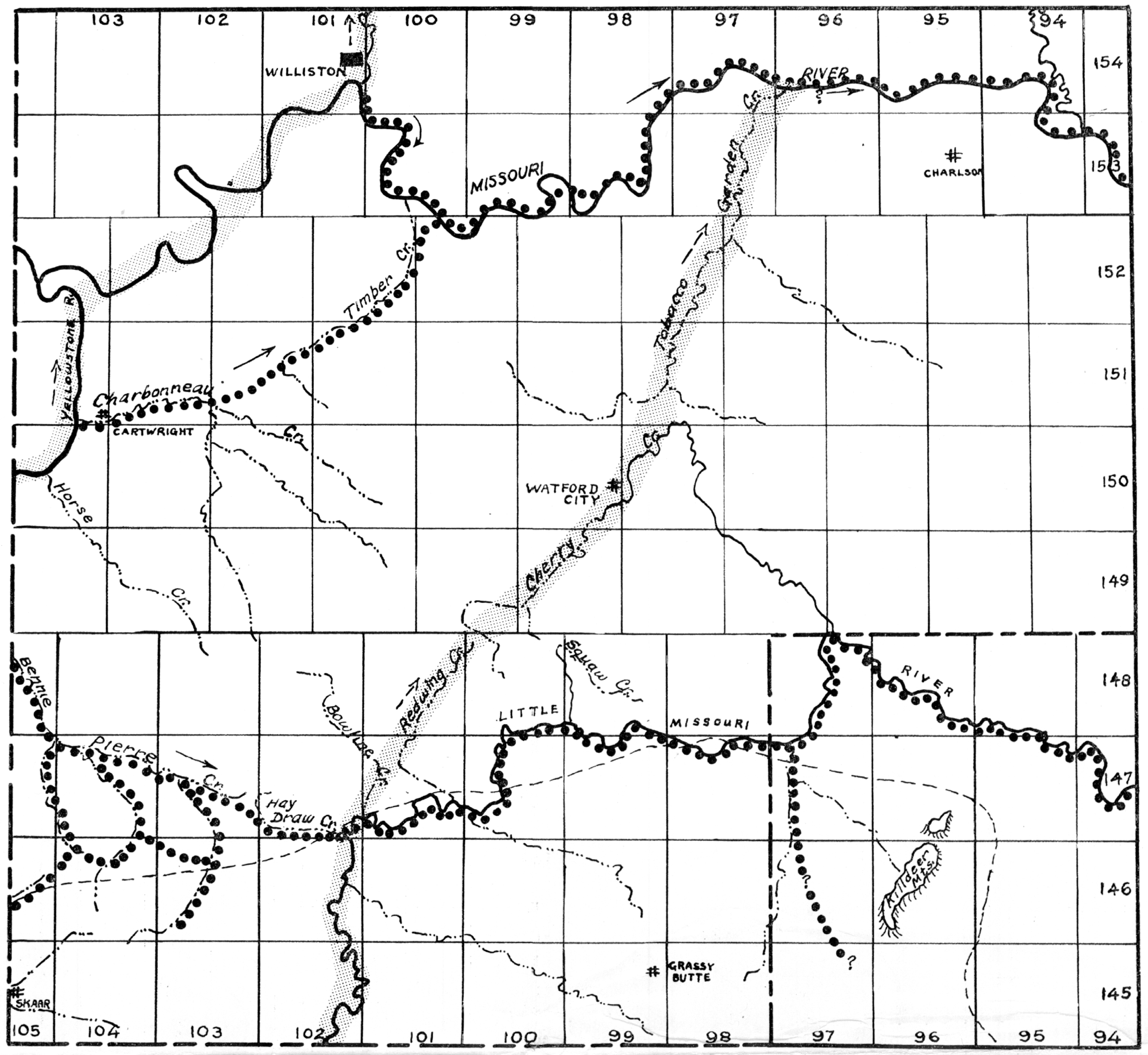


FIGURE I—Sketch map of McKenzie County and adjacent areas showing drainage changes caused by continental glaciation.

Pre-glacial drainage courses
Inter-glacial drainage channels
Present drainage courses
Approximate limit of glaciated area

The Geology of West Central McKenzie County, North Dakota

By STANLEY P. FISHER

General Statement

The area mapped for this report is located in west-central McKenzie County, North Dakota. It extends from State Highway 85 westward to the Montana state line, and its northern and southern boundaries are 3 miles north of Watford City and 6 miles north of the town of Grassy Butte respectively. About 945 square miles are included in this area.

Previous Work

A. G. Leonard (1916) has outlined the glacial drainage changes in much of western North Dakota including McKenzie County. In 1910 a United States Geological Survey party under Eugene Stebinger mapped in detail the outcrops of lignites in the area south of Sidney, Montana, immediately to the west of the area covered by this report. A small scale surface structure map showing the low and rather uniform northeasterly dip of the beds off the Cedar Creek anticline is included in this paper. The Keene Dome of eastern McKenzie County and the local stratigraphy has been discussed by C. M. Nevin (1946). Two papers by W. C. Alden (1924, 1932) describe the physiographic and glacial histories of eastern Montana and part of northwestern North Dakota.

Listed as references at the end of this report are other publications which are regional in scope or which concern areas in the vicinity of that covered here.

Methods of Field Work

Field work for this report was carried on during the summer of 1952. The first three weeks were spent in sketch-mapping the glacial deposits and topography north of the report area, and in measuring sections every 5 to 8 miles along the Yellowstone, Missouri, and Little Missouri Rivers, and along the Tobacco Garden Creek area. The actual structural mapping within the area of this report was done from early July to early September.

The latest State Highway Department map of McKenzie County, drawn on a scale of one inch to the mile, was adequate as a base map, and outcrops and some notes were located directly upon this map in the field. The Soil Survey map (1933) was helpful in locating outcrops and in working across covered areas.

Elevations were obtained with a Paulin altimeter reading to 2 feet. Very frequent checks were made to established bench marks along State Route 81, on the eastern margin of the area, and along the old State Route that bisects the area north and south from Alexander to Skaar. Elsewhere it was necessary to run networks of secondary elevation points most of which were placed no more than 6 to 8 miles apart. These were checked another day before they were used.

SURFACE GEOLOGY

The Topography of McKenzie County

Much of the following discussion is based upon unpublished field notes of Dr. A. G. Leonard, former State Geologist.

