PROVINCE OF ALBERTA

RESEARCH COUNCIL OF ALBERTA

BULLETIN 22

SURFICIAL GEOLOGY OF THE FOREMOST - CYPRESS HILLS AREA, ALBERTA

by

J. A. Westgate

Research Council of Alberta
87th Avenue and 114th Street
Edmonton
1968

CONTENTS

Page

ILLUSTRATIONS

Page

TABLES

Surficial Geology of the Foremost - Cypress Hills Area, Alberta

ABSTRACT

The Foremost-Cypress Hills area is divided into six physiographic units: Cypress Hills Plateau, upland areas, till plain, lacustrine plains, river channels, and canyons. The South Saskatchewan River drains the northern part of the area, and the Milk River drains the southern part. A small internal drainage basin is centred on Lake Pakowki.

Glaciation modified the preglacial physiography of the upland areas to a lesser extent than that of the lower tracts. The preglacial valleys in places contain more than 250 feet of glacial drift. Rivers in the Lethbridge and Medicine Hat Valleys drained the map-area in preglacial times; both occupied broad, open valleys and flowed northeastward.

End moraine, including washboard moraine, is the most widespread glacial land form. Others present include ground moraine, hummocky disintegration moraine, linear disintegration ridges, drumlins and drumlinoid ridges, kames, eskers, and flutings. Proglacial land forms present in the area include outwash aprons, a loess plain, glacial lake basins, meltwater channels, and spillways.

The colour, texture, pebble composition, heavy minerals, and carbonate content in the till matrix of the several till sheets in the map-area were studied. The texture of the tills is largely controlled by the underlying bedrock, and the younger tills generally contain less carbonate pebbles than the older. Preliminary work suggests that heavy minerals are of little value as parameters to differentiate the till sheets.

The maximum altitude reached by the Laurentide glaciers in the map-area was about 4500 feet. At this time the ice was at least 2300 feet thick at Medicine Hat, about 1500 feet thick at Foremost and Manyberries and about 1000 feet thick at Aden. The earlier more extensive glaciers moved across the map-area in a southeasterly direction, flowing between the Cypress Hills and the Sweet Grass Hills, which both stood as nunataks. The dominant direction of movement of later less extensive glaciers in the map-area was to the south and southwest, although directions varied considerably near to the ice margin.

The Pleistocene deposits are divided into the following stratigraphic units: Saskatchewan Gravels, Wolf Island sediments, Elkwater drift, Cypress Hills loess, Wild Horse drift, Pakowki drift, Etzikom drift, Oldman drift, and Manyberries volcanic ash. The drift sheets are morphostratigraphic units; each one was deposited at the time of a significant glacial advance. Reliable correlation of subsurface tills with these surface drift sheets is presently not possible because of the sparse number of C-14 dates and limited number of known critical sedimentary parameters.

The Saskatchewan Gravels are defined as those preglacial fluviatile sediments that floor the major preglacial valleys and cover the several alluvial terraces below the erosional surface situated at about 4000 feet above sea level. They lie unconformably upon Upper Cretaceous rocks and are composed predominantly of quartzite pebbles. Wolf Island sediments consist of sands, silts, and clays that accumulated in elongate proglacial lakes which formed along the preglacial valleys as a result of downstream damming by Laurentide ice. All drift sheets were deposited by Laurentide glaciers.

The presence of frost action structures and remains of *Mammuthus primigenius* and *Equus* sp. definitely indicates a Pleistocene age for the lower (and younger) part of the Saskatchewan Gravels. The uppermost levels of the Saskatchewan Gravels, as defined here, may well be late Tertiary in age. The Elkwater drift is regarded as post-Sangamon, pre-"classical" Wisconsin in age and all of the younger drifts are considered to belong to the "classical" Wisconsin. Manyberries volcanic ash is equivalent to Glacier Peak ash and hence is about 12,000 years old.

No severely weathered horizons have been observed between tills exposed along valley walls. However, two subsurface tills near Lethbridge are greater than 54,500 years old (GSC-237), indicating that tills of early Wisconsin age or older are present in southern Alberta.

INTRODUCTION

This study was undertaken to determine the distribution, thickness, composition, and origin of the Pleistocene deposits of the Foremost-Cypress Hills area, to provide maps that will aid future development of economic resources—especially groundwater and constructional materials—and to establish the Pleistocene stratigraphic succession. Basically, the report attempts to unravel the sequence of geologic events that took place in the map-area during the Pleistocene Epoch.

Location and Access

The Foremost-Cypress Hills area is situated in the southeastern corner of the province of Alberta. It covers approximately 6,200 square miles and is bounded by the parallels of latitude 49° and 50° and the meridians 110° and 112° west longitude (Fig. 1). The province of Saskatchewan lies immediately to the east, the United States of America to the south. Access to the western part of the map-area is provided by the hard-surfaced Provincial Highways 3 and 4. The northeastern corner is crossed by the Trans-Canada Highway from which Highway 48 leads southward to the Cypress Hills. Except for the southeastern corner of the region, the area is covered by a good network of gravel-surfaced roads.

Climate, Vegetation and Soils

Southeastern Alberta has a semi-arid climate with hot summers and bright, cold winters. Although a considerable distance east of the Rocky Mountains, the area is influenced by warm chinook winds at irregular intervals throughout the year. Southwesterly winds prevail during the winter months but are less frequent in summer (Kendrew and Currie, 1955). Precipitation and temperature data are shown in figure 2.

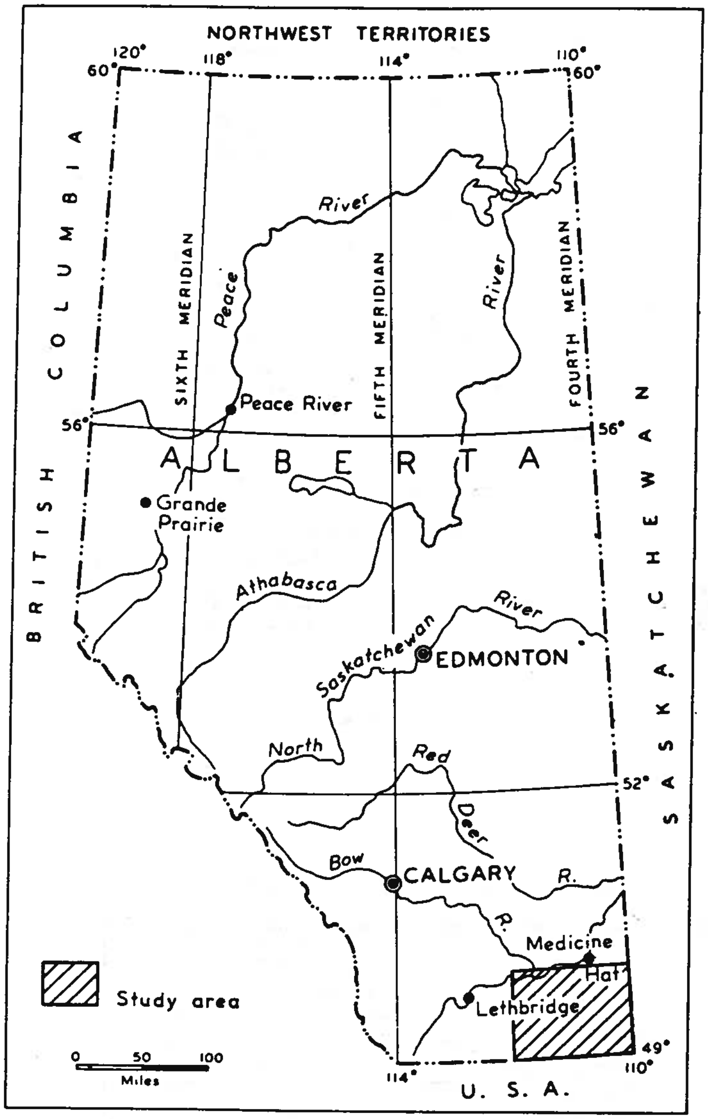


FIGURE 1. Location of the Foremost-Cypress Hills area, Alberta.

The mean annual temperature is 43°F. From November to March the mean monthly temperature is below 32°F and during the summer months (May to September) it exceeds 50°F. In winter the temperature has been known to fall to minus 50°F, whilst in summer, temperatures of over 150°F have been recorded.

The mean annual precipitation is 13 inches. Generally, the eastern half of the area receives less than the western, and in the extreme southeast the annual precipitation may not reach 10 inches. The upland areas attract more precipitation than the surrounding prairie. In the Cypress Hills the annual total often exceeds 18 inches.

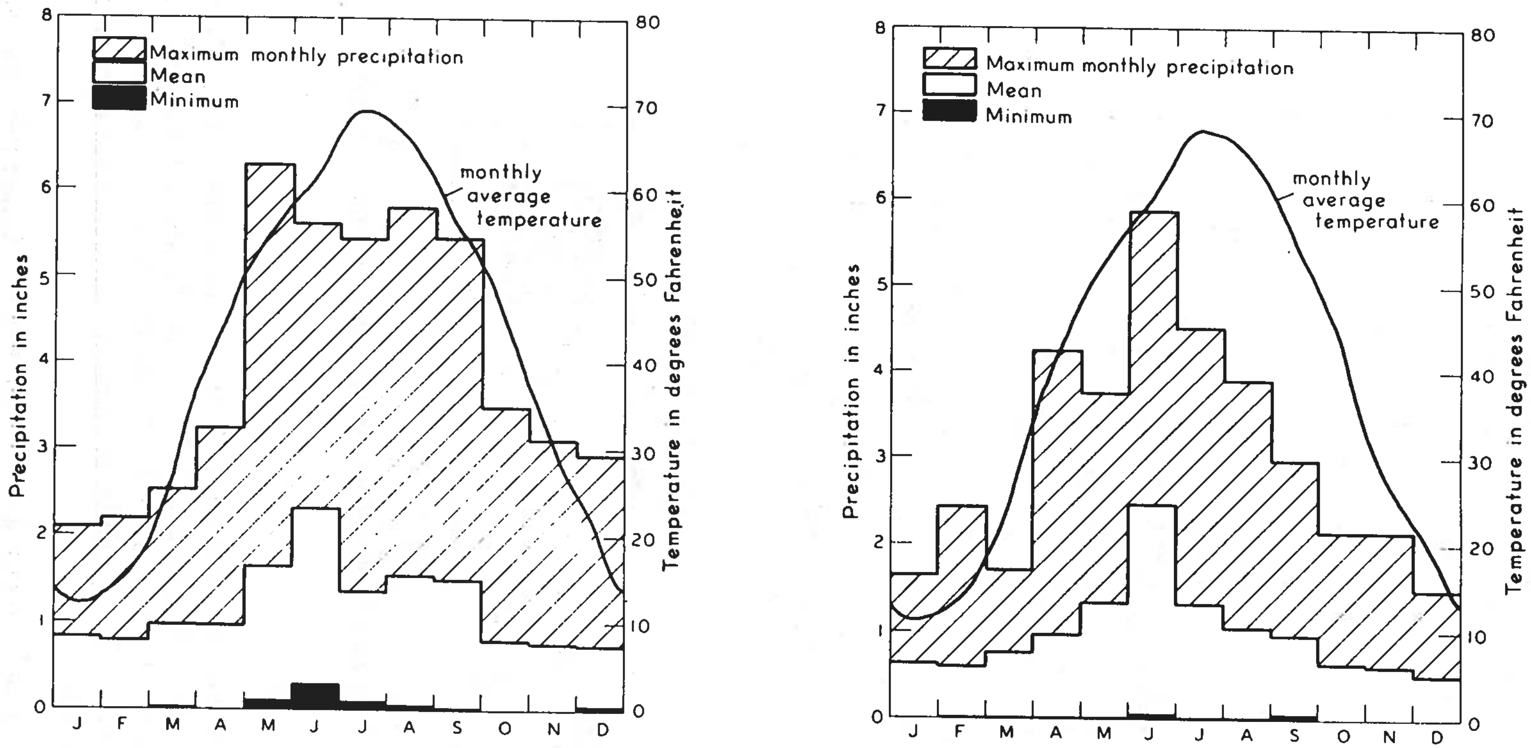


FIGURE 2. *Histograms showing monthly average temperature and precipitation at Medicine Hat and Manyberries, Alberta.*

Except for the Cypress Hills, the area is covered by a typical prairie flora of grasses and sagebrush. Trees are absent from the prairie but in some places exist along the coulees, associated with willow. The amount of precipitation received in the Cypress Hills region is sufficient to support tree growth. Forest clothes the northern escarpment and many coulees at the eastern end of the plateau are heavily wooded. Lodgepole pine forms the principal tree growth, with aspen, poplar, spruce, and black poplar occurring as local dominants. Grasses and low shrubs predominate on the plateau but there are a few wooded areas (Breitung, 1954).

Three soil zones are recognized in the Foremost-Cypress Hills area (Wyatt *et al.*, 1941). These zonal divisions are based principally on the colour of the soil profile which has developed as a result of certain soil moisture and vegetation conditions acting over a long period of time.

The brown soil zone covers about three quarters of the map-area and corresponds to the open prairie region. These soils have a shallow profile and the lime horizon is found about 12 inches below the surface. Dark-brown soils are found on the slopes of the Sweet Grass Hills and Cypress Hills. They have developed under more humid conditions and the depth to the lime horizon averages about 20 inches. Black soils occur on the Cypress Hills Plateau and surrounding slopes down to an elevation of about 4000 feet. The lime horizon is found at depths of 24 to 30 inches below the surface. Grey wooded or podsolised soils are found under heavy tree growth and moist soil conditions. Such soils exist in the wooded areas of the Cypress Hills.

Previous Work

Prior to the present study, no detailed survey of the Pleistocene deposits of the Foremost-Cypress Hills area had been carried out. In the course of mapping the bedrock geology, however, geologists had established the general physiographic evolution of the area, outlined some of the prominent morainal tracts and glacial lake basins, and described Pleistocene deposits exposed along the major river valleys.

The first geologist to visit the area was Sir James Hector (Hector, 1861), the physician and geologist on the Palliser Expedition of 1857-1860. He noticed the veneer of glacial drift present throughout the western prairies, and, like most of his contemporaries, believed it to have formed by the melting of debris-clogged icebergs in a glacial sea. Hector visited the Cypress ("Cyprés") Hills and commented on its capping of "shingle" to which he assigned a Tertiary age.

Dawson (1875) provided the first geological description of the area, for Hector's work dealt mainly with what is now central Alberta. Later, Dawson revisited southern Alberta for the Geological Survey of Canada, and produced the classic "Report on the region in the vicinity of the Bow and Belly Rivers" (Dawson, 1885). In this he ably describes the physiography, the extent to which glaciation modified the preglacial condition of the country, variation in drift thickness, stratigraphy of the "superficial" deposits, and the maximum elevation and provenance of glacial erratics. Although for the most part concerned with features in southwestern Alberta, his comments are very pertinent to the present map-area. Like Hector, Dawson believed that all glacial deposits originated in a glacial sea. He envisaged land submergence in southern Alberta of several thousand feet, subsequent incursion of a glacial sea from the northeast, and then its expulsion on emergence of the land. Holding these ideas, he found difficulty in explaining the great coulees which traverse southern Alberta, admitting that Warren Upham's theory of continental ice sheets and channel incision marginal to them was better. Nevertheless, Dawson still clung to his inundation concept.

McConnell (1886), Dawson's former assistant, described the geology of the Cypress Hills-Wood Mountain area. He presented the first detailed description of the Cypress Hills conglomerate, noting that its constituents came from the Rocky Mountains to the west. He thought the conglomerate to be of Miocene age (then including what is now called Oligocene) on the basis of vertebrate remains found in it, and said it was deposited "in a dilation of some large river flowing eastward from the Rocky Mountains" (*ibid.*, p. 35c).

McConnell found the maximum elevation of glacial deposits on the slopes of the Cypress Hills to be around 4400 feet and recognized rocks in the drift that had come from the northeast. In addition, he recorded the Pleistocene deposits exposed along the South Saskatchewan River and identified locations of some preglacial valleys. His views on the genesis of glacial deposits resembled those of Dawson.

Dowling (1917) rejected the glacial sea theory. In his report, "The Southern Plains of Alberta", he explains the numerous entrenched channels (Verdigris, Etzikom, Chin, and others) as ice-marginal valleys that formed during the recession of the "Glacial ice sheet". The sequence of changes in the drainage pattern of the area is broadly outlined and later workers have concurred with Dowling in this respect.

Alden (1924) wrote an important paper entitled "Physiographic Development of the Northern Great Plains", in which he identified Tertiary and Pleistocene erosional surfaces. The type locality for his oldest surface—the Cypress Plain—is the Cypress Hills, Alberta. This work was amplified in 1932 (Alden, 1932).

Allan (*in* Wyatt and Newton, 1926) discussed the relation of the geology to the soils in an appendix to the report on the soils of the Medicine Hat Sheet. He commented on the preglacial courses of the Oldman, Bow and South Saskatchewan rivers, the origin of the surficial deposits, and the glacial history. He wrote a similar report for inclusion in the bulletin on the soils of the Milk River Sheet (Wyatt *et al.*, 1941).

A comprehensive treatment of the physiography of the map-area is found in publications by Williams (1929) and Williams and Dyer (1930). Equivalents of Alden's erosional surfaces were recognized, glacial landforms described and post-glacial uplift postulated.

Johnston and Wickenden (1931) delineated the moraines and glacial lakes in southern Saskatchewan and southern Alberta. They believed that the moraines became progressively younger to the northeast, and their map shows these moraines to have an approximate northwest to southeast strike.

Later, Wickenden (1937) observed a moraine that extended northwestward across southwestern Saskatchewan to the northern side of the Cypress Hills in Alberta, then southwestward to the northern end of Lake Pakowki and from there westward and northwestward to Lethbridge. To him this marked the limit of a major glacial advance. (It is most likely that this moraine is the Etzikom End Moraine of the present report.)

A study of the age and distribution of Albertan end moraines was undertaken by Bretz (1943). During fifty days of fieldwork he mapped the moraines occurring in an area of about 40,000 square miles. His succession of meltwater dischargeways and associated glacial lakes in southeastern Alberta is very similar to that of Dowling (1917) and Williams (1929).

The Pleistocene deposits of southwestern Alberta have been studied by Dawson (1883, 1895), Dawson and McConnell (1895), Horberg (1952, 1954), and Stalker (1962, 1963a, 1963b). Parizek (1961, unpublished Ph.D. thesis, Univ. of Illinois) mapped the Willow Bunch Lake area, south-central Saskatchewan. The surficial deposits of Montana have been studied by Calhoun (1906), Alden and Stebinger (1913), Alden (1924, 1932), Smith *et al.* (1959), Witkind (1959), Howard (1960), Colton *et al.* (1961), Colton (1962), Jensen and Varnes (1964), and Lemke *et al.* (1965). A map of glacial deposits of the United States east of the Rocky Mountains was published by the Geological Society of America (Flint *et al.*, 1959).

The bedrock geology of the area was mapped by Russell (1940) and his work was published by the Geological Survey of Canada. There are two maps: the Foremost Sheet (map 566A) and the Dunmore Sheet (map 567A), both on a scale of 1 inch to 4 miles.

A soils map, on a scale of 1 inch to 3 miles, of the Medicine Hat area was prepared by Wyatt and Newton (1926). Later, Wyatt *et al.* (1941) compiled a map of the soils of the Milk River area. These two maps provide complete coverage of the soils of the map-area.

Present Study

In the present study, firstly, aerial photographs (scale 1:40,000) were examined with the aid of a stereoscope to classify the landforms and to deduce the probable lithologic composition of the surficial deposits. The boundaries so derived were then plotted on planimetric sheets on a scale of 1 inch to 1 mile.

This interpretation was then checked in the field and boundaries altered where necessary. Deposits were examined along road cuts, river valleys and commonly by shallow digging. Sections were recorded and samples collected for analysis in the laboratory. The eastern half of the map-area was systematically covered by north-south traverses 1 mile apart and east-west traverses 2 miles apart. The western half was mapped on a scale of 1 inch to 4 miles with traverses spaced 4 miles apart, as each landform unit is much more extensive and maintains its essential characteristics over long distances.

