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Sandstones of the Lance and Fort Union Formations

Alan G. Conner

SANDSTONES OF THE
LANCE AND FORT UNION FORMATIONS

By
ALAN G. CONNER

A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
BUTTE, MONTANA
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SANDSTONES OF THE LANCE AND FORT UNION FORMATIONS

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INTRODUCTION

The Fort Union and Lance formations are widespread terrestrial sediments exposed in Montana, North Dakota, South Dakota, Wyoming, and Canada. Their stratigraphic position, especially that of the Lance, has long been in doubt, and has provoked much controversy among geologists. In general, the two formations constitute a series of sandstones and shales which are transitional from late Cretaceous to Eocene.

The Fort Union formation is particularly well known for its tremendous reserves of coal, which, although of low grade, constitute one of the largest reserves in the world. In the Tongue River member alone there are over 300 billion tons of coal (Ref. 9, p. 22). Most of the coal land in Montana and the Dakotas has been mapped and described by the United States Geological Survey in more than 40 separate reports.

The purpose of this report is to give an account of the lithologic and sedimentary studies made by the author during the academic year 1947-1948 on a collected suite of rocks from the Lance and Fort Union formations. The work was primarily that of laboratory research performed in the laboratories of the Mineral Dressing and Geological departments at Montana School of Mines. After mechanical analysis of the disaggregated rocks, made to obtain information on grain size, sorting, and other textural characteristics, microscopic examinations of the grains and also of thin sections were conducted to obtain information regarding the constituent minerals.

All of the work contained in this report was done on samples collected from exposures in eastern Big Horn County, Montana, in T. 4 S., R. 36 E., and T. 4 S., R. 37 E. Detailed lithology of the two formations differs widely, depending upon conditions at time of deposition, and the writer wishes to emphasize that the data in this report deals with a single locality.

Previous Work The only work similar to that contained in this report was that of Renick (Ref. 8). The United States Geological Survey has done extensive work on the coal deposits of the region, and the general stratigraphy, floral and faunal assemblages, and age relationships of the Lance and Fort Union formations have been widely discussed. Much study also has been given to ground-water occurrence in southern Montana, not only by the United States Geological Survey, but by Montana Bureau of Mines and Geology.

Acknowledgements The writer is grateful to Dr. Eugene S. Perry, Head, Geology Department, Montana School of Mines for help extended on the many problems arising from this work.

To Mr. Eugene Conner, Garryowen, Montana, the author is indebted for the collection of a suite of samples under exacting requirements. Due to the inability of the author to personally visit the area, the crucial problem of collecting samples thus rested with Mr. Conner.

The writer owes thanks to Mr. Forbes S. Robertson for his assistance in petrographic analysis and to Professor Donald McGlashan for his generous help in allowing use of Mineral Dressing equipment.

All available geological literature was freely consulted in the preparation of this report. The publications of the United States Geological Survey were most helpful, especially those of Rogers and Lee (Ref. 3) and Renick (Ref. 8).