Over sixty percent of the county's surface is a rolling to rough upland which slopes eastward from an elevation of almost 2600 feet to less than 2400 feet. In many places streams have deeply dissected the surface with the result that only scattered remnants of the plateau surface remain as low divides. Rising above the general level of the upland are a number of buttes with elevations from 200 to 400 feet higher than the plain. The Blue Buttes, in the eastern part of the county, rise to 2800 feet above sea level and are the highest elevations in the county. Sheep Butte, in T. 148N., R. 103W., has an elevation of 2706 feet, and only 8 miles southwest of the southwestern corner of the county Blue Mountain rises to an elevation of 3084 feet.

These high buttes are all that remain of a former plateau surface having an elevation of at least 2800 to 3100 feet and from which erosion has cut the present upland surface. The high buttes have survived this long erosion because they were favorably located with reference to streams and, in most instances, were protected by a cap of resistant sandstone. In the case of Sheep Butte the cap-rock is over 50 feet of clinker or scoria formed from the baking of beds that overlay a burning lignite.

The major streams have cut valleys 400 to 600 feet deep into the present upland surface. In most places the uplands are set apart from the valley lowlands by abrupt slopes or bluffs, but elsewhere the two merge by gently rising slopes that make it impossible to draw a sharp boundary. The Missouri River trench is about 600 feet deep and varies from one to five miles in width. For most of its length the river is bordered by bluffs that rise 300 to over 500 feet above the floodplain. Terraces occur at many places along the valley, and two of these, one 20 to 25 feet and the other 40 to 80 feet above the water, are quite extensive. A still higher terrace, 90 to 110 feet above the river, is located along the mouth of Tobacco Garden Creek.

A portion of the Yellowstone River valley lies within McKenzie County. The valley bottom is from 2 to 3 miles in width with the river flowing below the high bluffs on the eastern side. On the west the slopes of the valley are rather gentle.

The trench of the Little Missouri River is 500 feet deep and over, and the bluffs which border the stream along almost all of its length are notably bare of vegetation. The valley bottom varies from one-half to one and a half miles in width, being geenrally narrower eastward. One of the features of this valley is the great amount of slumping which its walls have suffered in many places, especially on the north side of the valley in North Roosevelt National Park. Great blocks of the walls have broken away and, by means of a succession of minor slips, have moved over a quarter of a mile into the valley and at least 150 feet below their original position. The lower slopes of the trough often appear completely disturbed and jumbled, the strata of the displaced masses being tilted at all angles.

Dissection of the upland surface is most imposing in the areas adjacent to the main streams of the county. The Missouri River is bordered by a zone of rough terrain averaging 3 miles in width, but which may extend up the major tributaries for a distance of 8 to 10 miles. Such rugged areas or "badlands" are, however, best developed along the Little Missouri River. Here the numerous tributaries have eroded deep gorges and ravines over an area 15 to 25 miles wide except in the region east of Cherry Creek where the badlands narrow to widths of only 3 to 10 miles. The view from a commanding elevation is fascinating. Toward the river one looks down upon a chaos of bare ridges and bluffs, buttes, and pinnacles, gullies and canyons. In the opposite direction the monotonous plains stretch away toward the horizon, and the streams flow in shallow valleys with gentle, grass covered slopes.

The badlands have been formed by stream and rain erosion acting upon the soft clays, shales, and sandstones of the region. Erosion is greatly aided by the sparseness of vegetation which is especially notable on the south-facing slopes of most buttes and ridges. Although the region is one of camparatively light rainfall, every shower is highly effective in washing away the poorly consolidated rocks. Every slope is grooved or fluted by tiny channels or rills caused by the last shower. The greater part of the rain at once runs off into the streams, causing them to rise rapidly and become muddy torrents. These streams and their rivulet tributaries gradually expand, eating farther and farther back into the upland. In most areas the stream systems are so near together that the rough country along one merges into that along the next stream, thus making a continuous strip of badlands bordering he river.

One of the effects of the shower-flood is the excavation of great gulches in the bottom of the valleys. These often have a depth of 20 to 30 feet, vertical sides and flat bottom, and an overhanging bank over which the water spills, rapidly undermining and cutting back the head of the trench. Such miniature box-cayons are characteristic of the badlands and make travel along some of the valley very difficult.

Pleistocene Glacial Deposits

During the "glacial period" or pleistocene time North Dakota was invaded by an ice sheet from the north at least twice, and probably more times. When it melted away, each ice sheet left behind a mantle of rock debris known as "till", a heterogeneous deposit of rock flour or clay in which are scattered pebbles or even boulders. Most of these boulders are composed or rocks foreign to North Dakota, having been carried here from adjacent areas by the moving ice. One of the earlier ice invasions extended 35 to 40 miles southward into McKenzie County and, according to Alden (1924, p. 415), a small lobe reached up the Yellowstone valley to within 15 miles of Glendive. The writer observed boulders of igneous rocks in most areas south to the valley of the Little Missouri River and at points only 5 miles north of Skaar. (See figure 1).

True till deposits are largely restricted to the northeastern part of the county where exposures of 60 feet and more may be seen. However, most of this area, extending southwestward to Watford City, has only scattered patches of till which is usually 10 to 20 feet thick. The till is commonly a gray or drab clay containing many small cobbles of granite and limestone, and some dark gray shale fragments. It weathers to a dull yellow color.

From the center of T. 151N., R. 97W., northeast to the western part of T. 153N., R. 95W., the till has been heaped up to form an end moraine. The moraine marks a place where the ice front temporarily halted in its travel during which time the ice sheet continued to carry debris forward and pile it at the terminus. Here the till was deposited as irregular hills and ridges with a great number of undrained hollows and kettles among them. The hills rise 50 to 150 feet above the general surface of the upland, and they cover a zone from one to three miles in width.

Although boulders are associated with the tills in the areas described above, they constitute almost the sole evidence of glaciation in the remainder of the county. Beds of boulders are very common on uplands, and some are found also on the slopes of the older stream valleys. In some localities it is possible that the boulders are residual after erosion removed the finer glacial sediments. In a great many cases, however, the evidence points to such slight post-glacial erosion on the uplands that is seems probable the boulders over much of the southwestern area were deposited with a minimum, if any, of the finer glacial materials. Some may well have been carried into position by ice floating in the temporary lakes that are briefly mentioned below. A great majority of the boulders are composed of granite although other types or igneous rocks are represented and limestone is not uncommon. Boulders are present on top of Blue Buttes as well as many other high points in this area thus indicating that the ice was thick enough to cover and override these hills.

