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THE WHITEMUD AND BATTLE FORMATIONS ("KNEEHILLS TUFF ZONE") A STRATIGRAPHIC MARKER

(Report and 12 Figures)

E. J. W. Irish and C. J. Havard

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by C.J. Havard

Illustrations

ABSTRACT

The "Kneehills Tuff zone" comprises the white-weathering clays and argillaceous sands of the Whitemud Formation together with the overlying purplish-grey weathering, dark grey to black, clay and shale of the Battle Formation. In the Red Deer River - Bow River region the "Kneehills Tuff zone" divides the Edmonton Group into two parts and in the Oldman River region it separates the St. Mary River Formation from the overlying Willow Creek Formation.

The Battle Formation contains in its upper part a distinctive, thin, light grey-weathering, silicified, volcanic ash bed called the Kneehills Tuff.

Laboratory investigation has shown that the mineralogy of the Kneehills Tuff bed is that of a volcanic ash that was silicified prior to any appreciable chemical alteration and that samples from all localities studied are almost identical. The Battle Formation is composed, mainly, of decomposed volcanic ash with some added detritus, and samples are similar from all localities studied. Mineralogical differences exist between the Whitemud Formation in southeastern Alberta and the same formation in western Alberta, the most significant being the relative proportions of the various clay minerals in the rocks. The predominant clay mineral in the Whitemud Formation of southeastern Alberta is kaolin whereas that in samples from the west side of the Sweetgrass Arch is montmorillonite. The white colour of the rock where weathered, is due to the large proportion of clay minerals present.

The development of the relatively large kaolin content in the Whitemud Formation has been attributed to the subaerial weathering of potassium feldspar; a process that required a period of time during which temperatures were fairly moderate and uniform and when little detritus was being added by streams. The overlying Battle shale consists largely of decomposed volcanic ash. The original ash is thought to have been deposited by wind in an extensive body of shallow water free from much wave and current action. The small percentage of detrital material in this unit suggests that at this time, also, little sediment was being transported by the streams.

The Kneehills Tuff bed, wherever it occurs, represents contemporaneous deposition of wind-transported volcanic ash and, thus, the bed can be used as a time marker. For this reason, and because the combination of the Whitemud and Battle formations is unique, the "Kneehills Tuff zone" is considered to be a most valuable stratigraphic marker for surface geological mapping. The "zone" can, also, be recognized on electric logs of wells drilled for oil and gas throughout most of the western part of the southern Alberta Plains. It is, therefore, an important stratigraphic datum for subsurface correlation within the Upper Cretaceous, non-marine sediments.

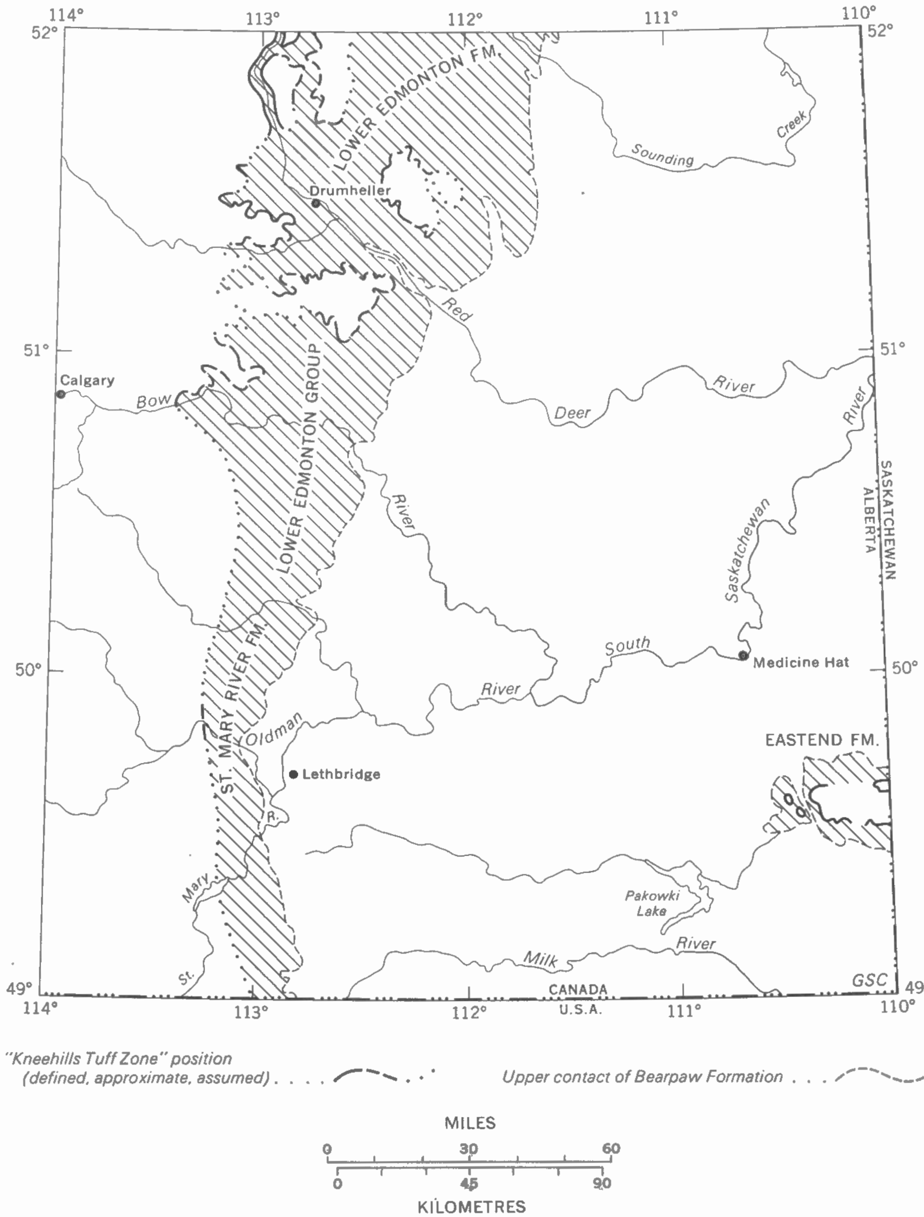

Figure 1 Map showing the outcrop pattern of the "Kneehills Tuff zone" and the approximate area where the surface formations are those lying between the Bearpaw Formation and the "Kneehills Tuff zone".

THE WHITEMUD AND BATTLE FORMATIONS ("KNEEHILLS TUFF ZONE") A STRATIGRAPHIC MARKER

PART I

SURFACE DISTRIBUTION AND MINERALOGY OF THE WHITEMUD AND BATTLE FORMATIONS ("KNEEHILLS TUFF ZONE")

by
E.J.W. Irish

INTRODUCTION

The predominant structure in the southern part of the Alberta Plains is the northern continuation of the Sweetgrass Arch, a broad anticline trending somewhat east of north and having a northward plunge of between 20 and 30 feet per mile. Erosion has removed all strata younger than the Oldman Formation from the central part of the arch so that younger formations now occur on either flank of the fold.

These late Upper Cretaceous and Tertiary formations have been studied by numerous workers since the early surveys of G.M. Dawson and R.G. McConnell. Due, however, to lithologic changes and interfingering of formations from north to south on the west side of the Arch and, also, lithologic changes on either side of the Sweetgrass Arch, correlation of the several formations has been difficult, and much detailed work remains to be done.

Much of the difficulty stems from the fact that the sediments younger than the marine Bearpaw Formation, and whose source was mainly to the west, are predominantly non-marine and of deltaic and floodplain origin. The local formations probably originated in different source areas and were deposited in different environments. The coalescing of these various facies units along the western margin of the basin and their interfingering with marine deposits across the basin has resulted in different stratigraphic successions from north to south along the western edge of the Plains and on either side of the Sweetgrass Arch. Thus, the succession in the southwestern part of the Alberta Plains is not the same as that in the Bow River-Red Deer River region, and both of these successions differ from that in the Cypress Hills region on the east side of the Arch.

Correlation to date has been based partly on stratigraphic position and partly on faunal evidence. For the most part, the invertebrate fauna is sparse and long ranging so that only broad correlations can be made. Vertebrate remains, where found, have been satisfactory in establishing the Cretaceous - Tertiary boundary within limits.

For these reasons a distinctive and widespread lithologic marker that can be easily recognized both in the western and eastern parts of the Alberta Plains would be of great value. The combined Whitemud and Battle formations appears to be such a marker.

N.B. Davis, in 1918, gave the name "Whitemud" to a group of white-weathering, kaolinized, feldspathic sandstones, siltstones and clay shales that overlie the Eastend Formation and which form a prominent marker over a large part of southern Saskatchewan and southeastern Alberta. The formation originally included the overlying mauve-weathering, dark brown to purplish black, bentonitic clay shales (Fraser, McLearn, Russell, Warren and Wickenden, 1935), but Furnival (1950) separated this unit as the Battle Formation and restricted the term "Whitemud" to the white-weathering beds lying above the Eastend Formation and overlain by the dark clays of the Battle Formation.

The colour and texture of these formations, where weathered, is such that the formations can be readily identified and serve as excellent stratigraphic markers.

In 1924, J.O.G. Sanderson (1931) recognized a tuff bed within a dark bentonitic shale in the Edmonton Formation along Red Deer River valley. He called this bed the Kneehills Tuff after Kneehills Creek where good exposures occur. The dark shale, which includes this tuff bed, and the underlying white-weathering, clayey sandstone were thought by Allan and Sanderson (1945) to be equivalents of the Whitemud and Battle formations of southeastern Alberta and the two were designated the "Kneehills Tuff zone". Russell (1933), Russell (1948), Russell and Landes (1940), and Furnival (1950) also considered that the white-weathering sandstone and dark shale were equivalents of the Whitemud and Battle Formations of the Cypress Hills region.

The Whitemud and Battle formations together ("Kneehills Tuff zone") form the only distinctive and widespread marker within the Edmonton Formation. They can be recognized in the field throughout most of the Red Deer River valley region from Twp. 37 south as far as Bow River valley, and have been reported to occur as far north as Athabasca River (Ower, 1960).

Allan and Sanderson first recognized the value of these beds as a stratigraphic marker and placed the units at the top of their Middle Edmonton member. Ower (1960) separated these strata as Member D of his five-fold division of the Edmonton Formation. Both Ower (1960) and Elliott (1960) used the zone in electric-log correlations and demonstrated its usefulness as a subsurface marker.

The division of the Edmonton Formation (Allan and Sanderson, 1945) into Lower and Middle members based on the so-called "Drumheller Marine Tongue", is not generally applicable because of the absence of this calcareous zone away from the Red Deer River valley. The lower three of Ower's (1960) five members (A, B, and C) were separated by the relative amounts of sandstone and shale and, also, by the presence or absence of coal seams. Such a division is suitable for local correlation only and is of doubtful value over any great distance. In electric-log correlations Ower (1960) found difficulty in determining the top and bottom of these members.

On the other hand, the "Kneehills Tuff zone", comprising the Whitemud and Battle formations, is widespread, and has proved to be an almost continuous marker both in surface exposures and in electric-log correlation. Thus, the simpler, two-fold subdivision of the Edmonton Formation appears to be the most convenient and practical. A similar conclusion was reached by Elliott (1960) for subsurface correlation.

Tozer (1952) recognized equivalents of the Whitemud and Battle formations, as well as the Kneehills Tuff, near the top of the St. Mary River Formation on Oldman River near McLeod, Alberta. He included the zone with the St. Mary River Formation thus making the formational boundary with the overlying Willow Creek Formation equivalent to the division between the lower and upper parts of the Edmonton Formation.

Still farther south, Furnival (in Ower, 1960) records the presence of the Whitemud equivalent, the Battle equivalent, and the Kneehills Tuff south of St. Mary River in Sec. 21, Twp. 4, Rge. 23W4. On the other hand, E.P. Williams (1951) placed the contact between the St. Mary River and Willow Creek formations on the banks of St. Mary River in Sec. 20, Twp. 4, Rge. 24W4. Because no outcrop of any beds resembling the "Kneehills Tuff zone" was seen by the writer (Irish) at or close to the location attributed to Furnival, it seems reasonable to assume that Rge. 23W4., as reported by Ower, is wrong and that the exposure was in Rge. 24W4. This would agree closely with the locality of the contact given by Williams. Unfortunately the presence of the "Kneehills Tuff zone" at that locality cannot be confirmed as it is now covered by the water of St. Mary Reservoir.