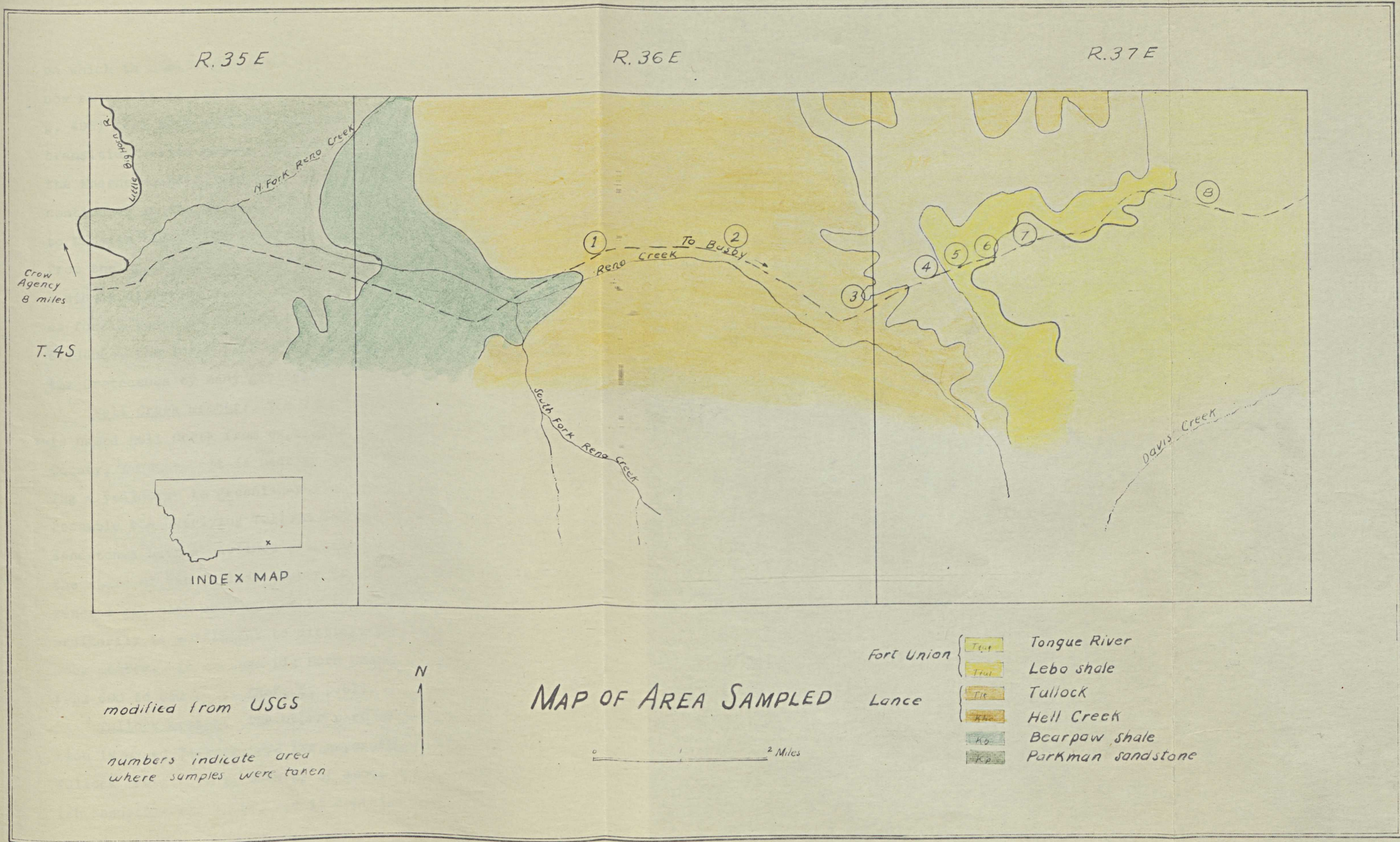
STRATIGRAPHY

The formations exposed in this area and considered in this report are shown on Plate 1. The oldest formation present, the Parkman sandstone, crops out on both sides of Little Big Horn River. It is overlain by about 1000 feet of Bearpaw shale, which, in turn, is overlain by the Lance, and then the Fort Union formations.

Lance Formation

There has long been doubt as to whether the Lance should be considered the initial formation of the Tertiary system or the last formation of the Cretaceous. There are no marked unconformities or distinctive changes in lithology

PLATE I


R. 35 E
R. 36 E
R. 37 E
T. 4S
Little Big Horn R.
N. Fork Reno Creek
Crow Agency 8 miles
Reno Creek
To Busby
South Fork Reno Creek
Davis Creek
1
2
3
4
5
6
7
8
INDEX MAP
modified from USGS
numbers indicate area where samples were taken
N
MAP OF AREA SAMPLED
0
2 Miles
Fort Union
Tongue River
Lebo shale
Lance
Tullock
Hell Creek
Bearpaw shale
Parkman sandstone

on which to make a division. The U. S. Geological Survey now refers it to the Tertiary. Thom and Dobbin (Ref.1, p. 496) feel that the Lance and Fort Union constitute a transition series between the Cretaceous Fox Hills and the Eocene Wasatch, and that terrestrial deposition was continuous in the western Great Plains area from Colorado to Wasatch time. The lower part of the Lance differs from the upper part in that it contains no coal, and has a widely differing faunal series of invertebrates as well as fossil bones of dinosaurs. In view of this fossil evidence, the lower part of the Lance is now assigned to the Cretaceous by many geologists.

Hell Creek member: The lower member of the Lanc is named Hell Creek from exposures on Hell Creek, Garfield County, Montana. It is made up of sandstone and shale having a yellowish to greenish-yellow color. These beds resemble the overlying Tullock member, but the shales and sandstones have a distinct greenish-gray color, whereas the shale of the Tullock member is commonly yellow. The general greenish cast of the lower part of the Lance ordinarily is sufficient to distinguish it from the Tullock member. In eastern Big Horn County thickness ranges from 600 to 650 feet. (Ref. 3, p.61).

Tullock member: The upper part of the Lance formation is named Tullock from its exposures in the valley of Tullock Creek. It is made up of about 300 feet of yellowish sandstone and shale, and it contains coal. Much of the sandstone and shale is calcareous. The general color is yellowish-gray to brownish, and is easily distinguished from the Hell Creek member by those familiar with these strata.

Fort Union Formation

The name Fort Union was originally proposed by Meek and Hayden, from its exposures near Buford, North Dakota, which was the site of old Fort Union. (Ref. 1, p. 493). In Big Horn County, the formation is separable into two divisions--a basal member about 150 feet thick is composed essentially of gumbo-clay shale in eastern Big Horn County, and is known as the Lebo shale member; an overlying thick series of shales and sandstones, which are yellow in color, is known as the Tongue River member. In many places the shales have been changed by burning coal to a brick red color.

