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THE CLAY MINERALOGY AND CHEMISTRY OF THE BEARPAW FORMATION OF SOUTHERN ALBERTA

by

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CONTENTS

ILLUSTRATIONS

TABLES

Clay Mineralogy and Chemistry of the Bearpaw Formation of Southern Alberta

ABSTRACT

This paper reports the results of studies undertaken to test the theory that clay minerals undergo diagenetic alteration when transferred from a nonmarine to a marine environment.

The Bearpaw marine shale of southern Alberta was sampled at three localities and the clay-sized fractions of 165 samples were analyzed mineralogically. The samples are composed of montmorillonite, illite, and chlorite, almost always in that order of abundance. No significant relationships were found between the clay mineralogy of the shales and the distance to the ancient shoreline.

Samples were also collected across the formational contact between the marine Bearpaw formation and the underlying nonmarine Oldman formation. Chemical and mineralogical analyses of the clay-sized fraction of 45 of these samples show that the Na_2O content of the samples decreases by a factor of four from the nonmarine to the marine strata. Only insignificant changes were found in K_2O, CaO, P_2O_5 and total iron as Fe_2O_3. The values for MgO, TiO_2, Al_2O_3 and SiO_2 are essentially constant. Illite increases slightly at the expense of montmorillonite going from the nonmarine to the marine strata.

The results offer but slight evidence to support the theory that the sedimentary environment controls the diagenetic alteration of clay minerals. However, this may be partially due to the masking effect of heavy outfalls of volcanic ash which fell into this sedimentary basin during Oldman and Bearpaw time. It is significant that the ash altered to montmorillonite whether it fell into a marine or a nonmarine environment.

The most remarkable feature of the shales is their mineralogical and chemical uniformity both laterally and vertically.

INTRODUCTION

Several investigators of Recent marine sediments have reported an apparent change in clay mineralogy in sediments carried from a nonmarine to a marine environment. This change has been attributed to alteration of the clay minerals to meet new conditions of equilibrium. The theory has been advanced that, if these alterations can be shown to be consistent, the clay mineral assemblage of a sediment might bear some relationship to its environment of deposition. If this feature is preserved after lithification it would be a valuable aid in the study of clay-bearing rocks.

The Bearpaw shale of southern Alberta was chosen as a suitable rock unit on which to test this theory because: (1) it is known to be a marine shale; (2) it crops out over a wide area and thus could be sampled at varying distances from the ancient shoreline; (3) its contact with the underlying Oldman strata of nonmarine origin is well exposed and no evidence of interruption in sedimentation is apparent. Thus, any change in the mineralogy and chemical composition of the clay minerals across the contact should be the result of diagenetic alteration under marine and nonmarine conditions.

Discussion of Previous Work

According to some authors, most of the clay minerals in sediments have formed as a product of the weathering of crystalline rocks. The lithology of the parent material is strongly reflected in the mineralogy of immature soils and even a few mature soils (Cady, 1950), but it is the environment of the weathered zone that is the controlling influence on the species of clay mineral formed (Jackson, et al., 1948). The process of laterization and its products—kaolinite, goethite, hematite, and gibbsite—give perhaps the best known example of this phenomenon.

As the clay mineral content of a soil profile can be altered by a change in environment one might suspect that the clay minerals can also be altered by changes in environment after erosion removes the clays from a soil profile. Such a change occurs when clays, suspended in fresh water, are carried into a marine environment and become incorporated in the bottom muds.

The bottom muds from various deltaic, estuarine, off-shore, and deep-sea environments have been the subject of many recent investigations. Although local variations in clay mineralogy have not been adequately explained, several recent investigations suggest that clay minerals which have been leached and degraded in a continental environment tend to pick up cations and recrystallize in a marine environment.

Grim, Dietz, and Bradley (1949) found evidence that a portion of the kaolinite in the sediments of the Colorado River undergoes diagenetic alteration to illite and chlorite off the coast of California. Montmorillonite content of the bottom muds decreases slightly away from shore, possibly due to alteration to illite or chlorite. Further alteration after burial has been suggested by the variation in K_2O and MgO content in core samples.

Grim and Johns (1954) found that the sediments of the Guadalupe River are predominantly montmorillonite, with minor illite, kaolinite, and chlorite. The same pattern of change in clay mineralogy as observed off the coast of California takes place where the sediments enter the Gulf of Mexico. Kaolinite is not present in the marine environment, probably because it has been altered — by addition of magnesium — to chlorite. Montmorillonite undergoes alteration to chlorite and illite in the marine environment. In this case, however, the core samples show no change with depth, the inference being that major diagenetic changes are contemporaneous with deposition.

Powers (1957) found a similar distribution of clay minerals in the Patuxent River and Chesapeake Bay. The clay minerals of the Patuxent

River are mainly illite and degraded illite with smaller amounts of kaolinite and chlorite. The chlorite content shows a steady increase at the expense of degraded illite as the salinity of the water increases downstream in the estuary. Core samples show an increase in chlorite and a decrease in degraded illite with increasing age of the sediment but this change is not as great as that due to changes in salinity.

Milne and Earley (1958) found that only minor changes occur where the clay minerals of the Mississippi sediments enter the Gulf of Mexico. However, a core taken near the shelf edge, several miles from the mainland, contained a much higher proportion of illite than the bottom muds near the mouth of the Mississippi. The difference between the clay mineralogy of the near-shore and off-shore sediments is thought by Milne and Earley to be the result of a slower rate of deposition in the shelf-edge region.

Griffin and Ingram (1955) have demonstrated that in the Neuse River estuary in North Carolina kaolinite is the dominant clay mineral introduced by the river. Downstream in the estuarine deposits kaolinite decreases in amount whereas chlorite and illite increase. They suggest that the considerable portion of the river sediments which is amorphous to X-rays is reconstituted to form chlorite or illite in the marine environment.

Millot (1952) and Murray (1953) both believe that clay minerals will adjust according to their environment and show that the resulting clay assemblage will be preserved after lithification. Millot believes that the original environment of deposition of the shales of the Paris basin is indicated by their clay mineralogy. The continental shales are high in kaolinite whereas the marine shales are composed mainly of three-layered clay minerals. According to Murray, shales of the Pennsylvanian cyclothems of Indiana and Illinois have clay assemblages which indicate the environments of deposition. Using X-ray diffraction analyses, Murray showed that the illite content of the shales increases and the kaolinite content decreases from a nonmarine through a brackish, to a marine environment.

On the other hand, Weaver (1958) presented considerable data to show that the clay mineralogy of the sedimentary basins of Oklahoma is determined by the mineralogy of the rocks of the source area. Weaver's work definitely relegates diagenesis to a minor role in the occurrence of clay minerals in sediments.

Scope of this Report

The main objective of this study is to determine the geographic and stratigraphic distribution of clay minerals within the marine Bearpaw shale of southern Alberta. For this purpose, representative shale samples were collected from the Bearpaw formation at three widely spaced localities (Fig. 1), and their clay mineral content analysed by X-ray diffraction techniques.

In addition, a supplementary suite of samples was collected across the contact of the Oldman and Bearpaw formations on the St. Mary River, and subjected to X-ray diffraction and chemical analysis. Because the Oldman-Bearpaw contact is inferred to represent a continuous transition from nonmarine to marine conditions of sedimentation on the basis of faunal and lithologic evidence, it is postulated that any change in the clay mineralogy or chemistry of the rocks across the formational boundary will also indicate a change in environment.

Acknowledgments

Capable field assistance was rendered by L. G. Bartlett and G. B. Mellon. H. L. Hansen carried out most of the sample preparation and obtained X-ray diffraction patterns. H. A. Wagenbauer was responsible for most of the chemical analyses of the samples. The figures were drafted under the supervision of S. J. Groot.

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GEOLOGIC SETTING

Regional Geology of the Southern Alberta Plains

The rocks of the southern Alberta plains are composed mainly of Upper Cretaceous shales and sandstones of marine and nonmarine origin.

The outcrop pattern is controlled by the Sweetgrass arch, a broad, north-plunging anticline, the axis of which approximately bisects the southern Alberta plains (Fig. 1). The strata along the axis of this structure are mainly flat-lying with a slight regional dip to the north due to the plunge. Both east and west limbs dip gently away from the axis at a few tens of feet per mile. The dip of the west limb becomes steeper towards the disturbed belt bordering the Rocky Mountains. This regional structure is modified at several localities by small, relatively tight folds (Russell and Landes, 1940).

Marine shales of the Alberta group are the oldest rocks of the southern Alberta plains; they crop out on the crest of the Sweetgrass arch in the valley of Deer Creek, near the International Boundary (Russell, 1940). A few miles to the north, the valley of the Milk River cuts across the structure exposing the younger formations, the Milk River sandstone and the overlying Pakowki marine shale. The predominantly nonmarine Foremost and Oldman formations overlie the Pakowki shale and underlie a large area along the axis of the arch. Younger strata are confined to two main outcrop belts on either side of the arch, and include the marine Bearpaw shale, the nonmarine Edmonton and correlative strata, and nonmarine Tertiary strata. Small scattered outcrops of Tertiary instrusives exist in several gullies near the International Boundary. A mantle of glacial drift covers almost the whole area.

In summary, the stratigraphy of the beds above the Alberta shale can be resolved into a sequence of marine shales alternating with nonmarine sandy shales and sandstones. The marine shales thin and eventually disappear to the west whereas the nonmarine beds thicken to the west and shale out to the east.

Russell (1932) has suggested that each marine shale represents a rapid advance of the sea from the east because of the sharp boundary between the nonmarine strata and overlying marine shale. The upper portions of the shale formations are intimately interfingered with the overlying nonmarine beds indicating an oscillating shoreline as the sea gradually withdrew eastward.

The Oldman Formation

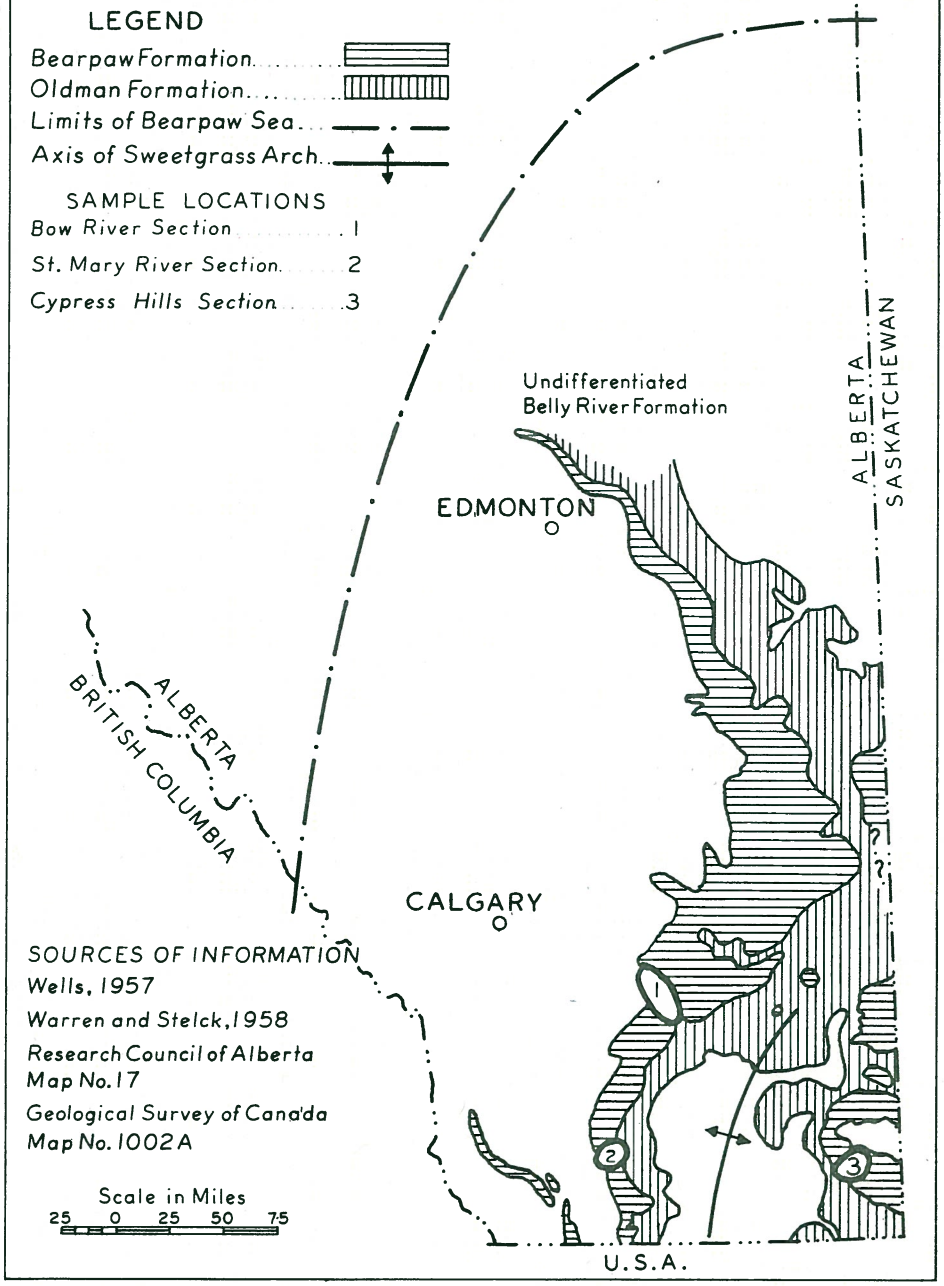
The Oldman formation was defined by Russell and Landes (1940) to comprise the upper part of Dawson's Belly River series (Dawson, 1875), and it is the surface formation over much of the Alberta plains (Fig. 1). It thickens toward the southwest, and in the disturbed belt of the Cordillera it is included with the upper part of the thick Belly River formation and is not distinguished from the underlying Foremost formation. Where it is encountered in the subsurface farther north it is also grouped with the Foremost under the name Belly River.

