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LITHOSTRATIGRAPHY OF THE UPPERMOST CRETACEOUS (LANCE) AND PALEOCENE STRATA OF THE ALBERTA PLAINS

by

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ABSTRACT

In Alberta relatively undisturbed nonmarine Cretaceous and Paleocene strata are preserved as a westerly dipping homoclinical wedge of sediment east of the Rocky Mountain Foothills, analogous to the molasse facies bordering the European Alps. This report describes the lithology of the uppermost Cretaceous and Paleocene beds overlying a thick widespread volcanic ashfall (Kneehills Member of the Edmonton Formation) which was deposited 65 million years ago. The post-Kneehills strata of the Alberta Plains are of considerable interest, for during their deposition thick beds of coal were formed, the Rocky Mountains began to emerge and dinosaurs became extinct.

The nomenclature of the post-Kneehills strata is revised by placing the lower boundary of the Paskapoo Formation at the top of the Kneehills Member of the Edmonton Formation in central Alberta and by lowering the base of the Ravenscrag Formation to the top of the Battle Formation in southeastern Alberta. The redefined Paskapoo and Ravenscrag Formations thus become equivalent to the Willow Creek Formation of southwestern Alberta and now include the Lance-equivalent beds and the Cretaceous - Tertiary transition. Evidence is presented to show that the Porcupine Hills Formation is much more extensive than formerly mapped and that it overlies the Paskapoo Formation in the vicinity of the Bow River. This discovery dates the thrust-folded foothills structures as an intra-Paleocene event.

Analysis of the cross stratification in the post-Kneehills strata indicates that a significant change in paleoslope took place between the deposition of the Paskapoo and Porcupine Hills Formations. A shift in the source area from a dominantly volcanic terrain in the interior of British Columbia in late Cretaceous and early Paleocene time to a dominantly sedimentary terrain in northern Montana during late Paleocene time is postulated to account for the change in detrital composition of the sandstones with time.

Most of Upper Cretaceous and Paleocene sandstones are subgreywackes or greywackes. Sandstones of the Paskapoo and Ravenscrag Formations are composed of detrital quartz, chert, volcanic and non volcanic rock fragments, and minor amounts of clastic carbonates. The heavy mineral assemblage is dominated by first-cycle grains of euhedral biotite, zircon, apatite, epidote and hornblende. Most common among a rich and varied series of intergranular authigenic minerals are clay minerals (montmorillonite, chlorite, kaolinite), zeolites (clinoptilolite) and carbonates (calcite). However, the bulk chemical composition of these sandstones is remarkably uniform, the most notable feature being the high alumina content and the predominance of soda over potash.

The Porcupine Hills Formation sandstones are composed of detrital quartz, chert, nonvolcanic rock fragments and clastic carbonates. The heavy mineral assemblage is a residual suite of small abraded grains of zircon, tourmaline and apatite. In contrast to the Paskapoo and Ravenscrag Formations, only three common intergranular mineral cements are present; quartz kaolinite and calcite. The bulk chemical composition of the Porcupine Hills Formation sandstone is characterized by a low alumina and high lime contents, and the predominance of potash over soda.

INTRODUCTION

In the Plains of central and southern Alberta, the upper part of the Cretaceous and the overlying Paleocene sections consist of a thick succession of nonmarine strata which has been divided into a number of mappable units. In the southern Plains and adjacent Foothills three formational units are recognized on the basis of differences in gross lithology. However, in the central Plains, where exposures are generally poor, and the gross lithology of the beds is more similar, the only subdivision of the near-surface bedrock succession that can be consistently made is based upon the presence of a thin but widespread tuffaceous, bentonitic interval 20 to 50 feet thick, variously known as the "mauve shale", or "member D" of the Edmonton Formation (Ower, 1960). Thin silicified layers of diagenetic origin within this interval have been called the "Kneehills tuff" (Sanderson, 1931), it is for this reason that the unit is referred to as the Kneehills Member in this report.

This report deals with the lithology of the strata overlying the Kneehills Member in the Alberta plains (Fig. 1). The distribution of these strata is shown on Map 32 (in pocket). The largest area underlain by these rocks covers 36,000 square miles marginal to the Rocky Mountains on the southwest, extending from a few miles below the International Boundary northward for a distance of about 500 miles to latitude 55 degrees. It varies in width from a few miles in the south to about 140 miles in north-central Alberta, narrowing to zero again near the Alberta-British Columbia boundary in the north. Outliers of correlative strata are f‹ ‹und in the Hand Hills in east-central Alberta and in the Cypress Hills straddling Alberta-Saskatchewan boundary 40 miles north of the United States border.

The post-Kneehills strata[1] of the Alberta Plains have a homoclinal structure, dipping 30 feet per mile to the west beneath a land surface sloping at an average of 10 feet per mile to the east (Figs. 2, 3). The strata thus form a wedge of sediment which thickens uniformly to the west to where it is abruptly cut off by thrust faults. West of this boundary Mesozoic and Tertiary strata are deformed into a complex series of thrust-folded structures which form a belt about 25 miles wide in front of the Rocky Mountains. In subsequent discussion the area underlain by the homoclinal strata is referred to as the Plains and the disturbed belt is called the Foothills.

The post-Kneehills strata of Alberta are of considerable economic and academic interest, for during their deposition thick beds of coal were formed, the Rocky Mountains began to emerge and dinosaurs became extinct. This last-named fact has encouraged geologists to search for the Cretaceous-Tertiary boundary within these strata and has resulted in a great deal of confusion between time units and rock units in this succession of beds. It is one of the objectives of this study to redefine

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[1]The term "post-Kneehills" as used in this report encompasses the extensive uppermost Cretaceous and lower Tertiary rock units of the Alberta plains, but not the several Tertiary units, largely gravel, capping the Cypress and Hand Hills, and other similar erosional remnants.

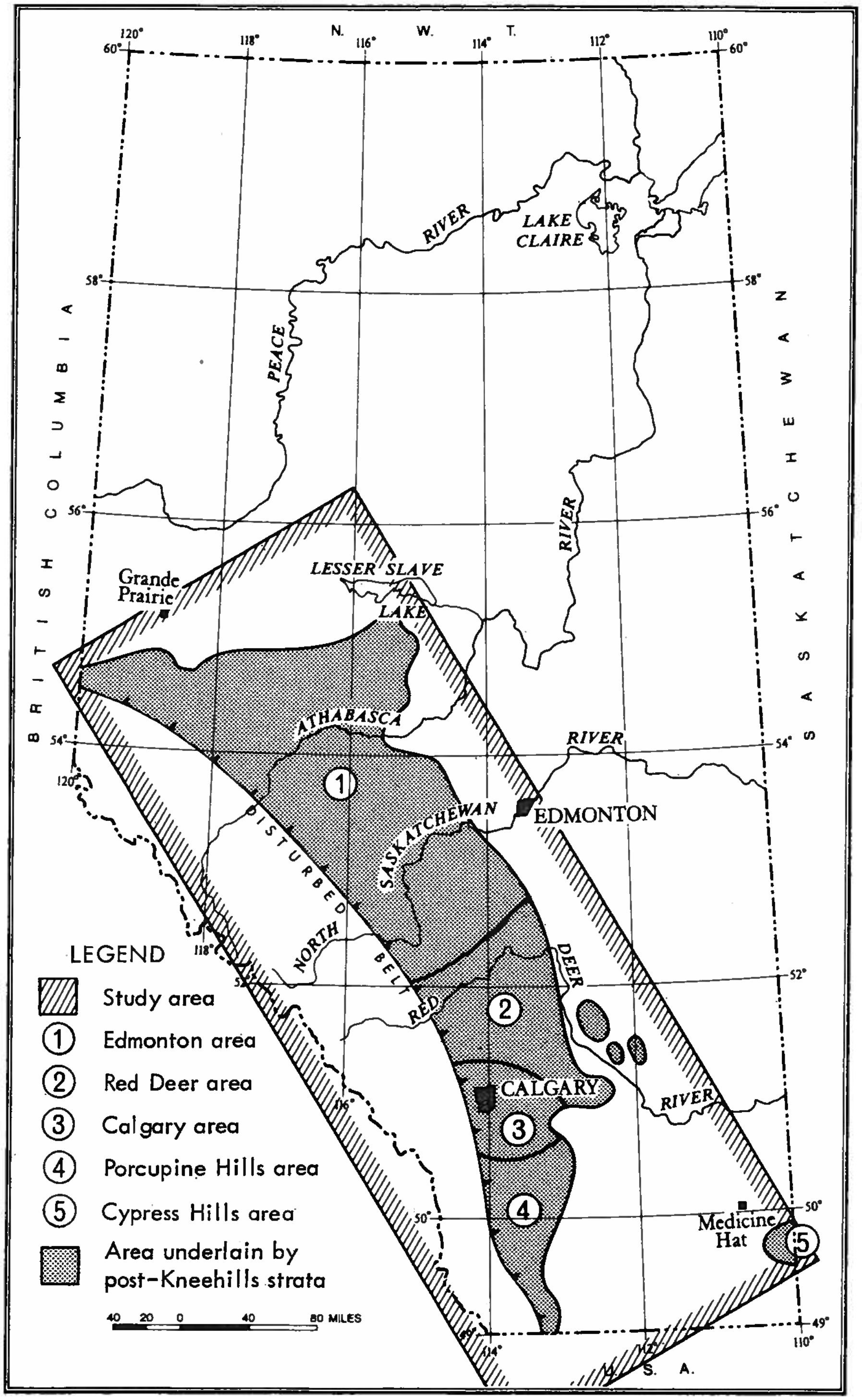


FIGURE 1. Location of the region studied.

the boundaries of the rock units above the Kneehills Member in conformity with the code recommended by the American Commission on Stratigraphic Nomenclature (1961). The other objective is to relate changes in lithology within the succession of beds to the emergence of the Rocky Mountains.

Sampling Locations

Most of the sandstone samples for this study were taken from outcrops of post-Kneehills rocks south of the Athabasca River (Map 32). Only two samples were obtained from the area north of this river. The large area underlain by post-Kneehill rocks south of the Athabasca River has been divided for convenience into smaller areas to facilitate discussion of the petrographic data in relation to the local stratigraphy (Fig. 1). The Edmonton area includes the upper parts of the North Saskatchewan and Athabasca River drainage basins. Similarly, the Red Deer area covers the upper part of the Red Deer River drainage system, and the Calgary area the upper part of the Bow River drainage basin. The Porcupine Hills area includes all the post-Kneehills strata of the Plains south of the Calgary area and is dominated by the Porcupine Hills, which rise to an elevation of nearly 6,000 feet adjacent to the Foothills. The Cypress Hills area refers to the high plateau area in southeastern Alberta and adjacent Saskatchewan underlain by strata of late Cretaceous and Tertiary ages. The locations of the outcrop samples are listed in appendix B. In addition to the geographic coverage obtained through outcrop sampling, stratigraphic control was provided by a core drilling program. Two coreholes were drilled in central Alberta to depths of 507 and 1,000 feet, respectively, and additional core material was obtained through damsite investigation surveys.

The first corehole was drilled in 1965 to a depth of 507 feet; it is located on a high bedrock ridge 32 miles southwest of Edmonton, near the northwest end of Wizard Lake (Map 32). The drill entered the Kneehills Member at a depth of 321 feet and penetrated another 180 feet into the Edmonton Formation. The well was drilled to provide information on the Edmonton-Paskapoo contact and to obtain a suite of rock samples across the inferred location of the Cretaceous-Tertiary boundary for palynological examination. A list of sample locations from this well is given in appendix B and a lithologic log in appendix C.

The second corehole is located on an outcrop of the Porcupine Hills Formation about 9 miles north of the City of Calgary (Map 32) and was drilled to get information on the boundary between the Porcupine Hills and Paskapoo Formations. Unfortunately, this boundary was not crossed before the projected depth of 1,000 feet was reached; data from logs of nearby oil wells indicate that the hole finished approximately 600 feet above the Kneehills Member. A list of sample locations for this well is given in appendix B and a lithologic log in appendix C.

Some core recovered from a series of shallow holes drilled during the preliminary investigation of a potential damsite on the McLeod River was made available to the Research Council by the Water Resources Division of the Alberta Department of Agriculture. These holes were drilled in the valley of the McLeod River, 11 miles southwest of the town of Whitecourt (Map 32). Locations of samples are given in appendix B and the lithologic logs in appendix C.

Previous Work

The foundation of our knowledge of the geology of the uppermost Cretaceous and Paleocene strata in the Alberta Plains was provided by the publication of G.M. Dawson's (1883) observations on the geology of the Bow and Belly Rivers region in southwestern Alberta. Soon after R.G. McConnell (1885) published a remarkably accurate map of the Cypress Hills area, which included a cross section of post-Kneehills strata known today as the Frenchman, Ravenscrag, and Cypress Hills Formations. As settlement progressed and more accurate topographic maps became available, a series of detailed geological surveys were made of the southern Plains of Alberta and Saskatchewan. The results of these surveys are reported in publications of the Geological Survey of Canada by Dowling (1917), Williams *et al.* (1928), Williams and Dyer (1930), Fraser *et al.* (1935), Russell and Landes (1940), and Furnival (1946). The most recent account of the geology of this region is given in the Guidebook to the Cypress Hills area prepared for the Fifteenth Annual Field Conference of the Alberta Society of Petroleum Geologists (Zell, 1965; Crockford and Clow, 1965; Irish, 1965). An interpretation of the structural relationships between the strata of the Plains and Foothills in southern Alberta based on geophysical and drilling data is given by Bossort (1957).

In central Alberta where the glacial drift is thicker, outcrops less numerous and formation boundaries more obscure, slower progress has been made. In 1887, J.B. Tyrrell published a geologic map and a full description of the sedimentary strata of central Alberta. Subsequent field mapping in this area was conducted mainly by members of the Department of Geology, University of Alberta, and results published in reports of the Research Council of Alberta and the Geological Survey of Canada (Allan, 1919; Rutherford, 1928, 1939a, b, c; Allan and Sanderson, 1945).

Since the discovery of the Leduc oilfield in central Alberta in 1947, many hundreds of wells have been drilled through nonmarine upper Cretaceous and Tertiary strata. In spite of this activity, few samples or cores of these strata are available for study, and little attention has been given to these rocks by oil company geologists. However, many electric and radioactivity logs of the beds below well-casing depths of approximately 600 feet are available and, from these, it is possible to establish that the Kneehills Member exhibits a characteristic response on the mechanical logs which can be recognized in wells over most of the Plains area. On this basis, using the Kneehills Member as a marker bed, Elliot (1960) and later Irish and Havard (1968) constructed structure contour maps which show that the Upper Cretaceous and Tertiary strata in front of the Foothills are preserved in a thrust-faulted, homoclinal structure (Fig. 2). At the same time Ower (1960) re-examined the classic outcrop sections of the Edmonton Formation along the Red Deer River in east-central Alberta and divided the formation there into five members which he correlated via intervening subsurface sections with exposures along the North Saskatchewan River. Some of the units he defined have been included on preliminary maps of the Plains area prepared by the Geological Survey of Canada (Irish, 1967; 1968 a, b, c). Campbell (1962) also has discussed the boundaries of the Edmonton and Paskapoo Formations in central Alberta, basing his findings partially on subsurface data.

The western boundary of the Tertiary strata of the Plains has been mapped in detail at a number of places by the Geological Survey of Canada (Hume, 1931, 1942, 1949; MacKay, 1939; Hume and Hage, 1941; Hage, 1945; Lang, 1947; Irish, 1947; Douglas, 1950; Erdman, 1950).

Comprehensive accounts of the geological history of the Upper Cretaceous and Tertiary rocks of Western Canada are given by Williams and Burk (1964) and Taylor *et al.* (1964).

Correlations between nonmarine rocks of Late Cretaceous and Tertiary age of Western North America have been based largely on vertebrate remains. The results of studies of vertebrate fossils in the Cretaceous-Tertiary strata of Western Canada are found in publications of Russell (1926a, 1928, 1929a, 1930a, b, 1932b, 1940, 1948, 1951, 1957, 1965a), Simpson (1927), Sternberg (1947, 1950, 1951), Clemens and Russell (1965), and Lillegraven (1969). Freshwater invertebrate fossils also are abundant in the Upper Cretaceous and Tertiary rocks of Alberta, but they are of less stratigraphic value than the vertebrates. Nevertheless, large invertebrate fossil collections have been made and numerous publications on this subject are available: Whiteaves (1885, 1887), Russell (1926b, 1929b, 1931), Warren (1926), and Tozer (1953). Freshwater algal and ostracode fossils in the Willow Creek and Porcupine Hills beds have been studied by Germundson (1965). Fossil leaves and plants have been identified by Berry (1926, 1935) and Bell (1949). Recently, palynological investigations of strata at or near the Cretaceous-Tertiary transition in central Alberta have been made by Srivastava (1967) and Snead (1969).

Little has been published on the petrography of the Cretaceous and Tertiary rocks of Alberta. Lerbekmo (1964) studied the distribution of heavy minerals in the Edmonton Formation outcrops along the Red Deer River valley and found hornblende and epidote to be rare below and abundant above the Kneehills Member. In the strata above the Kneehills Member epidote and hornblende were absent from the lowermost 100 feet (below the Ardley coal); epidote only was present in the next 100 feet or so of strata, and both epidote and hornblende were abundant in the sandstones above the upper Ardley coal. Lerbekmo (*op. cit.*) noted that the first appearance of epidote in this section coincided approximately with the Cretaceous-Tertiary time boundary, however, the more extensive data collected for this report (Fig. 20) suggest that the distribution of epidote and hornblende in the basal post-Kneehills strata is more erratic than previously suspected. The heavy minerals in equivalent strata in Saskatchewan were studied by Fraser *et al.* (1935), and some features of the authigenic cements of the Alberta sandstones were investigated by Carrigy and Mellon (1964). Recently, Nelson (1968) made a petrographic study of the St. Mary River, Willow Creek and Porcupine Hills sandstones in the Gulf Spring Point 2-4 well. Radiometric age dating of the Kneehills Member has been attempted by Ritchie (1960) and Folinsbee *et al.* (1961, 1965).

Studies of the economic potential of post-Kneehills rocks are included in reports of the Canada Department of Mines and the Research Council of Alberta. The suitability of the sandstones for building purposes was investigated by Parks (1916), and the clay resources of the Cypress Hills area were surveyed by Crockford (1951). Reports on the coal resources within the post-Kneehills strata of the Plains have been published by Pearson (1959, 1960), Campbell and Almadi (1964), and Campbell (1967). In the Foothills, partly correlative strata were mapped by Allan and Rutherford (1923, 1924) and Rutherford (1925, 1926, 1927, 1928).

The groundwater potential of areas underlain by the Porcupine Hills and Paskapoo Formations has been evaluated by Farvolden (1961), Meyboom (1961), Jones (1962), and Tóth (1966, 1968).

Acknowledgments

Field work for this study was begun in 1961 in the Porcupine Hills of southern Alberta and was extended northward until 1965. During this phase of the work, the writer was ably assisted by J.D. Adshead, A. Taube, R.W. Taubner, D.M. Hendrickson, R. Feser, and R.G. Snead. During the drilling of R.C.A. Corehole 66-1 P.F. Johnston gave valuable assistance.

Technical support was provided by staff members of the Research Council of Alberta. Data from the crossbedding measurements were reduced and analyzed on an IBM-1620 computer with a program written by P.J. Redberger. Miss L.L. Marsh computed the discriminant functions and other statistical data included in this report. Chemical analyses were performed under the direction of H.A. Wagenbauer, and the maps and diagrams were drafted under the supervision of S.J. Groot. X-ray work was efficiently performed by N.E. Andersen. The boundaries of the Kneehills Member shown on Map 32 were taken from a draft of a geological map of Alberta, prepared by R. Green.

Core material from the McLeod River Damsite was made available by the Water Resources Division of the Department of Agriculture.

G.B. Mellon brought the problem to the writer's attention and has given support and advice since its inception.

All this help and support is gratefully acknowledged.

STRATIGRAPHY

Terminology

The first subdivision of the Upper Cretaceous and Tertiary strata of the Alberta Plains was made by G.M. Dawson (1883). Dawson gave the name "Porcupine Hills series" to the massive crossbedded sandstones with scattered shaly layers that outcrop in the Porcupine Hills of southern Alberta, naming the underlying beds which outcrop extensively in the plains surrounding the Porcupine Hills the "Willow Creek series" (Table 1). Both series, together with the underlying "St. Mary River series", were correlated with beds of Laramie age in western United States.

In central Alberta, Tyrrell (1887) proposed the name "Paskapoo series" for the beds overlying the "Edmonton series", placing the lower boundary of the Paskapoo series at the top of the "big coal seam" which outcrops in the Red Deer River valley about the middle of range 24, west of the 4th meridian, and in the North Saskatchewan River valley near Goose Encampment in range 4, west of the 5th meridian. Tyrrell based his subdivision of the strata on the thesis that the Edmonton beds are a coal-bearing series containing dinosaur remains, and therefore of Cretaceous age, whereas the overlying Paskapoo series is non-coal-bearing and non-dinosaur-bearing, and therefore Tertiary in age. Tyrrell correlated the Paskapoo with Dawson's Porcupine Hills and Willow Creek series and all but the lowest 700 to 900 feet of the St. Mary River series.

One of the most useful contributions to the Upper Cretaceous stratigraphy of the Alberta Plains was the recognition of a widespread volcanic "ash" bed in the upper part of the Edmonton Formation (Sanderson, 1931). Sanderson traced this bed, which he called the Kneehills tuff, from the vicinity of Drumheller to Ardley in the Red Deer River valley and also recognized it in the Cypress Hills, 160 miles to the southeast. The "tuff" is hard, microcrystalline, siliceous bed or beds seldom more than 9 inches thick intercalated among bentonitic brown shales at the top of Allan and Sanderson's (1945) "middle member" of the Edmonton Formation.

Allan and Sanderson (1945) divided the Edmonton outcrops along the Red Deer River valley into three informal members: an "upper member", with a thickness of 200-240 feet, extending from about 100 feet above the "big coal seam" of Tyrrell (1887) to the top of the dark shale carrying the Kneehills tuff; a middle member, with a thickness of 300 feet, extending from the top of the dark shale to the top of the Drumheller marine tongue; and a "lower member", 600 feet thick, which includes all of the strata between the top of the Drumheller marine tongue and the marine Bearpaw shale.

It was not until 1960 that the Edmonton Formation was re-examined in the field and subdivided into five members (Ower, 1960). In this subdivision a "Kneehills tuff zone" is defined and called "member D"; this unit comprises the dark bentonitic shale enclosing the tuff, as well as locally intercalated basal white shales and shaly sandstones. That part of the Edmonton Formation above the zone and below the Paskapoo Formation is called "member E" (Table 1). Members A to

Table 1. Summary of Terminology of Upper Cretaceous and Lower Tertiary Strata in the Alberta Plains

SOUTHEASTERN ALBERTA (CYPRESS HILLS)			SOUTHWESTERN ALBERTA		CENTRAL ALBERTA		
McConnell (1886)	Davis (1918)	Furnival (1946)	Dawson (1883)	Tozer (1956)	Tyrrell (1887)	Allan and Sanderson (1945)	Ower (1960)
Miocene Conglomerate	Cypress Hills	Cypress Hills			Miocene Conglomerate	Hand Hills Conglomerate	
			LARAMIE: PORCUPINE HILLS	PORCUPINE HILLS			
LARAMIE	RAVENSCRAG	RAVENSCRAG	LARAMIE: WILLOW CREEK	UPPER WILLOW CREEK	PASKAPOO	PASKAPOO	PASKAPOO
		FRENCHMAN		LOWER WILLOW CREEK	EDMONTON	EDMONTON: Upper Member	EDMONTON: Member E
	WHITEMUD	BATTLE		ST. MARY RIVER: BATTLE			
				ST. MARY RIVER: Kneehills Tuff		EDMONTON: Kneehills Tuff	EDMONTON: Kneehills Tuff
		WHITEMUD	LARAMIE: ST. MARY RIVER	ST. MARY RIVER: WHITEMUD		EDMONTON: Middle Member	EDMONTON: Member D

C are found below the tuff zone and need not be considered further in this report.

In the Cypress Hills of the southern Plains, the Laramie beds of McConnell (1885) were named the Ravenscrag Formation by Davis (1918), which subsequently was divided into upper and lower units (Fraser *et al.*, 1935). Furnival (1946) proposed the name Battle Formation for the dark brown bentonitic shales of the upper unit containing the Kneehills tuff of Sanderson (1931) and suggested the name Frenchman Formation for the lower Ravenscrag of Fraser *et al.* (*ibid*).

The history of the terminology of post-Kneehills strata in the Alberta Plains is summarized in table 1.

In the Foothills and western Plains regions, where the Kneehills marker bed has not yet been recognized, only a rough approximation of the strata equivalent to the post-Kneehills beds of the central Plains can be made. In the central Foothills they were called the Saunders Group by Allan and Rutherford (1923). However, apparently no literature exists to support the application of the name "Saunders Group" to strata along the Embarras and McLeod Rivers, as shown on the 1951 geological map of Alberta (Geol. Surv. Can., 1951). This usage appears to be a compromise in the resolution of an error in earlier mapping of this area (Rutherford, 1928) in which the strata in question were placed in the Edmonton Formation. These rocks are now known to belong to the upper part of the Paskapoo Formation.

Descriptions of Formations

Southwestern Alberta

St. Mary River Formation

The St. Mary River Formation lies between the marine Bearpaw Formation and the nonmarine Willow Creek Formation, outcropping in southwestern Alberta in the St. Mary and Oldman River valleys. It is 1500 feet thick on the Oldman River in the Plains, and 2,500 feet thick in the Foothills to the west. The formation consists of alternating greenish sandstones and siltstones. The sandstones are medium-grained, massive rocks with a calcite cement, and the siltstones are soft and poorly bedded. The molluscan fauna is distinctive, indicating deposition in fresh and brackish water environments (Russell and Landes, 1940).

The St. Mary River Formation is correlated with the pre-Kneehills portion of the Edmonton Formation by Tozer (1956). Tozer also found the Whitemud- and Battle-equivalent beds of the Cypress Hills section in the St. Mary River Formation outcrops on the Oldman River and subsequently placed the upper boundary of the formation in the Plains at the top of the Battle-equivalent beds.

Willow Creek Formation

The Willow Creek Formation outcrops in the southwestern Alberta Plains from the Alberta - Montana border north to township 14 (Map 32). It consists of interbedded bentonitic shale and soft sandstone. The lower part of the formation is predominantly shale with sandstone beds becoming more numerous and thicker in the upper part. The bentonitic shale contains small white calcite concretions and is mottled with a red coloration, giving the outcrops a characteristic appearance which serves to distinguish them from the overlying and underlying formations. The lower boundary of the Willow Creek Formation is placed by Tozer (1952) at the top of Kneehills - equivalent (or Battle - equivalent) beds discovered by him in the Oldman River valley near the center of Sec. 25, Tp. 10, R. 25, W. 4th Mer. The upper boundary with the Porcupine Hills Formation appears to be transitional due to the similarity in lithology between sandstones above and below the assumed boundary. Structural and geophysical data, however, suggest that the contact is disconformable.

The Willow Creek beds have been deformed along the axis of an asymmetrical synclinal structure, with steeply dipping beds on the west side of the Porcupine Hills and gently dipping beds on the east side of the Hills (Fig. 3). Bossort (1957) cites geophysical and drilling data to show that the Willow Creek beds are cut by a low angle thrust plane which does not enter the overlying Porcupine Hills Formation (Fig. 3, Sec. J–K); this supports the field evidence of Douglas (1950) which showed an erosional contact between these two formations.

The thickness of Willow Creek strata as measured in outcrop varies from 4,135 feet in the Foothills on the west side of the Alberta Syncline (Tozer, 1953), to 1,200 feet on the flat-lying eastern limb (Russell and Landes, 1940). About 3,300 feet of Willow Creek strata were penetrated in the Gulf Spring Point 2 – 4 well drilled near the axis of the Alberta Syncline; 2,600 feet in the B.A. Willow Creek 5–12–14–30 well drilled 25 miles to the north; and over 2,000 feet in the Oilwell Operators *et al.* Nanton 8–28–16–29 well on the eastern limb. The well data does not support the contention of Douglas that the Willow Creek Formation thins rapidly to the north but suggests that it occupies a distinct structural basin, which is separated from the more northerly and larger structural basin occupied by the Paskapoo Formation. The sill or platform separating the two basins is in the Calgary-Bow River area where the Willow Creek-equivalent beds are thinnest (Map 32, Fig. 2). However, the change in lithofacies from Willow Creek to Paskapoo aspect seems to take place south of the structural divide, being evident in outcrops in the vicinity of the town of Nanton.

According to Tozer (1953), the Willow Creek Formation in the Foothills has two distinct molluscan faunas: the lower beds contain a Lance (uppermost Cretaceous) fauna and the upper beds contain a Fort Union (Paleocene) fauna. On the east side of the syncline, the lower Willow Creek beds are devoid of molluscan fossils.

Russell (1932a) believed the Willow Creek Formation to be thinner on the east side of the Alberta Syncline and the upper Cretaceous-equivalent beds missing there because no dinosaur remains had been found in the lower part of the formation. Later, Russell (1965b) attempted to reconcile the data by postulating a period of erosion between the deposition of the St. Mary River and Willow Creek beds.

However, both problems seem to have been resolved, the first by the drilling data mentioned above which indicates that the Willow Creek beds do not thin appreciably in an easterly direction, and the second by the discovery of dinosaur remains in the Willow Creek - equivalent beds in Montana, on the east side of the syncline (Russell, 1968).

Porcupine Hills Formation

The Porcupine Hills are a prominent topographic feature in southwestern Alberta rising from the Plains at an elevation of 3,300 feet to a maximum elevation of 5,800 feet. Outcropping extensively in these hills is a series of crossbedded sandstones and calcareous bentonitic shales called the Porcupine Hills Formation. In the Gulf Spring Point 2–4 well, located near the southern end of the hills at an elevation of 4,793 feet, the boundary between the Porcupine Hills and Willow Creek Formations was intersected at an elevation of 3,000 feet. In the B.A. Baysel 5–12–14–30 well, toward the northern end of the hills, the boundary is estimated to be at an elevation of 2,983 feet. In R.C.A. Corehole 66–1, 9 miles north of Calgary, the base of the formation is below 2,975 feet. The maximum preserved thickness of the formation is probably in the order of 3,000 feet, but because the upper boundary is an erosion surface, the original thickness cannot be determined.

Structurally, the Porcupine Hills beds form an asymmetrical syncline with 25 degree dips to the east on the western limb and low dips to the west on the eastern limb (Fig. 3). The boundary between the Willow Creek and Porcupine Hills beds is discussed in the preceding section; the evidence favors an erosional contact of undetermined magnitude.

In the type area the Porcupine Hills beds contain abundant freshwater molluscan remains of Paleocene age, which have been correlated with a similar assemblage in the upper part of the Paskapoo Formation by Tozer (1956). Dawson (1883) believed the beds in the Porcupine Hills to be equivalent to those outcropping in the Bow River valley near Calgary, whereas Tozer (1956) arbitrarily defined all Paleocene beds north of township 13 in western Alberta as Paskapoo, thus obscuring the true relationship between the Porcupine Hills and Paskapoo Formations. The recognition of the extension of the Porcupine Hills Formation to the area north of Calgary means that a reassessment of the paleontological data in this area will be necessary, for many of the vertebrate fossil localities in the vicinity of Calgary (Russell, 1929a) formerly assigned to the Paskapoo will now be in the Porcupine Hills Formation.

Southeastern Alberta

Frenchman Formation

The name Frenchman was given by Furnival (1946) to a crossbedded, medium - grained, sandstone unit, containing *Triceratops* remains, which is lithologically distinct from the overlying Ravenscrag beds in Saskatchewan. In Alberta no lithologic distinction between Frenchman- and Ravenscrag-equivalent beds is possible and the name should not be used for the lower Ravenscrag succession. There is an extensive unconformity at the base of the formation which brings these beds into contact with the Battle, Whitemud and Eastend Formations in different areas (McLearn, 1928).

Ravenscrag Formation

The Ravenscrag Formation outcrops in the Cypress Hills plateau of southeastern Alberta, where it consists of buff and grey, medium-grained, crossbedded sandstone. This lithology contrasts with the fine-grained, silty, carbonaceous beds of the type area on Ravenscrag Butte in southwestern Saskatchewan. In Alberta the Ravenscrag Formation contains molluscan remains of Paleocene age (Russell and Landes, 1940; Russell, 1965a).

Cypress Hills Formation

A bed of conglomerate capping the Cypress Hills plateau in Alberta and Saskatchewan has yielded vertebrate remains of early Oligocene age (Cope, 1891; Lambe and Osborn, 1902; Lambe, 1908; and Russell, 1934). The bed is relatively thin (50 to 100 feet) in Alberta but thickens to 250 feet or more to the east in Saskatchewan (Vonhof, 1965). The Cypress Hills Formation rests unconformably on the Ravenscrag Formation.

West-Central Alberta

Edmonton Formation

The Edmonton Formation underlies a large area in the central Alberta Plains, being best exposed along the North Saskatchewan River in the vicinity of the City of Edmonton, and along the Red Deer River valley in the vicinity of Drumheller. The formation varies in thickness from 1,100 to 1,700 feet, consisting of fresh- and brackish-water, fine-grained sandstones and silty shales, thick coal seams, and numerous bentonite beds. Siderite nodules and siderite-cemented beds are abundant, and the formation is renowned for its dinosaur remains. The lower boundary of the formation is diachronous and transitional with marine shales of the Bearpaw Formation, but the upper boundary with the lithologically similar Paskapoo Formation is poorly defined. Ower (1960) has divided the Edmonton Formation into five members labelled from A at the base to E at the top of the formation. The only units of Ower that are of concern here are members C, D and E.

The term Kneehills Member is applied to the 20 to 50 foot thick unit of black to brown, mauve-weathering tuff and tuffaceous shale called member D by Ower (1960), underlain by the white-weathering, light grey, argillaceous sandstones of member C, and overlain by bentonitic sandstones and greenish bentonitic shales of member E (Table 1). The unit is most widely recognizable on electric logs by its prominent smooth, lower than average resistivity curve, which contrasts with the higher resistivity of the usually accompanying sandstones.

"Kneehills tuff" was the term applied by Sanderson (1931) to the thin hard silicified tuff bands that are distributed through the poorly indurated tuff and tuffaceous shale of the Member; on the other hand Irish and Havard (1968) applied the term "Kneehills Tuff zone" to encompass both the dark tuff and tuffaceous shale unit and the underlying whitish argillaceous sandstone. Recognition of the volcanic ash nature of the Kneehills Member verifies its isochronous character and also accounts for its extremely wide distribution in the Alberta Plains region.

Both the overlying member E and the underlying member C contain sandstone units and bentonitic shales, as well as thick coal seams in many places. Member E contains the extensively developed Ardley Coal interval, and the lower part carries triceratopsian vertebrate faunas.

The upper boundary of the Edmonton Formation has been only obscurely defined; the resolution of this problem is essential for the clarification of the post-Kneehills stratigraphy of the Alberta Plains. Tyrrell (1887) placed the boundary between the Paskapoo and Edmonton Formations at the "big coal seam" on the North Saskatchewan and Red Deer Rivers, but subsequent work (Campbell, 1962) has revealed the presence of a rather diffuse coaly interval in this part of the section, and identification of the "big coal seam" is not always possible. This difficulty is even more pronouced to the south, on the Bow River, where coal seams are absent from apparently equivalent strata.

When mapping the Red Deer and Rosebud sheets in east-central Alberta, Allan and Sanderson (1945) used six physical criteria to separate the Edmonton from the Paskapoo Formation. They are:

(1) the widespread distribution and uniformity of Edmonton strata;

(2) the abundance of bentonite in the Edmonton Formation and absence of it in Paskapoo strata;

(3) the minutely and locally conglomeratic nature of the basal Paskapoo sandstone and its highly oxidized condition at the contact with the Edmonton Formation;

(4) the lower 300 feet of the Paskapoo Formation is composed predominantly of coarse quartzose sand, whereas the Edmonton is uniformly fine grained and the sands are feldspathic;

(5) the Edmonton strata weather in rounded slopes, whereas the Paskapoo (coarse-grained basal sandstones) form sheer cliffs;

(6) the color and degree of induration (or lithification) are different.

Using these criteria, Allan and Sanderson (1945) described the Edmonton-Paskapoo contact as a disconformity. However, Ower (1960) re-examined the localities listed by Allan and Sanderson where the disconformable contact could be observed and concluded that there is no evidence of widespread erosion of the Edmonton Formation beds before deposition of the Paskapoo Formation. Subsurface correlations (Elliot, 1960) also indicate that there was continuous deposition in the western Plains during late Cretaceous and Paleocene times.

The writer agrees with Ower's conclusion that there is no major single period of erosion within the post-Kneehills strata of the western Plains. The many minor disconformable contacts in these strata are typically associated with fluviatile continental sedimentation, in which channeling precedes deposition in an otherwise continuous succession, and the significance of these minor disconformities has been exaggerated. None of the six criteria for differentiating the Paskapoo from the Edmonton, listed by Allan and Sanderson (1945) has proved to be reliable for mapping purposes, it is for this reason that previous workers have failed to find a consistent lithological boundary between the Paskapoo Formation and the post-Kneehills portion of the Edmonton Formation.

The Edmonton Formation ranges in age from late Campanian through Maestrichtian.

Paskapoo Formation

The Paskapoo Formation, which overlies the Edmonton Formation in central Alberta, comprises a series of nonmarine sandstone, bentonitic shales, lignites, and conglomerate. It outcrops extensively in the area adjacent to the Rocky Mountain Foothills and forms the surface bedrock over a large area of the western Plains north of the City of Red Deer. The thickness varies from zero at the erosional edge in the Plains to 3,000 feet adjacent to the Foothills belt. The upper boundary of the formation is an erosion surface.

The Paskapoo Beds are preserved in an asymmetrical syncline or modified homocline (Figs. 2, 3). Steeply dipping Paskapoo strata have been observed at many places adjacent to the Foothills, but only low westerly dips are present over most of the Plains region.

The formation contains an abundant freshwater molluscan fauna together with fossil plants and mammalian vertebrate remains of Paleocene age.

Hand Hills Formation

A rock unit consisting of dark shales, marl, and thin conglomerate beds similar in appearance to the Cypress Hills Formation occupies a small area on the summit of the Hand Hills east of the City of Drumheller. Russell (1957, 1958) collected a horse bone from these beds which suggests a Pliocene age for this deposit.

Cretaceous-Tertiary Boundary

Geologists working in the Alberta Plains have hoped that the Cretaceous-Tertiary boundary would coincide with a marked discontinuity in the strata, above which the only vertebrate remains would be mammalian and below which they would be dominantly saurian. Similarly, paleobotanists have hoped that the Cretaceous-Tertiary boundary would be marked by a significant change in the floral succession.

Allan and Sanderson (1925, 1945) believed that they had found such an unconformity in the post-Kneehills succession of central Alberta, but the existence of a widespread break in sedimentation at this level has not been confirmed by later workers. There is no doubt, however, that a major change in the fossil fauna and flora takes place within the Willow Creek Formation of southern Alberta and within the upper part of the Edmonton Formation (as defined by Allan and Sanderson) of central Alberta. During the time interval covered by the deposition of these formations, dinosaurs became extinct and mammals became dominant. Support for an hiatus in the fossil record was given by Russell (1932a) who noted that no Lance (late Cretaceous), Puerca (early Paleocene), or Torrejon (middle Paleocene) fossils had been found in Alberta to that time. Subsequently, a Lance fauna was identified in strata above the Kneehills Member in the Red Deer River valley (Sternberg, 1947). This same interval has since yielded a rich Lance mammalian fauna (Clemens and Russell, 1965; Lillegraven, 1969) but convincing evidence of vertebrate faunas of early and middle Paleocene ages is still missing in the Alberta Plains (Russell, 1965a). Faunas of the Clarkforkian stage (late Paleocene) are well represented in Porcupine Hills Formation-equivalent beds around Calgary (Russell, 1929a). Recently, (Fox, 1968), a fossil mammal jawbone of probable Middle Paleocene (Torrejon) age was found in core from R.C.A. well 66-1 at a depth of 720 feet (elevation 3255 feet) also in Porcupine Hills Formation-equivalent strata.

Tozer (1953) could find no break in sedimentation at the inferred level of the Cretaceous-Tertiary transition on the Oldman River in southern Alberta, although he postulated an unconformity between the Edmonton and Paskapoo Formations on the Bow River because of the absence of Lance-equivalent vertebrates in the lower 300 feet of the post-Kneehills strata. Campbell and Almadi (1964), who did extensive shallow drilling for coal in this area, found no evidence of a widespread unconformity between the Edmonton and Paskapoo beds and suggested that the absence of saurian remains might be due to a change in environment, for the coal seams so characteristic of this interval in the Red Deer River valley also are absent. The sandstones in this section on the Bow River are rich in volcanic detritus and contain detrital epidote and hornblende as do Lance-equivalent beds on the Red Deer River. However, the age of these strata and the presence of a post-Kneehills unconformity in the succession along the Bow River valley must remain problematical until fossil evidence is unearthed.

Recent work on the microfloral assemblages of the Edmonton and basal Paskapoo beds in central Alberta has thrown new light on the position of the Cretaceous-Tertiary boundary and the nature of the contact between the two formations.

In R.C.A. Corehole 65-1, which was drilled 32 miles southwest of the City of Edmonton, Snead (1969) delineated three microfloral zones. The lowest zone, below the Kneehills Member, is Cretaceous (Maestrichtian); the uppermost zone, above the Ardley coal interval, is Paleocene in age. The beds between the Kneehills Member and the top of the Ardley coal interval (Lance - equivalent) constitute a transitional microfloral zone which carries both Cretaceous and Tertiary forms. Srivastava (1967), who studied this middle zone in the Red Deer valley, found a prolific microflora representing pteridophytes, gymnosperms, and angiosperms and an abundance of *Aquilapollenites*.

The large number of volcanic ash beds in post-Kneehills strata are favorable to the establishment of a chronology based on age determinations by radioisotope methods. The age of the Lance - equivalent beds at a number of localities has been estimated by the geochronology group at the University of Alberta (Folinsbee *et al.* 1961). The results of this work are summarized by Folinsbee *et al.* (1965), who estimate that the last ceratopsian dinosaur in Alberta died 64±1 million years ago.

An alternative placement of the Cretaceous-Tertiary boundary at the end of the Paleocene is advocated by Patterson (1965).

Proposed Revision of the Post-Kneehills Stratigraphic Nomenclature

It is evident from a review of the literature that there is considerable difficulty in correlating the nonmarine uppermost Cretaceous and Paleocene rock units in various parts of central and southern Alberta on the basis of existing formational boundaries. The major difficulties associated with this problem are:

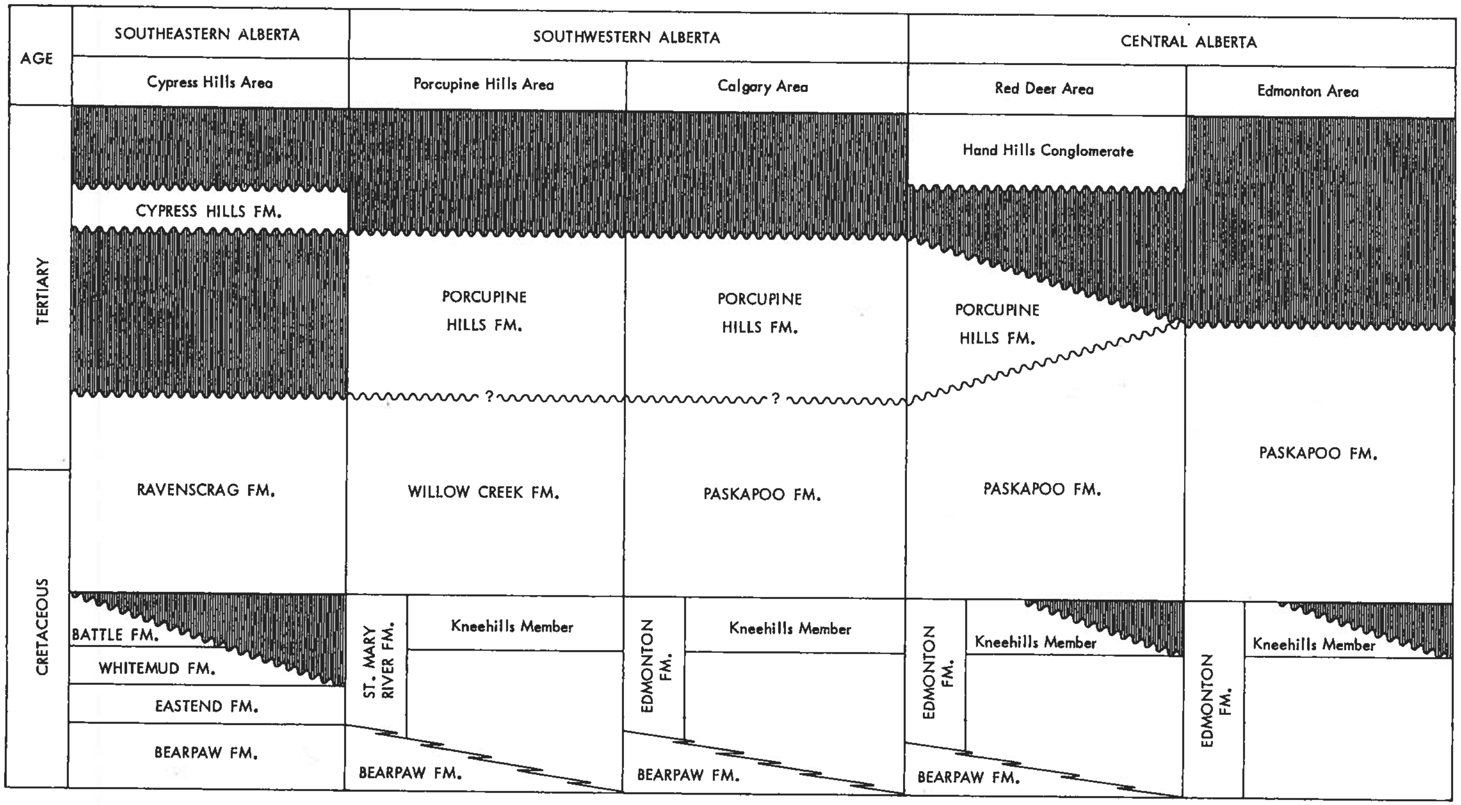
(1) the similarities in gross lithologies and the lack of widespread marker beds, as demonstrated by the controversy over the position and nature of the Edmonton-Paskapoo contact in the central Plains and the difficulties involved in tracing the formational units in southwestern Alberta north of the Bow River; and

(2) the scarcity or lack of diagnostic fossils in many parts of the succession, and hence the difficulty in defining the Cretaceous-Tertiary boundary with respect to rock units.

Detailed evaluation of the paleontological problems, including the position of the Cretaceous-Tertiary boundary, is outside the scope of this report, but the problem of defining and correlating rock unit boundaries can be partly overcome if it is accepted that the top of the Kneehills Member is the natural position for the upper boundary of the Edmonton Formation in the central Plains (Table 2). It is widely accepted that the Kneehills Member and the equivalent Battle Formation in southeastern Alberta are parts of a single, widespread volcanic ashfall, and hence time equivalents (Irish and Havard, 1968). It is also widely recognized that the Kneehills Member is the only marker bed in the uppermost Cretaceous succession that can be used for surface and subsurface correlation throughout the Alberta Plains (Fig. 3). By placing the upper boundary of the Edmonton Formation at this level, the St. Mary River Formation of southwestern Alberta becomes the equivalent of the Edmonton Formation of central Alberta, and the lower boundary of the Paskapoo Formation in Central Alberta coincides with the lower boundary of the Willow Creek Formation of southwestern Alberta. Similarly, the lower boundary of the Ravenscrag Formation of southeastern Alberta should be lowered to the top of the Battle Formation and the name Frenchman Formation restricted to the Saskatchewan portion of the Cypress Hills plateau.

Evidence is presented in subsequent sections of this report to show that the Porcupine Hills Formation, which overlies the Willow Creek Formation in

Table 2. Proposed Revision of Boundaries of Upper Cretaceous and Lower Tertiary Rock Units in the Alberta Plains



E. J. W. Irish (1970) proposed raising the Edmonton Formation to group status and lowering the top of the Edmonton Formation to conform to the Paskapoo Formation as defined in this Bulletin. In summary the Edmonton Formation as used here is equivalent to the Edmonton Group (*ibid.*), the Kneehills Member is equivalent to the Battle Formation (*ibid.*) and the Lance-equivalent beds of the Paskapoo Formation are equivalent to the Scollard Member of the Paskapoo Formation (*ibid.*). Recent nomenclature changes for the post-Kneehills strata have been summarized by the author in an earlier publication (Carrigy, 1970).

southwestern Alberta, also overlies the Paskapoo Formation on the Bow River. Unfortunately, insufficient outcrops exist north of the Calgary area to map a precise boundary between the Porcupine Hills and Paskapoo Formations, and the northern extent of the Porcupine Hills Formation (Map 32) remains problematical. In outcrops the Porcupine Hills Formation is characterized by calcareous siltstones and hard, lenticular, crossbedded calcareous sandstones. The Paskapoo siltstones are by contrast noncalcareous and highly bentonitic, and the Paskapoo sandstones are softer and more massive. Nevertheless, considerable field experience is necessary to recognize the differences between these formations, and petrographic studies of thin sections of the sandstones are needed to confirm the field observations.

A summary of the proposed revision of the correlation and nomenclature of the post-Kneehills strata of the central and southern Alberta Plains is given in table 2. With the boundary changes suggested in table 2, the Cretaceous-Tertiary transition takes place within the lower parts of the Paskapoo, Willow Creek, and Ravenscrag Formations. The available evidence suggests that the change in flora and fauna takes place within a continuous succession of sedimentary strata and is not marked by any catastrophic event or widespread unconformity. The revised nomenclature, with the lower boundary of the Paskapoo Formation at the top of the Kneehills Member (Battle Formation), is used throughout this report.

CROSS-STRATIFICATION

Regional studies of the dip directions of foreset beds in cross-stratified sandstone units within a formation can provide useful information about the currents that carried the sand, the direction of sediment transportation, and the paleoslope of the surface on which the sedimentary strata accumulated. When directional data are summarized and mapped, this information can be combined with changes in sandstone grain size and mineral composition to provide valuable clues as to the source of the sediments and the conditions that prevailed during the geological history of an area.

In the post-Kneehills succession of the Alberta Plains, only the Porcupine Hills Formation has a sufficient number of cross-stratified sandstone beds to allow a regional analysis of paleocurrents. In this unit it is uncommon to find a sandstone bed without crossbedding, with the result that it is possible to obtain dip-direction measurements at most Porcupine Hills Formation outcrops (Pl. 1, Fig. 1). Unfortunately, cross-stratification is not a common feature of sandstones in the underlying Paskapoo and Willow Creek Formations, and although some outcrops of the Ravenscrag Formation are cross-stratified (Pl. 1, Fig. 2), there are too few of them to make possible a regional analysis of late Cretaceous paleocurrents in central and southern Alberta. Nevertheless, the pre-Porcupine Hills formations seem to show a pattern of dip directions that indicates that a significant change in paleoslope took place during deposition of post-Kneehills strata.

In the Porcupine Hills Formation the sets of cross-strata have a curved lower boundary and contain foreset beds with concave surfaces. Numerous sets commonly are present within each outcrop (Pl. 1, Fig. 1) and are probably best described as medium scale trough-type (McKee and Weir, 1953). The sandstone bodies in which the crossbedding occurs are lenticular in cross section, suggesting deposition in well-defined channels. The sandstones are interbedded with siltstones in which the repeated presence of thin fossiliferous, carbonaceous beds containing freshwater gastropods is suggestive of deposition on a fluviatile floodplain covered by numerous shallow lakes.