Pleistocene Drainage Changes

The drainage changes induced upon McKenzie County by the Pleistocene ice sheets are, of course, only a part of a broad, regional pattern, the outlines of which have been previously published. (See Bauer, 1915; Leonard, 1916 and Alden, 1924, 1932). However, because the evidence for the local picture will be clear to anyone familiar with the county and because some of the older publications are not readily available, a brief summary of the events known to date will be offered as a mattter of interest.

It is generally agreed that the pre-Pleistocene Missouri River left its present channel at a point just east of Poplar, Montana, and flowed northeastward across Manitoba to the Hudson's Bay area. Two of its major tributaries, flowing from the south and adjoining it somewhere just north of Crosby, North Dakota, were the Yellowstone and Little Missouri Rivers. The Yellowstone valley trends directly toward that portion of the present Missouri valley between Buford and Williston. In preglacial time the river turned northward at this point and followed the broad, flat-bottomed valley presently occupied by small Muddy Creek. This old valley is obliterated about 25 miles north of Williston by the moraines of the last ice sheet.

One of the most notable topographic features of McKenzie County is the pre-glacial valley of the Little Missouri River which extends from the mouth of Bowline Creek in Section 30, T. 147N., R. 101W., northeastward to the Missouri River at the mouth of Tobacco Garden Creek. This old valley is now occupied by part of Redwing, Cherry, and Tobacco Garden Creek (see Figure 1). Its bottom varies in width from a little less than one mile to about two miles, although in places tributry valleys make it appear considerably wider. At the mouth of Bowline Creek the floor of the old valley is almost 200 feet about the present Little Missouri River, and elevations taken along the valley show a moderate and fairly uniform gradient to the northeast. The divides between the creeks now occupying the valley are inconspicuous, being only 5 to 15 feet in height.

The exact course of the pre-glacial Little Missouri River north of the present Missouri River trough is not known. In view of the northeasterly trend of the pre-glacial regional drainage and origin for the Missouri valley between Williston and Tobacco Garden Creek postulated below, it is suggested that the continuation of the pre-glacial Little Missouri is to be sought north or a short distance northeast of the mouth of Tobacco Garden Creek.

As the continental ice sheet advanced across the northern part of the county and extended up the valleys of the Yellowstone and Little Missouri Rivers, the flow of these streams was blocked and the waters forced to seek a new course. The Yellowstone flowed over the low areas to the east, cutting temporary but broad and deep trenches. One of these is marked by the courses of Bennie Pierre and Hay Draw Creeks, and another is located just a few miles to the south.

The combined waters of the two rivers probably followed part of the general course of the present Little Missouri valley below the mouth of Bowline Creek. For some time they may have flowed south of the Killdeer Mountains and continued to the southeast by way of the Knife River-Curlew Creek channels near Hebron (Leonard, 1916, p. 297). At a later time, when the ice had withdrawn from the region just north of the Killdeer Mountains, the Little Missouri River arrived at its present course through northern Dunn County.

According to unpublished investigation by Laird, there are at least two low terraces in the valley bottom of the Little Missouri River. In the North Roosevelt National Park the outer, higher portions of both terraces are cut into the bedrock whereas the inner, lower slopes are in fine, thin-bedded deposits believed to be lake beds. The present data indicates that the river had eroded a deep, narrow gorge which became a lake when the lower course of the stream was blocked by ice. Later the stream was twice enabled to incise the lake beds in the bottom of the gorge while contemporary tributary waters widened the valley cutting into the marginal bedrock.

The following evidence may be presented in support of the conclusion that the lower course of the Little Missouri River is post-glacial in age:

(1) The river turns east at, and its lower course follows quite closely the southern boundary of the glaciated area.

(2) The badlands bordering the lower section of the river are considerably narrower than those above the mouth of Bowline Creek. The tributary streams in the lower or eastern part of the valley have not had the equivalent time in which to erode and form badlands as have the streams along the upper or preglacial valley.

(3) In the upper part of the valley, for many miles south of Hay Draw Creek, there are broad terraces about 270 feet above the river. These represent remnants of the old valley floor formed prior to the glacial period. They are contiguous with the broad valley which trends northeastward past Watford Ctiy. Such high terraces are absent in the lower valley which fact indicates that this portion is more recent and was formed since the region was elevated enabling the rejuvenated river to cut an inner valley several hundred feet below the floor of the earlier one.

(4) The Killdeer Mountains are small plateau remnants located only six miles south of the Little Missouri River. The tributaries of the river are at present rapidly eroding the mountains, and it appears unlikely that the mountains would have persisted had the river long been in such close proximity.

The stream patterns of Cherry and Squaw Creeks disclose an interesting event. Both creeks have an abrupt turn-about or reversal of the direction of flow between their upper and lower courses. The upper part of Squaw Creek flows in a valley that was tributary to the pre-glacial Little Missouri River, a portion of whose broad valley is now occupied by the headwaters of Cherry Creek. After the river had cut its post-glacial trough, tributaries worked their way back from the major stream by headward erosion, captured the headwaters of the above creeks, and diverted them to their present southerly courses. Thus stream capture by the active tributaries of the present Little Missouri explains the abrupt bends in the two creeks.

One other valley, not yet described in other publications, requiries very brief mention. Timber Creek flows in a rather broad, deep valley that is bordered by the remnants of high terraces. Although it loses much of its identity in the eastern half of T. 151N., R. 102W., this valley can be traced southwestward into the wide lower portion of Charbonneau Creek in the southwestern corner of the same township. The high terraces in the lower section of Charbonneau Creek slope eastward or away from the bluffs bordering the Yellowstone River, and elevations along the terraces of this old valley all the way to the Missouri River show a northeasterly gradient. Also, it is noted that this valley may be extended directly down the Missouri River valley at least as far as the mouth of Tobacco Garden Creek where it intersects the pre-glacial Little Missouri trough. Thus, the extended valley is remarkably parallel to the general trend of the Yellowstone River including that part of the Missouri as far as Williston.

The writer suggests that an ice sheet projected a small lobe, somewhat in advance of the main ice mass, up the Yellowstone valley, and that these waters were turned along the margin of the lobe thereby sub-paralleling the parent valley and initiating the Charbonneau-Timber Creeks channel. The waters continued to flow eastward following the course of the present Missouri River to and probably beyond the mouth of Tobacco Garden Creek. Thus, it may well have been the Yellowstone and Little Missouri Rivers which determined a good part of the course the Missouri River was later to take through northwestern North Dakota. This series of events would help to explain several beds of glacial boulders that have been found within the Missouri Valley.