Lebo shale member: The Lebo shale member is typically developed on Lebo Creek, Montana, northeast of the Crazy Mountains. In that locality it is sandy and is known as the Lebo andesitic member; in Big Horn County the formation is made up mainly of shale, with lesser amounts of sandy shale, and arkosic sandstone. Brown, iron-stained sideritic concretions are common. Much of the finer material devitrified volcanic glass. (Ref. 3, p. 36). The presence of the volcanic material can probably by traced to the tuffs and flows far to the west. The outcrop area of the Lebo shale is commonly characterized by bad-land topography.

Tongue River member: The upper part of the Fort Union formation is well exposed along Tongue River between Carneyville, Wyoming, and Brandenburg, Montana, whence the formation receives its name. (Ref. 1, p. 495). This member consists of yellow sandstones, beds of sandy shale, and many thick seams of coal. In many places the rocks have been turned to clinker by natural burning of the coal beds. There is a marked difference between the beds of this member and those of the underlying Lebo which have very dissimilar lithologic characteristics, and are popularly known as the "somber beds" of the Fort Union formation. Along the larger rivers the outcrop area of the Tongue River sandstones develops a rugged topography, and in places forms cliffs.

TEXTURAL COMPOSITION

Preliminary Work

The problem of collecting a representative suite of rocks proved a difficult one, due to the inability of the author to visit the area while attending school. After consultation with Dr. E. S. Perry, it was decided to have Mr. Eugene Conner, brother of the writer, collect a number of specimens from exposures along Reno Creek Valley which is followed by the highway leading from Hardin to Busby. In this locality, the Hell Creek member, the Tullock member, the Lebo member, and the lower 600 feet of the Tongue River member are exposed. The sandstones are fairly resistant to weathering, and commonly crop out as ledges and cliffs which may be as high as 50 feet.

A method was devised so that Mr. Conner would take a sample near a prominent landmark, proceed by automobile for a pre-determined distance and collect another. A local map of the area and location of the samples is shown on Plate 1. The first specimens were taken near the base of the Hell Creek member. Succeeding ones were collected from the Tullock, Lebo, and Tongue River members, the last one, No. 8, being obtained from the high benchland that forms the divide between the drainages of Little Big Horn River and Rosebud Creek. The stratigraphic position of Sample No. 8 is below the main coal beds and clinker horizons of the Fort Union.

In every case the rocks are well indurated. A few grains can be rubbed off with the fingers, but breaking up the rock requires strong pressure. A chip rubbed in a wooden mortar with a rubber pestle proved too hard to be effectively disintegrated.

Samples collected from the Lance formation are fairly clean in appearance, but little limonite is present. In the Fort Union specimens, however, limonite is abundant, probably from the weathering of biotite and other ferromagnesian minerals. Most of the cementing material is calcite, as indicated by a vigorous effervescence with acid.

The method used for disaggregation was to crush to fragments to about one-quarter to one-half inch in a jaw crusher, and then to treat them with dilute hydrochloric acid. Grain shattering in the crusher was negligible. The rock fragments were leached for several days to dissolve the calcite and limonite cement. The grains were then washed, filtered and dried.

The screens used in the mechanical analysis were chosen from a set of standard Tyler screens for close sizing. By using the screens shown in Table 1, the products from the analysis corresponded to the fractions in the standard Wentworth size scale.

Table 1

Size Scale of Screens

Mesh	Opening in Mm.	Size Used In This Report
32	.495	1/2 mm.
60	.246	1/4 mm.
115	.124	1/8 mm.
250	.061	1/16 mm.

The nest of screens was shaken in a Ro-Tap machine for 30 minutes. The preponderance of clay minerals in each sample interfered with the sizing operation, and it is doubtful if a very accurate screen analysis can be made. Wet screening also would have been inaccurate and difficult, because of the expansion in water of the montmorillonite group of minerals. Results of the screen analyses are shown in Table 2. The cumulative weight percent of each screen cut has been plotted on a semi-logarithmic scale; the first four samples which are from the Lance being shown on Plate 2, and the second four which are from the Fort Union being shown on Plate 3.

Table 2

Results of screen analyses of eight samples showing the size distribution in per cent by weight and cumulative weight per cent

Sample 1

Screen Mesh	Weight	Weight Percent	Cumulative Weight Percent
32	0.03	0	0
32/60	0.23	0.2	0.2
60/115	25.77	22.4	22.6
115/250	75.32	65.5	88.1
250	13.58	11.8	99.9
	114.93		

Sample 2

Screen Mesh	Weight	Weight Percent	Cumulative Weight Percent
32	1.08	0.9	0.9
32/60	1.40	1.1	2.0
60/115	18.05	14.9	16.9
115/250	70.17	57.7	74.6
250	30.87	25.4	100.0
	121.57		

Sample 3

Screen Mesh	Weight	Weight Percent	Cumulative Weight Percent
32	0.44	0.2	0.2
32/60	6.37	3.5	3.7
60/115	138.66	75.3	79.0
115/250	26.75	14.5	93.5
250	11.80	6.4	99.9
	184.02		

Table 2 (Continued)