Seismic shot-hole data and logs of water wells provided valuable subsurface information that was used, in conjunction with field observations, to compile the maps on the drift thickness and bedrock topography.

Acknowledgments

This work was done whilst the writer* possessed a University of Alberta - Research Council of Alberta joint appointment in the field of Pleistocene geology. Sincere thanks are extended to Dr. L. A. Bayrock and Dr. R. Green, Research Council of Alberta, and Dr. R. E. Folinsbee, University of Alberta, for their helpful advice and encouragement throughout all stages of the work. Mr. L. Lindoe, Medicine Hat Brick and Tile Company, provided data on the bedrock structure and stratigraphy of the Cypress Hills district, the Pleistocene deposits of the Medicine Hat area, and loaned the writer several fossils which were collected from the local Pleistocene deposits. Dr. R. Green, Research Council of Alberta, identified the invertebrate fossils, and the vertebrate material was identified by Dr. L. S. Russell, Royal Ontario Museum.

The map of the topography of the bedrock surface was compiled from data supplied by Texaco Exploration Company, British American Oil Company, Pan American Oil Company, Hudson Bay Oil and Gas, Royalite Oil Company, Alberta Oil and Gas Conservation Board, and Renbar Drilling, Ltd., Medicine Hat. Drs. J. D. Campbell and K. W. Geiger, Research Council of Alberta, also provided useful information.

The writer is grateful to Dr. H. Peters, director of the Manyberries Range Experimental Station, for permission to use the facilities of the station whilst mapping in that area, and thanks are conveyed to the residents for their kindness and hospitality.

Excellent field assistance was provided by Messrs. G. Ryznar, L. Hanson, A. Vilyonay, and K. Smith.

---

* Present Address: Department of Geology, University of Alberta, Edmonton.

BEDROCK GEOLOGY

Several surveys of the bedrock geology of the Foremost-Cypress Hills area have been carried out. Dawson (1885) and McConnell (1886) did the pioneer work. Later, Dowling (1917), Williams and Dyer (1930), and Russell and Landes (1940) worked out and described in detail the stratigraphic succession and structure. The bedrock geology of the Cypress Hills area in Saskatchewan has been studied by Fraser *et al.* (1935), Russell (1948), Furnival (1950), and Kupsch (1956a).

The map of the bedrock geology of the Cypress Hills area included in this report is essentially that of Russell (1940) with minor alterations and additions. These include reinterpretation of the deformation localised around Bullshead Creek (northwest of the Cypress Hills), addition of small outliers of the Cypress Hills Formation north of Battle Creek, and structural data obtained from Mr. L. Lindoe (Medicine Hat Brick and Tile Company), later published data, and aerial photograph interpretation.

A review of the local bedrock geology is very relevant to the study of the surficial geology, if only for the following reasons:

(1) most of the mass of glacial drift in the Western Plains of Canada is local bedrock material (Bayrock, 1962),

(2) knowledge of the distribution of rock-types in the bedrock is a necessary prerequisite for the recognition of indicators, which are valuable tools in determining ice-movement directions,

(3) surficial materials may resemble bedrock materials, and,

(4) enquiry into the genesis of some land forms and drainage patterns demands a knowledge of the geologic structure.

Stratigraphy

Apart from the Tertiary conglomerate and sandstone that caps the Cypress Hills and the immediately adjacent lower buttes and plateaux, Upper Cretaceous rocks—a succession of sandstone and shale units with minor bentonite—cover the entire surface of the map-area. The stratigraphic column of the Foremost-Cypress Hills area is shown in figure 3.

Alberta Formation

The Alberta Formation underlies the whole map-area, but is seen at the surface only in two places: on the north flank of the West Butte of the Sweet Grass Hills, in township 1, range 12, and northwest of the Cypress Hills, in NW ¼, section 32, township 8, range 4 (Fig. 4). The latter exposure was discovered by Mr. L. Lindoe (Medicine Hat Brick and Tile) in 1962, and was confirmed on the basis of microfauna (pers. comm., J. H. Wall). This formation is composed of dark grey, marine shale with minor sandstone beds, and is approximately 1700 feet thick.

ERA	PERIOD	EPOCH	FORMATION
CENOZOIC	QUATERNARY	HOLOCENE	alluvium, aeolian deposits
		PLEISTOCENE	Glacial deposits
			Saskatchewan gravels
	TERTIARY	PLIOCENE MIOCENE	FLAXVILLE
		OLIGOCENE	CYPRESS HILLS
		PALEOCENE	RAVENSCRAG
MESOZOIC	CRETACEOUS	UPPER CRETACEOUS	FRENCHMAN
			BATTLE
			WHITEMUD
			EASTEND
			BEARPAW
			OLDMAN
			FOREMOST
			PAKOWKI
			MILK RIVER
		LOWER CRETACEOUS	ALBERTA

FIGURE 3. Stratigraphic column of Foremost-Cypress Hills area, Alberta.

Milk River Formation

Outcrops of this formation are restricted to the southwestern corner of the map-area, the beds being best exposed along Milk River and Verdigris Coulee. The lower part of the Milk River Formation consists of about 100 feet of light-coloured, massive sandstone underlain by 50 or more feet of beds transitional to the Alberta Shale. The upper part was deposited in freshwater, is 130 feet or less in thickness and consists of sombre grey shale and buff sandstone with thin lignite and ironstone beds.

Pakowki Formation

The Pakowki Formation is exposed west and south of Lake Pakowki. It is of marine origin and consists of dark grey shale, with occasional thin beds of sandstone, siltstone, and bentonite. The lower contact is commonly marked by thin beds of grey to black chert pebbles and the upper contact with the overlying Foremost beds is transitional. The thickness of the Pakowki Formation increases from west to east, and is about 500 feet in the southeast.

Foremost Formation

The Foremost Formation is exposed over the greater part of the western half of the map-area; to the east it is seen along the Milk River Canyon and the South Saskatchewan River Valley. It contains much shale, but is predominantly arenaceous. The Foremost beds are a mixture of brackish water and freshwater deposits, and consist of shaly siltstones, sandstones, coal seams, ironstone concretions and silicified oyster-shell beds. The thickness is about 370 feet in the north, nearly 500 feet in the central district, and about 270 feet in the southeast.

Oldman Formation

Good exposures of Oldman continental beds occur along Lost River Valley from the International Boundary northward, and in the badlands east of Manyberries, west of Bulls Head Butte, and south and east of Irvine (township 11, ranges 2 and 3). The formation is exposed mainly in the eastern half of the map-area, but outliers do exist as far west as township 11, range 12. The typical rocks are light-coloured, argillaceous sandstone, interbedded with green, sandy shales. Coal seams are present in the upper part of the formation. The coarser beds commonly show crossbedding and are lenticular. The thickness of the formation in drill holes near Eagle Butte is 480 feet.

Bearpaw Formation

The Bearpaw Formation borders the Cypress Hills on the south, west, and north. Extensive outcrops are present southeast and east of Manyberries, on the west side of Bulls Head Butte, along Ross Creek south of Irvine, and also in Gros Ventre Creek. The formation consists mainly of dark grey, greenish grey, and chocolate brown, fissile, marine shales with occasional sandy beds. Spheroidal ironstone concretions and bentonite beds are common. The thickness exceeds 630 feet near Manyberries and is about 830 feet in borings near Eagle Butte.

Eastend Formation

This formation is confined to the Cypress Hills area, where it occupies a belt at the foot of the main escarpment. It is made up of massive, medium-grained sandstones, dark shales (in part marine), and carbonaceous beds and is about 400 feet thick.

Whitemud Formation

Outcrops of the Whitemud Formation are few, occurring mainly to the west of the Cypress Hills, around Eagle Butte and Fly Lake. Some exposures exist at Graburn Gap to the east. The uppermost beds of the Eastend Formation in most places pass transitionally into the overlying

Whitemud Formation, which consists of sandstones, white clay, and kaolinised sandstones interbedded with carbonaceous shale and lignite. In Saskatchewan the Whitemud Formation is about 50 feet thick, but it is thinner in Alberta.

Battle Formation

The distribution of the Battle Formation corresponds closely to that of the Whitemud Formation. In many places both formations have been partly or entirely removed by erosion prior to the deposition of the Frenchman beds. Lithologically, the Battle Formation consists almost exclusively of dark, purplish grey, bentonitic shale with thin, but conspicuous tuff beds. The thickness is variable, but approaches 30 feet in places.

Frenchman Formation

Apart from a few isolated outliers near Eagle Butte and Fly Lake, the Frenchman beds in the map-area are confined to the Cypress Hills, where they underlie the upper part of the hills. This formation consists essentially of thick, massive or coarsely cross bedded, medium-grained sandstone with rare coaly beds, and is over 100 feet thick.

Ravenscrag Formation

The Ravenscrag Formation is exposed along the escarpment of the Cypress Hills. It is a nonmarine sequence of thinly bedded, fine-grained sands, silts, and shales with numerous coal beds and lignitic laminae. The upper limit of the formation is an erosional surface, so thicknesses are variable, but exceed 100 feet in the map-area.

Cypress Hills Formation

This formation underlies all of the summit region of the Cypress Hills. As developed in Alberta, it is composed almost exclusively of conglomerate with very minor lenses of sand and thin bentonite beds. The pebbles and boulders are mainly of quartzite, argillite, and chert, but a volcanic porphyry does occur. At the western end of the Cypress Hills the conglomerate is 25 feet thick and its thickness approaches 50 feet at the Alberta-Saskatchewan border.

Flaxville Formation (?)

Quartzose gravels, with minor amounts of sand, cover the buttes and plateaux immediately adjacent to the Cypress Hills. These deposits vary in elevation from about 4300 feet to about 3800 feet, and lithologically are very similar to the Cypress Hills conglomerate. Good exposures of these gravels may be seen at following locations: Lsd. 9, Sec. 25, Tp. 6, R. 1; Lsd. 5, Sec. 25, Tp. 6, R. 3; and Lsd. 10, Sec. 9, Tp. 8, R. 4. No fossils have been recovered from these gravels as yet so their exact age is uncertain, but their topographic position suggests a correlation, in a broad sense, with the Flaxville Gravels in Montana (Collier and Thom, 1918), dated as Miocene to lower Pliocene.

Structure

The southern Alberta plains are situated on a broad, northerly plunging anticline known as the Sweet Grass Arch. As the Foremost-Cypress Hills area lies east of this arch the dominant dip direction of the beds is to the east and northeast. Many subsidiary folds are associated with the Sweet Grass Arch and these are described in detail by Russell and Landes (1940, p. 102-124). Nose- and dome-like structures are developed around the igneous intrusions of the Sweet Grass Hills.

Several points of interest concerning the bedrock structure were noted during study of the surficial geology. These are listed below; the first two being brought to the writer's attention by Mr. L. Lindoe.

(1) Northwest of the Cypress Hills, in the Bullshead Creek district (townships 8 and 9, ranges 4 and 5) (Fig. 4), the bedrock is highly disturbed. Russell and Landes (1940, p. 124) attributed this to large-scale slumping, but the presence of Alberta Formation shales at the surface in NW ¼, Sec. 32, Tp. 8, R. 4 (necessitating a vertical displacement of over 3000 feet), discredits this hypothesis. The localised structural elevation of the Alberta, Milk River, and Pakowki (?) Formations may well be due to the emplacement of an igneous body at depth, probably synchronous with the Sweet Grass intrusions in northern Montana.

(2) Along the southern slope of the Cypress Hills the uppermost 50 feet of strata have been deformed by movement, under gravity, on underlying clay beds. This low-angle gravity sliding is also probably responsible for the large fissures and small tensional faults in the Whitemud beds exposed in the clay pit at Fly Lake (SW. ¼, Sec. 20, Tp. 8, R. 3).

(3) The nature and orientation of some surficial lineaments in the map-area can not be explained by glaciation. These non-glacial lineaments appear on aerial photographs as thin, dark lines. Some are several miles long, and may intersect, or be subparallel (Fig. 5). It is believed that these lineaments represent fault or joint traces that have been reflected through the unconsolidated glacial drift (Kupsch, 1956b; Kupsch and Wild, 1958; Mollard, 1957, 1958; Haites, 1960; Barton, 1962). This reflection occurred when adjustment took place along the faults (Kupsch and Wild, 1958), possibly due to differential isostatic rebound (Barton, 1962).

Some lineaments, however, are much more conspicuous and have obviously been formed over large faults in the bedrock. For example, in township 11, range 15, the fault trace is marked by a trough some 200 yards wide. The course of the South Saskatchewan River is controlled in part by this fault.

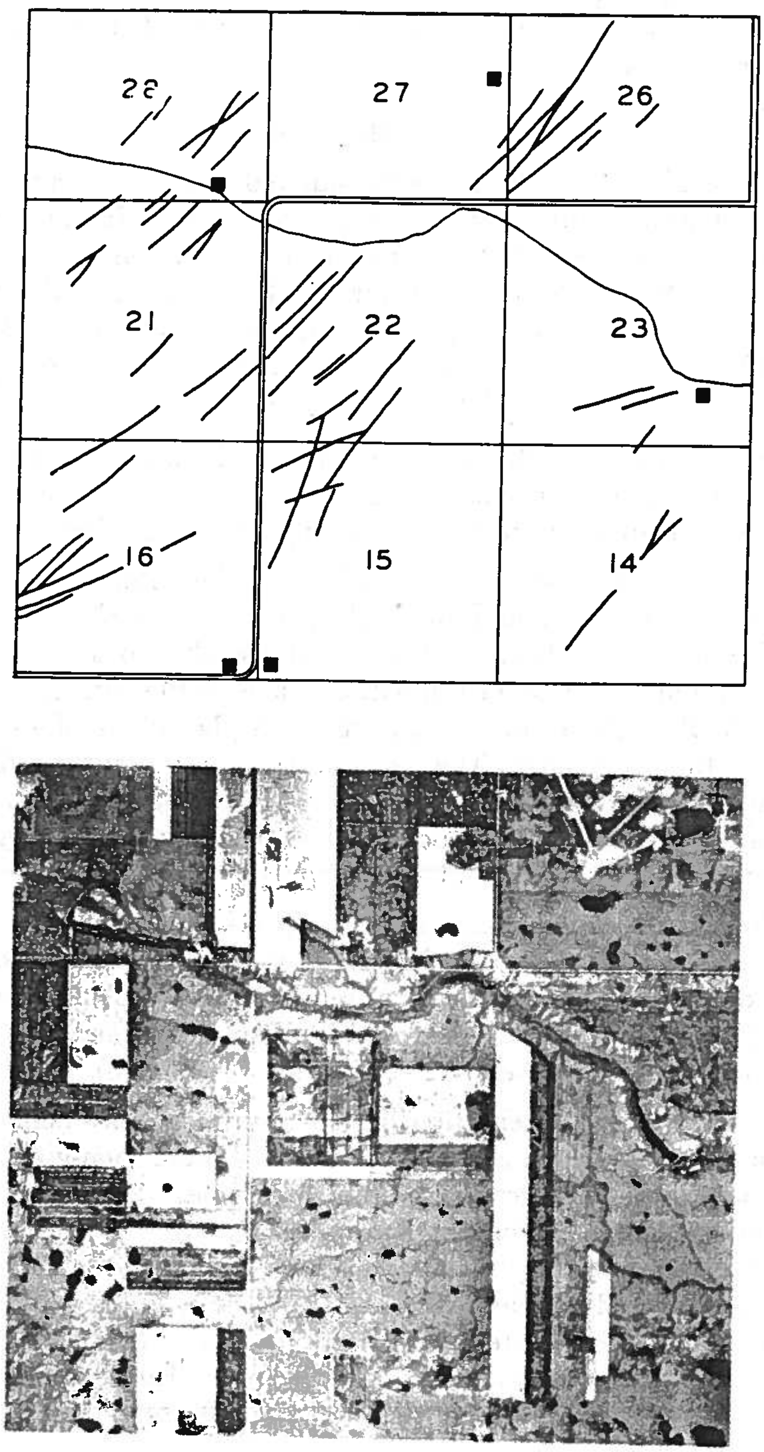


FIGURE 5. Structural lineaments showing through glacial drift, north of Seven Persons.
Reference Number: 160-4916
1926-109

GEOMORPHOLOGY

The Foremost-Cypress Hills area is an undulating to rolling plain dissected by steep-walled valleys and framed by the Cypress Hills to the east, the Milk River Ridge to the west, and the foothills of the Sweet Grass Hills to the south. The landscape of the present day has been produced as a result of the various agents of erosion acting on the bedrock of the area in preglacial, glacial, and postglacial times.

The preglacial topography of the region was modified by glaciation—that of the upland areas only slightly, but that of the lower tracts was changed considerably. Dawson (1885, p. 140) fully appreciated this fact when he said:

> The preglacial aspect of the country has been much rougher and more diversified than that which it at present presents. . . . . The glaciating agents have doubtless planed off many of these irregularities, and the surface has besides been deeply buried in its deposits. . . . . These have been laid down in greatest thickness in the pre-existing hollows and low tracts, and the general effect has been the filling up of the asperities and the production of wide areas of almost perfectly level prairie. That this has been the case has been evidenced by the fact that while some of the plateaus and ridges are but scantily covered with drift, the thickness shown in many of the river sections is over 200 feet.

Preglacial Landscape

In this study, examination of the preglacial landscape was achieved by use of a map of the topography of the bedrock surface (Fig. 6) and another showing the areal variation in the thickness of drift (Fig. 7). In the western half of the area, most of the control for map compilation was provided by seismic shot-hole logs. The bedrock surface contours in the eastern half, however, were drawn up from information obtained from field observations, a few water well and seismic shot-hole logs, and the topographic map (Foremost Sheet).

Bedrock Topography

The bedrock surface topographic map shows land forms that were formed in glacial as well as preglacial time. The glacial features, however, are quite distinctive; they are all meltwater channels (for only the erosional features would be recorded on a bedrock surface topographic map). Never more than 2 miles wide, they have steep, in some places vertical walls and cut across upland areas, commonly breaching preglacial divides. Thus, the preglacial divide from the Cypress Hills to the Sweet Grass Hills is breached by no less than four meltwater channels (Milk River Canyon, Lost River Channel, Sage Creek Channel, and Medicine Lodge Channel). Similarly, the preglacial divide extending from Lucky Strike to Winnifred is cut by the Etzikom, Chin, and Forty Mile channels. Some of the meltwater channels were later overrun by ice and completely filled with till (e.g. Granlea Channel in township 8, range 9).

The preglacial valleys are usually very wide and have gently inclined slopes. The Medicine Hat Valley, for example, is over 10 miles wide in places. In addition, the tributary valleys invariably intersect the main channels at acute angles.

The most conspicuous feature of the upland areas is their flat, plateau-like summits. The classic example of this is the Cypress Hills Plateau, but even the intrusive rocks of the Sweet Grass Hills have a flat top (Williams and Dyer, 1930, p. 92). Likewise, the lower interfluvial areas possess broad, approximately horizontal summits. These surfaces are believed to represent remnants of old peneplains or pediplains.

Erosional Surfaces

The significance of the elevated, commonly gravel-capped plateaux in the plains of western Canada was appreciated by McConnell as long ago as 1886. He realised that the plateau surface of the Cypress Hills was once the level at which rivers flowed and that uplift and subsequent degradation had lowered the surrounding country some 2000 feet. Formed in Oligocene time (Cope, 1891), this particular surface is now 4800 feet above sea level at its western extremity in Alberta and 3700 feet at its eastern limit in Saskatchewan.

Collier and Thom (1918) studied the physiography of northeastern Montana and recognised several younger erosional surfaces. The oldest of these is now represented by isolated, gravel-capped plateaux, some 3200 feet above sea level at the western end of Boundary Plateau (about 109° west longitude), and about 2600 feet near the town of Flaxville, Montana (about 105° west longitude). Collier and Thom designated this erosional surface the Flaxville Plain and considered it to be of Miocene or early Pliocene age on the basis of vertebrate remains recovered from the gravels.