The age relationships between the Bennie Pierre, Charbonneau-Timber channels, and a possible blockade-and-divergence at the site of Williston are uncertain at present. It seems likely, however, that they are still all the result of the same, early ice sheet. Much more work needs to be done before the entire history of the glacial drainage changes can be deciphered.

STRATIGRAPHY

The general classification of the surface rocks in this area is as follows:

Tertiary system
- *Oligocene series
  - *White River formation
- Eocene series
  - Golden Valley formation
- Paleocene series
  - Fort Union group
    - Tongue River formation (includes the Sentinel Butte facies)
    - Ludlow-Cannonball formation*

* Not present within McKenzie County.

Beds Above the Tongue River Formation

Golden Valley Formation

The beds of the Golden Valley formation were long recognized as an "unnamed formation" which, together with the Sentinel Butte shale, was known in North Dakota as the Wasatch group of Eocene age. The presence of the floating fern *Salvinia Preauriculata* Berry has proven these unnamed beds to be Eocene in age, and the name Golden Valley was applied by Benson and Laird (1947) to typical exposures in the vicinity of Golden Valley town in Mercer County. Sentinel Butte shale is now considered to be the upper facies of the Paleocene Tongue River formation (Brown, 1948).

The Golden Valley formation is made up of two members, the upper one of which is a series of fine to coarse, micaceous silts with some small, light colored clay lenses. The lower member contains purplish-gray, carbonaceous, clayey shales with some white, ashy and kaolinitic clays. The white clays very frequently are stained to a marked orange on weathered surfaces, giving this zone a characteristic mottling that greatly aids in rapid recognition. The formation is disconformably overlain by the White River sediments.

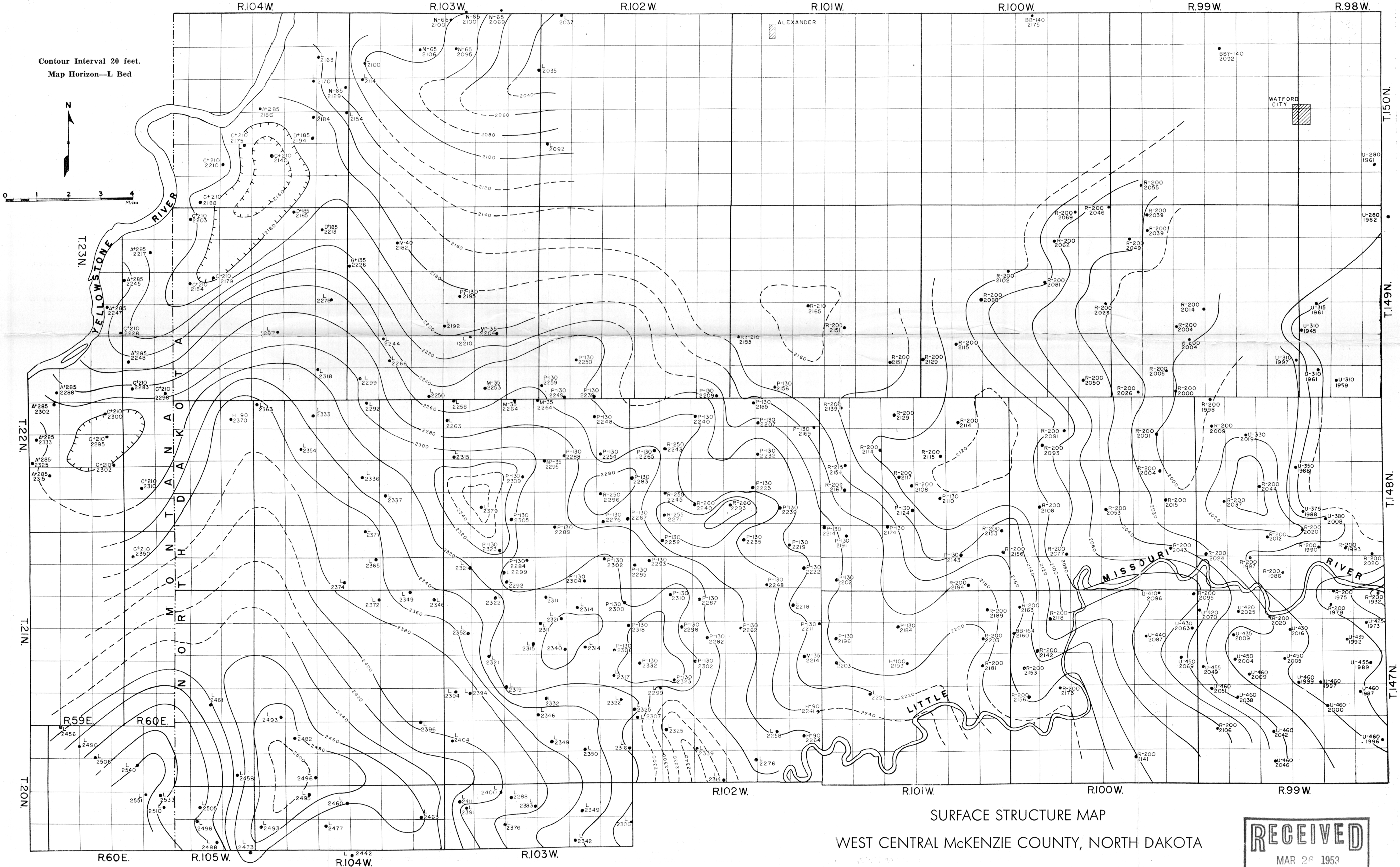
Although absent within the precise area covered in this report, the Golden Valley formation caps most of the higher buttes in eastern McKenzie County including the Blue Buttes which have heretofore been described as having a cap of White River sandstone. Long Butte, only four miles east of the southeastern corner of the map area, contains 122 feet of Eocene sediments. This measured section is shown in the generalized columnar section, Figure 2.

Tongue River Formation

Name, definition, and geologic age

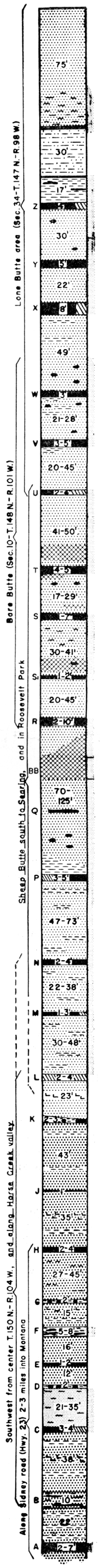
Taff (1909, p. 129) assigned the name Tongue River to lignite bearing beds underlying the approximate equivalent of the old Sentinel Butte shale of "Eocene" age. Present usage in North Dakota recognizes the Sentinel Butte shale as the upper facies of the Tongue River beds, the entirety being of Paleocene age. Thus, the formation now includes all sediments above the Ludlow-Cannonball formation and below the Golden Valley beds.