The Oldman formation is composed mainly of silty or sandy shales and fine-grained sandstones, many of which are bentonitic. Lenticular beds of coarse, clean, crossbedded sandstone are found locally, but argillaceous strata predominate in the section.

The Oldman samples used in this study were obtained from an outcrop of the upper Oldman formation along the St. Mary River. Here the lithology is more or less typical of the upper Oldman beds, consisting of predominantly dark-grey shales with thin siltstone stringers and coal seams from a fraction of an inch to several feet in thickness. Thin, discontinuous bentonite beds are found. The shale is commonly carbonaceous and silty, though unctuous clays are present. The strata carry dinosaur remains, invertebrate freshwater and brackish-water faunas, abundant plant remains, and are generally accepted as a nonmarine deposit. The strata were probably deposited in streams and lakes and marginal swamps during a withdrawal of the late Cretaceous sea.

FIGURE I

OUTCROP DISTRIBUTION OF BEARPAW AND OLDMAN FORMATIONS IN ALBERTA



The Bearpaw Formation

The Bearpaw formation was named by Stanton and Thatcher (1903) who established the type section in the Bearpaw Mountains of Montana, and later (1905) showed that the formation could be traced northward into Canada. Major contributions to the knowledge of the lithology, distribution, and paleontology of the formation were made by Dowling (1917), Williams and Dyer (1930), and Russell and Landes (1940).

The distribution of the Bearpaw formation in Alberta is indicated in figure 1. Three main outcrop belts are present. The Sweetgrass arch separates the eastern belt from the central belt. The eastern belt is confined to an area surrounding and extending north from the Cypress Hills where the formation is about 1,050 feet thick. The central outcrop belt extends from the International Boundary to the Edmonton area. The formation is up to 810 feet thick in the southern part of this belt and gradually thins northward, disappearing near Edmonton. The western outcrop belt is within the foothills of the Rocky Mountains where folding and faulting make precise thickness determinations difficult.

The Bearpaw formation was deposited during the last transgression of the Pierre Sea in late Campanian time (Warren and Stelck, 1958). It is a wedge of shale containing numerous marine fossils which has its greatest thickness in southeastern Alberta, and thins to the north and west (Russell and Landes, 1940). Nonmarine deposits overlie and underlie the formation. The overlying strata of the Edmonton (or equivalent) formation have a diachronous contact with the Bearpaw and gradually replace it to the north and west (Table I). The lower contact shows no break in sedimentation

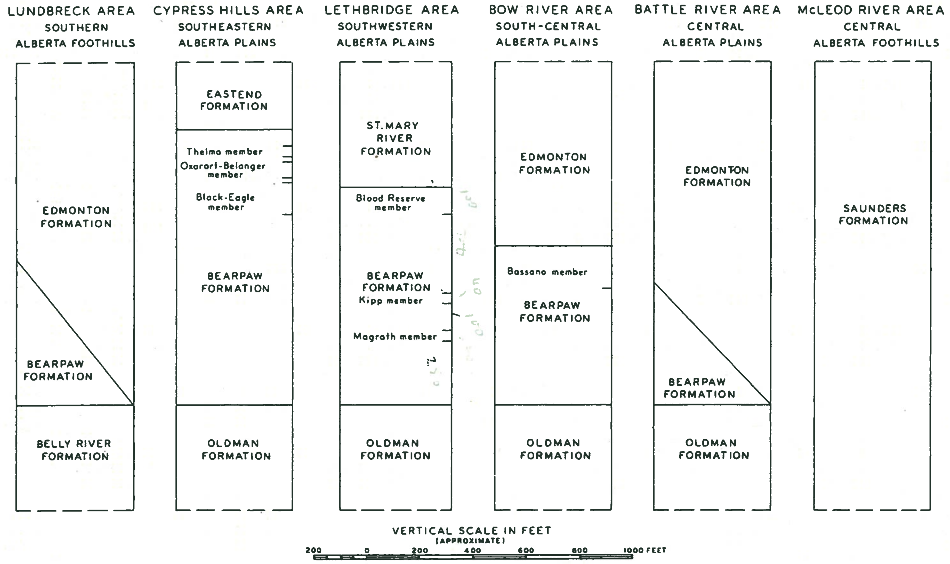


Table I. Correlation table showing relationships of Bearpaw formation to adjacent formations in Alberta. Information obtained from Russell (1932); Russell (1950); Loranger and Gleddie (1953).

between the Oldman and Bearpaw formations. Apparently the Bearpaw sea advanced rapidly across the surface of Oldman strata.

The marine shales constituting most of the Bearpaw formation are typically grey to brownish-grey, and soft, with a distinct flaky appearance on the weathered outcrop face. The fresh shale has a blocky habit. The harder and more massive beds tend to be made up of the siltier shales in the section and commonly have a blocky or concretionary appearance on the outcrop face. Selenite crystals showing "herringbone" twinning are locally abundant on the outcrop surface. Iron oxide stains are plentiful on fracture planes of the shale. Clay-ironstone concretions are scattered throughout the formation and are commonly concentrated to form continuous or semicontinuous bands which may be traced for several miles.

Sandstone beds in the Bearpaw formation are characteristically fine grained, poorly indurated, and argillaceous. Bentonite beds, ranging in thickness from a fraction of an inch to several feet and extending for several miles, are found throughout the Bearpaw. The bentonite is light bluish-grey, greenish-grey, or pale cream-colored on the weathered surface and is generally soft and plastic.

The concretionary zones, sandstone strata, and bentonite beds can be used as horizon markers to aid in compiling composite sections or in local structural surveys, but their value in correlating over long distances is questionable.

SAMPLING AND SAMPLE PREPARATION

The Bearpaw formation was sampled at three localities (Fig. 1). The St. Mary River section (Section 2) and the Cypress Hills section (Section 3) are composite, but nearly complete. The middle portion of the Bearpaw formation is not exposed in the Bow River section (Section 1). Each of the Bearpaw sections was described in the field, measured and sampled at approximately 10-foot intervals. Deviations from this 10-foot sampling interval were made in order to sample obvious changes in lithology and where portions of the section were covered. The samples were obtained by digging 10 to 18 inches into the outcrop face and collecting one pint of relatively fresh shale from the cut.

The portion of the St. Mary River section for approximately 50 feet above and below the Bearpaw-Oldman contact was sampled at 2-foot intervals. A detailed description of this portion of the St. Mary River section appears in figure 5.

In all, 201 samples were collected: 103 from the St. Mary River section, 71 from the Cypress Hills section and 27 from the Bow River section.

The samples were crushed to minus 60 mesh after removing most gypsum crystals by hand picking. In order to obtain a representative sample of the clay fraction for X-ray diffraction analysis, 100 grams of the crushed shale were placed in one litre of distilled water and boiled approximately one hour to break up the harder shale fragments. The water lost through boiling was replaced and the sample allowed to cool. At this stage, most samples flocculated to some extent. If the sample flocculated completely, the clear, supernatant liquid was poured off, more distilled water was added and the boiling procedure repeated. This procedure was continued for all samples until partial suspension of the clay was achieved upon cooling. The suspension was then filtered continuously by means of bacteriological-type filter candles to which a vacuum line was applied. The filtration was continued, fresh distilled water being added as required, until visual inspection indicated that substantially complete suspension of the clay had been achieved. The clay suspension was agitated vigorously and permitted to settle for 8 hours, after which an aliquot of 50 to 100 millilitres of the suspension was withdrawn from a point 10 centimetres below the surface of the suspension. The sample, according to Stokes' Law, contains particles under 2 microns in diameter (Krumbein and Pettijohn, 1938; Marshall, 1949).

By withdrawing a thin layer of the suspension from a depth of 10 centimetres rather than the entire suspension to this depth, an aliquot having a size distribution representative of the clay-size fraction as a whole was obtained (Chu, Davidson, Sheelar, 1953). The aliquot obtained from the suspension was evaporated to dryness in a flat-bottomed dish containing four glass slides. The platy particles in the suspension form an oriented aggregate parallel to the glass surface and the resulting slide is suitable for X-ray diffraction analysis (Grim, 1934).

A similar procedure was used to prepare samples for chemical analysis: the process of boiling, decanting, making up to volume, and boiling again was continued until, after standing overnight, the clay remained in suspension. The mixture was then agitated and allowed to stand. After 8 hours the entire top 10 centimetres of liquid was siphoned off. The remaining mixture was again made up to one litre with distilled water and the process was repeated several times in order to obtain approximately 8 grams of the clay-size fraction for chemical anlysis. The siphoned mixture contained particles 2 microns in size or smaller as noted above. This mixture was evaporated to dryness and the residue crushed to a fine powder and stored in a dessicator prior to chemical analysis.

MINERALOGY OF THE SHALES

Mineral Identification

X-ray diffraction powder photographs of the complete shale samples were obtained by mounting a portion of the sample, crushed to minus 60 mesh, in a wedge-type sample holder enclosed in a Hayes powder camera 14 centimetres in diameter. Copper Kα-radiation was used. The films thus obtained were used to identify chief mineral components of the shale.

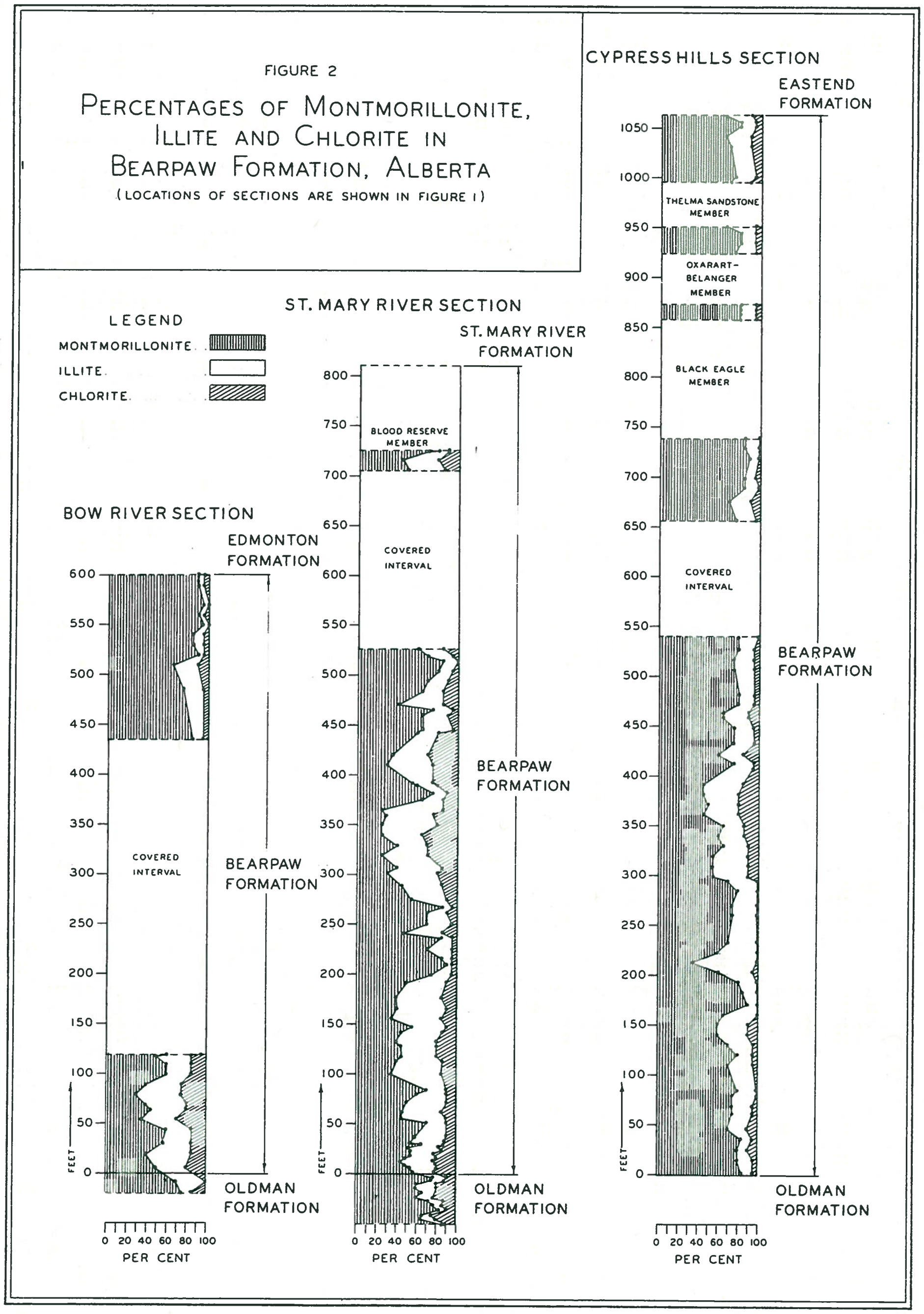


FIGURE 2

Percentages of Montmorillonite, Illite and Chlorite in Bearpaw Formation, Alberta

(Locations of sections are shown in Figure 1)

X-ray diffraction powder patterns were obtained for the clay-size fraction of each sample by mounting the oriented aggregates on the glass slides in a North American Philips diffractometer. In order to remove uncertainties regarding the identity of certain clay mineral species, all samples were re-scanned after treatment with ethylene glycol. Selected samples were heated in a muffle furnace to temperatures of 400° C, 500° C, and 600° C and re-scanned under similar conditions in order to distinguish among the chlorite, vermiculite, and kaolinite groups of clay minerals.