The importance of the Whitemud and Battle Formations ("Kneehills Tuff zone") as a stratigraphic marker is not confined to its ease of recognition. Work by Sternberg (1947) on the vertebrate fossils of the Red Deer River valley indicates that, although there is no faunal break within the Edmonton Formation below the Whitemud and Battle formations, there is a distinct break at this zone. According to Sternberg, the presence of Triceratops, Tyranosaurus, Thescalosaurus, and Ankylosaurus shows that Cretaceous strata above the Battle Formation are of Lance age, and that the zone marks a clear break in the saurian fauna of the time. W.A. Bell (1949, p. 19) showed that the terrestrial flora is significantly different above and below the "Kneehills Tuff zone".

At the western end of the Cypress Hills in southeastern Alberta, the Battle Formation is unconformably overlain by the Frenchman Formation (Furnival, 1950, p. 94). The presence of a Triceratops fauna in the Frenchman Formation in Saskatchewan indicates a late Upper Cretaceous or Lance age for these strata and a correlation between these beds and the Cretaceous beds above the Battle Formation in Red Deer River valley.

The Triceratops fauna has not, so far, been found in beds of the Willow Creek Formation which overlie the Whitemud and Battle Formations on Oldman River. However, Tozer (1956, p. 25) states that "the available evidence, both palaeontological and stratigraphic, supports the correlation of the lower Willow Creek beds with the upper part of the typical Edmonton Formation and, therefore, with other formations of Lance age".

The writer is well aware of the errors that may be made when lithologic markers are extrapolated over any great distance and that stratigraphic correlations over widely separated areas are usually suspect, especially in non-marine sediments. Correlation based on only one of the lithologic types (Whitemud or Battle) would be hazardous since tuffaceous beds other than the Kneehills Tuff; dark, bentonitic shales other than the Battle Formation; and light grey-weathering sandstones other than the Whitemud Formation; are known to occur within the Edmonton Group. Field work by Irish, during the summers of 1964, 1965, and 1966 has shown that the combination of the Whitemud and Battle formations is unique and forms a distinctive and easily recognized marker wherever it is exposed. This fact has been recognized or accepted by previous workers, but little information that deals specifically with those units has been published.

In this report the Whitemud and Battle units respectively are given formational status on both east and west sides of the Sweetgrass Arch, but, in order to be able to refer to the combined formations by a single name, the descriptive term "Kneehills Tuff zone" is retained. North of Little Bow River the Whitemud and Battle are considered to be formations within the Edmonton Group.

The purpose of this report is to emphasize the importance of the "Kneehills Tuff zone" as a regional lithologic marker by showing its present known distribution both on the surface and in the subsurface in the area south of latitude 52 degrees north and by showing the regional mineralogical and chemical similarity of each unit.

ACKNOWLEDGEMENTS

The writer wishes to express his appreciation for the assistance and co-operation rendered by J.A. Maxwell and S. Courville of the Analytical Chemistry Section, and by R.J. Traill, Miss A.P. Sabina, and R.N. Delabio of the X-Ray Laboratory, Geological Survey of Canada, Ottawa.

Special thanks are due to T.P. Chamney of the Micropalaeontological Laboratory, Institute of Sedimentary and Petroleum Geology, Calgary, Alberta. Mr. Chamney prepared samples of each unit from all outcrop locations and studied these for possible microfossils. Unfortunately, no diagnostic microfauna was found.

The preparation of all samples, other than for micropalaeontology, and which included crushing, disintegration, sizing, elutriation and bromoform separation, was done by A. L. Bowering of the Sedimentary Petrology Section, Institute of Sedimentary and Petroleum Geology, Calgary, Alberta. Mr. Bowering's work in developing special techniques for the treatment of these very argillaceous rocks was greatly appreciated.

Many courtesies were extended by the Medicine Hat Brick and Tile Company and the co-operation and help given by Mr. L.O. Lindoe of Medicine Hat is greatfully acknowledged.

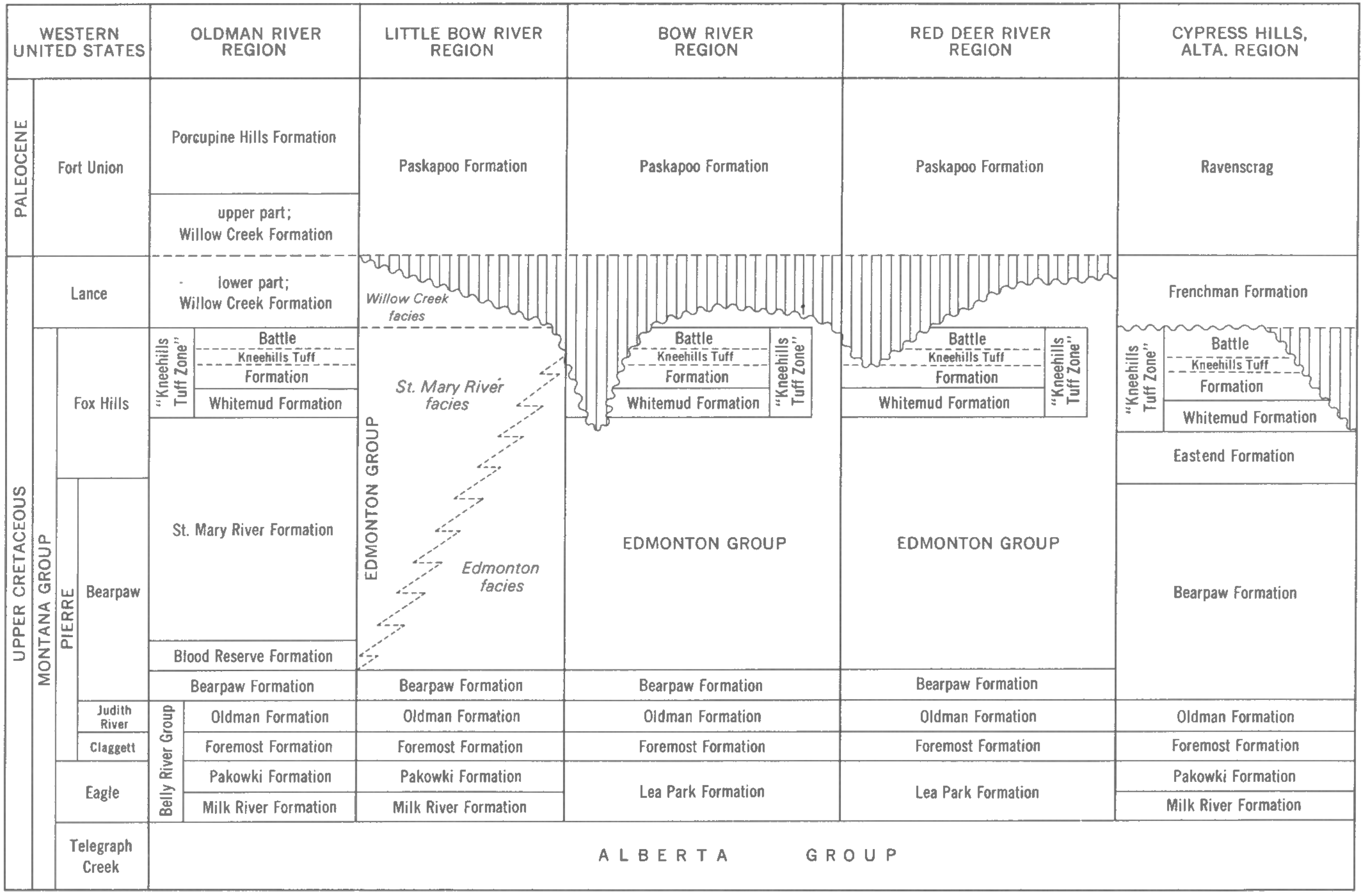

Figure 2 Correlation Chart of uppermost Cretaceous and Paleocene formations of the southern Alberta Plains.

DESCRIPTION OF UNITS

CYPRESS HILLS REGION

Whitemud Formation

Distribution

The Whitemud Formation can be traced by its lithologic features and stratigraphic position from the type locality near Whitemud, Saskatchewan to the western end of the Cypress Hills in Alberta (Plate I).

In southeastern Alberta outcrops of the formation occur at many places both on the north and south slopes of the Cypress Hills, on Eagle Butte, and along both sides of Medicine Lodge Coulée. However, because of its softness, good exposures are rare, and almost entirely confined to locations where the formation is quarried by the Medicine Hat Brick and Tile Company.

Lithology

A three-fold division of the formation can generally be recognized in the Cypress Hills region, though all three units may not be present in every exposure (see Russell, 1948 and Furnival, 1950).

The lower unit consists mainly of white-weathering, fine- to medium-grained, grey to greenish, feldspathic, crossbedded, argillaceous sandstone. It commonly contains beds of clay, and white mica is abundant. The lower contact of this unit, where seen by the writer, appears transitional across a few feet into the typical light buff and grey, soft sandstones of the underlying Eastend Formation (Plate II). Furnival (1950) reports that in some places the basal contact is irregular due to local erosion.

The middle unit is composed of white, grey, and buff clay and clayey siltstone with interbedded brown and black carbonaceous clay and shale. In Saskatchewan, lignite beds occur within this unit and fossil tap roots have been reported from some beds (Furnival, 1950, p. 78).

The upper unit consists of a series of white- to cream-weathering, grey, white and pale green clays with some interbedded, feldspathic sandstone and siltstone. In many places the uppermost one to one and one-half feet of the Whitemud Formation contains cylindrical fillings and fracture fillings as well as small blebs of dark grey to dark green-grey, very bentonitic clay such as occurs in the overlying Battle Formation. These fracture fillings and tubular inclusions have attitudes between 65 degrees and vertical.

There is considerable lateral variation of each of the three subdivisions and, also, of lithologic units within each subdivision, so it is rarely possible to follow individual beds for any great distance. The total thickness of the Whitemud Formation in southeastern Alberta is about 25 feet. The formation is overlain conformably, and in most places abruptly, by the dark shales and clays of the Battle Formation.

Battle Formation

Distribution

The name "Battle Formation" was given by Furnival (1950) to what was previously called "zone 4" of the Whitemud (Fraser et al., 1935). In southwestern Saskatchewan the Battle Formation is widespread and is well exposed in the valley of Frenchman River, along Adams Creek, and along Battle Creek after which the formation is named.

In southeastern Alberta, exposure of the Battle Formation is similar to that of the Whitemud and is confined, mainly, to outcrops on the north slopes of the Cypress Hills, both sides of Medicine Lodge Coulée, and to Eagle Butte. The formation is completely exposed in Quarry No. 45 of the Medicine Hat Brick and Tile Company on the north face of Eagle Butte. Here both the upper and lower contacts may be seen (Plate II, Plate V, and Plate VI).

Lithology

The unit consists of mauve-weathering, purplish-black, bentonitic shale. It has a thickness of about 30 feet and a "popcorn-like" crust is typical where the shale is weathered.

Kneehills Tuff: In southeastern Alberta a tuff bed is present in the upper part of the Battle Formation except where that part of the formation has been removed by pre-Frenchman erosion. From a distance the bed shows as a light streak across the outcrop and is particularly conspicuous against the dark grey to black background of the Battle Formation (Plates V and VI). Talus of the tuff was noted at several localities on the north side of Cypress Hills but the bed does not outcrop. It is best exposed in the quarry of the Medicine Hat Brick and Tile Company on Eagle Butte where the Battle Formation is nearly complete. There, the Kneehills Tuff proper occurs as a continuous band about 0.8 feet thick and between 23 and 24 feet above the base of the Battle Formation.

About 3 feet below the Kneehills Tuff is a zone about 2 feet thick composed of thin, discontinuous beds and lenses of impure tuff (Plate VI). These en echelon lenses range up to 6 inches in thickness and are separated by dark shale of the Battle Formation in which are interbedded numerous thin stringers of very tuffaceous shale up to one-half inch thick. Rock from this lower tuff zone weathers to a darker colour than the overlying Kneehills Tuff, but is very similar in other respects. The rock is brown to brownish grey when fresh and weathers to a very light grey colour. It is hard, compact, and breaks into sharp fragments that form a conspicuous talus. All samples show macroscopic vugs containing silica or clay.

