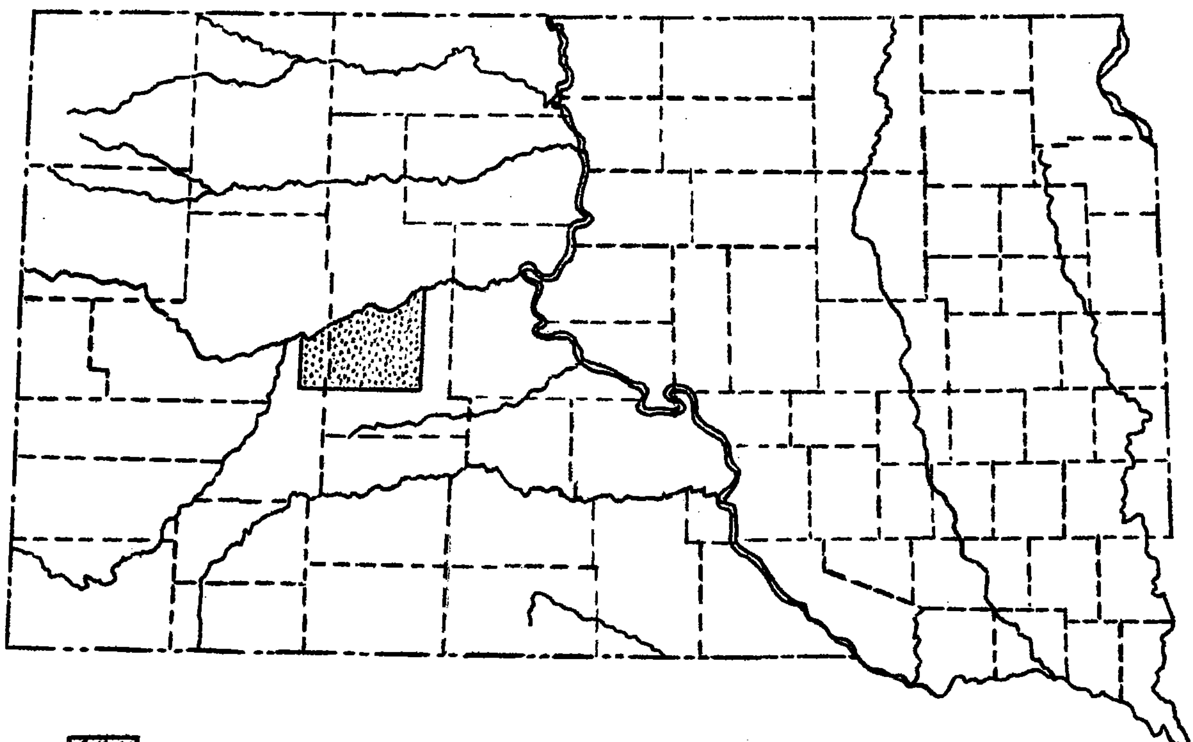
C. L. BAKER

INDEX MAP



 Area Covered By This Survey.

TABLE OF CONTENTS

Page

The Pennington-Haakon County Central Boundary Area
with general discussion of its surroundings

PHYSIOGRAPHY

The area described herein is situated half-way between the center of South Dakota and the Black Hills. Geologically, it is part of the center and trough of the depositional and structural Dakota Basin. Topographically, it is a plain, flattish on top, and sloping outwards at the edges, forming part of the drainage divide between the Cheyenne and Bad Rivers.

The interriverine divide is a loess-covered plain, covered largely by wind deposits, on which are scattered a number of shallow undrained depressions, scooped out by the wind, a part of which are now in the process of being drained by the headward encroachment of outward-flowing drainage. The flat divide area is a peneplain, presumably of earlier Pleistocene date, developed largely on Upper Cretaceous sandstones. Remnants of Cenozoic deposits, now preserved at lower altitudes, namely between headwaters of West Fork of Plum Creek and of the Bad River on the east, comprising Grindstone Buttes and a few small outliers to the north, and occupying a shallow syncline in the west part of the area, west of the boundary between the counties, rise in ridges, buttes, and mesas above the more general flat, suggesting that part of the plain may be exhumed by later erosion from a peneplain developed by Lower Oligocene time. The plain attains an altitude of 3000 feet or more north of Wall.

Below this plain is a lower surface whose altitude close to the upper plain is about 250 feet less than the latter; the lower plain slopes downwards along the creeks towards Cheyenne and Bad Rivers. This is a surface of old age valleys with broad, flattish basins reaching to near the headwaters of the drainage. Near Milesville and on West Fork Plum Creek this surface extends up to about 2350 feet altitude.

The old age basins are exceptionally broad and extensive at the head of Deep Creek, a tributary of the Cheyenne

River, and Poeno Creek, draining to Bad River, although nearly as well developed on Mix-His-Food and Ash Creeks of the Cheyenne drainage. The headwater ravines of these basin-like valley heads are young ravines flowing down the slopes or scarps separating the summit plain from the basins and now intrenching by gradual headward lengthening the summit plain.

The old age surface is extensively developed in flats between the creeks south of Cheyenne River in northern Haakon County, where, because the inter-river divide is a surface of non-resistant upper Pierre bentonitic clay, it merges with gentle slopes into the divide. The surface is covered with gravel of pebbles and boulders up to eight inches long of crystalline rocks of the Black Hills, abundant chalcedony from volcanic ash deposits and pink chert from the Amsden formation of the Powder River Basin of Wyoming. The gravel deposits reach upstream along West Fork Plum Creek to the middle of the east part of Township 6 North, Range 21 East, where they attain an altitude of 2300 feet. This gravel sheet contains the most extensive and best quality shallow underground water in the area, producing a perched layer of sheet water above the impermeable Pierre clay. The gravel is generally covered on the uplands with wind-deposited loess, the total thickness of the two being reported to reach up to 40 and 50 feet. The loess of the broad interstream flats is the most extensive area of fertile soil to be found in the region.

The old age second cycle topography, eroded below the peneplain of the interriver divide, was developed, at least in its later stage, during the time when Pleistocene ice sheet extended southwards east of the present Missouri River, forming a dam for the Cheyenne and Bad Rivers which was the local base level producing the old age valleys. Its gravels contain Pleistocene vertebrate fossils; a long crowned upper molar of horse (Equus) was found by Mr. Finch in Section 13, Township 6 North, Range 21 East.

Meltwater from a Pleistocene ice sheet cut the present course of the Missouri River, which rapidly entrenched itself in the extremely poorly resistant Pierre shale. This has produced along the Cheyenne River a downcutting of the present drainage lines below the old age valleys to a total depth of 600 feet along the lower course of the West Fork of Plum Creek. This latest rejuvenation has produced a young topography of deep, narrow ravines, dissecting the Pierre clay into the badlands formed along the present Cheyenne River tributaries. One extensive terrace capped by coarser deposits of fragments of Pierre concretions and silicified ash beds and eolian loess extends along West Fork Plum Creek between its north bend and the northeast quarter of Township 6, North, Range 21 East. Two extensive terraces, lower than the old age flat, occur at the northwest corner of Haakon County. Along Bad River, the old age valleys have been intrenched during the present erosion cycle to a short distance above the confluence of the North Fork with Cottonwood Creek below which, from Philip to Midland, are several terraces capped with gravels and boulders of the same kinds of rocks found capping the old age surface of the Cheyenne River Basin. These terrace deposits contain bones and teeth of Pleistocene vertebrates.