X-ray diffraction powder films of crushed shale show that various clay minerals predominate and that quartz and feldspar are present in all samples. Some films showed a small number of weak lines which could not be ascribed with certainty to any mineral.

The general order of abundance of the clay minerals in the clay-size fraction of all samples is: montmorillonite, illite and chlorite (Fig. 2). Quartz is present in all samples and possibly cristobalite in a few. Table II lists the X-ray diffraction powder data for the clay-size fractions. X-ray diffraction powder patterns of a typical sample before and after treating with ethylene glycol and heating are given in figure 3. Treatment of the samples with ethylene glycol confirms the predominance of montmorillonite and illite. The broad character of the peaks suggests that some of the minerals are very fine-grained or have defects in crystal structure, or both. There is little evidence of mixed layering present. Diffraction patterns of samples heated to 400° C, 500° C, and 600° C, indicate that the third major constituent is chlorite rather than kaolinite.

Quantitative Clay Mineralogy

In order to determine the relative proportions of the different clay minerals in the various samples, the intensities of the (001) lines of montmorillonite and illite and the (002) line of chlorite were obtained from the diffraction patterns of the glycol-treated samples by measuring areas under each peak. These intensities were multiplied, arbitrarily, by factors of 1, 4, and 1.6 for the montmorillonite, illite, and chlorite peaks respectively, as suggested by Johns, Grim and Bradley (1954), and by Murray (1953). These determinations are believed to be accurate to within about 5 per cent.

The results of these determinations are shown in figure 2. It was found that the data obtained from samples collected at 2-foot intervals across the Oldman-Bearpaw contact of the St. Mary River section could not be plotted adequately with the scale used, so the mean values for groups of two samples were plotted at a point midway between the positions at which the two samples were collected.

The results of quantitative clay mineral analysis of the Bearpaw shales are set out in appendix D. The analyses are also summarized graphically in figures 2 and 4. Figure 4 consists of frequency histograms

FIGURE 3

X-RAY DIFFRACTION POWDER PATTERNS OF THE CLAY-SIZE FRACTION OF A TYPICAL SAMPLE

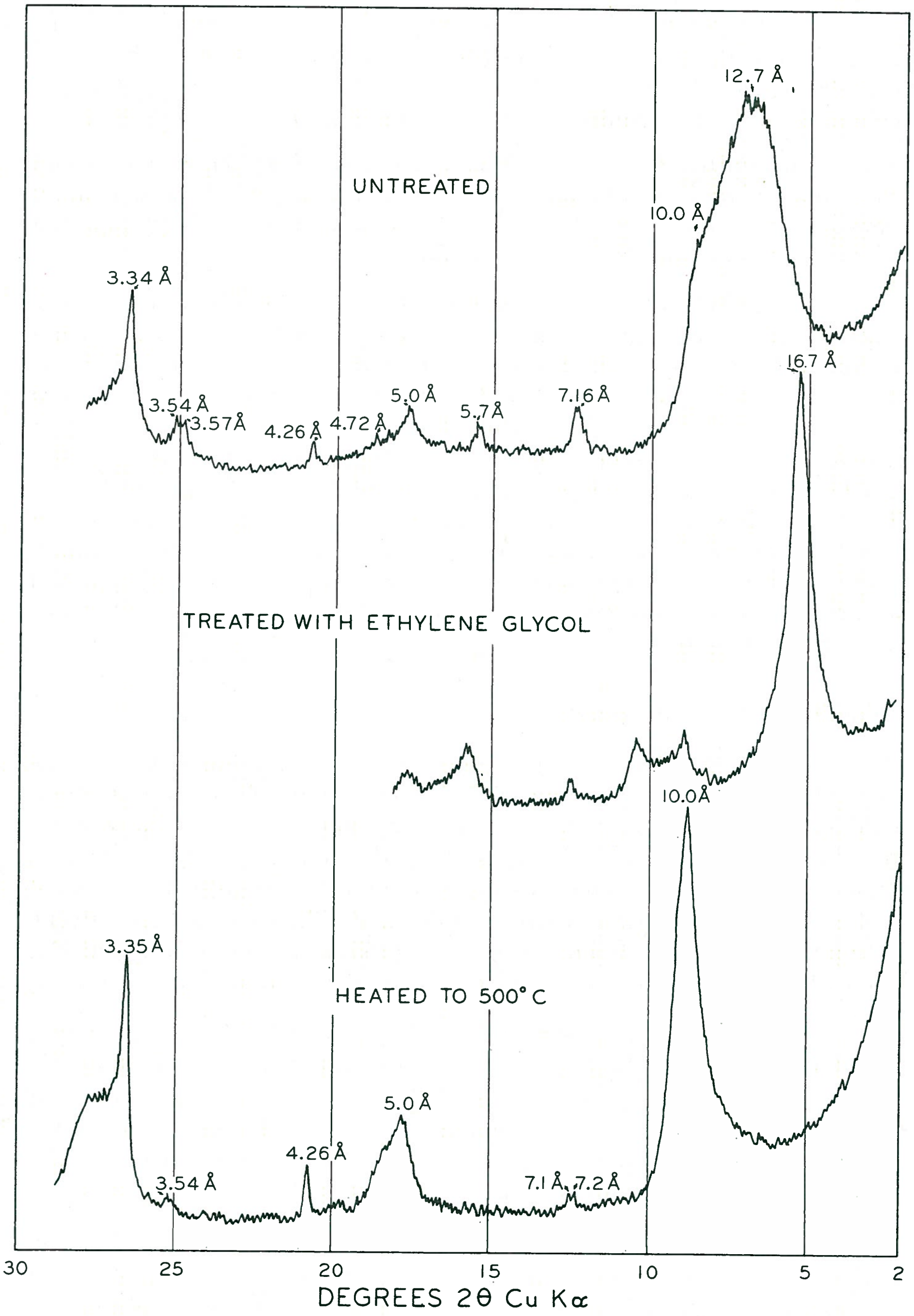


FIGURE 4

HISTOGRAMS SHOWING PROPORTIONS OF CLAY MINERALS IN THE BEARPAW SHALE

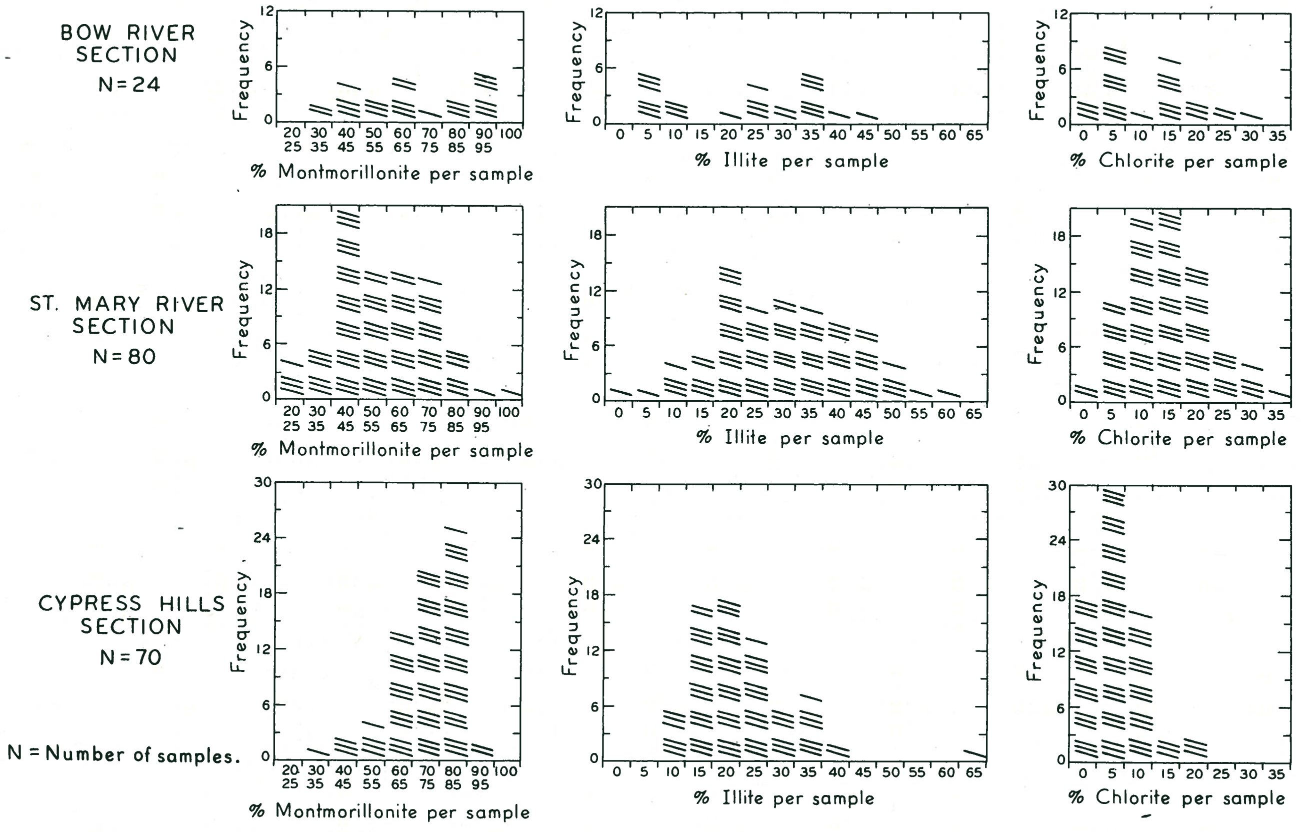


Table II. X-ray Diffraction Powder Data for Untreated Clay-size Fractions of Bearpaw Samples

d-spacing (Angstroms)	Intensity	Frequency of Occurrence	Interpretation
24 - 25	Weak	rarely	regularly interlayered illite-chlorite?
14	weak	sometimes	chlorite (001)
10 - 14	strong, broad	always	montmorillonite (001)
10	medium-strong	always	illite (001)
7.7	weak	rarely	montmorillonite (002?)
7.15 - 7.2	medium	always	chlorite (002)
5.75	very weak	rarely	?
5	medium-broad	always	illite (002)
4.75	weak	usually	chlorite (003)
4.48	weak	usually	clay minerals (110)
4.27	weak	always	quartz
4.07	weak	sometimes	cristobalite?
3.54 - 3.59	weak	always	chlorite (004)
3.34	strong	always	quartz
3.22	weak	sometimes	feldspar

showing the relative abundance in per cent of the three main clay minerals for each of the three sampled sections. Figure 2 shows the stratigraphic distribution of the relative proportions of the clay minerals within each sampled section. Statistics summarizing the geographic and stratigraphic distribution of the relative proportions of the clay minerals are set out in table III.

It is obvious from figures 2 and 4 that the relative abundance of the clay mineral constituents of the Bearpaw shales is montmorillonite, illite and chlorite, in that descending order. Montmorillonite occurs in all samples, illite in all but one, and chlorite in the majority of samples.