Below the Flaxville level in northeastern Montana are extensive areas varying in elevation from 2500 to 3000 feet above sea level. Around Boundary Plateau much of this surface is highly dissected. A horse tooth, found in sediments on this surface (Collier and Thom, 1918, p. 182) indicates a late Pliocene or early Pleistocene age.

The wide valley bottoms, 100 to 500 feet below the late Pliocene or early Pleistocene level, represent the youngest erosional surface which is believed by Collier and Thom to be of late Pleistocene age.

Alden (1924, 1932) agreed with the erosional levels of Collier and Thom and recognised respective equivalents over much of the northern Great Plains of the United States. Alden's sequence of levels is as follows:

Cypress Plain (No. 0 Bench)	Oligocene
Flaxville Plain (No. 1 Bench)	Miocene to early Pliocene
No. 2 Bench (or Terrace)	Early Pleistocene
No. 3 Bench (or Terrace)	Middle Pleistocene.

In northeastern Montana the Flaxville Plain is 700 to 1000 feet lower than the eastern part of the Cypress Plain and Alden states that this difference increases to 1500 feet or more at the mountain fronts to the west. The vertical distance between the Flaxville Plain and the No. 2 Bench, east of 109° west longitude, is generally 500 to 600 feet, but is only 100 to 300 feet near the Rocky Mountains. No. 3 Bench is about 100 to 500 feet below No. 2 Bench and represents the broad valley bottoms of the streams that cut into the No. 2 Bench. The Saskatchewan Gravels were deposited on the No. 3 Bench (Alden, 1924, p. 414).

In southeastern Alberta, the Saskatchewan Gravels floor the Lethbridge and Medicine Hat Valleys. Thus, these valley bottoms correlate with the No. 3 Bench of Alden and were certainly formed before the area was invaded by Laurentide ice (Fig. 8).

The divide between the Lethbridge and Medicine Hat drainage reaches 3200 feet above sea level at Lucky Strike in the south and about 2800 feet near Winnifred, to the north. This level most probably correlates with Alden's No. 2 Bench. The broad, flat-topped upland southeast of Lake Pakowki, between Craigower and Pinhorn, reaches 3400 feet above sea level, but is mainly around 3200 feet in elevation. This likewise is most probably a remnant of the No. 2 Bench. Collier and Thom (1918) show all the terrain surrounding the Cypress Hills, east of range 4 and south to the 49th Parallel, as part of their Pliocene or early Pleistocene terrace (that is, the No. 2 Bench of Alden).

An elevation of about 3500 feet is indicated for the Flaxville Plain in the map-area if the surface gradient of this plain in northeastern Montana is projected due west along the 49th Parallel. This surface would naturally rise towards the Cypress Plain. Williams and Dyer (1930, p. 94) show the Flaxville Plain to be about 4000 feet in elevation immediately away from the Cypress Hills Plateau. The small mesas and buttes just to the west of the Cypress Hills Plateau are probably remnants of the Flaxville Plain (Fig. 8) and quartzitic gravels, present in NE ¼, Sec. 9, Tp. 8, R. 4 and Sec. 19, Tp. 7, R. 3, may well belong to the Flaxville Formation. Other

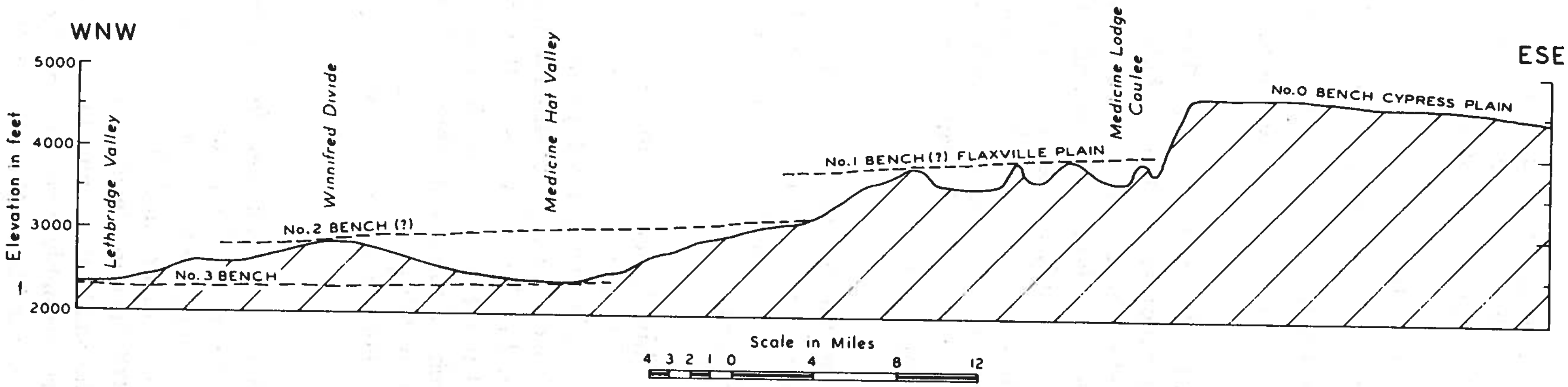


FIGURE 8. Erosional surfaces in the Foremost-Cypress Hills area.

probable Flaxville Plain remnants exist in SE ¼, Sec. 36, Tp. 6, R. 1 and SW ¼, Sec. 25, Tp. 6, R. 3 (see Appendix), where they are at an elevation of 3800 feet above sea level. North of the Cypress Hills Plateau, the Flaxville Plain has been completely covered by glacial deposits.

Preglacial Drainage

Two major rivers, occupying the Lethbridge and Medicine Hat valleys (Fig. 6), flowed across the map-area in preglacial time. The Lethbridge Valley (Oldman Bedrock Channel of Farvolden, 1963) extends in a northeasterly direction across the northwestern corner of the map-area, and is joined by substantial-sized tributary valleys from the south. The Skiff and Foremost valleys were the largest of these: they joined each other just south of the present site of Bow Island, and the combined waters flowed north to enter the Lethbridge Valley just outside the map-area (Figs. 6, 9).

The divide separating the Lethbridge Valley drainage from the Medicine Hat Valley (Medicine Hat Bedrock Channel of Farvolden, 1963) drainage extended from Winnifred in the north to Lucky Strike in the south, where it turned west to run along the crest of the Milk River Ridge. At Masinasin, this divide was breached by headward erosion in the Skiff Valley, which may well have captured the waters of the Whisky Valley (Geiger, 1965).

The Whisky Valley enters the map-area at essentially the same place as the present Milk River Valley. It runs eastwards to become the Medicine Hat Valley at Masinasin, and then extends eastwards between the Sweet Grass Hills Upland and the Lucky Strike Upland and gradually turns to the northeast to cross the area now occupied by Lake Pakowki. From here, the valley runs north to Murray Lake where it turns to the northeast to cross the present site of Medicine Hat. Tributaries of the Medicine Hat Valley lie on the northern and western slopes of the Cypress Hills as well as the eastern slopes of the Winnifred-Lucky Strike Divide.

The southeastern part of the map-area was drained by streams flowing to the southeast, and the divide that separated this drainage from that of the Medicine Hat Valley ran from the Sweet Grass Hills to the Cypress Hills.

Figure 9 shows the relationship of the preglacial valleys of the Foremost-Cypress Hills area to those of central and southern Alberta. The Lethbridge Valley joined the Medicine Hat Valley some distance north of Medicine Hat, and the single river so formed then flowed into the "Bow Channel" (Farvolden, 1963). This channel then conducted the waters northeastwards across the province of Saskatchewan. The southeasterly flowing streams entered Montana and joined the Ancestral Missouri River which flowed eastward across northern Montana and then turned north through North

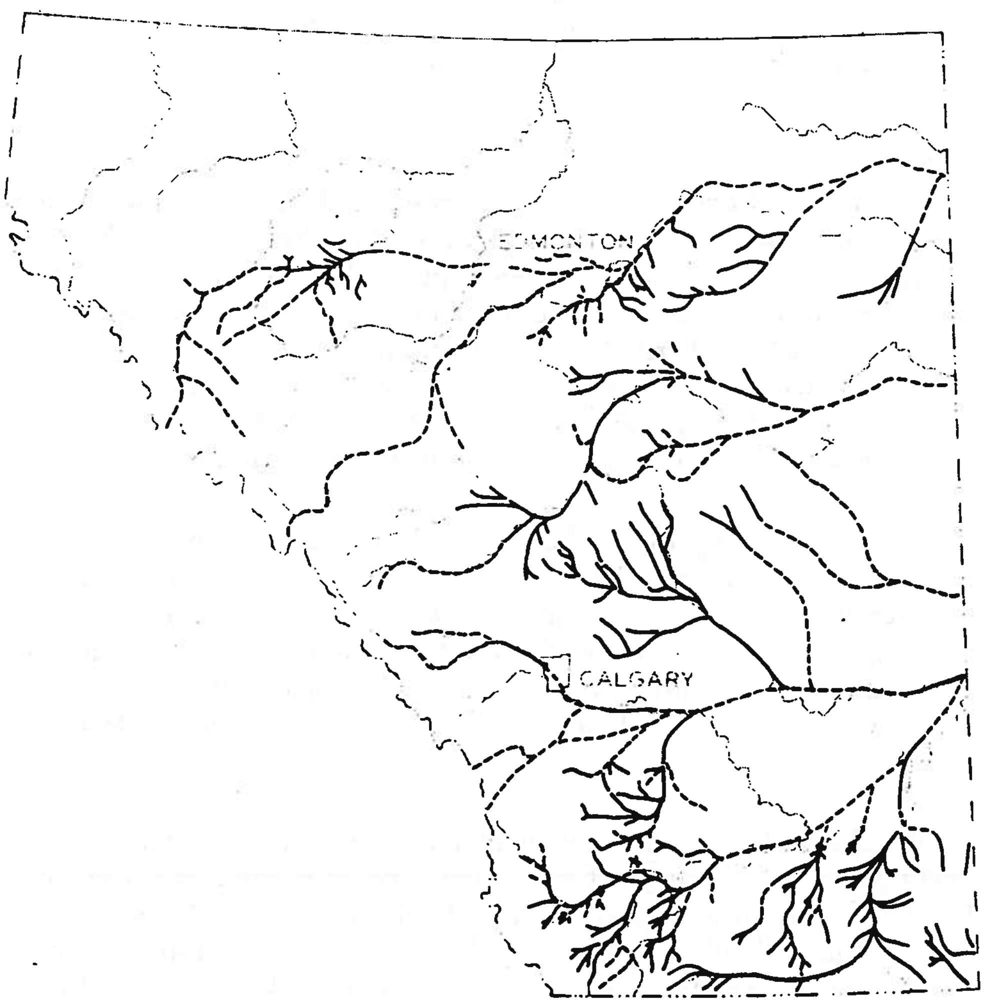


FIGURE 9. Preglacial drainage in central and southern Alberta.

Dakota into Saskatchewan (Meneley *et al.*, 1957) and eventually flowed into Hudson Bay. Whilst flowing on the No. 2 Bench level (Alden, 1924), however, its course was diverted to the south by the Kansan Laurentide ice sheet (Alden, 1924, 1932; Howard, 1960), and it then joined the Mississippi River, the waters eventually flowing into the Gulf of Mexico.

The preglacial landscape, therefore, was one of large rivers flowing in broad, mature valleys and draining mainly to the north and northeast. Except for the Cypress Hills Plateau, the interfluvial areas were considerably dissected. The youthful aspect of present rivers, the south-flowing Milk River, the buried valleys, and many of the badland areas are all products (directly or indirectly) of glaciation.

Glacial Land Forms

This section deals with those features formed inside the margin of the Laurentide ice sheet which covered most of the area.

The terminology of glacial land forms at present is not clearly defined. In this report, the writer has taken the nomenclature proposed by Gravenor and Kupsch (1959) as his main guide, and the terms used by other workers are given in appropriate places.

Ground Moraine

Gently undulating to undulating ground moraine covers about 1250 square miles, or 20 per cent of the map-area, and is present mainly in the northern half of the area (Map 29). It has a constructional topographic expression with a local relief seldom exceeding 10 feet. Numerous undrained depressions are characteristic (Plate 4).

Flint (1957, p. 131) defined ground moraine as that moraine having low relief devoid of transverse linear elements. As pointed out by Gravenor and Ellwood (1957, p. 7-8), this definition does not hold true for much of the ground moraine in western Canada, where transverse elements—small till ridges and aligned knobs—do exist in morainal areas of low relief, especially where the latter grade into hummocky disintegration moraine.

The glacial drift varies in thickness from 5 to over 100 feet in areas where ground moraine is developed. It consists predominantly of clayey till, the greater part of which is made up of local bedrock. Till is a nonsorted, nonstratified sediment deposited by a glacier. The upper part of the drift in areas of ground moraine commonly contains irregular lenses and pockets of sand and gravel, and, on the surface, small patches of lacustrine sand, silt, and clay are locally present.

The undulatory surface and compact nature of the till suggest that ground moraine was formed largely at the base of a moving glacier. Till deposited in this way—from drift in transport in the base of a glacier—is called *lodgment till* (Flint, 1957, p. 120). A thin blanket of *ablation till*, however, in many places overlies the lodgment or basal till but does not obscure the undulating character of the ground moraine. Ablation till consists of debris that was transported within or upon the ice and was deposited on the ground surface as the enclosing ice melted (Flint, *op. cit.*). Inclusions of stratified drift are not uncommon in ablation till and show that meltwater transported some of the drift for short distances during the settling process.

Hummocky Disintegration Moraine

Hummocky disintegration moraine covers about 670 square miles of the map-area, mainly in the upland area: around the Cypress Hills, the foothills of the Sweet Grass Hills, and on the northern part of the preglacial Winnifred Divide (Map 29, Plate 5).

This morainal land form is characterised by an irregular "knob-and-kettle" topography with steep-sided depressions, and both closed (circular, oval, and irregular) and linear ridges. Where the local relief of hummocky disintegration moraine is greater than 25 feet, the above elements are well developed and the till is thick, certainly more than 50 feet (Gravenor and Kupsch, 1959, p. 50); but only knobs and occasional linear ridges are present in areas of hummocky disintegration moraine with a local relief of less than 25 feet, and here the till is considerably thinner. In the map-area, moraine plateaux, which are relatively flat areas usually slightly higher than the surrounding knobs, are quite rare in the hummocky moraine whose local relief varies from 15 to over 50 feet. Knobs, kettles, and ridges are haphazardly arranged and so no trends are discernible. As mentioned above, hummocky disintegration moraine usually grades laterally into ground moraine, but in some places the contact is sharp.

Terms used by other workers to designate areas of knob-and-kettle topography include dead-ice moraine (Christiansen, 1956; Bayrock, 1958, 1960; Gravenor and Ellwood, 1957), knob and kettle moraine (Stalker, 1956), hummocky moraine (Hoppe, 1952; Christiansen, 1959; Stalker, 1960), and ablation moraine (Flint, 1957). The term hummocky ground moraine was used in a manuscript by Parizek (1961, unpublished Ph.D. thesis, Univ. of Illinois).

Hummocky disintegration moraine is composed mainly of till that is very similar in character to the till of ground moraine. The surface ablation till, however, is generally thicker and more widespread than in ground moraine areas. Pockets, lenses, and stringers of clay, silt, sand, and gravel occur in the till and commonly show "collapse" structures typical of ice-contact deposits. In places whole knobs are made up of sand and gravel, but usually the latter only caps the till knobs.

It is generally accepted that hummocky disintegration moraine formed in areas where blocks of ice stagnated during deglaciation, but the way in which this hummocky topography originated is still a subject of controversy. Two major hypotheses have been proposed: the ablation or "let-down" theory and the "squeezing-up" theory.

In the "squeezing-up" theory the hummocky topography is believed to have formed underneath the ice by the squeezing of debris into basal cavities caused by meltwater. The drift could be squeezed up into these cavities because it was soaked with water and therefore was in a plastic state.

The weight of the ice itself exerted the necessary pressure. Hoppe (1952) is a proponent of this theory and Stalker (1960) believes this mechanism to be responsible for the hummocky moraine in western Canada.

The ablation theory, which is generally favoured by most geologists working in western Canada, envisages englacial debris gradually accumulating on the surface of the ice, and, due to differential melting of the ice at the surface, let down irregularly on the ground. Gravenor and Kupsch (1959) present a strong argument for this ablation mechanism, but believe that squeezing-up of till into openings at the base of the ice may have taken place to some extent. The writer believes that the ablation mechanism best explains the morphology, lithology, and distribution of the hummocky disintegration moraine in the Foremost-Cypress Hills area.

Hummocky disintegration moraine is largely restricted to the upland areas, closely associated with end moraines (Map 29), and clearly formed near the ice margin. To elaborate on the origin of this land form, as the glacier moved uphill, obstructed flow commenced. Some of the basal debris was carried into an englacial or superglacial position along thrust planes. In this way the marginal belt of ice was covered with a thick mantle of debris. This ice then stagnated, but it did not downwaste evenly. Ice covered with thick debris melted more slowly than ice with only a thin debris cover. The hollows so formed were eventually filled with debris and topographic inversion of the ice surface resulted (Gravenor, 1955). This inversion was probably repeated several times before the debris finally came to rest on the ground surface as a hummocky mass.

This process explains the presence of deformed beds of fossiliferous lacustrine and glacio-fluvial materials in the till of hummocky disintegration moraine, and the gradation of this morainal unit into ground moraine is seen to be due to the gradual decrease of englacial and superglacial debris away from the ice margin—that is, away from the zone of obstructed ice flow.

End Moraine

The most extensive land form in the map-area is end moraine, which covers some 1700 square miles, or 27 per cent of the area. End moraine surrounds the Cypress Hills Upland, is well developed around Lake Pakowki, and covers almost the entire southwestern quadrant of the map-area (Map 29).

Flint (1957, p. 131) defined an end moraine as a ridgelike accumulation of drift built along the margin of an ice sheet. End moraines in the Foremost-Cypress Hills area have elongate, linear or curvilinear outlines, are usually several miles wide, and consist of a series of aligned ridges that parallel former positions of the ice front. Some end moraines in this area formed at or close to the ice front, but the major end moraines (especially hummocky end moraine) formed along a wide marginal zone of the glacier—chiefly by stagnation of fractured, debris-clogged ice. Three morphologically distinct types of end moraine exist in the map-area: hummocky end moraine, ridged end moraine, and washboard moraine. The first-named two types are differentiated only on the 1 inch to 1 mile maps (Westgate, 1965a).

Hummocky end moraine

Hummocky end moraine resembles hummocky disintegration moraine in all respects except that it occurs in linear or curvilinear belts rather than in irregular masses, and the knobs, closed ridges and linear ridges are aligned in a common direction (Plate 3). This alignment is most probably the result of ice-fracture control. Fractures developed at the margin of the active glacier and persisted when the glacier became stagnant. This marginal belt of stagnant ice then separated along the old fracture lines and ablation drift became concentrated in the linear ice depressions so produced.

Ridged end moraine

Ridged end moraine ("end moraine" of Westgate, 1965a) is characterized by a system of subparallel, discontinuous, generally arcuate ridges, composed mainly of till—very stony in places—with minor amounts of gravel and sand. Knobs are usually present but closed ridges are rare or absent (Plate 6). The local relief is variable, but is generally less than that of hummocky end moraine. East of Lake Pakowki it approaches 25 feet, but in the southeastern corner of the area the local relief is less than 15 feet. At the former locality, the main ridges are usually 200 to 300 yards apart (Plate 6), and the thickness of the till varies from 20 to 50 feet. To the west of Lake Pakowki, where the till is must thicker, ridged end moraine grades into hummocky end moraine. The main ridges most probably mark retreatal positions of the ice front; some of the smaller ridges may be crevasse fillings.

Washboard moraine

A series of small, parallel till ridges, which are generally referred to as washboard moraine, are well developed north of Seven Persons and south of the Milk River (Plate 6). These ridges are 2 to 10 feet high, 100 to 300 feet apart, and vary from a few yards to over a mile in length.