There is a noteworthy difference in surface land forms between the sandstone capped river divide and the interstream ridges to north and south of it in western Haakon County and the remainder and much the larger part of that county. In the western section is a butte and mesa topography with its caprocks of relatively resistant sandstone contrasting with low gentle, fairly even contoured slopes developed on Pierre clay in most of the rest of the county with the exception of the north part adjacent to Cheyenne River, where loess and gravel-covered old age surface breaks off abruptly into ravines and gullies where the drainage of the youthful erosion cycle has cut back to the edge of the depositional plain.

The caprock of Grindstone Buttes is a thin layer of crossbedded pebbly sandstone. The base of the Cenozoic remaining in the syncline extending diagonally across the northwest fourth of Township 2 North, Range 17 East, in central-east Pennington County, is thinly laminated ashy, limy and silicified deposits of a lake, pond, or swamp, containing small fresh water molluscan shells, and fishes, overlain by bentonitic clays, mostly light grey but in part varicolored like the Chadron clays of the Oligocene. In other parts of the area there are present residual boulders of varying sizes of highly silicified rock containing fresh water snails. Apparently at a former time the area was covered by Cenozoic rocks, now nearly all eroded away.

Summarizing the major events in the development of the present landscape we have a flattish eroded surface cut on Upper Cretaceous rocks and covered subsequently by Cenozoic deposits. Subsequently the Cenozoic deposits were eroded from all but two small areas during the development of a peneplain, Upper Cretaceous with the remnants of Cenozoic remaining as erosion residuals. During a second cycle of erosion an old age topography was developed at the end of which were formed very broad sub-flat basins at the heads of tributaries of the Cheyenne and Bad Rivers at altitude about 250 feet lower than the general level of the former peneplain. Residual gravels of Black Hills rocks were concentrated on the lower parts of the old age surface in both drainages. Since the present Bad River drainage basin does not extend into the Black Hills, the Black Hills derived gravels must have been spread over its drainage system by streams previous to the existence of the present north-south course of Cheyenne River west of Wall. The Cheyenne River derives most of its water from Black Hills tributaries but during the second known erosion cycle it apparently already drained part of the Powder River Basin of eastern Wyoming. In the present subcycle of youthful drainage the cutting of the present trench of the Missouri River across South Dakota has caused, by rejuvenation, rapid deepening progressively upstream of the Cheyenne and Bad Rivers and their tributaries' drainage courses dissecting the very poorly resistant Pierre clays into the badlands, especially characteristic of the Cheyenne River drainage basins. This dissection amounts to a maximum of 600 feet.

All three cycles are of relatively short time duration, since the bedrock formations possess very little resistance to erosion and differences in altitude of the three cycles is relatively small. The total amount of relief is from a maximum of 3000 feet altitude in the river divide of central eastern Pennington County to 1580 feet along the Cheyenne River, northeast corner of Haakon County.

The streams radiate away from the river divide area of central western Haakon County and central eastern Pennington County. Because altitudes determined by plane table surveys show that the sandstone beds rise in altitude about 300 feet in a westward direction from east of the middle of Township 3 North, Range 19 East, to the southwest part of Township 2 North, Range 17 East, and from the latter place lower northwards at least to the north line of Township 3 North, Range 18 East; it is evident that the drainage is consequent or downgrade down the dip in the rocks. However, the time when this arch was made has not been determined other than that it is post-Oligocene, which is indicated by the syncline developed in Oligocene or later deposits in the northwest part of Township 2 North, Range 17 East. There is a possibility that the arch was formed at as late a date as the Pleistocene, though it may be correlatable with folding within the Miocene known to exist in northwestern Nebraska.

The plains area of the western half of South Dakota shows that tributaries of the main eastward-flowing rivers have northwest-southeast courses regardless of their junctions with the main rivers. Consequently those draining the south sides of the river basins join the rivers at angles acute with the downstream whereas those entering from the north sides have normal obtuse angles downstreamward. Erosion of a land area can be accomplished by either running water streams, by wind or by glacier ice. Since the south half of the region has not been glaciated during the Pleistocene when the drainage lines were made glacial ice is eliminated. If the positions of the valleys were entirely results of erosion by running water it would be necessary to assume they were formed on an initial regional slope downwards either in the southeastward or northwestward direction after which it is conceivable that the major rivers were produced by an eastward downtilting greater than amount of gradient of tributaries either to southeast or northwest. Such late eastward tilting leading to the development of eastward-flowing rivers would have had to reverse the flows of half the tributaries, that is, if drainage was originally to the northwest those tributaries now flowing southeastward would have been reversed or if drainage was originally southeast those tributaries now flowing northwestward would be reversed. For the complicated sequence of events thus postulated there is no evidence. For example, if such had been the fact, wind gaps, that is, saddles or former valleys should still persist across the divides between the different river drainage basins, but such are not known. Furthermore, the creek courses should converge in original downstream direction either northwestward or southeastward, depending on original direction of flow. This, also, is contrary to fact: the tributaries have markedly parallel courses.

These plains are in the belt of the planetary westerly winds, in which they have remained for times far longer than that lapsing since the present surface began to be formed. The strongest winds in western South Dakota blow from the northwest. There still exist well distributed through the region, shallow wind-scooped hollows (similar to the dry lakes of the Staked Plains of west Texas and east New Mexico) which have their larger dimensions northwest-southeast. In this particular area such are found on the summit peneplaned area of the Cheyenne-Bad River divide, where they are most numerous, and also in the wide headwater basins of Poeno and Deep Creeks, also on the loess-covered flat south and west of Milesville, and on the terrace of West Fork of Plum Creek between its north bend and the old age gravel and loess-capped surface of northern Haakon County. In the latter area, mainly in Township 5 North, Range 22 East and to the southwest and west, are a number of parallel narrow-crested northwest-southeast trending ridges gradually sloping down until they merge into the terrace flat, separated by parallel valleys with three wind-eroded hollows on the terrace in the section just north of the northwest corner of Township 5 North, Range 22 East. The ridges are eroded from a very tenacious bentonitic Upper Pierre clay which, when dry, forms a compact, hard gumbo, with all essential properties of the adobe of the Southwest. When this clay is thoroughly wetted it becomes a sticky ooze capable of flowing like a viscuous pitch downward on slopes of relatively low declivity. Consequently, the drainage courses between the ridges are clogged with it, the streams wandering in intricate meanders through their overloaded courses.

Among the deeply incised creeks trenching the wide terrace flat of the old age cycle in the north part of Haakon County five are perhaps worthy of note. These have markedly simple, straight courses with narrow drainage basins and join the Cheyenne River at a right angle. Four of them are north to northwest of Milesville in the midst of an area of wind-eroded hollows. The other is Deep Run Creek next east of the East Fork of Plum Creek. All five, as well as the others north of the Cheyenne-Bad River divide, if normally developed by headward gully and ravine development upon the flattish plain of the old age surface would flow north-northeast instead of north-northwest as they do.

In regions of strong, prevalent one direction winds, and abundant amount of loose fine material for wind to transport and deposit, such as central and northwestern Australia, the south Texas coast and practically all the large desert regions, long dune sand and clay ridges form parallel to the strongest wind direction. Between the ridges are long, narrow troughs swept bare of wind deposits which become the surface water courses wherever there is sufficient water available. During the Pleistocene glacial epochs there existed to the northwest of the Dakota plains the Cordilleran ice sheet, extending from the Missouri River to the Pacific Ocean, and to the south a fairly extensive ice cap in northwest Wyoming and central-southern Montana. Winds descending southeastwards from the ice (chinook or foehn winds) would be stronger, colder, and drier than present winds from the same direction. The cold would prevent, or at least inhibit greatly, growth of vegetation. The dryness would prevent freezing together of particles of soil and surface-weathered rock. Both would increase supply of loose, finer materials which the winds could move. As the latter reached lower altitudes, because of increase in friction, dying out in intensity and warming, conditions would change, leading to deposition of materials formerly in transport by the wind. South of the White River in southern South Dakota and northern Nebraska is the present extensive sand hill area. One can ask whether in former time, before the climate became wetter and warmer subsequent to final melting away of the ice sheets, the sand hill area may not have extended more widely over western South Dakota and the wind and cold being then greater farther northwest the wind deposits may have been swept away to accumulate farther south before grass again grew to prevent removal of the wind deposits. The wind formerly being stronger in western South Dakota, its deposits would accumulate in long northwest-southeast ridges separated by troughs.