The frequency histograms of figure 4 also indicate differences in the geographic distribution of each clay mineral. Thus, the samples from the Cypress Hills section have a higher montmorillonite content and a lower illite and chlorite content than samples from the St. Mary River section. Furthermore, the smaller dispersions (spread or range of the samples) of the frequency histograms of the Cypress Hills samples, as compared to those of the St. Mary River samples, indicate that the distribution of clay

Table III. Mean Percentages of Montmorillonite, Illite and Chlorite in Sections of the Bearpaw Formation, Alberta

Name of Section	Portion of Section	Number of Samples	Mean Per Cent Montmorillonite	Standard Deviation	Mean Per Cent Illite	Standard Deviation	Mean Per Cent Chlorite	Standard Deviation
Bow River Section	Entire Bearpaw formation	24	65.4	21.5	22.3	13.5	11.9	8.4
	Upper 158 ft. Bearpaw formation	8	86.9	9.6	8.8	6.9	4.4	3.2
	Basal 137 ft. Bearpaw formation	16	54.7	26.8	29.1	10.5	15.6	7.7
St. Mary River Section	Entire Bearpaw formation	80	55.5	16.8	29.8	12.3	14.7	7.4
	Upper 25 ft. Bearpaw formation	4	61.3	16.5	25.0	12.2	13.8	4.8
	Lower 525 ft. Bearpaw formation (excluding basal 50 ft.)	54	55.2	19.3	31.2	14.0	13.6	7.9
	Basal 50 ft. Bearpaw formation	22	55.2	8.7	27.3	6.5	17.5	5.7
	Upper 50 ft. Oldman formation	22	71.6	10.8	12.5	6.5	15.9	6.1
Cypress Hills Section	Entire Bearpaw formation	70	71.6	11.6	22.4	9.3	5.2	5.1
	Upper 400 ft. Bearpaw formation	22	77.3	7.2	17.5	4.8	6.3	3.3
	Basal 550 ft. Bearpaw formation	48	69.1	12.4	24.7	10.0	5.9	5.7

minerals within the Cypress Hills section is more homogeneous than in the St. Mary River section. It is difficult to compare the relative proportions and distribution of clay minerals of the Bow River section with those of the other two sections because less than half the Bearpaw formation is exposed at this locality. The available evidence indicates, however, that the distribution of clay minerals within the Bow River section is relatively heterogeneous and similar to that of the St. Mary River section, rather than that of the Cypress Hills section.

No well-defined trends are obvious from the stratigraphic distribution of clay minerals shown in figure 2. The upper Bearpaw of the Bow River section contains more montmorillonite than the lower Bearpaw, but the relative proportions of the three clay minerals are similar in the upper and lower parts of the Cypress Hills and St. Mary River sections.

In summary, montmorillonite, illite and chlorite occur in that descending order of abundance in nearly all of the Bearpaw shale samples. Montmorillonite is more abundant in the Cypress Hills samples than in the St. Mary River samples, and the distribution of clay minerals is more homogeneous in the Cypress Hills section than in the St. Mary River or Bow River sections. Nevertheless, the differences in the geographic and stratigraphic distribution of the clay minerals within the Bearpaw shale are not of the magnitude that permits their interpretation in terms of geological causes and effects.

CHEMICAL COMPOSITION OF THE SHALES ACROSS THE BEARPAW-OLDMAN CONTACT

Analytical Procedures

The minus 2 micron size fraction from each of 45 samples was analyzed for SiO_2, TiO_2, Al_2O_3, total iron as Fe_2O_3, MgO, CaO, Na_2O, K_2O, loss on ignition, and P_2O_5. The methods used were those of Shapiro and Brannock (1956) except for Al_2O_3 and loss on ignition. The method outlined by M. L. Jackson* was used for Al_2O_3, after it was found that results obtained using Brannock and Shapiro's method were not reproducible. The samples were ignited at 950°C, in an electric furnace to obtain loss-on-ignition values. No attempt was made to differentiate between ferric and ferrous iron as such results might be more indicative of recent weathering than of a depositional factor.

Every chemical analysis was duplicated. Where SiO_2 and Al_2O_3 values were reproduced to within one per cent the precision was considered adequate. In most analyses the results were reproduced within 0.5 per cent for SiO_2 and Al_2O_3. Considerably greater absolute precision was obtained for other constituents. The totals for most of the analyses are

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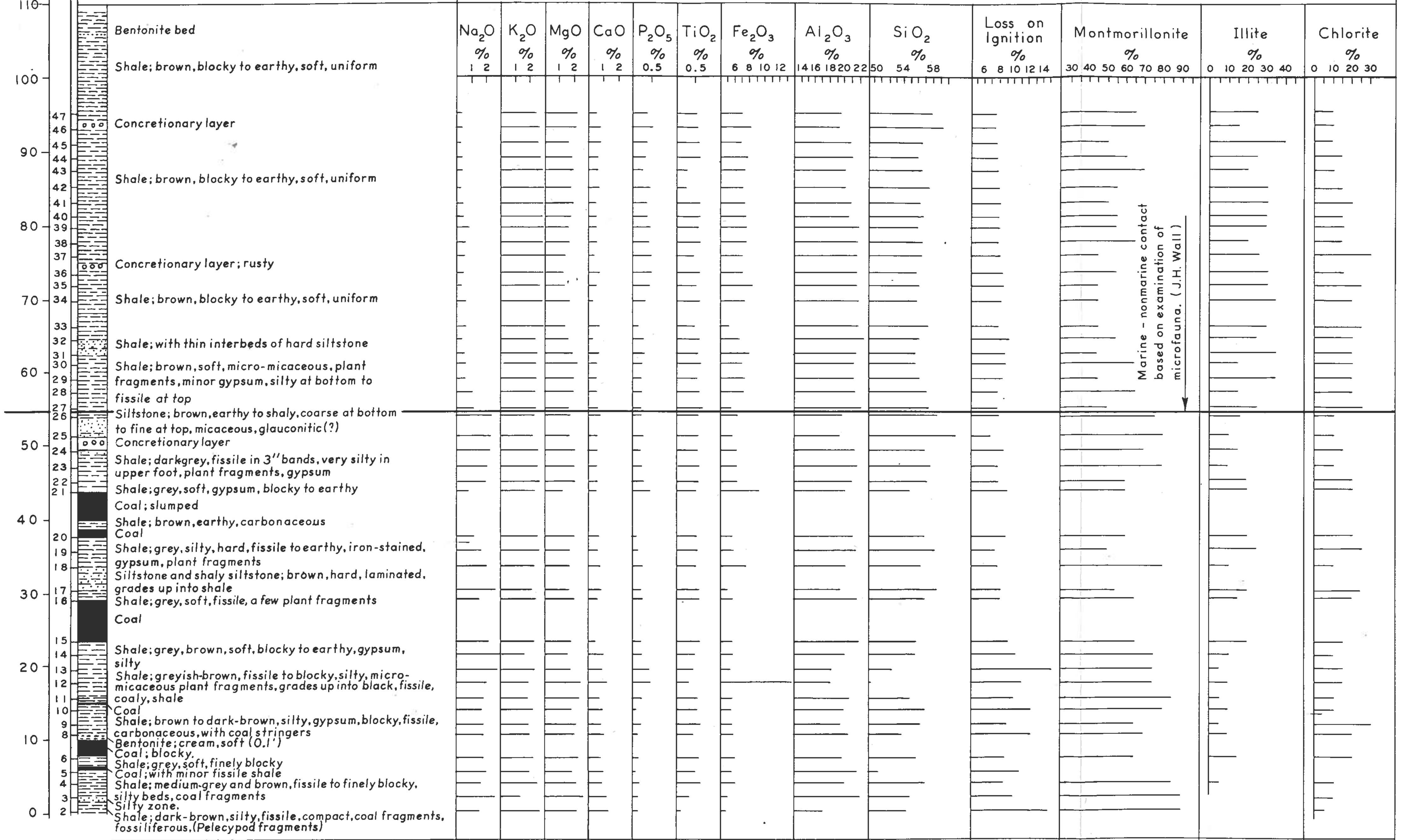
*Professor of Soils, University of Wisconsin. Details of the method were obtained from Prof. Jackson's lecture notes on soil analysis.

FIGURE 5

CHEMICAL COMPOSITION AND CLAY MINERALOGY ACROSS THE OLDMAN-BEARPAW CONTACT, ST. MARY RIVER SECTION, ALBERTA



Mean Values		Na_2O	K_2O	MgO	CaO	P_2O_5	TiO_2	Fe_2O_3	Al_2O_3	SiO_2	Loss on Ignition	Montmorillonite	Illite	Chlorite
Mean Values	Above Oldman - Bearpaw Contact	0.45	2.64	1.69	0.48	0.34	0.57	7.01	20.90	56.33	7.83	55.0	27.1	17.9
	Below Oldman - Bearpaw Contact	1.91	2.12	1.82	0.72	0.19	0.50	5.92	19.90	55.44	9.33	72.4	12.0	15.7

from 1.0 to 2.5 per cent low. The general tendency of the totals to be low is attributed to a systematic error in the loss-on-ignition determinations.

For purposes of comparison, a sample was sent to the University of Minnesota Rock Analysis Laboratory and the results obtained are given with the authors' analysis in table IV. The only major difference is in the loss-on-ignition determinations. This difference might be due to the different temperatures at which the samples were ignited.

The results of the chemical analyses are presented graphically in figure 5. The shales are close to the average composition for shales (Clarke, 1924, page 34). Variations may be attributed to rather high loss on ignition and the removal of silt and sand sized grains in sample preparation.

Quantitative Clay Chemistry

The results of the chemical analyses are set out in appendix E. These results are presented graphically in figure 5, and mean values are shown for each constituent above and below the formational contact. The clay mineralogy of the samples and the lithologic log of the section are included in the figure for easy comparison.

The chemistry of the shales closely follows the mineralogy and is remarkably constant. The only obvious variations in the series are in the proportions of the oxides of sodium, potassium, calcium, phosphorous and (total) iron.

Table IV. Comparison of Rapid Analysis Results with a Check Analysis for Sample 13

Constituent	Rock Analysis*	University of Minnesota Rock Analysis Laboratory**
SiO_2	51.99	51.45
TiO_2	0.39	0.58
Al_2O_3	17.76	17.75
Fe_2O_3	5.03	4.65
MnO	—	0.04
MgO	1.62	1.69
CaO	0.81	1.09
Na_2O	2.71	2.15
K_2O	2.26	2.19
H_2O	—	2.76
Loss on Ignition	14.83	15.45
P_2O_5	0.37	0.18
	97.77 per cent	99.98 per cent

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*Analysts: H. Wagenbauer and R. Farvolden.

**Analyst: Eileen H. Oslund.

The mean values for Na_2O are higher in the Oldman samples than in the Bearpaw samples by a factor of about 4 and the change in Na_2O values coincides with the formational contact. CaO mean values are slightly higher in the samples from the lower part of the Oldman section but there is no abrupt change at the formational contact. The mean values for K_2O, TiO_2 and Fe_2O_3 are higher in the Bearpaw samples than in the Oldman samples but, as with CaO, the formational contact does not mark a "break" in the concentration of these constituents.

It was suspected that the apparent "break" in Na_2O content of the shales might have been caused by differential leaching of the crushed shales by boiling during sample preparation. To check this possible source of error this stage of sample preparation was repeated for three Bearpaw samples and a "blank" sample—a beaker containing only distilled water. The leachate in each sample showed insignificant increases in Na_2O as boiling progressed and these increases were approximately the same as those in the blank sample containing only distilled water. It was therefore concluded that the Na_2O values found in the analyses are the true concentration of Na_2O in the shales.

DISCUSSION OF RESULTS

The general similarity of all samples tends to support Weaver's conclusion that the major factor controlling the clay mineral content of a sediment is the source area rather than the environment of deposition (Weaver, 1958). Mineralogical and chemical differences which do occur within the Bearpaw formation and across the Bearpaw-Oldman contact may be ascribed to diagenetic alteration but these are only minor variations in relative abundance of the same clay minerals present in all samples. Differences of this magnitude would not enable one to predict, from a small number of analyses, the environment of deposition of a given sediment.

The clay minerals present in these samples appear to be of the type that would be altered easily in that they are all three-layered, fine-grained, and have a low degree of crystallinity. Rowland (1956) suggests that the montmorillonite of the Bearpaw shales has not converted to illite or chlorite because most of the charge deficiency responsible for holding interlayer cations is in the octahedral layer. This suggestion was tested, using a procedure outlined by Greene-Kelley (1955) involving X-ray diffraction analysis of samples treated with lithium chloride and heated to 200° C. The results indicated both octahedral and tetrahedral substitution in the montmorillonite. Conversion of this type of montmorillonite might be a rather slower process than conversion of a beidellite-type montmorillonite.