The Paskapoo and Ravenscrag cross-stratification is developed within thick, friable, coarse-grained sandstones. The crossbedding is commonly on a larger scale (Pl. 1, Fig. 2) than in the Porcupine Hills Formation but outcrops in which the cross-stratification can be measured are not as numerous. In the sandstone units of the Paskapoo Formation, the lower surface is commonly erosional, whereas the other boundaries are ill-defined, sandstone grading laterally and vertically into silty beds. Thin quartzite conglomerate beds of limited lateral extent may be present within the sandstone bodies. Outcrops of sandstone reaching thicknesses of 50 to 60 feet and extending over distances of a mile or more are not uncommon. Thick coal seams are interbedded with and sometimes cut by channels filled with sandstone. In the lower part of the Paskapoo Formation, thick sandstones directly overlie the coal seams at a number of localities. The environment during the deposition of the Paskapoo is envisaged as an extensive subsiding swampy plain cut by broad drainage channels.

The dip - azimuth direction and slope of the cross-stratification for each formation were measured at several stratigraphic levels at each locality. To get as uniform a geographic coverage as possible, a sampling plan was adopted whereby no more than 50 readings were taken per locality, and seldom more than 10 readings per outcrop made up of one or two readings per set of cross-strata. All measurements for strata tilted more than 10 degrees were restored to the horizontal by use of a stereographic net. The 1,155 measurements were coded for calculation of the vector means by computer. The vector means of the dip - azimuths were calculated for each locality and for each formation.

The direction of the paleoslope deduced from 864 individual measurements at 19 localities for the Porcupine Hills Formation is 28 degrees and indicates a source for the sediment in a direction just west of south. The estimated paleoslope direction for the Paskapoo Formation derived from 140 measurements at five localities is 108 degrees and suggests a westerly source for the sediment of this formation. For the Ravenscrag Formation, in which only 51 measurements were made at two localities, a northwesterly source for the sediment is postulated. The mean paleocurrent direction for each locality is shown on figure 4, and a summation of the directional data for each formation is shown on figure 5.

Histograms showing the dip slope frequencies of the foreset beds in the cross-stratified units of the three formations are shown in figure 6. The mean dips range from 21.3 degrees in the Porcupine Hills Formation to 16.6 degrees in the Paskapoo Formation. The average for the Paskapoo Formation is less than the range of 18-25 degrees for crossbedded sandstones reported by Potter and Pettijohn (1963, p. 79). Dips of the foreset bedding apparently in excess of the angle of repose for sand (32°) are more numerous in the Porcupine Hills Formation than in the Ravenscrag or Paskapoo Formations. This may be due to some error in estimating the degree of rotation required to bring the beds back to the horizontal and to neglect of correction for tectonic dips up to 10 degrees.

In summary, the Paskapoo and Ravenscrag Formations, which are correlative on the basis of other evidence, show similarities in paleocurrent direction, the mean direction of sediment transport being to the southeast. In contrast, the mean direction of sediment transport for the Porcupine Hills Formation has a strong northern component, which change in direction coincides with a marked change in sandstone composition at this level, as described below. The Paskapoo and Ravenscrag sandstones also show lower mean crossbedding (plane) dips, although the seemingly higher dip values for the Porcupine Hills sandstones may be due to errors in correcting for tectonic dips.

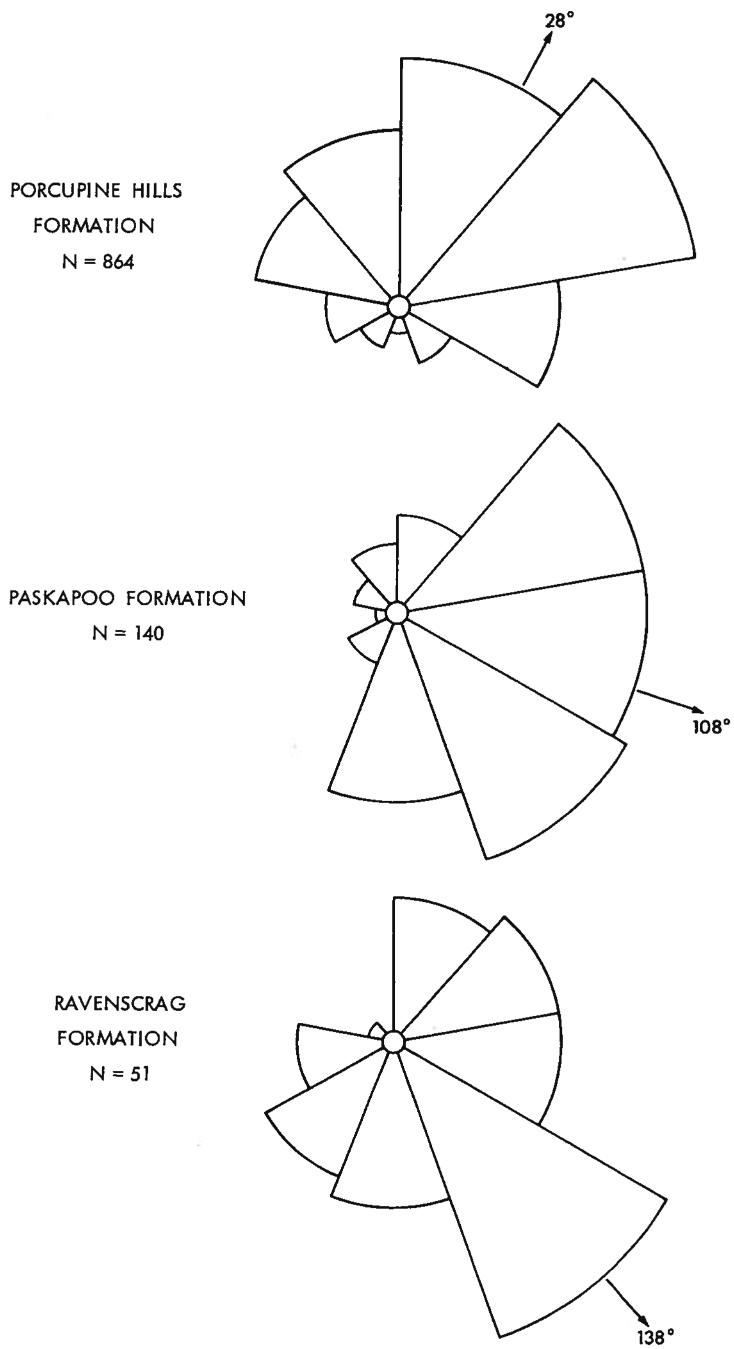


FIGURE 5. Distribution of dip-azimuth directions of cross-stratification in the Porcupine Hills, Paskapoo and Ravenscrag Formations.

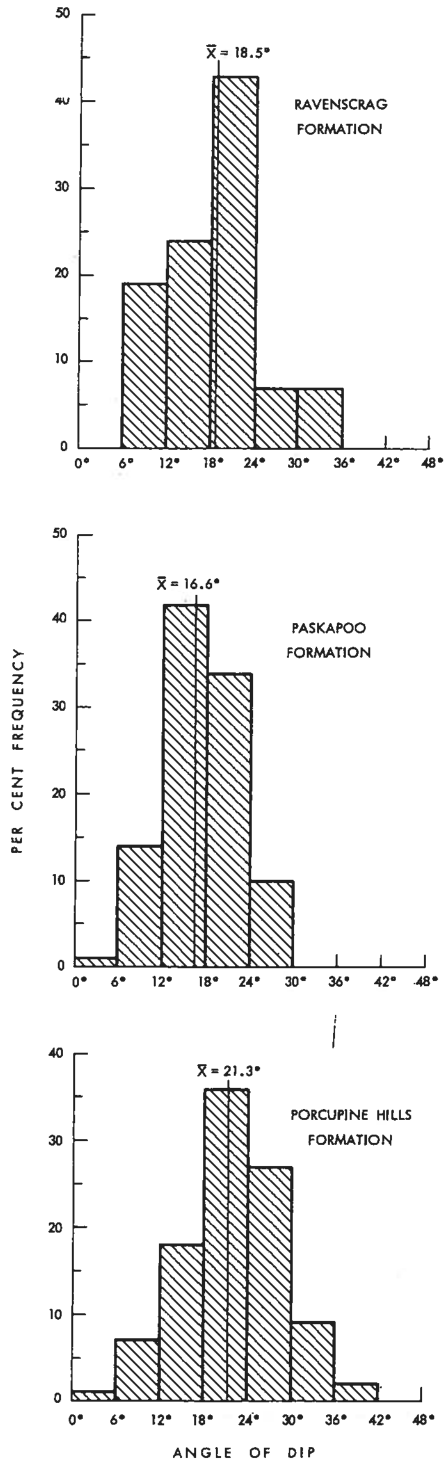


FIGURE 6. Frequency histograms of the slopes of foreset beds in cross-stratified sandstones of the Porcupine Hills, Paskapoo and Ravenscrag Formations.

PETROGRAPHY

Sampling and Analytical Procedures

Sampling

A total of 260 sandstone samples of post-Kneehills strata were collected and prepared for petrographic study, 89 from outcrops and 171 from corehole material.

Initially, sandstone samples were taken only at locations where crossbedding measurements were obtained. In the Porcupine Hills Formation outcrop area of southwestern Alberta this procedure provided adequate coverage, but in the central and northern Plains, where outcrops are confined mainly to the deeper river valleys owing to heavy vegetation and thick glacial drift, all sandstone outcrops regardless of cross-stratification were sampled. Some of the sandstones collected in these areas are finer grained than desired for thin section study. Even if these limitations were ignored, it soon became obvious that the main objective of the study could not be achieved by outcrop sampling, and two coreholes were drilled to obtain samples for information on the vertical variability in sandstone composition.

The first of these was drilled in 1965, in Sec. 8, Tp. 48, R. 27, W. 4th meridian, about 32 miles southwest of the City of Edmonton, to a depth of 507 feet. The hole transected the basal beds of the Paskapoo Formation and upper portion of the Edmonton Formation, including the Kneehills Member. The second corehole was drilled in 1966 in Lsd. 2, Sec. 25, Tp.26, R.2, W. 5th meridian, about 9 miles north of the City of Calgary, to a depth of 1,000 feet. The hole started and finished in beds correlated with the Porcupine Hills Formation, the base of the cored section being estimated at about 600 feet above the top of the Kneehills Member at this locality. In addition to material from these two coreholes, 943 feet of core in the lower beds of the Paskapoo Formation was obtained from nine closely spaced wells in Sec. 33, Tp. 57, R. 13, W. 5th meridian on the McLeod River, about 100 miles northwest of the City of Edmonton. In all, the total length of core sampled is 2,267 feet; descriptions of the wells are given in appendix C. All sandstone intervals in the cored sections were sampled, those exceeding 10 feet in thickness being sampled at 5 - to 10 - foot intervals.

The location of all samples are listed in appendix B, and the sampling localities are shown on Map 32. Of the 260 samples collected, 79 outcrop samples and 44 core samples were selected for detailed petrographic analysis. The geographic and stratigraphic distribution of these samples is given in table 3. Although the distribution of samples among formations is uneven, a sufficient number of samples has been collected to establish the main features of the sandstone composition for each stratigraphic unit and to separate on the basis of sandstone composition the Paskapoo Formation from the Porcupine Hills Formation in the Calgary area. However, additional sampling is needed to establish the position of the boundary between these two formations in the Red Deer area.

Table 3. Geographic and Stratigraphic Distribution of Analysed Post-Kneehills Samples

Formation	Porcupine Hills Area		Calgary Area		Red Deer Area		Edmonton Area		Cypress Hills Area	
	A	B	A	B	A	B	A	B	A	B
Porcupine Hills	15	3	29	13	3	–	–	–	–	–
Paskapoo	–	–	10	3	14	2	47	13	–	–
Willow Creek	4	–	–	–	–	–	–	–	–	–
Ravenscrag	–	–	–	–	–	–	–	–	1	1

A – Petrographic Analyses
B – Chemical analyses

Analytical Techniques

Most samples were thin sectioned and examined under the petrographic microscope. All of the thin sections were scanned systematically to get an estimate of their grain size and composition, many were stained with Alizarine Red-S to distinguish calcite from dolomite (Friedman, 1959) and with sodium cobaltinitrite to identify potash feldspar grains (Chayes, 1952).

The point-count technique used to determine composition is a modification of the procedure outlined by Griffiths (1960); briefly, it consists of identifying the grain or constituent under the crosshair at predetermined intervals. The main purpose of point-counting a thin section of sedimentary rock is not to determine the "mode" or relative proportions of minerals present but to get information about the proportions of particles or grains derived from similar source rocks. It is only in the estimation of the amounts of certain monomineralic constituents such as cements or diagenetic minerals that the technique approaches the objective of a modal analysis. It is seldom necessary to count between one and two thousand points per sample, as is commonly done in the modal analysis of igneous rocks (Chayes, 1956), to get a sufficiently precise estimate of the "composition" of a sedimentary rock. In fact, 200 randomly distributed "points" are considered sufficient to estimate the relative abundance of the operational entities with a view to identifying source terrains and to classifying sandstones as belonging to one or other of petrographically dissimilar stratigraphic units. The results of the point-count analyses are given in appendix D, table 12.

Even though most of the sandstone samples collected are friable and easily disaggregated, any estimate of the grain size based on sieving would give a high percentage of clay or "matrix" because of the ubiquitous presence of clay mineral cements. Estimates of the grain size were therefore made on thin sections under the microscope. Two grains of each of the four most common framework constituents (i.e. the transported elements) in each sample were measured under the microscope. To ensure some degree of randomness in the measurements, a procedure was adopted whereby the size of one grain of each of the four constituents was measured in turn as it came under the crosshairs. When one measurement had been made on each constituent, the sequence of measurements was repeated. The grain size estimates derived by this method have been found to be sufficiently precise to be used for comparative purposes. The average of the eight measurements in each thin section is the figure given under "grain size" in table 12.

In addition to being thin sectioned, each sandstone was disaggregated and washed through a sieve with 62-micron openings. The heavy mineral fraction was separated from that portion of the sample retained on the 62-micron sieve, and the −2-micron fraction of the sample passing the 62-micron sieve was used to make oriented clay slides for X-ray identification of the clay minerals. The Paskapoo sandstones are easily disaggregated in water, but many of the Porcupine Hills Formation sandstones require treatment with dilute acetic acid before they can be broken down.

The heavy mineral separation was made with tetrabromoethane (s.g. = 2.95) and the heavy grains were mounted in aroclor (r.i. = 1.6) for identification. Each grain mount was examined under the petrographic microscope and the nonopaque heavy minerals identified. No attempt was made to make quantitative estimates of the proportions of heavy minerals in each slide, but thorough searches were made for certain index minerals such as epidote and hornblende, which appear to be absent from the Porcupine Hills Formation heavy mineral suite.

The clay slides were scanned three times to get X-ray diffractograms of the untreated, glycolated and heated states. The heat treatment consisted of placing the sample in a furnace at 550° C for 30 minutes. The clay minerals were identified from the reactions of their basal spacings to the ethylene glycol and heat treatments. No attempt was made to identify clay mineral species or to make quantitative estimates of their relative proportions. If zeolite peaks were present on the X-ray diffractograms, or if zeolites were identified in thin sections, a separation in a liquid of specific gravity of 2.3 was made, and the identification was confirmed by analyzing the lighter fraction in an X-ray powder camera.

Grain Size

To get an unbiased estimate of the proportion of sandstone and siltstone in the Paskapoo and Porcupine Hills Formations, the grain size of samples taken from all available core material was measured in thin sections. Frequency histograms constructed from this data (Fig. 7) show that the Porcupine Hills Formation is comprised of 21 per cent fine-grained sandstone, 59 per cent very fine grained sandstone, and 20 per cent siltstone, whereas the Paskapoo Formation is 10 per cent medium-grained sandstone, 24 per cent fine-grained sandstone, 40 per cent very fine grained sandstone, and 26 per cent siltstone. An unusual feature of both formations is the virtual absence of beds of original clay-size sediment, that is,

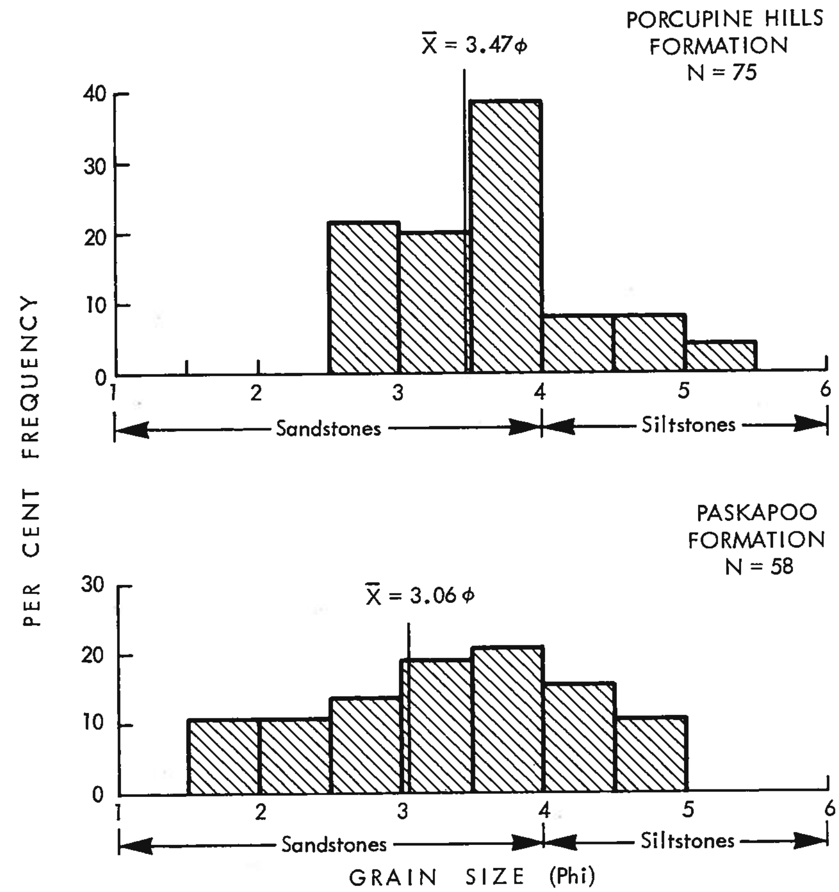


FIGURE 7. Percentage grain-size distributions of sandstones and siltstones from the Porcupine Hills and Paskapoo Formations, as determined from thin sections.

"shale" or "mudstone". Thin beds of bentonite composed of montmorillonite account for most beds that might be described in the field as "shale".

The mean size of the sandstone samples selected for petrographic analysis is 0.19 mm for the Paskapoo Formation and 0.15 mm for the Porcupine Hills Formation. The geographical distribution of the average grain size of individual samples is plotted on figure 8 and gives no indication of any consistent difference in average grain size between sandstones of the two formations.

The grain size distributions of each of the five types of the framework grains show a marked difference between formations (Figs. 9, 10) but small differences within each formation. The only effect of composition on grain size is the slight difference in both formations in mean grain size between quartz, feldspar, and clastic carbonate grains on the one hand and the chert and rock fragments on the other hand. These data show that sorting during transportation has had no measurable effect on composition and that diagenesis subsequent to deposition has had little effect on the grain size of the framework constituents.

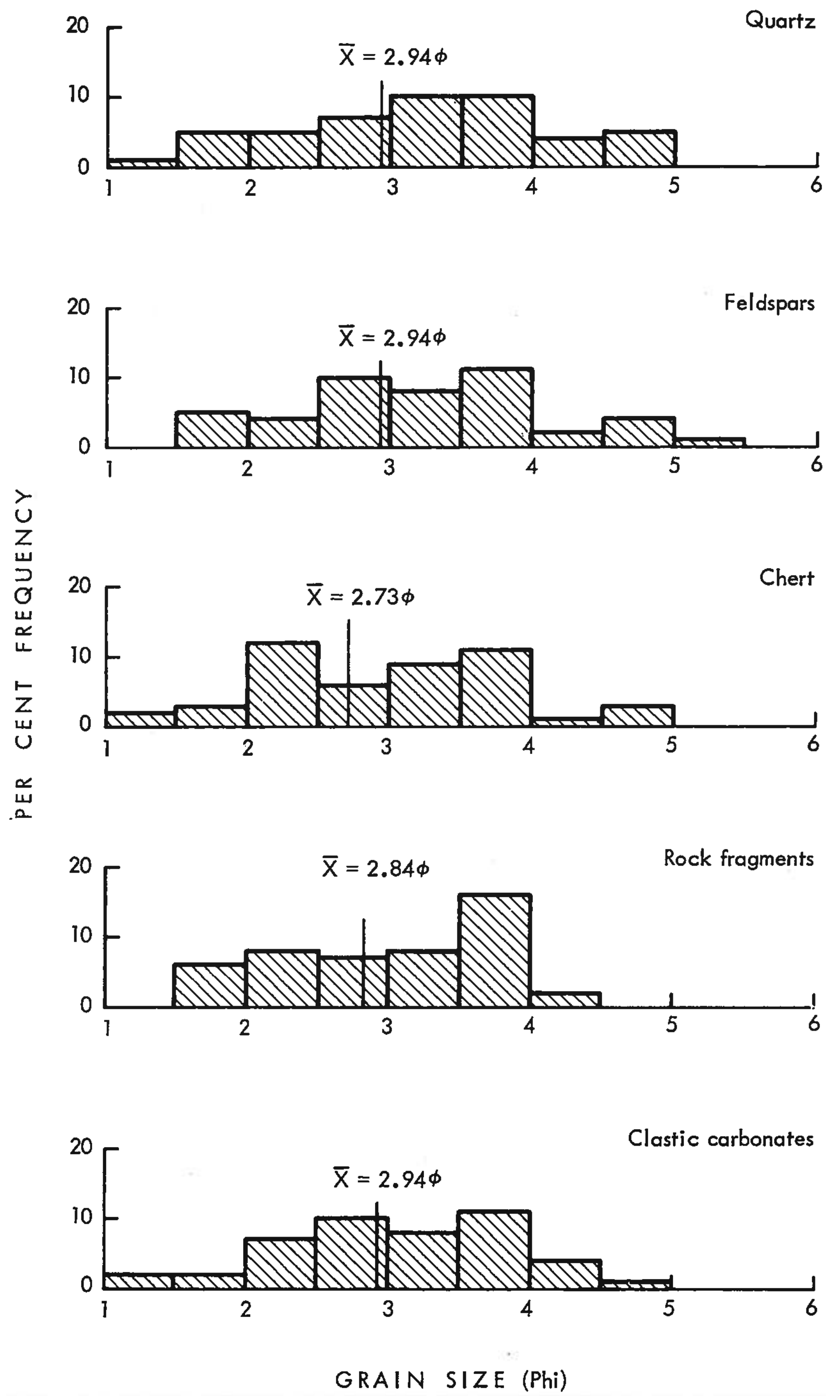


FIGURE 9. Size distributions of major framework (clastic) grains in sandstones of the Paskapoo Formation, as determined from thin sections. Samples studied were obtained from R.C.A. Corehole 65-1 and the McLeod River damsite wells.

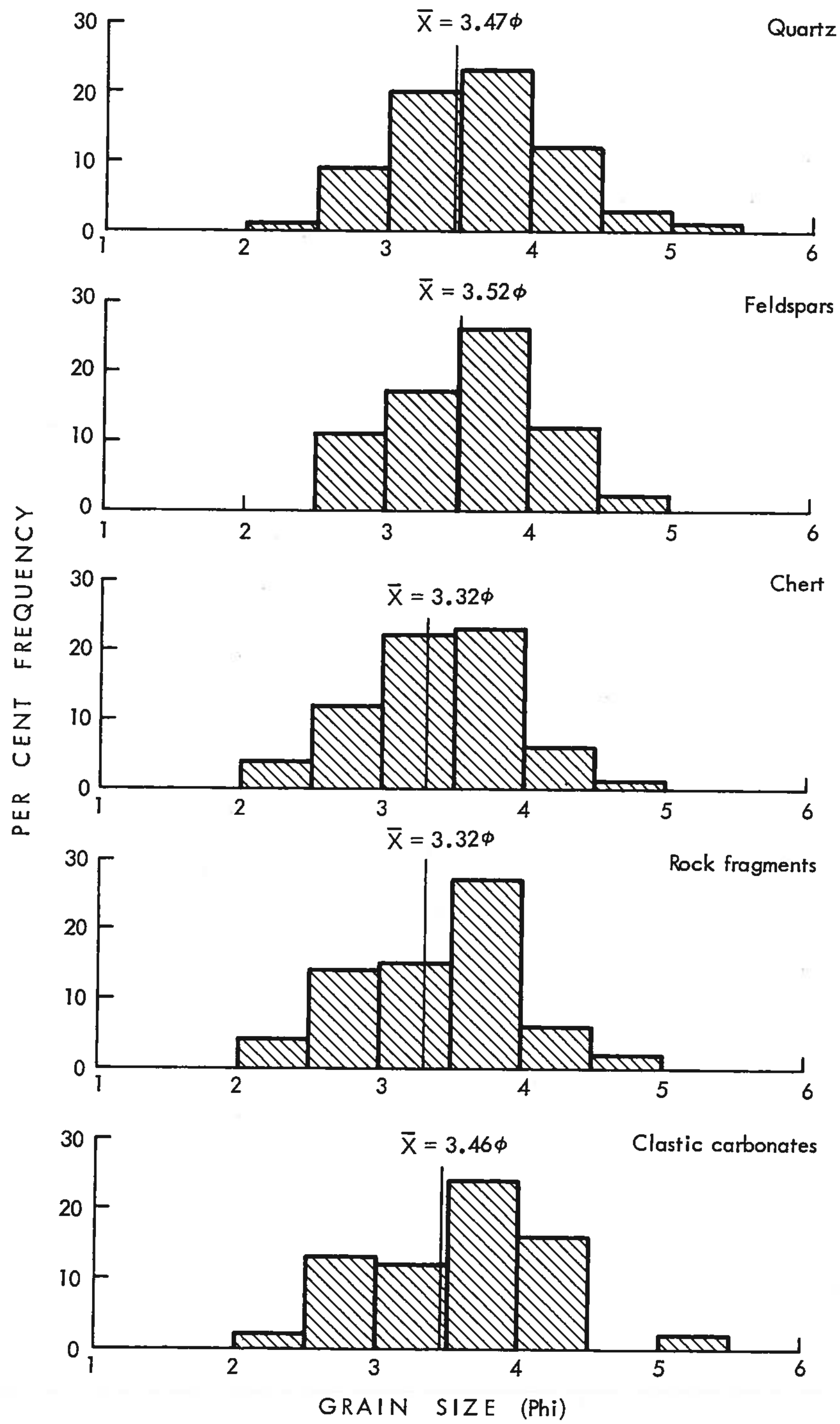


FIGURE 10. Size distributions of major framework (clastic) grains in sandstones of the Porcupine Hills Formation, as determined from thin sections. Samples studied were obtained from R.C.A. Corehole 66-1.

Composition

During the petrographic examination of the sandstones, the operational definitions listed below were adopted to divide the components of the rock into the minimum number of mutually exclusive entities sufficient to establish the mineralogical or petrographical composition of the textural elements of the rock. The textural elements – grains, matrix and cement – are used in the sense of Krynine (1948), and in many rocks a mineral may be present in all three textural elements. For example, in the Paskapoo Formation sandstone the clay minerals chlorite and montmorillonite are commonly present as altered volcanic grains, as a detrital interstitial clay matrix, and as chemically precipitated cement. Distinguishing among the textural elements in such a rock requires considerable experience; errors in assignment are often unavoidable. In deciding whether metasomatic replacement of grains has taken place, it is useful to recall that cement plus matrix should not exceed the original amount of intergranular pore space, which rarely exceeds 30 per cent of the total rock volume in an unconsolidated sand.

Detrital Constituents

Detrital grains are distinguished by their "form" or "shape", which is usually indicative of some abrasion during transportation. Contacts with other grains are sharp and well defined for the rigid grains, but some micas and plastic grains (such as clay pellets and glauconite) may be bent or squeezed into the surrounding pore space by intergranular pressure subsequent to burial. In some rocks plastic grains may be so numerous as to form a groundmass or "matrix" between the more rigid grains, a condition which reduces permeability and inhibits cementation.

Quartz and Quartzite

Because monocrystalline and polycrystalline grains of quartz exhibit similar behaviour during sediment transportation and diagenesis, it is convenient to treat them together as an operational entity and to refer to them collectively as "quartzose grains". Quartz grains are defined as clear grains with low birefringence, very low relief, lack of cleavage, and undulose or sharp extinction. Quartzite grains are coarsely crystalline aggregates of quartz with patchy extinction. These grains also are referred to as polycrystalline quartz.

Slightly less than one third of the detrital material of the sandstones in the post-Kneehills rock units in Alberta is comprised of quartzose grains. In the southwestern part of the province the Willow Creek and Porcupine Hills Formations average 33 and 32 percent quartzose grains respectively, whereas the Ravenscrag and Paskapoo Formations of southeastern and west-central Alberta, respectively, contain 30 per cent each. The variation in percentages of quartzose grains within individual formations is large but the variation between formations is small (Fig. 11).

The grain-size distributions of the quartzose grains in the Paskapoo and

Porcupine Hills Formation sandstones are shown in figures 9 and 10. As expected, the quartzose grains show ranges and frequencies of sizes similar to those of their respective detrital fractions and to those of the other detrital constituents. Although insufficient samples are available to allow similar diagrams to be constructed for the size distribution of quartzose grains in the Willow Creek and Ravenscrag Formations, they probably are similar to that of the Paskapoo. It can be seen from table 5 that there is a significant negative correlation between the percentage of quartzose grains and "grain size" in the Porcupine Hills Formation, indicating that the finer grained sandstones are more quartzose than the coarser grained sandstones although no such correlation is present in the Paskapoo Formation sandstones.

The shape of the quartzose grains is a function of size. In all of the fine-grained and most of the medium-grained sandstones the quartzose grains are angular. Only in a few of the coarsest (medium-grained) sandstones is there any evidence of abrasion, although overgrowths on some of the monocrystalline grains in the Porcupine Hills Formation rocks appear to have grown on rounded cores. Taken as a whole, the quartzose grains in the post-Kneehills sandstones of Alberta show little evidence of rounding.

Blatt and Christie (1963) have demonstrated that polycrystallinity and undulatory extinction in quartz are not reliable indicators of the provenance of a sedimentary rock. Nevertheless, the relative proportions of monocrystalline and polycrystalline grains may provide some evidence as to the maturity of the sandstones and might prove useful for correlation among post-Kneehills strata. The number of quartzose grains showing a polycrystalline habit is obviously dependent on the size of the grains. The first requirement is that the grains must be larger in size than the individual crystals in the mosaic; thus it is to be expected that the larger the grain size the higher will be the percentage of polycrystalline grains. To get some idea of the proportions of polycrystalline grains in the post-Kneehills rock units and the relations of these proportions to grain size, 50 quartzose grains were classified in at least one fine- and one medium-grained sandstone from each formation where possible. The results of this sampling are shown in table 4, from which it can be seen that the Paskapoo Formation sandstones have the highest proportion of polycrystalline quartz grains.

Chert

Chert is microcrystalline quartz. It has an abrasion resistance about equal to that of quartzose grains but is more soluble and chemically reactive during diagenesis. Little difficulty is experienced in distinguishing chert from fine-grained quartzose grains, but some finely crystalline volcanic detritus (felsite) may be included in this class. Detrital chert is given the status of an operational entity because of its characteristic appearance in polarized light, which enables it to be easily identified in thin sections and because of its value as an indicator of provenance.

Many varieties of chert have been recognized in sedimentary rocks, but in the post-Kneehills strata of Alberta the commonest form has a microcrystalline habit

Table 4. Percentages of Quartz showing Polycrystalline Habit in Post-Kneehills Sandstones

Formation	Number of Samples	Medium Sand	Fine Sand
Porcupine Hills	4	41	12
Paskapoo	6	64	35
Willow Creek	2	–	17
Ravenscrag	2	28	15

which gives "pinpoint extinction" under crossed nicols. Other varieties, present in smaller amounts, have a spherulitic or fibrous habit (chalcedony) or contain relict fossil structures. Many of the chert grains have dolomite rhombs embedded in them, and some grains have been partially replaced by carbonate minerals.

Sandstones of the Porcupine Hills Formation show a significant negative correlation between chert and clastic carbonate grains, but in the Paskapoo Formation sandstones chert does not appear to be highly correlated with any other constituent (Table 5).

On the average, chert is about three times as common in the detrital fraction of the Porcupine Hills sandstones than in the Paskapoo sandstones. The average frequency percentage of chert in the Porcupine Hills sandstones is 21.6 per cent whereas the Paskapoo sandstones average 6.9 per cent. However, differences in chert content between individual samples is large (Fig. 11), and the geographic distribution appears to be independent of formation boundaries (Fig. 12). Thus, chert is most common in the post-Kneehills strata of southwestern Alberta, where the Willow Creek Formation sandstones average 32.3 per cent and the Porcupine Hills Formation sandstones 30 per cent chert. In the Calgary area the Porcupine Hills Formation averages only 18 percent whereas the Paskapoo Formation in this area averages 10.3 per cent.

Because chert has a slightly lower specific gravity (2.60) than quartz, its average grain size is slightly greater than that of the quartzose grains but the distribution of sizes about the mean as shown in figures 9 and 10 is essentially the same as for the quartzose grains. Table 5 shows that the percentage of detrital chert in most samples is highly correlated with size, particularly in the Porcupine Hills Formation where coarser-grained sandstones are composed of as much as 50 per cent chert, whereas the finer-grained sandstones carry as little as 5 per cent. This relationship is illustrated in figure 13 and can be compared with a similar diagram for the Paskapoo sandstones (Fig. 14).

The chert grains in all of the post-Kneehills sandstones are predominantly angular, although some abraded grains are found in the coarser-grained sandstones.

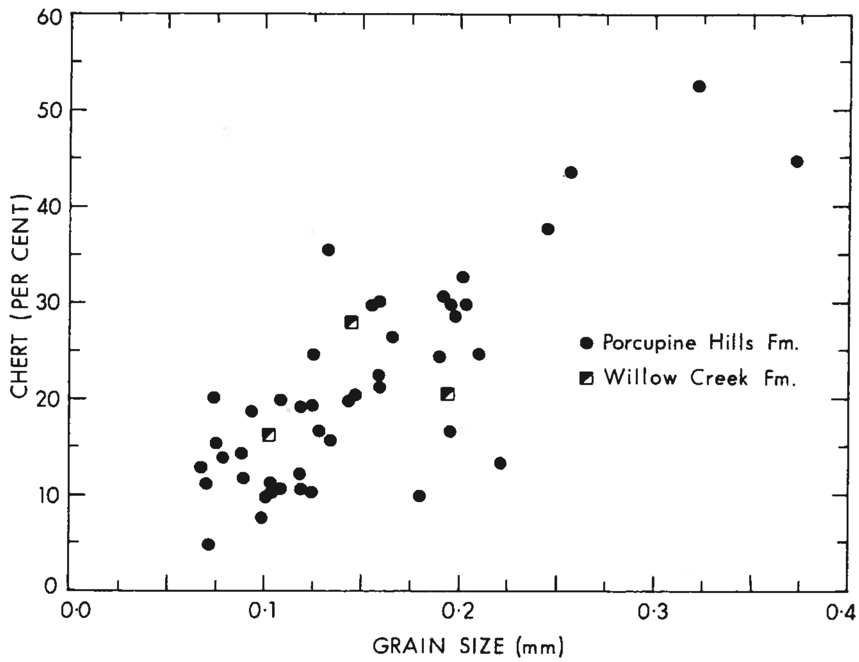


FIGURE 13. Relationship between percentage of chert and grain size in sandstones of the Porcupine Hills and Willow Creek Formations.

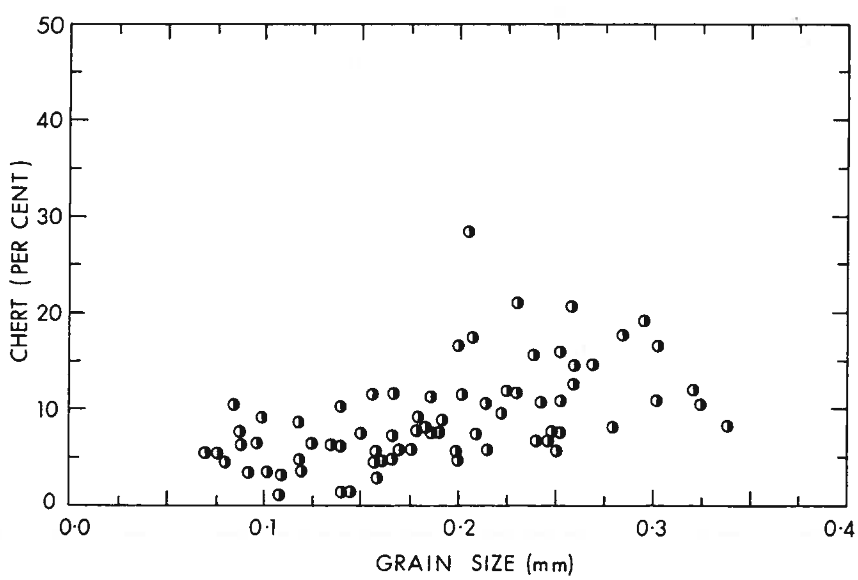


FIGURE 14. Relationship between percentage of chert and grain size in sandstones of the Paskapoo Formation.

Feldspars

Although feldspars are present in the post-Kneehills sandstones as microlites and lath-shaped phenocrysts in volcanic rock fragments as well as individual feldspar grains, only the single crystal form is included in the point counts of this entity. This restriction simplifies the operational procedure by reducing the decision making to a minimum and increases the precision of the data, but the actual quantity of feldspars in some sandstones may exceed the amount reported under this heading by a considerable amount.

Single grains of feldspar are present in the detrital fraction of most sedimentary rocks, the amount depending on the composition of the source rocks and the subsequent depositional and diagenetic history of the raw detritus. Although feldspar grains have an abrasion resistance similar to that of quartzose grains during transportation, in certain high energy loci of deposition, such as beaches, they tend to break up much more readily than quartz. Thus, many marine sandstones are distinctly more quartzose than contiguous nonmarine (fluvial) sandstones. Similarly, feldspars are more prone to alteration and replacement during diagenesis, reacting with pore solutions to form various types of secondary clay minerals, zeolites, and carbonates.

In spite of this propensity to mechanical breakup and chemical replacement, the amounts and types of feldspars in sandstones can be used within limits to interpret the composition and distribution of source rocks. In particular, the habit and type of feldspars present in a sandstone can be valuable indicators of igneous source rocks. For example, a high potash-feldspar (orthoclase) content suggests an acid plutonic (granitic) rock source, a high anorthite content a basic source rock, and the presence of sanidine and oscillatory zoned feldspars, a volcanic rock source.

The specific identification of feldspars in sediments is difficult because of the wide range in size, the wide variation in composition, and the high degree of alteration. Staining with a sodium cobaltinitrite solution (Chayes, 1952) helps to distinguish between potash and plagioclase feldspars, but the method is not always effective due to the presence of alteration products. Also the ratio of potash to plagioclase feldspar can be estimated rather crudely by counting the number of feldspar grains showing no twinning or simple twinning as distinct from grains showing multiple lamellar (albite) twinning but the results of such counts are quite inaccurate in many cases. No special effort has been made here to identify the types of potash and plagioclase feldspars present although a few refractive index measurements and the high soda content in the chemical analyses of the Paskapoo sandstones suggest that most of the plagioclase in that formation is a high soda (albite) variety.

In the post-Kneehills sandstones the feldspar grains are commonly angular cleavage fragments; only 5 per cent show any evidence of rounding. About half of the feldspar grains show well-developed cleavage traces and about half of the grains have been altered in some way. The most common form of alteration gives a cloudy appearance to the grains in thin sections which is probably due to incipient sericitization or kaolinization. Other grains are altered to chlorite or zeolite, but

Table 5. Simple Correlation Coefficients (r) Showing Association between Petrographic Properties in the Paskapoo and Porcupine Hills Formations

	Grain Size (microns)	Quartz (%)	Feldspar (%)	Chert (%)	Rock Fragments (%)	Volcanic Rock Fragments (%)	Clastic CO_3 (%)	Calcite (%)	Kaolinite (%)	Montmorillonite (%)	Pore Space (%)
Grain Size (microns)		-0.251 -0.617*	-0.154 0.000	0.586* 0.742*	0.481* 0.326	0.089 0.291	0.015 -0.484*	0.001 -0.071	-0.054 0.043	-0.461* -0.294	0.324* 0.101
Quartz (%)			-0.277 -0.058	-0.154 -0.628*	-0.356* -0.403*	-0.465* -0.084	-0.066 0.009	0.193 0.100	0.076 -0.068	-0.086 0.058	-0.010 -0.178
Feldspar (%)				-0.262 -0.011	-0.262 -0.031	0.269 0.142	-0.095 -0.320	0.088 0.519*	-0.282 -0.162	0.013 0.219	0.024 -0.296
Chert (%)					0.191 0.055	0.030 0.003	-0.026 -0.480*	-0.022 0.012	0.053 0.166	-0.259 -0.311	0.121 0.111
Rock Fragments (%)						0.043 0.085	-0.358* -0.253	-0.322* -0.243	0.046 0.221	-0.203 0.063	0.205 -0.025
Volcanic Rock Fragments (%)							-0.402* -0.361*	-0.210 0.044	-0.007 -0.147	-0.060 0.004	0.240 -0.204
Clastic CO_3 (%)								0.161 -0.295	-0.115 -0.123	0.109 0.120	0.045 0.375*
Calcite (%)									-0.106 -0.086	-0.320* -0.069	-0.410* -0.484*
Kaolinite (%)										-0.016 -0.255	-0.036 -0.275
Montmorillonite (%)											-0.334* -0.209
Pore Space (%)											

Note –
upper numbers: Paskapoo Formation (N=69)
lower numbers: Porcupine Hills Formation (N=52)
*significant at the 1% level

there is little evidence of replacement by calcite cement. In general grains showing albite twinning are fresher in appearance than untwinned grains.

The average proportion of feldspar grains in the detrital fraction of sandstones from the Paskapoo, Ravenscrag, and Willow Creek Formations is fairly constant at about 10 per cent, which contrasts with an average of only 2.6 per cent in the Porcupine Hills Formation sandstones. The total feldspar content is one of the features which distinguishes the Porcupine Hills Formation from older formations, as indicated in figure 11. With few exceptions samples containing less than 5 per cent feldspars fall in the area mapped as Porcupine Hills Formation (Fig. 15).

Because of the relatively small number of feldspar grains counted, only the total feldspar contents of the samples are given in table 12. However, cursory examination of the distribution of feldspar types suggests both geographic and stratigraphic variation in the proportions of untwinned (potash) and twinned (plagioclase) feldspar exist in the post-Kneehills strata. In southwestern Alberta (Porcupine Hills and Willow Creek Formations) potash feldspar is dominant, whereas in west-central (Paskapoo Formation) and southeastern Alberta (Ravenscrag Formation) plagioclase is more common than potash feldspar. Also, in west-central Alberta the upper Paskapoo Formation sandstones appear to have a higher proportion of potash feldspar than the lower Paskapoo sandstones. These generalizations are based on rather limited evidence; it will require much more sampling and detailed study of the feldspars in these rocks to confirm these observations.

The average grain size of feldspars in the post-Kneehills sandstones is similar to that of the quartzose grains (Figs. 9, 10), but in contrast to the quartzose grains there is no correlation between sample grain size and feldspar content. This absence of correlation must be due to the relatively small percentages of feldspar grains in the detrital fraction and to the large variation in feldspar content between samples.

Also, unlike the quartzose grain content the feldspar content of the post-Kneehills sandstones is not highly correlated with that of any other detrital constituent (Table 5) and in fact, the only petrographic entity with which feldspar content shows a moderate degree of correlation ($r=0.519$), is the distribution of calcite cement in the Porcupine Hills Formation sandstones. The significance of this relationship is obscure but it does indicate indirectly that feldspar is not being replaced by calcite in this formation.

Rock Fragments

The presence of abundant rock fragments in a sandstone is considered to be a sign of "immaturity" and is one of the features commonly used for sandstone classification. Feldspar and rock fragments are referred to collectively as labile constituents and are used by Pettijohn (1957) in defining greywackes as those sandstones containing more than 25 per cent labile constituents and more than 15 per cent interstitial "matrix". Sandstones containing more than 25 per cent labile constituents and little or no matrix are called subgreywackes by Pettijohn (*op. cit.*) and lithic wackes by Gilbert in Williams *et al.* (1954).

The term rock fragments is, like most other terms used in point-counting petrographic entities, a convenient label. In this case it is applied to a group of sandstones grains of heterogeneous mineral composition and texture, specifically excluding monomineralic rock fragments such as chert, quartzite, and clastic carbonates. Because of the variety of source rocks contributing to this category, the problem is to devise a minimum number of groupings that will have sufficient genetic significance and that will be applicable to all of the post-Kneehills sandstones. The most basic and perhaps the most useful subdivision of rock fragments is to classify them as sedimentary, metamorphic and igneous. Even this elementary objective is not always attainable and nongenetic, but mutually exclusive classes, may become an operational necessity.

Rock fragments are derived from source rocks by erosion and may be of local or distant origin. On the one hand those derived from a distant source will be from rocks most resistant to weathering and abrasion and thus not representative of the less resistant source rocks. Detrital material of local origin on the other hand is commonly incorporated into the sandstones before it is lithified and the original granular form is destroyed by compactive forces which squeeze the plastic grains into the interstitial space between the rigid grains to form a groundmass or "matrix". This phenomenon is perhaps more common than is generally recognized (Mellon, 1967) and is certainly recognizable in some of the post-Kneehills sandstones.

For the post-Kneehills sandstones a twofold subdivision of the rock fragments into volcanic and nonvolcanic classes has been adopted to facilitate point-counting and to provide a basis for stratigraphic subdivision. The percentages of the two types of rock fragments in the post-Kneehills sandstones are given in table 12.

Volcanic rock fragments (Pl. 2) are recognized by the abundance of aligned feldspar laths, by the presence of subequant feldspar phenocrysts in a felsitic groundmass or by complex feldspathic intergrowths. Some grains of volcanic origin have been altered to montmorillonite or chlorite and can be easily misclassified as "matrix" whereas other cryptocrystalline grains (felsite) may be confused with chert. Nonvolcanic rock fragments include siltstones composed of quartz grains embedded in a clayey groundmass. Low rank metamorphic rocks – slates and phyllites – are probably represented by grains of foliated micromica with varying amounts of quartz. Opaque or cryptocrystalline grains with microlamination are classed together with the siltstones as sedimentary rock fragments. Others, without lamination, are classed simply as nonvolcanic rock fragments.

Volcanic rock fragments are most common in the Ravenscrag and Paskapoo Formation sandstones, where they comprise about 10 per cent of the detrital grains. In the Porcupine Hills and Willow Creek Formation sandstones, volcanic rock fragments are rare, averaging less than 1 per cent of the detrital grains in the Porcupine Hills sandstones and less than 2 per cent in the underlying Willow Creek sandstones. The differences in volcanic detritus content between the Paskapoo and overlying Porcupine Hills sandstones has considerable stratigraphic value in the Calgary and Red Deer areas but is of little value in differentiating the Porcupine Hills and Willow Creek Formations in the Porcupine Hills area (Fig. 16).

The percentage of volcanic rock fragments shows significant correlations with the percentages of quartzose and clastic carbonate grains in the Paskapoo sandstones and with clastic carbonates in the Porcupine Hills sandstones (Table 5). The correlations are negative and may in part be due to the use of percentage data, from which it follows that an increase in the proportion of one constituent involves a concomitant decrease in the percentage of one or more of the other detrital constituents.

Nonvolcanic Rock Fragments are second only to quartzose grains in abundance. In the Paskapoo and Ravenscrag sandstones, the nonvolcanic rock fragments average close to 30 per cent, whereas in the Willow Creek and Porcupine Hills sandstones they average about 20 per cent. The geographic distribution of nonvolcanic rock fragments content (Fig. 17) does not follow the formation boundaries but resembles the regional northern and southern lithofacies pattern displayed by the distribution of volcanic rock fragments and chert.

In addition to differences in the total nonvolcanic rock fragment contents of the post-Kneehills sandstones, the ratio of sedimentary to metamorphic rock fragments shows marked variation between formations of equivalent stratigraphic position. For example, in southern Alberta grains of sedimentary origin outnumber those of metamorphic origin by a ratio of 5 to 1 in sandstones from the Willow Creek Formation, whereas in west-central Alberta the stratigraphically equivalent Paskapoo Formation sandstones contain two metamorphic grains for every sedimentary rock fragment. Within the Paskapoo Formation there is an upward increase in the number of metamorphic grains as evidenced by the high metamorphic rock fragment content of the Paskapoo Formation sandstones near the Foothillls. The relative abundance of sedimentary, metamorphic and volcanic contributions to the rock fragment content of the post-Kneehills sandstones can be summarized as follows:

Paskapoo Formation: metamorphic > volcanic > sedimentary
Ravenscrag Formation: volcanic > sedimentary > metamorphic
Willow Creek Formation: sedimentary > volcanic > metamorphic
Porcupine Hills Formation: sedimentary > metamorphic > volcanic.

The average grain size of the rock fragments in the Paskapoo and Porcupine Hills sandstones is slightly greater than those of the quartzose and feldspar grains, the size distribution being similar to that of the chert grains (Figs. 9, 10). The fragments show little evidence of abrasion, and many of the softer grains have been squeezed by compactive forces. As a result they occupy much of the interstitial pore volume, thus reducing the overall porosity and permeability of the sandstones.

Clastic Carbonates

Included in this class are fragments of limestone and dolomite which were transported and deposited together with the other detrital constituents of the sandstones. The minerals calcite and dolomite, which make up the bulk of the clastic carbonate grains, are relatively soft and soluble and therefore are rarely found in the detrital fraction of sandstones that have been through more than one depositional cycle.

Carbonate grains are easily identified in thin sections by the change in relief on rotation of the slide, extreme birefringence, and perfect rhombohedral cleavage. Although parallel lamellar twinning is diagnostic of calcite, considerable difficulty is experienced in distinguishing between single grains of calcite and dolomite in thin sections, and staining is recommended for ease of identification in point-counting (Friedman, 1959). For this study the thin sections were stained with Alizarine-Red S, which gives calcite crystals a red coating and leaves the dolomite crystals clear. The small amount of siderite also believed to be present in the sandstones, was counted as dolomite. The clastic carbonate contents of the sandstones are reported as one entity (CO_3) in table 12.

In the post-Kneehills sandstones clastic carbonate grains are mainly present as polycrystalline aggregates or as single rhombohedral cleavage fragments (Pl. 3, Fig. 2; Pl. 4; Pl. 8, Fig. 2). Most of the carbonate grains have been abraded and, in contrast to the other detrital grains, show varying degrees of rounding.

Carbonate grains are most abundant (17%) in the uppermost post-Kneehills sandstones of southwestern Alberta (Porcupine Hills Formation) and least abundant in the lowermost post-Kneehills sandstones of southeastern Alberta (Ravenscrag Formation). In central and southwestern Alberta sandstones from Ravenscrag-equivalent beds (Paskapoo and Willow Creek Formations) average 5 and 7 per cent clastic carbonate respectively.

The geographic distribution of clastic carbonate grains in the post-Kneehills sandstones shows a general increase in amount from east to west and from north to south (Fig. 18). There appears to be no marked change in clastic carbonate content at the formation boundaries but an increase in the volume of clastic carbonate from the oldest to the youngest strata is evident. This increase is illustrated by the well data (Fig. 11) which shows a low but erratic distribution in the lower part of the Paskapoo Formation in R.C.A. Corehole 65-1 and a uniformly higher percentage in the Porcupine Hills Formation in R.C.A. Corehole 66-1. Concomitant with the increase in total clastic carbonates is an increase in the number of limestone fragments. For example, in the lower Paskapoo sandstones dolomite grains are twice as abundant as calcite grains, whereas they are about equal in number in the Porcupine Hills sandstones of southwestern Alberta and the upper Paskapoo sandstones of central Alberta.

The percentage of clastic carbonate grains shows a significant positive correlation with pore space in sandstones of the Porcupine Hills Formation and significant negative correlations with the percentages of rock fragments and volcanic rock fragments in sandstones of the Paskapoo Formation (Table 5). The correlation between clastic carbonates and pore space may be geologically significant, but the negative correlations with the rock fragments in the Paskapoo sandstones probably arise from use of percentages in the analyses.