RED DEER RIVER - BOW RIVER REGION

Whitemud Formation

Distribution

The Whitemud Formation is widespread in this region. Outcrops occur in the valleys of Red Deer River, Kneehills Creek and Threehills Creek; on the west and south flanks of the Hand Hills; at several places on the north slope of the Wintering Hills; and in, and just north of, Bow River valley. It has been partly or wholly removed by erosion at several places owing to channeling and, at such places has been replaced by a medium- to coarse-grained, buff-to brown-weathering sandstone.

Lithology

The Whitemud Formation within the Edmonton Group comprises only one unit as opposed to three in the Cypress Hills region. The formation consists of white-weathering, light grey and light greenish grey, clayey, siltstone and sandstone with interbedded, white- to cream-weathering, silty or sandy, grey and green clay. The proportion of these lithologic types differs considerably from one outcrop to another, but argillaceous sand predominates. The silty and sandy clays may be interbedded or interlensed with the sandstone. In some outcrops thin bands of clay appear to outline crossbedding in the sandstone unit.

The rock is solid when dry, but soft and slippery when wet. Normally the outcrop is coated with a weathered crust that is much whiter than the weathered colour of other sandstones or shales within the Edmonton Group. Its white colour and its association with the overlying Battle Formation make it an easily recognized marker (Plates III and IV).

The Whitemud Formation, itself a non-marine deposit, overlies, at different places, different lithologic types within the Edmonton Group. At some localities the contact appears gradational, as on Bow River, where the underlying bed is a light grey-weathering, argillaceous sandstone or, as on Red Deer River (Sec. 9, Twp. 30, Rge. 21W4), where light grey-weathering, grey shale grades upward into white-weathering, light green-grey shale which, in turn, underlies typical white-weathering, clayey sandstone. At such places, the lower contact must be placed arbitrarily. Where the Whitemud Formation is underlain by brown, carbonaceous and coaly shale, as in Horseshoe Canyon (Secs. 26 and 27, Twp. 28, Rge. 21W4), in Hand Hills (Sec. 24, Twp. 29, Rge. 18W4.), and on the north slope of the Wintering Hills (Sec. 33, Twp. 26, Rge. 19W4.), no difficulty is experienced in placing a lower boundary.

The contact with the overlying Battle Formation is, generally, abrupt. At places where this upper contact is well exposed, the upper 6 inches to 2 feet of the Whitemud contains numerous stem-like tubes and vertical fractures filled with dark purplish black, bentonitic shale like those occurring in the Cypress Hills exposures.

The thickness of the Whitemud Formation in the Red Deer River - Bow River region ranges between 6 and 20 feet depending, to some extent, on the arbitrary placement of the lower contact.

Battle Formation

Distribution

The Battle Formation has the same distribution as the Whitemud Formation in this region and, like the Whitemud, has been partly or wholly removed by erosion at several places.

Lithology

The formation consists essentially of mauve-grey-weathering, dark grey to black or purplish black, bentonitic shale. This material, which contains some silt, is normally rubbly to chunky and is rarely fissile. At places where the bentonite content is very high, fragments are bounded by shiny, curved surfaces resembling slickensides. Both the texture and the colour appear to be determined by the amount of bentonite present.

At some localities, as at Horseshoe Canyon (Sec. 26 and 27, Twp. 28, Rge. 21W4.) and just south of the mouth of Big Valley Creek (Sec. 18, Twp. 34, Rge. 21W4.), a band of white-weathering, green-grey bentonite, ranging from 2 to 4 inches in thickness, is present just above the base of the formation. Such bentonite beds may be more common than is known at this time because they tend to be obscured where the shale is deeply weathered.

The Battle Formation weathers readily, resulting in the formation of a porous crust 3 inches to 2 feet thick having a "popcorn" or "cauliflower" texture. This residuum is typical, and its mauve-grey colour makes it conspicuous.

At a small exposure west of the Trans Canada highway in Sec. 26, Twp. 23, Rge. 23W4., brownish shale that weathers to a light buff colour is interbedded with the purplish black shale. It is similar to the black shale except for its lighter colour. The colour change, both in fresh and weathered material is thought to be due to a substantially greater proportion of white-weathering bentonite in these zones.

At most exposures Battle strata are underlain by the typical clayey sandstone of the Whitemud Formation. At others they are separated from typical Whitemud strata by up to one foot of dark grey or dark brown, fissile, carbonaceous, silty shale. In all cases the contact appears conformable but the occurrence of "fracture fillings" would seem to indicate a diastem with little or no erosion.

The upper contact appears conformable at most places but, at others, it is definitely unconformable. For example, on the west slope of the Hand Hills (Sec. 24, Twp. 29, Rge. 18W4.) the Battle Formation is conformably overlain by interbedded carbonaceous shale, grey sandstone and greenish grey shale. Similar sediments, though not always in the same order, conformably overlie the Battle beds in Sec. 12, Twp. 36, Rge, 22W4.; Sec. 9, Twp. 30, Rge. 21W4.; and at many other places along Red Deer River valley.

At some localities, on the other hand, the Battle Formation has been partly or wholly removed by erosion and its place taken by grey, medium- to coarse-grained, buff-weathering sandstone. This situation may be seen at localities along Red Deer River valley, on Three Hills Creek, on the north flank of the Wintering Hills in Sec. 20, Twp. 26, Rge. 21W4., and north of Bow River valley in Sec. 25, Twp. 22, Rge. 23W4. On the north side of Bow River valley in Sec. 13, Twp. 22, Rge. 24W4. the Whitemud Formation and most of the overlying Battle Formation are present but, on the south side of the valley, Battle and Whitemud beds have been removed.

The thickness of this shale unit ranges from zero to about 30 feet in the Red Deer River - Bow River region.

Kneehills Tuff: This bed occurs within the upper part of the Battle Formation throughout the region except where these beds have been removed by post-Battle erosion. Normally it is present as a single bed between 6 and 10 inches thick but, locally, may occur as two or three, thin beds between 2 and 3 inches thick separated by Battle shale.

Two exposures of Battle beds just north of Bow River contain tuff beds other than and occurring below the Kneehills Tuff bed. In Sec. 26, Twp. 23, Rge. 23W4. 4 separate bands of tuff occur. The lower bed is 5 feet above the base of the formation and is about 4 inches thick. Above this, and separated from it by one foot of shale is another 4-inch thick tuff bed. The third tuff bed is 29 feet above the base of the shale unit and is about 6 inches thick. This is overlain by 7 feet of dark shale and then by another band of tuff that is 6 inches thick. There appears to be very little difference in the samples from different bands though the three lower beds have a more platy structure and weather to a blue-grey rather than a light grey colour and are dark grey rather than brownish grey when fresh.

In the exposure near Gleichen (Sec. 25, Twp. 22, Rge. 23W4.) two, grey-weathering, platy tuff beds occur 20 and 24 feet respectively above the base of the Battle Formation. The uppermost light grey-weathering tuff bed (Kneehills) has, apparently, been eroded at this locality.

The tuff is a pale grey weathering, brown-grey, hard rock of very fine grain containing macroscopic vugs either lined or completely filled with chalcedonic or opaline silica and/or bentonitic clay. The rock does not decompose readily, but breaks into sharp-edged, angular fragments that form a conspicuous talus. At some localities the tuff bed is not exposed but its presence is indicated by the talus. (Plate IV).

Samples from this region appear to be identical with those from the Cypress Hills area.

OLDMAN RIVER REGION

Whitemud Formation

Distribution

South of Bow River the Whitemud and Battle formations were found only at one locality. These strata outcrop in both banks of Oldman River in Sec. 25, Twp. 10, Rge. 25W4.

In the region between the Bow and the Oldman rivers exposures of the Whitemud and Battle have not been found and there is a possibility that these beds have been eroded from a large part of this area although, farther west, the zone appears to be present in the subsurface. On the north side of Bow River valley in Secs. 21 and 22, Twp. 22, Rge. 24W4. erosion has removed the upper part of the Battle Formation and on the south side of the river sandstones similar to the Paskapoo Formation rest on strata typical of the Edmonton Group below the Whitemud Formation indicating deeper erosion from north to south. Present data, however, are not sufficient to determine to what extent the "Kneehills Tuff zone" has been wholly or partially removed by erosion.

The "Kneehills Tuff zone" has not been found by the writer between Oldman River and the International Boundary. Throughout much of this region bedrock outcrop is poor. However, a good section of the upper part of the St. Mary River and lower part of the Willow Creek formations is exposed in the vicinity of Whiskey Gap near the southern border of the Province and the Whitemud and Battle formations were not recognized. The decrease in thickness of the Battle Formation between Red Deer River and Oldman River may indicate thinning and the eventual disappearance of the unit somewhere north of the United States border.

Lithology

The Whitemud Formation on Oldman River comprises one unit as it does north of Bow River valley. It is 9 feet thick, and consists of white-weathering, grey to pale green, fine-grained, clayey sandstone containing in the uppermost 18 inches, vertical fractures filled with, and cylindrical inclusions of, the overlying dark, purplish black shale. The unit is underlain by light grey weathering, grey-green, soft, clay shale and overlain abruptly by the dark shale of the Battle Formation. The weathering characteristics are similar to those of the same unit north of Bow River.

Battle Formation

Distribution

Like the Whitemud strata, the Battle Formation outcrops at only one locality south of Bow River. The dark shales outcrop above the Whitemud beds in both banks of Oldman River in Sec. 25, Twp. 10, Rge. 25W4.

Lithology

The Battle Formation is 12 feet thick in the exposure on Oldman River. This is somewhat thinner than the same unit in the Red Deer River region and considerably thinner than at the west end of the Cypress Hills. The rock is similar to the same unit at the other localities and consists of mauve grey-weathering, purplish-black, bentonitic, silty shale which, where weathered, has the typical porous, "popcorn-like" crust. It is overlain conformably by grey and green, soft, clay shales of the Willow Creek Formation.

Kneehills Tuff: This bed, about 8 inches thick, occurs approximately 3 feet below the top of the Battle at this locality. It is a light grey-weathering, brownish grey, dense, rock that is similar in all respects to the Kneehills Tuff at the other localities.

LABORATORY INVESTIGATION

METHODS OF STUDY

Samples of the various rock units were prepared for study by the following methods: -

(1) A total of 30 thin sections were prepared and studied by means of the petrographic microscope.

(2) Twenty mechanical analyses were made as follows: -

- (a) The samples were crushed and/or disintegrated.
- (b) The samples were treated with sodium hexametaphosphate to aid the dispersion of clay.
- (c) The clay was separated from the silt and sand fraction by elutriation with water and sodium carbonate.
- (d) All grains larger than clay from each sample were divided into 3 size fractions: - one larger than 0.125 mm ; one between 0.053 mm and 0.125 mm ; and one smaller than 0.053 mm. For practical purposes the two larger sizes were combined in the tables.
- (e) Each size fraction was separated into a light and heavy part by means of bromoform (S.G. 2.87).
- (f) Samples of each grain size and weight were mounted as grains and studied by means of the petrographic microscope.
- (g) The presence of potassium feldspar was determined by etching with HF and staining with sodium cobaltinitrite solution.

The grain size classification most commonly used is that proposed by C.K. Wentworth and given below: -

Sand............................	0.0625 mm to 2.0 mm
Silt............................	0.004 mm to 0.0625 mm
clay............................	Smaller than 0.004 mm

For the preparation of the samples for the analyses given in this report, however, it was neither convenient nor feasible to use the precise Wentworth sizes, and slightly different boundaries between the sand and silt sizes have been used.

For the purpose of this report sand is considered to consist of all grains larger than 0.053 mm in diameter. Silt consists of all grains less than 0.053 mm and larger than 0.004 mm (approximately) in diameter. The clay fraction includes all material less than 0.004 mm in diameter.

WHITEMUD FORMATION

Mineralogy

No intensive study of the Whitemud Formation was made but several samples were compared in order to ascertain any obvious similarities or differences is samples from different localities. These sediments, whether from east or west of the Sweetgrass Arch, are very friable. The white colour is due to the content of kaolin and/or montmorillonite that coats the grains and occupies the interstices between the grains.