Grim (1953) and Glass (1957) have suggested that where deposition is rapid, clay alteration will be slight since the sediments are quickly removed from the marine environment by burial. However, the Bearpaw shales of the area exhibit no evidence of rapid deposition so the deposition rate was not the factor preventing diagenesis.

There are two feasible explanations for the dominance of montmorillonite throughout the Bearpaw formation. Firstly, montmorillonite can be the dominant clay mineral in sediments derived from a source area where there is little leaching of the solum (Milne and Earley, 1958; Grim, 1953). Secondly, montmorillonite is known to occur in sediments as an alteration product of volcanic ash. The montmorillonite of the Bearpaw formation was likely supplied by both of these mechanisms.

The presence of bentonite beds within these shales is indicative of volcanic activity for, according to Grim (1953), bentonite represents altered volcanic ash.

Mineralogical analyses of eight bentonite samples chosen at random showed montmorillonite to be the only clay mineral present, and quartz, a ubiquitous constituent of shales of normal sedimentary origin, is virtually absent. Cristobalite was observed in four of the eight samples. This mineralogical evidence strongly suggests a volcanic ash origin for the Bearpaw bentonites. Field studies confirm this theory. The bentonite beds, always thin, may persist for several miles. They are marked by an abrupt lower and somewhat gradational upper contact, and are light-colored in contrast to the surrounding shales which presumably owe their dark color to organic material and iron oxides. In the Cypress Hills area bentonites have been observed to grade laterally into volcanic ash (Sanderson, 1931).

Volcanic ash, falling on the Bearpaw Sea, would be preserved in distinct beds only where limited circulation prevented its mixing with sediments brought into the basin by streams. Each of the preserved bentonite beds indicates a fall of ash into the basin, probably over a large area. Bentonite beds are numerous and are found throughout the Bearpaw section. It is considered that the number of bentonite beds found in any one section does not represent the total ash fall-out. Additional ash fall-outs took place—as proven by bentonite beds at other levels in other sections—but locally the resulting ash was mixed, by fluctuating currents, with stream-derived muds. Thus a large portion of the montmorillonite in the Bearpaw shale has a volcanic origin.

Thin bentonite beds are also found in the Oldman formation, though less commonly than in the Bearpaw formation. The similarity of occurrence and appearance between the bentonites of the two formations is so strong that there seems no doubt that their origins and depositional histories are nearly identical. Thus, it can be stated that for these strata bentonite became the end product of the alteration of volcanic ash whether that ash fell into a marine or a nonmarine environment.

An ash fall-out and generation of montmorillonite would tend both to mask and reduce the effects of diagenesis. Firstly, large quantities of material introduced into the system in this manner would mask the minor changes involved in clay diagenesis. Secondly, the large percentage of montmorillonite would reduce the permeability of the clay which in turn would inhibit diagenesis by removing the clay from contact with the marine environment.

From consideration of the method of sample preparation it seems certain that the sodium of the clays is firmly adsorbed onto the basal planes of clay-mineral structures, most likely montmorillonite. Thus the decrease in sodium content from the Oldman to the Bearpaw portion of the section and the accompanying small increase in potassium might be interpreted as an indication that a portion of the montmorillonite of the ancient continental environment has altered to illite in the marine environment. The mineralogical break at the Oldman-Bearpaw contact (Fig. 4) supports this argument.

From the review of the work of other investigators one would expect a distinct change in the chlorite and therefore in the MgO content of the samples over the marine-nonmarine contact. There is no such change and it is obvious that chlorite was not formed in the Bearpaw Sea bottom muds. Similarly, if the proposed alteration of kaolin to a three-layered mineral had taken place in this sedimentation system it should be reflected in the composition of the shales with respect to alumina and silica. Again the mineralogical and chemical analyses are complementary for little or no kaolin is present in the shales and the alumina-silica ratio is constant.

Both P_2O_5 and total iron show enrichment in the marine portion of the section. Enrichment in both oxides has environmental significance but it is of no value in interpreting the clay mineralogy or clay chemistry.

The point might be raised that the present chemistry of these samples does not indicate the chemistry of the shales during deposition and early diagenesis because of chemical changes brought about, after lithification, by interstratal solutions and other late diagenic changes. This does not seem feasible when one considers the impermeable nature of the shales involved. Likewise, erosion on the cliff face from which the samples were collected is extremely active and it is unlikely that weathering processes have significantly affected the chemistry of the clays in the samples. To check this point, the clay mineralogy of twenty samples of sandy or silty shales of the St. Mary River and Cypress Hills sections was compared to the clay mineralogy of twenty nonsilty samples from the same sections. One would suspect greater weathering in the more porous sandy and silty shales. However, the analyses showed no significant change in clay mineralogy from porous to nonporous beds.

CONCLUSIONS

The results of this investigation indicate that the clay mineralogy of the Bearpaw formation is not controlled by the proximity of the ancient shoreline to the environment of the site of deposition. There is some evidence of a slight change in mineralogy and chemistry of the clays across the marine-nonmarine contact which may indicate that a minor portion of the clays have undergone diagenesis.

The shales of the Bearpaw and upper Oldman formations contain a large proportion of montmorillonite throughout. This montmorillonite indicates intensive vulcanicity during the deposition of these sediments. The volcanic ash altered to montmorillonite whether it fell into a marine or a nonmarine environment.

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APPENDIX A

Bow River Section

Top of section	Thickness ft.	Cumulative thickness ft.
SANDSTONE, light greenish-grey, fine-grained, argillaceous, white-weathering; Sample *28* taken 3 ft. above base	14.0	
SILTSTONE, argillaceous, white-weathering	2.0	
EDMONTON-BEARPAW CONTACT		
CLAY, greenish-brown, silty, somewhat bentonitic; Sample *27* taken 2 ft. above base	9.0	595.5
SILTSTONE, argillaceous, white-weathering	2.0	586.5
SHALE, greenish-brown to greyish-brown, hard, somewhat flaky, silty with numerous thin silt bands, bentonitic weathering; Sample *24* taken 5 ft. above base, Sample *25* 25 ft. above base, Sample *26* 35 ft. above base	39.0	584.5
SHALE, as above, but less silty; occasional carbonaceous fragments; Sample *21* taken 10 ft. above base, Sample *22* 20 ft. above base, Sample *23* 30 ft. above base	35.0	545.5
SILT, greenish-grey, argillaceous, white-weathering; contains *Baculites* and *Arctica ovata* (Meek and Hayden) at top; Sample *20* taken of green sand at top	15.0	510.5
SHALE, greenish-brown, coarsely flaky; Sample *18* taken at base, Sample *19* at top	10.0	495.5
SHALE, grey to greenish-grey, coarsely flaky	3.5	
SILT, dark-brown, soft, argillaceous	25.0	482.0
SANDSTONE, massive, slightly argillaceous, fine-grained; contains *Baculites compressus* Say, *Arctica ovata* (Meek and Hayden), and *Inoceramus* sp.; concretions scattered through lower part; Sample *17* taken at base	20.0	457.0
Covered approximately	300	437.0
SHALE, grey, blocky	16.0	137.0
SHALE, greenish-grey, soft, silty	3.0	121.0
BENTONITE, yellowish-grey, rusty stains; Sample *16*	0.2	
SHALE, dark-grey, hard, coarsely blocky to nodular; Sample *15* taken 5 ft. above base	5.5	117.8
BENTONITE, yellowish-grey	0.1	
SHALE, grey to greyish-brown, finely blocky, scattered clay-ironstone concretions; Sample *13* taken 3 ft. above base, Sample *14* 13 ft. above base	17.0	112.2

Top of section	Thickness ft.	Cumulative thickness ft.
BENTONITE, yellowish-grey, iron stained	0.1	
SHALE, greyish-brown, finely blocky, scattered clay-ironstone concretions; Sample *7* taken 5 ft. above base, Sample *8* 15 ft. above base, Sample *9* 25 ft. above base, Sample *10* 30 ft. above base, Sample *11* 40 ft. above base and Sample *12* 50 ft. above base; *Placenticeras* found 12 ft. from base	57.0	95.1
BENTONITE, cream-colored and iron-stained at base, grey-green at top; shale laminae interbedded at top; Sample *6*	0.2	38.1
SHALE, grey, blocky to flaky, occasional clay-ironstone concretions; Sample *4* taken 5 ft. above base, Sample *5* 15 ft. above base	24.0	37.9
BENTONITE, cream-colored, iron-stained, soft, plastic	0.3	13.9
SHALE, grey, blocky to flaky	1.8	13.6
BENTONITE, cream-colored, iron-stained, soft, plastic	0.2	11.8
BENTONITE, bluish-grey, soft, plastic	0.1	11.6
SHALE, grey, blocky to flaky, occasional clay-ironstone concretions; Sample *3* taken 5 ft. above base	11.5	11.5
BEARPAW-OLDMAN CONTACT		
SHALE, brownish-grey to brown, flaky, silty, thin silt interbeds 2 ft. from base and at top; considerable iron-staining	7.0	
SANDSTONE, grey-green, fine-grained, micaceous, feldspathic, argillaceous, contains many carbonaceous fragments; Sample *2* taken 1 ft. above base	2.0	
COAL, soft, dull, flaky	2.0	
SHALE, dark-brown, flaky, carbonaceous	2.0	
SILTSTONE, pale greenish-grey, somewhat argillaceous, finely laminated, shows micro-crossbedding	5.5	
SHALE, dark-grey, flaky; Sample *1* taken at base	1.0	
SHALE, brown, flaky, carbonaceous	2.5	
SHALE, greenish to greyish-brown, very sandy	7.0	
COAL, top only exposed	1.0	
BASE OF SECTION		

St. Mary River Section

Top of section	Thickness ft.	Cumulative thickness ft.
SHALE, dark-grey, flaky, numerous *Ostrea* sp., not measured		
SHALE, greenish-grey, finely blocky, iron-stained	2.5	
SHALE, grey, finely blocky, iron-stained	2.0	
ST. MARY RIVER-BEARPAW CONTACT		
SANDSTONE, grey, massive, cliff-forming, non-calcareous, contains carbonaceous fragments towards top, medium-grained; *Blood Reserve member* approximately	90	820.1
SHALE, grey, blocky to flaky, iron-stained, small selenite crystals near surface; Sample *135* taken at base	5.5	730.1
SHALE, grey, friable, flaky, with thin sandy partings; Sample *134* taken at top	4.2	724.6
SHALE, grey to rusty brown, blocky	1.0	720.4
SHALE, grey to reddish-brown, blocky to flaky, occasional thin lenses of bentonite	0.8	719.4
CLAY, brownish-grey, soft, earthy, plastic	0.1	718.6
SHALE, grey, blocky to flaky, iron-stained on fracture surfaces, thin sandy partings; Sample *133* taken 1 ft. above base	3.0	718.5
SANDSTONE, light-grey, poorly indurated, medium-to fine-grained	0.7	715.5
SHALE, grey, blocky to flaky, locally iron-stained	1.0	714.8
CONCRETIONS, rusty-brown, fairly soft, weathered	0.5	713.8
SHALE, grey, blocky to flaky, iron-stained on fracture surfaces, sandy lenses at base	6.5	713.3
IRONSTONE CONCRETIONS	0.5	706.8
SHALE, light-grey to brown, soft, friable, sandy, abundant *Arctica ovata* (Meek and Hayden); Sample *132* taken at top	4.9	706.3
Covered approximately	175	701.4
SHALE, greenish-brown, flaky, occasional carbonaceous fragments; Sample *131* taken at base	1.0	526.4
SHALE, dark-grey, blocky, weathering flaky	4.5	525.4
SHALE, dark-grey, hard, blocky; Sample *130* taken 3 ft. above base	6.0	520.9
SHALE, dark-grey, blocky, weathering flaky; Sample *129* taken 8 ft. above base	9.0	514.9

Top of section	Thickness ft.	Cumulative thickness ft.
SHALE, dark-grey, finely flaky to flaky, locally iron-stained; concretions 7.5 ft. above base contain *Pteria linguiformis* (Evans and Schymard) and *Inoceramus barabini* (Morton); thin bentonite stringer 15 ft. from base; Sample *126* taken 10 ft. above base, Sample *127* 20 ft. above base, Sample *128* 30 ft. above base	33.0	505.9
BENTONITE, yellowish-green, soft, plastic (bentonite No. 11)	0.1	472.9
SHALE, as above; Sample *125* taken 2 ft. above base	5.0	472.8
SHALE, rusty-brown, silty, friable; Sample *124* taken at base	2.5	467.8
SHALE, dark-grey to rusty-brown, somewhat friable, somewhat silty	3.5	465.3
BENTONITE, mealy, plastic, intermixed with shale	0.1	461.8
SHALE, dark-grey, iron-stained; Sample *123* taken 8 ft. above base	11.7	461.7
BENTONITE, yellowish-grey, earthy, plastic, silty (bentonite No. 10)	0.2	450.0
SHALE, dark-grey, iron-stained, slightly silty, contains much gypsum	2.5	449.8
SHALE, rusty-brown, friable, blocky, silty, contains much gypsum; Sample *122* taken at base	2.3	447.3
BENTONITE, lemon-yellow with local patches of green or blue, soft, chippy, locally iron-stained (bentonite No. 9)	0.1 to 0.7	445.0
SHALE, light-grey to rusty-brown, blocky, friable, somewhat silty, becoming siltier towards top; Sample *121* taken 12 ft. above base	14.8	444.6
BENTONITE, lemon-yellow, chippy (bentonite No. 8)	0.3	429.8
SHALE, dark-grey, locally iron-stained, finely blocky to flaky; Sample *120* taken 5 ft. above base	14.5	429.5
SHALE, grey to rusty-brown, blocky, silty, with layers of clay-ironstone concretions at base and 2.0 feet above base; Sample *119* taken 5 ft. above base	11.0	415.0
TOP OF KIPP SANDY MEMBER		
SHALE, grey to greenish-grey, hard, very sandy; Sample *118* taken at base	12.0	404.0