Minor end moraines, minor recessional ridges (Christiansen, 1956), and swells and swales (Gwynne, 1942) are other names that have been given to this morainal form.

The origin of washboard moraine is uncertain, but the gradation into hummocky and ridged end moraine and the lobate patterns described by the ridges clearly show that washboard moraine is formed near the ice margin, with the ridges paralleling former positions of the ice front. Gwynne (1942, p. 206) visualized washboard moraine as being formed by periodic retreat and readvance of the live glacier front, the advances pushing previously deposited ground moraine into ridges. He suggested that the ridges were formed annually. Elson (1957, p. 1721) studied washboard moraines in Manitoba and concluded that the ridges were deposited subglacially at the base of thrust planes in the ice. Gravenor and Kupsch (1959, p. 36-55) agreed with Elson's idea and regarded the preservation of the ridges as the result of ultimate stagnation of the ice.

Linear Disintegration Ridges

"Linear disintegration ridge" is a general term proposed by Gravenor and Kupsch (1959, p. 53) for a ridge that originated during stagnation or near-stagnation of the ice. Debris that had accumulated in crevasses on the ice surface or fissures at the base of the stagnant ice, would be left as linear ridges on the ground when the ice disappeared.

In some areas these constructional ridges are composed chiefly of till with or without included pockets of sand and gravel; in other places stratified material predominates. Linear disintegration ridges are straight or slightly arcuate, vary in height from 5 to over 40 feet, and in length from a few yards to several miles. Their most common orientation is normal or parallel to the direction of ice movement.

Flint (1928, p. 415) proposed the term "crevasse filling" for the ridges that were composed of stratified material. Christiansen (1956, p. 15) used this term for ridges composed of till, but Gravenor (1956, p. 10) preferred the term "till crevasse filling". Sproule (1939, p. 104) noted similar features in the Cree Lake area, Saskatchewan, which he called "ice-crack moraine". Another term is "till and till-cored esker ridges" (Stalker, 1960, p. 13).

In the Foremost-Cypress Hills area, linear disintegration ridges are largely composed of till where associated with hummocky disintegration moraine, hummocky end moraine, and ground moraine. The best examples, however, are made up of stratified gravel and sand and are found at the northwestern corner of Lake Pakowki (Plate 7) and beside Lost River.

At the Lake Pakowki locality the ridges are arcuate, subparallel and locally intersecting. They are composed of rudely sorted stratified sediment with cobble-sized material predominating in the west, whilst to the east fine gravel grades eastward into sand. These linear disintegration ridges are approximately parallel to former positions of the ice front. In the Lost River district, however, the ridges lie parallel to the direction of ice movement. They were formed by meltwater concentrating sand and gravel into longitudinal crevasses in the stagnant ice. This sediment was let down as the ice melted and it eventually settled on the ground to form ridges.

Drumlins and Drumlinoid Ridges

Many of the linear ridges in the Lost River district have been "drumlinized". This occurred when a localized reactivation of the glacier shaped the stratified sediment in the crevasses into the streamlined form characteristic of drumlins. On the maps, such features are called "drumlinoid ridges"; they are always parallel to the direction of ice movement and their stoss end is "up-ice". In places, classical drumlins have been formed over 50 feet high and are composed entirely of gravel and sand (Plate 7).

A swarm of very similar drumlins occurs north of Deadhorse Coulee (township 2, range 11). They were probably formed by ice readvancing over a small outwash plain.

A point of interest with regard to the origin of drumlins and drumlinoid ridges in the map-area is that they all are present in areas where the regional slope was away from the ice front. It is possible that during the latter stages of stagnation, when the ice was "warm", actual flowage under gravity occurred, remoulding the englacial debris into streamlined forms.

Kames

Holmes (1947, p. 248) proposed the following definition for the term kame: "A kame is a mound composed chiefly of gravel or sand, whose form has resulted from original deposition modified by any slumping incident to later melting of glacial ice against or upon which the deposit accumulated."

Mounds of stratified drift are scattered throughout the map-area, but are more abundant in areas of hummocky disintegration moraine and hummocky end moraine. The best examples, however, exist in Glacial Lake Medicine Hat (township 12, ranges 4 and 5) and in the southeastern part of the area, where kames are associated with eskers, drumlins and linear disintegration ridges (Plate 7).

Eskers

An esker is a long narrow ice-contact ridge, straight or sinuous, and composed chiefly of stratified drift. A system of eskers, aligned parallel to the direction of ice movement, lies in the southeastern corner of the map-area (Map 29). Straight and sinuous types are present (Plate 8); the former are indeed spectacular examples.

The best developed esker extends from the Manyberries Range Station southeastward to Wild Horse, a distance of over 12 miles, and continues into Montana. In places it rises 50 feet above the surrounding prairie level and is over a mile wide for a considerable part of its length. Linear, circular, and irregular kettles pit the esker and a few channels, abandoned and unrelated to the present drainage, cut right across the ridge (Plate 8). Sections in scattered gravel pits show crossbedded gravel and sand that indicate transportation to the southeast, that is, in the direction of the regional slope.

The large width of these eskers suggests that they were formed by deposition of glacio-fluvial material in ice-walled channels opened to the sky rather than in subglacial tunnels. Superglacial streams eroded into the esker's sediment when the surface of the stagnant glacier had downwasted to the level of the esker, and dry gullies were left in the esker ridge when the ice finally disappeared. The kettles were formed when buried blocks of ice melted and caused subsidence of the overlying sediment, but those along the flanks of the ridge are more likely related to the loss of the confining walls of ice.

Flutings

Flutings are narrow, straight, parallel ridges and grooves, composed of till or bedrock. They are oriented in the direction of ice movement, and occur in swarms and not as single isolated ridges or grooves (Plate 9).

Flutings are present on the Lucky Strike Upland, the foothills of the Sweet Grass Hills south of the Milk River, on the preglacial divide southeast of Lake Pakowki, and in the area just north of Milk River and east of Pakowki Coulee (Map 29). The first three localities are upland areas, where the drift is very thin and bedrock is commonly exposed at the surface. At the last locality, the flutings are entirely in drift.

The relief on flutings is usually only a few feet; the length of the ridges and grooves, however, is commonly more than a mile. Hence it is difficult to discern flutings from the ground, but they show up very clearly on aerial photographs.

Flutings in the bedrock, south of the Milk River (Plate 9), show that glacial erosion is the dominant factor in their origin, but the exact mechanism whereby flutings are created is still a matter of conjecture.

Drift-Veneered Bedrock Upland

As the heading implies, this is not a specific glacial land form, but essentially a dissected bedrock upland area which has been slightly modified by the deposition of glacial drift. The surface expression of this drift is constructional in places, but is more commonly controlled by the bedrock surface. The drift is usually thin, except in the preglacial valleys, and bedrock exposures are numerous.

Superglacial lakes

Small patches of lacustrine sand, silt and clay are common in areas of hummocky moraine. These lacustrine deposits may be draped over till knobs or occur as deformed stringers in ablation till. They undoubtedly accumulated in shallow ponds on a stagnant ice surface, and were let down, together with the ablation till, on to the basal till as the ice melted away.

Glacial Lake Wild Horse

The northern part of the Lake Wild Horse Basin lies in the southeastern corner of the Foremost-Cypress Hills area, where it covers about 35 square miles (Map 29). Lake Wild Horse sediments are mainly sand and fine gravel with some silt, but in township 1, range 2, they are covered by recent alluvial and lacustrine silt and clay. In areas of recent sedimentation the topography is flat, but it is undulating and locally hilly over the remainder of the basin and in some places the surface is pitted with kettles.

Lake Wild Horse formed in an area where the regional slope was away from the ice front, namely to the southeast. The esker that passes through Wild Horse dammed the glacial waters to the north. The last glacier to affect the southeastern part of the map-area became stagnant southeast of the preglacial divide that runs through Comrey (township 2, range 6). Superglacial and subglacial meltwater flowed to the southeast. Downwasting of the stagnant ice eventually resulted in the exposure of the eskers that were formed in the ice-walled channels. Once above the ice surface, the eskers impeded the flow of superglacial meltwater and, as a result, the superglacial Lake Wild Horse was formed. Sand and fine gravel were deposited in this superglacial lake and were let down on to the underlying till as the ice melted.

Fossiliferous superglacial lacustrine sediments were sampled at two localities. Figure 10 illustrates the geologic setting of sample 3261 (Lsd. 13, Sec. 28, Tp. 8, R. 4), and the fauna recovered from this sample is listed below.

Ostracoda

Limnocythere trapeziformis Staplin
Limnocythere staplini Gutentag and Benson
Ilyocypris gibba (Ramdohr)

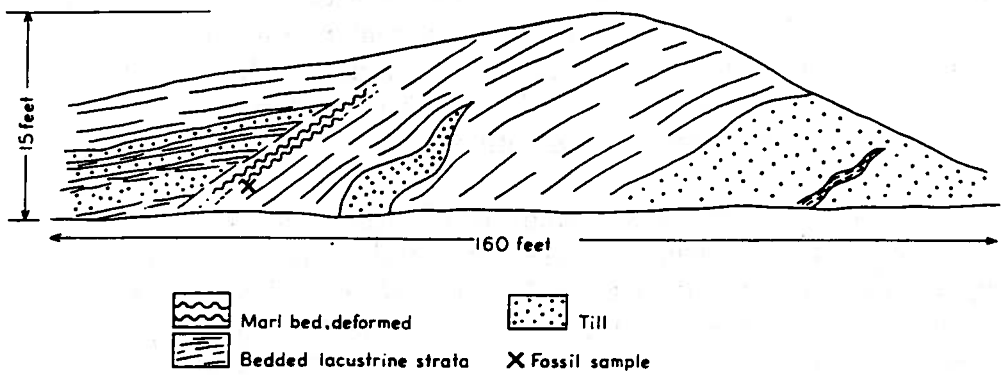


FIGURE 10. Geologic setting of fossil sample 3261.

Candona obtusa Bronstein
Candona rostrata Brady and Norman
Candona caudata Kaufman
Cyclocypris ampla Furtos
Cypris pubera Müller
Cyprinotus incongruens (Ramdohr)
Cypridopsis vidua (Müller)

Gastropoda

Stagnicola palustris nuttalliana Lea
Stagnicola palustris (Müller)
Gyraulus cyclostomus Baker
Physa sp.

Pelecypoda

Pisidium sp.

At the other locality, 3 feet of deformed sand and gravel with clay inclusions overlie till and contain the following fauna (sample 3663, Lsd. 10, Sec. 18, Tp. 10, R. 2):

Ostracoda

Limnocythere trapeziformis Staplin
Ilyocypris bradyi Sars
Candona candida (Müller)
Candona rostrata Brady and Norman
Cypridopsis vidua (Müller)

Gastropoda

Stagnicola palustris (Müller)
Gyraulus sp. (intermediate between *G. altissimus* (Baker) and *G. cyclostomus* Baker)
Physa sp.

Both assemblages, together with the presence of marl, indicate shallow, cool but not cold lakes on the stagnant ice surface: the water probably warmed up to above 50°F (10°C) during the summer. In addition, the lakes were alkaline (that is, the same as present Alberta lakes) and probably were surrounded by a moderate growth of vegetation.

Where an alignment of glacial land forms exists, the line passing through these land forms, showing the orientation and lateral extent of their alignment, is called a "glacial lineament". Most of these lineaments are not observable at ground level, but can readily be seen on aerial photographs (Plate 3). A study of such trends has proved very helpful in determining the directions of ice movement and in elucidating the glacial history.

Proglacial Land Forms

Proglacial land forms comprise those features formed along the edge and outside, or away from the ice margin.

Outwash Plains

Outwash plains cover only a restricted part of the Foremost-Cypress Hills area. This is because the regional slope over much of the area was *into* the glacier and not away from it. During deglaciation, therefore, meltwater was forced to flow along the ice margin, carrying glacio-fluvial material with it. Wherever the slope of the land was away from the glacier, outwash plains or aprons resulted (Map 29).

The largest outwash plain lies in the southeastern corner of the map-area and covers about 100 square miles. It is flat to undulating and is composed of thin stratified gravel, sand and silt, with the underlying till and bedrock commonly showing at the surface. Stagnant ice features (linear disintegration ridges, kames and eskers) sit on this plain together with a few drumlins composed of stratified gravel and sand (see above).

The southern slopes of the Lucky Strike Upland are covered by thin outwash gravel and sand. Drumlins composed of glacio-fluvial material also are present on this plain.

A few miles to the northeast of the Lucky Strike Upland, a fan-shaped patch of outwash sand, about 15 square miles in area, overlies till and narrows northward to a small interlobate system of kames. A superglacial stream must have flowed between two ice lobes here and built up an outwash apron in front of the ice. The slope of the land was away from the glacier at this locality, where the south-sloping north bank of the Medicine Hat Valley is situated (Fig. 6).

Small outwash aprons exist in front of the end moraines north of the Cypress Hills.

The remaining outwash plains or aprons are associated with meltwater channels, and lie in the northwestern quadrant of the map-area (Map 29). Although the regional slope was into the ice throughout this area, over sites of preglacial valleys the slope was locally away from the ice margin, and in such situations outwash aprons were formed. The largest of these (and the second largest in the map-area) is the sandy outwash plain, 60 square miles in area, south of Purple Springs and Grassy Lake (townships 9 and 10, ranges 13 and 14).

Loess Plain

The loess plain is co-extensive with the unglaciated Cypress Hills Plateau and adjacent slopes to the south, and covers about 120 square miles (Map 29). The loess overlies the weathered, oxidized cap of the Cypress Hills conglomerate, varies in thickness from 1 to 8 feet, and contains numerous quartzite pebbles from the underlying Cypress Hills conglomerate that were elevated into the loess by frost action (Plate 10). The resultant fabric of the loess resembles that of till (that is, unsorted), but no erratic pebbles are present. An interesting point about these displaced pebbles is that their long axes are usually in a vertical position, clearly indicating post-depositional changes in the loess as well as the underlying Cypress Hills conglomerate. Indeed, the uppermost 6 feet of the Cypress Hills conglomerate has been deformed by frost action, as is evidenced by the presence of deranged pebbles (Fig. 11) and involutions (Plate 10; Sharp, 1942; equivalent to "festoons" of Schafer, 1949).

The textural variation of the Cypress Hills loess suggests the presence of prevailing northerly winds during the period of loess deposition (Fig. 12). These winds picked up part of the finer fraction of the glacial drift and deposited some of it on the unglaciated Cypress Hills Plateau. That this was the case is shown by the presence of mineral species in the loess that are common in the neighbouring drift but absent from the underlying Cypress Hills Formation (e.g. fresh green hornblende—see Fig. 12 and p. 56). The loess at the northern end of the plateau is coarse-grained and in places is over 50 per cent sand (Fig. 25). The winds that transported this material, therefore, must have been strong, and were most probably katabatic in nature, blowing off the nearby ice sheet.

The deformation of the Cypress Hills conglomerate and the loess by frost action must have occurred when the area was in a periglacial en-

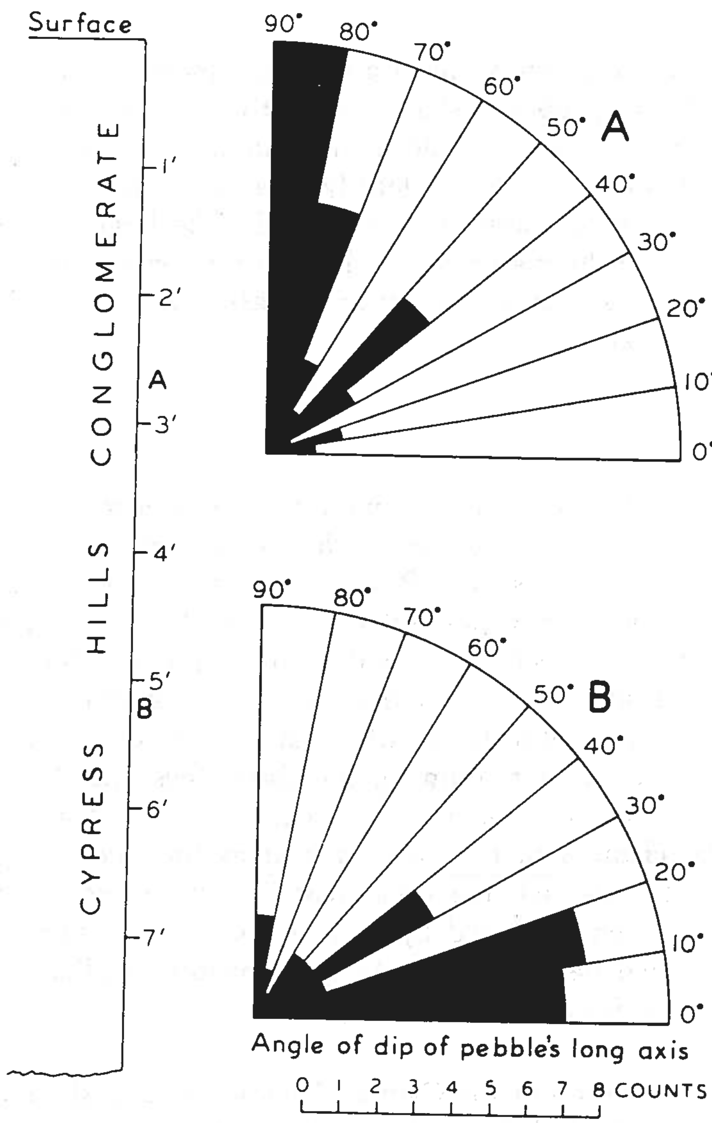


FIGURE 11. Rearrangement of pebbles in the upper part of the Cypress Hills conglomerate—the result of frost action.

vironment. Low temperatures, strong winds, and many fluctuations across the freezing-point at certain seasons characterize such an environment (Sharp, 1942). With the mean annual temperature less than 0°C, perennially frozen ground developed, and the sediment in the active layer—the surface layer which is repeatedly subjected to fluctuations across the freezing-point—was deformed as a result of the repeated formation and subsequent thawing of ice. In the Cypress Hills the active layer was about 6 feet thick.

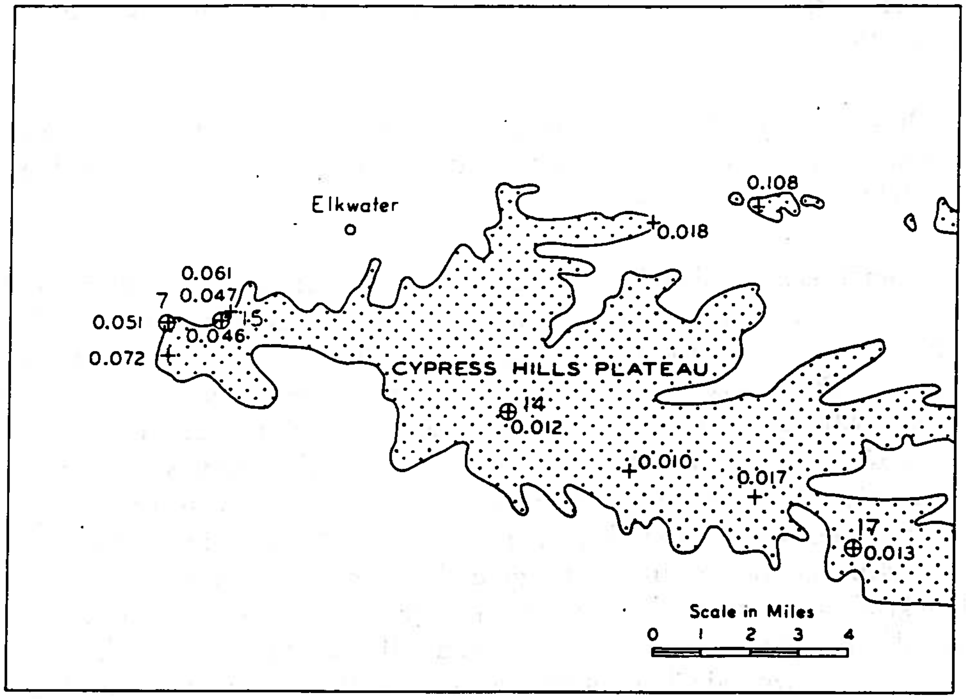


FIGURE 12. Textural variation and hornblende content of Cypress Hills loess.