The above is possible, but the "yardang" process, especially prevalent in the Tarim Basin of central Asia but found in other dry areas, such as the Mohave Desert of southeast California, may have been the prevalent one during the glacial epochs in this region. This process is prevalent wind scooping or trenching (deflation) instead of wind deposition. It would be especially favored in western South Dakota south of the area covered by glacial drift because all the surface outcropping rocks are high in bentonite, a highly flocculent, fine, loose, colloidal material when dry, as easily removed by the wind as the loose saline and alkaline fine lake and wind sediments of the Tarim Basin.

Bentonite swells greatly by absorption of water, when the latter is available. Although in the aggregate markedly impermeable to water in the interior of the mass, the outer surface disrupts by swelling and this being calcium bentonite, which does not form a coherent jelly, but slakes into loose fine particles, it is easily transported by either wind or water in motion. Therein lies the reason why the Missouri River means "The Big Muddy" in the Sioux Language, because its water, so long as it is fairly pure without sufficient dissolved mineral content to form an electrolyte capable of precipitating the bentonite carried in suspension, is carrying much fine solid colloidal matter in suspension. And, also, incidentally, it explains why dust storms are frequent during drier weather.

A wind-scooped depression once formed collects surface water and retains it longer than its higher surroundings. This water can't seep through the impermeable floor but it is depleted or exhausted by evaporation. When it dries up much loose dust remains, easily picked up and removed by the wind. This, combined with more dust formation (powdering or flocculation) in the depressions where there is more moisture for disintegration by swelling and slaking, tends to perpetuate the wind-scooped hollows, gradually making them broader and deeper. However, something else is going on. Sometimes, during exceptional rainfall, the depressions fill up and overflow at the lowest point of their rims. The overflow rapidly cuts a drainage channel through the weak bentonitic material, gravel, or loess. Besides, in the now prevailing stage of young valleys, rapidly extending and deepening in unresistant surface materials, heads of ravines and gullies cut back rapidly into the uplands and drain wind-scooped hollows. Some instances of this taking place at present may be seen on the river divide upland near the northwest corner of Township 3 North, Range 18 East.

Thus stream courses arise by integration or combination, following in the main depressions paralleling the prevalent northwesterly wind originally forming depressions with longer axis of the same direction.

Combining deposition by wind in parallel ridges with depression scouring in the same direction would lead in the end to the same results as either, namely, parallelism of the river tributaries in northwest-southeast direction, conditioning factors in this region being especially favorable for such a development.

Extending outwards from the divide between the rivers and between the creek valleys in central-western Haakon and central-eastern Pennington counties, namely in Townships 2, 3, and 4 North, Ranges 17, 18, and 19 East, are long, flattish surfaces, gradually tapering to points in downstream directions of creek flow. These flats are upper surfaces of consolidated thin sandstone beds, covered in part by a thin capping of loess and gravels, the latter being remains of Cenozoic rocks which once covered the area. Locally there may be present a lower sandstone layer which forms a bench or tread of a step on the slope between the upland flat and the bottom of the valley. One of these long and narrow intercreek divide flats extends northward as far as a point southwest of Dowling church and overlooks the wide valley flat of the second old age cycle of erosion, intrenched farther down the grade, farther north, by the young valleys of the present or third cycle of erosion. South of the river divide in the area drained by Mexican, Deadman's, Dirty Woman's, and Poeno Creeks, which are the headwater drainage courses of the North Fork of the Bad River in Townships 2 and 3 North, Ranges 17, 18, and 19 East, an observer standing on one of these interdivides, possessed of requisite good eyesight, adequately trained to perceive slopes of slight declivity, can note that the general slope of the intercreek surfaces is downwards to the southeast, which observation can readily be confirmed through the use of any telescopic lovelling instrument. However, when he actually surveys by tracing through the area one or more of these thin sandstone layers, determining their actual altitude at different places along their outcrops, disregarding as he must, in order to determine their actual structure all but the points of highest altitude, he finds that the sandstone actually slopes downwards, or dips, nearly due eastward. How, then, was the original false impression of southeastward dip derived?

In the course of his instrumental survey, if he has determined the altitudes of all the existing, visible outcrops of the same sandstone layer the field investigator has found that every outcrop interstream area appears to show that the sandstone has a structure of half a narrow arch, warped downwards towards creek courses on either side and downwards in the direction of creek flow at the downstream ends of the ridges but rising in altitude in the upstream direction as far as the sandstone can be found. Also, interdivide areas between the creek tributaries have the same hemi-arch structure with the axial ridge of the arch lowering in the direction of the surface slope between the tributary drainage ways and in their downstream directions. But the hemi-arches are not even or uniform surfaced; the upper surface of the sandstone being knobbed or hill-like in some places and sagging down into a trough or basin at other places.

In the course of the field study a rather painstaking examination, with determination of the altitudes of a definite horizon or layer in the rock formation, was made of the east side of the valley of the West Fork of Plum Creek (or Snake Creek) across Township 6 North, Range 21 East and the north half of Township 5 North, Range 21 East. Here drainage lines of the present young erosional cycle have cut deeply into the soft upper Pierre bentonitic clays, supplying many bare clay surfaces of varying degrees of steepness. We find here exactly the same fact as in the other area, namely, that the rocks slope downwards in the same directions as the surface of the slopes and the downstream course of the drainage. But because of much more extensive exposures of the bedrock formation we are able to see what has brought about the conditions. Before stating the process it should be pointed out that on surface slopes facing to the north and east, or the shaded sides, the dips or down slopes of the rocks are greater and the minor departure from uniformity in rates are more prevalent, because the sun's evaporating power being less on those slopes, the surface rocks are wetter and water aids movement between the loose particles or of masses of larger size. There are readily observable whole interstream spurs, steep in slope, which have moved as a unit downwards and are now separated from the blocks which originally were joined to them by zones or surfaces of displacement along which movement downwards has taken place parallel to the surface ("plane" or zone) of the displacement, thus producing a fault. In other places the subsided block has rotated in its lowering along a displacement surface concave upwards, its outer and lower end being upturned, the rocks in it dipping towards the uphill side, or, again, it generally occurs where a whole block, itself adhering together, moves downwards in a landslide. When this has happened so recently that subsequent erosion has not yet been able to destroy the surface there will be a basin-like surface hollow between the upslope part which has not moved, and the outer part of the subsided block which, upon rotation, has risen into a ridge higher in position than it was before the subsidence occurs. In other places the beds are warped in low arches convexly upwards but the bed gradually becomes lower where traced down the slope. This is actual flowage by movements between particles, movement increasing in amount in direct proportion as the surface slope lowers in altitude, that is, the lower the surface, the greater the movement.