The grain-size distributions of the clastic carbonate grains in the Paskapoo and Porcupine Hills Formation sandstones (Figs. 9, 10) are similar to those of the quartzose grains. However, in the Porcupine Hills Formation the clastic carbonate content of the sandstones shows a significant negative statistical correlation with grain size (Table 5) which indicates that clastic carbonates are on the average more abundant in the finer-grained sandstones than in the coarser-grained sandstones. This correlation should be compared with the high positive correlation between chert content and grain size in the same formation. If it is assumed that chert and clastic carbonates are derived from the same source rocks, then it can be deduced from these correlations that the chert fragments were sorted out and deposited in coarser-grained sands than the limestone and dolomite fragments.

Micas

Detrital micas are not commonly present in large quantities in sandstones; thus, they are regarded as accessory minerals. Micas occur in a variety of forms in sedimentary rocks, but for point-counting purposes they are defined as monocrystalline flakes which in transverse section have an elongated shape, perfect basal cleavage, and high birefringence. A threefold subdivision into colorless, brown, and green varieties is convenient, the colored flakes exhibiting pleochroism with maximum absorption parallel to the cleavage. These subclasses do not have strict mineralogical relevance, but they are believed to approximate to muscovite, biotite, and chloritized biotite. In heavy mineral separations the colored varieties (biotite) sink and the colorless varieties (muscovite) float, thus lending some substance to the belief that different colors denote different micaceous minerals.

Because of their flaky habit micaceous minerals exhibit a different hydraulic behaviour to the other detrital minerals, which results in accumulation of thin micaceous layers at the water sediment interface. These layers become the bedding planes in sedimentary rocks. In a sandstone, mica flakes have two dimensions significantly greater than the other detrital grains and because of this they are commonly deformed by differential intergranular pressures and squeezed into pores. Kink banding induced by extreme pressure is frequently encountered in deformed biotite flakes in sandstones.

Micas in sedimentary rocks can be derived from granites, or schists, in which case they are transported to the site of deposition by water, or they can be derived from volcanic ejecta, in which case they may be airborne most of the way to the site of deposition. Mica of pyroclastic origin is mainly biotite and is recognized by its hexagonal outline and inclusions of apatite. Water-transported mica commonly has a rounded or ragged shape.

In the post-Kneehills sandstones all three colored varieties of mica are present. The colorless and brown mica flakes have a fresh appearance, whereas the green variety shows alteration products and may represent the first stage in the alteration of biotite to chlorite. Between 10 and 20 per cent of the biotite flakes in the heavy mineral grain mounts exhibit hexagonal faces, which suggests that they are of volcanic origin.

Because of the small amounts of micas present and their erratic distribution within sandstones due to sorting, only total mica counts are shown in table 12. The stratigraphic distribution of micas is shown in figure 11 from which it can be seen that they are most abundant in the Paskapoo Formation and least abundant in the Porcupine Hills Formation. The average mica content of the Paskapoo and Willow Creek Formation sandstones is 1.5 per cent, and the Porcupine Hills Formation

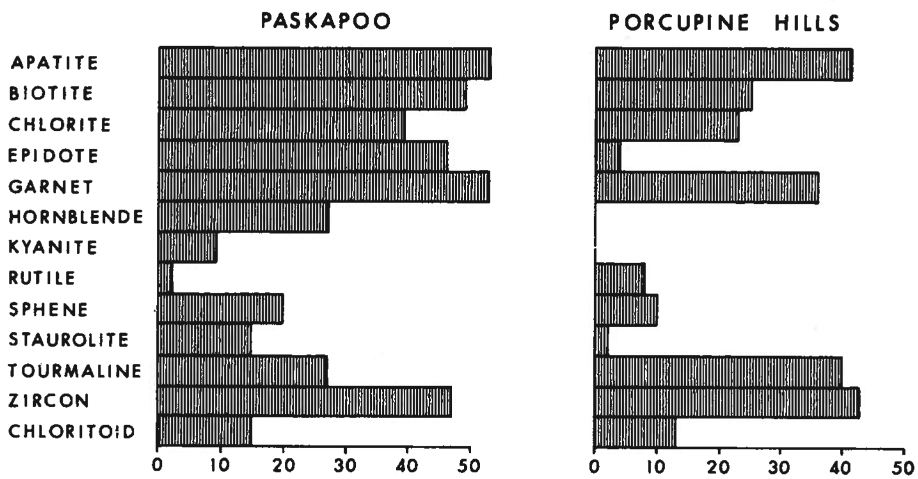


FIGURE 19. Sample frequency distribution of heavy minerals in sandstones of the Porcupine Hills and Paskapoo Formations.

sandstones average less than 0.5 per cent. Some sandstones in the lower part of the Paskapoo Formation contain as much as 8 per cent mica, and in these the flakes are more equidimensional in transverse sections due to greater thickness. Insufficient data are available to map the distribution of the varieties of detrital mica but preliminary counts on a number of thin sections indicate that brown mica is the most common variety in the Porcupine Hills Formation, whereas green and brown varieties predominate in the Willow Creek and Ravenscrag Formations and colorless and brown varieties in the Paskapoo Formation.

Heavy Minerals

Accessory "heavy" minerals (s.g. >2.9) are a minor constituent in sandstones, but because of their widespread distribution and their resistance to erosion and abrasion, they are useful for identification of source rocks and for stratigraphic correlation. The assemblage of heavy minerals in a sedimentary rock is ultimately derived from igneous and metamorphic rocks and is concentrated by a process of sorting, based on weight and size, in the finer sand-size fraction. The first cycle of erosion of an igneous rock releases a suite of stable and unstable heavy minerals in the form of cleavage fragments and single crystals; however, after passing through several cycles of erosion only a few resistant stable minerals remain.

The high specific gravity of heavy minerals causes them to be concentrated by currents into depressions and along bedding planes. This erratic distribution within a sandstone body makes fluctuations in the proportions of heavy mineral species difficult to interpret; nevertheless, heavy mineral assemblages can be of great assistance in correlation and provenance studies when used in conjunction with other petrographic data.

The most common nonopaque heavy minerals in each formation of the post-Kneehills stratigraphic units are listed below in alphabetical order:

Porcupine Hills	*Paskapoo*	*Willow Creek*	*Ravenscrag*
Apatite	Apatite	Apatite	Apatite
Biotite	Biotite	Biotite	Biotite
Chlorite	Chlorite	Chlorite	Chlorite
Chloritoid	Chloritoid	Epidote	Epidote
Garnet	Epidote	Garnet	Garnet
Rutile	Garnet	Sphene	Hornblende
Sphene	Hornblende	Tourmaline	Rutile
Staurolite	Kyanite	Zircon	Tourmaline
Tourmaline	Rutile		Zircon
Zircon	Sphene		
	Tourmaline		
	Zircon		

There is little difference in the minerals present in the four formations except for the absence of epidote and hornblende from the Porcupine Hills Formation sandstones. However, examination of the nonopaque heavy mineral fractions of the post-Kneehills succession shows that two distinct suites are present. The Porcupine Hills Formation heavy mineral suite is characterized by abundant, well-rounded zircon, tourmaline, and apatite, whereas the Paskapoo Formation suite is dominated by euhedral biotite, zircon, and apatite together with epidote and hornblende. The Porcupine Hills suite is comprised of resistant, second-cycle, stable heavy-mineral grains, and the Paskapoo suite is an unstable assemblage derived from a volcanic source.

Apart from the difference in habit and abundance of nonopaque heavy minerals common to both suites, the most significant difference is in the distribution of epidote and hornblende. A bar diagram showing the sample frequency distribution of heavy minerals in sandstones of the two formations is shown in figure 19. Epidote is present in 46 of 53 sandstones from the Paskapoo Formation but in only 6 out of 40 sandstones from the Porcupine Hills Formation. Similarly, hornblende is present in half of the Paskapoo Formation sandstones and absent from all of the Porcupine Hills Formation sandstones.

A map showing the distribution of epidote and hornblende (Fig. 20) based on outcrop samples, indicates how closely the distribution of these two minerals corresponds to the formation boundaries established by field lithologic criteria. One notable feature is the presence of an interval containing both hornblende and epidote near the eastern outcrop in central Alberta. This interval coincides more or less with the projected outcrop area of post-Kneehills Edmonton Formation strata (member E of Ower, 1960)[1] but it appears to be insufficiently defined for use as a formation boundary. The area underlain by sandstones containing only epidote corresponds to known outcrops of the Paskapoo and Willow Creek Formations, and the area in which both epidote and hornblende are absent corresponds to the area of outcrop of known or suspected Porcupine Hills Formation beds. Several sandstone outcrops along the western boundary of the Plains region adjacent to the disturbed belt contain epidote and hornblende; these are believed to be Paskapoo-equivalent beds brought to the surface on the western limb of the syncline (Fig. 3).

Hornblende and epidote are both present in the Ravenscrag Formation of southeastern Alberta, suggesting a correlation with the lower Paskapoo beds as defined here.

Another feature of the post-Kneehills heavy mineral suites is the variation in the amounts of zircon. Zircon is rare in the Paskapoo and Ravenscrag Formations of central and southeastern Alberta but abundant in the Willow Creek and Porcupine Hills Formations of southwestern Alberta. In addition to the difference in amounts there are variations in the proportions of three varieties of zircon (Table 6). Paskapoo Formation sandstones yield mainly small colorless, idiomorphic crystals whereas the Willow Creek and Porcupine Hills Formation samples yield zircons that are mostly well rounded. The idiomorphic zircons are derived probably together with the associated biotite and hornblende from pyroclastic debris, and the rounded zircons are undoubtedly from a sedimentary source rock, having passed through several previous cycles of deposition.

Table 6. Percentages of Zircon Varieties in Post-Kneehills Sandstones

Formation	Zircon variety (%)		
	Rounded	Idiomorphic	Nonrounded Nonidiomorphic
Paskapoo	21	55	24
Willow Creek	41	22	37
Porcupine Hills	51	29	20

[1]Scollard Member of the revised Paskapoo Formation (Carrigy, 1970)

Matrix

Krynine (1948) used the term "matrix" to describe fine-grained detrital constituents deposited within the granular framework of a sedimentary rock. In conglomerates the matrix is sand-sized material, in sandstones the matrix is silt-sized material, and in siltstones the matrix is clay-sized material. Matrix is thus a relative textural concept and is independent of the composition and absolute size of the framework grains. Prior to the usage of the word in the above context by Krynine, "matrix" was defined in Webster's Dictionary as "something within which something else originates, takes form or develops or is embedded". The word is derived from the latin *mater* (mother) and implies growth within or birth from. Igneous petrologists use the term in the dictionary sense to describe the groundmass of a porphyry. Carbonate petrologists have used the term in both senses; for example, Plumley *et al.* (1962) defines matrix as the material in which any sedimentary particle is embedded. However, Folk (1962) uses the term "micrite" to refer to the matrix of a carbonate rock, and Leighton and Pendexter (1962) have suggested using the word matrix for the interstitial material, whether this interstitial material be smaller grains, lime mud, or cement. It is obvious from the foregoing examples that the usage of the term matrix has not been standardized, and the introduction of the word into sedimentary petrology as a textural term by Krynine in a manner completely foreign to its etymology is to be regretted. Nevertheless, the word is now generally accepted by sedimentary petrologists as a textural term and has been incorporated into the nomenclature of sedimentary rocks (Pettijohn, 1957: Crook, 1960).

Even if the definition of matrix given by Krynine is accepted, considerable practical difficulty is experienced in deciding what to call matrix during a point-count analysis of a thin section. Griffiths (1960) has discussed the problem and proposed that the term be used to describe those constituents not readily classifiable during point-counting. He concludes that the class name "miscellaneous" is more correct and less misleading. Unfortunately, such a solution to the problem does not help in understanding the processes leading to lithification of sandstones, which often is one of the objectives of a petrographic examination. Cummins (1962) has pointed out that the origin of the "paste" or "matrix" is the key to the "greywacke problem" and has argued that the matrix of greywackes must be the result of post-depositional alteration of "normal" detrital material.

In view of the confused state of the terminology used to describe the interstitial material in sedimentary rocks, it is pertinent to examine the sequence of events which lead to the lithification of "clean" and "muddy" sandstones. All sands when deposited have a high proportion of voids or pore space which is occupied by water in "clean" sands or mud (finer sediment) in "dirty" sands. But even the muddiest of sands has considerable void space when dried. In clean sands with strong rigid grains, the initial pore space may be filled subsequently by a chemically precipitated mineral cement bearing no chemical similarity to the surrounding grains, or the pore space may be destroyed by simultaneous solution at the grain contacts and precipitation of chemically similar cements in the adjacent voids.

However, if some of the grains of sand are plastic, compaction after burial may squeeze these grains into the surrounding voids. Or, if the rock has a heterogeneous mineral composition, some of the chemically unstable grains may be altered to plastic minerals and then squeezed into the voids on burial. In a muddy sand the interstitial clay or silt particles of near colloidal dimensions may migrate to nearby grain surfaces and be adsorbed onto them or they may be dissolved in circulating water. Alternatively, they may remain unaltered within the pores to be admixed with a later deposited mineral cement.

It is not difficult to identify a mineral cement in a sandstone if it has optical properties distinct from those of the grains, e.g. carbonate cement in a quartz sandstone. Recognition of quartz cement in a quartz sandstone and calcite cement in a calcarenite are more challenging problems, although relatively simple compared with the task of deciding what to call "matrix" in a poorly sorted sandstone containing volcanic rock fragments altered to chlorite and montmorillonite with quartz, chlorite, montmorillonite, and zeolite cement. After examination of many greywacke-type sandstones, and bearing in mind that clay mineral cements are common (Carrigy and Mellon, 1964), the writer has concluded that the intergranular void space in sandstones may be reduced or destroyed in one of the following ways:

(a) by primary deposition, such as by sand in gravel, and by organic matter and clay in siltstones;
(b) by squeezing of plastic grains between rigid grains due to intergranular pressure after burial;
(c) by chemical alteration of rigid grains to plastic minerals, which are subsequently deformed by intergranular pressures;
(d) by growth of one or more mineral cements in the voids (the crystal size of minerals is rarely an indication of an early *versus* a late origin for the intergranular mineral);
(e) by simultaneous solution at grain contacts and precipitation in adjacent voids;
(f) by metasomatic replacement of the original interstitial material by another mineral or minerals;
(g) by recrystallization of the original interstitial material into larger crystals of the same mineral.

How to distinguish among the effect of these processes is a problem analogous to unravelling the paragenesis of mineral crystallization in igneous and metamorphic rocks, and progress will depend, firstly, on the recognition that a problem exists and, secondly, on the accumulation of records of careful petrographic studies of thin sections of sedimentary rocks. In particular, re-examination is urgently required of the "matrix" of so-called "greywackes" to determine if possible what processes have resulted in the lithification of this group of sandstones. It is conceded that in many sandstones the origin of the interstitial material will remain problematical, but undoubtedly in many others, techniques exist for determining the nature and sequence of lithification processes.

In this report, the term matrix is used only where it is not possible to identify the interstitial clay-size material as a mineral cement on the basis of compositional and textural criteria such as intergrowth relationships. This situation arises generally in the finer-grained rocks. In most of the sandstones, the interstitial clay minerals possess a distinct layer structure analogous to the infilling of a vug, the mineral paragenesis being determined by the order of deposition outward from the grain boundary toward the center of the void. Voids containing one, two and even three mineral layers are not uncommon in these rocks (Carrigy and Mellon, 1964) (e.g. Pl. 5).

Cements

Quartz

Quartz cement as overgrowths in optical continuity with clastic quartz grains is common in the Porcupine Hills and Willow Creek Formation sandstones and uncommon in the Paskapoo and Ravenscrag Formation sandstones. The overgrowths commonly develop crystal faces but do not grow large enough to reduce significantly the porosity of the rocks. No estimate of the quantity of secondary quartz has been made because of the difficulty in determining grain-overgrowth boundaries.

Overgrowths on quartz grains are common in quartzose sandstones, and most petrographers agree that they are one of the first cements to be precipitated. In the Porcupine Hills and Willow Creek sandstones quartz overgrowths appear to have preceded all other cements. There is no evidence of corrosion or replacement by calcite, and many grains have crystal faces in contact with the calcite cement (Pl. 6, Figs. 1, 2).

Calcite

Calcite is the most common mineral cement in the post-Kneehills sandstones. Scattered calcite-cemented layers from a few inches to a few feet in thickness are found in many apparently massive sandstones beds. In the Paskapoo and Ravenscrag Formations, sandstones are either friable or completely cemented with calcite, partial cementation being rare, whereas calcite cementation in nearly all Porcupine Hills and Willow Creek Formation sandstones is incomplete.

Calcite cement is present as small anhedral crystals in most sandstones (Pl. 7, Fig. 1). In some of the coarser-grained sandstones calcite cement is in optical continuity over areas of several square millimeters. The numbers of crystals formed during cementation may be related to the number of seed crystals available. In those sandstones containing a high proportion of clastic carbonate grains, minute cleavage fragments may have been relatively common providing many nucleation centers for the simultaneous growth of numerous small crystals. In sandstones free of calcite, widely spaced growth centers probably developed spontaneously, allowing fewer but larger crystals to grow. Most of the calcite cement is not in optical continuity with clastic calcite grains which suggests that the larger grains do not act as growth centers for calcite crystallization. Also, the clastic grains show no evidence of corrosion, indicating that they are not being dissolved and reprecipitated as cement.

In some sandstones calcite has developed as fan-shaped, radial crystal aggregates which show spherulitic extinction (Pl. 7 Fig. 2). In these samples calcite is very abundant (39 per cent) and metasomatic replacement is evident. It is possible that this structure is characteristic of replacement cements; similar structures are observed in anhydrite that replaces dolomite (Carozzi, 1960, p. 435).

In the Porcupine Hills Formation sandstones, the amount of calcite cement shows a significant positive correlation with feldspar content (Table 5), the geological significance of which is not evident. In the Paskapoo Formation calcite content shows a significant negative correlation with nonvolcanic rock fragments, which association may indicate preferential metasomatic replacement of this material in this formation. Significant negative correlations with montmorillonite cement and pore space indicate that most of the calcite is being deposited between the grains.

Calcite shares the intergranular space in these sandstones with clay mineral and zeolite cements and there is no textural evidence that would indicate a consistent paragenetic relationship to the other pore-filling minerals. It is probable that calcite cementation and metasomatism were active throughout the entire post-depositional history of these sandstones.

Kaolinite

Kaolinite is a white, alumino-silicate clay mineral commonly formed at relatively low temperatures and pressures from the alteration of feldspars and micas. Also, kaolinite can be precipitated from circulating formation waters in the pores of sandstone, forming a true chemical cement. It is surmised here that the abundance of authigenic kaolinite cement in the post-Kneehills sandstones of Alberta is related to the breakdown of volcanic (pyroclastic) glass, which process released an excess of alumina and silica into the formation waters.

Authigenic kaolinite is recognized in thin sections of sandstones by its microcrystalline habit and low birefringence. It resembles superficially microcrystalline chert but differs from chert in having a higher refractive index than Canada balsam and higher relief. The optical identification of kaolinite in these rocks has been confirmed by X-ray microcamera patterns taken *in situ* and by X-ray powder patterns of clay mounts (Carrigy and Mellon, 1964).

Authigenic kaolinite is most common in the Porcupine Hills Formation sandstones, although patches of interstitial kaolinite can be found in most post-Kneehills sandstones (e.g. Pl. 8, Fig. 1; Pl. 5, Fig. 3). The average authigenic kaolinite content of the Porcupine Hills Formation sandstones is 2.5 per cent, which is about four times the average content of the Paskapoo Formation sandstones (0.6%). The stratigraphic distribution of authigenic kaolinite in cored sections of these formations is shown in figure 11.

The distribution of kaolinite appears unrelated to detrital sandstone composition (Table 5), being found in rocks rich in volcanic detritus and in rocks low in volcanic detritus. With respect to cements it is commonly associated with authigenic quartz and calcite, but also fills the central portions of pores lined with chlorite in some sandstones. The textural evidence from these rocks indicates that kaolinite is the last clay mineral to be precipitated in the pores, being preceded by montmorillonite and chlorite in every case where both are present.

Chlorite

Chlorite is a green iron- and magnesium-rich, alumino-silicate mineral known to be stable at elevated temperatures and pressures. Authigenic chlorite is present in microcrystalline form in the post-Kneehills sandstones as a secondary replacement of volcanic rock fragments and as a fibrous growth in the pores. In thin sections chlorite is recognized by its light green color and low birefringence and by its refractive index, which is greater than that of Canada balsam. The optical identification has been confirmed by X-ray microcamera patterns taken *in situ* and by X-ray powder patterns of clay mounts (Carrigy and Mellon, 1964). No data on the chemical composition of the chlorite is available.

Authigenic chlorite averages about 0.8 per cent by volume in the Paskapoo Formation sandstones and is virtually absent from the Porcupine Hills Formation sandstones. Authigenic chlorite and montmorillonite where present in the same sandstones tend to be physically separated; if one is present in altered volcanic rock fragments the other forms the pore lining or *vice versa*. Where very abundant, chlorite may form a continuous groundmass or "matrix" which shows compaction features that indicate that it is one of the early diagenetic minerals. Chlorite-lined pores may be filled with kaolinite or calcite (Pl. 5, Fig. 2), but many are empty (Pl. 5, Fig. 1).

Montmorillonite

Montmorillonite (*sensu lato*) is a greenish iron magnesium alumino-silicate clay mineral with readily exchangeable calcium and sodium cations. It is characterized by its expandable lattice and high sensitivity to water. Formed from the breakdown of volcanic glass, montmorillonite is common throughout the post-Kneehills succession, in which it is found as bentonite beds, in bentonitic siltstones, and as a cement in sandstones. The stratigraphic distribution of montmorillonite in sandstones from cored sections of the post-Kneehills formations is shown in figure 11.

In the post-Kneehills sandstones montmorillonite is present as an alteration product of detrital volcanic grains and as a pore lining. The pore lining takes the form of a thin fibrous film, yellowish-brown to green in color, with "pin point" extinction and moderate birefringence (first order yellow). The optical identification has been verified by X-ray microcamera and staining techniques (Carrigy and Mellon, 1964).

The average montmorillonite content of the Paskapoo sandstones is 6.1 per cent, and of the Porcupine Hills sandstones, 2.4 per cent. The montmorillonite content in the Porcupine Hills sandstones shows no correlation with variation in composition, grain size, or pore space (Table 5) but in the Paskapoo sandstones shows a significant negative correlation with grain size, which supports the observation that montmorillonite forms the groundmass in many fine-grained rocks.

The negative correlations with calcite and pore space in the Paskapoo sandstones support the textural evidence that most of it is present interstitially and not as an alteration product of detrital grains.

Zeolites

Clinoptilolite (K_2Na_2 $[Al_2Si_7O_{18}]$. $6H_2O$), the silica rich variety of heulandite, has been identified as a cement in sandstones from the Paskapoo Formation at five localities in west-central Alberta. In addition to its presence as continuous cement, small crystals of clinoptilolite are found in most of the Paskapoo sandstones.

Clinoptilolite is recognized by its low refractive index (1.478) and by its low birefringence. Small crystals of it can be easily confused with authigenic potash feldspar. The optical identification has been confirmed by X-ray powder patterns and chemical analyses of purified samples.

The literature on zeolites in sedimentary rocks has recently been reviewed by Hay (1966), from which it is evident that clinoptilolite is a common alteration product in the diagenesis of tuff but has not been widely recognized in less volcanic sediments by North American petrologists. In the United States clinoptilolite in sandstones has been described by Spotts (1964) and Wermund and Moiola (1966), and the authigenic heulandite described by Gilbert and McAndrews (1948) in sandstones from California undoubtedly would now be called clinoptilolite.

In west-central Alberta clinoptilolite cement is found in sandstones from the McLeod River damsite cores (Tp. 57, R. 13, W. 5th Mer.), 100 miles west of Edmonton, in the Red Deer River valley (Tp. 39, R. 27, W. 4th Mer.), in the Wintering Hills (Tp. 26, R. 21, W. 4th Mer.), in southern Alberta at Hammer Hill, (Tp. 23, R. 23, W. 4th Mer.), and at two localities in the Bow River valley (Tp. 21, Rs. 26 and 28, W. 4th Mer.) near Calgary. At all of these localities clinoptilolite is associated with montmorillonite. In sample MRD-1- 40 from McLeod River Corehole No. 1 randomly oriented, fibrous crystals completely fill the centers of voids lined with montmorillonite (Pl. 9). At Hammer Hill north of Stobart (sample 773), a few crystals of fibrous clinoptilolite are present in otherwise empty pores lined with montmorillonite. In sample 897A, from the Red Deer River valley, the intergranular area is filled with single crystals of clinoptilolite. In other parts of this sandstone, clinoptilolite has replaced the groundmass of volcanic rock fragments and has grown in some of the feldspar grains and filled up all cracks. Sample 886, from the Bow River valley, contains an interstitial groundmass composed of an intimate mixture of clinoptilolite and montmorillonite. In this thin section it appears that the clinoptilolite is replacing the montmorillonite. In sample 774, from the Wintering Hills, kaolinite and clinoptilolite are found together in the central area of montmorillonite-lined voids (Pl. 10), but unfortunately no clear textural evidence exists as to the paragenetic relationship between these two constituents.

The meager data available on the distribution of clinoptilolite cement in the Paskapoo Formation sandstones suggest that it is more common in porous sandstones close to the outcrop face than in the main sandstones body. It is clearly unrelated to hydrothermal activity but does seem to be confined to rocks with a high proportion of volcanic detritus. The available evidence suggests that the transformation from volcanic glass to montmorillonite to clinoptilolite has taken place in these rocks at or near the surface at low temperatures and pressures.

Pore Space

Inasmuch as the post-Kneehills rocks of Alberta are poorly lithified, pore space is of considerable value in assessing the potential of these rocks as aquifers or oil reservoirs. Although every effort has been made to minimize the loss of interstitial material during the preparation of the thin sections (by impregnation and dry grinding) some overestimation of the true porosity is to be expected, and the figures given in the petrographic tables should be regarded as maximum values for the pore space. The stratigraphic distribution of pore space is given in figure 11.

Miscellaneous

This category includes unidentifiable rock fragments, heavy minerals, opaque minerals, vegetable matter, and so on. In some fine-grained rocks this class is assigned a high proportion of the constituents, in which case it is an indication that the limits of identification by light microscope are being approached.

LITHOSTRATIGRAPHY

Lithology

The main objective of this investigation is to determine whether the post-Kneehills succession of the central Alberta Plains can be divided into mappable, lithostratigraphic units and, if so, how these units correlate with the latest Cretaceous-Paleocene strata of southwestern Alberta. Prior to this study, the post-Kneehills succession of the central Plains was divided into a lower unit about 200 feet thick called "member E" of the Edmonton Formation (Ower, 1960) and an upper unit, the overlying Paskapoo Formation, from zero to 4,000 feet thick. Member E was defined as extending from the top of the Kneehills Member to the base of the first thick sandstone unit above the Ardley coal interval; the Edmonton Formation was thought by Allan and Sanderson (1925, 1945) to be separated from the overlying Paskapoo Formation by a major unconformity. More recent surface- and subsurface stratigraphic work has failed to verify the existence of a significant unconformity in this succession (Ower, 1960; Elliot, 1960), and a new basis for subdivision must be sought.

The approach used here is to compare variation in sandstone composition of beds from just below the Kneehills Member to the approximate upper boundary of the Paskapoo Formation with the sandstone composition of equivalent beds in southern Alberta (Ravenscrag, Willow Creek and Paskapoo Formations). The major problem in using this approach is the lack of stratigraphic continuity of section in central Alberta; although many outcrops of Paskapoo Formation are present in the Edmonton and Red Deer areas, few are greater than 50 feet in height (most are considerably less), and these are scattered over a wide area (Map 32). An exception is found in the lower part of the section, between the Kneehills Member and the top of the Ardley coal interval which is well exposed along the Red Deer River valley near Ardley. A more complete section is found in the upper 140 feet of R.C.A. Corehole 65-1 (Fig. 21) and in the composite 345-foot interval cored in the McLeod River damsite coreholes (Fig. 22). From these "standard" sections, sandstones have been obtained and point-counted (Table 12, Fig. 23), permitting a study of compositional changes across the Edmonton-Paskapoo Boundary of Allan and Sanderson, and variation in sandstone composition of beds in west-central and southern Alberta.

Comparisons of the proportions of chert, volcanic rock fragments and clastic carbonate detritus in sandstones above and below the top of the Ardley coal interval are shown in figure 1 *in* Carrigy (1970) which shows that considerable overlap exists in the proportions of the three constituents; this is confirmed by the variability of the same three components in sandstones from outcrops of the Paskapoo Formation (Fig. 24). Although the sandstones between the Kneehills and the top of the Ardley interval are lithologically similar to those in the Edmonton Formation below the Kneehills Member, the point-count data alone are not sufficient to provide a basis for putting them in a stratigraphic unit separate from the overlying sandstones (basal Paskapoo beds of previous investigators). In the

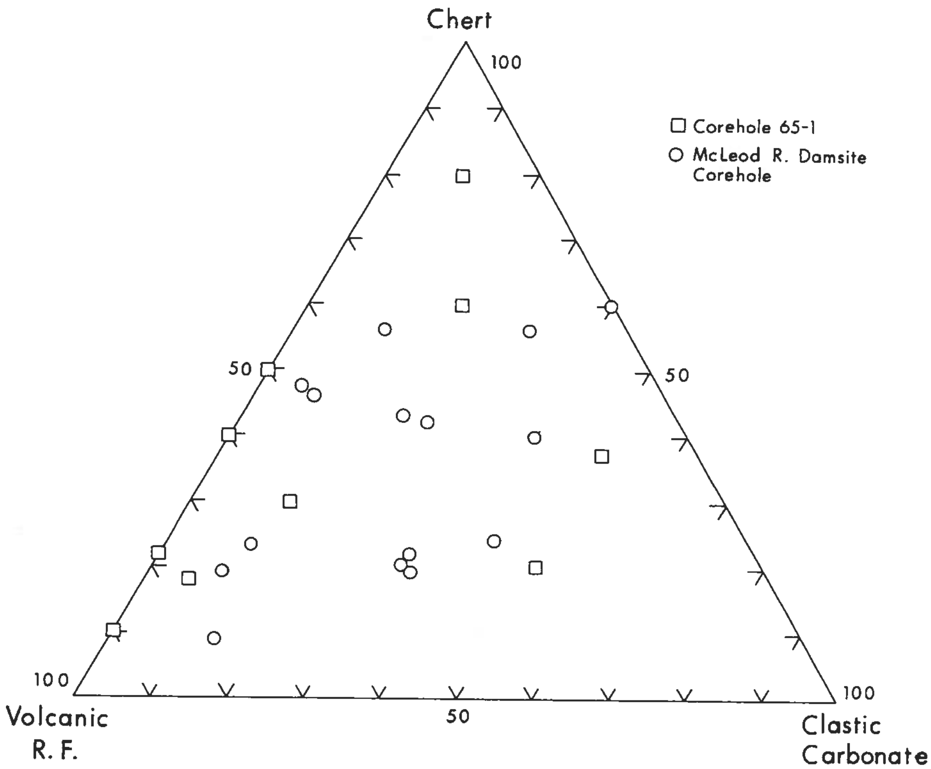


FIGURE 23. Proportions of chert, volcanic rock fragments and clastic carbonate grains in sandstones from above and within the Ardley coal interval in R.C.A. Corehole 65-1 and the McLeod River damsite coreholes.

absence of any other positive data to support a formation boundary at this level, the boundary of the Paskapoo must be lowered to the top of the Kneehills Member to give it valid formational status (cf. recommendations of the American Commission on Stratigraphic Nomenclature, 1961). The lowering of the base of the Paskapoo Formation to the top of the Kneehills Member of the Edmonton Formation allows the redefined formation to be equated with the Willow Creek Formation (Table 2). Also, the Kneehills Member is a widespread, lithologically distinctive, isochronous stratigraphic unit that marks a natural break in the uppermost Cretaceous succession of the Alberta Plains and thus is eminently suitable to use as a formation boundary.

Qualitative data obtained during the course of petrographic examinations of thin sections of sandstones below and above the Kneehills Member in central Alberta indicate that there is less volcanic detritus in the younger than in the older

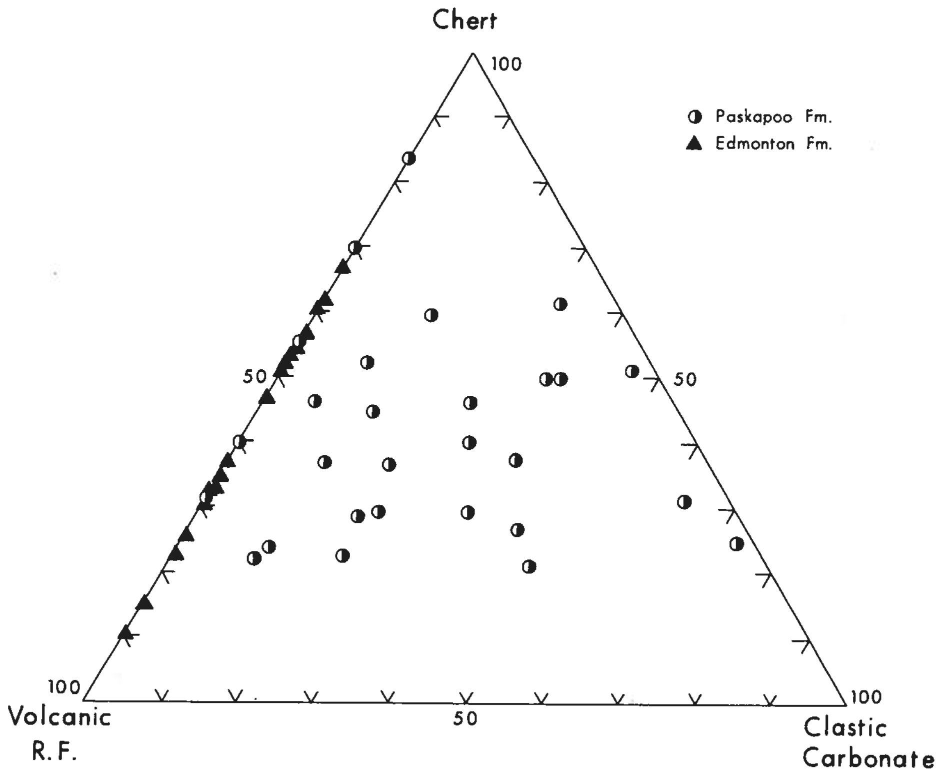


FIGURE 24. Proportions of chert, volcanic rock fragments and clastic carbonate grains in sandstones from the Edmonton and Paskapoo Formations in central Alberta.

beds. A plot of the relative proportions of quartz, volcanic detritus, and nonvolcanic rock fragments in sandstones below the Kneehills Member (Edmonton Formation) and above the Kneehills (Paskapoo Formation), together with the Porcupine Hills Formation sandstones (Fig. 25), confirms these indications, but the broad subdivisions used for the end members on this diagram do not separate the sandstones of the three formations into distinct groups.

Closer examination of the data reveals that clastic carbonate grains are rare in the Edmonton Formation sandstones (i.e. below the Kneehills Member) and that volcanic rock fragments comprise less than 10 per cent of the clastic constituents in the Porcupine Hills Formation sandstones. On a ternary diagram showing the proportions of chert, clastic carbonates, and volcanic rock fragments, the sandstones below the Kneehills Member (Edmonton Formation) (Fig. 24) plot along one side of the triangle, whereas the sandstones of the Porcupine Hills

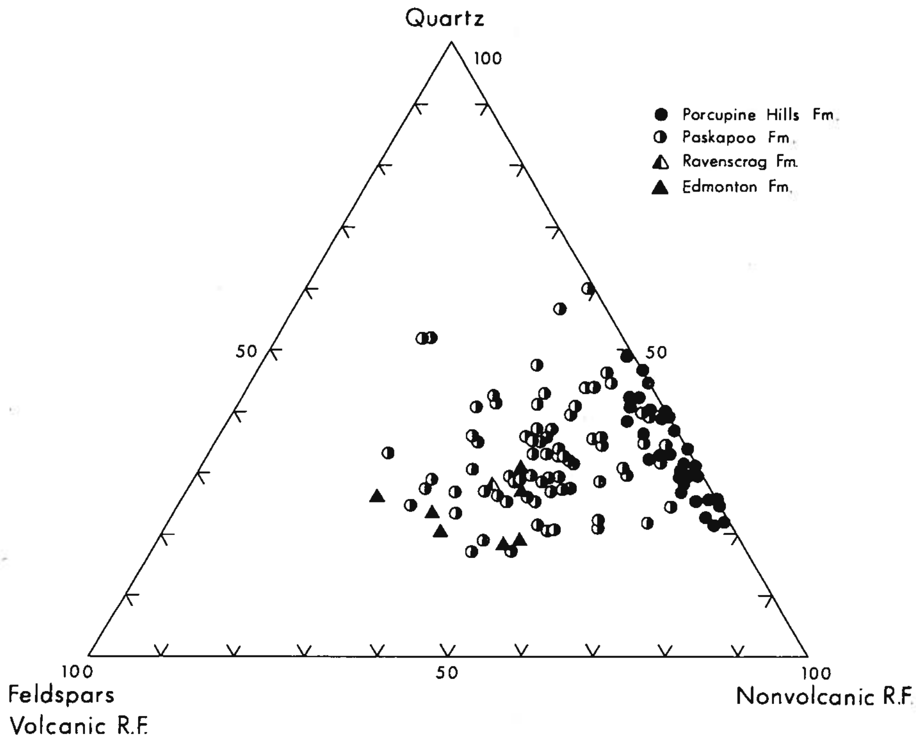


FIGURE 25. Proportions of quartz, volcanic detritus (feldspar grains and volcanic rock fragments), and nonvolcanic detritus (rock fragments, chert, mica and clastic carbonate grains) in sandstones from the Porcupine Hills, Paskapoo, Edmonton and Ravenscrag Formations.

Formation are close to or along the other side of the triangle (Fig. 26). The central area of the triangle (Fig. 24) is occupied by the Paskapoo Formation sandstones (above the Kneehills Member and below the Porcupine Hills Formation). Thus, knowledge of the proportions of these three constituents is sufficient to place a post-Kneehills sandstone from the central Plains into either the newly defined Paskapoo Formation or the Porcupine Hills Formation. However, the petrographic data (Figs. 23-27) emphasize the transitional nature of the post-Kneehills but pre-Porcupine Hills sandstones (i.e. Paskapoo sandstones) and the futility of trying to establish a lithologic boundary within them.

In southwestern Alberta post-Kneehills strata are divided into the Willow Creek and Porcupine Hills Formations. The proportions of chert, volcanic rock fragments, and clastic carbonate detritus in the type area of the Porcupine Hills Formation are shown in figure 26. Comparison with equivalent data for the Willow Creek and St. Mary River Formations indicates that the sandstones in the three formations have very similar lithologies, and, as previous workers have found, there is little basis for a stratigraphic subdivision based on sandstone composition in the southern Plains east of the Porcupine Hills. This suggests that there is a distinct southern facies of nonvolcanic sediment and a northern facies of volcanic sediment in the uppermost Cretaceous and Tertiary strata of the Alberta Plains. Thus, in the vicinity of Calgary

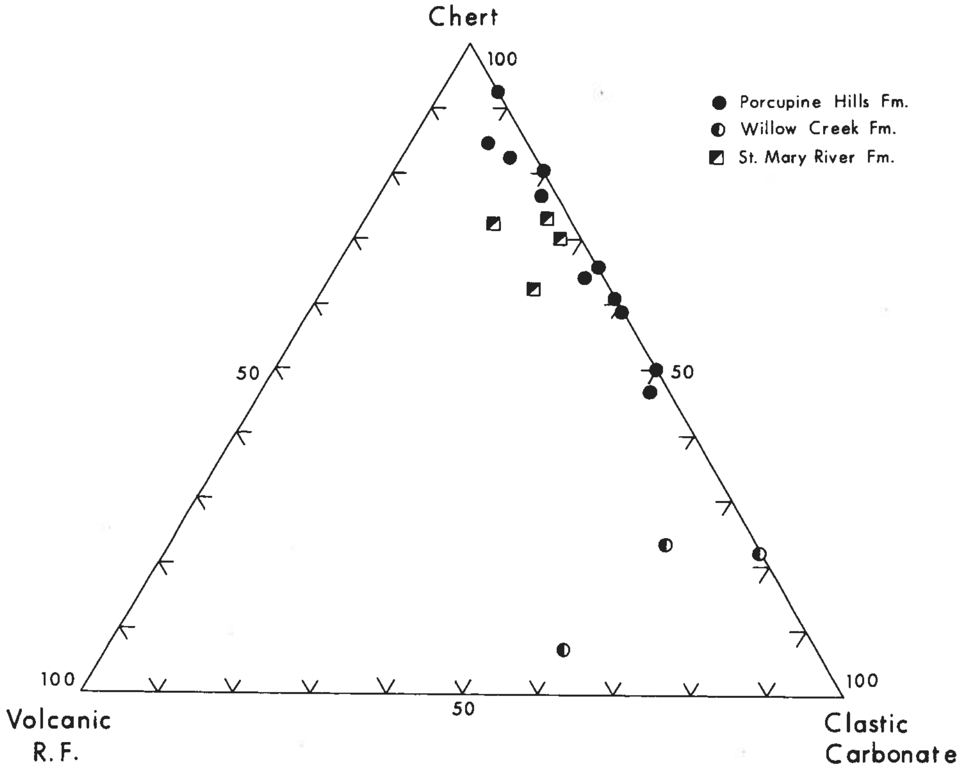


FIGURE 26. Proportions of chert, volcanic rock fragments and clastic carbonate grains in sandstones from the Porcupine Hills, Willow Creek and St. Mary River Formations in southwestern Alberta.

the Willow Creek sandstones are replaced in the stratigraphically equivalent position by sandstones containing a much greater proportion of volcanic rock fragments, although these beds are overlain in this area by strata containing sandstones indistinguishable from the Porcupine Hills Formation sandstones of the type area. This means that a distinct break exists in the composition of outcrop sandstones collected in the Calgary area, which could form the basis for subdivision of the post-Kneehills succession there into an upper, Porcupine Hills-equivalent formation, and a lower, Paskapoo-equivalent formation. The boundary between these two units occurs at an elevation of approximately 3,500 feet in the Calgary area (Fig. 27).

Because the interval where the contact between the two formations should be exposed is covered in the Bow River valley, it was planned to take core across the boundary in R.C.A. Corehole 66-1, 9 miles north of Calgary. However, as

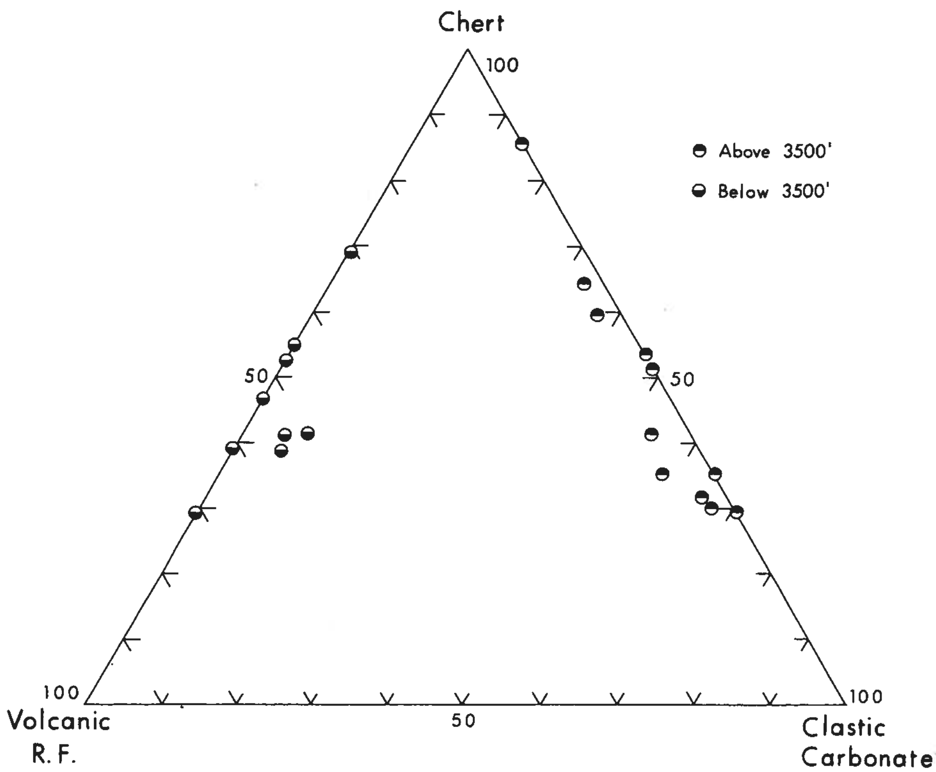


FIGURE 27. Proportions of chert, volcanic rock fragments and clastic carbonate grains in sandstones from the Calgary area, subdivided on the basis of elevation.

mentioned in a preceding section of this report, an unexpected thickness of Porcupine Hills strata was encountered in this well, and the Paskapoo-equivalent beds must therefore be below an elevation of 3,000 feet.

If this interpretation is accepted, the upper surface of the Paskapoo Formation is not a horizontal plane. Some evidence of tectonic disturbance of Paskapoo beds is provided by the presence of an anticlinal structure in outcrops of this formation at the mouth of the Highwood River. The Porcupine Hills strata appear to have been unaffected by similar disturbances, and an unconformable boundary between the two formations may account for the apparent difference in elevation of the boundary (about 500 feet) between the outcrops south of the City of Calgary and the cored well 9 miles north of Calgary.

The lithology of the strata in R.C.A. corehole 66-1 is described in appendix C and shown graphically in figure 28. Point-count data on the sandstones from this

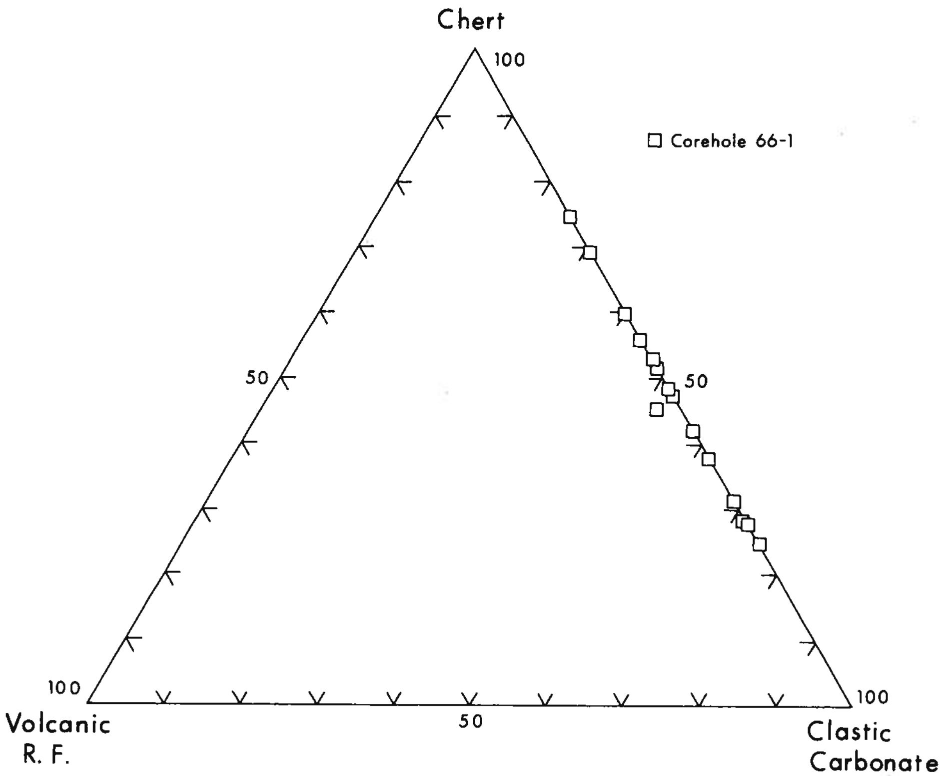


FIGURE 29. Proportions of chert, volcanic rock fragments and clastic carbonate grains in sandstones from the Porcupine Hills Formation in R.C.A. Corehole 66-1.

well are given in table 12 and the results are shown graphically in figure 11. The proportions of chert, volcanic rock fragments, and clastic carbonates as shown in figure 29 fall into the same area of the triangular diagram as the outcrop sandstones from the Porcupine Hills (Fig. 26). They are low in volcanic detritus and have a high chert and clastic carbonate content.

In the Porcupine Hills area, the boundary between the Willow Creek and Porcupine Hills Formations is difficult to define, it has been mapped at about the 3,200-foot contour, which lies at the break in slope at the base of the hills. Evidence of an unconformable contact present on the western side of the hills (Douglas, 1950) is not recognizable on the eastern side, although Bell (1949, p. 12) notes that the Willow Creek beds east of the Porcupine Hills undulate at low angles. The writer did not observe any such undulations in the Porcupine Hills Formation, and a disconformable contact analogous to that between the Porcupine Hills and Paskapoo Formations described above for the Calgary area probably is present.

Although little sandstone compositional data exists to support the separation of the Willow Creek and Porcupine Hills Formations, differences in gross lithology of the two units in the field are distinctive enough to support the present subdivision.

In summary, the following general lithologic distinctions can be made among the post-Kneehills strata of the central and southern Alberta Plains:

(1) in central Alberta, insufficient compositional or gross lithologic differences are present to permit subdivision of the post-Kneehills into distinct rock units;

(2) in southwestern Alberta, the post-Kneehills Willow Creek and Porcupine Hills Formations can be distinguished on the basis of gross lithologic (field) criteria, although the sandstone composition of the two units is similar;

(3) A distinction can be made between two distinct sandstone composition facies that coalesce in the vicinity of the Bow River. The southern facies, comprising the Willow Creek and Porcupine Hills Formations, is characterized by the abundance of clastic carbonates and extends in the upper part of the succession, as the Porcupine Hills Formation, north to the Red Deer River in the western part of the Plains. The northern facies, essentially the Paskapoo Formation, is characterized by the abundance of volcanic detritus, and is coextensive with the Willow Creek and St. Mary River Formations of southern Alberta.

These concepts are summarized schematically in figure 30.

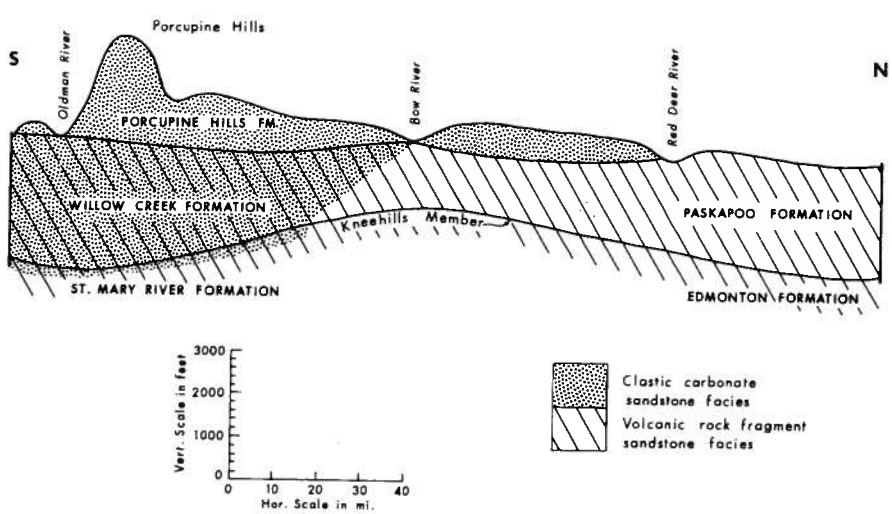


FIGURE 30. Schematic cross section showing the correlation of rock units and facies in post-Kneehills strata of central and southwestern Alberta.

Lithofacies

Maps showing the areal distribution of percentages of important clastic constituents in outcrop sandstones of the Willow Creek, Porcupine Hills and Paskapoo formations are given in figures 12, 15 to 18 and 20. In conjunction with the maps, histograms showing the frequency distributions of percentages of major detrital constituents in the combined sets of samples are given in figure 31. Each map shows at least some tendency toward a natural grouping of samples corresponding to formation or facies boundaries, but discrepancies in these boundaries warrant some discussion.