Proglacial Lakes

As the regional slope was into the glacier over much of the area, proglacial lakes—lakes that ponded against the ice margin—are common. In addition to small patches of lacustrine sediment on ground moraine, four large proglacial lakes existed in the Foremost-Cypress Hills area.

Glacial Lake Pakowki

Glacial Lake Pakowki basin occupies the centre of the map-area, covers about 120 square miles, and overlies the Medicine Hat Valley. To the northwest, the topography is hilly and the dominant sediment-type is sand and gravel (see linear disintegration ridges, p. 25). This changes to a flat plain in the southeastern part of the basin, where a few feet of clay overlie sand. The thickness of the lacustrine sediment is not known.

Two deltas project into the lake basin. The larger one lies in front of Etzikom Coulee. It is composed of sand and gravel and the "cut and fill" structure, or large-scale festoon crossbedding, indicates deposition in shallow water. The other delta, situated just west of where Irrigation Creek enters Lake Pakowki (Map 29), is much sandier and contains transported and *in situ* remains of *Equisetum* sp., together with fragmental bison bones.

The presence of *Equisetum* sp. indicates deposition in shallow water, and its recent age (C-14 date S-214) shows that part of this delta formed in modern times.

Only one strandline of Glacial Lake Pakowki was found (section 19, township 3, range 6). It is marked by a sandy beach deposit that is just over 2900 feet above sea level.

Glacial Lake Pakowki was formed when meltwater accumulated in front of the ice margin as the latter retreated downslope towards the Medicine Hat Valley from the preglacial divide near Comrey (township 2, range 6). The earliest spillways to be used were Canal Creek Channel, just over 3000 feet above sea level, and Lost River Channel, at an elevation of approximately 2950 feet. Canal Creek Channel becomes an esker near Manyberries Range Station (township 2, range 4), indicating that at this point the meltwater entered a channel in the stagnant ice. With further backwasting of the ice front, the glacial waters found a lower outlet, the Pakowki Channel, which is less than 2900 feet above sea level. A considerable volume of meltwater entered Glacial Lake Pakowki via the Etzikom Ice-Marginal Channel and left via the Pakowki Channel (Map 29).

Glacial Lake Medicine Hat

The southern part of the Lake Medicine Hat basin lies in the map-area and covers about 25 square miles of township 12, ranges 5 and 6. It overlies the Medicine Hat Valley, slopes gently to the north, and contains "islands" of till and numerous kames (Map 29). The Seven Persons Channel enters this lake basin from the south in township 11, range 5, where the sediment is mainly sand and gravel. Sand predominates to the north and west, with silt and clay becoming more conspicuous in the extreme western part of the basin. The lake formed as a result of the confinement of meltwater to the lowland around Medicine Hat when drainage to the north was prevented by the glacier.

Other Lakes

A thin, discontinuous blanket of lacustrine sediment covers till over most of the northwestern quadrant of the Foremost-Cypress Hills area. This sediment accumulated in proglacial lakes which formed here during deglaciation. As the ice front retreated downslope to the north, high lake levels were succeeded by lower lake levels. Sandy beach deposits in section 16, township 8, range 12, and in section 36, township 8, range 14, at an elevation of about 2750 feet, belong to the earliest of these proglacial lakes which most probably drained via the Forty Mile Channel. The topography varies from a flat to gently undulating plain in townships 8 and

9, ranges 11, 12, and 13 to an undulating occasionally hilly terrain north of the Oldman and South Saskatchewan Rivers, where the lacustrine sands and silts are too thin to mask completely the hummocky till surface.

Another proglacial lake formed over the site of the preglacial valley in the vicinity of Walsh, in the northeastern corner of the map-area. The lacustrine plain is nearly flat here and passes into the adjacent till plain at an elevation just below 2500 feet.

Proglacial lake sediments were sampled at section 33, township 9, range 1 (sample 4961). Here, 15 feet of lacustrine sand, silt, clay and marl overlie outwash sand and gravel which is underlain by till. Fossils recovered from the lacustrine sediment include:

Ostracoda
- *Cyclocypris ampla* Furtos
- *Potamocypris smaragdina* (Vavrà)
- *Cypridopsis vidua* (Müller)
- *Candona obtusa* Bronstein
- *Cyprinotus incongruens* Ramdohr

Gastropoda
- *Succinea avara* Say
- *Gyraulus altissimus* (Baker)
- *Gyraulus cyclostomus* Baker
- *Stagnicola palustris* (Müller)
- *Physa* sp.

Plants
- *Chara* sp.

The fauna and flora is considered to indicate a shallow, cool lake, with moderate vegetation. It is most likely that this lake continued to exist after the disappearance of the glacier.

In section 18, township 10, range 5, 35 feet of bedded, in part fossiliferous, sand, silt and clay cover till and lie just south of a well-developed end moraine. Hence, it is presumed that these sediments were deposited in a proglacial lake. The following gastropods were identified (sample 4262), being present mainly in the clay beds. Oddly, these are all terrestrial gastropods [*Succinea avara* Say, *Vertigo modesta* (Say), *Euconulus fulvus* (Müller), and *Vallonia gracilicosta* Reinhardt]. They were most probably derived from nearby sediments. All require damp to somewhat humid conditions, certainly not dry, with no high summer temperatures and at least enough vegetation to offer shade close to the ground.

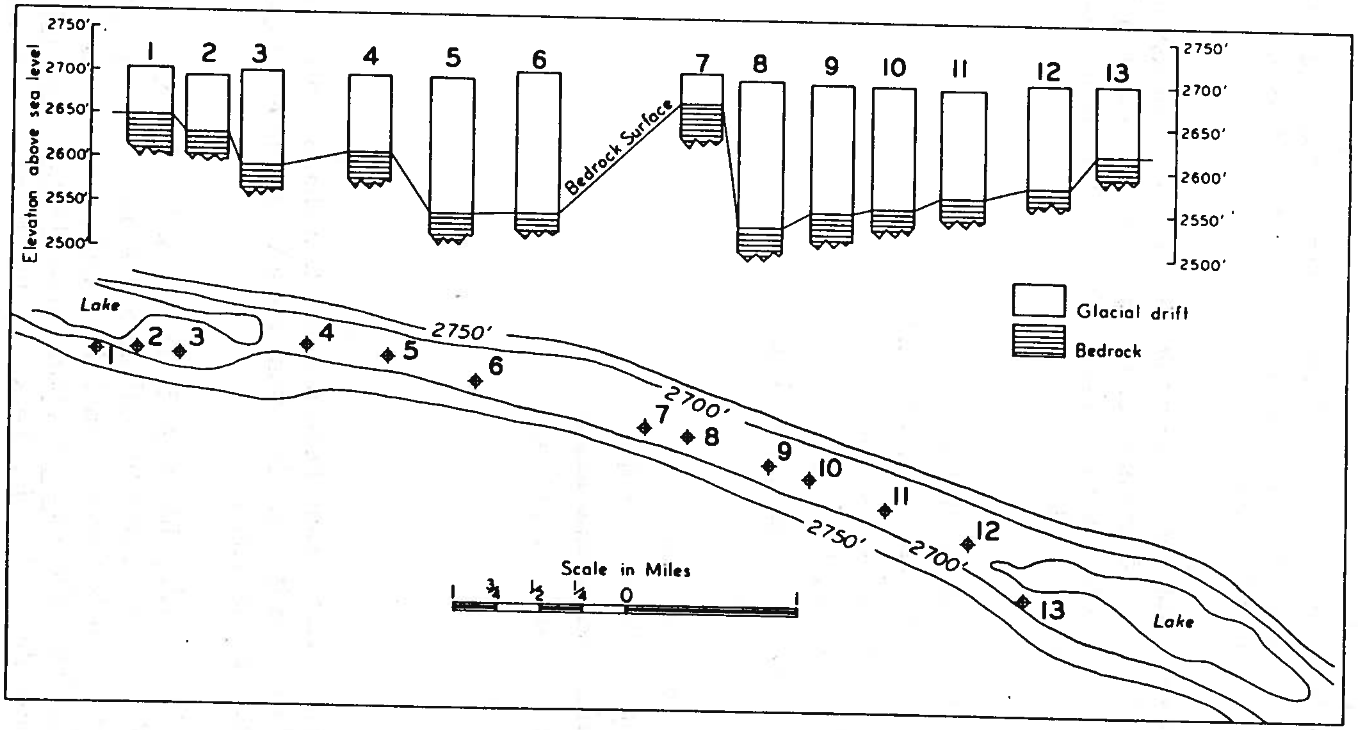


FIGURE 13. Geological section along Chin Coulee, northwest of Legend, Alberta.

Meltwater Channels

The term "meltwater channel" is here used to describe any channel that conducted meltwater from the glacier. The meltwater channels of the Foremost-Cypress Hills area may be classified into three types: ice-marginal channels, consequent channels, and buried channels.

Ice-marginal channels are the most numerous type of meltwater channel in the map-area. Some are over one mile wide and 400 feet deep (Milk River Channel, Plate 2); others are less than 300 feet wide and only 10 feet deep (channels in townships 7 and 8, ranges 12 and 13; Plate 4). Most have steep-sided walls and a trench-like transverse profile and, because their path was determined by the position of the glacier margin, ice-marginal channels locally cut through preglacial hills and divides (Fig. 6). The Medicine Lodge, Verdigris, Milk River, Etzikom, Chin, Forty Mile, Seven Persons and South Saskatchewan channels are all ice-marginal channels. The broad upland of the preglacial Winnifred Divide diverted east-flowing meltwater to the south and southeast, along its western flank (Map 29). This explains the seemingly anomalous orientation of the Forty Mile Channel. Because ice-marginal channels mark successive positions of the retreating ice front they are very helpful in unravelling the glacial history.

Consequent meltwater channels conducted meltwater away from the glacier, in the direction of the regional slope. Only a few of these channels exist in the map-area and most are situated south of the Milk River. Coutts Channel (township 1, range 15), Clarinda Channel (township 1, range 14), and Pinhorn Channel (township 1, range 7) all carried meltwater to the south, away from the glacier margin (Map 29).

Both ice-marginal and consequent channels are cut in glacial drift and usually into the underlying bedrock also (Map 29; Figs. 6 and 13). They are floored with recent alluvial and lacustrine silt and clay, which most likely cover glacio-fluvial material. Alluvial fans commonly extend into them.

Terraces are present along many of the channels. In the South Saskatchewan Channel they are carved in bedrock, their surfaces being covered by a veneer of glacio-fluvial material (section 15, township 11, range 12). Elsewhere, terraces are composed of glacio-fluvial sand and gravel, as in the Seven Persons Channel, just before it enters the Lake Medicine Hat Basin, and in the Medicine Lodge Channel. Along part of the Etzikom Channel (township 5, range 15) and Milk River Channel (township 2, ranges 10 and 11), the terraces are covered by till, indicating two phases of meltwater flow interrupted by a glacial advance.

A buried meltwater channel lies just to the north of Crow Indian Lake (township 5, range 14) and another runs from the junction of Chin, Forty Mile and Seven Persons Coulees northwards through Granlea, to Murray Lake (Map 29; Fig. 6). The former channel was clearly part of the Etzikom Channel at one time. Both channels were filled with till when the glacier readvanced over them.

Spillways

Spillways are channels that were formed as drainage outlets of glacial lakes. Canal Creek Channel, Lost River Channel, Pakowki Channel and Milk River Canyon are spillways that drained Glacial Lake Pakowki (Map 29, Fig. 30). Most of the water drained via the two last-mentioned channels which are, therefore, considerably larger than the others. Verdigris, Etzikom and Chin ice-marginal channels drained glacial lakes to the west of the map-area (Stalker, 1962) and may be considered as ice-marginal spillways.

Eroded Plains

Severely eroded plains are present on the broad upland of the preglacial divide southeast of Lake Pakowki (Map 29). The drift is either thin or absent, bedrock exposures are common, badland is extensive, and ill-defined ice-marginal meltwater channels dissect the surface in places, especially south of the Milk River. Till caps the higher areas, and gravel, sand, silt and clay occur in the lower parts. In places the sand and silt has been transported by the wind for a short distance, producing dunes.

Postglacial Land Forms

Postglacial land forms comprise those features formed after the complete disappearance of the last ice sheet from the area. These fall into three general categories: river valleys, dunes and slump areas.

River Valleys

Although the Milk, South Saskatchewan, Oldman and Bow Rivers flow for the most part along old meltwater channels, they owe part of their present-day appearance to postglacial erosion. The western stretch of Milk River (township 2, ranges 14 and 15), for example, meanders in a 50-foot deep, box-like canyon that was formed entirely in postglacial times. In addition, postglacial terraces are present along the above-mentioned valleys, which have been considerably deepened since the retreat of the last glacier.

North of the Cypress Hills many postglacial valleys exist. All are incised into drift and bedrock, some to over 100 feet deep. In the southeastern part of the map-area, postglacial valley degradation was interrupted by a period of aggradation. Thus, Pinhorn Channel (township 1, range 7) has a fill of fine gravel, sand and silt over 20 feet thick. Many of the valleys on the southeastern side of the preglacial divide that runs northeastwards through Comrey (township 2, range 6) are also aggraded. The valley in section 30, township 2, range 3 has a fill composed of gravel, sand, silt and clay from which a skull of *Bison bison bison* (Research Council of Alberta catalogue number Westgate, 263) was recovered. Wood from this valley fill deposit has a C-14 age of 1600±300 years B.P. (S-223).

Dunes

Extensive dune development is found in two districts: the northeastern part of Lake Pakowki and the environs of the Oldman, Bow and South Saskatchewan Rivers. Minor patches occur within the outwash plains (Map 29).

At Lake Pakowki, lacustrine sand has been blown onto the adjacent ground and end moraine by westerly winds. The sand extends onto the till as a group of lobes, convex to the east, within which exist blow outs, parabolic and transverse dunes (Plate 11). These thin, lobate sheets of sand, together with their superimposed dunes, are now stabilised by grasses, shrubs, and trees, but in places have been reactivated as a result of prolonged periods of drought.

Parabolic and longitudinal dunes, developed by west-southwesterly winds, are present in the northwestern corner of the map-area. They are composed of lacustrine sand which overlies the Oldman End Moraine. Some of the parabolic dunes have arms over a mile long and many of the longitudinal dunes are merely linked parabolic dunes (Plate 11). These dunes are now stabilised by vegetation.

The age of these dunes is not known exactly. They are certainly postglacial and may well have formed during the "climatic optimum".

Slump Areas

Landslides are common along many of the meltwater channels and postglacial valleys. This is particularly true in valleys where the streams have cut through the drift into Bearpaw Formation strata (Christiansen, 1959, p. 21) or into shaly, bentonitic beds of other rock units. Landslides of the rotational slump-type are the most numerous, the slump blocks being topographically expressed as a series of sub-parallel ridges flanking the undisturbed valley walls. Examples occur along Medicine Lodge Coulee, the northern escarpment of the Cypress Hills, and along valleys to the north and south of the Cypress Hills.

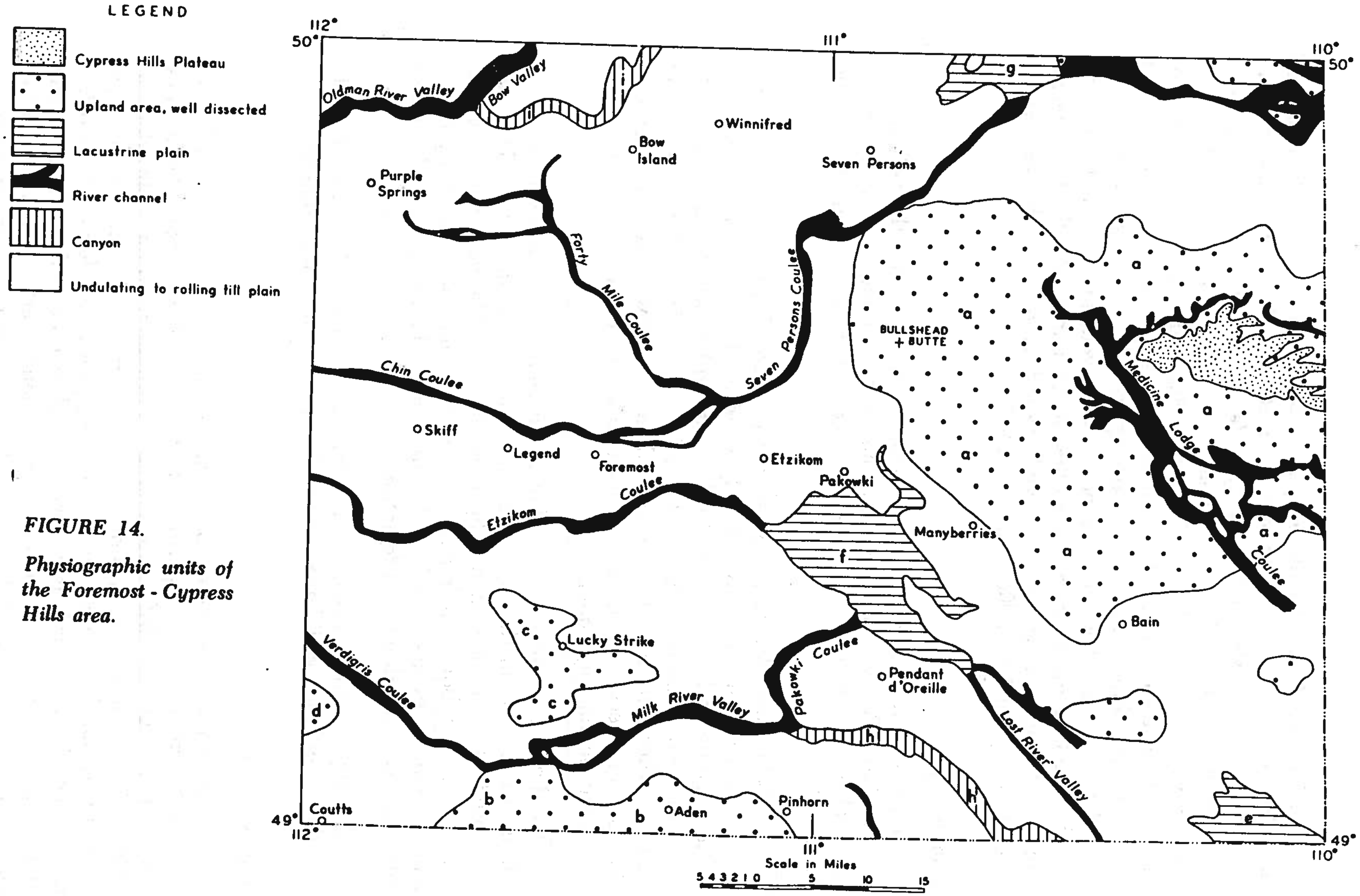


FIGURE 14.

Physiographic units of the Foremost - Cypress Hills area.

Present Topography

As stated previously, the present topography of the region has resulted from preglacial, glacial and postglacial erosion and deposition. In terms of present physiography, the region can be divided into six units: Cypress Hills Plateau, upland areas, till plain, lacustrine plains, river channels, and canyons (Fig. 14).

Cypress Hills Plateau

The dominating physical feature of the Cypress Hills is the nearly level plateau which slopes gently to the east and south (Plate 1). This plateau drops from its western extremity or "Head of the Mountain", with a maximum elevation of 4800 feet, to less than 4500 feet at the Alberta-Saskatchewan border, some 15 miles to the east. Its elevation and surface gradient is determined by the Cypress Hills conglomerate. To the north and west the plateau ends abruptly in steep escarpments, formed in part by ice-marginal meltwater flow, whereas on the south it gradually merges into the plain. The northern part of the plateau is dissected by trough-shaped valleys excavated into the Cypress Hills conglomerate. Most of these valleys were formed after the incision of the ice-marginal channels immediately to the north, when the local base level of the north-flowing streams was significantly lowered.