Top of section	Thickness ft.	Cumulative thickness ft.
SHALE, grey, blocky, silty towards top; Sample *116* taken 3 ft. above base, Sample *117* 10 ft. above base	13.0	392.0
SHALE, grey, hard, coarsely blocky, very silty	2.0	379.0
BASE OF KIPP SANDY MEMBER		
SHALE, grey, blocky, somewhat silty towards top, contains scattered concretions bearing poorly preserved *Placenticeras* sp.; Sample *109* taken at base, Sample *110* 10 ft. above base, Sample *111* 20 ft. above base, Sample *112* 30 ft. above base, Sample *113* 40 ft. above base, Sample *114* 45 ft. above base, and Sample *115* 55 ft. above base	58.0	377.0
BENTONITE, bluish-grey, soft, somewhat silty, white soluble salts on surface (bentonite No. 6)	0.4	319.0
SHALE, grey, blocky to flaky	0.5	318.6
BENTONITE, admixed with shale	0.3	318.1
Covered interval	11.5	317.8
SHALE, as above; Sample *107* taken 4 ft. above base	8.6	306.3
SHALE, light-grey, coarsely blocky, very sandy	2.5	297.7
SHALE, grey, blocky to flaky, becoming siltier and more coarsely blocky towards top	1.0	295.2
BENTONITE, grey, iron-stained, silty, locally admixed with shale	0.1	294.2
SHALE, grey, finely blocky to flaky, iron-stained on fracture surfaces except in basal 2 ft.; Sample *106* taken 4 ft. above base	8.9	294.1
SANDSTONE, fine-grained, argillaceous, blocky, fairly friable, disseminated gypsum; numerous *Arctica ovata* (Meek and Hayden)	1.0	285.2
SHALE, as above, Sample *105* taken at base	10.0	284.2
SANDSTONE, as above	3.0	274.2
SHALE, dark-grey, finely blocky, somewhat silty, becoming siltier towards top; Sample *104* taken 1 ft. above base	5.0	271.2
SHALE, grey, finely blocky to flaky, locally iron-stained along fractures; Sample *103* taken at base	4.2	266.2
BENTONITE, grey, admixed with shale and selenite crystals	0.8	262.0

Top of section	Thickness ft.	Cumulative thickness ft.
TOP OF MAGRATH SANDY MEMBER		
SANDSTONE, brown, blocky, iron-stained, argillaceous, fine-grained	1.0	261.2
SHALE, greenish-grey, silty, blocky	2.2	260.2
CLAY, grey, plastic	1.0	258.0
CLAY, grey, bentonitic, with thin stringers of bentonite	0.3	257.0
SHALE, grey, finely blocky to flaky	1.5	
CLAY, buff, iron-stained, silty; Sample *102* taken at top	3.0	
BASE OF MAGRATH SANDY MEMBER		
CLAY, grey, plastic	1.0	252.2
BENTONITE, yellow at top, bluish-grey at base, silty (bentonite No. 5)	0.8	251.2
SHALE, grey, hard, blocky; Sample *101* taken at top	6.5	250.4
CLAY, brownish-grey with green tinge, very silty; Sample *100* taken at base	2.0	243.9
SHALE, grey, blocky, iron-stained, somewhat silty 9 ft. from base; Sample *99* taken 8 ft. above base	13.0	241.9
SHALE, grey to brown, somewhat silty; Sample *98* taken at base	4.7	228.9
SILTSTONE, buff, soft, blocky, argillaceous	0.2	224.2
SHALE, grey to brown, fairly plastic, silty towards top	5.0	224.0
SILTSTONE, buff, soft, blocky, very argillaceous	4.5	219.0
SHALE, grey to brown, blocky, locally iron-stained, somewhat silty; Sample *97* taken at top, Sample *96* at base	7.0	214.5
SHALE, grey, hard, spheroidal to coarsely blocky, silty; Sample *95* taken at base	9.0	207.5
Covered approximately	5.0	198.5
BENTONITE, olive-green, finely blocky, impure at top (bentonite No. 4)	2.0	193.5
SHALE, grey, blocky; Sample *93* taken 5 ft. above base, Sample *94* at top approximately	20.0	191.5
CLAY, brown, plastic, incrustation of gypsum on surface	0.5	171.5
BENTONITE, admixed with brown clay	0.1	171.0
SHALE, grey, hard, blocky, layer of ironstone concretions at base; Sample *92* taken 5 ft. above base	12.0	170.9

Top of section	Thickness ft.	Cumulative thickness ft.
BENTONITE, yellowish-green	0.1	158.9
SHALE, grey, hard, blocky; Sample *91* taken at base	4.0	158.8
CLAY, brown, plastic	0.2	154.8
BENTONITE, light-grey to yellowish-grey (bentonite No. 3)	0.2	154.6
CLAY, brown, plastic	0.2	154.4
SHALE, grey, hard, blocky	2.4	154.2
CLAY, brown, plastic, incrustation of gypsum on surface	0.3	151.8
BENTONITE, bluish-grey, locally iron-stained	0.1	151.5
SHALE, grey, hard, spheroidal to blocky, iron-stained on fracture surfaces, becoming flakier towards base; Sample *88* taken 5 ft. above base, Sample *89* 15 ft. above base and Sample *90* 20 ft. above base	24.0	151.4
SHALE, grey, soft, blocky to flaky, iron-stained; Sample *87* taken at top	1.0	127.4
SHALE, grey, spheroidal to blocky; Sample *85* taken 10 ft. above base, Sample *86* 15 ft. above base	24.5	126.4
SHALE, grey, spheroidal to blocky, locally iron-stained; Sample *84* taken at base	3.5	101.9
BENTONITE, cream to blue-grey, iron-stained, admixed with shale	0.1	94.8
SHALE, grey, blocky to flaky, iron-stained, layer of clay-ironstone concretions at base	2.7	94.7
SHALE, grey, spheroidal to flaky, thin interbeds of sand, bentonitic stringer 4.5 ft. above base; Sample *83* taken 1 ft. above base	10.2	92.0
BENTONITE, greenish-blue, highly plastic (bentonite No. 2)	0.8	81.8
SHALE, dark-grey, spheroidal to blocky to flaky; Sample *82* taken 4 ft. above base	6.0	81.0
SHALE, grey, blocky to flaky, locally iron-stained; Sample *81* taken 5 ft. above base	9.5	75.0
BENTONITE, creamy-white, iron-stained	0.1	65.5
SHALE, grey, blocky to flaky, locally iron-stained; Sample *80* taken at base	4.2	65.4
CLAY-IRONSTONE concretions	0.7	61.2
SHALE, grey, blocky to flaky, locally iron-stained; Sample *79* taken 3 ft. above base	8.5	60.5
BENTONITE, creamy-white, soft, blocky; only present locally	0.3	52.0

Top of section	Thickness ft.	Cumulative thickness ft.
SHALE, grey, blocky to flaky, locally iron-stained; Sample *78* taken at base	2.0	51.7
BENTONITE, yellowish-grey, locally bluish-grey at base, somewhat silty (bentonite No. 1)	1.2	49.7
SHALE, dark-grey, soft, blocky to flaky, iron-stained on fracture surfaces; concretionary horizons 8, 19 and 30 feet from base contain *Placenticeras meeki* Boehm; Sample *75* taken 2 feet above base, Sample *76* 16 feet above base, Sample *77* 26 ft. above base	42.2	48.5
SHALE, grey, blocky, silty	1.2	6.3
SHALE, dark-grey, blocky to flaky, locally iron-stained, somewhat silty	5.1	5.1
Approximate thickness of Bearpaw formation: 800		
BEARPAW-OLDMAN CONTACT		
SHALE, as above	2.7	
SHALE, grey, blocky	1.5	
SHALE, grey, blocky, sandy, especially near base	3.0	
SANDSTONE, greenish-grey, friable, argillaceous, fine-grained	1.0	
SANDSTONE, grey, fine-grained, concretionary	0.4	
SHALE, dark-grey, silty, plastic	5.0	
SHALE, dark-grey to brown, flaky, plastic	1.2	
COAL	0.1	
SHALE	0.3	
COAL	2.5	

BASE OF SECTION

Cypress Hills Section

Top of section	Thickness ft.	Cumulative thickness ft.
SAND, brown, poorly consolidated, very fine-grained, not measured		
EASTEND-BEARPAW CONTACT		
SHALE, grey to rusty-brown, finely blocky, sand lenses and stringers in upper part; Sample *208* taken 2 feet above base	3.0	1062.8
SANDSTONE, greyish-brown, soft, fine-grained	2.8	1059.8
SHALE, greyish-brown, soft, plastic, locally iron-stained, somewhat silty, occasional sandy bands towards top; Sample *204* taken 5 ft. above base, Sample *205* 15 ft. above base, Sample *206* 25 ft. above base, Sample *207* 30 ft. above base	31.0	1057.0
Covered	25.0	1026.0
SHALE, brownish-grey, blocky; Sample *202* taken 2 ft. above base, Sample *203* taken 7 ft. above base	7.0	1001.0
SANDSTONE, light-grey to greenish-grey, massive, poorly indurated, fine-grained, slaty and carbonaceous in upper 2 ft. (*Thelma member*)	42.0	994.0
SHALE, grey blocky, interbedded with fine-grained sandstone	1.5	952.0
SHALE, grey, blocky to flaky; Sample *199* taken 5 ft. above base, Sample *200* 15 ft. above base, Sample *201* at top	20.5	950.5
SHALE, grey, blocky to flaky, silty, contains thin bands of fine-grained grey to green sand; Sample *198* taken at base	6.7	930.0
SANDSTONE, greenish-grey, massive, micaceous, fine-grained; fossiliferous concretions occur about 10 ft. above base (*Oxarart-Belanger member*) approximately	45	923.3
SHALE, grey, blocky to flaky, iron-stained on fracture surfaces, silty; Sample *196* taken 2 ft. above base, Sample *197* 7 ft. above base	12.5	878.3
SHALE, as above, but somewhat less silt; Sample *195* taken 5 ft. above base	8.0	865.8

Top of section	Thickness ft.	Cumulative thickness ft.
SANDSTONE, grey, massive, fairly well indurated, fine-grained to medium-grained; argillaceous in upper few feet; Sample *194* taken at top (*Black Eagle member*) approximately	120	857.8
SHALE, light-brownish-grey, soft, blocky, silty, occasional bands of silt; Sample *193* taken at top	2.0	737.8
SANDSTONE, grey, iron-stained, fine-grained	1.0	735.8
SHALE, as above; Sample *191* taken 10 ft. above base, Sample *192* 20 ft. above base	27.0	734.8
SHALE, brownish-grey, occasional silty beds, considerable gypsum in fractures; Sample *189* taken 9 ft. above base, Sample *190* 19 ft. above base	28.0	707.8
SHALE, dark-grey, silty, sandstone interbed	1.0	679.8
SHALE, dark-grey, blocky to flaky, occasional bands of sandstone; Sample *188* taken 12 ft. above base	14.5	678.8
SHALE, dark-grey, hard, blocky, somewhat silty; Sample *187* taken 5 ft. above base	13.5	664.3
Covered approximately	100	650.8
SILT, light-brown, argillaceous, somewhat bentonitic	0.5	550.8
BENTONITE, yellowish-green to rusty brown	0.2	550.3
SHALE, grey, silty, partially covered, bentonitic weathering; Sample *186* taken at base	11.0	550.1
SHALE, grey, blocky to flaky, locally iron-stained	3.5	539.1
SHALE, grey-brown, hard, silty	3.0	535.6
SHALE, grey, blocky to flaky, locally iron-stained; Sample *183* taken at base, Sample *184* 10 ft. above base, Sample *185* 20 ft. above base	25.0	532.6
Covered	18.0	507.6
SHALE, grey, blocky, silty, bentonitic, becoming more bentonitic towards top; Sample *182* taken 3 ft. above base	10.0	489.6
SHALE, grey, finely blocky, locally iron-stained, abundant gypsum on outcrop surface at base; occasional concretions contain *Baculites compressus* Say and *Inoceramus barabini* Morton; Sample *179* taken 7 ft. above base, Sample *180* 12 ft. above base, Sample *181* 22 ft. above base	28.1	479.6
BENTONITE, yellowish-green, much gypsum on outcrop surface	0.2	451.5