The boundary between those sandstones containing hornblende, epidote, or both and those in which these heavy minerals are absent (Fig. 20) coincides with the Porcupine Hills-Willow Creek Formations contact in the southwestern part of the province. The map also shows that the Porcupine Hills heavy mineral suite extends some 100 miles north of its previous boundary into an area that was formerly mapped as Paskapoo Formation. On the basis of heavy mineral content it is therefore logical to extend the Porcupine Hills Formation over an area of about 4,000 square miles, a much greater area than has been previously mapped as being underlain by this rock unit. Also, sandstone containing both hornblende and epidote are found along the eastern boundary of the outcrop area of post-Kneehills strata, a distribution giving support to the previous identification of the lower 200 feet of post-Kneehills strata in the plains as Edmonton Formation, that rock unit having hornblende and epidote present throughout.

The distribution of clastic carbonates (Fig. 18) in the post-Kneehills strata shows that the Paskapoo and equivalent-beds have low percentages of these constituents in contrast to the high values in the Porcupine Hills sandstones, although the combined frequency distributions of clastic carbonates (Fig. 31) is typically highly skewed and apparently unimodal. A division into two populations corresponding to the Porcupine Hills- and the Paskapoo-equivalent beds can be made at the 10 per cent level. Most samples with less than 10 per cent clastic carbonates are from the area mapped on field criteria as Paskapoo, Willow Creek or Ravenscrag Formation, whereas those sandstones with more than 10 per cent clastic carbonates are from the area mapped as Porcupine Hills Formation. However, the 10 per cent isopleth does not entirely fit the formation boundaries, extending to the west of the Porcupine Hills-Willow Creek contact in southwestern Alberta. Other exceptions are the single sample from the Hand Hills, an outlier east of the main area underlain by Paskapoo beds, which is high in clastic carbonates, as are two samples on the North Saskatchewan River near Rocky Mountain House and one at Entwistle on the Pembina River.

The frequency distribution of nonvolcanic rock fragments in the post-Kneehills sandstones (Fig. 31) is nearly symmetrical, with a mode in the 25 to 30 per cent class; thus any percentage chosen to divide the rocks into two populations is artificial. Nevertheless, the 30 per cent isopleth divides the sandstones into two main groups (Fig. 17), which, although unrelated to formation boundaries, indicates a moderate facies difference between the strata in north central and in southwestern Alberta. As with clastic carbonates, the single sample from the Hand

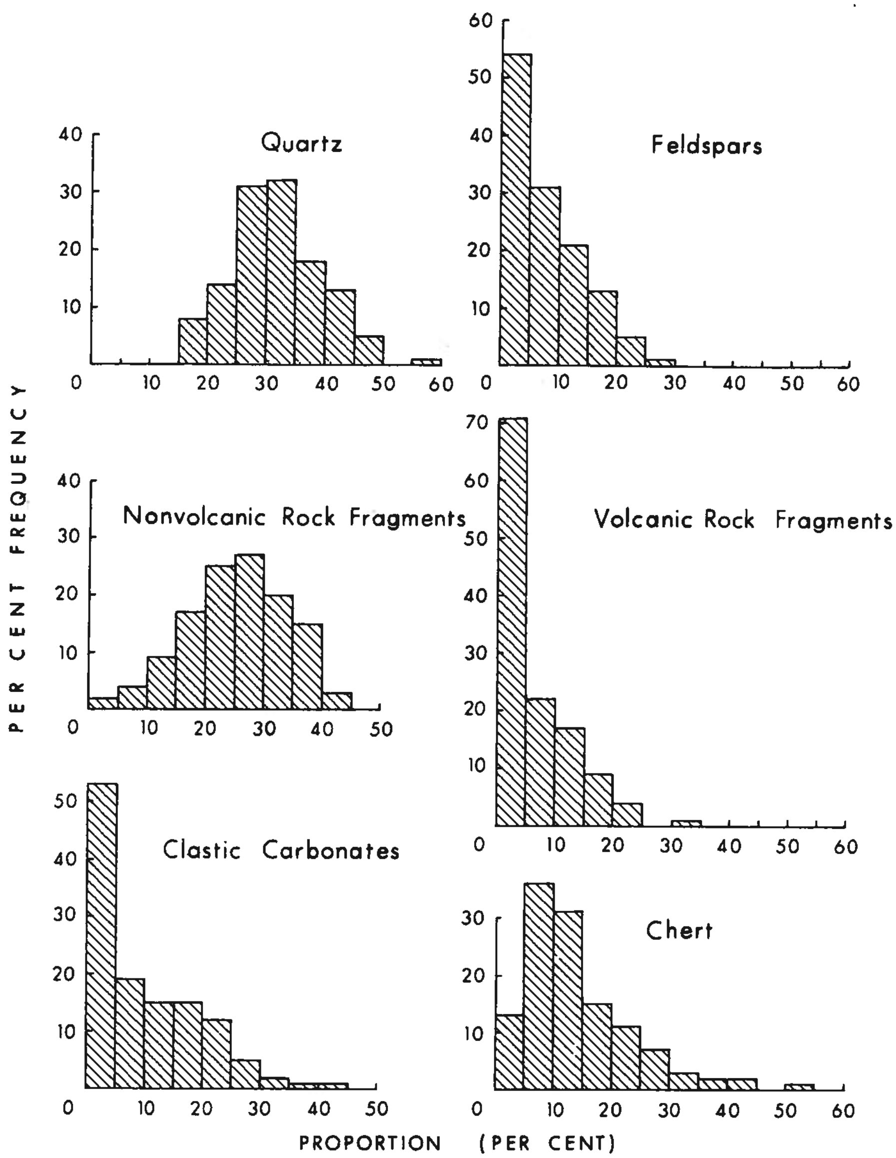


FIGURE 31. Combined frequency distributions of percentages of major detrital constituents in all post-Kneehills sandstone samples.

Hills is different from the main body of Paskapoo Formation sandstones to the west, whereas the sandstone from the Ravenscrag Formation in the Cypress Hills is similar.

The frequency distribution of chert in the post-Kneehills sandstone (Fig. 31) is highly skewed with the main mode in the 5 to 10 per cent class. By choosing a value of 10 per cent, it is possible to separate the sandstones into two populations that fall into separate areas on the map (Fig. 12). Those sandstones with more than 10 per cent chert are from southwestern Alberta whereas those containing less than 10 per cent chert are from the central part of the province. This twofold division is clearly unrelated to existing formation boundaries.

Although the sandstones are not from a single stratigraphic level, it seems reasonable to conclude that most of the chert in the post-Kneehills strata of Alberta was derived from a southwesterly source.

The frequency distribution of feldspars in the post-Kneehills sandstones (Fig. 31) is highly skewed with a single mode in the 0 to 5 per cent class. By dividing the samples at the 5 per cent level, a line can be drawn on the map (Fig. 15) which closely follows the Porcupine Hills-Willow Creek contact in southwestern Alberta and the Porcupine Hills-Paskapoo boundary in central Alberta. The distribution of feldspars is in good agreement with those of clastic carbonates and of heavy minerals, and appears to have stratigraphic value. Nevertheless, the single sandstone sample from the Hand Hills again differs from the Paskapoo Formation sandstones in the main outcrop area to the west, whereas the Ravenscrag sandstone sample from southeastern Alberta is similar.

The frequency distribution of the percentage of volcanic rock fragments (Fig. 31) in samples of the post-Kneehills sandstones is highly skewed with a modal value in the 0 to 5 per cent class. A good separation unrelated to formation boundaries is achieved by drawing the 5 per cent isopleth on the map (Fig. 16). The highest percentages of volcanic rock fragments are found in sandstones samples from the lower part of the Paskapoo Formation which outcrops in the east and northeastern areas, whereas the lowest percentages are found in sandstones from the west and southwestern areas.

The maps showing the distribution of detrital constituents in post-Kneehills sandstones demonstrate that the areal dispositions of these constituents do not necessarily accord with one another nor with existing formation boundaries. The map showing the presence or absence of hornblende and epidote shows best agreement with the stratigraphy. The lack of accord in the other detrital constituents is due to the presence of two petrogenetically distinct source areas, one to the northwest and the other to the southwest. During early post-Kneehills (Paskapoo) time, most of the detrital constituents were derived from a volcanic terrain to the northwest, whereas later (Porcupine Hills) the major source of detrital constituents was from a predominantly sedimentary terrain to the southwest.

To test this hypothesis objectively, multivariate statistical techniques were used to relate the data on sandstone composition to rock-unit boundaries. To do this it was assumed that two populations exist which can be identified with two petrogenetically distinct source areas. The southwestern source is characterized by the composition of the Porcupine Hills Formation sandstones in southwestern Alberta and the northwestern source by the Paskapoo Formation sandstones in the type section on the Red Deer River. Samples were assigned to one or other of the populations according to the presence or absence of hornblende and epidote; thus, the Willow Creek Formation sandstones were assigned initially to the Paskapoo "population", and the sandstones north of township 14 not carrying hornblende or epidote were placed in the Porcupine Hills "population". Upon the initial assignment of "known" samples to one or other population, a discriminant function of the form: –

$$R_o = \lambda_a A + \lambda_b B + \ldots\ldots \lambda_k K$$

where R_o = discriminant index
λ_k = weighted coefficients
K = petrographic variables (grain size and point count data).

The objective of a discriminant function is to weight the independent variables (X_n) in such a way as to obtain the maximum difference between the multivariate population means (R_1, R_2) and, ideally, zero overlap between the two sets of population R values. In such a case "unknown" samples can be unequivocally assigned to one or other of the two discrete populations on the basis of their calculated R values, although with increasing degree of population overlap the chance for misclassification of unknown R values increases. The procedure used here for calculation and interpretation of the discriminant function is from Davis and Sampson (1966) and is described fully in appendix E of this report.

Several trial runs were made with values from outcrop samples for seven variables, (grain size, quartz, feldspar, chert, nonvolcanic rock fragments, volcanic rock fragments, and clastic carbonate). Although the point count data involved in the analysis are reported as frequency percentages and therefore are not completely "independent" (formal tests of significance may not be valid), nevertheless, the analysis provides an objective approach to determining a consistent basis for separation of the two populations. After each determination of the discriminant equation, samples were transfered to the correct population based on their R values until the minimum number of samples were misclassified. Examination of the final analysis in this series of trials (outcrop samples with seven variables, Table 13A) showed that feldspar and nonvolcanic rock fragments are not contributing to the discrimination of the populations and these variables were dropped and the same samples were rerun with the five remaining variables (Table 13B). From these results it appears that quartz and volcanic rock fragments are not adding to the discrimination of the two populations; thus these two variables were dropped and the same samples were analyzed using only grain size, chert, and clastic carbonate percentages (Table 13C). However, it should be noted that the distance (D^2) between the population means decreases with each reduction in the number of variables. The final analysis (Table 13) is based on all seven variables for both outcrop and corehole sandstones, the R values for all samples being listed in table 13. Seven samples are misclassified in this analysis (five Paskapoo and two Porcupine Hills sandstones), reasons for which are discussed below: – A summary of the results of successive discriminant analyses is given in table 7.

In the final analysis 121 samples and all seven variables were used. These values are plotted in figure 32 and reprinted in table 13. In this analysis five Paskapoo and two Porcupine Hills Formation samples are misclassified. Five of these sandstones can be reclassified without causing any stratigraphic problems. Of the two remaining samples, one (776) is from the Hand Hills, 18 miles east of Drumheller,

Table 7. Summary of Results of Discriminant Analysis[1]

Trial Number	Number of Variables	Number of Samples	D^2	Number of Misclassified Samples	
				Porcupine Hills	Paskapoo
1[2]	7	80	10.13	0	4
2[2]	7	80	17.67	1	2
3[2]	5	80	14.56	0	2
4[2]	3	80	8.13	0	5
5[2]	3	80	13.07	0	2
6[3]	7	121	15.12	2	5

[1] For more details see appendix E.

[2] Samples from outcrops and corehole which can unequivocally be assigned to Porcupine Hills or Paskapoo Formations from stratigraphic evidence.

[3] All samples and all variables.

and although it is from a Paskapoo Formation outcrop and has a Paskapoo heavy mineral suite, it has the bulk composition of a Porcupine Hills Formation sandstone. The other problem sample (740) from the Brazeau River valley has a similar hybrid composition. Sandstones at both localities require further investigation to determine if the samples described above are representative of the rock units in these areas.

Discriminant analysis shows that all the Willow Creek Formation sandstones in southwestern Alberta belong in the Porcupine Hills "population" or facies. This implies that sandstone facies and formation boundaries coincide only north of township 16 where "undiluted" Porcupine Hills sandstones overlie normal Paskapoo sandstones (Fig. 30). This point is well illustrated in table 8, in which R values calculated from the equation in table 13 are used to determine the approximate elevation of the contact between the Porcupine Hills and Paskapoo Formations along the Bow River valley in the vicinity of Calgary. The results thus confirm the extension of the boundaries of the Porcupine Hills Formation northward to beyond the Bow River as shown on Map 32.

Table 8.

Table 8. Discriminant (R) Values for Sandstones mapped as Paskapoo or Porcupine Hills Formation along the Bow River in the vicinity of Calgary

Sample Number	Elevation (feet)	Discriminant Value[1]	Formation		
593	4100	-25.51202			
911	3975	-24.80079			
584	3900	-25.25432			
854	3850	-24.90431			
583	3800	-20.70630			
587	3700	-27.08883			
891	3690	-30.45089	R_2	-25.7940	PORCUPINE HILLS
892	3620	-19.96164			
590	3600	-22.40219			
895	3500	-29.84019			
893	3500	-23.87002			
851	3500	-27.20726			
			R_0	-17.1712	
859	3500	-11.85206			
852	3500	- 6.91619			
909	3500	- 6.52033			
972	3300	-12.18670			
857	3225	- 5.05278	R_1	-10.6728	PASKAPOO
888	3200	-13.57702			
773	3200	- 8.42120			
771	3200	-11.69202			
886	3100	-13.03169			

[1] See appendix E for analytical data

CHEMICAL COMPOSITION

Introduction

In comparison with igneous and metamorphic rocks, the chemical compositions of sedimentary rocks are not well known. This is largely because postdepositional alteration and cementation may change the chemical composition of initially similar rocks so drastically that comparison of bulk analyses becomes meaningless. To overcome these difficulties Middleton (1960) has suggested that comparisons of sedimentary rock analyses can best be made by using variations in the ratios of pairs of oxides, particularly the soda (Na_2O), potash (K_2O), and alumina (Al_2O_3) values, for these three oxides are present mainly in clay minerals and feldspars which are commonly regarded as detrital constituents in sedimentary rocks. However, this generalization cannot be accepted for the Cretaceous and Tertiary sandstones of Alberta in which authigenic silicates, including clay minerals, are the most common cements (Carrigy and Mellon, 1964).

The bulk chemical composition of these sediments is controlled by the composition of the source rocks plus mineralogical changes effected by diagenesis, the contribution of these two factors can be estimated only by reference to petrographic data on the corresponding rocks. In other words, some knowledge of the distribution of minerals among the textural elements is essential for interpretation of the chemical analyses.

Attempts to group chemical analyses of sandstones without the benefit of petrographic data have given rise to the implication that the chemical composition of a sandstone is somehow related to its depositional environment (Pettijohn, 1957). The high soda (Na_2O), alumina (Al_2O_3), and magnesia (MgO) contents in greywackes have been interpreted in this way by some geologists. The petrographic data on the "type" greywackes of the Harz Mountains demonstrate that the chemical composition of these rocks is directly related to the source rocks (Huckenholz, 1963), the high soda content being due to the abundance of soda feldspar and the high magnesia and alumina contents to the presence of chlorite and effusive igneous rock fragments. No matrix was found in these rocks by Huckenholz. Similarly, from petrographic analyses of the rocks under discussion, it can be deduced that the important oxides are present in the minerals listed below:

Na_2O – sodic felspar (albite), and exchangeable ions absorbed on clay minerals;
K_2O – potash feldspars (orthoclase, sanidine), and micas (biotite, muscovite and illite);
Al_2O_3 – clay minerals, micas, feldspars, and rock fragments;
MgO – dolomite, chlorite, montmorillonite and volcanic rock fragments;
CaO – calcite cement, limestone and dolomite fragments;
FeO, Fe_2O_3 – chlorite, biotite, siderite, pyrite, and volcanic rock fragments.

Table 9. Average Chemical Composition of the Nonmarine Cretaceous and Tertiary Sandstones of the Alberta Plains

Constituent	Formation			
	Porcupine Hills[1]	Paskapoo[2]	Edmonton[3]	Oldman[4]
SiO_2	72.43	69.28	71.66	74.21
Al_2O_3	3.91	10.69	12.63	12.15
Total iron (as Fe_2O_3)	1.42	3.35	2.65	2.17
TiO_2	0.20	0.41	0.44	0.51
P_2O_5	0.11	0.12	0.09	0.16
MnO	0.05	0.08	0.05	0.05
CaO	9.35	4.88	2.85	2.31
MgO	1.82	1.65	1.14	1.35
Na_2O	0.35	1.93	2.33	2.50
K_2O	0.72	1.83	2.19	1.83
L.O.I.	9.72	5.61	4.09	2.48
TOTAL	100.08	99.83	100.12	99.72

Analyses performed at the Research Council of Alberta
[1]average of seven analyses (Appendix F, page 137)
[2]average of seventeen analyses (Appendix F, page 137)
[3]average of seven analyses (Appendix F, page 137)
[4]average of three analyses

Comparison of Results

Selected sandstones from Upper Cretaceous and Paleocene strata of central and southern Alberta were chemically analysed by means of conventional "wet" techniques for their main constituents. The results of individual analyses for post–Kneehills sandstones (Paskapoo and Porcupine Hills Formations) are given in appendix F (Table 14); those for the Cretaceous Edmonton and Oldman Formations are given only in summary form below.

Edmonton and Oldman Formations

The average chemical compositions of the Upper Cretaceous Edmonton and Oldman[1] Formation sandstones (Table 9) are similar to the composition of the Paskapoo Formation sandstones. The main differences are in lower lime contents and higher soda contents of the older formations. On a ternary diagram the proportions of alumina, potash, and soda in these formations (Fig. 33) lie within or close to the greywacke field, occupying the same area of the ternary diagram as the Paskapoo Formation samples (Fig. 34).

[1] Oldman Formation: nonmarine sandstones and bentonitic siltstones underlying the pre-Edmonton, Bearpaw shale in east-central Alberta. Similar to the Edmonton Formation in lithology, the Oldman Formation is generally considered to be Santonian in age.

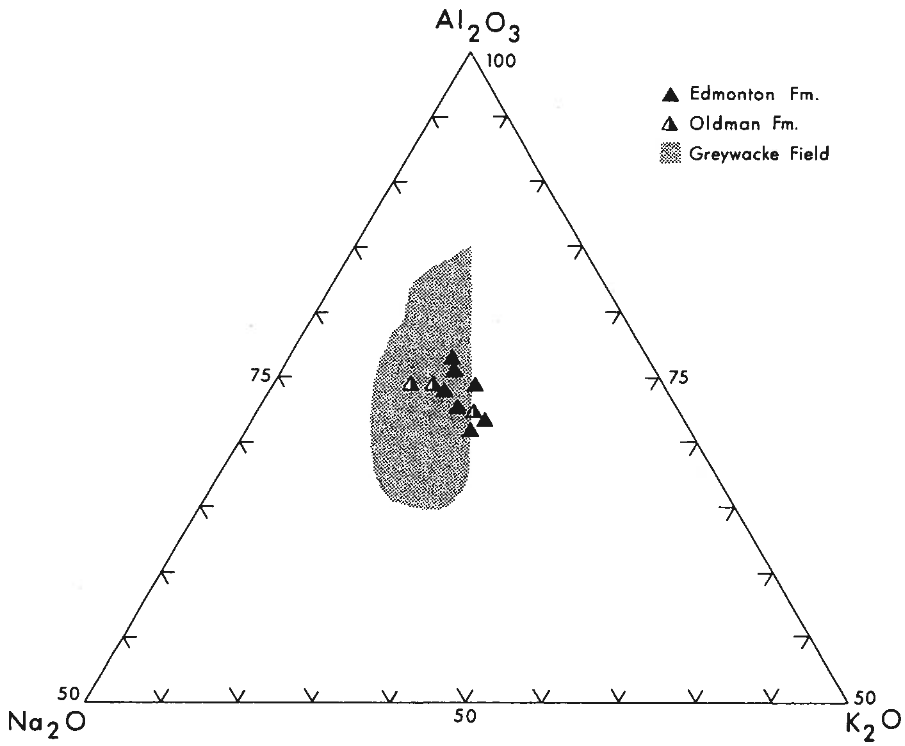


FIGURE 33. Proportions of alumina, soda and potash in sandstones from the Edmonton and Oldman Formations. Stippled area is greywacke field.

Paskapoo Formation

Chemical analyses of samples from the re-defined post-Kneehills Member (Paskapoo Formation) are given in appendix F. The analyses in table 14 are of samples with a range of grain sizes from R.C.A. Corehole 65-1 and McLeod River Damsite Coreholes 1 and 2 outcrop samples from scattered localities in the central and southern Plains.

In the core samples the ratio of potash (K_2O) to soda (Na_2O) varies from 0.63 to 2.3. In the outcrop sandstones the potash to soda ratio varies from 0.55 to 1.25, although, on the average, soda exceeds potash by a small amount.

The alumina (Al_2O_3) to soda (Na_2O) ratio for the core samples ranges from 6 to 12 and for the outcrop samples from 5 to 6. The highest alumina to soda ratio (S_{12} Table 14) is the result of a low soda rather than a high alumina content. The porportion of alumina to soda in the Paskapoo Formation is much lower than in

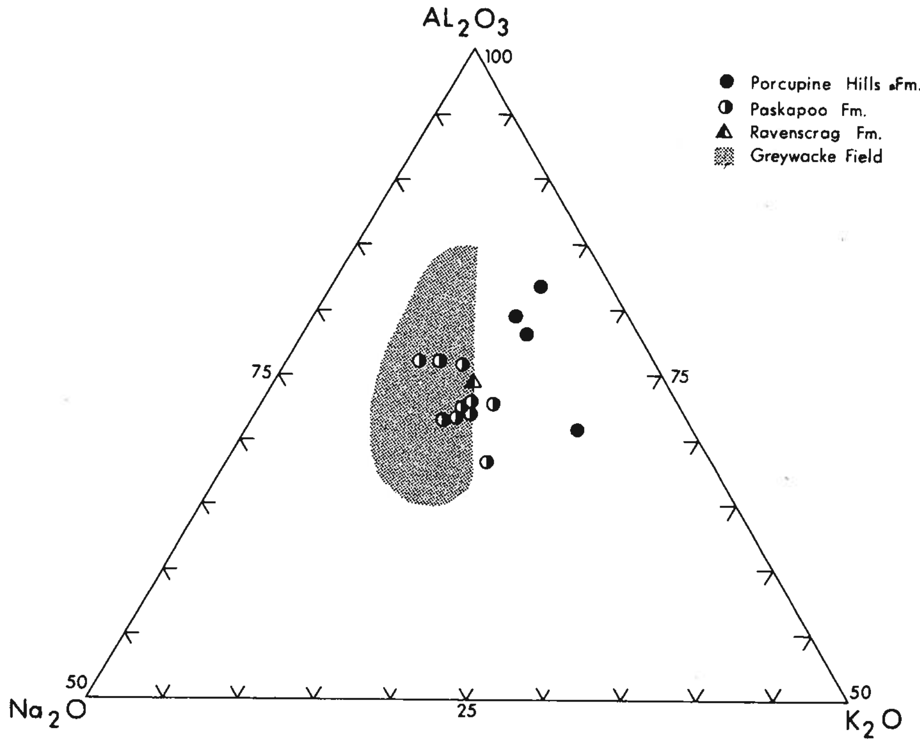


FIGURE 34. Proportions of alumina, soda and potash in sandstones from the Porcupine Hills, Paskapoo and Ravenscrag Formations.

the Porcupine Hills Formation in spite of an overall three- to four-fold increase in the percentage of alumina in the Paskapoo sandstones over that in the Porcupine Hills.

The high percentage of soda in the Paskapoo rocks (Table 9) is related to the greater volcanic content of the detritus, which results in a higher proportion of soda feldspar grains and Na-montmorillonite. The relative proportions of soda, potash, and alumina in sandstones from the Paskapoo Formation are shown in figures 34 and 35, and the similarity of these ratios to the same ratios in sandstones from the Edmonton and Oldman Formations (Fig. 33) is quite apparent.

The lime (CaO) to magnesia (MgO) ratio in the Paskapoo sandstones is less than 1 in only three out of seventeen sandstone analyses (Table 14) and in the single shale analysis (Table 10). The low lime content is due to the absence of clastic limestone, the small amount of calcite cement and the presence of abundant volcanic detritus and its authigenic equivalents, montmorillonite and chlorite.

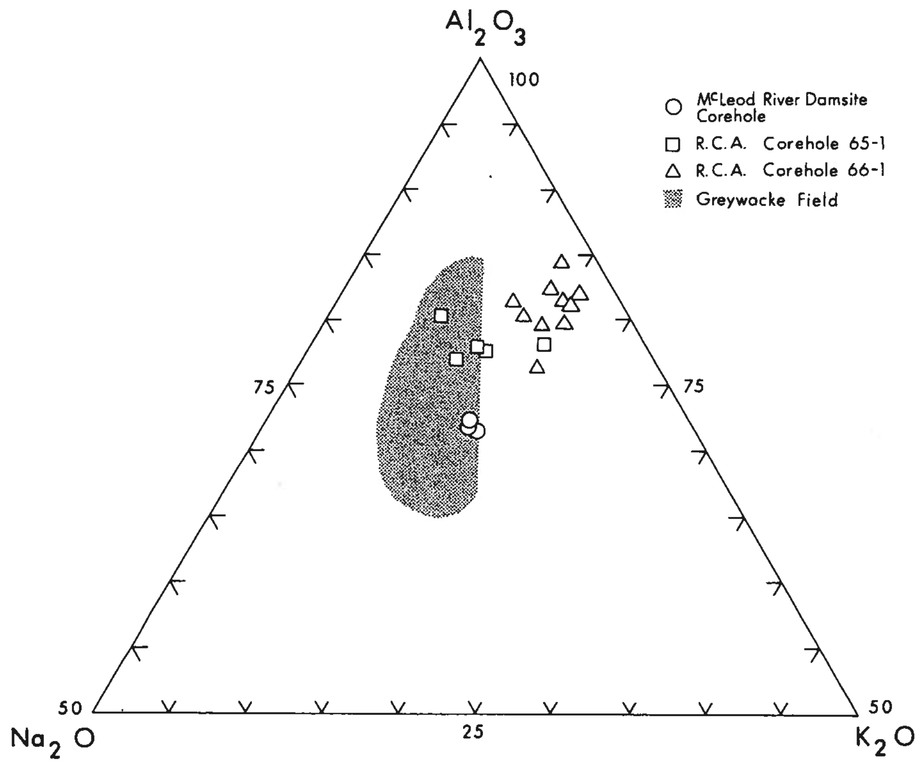


FIGURE 35. Proportions of alumina, soda and potash in sandstones from R.C.A. Corehole 65-1 and McLeod River damsite coreholes, and siltstones and sandstones from R.C.A. Corehole 66-1.

One notable feature of the chemical analyses of the Paskapoo sandstones (Table 14) is the relatively small range of variation in the oxides, especially in view of the variation in composition and amounts of authigenic silicate cements. For example, sample 897B has a calcite cement; 771B and 886 have zeolite (clinoptilolite) and montmorillonite cements; 664 and 671 have a small amount of montmorillonite cement; 607 has a small quantity of kaolinite, montmorillonite and calcite cements; 609 has calcite and chlorite cement; 605 has montmorillonite cement, and 744 has a large amount of authigenic montmorillonite and chlorite cements. The consistency of the chemical compositions is strongly suggestive of a local origin for the silicate cements in these sandstones.

Ravenscrag Formation

The single chemical analysis of a sandstone from the lower Ravenscrag

Table 10. Chemical Composition of Some Sandstones, Siltstones and Shales from the Porcupine Hills and Paskapoo Formations

		Constituents													Remarks
		SiO_2	Al_2O_3	Fe (as Fe_2O_3)	TiO_2	P_2O_5	MnO	CaO	MgO	Na_2O	K_2O	S (as SO_3)	L.O.I.	Total	
SANDSTONES	Porcupine Hills	74.89	3.56	1.22	0.17	0.10	0.03	8.97	1.53	0.31	0.74	-	8.83	100.35	Average of four analyses of outcrop sandstones from the Porcupine Hills and Calgary areas (Appendix F, page 137).
SANDSTONES	Porcupine Hills	69.16	4.37	1.69	0.25	0.13	0.08	9.86	2.22	0.40	0.69	0.01	10.90	99.76	Average of three analyses of fine-grained sandstones from R.C.A. Corehole 66-1, 9 miles north of Calgary (Appendix F, page 137).
SANDSTONES	Paskapoo	71.09	10.31	2.97	0.38	0.12	0.10	4.81	1.52	2.01	1.79	0.01	4.57	99.68	Average of ten analyses of outcrop sandstones from the Calgary, Red Deer and Edmonton areas (Appendix F, page 137).
SANDSTONES	Paskapoo	73.42	10.15	2.77	0.40	0.12	0.03	2.93	1.77	2.04	1.92	-	4.14	99.69	Average of three analyses of sandstone from McLeod River Damsite Coreholes northwest of Edmonton (Appendix F, page 137).
SANDSTONES	Paskapoo	62.55	13.03	4.88	0.49	0.15	0.06	5.60	1.88	1.81	1.80	0.24	8.26	100.75	Average of five analyses of fine-grained sandstone from R.C.A. Corehole 65-1, 32 miles southwest of Edmonton (Appendix F, page 137).
SILTSTONES	Porcupine Hills	59.76	12.83	4.39	0.57	0.81	0.07	7.11	2.36	0.58	2.29	0.11	9.49	100.37	Average of seven analyses of noncarbonaceous siltstones and silty shales from R.C.A. Corehole 66-1, 9 miles north of Calgary (Appendix F, page 137).
SILTSTONES	Porcupine Hills	53.56	16.56	4.90	0.52	0.23	0.01	2.37	1.81	0.55	2.28	0.44	16.41	99.64	Average of three analyses of carbonaceous siltstone from R.C.A. Corehole 66-1, 9 miles north of Calgary (Appendix F, page 137).
SHALES	Paskapoo	62.81	17.68	5.73	0.01	0.01	0.03	2.44	2.72	1.71	1.77	-	5.46	100.37	Analysis of green bentonitic shale, from the mouth of the Blindman River, 6 miles north of Red Deer.

Formation (Table 14) is of an uncemented rock, and the results are believed to give a good approximation of the bulk chemical composition of the clastic constituents of this formation. The sample has a potash to soda ratio of 1, an alumina to soda ratio of 6, and a lime to magnesia ratio slightly greater than unity. These ratios, together with the overall chemical composition of this sandstone, are quite similar to those from the Paskapoo Formation sandstones.

Porcupine Hills Formation

The Porcupine Hills Formation is represented by a wide variety of rock types. Analyses of the predominantly fine-grained rocks in R.C.A. Corehole 66-1 and four analyses of outcrop sandstones are given in table 14.

The chemical composition of these rocks varies with their grain size. For all samples the ratio of potash (K_2O) to soda (Na_2O) is greater than 1, ranging from 1.6 to 6.8 in the fine-grained, non-carbonaceous shales and siltstones and from 1.7 to 2.9 in the sandstones. The potash content of the sandstones is roughly half that of the siltstones.

The alumina (Al_2O_3) to soda (Na_2O) ratio ranges from 13 to 39 in the fine-grained rocks and from 9 to 17 in the sandstones. This ratio is a reflection of the greater amount of clay minerals in the finer-grained rocks. However, the proportions of alumina and alkalies in both the siltstones and sandstones are similar.

Lime (CaO) is mainly present in calcite cement and in limestone and dolomite fragments, whereas magnesia (MgO) is contained mainly in clastic dolomite, with minor amounts being present in chlorite and montmorillonite. The ratio of lime to magnesia varies widely but is not less than unity in any of the sandstones and in only three out of ten fine-grained samples. The three samples in which magnesia exceeds lime are bentonitic siltstones, which contain large amounts of montmorillonite. The high value for lime in one of the carbonaceous siltstones (R_1, Table 14) is due to fossil shells. The overall bulk chemical composition of the siltstones and bentonites is quite different from that of the sandstones, being comparable to the composition of the Paskapoo sandstones (Tables 10, 14) except that the potash to soda ratio remains significantly higher.

Discussion

The bulk chemical compositions of sandstones of the later Cretaceous and early Tertiary ages in the Alberta Plains reflect differences in their gross mineralogical composition. The sandstones of the younger Porcupine Hills Formation are characterized by their low alumina content (less than 5 per cent) and high lime content (more than 6 per cent) and a potash to soda ratio greater than 1 (Table 10). In contrast, the Paskapoo sandstones are high in alumina (more than 6 per cent) and, except for calcite-cemented beds, low in lime with a potash-to-soda ratio of less than 1. These differences in the proportions of three major oxides can be clearly seen on ternary diagrams on which the proportions of potash, soda, and alumina have been plotted (Figs. 33, 34, 35). The interesting feature of the field encompassed by the analyses of the Paskapoo and Upper Cretaceous sandstones (Figs. 33, 34) is that it overlaps the greywacke field (as based on analyses in Pettijohn, 1957). The analyses are similar to greywacke analyses in that soda predominates over potash, a feature which, according to Middleton (1960), sets greywackes apart from all other sandstones, except probably for a few noneugeosynclinal volcanic sandstones.

Differences in chemical composition can exert considerable influence on the course of diagenesis. As pointed out by Dapples (1962), early burial in quartzose sandstones is characterized by the precipitation of quartz overgrowths, and in subgreywackes by the reaction of chert with clay to form authigenic clay minerals and micas. In the quartzose sandstones of the Porcupine Hills Formation, the diagenetic minerals are quartz (overgrowths), kaolinite, and calcite. In the greywackes or subgreywackes of the Paskapoo Formation, the grain size of detrital chert (Fig. 9) is on the average larger than that of the associated quartz indicating that they have not taken part in the reaction to form the clay minerals present. These clay minerals are almost certainly derived from the breakdown of volcanic glass and felsite, the most common cements being calcite, montmorillonite, kaolinite, chlorite and zeolite (clinoptilolite). The zeolite cement seems to be developed at the outcrop faces and may not extend far into the formation.

There is a distinct contrast in chemical composition between the siltstones and sandstones of the Porcupine Hills Formation (Table 10). In the sandstones the only clay mineral, with rare exceptions, is a kaolinite cement, whereas in the siltstones the predominant clay mineral is montmorillonite. The clay in the siltstones forms a continuous groundmass. The predominance of the clay mineral montmorillonite in this groundmass suggests that although the source of coarse-grained water-transported, volcanic detritus was cut off by the emergence of the Rocky Mountains, volcanic ash continued to fall in substantial quantities during the deposition of the Porcupine Hills Formation sediments.

PETROLOGY

Bulk Composition

The sandstones of the post-Kneehills succession show a gradual change in detrital composition with change in time. This change is due in part to a gradual shift in source area from northwest to southwest concomitant with the emergence of the Rocky Mountains although it is masked to some extent by regional facies changes in sandstone composition. The salient features of the differences in bulk composition of the major rock-units are reviewed below.

Paskapoo and Ravenscrag Formations

Sandstones of the Paskapoo and Ravenscrag Formations are composed of quartz, chert, and nonvolcanic rock fragments (Table 11), together with abundant feldspars, volcanic rock fragments, and minor amounts of clastic carbonates (limestone and dolomite). The heavy mineral assemblage is dominated by euhedral biotite, zircon, apatite, epidote and hornblende. Most of the detrital constituents show little systematic variation from area to area, the only apparent difference being the low percentage of clastic carbonates in outcrops in the Calgary area.

Because of the high proportion of volcanic detritus, the Paskapoo sandstones are characterized by higher alumina, soda, potash, and iron oxide contents than the overlying Porcupine Hills Formation, being similar in chemical composition to sandstones of the underlying Edmonton and Oldman Formations (Table 9). Their chemical composition remains remarkably constant in spite of the variation in amount and composition of abundant authigenic alumino-silicate mineral cements (clay minerals, zeolites).

Willow Creek Formation

Too few samples of the Willow Creek Formation sandstones are available to allow reliable generalizations about the distribution of detrital constituents. The existing data indicate that the common detrital constituents are essentially the same as those of the overlying Porcupine Hills Formation sandstones, but with a greater volume of volcanic detritus towards the base of the formation. The heavy mineral assemblage is also of mixed origin, containing biotite, epidote, rounded zircons, and tourmaline.

Porcupine Hills Formation

The major detrital constituents of the Porcupine Hills Formation sandstones are quartz, chert, nonvolcanic rock fragments, and clastic carbonates (limestone and dolomite) (Table 11). Volcanic rock fragments and feldspars are rare. The heavy mineral suite is a residual assemblage consisting mainly of abraded grains of zircon, tourmaline and apatite.

Compared with the underlying Paskapoo sandstones, the average chemical

Table 11. Average Grain Size, Porosity and Percentage Frequency of Rock and Mineral Constituents in the Paskapoo, Ravenscrag and Porcupine Hills Formation Sandstones

Formation	Locality	Average Grain Size (mm)	Constituents: Framework Grains								Constituents: Cements					Pore Space
			Q	F	Ch	Mi	RF	VRF	CO_3	Ms	Ct	K	Mo	Cl	Z	
PASKAPOO	Edmonton Area (outcrops)	0.22	22.6	8.8	6.9	1.3	23.2	6.1	4.6	1.6	5.6	0.4	3.8	2.5	-	12.6
	McLeod River Damsite Coreholes	0.21	23.7	10.3	6.9	0.9	22.2	8.1	4.0	5.2	3.5	0.2	1.3	-	-	13.7
	R.C.A. Corehole 65-1 (Wizard Lake)	0.12	22.3	7.6	4.2	2.6	15.4	4.9	4.4	11.1	10.0	1.4	14.6	-	-	1.5
	Red Deer Area (outcrops)	0.19	24.0	6.4	8.2	1.1	22.4	5.6	5.9	1.7	5.1	0.6	4.5	1.1	0.2	13.2
	Calgary Area (outcrops)	0.19	24.3	8.9	8.4	1.2	22.7	9.8	0.6	5.9	3.4	1.0	6.2	0.8	3.0	3.8
RAVENS-CRAG	Cypress Hills[1]	0.13	16.5	3.5	2.5	0.5	16.0	1.0	14.0	2.0	43.0	-	-	-	-	1.0
PORCUPINE HILLS	Calgary Area (outcrops)	0.17	31.3	2.3	15.9	0.2	17.3	1.5	14.9	4.3	2.0	3.7	0.5	-	-	6.1
	R.C.A. Corehole 66-1 (Balzac)	0.11	27.8	2.0	12.7	0.3	16.0	0.1	17.0	3.8	4.0	1.2	6.2	0.2	-	8.5
	Porcupine Hills Area (outcrops)	0.21	22.5	2.5	26.4	0.5	22.4	0.2	10.9	1.5	5.5	3.5	-	0.1	-	4.5

[1]one sample only

composition of the Porcupine Hills sandstones (Table 9) is higher in silica and lower in alumina. The higher lime content is due to the high percentage of clastic carbonates and the ubiquitous presence of calcite cement. The relatively high magnesia content is due to clastic dolomite.

Source

Due to foreshortening and erosion concomitant with the building of the Rocky Mountains (Bally *et al.*, 1966), the source area of the uppermost Cretaceous and Tertiary rocks of the Alberta Plains can be defined only in the most general terms. The abundant volcanic detritus of the Paskapoo and Ravenscrag Formations probably was derived from the breakdown of effusive rocks located in the interior of British Columbia. This region today contains large volumes of volcanic rocks, many of which contain phenocrysts of feldspar, hornblende and biotite in a trachytic groundmass, similar in texture to the volcanic rock fragments of the Alberta sandstones.

In contrast to the Paskapoo detritus, the Porcupine Hills, and to a lesser extent the Willow Creek, sediment most likely was derived from an area underlain by limestones and dolomites similar to the present day Front Ranges of the Canadian Rockies. The paleocurrent data point to a source area south and west of the Porcupine Hills, in the southern extension of the Rocky Mountains where Precambrian sedimentary rocks now outcrop. However, the absence of red beds, fine-grained slate or argillite, and the predominance of chert and limestone over dolomite in the Porcupine Hills sandstones indicates that the source was not the Precambrian Belt Series or equivalent strata but rather an area underlain by Paleozoic carbonates and cherts. These rocks probably were brought to the surface during the early stages of thrust fault development that preceded the major uplift of the Rocky Mountains proper, thereby cutting off the supply of volcanic detritus to the west.

Authigenesis

Superimposed on the changes in detrital composition are post-depositional modifications brought about by growth of minerals from formation fluids and exchanges of ions between minerals as the individual grains react to establish equilibrium with a physical and chemical environment that is constantly changing due to tectonic movements and erosion.

Authigenic minerals are formed in sediment after the particles have come to rest. Some early authigenic minerals (glauconite, siderite) grow in the basin of deposition before burial, but most are deposited from interstitial fluids on the grain surfaces or pore walls after burial. The composition of the minerals deposited in the pores is controlled by the composition of the interstitial fluids which in turn depends on the temperature, pressure, dissolved gases, and the chemical and mineralogical composition of the rocks through which the fluid has migrated. Migrating fluids reach equilibrium by dissolving mineral matter on the one hand and by precipitating new minerals on the other. Thus, the composition of the minerals

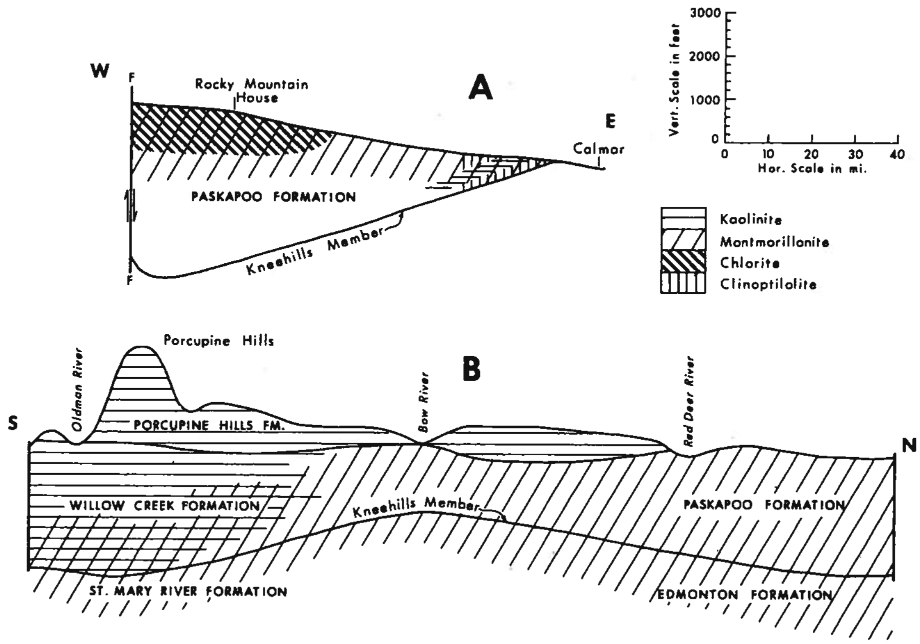


FIGURE 36. Schematic cross sections showing the distribution of authigenic mineral facies in post-Kneehills strata: (A) across the strike of strata in central Alberta; (B) parallel to the strike of strata in Western Alberta.

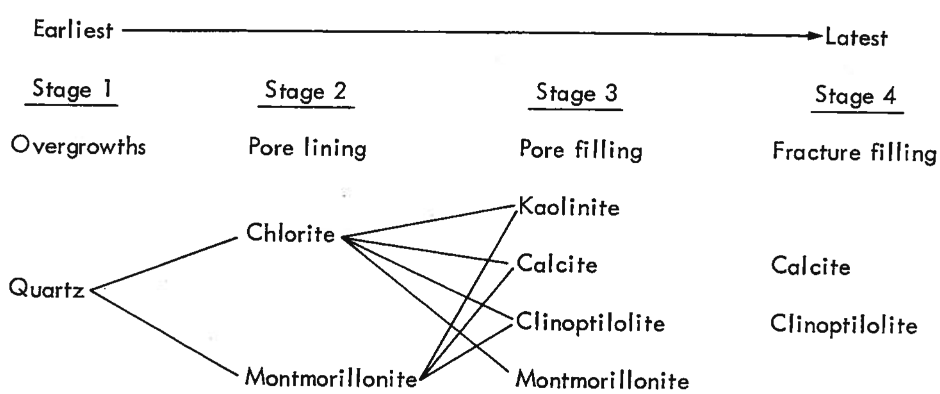
deposited in the pores depends not only on the factors listed above but also on time, with the result that it is common in many sandstones to find a concentrically deposited series of authigenic minerals within a single pore. Similarly, local differences in fluid flow systems can result in different minerals being deposited simultaneously in adjacent parts of the same sandstone body, although in general the similarity of physical factors favors the precipitation of one particular authigenic mineral assemblage in large volumes of rock. Recognition of this fact leads to the concept of authigenic mineral facies which may be unrelated to formation boundaries.

In the post-Kneehills sandstones of the Alberta Plains, three major authigenic mineral facies have been recognized. In southwestern Alberta a quartz-kaolinite facies is found mainly in the nonvolcanic Porcupine Hills Formation sandstones, extending down into the more volcanic Willow Creek Formation sandstones in which it coexists with the montmorillonite facies typical of the lower part of the Paskapoo Formation. Montmorillonite cement predominates in sandstones from the lower part of the Paskapoo Formation from the eastern outcrop boundary of the formation towards the west where, in the vicinity of Edson and Rocky Mountain House, it merges with the chlorite facies of the upper part of the Paskapoo Formation which extends to the edge of the Foothills. The chlorite facies of the Paskapoo Formation was erroneously mapped as Edmonton-equivalent beds by Rutherford (1928) and is shown on the geological map of Alberta as "Saunders Group" (Geol. Surv. Can., 1951). A schematic diagram showing the stratigraphic relationships of these facies is given in figure 36.

Within the three major facies are many subfacies, such as the kaolinite cemented sandstones in the coaly interval (Ardley coal zone) above the Kneehills Member and the clinoptilolite cemented sandstones in the montmorillonite facies found at a number of localities near the eastern outcrop margin of the Paskapoo Formation. Unfortunately, there is insufficient data at present to determine the subsurface extent of these facies or to explain their origin.

In addition to presence of pore-filling authigenic minerals, there is some replacement of detrital grains. Fewer grains are altered in the Porcupine Hills sandstones than in the Paskapoo; the most common alterations observed are the breakdown of feldspars to sericite, kaolinite and zeolites. In the Paskapoo Formation many volcanic rock fragments are replaced by chlorite, montmorillonite and clinoptilolite, and some biotite flakes are centers of growth for siderite.

The paragenesis of the authigenic minerals in the uppermost Cretaceous and lower Tertiary sandstones of the Alberta Plains seems to have proceeded in four stages. Stage 1 is characterized by overgrowths on detrital quartz grains, usually preceding deposition of a thin coating of chlorite or montmorillonite on the grain surfaces (stage 2). Stage 3 is a time of pore filling and major porosity reduction, during which kaolinite, calcite, or clinoptilolite is deposited in the central portions of the pores. In stage 4 fractures formed subsequent to lithification are filled with calcite or clinoptilolite. This sequence of mineralizing events can be summarized as follows:



In the Porcupine Hills Formation sandstones, stage 2 is seldom observed; in the Paskapoo Formation sandstones stage 1 is commonly missing and in many sandstones stage 2 also is lacking. In the more porous Paskapoo sandstones stage 3 has not been reached, and only slight porosity reduction has taken place even though permeability has been severely impaired. This factor has considerable importance for the groundwater geologist, who may be puzzled by the inability of many apparently porous sandstones to produce large supplies of groundwater.

Assemblages of authigenic mineral cements observed in thin sections of post-Kneehills sandstones are listed below in decreasing order of frequency:

Paskapoo Formation	*Willow Creek Formation*	*Porcupine Hills Formation*
1. Montmorillonite	1. Quartz-calcite-montmorillonite	1. Quartz-kaolinite-calcite
2. Calcite	2. Quartz-calcite	2. Quartz-calcite
3. Kaolinite		3. Quartz-calcite-montmorillonite
4. Montmorillonite-clinoptilolite		
5. Montmorillonite-calcite		
6. (*No cement*)		
7. Chlorite		
8. Chlorite-montmorillonite		
9. Chlorite-calcite		
10. Chlorite-kaolinite		
11. Montmorillonite-clinoptilolite-kaolinite		

One obvious feature of this list is the greater number of authigenic minerals and the large number of combinations of authigenic silicate minerals found in the Paskapoo Formation sandstones. This is undoubtedly related to the abundance of volcanic detritus and the variety of cations available for combination with silica and alumina in the interstitial fluids.

SUMMARY

Although only a small segment of the total sediment deposited in Western Canada during the latest Cretaceous and Paleocene time is exposed in the Alberta Plains, a reasonably reliable reconstruction of the major geologic events during this time is possible.

The most significant episode in the geological history of this long period of rapid continental sedimentation was the deposition of a widespread bed of volcanic ash over tens of thousands of square miles of southwestern Alberta. This event, which took place 65 million years ago, gave rise to the Kneehills Member, an easily recognizable lithologic unit that provides the only reliable datum for correlation in the nonmarine uppermost Cretaceous-lower Tertiary strata of the Alberta Plains.

Following this great ash fall, the landscape of southern and central Alberta and adjacent British Columbia can be construed as a relatively featureless depositional surface sloping gently to the south and east, toward the margin of the late Bearpaw sea. The ground was swampy and the climate hot and humid. During this time ceratopsian dinosaurs flourished and small mammals were abundant. Subsidence synchronous with the sedimentation continued in the major depocenters to the north and south of the present site of the City of Calgary. The area of thickest sediment accumulation at this time was undoubtedly some distance to the west of the present Alberta Foothills, having since been stripped of its Upper Cretaceous and Tertiary strata by post-Paleocene uplift and erosion.

In early Tertiary time (Paleocene) the rate of subsidence decreased, or the sediment supply increased, sufficiently to build out alluvial fans onto the Plains. During this period thick crossbedded channel sands and local gravels were deposited among shallow lakes and swampy areas. Volcanic ash continued to fall, but in decreasing amounts, being preserved only in local depressions. By the end of Paskapoo (middle Paleocene) deposition, the first phase of the Laramide orogeny was in progress to the west. Tectonic movements at this time disrupted the established drainage system, deformed the Willow Creek and Paskapoo strata, brought Paleozoic limestones to the surface in front of the volcanic source rocks, and moved the major depocenters for sediment eastward.

Following a short period of erosion in late Paleocene time, the nonvolcanic sediments of the Porcupine Hills Formation were deposited in a poorly drained area in front of the newly emerged highlands to the west. Abundant paleocurrent data from the Porcupine Hills sandstones indicate a southwesterly source of sediments. The entire area continued to rise slowly and the former depocenters of Paleocene sediment became areas of erosion. With accelerated uplift to the west in Eocene time, the area was bypassed by sediment eroded from the emerging Rocky Mountains, and only remnants of extensive piedmont conglomerates deposited in post-Eocene times are preserved.

REFERENCES CITED

Allan, J. A. (1919): Geology of the Swan Hills in Lesser Slave Lake district, Alberta; Geol. Surv. Can. Summ. Rept. 1918, Pt. C, p. 7-13.

Allan, J. A. and R. L. Rutherford (1923): Saunders Creek and Nordegg coal basins, Alberta, Canada; Res. Coun. Alberta Rept. 6, 39 pages.

.... (1924): Geology along the Blackstone, Brazeau and Pembina Rivers in the Foothills belt, Alberta; Res. Coun. Alberta Rept. 9, 53 pages.

Allan, J. A. and J. O. G. Sanderson (1925): An Upper Cretaceous disconformity in Alberta; Bull. Geol. Soc. Am. Vol. 36, p. 161.

.... (1945): Geology of Red Deer and Rosebud sheets, Alberta; Res. Coun. Alberta Rept. 13, 115 pages.

American Commission on Stratigraphic Nomenclature (1961): Code of stratigraphic nomenclature; Bull. Am. Assoc. Petroleum Geol., Vol. 45, p. 645-65.