Upland Areas

For the purpose of this report, an upland is a relatively elevated area possessing considerably greater relief than the adjacent plains. A conspicuous change in slope marks the junction of the plains and upland areas. Usually, this occurs at an elevation of 3000 to 3500 feet. The survival of these upland areas is largely due to their interstream position (in preglacial times), structural elevation, and resistance to erosion.

The well-dissected Cypress Hills Upland descends northward from the plateau to about 3500 feet above sea level. Westward, it falls to about 3000 feet, just west of Bulls Head Butte, and southward it drops to approximately 3200 feet at Bain (township 4, range 3).

The Sweet Grass Hills of northern Montana lie just south of the 49th Parallel, but their foothills, with a maximum height of 4200 feet, extend northward into the map-area south of the Milk River between ranges 9 to 13.*

The Lucky Strike Upland, whose summit lies 3300 feet above sea level, is situated north of the Milk River and south of Etzikom Coulee.

---

* All locations in the text are west of the fourth meridian.

The eastern end of the Milk River Ridge extends into the map-area at an elevation of 3500 feet and is located to the southwest of Verdigris Coulee.

Till Plain

Almost three quarters of the area is a till plain of undulating to rolling relief. Generally speaking, north and west of the Cypress Hills the regional slope is towards the northeast. Thus Coutts is 3468 feet, Foremost 2915 feet, and Seven Persons 2480 feet above sea level. In the southeastern part of the area the regional slope is to the southeast.

Lacustrine Plains

There are three notable lacustrine plains in the area: all are of Pleistocene age, and, except for Lake Pakowki, no longer contain water. The largest is the Lake Pakowki plain, just over 2800 feet above sea level. The Lake Wild Horse plain, situated in the southeastern corner, is approximately at the same elevation. To the north, the plain of Lake Medicine Hat is less than 2400 feet above sea level.

River Channels

The continuity of the plains surface is broken by a system of deeply entrenched coulees that are commonly more than a mile wide and 100 feet deep (e.g. Verdigris, Etzikom, and Chin Coulees, Plate 1). Most of them are dry today or contain misfit streams. Similar channels surround the Cypress Hills.

Canyons

In two places, the above-mentioned channels become so entrenched and steep-sided that the term "canyon" is more appropriate. The Milk River Canyon extends downstream from the junction of Pakowki Coulee and the Milk River Valley. It is over 400 feet deep and one and one-half miles wide, and is cut entirely into bedrock. The South Saskatchewan River occupies a canyon more than 300 feet deep and one mile wide. It likewise is cut largely into bedrock (Plate 2). The sides of Milk River Canyon are well dissected, especially the southern side (Plate 9). The younger South Saskatchewan Canyon, on the other hand, has few subsidiary gullies.

Present Drainage

Apart from the internal drainage basin centred on Lake Pakowki, two great river systems, the Missouri and South Saskatchewan, drain the region (Fig. 15). Milk River, Lost River, Sage Creek and Lodge Creek all flow into Montana to join the Missouri River by which their water is eventually conducted to the Gulf of Mexico. To the northwest, the Oldman and Bow Rivers join to form the South Saskatchewan River into which drain the

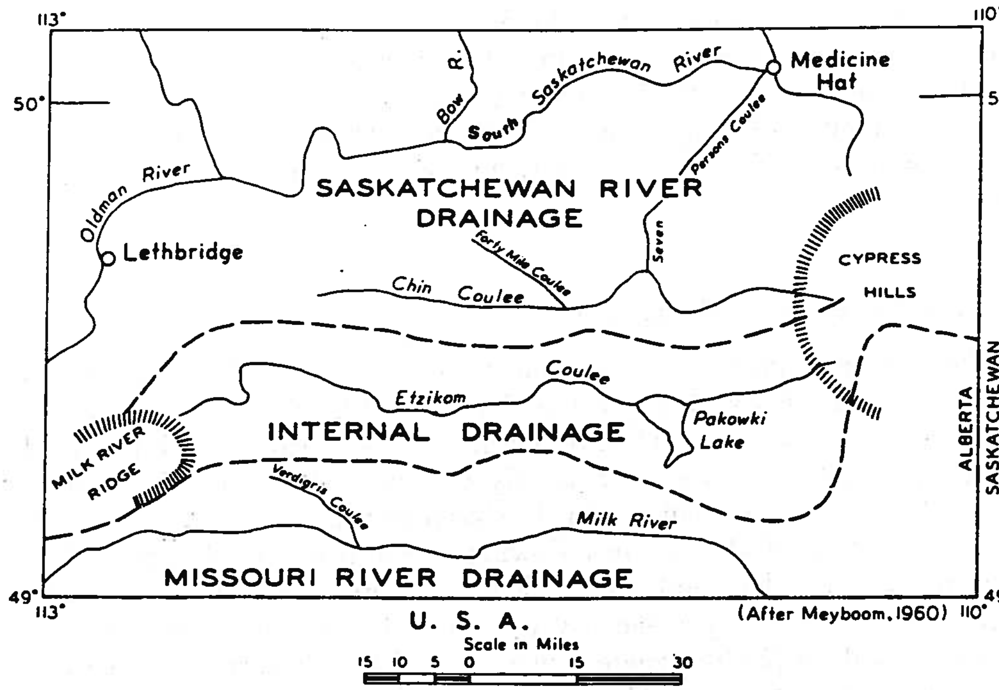


FIGURE 15. Drainage systems of southern Alberta.

north-flowing Seven Persons, Bullshead, and Ross Creeks. The South Saskatchewan River unites with the North Saskatchewan below Prince Albert, Saskatchewan, and their combined waters flow into the Hudson Bay by way of the Nelson River.

Drainage features readily show that the area was glaciated. To mention a few, Medicine Lodge Coulee and Milk River Canyon cut across a preglacial divide; the entrenched coulees were obviously not formed by the present streams that occupy them, but by meltwater run-off from ablating ice sheets; some channels have sidehill positions (Seven Persons Coulee), others form lobate patterns and must mark retreatal stages of an ice lobe (small channels west of Forty Mile Coulee).

Missouri Drainage Basin

The northern limit of the Missouri Drainage Basin is illustrated on figure 15. In the map-area the only perennial stream of this basin is the Milk River. The latter enters the area in township 2, range 15, and, strongly meandering and incised into the Milk River Sandstone, it flows eastward along the axis of a preglacial valley (Whisky Valley). Verdigris Coulee, now dry and some 50 feet above the Milk River, enters the Milk River Valley from the northwest in township 2, range 14. Farther east, Deadhorse

Coulee (Black Coulee) opens into the Milk River Valley at both ends and represents another abandoned channel. In township 2, range 10, the Milk River begins to leave the preglacial valley and flows east to Pakowki Coulee and then southeast, through the Milk River Canyon into Montana. All streams south of the Cypress Hills Plateau contain water only during early summer.

South Saskatchewan Drainage Basin

The southern margin of the South Saskatchewan Drainage Basin extends from Milk River Ridge to the Cypress Hills (Fig. 15). The major rivers are the Oldman, Bow, and South Saskatchewan, the last-named flowing out of the area in a northeasterly direction. The Chin-Forty Mile-Seven Persons Coulee system lies in this basin but presently conducts very little water. Most of the streams flowing north from the Cypress Hills occupy preglacial valleys, but some follow meltwater channels. Thus, Gros Ventre Creek flows in a preglacial valley from the northwestern corner of the Cypress Hills to Norton where it makes a right-angle turn to the east to flow along a meltwater channel and join Ross Creek. East of Ross Creek, there is a small internal drainage basin, Mackay Creek draining into a series of shallow lakes north of the map-area.

Lake Pakowki Internal Drainage Basin

The Lake Pakowki Internal Drainage Basin is sandwiched between the South Saskatchewan and Missouri basins and occupies a linear belt of land, longitudinally bisected by Etzikom Coulee. Although this coulee is the main channel of the basin, it contains only a small stream that flows into the now almost dry Lake Pakowki.

During the greater part of Pleistocene time no internal drainage existed in the map-area. Before the Laurentide glaciers entered the region, drainage was to the north (Fig. 6). During the glacial period meltwater flowed eastward along Etzikom Coulee, debouched into Lake Pakowki, and from there was conducted south via Pakowki Coulee to the Milk River. With the cessation of meltwater flow, the southern part of Pakowki Coulee became plugged by Milk River alluvium (Williams and Dyer, 1930), reversing the gradient of the coulee. This event, coupled with thick morainal deposits north of Lake Pakowki, resulted in the formation of the internal drainage basin.

PETROGRAPHY OF GLACIAL DEPOSITS

Only the tills and Cypress Hills loess are considered in this section. Textural and compositional studies have been made on the several till sheets in the map-area in an attempt to provide physical criteria by which these till sheets may be differentiated and correlated. Field studies alone did not reveal how the sediment on the Cypress Hills Plateau originated: only after the texture and mineralogy had been examined did it become evident that this sediment was a loess.

Petrography of Tills

The colour, texture, pebble composition, heavy minerals, and carbonate content of the tills were studied.

Colour

The colours of about fifty dry till samples were examined using the rock-colour chart distributed by the Geological Society of America (second edition, 1951). The most common colour is yellowish olive grey (5Y 6/2), but light olive grey (5Y 5/2 or 5Y 5/1) tills are present. The oxidised tills are dusky yellow (5Y 6/3), and yellowish brown (10YR 5/2 or 10YR 6/3).

Texture

Grain-size analysis of the till samples was carried out according to the procedure given by Folk (1961). Figure 16 shows the range in grain size of the till samples. It can be seen that the tills are ill-sorted and contain an appreciable amount of clay. The percentages of sand (2.0 - 0.062 mm), silt (0.062 - 0.002 mm), and clay ($<$0.002 mm) in the till samples were plotted on a triangular diagram (Fig. 17) which shows that most of the tills have a clayey loam to loamy texture. Clay loam is the average texture of tills overlying the Bearpaw Formation: loam is the average texture of tills overlying the Oldman and Foremost Formations.

After studying the distribution on a ternary diagram of more than five hundred published till size analyses, Elson (1961) devised a grain-size classification of tills. According to Elson's textural classification, most of the tills in the Foremost-Cypress Hills area have a clay, silty clay, or clayey silt texture (Fig. 18). Elson also studied the relation of grain-size distribution to the dominant rock types composing tills (1961, p. 12 and figure 5). The grain-size distributions of the tills that overlie the Bearpaw, Oldman, and Foremost Formations—largely shale and siltstone with some sandy beds—agree closely with Elson's distribution for tills made up largely of such rocks (Fig. 18).

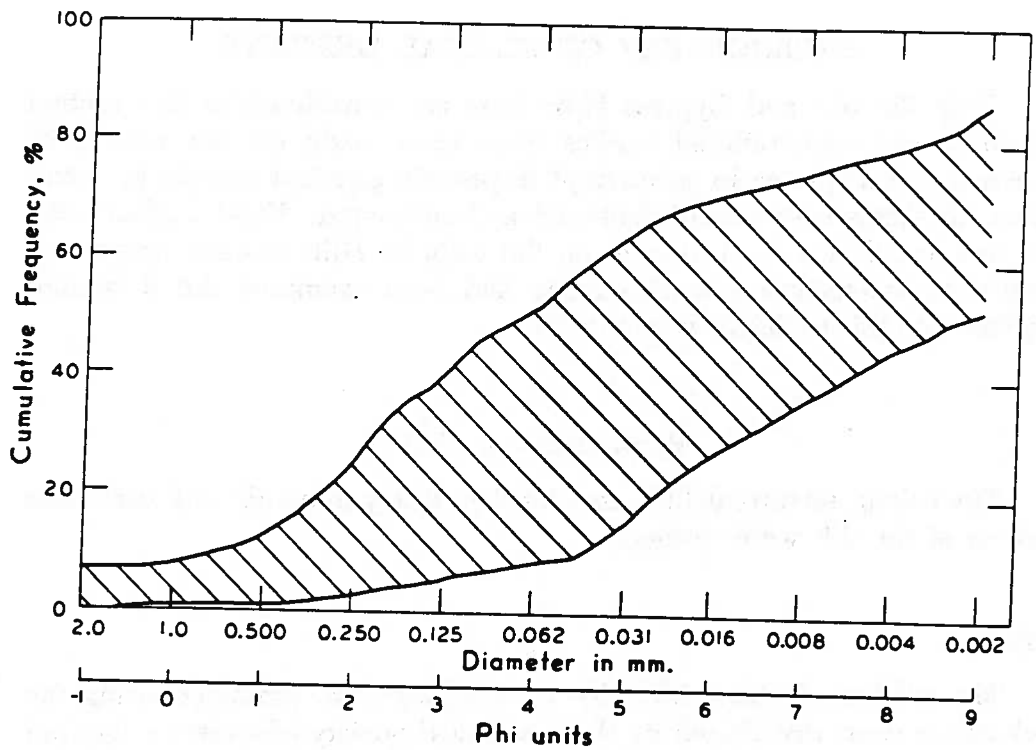


FIGURE 16. Range in grain size of till samples from the Foremost-Cypress Hills area.

Figure 19 shows the variation in texture of the tills with respect to the underlying bedrock. Tills on the Foremost Formation are clearly coarser grained than those on the Bearpaw Formation, and the field embracing the tills on the Oldman Formation is placed more towards the sand end-member than that of the tills on the Bearpaw Formation. This suggests that the texture of the tills is controlled to some extent by the underlying bedrock.

A study of the areal variation of the texture of tills with respect to the bedrock was made by plotting the graphic mean (Folk, 1961, p. 44) of each till sample on a map of the bedrock geology. Figures 20 and 21 show that a change in texture of the local bedrock is almost immediately reflected in the overlying till. The graphic mean is the average of the 16, 50, and 84 percentiles on the cumulative curve. The average graphic means of tills overlying certain bedrock formations are given below:

tills overlying the Bearpaw Formation .... 0.055 ± 0.017 mm
tills overlying the Oldman Formation .... 0.068 ± 0.022 mm
tills overlying the Foremost Formation .... 0.094 ± 0.03 mm.

The large dispersion about the mean is due to the fact that some till samples are located near the boundaries of bedrock formations.

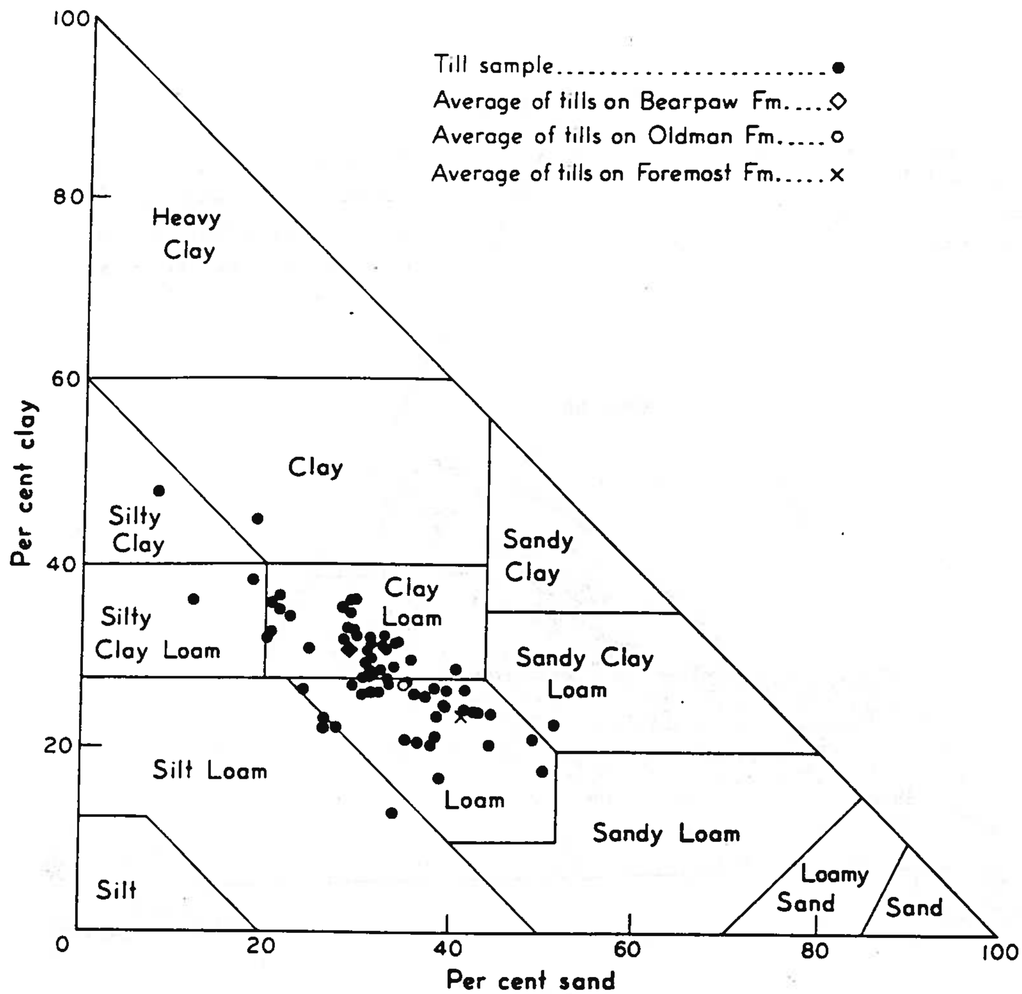


FIGURE 17. Textural classification of tills in the Foremost-Cypress Hills area.

The tills behind the Pakowki End Moraine (Fig. 30) for the most part overlie the Foremost and Oldman Formations. Consequently they are coarser grained than the older tills to the east and south which overlie argillaceous rocks of the Bearpaw and Pakowki Formations.

Pebble Composition

Two methods of collecting pebbles from till were used: for the purpose of this report one may be called "the field method" and the other "the bulk-till method". The field method involved the collection of about 200 pebbles from an outlined area of about 4 square feet. All pebbles between 2 and 70 millimetres in diameter were gathered, but clay pebbles were excluded because their colour was very similar to that of the till matrix, making it very difficult to get a representative value.

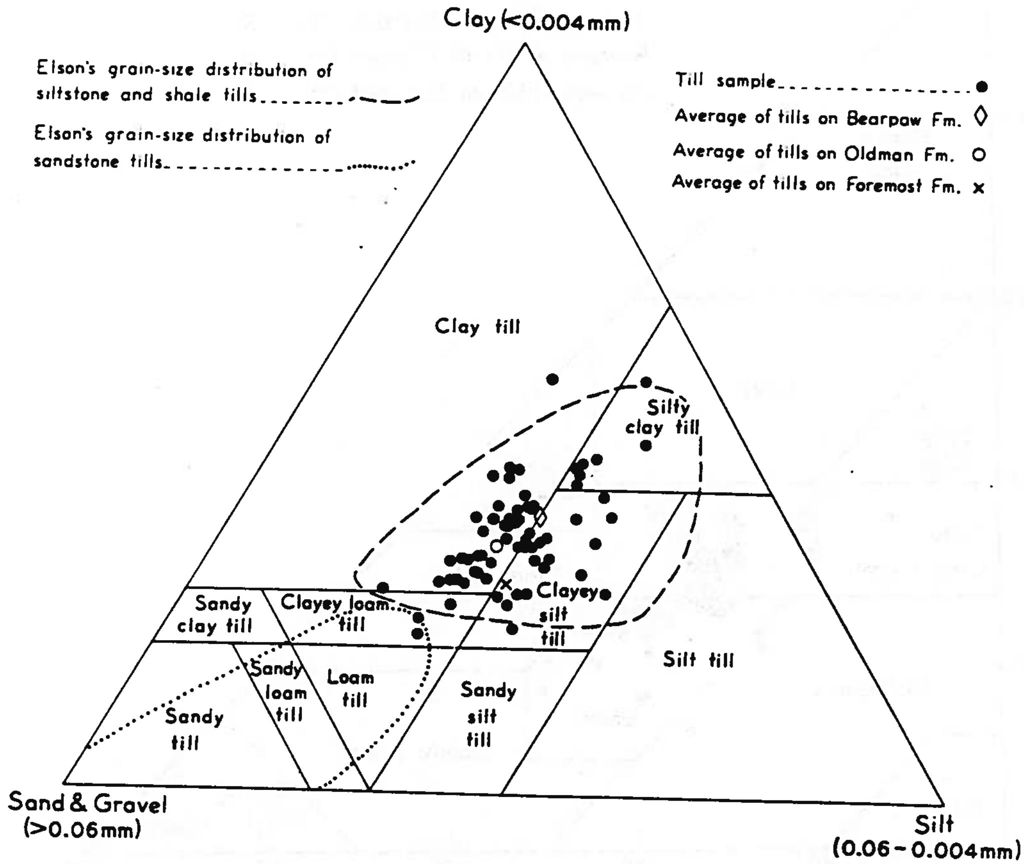


FIGURE 18. Textural classification of tills in the Foremost-Cypress Hills area, according to Elson (1961).