Sample 4

Screen Mesh	Weight	Weight Percent	Cumulative Weight Percent
32	2.77	1.9	1.9
32/60	6.20	4.1	6.0
60/115	94.02	62.8	68.8
115/250	26.11	24.2	93.0
250	10.52	7.0	100.0
	149.62		

Sample 5

Screen Mesh	Weight	Weight Percent	Cumulative Weight Percent
32	1.72	1.6	1.6
32/60	3.20	3.0	4.6
60/115	53.13	49.5	54.1
115/250	34.80	32.4	86.5
250	14.39	13.4	99.9
	107.24		

Sample 6

Screen Mesh	Weight	Weight Percent	Cumulative Weight Percent
32	0.18	0.1	0.1
32/60	0.85	0.7	0.8
60/115	29.65	24.4	25.2
115/250	65.54	53.9	79.1
250	25.47	21.0	100.1
	121.69		

Sample 7

Screen Mesh	Weight	Weight Percent	Cumulative Weight Percent
32	0.10	0.1	0.1
32/60	4.03	5.7	5.8
60/115	41.95	58.8	64.6
115/250	18.28	25.6	90.2
250	7.00	9.8	100.
	71.36		

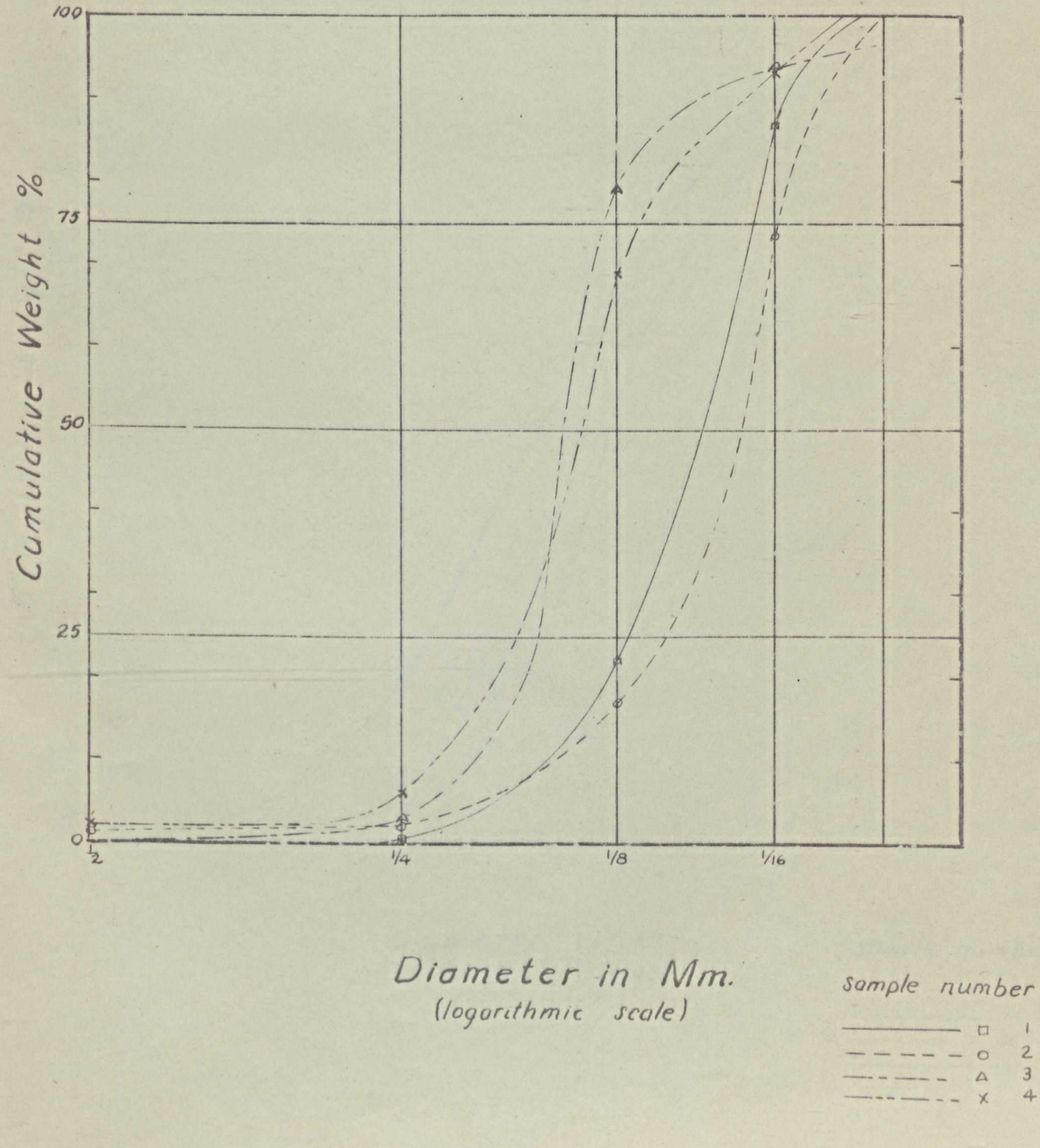
Sample 8

Screen Mesh	Weight	Weight Percent	Cumulative Weight Percent
32	0.10	0.1	0.1
32/60	21.74	19.8	19.9
60/115	52.35	47.7	67.6
115/250	25.54	23.2	90.8
250	10.10	9.2	100.0
	109.83		