Bally, A. W., P. L. Gordy and G. A. Stewart (1966): Structure, seismic data, and orogenic evolution of Southern Canadian Rocky Mountains; Bull. Can. Petroleum Geol., Vol. 14, p. 337-81.

Beach, H. H. (1942): Bearberry; Geol. Surv. Can. Map 670A.

Bell, W. A. (1949): Uppermost Cretaceous and Paleocene floras of western Alberta; Geol. Surv. Can. Bull. 13, 231 pages.

Berry, E. W. (1926): On fossil plants from the Paskapoo Formation of Alberta; Trans. Roy. Soc. Can., 3rd Ser., Sec. 4, Vol. 20, p. 189-200.

.... (1935): A preliminary contribution to the floras of the Whitemud and Ravenscrag Formations; Geol. Surv. Can. Mem. 182, p. 1-65.

Blatt, H. and J. M. Christie (1963): Undulatory extinction in quartz of igneous and metamorphic rocks and its significance in provenance studies of sedimentary rocks; Jour. Sedimentary Petrology, Vol. 33, p. 559-79.

Bossort, D. O. (1957): Relationship of the Porcupine Hills to Early Laramide movements; *in* 15th Ann. Field Conf. Guidebook, Alberta Soc. Petroleum Geol., p. 46-51.

Campbell, J. D. (1962): Boundaries of the Edmonton Formation in the central Alberta Plains; Jour. Alberta Soc. Petroleum Geol., Vol. 10, p. 308-19.

.... (1967): Ardley coal zone in the Alberta Plains: central Red Deer River area; Res. Coun. Alberta Rept. 67-1, 28 pages.

Campbell, J. D. and I. S. Almadi (1964): Coal occurrences of the Vulcan-Gleichen area, Alberta; Res. Coun. Alberta Rept. 64-2, 58 pages.

Carozzi, A. V. (1960): Microscopic Sedimentary Petrography; John Wiley & Sons, Inc., New York, 485 pages.

Carrigy, M. A. (1970): Proposed revision of the boundaries of the Paskapoo Formation in the Alberta Plains; Bull. Can. Petroleum Geol., Vol. 18, p. 156-65.

Carrigy, M. A. and G. B. Mellon (1964): Authigenic clay mineral cements in Cretaceous and Tertiary sandstones of Alberta; Jour. Sedimentary Petrology, Vol. 34, p. 461-72.

Chayes, F. (1952): Notes on the staining of potash feldspar; Am. Mineral., Vol. 37, p. 337-40.

.... (1956): Petrographic Modal Analysis; John Wiley & Sons, Inc., New York, 113 pages.

Clemens, W. A. and L. S. Russell (1965): Mammalian fossils from the upper Edmonton Formation; *in* Vertebrate Paleontology in Alberta, Univ. Alberta, Edmonton, p. 32-40.

Cope, E. D. (1891): On vertebrata from the Tertiary and Cretaceous rocks of the Northwest Territory: 1. The species from the Oligocene or Lower Miocene Beds of the Cypress Hills; Geol. Surv. Can., Contrib. Can. Paleont., Vol. 3, Pt. 1, 25 pages.

Crockford, M. B. (1951): Clay deposits of Elkwater Lake area of Alberta; Res. Coun. Alberta Rept. 61, 102 pages.

Crockford, M. B. and W. H. Clow (1965): Upper Cretaceous formations of the Cypress Hills-Milk River area, southeastern Alberta and southern Saskatchewan; *in* 15th Ann. Field Conf. Guidebook, Alberta Soc. Petroleum Geol., p. 184-97.

Crook, K. A. (1960): Classification of arenities; Am. Jour. Sci., Vol. 258, p. 419-28.

Cummins, W. A. (1962): The greywacke problem; Liverpool and Manchester Geol. Jour., Vol. 3, Pt. 1, p. 51-72.

Dapples, E. C. (1962): Stages of diagenesis in the development of sandstones; Bull. Geol. Soc. Am., Vol. 73, p. 913-34.

Davis, J. C. and R. J. Sampson (1966): Fortran II program for multivariate discriminant analysis using an I.B.M. 1620 computer; Computer Contrib. No. 4, Kansas State Geol. Surv., 8 pages.

Davis, N. B. (1918): Report on the clay resources of southern Saskatchewan; Can. Mines Branch, Rept. 468.

Dawson, G. M. (1883): Preliminary report on the geology of the Bow and Belly River region, N.W.T. with special reference to the coal deposits; Geol. Surv. Can. Rept. Prog. 1880-81-82, Pt. B, p. 1-23.

Dawson, G. M. and R. G. McConnell (1885): Report on the region in the vicinity of the Bow and Belly Rivers, Northwest Territory; Geol. Surv. Can. Rept. Prog. 1882-84, Pt. C, 168 pages.

Douglas, R. J. (1950): Callum Creek, Langford Creek and Gap map-areas, Alberta; Geol. Surv. Can. Mem. 225, 124 pages.

Dowling, D. B. (1917): The southern Plains of Alberta; Geol. Surv. Can. Mem. 93, 200 pages.

Elliot, R. H. (1960): Subsurface correlation of the Edmonton Formation; Jour. Alberta Soc. Petroleum Geol., Vol. 8, p. 324-37.

Erdman, O. A. (1950): Alexo and Saunders map-areas, Alberta; Geol. Surv. Can. Mem. 254, 100 pages.

Farvolden, R. N. (1961): Groundwater resources Pembina area, Alberta; Res. Coun. Alberta Rept. 61-4, 26 pages.

Folinsbee, R. E., H. Baadsgaard, G. L. Cumming, J. Nascimbene and M. Shafiquallah (1965): Late Cretaceous radiometric dates from the Cypress Hills of Western Canada; *in* 15th Ann. Field Conf. Guidebook, Alberta Soc. Petroleum Geol., p. 162-74.

Folinsbee, R. E., H. Baadsgaard and J. Lipson (1961): Potassium-argon dates of Upper Cretaceous ash falls, Alberta, Canada; Ann. New York Acad. Sci., Vol. 91, p. 352-59.

Folk, R. L. (1962): Spectral subdivision of limestone types; *in* Classification of carbonate rocks, Am. Assoc. Petroleum Geol. Mem. 1, 279 pages.

Fox, R. C. (1968): A new Paleocene mammal (*Condylarthra: Arctocyonidae*) from a well in Alberta, Canada; Jour. Mammalogy, Vol. 49, p. 661-64.

Fraser, F. J., F. H. McLearn, L. S. Russell, P. S. Warren and R. T. Wickenden (1935): Geology of Southern Saskatchewan; Geol. Surv. Can. Mem. 176, 137 pages.

Friedman, G. M. (1959): Identification of carbonate minerals by staining methods; Jour. Sedimentary Petrology, Vol. 29, p. 87-97.

Furnival, G. M. (1946): Cypress Lake map-area, Saskatchewan; Geol. Surv. Can. Mem. 242, 161 pages.

Gallup, W. B. (1954): Relation of Laramide movements to the Cretaceous and Tertiary sediments of Western Canada; Jour. Alberta Soc. Petroleum Geol., Vol. 5, p. 125-26.

Geological Survey of Canada (1951): Geological map of Alberta; Geol. Surv. Can. Map 1002A.

Germundson, R. K. (1965): Stratigraphy and micropaleontology of some late Cretaceous-Paleocene continental formations, Western Interior, North America; unpublished Ph. D. thesis, Univ. of Missouri.

Gilbert, C. M. and M. G. McAndrews (1948): Authigenic heulandite in sandstone, Santa Cruz County, California; Jour. Sedimentary Petrology, Vol. 18, p. 91-9.

Griffiths, J. C. (1960): Modal analysis of sediments; Révue de Géographie Physique et de Géologie Dynamique, Vol. 3, p. 29-48.

Hage, C. O. (1945): Cowley; Geol. Surv. Can. Map 816A.

Hay, R. L. (1966): Zeolites and zeolitic reactions in sedimentary rocks; Geol. Soc. Am. Special Paper 85, 130 pages.

Huckenholz, H. G. (1963): Mineral composition and texture in graywackes from the Harz Mountains (Germany) and in arkoses from the Auvergne (France): Jour. Sedimentary Petrology, Vol. 33, p. 914-18.

Hume, G. S. (1931): Turner Valley; Geol. Surv. Can. Map 257A.
......................(1942): Jumping Pound; Geol. Surv. Can. Map 653A.
......................(1949): Stimson Creek; Geol. Surv. Can. Map 934A.
Hume, G. S. and C. O. Hage (1941): Wildcat Hills (east half); Geol. Surv. Can. Map 652A.
Irish, E. J. W. (1947): Gregg Lake; Geol. Surv. Can. Map 899A.
......................(1965): Notes to accompany the geological map Cypress Hills region, Alberta and Saskatchewan; *in* 15th Ann. Field Conf. Guidebook, Alberta Soc. Petroleum Geol., p. 15-22.
......................(1967): Drumheller; Geol. Surv. Can. Prelim. Map 5-1967.
......................(1968a): Gleichen; Geol. Surv. Can. Prelim. Map 19-1967.
......................(1968b): Lethbridge; Geol. Surv. Can. Prelim. Map 20-1967.
......................(1968c): Foremost; Geol. Surv. Can. Prelim. Map 22-1967.
Irish, E. J. W. and C. J. Havard (1968): The Whitemud and Battle Formations ("Kneehills Tuff Zone") – a stratigraphic marker; Geol. Surv. Can. Paper 67-63, 51 pages.
Jones, J. F. (1962): Reconnaissance groundwater study Swan Hills and adjacent areas, Alberta; Res. Coun. Alberta Rept. 62-5, 43 pages.
Krynine, P. D. (1948): The megascopic study and field classification of sedimentary rocks; Jour. Geol., Vol. 56, p. 130-65.
Lambe, L. M. (1908): The vertebrata of the Oligocene of the Cypress Hills, Saskatchewan; Geol. Surv. Can., Contrib. Can. Paleont., Vol. 3, pt. 4, 65 pages.
Lambe, L. M. and H. F. Osborn (1902): On *Vertebrata* of the Mid-Cretaceous of the North-West Territory; Geol. Surv. Can., Contrib. Can. Paleont., Vol. 3, Pt. 2.
Lang, A. H. (1947): Brûlé and Entrance map-areas, Alberta; Geol. Surv. Can. Mem. 244, 65 pages.
Leighton, M. W. and C. Pendexter (1962): Carbonate rock types; *in* Classification of carbonate rocks, Am. Assoc. Petroleum Geol. Mem. 1, 279 pages.
Lerbekmo, J. F. (1964): Heavy minerals and the Cretaceous-Tertiary boundary in Alberta, Canada; Proc. 22nd Int. Geol. Congress (India), Pt. 3, Sec. 3, p. 137-43.
Lillegraven, J. A. (1969): Latest Cretaceous mammals of upper part of Edmonton Formation of Alberta, Canada, and review of marsupial-placental dichotomy in mammalian evolution; Univ. Kansas Contrib. Paleont., Article 50, 122 pages.
MacKay, B. R. (1939): Fallentimber (east half): Geol. Surv. Can. Map 548A.
McConnell, R. G. (1885): Report on the Cypress Hills, Wood Mountain and adjacent country; Geol. Surv. Can. Ann. Rept., Vol. 1, Pt. C, p. 1-78.
McKee, E. D. and D. W. Weir (1953): Terminology for stratification and cross-stratification in sedimentary rocks; Bull. Geol. Soc. Am., Vol. 64, p. 381-90.
McLearn, F. H. (1928): Stratigraphy, structure and clay deposits of Eastend area, Cypress Hills, Saskatchewan; Geol. Surv. Can. Summ. Rept. 1927, Pt. B. p. 21-53.
Mellon, G. B. (1967): Stratigraphy and petrology of the Lower Cretaceous Blairmore and Mannville Groups, Alberta Foothills and Plains; Res. Coun. Alberta Bull. 21, 270 pages.
Meyboom, P. (1961): Groundwater resources of the City of Calgary and vicinity; Res. Coun. Alberta Bull. 18, 72 pages.
Middleton, G. V. (1960): Chemical composition of sandstones; Bull. Geol. Soc. Am., Vol. 71, p. 1011-26.
Nelson, H. W. (1968): Petrography of sandstone interbeds in the upper Cretaceous-Paleocene of Gulf Spring Point; Bull. Can. Petroleum Geol., Vol. 16, p. 425-30.
Ower, J. R. (1960): The Edmonton Formation; Jour. Alberta Soc. Petroleum Geol., Vol. 8, p. 309-23.
Parks, W. A. (1916): Report on the building and ornamental stones of Canada; Provinces of Manitoba, Saskatchewan and Alberta; Can. Mines Branch Rept. 388, 325 pages.
Patterson, J. R. (1965): Danian problems affecting the Cretaceous-Tertiary boundary in North America; *in* 15th Ann. Field Conf. Guidebook, Alberta Soc. Petroleum Geol., p. 175-83.
Pearson, G. R. (1959): Coal reserves for strip-mining, Wabamun Lake district, Alberta; Res. Coun. Alberta Rept. 59-1, 55 pages.

........................(1960): Evaluations of some Alberta coal deposits; Res. Coun. Alberta Rept. 60-1, 61 pages.

Pettijohn, F. J. (1957): Sedimentary Rocks; Harper & Bros., New York, 525 pages.

Plumley, W. J., G. A. Risley, R. W. Graves, Jr. and M. E. Kaley (1962): Energy index for limestone interpretation and classification; *in* Classification of carbonate rocks, Am. Assoc. Petroleum Geol. Mem. 1, 279 pages.

Potter, P. E. and F. J. Pettijohn (1963): Paleocurrent and Basin Analysis; Academic Press, New York, 296 pages.

Ritchie, W. D. (1960): The Kneehills Tuff; Jour. Alberta Soc. Petroleum Geol., Vol. 8, p. 339-41.

Russell, L. S. (1926a): A new species of the genus *Catopsalis* Cope from the Paskapoo Formation of Alberta; Am. Jour. Sci., Vol. 12, p. 230-34.

......................(1926b): Mollusca of the Paskapoo Formation in Alberta; Trans. Roy. Soc. Can., Sec. 4, Vol. 20, p. 207-20.

......................(1928): A new fossil fish from the Paskapoo beds of Alberta; Am. Jour. Sci., Vol. 15, p. 103-07.

......................(1929a): Paleocene vertebrates from Alberta; Am. Jour. Sci., Vol. 17, p. 162-78.

......................(1929b): Upper Cretaceous and Lower Tertiary gastropoda from Alberta; Trans. Roy. Soc. Can., Vol. 23, Sec. 4, p. 81-90.

......................(1930a): A new species of *Aspideretes* from the Paskapoo Formation of Alberta; Am. Jour. Sci., Vol. 20, p. 27-32.

......................(1930b): Early Tertiary mammal tracks from Alberta; Trans. Roy. Can. Inst., Vol. 17, Pt. 2, p. 217-21.

......................(1931): Mollusca from the Upper Cretaceous and Lower Tertiary of Alberta; Trans. Roy. Soc. Can. Vol. 25, Sec. 4, p. 9-19.

......................(1932a): The Cretaceous-Tertiary transition of Alberta; Trans. Roy. Soc. Can., Vol. 26, Sec. 4, p. 121-56.

......................(1932b): New data on Paleocene mammals of Alberta, Canada; Jour. Mammalogy, Vol. 13, p. 48-54.

......................(1934): Revision of the Lower Oligocene vertebrata of the Cypress Hills, Saskatchewan; Trans. Roy. Can. Inst., Vol. 20, Pt. 1, p. 49-66.

......................(1940): *Micrichnus* tracks from Paskapoo Formation of Alberta; Trans. Roy. Can. Inst., Vol. 23, Pt. 1, p.67-74

......................(1948): A Middle Paleocene mammal tooth from the Foothills of Alberta; Am. Jour. Sci., Vol. 246, p. 152-56.

......................(1951): Age of the Front Range deformation in the North American Cordillera; Trans. Roy. Soc. Can., Vol. 45, Sec. 4, p. 47-69.

......................(1957): Tertiary plains of Alberta and Saskatchewan; Proc. Geol. Assoc. Can., Vol. 9, p. 17-9.

......................(1958): A horse *Astragalus* from the Hand Hills Conglomerate of Alberta; Nat. Mus. Can. Natural Hist. Paper 1, 3 pages.

......................(1965a): The continental Tertiary of Western Canada; *in* Vertebrate Paleontology in Alberta, Univ. Alberta, Edmonton. p. 41-52.

......................(1965b): The problem of the Willow Creek Formation; Can. Jour. Earth Sciences; Vol. 2, p. 11-4.

......................(1968): A dinosaur bone from Willow Creek beds in Montana; Can. Jour. Earth Sciences, Vol. 5, p. 327-29.

Russell, L. S. and R. W. Landes (1940): Geology of the southern Alberta Plains; Geol. Surv. Can. Mem. 221, 223 pages.

Rutherford, R. L. (1925): Geology of the Foothills belt between McLeod and Athabasca Rivers, Alberta; Res. Coun. Alberta Rept. 11, 61 pages.

.............................(1926): Geology of the area between Athabasca and Embarass Rivers, Alberta; Res. Coun. Alberta Rept. 15, 29 pages.

.............................(1927): Geology along the Bow River between Cochrane and Kananaskis, Alberta; Res. Coun. Alberta Rept. 17, 46 pages.

............................(1928): Geology of the area between North Saskatchewan and McLeod Rivers, Alberta; Res. Coun. Alberta Rept. 19, 37 pages.

............................(1939a): Stettler; Geol. Surv. Can. Map 503A.

............................(1939b): Red Deer; Geol. Surv. Can. Map 504A.

............................(1939c): Edmonton; Geol. Surv. Can. Map 506A.

Sanderson, J. O. G. (1931): Upper Cretaceous volcanic ash beds in Alberta; Trans. Roy. Soc. Can., Vol. 25, Sec. 4, p. 61-71.

Shafiqullah, M., R. E. Folinsbee, H. Baadsgaard, G. L. Cumming, and J. F. Lerbekmo (1964): Geochronology of Cretaceous-Tertiary boundary, Alberta, Canada; Proc. 22nd Int. Geol. Congress (India) Pt. 3, Sec. 3, p. 1-20.

Simpson, G. G. (1927): Mammalian fauna and correlation of the Paskapoo Formation of Alberta; Am. Mus. Novitates, No. 268, 10 pages.

Snead, R. G. (1969): Microfloral diagnosis of the Cretaceous-Tertiary boundary, Central Alberta; Res. Coun. Alberta Bull. 25, 148 pages.

Spotts, J. H. (1964): Grain orientation and imbrication in Miocene turbidity current sandstones California; Jour. Sedimentary Petrology, Vol. 34, p. 229-53.

Srivastava, S. K. (1967): Palynology of Late Cretaceous mammal beds, Scollard, Alberta (Canada); Paleogeography, Palaeoclimatology, Palaeoecology, Vol. 3, p. 133-50.

Sternberg, C. M. (1947): The upper part of the Edmonton Formation of Red Deer valley, Alberta; Geol. Surv. Can. Paper 47-1, 11 pages.

............................(1950): *Leptoceratops,* the most primitive horned dinosaur from the upper Edmonton of Alberta; Trans. Roy. Soc. Can., Vol. 44, p. 229.

............................(1951): Complete skeleton of *Leptoceratops gracilis* Brown from the upper Edmonton member on Red Deer River, Alberta, Canada; Nat. Mus. Can. Bull. 123, p. 225-55.

Taylor, R. S., W. H. Mathews and W. O. Kupsch (1964): Tertiary; *in* Geological History of Western Canada, Alberta Soc. Petroleum Geol., p. 190-94.

Tóth, J. (1966): Groundwater geology, movement, chemistry and resources near Olds, Alberta; Res. Coun. Alberta Bull. 17, 126 pages.

..............(1968): A hydrogeological study of the Three Hills area, Alberta; Res. Coun. Alberta Bull. 24, 117 pages.

Tozer, E. T. (1952): The St. Mary River - Willow Creek contact on Oldman River, Alberta; Geol. Surv. Can. Paper 52-3, 9 pages.

.....................(1953): The Cretaceous-Tertiary transition in southwestern Alberta; 3rd Ann. Field Conf. and Symp., Alberta Soc. Petroleum Geol., p. 23-31.

.....................(1956): Uppermost Cretaceous and Paleocene non-marine molluscan faunas of Western Alberta; Geol. Surv. Can. Mem. 280, 125 pages.

Tyrrell, J. B. (1887): Report on part of northern Alberta and portions of adjacent districts of Assiniboia and Saskatchewan embracing the country lying south of the North Saskatchewan River and north of Lat. 51° 6' between Long. 110° and 115° 15' west; Geol. and Nat. Hist. Surv. Can. Ann. Rept. 1886, Vol. 2E, 176 pages.

Vonhof, J. A. (1965): The Cypress Hills Formation and its reworked deposits in southwestern Saskatchewan; *in* 15th Ann. Field Conf. Guidebook, Alberta Soc. Petroleum Geol., p. 142-61.

Warren, P. S. (1926): The invertebrate fauna of the upper part of the Edmonton Formation on the Red Deer River, Alberta; Trans. Roy. Soc. Can., 3rd Ser., Vol. 20, p. 1-7.

Wermund, E. G. and R. J. Moiola (1966): Opal, zeolites and clays in Eocene neritic bar sand; Jour. Sedimentary Petrology, Vol. 36, No. 1, p. 248-53.

Whiteaves, J. F. (1885): Report on the invertebrata of the Laramie and Cretaceous rocks of the vicinity of the Bow and Belly Rivers and adjacent localities in the Northwest Territory; Geol. Surv. Can., Contrib. Can. Paleont, Vol. 1, p. 1-89.

..........................(1887): On some fossils from the Cretaceous and Laramie rocks of the North Saskatchewan and its tributaries, collected by Mr. J. B. Tyrrell in 1885 and 1886; Geol. Surv. Can. Ann. Rept. 1886, Pt. E, p. 153-66.

Williams, G. D. and C. F. Burk (1964): Upper Cretaceous; *in* Geological History of Western Canada, Alberta Soc. Petroleum Geol., p. 169-89.

Williams, H., F. J. Turner and C. M. Gilbert (1954): Petrography; W. H. Freeman and Company, San Francisco, 406 pages.

Williams, M. Y. and W. S. Dyer (1930): Geology of Southern Alberta and Southwestern Saskatchewan; Geol. Surv. Can. Mem. 163, 160 pages.

Williams, M. Y., W. S. Dyer, E. J. Whittaker, B. Rose and P. S. Warren (1928): Calgary; Geol. Surv. Can. Map 204A.

Zell, R. L. (1965): Cypress Hills Plateau, Alberta and Saskatchewan; 15th Ann. Field Conf. Guidebook, Alberta Soc. Petroleum Geol., Pt. I, 222 pages; Pt. II, 22 pages.

APPENDIX A. SYMBOLS AND ABBREVIATIONS

Land Survey Location

Lsd.	: legal subdivision (16 per section)
Sec.	: section (36 per township)
Tp.	: township (6-mile square, 126 townships between north and south boundaries of Alberta)
R.	: range (distance of township west of meridian, maximum of 30 between meridians)
W. 4th Mer.	: west of fourth meridian
Meridian	: marked and surveyed longitude
m	: mile(s)

Statistical Analyses

D^2	: distance between multivariate means
F	: Fisher's variance ratio
R_1	: discriminant function for population 1
R_0	: discriminant index
R_2	: discriminant function for population 2
r	: simple correlation coefficient
N	: total number of samples
$\bar{x}$	: mean

Petrographic Analyses

Framework grains

Q	: quartz and quartzites
F	: feldspars
Ch	: chert
Mi	: micas
RF	: nonvolcanic rock fragments
VRF	: volcanic rock fragments
CO_3	: clastic carbonates
Ms	: miscellaneous

Pore filling constituents

Ct	: calcite cement
K	: kaolinite cement
Mo	: montmorillonite cement
Cl	: chlorite cement
Z	: clinoptilolite
Ot	: others

General

mm	: millimeter(s)
s.g.	: specific gravity
r.i.	: refractive index
R.C.A.	: Research Council of Alberta

APPENDIX B. INDEX OF SAMPLE LOCATIONS

Sample No.	Location Sec.	Tp.	R.	W. of Mer.	Locale	Elevation (feet) (approx.)	Formation
572	32	36	28	4	Bank of Red Deer River, 4 miles W. of Penhold	2,900	Paskapoo
576	13	8	3	4	Roadcut, 1 mile W. of Elkwater	4,100	Ravenscrag
577	13	8	3	4	Roadcut, 1 mile W. of Elkwater	4,100	Ravenscrag
579	3	38	25	4	S. bank of Red Deer River, 4 miles E. of Hillsdown	2,700	Paskapoo
583	11	28	2	5	McPherson Coulee, 2 miles S. of Nier	3,800	Porcupine Hills
584	5	18	1	5	N. bank of Highwood River, 13 miles SW. of High River	3,850	Porcupine Hills
585	13	8	30	4	Tennesee Creek, 9 miles N. of Pincher Station	4,300	Porcupine Hills
586	23	30	29	4	Rosebud River, 5 miles ENE. of Carstairs	3,200	Porcupine Hills (?)
587	1	26	2	5	Beddington Creek, 6 miles WSW. of Balzac	3,700	Porcupine Hills
588	21	39	7	5	North Saskatchewan River, 1 mile W. of Rocky Mountain House	3,200	Paskapoo
589	1	9	28	4	Olsen Creek, 13 miles W. of Fort McLeod	3,800	Porcupine Hills
590	15	20	1	5	Spring Creek, 3 ½ miles WSW. of Okotoks	3,600	Porcupine Hills
591	34	17	29	4	Mosquito Creek, 4 miles NW. of Cayley	3,500	Porcupine Hills

Sample No.	Location				Locale	Elevation (feet) (approx.)	Formation
	Sec.	Tp.	R.	W. of Mer.			
592	28	10	29	4	Craig Creek, 16 miles W. of Granum	4,500	Porcupine Hills
593	11	26	4	5	Bighill Creek, 1 mile N. of Cochrane	4,100	Porcupine Hills
594	27	9	1	5	Oldman River, 14 miles N. of Cowley	4,550	Porcupine Hills
595	8	14	28	4	Roadside outcrops, 6 miles W. of Stavely	3,800	Porcupine Hills
596	28	10	1	5	Indian Creek, 20 miles N. of Cowley	4,600	Porcupine Hills
597	11	14	2	5	Rice Creek, 40 miles N. of Lundbreck	5,000	Porcupine Hills
598	12	14	30	4	Willow Creek, 15 miles W. of Stavely	4,100	Porcupine Hills
599	15	16	29	4	Williams Coulee, 7 miles W. of Nanton	4,000	Porcupine Hills
600	1	11	1	5	Sharples Creek firetower, Rocky Mountains Forest Reserve	5,800	Porcupine Hills
601	4	12	1	5	Burton Creek, 4 miles W. of Furman	5,500	Porcupine Hills
602	20	53	7	5	Pembina River, Entwistle railroad bridge	2,400	Paskapoo
603	20	53	7	5	Pembina River, Entwistle railroad bridge	2,400	Paskapoo
605	20	53	16	5	McLeod River, 4 miles E. of Edson	2,800	Paskapoo

Sample No.	Location Sec.	Tp.	R.	W. of Mer.	Locale	Elevation (feet) (approx.)	Formation
606	21	52	23	5	Roadcut, Highway 16, 1½ miles S. of Dalehurst	3,800	Paskapoo
607	2	53	21	5	Roadcut, Highway 16, 1 mile E. of Medicine Lodge	3,400	Paskapoo
608	27	39	7	5	North Saskatchewan River, 1 mile W. of Rocky Mountain House	3,110	Paskapoo
609	27	39	7	5	North Saskatchewan River, 1 mile W. of Rocky Mountain House	3,150	Paskapoo
610	27	39	7	5	North Saskatchewan River, 1 mile W. of Rocky Mountain House	3,175	Paskapoo
650	14	50	6	5	North Saskatchewan River, 2 miles N. of Berrymoor	2,400	Paskapoo
651	15	53	5	5	Wabamun Lake, 1 mile S. of Fallis	2,500	Paskapoo
660	1	34	22	4	Red Deer River, 8 miles SW. of Scollard	2,800	Paskapoo
662	17	30	22	4	Threehills Creek, 13 miles SE. of Three Hills	2,500	Paskapoo
663	20	30	25	4	Kneehills Creek, 1 mile S. of Linden	2,800	Porcupine Hills
664	17	38	23	4	Red Deer River, 1 mile NW. of Ardley	2,600	Paskapoo

Sample No.	Location				Locale	Elevation (feet) (approx.)	Formation
	Sec.	Tp.	R.	W. of Mer.			
666	13	39	27	4	Red Deer River, ½ mile S. of Burbank	2,800	Paskapoo
670	5	67	10	5	Swan Hills townsite	3,900	Paskapoo
671	6	67	10	5	Swan Hills townsite	3,900	Paskapoo
678	32	42	24	4	Roadcut, Highway 53, 7 miles E. of Ponoka	2,850	Paskapoo
681	15	58	13	5	McLeod River, 11 miles SSW. of Whitecourt	2,500	Paskapoo
682	15	39	1	5	Sylvan Lake, Highway 20, 2 miles E. of Sunnyside	3,200	Paskapoo
684	2	27	5	5	Grand Valley, 8 miles NW. of Cochrane	4,100	Paskapoo
685	21	32	6	5	Red Deer River, 7 Miles NW. of Bergen	3,900	Paskapoo
740	34	45	10	5	Brazeau River, ½ mile upstream from power plant	2,850	Paskapoo
744	18	46	11	5	Brazeau River, ½ mile downstream from dam	3,000	Paskapoo
770	34	45	10	5	Brazeau River, ½ mile upstream from power plant	3,000	Paskapoo
771	35	21	28	4	Bow River, 6 miles S. of Indus	3,200	Paskapoo
772	35	21	28	4	Bow River, 6 miles S. of Indus	3,300	Paskapoo
773	16	23	23	4	Hammer Hill, 4 miles N. of Stobart	3,200	Paskapoo

Sample No.	Location Sec.	Tp.	R.	W. of Mer.	Locale	Elevation (feet) (approx.)	Formation
774	20	26	21	4	Outcrops above coal mine, 5 miles SSE. Rosebud	3,000	Paskapoo
775	19	29	23	4	Kneehills Creek, 3½ miles W. of Carbon	2,600	Paskapoo
776	11	29	17	4	Hand Hills, 18 miles E. of Drumheller	3,200	Paskapoo
800	27	45	1	5	Battle River, 7 miles N. of Homeglen	2,900	Paskapoo
843	34	15	27	4	Mosquito Creek, 4 miles E. of Durward	3,300	Willow Creek
844	5	14	1	5	South branch of Willow Creek	4,400	Porcupine Hills
845, 846	1	11	27	4	Willow Creek, 2 miles W. of Granum	3,200	Willow Creek
847	28	13	28	4	Willow Creek, 11 miles NW. of Claresholm	3,400	Porcupine Hills
848	32	13	28	4	Willow Creek, 12 miles NW. of Claresholm	3,450	Porcupine Hills
849	15	14	28	4	Pine Creek, 4 miles W. of Stavely	3,450	Porcupine Hills
850	15	14	28	4	Pine Creek, 4 miles W. of Stavely	3,400	Porcupine Hills
851	17	19	29	4	Tongue Creek, 8 miles S. of Okotoks	3,500	Porcupine Hills
852	27/28	21	29	4	Roadcut, 6 miles N. of Okotoks	3,500	Porcupine Hills
853	4	14	29	4	Willow Creek, 17 miles NW. of Claresholm	3,850	Porcupine Hills

Sample No.	Location Sec.	Tp.	R.	W. of Mer.	Locale	Elevation (feet) (approx.)	Formation
854	4/5	20	29	4	Middle Heights, 4 miles S. of Okotoks	3,850	Porcupine Hills
857	16	21	28	4	Bridge over Highwood River, 8 miles NE. of Okotoks	3,250	Paskapoo
858	26/27	14	25	4	Little Bow River, 15 miles ENE. of Stavely	3,100	Willow Creek
859	36	21	1	5	Quarry for lightweight aggregate, 1 mile E. of De Winton	3,500	Paskapoo
886	28	21	26	4	Bow River, 4 miles SW. of Carseland	3,100	Paskapoo
888	28	21	26	4	Bow River, 4 miles SW. of Carseland	3,225	Paskapoo
889	35	21	28	4	Bow River, 6 miles S. of Indus	3,300	Paskapoo
890	23	24	2	5	Bow River, Brickburn, City of Calgary	3,590	Porcupine Hills
891	23	24	2	5	Bow River, Brickburn, City of Calgary	3,690	Porcupine Hills
892	12	25	3	5	Bow River, ½ mile SE. of Bearspaw Dam	3,620	Porcupine Hills
893	32	23	1	5	Elbow River, base of Glenmore Dam	3,500	Porcupine Hills
895	5	23	1	5	Fish Creek, 1½ miles N. of Midnapore	3,500	Porcupine Hills
896	12	34	28	4	Spruce Creek, 2 miles E. of Nisbet	3,200	Porcupine Hills (?)

Sample No.	Location				Locale	Elevation (feet) (approx.)	Formation
	Sec.	Tp.	R.	W. of Mer.			
897	13	39	27	4	Red Deer River, ½ mile S. of Burbank	2,800	Paskapoo
898	4	39	26	4	Red Deer River, 12 miles W. of Haynes	2,900	Paskapoo
905	8	48	27	4	Wizard Lake, 8½ miles S. of Buford	2,700	Paskapoo
906	24/25	48	28	4	Roadcut, 5 miles SSW. of Buford	2,625	Paskapoo
909	23	21	29	4	Roadcut, 6 miles NW. of Okotoks	3,525	Paskapoo (?)
911	24/25	26	2	5	Roadcut, 7 miles WNW. of Balzac	3,975	Porcupine Hills
927	1	26	2	5	Beddington Creek, 6 miles WSW. of Balzac	3,650	Porcupine Hills
949	18	34	21	4	Red Deer River, 6 miles WSW. of Scollard	2,600	Paskapoo
957	2	56	19	5	Shining Bank Ridge, 19 miles NW. of Edson	3,600	Paskapoo
958	22	56	19	5	Shining Bank Ridge, 23 miles NW. of Edson	4,200	Paskapoo

Coreholes

R.C.A. Corehole 65-1

Sec. 8, Tp. 48, R. 27, W.4th Mer.
K.B. elevation: 2,694 feet
Total depth: 507 feet

Sample No.	Depth (feet)
65-1-S-1	14.0
S-2	20.0
S-3	40.0
S-4	50.0
S-5	51.0
S-6	66.0
S-7	78.0
S-8	96.0
S-9	104.0
S-10	108.5
S-11	113.0
S-12	124.5
S-13	128.0
S-14	133.0
S-15	139.0
S-16	162.0
S-17	171.0
S-18	181.0
S-19	188.0
S-20	198.0
S-21	205.0
S-22	206.0
S-23	208.0
S-24	215.0
S-25	238.0
S-26	251.0
S-27	254.0
S-28	279.5
S-29	282.0
S-30	294.0
65-1-S-31	298.0
S-32	314.0
S-33	319.0
S-34	362.0
S-35	369.0
S-36	372.5
S-37	379.0
S-38	381.0
S-39	386.0
S-40	398.0
S-41	409.0
S-42	414.0
S-43	415.0
S-44	428.0
S-45	434.5
S-46	440.0
S-47	448.0
S-48	450.5
S-49	457.0
S-50	462.0
S-51	468.5
S-52	470.5
S-53	479.0
S-54	485.0
S-55	490.0
S-56	493.0
S-57	499.0

R.C.A. Corehole 66-1

Sec. 25, Tp. 26, R. 2, W.5th Mer.
K.B. elevation: 3,975 feet (approx.)
Total depth: 1,000 feet

Sample No.	Depth (feet)
66-1-S-1	20.0

66-1-S-2	22.5
S-2A	30.0
S-3	40.0
S-4	61.0
S-5	85.0
S-6	90.0
S-7	99.0
S-8	103.0
S-9	110.0
S-10	115.0
S-11	124.0
S-12	137.0
S-13	145.0
S-14	151.0
S-15	162.0
S-16	170.0
S-17	185.0
S-18	187.0
S-19	201.0
S-20	203.0
S-21	210.0
S-22	221.0
S-23	234.0
S-24	243.5
S-25	255.0
S-26	262.0
S-27	265.0
S-28	272.0
S-29	314.0
S-30	336.0
S-31	343.0
S-32	347.5
S-33	398.0
S-34	400.0
S-35	405.0
S-36	410.0
S-37	420.0
66-1-S-38	427.0
S-39	450.0
S-40	454.0
S-41	460.0
S-42	465.0
S-43	469.0
S-44	480.0
S-45	501.0
S-46	510.0
S-47	515.0
S-48	520.0
S-49	525.0
S-50	529.0
S-51	540.0
S-52	547.0
S-53	555.0
S-54	556.5
S-55	560.0
S-56	565.0
S-57	570.0
S-58	615.0
S-59	620.0
S-60	628.0
S-61	663.5
S-62	668.0
S-63	693.0
S-64	736.0
S-65	805.0
S-66	821.0
S-67	825.0
S-68	831.0
S-69	835.0
S-70	847.0
S-71	859.0
S-71	859.0
S-72	876.0
S-73	880.0

66-1-S-74	932.5
S-75	961.0
S-76	966.0
S-77	972.0
S-78	989.0
S-79	1000.0
66-1-C-1	51.0
C-2	96.0
C-3	189.5
C-4	385.0
C-5	708.0
C-6	898.0
C-7	999.0
66-1-R-1	359.0
R-2	903.0
R-3	962.0

McLeod River Damsite Corehole No. 1
Sec. 33, Tp. 57, R. 13, W.5th Mer.
Surface elevation: 2,605.6 feet
Total depth: 190 feet

Sample No.	Depth (feet)
MRD-1-30	30.0
1-40	40.0
1-63	63.0
1-71	71.0
1-80	80.0
1-90	90.0
1-110	110.0
1-120	120.0
1-130	130.0
1-151	151.0
1-158	158.0
1-170	170.0
1-180	180.0
1-190	190.0

McLeod River Damsite Corehole Nos. 2 and 2A
Sec. 33, Tp. 57, R. 13, W.5th Mer.
Surface elevation: 2,440.5 feet
Total depth: 2 - 65.0 feet
2A-217.5 feet

Sample No.	Depth (feet)
MRD-2-20	20.0
2-30	30.0
2-40	40.0
2-50	50.0
2-60	60.0
2A-88	88.0
2A-154	154.0
2A-160	160.0
2A-180	180.0
2A-200	200.0
2A-210	210.0

APPENDIX C. DESCRIPTIONS OF CORED SECTIONS

Name of well: R.C.A. Corehole 65-1 (Wizard Lake)

Location: 4,200 feet S. of NW. corner Sec. 8, Tp. 48, R. 27, W. 4th Mer. (8.6 miles S. of Buford)

Elevation: K.B. 2,694± feet

Total depth: 507 feet

Core recovered: 494 feet

Date completed: November 4, 1965

Mechanical well logs: Dual induction-laterolog, (spontaneous) self potential, sonic, gamma ray

Depth (feet)	Thickness (feet)	Lithology
13.20		
15.45	2.25	yellowish-grey siltstone, numerous vertical and horizontal fractures, coated with greyish-red film.
21.25	5.80	yellowish-grey, laminated siltstone, dark carbonaceous millimeter laminae, numerous fractures.
21.60	0.35	green shale.
23.60	2.00	yellowish-grey siltstone.
35.00	11.40	dark greenish-grey shale, waxy, soft; carbonaceous beds present.
35.50	0.50	greenish-grey bentonite.
38.00	2.50	dark greenish-grey shale.
40.16	2.16	yellowish-grey, fractured siltstone.
40.50	0.34	light bluish-grey siltstone.
44.90	4.40	bluish-grey sandstone, underlain by 0.25 feet of bluish-grey siltstone.
49.00	4.10	dark greenish-grey shaly siltstone, carbonaceous at base.
49.90	0.90	light bluish-grey, siltstone mottled with yellowish grey siltstone.
50.70	0.80	bluish-grey sandstone.
51.50	0.80	yellowish-grey sandstone.
51.90	0.40	bluish-grey and yellowish-grey siltstone.
53.90	2.00	dark greenish-grey shale.
54.23	0.33	bluish-grey, fine-grained sandstone.
64.40	10.17	dark greenish-grey shale.
65.20	0.80	bluish-grey, carbonaceous clay.

Depth (feet)	Thickness (feet)	Lithology
66.20	1.00	dark greenish-grey shale.
66.36	0.16	bluish-grey clay and sand.
70.22	3.86	greenish-grey laminated sandstone.
75.72	5.50	dark greenish-grey shale, grading downward through siltstone into sandstone.
80.20	4.48	dark greenish-grey siltstone, grading downward into a fine sandstone with carbonaceous laminae.
95.47	15.27	dark greenish-grey shale, carbonaceous laminae.
101.54	6.07	dark greenish-grey silty sandstone, some festoon bedding.
115.54	14.00	bluish-grey, silty sandstone, mottled yellowish-grey adjacent to fractures, carbonaceous laminae with a few 1- to 2-inch beds of medium-grained sand interbedded.
124.18	8.64	bluish-grey, medium-grained, friable sandstone mottled with yellowish-grey.
124.68	0.50	bluish-grey, medium-grained sandstone, cemented.
134.18	9.50	bluish-grey, medium-grained friable sandstone, with green shale pellets, shells and thin beds of coal.
142.18	8.00	dark greenish-grey shale, interbedded with bluish grey siltstone with carbonaceous laminae, and 1-inch beds of sandstone.
150.50	8.32	dark brown shale and lignite, 1.56 feet; coal, 1.50 feet; brown carbonaceous shale, 1.64 feet; lignite, 0.33 feet.
157.34	6.84	carbonaceous shale, 0.80 feet; greenish grey shale, 0.16 feet; lignite, coal and hard black shale, 2.00 feet; dark greenish grey shale, hard, 0.66 feet; dark greenish grey shale, carbonaceous, 0.25 feet.
164.82	7.48	coal, friable, 4.16 feet; dark greenish grey silt with carbonaceous laminae, and thin coal beds, 1 foot; coal, friable, 0.75 feet; carbonaceous shale, 0.56 feet; coal, 0.66 feet.
170.66	5.84	dark greenish-grey shale, fractured with slickensides, some thin carbonaceous beds and thin coal beds.
174.62	3.96	medium grey laminated siltstone grading downward into a fine-grained sandstone.
180.62	6.00	carbonaceous shale, 0.56 feet; coal, 0.16 feet; carbonaceous shale, 0.50 feet; coal, 0.33 feet; brown carbonaceous shale, 1.16 feet; coal, 3.16 feet.
182.12	1.50	dark greenish-grey, fine-grained sandstone with near vertical stringers of coal in upper 1 foot.
185.54	3.42	greenish grey clayey siltstone, laminated, soft.

Depth (feet)	Thickness (feet)	Lithology
211.74	26.20	dark greenish-grey laminated siltstone and sandstone interbedded with thin beds of carbonaceous shale.
217.46	5.72	greenish-grey sandstone, friable, 2.00 feet; greenish-grey sandstone, cemented, 1.72 feet; greenish-grey sandstone, friable, 2.00 feet.
228.96	11.50	dark greenish-grey laminated siltstone grading downward into silty shale.
232.78	3.82	dark grey shale with a 0.5 foot carbonaceous layer and 0.3-foot coal bed underlain by a dark grey siltstone with plant remains.
260.00	27.22	grey siltstone with plant remains, fine-grained sandstone, siltstone and laminated silty shale, in beds 0.50 to 2.00 feet thick.
277.42	17.42	dark grey shale, 3.5 feet; carbonaceous shale, 3.0 feet; coal, 3.75 feet; carbonaceous shale, 1.0 feet; bentonite, 0.75 feet; carbonaceous shale, 1.66 feet; coal, 0.75 feet; dark greenish-grey shale, 1.75 feet.
297.00	19.58	greenish-grey siltstone, sandstone and shale with some laminated and carbonaceous beds.
298.25	1.25	greenish-grey sandstone, cemented.
322.00	23.75	greenish-grey shale, siltstone and sandstone interbedded.
335.75	13.75	carbonaceous shale, 0.25 feet; brown mottled silt, 0.25 feet; brownish-black, waxy, bentonitic shale, 13 feet.
362.00	26.25	hard brown silicified tuff bed 0.75 feet; brownish-black, waxy, shale, 0.33 feet; brown tuffaceous shale, dry, 0.75 feet; light brown tuff, carbonaceous, 0.16 feet; laminated tuff, pumiceous, 0.75 feet; brown shale, 0.56 feet; laminated tuff, pumiceous, 0.08 feet; brown shale, 1.00 feet; tuff interbedded with brown shale and carbonaceous material, 2.16 feet; brown waxy shale, 0.32 feet; brown tuffaceous rock, 3.66 feet; brownish-black waxy shale, 3.80 feet; dark greenish-grey bentonite, 1.00 feet; carbonaceous shale, 0.33 feet; brownish-black waxy bentonitic shale, 8.0 feet.
364.70	2.70	greenish-grey siltstone and bentonitic shale.
396.00	31.30	greenish-grey, medium-grained sandstone, friable.
398.00	2.00	greenish-grey medium-grained sandstone, cemented.
410.00	12.00	greenish-grey coarse-grained sandstone, friable.
412.33	2.33	greenish-grey coarse-grained sandstone, cemented.
430.00	17.67	greenish-grey coarse-grained sand.
430.66	0.66	dark brown siltstone with some shells.
433.16	2.50	olive grey siltstone mottled with yellowish grey.

Depth (feet)	Thickness (feet)	Lithology
443.42	10.26	greenish-grey fine-grained sandstone, 0.40 feet; greenish-grey siltstone, laminated with plant remains on bedding planes, 4.16 feet; carbonaceous shale, siltstone and sandstones interbedded in layers 0.5-1.5 feet thick, 4.00 feet.
445.92	2.50	brownish-black siltstone.
449.00	3.08	greenish-grey siltstone with carbonaceous fragments.
454.00	5.00	greenish-grey silty sandstone, 2.25 feet; coal, bentonite and carbonaceous shale interbedded, 2.50 feet.
469.00	15.00	greenish-grey bentonitic shale grading downward through siltstone into a laminated carbonaceous sandstone.
474.00	5.00	coarse-grained sandstone, 2.00 feet; coal, 1.25 feet; olive green bentonitic shale, 0.75 feet.
482.16	8.16	grey siltstone with abundant plant remains.
491.75	9.59	grey coarse-grained sandstone friable, 5.25 feet; grey coarse-grained sandstone cemented, 2.50 feet; grey coarse-grained sandstone friable, 0.80 feet.
506.94	15.19	brownish-black shale, 1 foot; hard layer (siderite nodules?), 0.16 feet; dark greenish-grey siltstone, 2.5 feet; dark greenish-grey fine-grained sandstone friable, 4.00 feet; cemented sandstone, 0.25 feet; greenish-grey sandstone, 1.75 feet; grey shaly siltstone, 3.25 feet; coaly and carbonaceous material, 0.5 feet.

T.D. 507 feet.

Name of well: R.C.A. Corehole 66-1 (Balzac)

Location: Lsd. 2, Sec. 25, Tp. 26, R. 2, W. 5th Mer.

Elevation: K.B. 3,975± feet

Total depth: 1,000 feet

Core recovered: 830 feet

Date completed: July 26, 1966

Mechanical well logs: Dual induction-laterolog, self potential, sonic, gamma ray

Depth (feet)	Thickness (feet)	Lithology
19.0		
21.0	2.0	yellowish-grey sandstone.
23.0	2.0	grey sandstone, hard, 0.5 feet; yellowish-grey sandstone, 1.0 foot; grey sandstone, with thin lignite beds, 0.5 feet.
26.5	3.5	yellowish-grey silty shale grading downward into siltstone.
35.0	8.5	yellowish-grey silty shale with carbonaceous beds.
43.0	8.0	dark greenish-grey and yellowish-grey hard and soft siltstones interbedded with greenish grey sandstone.
48.5	5.5	dark greenish-grey bentonitic calcareous shale.
49.0	0.5	light greenish-grey siltstone.
50.0	1.0	dark greenish-grey carbonaceous siltstone, hard.
53.0	3.0	hard and soft siltstone and silty shale with some coaly fragments.
59.0	6.0	greenish-grey bentonitic shale, blocky fracture noncalcareous, thin two inch bed of coal.
60.3	1.3	greenish-grey silty shale, calcareous.
63.5	3.2	greenish-grey fine-grained sandstone, with vertical fractures and abundant comminuted carbon.
68.8	5.3	silty shale, fine-grained sandstone and silty shale interbedded in layers 0.25 to 1.5 feet thick.
70.3	1.5	greenish-grey silty shale containing small snail shells underlain by 0.3 feet of carbonaceous shale.
85.0	14.7	dark greenish-grey siltstone, massive bentonitic with small gastropods and freshwater pelecypods scattered throughout.
90.0	5.0	greenish-grey carbonaceous siltstone underlain by medium-grained sandstone.
103.0	13.0	greenish-grey massive siltstone and highly fractured bentonitic shale and fine-grained laminated sandstone interbedded in layers 2 to 4 feet thick; carbonaceous layer with abundant gastropods at 100 feet.

Depth (feet)	Thickness (feet)	Lithology
129.0	26.0	greenish-grey sandstone with calcareous cement interbedded with massive siltstones and carbonaceous shale.
130.0	1.0	carbonaceous clay underlain by very hard, greenish-grey siltstone containing numerous gastropods.
147.5	17.5	silty shale with numerous gastropods throughout underlain by sandy siltstone and carbonaceous sandstone.
161.5	14.0	siltstone containing freshwater pelecypods underlain by massive hard and soft siltstone beds containing scattered gastropods.
162.0	0.5	fine-grained sandstone, cemented.
168.0	6.0	silty shale.
171.0	3.0	very fine grained sandstone passing downward through a 0.5 foot bed of medium-grained sand to 0.5 feet of fine-grained laminated sand.
177.0	6.0	siltstone, freshwater pelecypods at 174 feet and small gastropods scattered throughout.
184.0	7.0	light olive bentonite containing a layer of carbonate nodules and thin beds of silty shale.
186.0	2.0	medium-grained sandstone.
194.0	8.0	siltstone, massive, large pelecypods at 188 feet and bone fragments at 189.5 feet and calcareous nodules at 194 feet.
196.0	2.0	siltstone with fossil shells scattered throughout.
207.0	11.0	dark greenish-grey siltstone.
208.0	1.0	medium-grained sandstone.
225.0	17.0	massive greenish-grey siltstone.
228.5	3.5	greenish-grey siltstone with carbonaceous fossiliferous bands.
231.0	2.5	siltstone bentonitic.
238.0	7.0	dark grey shale, 1.3 feet; medium-grained sandstone with carbonaceous laminae and fossils, 0.8 feet; greenish-grey shale, 0.5 feet; carbonaceous shale, fossiliferous 1.0 foot; grey medium-grained sand, carbonaceous with calcareous nodules, 0.5 feet; medium to coarse-grained sand with calcarous pebbles and carbonized wood, covered with yellow powder.
248.0	10.0	siltstone, massive, blocky fracture, mottled brown areas where nodules appear to be forming.
250.0	2.0	siltstone, with abundant carbonized wood.
253.0	3.0	siltstone.
257.0	4.0	medium-grained cross-bedded sandstone.