In order to check the supposition that a 200-pebble sample collected in this way (field method) was representative of the true pebble composition of the till, five adjacent samples were taken from the same till sheet at one locality and subjected to a chi-square analysis.
Chi-square is given by the formula:

$$\chi^2 = \sum \left[\frac{(O-E)^2}{E} \right]$$

where O is the observed frequency and E is the expected frequency. Table 1 shows the frequency of erratic pebble types in the till samples, $\chi^2 = 8.21$. The tables (Yule and Kendall, 1958, p. 665) show that for a probability of 0.05, the usually accepted level of significance, for 8 degrees of freedom, $\chi^2 = 15.51$. As the obtained value of χ^2 is less than 15.51, it is concluded

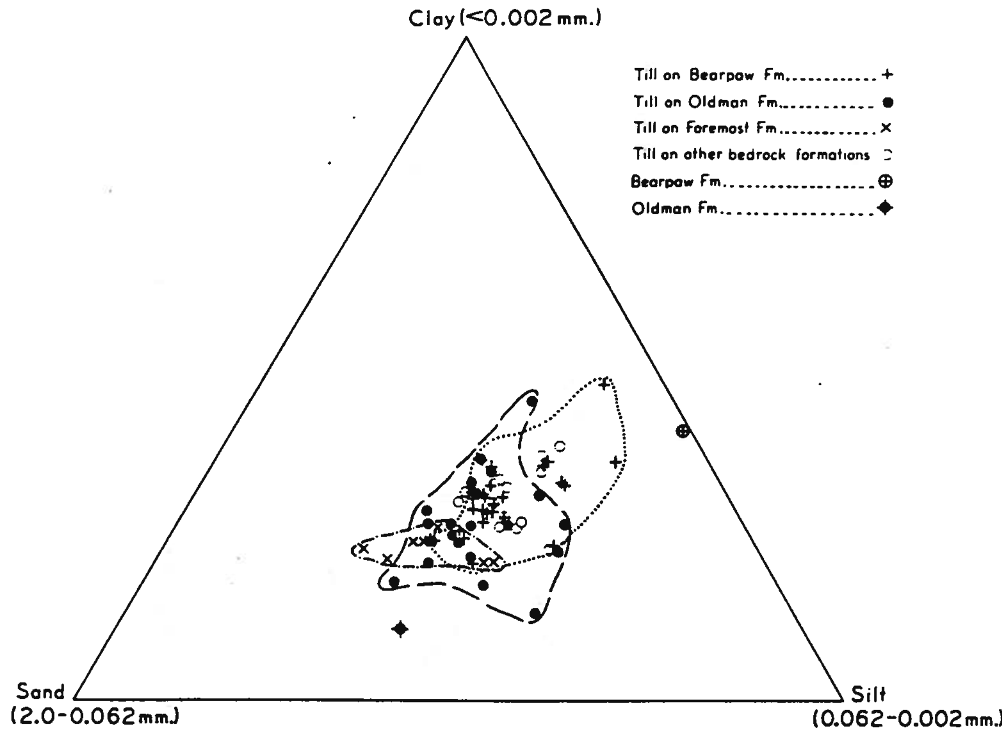


FIGURE 19. Texture of tills in the Foremost-Cypress Hills area—underlying bedrock identified.

that the variation in frequency of the three erratic pebble types in the samples is not significant. In other words, the variation in frequency does not exceed that which one would expect from random sampling. Hence, a 200-pebble sample obtained by the field method shows no detectable differences in the erratic pebble composition of the till. When the frequencies of the pebbles of local origin are considered (Table 2), χ^2 increases to 33.57. The tables show that at $P = 0.05$, with 12 degrees of freedom, $\chi^2 = 21.03$. As the obtained value of χ^2 is greater than 21.03, it can be concluded that the difference in frequency of pebbles of local origin is significant. This means that, unlike the erratic pebbles, the local pebbles are unevenly distributed throughout the till—variations in concentration being detectable at one locality using 200-pebble samples.

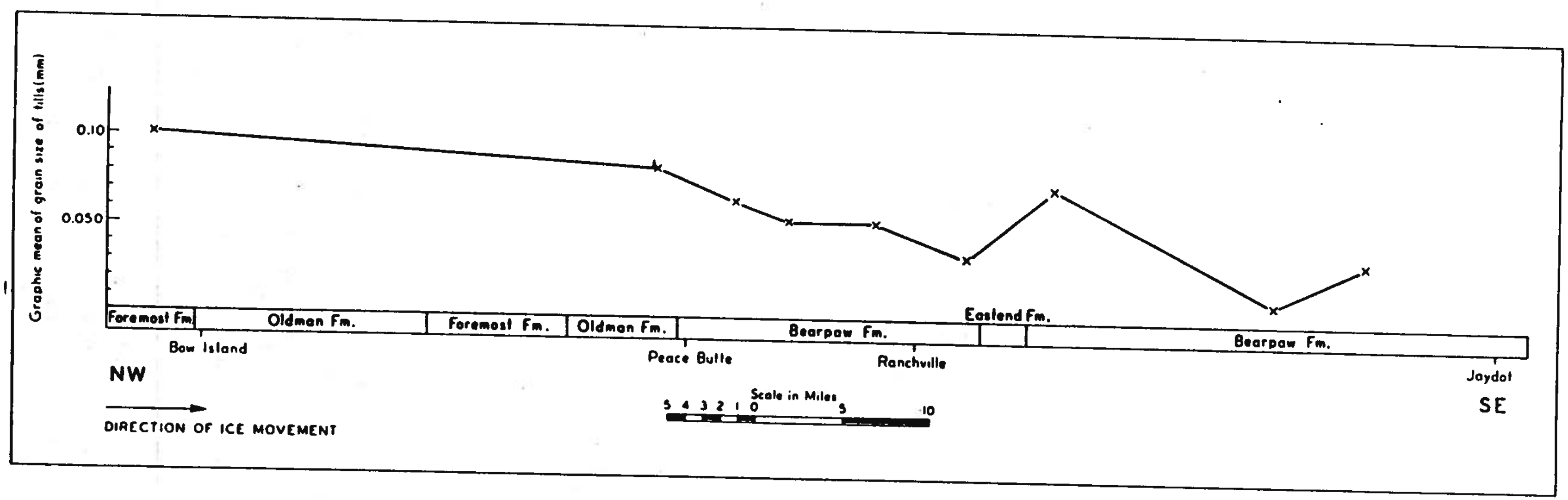


FIGURE 21. Variation in graphic mean of tills with respect to the underlying bedrock.

Table 1. Contingency Table: Frequency Variation of Erratic Pebbles in Till Samples taken from the Same Horizon at the Same Locality

ROCK TYPE	SAMPLE NUMBER 3062	3162	3262	3362	9761	TOTAL
Precambrian acidic rocks	74	57	60	61	68	320
Precambrian basic rocks	26	22	26	27	15	116
Paleozoic carbonate rocks	79	91	86	96	89	441
TOTAL	179	170	172	184	172	877

Table 2. Contingency Table: Frequency Variation of Erratic and Local Pebbles in Till Samples taken from the Same Horizon at the Same Locality

ROCK TYPE	SAMPLE NUMBER 3062	3162	3262	3362	9761	TOTAL
Precambrian acidic rocks	74	57	60	61	68	320
Precambrian basic rocks	26	22	26	27	15	116
Paleozoic carbonate rocks	79	91	86	96	89	441
Mesozoic and Cenozoic rocks of local derivation	12	19	29	11	40	111
TOTAL	191	189	201	195	212	988

The field method was used in 1961 and part of 1962 but was abandoned in favour of the more objective bulk-till method. In the latter method approximately 20 pounds of till was collected at each locality. All of the minus 4 millimetre material was removed by wet sieving in the laboratory and the composition of the +4 —40 mm size fraction was recorded (Fig. 22). The change in sampling procedure, however, has hindered the recognition of significant changes in pebble lithology of the tills, for time did not permit bulk-till samples to be collected over the whole area.

The pebbles are classified into three main groups: Precambrian rocks from the Canadian Shield, Paleozoic carbonate rocks from the rim of the Canadian Shield, and Mesozoic and Cenozoic rocks of local origin.

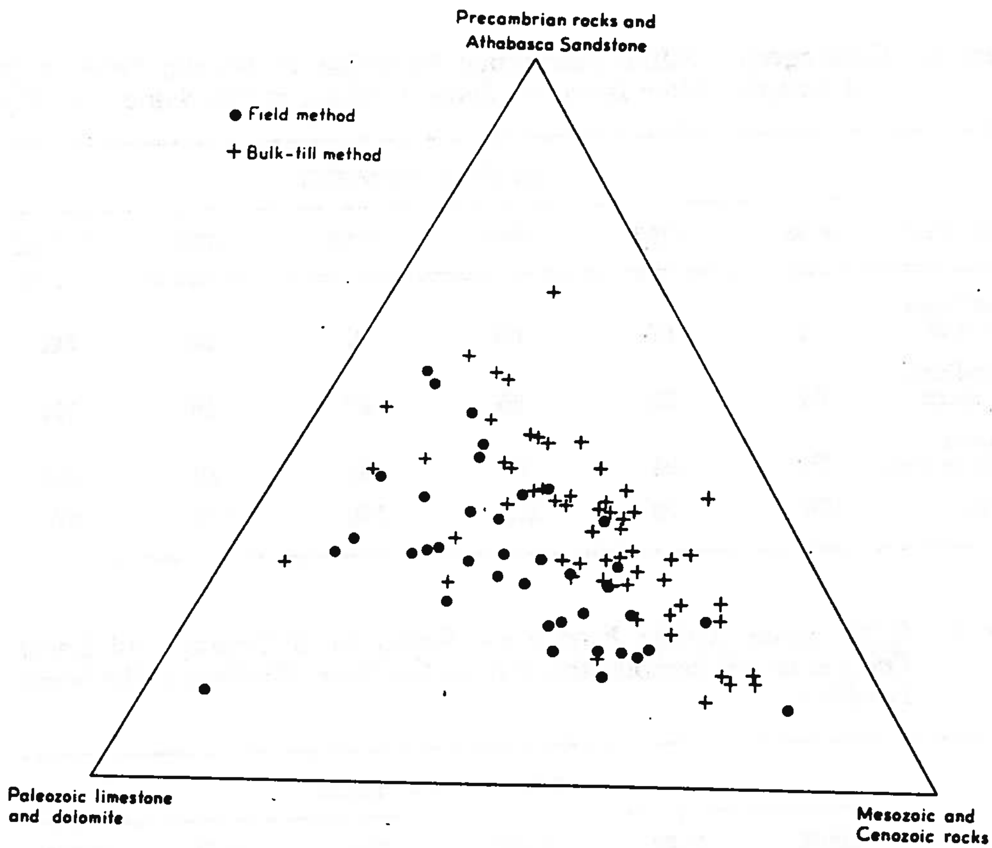


FIGURE 22. Pebble composition of tills in the Foremost-Cypress Hills area. Size range of pebbles 4 to 40 mm.

Precambrian Rocks

Igneous and metamorphic rocks of acidic composition are the most abundant rock types from the Canadian Shield. Granite, granophyre, pegmatite, syenite, quartz-feldspathic gneiss and metasediment, mica schist, and vein quartz are present.

All dark-coloured igneous and metamorphic rocks are grouped together into a basic rock category. Amphibolite is the most common rock type in this class: diorite and gabbro with their fine-grained equivalents and greenstone also occur.

White, grey, pink, red or purple orthoquartzite, medium to coarse-grained, and poorly to moderately cemented by silica is classed as Athabasca Sandstone. This rock is exposed over a large area south and east of Lake Athabasca. Orthoquartzite is not abundant in most of the till samples and it is likely that some of it is not Athabasca Sandstone but material derived from the Rocky Mountains.

Paleozoic Carbonate Rocks

Buff, cream, in some instances pink, fine-grained dense dolomite and grey, fossiliferous limestone constitute the rock types of this catagory. They are always present in conspicuous amounts and rarely form less than 20 per cent of the pebbles in the till, and locally may exceed 80 per cent.

Mesozoic and Cenozoic Rocks

Brown quartzite, black chert, arkose, quartzitic sandstone and conglomerate occur in this group. Most of the pebbles are well rounded and all were derived from gravels that capped elevated remnants of Tertiary erosional surfaces or floored preglacial channels. All other rocks in this class are derived from the Upper Cretaceous bedrock. They include soft, buff sandstone, clay ironstone, lignite, petrified wood, fragments of fossils, and semi-indurated shale.

The results of the pebble analyses are plotted on a triangular diagram (Fig. 22). The ratio of Paleozoic carbonate to Precambrian crystalline pebbles was plotted on a map as a test of the variation of erratic pebble composition of the till sheets. Figure 23 suggests that tills of Pakowki age and younger contain less carbonate pebbles than the older tills to the east and south, with the exception of the till in the northeastern corner of the map-area (cf. Horberg, 1952, p. 317). However, the higher percentage of carbonate pebbles recorded around the Cypress Hills may in part be due to the sampling technique (field method) as is suggested in figure 22.

Heavy Minerals

The −120 +230 mesh sand fraction was obtained from 50- to 100-gm till samples by wet sieving, and the heavy minerals were separated in tetrabromoethane (s.g. = 2.96). A representative sample of the heavy minerals was obtained using the Jones' sample splitter. The grains were mounted in Aroclor (n = 1.66 to 1.67) and examined under the microscope. Over three hundred grains were counted from each slide. A description of the heavy minerals is given below. The percentage frequency of each mineral species has been recorded in detail elsewhere (Westgate, 1964, unpubl. Ph.D. thesis, Univ. of Alberta).

The opaque minerals are divided into three groups based on their colour in reflected light: black (magnetite and ilmenite), and white (leucoxene), and others. Hematite and limonite, reddish-brown and yellowish-brown respectively, constitute most of the third group but pyrite is conspicuous in some samples. In most till samples, opaques exceed 30 per cent of the heavy mineral fraction. The local bedrock is undoubtedly the source of some opaque minerals in the till.

Two types of tourmaline occur. One variety is pleochroic in pink and dark-green, commonly peppered with inclusions, and is only slightly abraded; the other is pleochroic in olive and very dark green, is rounded and commonly contains secondary overgrowths. Most samples possess only trace amounts (less than 1 per cent).

The most common type of zircon is colourless and usually a prism with pyramid terminations. Rounded, subrounded, fractured, and idiomorphic grains occur. The hyacinth variety is always well-rounded and in some instances shows zoning as does a brown, prismatic variety. Most of the zircon crystals contain rod-shaped and globular inclusions. In tills that overlie the Oldman Formation, zircon commonly makes up 2 per cent of the heavy mineral suite, but is present only in trace amounts in other tills. This suggests a local source for at least some of the zircons (most likely the idiomorphic zircons).

Most of the garnet is colourless to pale pink, clear and angular; the grains are bounded by conchoidal fracture surfaces. Dark brown and green garnets are present but rare. Inclusions of quartz, magnetite, and rutile are not uncommon. Garnet is an abundant heavy mineral in all till samples, constituting 10 to 20 per cent of the heavy mineral fraction.

Subangular to subrounded equant epidote grains predominate, but some elongate ones are present. Some grains are partially altered and cloudy, and a few possess inclusions. Occasional grains of clinozoisite are included with epidote, which forms more than 5 per cent of the heavy minerals in most samples.

Deep reddish-brown to red rutile occurs in trace amounts.

Colourless, pale yellow, and brown sphene is present as equant grains that show variable degrees of roundness. Sphene occurs in small amounts in most of the slides and seldom exceeds 3 per cent of the heavy mineral suite.

Only a few grains of the kyanite-staurolite-andalusite-sillimanite assemblage were observed.

The most common type of hornblende is pleochroic from green to bluish-green, and a variety pleochroic from green to brown is conspicuous. The majority of the hornblende grains are fresh-looking, prismatic cleavage fragments that seldom show any noticeable degree of rounding. Inclusions are present in some grains. Occasional grains of actinolite are counted as hornblende, which is the second most-abundant heavy mineral in the tills, commonly exceeding 30 per cent of the heavy mineral fraction.

Hypersthene, with its marked pleochroism from bluish-green to red to reddish-green, enstatite, and augite predominate in the pyroxene group. They are scarce and seldom constitute more than 3 per cent of the heavy mineral suite.

Apatite occurs as rounded, fractured, and euhedral grains which are always clear and colourless and which contain rod-shaped inclusions in some grains. This mineral forms 1 to 5 per cent of the heavy mineral fraction. The idiomorphic forms are most likely derived from the local Cretaceous bedrock.

Brown, brownish-red, red, olive, and green biotite flakes are present, with some containing globular or rod-shaped inclusions surrounded by pleochroic haloes. A few hexagonal euhedral flakes were observed. The high percentage of biotite in the bedrock samples and in some till samples, and the presence of euhedral flakes, suggest that most of the biotite in the till was derived from the local Cretaceous bedrock, some of it being volcanic in origin.

Over most of the map-area, hornblende is more than twice as abundant as garnet in the till samples, but variations in the relative abundance of these two minerals show no noticeable trends (Fig. 24).

Carbonate Content

The percentage carbonate (calcite plus dolomite) in the matrix of each till sample was determined by means of the Chittick gasometric apparatus using the procedure of Dreimanis (1962). All till samples were taken below the soil profile.

The results (Fig. 23) show the carbonate content of the tills to be quite variable, ranging from 24 per cent to less than 1 per cent. This figure also shows that in general a positive correlation exists between the carbonate content of the till matrix and the carbonate pebble content of the till. Thus, a relatively large amount of carbonate is present in the matrix of tills immediately north of the Cypress Hills: the same tills contain relatively large amounts of dolomite and limestone pebbles. In the southeastern part of the map-area, the carbonate content of the till matrix is variable, high and low values being juxtaposed: the same situation exists with respect to the carbonate pebble content. This suggests that the carbonate in the till matrix is largely derived from the comminution of dolomite and limestone pebbles. Sandstones of the Oldman Formation, however, contain dolomite, thus some of the carbonate in the matrix of tills on this formation is of local origin.

The results show considerable variation within one till sheet. The reason for this is not fully understood as yet and the carbonate content of the till matrix must presently be regarded of little use as a parameter to differentiate till sheets in the map-area.