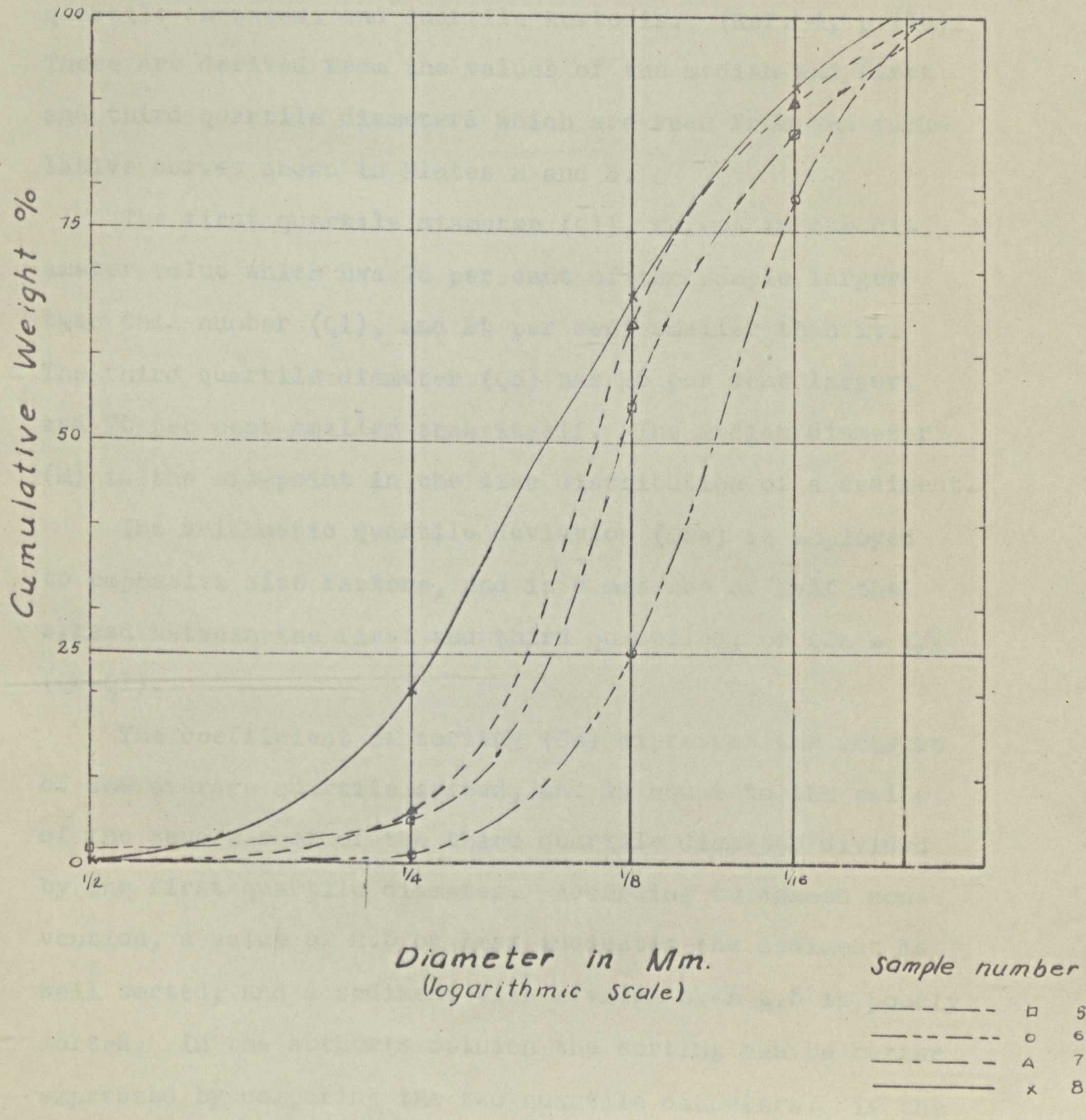
Cumulative Curves

showing grain sizes for

Lance Sandstones



Cumulative Curves showing grain size for Fort Union Sandstones



Statistical Measures of the Sediments

A series of mathematical values are employed to better express the character of sediments. The most widely used statistical devices for comparing and describing sandy sediments are quartile measures, median sorting coefficient, quartile skewness, and quartile kurtosis. (Ref. 4, p.110). These are derived from the values of the median and first and third quartile diameters which are read from the cumulative curves shown in Plates 2 and 3.