Thin sections of the rock show it to be composed of potassium feldspar that is predominantly orthoclase together with lesser amounts of quartz, quartzite, and chert. Small amounts of twinned plagioclase, white mica, biotite, and chlorite are usually present. Some clear grains of feldspar are present, but the mojority of grains show considerable alteration to clay minerals. Numerous grains are now composed entirely of clay, though they still retain the outline of the original feldspar. The small number of twinned plagioclase grains seen are clear and appear to be in the albite-oligoclase range.

The quartz, quartzite, and chert grains are predominantly angular. These minerals show little alteration and, where sericitization occurs, it is confined to the grain edges. The relative percentage of quartz present appears to be greater in the silt size.

White mica and biotite occur as scattered discrete grains. No carbonate was seen in any sample from the southeastern part of the Province. The interstices between grains are filled with a fine aggregate of clay minerals that were not identified in the thin sections.

One of the principal differences between the Whitemud Formation in the Cypress Hills region and the same formation along the western border of the plains is the presence of up to 3 per cent of carbonate in all samples collected between Red Deer River and Oldman River. Samples from the western regions also contain a larger percentage of quartz, quartzite, and chert relative to feldspar. Microcline is slightly more abundant, but twinned plagioclase is scarce in the samples studied. The feldspar present does not appear to be altered to the same extent as that in the Cypress Hills region.

The characteristic heavy minerals of the Whitemud beds are zircon, tourmaline and rutile, although garnet, and staurolite were found in some samples, and one or two grains of kyanite were identified. The minerals present suggest that the suite is mainly restricted to the more stable varieties.

Figure 3 records the results of the mechanical analyses of six samples. Four of these are from southeastern Alberta, one from the Red Deer valley and one from the Oldman River valley.

	Locality	Per Cent Sand	Per Cent Silt	Per Cent Clay
1	N. slope of Eagle Butte; W. end of Cypress Hills. Sec. 9, Twp. 8, Rge. 4W4. (lower Whitemud)	49	27	24
2	Lodgepole Coulée, W. side; W. end of Cypress Hills. Sec. 3, Twp. 8, Rge. 4W4. (lower Whitemud)	46	20	34
3	N. slope of Eagle Butte; W. end of Cypress Hills. Sec. 9, Twp. 8, Rge. 4W4. (upper Whitemud)	10	30	60
4	Quarry near Fly Lake; near W. end of Cypress Hills. Sec. 21, Twp. 8, Rge. 4W4. (Whitemud)	17	28	55
5	N. bank of Oldman River. Sec. 25, Twp. 10, Rge. 25W4. (Whitemud)	1.4	38.6	60
6	Horseshoe Canyon, Red Deer River valley. Sec. 26, Twp. 28, Rge. 21W4. (Whitemud)	40	15	45

Figure 3: Table showing the percentages of sand, silt and clay in samples of the Whitemud Formation.

In the Eagle Butte (1) and Lodgepole Coulée (2) samples, sand is more abundant than silt in the lower sandy unit but, in the upper unit (3), where clay predominates, only 10 per cent of the rock is composed of sand and 30 per cent of the sample is of silt size.

The two samples of Whitemud from the west side of the Sweetgrass Arch (5 and 6) both contain substantial amounts of clay but, in that from the outcrop on Oldman River (5) only 1.4 per cent of the grains are of sand size and, in the samples from the Red Deer River exposure (6), 40 per cent of the grains are of sand size.

The three samples having the largest percentage of clay also contain more silt than sand. It seems likely that this relationship is due to selective sorting during deposition of the sediments and, perhaps, also to re-working of the original sediments.

Figure 4 shows the approximate relative percentages of the different clay minerals from three of the same localities as those in Figure 3. Both samples of the Whitemud Formation contain relatively large percentages of illite and kaolinite and only a moderate amount of montmorillonite. Samples of the two western equivalents, however, contain a very large percentage of montmorillonite, and only small amounts of the other clay minerals.

Whitaker (1965) has reported the kaolinite content in samples from the west end of the Cypress Hills to range between 24 and 87 per cent of the total clay present.

Palaeontology

No fossils were seen in any of the outcrops examined and no microfossils were recovered from samples collected. In parts of Saskatchewan the Whitemud Formation has yielded both plant and mollusc remains, but neither of these are particularly diagnostic of age (Fraser et al., 1935). Correlation of the Whitemud Formation is based, almost exclusively, upon stratigraphic evidence (Fraser, et al., 1935, pp. 34-35).

Summary

The sands, sandy clays and clays that comprise the Whitemud Formation were deposited as part of a large delta and floodplain complex. The results of this study show little significant mineralogical difference between the sand fractions from various locations. The clay content, however, is remarkably different between the eastern and western parts of Alberta. The clay content of western samples has been shown to be about 90 per cent montmorillonite with only a small amount of kaolinite plus illite. In contrast to this, samples from the west end of the Cypress Hills contain up to 68 per cent kaolinite plus illite with only about 27 per cent montmorillonite. Still farther east, in Saskatchewan, the relative proportion of kaolinite plus illite becomes progressively larger (Fraser et al., 1935) and (Spyker, Carlson, and Babey, 1954).

Sample	FIELD SAMPLE NUMBER	FORMATION	LOCALITY	APPROXIMATE RELATIVE PERCENTAGE			
				Montmorillonite	Illite	Kaolinite	Chlorite
1	1A—4-sec. 31, 1966	Whitemud (lower part)	sec. 9, Tp. 8, Rge. 4W4 N slope of Eagle Butte; W end of Cypress Hills	27	45	23	5
2	1A—5-sec. 31, 1966	Whitemud (upper part)	sec. 9, Tp. 8, Rge. 4W4 N slope of Eagle Butte; W end of Cypress Hills	37	40	15	8
3	1A—3-sec. 41, 1966	Whitemud (equivalent)	sec. 25, Tp. 10, Rge. 25W4 N bank of the Oldman River	75	14	8	3
4	1A—2-sec. 1, 1966	Whitemud (equivalent)	sec. 26, Tp. 28, Rge. 21W4 Horseshoe Canyon	73	5	16	6
5	1A—7-sec. 31, 1966	Battle	N slope of Eagle Butte; W end of Cypress Hills	90	5	3	2
6	1A—4-sec. 41, ..966	Battle (equivalent)	sec. 25, Tp. 10, Rge. 25W4 N bank of the Oldman River	96	4	0	0
7	1A—6-sec. 1, 1966	Battle (equivalent)	sec. 26, Tp. 28, Rge. 21W4 Horseshoe Canyon	97	0	2	1

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Figure 4 Table showing X-ray analyses of clay minerals from the Whitemud and Battle Formations.

Thus, the relative proportion of montmorillonite decreases from west to east and the relative proportion of kaolinite plus illite increases from west to east.

The heavy minerals found to be present are the same in all samples of the Whitemud and consist of only the most stable minerals. This suggests that leaching for a long period of time has removed minerals such as apatite, hornblende, and augite.

BATTLE FORMATION

Mineralogy

General

Ten samples of the Battle Formation were studied. These were collected from the Cypress Hills region, the Red Deer River - Bow River region, and from the Oldman River locality.

The shale, when viewed under a binocular microscope appears to be a mixture; one part, grey-green in colour, consists of clay, silt, and sand; and the other, dark green in colour, consists of waxy and flaky bentonite. The bentonite, which is nearly pure montmorillonite, occurs as curved and curled fragments due to its conchoidal structure. The relative amount of bentonite ranges considerably between samples.

Conventional thin sections of the material were found to be unsatisfactory for determining the mineral content because of the large percentage of clay present in all samples. For this reason the samples were disintegrated, separated into sand, silt and clay fractions, and the mounted grains studied by means of a petrographic microscope.

The silt- and sand-size grains consist of quartz and feldspar with lesser amounts of quartzite and chert. Much of the quartz is clear and shows the bipyramidal form of B-quartz. Shreds of white mica and chlorite are present in some samples, and organic debris is common in nearly all samples. Most of the quartz is angular. The quartzite and chert grains are angular to subangular. Orthoclase and/or sanidine are the most common feldspars present and most of these grains are clear with sharply defined edges. Some grains are altered around the edges. Microcline and twinned plagioclase are rare, though a few small grains were seen in most sections.

Microscopic organic debris is common in all samples studied. It consists of ragged, cellular fragments; short, rod-like forms, some of which are segmented; short, conical, hollow forms; and rounded fragments. This material has a light green to light brown colour and is isotropic.

	Locality	Per Cent Sand	Per Cent Silt	Per Cent Clay
1	Horseshoe Canyon, Red Deer River valley; Sec. 26, Twp. 28, Rge. 21W4. (near base of section)	8.3	1.7	90.0
2	Horseshoe Canyon, Red Deer River valley; Sec. 26, Twp. 28, Rge. 21W4. (20 feet above base of section)	3.3	1.2	95.5
3	West side Red Deer River, 1 mile downstream from Tollman bridge; Sec. 14, Twp. 33, Rge. 22W4.	4.7	2.3	93.0
4	SW. side of Trans Canada highway near Gleichen; Sec. 25, Twp. 22, Rge. 21W4. (10 feet above base)	35.5	10.1	54.4
5	SW. side of Trans Canada highway near Gleichen; Sec. 25, Twp. 22, Rge. 21W4. (20 feet above base)	44.7	4.1	51.2
6	One mile west of Trans Canada highway; Sec. 26, Twp. 23, Rge. 23W4.	14.4	2.3	83.3
7	N. slope of Wintering Hills; Sec. 6, Twp. 26, Rge. 21W4.	35.3	4.2	60.5
8	N. slope of Wintering Hills; Sec. 33, Twp. 26, Rge. 19W4.	3.4	0.6	96.0
9	N. band of Oldman River; Sec. 25, Twp. 10, Rge. 25W4.	5.5	2.7	91.8
10	Eagle Butte; W. end of Cypress Hills; Sec. 9, Twp. 8, Rge. 4W4.	18.3	6.4	75.3

Figure 5. Table showing the percentages of sand, silt, and clay in samples of the Battle Formation.

Figure 5 records the results of the mechanical analyses of 10 samples and shows the approximate relative percentages of clay, silt, and sand in each. It is evident that the relative percentages of sand-sized grains is always greater than the percentage of those of silt-size in any one sample. Also, if the amount of sand in a sample is large then the amount of silt will be correspondingly large. The relative percentage of sand present in the 10 samples ranges between 3.3 and 44.5. This difference is considerable but there is, apparently, no regular change in the sand content either from east to west or from north to south. In fact is is probable that sequential sampling would show as great a change in sand content in different parts of any one section as that occurring between sections.

The most important fact illustrated by the results shown in Figure 4 is that clay comprises the most abundant size-fraction in all samples. X-Ray analyses of the clay fraction of samples from the west end of the Cypress Hills, the Red Deer River valley, and from the Oldman River valley show that montmorillonite is by far the most abundant clay mineral present. Samples 5, 6, and 7 of Figure 4 contain between 90 and 97 per cent montmorillonite together with very small percentages of illite, kaolinite, and chlorite. Thus, montmorillonite appears to be the most important clay mineral constituent of the Battle shale, regardless of the geographic location of the sample.

Heavy Minerals

Figure 6 shows the relative abundance of heavy minerals present in 13 samples from different localities. In order of abundance the non-opaque minerals are zircon, tourmaline, rutile, and titanite. The amount of zircon present is far greater than all the others together and the proportion of zircon is much greater in the smaller size-fraction. The proportion of the other three non-opaque minerals is also larger in the smaller size-fraction.

The opaque minerals consist entirely of magnetite with some pyrite. The former is extremely abundant in both size-fractions and is particularly so in the sizes less than 0.053 mm in diameter. Pyrite occurs in most samples but generally is rare.

Zircon and magnetite together account for more than 90 per cent of the heavy minerals in each sample.

<u>Zircon</u> is present in large amounts in all samples. It occurs as fresh, colourless, euhedral grains more than one-half of which have a bi-pyramidal form. The remainder have well-developed prismatic faces which results in short and long

prisms with pyramidal terminations. Irregularly dispersed inclusions in the crystals are common. Besides the colourless crystals, each sample contains one or two very small purplish pink zircons, the crystal edges of which are rounded. Two samples contained one or two euhedral grains having a honey-yellow colour. Zircon is much more abundant in the <0.053 mm size-fraction than in the fraction containing grains larger than 0.053 mm.