The slumping, settling, sliding, and flowage downwards and outwards is especially well shown in the narrow ridge of Pierre clay crossed by the Old Cherry Creek stage road where, near the mouth of the creek, it climbs out of Plum Creek valley and mounts over the ridge before descending into Cheyenne River valley, where the light brownish cream Mobridge member above has a sharp contrasting color contact with the dark, slaty grey underlying Virgin Creek member, the contact being abruptly displaced along fracture places at several places. That contact is 300 feet lower there than upstream on Plum Creek at the north line of Township 6 North, Range 21 East. How much of the 300 feet difference in altitude is attributable to the original northwestward dip of the rocks and how much has been brought about by subsequent subsidence and downslope flowage of the clays since they have been exposed at the surface by stream trenching during the present erosion cycle would be a matter quite difficult to decide.

A little reflection should suffice to convince one that the longer the process of subsidence has been operative and the steeper the slope and the greater the difference in elevation between stream course at the bottom of the valley and the top of the intervalley ridge the greater has been the amount of subsidence. Lower down the valley it is more than at the top of the ridge. Its prime cause is weight of material from above pressing down onto that below causing the latter to move outwards and downwards where it reaches the surface and becomes deprived of support at the side. During the movement the surface above subsides as the outward and downward flowage or landslide block subsidence takes place.

Since nearly all the plains of western South Dakota are eroded surfaces of Mesozoic and Cenozoic rocks, all containing large amounts of bentonite of virtually no strength or resistance to streams or erosion agencies of any nature whatever, it should be apparent that it is quite difficult to determine real structures in the rocks underlying the surface from what is actually seen at the surface. In fact, the best chances of doing it are confined to those areas, exasperatingly fairly rare, where rocks are really coherent or else where the structure is of such areal extent or vertical magnitude that evidently effects of surface slumping, sliding, flowage, creeping, heaving, collapse, rotation, swelling, contraction, and falling are overcome in relative magnitude. In areas where clays are exposed at or immediately underlie the surface the latter has a characteristic distinctive hummocky or dimpled aspect of rounded humps or swells separated by swales or irregularly aligned and formed depressions.

The swelling of bentonite upon absorption of water and subsequent cracking upon contraction through drying, breaks it up into fine particles of light weight, easily moved by wind or water in motion. This is conducive to rapid removal. Therefore, when once the cover and root-binding of roots is destroyed either by drought, overgrazing, plowing and cultivation or by gullying and channeling by water currents, erosion is powerful and rapid. Because whatever surface material rendered permeable, that is, accessible to entrance of water, is removed about as fast as it is formed, there is no chance for weathering processes to form real soils in any material possessed of much bentonite. No mature fertile soil can be formed under such conditions, and moreover, the clays have absorbed during their formation fairly large quantities of deleterious alkalies and salines. Consequently, about all the surface material which can be properly called soil in this area is loess, in particles from silt down to dust sizes, trapped by vegetation cover when it settles from the air. When once the protecting cover of vegetation is denuded the loess also is easily blown and washed away. So it is scarcely possible to overemphasize the destructive effects of drouth overgrazing and of plowing and cultivation. Land once cultivated is rapidly covered by nearly worthless weeds, which, however, now can be destroyed by overstimulation of their growth by the spraying of various hormones, narrow-leaved monocotyledonous grasses and grains not being seriously affected by such though dicotyledenous plants are.

The real soils of the area are therefore to be found mainly on the terrace flats of the old age erosion surface south of Cheyenne River and on the peneplained area of the Cheyenne-Bad River divide where loess has remained on the subflat surfaces where erosion is slow. The loess is more permeable than the clay bedrock. In the divide area the immediately underlying silty and sandy formation also permits absorption and retention of moisture and does not dry out so rapidly as the Pierre formation. The remaining soil of the area has accumulated on the flattish valley flood plains where also there is greater moisture content which produces greater protection by more vigorous vegetation cover.

Because the area is underlain by impermeable rocks to depths of 1500 feet or more and the water-bearing sandstones at still greater depths contain highly mineralized water available underground water suitable for almost any use is an exceedingly scarce commodity. Exceptions are the loess-covered flats and the narrow syncline of Cenozoic rocks of the divide area in Township 2 North, Range 17 East, where there exist limited supplies of good ground water at shallow depths. Some water on the larger flats such as Milesville Flat, is available for irrigation, since its depth is only 40 to 50 feet and a 6 x 6 foot shaft can be sunk cheaply in the soft loess, sand and gravel and horizontal turbine centrifugal pumps will give a yield of from 1000 gallons per minute upwards. But, we repeat, the supply is limited because the water readily seeps out at the margins of the flats where the valleys, gullies and ravines have been excavated to a depth below the contact of the water-bearing gravels and sand with the underlying impermeable Pierre clay. In some of the wind-scooped hollows and shallow heads of the draws, where drainage channels have not cut as deep as the underlying Pierre clay, the water table is within reach of alfalfa roots, provided that plant is fortunate enough to get a start provided by adequate surface moisture, and in these places subirrigated alfalfa can be produced.

Since any heavy footfall will displace Pierre clay, either wet or dry, it is evident that flowage, that is interstitial or interparticle movement, can take place down almost any angle of slope from vertical to horizontal, including actual movement upgrade where there is sufficient mass settling. As a consequence, valley walls or slopes of the uppermost drainage in the still operative old age second cycle, the underlying Pierre undermining the overlying thin sandstone member, retreat uniformly headwards as a drainage basin is widened. Steep slopes are therefore maintained until the removal of the whole sandstone member, as can be seen in the narrow divide between Deep Creek and North Fork Bad River west of Knodel triangulation station; just to the south of this part of the divide the upper member being removed, the divide is a gentle rolling ridge of the underlying clays.

Most of the loess falling on surfaces of the two older erosion cycles is rapidly and readily removed by wind or water. Loess can persist only on flattish surfaces where water is unable to wash it away. There it is removed by wind scour wherever the surface is denuded of vegetation cover during dry times.

BEDROCK GEOLOGY

The Pierre deposits along lower West Fork Plum Creek have been described very minutely by Freeman Ward in Circular 22, South Dakota State Geological Survey, the uppermost light, tawny, "chalky" shale member being now called the Mobridge and the underlying slate gray clays are known as the Virgin Creek. Strata intervening between these and the higher Cretaceous sandstone and sandy and silty clay member of the interriverine divide have not been studied because of lack of good or continuous exposures. The uppermost predominant slate grey clays are silty and sandy, there being near the top some interbedded laminated soft sands up to a few inches thick.

The topmost Cretaceous of the Bad-Cheyenne River divide aggregates 100 to 125 feet in thickness. A section of this member near the head of south fork Poeno Creek is as follows:

4. Top
   Interbedded soft sandstone, medium grey, and bentonite, arkosic, grey drab with prominent sandstone concretions, fine grained and septarian veined in the middle. The thin sandy layers are oxidized to yellow brown on the surface. 50 feet

3. Much like (4) but with thicker sandstone layers at top and base, more or less continuous up to six inches thick, fine grained, grey when fresh but oxidizing yellowish to dark brown. The bottom layer is the key bed used in plane table mapping. 3½ feet

2. Irregular, interlaminated grey drab bentonite and medium grained light grey sandstone in thin films, calcite-cemented; concretionary sandstone weathers light brown and the bentonite green drab. 20 feet

1. Sand, unconsolidated, light yellow, medium grain, weathering green drab, arkosic, bentonitic with local dark brown concretions, cellular, and more persistent in upper part, which has fish teeth, crab fragments, and small chert pebbles. Exposed thickness. 15 feet

Farther north and east, strata occupying (4) in the last section are fine sand and silty with vertical pipe iron oxide-cemented concretions having concentric layered cores and knobby or warty exteriors, above which is a persistent sand member with light yellowish or grey exposures which, in the divide area between Deep Creek and North Fork, is a delta with an inch or two of flat top set beds at top and several feet of four set beds below which dip up to 55° and in places have vertical ripple marks. Farther east this sandstone becomes very contorted and shows dome and basin structures, suggesting that it was quicksand before hardening. The highest fossil found is a slim, long Belemnitella which lay upon the top of the lower sandstone of member (3). A few fragments of wood occur in the sandstone member but the strata of the sandy member can be either Fox Hills or Lance.