(Continued on Plate IV)



SURFACE STRUCTURE MAP

WEST CENTRAL McKENZIE COUNTY, NORTH DAKOTA



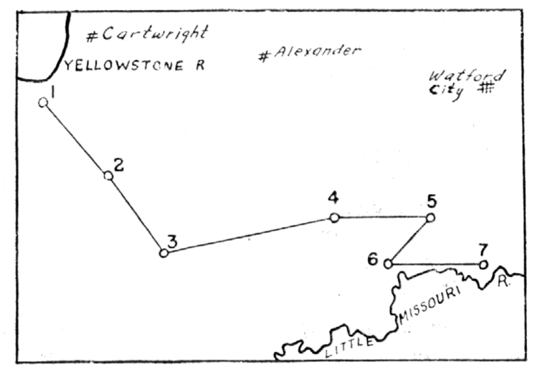
LEGEND

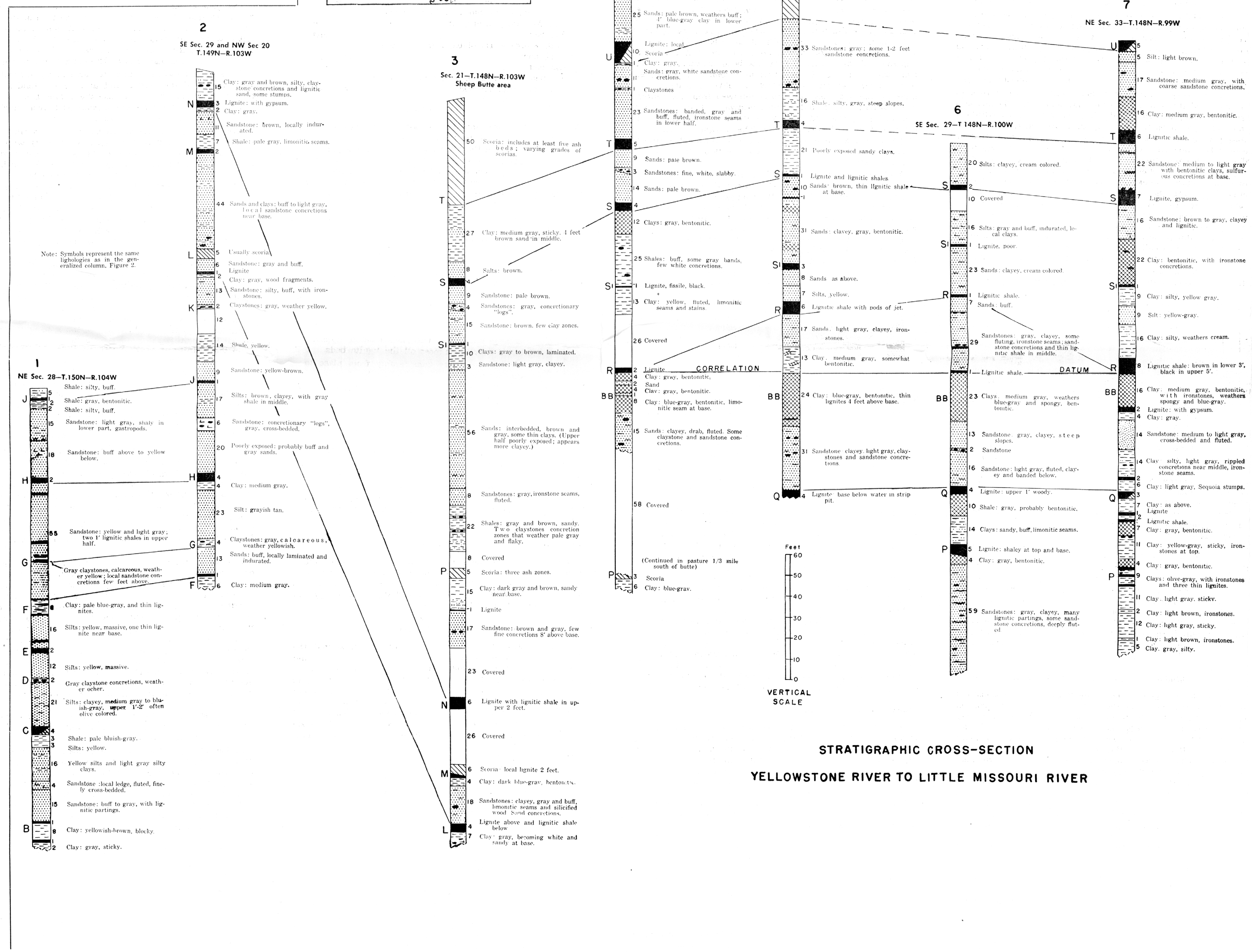
FIGURE 2.—Generalized Stratigraphic Section of the Surface Beds of Western McKenzie County.

- Sands and silts
- Sandy shales
- Shales or clays
- Bentonitic clays
- Lignite or lignitic shale
- Scoria
- Sandstone ledges
- Concretions

Vertical Scale in feet

(Note: Somber-colored beds are marked by shading along margin of column.)





STRATIGRAPHIC CROSS-SECTION

YELLOWSTONE RIVER TO LITTLE MISSOURI RIVER

Occurrence

The upper facies (Sentinel Butte sediments) of the Tongue River formation is exposed over almost all of the map area north and east of a line from Section 1, T. 149N., R. 104W., to Section 36, T. 147N., R. 102W., It is believed that these upper beds also surface the whole of northwestern and central McKenzie County with the probable exception of the lower slopes of the bluffs bordering the Missouri and Yellowstone Rivers. In addition to the southwestern part of the county, the standard Tongue River rocks underlie the low terraces or crop out in the lower slopes of the Little Missouri River valley at least as far east as the entrance to North Roosevelt Park.