Tourmaline is not abundant, but when present occurs as euhedral doubly-terminated prisms, or prismatic fragments, having a green or brown colour. Two samples contain one or two well-rounded, green grains of this mineral.

Rutile is rare but from one to several small grains are present in most samples. It is present as amber, red-brown, or red prismatic to acicular fragments. One or two twinned crystals were seen. In some samples the rutile grains are coated with a white alteration product (leucoxene?).

Titanite is extremely rare. The grains have a yellow-brown colour and are irregular to slightly diamond-shaped in outline.

Magnetite and/or titaniferous magnetite is abundant in both size-fractions. It occurs as euhedral to subhedral octahedrons and dodecahedrons but all forms exist between euhedral grains having sharp crystal edges, through those showing some rounding of the edges, to those that are globular or tear-shaped. All are black in colour and have a high lustre. Besides the individual grains, some samples contain long, wire-like forms with or without attached rounded blebs or strings of blebs. (Such 'strings' and 'blebs' may have formed during the ejection of semi-molten material from a volcanic vent). Some limonite is present in most samples. X-Ray analysis indicates the presence of titanium in many of the grains.

Pyrite is generally present in all samples but is not abundant. It occurs mainly as irregular grains or as deformed pyritohedrons.

Palaeontology

The Battle Formation is remarkable for its lack of fossils. No megafossils and no diagnostic microfossils have been found in these strata.

Twenty-five samples were prepared and studied by T.P. Chamney who identified the following microscopic material.

Algal remains
Megaspores
Siliceous megaspores (Selaginellites borealis Miner, 1932)
Bone fragments (vertebrate remains)
Tooth (reptile?)
Ostracod? (shell fragments)
Carbonized wood fragments
Foraminifera (? Haplophragmoides sp.)

The above list of fossilized remains is not of much value for determining the environment of deposition of the unit. The foraminifer ?Haplophragmoides sp. is typical of marine conditions but, since only one poorly preserved specimen was found in the samples, it is not considered to be indicative. Algae may have been carried by wind and/or water to the site or sites of deposition. The megaspore Selaginellites borealis Miner is present in nearly all samples examined. The fact that is silicified wherever it occurs in unusual.

Summary

The uniform thickness and composition of the Battle Formation suggests that these sediments were deposited in water. However, the lithologic unit contains no structures indicative of waterlain sediments. Bedding is not discernible except for thin beds of bentonite.

The analyses given in Figure 5 show that this stratigraphic unit consists predominantly of clay, of which about 90 per cent is montmorillonite. Montmorillonite is considered to be one of the products of decomposition of volcanic ash in an aqueous environment and a general formula illustrating this decomposition process is given by Slaughter and Earley, (1965) as follows: -

Glass + H_20 = montmorillonite + zeolite + silica + metal ions in solution.

Kaolinite and chlorite also may be products of this hydrolysis under some circumstances.

Montmorillonite is the most important product of the above process and is present in large amounts in the Battle Formation. Minerals of the zeolite group were not identified, so it is possible that kaolinite and/or chlorite may have been formed instead of zeolites. Amorphous silica, an important product of the hydrolysis of vitric tuff, is not found as a constituent of the Battle Formation except in the Kneehills and other tuff beds. Silicification within the Battle shales is restricted to the tuff beds and to some of the organic remains.

The small amount of silica now present suggests the the system undergoing alteration had some access to the overlying body of water, and that large quantities of silica were carried upward and dispersed into the basin.

The sand- and silt-size minerals present appear to be derived from two sources. The quartzite, chert, and some of the quartz and feldspar is somewhat rounded and weathered and, likely, has been brought to the site of deposition by streams and wind. Some quartz, especially that having a B-quartz form; some of the feldspar; and all of the heavy minerals were probably derived by the in situ disintegration of wind-blown volcanic ash.

It is evident, from the heavy mineral analyses shown in Figure 6, that this is a restricted suite that is uniform in all samples regardless of locality. The uniformity of the mineralogy in all samples, the fine size of all minerals present, the lack of weathering, the euhedral and doubly-terminated crystals of zircon and tourmaline, and the euhedral to globular nature of the titaniferous magnetite suggests that they were, originally primary constituents of a volcanic ash rather than multicycle residual minerals.

This heavy mineral suite, except for the few grains of garnet and hornblende is identical with that from the Kneehills Tuff as shown in Figure 8.

Thus the Battle "shale" appears to consist of two parts each of which has a different origin. Part of the quartz and feldspar together with all of the quartzite, chert and organic remains, were probably washed or blown from the surrounding land. The greater part of the sediment, consisting of quartz, feldspar, zircon, tourmaline, rutile, magnetite and montmorillonite have been derived from windblown volcanic ash similar to that comprising the Kneehills Tuff bed prior to its silicification.

Present data are sufficient to establish the fact that the ash was deposited in water, but whether this water was a fresh-water lake or a shallow sea is still in doubt. The large area covered by this body of water suggests a shallow sea, but no diagnostic marine fossils have been found. Based on present information the writer is of the opinion that the site of deposition was a large body of fresh water that was little disturbed by waves or currents.

KNEEHILLS TUFF BED

Mineralogy

General

A study of thin sections of the rock shows that the tuff consists, mainly, of fresh, angular grains, between 0.03 mm and 0.05 mm in diameter, of quartz and feldspar together with isotropic glass "shards" in an isotropic or weakly anisotropic, dense, microfelsitic groundmass. Some tiny biotite grains are usually present. No two samples are alike regarding the proportion of anisotropic mineral grains present. Some thin sections show very few and others a very large number of such grains. Generally, those thin sections having a large proportion of anisotropic grains show few, if any, recognizable fragments of glass. On the other hand, samples in which anisotropic minerals are rare contain a large proportion of irregularly-shaped, isotropic glass fragments. The groundmass material appears to contain both opaline silica and the clay mineral montmorillonite.

Quartz, plagioclase, some reddish brown biotite and a little potassium feldspar are present in most of the thin sections. The quartz grains are clear and show sharp extinction. Some of the twinned plagioclase is unaltered and appears to be near oligoclase in composition. Orthoclase and/or sanidine is assumed to be present but was not definitely identifed.

Figure 7 shows chemical analyses for samples of tuff from nine different localities in southern Alberta. All but No. 7 in this table are analyses of samples of the Kneehills Tuff bed proper. Number seven is a sample of a tuff lens occurring about 20 feet lower than the Kneehills bed but still within the Battle Formation. The analyses were made by the rapid X-Ray Fluorescence method and the degree of accuracy is slightly less than that which would be obtained by the more tedius and time-consuming "wet analyses" method.

The following table gives the estimated precision of the individual determinations expressed as percentages.

XRF		Rapid Chemical	
SiO_2(30%-70%)	1.2 %	Na_2O(up to 10%)	0.15%
Al_2O_3(up to 20%)	0.7 %	P_2O_5 (up to 1%)	0.04%
Total Fe. as Fe_2O_3(up to 15%)	0.5 %		
CaO (up to 40%)	0.3 %		
MgO (up to 40%)	1.0 %		
K_2O (up to 5%)	0.1 %		
TiO_2 (up to 2%)	0.05%		
MnO (up to 1%)	0.02%		

The degrees of precision, given above, for each determination indicates that discrepancies in the percentage of most of the oxides would be rather small. However, in the case of silica, the percentages listed as present could be in error as much as ± 10.

For purposes of comparison with the longer and more complicated wet chemical analysis, the following table, given by Allan and Sanderson (1945) on page 69 is included here.

	Ash Horseshoe Canyon near Drumheller	Ash Cypress Hills above Fly Lake
SiO_2	87.0	89.6
Al_2O_3	4.8	3.6
CaO	1.5	1.2
MgO	2.0	2.0
K_2O	0.7	0.4
Na_2O	0.9	0.4
Ignition loss	2.8	3.4

(Analyzed by Wm. Gerrie, Toronto University, 1927)

Sample	FIELD SAMPLE NUMBER	LOCALITY	Percentage of Oxides										
			TOTAL Fe_2O_3	MnO	TiO_2	CaO	K_2O	SiO_2	Al_2O_3	MgO	Na_2O	P_2O_5	Ignition Loss
1	1A—2-sec. 3, 1966	sec. 14, Tp. 29, Rge. 23W4 Gully on S side of Kneehills Creek	0.90	0.02	0.66	0.50	0.67	91.13	2.10	0.50	1.10	0.02	2.40
2	1A—4-sec. 6, 1966	sec. 14, Tp. 33, Rge. 22W4 W side of Red Deer River	0.90	0.02	0.75	0.70	0.75	89.76	2.60	0.50	0.80	0.02	3.20
3	1A—7-sec. 7, 1966	sec. 18, Tp. 34, Rge. 21W4 E side of Red Deer River	0.90	0.02	0.73	0.40	0.58	90.54	2.70	0.50	0.70	0.03	2.90
4	1A—7-sec. 9, 1966	sec. 24, Tp. 29, Rge. 18W4 W slope of Hand Hills	0.70	0.02	0.74	0.40	0.49	92.73	0.40	0.50	0.70	0.02	3.30
5	1A—2-sec. 11, 1966	sec. 33, Tp. 26, Rge. 18W4 N W side of the Wintering Hills	0.70	0.02	0.64	0.50	0.55	90.76	1.50	0.50	1.00	0.03	3.80
6	1A—5-sec. 14, 1966	sec. 6, Tp. 26, Rge. 21W4	0.70	0.02	0.64	0.60	0.55	89.67	2.40	0.50	0.90	0.02	4.00
7	1A—3-sec. 16, 1966 Tuff band 20 feet below Kneehills tuff	sec. 25, Tp. 22, Rge. 23W4 S W side of No. 1 Hwy.	3.00	0.02	0.54	0.40	0.05	88.27	1.00	0.50	0.60	0.02	5.60
8	1A—10-sec. 31, 1966	sec. 9, Tp. 8, Rge. 4W4 N slope of Eagle Butte	0.80	0.02	0.75	0.40	0.31	92.50	0.50	0.50	0.30	0.02	3.90
9	1A—5-sec. 41, 1966	sec. 25, Tp. 10, Rge. 25W4 N bank of Oldman River	1.10	0.02	0.63	0.60	0.38	91.05	2.10	0.60	1.30	0.02	2.20

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Figure 7 Table showing chemical analyses of Kneehills Tuff samples by X-Ray fluorescence.

The table shows, also, that the chemical composition of the rock is very similar wherever it occurs in southern Alberta.

Sample No. 7 of Figure 7 is a much darker rock than the Kneehills Tuff proper and samples show a patchy texture probably due to admixture of other sediment. Compared with the Kneehills Tuff bed the chemical analysis shows a slightly larger percentage of total iron oxide and of ignition loss together with a small decrease in silica. These small differences are attributed to impurities introduced due to some re-working of this bed or lens.

Figure 8 shows the results of heavy mineral analyses of ten samples of the Kneehills Tuff bed from different localities. Disintegration of the tuff samples was in all cases incomplete, but the separation was adequate to show the kind and relative proportions of the minerals. The table shows a very restricted but identical suite of heavy minerals to be present in all samples. The non-opaque minerals consist of zircon, tourmaline and rutile in that order of decreasing abundance. Magnetite and/or titaniferous magnetite with some pyrite are the only opaque minerals in the samples. The heavy separate from each sample consists almost entirely of zircon and magnetite.

Heavy Minerals

Zircon is ubiquitous and is the most abundant of the non-opaque minerals. It occurs as fresh, clear, colourless, euhedral grains. The majority of grains have a bi-pyramidal form with little or no development of the prismatic faces. Some grains, however, have well-developed prismatic faces and occur as long and short prisms with pyramidal terminations. Small inclusions are common and are irregularly dispersed. Rarely, one or two purplish pink grains occur and these show some rounding of the edges. The table shows that zircon is almost entirely confined to the <0.053 mm size-fraction.

Tourmaline is rare but when present occurs as brownish, doubly-terminated, euhedral prisms.

Rutile is extremely rare but up to three grains were seen in some samples. This mineral is present as amber-coloured, prismatic fragments.