This member can be characterized briefly as thin sandstones, weathering shades of reddish brown, interbedded with tawny and light grey bentonitic sands and silts containing concretions coated with brown iron oxide, evidently nonmarine and deposited on low gradient surfaces. It is possible that the Fox Hills is beneath in a bentonitic clay facies with thin interlaminated fine sand and silt deposited beyond the area in which sands were carried into the depositional basin.

It appears more probable, though not certain, that strata given in the foregoing section are lower Lance, the underlying Fox Hills here containing less sand than farther north, northeast and west and resembling more a phase of Pierre but more sandy and silty. Some evidence for this is that in the strata next underlying, the highest in which fossils were found, there occur in a lime-cemented, dark brown, medium, angular to subangular grained sandstone, made up of quartz, serpentine, glauconite, biotite, green and gray chert and olivine fragments, DISCOSCAPHITES MANDANENSIS and partial outer shells of possibly SPHENODISCUS though with no sutures preserved. At another locality DISCOSCAPHITES CHEYENNENSIS was found in brown gray clay ironstone concretions while the highest fossil found, previously noted, resembles BELEMNITELLA BULBOSA. These fossils are of Fox Hills age but Fox Hills fossils are known to extend 200 feet down into the uppermost Pierre clays.

The Pierre, in horizons above a level 250 feet below the top of the Virgin Creek, contains numerous BACULITES, rarer SCAPHITES and locally, considerable numbers of large INOCERAMUS. However, no PLACENTICERAS as found above the exposure in south bluff of Cheyenne River at the steel bridge across the river at the northwest corner of Haakon County, where also there are many large BACULITES. Most of the Pierre fossils are in the disk to spheroidal shaped septarian limy or clay ironstone concretions though locally they are abundant in the clays.

Interlaminated sand and clays which appear to be Fox Hills outcrop on the north slope of the south side of Bad River valley along the highway about one to one-half miles south of Philip.

SUBSURFACE GEOLOGY

Information concerning rocks underlying this area is available from cuttings collected from four deep borings, namely; the Gypsy Hunter 1, NE $\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 28, T. 3N. R. 16 E. Pennington County; the Red Scaffold, U. S. Indian Service, SE$\frac{1}{4}$, Sec. 6, T. 9N, R. 19E, Ziebach County; the Haakon County Development Company Daniel Bierwagon, Sec. 11, T. 6N, R. 21 E. and the John Stroppel, Midland Hotel, Lots 5 and 6, Block 3, Sec. 6, T. 1N, R. 25 E, the last two in Haakon County. Other wells from which cuttings are not available include those at Philip and Nowlin; the J. T. Singleton, NW of SE$\frac{1}{4}$, Sec. 30, T. 6N, R. 23E, top of Dakota reported at 1921 feet; the Julius Roseth, SE of SW$\frac{1}{4}$, Sec. 5, T. 6N, R. 23E, altitude 2036 feet, top of Dakota reported at 1960 feet to 1980 feet; the Wm. B. Alleman, SW of SE$\frac{1}{4}$ Sec. T. 9N, R. 24E, altitude 1662 feet, top of Dakota reported at 1630 feet, all in Haakon County, and the U.S. Indian Service well at junction of Cherry Creek and Cheyenne River, Sec. 31, T. 7N, R. 22E, altitude 1739.8 feet, Ziebach County.

Study of well cuttings has shown that the Cretaceous rocks thicken westwards in South Dakota, demonstrated in the accompanying table by the thickness from top of Niobrara to top of Dakota increasing from 790 feet in the Midland Hotel well to 986 feet in the Gypsy Hunter and to 1025 feet in the Red Scaffold wells. However, the thickness of Graneros shale decreases 100 feet from Midland to the Bierwagon and Cherry Creek wells while the Carlile shale increases by 100 to 125 feet northwestward from Midland to these two wells; this appears to indicate some movement in the sea bottom, shallowing to the southeast in Carlile time but to the northwest in Graneros time, assuming the Greenhorn limestone to have been flat when deposited. Alternatively there is a possibility that the Bierwagon and Cherry Creek wells found sands in the lower half of the Graneros above those in other wells.

In the Gypsy Hunter boring surface measurements indicate that the top 100 to 125 ft. is to be referred to what is more probably Lance with a few feet at the surface of the Cenozoic found at the well site. The thickness of supposed Fox Hills in this boring is not known but is probably not over 150 feet. This boring penetrated 1800 feet or more of Pierre slate gray bentonitic clay.

The deepest of these borings is the Gypsy Hunter 1, cuttings from which have been described in Report of Investigations No. 57, South Dakota State Geological Survey, pages 31-36. The formations in this boring are summarized from top downwards in the following:

The boring started in a grit or fine conglomerate of Cenozoic age. This probably is only a few feet thick and is underlain by the sandstone and sandy shale member thought to be more likely Lance in age. Level lines run northwards from the North Wall triangulation station near the well to the basal or key bed sandstone of the supposed Lance, 4250 ft. away, showed a difference in elevation between the surface at the well and the key bed of 119 feet but the rocks have a northward slope, probably produced by flowage and settling down in the direction of the drainage courses, indicating a probable thickness of the supposed Lance of less than 100 feet. No cuttings were taken of the upper 243 feet drilled. Cuttings from 243 to 2,050 feet depths are of Pierre clay, bentonitic, slate gray in color, with some beds of pure bentonite, some silt and chalk beds and numerous horizons of brown and dark blue gray clay, and silty ironstone concretions with septarian veinlets of calcite and aragonite. The Sharon Springs or basal member of the Pierre, has apparently the exceptional thickness of 390 feet. It is very dark gray, bituminous, and more of a flaky laminated shale than the rest of the Pierre above. Below 1900 depth it contains small spots of light gray chalk.

The Niobrara marl extends from 2050 to 2170 feet depths. It contains small flattened chalk pellets in a darker gray clay and is purer chalk in the lower 40 feet.

The Carlile dark blue gray bentonitic shale, with beds of pure bentonite, bituminous at the top and with two thin fine sandstones at 2260-2270 feet depths, extends from 2170 to 2563 feet depths. Below 2500 feet depth the shale is almost black bituminous and contains some small fine flattened chalk pellets, which may be shells of the foraminifer, GLOBIGERINA.

The Greenhorn limestone, composed, as usual, of INOCERAMUS shell prisms and GLOBIGERINA, with some clay, light gray in color, lies beneath. Fragments of the limestone continues down to 2600 feet though the Gypsy Oil Co. geologists place the Greenhorn at 2563 to 2575 depths.

The Graneros dark gray shale, with bentonite, extends from 2575 to perhaps 2980 feet depths. It contains two thin sandstones, one, coarser and, in part cemented to a quartzite, at 2880 feet, and another quite fine, cream-colored, and with carbonized plant fragments at 2920 feet, below which are thin laminae of light gray siltstone interbedded with shale.

M. S. Littlefield, the Gypsy Co. geologist, places the underlying formation, the Dakota sandstone between 3024 and 3082 feet depths. However a fine silty light gray sandstone appears in the cuttings between 2980 and 3010 feet and increases in amount downwards. Also, at 3060 feet depth appears the manganese-bearing concretionary pellets, in sizes of medium to coarse sand grains, which everywhere in South Dakota distinguish the top of the Fuson formation. Fresh water rose 1400 feet in one hour during a drill stem test from sands between 3026 to 3041 feet.