Top of section	Thickness ft.	Cumulative thickness ft.
SHALE, grey, finely blocky to flaky, locally iron-stained; Sample *178* taken 9 ft. above base	11.6	451.3
BENTONITE, yellowish-green, powdery, much gypsum on outcrop surface	2.4	439.7
SHALE, grey, finely blocky to flaky, locally iron-stained, occasional concretions containing *Baculites compressus* Say; thin bentonite stringer 16.5 ft. above base; Sample *174* taken 5 ft. above base, Sample *175* 15 ft. above base, Sample *176* 25 ft. above base, Sample *177* 35 ft. above base	38.2	437.3
SHALE, grey, hard, blocky, slightly silty	5.0	399.1
SHALE, grey, blocky to flaky, locally iron-stained; Sample *173* taken 3 ft. above base	3.7	394.1
BENTONITE, yellow to greenish-grey, much gypsum on outcrop surface	0.2	390.4
SHALE, grey, blocky to flaky, local iron-staining; Sample *170* taken 3 ft. above base, Sample *171* 13 ft. above base, Sample *172* 23 ft. above base	30.0	390.2
BENTONITE, light-yellow to greenish-grey, locally iron-stained, gypsum on outcrop surface	0.2	360.2
SHALE, grey, blocky to flaky, iron-stained	6.8	360.0
BENTONITE, creamy yellow, considerable gypsum on outcrop surface	0.8	
SHALE, grey to grey-brown, blocky to flaky, occasional streaks of iron-staining, slightly silty near base; Sample *167* taken 10 ft. above base, Sample *168* 20 ft. above base, Sample *169* 30 ft. above base	31.5	352.4
BENTONITE, yellow, intermixed with shale	0.1	320.9
SHALE, grey to brownish-grey, bentonitic at base; Sample *164* taken 2 ft. above base, Sample *165* 12 ft. above base, Sample *166* 22 ft. above base	23.2	
BENTONITE, light-yellow to grey, gypsum on outcrop surface	0.3	297.6
SHALE, greyish-brown, blocky, silty; Sample *163* taken at base	1.5	297.3
CONCRETIONS, containing numerous *Arctica ovata* (Meek and Hayden)	1.5	295.8
SHALE, greyish-brown, blocky, silty; Sample *162* taken 2 ft. above base	10.0	294.3

Top of section	Thickness ft.	Cumulative thickness ft.
SHALE, greyish-brown, blocky to flaky, somewhat silty	9.5	284.3
BENTONITE, yellowish-green to greenish-brown, silty	4.0	274.8
SHALE, greyish-brown, blocky, silty; gypsum on outcrop surface and fracture surfaces; Sample *160* taken 3 ft. above base, Sample *161* 13 ft. above base	13.2	270.8
SHALE, grey, hard, blocky	7.8	257.6
SHALE, grey, blocky to flaky, silty	1.4	249.8
BENTONITE, light-yellowish-grey, impure towards top, somewhat silty, weathered surface has "popcorn" texture	5.0	248.4
SHALE, light-grey, blocky to flaky, very silty; Sample *159* taken 7 ft. above base	16.1	243.4
SHALE, greyish-brown, blocky to flaky, slightly silty towards top; Sample *156* taken 4 ft. above base, Sample *157* 14 ft. above base, Sample *158* 24 ft. above base	27.8	227.3
SHALE, greyish-brown, finely blocky, somewhat silty at top; contains *Baculites compressus* Say; Sample *154* taken at base, Sample *155* 10 ft. above base	16.0	199.5
Covered	5.0	
CLAY, brown, earthy, bentonitic; contains selenite crystals	1.7	178.5
SHALE, grey, blocky to flaky, iron-stained; Sample *152* taken 5 ft. above base, Sample *153* 15 ft. above base	20.5	176.8
SHALE, grey, blocky to flaky, locally iron-stained; thin bentonite stringer 16.3 ft. above base; Sample *147* taken 10 ft. above base, Sample *148* 20 ft. above base, Sample *149* 30 ft. above base, Sample *150* 40 ft. above base, Sample *151* 50 ft. above base	55.0	156.3
BENTONITE, light-yellow, contains biotite, weathered surface has "popcorn" texture, gypsum on weathered surface (bentonite No. 4)	1.9	101.3
SHALE, grey, blocky, locally iron-stained, somewhat silty and hard towards top	13.0	99.4
SHALE, grey, blocky to flaky; Sample *146* taken 4 ft. above base	5.0	86.4

Top of section	Thickness ft.	Cumulative thickness ft.
BENTONITE, greenish-yellow, massive, gypsum on outcrop surface, weathered surface has "popcorn" appearance (bentonite No. 2)	1.2	81.4
SHALE, grey, blocky to flaky, somewhat silty towards top; Sample *145* taken at top	6.0	80.2
CLAY, hard, bentonitic	1.5	74.2
SHALE, brownish-grey, blocky to flaky; Sample *144* taken 3 ft. above base	8.0	72.7
BENTONITE, light-yellow, finely blocky, contains much biotite (bentonite No. 1)	0.5	64.7
SHALE, brownish-grey, flaky, somewhat silty; Sample *143* taken 3 ft. above base	5.7	64.2
SHALE, brownish-grey, blocky to flaky; Sample *142* taken 6 ft. above base	18.0	58.5
Covered	4.0	40.5
SHALE, grey, blocky to flaky; Sample *141* taken at top	5.0	36.5
Covered	1.5	31.5
SHALE, grey, blocky to flaky, several thin bentonite stringers; clay-ironstone concretions, weathering dark purplish-blue, at top	2.0	30.0
Covered	3.0	28.0
SHALE, brownish-grey, flaky, occasional thin bentonite stringers with gypsum on outcrop surface; Sample *139* taken 8 ft. above base, Sample *140* 18 ft. above base	18.0	25.0
SILT, greyish-brown, argillaceous; gypsum on outcrop surface	4.0	7.0
SHALE, brownish-grey, blocky to flaky, locally iron-stained; Sample *138* taken 1 ft. above base	2.0	3.0
SILT, brown, very argillaceous, much gypsum on surface	1.0	1.0
OLDMAN-BEARPAW CONTACT		
SHALE, brown, flaky, very carbonaceous; Sample *137* taken 10 ft. above base	11.0	
SHALE, grey, soft, flaky, scattered silt lenses; Sample *136* taken 8 ft. above base	10.0	
CLAY, greenish-brown, bentonitic	10.0	
Covered	5.0	
CLAY, as above	0.5	
SHALE, black, flaky, very carbonaceous	1.0	
BASE OF SECTION		

APPENDIX D

Clay Mineralogy of Samples

1. Bow River Section

Sample No.	Feet above base of Bearpaw	Sample description	Approximate % montmorillonite	illite	chlorite
28	Edmonton fm.	Sandstone, argillaceous	90	5	5
27	589	Clay, silty, somewhat bentonitic	90	5	5
26	570	Shale, hard, silty	95	5	tr.
25	560	Shale, hard, silty	90	5	5
24	550	Shale, hard, silty	95	5	tr.
23	540	Shale, hard, somewhat silty	85	10	5
22	530	Shale, hard, somewhat silty	85	10	5
21	520	Shale, hard, somewhat silty	90	5	5
20	510	Sand, green (glauconitic?)	65	25	10
19	495	Shale, green-brown, flaky			
18	485	Shale, green-brown, flaky	75	20	5
17	435	Sandstone, fine-grained, argillaceous	85	10	5
16	118	Bentonite, impure	60	35	5
15	117.5	Shale, grey, hard	50	35	15
14	108	Shale, grey to greyish-brown	60	25	15
13	98	Shale, grey to greyish-brown	60	25	15
12	88	Shale, grey to greyish-brown	40	35	25
11	78	Shale, greyish-brown, blocky	30	35	25
10	68	Shale, greyish-brown, blocky	40	40	20
9	63	Shale, greyish-brown, blocky	45	35	20
8	53	Shale, greyish-brown, blocky	35	35	30
7	43	Shale, greyish-brown, blocky	60	25	15
6	38	Bentonite, impure	90	5	5
5	29	Shale, grey	55	30	15
4	19	Shale, grey	40	45	15
3	5	Shale, grey	50	30	20
2	Oldman	Siltstone, argillaceous	70	30	tr.
1	Oldman	Siltstone, argillaceous	75	10	15
		2. St. Mary River Section			
135	725	Shale, grey, blocky	80	10	10
134	724	Shale, grey, flaky, friable	70	20	10
133	716	Shale, grey, blocky to flaky	45	35	20
132	706	Shale, grey to brown, sandy to friable	50	35	15
131	526	Shale, greenish-brown, flaky	60	25	15
130	518	Shale, grey, blocky, hard	70	25	5
129	514	Shale, grey, blocky	85	15	tr.

Sample No.	Feet above base of Bearpaw	Sample description	Approximate %		
			montmorillonite	illite	chlorite
128	503	Shale, grey, blocky to flaky	80	15	5
127	493	Shale, grey, blocky to flaky	70	20	10
126	483	Shale, grey, blocky to flaky	65	20	15
125	470	Shale, grey, blocky to flaky	40	45	15
124	465	Shale, rusty-brown, silty, friable	75	20	5
123	458	Shale, grey	65	25	10
122	445	Shale, rusty-brown, silty, friable	65	30	5
121	442	Shale, grey to brown, somewhat silty, friable	60	20	20
120	420	Shale, grey, blocky to flaky	35	35	30
119	409	Shale, grey to brown, silty, blocky	30	45	25
118	392	Shale, grey, very sandy, hard	55	20	25
117	389	Shale, grey, blocky	60	20	20
116	382	Shale, grey, blocky	75	15	10
115	374	Shale, grey, blocky	65	20	15
114	364	Shale, grey, blocky	25	60	15
113	359	Shale, grey, blocky	30	45	25
112	349	Shale, grey, blocky	25	55	20
111	339	Shale, grey, blocky	25	40	35
110	329	Shale, grey, blocky	40	30	30
109	319	Shale, grey, blocky	25	45	30
108	306	Shale, grey, blocky to flaky	40	45	15
107	301	Shale, grey, blocky to flaky	30	50	20
106	289	Shale, grey, blocky to flaky	45	40	15
105	274	Shale, grey, blocky to flaky	55	35	10
104	267	Shale, dark-grey, blocky, somewhat silty	85	10	5
103	262	Shale, grey, blocky to flaky	70	20	10
102	255	Clay, buff, silty	100	0	0
101	250	Shale, grey, blocky, hard	70	25	5
100	242	Clay, brownish-grey, very silty	45	40	15
99	237	Shale, grey, blocky, somewhat silty	85	10	5
98	224	Shale, brownish-grey, somewhat silty	70	25	5
97	215	Shale, brownish-grey, somewhat silty	85	10	5
96	208	Shale, brownish-grey, somewhat silty	90	5	5
95	199	Shale, grey, hard, silty	75	20	5
94	192	Shale, grey, blocky	50	40	10

Sample No.	Feet above base of Bearpaw	Sample description	Approximate %		
			montmorillonite	illite	chlorite
93	177	Shale, grey, blocky	40	45	15
92	164	Shale, grey, blocky, hard	40	50	10
91	155	Shale, grey, blocky, hard	35	50	15
90	147	Shale, grey, blocky, hard	55	35	10
89	142	Shale, grey, blocky, hard	45	40	15
88	132	Shale, grey, blocky, hard	40	40	20
87	127	Shale, grey, blocky to flaky	45	35	20
86	117	Shale, grey, blocky	45	35	20
85	112	Shale, grey, blocky	40	45	15
84	98	Shale, grey, blocky	35	50	15
83	83	Shale, grey, spheroidal to flaky	70	20	10
82	79	Shale, grey, spheroidal to flaky	60	30	10
81	71	Shale, grey, blocky to flaky	50	40	10
80	61	Shale, grey, blocky to flaky	45	40	15
79	55	Shale, grey, blocky to flaky	45	45	10
78	50	Shale, grey, blocky to flaky	70	20	10
77	45	Shale, grey, blocky to flaky	60	30	10
76	36	Shale, grey, blocky to flaky	65	25	10
75	34	Shale, grey, blocky to flaky	70	20	10
74	32	Shale, grey, blocky to flaky	50	40	10
73	30	Shale, grey, blocky to flaky	60	25	15
72	28	Shale, grey, blocky to flaky	70	20	10
70	27	Shale, grey, blocky to flaky	55	30	15
69	26	Shale, grey, blocky to flaky	50	30	20
68	24	Shale, grey, blocky to flaky	55	30	15
67	22	Shale, grey, blocky to flaky	55	30	15
66	20	Shale, grey, blocky to flaky	65	20	15
65	18	Shale, grey, blocky to flaky	45	25	30
64	16	Shale, grey, blocky to flaky	55	30	15
62	14	Shale, grey, blocky to flaky	45	30	25
61	13	Shale, grey, blocky to flaky	45	35	20
60	12	Shale, grey, blocky to flaky	45	30	25
59	10	Shale, grey, blocky to flaky	55	25	20
58	8	Shale, grey, blocky to flaky	45	35	20
57	6	Shale, grey, blocky to flaky	65	15	20
56	4	Shale, grey, blocky to flaky	45	35	20
55	2	Shale, grey, blocky to flaky	65	15	20
54	0	Shale, grey, blocky to flaky	50	25	25
53	—2	Shale, grey, blocky to flaky	75	15	10
52	—4	Shale, grey, blocky to flaky	80	10	10
51	—6	Shale, grey, blocky to flaky	70	15	15