The first quartile diameter (Q1), refers to the diameter value which has 75 per cent of the sample larger than this number (Q1), and 25 per cent smaller than it. The third quartile diameter (Q3) has 25 per cent larger, and 75 per cent smaller than itself. The median diameter (M) is the mid-point in the size distribution of a sediment.

The arithmetic quartile deviation (QDa) is employed to emphasize size factors, and is a measure of half the spread between the first and third quartiles, or $QDa = 1/2 (Q3-Q1)$.

The coefficient of sorting (So) expresses the measure of the average quartile spread, and is equal to the value of the square root of the third quartile diameter divided by the first quartile diameter. According to common convention, a value of 2.5 or less indicates the sediment is well sorted; and a sediment with a value over 4.5 is poorly sorted. In the author's opinion the sorting can be better expressed by comparing the two quartile diameters. If the two are nearly the same, and if that portion of the curve between the two quartile diameters is nearly vertical, the sediment is well sorted. By comparison of the cumulative curves of the Fort Union and Lance, it is seen that the Lance sandstones are better sorted than those of the Fort Union, and are of more uniform grain size.

The finer degree of sorting in the Lance is probably indicative of more stable environmental conditions prevailing at the time of deposition.

The coefficient of germetrical quartile skewness (SK) indicates the side of the median on which the sorting is greatest. If the skewness (lack of symmetry) is greater than unity, the maximum sorting lies on the fine side of the median diameter; if it is less than unity, the maximum sorting lies on the coarse side. It is expressed by the following formula: $Sk = \frac{Q1Q3}{M2}$.

The various textural coefficients discussed are tabulated and averaged in Table 3.

TABLE 3

Summary of the Textural Characteristics of the Lance and Fort Union Sandstones

Value	Sample 1	Sample 2	Sample 3	Sample 4	Average
Q1	.07	.06	.13	.11	.09
Q3	.12	.10	.17	.18	.14
M	.10	.08	.16	.14	.12
QDa	.025	.02	.02	.035	.025
SK	.84	.94	.86	1.01	0.91
SO	1.3	1.3	1.1	1.3	1.2

TABLE 3 (Continued)

Value	Sample 5	Sample 6	Sample 7	Sample 8	Average
Q1	.08	.07	.11	.11	.09
Q3	.17	.12	.18	.23	.18
M	.15	.10	.14	.17	.15
QDa	.045	.025	.035	.06	.041
SK	.60	.84	1.01	.87	0.84
SO	1.5	1.3	1.3	1.4	1.3

In general, the sediments of the Lance formation are characterized by finer sizes and better sorting than those of the Fort Union formation. Both can be considered fine-grained sandstones.

Porosity

The determination of porosity was made only to obtain a general idea of the compaction and pore space. Differences in porosity of the specimens are, as expected, quite large. Exact permeability tests were not made, but all samples readily absorbed a large amount of liquid, and bubbled vigorously when immersed,indicating a high degree of permeability. Table 4 shows the porosity of a few samples.

TABLE 4

Porosity of Lance and Fort Union Sandstones

Sample	Porosity
1	15.6%
3	23.0%
4	17.7%
6	23.5%
8	31.4%
Average Porosity -	22.6%

Stearns, working with Renick in Water Supply Paper 600 (Ref. 8, pp. 36-37), lists the porosity of rocks from several localities in Rosebud County about twenty-five miles east of the locality discussed in this report. The average porosity of ten samples from the Fort Union is given as 31.3%. For ten samples from the Lance, the average porosity is given as 31.3%.

MINERALOGICAL STUDIES

The mineralogy of the two formations proved to be quite interesting, and led to observations given later regarding the origin of the sandstones. Most of the work was conducted with a petrographic microscope, using disaggregated grains from screen analyses, heavy liquid concentrates, and thin sections.

Thin sections prepared from the consolidated material were difficult to prepare due to the friability of the rocks. A quick method that was fairly satisfactory was impregnation with "Lakeside 76", an artificial plastic cement. A chip was ground to a plane surface and smoothed with fine abrasive, and after heating, was coated with the cement which worked itself about 1/16 inch into the pores of the rock. Successful thin sections depended on the degree of penetration of the cement into the rock. Photomicrographs on Plate 4 show the general dirty appearance of the consolidated rock and the angularity of the quartz grains. Thin sections are unsatisfactory for the study of the mineral content of the rocks, due to the large amount of clay-forming minerals which are present.