The Fuson formation, bentonitic to sandy clay, gray, drab and maroon, extends between 3060 and 3240 feet depths, with a brown to grey limestone, containing iron carbonate, present between 3160 to 3170 feet; this may be the Minnewaste, which outcrops on the southeast flank of the Black Hills. Perhaps this limestone extends from 3154 to 3178 feet.

The Lakota sandstone may extend from 3178 to 3420 feet depths. The cuttings from 3240 to 3280 feet are fine grained sandstone with a bentonite matrix with 10 feet of blue gray mudstone containing dark green bentonite pellets immediately above. Dark blue gray shale apparently occurs from 3390 to 3410 feet unless it has caved in, and a fairly coarse sandstone from 3410 to 3420 feet. The main horizon of Lakota sandstone occurs from 3330 to 3390 feet depths. Water from Lakota at 3325 feet depth rose 2300 feet in one hour on a drill stem test.

Morrison mudstone, siltstone and sandstone, with much bentonite, green, buff, drab, terra cotta and gray, extends from 3420 to 3580 feet depths. A drill stem test at 3461 feet depth showed fresh water rising 3000 feet in the hole in 15 minutes.

The Sundance formation, from 3580 to 3767 feet depths, consists of an upper sandstone, light gray, medium grained and glauconitic, between 3580 and 3600, an intermediate siltstone, light gray glacuconitic, from 3600 to 3730 feet and a lower sandstone, buff to gray, fine grained and glauconitic, between 3730 and 3767 feet depths.

Spearfish fine silty sandstone, salmon above but light gray in the bottom 14 feet, extends from 3767 to 3850 feet depth, with about 100 feet of anhydrite (calcium sulphate) and dull brown red siltstone immediately beneath.

Minnekahta magnesian and anhydritic limestone, dense, fine powdery textured, was encountered between 3950 and 3980 feet depths.

Opeche siltstone, dark red brown, with some light gray anhydrite and limestone, occurs between 3980 and 4082 feet depths.

The Pennsylvanian Minnelusa formation extends from 4082 to 4831 feet depths. This formation is composed of limestone, anhydrite, sandstone, siltstone, mudstone and shales. The upper 120 feet is largely magnesian and dolomitic limestone with anhydrite. From 4200 to 4500 are 6 beds of sandstone, cream, gray, pink, brown, and salmon, interbedded with anhydrite, 4300 to 4330, and dolomitic limestone 4430 to 4450 feet. Black extremely bituminous shale extends from 4500 to 4520 feet depths, dolomitic and magnesian gray limestone from 4520 to 4600, then a thin bituminous shale, shiny black, to 4605 feet, light gray sandstone, 4605 to 4622 feet, then mostly magnesian and dolomitic limestone, mudstone and siltstone, 4622 to 4810 feet, with one bed of anhydrite at 4693 to 4710 feet. The mudstones, siltstones and shales in this succession are varicolored, gray, light green, lavender, red, butternut brown, down to 4729 feet depth, with black and dark gray shales interbedded with limestone between 4739 and 4751 feet and black shale from 4768 to 4775 feet. There are two red siltstone and shale zones in the Minnelusa, one extending between 4330 and 4420 feet and the other from 4661 to 4683 feet in depth. The bottom of the Minnelusa consists of lavender and gray coarse sandstone between 4810 and 4817 feet, a dark Indian red sandy and clayey laterite from 4817 to 4823 feet and a basal white medium to coarse sandstone, from 4823 to 4830 feet depths.

Madison (Pahasapa) limestone is the basal formation in the Gypsy Hunter boring, extending from 4830 to 5001 feet in depth. The light gray to brown limestone contains chert from

4856 to 4917 feet and is dolomitic from 4917 to 5001 feet. Fresh water rose 4000 feet in the hole from a depth of 4934 feet.

We will summarize the above record as follows:

Cretaceous

Lance (?) about 100 ft.
Fox Hills (?) about 150 ft.
Pierre clay 1807 ft.
Niobrara marl 120 ft.
Carlile shale 393 ft.
Greenhorn limestone 12-37 ft.
Graneros shale 380-499 ft.
Fuson bentonitic clay 158-180 feet.
Lakota sandstone and sand 180-270 ft.
Dakota sandstone and sand 38 feet.

Range in thicknesses of the last five formations are various possible interpretations of the cuttings, as noted in the foregoing. According to all, the base of the Cretaceous is at 3420 feet depth.

Upper Jurassic

Morrison bentonitic clay, siltstone and sandstone 160 feet.
Sundance sandstone and siltstone 187 feet.

Red Beds

Spearfish sandstone and anhydrite 163 feet.
Minnekahta limestone 30 feet.
Opeche siltstone, limestone and anhydrite 102 feet.

Paleozoic

Pennsylvanian

Minnelusa limestone, sandstone, anhydrite, shale and siltstone 749 feet.

Lower Mississippian

Madison limestone 170 feet.

In conformity with the fact established by deep borings throughout South Dakota the Cretaceous rocks thicken westwards, shown in this area by their thickness from top of Niobrara to top of Dakota increasing from 790 feet in the well at Midland to an average of 1000 feet in the Gypsy Hunter and Red Scaffold wells. The Codell sand, at or near the base of the Niobrara, occurs in the Bierwagon and Red Scaffold wells. The sand in the Graneros which is found on an average about 100 feet above the top of the Dakota, called the first sand in the following table, may be the Newcastle or Muddy sand of the area surrounding the Black Hills.

SUMMARY DATA ON CRETACEOUS FORMATIONS AND THEIR THICKNESSES FROM WELLS OF THE AREA

Surface Altitude	2956.8	2007.7	1740	2079	1880	2158
Well	Gypsy Hunter	Red Scaffold	Cherry Creek	Bier-Wagon	Mid-land	Philip
<u>Formations</u>						
Pierre thickness	1807	1225	1120?	1206	945	
Niobrara thickness	120	135	145?	194	200	
Carlile thickness	393	430	374?	400	275	
Greenhorn thickness	12	30	30	35	30	
Graneros thickness	449	430	185??	180?	285	
Depth to first sand	2880	2140	1755	2015	1615	1980?
Altitude of first sand	+57	-132	-15	+64	+265	+178
Depth to Dakota sand	3024	2250	1854	2070	1735	2080?
Altitude top Dakota	-67	-242	-115	+9?	+145	+78?

Data for Cherry Creek and Philip wells are from driller's logs only; the other four from a study of cuttings. The most uniform Cretaceous formation in the Dakota Basin in South Dakota is the Greenhorn and the only reasonable way to account for the supposed thinning of the Graneros in the Bierwagon and Cherry Creek wells would be uplift of the sea bottom there during Graneros. It seems more probable that the upper sands in these two wells is a higher one than the upper sand in the other four, meaning that the lower sands in the two are more likely the upper sand in the other four.

Some evidence is available from analyses of waters occuring in the sands. Water from sands occurring largely from 2015 to 2090 feet depth in the Bierwagon well (though the record states that the first water was encountered in sand streaks from 1956 to 1976 feet depth though first flowing water was reported at 2000-2009 feet) contains 7933.6 parts per million of dissolved solids, mainly sodium sulphate, much less sodium chloride and a small amount of calcium and magnesian bicarbonates, primary salinity being 95.32 per cent. Water from the Red Scaffold well, probably a mixture of Newcastle (?), Dakota and Fuson sands water, has a total of 5,477 parts per million of dissolved solids but is a sodium chloride (common salt) and sodium bicarbonate (soda) water, entirely alkaline. The Philip water, a mixture of Newcastle (?) and Dakota sands water, has about the same composition as the Red Scaffold though more dilute, containing 2055 parts per million of dissolved solids. The Nowlin well and Midland well waters, total dissolved solids 2096.5 parts per million, is from the same sand and have the same chemical composition as the water from the Philips well. It would appear from these facts that most of the Bierwagon well water comes from a sand not yielding water in the other four wells. All the wells yield abnormally hot waters (96-120°F.) and produce a little inflammable gas with the water.