Magnetite and/or titaniferous magnetite is abundant in both size-fractions. It occurs, mainly, as euhedral to subhedral crystals but there is a gradation between euhedral grains with sharp crystal edges, through grains showing some rounding to grains having a globular or tear-shaped form. A few crystals contain round cavities. All are black in colour and have a high lustre. Besides the above forms some samples contain long, thin, curved or twisted, wire-like forms with or without attached rounded blebs. Hollow, spherical grains are also present in some samples. Many of these show incipient alteration to limonite. X-Ray identification shows the presence of titanium in many of these grains.

Pyrite is usually present in small amounts and occurs as tiny pyritohedrons or as irregular grains.

One or two ragged grains of garnet and hornblende were seen in one sample. These are not shown on the chart.

Palaeontology

No megafossils occur in the tuff and no microfossils were found in any of the samples examined.

Summary

The composition of the Kneehills Tuff bed suggests that it was originally a wind-transported, volcanic ash that was deposited very rapidly in an extensive body of water that covered a large part of southern Alberta. The fact that the tuff contains practically no sedimentary structures, and is free of extraneous sedimentary detritus indicates little or no movement of this water.

The uniformity of the mineralogy of all samples, the fine size of all minerals present, the lack of weathering, the euhedral and doubly-terminated crystals of zircon and tourmaline, and the euhedral to globular nature of the titaniferous magnetite indicates that they are original constituents of the ash. Opaline silica and a small amount of bentonitic material are the only secondary minerals present.

The mineral suite is typically volcanic and about the same as that which one would expect to fine as phenocrysts in a fine-grained igneous rock of the calc-alkalic series which contains orthoclase, sanidine, some quartz, B-quartz forms, and a small proportion of early-formed biotite and plagioclase. The well-preserved character of the biotite and plagioclase shows that the transportation process permitted migration of these relatively unstable minerals from the source to the site of deposition without significant physical or chemical alteration. One of the few processes for the formation of such deposits is wind transportation of ejected volcanic material.

The relative amount of anisotropic minerals present indicates the degree of devitrification that occurred prior to ejection, during transport, subsequent to deposition or during all three of these events. The amount of devitrification is different in different samples.

The original material, when deposited in the water, and prior to compaction, is considered to have been a vitric-crystal ash having a very porous to pumiceous texture. The interstices of the deposit were filled with opaline silica within a relatively short time after deposition thus inhibiting decomposition of the tuff to bentonite. The silica may have been derived from the decompostion of the ash content in the beds above and below the tuff.

The Kneehills Tuff bed, because of its almost identical mineralogy and contemporaneous deposition at all places in southern Alberta, is considered to represent the same geological time at all localities. For this reason and because of its ease of recognition it is a valuable stratigraphic marker.

Attempts to obtain an absolute age for the Kneehills Tuff have been made by Ritchie (1958) and by Folinsbee, Baadsgaard and Lipson (1960). Ritchie (1960) summarized this work and concluded that the results were inconclusive and that more data were required.

CONCLUSIONS

Samples of the Whitemud Formation from all localities in southeastern Alberta are similar, in that the rocks are all soft, friable, greenish grey and light grey, white-weathering clayey sandstones, sandy clays and clays. In all regions they occupy the same stratigraphic position below the dark coloured Battle Formation. The present study has shown mineralogical difference between samples from the east and west sides of the Sweetgrass Arch; the most important of which are the relative proportions of the various clay minerals in the unit. In southeastern Alberta kaolinite is the predominant clay mineral present but, in the west, montmorillonite is the most important clay mineral in the rock. Another difference is in the relative proportion of feldspar to quartz, quartzite and chert in the rock. In the Whitemud Formation of the Cypress Hills region the proportion of feldspar to the silica minerals is larger than it is in the same formation in western Alberta. There is, also, much more alteration of the feldspar grains in the eastern than in the western part of the plains.

In southeastern Alberta the kaolinite content of the Whitemud Formation is thought to have resulted from chemical weathering of feldspathic sandstones (Fraser et al., 1935). Thus, there must have been a considerable length of time during which there was crustal stability that inhibited the inflow of newly transported and unaltered sediments from the source areas. The climate, also, must have been moderate and stable during the time the Whitemud sediments were exposed to the atmosphere.

It seems reasonable to assume that these conditions were much the same in the western part of the plains as they were in the east so that the environmental conditions affecting weathering of the rocks were similar throughout the southern plains. The present mineralogical differences are probably the result of different source areas and the inclusion of large quantities of volcanic ash in the western sediments. The alteration of this ash has produced the large proportion of montmorillonite now typical of these rocks.

Following the period of subaerial weathering that produced the present mineral content of the Whitemud sediments, a large part of southern Alberta and Saskatchewan was further depressed and became covered with water. Whether this was one continuous inundation or several large lakes and whether the water was brackish or fresh is not known.

The writer has assumed one large body of fresh water that was little disturbed by waves and currents.

This was a time, apparently, of tremendous explosive volcanic activity in the land areas to the west, and large amounts of ash from this region were spread by winds over vast areas to the east. Large quantities of this ash were deposited in the water covering much of southern Alberta and Saskatchewan to form the predominant part of the Battle Formation. The deposition of this ash continued throughout 'Battle' time.

It has been shown that sediments of the Battle Formation do contain some sediment other than ash, the proportion differing from place to place. Much of this foreign material is thought to have been deposited by wind and what little sediment was supplied by streams was probably confined to the margin of the water body.

No megafossils have been found in the Battle Formation and the microfossils listed were probably carried by wind to the site of deposition. This lack of fossils suggests that environmental conditions were prohibitive to aquatic life, probably because of the constant supply of ash to the water.

Except for the Kneehills Tuff bed and other thin lenses of silicified ash, the lithology of the Battle Formation is relatively constant. The original subaqueous deposit was undoubtedly porous and permeable and remained so long enough for the vitric part of the ash to be altered mainly to montmorillonite and amorphous silica. Most of the silica was subsequently removed from the sediment. That amorphous silica was present in the waters is indicated by the silicified megaspores and the silicified tuff beds.

It is interesting to note that the composition of the Kneehills Tuff prior to its silicification would have been that of a tuff identical in composition with the ash part of the Battle shale before its alteration. This suggests that the Kneehills Tuff and other tuff lenses were originally parts of the Battle Formation sediments which, for reasons not known, were fortuitously silicified at an early stage and before any decomposition to bentonite occurred.

The work of Sternberg (1947) and of Bell (1949) showed that the Kneehills Tuff zone" marked a distinct change in both the saurian fauna and the flora respectively within the Upper Cretaceous of the Plains.

The writer has shown, (1) that the lithologies of the Battle shale and Kneehills Tuff are remarkably constant at all occurrences in southern Alberta; (2) that the combination of the Whitemud and Battle formations is unique; and (3) that the time during which the Whitemud sediments were undergoing chemical weathering plus the time during which the clays of the Battle Formation were accumulating, represents an interval within the Late Cretaceous when little or no sediment was being supplied by streams from the west.

It has been pointed out that the "Kneehills Tuff zone" can be readily identified in outcrop by the colour and texture of each unit where weathered. Also, Havard (this paper) and previously Ower (1960) and Elliot (1960) have shown that the zone can be identified on well logs and is a very useful marker for subsurface correlation.

Therefore, because of its ease of recognition, its uniform composition and because the Kneehills Tuff represents an approximate time surface, the "Kneehills Tuff zone" comprising the Whitemud and Battle Formations, is a stratigraphic marker of great inportance within the non-marine Upper Cretaceous sediments of the southern plains of Alberta.

PART II

SUBSURFACE DISTRIBUTION OF THE "KNEEHILLS TUFF ZONE" AND UNDERLYING UPPER CRETACEOUS UNITS ABOVE THE LEA PARK - PAKOWKI FORMATIONS

by
C.J. Havard

INTRODUCTION

The "Kneehills Tuff zone", consisting of the Battle and the Whitemud formations, occurs near the top of uppermost Cretaceous non-marine sediments in central and southern Alberta. It has been used as a stratigraphic marker in a succession of interlensed and interbedded sandstones, siltstones, shales, and coal beds. The thin Kneehills Tuff bed, or beds, occurring within the Battle Formation is uniform in composition and similar in position over the entire area mapped suggesting that the tuff is isochronous.

Ower (1960) traced the "Kneehills Tuff zone" from surface exposures on the Red Deer River to subsurface well sections to the west by means of electric well logs. He used coal horizons as an aid to locate the tuffaceous zone and to subdivide the Edmonton Formation into five units. Elliott (1960), using subsurface data only, mapped the "Kneehills Tuff zone" from Twp. 67 in central Alberta to Twp. 24 in the vicinity of Calgary and used the "zone" to divide the Edmonton Formation into the lower-middle and the upper units.

This subsurface study of the "Kneehills Tuff zone" demonstrates its usefulness as an aid to mapping the uppermost Cretaceous sediments in southwestern Alberta. The maps and cross-sections accompanying this report indicate that the top of this "zone" can be used from Twp. 34 to Twp. 1 as a datum in a section otherwise devoid of any continous stratigraphic markers.

ACKNOWLEDGMENTS

The writer would like to thank the members of the staff of the Institute of Sedimentary and Petroleum Geology who assisted in all phases of the project. Special thanks are extended to J.R. Ower of Chevron Standard Ltd. and L. Hanson of the Alberta Oil and Gas Conservation Board whose suggestions concerning the project were most valuable.

SCOPE OF REPORT

The available subsurface data have been combined with the field and laboratory data of Irish (see Part I of this publication) to show that the "Kneehills Tuff zone" is relatively continuous in the subsurface from central to southernmost Alberta. Because of its contained characteristic tuff bed, the "Kneehills Tuff zone" is considered to be isochronous and is used as a datum for the subsurface mapping of uppermost Cretaceous units.

Ower's (1960) five subdivisions of the Edmonton Formation, based on coal horizons, could not be traced in subsurface sections southwards into the equivalent St. Mary River Formation.

METHODS

Where possible, one well per township was used as a control point for basic regional coverage. In some townships, no subsurface information was available and, in a few townships, more than one well was used because of structural complexity and the consequent need for additional data. The data for the well sections used in the study are listed in the appendix.

The electric or induction electric log was used for each well. In many cases additional information and/or accuracy was obtained by using other types of logs, particularly radioactivity logs.

Fifteen of the wells used as control points had sample coverage of the Edmonton Group and, of these, seven were examined. Although the samples were reasonably good in quality, they were of limited use for a regional study of this nature. Rapid vertical changes in the type of sediment and the disintegration of bentonitic shale fragments in the samples by drilling fluids make these samples difficult to interpret. Also, well-drilling speeds at shallow depths are so rapid that correct sampling methods are difficult to maintain. Fragments of the tuff bed within the Battle Formation were found in the samples of one well, H.B. Garrington 11-33-34-4 W5. Shales of the Battle Formation were rarely represented in the samples due to their bentonitic nature.

The subsurface information is presented as stratigraphic cross-sections, structure contour maps, and isopach maps. Three cross-sections have been prepared (Figures 10, 11, and 12): one (Figure 10) in an approximate north-south direction paralleling the mountain and foothill belt, and two (Figures 11 and 12) in an east-west direction. Structure contour maps are drawn for the top of the "Kneehills Tuff zone" (Figure 9A) and the top of the Belly River Group (Figure 9B). Isopach maps of the Bearpaw Formation (Figure 9D) and of the interval from the top of the Belly River Group to the base of the "Kneehills Tuff zone" (Figure 9C) are included. The latter includes the Bearpaw Formation and the lower part of the Edmonton Group. In the northern part of the area mapped, the Bearpaw Formation is equivalent in age to lowermost Edmonton beds (Ower, 1960) and, over the entire area, the base of the Bearpaw Formation is approximately isochronous (Lines, 1963). Therefore, this isopach interval represents deposition over a uniform time unit.

STRATIGRAPHY

The correlation of the units is given in Figure 1 of this report. A brief description of the lithology and the location of each unit and its correlatives is presented systematically from oldest to youngest. Much of the information is found in the Lexicon of Geologic Names in the Western Canada Sedimentary Basin and Arctic Archipelago.

Lea Park Formation

This formation consists of two parts comprising an upper brown shale unit and a lower dark grey shale unit. It extends from the northern portion of the area studied southward to about Twp. 25.