Depth (feet)	Thickness (feet)	Lithology
260.0	3.0	siltstone, massive with scattered carbon and shells underlain by carbonaceous siltstone and fine-grained sandstone.
285.0	25.0	siltstone and sandstone and bentonitic shale interbedded, small piece of bone at 282 feet.
290.0	5.0	fossiliferous (gastropods) siltstone, hard, calcareous.
297.0	7.0	olive green bentonitic siltstone.
306.0	9.0	olive green bentonitic shale with mottled yellowish brown alteration products.
324.0	18.0	siltstone, massive with single gastropods scattered throughout.
347.0	23.0	laminated siltstone grading downward to fine sand, 5 feet; fine-grained laminated sandstone with siltstone interbedded; carbonized wood fragments abundant, 5 feet; siltstone, carbonaceous with gastropods, 3.75 feet; fine-grained laminated sandstone, 2.25 feet; siltstone, massive, scattered single gastropods, 4.0 feet.
350.0	3.0	medium-grained cross-bedded sandstone with abundant comminuted carbon; upper 0.5 feet coarser grained than underlying beds.
358.0	8.0	siltstone and shaly siltstone, massive.
358.5	0.5	carbonaceous fossiliferous siltstone; high gamma ray reading on the radioactivity log.
370.0	11.5	massive siltstone with scattered gastropods.
380.0	10.0	very fine grained massive sandstone.
385.5	5.5	massive siltstone with occasional gastropods.
390.0	4.5	very fine grained massive sandstone with scattered single gastropods, becoming darker in color at 390 feet.
403.0	13.0	fine-grained, massive sandstone.
419.0	16.0	medium-grained, cross-bedded sandstone.
420.0	1.0	conglomerate with clasts (3 inches diam.) of siltstone and laminated sandstone in a coarse sand matrix, 0.5 feet; coarse-grained sandstone, 0.5 feet.
446.0	26.0	massive siltstone with a few thin beds of fine-grained sandstone; one 2-inch carbonaceous bed at 437 feet.
483.0	37.0	mainly fine-grained laminated sandstone interbedded with shaly bentonitic siltstone and medium grained sandstone.
487.0	4.0	dark greenish-grey fossiliferous siltstone.
501.0	14.0	hard and soft massive siltstone, bentonitic throughout; a 1-inch carbonaceous fossiliferous bed at 500 feet.

Depth (feet)	Thickness (feet)	Lithology
504.0	3.0	dense fossiliferous silty limestone containing abundant gastropods.
507.0	3.0	massive siltstone.
524.0	17.0	medium-grained, cross-bedded sandstone with carbonaceous laminae.
529.0	5.0	coarse-grained, cross-bedded sandstone with carbonaceous laminae.
532.0	3.0	massive siltstone.
556.5	24.5	medium- to coarse-grained sandstone.
557.0	0.5	conglomerate, with clasts of shale and limestone in a sandstone matrix, underlain by massive carbonaceous silt-stone.
574.0	17.0	medium- to coarse-grained sandstone, with a thin siltstone bed at 564 feet.
605.0	31.0	hard massive siltstone with incipient calcareous nodules throughout.
605.3	0.3	carbonaceous bed.
631.0	25.7	massive siltstone and fine-grained sandstone, interbedded.
631.16	0.16	carbonaceous bed.
639.0	7.84	soft, wet siltstone underlain by hard massive siltstone.
641.0	2.0	soft bentonitic siltstone.
643.0	2.0	fossiliferous, carbonaceous siltstone.
661.0	18.0	greenish-grey bentonitic siltstone grading downward into fine-grained sandstone.
663.5	2.5	fine-grained, laminated sandstone.
664.0	0.5	fossiliferous and carbonaceous siltstone.
694.5	30.5	siltstone and sandstone interbedded; thin carbonaceous beds at 683.5 feet, and 686.5 feet.
701.0	6.5	fossiliferous and bentonitic carbonaceous shale.
704.5	3.5	massive sandy siltstone with a few gastropods.
705.0	0.5	bentonite.
710.0	5.0	massive bentonitic shale.
717.0	7.0	massive siltstone and sandy siltstone.
722.0	5.0	fine-grained laminated carbonaceous sandy siltstone; jawbone of small marsupial embedded in carbonaceous layer at 720 feet.
764.5	42.5	sandy siltstone and bentonitic siltstone beds.

Depth (feet)	Thickness (feet)	Lithology
766.0	1.5	fossiliferous (gastropods) massive siltstone.
777.5	11.5	hard and soft massive siltstone with a thin carbonaceous bed at 771 feet.
778.5	1.0	carbonaceous siltstone.
796.0	17.5	massive siltstone with hard and soft layers.
803.0	7.0	carbonaceous, bedded fossiliferous siltstone.
808.0	5.0	massive siltstone.
810.3	2.3	siltstone carbonaceous with leaf impressions and gastropods.
817.0	6.7	massive siltstone underlain by fine-grained sandstone, scattered gastropods.
819.0	2.0	bentonitic shale.
825.0	6.0	fine- to medium-grained sandstone, cross-bedded.
833.5	8.5	hard and soft siltstone.
834.5	1.0	massive carbonaceous siltstone.
837.0	2.5	massive bentonitic sandstone containing some comminuted carbon.
845.0	8.0	bentonitic shale.
847.5	2.5	fine-grained sandstone.
851.0	3.5	fossiliferous carbonaceous siltstone, containing freshwater shells and plant remains.
867.0	16.0	greenish grey bentonitic siltstone interbedded with fine-grained sandstone.
879.0	12.0	shaly bedded bentonitic siltstone underlain by hard massive bentonitic siltstone.
882.0	3.0	medium-grained sandstone underlain by 1 foot of massive siltstone.
883.5	1.5	fossiliferous, carbonaceous siltstone.
899.0	15.5	massive siltstone.
900.0	1.0	lignitic siltstone
903.0	3.0	greenish-grey soft siltstone.
903.5	0.5	carbonaceous siltstone.
910.0	6.5	greenish-grey massive siltstone.
910.5	0.5	carbonaceous siltstone.
928.0	17.5	massive siltstone, hard and soft layers.
929.0	1.0	carbonaceous siltstone.
952.0	23.0	massive siltstone, hard and soft layers; carbonaceous beds at 936 feet; shell fragments at 937 feet.

Depth (feet)	Thickness (feet)	Lithology
952.5	0.5	fossiliferous carbonaceous siltstone.
959.0	6.5	massive siltstone with minor sandy beds; one 2-inch carbonaceous bed at 957 feet.
965.0	6.0	carbonaceous siltstone, 0.3 feet; fine-grained, laminated sand, 1.5 feet; hard massive fossiliferous siltstone, 1.0 feet; lignitic siltstone overlying black clay, 0.5 feet.
966.5	1.5	sandstone.
971.0	4.5	sandy siltstone.
971.5	0.5	shell bed.
978.0	6.5	massive siltstone with shells at 976 feet.
980.0	2.0	siltstone with carbonaceous beds.
989.0	9.0	hard and soft bentonitic siltstone.
989.5	0.5	carbonaceous siltstone.
1,000.0	10.5	massive bentonitic siltstone and fine-grained sandstone.

T.D. 1,000.0 feet.

Name of well: McLeod River Damsite Corehole 1

Location: Lsd. 7, Sec. 33, Tp. 57, R. 13, W. 5 Mer. (680 feet W. and 360 feet S. of Hole 2)

Elevation: 2,605.6 feet

Total depth: 190 feet

Core recovered: 110 feet

Date completed: February, 1966

Depth (feet)	Thickness (feet)	Lithology
0.0		
20.0	20.0	glacial drift.
35.0	15.0	yellowish-grey, fine-grained sandstone, blocky fractures.
40.0	5.0	buff to grey sandstone coarser grained than overlying sand.
45.0	5.0	core missing.
50.0	5.0	grey siltstone grading downward to greenish-grey bentonitic siltstone; minor pebble conglomerate at 45.2 feet.
55.0	5.0	greyish-green bentonite.
60.0	5.0	massive, soft greenish shale.
75.0	15.0	yellowish green, fine- to medium-grained sandstone, with carbonaceous laminae.
76.0	1.0	cemented sandstone, as above.
77.0	1.0	medium-grained sandstone, friable.
85.0	8.0	core missing.
90.0	5.0	buff coarse-grained friable sandstone.
95.0	5.0	medium- to coarse-grained sandstone, 2 feet; coarse-grained friable sandstone, 2 feet; shale chip conglomerate at 94 feet.
109.0	14.0	friable sandstone with one 3-inch cemented layer carbonaceous fragments common.
110.0	1.0	shale chip conglomerate.
114.0	4.0	friable coarse-grained sandstone, cross-bedded, carbonaceous.
120.0	6.0	sandstone, as above, with shale chip conglomerate underlain by bentonite.
126.0	6.0	massive, coarse-grained sandstone, 1 foot; greenish-grey bentonitic siltstone with plant impressions on bedding planes, 5 feet.
132.0	6.0	greenish-grey fine- to medium-grained sandstone.
135.0	3.0	bentonitic shale with plant impressions on the bedding planes.

Depth (feet)	Thickness (feet)	Lithology
140.0	5.0	core missing.
142.0	2.0	dark grey bentonitic shale, becoming very carbonaceous at base.
147.0	5.0	greenish-grey siltstone containing freshwater shell fragments in upper 2 feet, becoming darker green and more bentonitic in lower part of the core.
150.0	3.0	greenish-grey siltstone.
152.0	2.0	fine-grained sandstone.
154.5	2.5	massive bentonitic siltstone.
157.5	3.0	olive green bentonite.
158.0	0.5	sandy siltstone.
164.0	6.0	bentonitic siltstone.
170.0	6.0	very fine grained sandstone.
177.5	7.5	coarse-grained, cross-bedded sandstone.
180.0	2.5	fine- to medium-grained cross-bedded sandstone.
190.0	10.0	coarse-grained, cross-bedded sandstone with carbonaceous laminae.

T.D. 190 feet.

Name of well: McLeod River Damsite Corehole 2 and 2A

Location: NE Cor. Lsd. 7, Sec. 33, Tp. 57, R. 13, W. 5 Mer. (14 miles SW. of Whitecourt)

Elevation: 2,440.4 feet

Total Depth: No. 2 65.0 feet
No. 2A 217.5 feet

Core recovered: 130 feet

Date completed: February, 1966

Depth (feet)	Thickness (feet)	Lithology
0.0		
7.0	7.0	ice, water and Recent river deposits.
22.5	15.5	greenish-grey, medium-grained sandstone with carbonaceous laminae, underlain by medium- to coarse-grained cross-bedded sandstone.
45.0	22.5	coarse-grained, cross-bedded sandstone.
60.0	15.0	medium-grained, cross-bedded sandstone.
65.0	5.0	core missing.
77.5	12.5	grey bentonite, 0.75 feet; bentonite containing freshwater shell fragments, 0.5 feet; bentonitic siltstone, 2 feet; hard cemented siltstone, 2 feet; bentonitic siltstone, 1.5 feet.
87.5	10.0	core missing.
97.5	10.0	grey laminated siltstone with leaf impressions on bedding planes, 2 feet; greenish-grey, fine-grained sandstone, 3.5 feet; grey, fissile siltstone with leaf impressions on bedding planes, 1.5 feet; bentonitic siltstone, 1.0 foot.
102.0	4.5	massive grey siltstone.
102.5	0.5	coal, 1 inch; grey silt, 3 inches; coal, 1 inch.
109.5	7.0	greenish-grey siltstone with several carbonaceous layers about 1 inch thick.
123.5	14.0	greenish-grey, massive, bentonitic siltstone, some pyrite in lower part of core.
124.5	1.0	greenish-grey fissile siltstone, with partly pyritized plant fragments.
130.5	6.0	bentonitic siltstone with freshwater shell fragments.
135.0	4.5	grey, laminated fissile siltstone.
140.0	5.0	grey fissile shale with plant fragments and pyrite nodules.
140.5	0.5	carbonaceous layer containing freshwater gastropods.
143.5	3.0	greenish-grey, bentonitic siltstone.

Depth (feet)	Thickness (feet)	Lithology
146.5	3.0	very fine grained sandstone.
151.0	4.5	massive bentonitic shale with freshwater shells scattered throughout and 1-inch thick carbonaceous layer at base.
153.0	2.0	greenish, bentonitic siltstone.
155.5	2.5	fine-grained sandstone.
158.0	2.5	grey, fissile, carbonaceous siltstone.
158.5	0.5	light grey siltstone.
165.0	6.5	green bentonite.
172.5	7.5	greenish, silty bentonite.
178.0	5.5	bentonite.
180.0	2.0	greenish massive siltstone.
187.5	7.5	sandstone, 1 foot; fissile, carbonaceous siltstone, 2 feet; grey bentonite, 0.66 feet.
192.5	5.0	greyish brown bentonite.
195.0	2.5	carbonaceous bentonite.
210.0	15.0	carbonaceous siltstone, 1 foot; coal, 2.5 feet; dark brown bentonitic siltstone, 1 inch; coal, 2.0 feet; bentonite, 1½ inches; coal, 0.8 feet; siltstone, 0.5 feet.
217.5	7.5	grey green, fine-grained sandstone with small plant impressions on the bedding planes.

T.D. 217.5 feet.

Name of well: McLeod River Damsite Corehole 3

Location: Lsd. 9, Sec. 33, Tp. 57, R. 13, W. 5 Mer. (800 feet E and 280 feet N of Hole No. 2)

Elevation: 2617.9 feet

Total depth: 200 feet

Core recovered: 95 feet

Date completed: March, 1966

Depth (feet)	Thickness (feet)	Lithology
0.0		
70.0	70.0	glacial drift.
78.5	8.5	yellowish-grey, coarse-grained sandstone, friable.
80.0	1.5	carbonaceous sandstone.
85.0	5.0	medium-grained sandstone, friable.
102.0	17.0	medium- to coarse-grained sandstone.
102.5	0.5	grey, cemented, medium- to coarse-grained sandstone.
115.0	12.5	yellowish-grey sandstone, friable.
117.0	2.0	coarse-grained sandstone, as above, cross-bedded.
119.5	2.5	yellowish-green, medium-grained sandstone.
121.0	1.5	coarse-grained sandstone.
130.0	9.0	grey silty shale with some carbonaceous layers.
134.0	4.0	silty sandstone with carbonaceous beds.
137.5	3.5	greenish-grey siltstone.
140.0	2.5	grey, fine-grained sandstone, yellowish stain on fractured surfaces.
145.0	5.0	grey, laminated siltstone, carbonaceous.
147.0	2.0	grey siltstone, cemented by calcite.
160.0	13.0	lignite, 0.08 feet; grey siltstone, 0.5 feet; carbonaceous shell bed, 0.16 feet; hard, grey siltstone, 2.5 feet; greenish-grey, bentonitic shale, 2.0 feet; carbonaceous shell bed, 0.16 feet; greenish-grey, bentonitic shale, 2.0 feet; olive green, bentonitic siltstone, 2.5 feet.
194.0	34.0	fine-grained sandstone underlain by medium-grained sandstone, some small-scale cross stratification and carbonaceous lamination.
196.5	2.5	coarse-grained sandstone.
200.0	3.5	medium-grained sandstone, 1 foot; cemented sandstone, 1 foot; coarse-grained sandstone with carbonaceous streaks.

T.D. 200 feet.

Name of well: McLeod River Damsite Corehole 4

Location: Lsd. 12, Sec. 34, Tp. 57, R. 13, W. 5 Mer. (2,120 feet E and 920 feet N of Hole No. 2)

Elevation: 2,530.3 feet

Total depth: 120 feet

Core recovered: 28 feet

Date completed: March, 1966

Depth (feet)	Thickness (feet)	Lithology
0.0		
57.0	57.0	glacial drift.
67.5	10.5	grey, medium-grained sandstone weathered to yellowish green.
75.5	8.0	mainly friable medium-grained sandstone with one cemented layer about 10 inches in thickness. (The exact location of the cemented layer is uncertain due to poor core recovery.)
82.5	7.0	mainly friable, medium grained sandstone 2 feet of cemented core recovered in this interval.
90.0	7.5	medium-grained, friable sandstone with carbonaceous beds.
97.5	7.5	grey, coarse-grained sandstone, upper 15 inches cemented by calcite.
112.5	15.0	friable sandstone, less than 4 feet of core recovered.
120.0	7.5	friable sandstone, 5 feet of core recovered.

T.D. 120 feet.

Name of well: McLeod River Damsite Corehole 5

Location: Lsd. 7, Sec. 33, Tp. 57, R. 13, W. 5 Mer. (800 feet W, 1,160 feet S of Hole No. 2)

Elevation: 2,614.9 feet

Total depth: 210 feet

Core Recovered: 161 feet

Date completed: March, 1966

Depth (feet)	Thickness (feet)	Lithology
0.0		
39.0	39.0	glacial drift.
70.0	31.0	greenish-grey, carbonaceous siltstone.
73.5	3.5	greenish, bentonitic siltstone.
78.5	5.0	fine-grained, silty sandstone weathered yellow in fractures.
83.0	4.5	yellowish-green, medium-grained sandstone, friable.
85.0	2.0	cemented sandstone.
98.0	13.0	medium-grained sandstone, friable.
100.5	2.5	cemented sandstone.
107.5	7.0	cemented sandstone, three feet of core recovered.
132.5	25.0	fine- to medium-grained sandstone with 0.5-foot cemented layer at 120 feet.
133.5	1.0	conglomerate with quartzite pebbles.
139.5	6.0	soft sandstone.
140.0	0.5	cemented sandstone.
146.0	6.0	grey, coarse-grained sandstone, very friable.
148.0	2.0	thin carbonaceous siltstone underlain by soft greenish bentonitic siltstone.
155.0	7.0	soft sandstone.
162.0	7.0	soft grey siltstone.
165.0	3.0	dark grey, carbonaceous siltstone with well preserved leaf impressions.
170.0	5.0	dark grey, carbonaceous, freshwater shell bed, 0.25 feet; greenish siltstone with plant fragments, 3 feet; dark green bentonite, 1 foot; carbonaceous siltstone, 0.25 feet; greenish siltstone, 0.5 feet.
175.0	5.0	greenish-grey sandstone.
177.0	2.0	grey siltstone.

Depth (feet)	Thickness (feet)	Lithology
180.0	3.0	thin carbonaceous bed, underlain by 1 foot of olive green bentonite grading downward into massive bentonitic siltstone.
185.5	5.5	greenish-grey, fine-grained sandstone.
190.5	5.0	hard and soft bentonitic siltstone beds.
195.5	5.0	greenish-grey, medium- to coarse-grained sandstone.
200.0	4.5	greenish-grey, cemented sandstone.
205.0	5.0	medium-grained sandstone.
210.0	5.0	coarse sandstone interbedded with fine-grained sandstone.

T.D. 210 feet.

Name of well: McLeod River Damsite Corehole 6.

Location: Lsd. 8, Sec. 33, Tp. 57, R. 13, W. 5 Mer. (520 feet E and 800 feet S of Hole No. 2).

Elevation: 2,474.4 feet

Total depth: 200 feet

Core recovered: 123 feet

Date completed: March, 1966

Depth (feet)	Thickness (feet)	Lithology
0.0		
25.0	25.0	glacial drift.
31.0	6.0	greenish, hard, massive siltstone.
33.5	2.5	cemented sandstone.
95.0	61.5	friable sandstone with some carbonaceous zones; coarse-grained and cross-bedded in places.
97.0	2.0	greenish, massive siltstone, very hard.
102.5	5.5	greenish, bentonitic siltstone, soft.
103.5	1.0	grey, fissile siltstone with pyrite nodules.
105.0	1.5	greenish-grey, silty sandstone, soft.
109.0	4.0	grey, calcareous shale.
109.5	0.5	carbonaceous shale.
110.0	0.5	greenish-grey siltstone.
120.0	10.0	core missing.
122.0	2.0	grey, laminated, lithographic siltstone.
130.0	8.0	grey siltstone with abundant leaf impressions.
133.5	3.5	hard massive siltstone.
134.5	1.0	fissile siltstone containing freshwater shells.
135.0	0.5	hard massive siltstone.
142.5	7.5	hard and soft siltstone.
150.5	8.0	hard and soft, bentonitic siltstone with carbonaceous zones.
157.5	7.0	very fine grained sandstone containing freshwater shell fragments.
170.0	12.5	greyish-green, medium-grained sandstone.
170.5	0.5	shell bed in carbonaceous sandstone.
173.0	2.5	greenish-grey, bentonitic siltstone.

Depth (feet)	Thickness (feet)	Lithology
182.0	9.0	grey, lithographic siltstone with many plant impressions replaced by pyrite.
182.5	0.5	yellowish-green bentonite.
187.5	5.0	greenish-grey, fine-grained sandstone.
190.0	2.5	hard siltstone containing large calcareous nodules.
191.0	1.0	soft, fissile, bentonitic siltstone with plant fossils.
193.0	2.0	calcareous, bentonitic shale.
195.0	2.0	silty sandstone.
200.0	5.0	hard, bentonitic siltstone.

T.D. 200 feet.

Name of well: McLeod River Damsite Corehole 7

Location: Lsd. 12, Sec. 34, Tp. 57, R. 13, W. 5 Mer. (1,480 feet E and 160 feet N of Hole No. 2)

Elevation: 2,614.5 feet

Total depth: 174 feet

Core recovered: 69 feet

Date completed: February, 1966

Depth (feet)	Thickness (feet)	Lithology
0.0		
69.0	69.0	glacial drift.
101.0	32.0	grey, medium-grained sandstone weathered to a yellowish-green color. Upper 2.5 feet cemented by calcite.
102.0	1.0	grey, medium-grained sandstone, cemented by calcite.
109.5	7.5	yellowish-green sandstone, friable.
114.0	4.5	core missing.
121.0	7.0	massive, yellowish-green siltstone.
124.5	3.5	yellowish-green, bentonitic siltstone with abundant root structure.
128.0	3.5	siltstone, as above, mottled with wormlike burrows.
133.0	5.0	greenish siltstone with carbonaceous laminae.
135.0	2.0	grey, carbonaceous siltstone.
138.5	3.5	grey, massive siltstone with nodules.
140.5	2.0	coaly bed, poor core recovery.
141.0	0.5	carbonaceous shell bed.
144.0	3.0	greenish, massive siltstone with root structures.
145.5	1.5	grey, laminated siltstone.
146.0	0.5	greenish bentonite.
146.5	0.5	carbonaceous siltstone.
159.0	12.5	greenish grey siltstone.
166.5	7.5	sandy siltstone.
174.0	7.5	grey, medium-grained sandstone.

T.D. 174 feet.

Name of well: McLeod River Damsite Corehole 8

Location: Lsd. 10, Sec. 33, Tp. 57, R. 13, W. 5 Mer. (480 feet W. and 800 feet N. of Hole No. 2)

Elevation: 2,439.5 feet

Total depth: 150 feet

Core recovered: 112 feet

Date completed: February, 1966

Depth (feet)	Thickness (feet)	Lithology
0.0		
6.0	6.0	ice and water.
25.0	19.0	grey, medium-grained sandstone, cemented by calcite.
61.5	36.5	coarse-grained, cross-bedded sandstone with carbonaceous fragments, several cemented layers in sandstone.
63.5	2.0	conglomerate with clasts of bentonitic siltstone in a sandy matrix.
66.5	3.0	grey, laminated silt with root structures.
69.0	2.5	grey sandstone.
70.0	1.0	grey siltstone containing freshwater shell fragments.
74.0	4.0	fine-grained silty sandstone with carbonaceous laminae.
77.5	3.5	massive, calcareous siltstone with scattered shell fragments and incipient nodules.
80.5	3.0	hard, grey laminated siltstone.
83.0	2.5	thin, carbonaceous shale underlain by two feet of calcareous bentonite with a shell bed at base.
85.0	2.0	greenish, bentonitic siltstone.
87.0	2.0	hard, grey, massive siltstone with thin carbonaceous beds.
92.5	5.5	greenish, silty bentonite.
100.0	7.5	hard and soft, light greenish grey, bentonitic siltstone.
100.5	0.5	carbonaceous shale.
103.0	2.5	greenish grey, bentonitic siltstone.
103.5	0.5	carbonaceous shale.
112.5	9.0	greenish grey bentonitic siltstone with freshwater shells at base.
114.5	2.0	grey siltstone.
117.5	3.0	thin coal bed underlain by carbonaceous shale and silt.
120.0	2.5	greenish grey siltstone.

Depth (feet)	Thickness (feet)	Lithology
124.5	4.5	grey, carbonaceous siltstone.
127.0	2.5	dark greenish grey, mottled siltstone.
130.0	3.0	hard calcareous siltstone with brownish mottles or incipient nodules.
132.0	2.0	grey, shaly siltstone.
137.5	5.5	greenish grey, bentonitic siltstone.
140.0	2.5	greenish grey, hard bentonitic siltstone mottled by small burrowing structures.
143.0	3.0	carbonaceous siltstone.
145.0	2.0	greenish grey laminated siltstone.
150.0	5.0	greenish grey bentonitic siltstone.

T.D. 150 feet.

Name of well: McLeod River Damsite Corehole 9

Location: Lsd. 10, Sec. 33, Tp. 57, R. 13, W. 5 Mer. (720 feet N of Hole No. 2)

Elevation: 2,479.6 feet

Total depth: 150 feet

Core recovered: 115 feet

Date completed: February, 1966

Depth (feet)	Thickness (feet)	Lithology
0.0		
17.0	17.0	glacial drift.
21.0	4.0	buff, weathered sandstone.
24.5	3.5	grey, cemented sandstone.
41.0	16.5	grey to buff, medium-grained sandstone.
48.5	7.5	grey, coarse-grained sandstone, lower 5 feet very friable.
51.0	2.5	finer grained sandstone, cemented.
55.0	4.0	grey, coarse-grained, cross-bedded sandstone with coaly lenses.
66.0	11.0	coarse-grained friable sandstone.
73.5	7.5	cemented sandstone; 2.5 feet recovered.
74.5	1.0	coarse-grained sandstone, friable.
75.5	1.0	greenish grey, bentonitic siltstone.
81.0	5.5	coarse-grained sandstone, friable.
88.5	7.5	greenish grey siltstone.
89.5	1.0	laminated siltstone with plant impressions and 1-inch carbonaceous bed at the base.
94.5	5.0	grey sandstone.
100.0	5.5	greenish-grey, bentonitic siltstone.
105.0	5.0	greenish-grey, silty sandstone.
107.5	2.5	grey, massive siltstone.
111.0	3.5	grey, fine-grained, cross-bedded sandstone with carbonaceous laminae.
112.0	1.0	grey, silty shale, fissile.
116.0	4.0	grey sandstone.
122.5	6.5	grey, massive siltstone, becoming fissile at base.
123.5	1.0	coaly carbonaceous bed.
127.5	4.0	grey siltstone containing plant fragments.
128.0	0.5	carbonaceous shell bed.

Depth (feet)	Thickness (feet)	Lithology
131.0	3.0	greenish-grey, massive siltstone.
132.0	1.0	carbonaceous siltstone.
139.5	7.5	greenish, soft bentonitic siltstone with abundant plant fragments and thin carbonaceous beds.
142.0	2.5	grey, sandy siltstone.
144.0	2.0	greenish-grey siltstone, carbonaceous at base.
147.0	3.0	greenish-grey bentonitic siltstone with abundant plant fragments.
147.5	0.5	carbonaceous siltstone.
150.0	2.5	greenish-grey, bentonitic siltstone.

T.D. 150 feet

APPENDIX D.

PETROGRAPHIC DATA

(Table 12)

Table 12. Grain Sizes and Percentages of Mineral Constituents for Selected Sandstone Samples from Various Localities in the Alberta Plains

SAMPLE NUMBER	ELEVATION (feet above m.s.l.)	LOCALITY	AVERAGE GRAIN SIZE (microns)	FRAMEWORK GRAINS								PORE FILLING CONSTITUENTS					PORE SPACE
				Q[1]	F	Ch	Mi	RF	VFR	CO_3	Ms	Ct	K	Mo	Cl	Z	
Paskapoo Formation outcrops in the Edmonton area																	
671	4000	Swan Hills	161	23.0	9.0	3.0	3.0	19.0	5.0	3.0	2.0	-	-	2.0	-	-	31.0
670	4000	Swan Hills	166	20.5	4.0	3.0	2.0	21.5	10.0	-	2.0	-	-	2.0	-	-	35.0
958	4000	Shining Bank Ridge	248	19.0	5.0	5.0	2.0	26.0	9.0	2.0	-	29.0	-	-	-	-	3.0
606	3800	Shining Bank Ridge	302	30.0	2.0	9.5	-	33.5	2.0	7.0	3.0	-	-	4.0	-	-	9.0
957	3600	Shining Bank Ridge	337	13.0	6.0	5.0	2.0	24.0	6.0	6.0	-	33.0	-	-	-	-	5.0
607	3400	Highway 16 (Medicine Lodge)	295	19.5	4.0	15.5	-	32.0	2.0	8.0	-	1.0	1.0	2.0	-	-	15.0
588	3200	Rocky Mountain House	140	27.5	15.0	1.0	2.0	23.0	2.0	7.0	-	-	-	-	22.5	-	-
610	3175	Rocky Mountain House	278	27.5	6.5	6.5	-	32.0	3.0	2.0	3.0	14.5	1.0	-	3.0	-	1.0
609	3150	Rocky Mountain House	243	23.0	7.5	9.0	-	31.5	5.0	5.0	2.0	7.0	-	-	5.0	-	5.0
608	3110	Rocky Mountain House	178	26.0	12.0	6.0	1.0	17.0	2.0	9.0	5.0	22.0	-	-	-	-	-
744	3080	Brazeau River (dam)	177	19.0	10.0	7.0	3.0	16.0	8.0	4.0	9.0	-	-	19.0[2]		-	5.0
770	3050	Brazeau River (powerhouse)	186	26.0	14.0	10.0	3.0	24.0	7.0	3.0	-	-	-	9.0[2]		-	4.0
800	2900	Pigeon Lake (4 m south)	138	23.0	18.0	8.0	1.0	14.0	6.0	6.0	-	-	-	11.0	-	-	13.0
740	2850	Brazeau River (powerhouse)	207	36.0	5.0	14.0	1.0	21.0	2.0	3.0	-	-	-	8.0	-	-	10.0
605	2800	McLeod River (Edson)	183	14.0	10.0	6.0	-	26.0	18.0	3.0	-	-	-	11.0	-	-	12.0
905	2700	Wizard Lake	95	25.0	7.0	4.0	3.0	13.0	6.0	-	6.0	-	-	2.5	-	-	11.0
681	2500	McLeod River (9 m south of Whitecourt)	222	22.0	4.0	7.0	-	32.0	4.0	4.0	-	-	3.0	-	-	-	24.0
651	2500	Lake Wabumun (Fallis)	230	20.0	5.5	9.0	1.5	28.0	12.0	-	-	-	3.0	-	-	-	21.0

603	2400	Pembina River (Entwistle)	250	19.0	16.0	4.0	-	13.0	7.0	13.0	-	5.0	-	-	-	-	23.0
602	2400	Pembina River (Entwistle)	240	19.0	15.0	5.0	1.0	18.0	7.0	8.0	-	-	-	2.0	-	-	25.0
Paskapoo Formation outcrops in the Red Deer area																	
685	3900	Red Deer River	88	47.5	-	5.0	1.0	24.5	1.0	-	1.0	-	-	-	18.0	-	2.0
896[3]	3200	Spruçe Creek	85	26.0	1.0	8.0	-	16.0	1.0	24.0	2.0	6.0	-	-	-	-	16.0
682	3200	Sylvan Lake	157	23.5	10.5	2.0	2.0	24.5	3.0	1.5	1.0	-	-	2.2	-	-	10.0
586[3]	3200	Rosebud River	258	16.5	5.5	15.5	1.0	23.0	3.5	10.5	-	24.5	-	-	-	-	-
776	3200	Hand Hills	88	25.0	2.0	5.0	2.0	9.0	1.0	10.0	12.0	24.0	-	-	-	-	10.0
774	3000	Wintering Hills	214	17.0	14.0	9.0	-	33.0	8.0	3.0	3.0	-	2.0	5.0	-	1.0	5.0
898	2900	Red Deer River	176	18.0	8.0	4.0	1.0	23.0	7.0	3.0	4.0	31.0	-	1.0	-	-	-
572	2900	Red Deer River	230	25.0	3.0	17.0	-	21.0	1.0	13.0	-	1.0	1.0	-	-	-	18.0
678	2850	Ponoka (6 m east)	186	28.5	5.0	5.5	1.0	22.5	5.0	4.5	-	-	-	6.5	-	-	21.5
663[3]	2800	Kneehills Creek	204	17.5	1.0	20.0	-	11.0	-	19.5	2.0	-	1.0	-	-	-	28.0
666	2800	Blindman River	252	28.0	4.0	6.0	1.0	34.0	6.0	-	-	-	-	1.0	-	-	20.0
897	2800	Red Deer River	199	27.0	7.0	4.0	6.0	16.0	15.0	-	1.0	-	-	15.0	-	2.0	7.0
660	2700	Red Deer River	191	27.5	7.5	6.5	0.5	24.0	7.0	1.0	-	-	2.5	3.5	-	-	20.0
579	2600	Red Deer River	249	20.0	7.5	5.5	0.5	22.5	7.0	9.5	1.0	-	-	17.0	-	-	9.5
775	2600	Kneehills Creek	259	14.0	14.0	10.0	1.0	28.0	12.0	-	-	-	1.0	1.0	-	-	19.0
949	2600	Red Deer River	238	20.0	9.0	11.0	-	21.0	9.0	-	-	-	2.0	-	-	-	28.0
664	2600	Red Deer River	209	27.5	9.5	6.0	2.5	27.0	9.0	1.5	2.0	-	-	5.0	-	-	10.0

[1]For key to petrographic abbreviations see Appendix A [2]Mixture of chlorite and montmorillonite [3]Samples 896, 586 and 663 are questionably Porcupine Hills Formation

SAMPLE NUMBER	ELEVATION (feet above m.s.l.)	LOCALITY	AVERAGE GRAIN SIZE (microns)	FRAMEWORK GRAINS								PORE FILLING CONSTITUENTS					PORE SPACE
				Q[1]	F	Ch	Mi	RF	VRF	CO_3	Ms	Ct	K	Mo	Cl	Z	
Porcupine Hills Formation outcrops in the Calgary area																	
593	4100	Bighill Creek	158	30.5	5.0	18.5	-	12.5	-	13.0	4.0	1.5	2.0	-	-	-	13.0
911	3975	Beddington Creek	118	38.0	-	11.0	-	17.0	-	20.0	7.0	-	4.0	-	-	-	3.0
584	3900	Highwood River	104	31.0	4.0	9.5	0.5	20.0	-	20.5	1.0	3.5	5.0	-	-	-	5.0
854	3850	Middle Heights	160	38.0	4.0	19.0	1.0	11.0	1.0	12.0	3.0	2.0	3.0	-	-	-	6.0
583	3800	McPherson Coulee	223	27.0	1.5	11.0	-	22.0	-	17.5	3.0	1.0	3.0	-	-	-	14.0
587	3700	Beddington Creek	210	30.5	2.5	21.0	-	12.0	-	17.5	1.5	2.0	-	-	-	-	13.0
891	3690	Bow River	155	24.0	1.0	25.0	-	17.0	1.0	13.0	3.0	1.0	9.0	-	-	-	6.0
892	3620	Bow River	180	26.0	1.0	9.0	-	26.0	1.0	20.0	8.0	-	-	-	-	-	9.0
590	3600	Spring Creek	196	35.5	2.5	15.0	-	22.5	-	13.5	1.0	1.5	3.5	-	-	-	5.0
895	3500	Fish Creek	108	37.0	1.0	18.0	-	8.0	2.0	22.0	4.0	2.0	2.0	-	-	-	4.0
893	3500	Elbow River	104	31.0	-	9.0	1.0	18.0	-	21.0	10.0	-	8.0	-	-	-	2.0
851	3500	Tongue Creek	157	31.0	4.0	24.0	-	14.0	-	4.0	3.0	12.0	8.0	-	-	-	-
Paskapoo Formation outcrops in the Calgary area																	
684	4100	Grand Valley	284	28.0	3.0	16.5	0.5	24.5	14.0	-	7.5	-	-	6.0	-	-	-
859	3500	Consolidated Concrete quarry	135	34.0	4.0	5.0	3.0	18.0	6.0	1.0	10.0	10.0	9.0	-	-	-	-
852	3500	Consolidated Concrete quarry	258	13.0	13.0	12.0	-	20.0	17.0	2.0	5.0	16.0	-	2.0	-	-	-
909	3500	Bow River	324	35.0	9.0	9.0	-	24.0	4.0	1.0	4.0	5.0	-	-	7.0	-	2.0
772	3300	Bow River	140	31.0	6.0	5.0	2.0	29.0	4.0	-	5.0	-	-	18.0	-	-	-
857	3300	Bow River	157	17.0	15.0	5.0	1.0	23.0	12.0	-	14.0	-	-	13.0	-	-	-

888	3225	Bow River	199	26.0	7.0	12.0	-	14.0	14.0	-	-	-	-	5.0	-	3.0	19.0
773	3200	Hammer Hill	202	17.0	7.0	9.0	-	22.0	14.0	-	10.0	-	-	4.0	-	4.0	13.0
771	3200	Bow River	166	23.0	14.0	10.0	2.0	29.0	9.0	1.0	-	-	-	5.0	-	7.0	-
886	3100	Bow River	156	23.0	5.0	9.0	3.0	25.0	8.0	-	5.0	-	-	9.0	-	13.0	-
Porcupine Hills Formation outcrops in the Porcupine Hills area																	
600	5800	Sharples Creek	202	19.0	1.0	28.5	-	24.0	0.5	14.5	-	0.5	-	-	-	-	12.0
601	5500	Burton Creek	246	22.5	0.5	33.0	-	22.5	0.5	8.5	-	3.0	2.0	-	-	-	7.5
597	5000	Rice Creek	193	22.5	2.5	27.0	-	19.5	-	17.0	-	5.0	4.5	-	-	-	2.0
596	4600	Indian Creek	196	26.0	4.0	25.0	-	21.0	1.5	3.5	3.0	7.0	5.0	-	-	-	4.0
594	4600	Olsen Creek	204	28.0	4.0	25.5	-	22.0	-	6.0	-	3.5	2.0	-	-	-	9.0
592	4500	Meadow Creek	373	20.0	-	36.0	-	21.5	-	3.0	-	15.0	3.0	-	-	-	1.5
844	4400	South Willow Creek	72	29.0	3.0	8.0	1.0	6.0	-	11.0	14.0	27.0	1.0	-	-	-	-
585	4300	Tennesee Creek	190	19.0	3.0	20.5	-	19.5	-	23.0	-	9.0	3.0	-	-	-	3.0
598	4100	Willow Creek	197	22.5	4.0	25.0	-	20.0	1.0	13.0	2.5	3.0	4.0	-	-	-	5.0
599	4000	Williams Coulee	147	26.0	3.0	18.0	0.5	23.0	-	18.0	-	2.0	2.5	-	-	-	7.0
595	3800	Stavley (6 m west)	120	24.0	3.0	15.5	-	28.5	-	10.5	-	4.0	11.0	-	-	-	3.5
589	3800	Olsen Creek	256	18.0	2.0	36.0	-	23.0	1.0	3.0	-	6.0	6.0	-	-	-	5.0
591	3500	Cayley (3 m west)	322	15.0	1.5	46.0	-	20.0	-	1.5	4.0	-	2.0	-	-	-	10.0
848	3450	Willow Creek	89	36.0	2.0	9.0	-	10.0	-	8.0	14.0	10.0	-	11.0	-	-	-
850	3400	Pine Creek	102	37.0	-	8.0	1.0	24.0	-	6.0	5.0	9.0	9.0	-	-	-	1.0
Willow Creek Formation outcrops in the Porcupine Hills area																	
843	3300	Mosquito Creek	104	33.0	6.0	13.0	1.0	13.0	2.0	6.0	6.0	18.0	2.0	-	-	-	-
846	3200	Willow Creek	125	31.0	1.0	21.0	-	20.0	1.0	8.0	4.0	11.0	-	3.0	-	-	-

SAMPLE NUMBER	ELEVATION (feet above m.s.l.)	LOCALITY	AVERAGE GRAIN SIZE (microns)	FRAMEWORK GRAINS								PORE FILLING CONSTITUENTS					PORE SPACE
				Q[1]	F	Ch	Mi	RF	VRF	CO_3	Ms	Ct	K	Mo	Cl	Z	
845	3180	Willow Creek	196	18.0	8.0	13.0	-	14.0	2.0	3.0	5.0	36.0	-	-	-	-	1.0
858	3100	Little Bow River	145	23.0	9.0	21.0	-	12.0	1.0	7.0	2.0	25.0	-	-	-	-	-
Paskapoo Formation in R.C.A. Corehole 65-1																	
1[1]	14		71	26.0	13.0	3.0	4.0	2.0	1.0	1.0	4.0	46.0	-	-	-	-	-
5	51		76	25.0	10.0	4.0	2.0	9.0	-	10.0	17.0	-	-	23.0[2]	-	-	-
6	66		107	15.0	13.0	2.0	2.0	13.0	7.0	-	9.0	-	-	39.0[2]	-	-	-
8	96		79	21.0	2.0	3.0	3.0	3.0	-	24.0	12.0	-	-	32.0[2]	-	-	-
12	124.5		157	28.0	3.0	3.0	3.0	7.0	-	5.0	17.0[3]	31.0	-	3.0	-	-	-
13	128		190	33.0	5.0	6.0	2.0	19.0	2.0	8.0	5.0	-	5.0	5.0	-	-	10.0
15	139		225	23.0	1.0	8.0	2.0	23.0	1.0	1.0	8.0	4.0	4.0	21.0	-	-	4.0
24	215		124	29.0	9.0	4.0	2.0	6.0	6.0	-	5.0	39.0	-	-	-	-	-
26	251		98	18.0	4.0	7.0	3.0	14.0	13.0	3.0	14.0[3]	-	6.0	18.0[2]	-	-	-
28	279.5		102	18.0	8.0	3.0	3.0	24.0	13.0	1.0	20.0	-	1.0	9.0[2]	-	-	-
31	298		117	15.0	12.0	7.0	4.0	29.0	7.0	-	7.0	-	-	15.0[2]	-	-	4.0
33	319		108	16.0	11.0	1.0	1.0	36.0	9.0	-	15.0	-	1.0	10.0[2]	-	-	-
Edmonton Formation in R.C.A. Corehole 65-1																	
36	373		163	13.0	9.0	7.0	1.0	27.0	13.0	-	10.0	-	19.0		-	-	1.0
37	379		144	14.0	10.0	7.0	1.0	20.0	14.0	-	12.0	-	4.0	18.0	-	-	-
38	381		158	21.0	18.0	7.0	3.0	12.0	20.0	-	8.0[4]	-	2.0	6.0	-	-	3.0

For coreholes 'ELEVATION' column figures indicate depth in feet

39	386	160	17.0	16.0	6.0	-	21.0	20.0	-	8.0[4]	-	5.0	4.0	-	-	3.0
40	398	312	13.0	11.0	22.0	1.0	13.0	14.0	-	2.0	24.0	-	-	-	-	-
41	409	238	11.0	6.0	19.0	-	26.0	17.0	-	3.0	-	1.0	2.0	-	-	15.0
42	414	243	14.0	8.0	9.0	1.0	16.0	20.0	-	10.0	6.0	2.0	-	-	-	7.0
43	415	344	17.0	8.0	23.0	-	24.0	17.0	-	1.0	-	6.0	1.0	-	-	3.0
44	428	305	16.0	7.0	19.0	1.0	25.0	16.0	-	3.0	-	6.0	2.0	-	-	5.0
50	462	103	18.0	17.0	2.0	1.0	24.0	14.0	-	11.0	-	-	12.0	-	-	1.0
52	471	248	20.0	16.0	8.0	-	12.0	17.0	-	4.0	-	-	19.0	-	-	4.0
54	485	230	25.0	5.0	14.0	2.0	20.0	15.0	-	7.0	-	7.0	3.0	-	-	2.0
55	490	275	23.0	9.0	8.0	-	15.0	4.0	1.0	4.0	34.0	2.0	-	-	-	-
Porcupine Hills Formation in R.C.A. Corehole 66-1																
1[5]	20	125	22.0	3.0	8.0	-	20.0	-	24.0	2.0	-	-	-	-	4.0[8]	17.0
4	61	89	23.0	8.0	10.0	-	17.0	-	9.0	4.0	-	-	26.0[7]	-	-	3.0
8	103	121	20.0	2.0	7.0	-	21.0	-	17.0	-	-	-	25.0[7]	-	-	8.0
13	145	71	32.0	3.0	4.0	-	21.0	-	15.0	9.0	2.0	1.0	13.0[7]	-	-	-
27	265	75	18.0	1.0	10.0	-	6.0	-	26.0	4.0	14.0	4.0	16.0[7]	-	-	1.0
34	400	144	25.0	2.0	16.0	-	15.0	-	17.0	5.0	9.0	3.0	-	-	-	8.0
35	405	166	25.0	3.0	23.0	-	14.0	-	18.0	4.0	2.0	2.0	1.0	-	-	8.0
46	510	98	37.0	1.0	6.0	1.0	18.0	-	13.0	5.0	5.0	-	1.0	-	-	13.0
48	520	109	37.0	-	9.0	-	12.0	-	22.0	5.0	2.0	-	-	-	-	13.0
51	540	132	25.0	-	26.0	-	11.0	-	12.0	-	-	2.0	-	-	-	24.0
55	560	125	26.0	3.0	16.0	-	15.0	-	22.0	2.0	3.0	2.0	-	-	-	11.0

[1]Complete sample number 65-1-S-1, etc. [2]Clay groundmass [3]Carbonaceous fragments [4]Siderite [5]Complete number 66-1-S-1, etc. [6]Includes authigenic overgrowths
[7]Mainly detrital clay groundmass [8]Iron oxide

SAMPLE NUMBER	ELEVATION (feet above m.s.l.)	LOCALITY	AVERAGE GRAIN SIZE (microns)	FRAMEWORK GRAINS								PORE FILLING CONSTITUENTS					PORE SPACE
				Q[1]	F	Ch	Mi	RF	VRF	CO_3	Ms	Ct	K	Mo	Cl	Z	
57	570		75	29.0	-	15.0	2.0	12.0	-	14.0	3.0	2.0	-	5.0[1]	-	-	18.0
58	615		127	28.0	1.0	14.0	-	22.0	-	18.0	1.0	1.0	4.0	5.0[1]	-	-	6.0
62	668		69	27.0	-	11.0	-	25.0	-	18.0	4.0	6.0	1.0	-	-	-	8.0
66	821		95	32.0	1.0	17.0	-	18.0	1.0	18.0	5.0	1.0	2.0	-	-	-	5.0
77	972		135	28.0	5.0	12.0	2.0	18.0	-	8.0	4.0	11.0	-	10.0[1]	-	-	2.0
78	989		79	39.0	1.0	12.0	-	11.0	-	16.0	8.0	10.0	-	3.0[1]	-	-	-
Paskapoo Formation in the McLeod River Damsite Coreholes 1, 2 and 2A																	
1-75[2]	2530		253	21.0	8.0	9.0	-	28.0	-	6.0	12.0	-	1.0	-	-	-	15.0
1-80	2525		258	17.0	9.0	8.0	-	13.0	4.0	8.0	5.0	36.0	-	-	-	-	-
1-90	2515		119	29.0	12.0	3.0	2.0	14.0	7.0	5.0	6.0	11.0	-	-	-	-	11.0
1-120	2485		252	25.0	7.0	13.0	1.0	21.0	7.0	3.0	5.0	1.0	-	-	-	-	17.0
1-130	2475		144	27.0	24.0	1.0	-	17.0	10.0	2.0	2.0	3.0	-	-	-	-	14.0
1-151	2454		91	29.0	10.0	3.0	2.0	29.0	4.0	2.0	8.0	-	-	4.0	-	-	9.0
1-170	2435		215	24.0	13.0	5.0	-	33.0	4.0	3.0	6.0	-	-	-	-	-	12.0
1-180	2425		302	18.0	7.0	14.0	1.0	31.0	8.0	3.0	3.0	-	-	1.0	-	-	14.0
1-190	2415		245	23.0	6.0	5.0	2.0	19.0	7.0	9.0	3.0	2.0	-	-	-	-	24.0
2-20	2420		166	21.0	14.0	6.0	-	17.0	17.0	3.0	6.0	-	-	-	-	-	16.0
2-30	2410		321	24.0	6.0	9.0	1.0	23.0	9.0	1.0	3.0	-	-	-	-	-	24.0
2-40	2400		269	34.0	7.0	12.0	-	15.0	12.0	2.0	1.0	-	1.0	-	-	-	16.0
2-50	2390		168	21.0	10.0	5.0	1.0	27.0	12.0	9.0	5.0	-	-	-	-	-	10.0

2-60	2380		199	21.0	14.0	4.0	2.0	22.0	15.0	2.0	4.0	-	1.0	-	-	-	15.0
2A-180	2260		151	22.0	7.0	6.0	1.0	24.0	5.0	3.0	9.0	-	-	15.0	-	-	8.0
Edmonton Formation outcrops																	
656		Munson Ferry		20.5	5.0	2.0	1.0	23.0	11.0	-	5.0	15.0	-	13.5	-	-	4.0
657		East Coulee		19.5	4.0	7.0	-	15.0	12.0	-	3.0	1.0	-	23.5	-	-	15.0
668		Alix		19.0	6.0	6.0	1.0	21.5	10.0	1.0	1.0	31.5	-	-	-	-	3.0
674		Edmonton		15.0	4.0	13.0	-	31.0	10.0	-	4.0	-	-	15.0	-	-	8.0
676		Devon		17.0	4.0	15.0	-	26.0	13.0	-	11.0	-	-	9.0	-	-	5.0
677		Edmonton		26.0	10.0	8.0	-	17.0	5.0	-	3.0	30.0	-	-	-	-	1.0
679		8 m south of Rosalind		18.0	8.0	7.0	-	30.0	8.0	-	4.0	-	-	19.0	-	-	6.0
842		Wetaskiwin		12.0	22.0	7.0	-	20.0	16.0	-	5.0	-	4.0	-	-	-	14.0
St. Mary Formation outcrops																	
654		Carmangay		27.0	6.0	4.5	2.0	17.0	-	17.5	4.0	11.0	7.0	-	-	-	4.0
655		Carmangay		28.0	4.0	1.0	-	23.0	-	11.0	3.0	27.0	3.0	-	-	-	-
661		St. Mary River Dam		21.0	4.5	1.0	3.0	37.0	5.0	8.5	-	-	-	18.0	-	-	2.0
667		Pearce		27.0	7.0	4.0	2.0	33.0	2.0	11.0	3.0	-	7.0	-	-	-	4.0

[1]Mainly detrital clay groundmass [2]Complete number MRD-1-75, etc. The last number refers to depth in feet

APPENDIX E.

DISCRIMINANT ANALYSES

(Table 13)

Discriminant Analysis[1]

Discriminant analysis is a statistical procedure for assigning samples to previously defined populations by the simultaneous consideration of a number of variables measured on each sample to produce a linear discriminant function, R, which takes the form:

$$R = \lambda_a A + \lambda_b B + \lambda_c C + \ldots + \lambda_k K$$

The discriminant index, R_0, is calculated to provide equal probability of misclassification of samples from either population.

Discriminant analysis is based on the assumption that there are two different populations. A test of the significance of this assumption is provided by Mahalanobis' Generalized Distance (D^2), which is a measure of the "distance" between the multivariate means of the two populations. The contribution that each variable makes to the total distance between the multivariate means is determined by the equations of the form:

$$\% \text{ contributed by } A = \lambda_a \Delta \bar{A} / D^2 \times 100.$$

In this way those variables making significant contributions to D^2 can be detected and the minimum number of independent variables needed to provide the discrimination chosen.

A calculated F-value measures the significance of the difference between the multivariate means for (K) and (n_1+n_2-k-1) degrees of freedom.