The Dakota sand waters in this general territory are soft and alkaline, characterized by common salt and soda as their principal dissolved mineral constituents. The waters of the underlying Lakota sands, on the contrary, have less mineral matter in solution, are hard, are dominantly sulphate in composition and are suitable for irrigation. In order to utilize the deeper, better quality water it will be necessary to force cement up around the casing so as to entirely exclude from the pipe the very corrosive pipe-destroying Dakota and higher waters. Accordingly it is necessary to drill into the Fuson formation setting and cementing casing therein. In order to procure an ample supply of flowing water for towns or irrigation the casing set in the Fuson should not be less than six inches in diameter.

STRUCTURE

Dip of rock strata in the eastern half of Haakon County, determined by study of well cuttings from the subsurface, is northwest, increasing from a rate of about five feet per mile in the southeast part of the county to about 10 feet per mile in the north part along the Cheyenne River. This seems to be confirmed by plane table survey along West Fork Plum Creek (Snake Creek) in Townships 5 and 6 North, Range 21 E and by lowering northward of the Mobridge member of the Pierre clay to the northwest quarter of T. 7 N, R. 22 E although, since the drainage lines run downstream north to northwest, slumping or lowering of the surface Pierre clay is in the same direction.

The dip in the westernmost two tiers of Haakon County townships, determined by plane table work, by using as data the highest points on the basal sandstone, that is those of highest altitude farthest upstream in drainage courses where slumping or lowering has been least, is nearly due east at the rate of about 16 feet per mile across T. 3N, R. 18 E.

Within the area surveyed the highest altitude of the lowest sandstone bed is 2870 feet in the north half of Sec. 29, T. 2N, R. 17E, in Pennington County in its eastern tier of townships. The same bed descends eastwards to 2600 feet altitude in the middle of T. 3N, R. 19E, Haakon County. The same bed, though in all probability lowered somewhat by slumping, has an altitude of 2616 feet, one and one-fifth mile north and a little east of the town of Cottonwood, Jackson County, near northeast corner Sec. 12, T. 1S, R. 18E.

In the area between the northwest dips in the east part of Haakon County and the east dips in the west part there must exist a downfold or synclinal trough in the rocks, the lowest part or axis of which must plunge northwestward, as shown by the northwest dip first to the east. This northwest plunging trough is the bottom of the synclinal or downwarped Dakota Basin.

Another regional downwarp or syncline, plunging north-northeast from the east part of Fall River County, separating the Black Hills from the Chadron uplifts, may be followed more or less by the north-northeast downstream course of Cheyenne River between the northwest corner of Washington County and the junction of the Belle Fourche and Cheyenne Rivers; somewhere near the latter place this syncline should join that of the Dakota Basin. Thus there is apt to exist an updoming or at least a northward plunging structural ridge or upwarp in eastern Pennington County east of Cheyenne River, in the area between the two downwarps or synclines. The exact positions of the troughs of the two synclines or of the highest structural part of the upwarp between are unknown at present.

There is some possibility that the north-northeast course of the Cheyenne River between the northwest corner of Washington County and the mouth of Belle Fourche River originated and was determined as a result of earth movements after the formation of the peneplain whose surface is that of the flat divide between Cheyenne and Bad Rivers or that part of the Cheyenne's course may have existed before the development of the peneplain but from the same cause, namely, the formation of a structural north-northeast plunging downwarp or syncline, which becoming the lowest belt on the surface, was followed by the river. The surface geology of the outcropping formations bears out this idea at least to some extent, the Fox Hills and Lance, the highest and youngest formations of the region, having been eroded away from their once higher out crops between Cheyenne and Belle Fourche Rivers and the Black Hills, but still existing, as they would do if they were in a general synclinal or downwarped area, not so subject to previous erosion as they would be in higher areas, in the high plain of the Cheyenne-Bad River divide and to the north, north of the Belle Fourche and Cheyenne Rivers, in north eastern Meade County. The existence of the Fox Hills and Lance formations and pre-Pleistocene Cenozoic rocks in eastern Pennington and central western Haakon Counties in the area between the headwaters tributaries of Bad River and the nearly northward downstream course of Cheyenne River next above its junction with the Belle Fourche probably indicates their position there in structural downwarp in the rocks.

There is, however, some possible objection to the view expressed above. When a region nears the stage of peneplanation its drainage courses (streams) wander over the flattish surfaces irrespective of the structure and differential resistances of the rocks exposed at the surface and also, since the valley of the Cheyenne in the region we are considering is entirely within the Pierre clay, which presents extremely little resistance to forces eroding the surface of the land the present course of the river may not coincide with the trough or lowest part of the downwarp or syncline.

There isn't much doubt that the present slope of the Pierre, Fox Hills and Lance formations is towards the channel of the Cheyenne because the tributary creeks and drainage lines slope downwards towards the river channel, towards the east on the west side of the channel, and towards the west on the east side. We have seen in the preceeding part of this discussion that the rocks slump or flow downwards in the direction the drainage flows. But whether the slopes of the rocks found on the surface are the real dips in the rocks beneath the plane whose top is the bottom of the river channel is another problem which it may be difficult to solve.

Hence it must be reiterated that though we know the general downwarped structure of the rocks occurs somewhere in this area the precise situations of the troughs or deepest parts of the synclines are not yet certain.

Oil and gas occur in permeable rocks pushed up into the highest parts of the same under the artesian or static power of the heavier water remaining as a consequence in lower parts of these rocks. It is therefore necessary to find an uparch (dome or anticline) with the permeable rock extending to lower elevations on each and every side, or else the highest part of a sealed-off fault block or else a permeable zone or layer of a rock, such as a sandstone, which wedges or lenses out into impermeable rock on the side up the dip, in order to get a "closed trap" for a commercially productive oil or gas field. Some of the sands occurring above the Dakota sandstone in this region, which have been shown to exist, may wedge out up the dip at some place or other or there may be lenses or wedges occurring under similar conditions of dip at one or more places. Such, being of course entirely concealed from view, have to be found either by accident in drilling or else by logical correct deduction from what is known of the nature of the underlying rocks.

The northwest end of an uparch or anticline has been found in the southeast fourth of T. 3N, R. 17E, easternmost Pennington County, but the southeastern major part of this anticline will evidently be hard to determine because of the lack of bedrock clay exposure of which the real structure can be determined. An unmistakable syncline or downwarp exists just southwest of this upwarp in Sections 4, 5, 8, 9, and 16 of Township 2 North, Range 17 East. From points on the high peneplaned flat to the west and southwest of it the syncline is readily visible in the downwarped Cenozoic lake or pond deposits, producing down sag in these deposits and altitudes on two beds of sandstone flanking and underlying the Cenozoic deposits denote the synclinal structure as shown on the accompanying map. This is real rock structure and not attributable to surface slumping or lowering, as shown by the regularity of the trough and its occurrence in part beneath the summit divide plain in a situation such as it has not been subject to the surface movements so prevalent in most of the region. This is equivalent to saying that part of the downwarp at at least exists in a situation where surface slumping successfully can be eliminated from the picture.