Pakowki Formation

The marine shales of this formation are present in Alberta as far north as Twp. 25. Pakowki sediments are laterally equivalent to those of the upper part of the Lea Park Formation.

Belly River Group

In the study area, the Belly River Group consists of the Foremost and Oldman Formations which have been mapped as a single unit in the subsurface. The succession of sandstone, siltstone, shale and coal ranges in thickness from 700 to 1,200 feet.

Bearpaw Formation

The Bearpaw Formation consists of dark marine shales interbedded with sandstone and minor amounts of bentonite. It ranges from less than 100 feet to more than 700 feet in thickness in the area studied. Mapping, based on persistent bentonite beds near the base of the Bearpaw (Lines, 1963), indicates that the base of the formation is approximately isochronous. The transitional Edmonton-Bearpaw contact, a facies boundary, reflects the slow southward retreat of the Bearpaw sea (Ower, 1960). The Bearpaw Formation becomes thinner to the west and north.

Edmonton Group

Interbedded and interlensed sandstone, siltstone, shale, bentonite, ironstone, and coal comprise the sediments of the Edmonton Group. In the area of study, the thickness ranges from 1,400 feet to 2,500 feet. The lowermost part of the Edmonton Group in the north is laterally equivalent to shales and sandstones of the Bearpaw Formation in the south (Williams and Burk, 1964).

The stratigraphic marker, the "Kneehills Tuff zone", is composed of the Battle and Whitemud formations and appears to be continuous within the Edmonton sediments of southwestern Alberta. The Kneehills Tuff bed which occurs within the Battle Formation is considered to be isochronous and marks the boundary between Lance and pre-Lance beds. This is based upon the occurrence of Triceratopsian dinosaurian fauna in the overlying beds (Rithchie, W.D., 1960). The thickness of the "zone" ranges between 30 and 60 feet in the northern part of the area studied and between 10 and 20 feet in the southern part.

The thickness of the Edmonton sediments above the "Kneehills Tuff zone" varies considerably because of pre-Paskapoo erosion which, in places, has removed strata down to and including the "Kneehills Tuff zone".

Blood Reserve Formation

This massive, medium-grained sandstone is present only in southernmost Alberta, and represents the initial phase of St. Mary River sedimentation. Near the International Boundary, the Blood Reserve Formation is about 80 feet thick, but it becomes progressively thinner to the north and disappears entirely in the vicinity of Twp. 13.

St. Mary River Formation

The St. Mary River Formation, a southern Alberta succession of lenticular sands, shales, and sandy shales, is equivalent to that portion of the Edmonton Group lying below the "Kneehills Tuff zone". The thickness ranges from 1,000 to 1,500 feet in the area studied.

Willow Creek Formation

Red, green, and purple shales interbedded with lenticular sandstones characterize this formation. It is present only in the southernmost part of Alberta. Willow Creek sediments are considered to range in age from late Cretaceous to Tertiary (Russell, 1932; Bell, 1949); the Upper Cretaceous portion being equivalent to the uppermost Edmonton sediments to the north.

DISCUSSION

Stratigraphy

The top of the "Kneehills Tuff zone" is a valuable stratigraphic marker in the subsurface of central and southern Alberta and is used as a datum for the three cross-sections of this report. These sections indicate that all units mapped, except the "Kneehills Tuff zone" and the Bearpaw Formation, become thicker to the west.

The thickness of the "Kneehills Tuff zone" within the area studied ranges from 10 feet in the south to 60 feet in the north. South of Twp. 14, the "zone" does not exceed 20 feet in thickness. Although no information is available regarding this "zone" within the Foothills region, subsurface data indicate that it becomes thinner towards the west. This suggests that the Battle shoreline is being approached west of the area studied. Outcrops of the Kneehills Tuff bed likely occur within the Foothill region, but the tuff would probably not be accompanied by either the bentonitic shale or the white sandstone which are essential for its recognition. The variable thicknesses and occasional absence of the "zone" suggest post-Battle erosion to a level within or below the marker and such erosion can be shown in the surface exposures (see Part I of this publication). Just south of Calgary is an area where the Whitemud and Battle formations are missing, and presumably are eroded. This area coincides with a structural high mapped on the top of the "Kneehills Tuff zone".

The cross-sections indicate that the lower portion of the Edmonton Group below the "Kneehills Tuff zone" thins to the south as it grades into the St. Mary River sediments. In this southern region, the Bearpaw sediments are thick; the upper portion being laterally equivalent to lowermost Edmonton sediments in the north. Sediments of the St. Mary River type, including numerous porous and non-porous sandstones, first occur in the vicinity of Twp. 16. In the Little Bow River region, typical Edmonton sediments containing a large proportion of siltstones occur between St. Mary River sandstones. This indicates that non-marine St. Mary River sediments wedge northwards and interfinger laterally with the non-marine lower Edmonton sediments.

Figure 9C, an isopach map of the sediments between the "Kneehills Tuff zone" and the top of the Belly River Group, shows the lobate configuration of these largely non-marine sediments. This unit, roughly equivalent in time from north to south thickens gradually to the west in the northern part of the region and much more rapidly in the south where the area of study is closer to the mountain front. In the southern portion of the area studied, this map should be considered to be an isochore map, a map of drilled thicknesses, rather than an isopach map because of the high formational dips in this region.

The isopach map of the Bearpaw Formation, Figure 9D, indicates that this formation in subsurface thins to the north and to the west within the area studied. The regular nature of the isopach and the small variations in thickness of this marine formation are a contrast to the irregular nature of the isopach of the non-marine sediments shown in Figure 9C.

Structure

Structure contours drawn for the top of the "Kneehills Tuff zone" (Figure 9A) show the present extent and configuration of this marker. The sediments dip toward the west with increasing angle of dip in the southern part of the area mapped because of the increasing proximity to the mountain front. In the vicinity of Twp. 33, the "Kneehills Tuff zone" dips westward at a rate of about 35 feet per mile. To the south, in the vicinity of Twp. 10, the marker has a westward dip of about 95 feet per mile. The contours suggest a structural high just south of Twp. 25 which divides the area mapped into two basins.

The structure contour map drawn for the top of the Belly River Group, Figure 9B, is generally similar to the structure contour map of the "Kneehills Tuff zone". The contour lines again suggest two basinal areas but the relief on the structural high is very slight.

The division of this area into two basins with the trend of the northern contours being slightly north-east and the trend of the southern contours being approximately north reflects similar structures mapped on the First White Specks zone (Williams and Burk, 1964). These authors divide the Alberta basin into two portions with a shelf area, the Calgary platform, located in the same area as the structural high mapped in this report.

SUMMARY

This subsurface study has shown that:

(1) The "Kneehills Tuff zone", composed of the Battle and the Whitemud formations, can be traced in the subsurface by means of electric logs from Twp. 34 as far west as range 6 W5. to Twp. 4 as far west as Rge. 25 W4.

(2) The top of the "Kneehills Tuff zone" can be used as a datum for subsurface correlation throughout this portion of southern Alberta and is the only known reliable marker above the top of the Belly River Group.

(3) A structural high is present in the area just south of Twp. 24, Rge. 11, W5. which divides the area mapped into two basins similar to those mapped by Williams and Burk (1964).

(4) The St. Mary River Formation wedges northwards above the lower portion of the Edmonton Group, laterally interfingering with it. The northernmost extent of the St. Mary River Formation is in the vicinity of Twp. 16.

(5) The northernmost extent of the Blood Reserve Formation is in the vicinity of Twp. 13.

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PLATE I (E.J.W.I. 117643)

View northeast across valley of the Frenchman River. Exposures of the Whitemud Formation are conspicuous along the opposite side of the valley. Town of Eastend, Sask. lies below in the valley

PLATE II (E.J.W.I. 117636)

View showing the gradational contact between the Eastend Formation (E) and the lower member of the Whitemud Formation (W). Quarry No. 45, Eagle Butte, Alberta.

PLATE III (E.J.W.I. 1-9-66)

View looking west across the Red Deer River valley in Sec. 18, Twp. 34, Rge. 21W4. showing the Whitemud (W) and Battle (B) Formations in the canyon walls, Alberta.

PLATE IV (E.J.W.I. 4-8-64)

View looking north across Horseshoe Canyon, Red Deer River region, in Sec. 26, Twp. 28, Rge. 21W4. showing exposures of the Whitemud (W) and Battle (B) Formations. The Kneehills Tuff bed (KT) is represented by the light-grey weathering talus at the top of the Battle Formation, Alberta.

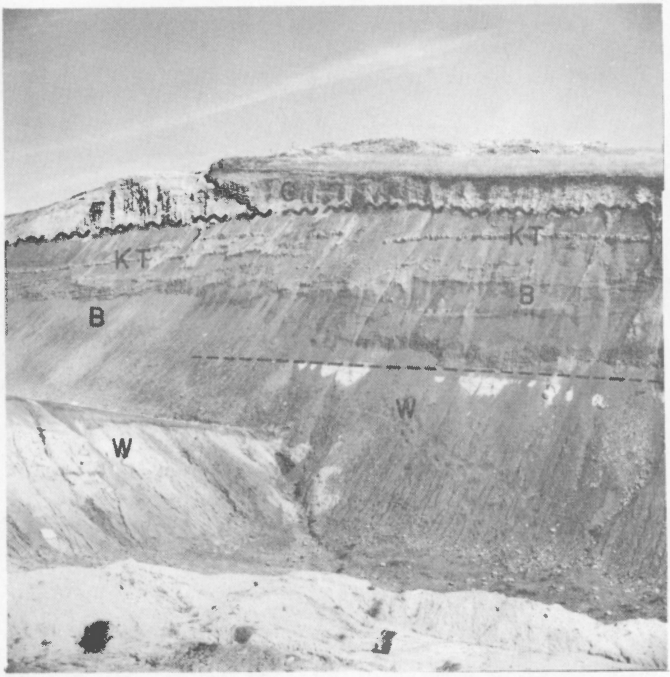

PLATE V (E.J.W.I. 2-10-66)

View showing the Whitemud Formation (W) - Battle Formation (B) contact; the Kneehills Tuff bed (KT); glacial gravel (G) overlying the partially eroded Battle Formation. Quarry No. 45, Eagle Butte, Alberta.

PLATE VI (E.J.W.I. 2-11-66)

View showing the Whitemud Formation (W) - Battle Formation (B) contact; the Battle Formation (B) with included Kneehills Tuff bed (KT) overlain unconformably by the Frenchman Formation (F) which, in turn, is overlian unconformably by a mixture of reworked Cypress Hills Formation gravel and glacial gravel (G). Quarry No. 45, Eagle Butte, Alberta.