Lithology of the standard Tongue River beds

Figure 2 (Plate III) is a generalized columnar section of the Tongue River formation alongside which are noted the main areas of outcrops for the various portions of the section. Considerable difficulty was encountered compiling and carrying the lower part of the section from the Montana line eastward across grass-covered slopes to areas where the upper beds were edequately exposed. For that reason a few rather insignificant but recognizable and useful lower beds are designated by letter.

The standard Tongue River sediments, those below the Sentinel Butte facies, consist of clays and shales, lignites, and soft sandstones with occasional and local concretionary sandstone masses or ledges. The predominant color of the fresh sands and shales is light gray or drab olive. Weathering gives shades of yellow to buff or pale gray, and, because the sediments tend to slump and cover the lignites, the color is monotonously uniform.

There is every possible gradation from one type of rock to another, and this gradation occurs not only vertically but also laterally along the same bed. Two vertical sections within a short distance of each other may show very little correspondence between their strata. The sandstone ledges in particular cannot be relied upon to continue any distance or to remain at the same horizon. Interval C-D is a good marker zone from the bend of the Yellowstone River south along the state line to Bennie Pierre Creek. It consists of about 22 feet of blue-gray clayey silts the upper few feet of which are greenish in color, and the zone is set off from the rest of the section by a prominent lignite below and orange concretions above. Claystone D and G weather to orange and cream respectively, and are further differentiated by their lithologies. Their persistence and resistence to weathering often makes them the sole means of carrying the section across the grassy slopes in this locality.

One of the outstanding characteristics of the entire Tongue River formation is the large proportion of lignitic shales and lignites. The lignitic shales are brown, woody and fissle wheeras the lignites may be brown to black, woody to dense and frequently display good jointing. Upon weathering the lignites become brittle and slack to a mass of fine particles. Silicified stumps and wood fragments along with impurities of gypsum, pyrite, and marcasite occur in almost all the lignite beds.

Thicknesses of these beds vary considerably from place to place, but are usually from 2 to 5 feet. The lignites may be locally replaced by lignitic shales, or may be split by clay seams some of which are several feet thick, Nonetheless, a number of the lignites are persistent over considerable distances, much more so than the shales and sandstones. The L lignite of this report can be traced over 30 miles southeast from the bend of the Yellowstone River. Also, the red scorias, which are the baked sediments overlying a burned lignite, greatly aid in following a particular bed across country. Even where other beds tend to slump and cover lignites, their presence is usually indicated by narrow benches cut into the slope, or by seepages of water which support a line of vegetation along the otherwise barren slope.

Lignites A and C are conspicuous along the eastern bluffs of the Yellowstone River and Bennie Pierre Creek. Bed A is a hard, black coal about 5 feet thick, is mined in many small cuts along the river road. Bed C is locally marked by scoria.

That part of the section between bed G and the base of the Sentinel Butte facies (lignite L) has few distinguishing horizons, and, over most of the area where it occurs, this interval is covered. It is believed, however, that the thicknesses shown on the general columnar section (Figure 2) are reasonably appropriate. In support of this claim, it may be noted that a good lignite (H) is found between 90 and 115 feet below the L scoria in only three separated areas: Section 20, T. 149N., R. 130W.; Sections 2 and 4, T. 147N., R. 103W.; and Section 25, T. 147N., R. 102W.

Lithology of the Sentinel Butte facies

Most of the statements concerning the lateral variations and difficulty of correlation of the standard Tongue River section apply equally well to the Sentinel Butte beds, but the lithology of the latter is suficiently distinctive to warrant separate description. The Sentinel Butte sediments are generally more somber than those below. Brown (1948), in his review of the Paleocene rocks of west-central North Dakota, has shown them to be a facies of the Tongue River formation; a color change that moves vertically across the section. A similar condition is indicated in McKenzie County for the upper part of the river bluffs in the northwestern portion of the county contain beds which are probably high in the section, but are chiefly buff in color. The writer cannot be certain of this fact because correlations were not carried into that area.

In the area mapped for this report, the base of the Sentinel Butte member is persistently marked by the prominent L scoria, and the member contains more lignites, scorias, and gray clays, a number of which are bentonitic, than does the regular Tongue River. Where the dark clays predominate and are in close association with limonitized shale seams and black iron nodules a "rounded mud-butte" type of topography is formed. This terrain resembles the weathering features of the Hell Creek formation where it is found in eastern Montana or other parts of North Dakota. Such localities are found from Section 13, T. 147N., R. 99W., southeast past Lone Butte to the vicinity of the Killdeer Mountains.

The L scoria forms the rimrock in much of the western half of the area. It is the thickest single scoria in the area, ranging up to 45 feet although usually less than half that thick. It is further characterized by a number of large, black slag-masses or clinkers and by a concretionary sandstone ledge which occurs about 16 feet below L at a great majority of the localities. This sandstone is 4 to 6 feet thick, coarse to medium grained, pale brown in color, and often occurs as cross-bedded, log-like forms. As previously mentioned the L scoria marks the boundary between the buff to cream sediments of the usual Tongue River and the overlying gray and brown beds of the Sentinel Butte facies.

In this area the lignites, as well as other types of sediments, of the Sentinel Butte section generally have more silicified logs and stumps than do the coals lower in the section. This is particularly true of the L, M, and N horizons which are often marked by a line of white stumps along the hillside and whose benches may be solidly carpeted with mineralized wood fragments. The largest stump observed measured 7 feet across at the very base of the trunk. One among many instances is an exposure of 5 feet of black lignite in which lies a somewhat compressed, completely silicified log over 10 feet in length. Such occurrences suggest that petrification is selective and that the process may take place while the coal is being formed.

About half way up the walls of the Little Missouri River valley and roughly 200 feet above the L. scoria is a distinctive sequence of three units which has been continuously traced from the vicinity of Sheep Butte in T. 148N., R. 103W., eastward at least at far as T. 148N., R. 95W., a distance of 45 miles. These beds have also been followed from the center of the southern map boundary northeastward along the pre-glacial valley of the Little Missouri River to localities 7 miles north and east of Watford City. The sequence consists of a bluish clay conveniently but informally called "the Blue", a chocolate-colored lignitic shale, and a yellow silt zone called "the low yellow".

The Blue is a medium bluish-gray, bentonitic clay most often a little more than 20 feet thick. When wet it is almost black, but upon drying it forms small spongy curds, and its color is then unique among the Sentinel Butte beds of this region. The clay is more resistent to erosion than the adjacent strata and forms fairly wide benches characterized by draped or "bread loaf" tops. Masses of clay spill over the edges of the benches, often flowing through small clefts to form steep flowage cones far down the slopes. An excellent bench can be observed just below the overlook house in North Roosevelt Park. The basal contact of the Blue is always a sharp, surface locally scoured and usually with a thin lignitic shale lying a few feet below the contact. Underlying the clay are 20 to 55 feet of drab, fluted sands containing some white sandstone concretions. Where the sands are thin, they are partially replaced by gray shales down to the P lignite-scoria.