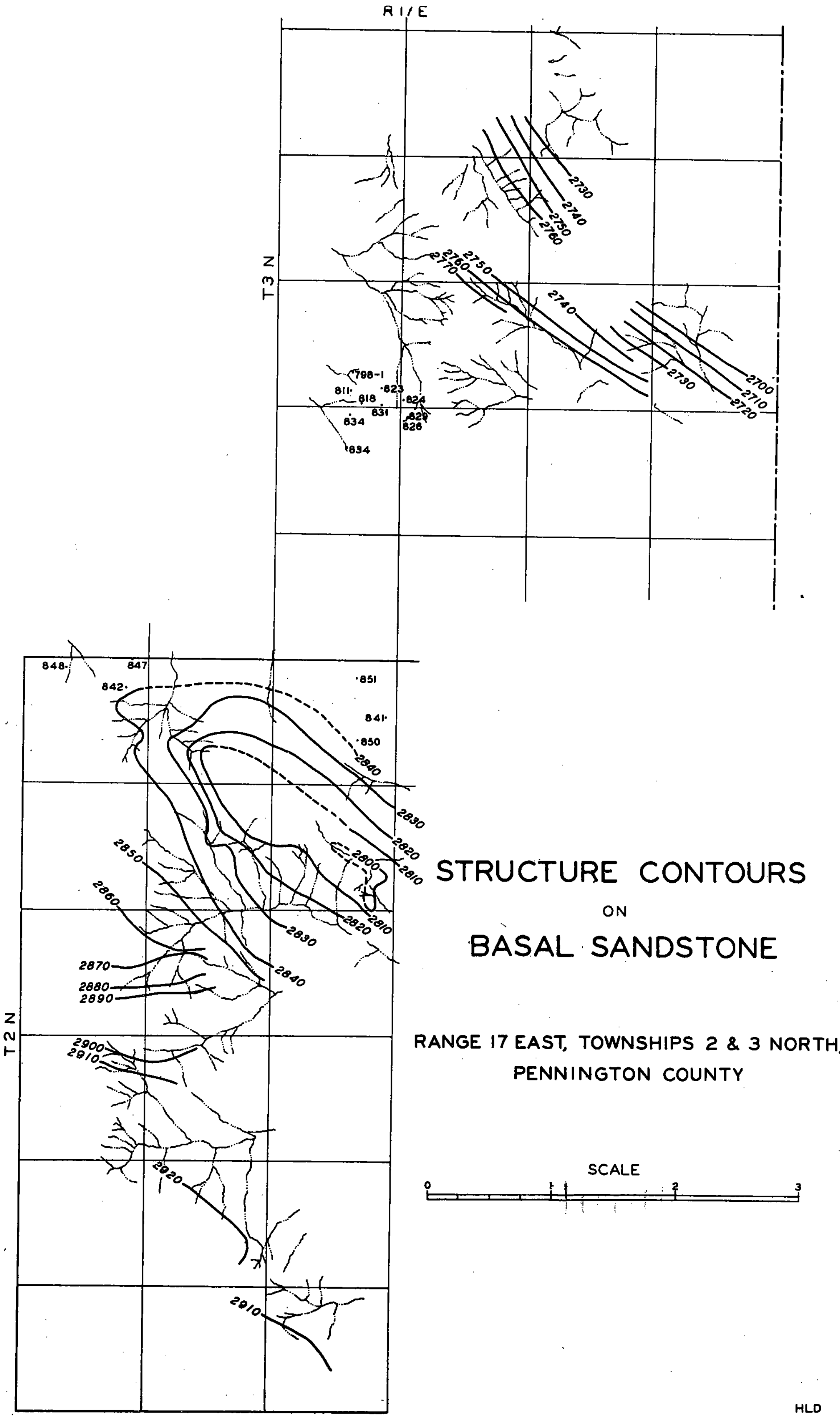
The northeast flank of the anticline, also shown on the map, occurs in Sections 22, 23, and 24, T. 3N, R. 17E. There are two sandstone layers which can be traced in a large part of these three sections, the structure being the same in the two. Also, the northeast dip here is the strongest found in the entire area and is reasonably consistent in the same direction and amount in the highest parts of the heads of the drainage courses, the total amount of northeastward dip within a mile being about 70 feet. In addition, the drainage courses parallel the strike of the sandstone beds, which means in other words that the drainage is subsequent to the structure, being forced to run on clay beds of less resistance lying between the more resistant sandstones.

Between this area of marked and consistent, unusually strong, northeast dips and that of the syncline there must exist the northwest end of an uparched area (anticline), the northeast-dipping area being the northeast flank of the arch and the southwest dips on the northeast side of the synclinal trough being the southwest flank of the same arch. Unfortunately, farther southeast there lies a broad and flat valley basin, 8 miles broad from north to south, eroded by the headwaters tributaries of Poeno or Ash Creek cut beneath the horizon of formerly present sandstone layers which, if they still existed, could be utilized, as they have been in the rims of the basin, in order to determine the true rock structure, and therefore the highest part of the uparch perhaps cannot be found from surface geologic evidence. The basin has been eroded downwards to the level of the indistinctive, nondescript upper Pierre or Fox Hills clays in which definitely traceable persistent and distinctively recognizable rock layers are probably nonexistent. Also, a great deal of the basin flat is covered with stream and wind deposits and contains a number of wind-scooped-out depressions. A search should be made for possible traceable rock members or structural key horizons within it, however. The south rim of Poeno basin extends nearly due east for a number of miles from section 33, T. 2N, R. 17E, the key sandstone beds outcropping in the upper slopes of the rim and possibly an uparching in these sandstone beds can be found to indicate the position of the southeast axis of the anticline occupying in part the flat basin to the northeast. Also, it is possible within the lowlands of the basin to determine by shallow drill holes a characteristic and distinctive horizon in the chalky Mobridge member of the Pierre and thereby discover the highest part of the anticline. Also, there remains some possibility that the top of the uparched structure may be determinable by the use of geophysics.

A remnant of the lower sandstone key bed exists near the middle of the north line of Section 28, T. 3N, R. 17E, where it has an altitude of 2835 feet in the summit knob of a narrow east-west ridge dividing drainages flowing northward to Cheyenne River by way of Deep Creek and southeastward to Bad River by way of Poeno Creek; this remnant has very likely been lowered somewhat by subsidence of the surface. South of it is a wind gap 2 miles wide north to south which forms a low saddle between the headwaters of the two creeks; it is cut down to the level of the upper Pierre or Fox Hills clays. The south rim of the wind gap, in NW$\frac{1}{4}$ of NE$\frac{1}{4}$ Sec. 4, T. 2N, R. 17E, has exposures of two sandstone layers one at the top at 2851 feet altitude and the lower on the north slope, at 2812 feet altitude. The upper sandstone is the one which is more readily traceable in this township though the lower one appears in some of the deep gullies in Sections 28, 29 and 33.

There is considerable probability that the northwest-southeast trending axis of the anticline extends through the wind gap and south eastwards into the broad eroded basin of Poeno Creek, the key bed sandstone formerly present having been eroded from its highest part where initial surface and drainage slopes would be eroded most rapidly because of greater altitude and relief. When the sandstones were worn away, the lowering and widening of the upper drainage basins of Poeno and Deep Creek, in the underlying very poorly resistant Pierre clay would be accomplished very rapidly.

The lowermost sandstone is apparently high structurally in the upper end of gullies in the NW$\frac{1}{4}$ Section 15, Township 3 North, Range 18 East, central western Haakon County, but the high flat interriver divide plain in the vicinity affords so few exposures that little can be learned there.


STRUCTURE CONTOURS
ON
BASAL SANDSTONE
RANGE 17 EAST, TOWNSHIPS 2 & 3 NORTH,
PENNINGTON COUNTY
SCALE
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