APPENDIX

Well Location	Well Name	Kelly Bushing	Top "Kneehills Zone" (depth)	Top Bearpaw Formation (depth)	Top Belly River Formation (depth)
10-30- 4-25 W4	White Rose - Home - Western Blood 10-30	3623	1213	2447	3215
9-17- 5-25 W4	Western Blood 17-9	3498	771	1977	2776
1- 4- 7-24 W4	Blood Indian Reserve 1	3518	--	1362	2102
6-21- 7-25 W4	Royalite Sinclair Stand Off 6-21	3293	--	2053	2705
1-34- 8-25 W4	Sinclair Baysel Macleod Crown 1	3098	--	1422	2113
4-24- 8-26 W4	Sinclair Baysel Macleod 4-24-8-26	3298	996	2355	2960
13-25-10-25 W4	Bailey Pearce No 1	3136	--	1333	1890
2- 4-10-29 W4	Gulf Spring Point 2-4	4793	4553	6973	7348
15- 1-11-23 W4	Imp Nobleford 15-1-11-23	3286	--	639	1237
1-25-11-26 W4	Socony Granum 1	3258	--	1763	2363
15-35-12-24 W4	RI Smith Soc North Barons CPR 1	3164	--	1136	1716
8-10-13-24 W4	RI Smith Barons Crown No 1	3194	--	1185	1761
1-31-13-26 W4	C F P Stavely 1	3300	778	2213	2704
4- 8-13-27 W4	Sinclair E Mathew 1	3417	1363	3135	3646
6-30-14-25 W4	CPOG Carmangay 6-30-14-25	3213	--	2012	2515
16-11-14-28 W4	Baysel Stavely Syndicate No 16-11	3469	1762	3349	3908
11-32-14-28 W4	Texaco Baysel Pine Coulee A-11-32	3675	2032	3698	4213
5-12-14-30 W4	BA Bay Willow Creek 5-12-14-30	4163	3558	5538	6080
16-23-15-25 W4	Mobil CPR Parkland 16-23-15-25	3248	--	1848	2340
11-28-15-26 W4	CPOG Parkland 11-28-15-26	3280	880	2282	2781
6-27-15-27 W4	Banff et al Parkland 6-27-15-27	3411	1492	2812	3293
11- 7-15-28 W4	Texaco Baysel Parkland W 11-7-15-28	4180	2667	4384	4921
7-24-16-25 W4	Cancrude BA Vulcan 7-24-16-25	3444	--	1743	2247
6-10-16-26 W4	Cancrude Parkland 6-10-16-26	3260	888	2228	2707
6- 4-16-27 W4	Richfield Cal Standard Lind 6-4	3364	1197	2704	3168

Well Location	Well Name	Kelly Bushing	Top "Kneehills Zone" (depth)	Top Bearpaw Formation (depth)	Top Belly River Formation (depth)
11-12-16-28 W4	Banff Scurry Nanton 11-12-16-28	3364	1493	2959	3484
8-28-16-29 W4	Oil Well Operators et al Nanton 8-28	3593	2052	3797	4275
1- 4-17-25 W4	Cancrude et al Vulcan 1-4-17-25	3507	--	1827	2274
6-35-17-26 W4	CPOG C and E Brant 6-35-17-26	3274	--	1881	2347
10-20-17-27 W4	Jeff Lake Oxy Cayley E 10-20-17-27	3395	1210	2687	3171
10-32-17-28 W4	Jeff Lake Oxy Cayley 10-32-17-28	3436	1647	3145	3585
11-25-17-29 W4	Texaco C and E Cayley 11-25-17-29	3558	1861	3393	3802
10- 2-18-25 W4	Cancrude C E Ensign 10-2-18-25	3393	--	1463	1908
7-21-18-26 W4	HB New Superior Brant 1	3283	--	2040	2471
11-35-18-27 W4	HB Blackie 1	3357	--	2170	2599
10- 2-19-25 W4	Pure TPC and O Herronton 10-2-19-25	3402	--	1557	1971
11-29-19-26 W4	RO Corp Med Herronton 11-29-19-26	3442	--	2075	2507
10-28-19-27 W4	Apache et al Mazeppa 10-28-19-27	3389	977	2594	2983
10-23-19-28 W4	Canso et al Mazeppa 10-23-19-28	3350	1123	2790	3154
11-12-20-26 W4	N Can N Pac Selbay Twin Dome 1	3559	--	2114	2493
10-21-20-27 W4	Kiss et al Shell Gladys 10-21-20-27	3651	965	2695	3050
13- 3-20-28 W4	White Rose et al Okotoks 13-3-20-28	3432	1090	2803	3184
13- 8-20-28 W4	Pamoil Aldersyde 13- 8-20-28	3425	1247	2913	3306
10-31-20-28 W4	Christie Mit Damon Okotoks 10-31	3399	1090	2807	3197
7-10-20-29 W4	WR Security Aldersyde 7-10-20-29	3697	1761	3548	3880
10- 1-20- 1 W5	Texaco Longview 10-1-20-1	3676	1767	3692	4043
11-15-21-26 W4	White Rose et al Dale 11-15-21-26	3312	--	1967	2307
1-19-21-28 W4	Shell Mackid 1	3494	1038	2683	3037
10-16-21-29 W4	Shell Bice No 1	3645	1300	3178	3498

16-33-21- 1 W5	Union KCY - HB Twin Dome 16-33-21-1	3764	1347	3584	3725
13-13-22-27 W4	Honolulu Mobil Oil CPR Daleme 13-13	3351	716	2176	2532
11-33-22-28 W4	Kerr McGee Indus 11-33-22-28	3373	924	2458	2798
16- 8-22- 1 W5	HB Twin Dome 1	3719	1374	3490	3754
2-14-22- 2 W5	HB Calvan Lloyd Lake 2-14-22-2	3804	1670	4103	4332
10-27-23-26 W4	Grt Plains CPOG Cheadle 10-27-23-26	3288	--	2007	2356
1- 3-23-27 W4	Sun Langdon C.P.R. 1	3323	788	2244	2621
10-15-23-28 W4	Triad Sun Shepard 10-15	3375	1002	2515	2814
8-12-23-29 W4	Canpet Shepard 8-12-23-29	3353	eroded	2713	2941
10-14-23- 1 W5	A N D 1	3429	eroded	3080	3336
10- 7-24-27 W4	CPOG Canpet Cross 10-7-24-27	3353	877	2520	2697
10- 2-24-28 W4	Banff Dea Chestermere 10-2-24-28	3383	948	2619	2883
11-18-24-28 W4	Mobil Canamerican Chestermere 18-11	3476	1294	2942	3187
6- 2-24-29 W4	Canpet AP Con Calg Cross 6-2-24-29	3447	eroded	2953	3163
6-20-25-28 W4	Jeff Lake Mobil Cross 6-20-25-28	3532	1413	3014	3264
11- 1-25-29 W4	Jeff Lake CPR Calgary 11-1-25-29	3601	1483	3130	3367
6-33-25-29 W4	Jeff Lake et al Cross 6-33-25-29	3565	1603	3270	3514
8-26-25- 1 W5	Canpet et al Calg Cross 8-26-25-1	3527	1566	3304	3556
9-22-25- 2 W5	Western Bearpaw 22-9	4137	2358	4232	4451
11- 3-25- 3 W5	Fina Triad Calvan Bearpaw 11-3	3917	2517	4610	4914
11-36-25- 3 W5	Triad Shell Glenbow 11-36	4286	2819	4723	5004
3- 5-26-27 W4	Mobil Oil CPR Delacour 5-3	3275	973	2528	2767
6-20-26-28 W4	Jeff Lake CPR Cross 6-20-26-28	3635	1488	3154	3396
7-25-26-29 W4	Jeff Lake et al Cross 7-25-26-29	3629	1549	3247	3510
16- 3-26- 1 W5	Ang Amr Grid Balzac 16-3-36-1	3631	1747	3451	3685
7-22-27-27 W4	Osborn Mobil CPR Irricana 7-22-27-27	3200	954	2505	2667
10- 8-27-28 W4	Jeff Lake et al Cross 10-8-27-28	3655	1617	3243	3378
7- 3-27- 1 W5	Climax Alcon et al Airdrie 7-3-27-1	3680	1936	3593	3813
10-11-27- 2 W5	Triad et al Cross 10-11-27-2	4041	2473	4237	4386
10- 2-27- 3 W5	Continental et al Lochend 10-2-27-3	4184	2815	4663	4938
10-28-27- 3 W5	Dome Provo Shell Lochend 10-28-27-3	4161	3000	--	5096
6-25-28-28 W4	Osborn C and E Irricana 6-25-28-28	3266	1222	2772	3058
11-35-28-29 W4	Pan Am CE E 1 Cross 11-35-28-29	3470	1629	3282	3531
10- 2-28- 1 W5	Pan Am Purvis Cross 10-2-28-1	3586	1765	3487	3719

Well Location	Well Name	Kelly Bushing	Top "Kneehills Zone" (depth)	Top Bearpaw Formation (depth)	Top Belly River Formation (depth)
16-15-28- 2 W5	Baysel Shell Cross 16-15-28-2	3879	2367	4109	4348
10- 5-28- 3 W5	LaBorde Lochend	4124	3006	5059	5136
14-30-29-26 W4	Jackson 14-30	3171	947	2444	2648
6-23-29-29 W4	C and E Cross E 6-23-29-29	3405	1623	3224	3491
7-15-29- 1 W5	C and E Cross E 7-15-29-1	3605	1920	3573	3837
1- 4-29- 2 W5	Tenn D-1 Crossfield 1-4-29-2	3920	2463	4188	4355
6-26-29- 3 W5	Can Am Penwa Crossfield 6-29-29-2	3702	2397	4232	4386
10-15-29- 4 W5	Suptst et al Dogpound 10-15-29-4	3995	3056	4997	5198
10-20-30-27 W4	H.B. Texaco Olds 10-20-30-27	3126	1087	2592	2840
10-16-30-28 W4	H.B. Olds 10-16-30-28	3302	1388	2932	3181
6- 8-30- 1 W5	Pan Am Shell A-1 Carstairs 6-8-30-1	3487	1894	3559	3812
7-28-30- 2 W5	Triad Uno Tex Carstairs 7-28-30-2	3583	2249	3948	4202
6- 2-30- 3 W5	Cree Cego Carstairs 6-2-30-3	3557	2290	4094	4331
6-20-30- 4 W5	Can Sup O.W.O. Crown Coleman 6-20	3844	2933	4975	5138
9-29-31-25 W4	Cree Banff H B Allingham 9-29	3230	914	2380	2601
7-30-31-26 W4	Hudsons Bay Green Burns Lake 1	3182	1062	2501	2733
10- 3-31-27 W4	H B et al L Pine Ck 10-3-31-27	3069	1056	2484	2676
6- 4-31-28 W4	H B Olds 6-4-31-28	3227	1398	2964	3173
10-20-31- 1 W5	Amerada Cr Unit Olds 10-20-31-1	3376	1834	3450	3646
6- 6-31- 2 W5	Triad Uno La Westcott 6-6-31-2	3517	2177	4010	4230
11- 6-31- 3 W5	Great Plains et al Elkton No. 11-6	3707	2675	4669	4744
10-33-31- 4 W5	Shell et al Harm 10-33-31-4	3542	2579	4394	4600
10-34-32-26 W4	Shell H.B. Wimborne 10-34-32-26	3053	834	2284	2470
10-13-32-27 W4	W Rose Plymouth H B Stewart Lk. 10-13	3102	976	2455	2651
16-21-32-28 W4	Hudsons Bay Lone Pine No. 1	3202	1385	2887	3063

10-20-32- 1 W5	Amerada Cr. Unit Olds 10-20-32-1	3437	1891	3507	3699
8-30-32- 2 W5	Shell Cdn Sup Barrie Lk. 8-30-32-2	3485	2166	3934	4078
11-20-32- 3 W5	Great Plains E in 11-20-32-3	3480	2377	4078	4257
11-22-32- 4 W5	Amerada Crown E J Harm 11-22-32-4	3639	2645	4456	4626
1- 4-33-26 W4	Wh. Rose Marathon Wim 1-4-33-26	3030	842	2228	2486
10-23-33-27 W4	Tenn A 1 Mayton 10-23-33-27	3176	1138	2565	2793
16-21-33- 1 W5	Altair Security Netook 16-21-33-1	3381	1810	3347	3608
12-24-33- 2 W5	H B et al Netook 12-24-33-2	3330	1817	3454	3693
15-33-33- 3 W5	Shell Westerdale C and E A-15-33	3411	2253	3977	4210
9- 5-33- 4 W5	H B Home Oil West Ho No 9-5-33-4	3590	2733	4489	4650
7-27-33- 5 W5	H B Sundre 7-27-33-5	3576	2915	4760	4923
16-23-33- 6 W5	Shell Can Superior Lobley A-16-23	3924	3378	5423	5620
6-15-34-26 W4	B A CPR Smith 6	3181	992	2372	2501
10-22-34-27 W4	C D R et al Davey Lake 10-22-34-27	3177	1145	2555	2790
12-19-34-28 W4	C E Nisbet 12-19-34-28	3195	1467	2937	3107
6-12-34-29 W4	C D P et al Bowden 6-12-34-29	3317	1587	3111	3326
10- 2-34- 1 W5	Grt. Plains H.B. Netook 10-2-34-1	3282	1633	3157	3311
16-32-34- 2 W5	C S et al Red Lodge A 16-32-34-2	3119	1734	3348	3603
6- 6-34- 3 W5	Dekalb Garr S 6-6-34-3	3538	2450	4125	4279
11-33-34- 4 W5	H B Garrington 11-33-34-4	3497	2568	4225	4410
6-29-34- 5 W5	Altana Sundre North 6-29-34-5	3681	3067	5043	5130
11-36-34- 6 W5	Altana H B Caroline 11-36-34-6	3822	3285	5150	5394