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[1]Based on the computer program published by Davis and Sampson, 1966

Table 13. Summaries of Results of Discriminant Analyses run on Paskapoo and Porcupine Hills Formation Sandstones using Different Numbers of Samples and Petrographic Variables

Summary of Results of Discriminant Analysis of 41 Paskapoo and 39 Porcupine Hills Sandstones on the basis of A - Seven Petrographic Variables, B - Five Petrographic Variables, and C - Three Petrographic Variables

		Variable	Constant	Per Cent Added
A	F = 46.5906 with 7 and 72 degrees of freedom	1. Average grain size (microns)	0.0682	11.6676
	D^2 = 17.67668	2. Quartz (%)	- 0.0357	2.1568
	R_1 = -20.1105	3. Feldspar (%)	- 0.0150	- 6.7527
	R_0 = -28.7279	4. Chert (%)	- 0.0924	71.8038
	R_2 = -37.7872	5. Nonvolcanic rock fragments (%)	- 0.0350	- 9.4777
		6. Volcanic rock fragments (%)	- 0.0040	- 1.8471
		7. Clastic carbonate (%)	- 0.0509	32.4493
B	F = 55.2293 with 5 and 74 degrees of freedom	1. Average grain size (microns)	0.0452	9.3929
	D^2 = 14.56278	2. Quartz (%)	- 0.0115	0.8432
	R_1 = - 0.3773	3. Chert (%)	- 0.0628	59.2852
	R_0 = - 7.4767	4. Volcanic rock fragments (%)	0.0171	9.5166
	R_2 = -14.9401	5. Clastic carbonate (%)	- 0.0271	20.9619
C	F = 84.9002 with 3 and 76 degrees of freedom	1. Average grain size (microns)	0.0517	11.9476
	D^2 = 13.07834	2. Chert (%)	- 0.0615	64.6123
	R_1 = 3.0009	3. Clastic carbonate (%)	- 0.0272	23.4400
	R_0 = - 3.3747			
	R_2 = -10.0774			

Summary of Results of Discriminant Analysis of 69 Paskapoo and 52 Porcupine Hills Sandstones on the basis of Seven Petrographic Variables†

	Variable	Constant	Per Cent Added
F = 60.8255 with 7 and 113 degrees of freedom	1. Average grain size (microns)	0.0450	11.4114
D^2 = 15.12116	2. Quartz (%)	- 0.0220	3.6450
R_1 = -10.6728	3. Feldspar (%)	0.0076	4.0703
R_0 = -17.1712	4. Chert (%)	- 0.0691	55.6512
R_2 = -25.7940	5. Nonvolcanic rock fragments (%)	- 0.0179	- 7.8746
	6. Volcanic rock fragments (%)	- 0.0034	- 1.8925
	7. Clastic carbonate (%)	- 0.0450	34.9890

† The 'R' value for each of these 121 samples is listed below. The misclassified samples are indicated with an asterisk (*)

Paskapoo				Porcupine Hills		
- 9.75677	- 7.75454	- 6.52033	-10.32574	-28.03259	-30.34108	-25.39310
- 9.17101	-18.99719*	-12.18670	- 6.49673	-23.00156	-24.65272	-22.00601
- 8.16584	- 8.96767	- 5.05278	- 9.93491	-30.71270	-25.99781	-25.12855
-11.92182	-18.92753*	-13.57702	-11.27512	-10.87208*	-25.98834	-20.77039
- 5.90500	-18.69106*	- 8.42120	-10.66073	-25.51202	-21.35749	-32.89935
-16.45473	- 9.17703	-11.69202	-12.13121	-24.80079	-29.05582	-26.98893
- 8.20746	- 9.47295	-13.03169	- 4.46457	-25.25432	-26.80745	-29.02492
-11.64093	-13.68423	-11.01705	-11.86657	-24.90431	-27.41296	-21.85128
-12.63225	- 9.25369	-14.28513	- 7.53766	-20.70630	-25.98994	-26.17822
- 9.40898	- 6.27276	- 5.46699	-10.27270	-27.08883	-29.67244	-35.71170
-11.67430	-11.65986	-22.74206*	-10.31290	-30.45089	-30.07386	-29.04830
-13.03034	-10.91011	-10.35272	- 7.59504	-19.96164	-20.54372	-30.24822
-18.05007*	- 6.51788	-14.08870	- 6.46581	-22.40219	-20.94468	-27.38448
- 8.77623	-11.25519	-12.39512	-11.11193	-29.84019	-21.48597	-27.61638
-11.81659	- 8.64292	-10.40472	-10.91740	-23.87002	-27.46710	-28.45470
-13.34979	-11.85206	-12.39826	- 4.97358	-27.20726	-16.98198*	-21.09178
-10.16893	- 6.91619	- 7.15917	-11.75945	-30.51817	-25.75941	-26.25540
- 8.45022				-29.56929		

APPENDIX F.

CHEMICAL ANALYSES

(Table 14)

Table 14. Chemical Analyses of Upper Cretaceous and Tertiary Sediments of the Alberta Plains

SAMPLE NUMBER	SiO_2	Al_2O_3	Total iron as Fe_2O_3	TiO_2	P_2O_5	MnO	CaO	MgO	Na_2O	K_2O	L.O.I.	TOTAL	S as SO_3	CO_2	FeO	H_2O^-	Organic carbon	Remarks
Porcupine Hills Formation outcrops in the Porcupine Hills area																		
600	78.07	3.84	1.24	0.17	0.13	0.02	6.96	1.53	0.41	1.17	7.06	100.60	-	-	-	-	-	Analyst - H. Wagenbauer.
597	69.96	3.51	1.21	0.21	0.12	0.04	11.24	1.85	0.34	0.58	11.19	100.24	-	-	-	-	-	Analyst - H. Wagenbauer.
592	76.87	2.37	1.06	0.11	0.06	0.03	9.33	0.93	0.22	0.45	8.26	99.69	-	6.60	-	0.18	-	Analyst - H. Oikawa.
Porcupine Hills Formation outcrops in the Calgary area																		
891	74.65	4.52	1.37	0.19	0.08	0.02	8.33	1.79	0.26	0.74	8.80	100.75	-	6.91	-	1.07	-	Analyst - H. Oikawa.
Paskapoo Formation outcrops in the Calgary area																		
684	80.99	7.53	2.58	0.31	0.14	0.06	1.10	1.43	1.40	1.43	1.95	98.92	-	-	-	0.67	-	Analyst - H. Oikawa.
886	70.03	13.41	3.85	0.54	0.09	0.06	2.68	1.73	2.49	1.74	3.12	99.74	-	n.d.	-	0.83	-	Analyst - H. Oikawa.
771B	70.91	12.91	3.14	0.50	0.08	0.09	3.41	1.07	2.59	1.45	2.71	98.86	-	n.d.	-	0.58	-	Analyst - H. Oikawa.
Paskapoo Formation outcrops in the Red Deer area																		
897B	55.93	6.94	1.89	0.29	0.05	0.45	17.08	1.20	1.47	1.26	13.30	99.86	-	11.71	-	0.34	-	Analyst - H. Oikawa.
664	76.95	11.50	2.24	0.39	0.14	0.05	1.81	0.76	2.50	2.87	1.60	100.81	-	-	-	-	-	Analyst - H. Wagenbauer.
Paskapoo Formation outcrops in the Edmonton area																		
671	70.92	11.95	4.05	0.54	0.18	0.08	3.34	1.44	2.60	2.13	3.37	100.60	-	-	-	-	-	Analyst - H. Wagenbauer.
607	76.61	6.50	2.40	0.29	0.12	0.03	4.39	1.70	1.08	1.36	4.91	99.39	-	-	-	0.59	-	Analyst - G. Schmitz.
609	66.48	9.89	3.70	0.43	0.17	0.09	6.83	2.24	1.92	1.91	6.95	100.61	-	-	-	-	-	Analyst - H. Wagenbauer.
744	72.46	11.11	2.79	0.36	0.16	0.03	2.84	1.63	2.20	2.02	3.18	98.83	0.06	-	-	1.45	-	Analyst - R. N. Barrett.
605	69.65	11.40	3.06	0.13	0.04	0.04	4.59	2.01	1.89	1.74	4.71	99.26	-	-	-	1.49	-	Analyst - G. Schmitz.
Ravenscrag Formation outcrops in the Cypress Hills area																		
577	78.50	10.12	2.19	0.24	0.05	0.02	1.67	1.02	1.73	1.78	2.21	99.53	-	-	-	1.27	-	Analyst - G. Schmitz.
Paskapoo Formation in R.C.A. Corehole 65-1																		
S6	66.15	16.98	5.43	0.49	0.14	0.03	1.95	1.83	2.56	1.61	4.13	101.30	0.17	0.21	1.31	-	-	Analyst - H. Oikawa. Greenish grey siltstone; depth 66 feet.

S12	70.97	7.69	2.80	0.30	0.13	0.05	5.66	2.17	0.66	1.50	8.39	100.32	0.90	5.44	1.72	-	-	Analyst - H. Oikawa. Bluish grey, fine-grained sandstone, cemented by calcite; depth 124.5 feet.
S24	42.64	10.08	6.61	0.38	0.17	0.16	17.52	1.64	1.68	1.36	17.89	100.13	n.d.	15.94	5.69	-	-	Analyst - H. Oikawa. Grey, fine-grained sandstone, cemented by calcite; depth 215 feet.
S27	66.36	14.48	3.61	0.58	0.14	0.05	1.82	2.33	1.91	2.22	6.63	100.13	n.d.	2.22	2.54	-	-	Analyst - H. Oikawa. Grey, fine-grained, laminated sandstone; depth 254 feet.
S30	66.61	15.94	5.93	0.70	0.15	0.02	1.06	1.44	2.23	2.29	4.27	100.64	0.14	n.d.	1.79	-	-	Analyst - H. Oikawa. Greenish grey, fine-grained sandstone; depth 294 feet.
Paskapoo Formation in McLeod River Damsite Corehole 1																		
1-120	75.37	9.73	2.48	0.37	0.10	0.03	2.61	1.50	1.92	1.92	3.63	99.66	n.d.	1.89	2.02	-	-	Analyst - I. Davidson. Greenish grey, medium-grained sandstone; depth 120 feet.
1-180	74.89	9.58	2.65	0.39	0.13	0.03	2.46	1.92	1.95	1.77	3.99	99.76	n.d.	2.16	2.27	-	-	Analyst - I. Davidson. Greenish grey, medium-grained sandstone; depth 180 feet.
Paskapoo Formation in McLeod River Damsite Corehole 2																		
2-60	70.00	11.13	3.18	0.44	0.13	0.04	3.73	1.89	2.26	2.08	4.81	99.69	n.d.	2.76	2.53	-	-	Analyst - I. Davidson. Greenish grey, fine-grained sandstone; depth 60 feet.
Porcupine Hills Formation in R.C.A. Corehole 66-1																		
C1	57.37	12.62	3.86	0.59	0.20	0.03	7.76	3.26	0.35	2.40	12.01	100.45	0.26	6.94	1.60	-	-	Analyst - D. J. Benkie. Greenish grey, silty shale; depth 51 feet.
C2	53.11	11.76	6.23	0.63	0.26	0.23	9.50	3.06	0.49	2.22	13.29	100.78	0.16	9.38	4.17	-	-	Analyst - D. J. Benkie. Greenish grey, silty shale; depth 96 feet.
C3	56.38	11.11	4.45	0.53	4.70	0.10	10.24	1.54	0.66	2.15	7.31	99.17	0.11	2.73	1.73	-	-	Analyst - D. J. Benkie. Massive siltstone containing bone fragments; depth 189 feet.
C4	49.02	10.68	4.02	0.43	0.16	0.07	14.96	2.62	0.47	1.95	15.72	100.10	0.25	12.02	2.35	-	-	Analyst - D. J. Benkie. Greenish grey, massive siltstone; depth 385 feet.

SAMPLE NUMBER	SiO_2	Al_2O_3	Total iron as Fe_2O_3	TiO_2	P_2O_5	MnO	CaO	MgO	Na_2O	K_2O	L.O.I.	TOTAL	S as SO_3	CO_2	FeO	H_2O^-	Organic carbon	Remarks
Porcupine Hills Formation in R.C.A. Corehole 66-1																		
C5	67.42	17.13	4.37	0.71	0.12	0.01	0.95	1.71	0.47	2.72	5.31	100.92	n.d.	0.31	1.87	-	-	Analyst - D. J. Benkie. Massive, bentonitic, calcareous, silty shale; depth 708 feet.
C6	59.26	14.37	4.81	0.54	0.11	0.03	5.61	3.06	0.70	2.39	9.52	100.40	n.d.	4.39	1.96	-	-	Analyst - D. J. Benkie. Massive siltstone; depth 898 feet.
C7	75.76	12.14	2.96	0.57	0.15	0.01	0.78	1.30	0.92	2.18	3.30	100.07	n.d.	n.d.	1.79	-	-	Analyst - D. J. Benkie. Massive siltstone; depth 999 feet.
S35	72.29	3.95	1.47	0.22	0.13	0.04	8.13	2.42	0.34	0.62	9.77	99.38	0.01	8.35	1.13	-	-	Analyst - I. Davidson. Greenish grey, fine-grained sandstone; depth 405 feet.
S52	68.03	3.05	1.03	0.16	0.10	0.04	12.82	1.66	0.32	0.62	12.15	99.98	0.01	11.05	0.83	-	-	Analyst - I. Davidson. Greenish grey, fine-grained sandstone; depth 547 feet.
S78	67.16	6.11	2.57	0.38	0.16	0.15	8.64	2.58	0.54	0.85	10.78	99.92	n.d.	8.72	1.93	-	-	Analyst - I. Davidson. Greenish grey, very-fine grained sandstone; depth 989 feet.
R1	58.36	15.62	4.54	0.59	0.45	0.02	5.53	2.15	0.48	3.11	9.33	100.18	n.d.	3.27	2.19	-	1.42	Analyst - D. J. Benkie. Carbonaceous siltstone; depth 359 feet.
R2	57.64	20.89	5.03	0.48	0.03	0.01	0.83	1.71	0.84	1.39	10.24	99.40	0.31	n.d.	1.60	-	1.79	Analyst - D. J. Benkie. Carbonaceous siltstone; depth 903 feet.
R3	44.67	13.18	5.14	0.48	0.22	0.01	0.76	1.56	0.34	2.33	29.65	99.98	1.00	n.d.	*	-	18.04	Analyst - D. J. Benkie. * Indeterminate, due to high percentage of organic carbon present. Lignitic siltstone, shelly; depth 962 feet.
Edmonton Formation outcrops in the Battle River area																		
679	62.05	10.90	1.54	0.35	0.11	0.12	11.36	0.61	2.23	2.25	9.49	101.01	-	-	-	-	-	Analyst - H. Wagenbauer.
Edmonton Formation outcrops in the Bullpound Creek area																		
779	76.96	12.08	0.98	0.24	-	0.01	1.42	0.94	2.22	2.66	1.74	99.25	-	-	-	-	-	Analyst - G. Schmitz.
Edmonton Formation outcrops in the Edmonton area																		
674	74.54	11.41	3.15	0.43	0.02	0.05	1.68	0.92	2.00	1.70	2.80	98.70	-	-	-	-	-	Analyst - H. Oikawa.

Edmonton Formation in R.C.A. Corehole 65-1																		
S37	72.09	13.92	3.12	0.58	0.13	0.05	1.49	1.11	2.78	2.11	2.85	100.23	-	-	-	-	-	Analyst - H. Oikawa.
S43	77.86	11.06	2.20	0.39	0.11	0.02	1.09	0.98	2.22	2.00	2.24	99.25	-	-	-	-	-	Analyst - H. Oikawa.
S50	71.48	14.25	3.28	0.55	0.09	0.04	0.87	1.39	2.32	2.55	4.06	100.88	-	-	-	-	-	Analyst - H. Oikawa.
S57	66.61	14.82	4.27	0.56	0.17	0.07	2.05	2.04	2.51	2.09	5.42	100.61	-	-	-	-	-	Analyst - H. Oikawa.

PLATES 1-10

PLATE 1

FIGURE 1. Outcrop of cross-stratified sandstone in the Porcupine Hills Formation of southwestern Alberta.

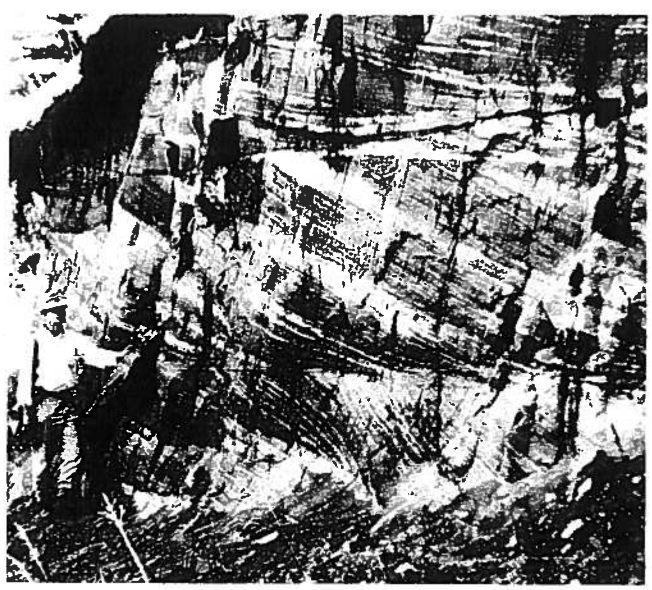
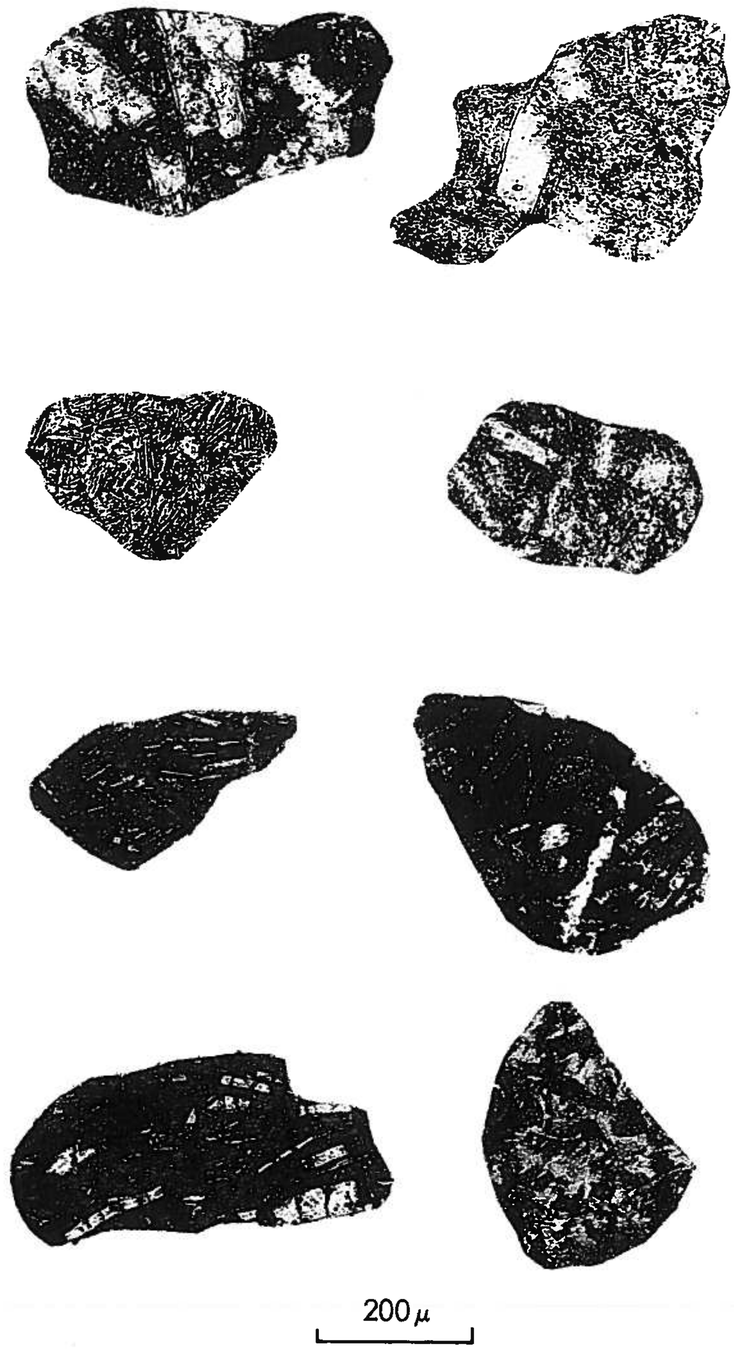


FIGURE 2. Outcrop of cross-stratified sandstone in the Ravenscrag Formation, Cypress Hills, southeastern Alberta.

PLATE 2



Volcanic rock fragments from Paskapoo Formation sandstones.

PLATE 3

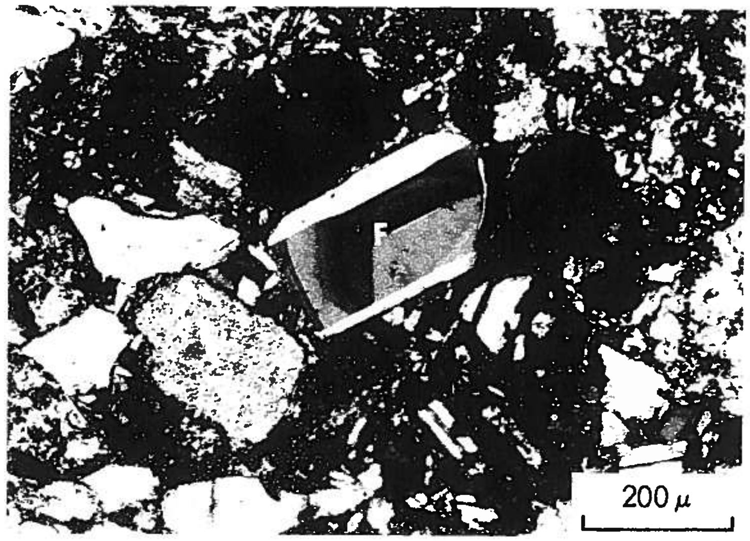


FIGURE 1. Zoned feldspar grain (F) in thin section of Paskapoo Formation sandstone (crossed nicols). Sample 771B.

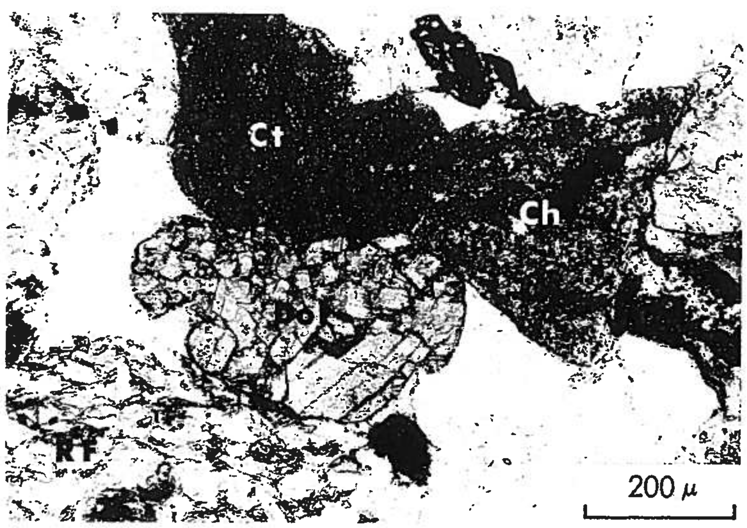


FIGURE 2. Rounded and crushed calcite (CT), dolomite (Dol) and chert (Ch) grains in a thin section of Paskapoo Formation sandstone. Sample 607.

PLATE 4

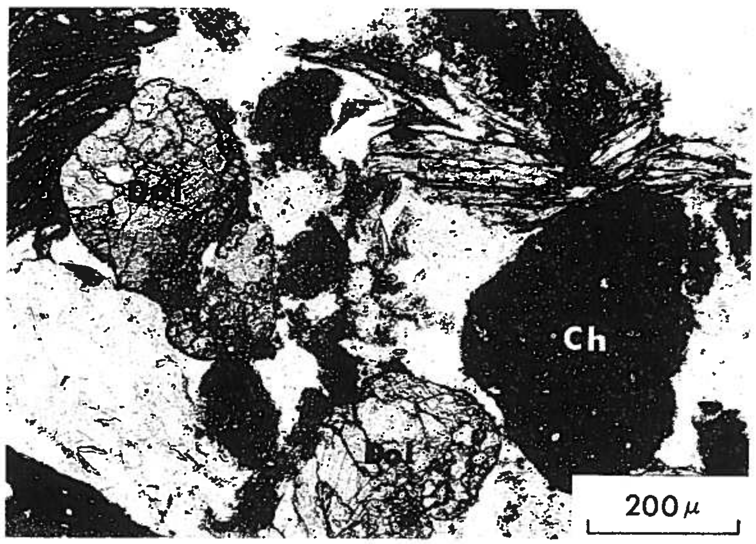


FIGURE 1. Rounded dolomite (Dol) grains in a thin section of Paskapoo Formation sandstone. Sample 607.

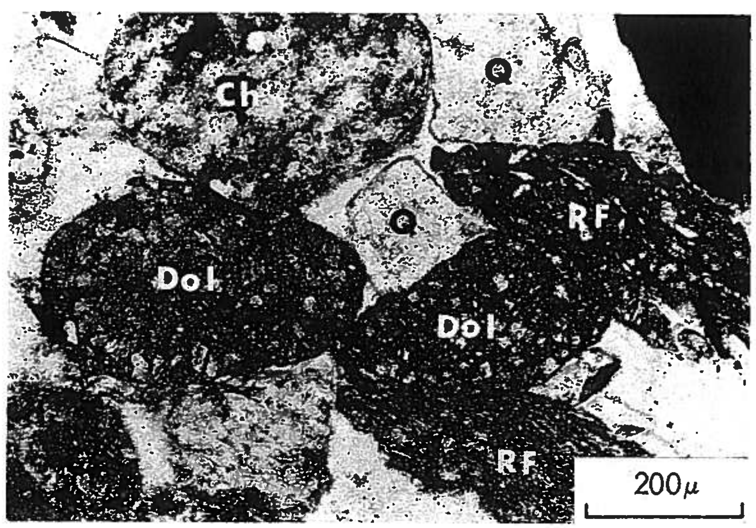


FIGURE 2. Dolomite (Dol), quartz (Q), chert (Ch) and rock fragments (RF) in a thin section of a Paskapoo Formation sandstone. Sample MRD 1-1-80.

PLATE 5

FIGURE 1. Pore space (P) lined with chlorite film (arrows) in a thin section of a Paskapoo Formation sandstone. Sample 610.

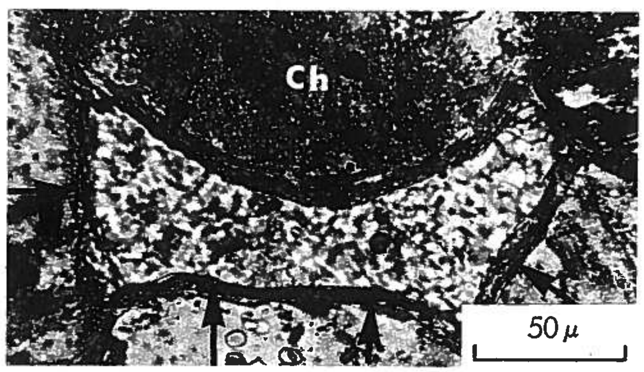


FIGURE 2. Calcite (Ct) in central part of intergranular area lined with chlorite (arrows) in same sample as above.

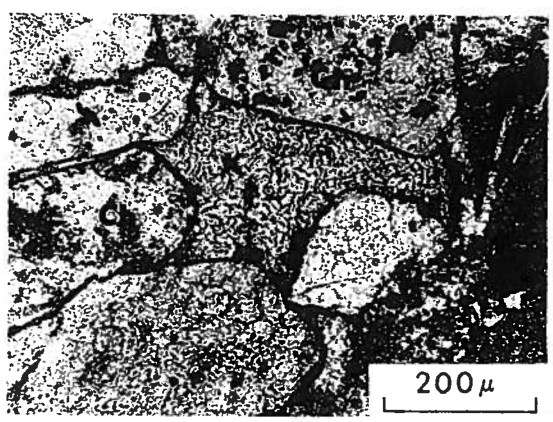


FIGURE 3. Kaolinite (K) filling intergranular area in thin section of a Porcupine Hills Formation sandstone. Sample 589.

PLATE 6

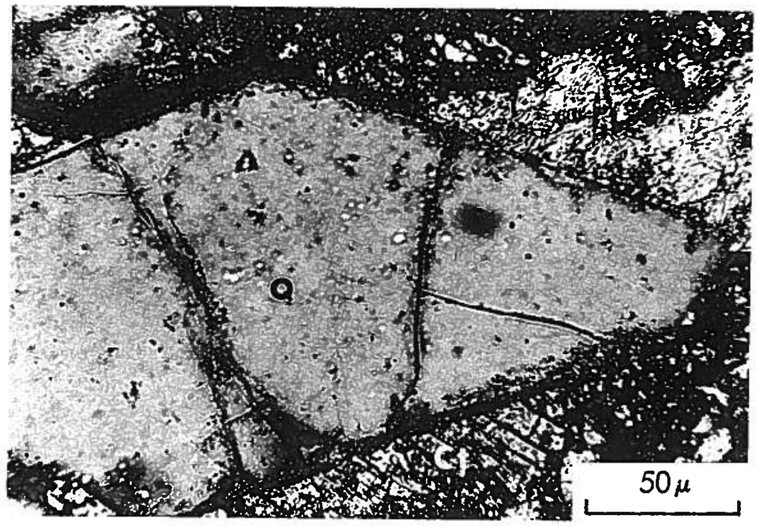


FIGURE 1. Euhedral quartz (Q) in a thin section of calcite-cemented sandstone of the Willow Creek Formation. Sample 845.

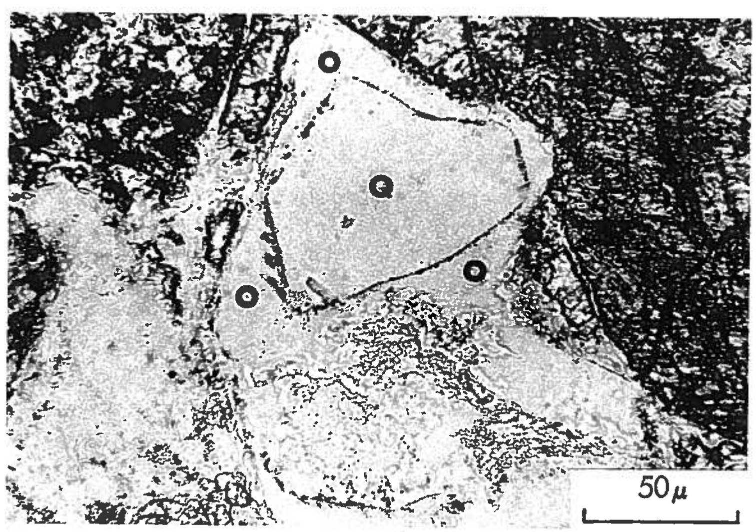


FIGURE 2. Large quartz overgrowth (O) in optical continuity with quartz grain (Q) in the thin section of sample 845.

PLATE 7

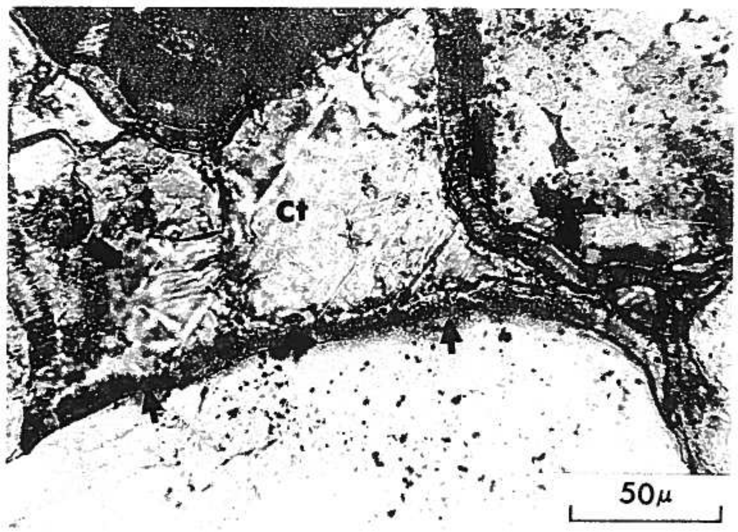


FIGURE 1. Calcite (Ct) occupying central area of chlorite-lined (arrows) pore in a thin section of Paskapoo? Formation sandstone. Sample 909B.

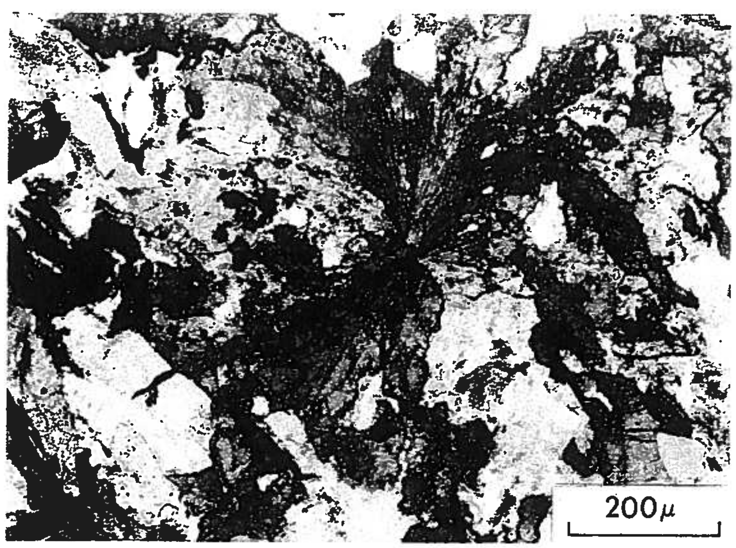


FIGURE 2. Spherulitic texture of calcite replacement in thin section of Paskapoo Formation sandstone in R.C.A. Corehole 65-1. Sample S-24.

PLATE 8

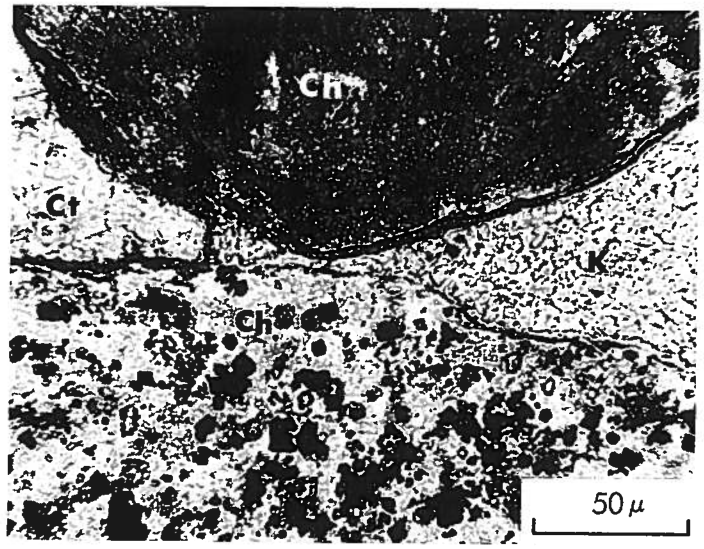


FIGURE 1. Relationship between calcite (Ct) and kaolinite (K) cements occupying adjacent pores as seen in a thin section of a Porcupine Hills Formation sandstone. Sample 589.

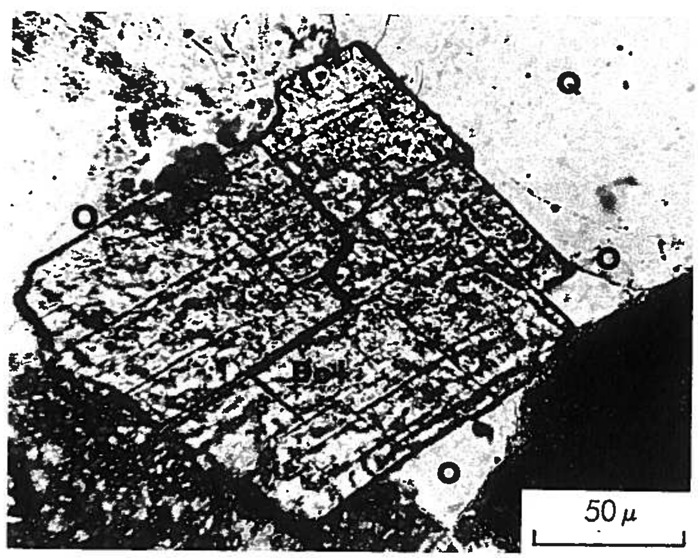
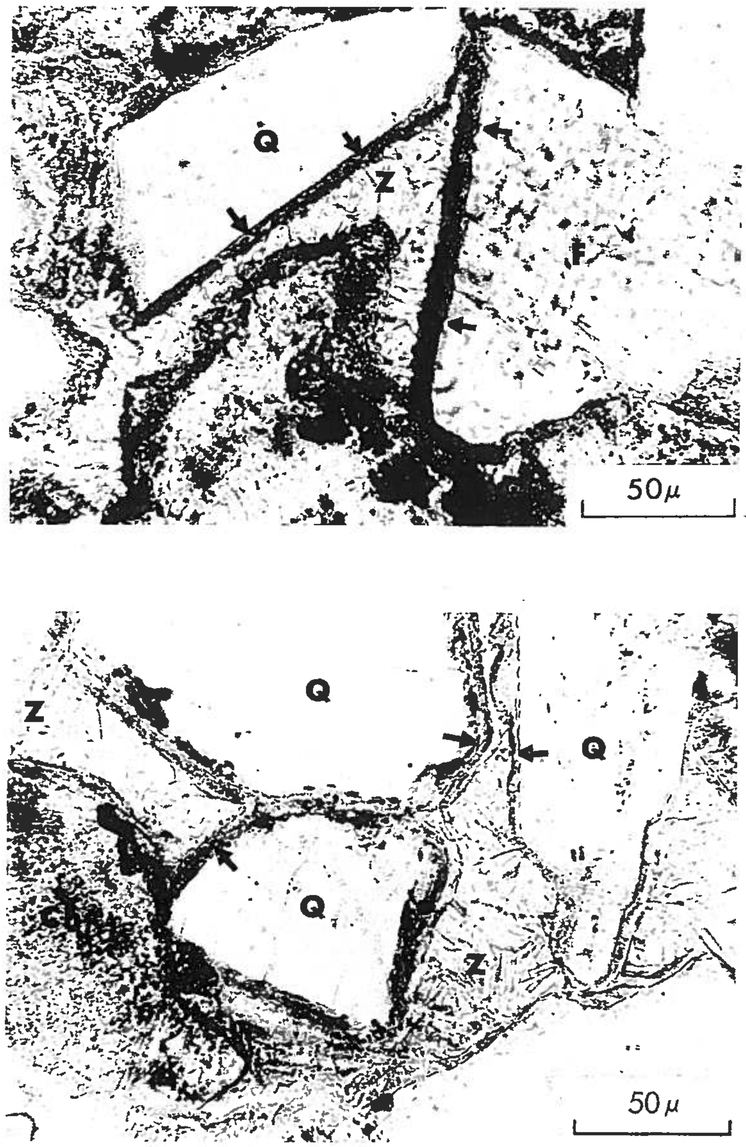


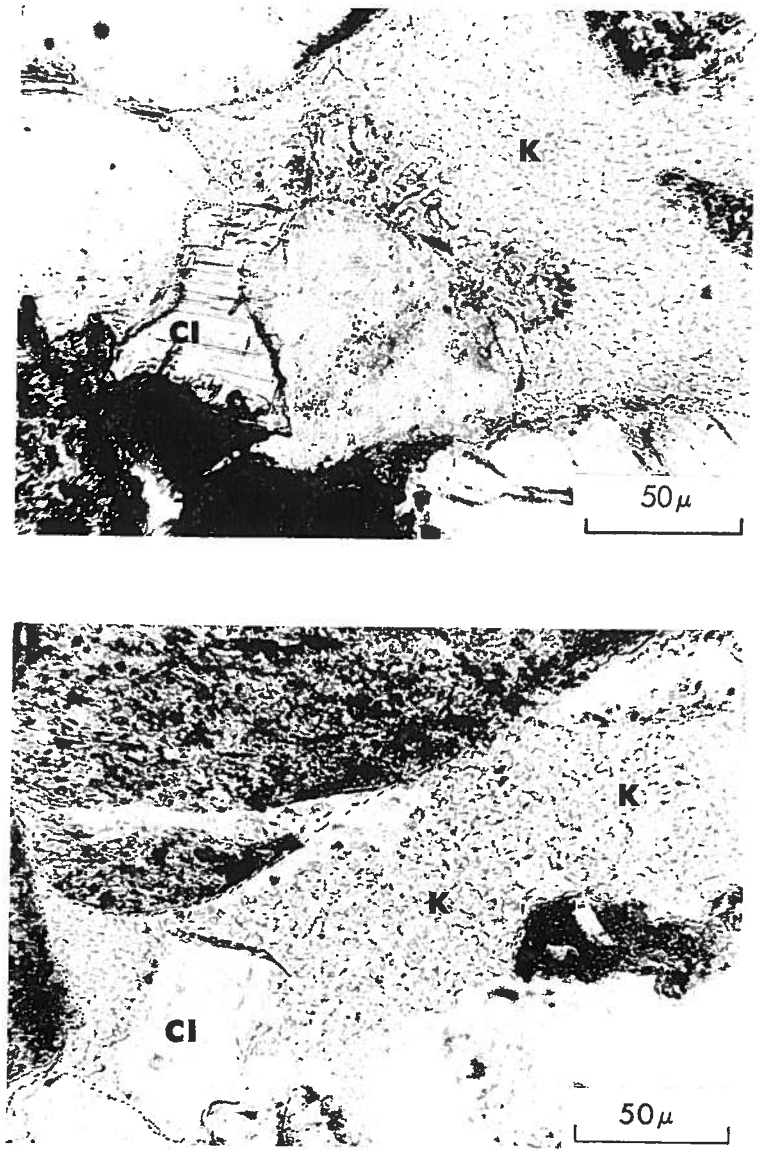
FIGURE 2. Dolomite rhombs (Dol) surrounded by quartz overgrowths (0) in a thin section of a Porcupine Hills Formation sandstone in R.C.A. Corehole 66-1. Sample S-35.

PLATE 9



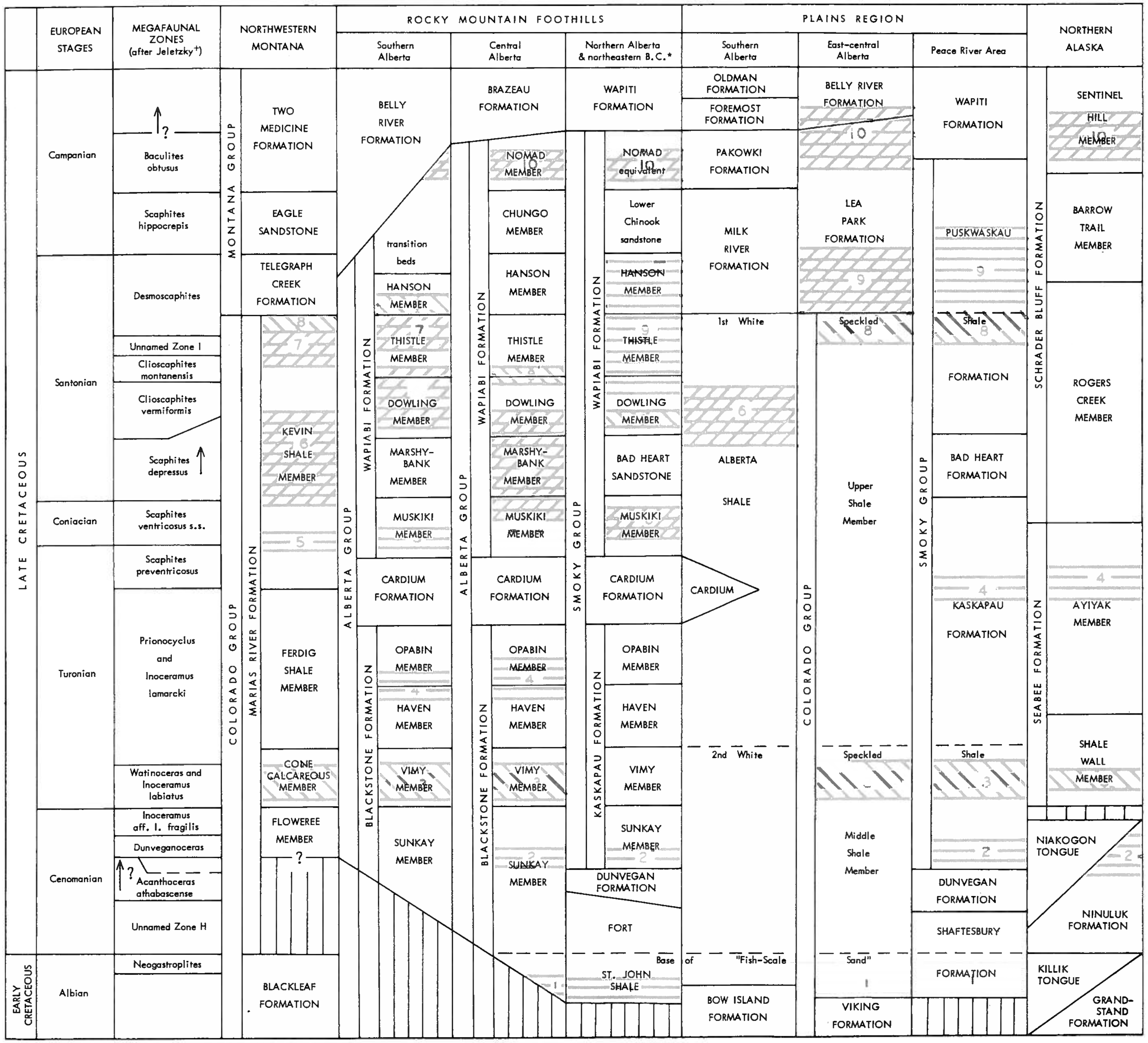
Clinoptilolite (Z) occupying central areas of pores lined with montmorillonite (arrows) in a thin section of a Paskapoo Formation sandstone from McLeod River Damsite Corehole No. 1. Sample MRD-1-1-40.

PLATE 10



Thin section showing kaolinite (K) and clinoptilolite (Cl) in two pores of a Paskapoo Formation sandstone. Sample 774B.

INDEX



LEGEND

Microfaunas

10 *Lenticulina*
9 *Trochammina ribstonensis*
8 Upper pelagic
7 *Anomalinoides henbesti*
6 *Brachycythere-Bullopora*
5 *Trochammina* sp. 1
4 *Pseudoclavulina* sp.
3 Lower pelagic
2 *Verneuilinoides kansasensis*
1 *Miliammina manitobensis.*

agglutinated

dominantly pelagic

mixed agglutinated and calcareous benthonic

\+ Jeletzky (in Stott, 1963, Table IV)

* Composite section
Author's terminology used for Wapiabi Formation in the upper Wapiti River area of n.e. B.C.
Stott's terminology used for pre-Wapiabi beds on Little Berland River of northern Alberta

FIGURE 4. Regional correlation of the Upper Cretaceous with stratigraphic positions of microfaunas superimposed.