In the vicinity of North Roosevelt Park the Blue clay is directly overlain by 6 or 7 feet of chocolate-colored lignitic shale or darker lignite, the R horizon. Above are 20 to 40 feet of fine sands and silts which weather to a notable yellow-cream color and, occasionally, into vertical columns. This Low Yellow zone is eye-catching and first calls attention to the Blue clay marker bed with which it seems to be coextensive. North and particularly west of the Park the R horizon and the yellow silts are usually separated by a wedge of olive or brown sands measuring up to 30 or more feet in thickness.

About 110 feet higher in the section is another unit of yellowish silts closely resembling the Low Yellow beds. In addition to stratigraphic position, the two zones can often be differentiated by the massive character and the black basal lignite (U) of the High Yellow silts. Exposures of the High Yellow zone are present over much of the eastern third of the map area and are especially apparent along the rim of the valley in the Park. Another outcrop is found in Bare Buttes (Section 10, T. 148N., R. 101W.), but here the color is buff. The cream-colored bed a little above and at the top of that butte is probably even higher in the section. The U lignite is responsible for the intermittent scoria seen between Watford City and the Little Missouri River, but is not to be confused with the few scorias formed within the Park area by the lower T lignite.

Erosion has left few localities where the sediments above the High Yellow zone can be observed. In some places this zone is overlain by about 30 feet of massive dark brown sands, elsewhere by gray clays with limonitic seams which upon weathering resemble the somber Hell Creek lithology. For the remaining beds up into the Eocene series the reader if referred to the general stratigraphic column (Figure 2).

General Notes on Scoria Beds

Several coal beds in this area, as in most of western North Dakota, have burned thereby baking and discoloring the overlying sediments to a red clinker locally known as "scoria". The name probably was first applied to the black and red, slaggy masses which are usually associated with the discolored baked clays, and which resemble true scoria or volcanic slag. These baked beds are a prominent feature of badlands terrain. Although some of the lignites may have ben ignited by prairie fires, spontaneous combustion resulting from rapid oxidation probably was the chief cause.

As the lignite burns farther and farther back from the outcrop the overlying rocks break off and settle, and air is admitted through the cracks in the broken rock. Cases are known where lignites have smouldered for at least 25 or 30 years. It is doubtful, however, if the coal can burn more than a hundred feet or so back from an outcrop on a slope. Slumping of the thickening overburden will eventually smother and extinguish the fire. Thus it is believed that the most widespread of the burned lignites were exposed or near the surface at the time of their ignition. It would seem that the scorias in the post-glacial valley of the Little Missouri River were formed since the ice sheet left the area and the new portion of the valley was cut perhaps less than 50,000 year ago.

Although the thicker and more completely fused scorias generally indicate that the lignite responsible was quite thick and pure, the character of the fused material is also dependent upon the composition of the sediments and the draft available to the fires. After observation and taking notes on half a dozen or more extensive scorias within the area, it appears to the writer that silts and sands most often bake to a salmon or dull rose color and to short columnar fragments or chunky blocks throughout. On the other hand, the clays, which are thin-bedded and usually contain appreciable iron, bake to deeper shades of red and from blocks in the lower few feet to plates or thin chips above.

The composite scoria capping Sheep Butte (Section 21, T. 148N., R. 103W.,) may provide an example of the effects of original composition upon the resultant scoria. The original lithology of the section visualized in this example is admittedly surmised and projected from outcrops somewhat removed, but comparable alteration can be seen at a number of localities elsewhere in the area. The present section is as follows:

Dull rose to red scoria chips	7	feet
Black slag-clinker	1½	feet
Bright red scoria blocks with local black clinker and ash-gray chips	23	feet
Ash bed	½	feet
Dull, orange scoria plates with local thin ash beds	15	feet
Ash bed	1	feet
Ash bed 1½ feet thick; two thin buff scorias and two thin ash beds above	4	feet
Total	52	feet

The basal 5 feet, predominantly an ash bed, is apparently correlative with the good, black U lignite to the east. The High Yellow silts overlying the U coal are likely represented by the 15 feet of dull orange scoria, and above are deeply colored, blocky to chippy scorias derived from the gray, limonitic shales often found above the yellow silts. The associated slaggy clinkers may be accounted for by the low-grade lignites encountered next above the U zone.

The lower contact of a scoria bed almost always seems to be a few feet lower than it actually is because the chips of baked clay readily slide downslope. The position of the old lignite is, of course, marked by an ash bed which may be entirely composed of gray to white powdery ash or which may have a lower seam of slag. The thickness of the ash is about one-quarter to one-fifth that of the original coal bed. A number of the scorias, the L scoria in particular, contain heavy, black, slag-like masses or clinkers. The origin of some of these masses could not be ascertained, but others were clearly formed from partially petrified tree stumps the woody texture and unfused portions of which are discernible. Strangely enough the clinkers may occur not only within the scoria, but also a few feet above.

Thickness

As compiled in the generalized columnar section the thickness of the Tongue River formation exposed within the map area varies from 745 to 1010 feet, the average being 880 feet. Of this thickness approximately 575 feet are included in the Sentinel Butte facies. Stebinger (1910, pp. 285-287) took the lowest good lignite as the contact of the old Lance and the overlying Fort Union (Tongue River) formations, and he measured a thickness of 1190 feet of Fort Union beds between Glendive and Sidney, Montana. His section contains 980 feet of the present, regular Tongue River sediments which, when combined with the 575 feet of Sentinel Butte beds exposed in McKenzie County, gives a total average thickness of 1555 feet for the entire Tongue River formation of this region.

Relations to beds above and below

The contact of the Tongue River formation with the Ludlow beds below is gradational and is usually chosen at the base of the lowest substantial lignite stratum. The upper contact is most often well defined by the abrupt change in lithology and color of the Golden Valley formation above.