PLATE IV

Photomicrographs of Lance and Fort Union Sandstones

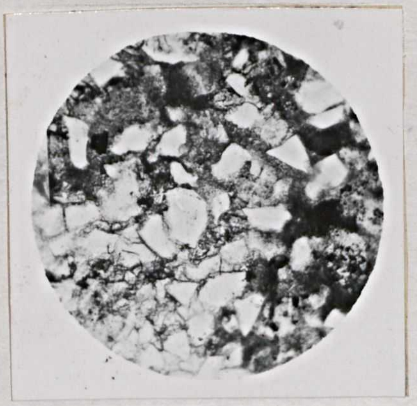
A. Thin Section of Lance x35

B. Thin Section of Fort Union x35

C. Minus 32 Plus 60 Mesh Grains from Lance x40

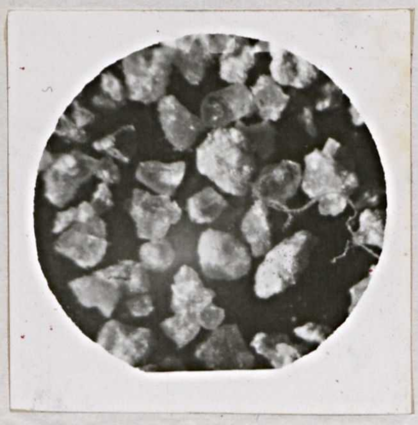
D. Minus 115 Plus 250 Mesh Grains from Fort Union x40

E. Minus 250 Mesh Grains from Fort Union x40

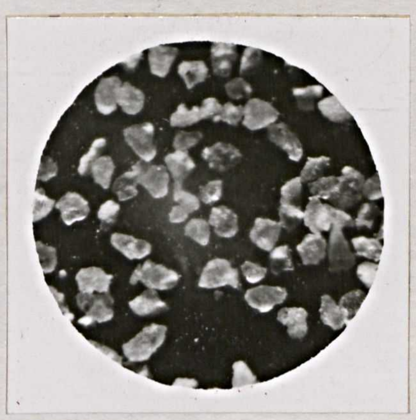


A

B



C



D

E

Photomicrographs of Lance and Fort Union Sandstones

The heavy and light mineral grains were separated with a mixture of acetylene tetrabromide and carbon tetrachloride. By using a liquid of specific gravity 2.90, the quartz, feldspar, and calcite were separated from the heavier fraction. Initial attempts at separation failed because of the interference of clay minerals, buoying up the other grains, but separation was effected after the grains were freed of clay by washing and decantation.

The Light Minerals of the Lance and Fort Union.

Quartz: Grains of quartz, comprising about 50 per cent of the sandstones, range in size from 0.12 mm. to less than 0.03 mm. Larger grains are sub-angular in shape while the smaller sizes are marked by extreme angularity. Quartz is of a clear variety, and free of bubbles and inclusions.

Calcite: Calcite is the second most abundant mineral. It is probably of secondary origin, formed during lithification of the clastic material. It occurs as a cement, and calcite commonly encloses other heavy and light minerals, as well as clay particles and limonite.

Feldspar: The sandstones are quite arkosic, especially those of the Fort Union. Orthoclase is a little more common than plagioclase, but no evidence of authigenic origin was observed. Plagioclase with recognizable albite twinning is present in small amounts. The two feldspars occur in cloudy, irregular grains.

The remaining light minerals are members of the clay group, together with volcanic glass and its derivatives.

Heavy Minerals

The heavy minerals constitute from one to five per cent of the sandstones. Minerals indicative of both a metamorphic and igneous origin are present; those of the Lance are characterized by several varieties of garnet, and those of the Fort Union contain large amounts of biotite, easily seen in hand specimen.

Apatite: Detrital apatite is present in the form of crystals which are terminated by pyramids. The grains show no rounding. Size averages about 0.07 mm.

Biotite: In the Fort Union, biotite is quite conspicous both in hand specimen and in thin section, and it may amount to as much as five per cent of the sandstone, giving it the appearance of a weathered granite. The flakes are dark brown, range in size up to 5 mm., and show little alteration. Pleochroism in shades of brown was noted.

Garnet: Garnet is the most abundant heavy mineral in Lance sands. The grains are most irregular, have sharp edges, and occur in sizes from 0.04 to 0.12 mm. Color is in tones of yellow, brown, reddish brown, apricot yellow, and green, and it may appear colorless. Nearly all the grains show anomalous birefringence.

Muscovite: This mineral was not found in the heavy mineral concentrate, but cleavage flakes are found in the hand specimen. It is not nearly as common as biotite. The platy minerals such as muscovite and biotite do not separate readily in heavy liquids.

Opaque Minerals: Magnetite, ilmenite, and leucoxene comprise a large fraction of the heavy minerals. Magnetite occurs most commonly in the smaller size ranges as octahedrons showing no rounding. Ilmenite and leucoxene are present in grains about 0.05 mm, in size. Leucoxene is identified by its dull white color in reflected light, while ilmenite is black in both transmitted and reflected light, and relatively non-magnetic.

Rutile: Rutile occurs as dark reddish brown, elongate grains with a prismatic shape. It has a high relief and an extremely high birefringence.

Spinel: Only a few octahedrons of spinel were found.

Staurolite: Grains of staurolite are uncommon but those found exhibit striking pleochroism in shades of yellow. Grains are angular and have numerous inclusions.

Titanite: Due to its high relief this mineral was difficult to identify. Common forms are diamond-shaped grains and faceted crystals. Identification was made by its high index of refraction and incomplete extinction.