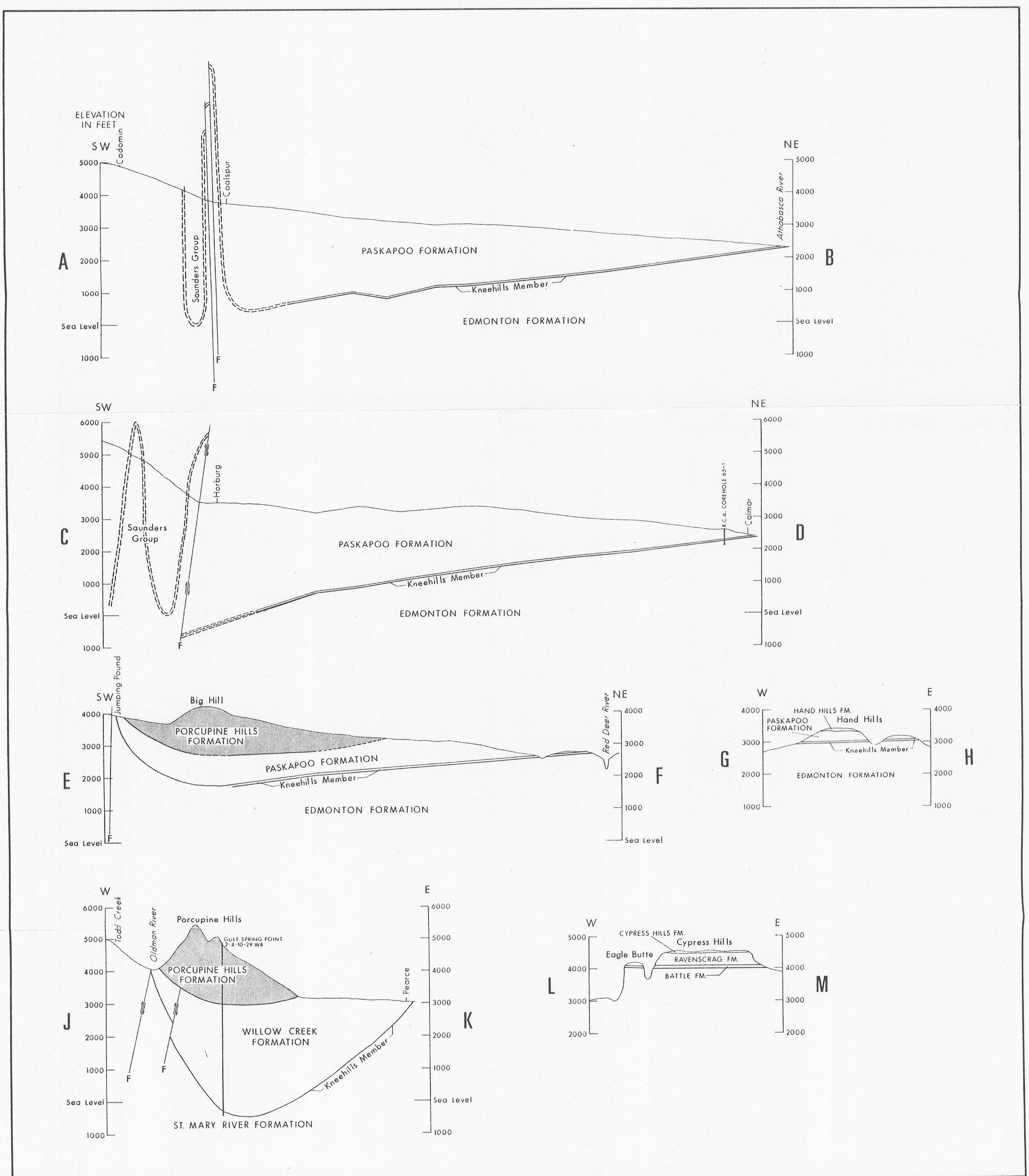


FIGURE 3. STRUCTURE CROSS SECTIONS THROUGH POST-KNEEHILLS STRATA OF CENTRAL AND SOUTHERN ALBERTA (CROSS SECTIONS ARE LOCATED ON MAP 32)

To accompany Research Council of Alberta Bulletin 27, by M. A. Carrigy

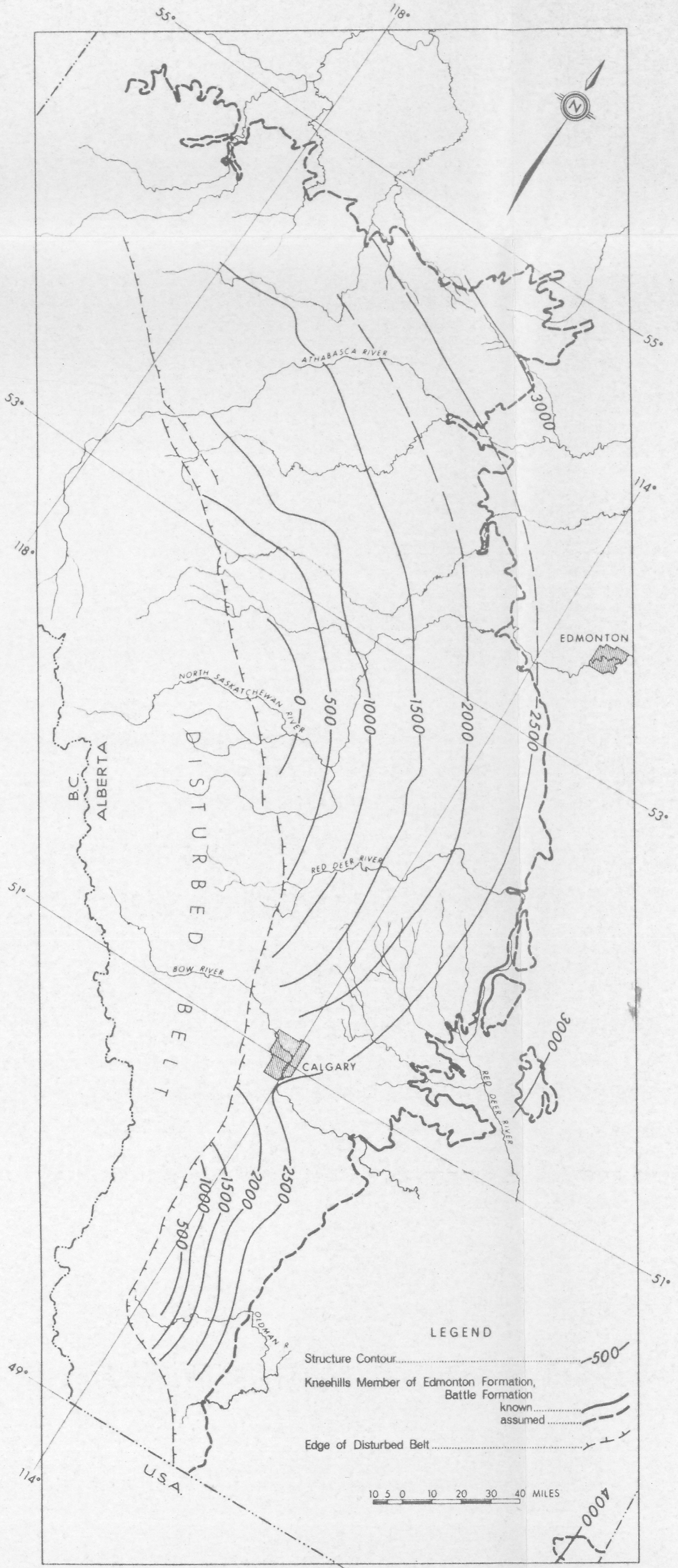


FIGURE 2. STRUCTURE CONTOURS ON TOP OF THE KNEEHILLS MEMBER OF THE EDMONTON FORMATION [AFTER ELLIOTT (1960) AND IRISH AND HAVARD 1968)]

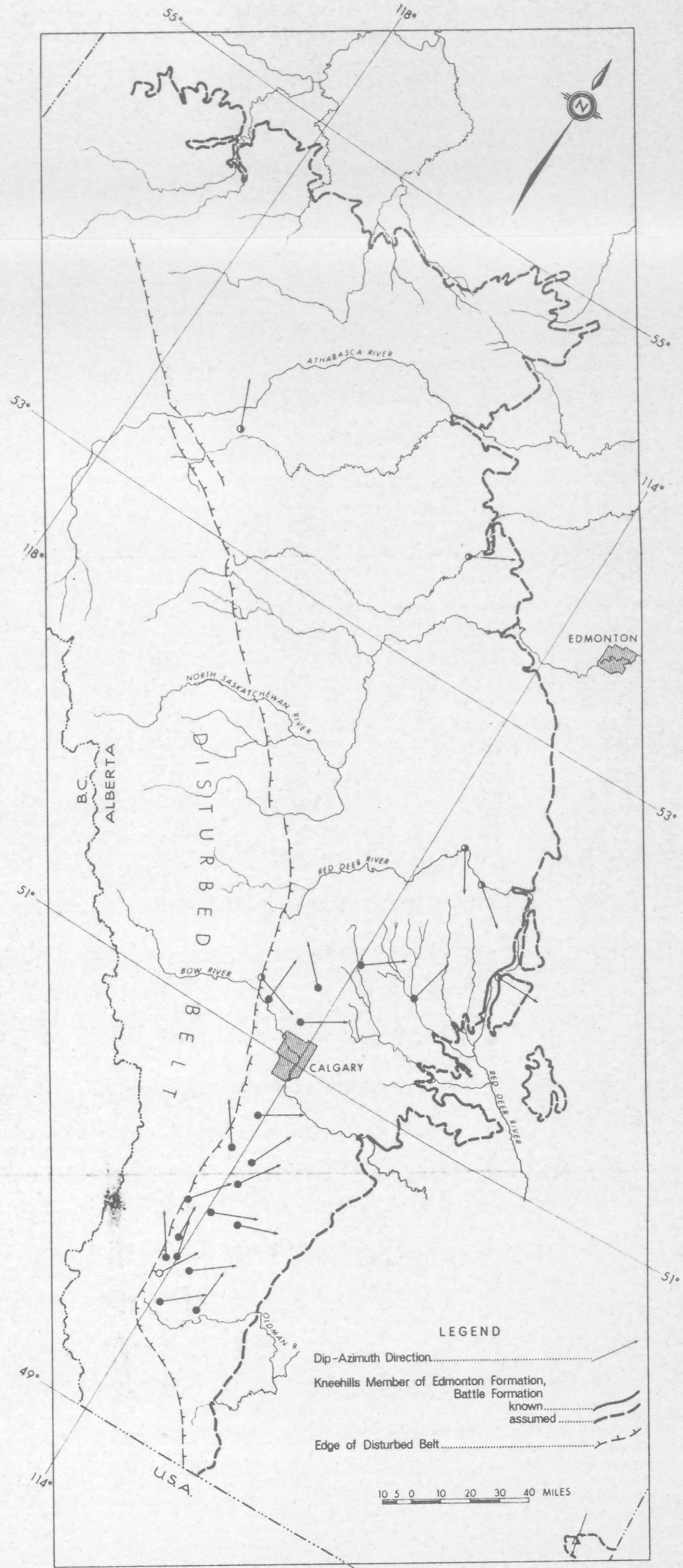


FIGURE 4. MEAN PALEOCURRENT DIRECTIONS FOR LOCALITIES IN POST-KNEEHILLS STRATA OF ALBERTA PLAINS

- ● Porcupine Hills Formation
- ◑ Paskapoo Formation
- ○ Willow Creek Formation

To accompany Research Council of Alberta Bulletin 27, by M. A. Carrigy

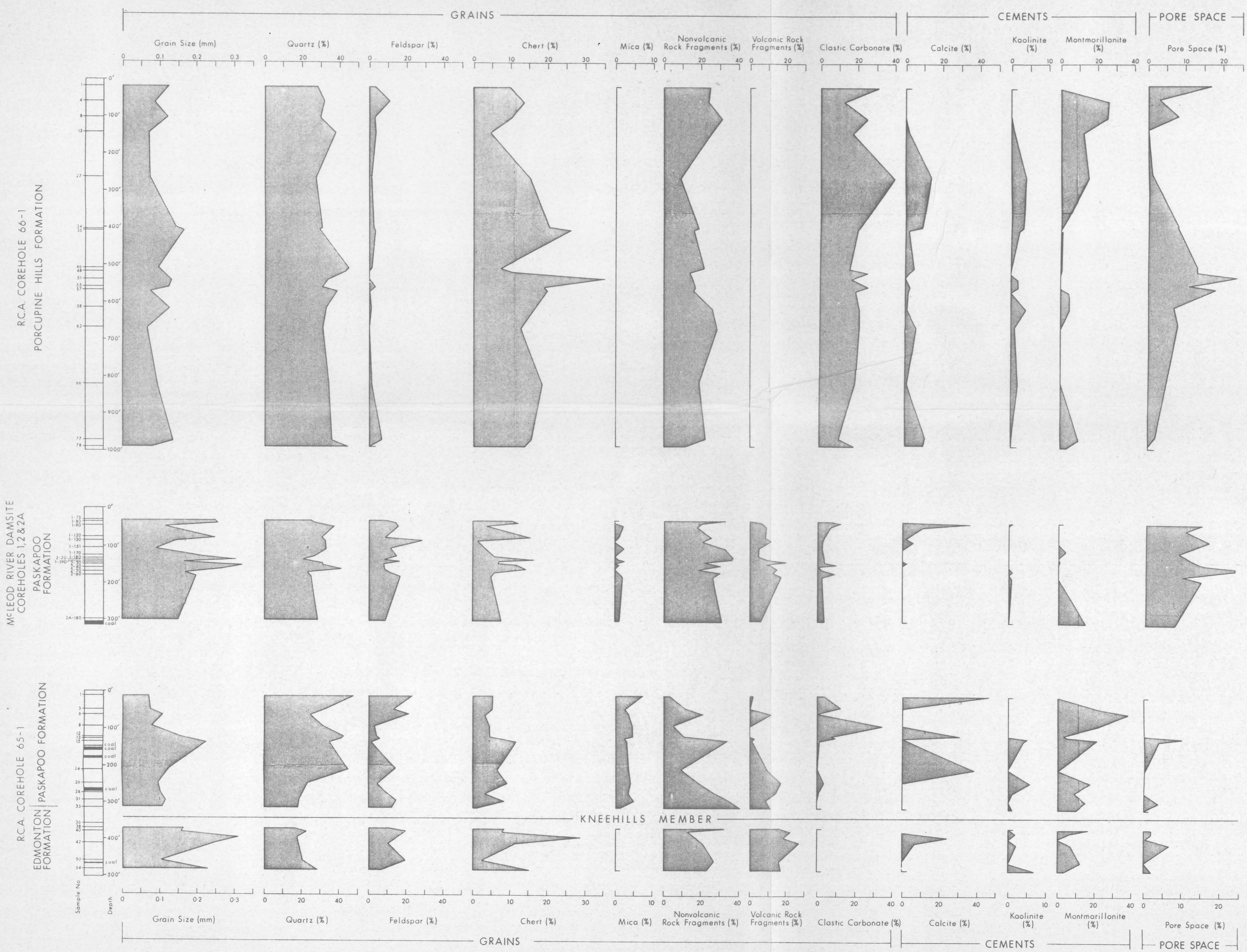


FIGURE 11. STRATIGRAPHIC DISTRIBUTION OF GRAINS, CEMENTS AND PORE SPACE IN SANDSTONES FROM R.C.A. COREHOLES 65-1 AND 66-1, AND THE McLEOD RIVER DAMSITE COREHOLES.

To accompany Research Council of Alberta
Bulletin 27, by M. A. Carrigy

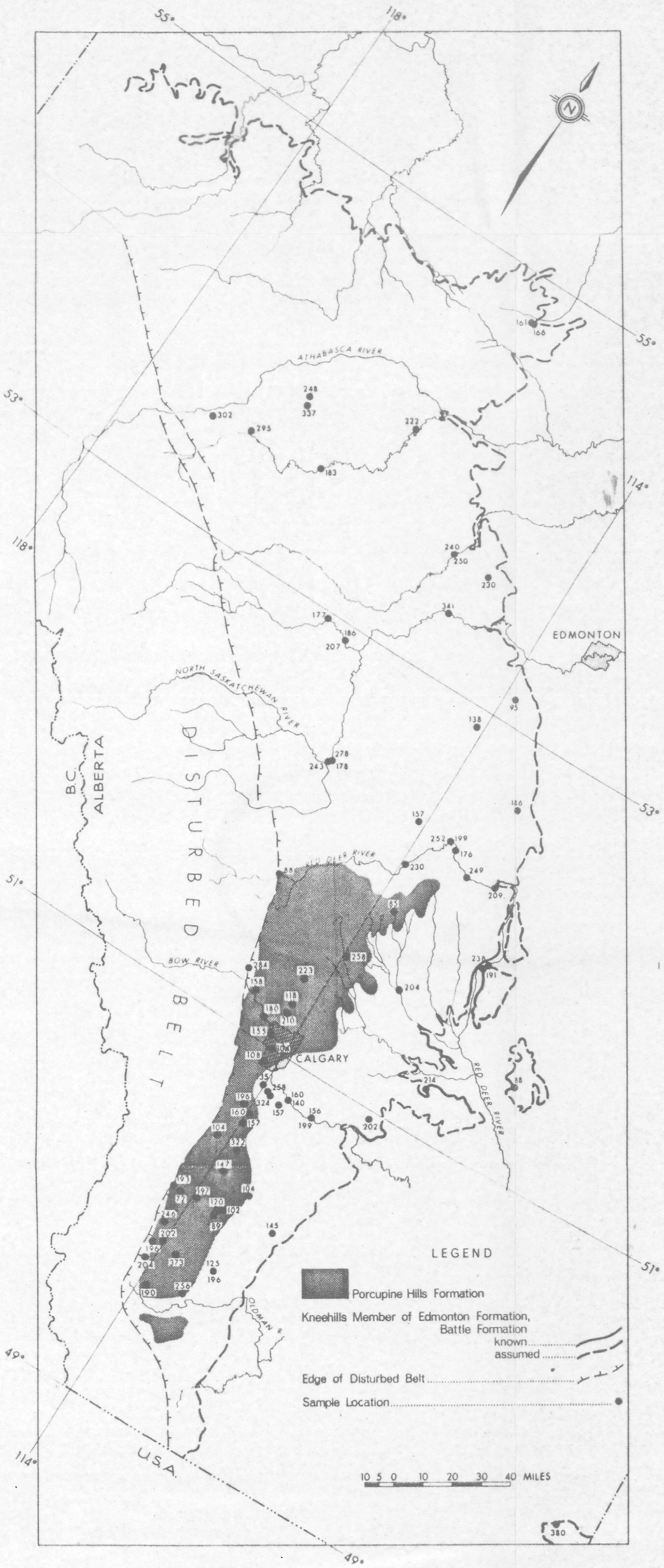


FIGURE 8. DISTRIBUTION OF MEAN GRAIN SIZES (IN MICRONS) IN POST-KNEEHILLS SANDSTONE SAMPLES

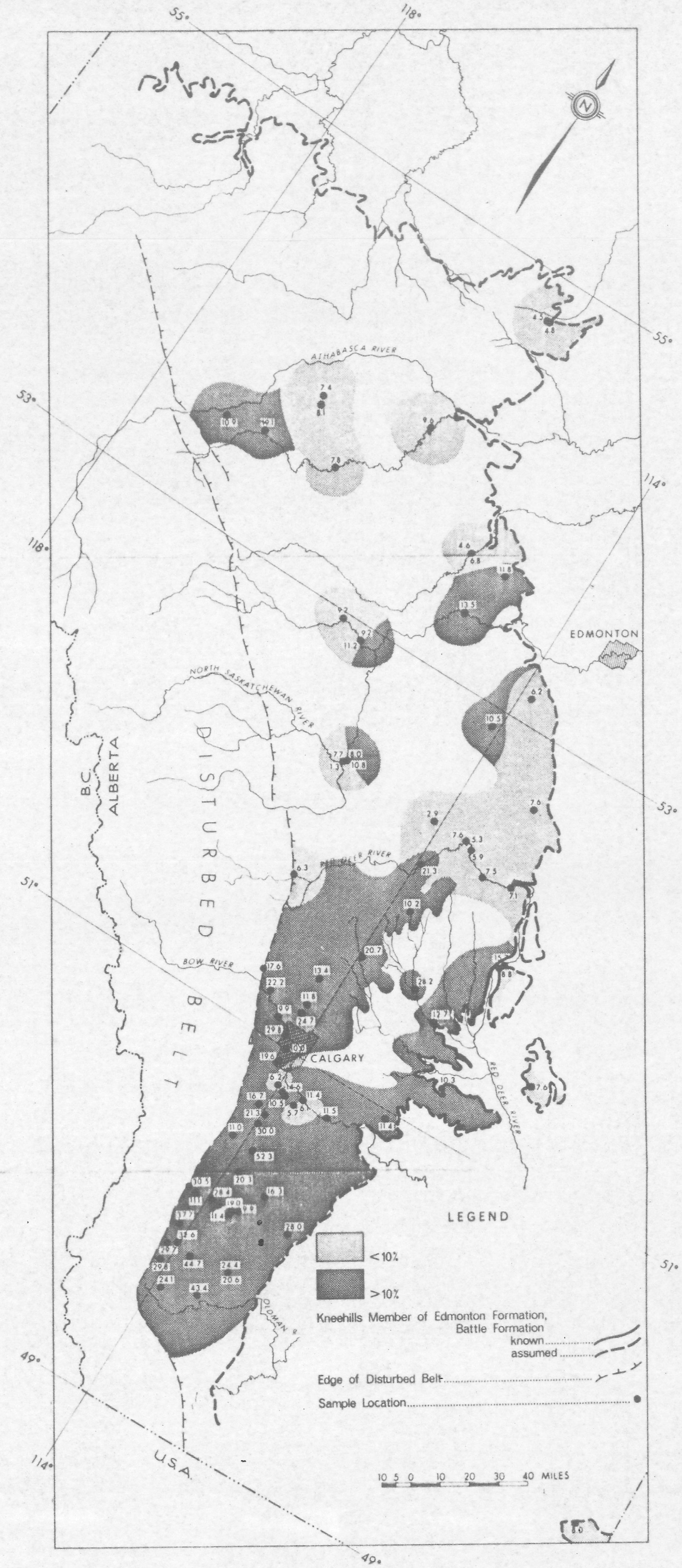


FIGURE 12. PERCENTAGE DISTRIBUTION OF CHERT GRAINS IN POST-KNEEHILLS SANDSTONES OF CENTRAL AND SOUTHWESTERN ALBERTA PLAINS

To accompany Research Council of Alberta Bulletin 27, by M. A. Carrigy

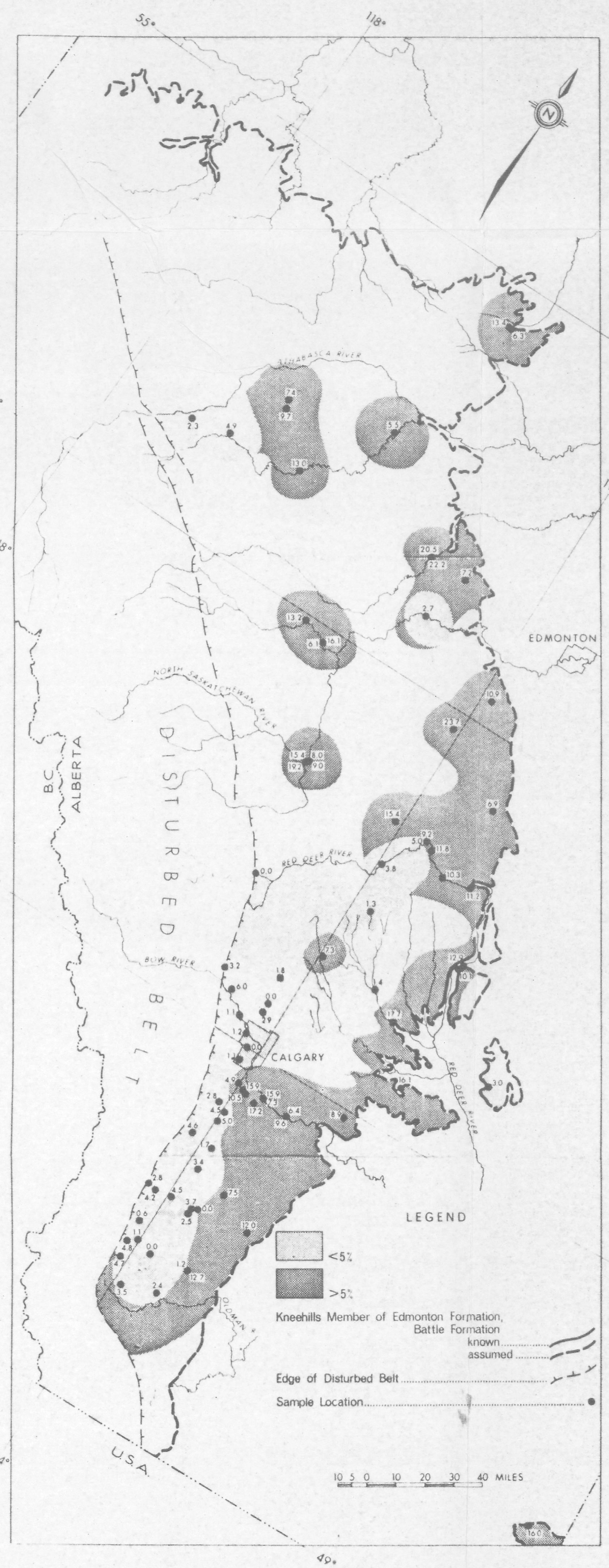


FIGURE 15. PERCENTAGE DISTRIBUTION OF FELDSPAR GRAINS IN POST-KNEEHILLS SANDSTONES OF CENTRAL AND SOUTHWESTERN ALBERTA PLAINS

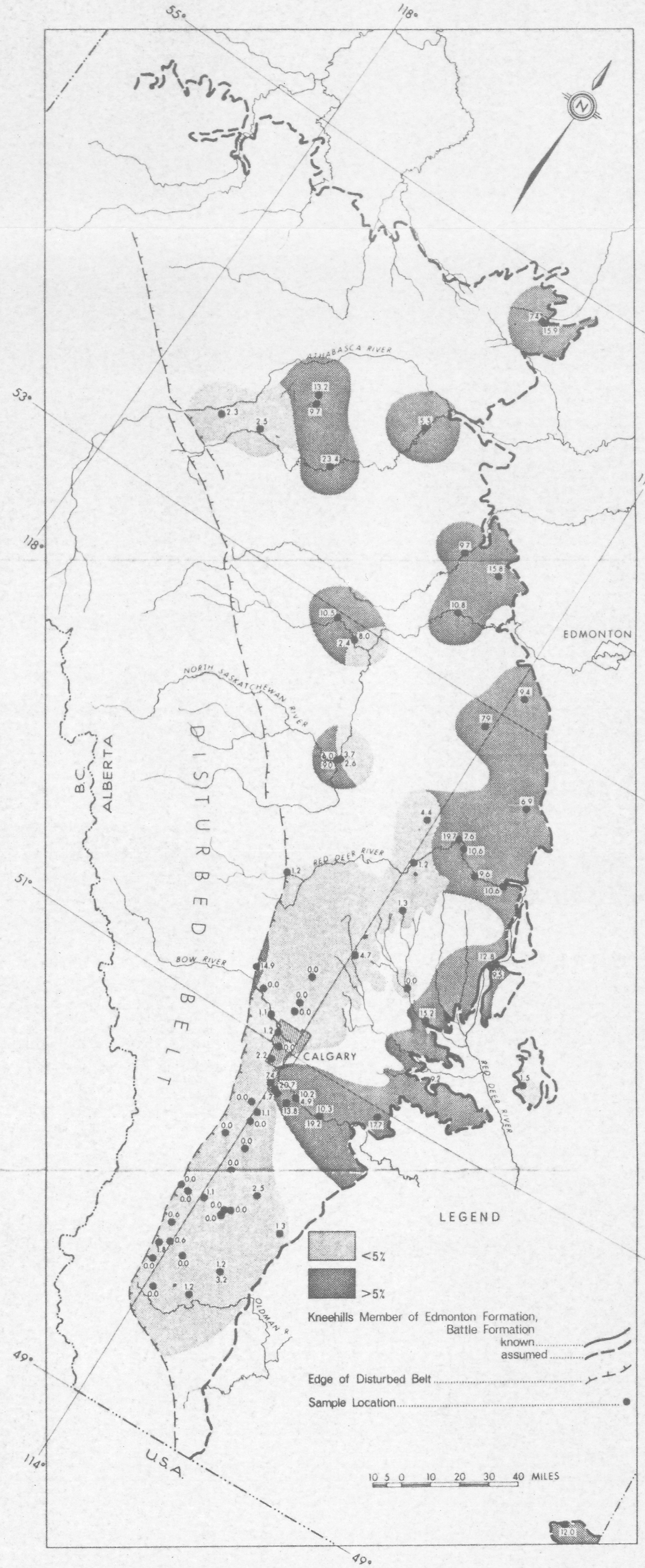


FIGURE 16. PERCENTAGE DISTRIBUTION OF VOLCANIC ROCK FRAGMENTS IN POST-KNEEHILLS SANDSTONES OF CENTRAL AND SOUTHWESTERN ALBERTA PLAINS

To accompany Research Council of Alberta Bulletin 27, by M. A. Carrigy

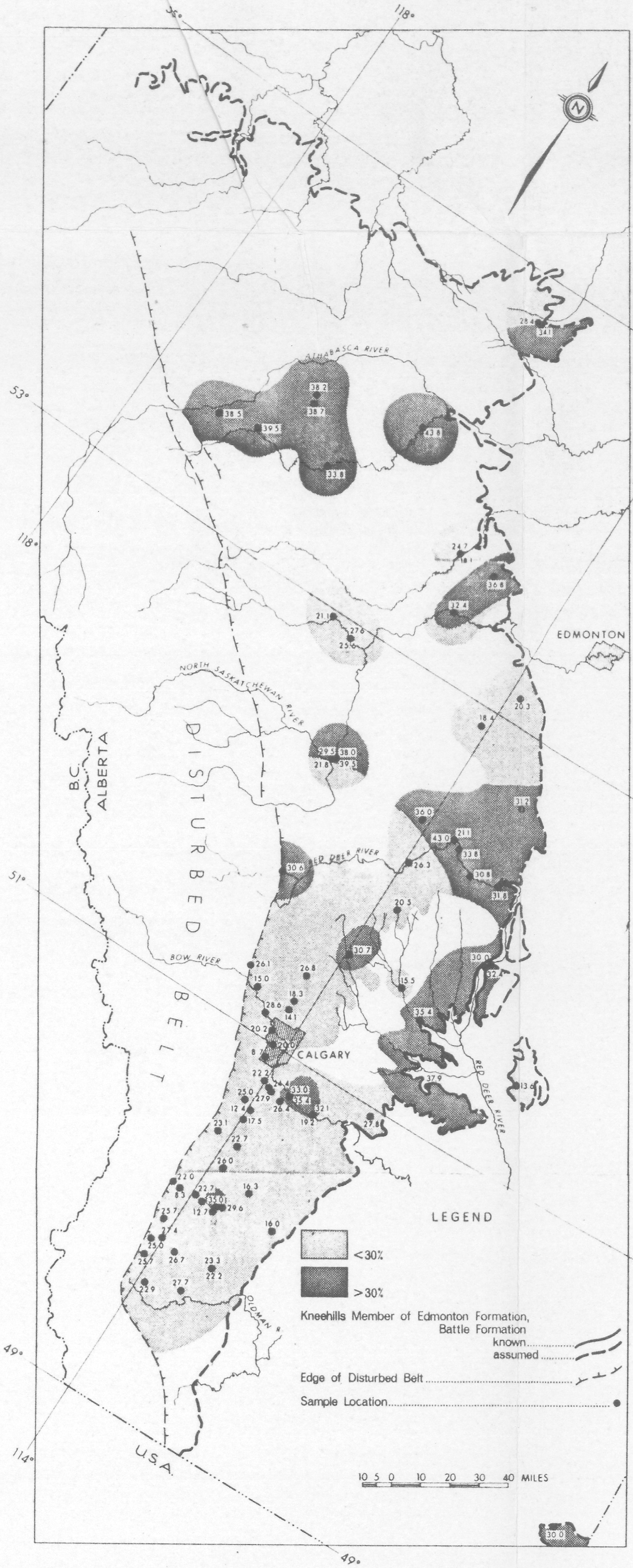


FIGURE 17. PERCENTAGE DISTRIBUTION OF NONVOLCANIC ROCK FRAGMENTS IN POST-KNEEHILLS SANDSTONES OF CENTRAL AND SOUTHWESTERN ALBERTA PLAINS

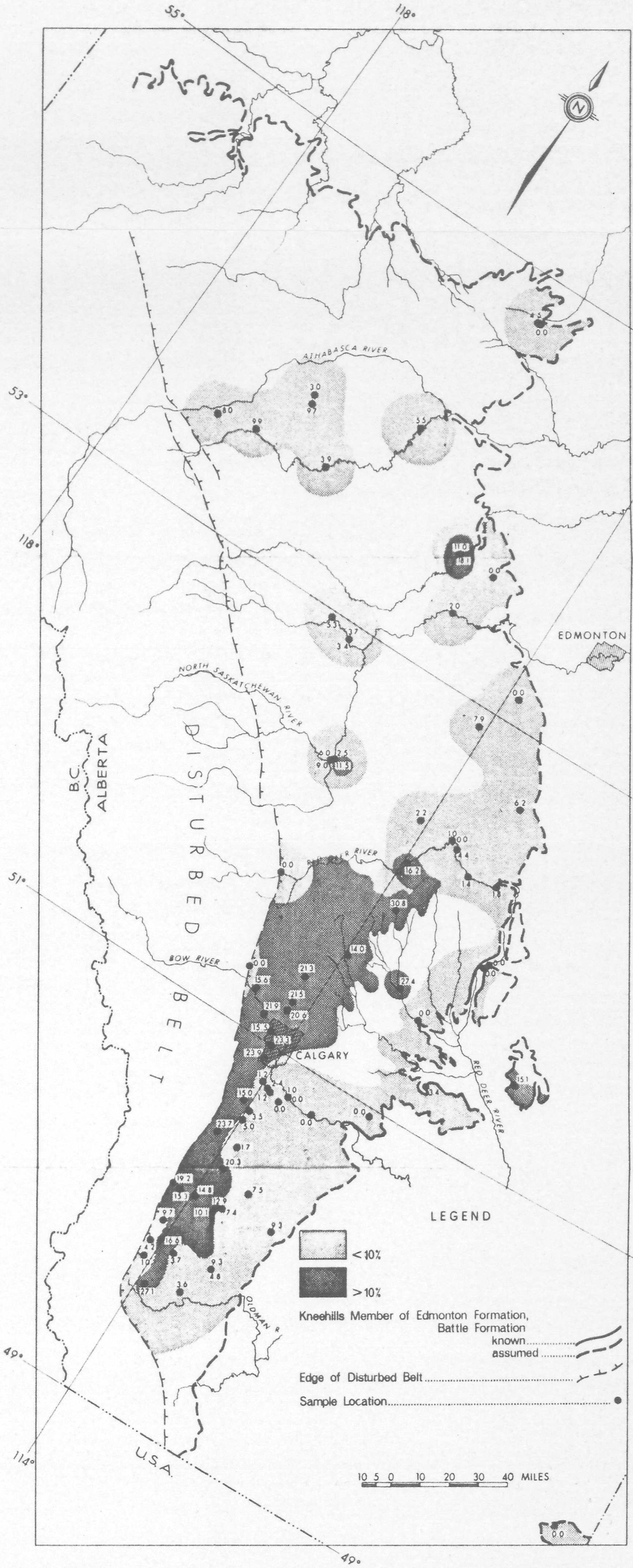


FIGURE 18. PERCENTAGE DISTRIBUTION OF CLASTIC CARBONATE GRAINS IN POST-KNEEHILLS SANDSTONES OF CENTRAL AND SOUTHWESTERN ALBERTA PLAINS

To accompany Research Council of Alberta Bulletin 27, by M. A. Carrigy

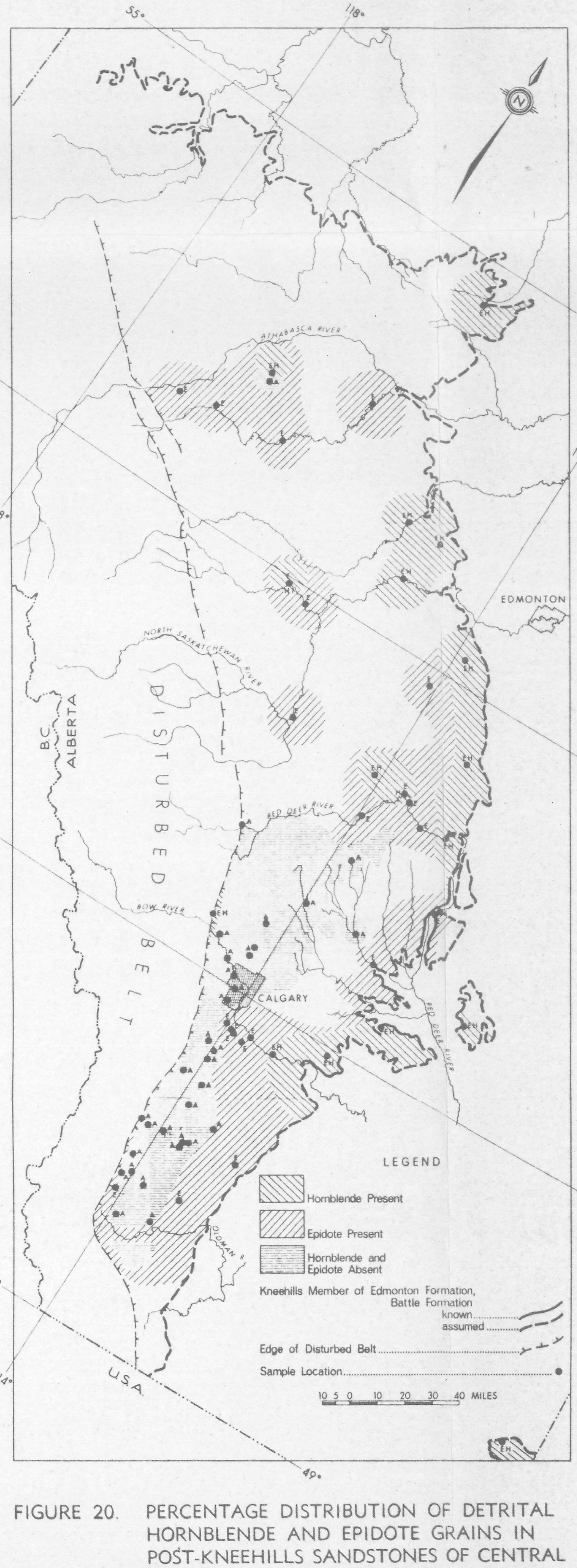


FIGURE 20. PERCENTAGE DISTRIBUTION OF DETRITAL HORNBLENDE AND EPIDOTE GRAINS IN POST-KNEEHILLS SANDSTONES OF CENTRAL AND SOUTHWESTERN ALBERTA PLAINS

E = Epidote

H = Hornblende

A = Absence of hornblende and epidote

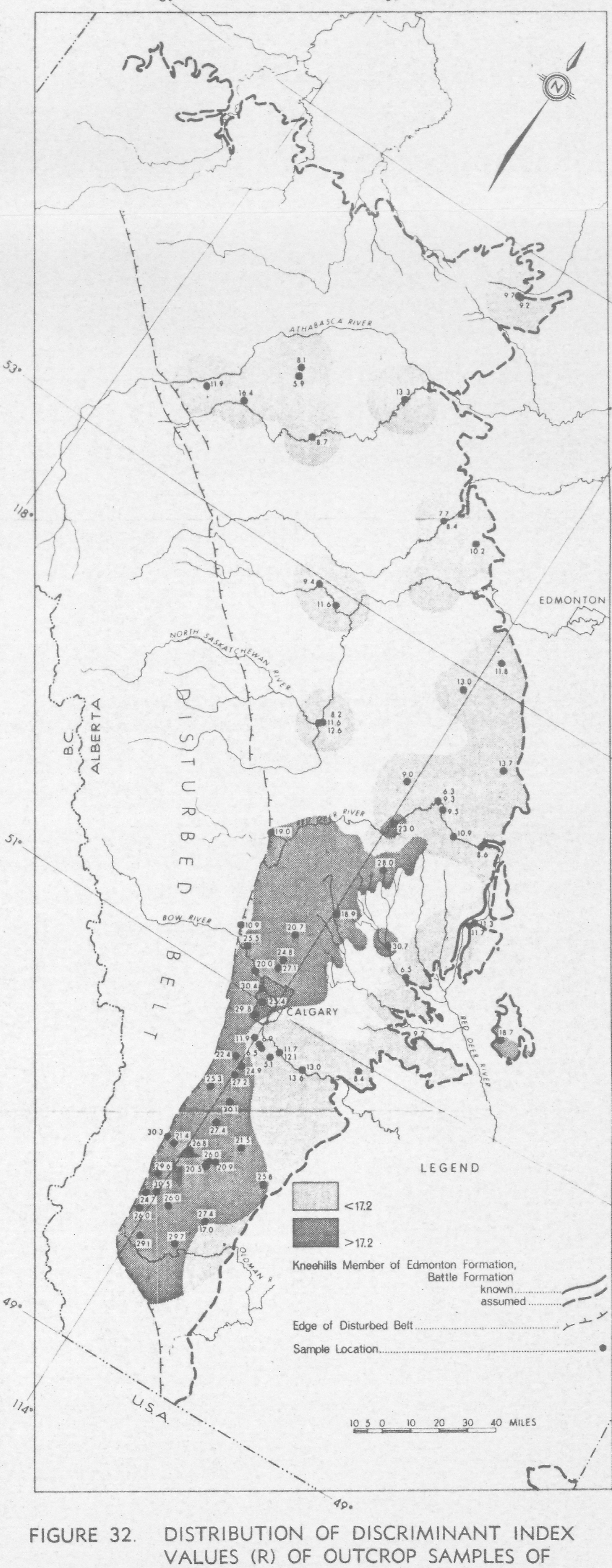


FIGURE 32. DISTRIBUTION OF DISCRIMINANT INDEX VALUES (R) OF OUTCROP SAMPLES OF POST-KNEEHILLS SANDSTONES IN CENTRAL AND SOUTHWESTERN ALBERTA PLAINS

To accompany Research Council of Alberta Bulletin 27, by M. A. Carrigy

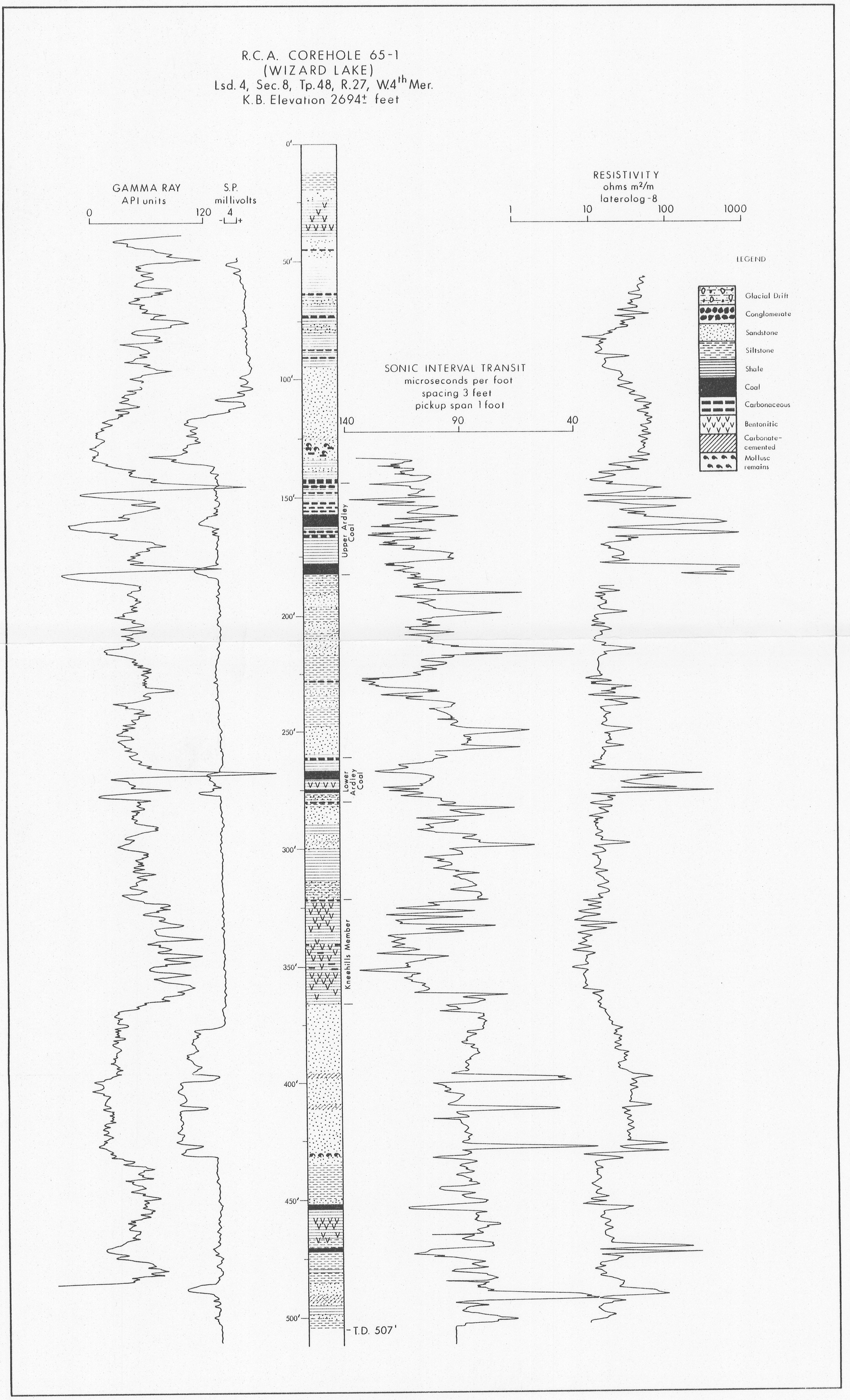


FIGURE 21. LITHOLOGY AND GEOPHYSICAL LOG CHARACTERISTICS OF THE STRATA PENETRATED IN R.C.A. COREHOLE 65-1

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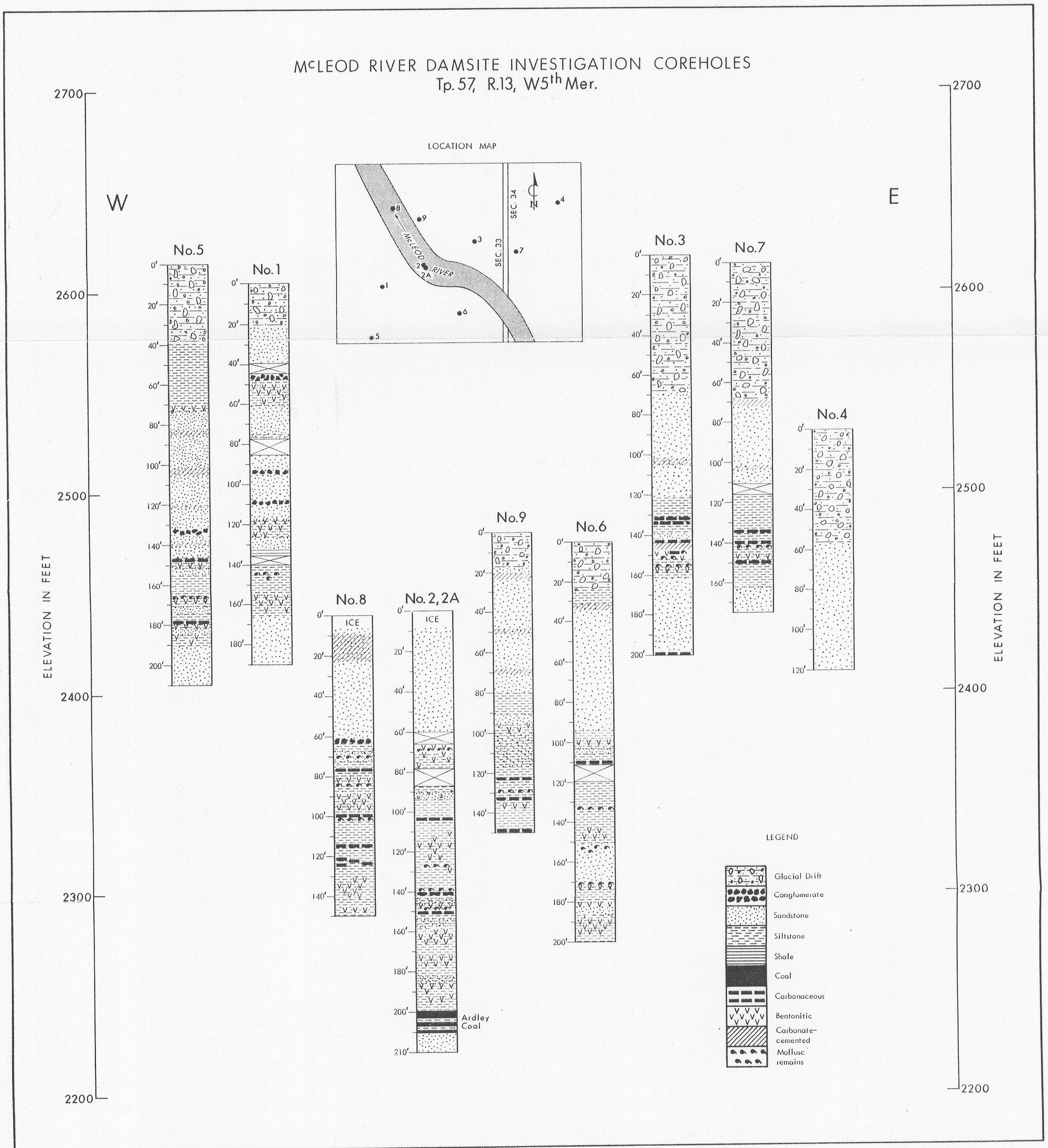

FIGURE 22. LITHOLOGY OF THE STRATA IN THE McLEOD RIVER DAMSITE COREHOLES

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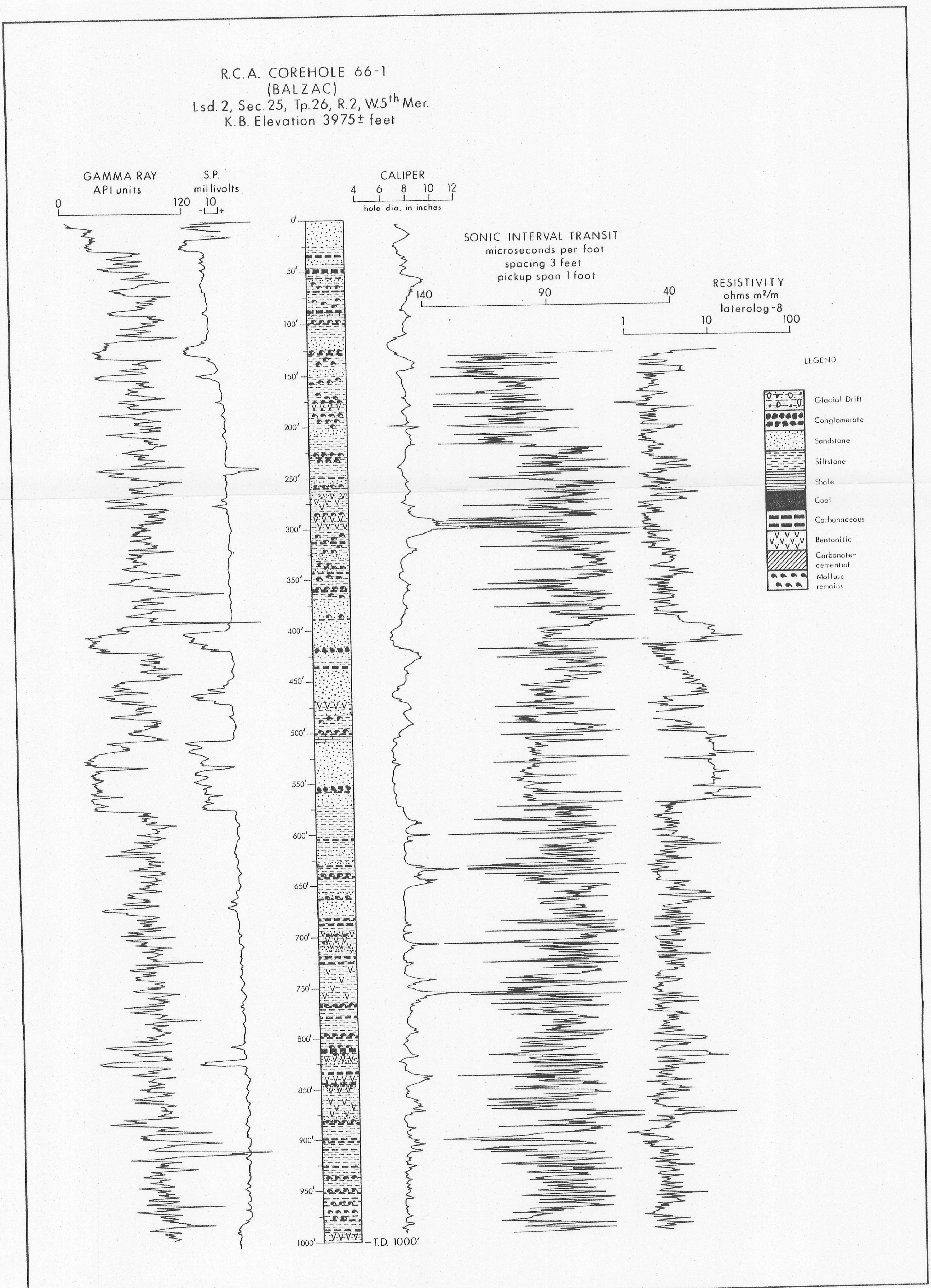
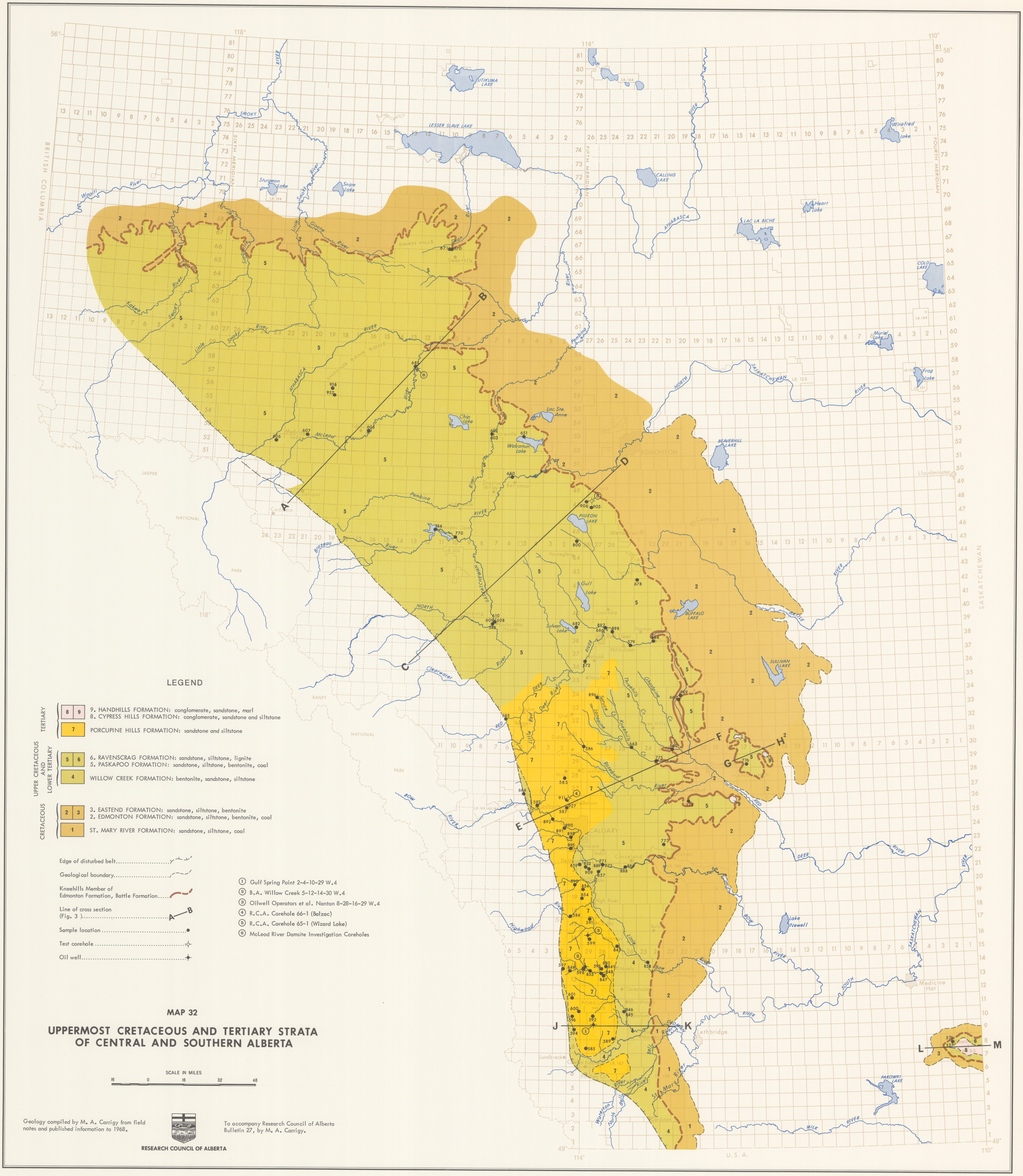


FIGURE 28. LITHOLOGY AND GEOPHYSICAL LOG CHARACTERISTICS OF THE STRATA PENETRATED IN R.C.A. COREHOLE 66-1

To accompany Research Council of Alberta Bulletin 27, by M. A. Carrigy



MAP 32

UPPERMOST CRETACEOUS AND TERTIARY STRATA OF CENTRAL AND SOUTHERN ALBERTA

Geology compiled by M. A. Carrigy from field notes and published information to 1968.

RESEARCH COUNCIL OF ALBERTA

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