Paleontology and Environment of deposition

Fossil remains of both plants and animals show that the Tongue River sediments were deposited in a temperate and moist continental environment. Such varieties of trees as sequoia, cypress, fir, juniper, and arbor vitae grew in and around wide, shallow water swamps only to be buried by muds and sands and compressed into lignite. Elsewhere grew oak, elm, walnut, birth, apple, alder, hickory, poplar, dogwood, and other trees. A number of the clay and shale beds in McKenzie County contain the shells of fresh water snails and clams, among which are:

Unio priscus Meek & Hayden
Viviparus trochiformis (Meek & Hayden)
Viviparus leai (Meek & Hayden)
Goniobasis nebrascensis (Meek & Hayden)
Lymnaea tenuicosta Meek & Hayden
Campeloma nebrascensis (Meek and Hayden)
Pseudocolumna vermicula (Meek & Hayden)
Corbula mactriformis Meek & Hayden
Planorbis planoconvexus Meek & Hayden

Time and time again the extensive swamps spread across the plains of North Dakota, and were filled with sediments washed in from nearby slopes and carried in by streams. That most of the sediments of the Tongue River formation were deposited in relatively quiet waters, presumably lakes, is indicated by the predominance of well bedded, fine grained rocks like shales and silts. The "scour and fill" and small erosion surfaces or diastems suggestive of a floodplain sequence are notably scarce. Even cross-beds, which are formed by active currents of water, are relatively rare although a few do occur in the sand layers and in the concretions. The lake environment is also indicated by the grayish color of many of the beds because considerable organic matter must have been present to maintain the iron of the deposits in a reduced state. On the other hand, stream currents with at least moderate velocities were required to transport the coarser grains of the sandy shales and sandstones.

Thus, one may visualize the depositional environment as a broad alluvial plain stretching eastward from the Rock Mountains, and across which several large streams meandered. Only the finer materials were carried as far east as the Dakotas where they were reworked by rainwash, small streams, and the wind. This working may account in part for the extreme lateral and vertical variations in the lithology of the sediments, and for the destruction of many of the original features of stream deposition. The large number of lakes and swamps which dotted the palin played a substantial if not a leading role in the sedimentational history of the Tongue River formation.

STRUCTURAL GEOLOGY

The generalized surface structure map of west central McKenzie County (Plate II) is drawn on the base of the L scoria. The actual correlation used at each station is denoted by a letter which refers to the beds marked on the stratigraphic section of Figure 2, and the interval used to bring the beds to the datum L is also shown. The contour interval is 20 feet.

Correlation between stations is made rather difficult by the very nature of the section and also by the tendency of the beds to slide and slump. Because the unique L scoria and the Blue clay-R lignite zone are encountered over much of the area, the problem was somewhat relieved.

The following statements can be made concerning the correlation of the stratigraphic section (Figure 2) with the sections in adjacent areas. In the Sidney, Montana region, Stebinger's (1910) I lignite is equivalent to bed A, and his J bed is represented here by bed C. Both of these beds are almost continuously exposed along the Yellowstone River road. The L scoria is the same as Stebinger's K bed in O'Brien Butte (Section 9, T. 20N., R. 60E.), from which point he remarked upon the "very large clinker margin on this bed which extends over many miles" in North Dakota. Most of the elevations in the Montana portion of the structure map were obtained from the original field sheets which are graciously loaned to the writer by Dr. W. E. Wrather, Director of the United States Geological Survey.

The Blue clay-R lignite zone was recognized at six or more localities north and east of Watford City, and the R lignitic shale appears to be correlative with the H bed of Nevin (1946). Comparative intervals would therefore indicate that the present datum horizon L is equivalent to the E beds of both Nevin and Bauer and Herald (1921). Nevin shows a questionable fault southeast of Schafer which may be the result of a miscorrelation over an area of river alluvium and poor exposures. A cursory examination of outcrops in T. 148 and 149N., R. 95W., suggests that the U bed of the writer is probably the same as Nevin's JK horizon whereas southwest of the fault in question the U bed, traced from the south, matches his M bed. A readjustment of interval raises Nevin's points southwest of the fault from 1632-1785 feet to between 2000 and 2060 feet and so eliminates the necessity of a probable fault.

The regional dip of the rocks in west-central McKenzie County is between 10 and 40 feet per mile to the northeast and east. The controlling structural features in this region are the Cedar Creek and Poplar anticlines both of which strike northwestward in eastern Montana. Immediately to the east of the report area is the north-south trending Nesson anticline. Although not indicated on the structure map (Plate II), the reversal of dip caused by the beds rising onto the Nesson upfold is located within a few miles east of the border of the map.

The chief structural feature within the present area is a broad high located just east of the state line. It plunges northward and its southern extremity, like that of the Nesson anticline as mapped by Nevin (1946, Plate I), has a small nose diverging from the main axis to the southeast. West of this high is a structural trough which parallels the Yellowstone River. Both structures may continue southward. Stebinger's surface structure map of the Sidney Montana lignite field (1910, p. 286) shows a marked syncline or chute plunging northward in T. 19N., R. 60E., about 25 miles south of Sidney; and immediately to the east of the chute a relatively broad, northward plunging high is suggested. These trends may be substantiated by the small scale structure map of the Montana plains by Dobbin and Erdman (1946). This map is contoured on the base of the Colorado shale and its shows a broad depression, in eastern Richland County the axial area of which may coincide with the synclinal trend mentioned above.

In the central part of the present area are a number of small domes the significance of which is uncertain. However, it seems plausible that the majority follow a generally high area extending from the southwestern corner of T. 147N., R. 102W., through the western half of T. 148N., R. 103W., thence curving northeastward into T. 149N., R. 102W. Thus this pattern parallels the structural high along the state line. These several small domes may have resulted from faulting of a single large structure.

The larger structures of the Williston Basin appear to have been formed by successive differential subsidences and uplifts, accompanied by faulting in the basement and deeper sedimentary rocks. Thus, the dips on the flanks of the folds should steepen and closure should increase with depth. Such has been found to be the case of several structures within the basin. Some of the smaller structures also probably formed very early and in the same manner, but others may have resulted from shallow faults associated with the most recent vertical movements of the region.

NORTH DAKOTA GEOLOGICAL SURVEY

WILSON M. LAIRD, State Geologist

Geology of West Central McKenzie County North Dakota

by

STANLEY P. FISHER

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That vertical movements accompanying the growth of the North American Cordillera affected the plains region in Paleocene time is shown by the folds in these rocks. Younger rocks have largely been removed from North Dakota by erosion, but the record of movements still more recent than Paleocene time can be read from the study of physographic features. Alden (1924, pp. 400, 409 & 414) presents such evidence indicating that movements continued into Oligocene and Pliocene and probably well into Pleistocene time.

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