Tourmaline: Tourmaline is next in abundance to magnetite and garnet. Shape of the grains differs widely, some having a distinct hexagonal outline, and others having a well-rounded oval shape. Tourmaline is the only heavy mineral showing any degree of sphericity which suggests a re-working of the grains. Pleochroism is very pronounced from light gray to black. Average grain size is 0.10 mm.

Zircon: Prismatic grains of zircon with pyramidal terminations are very common in the Lance and Fort Union sediments. In most cases the crystals are colorless; a few are yellow. Zircons are characterized by numerous inclusions of gas bubbles and other minerals, and by their zoning.

Other Minerals: Limonite was found in all samples studied as colloidal particles which sometimes firmly cemented other mineral grains. It is so prevalent that in order to get a clean assemblage of grains for immersion work, it was necessary to dissolve the limonite with acid.

Hornblende and augite were noted, but in very minor amounts.

ORIGIN OF THE SAMDSTONES

The mineralogical and physical characteristics of the sands point to crystalline rocks as the immediate source of the sediments. Minerals indicative of both igneous and metamorphic origin are found. Krumbein (Ref. 5, p. 463) tabulates diagnostic minerals, in addition to feldspar, as follows:

Acid Igneous Rocks	Dynamic Metamorphic Rocks
Apatite	Andalusite
Biotite	Garnet
Hornblende	Hornblende (green)
Muscovite	Kyanite
Titanite	Staurolite
Zircon (euhedra)	Sillimanite

Renick (Ref. 8, p. 17) found plagioclase, muscovite, biotite, garnet, zircon, and pyroxene in the Lance. He found in the Fort Union essentially the same minerals, excepting that there were lesser amounts of garnet. The author found that the only notable difference in mineral composition of the two formations was the abundance of garnet in the Lance, and the abundance of biotite in the Fort Union. Absence of kyanite, andalusite, sillimanite, the small amounts of staurolite, and the universal abundance of titanite, zircon, and apatite give weight to the theory that the bulk of the land mass supplying sediments was of igneous origin.

Previous writers have not accurately defined the clay minerals in the sandstones. The two larger groups of clay-forming minerals belong to the kaolin and montmorillonite groups. The apparent source of the kaolin minerals is the feldspar which is so common in the sandstones. The montmorillonite group of minerals is formed from weathering of volcanic ash and tuff.

Grains of volcanic glass and their alteration products, so prevalent in the Lebo shale member, can be traced to the flows near the Crazy Mountains and elsewhere in western Montana. Otherwise, the bulk of the material probably came from a rising land mass to the west. This theory has been suggested by Renick and Thom. If the sediments had passed through more than one cycle of erosion, it would appear that the degree of rounding would have been much greater than is found to be the case.

After deposition of the Bearpaw shale, the marine sea gradually withdrew to the east. The basal sandstone of the Lance formation was deposited in the shallow near-shore area, and farther out the sands were mixed with silt and clay. Sedimentation was continuous, but at an uneven rate. Renick (Ref. 8, p. 32) states that the Lance was deposited in broad epicontinental bodies of fresh water, while Rogers and Lee (Ref. 3, p. 55) feel that the eastern Montana region was a low-lying plain, bordering on the sea. Conditions differed widely from place to place; while some deposits were being laid down on flood plains, others were laid down in deltas, fresh water lakes, or in swamps. Deposits of the lower part of the Lance formation are characterized by fossil remains of large dinosaurs, which probably thrived in a semi-tropical or swampy environment.

During deposition of the Tullock member, the supply of material ceased periodically, and accumulated vegetal matter in swamps formed coal. The alternation of coal, shale, and sandstone is characteristic of the Tullock in most of eastern Montana. According to Rogers and Lee (Ref. 3, p. 55), the whole surface was slowly but constantly sinking, and at the same time built up by sediments as fast as it sunk. The balance between supply of material from the western mountains, and the rate of at which it was being deposited must have been rather close.

The differences in lithology of the Lebo shale member is attributed to the mingling with the sediments of volcanic tuffs from the west. After deposition of this member, the sands became coarser and took on a yellow look, possibly due to more oxidizing conditions and the presence of ferris iron. Alternating periods of deposition and equilibrium prevailed resulting in extensive and long lasting swamps in which accumulated the vegetal material which we now see as coal.

SUMMARY

The important facts and deductions derived from the study of the Lance and Fort Union sandstones are as follows:

1. The light minerals (sp.gr. less than 2.90) include quartz, calcite, orthoclase, plagioclase, and the clay-forming minerals.

2. The heavy minerals (sp.gr. greater than 2.90) include apatite, biotite, garnet, muscovite, magnetite, ilmenite, leucoxene, rutile, spinel, staurolite, titanite, tourmaline, zircon, and limonite.

3. Lance sands are better sorted than the sands of the Fort Union group, and are slightly finer in grain size.

4. Almost all of the grains are angular or subangular.

5. The rising Rocky Mountains to the west are considered to be the source of most of the sediments.

6. The sands were deposited on the fringes of a retreating sea, in deltas, on flood-plain, and in lakes and swamps.

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