Sample No.	Feet above base of Bearpaw	Sample description	Approximate %		
			montmorillonite	illite	chlorite
50	—8	Shale, grey, blocky to flaky	80	10	10
49	—10	Shale, grey, blocky to flaky	60	20	20
48	—12	Shale, grey, blocky to flaky	60	20	20
47	—14	Shale, grey, blocky to flaky	60	20	20
46	—18	Shale, grey, blocky to flaky	50	25	25
45	—20	Shale, grey, blocky to flaky	80	10	10
44	—22	Shale, grey, blocky to flaky	55	20	25
43	—24	Shale, grey, blocky to flaky	65	15	20
42	—26	Shale, grey, blocky to flaky	65	20	15
41	—28	Shale, grey, blocky to flaky	80	10	10
40	—30	Shale, grey, blocky to flaky	80	5	15
39	—32	Shale, grey, blocky to flaky	75	10	15
38	—34	Shale, grey, blocky to flaky			
37	—36	Shale, grey, blocky to flaky	85	5	10
36	—38	Shale, grey, blocky to flaky	80	10	10
35	—40	Shale, grey, blocky to flaky	65	5	30
34	—42	Shale, grey, blocky to flaky	70	10	20
33	—46	Shale, grey, blocky to flaky	65	15	20
32	—48	Shale, grey, blocky to flaky			
31	—50	Shale, grey, blocky to flaky	85	5	10
30	—52	Shale, grey, blocky to flaky	90	0	10
29	—54	Shale, grey, blocky to flaky	90	0	10
		3. Cypress Hills Section			
208	1062	Shale, grey to rusty-brown, finely blocky	65	25	10
207	1056	Shale, greyish-brown, soft, somewhat silty	80	15	5
206	1051	Shale, greyish-brown, soft, somewhat silty	80	15	5
205	1041	Shale, greyish-brown, soft, somewhat silty	65	25	10
204	1031	Shale, greyish-brown, soft, somewhat silty	70	20	10
203	1001	Shale, brownish-grey, blocky	75	20	5
202	996	Shale, brownish-grey, blocky	70	20	10
201	951	Shale, grey, blocky to flaky	65	30	5
200	945	Shale, grey, blocky to flaky	80	15	5
199	935	Shale, grey, blocky to flaky	80	15	5
198	924	Shale, grey, blocky to flaky, silty	75	20	5
197	873	Shale, grey, blocky to flaky, silty	80	15	5

Sample No.	Feet above base of Bearpaw	Sample description	Approximate %		
			montmorillonite	illite	chlorite
196	868	Shale, grey, blocky to flaky, silty	80	15	5
195	863	Shale, grey, blocky to flaky	80	15	5
194	858	Sandstone, fine-grained, argillaceous	80	15	5
193	738	Shale, brownish-grey, soft, silty	85	15	tr.
192	728	Shale, brownish-grey, soft, silty	85	15	tr.
191	718	Shale, brownish-grey, soft, silty	90	10	tr.
190	699	Shale, brownish-grey	85	10	5
189	689	Shale, brownish-grey	85	15	tr.
188	676	Shale, dark-grey, blocky to flaky	70	20	10
187	656	Shale, dark-grey, blocky, somewhat silty	75	20	5
186	539	Shale, grey, somewhat silty	80	20	tr.
185	528	Shale, grey, blocky to flaky	80	15	5
184	518	Shale, grey, blocky to flaky	75	20	5
183	508	Shale, grey, blocky to flaky	75	20	5
182	483	Shale, grey, blocky, silty	80	15	5
181	474	Shale, grey, finely blocky	80	15	5
180	464	Shale, grey, finely blocky	65	25	10
179	459	Shale, grey, finely blocky	65	25	10
178	449	Shale, grey, finely blocky to flaky	75	20	5
177	434	Shale, grey, finely blocky to flaky	75	20	5
176	424	Shale, grey, finely blocky to flaky	60	25	15
175	414	Shale, grey, finely blocky to flaky	75	20	5
174	404	Shale, grey, finely blocky to flaky			
173	393	Shale, grey, blocky to flaky	45	40	15
172	383	Shale, grey, blocky to flaky	45	35	20
171	373	Shale, grey, blocky to flaky	50	30	20
170	363	Shale, grey, blocky to flaky	45	35	20
169	351	Shale, grey, blocky to flaky	65	25	10
168	341	Shale, grey, blocky to flaky	60	25	15
167	331	Shale, grey, blocky to flaky	65	25	10
166	320	Shale, grey to brownish-grey	55	35	10
165	310	Shale, grey to brownish-grey	55	35	10

Sample No.	Feet above base of Bearpaw	Sample description	Approximate % montmo-rillonite	illite	chlorite
164	300	Shale, grey to brownish-grey	55	35	10
163	296	Shale, brownish-grey, silty	70	30	tr.
162	286	Shale, brownish-grey, silty	80	20	tr.
161	271	Shale, brownish-grey, silty	75	25	tr.
160	261	Shale, brownish-grey, silty	75	25	tr.
159	234	Shale, brownish-grey, silty	70	30	tr.
158	224	Shale, greyish-brown	60	40	tr.
157	214	Shale, greyish-brown	35	65	tr.
156	204	Shale, greyish-brown	60	35	5
155	194	Shale, greyish-brown	80	20	tr.
154	184	Shale, greyish-brown	85	15	tr.
153	171	Shale, grey, blocky to flaky	90	10	tr.
152	161	Shale, grey, blocky to flaky	65	35	0
151	151	Shale, grey, blocky to flaky	60	30	10
150	141	Shale, grey, blocky to flaky	60	30	10
149	131	Shale, grey, blocky to flaky	70	25	5
148	121	Shale, grey, blocky to flaky	80	15	5
147	111	Shale, grey, blocky to flaky	70	25	5
146	85	Shale, grey, blocky to flaky	80	20	tr.
145	80	Shale, grey, blocky to flaky, somewhat silty	75	25	tr.
144	68	Shale, brownish-grey	75	20	5
143	62	Shale, brownish-grey, somewhat silty	75	20	5
142	47	Shale, brownish-grey	70	20	10
141	37	Shale, grey, blocky to flaky	85	10	5
140	25	Shale, brownish-grey, flaky	80	10	10
139	15	Shale, brownish-grey, flaky	80	15	5
138	2	Shale, brownish-grey, flaky	85	10	5
137	Oldman	Shale, very carbonaceous			
136	Oldman	Shale, grey, soft, flaky	95	1	5

Results of Chemical Analysis

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	K_2O	Na_2O	Ignition Loss	Total
47	57.75	19.48	6.88	0.53	0.35	0.43	2.09	2.42	0.22	7.50	97.65
46	58.97	18.96	8.09	0.54	0.49	0.77	2.09	2.56	0.23	7.51	100.21
45	56.34	20.64	6.63	0.60	0.33	0.77	1.65	2.66	0.19	7.68	97.49
44	55.70	20.64	7.73	0.58	0.36	0.53	1.72	2.64	0.25	7.39	97.54
43	56.21	19.71	7.24	0.57	0.54	0.48	1.79	2.88	0.25	7.70	97.37
42	57.00	19.71	6.96	0.57	0.43	0.58	1.68	2.96	0.20	7.82	97.91
41	55.82	20.46	7.12	0.61	0.35	0.38	1.75	2.78	0.25	7.83	97.35
40	56.67	20.16	7.37	0.62	0.34	0.38	1.65	2.84	0.25	7.81	98.09
39	55.56	21.57	7.24	0.59	0.42	0.38	1.55	2.90	0.75	7.66	98.62
38	56.35	21.60	7.40	0.61	0.41	0.34	1.65	2.82	0.49	7.77	99.44
37	56.22	21.51	6.76	0.50	0.47	0.34	1.42	3.02	0.40	8.14	98.78
36	55.30	21.24	6.78	0.59	0.44	0.58	1.25	2.83	0.44	7.95	97.40
35	55.58	21.33	8.14	0.50	0.39	0.43	1.38	2.57	0.37	8.20	98.89
34	55.71	21.60	7.32	0.57	0.30	0.19	1.55	2.76	0.55	8.01	98.56
33	57.08	21.63	5.20	0.45	0.15	0.58	1.22	2.77	0.55	7.88	98.51
32	55.91	22.49	6.42	0.58	0.27	0.24	1.59	2.24	0.35	8.98	99.07
31	55.38	21.12	7.73	0.56	0.28	0.67	1.89	2.29	0.43	8.61	98.96
30	55.38	21.12	6.83	0.61	0.20	0.48	2.16	2.40	0.53	8.53	98.24
29	55.98	20.88	6.96	0.58	0.22	0.57	1.89	2.44	0.66	8.25	98.43
28	56.64	21.12	7.02	0.58	0.19	0.48	1.79	2.37	0.97	7.64	98.80
27	57.29	21.84	5.49	0.67	0.21	0.48	1.65	2.31	1.14	7.49	98.57
26	58.14	19.32	5.73	0.53	0.22	0.57	1.69	2.14	2.27	7.05	97.66
25	60.82	18.96	5.41	0.52	0.22	0.48	1.45	2.15	2.20	6.45	98.66

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	K_2O	Na_2O	Ignition Loss	Total
24	56.45	20.76	5.91	0.56	0.18	0.38	1.86	2.39	2.18	8.39	99.06
23	57.43	21.24	5.69	0.60	0.20	0.38	1.75	2.42	2.00	7.61	99.32
22	56.97	20.70	5.96	0.57	0.24	0.57	1.86	2.54	1.82	7.67	98.90
21	54.59	19.80	9.12	0.48	0.38	0.48	1.18	2.12	0.51	8.81	97.47
20	56.48	20.88	5.30	0.54	0.09	0.57	1.89	2.40	1.06	8.74	97.95
19	57.71	21.12	5.45	0.56	0.13	0.67	1.55	2.45	1.63	7.23	98.50
18	56.15	19.74	7.11	0.56	0.24	0.72	1.72	2.19	2.01	7.55	97.99
17	58.17	19.08	4.60	0.60	0.19	0.72	1.55	2.17	2.58	7.98	97.64
16	56.41	21.48	5.36	0.61	0.26	0.53	1.79	2.35	1.37	8.00	98.16
15	55.24	21.24	5.47	0.59	0.17	0.48	1.55	2.09	2.18	8.99	98.00
14	55.24	19.56	5.19	0.46	0.20	0.91	1.45	1.66	3.12	9.92	97.71
13	51.99	17.76	5.03	0.39	0.37	0.81	1.62	2.26	2.71	14.83	97.77
12	48.55	17.76	13.40	0.29	0.41	1.15	2.30	1.81	2.01	10.73	98.41
11	54.59	20.28	5.43	0.55	0.21	0.76	2.23	1.85	1.78	9.80	97.48
10	56.53	19.80	5.11	0.56	0.06	0.76	1.72	2.22	1.68	12.25	100.69
9	56.08	19.20	5.38	0.62	0.18	0.76	2.09	1.73	1.87	8.84	96.75
8	53.23	20.40	5.43	0.42	0.15	0.91	1.79	1.81	1.75	12.30	98.19
6	55.20	19.20	5.89	0.57	0.11	0.67	2.19	2.23	1.60	8.43	96.09
5	50.02	21.48	5.10	0.48	0.01	0.86	1.86	1.82	1.93	10.61	94.17
4	56.45	19.44	5.79	0.61	0.13	0.76	2.06	2.50	1.53	8.26	97.53
3	54.15	21.72	4.67	0.25	0.06	1.05	2.49	1.09	2.68	9.16	97.32
2	53.95	16.56	4.44	0.02	0.12	1.33	2.06	2.50	1.45	14.22	96.65