Table 3. Heavy Mineral Composition of Cypress Hills Loess and underlying Cypress Hills Formation

SAMPLE NUMBER	SIZE RANGE (MM)	HEAVY MINERALS*																		
		Opaque																		
		Black	White	Others	Tourmaline	Zircon	Garnet	Epidote	Rutile	Sphene	Kyanite	Staurolite	Andalusite	Sillimanite	Hornblende	Orthopyroxenes	Clinopyroxenes	Apatite	Biotite	Others
Cypress Hills Formation																				
2661	.177—.062	37	13	15	1	6	7	11	—	2	—	tr	tr	—	tr	—	—	+	—	8
4461	.125—.062	27	22	12	2	tr	4	9	—	9	—	—	1	—	—	—	—	2	tr	9
Cypress Hills loess																				
1061	.177—.062	19	8	21	1	tr	9	11	tr	3	—	—	—	—	17	—	—	—	tr	10
1661	.177—.062	19	10	21	2	1	8	12	tr	4	tr	tr	—	—	14	—	tr	—	—	8
1761	.177—.062	22	6	40	tr	1	3	8	tr	4	—	—	—	—	5	—	tr	—	—	9
2561	.125—.088	22	9	17	tr	tr	5	10	—	6	—	—	3	—	8	—	tr	tr	tr	19
2561	.088—.062	28	11	14	1	2	6	11	tr	6	—	tr	—	—	5	—	tr	2	tr	12
2761	.177—.062	18	7	11	2	1	5	13	—	6	—	—	1	tr	15	—	tr	5	tr	15

* Figures indicate frequency percentages of grains.

+ Sample treated with HCl to remove iron staining—therefore no apatite.
Trace amounts are less than 1 per cent.

Petrography of Cypress Hills Loess

Heavy mineral studies verified the loessic origin of the sediment on the Cypress Hills Plateau. The heavy minerals present in the Cypress Hills loess and the underlying Cypress Hills Formation are shown in table 3. The Cypress Hills Formation possesses a resistant suite of heavy minerals: opaques, tourmaline, zircon, epidote, sphene, and garnet are all present. Less stable minerals such as hornblende are very rare and occur as cloudy, dentate grains in trace amounts. The Cypress Hills loess, on the other hand, contains up to 17 per cent fresh blue-green hornblende as well as heavy minerals that are common to the Cypress Hills Formation. This hornblende is identical to that found in nearby tills, and as the Laurentide glaciers did not overrun the Cypress Hills Plateau in the map-area, the hornblende could have been transported to the plateau only by the wind. A glacio-lacustrine origin is excluded because the Laurentide glaciers did not reach high enough around the Cypress Hills for an impounded glacial lake to form on the plateau. Moreover, the absence of bedding and ice-rafted erratics is evidence against such an origin.

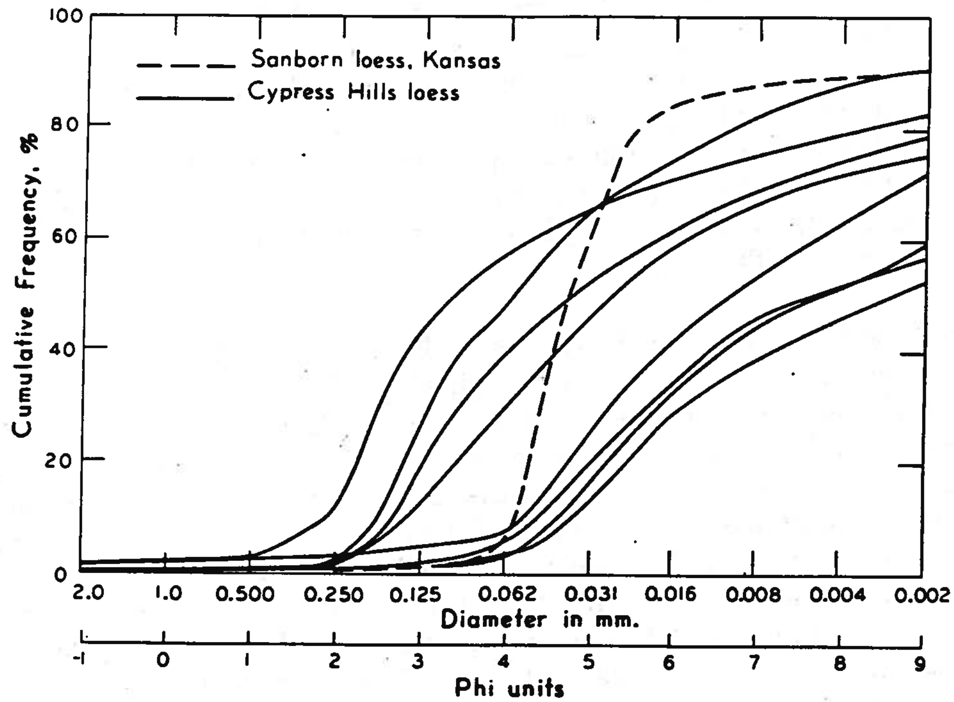


FIGURE 25. Cumulative curves of Cypress Hills loess.

Cumulative curves of the Cypress Hills loess (Fig. 25) show the sediment to be poorly sorted and in places coarse grained; the median diameter of some loess samples is in the fine sand fraction. These are atypical characteristics for a loess. It is felt that both may be explained, at least in part, by frost action churning up the loess itself and also bringing up into it coarse material from the underlying Cypress Hills conglomerate (see p.). However, the gradation from a sandy loess in the northern part of the plateau to a silty and clayey one farther south indicates that much of the sand-sized material is loessic in origin, being transported to the plateau by strong northerly prevailing winds. Laprade (1957) has shown that with maximum sustained wind velocities in excess of 25 m.p.h., sand-sized material may be carried to an elevation of 65 feet. This approaches transportation in limited suspension (Westgate, in press).

ICE THICKNESS AND ICE-MOVEMENT DIRECTIONS

Surface Gradients and Ice Thickness

In the map-area and its immediate vicinity, three nunataks projected above the surface of the ice sheet at the time of the most extensive Laurentide glaciation. In Alberta, the Cypress Hills formed a nunatak 120 square miles in area and approximately 300 feet high. The Sweet Grass Hills, just south of the International Border, stood up as nunataks (Calhoun, 1906), as did the Del Bonita Upland, west of the map-area (township 1, ranges 21 and 22; Stalker, 1962).

The northern slopes of the Cypress Hills were glaciated up to a height of 4500 feet above sea level. The highest glacial drift observed lies in section 29, township 8, range 1, where 8 feet of glacial gravel rests on the Cypress Hills Formation. The southern slopes of the Cypress Hills were not glaciated above 4050 feet. On the Del Bonita Upland, erratics are present up to 4550 feet above sea level (Stalker, 1965), whilst farther to the east, in the Sweet Grass Hills, the maximum altitude of erratics on the north flank of West Butte is approximately 4950 feet (Lemke *et al.*, 1965). Drift extends to an altitude of 4250 feet on the north side of the Bearpaw Mountains, south of Havre, Montana, and to an altitude of 3900 feet along the north flank of the Highwood Mountains, east of Great Falls, Montana (Lemke *et al.*, 1965). The progressive southeastward decrease in elevation of the highest erratics on these uplands, therfore, is interrupted by the relatively high altitude of erratics on West Butte. The explanation for this is not known.

If it be assumed that the most extensive Laurentide glacier reached its maximum height against the north flanks of these upland areas at about the same time, the regional slope to the ice surface south of the Cypress Hills must have been to the south at less than 3 feet per mile. Locally, however, around the Cypress Hills, the slope of the ice surface steepened to about 45 feet per mile. Between the Cypress Hills and the Del Bonita Upland the glacier's surface must have been almost horizontal.

Over the Foremost-Cypress Hills area, therefore, minimum estimates of ice thickness at the time of the most extensive Laurentide glaciation can be given as 2300 feet at Medicine Hat, and 1500 feet at Foremost, Manyberries, Aden, and Wild Horse (Map 29).

Local Directions of Ice Movement

Glacial lineaments, petrofabric analyses of till samples, sole marks on till sheets, streamlined land forms and indicators have all been used to determine the directions of ice movement in the map-area.

Glacial lineaments are best developed in the western half of the Foremost-Cypress Hills area, where, for the most part, the relief is small. They are rare in the dissected Cypress Hills Upland (Map 29). The common alignment of glacial lineaments parallel to ice-marginal channels and perpendicular to flutings shows that the dominant lineament trend parallels former positions of the ice front. The glacial lineaments and end moraines on map 29 clearly show the influence of local topography on the directions of ice movement and configuration of the ice front. Thus, in the southwestern part of the area glaciers locally moved to the south, but farther east they were forced to flow southeastwards along the stretch of low land between the Cypress Hills and Sweet Grass Hills. This southeasterly movement is well recorded by flutings, drumlins, drumlinoid ridges, and, in township 5, range 2, by numerous blocks of cemented Cypress Hills conglomerate that could have come only from the north-northwest.

Where glacial lineaments are not well developed, as in the vicinity of the Cypress Hills, till-fabric studies were conducted to determine the local directions of ice movement. It has long been known that stones in till have a preferred orientation (Miller, 1884). Richter (1932), however, was the first person to realize that stones in till tend to have their long axes aligned parallel to the direction of ice movement. He came to this conclusion after observing striations on elongate tillstones parallel to the long axes of these stones.

Oriented till blocks were collected in the field and the azimuth of the long axis of each stone was measured in the laboratory with a contact goniometer. Figure 26 suggests that 50 measurements will give the preferred orientation of the stones. One hundred measurements were made on each sample that was studied in the laboratory, but when measurements were made directly in the field, using a Brunton compass, they were limited to 50. The results are shown in figure 27 and map 29. Most of the rose diagrams display a distinct preferred orientation of the long axes of the tillstones. At several localities, glacial lineaments are aligned perpendicular to the long axis orientation of the tillstones (Fig. 27). This confirms the latter orientation as being parallel to the direction of ice movement, for the glacial lineaments here parallel former positions of the ice front.

At one locality (section 1, township 12, range 11), ice movement towards the southeast is indicated by sole marks on the bottom of the surface till sheet (Plate 12 and Map 29). Glacial lineaments in the area agree with this direction of ice movement and show that it was localized at the southeastern end of an ice lobe which extended into the northwestern corner of the map-area. The sole marks are composed entirely of till and consist of parallel ridges on the bottom of the till sheet. They were formed

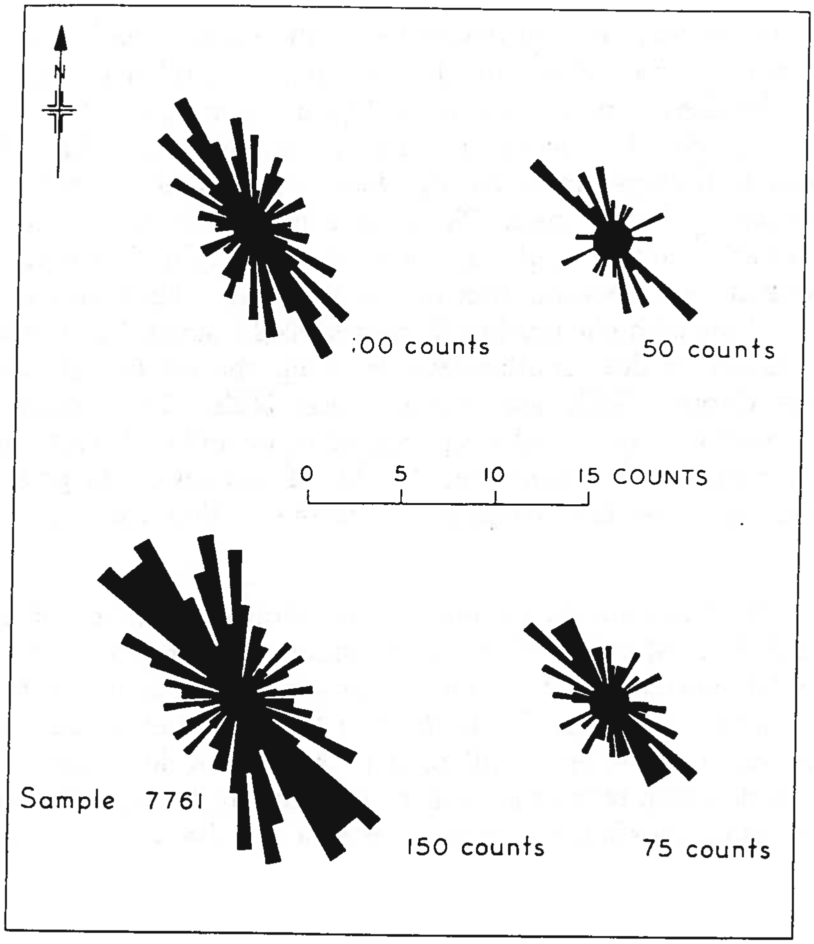


FIGURE 26. Variation of estimated preferred long-axis orientation of stones in a till as the number of measurements is increased.

when the glacier overran and deformed the underlying sands (Plate 12). At this time, the surface of the sand was furrowed, possibly by the scratching action of rock fragments at the base of the glacier, and, as the glacier continued to move, till was smeared into these linear furrows.

Where sand inclusions exist in till, a lineation may be present at the till-sand contact. In sample 561 (Fig. 27) this lineation is parallel to the long-axis orientation of the tillstones, and hence is parallel to the direction of ice movement.

A detailed account of the local ice-movement directions of the several glaciers that entered the map-area is given in the glacial history section.

Regional Directions of Ice Movement

Dolomite- and limestone-rich tills exist in the map-area (Fig. 23) but are absent from central and eastern Alberta. This observation prompted an

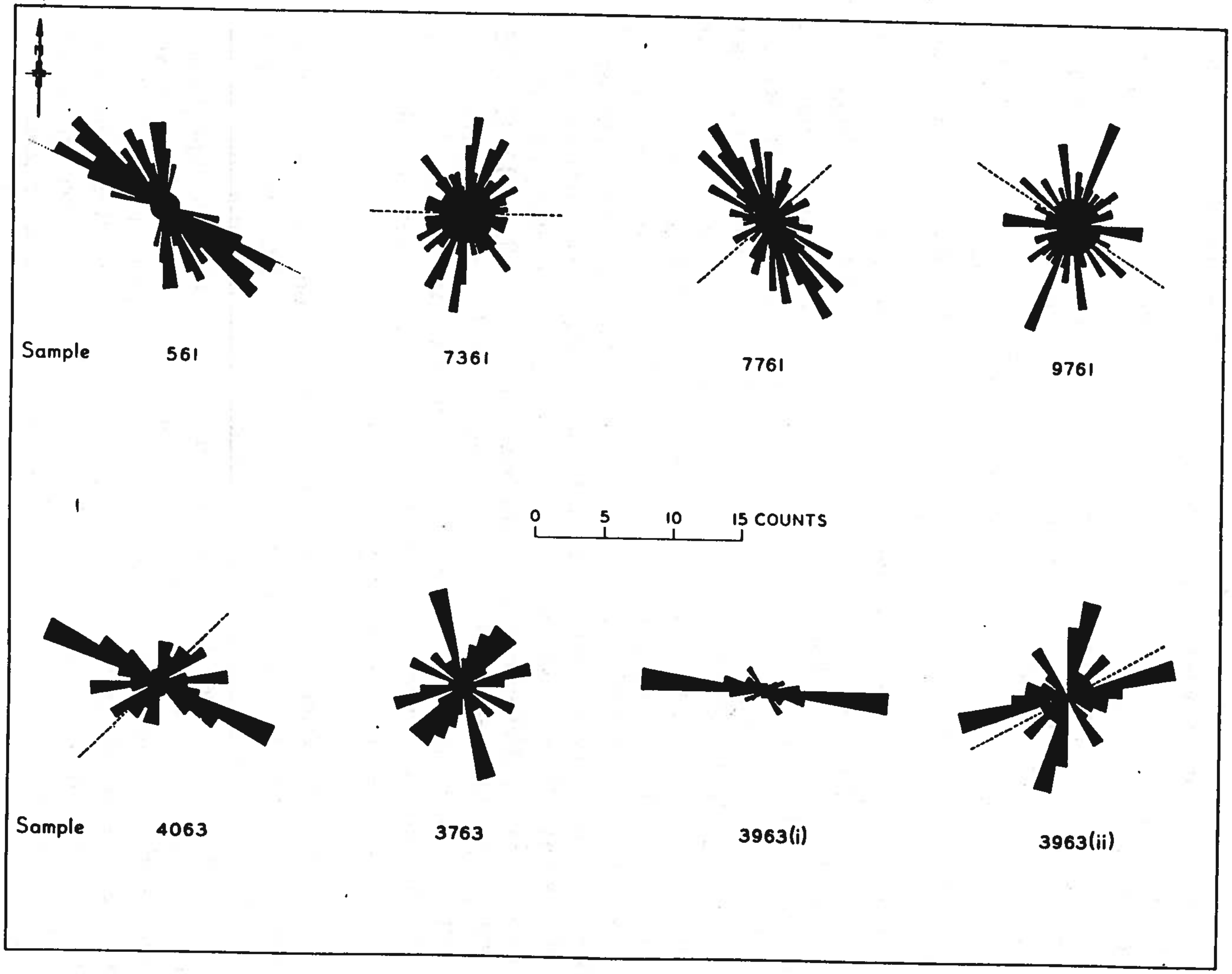


FIGURE 27.
Rose diagrams showing long-axis orientation of stones in tills.

examination of the significance of the change in erratic pebble composition of the uppermost tills in Alberta with respect to the regional directions of ice movement in the Western Prairies. Data on the pebble composition of tills in eastern Alberta were obtained from the Soils Division, Research Council of Alberta.

The erratic pebble composition of tills together with other relevant data on ice-movement directions are shown in figure 28, out of which arise several important facts.

Ice-flow markings indicate a southerly flow of ice, parallel to the Rocky Mountain Front, in west-central and southwestern Alberta at the time of the major glacial advance (Stalker and Craig, 1956). The erratic pebble content of the surface tills in eastern Alberta, however, can not be explained by movement in this direction. From the Cold Lake area south to Medicine Hat, there is a dilution of orthoquartzite, accompanied by an increase in dolomite and limestone. A sudden and striking increase in carbonate pebbles occurs in the tills of the Medicine Hat district. A large area of orthoquartzite (Athabasca Sandstone) exists south of Lake Athabasca, and extensive outcrops of Paleozoic carbonate rock occur southeast of Lac la Ronge (Fig. 28). Thus the changes in erratic composition of the surface tills in eastern Alberta are best explained by ice moving into this region from the northeast. The carbonate-rich tills at Medicine Hat and around the Cypress Hills were most probably deposited from ice that had crossed the wide belt of Paleozoic rocks just southeast of Lac la Ronge, Saskatchewan. This means that the last major Laurentide glacier to move into eastern Alberta flowed in a general direction of south 35 to 40 degrees west, which agrees with the ideas expressed in much of the early literature and by Gravenor and Bayrock (1955, 1956). The surface tills in northeastern Montana and northwestern North Dakota contain even more carbonate pebbles than those in southeastern Alberta, again indicating an over-all advance of the last glacier from the northeast (Lemke, 1960, p. 111; Howard, 1960, p. 41). Stalker (1965), however, argues that the southwesterly movement directions predominated only during the retreatal phases of the last major Wisconsin glacier which initially had advanced across the plains of Western Canada in a southeasterly direction.

In southern Alberta, south of 50° north latitude, the earlier, more extensive glaciers did advance to the southeast and later less extensive glaciers moved to the southwest (Westgate, 1965b). Directions of ice movement here, however, were considerably influenced by the topography. Irrespective of an easterly or westerly component to the southerly movement of glaciers across the central plains area, in southern Alberta these major glaciers would be forced to flow to the south and southeast, between the foothills of the Rocky Mountains on the west and the Tertiary uplands of southeastern Alberta and southern Saskatchewan on the east (Fig. 28).

PLEISTOCENE STRATIGRAPHY

Historical Review

Dawson and McConnell, working mainly in southwestern Alberta, distinguished four major stratigraphic units (Dawson, 1885, 1890, 1891, 1895; Dawson and McConnell, 1895): a Cordilleran till of Nebraskan age grading eastward into outwash gravels, named "Saskatchewan gravels" by Dawson; a Kansan Laurentide till; lignite-bearing interglacial beds of Yarmouth age; and a Laurentide till of Iowan age. Wisconsin drift was believed to be absent west of the Missouri Coteau. The stratigraphic column of the Pleistocene Series is given in figure 29. Johnson and Wickenden (1931) recognized the same stratigraphic units in southern Alberta as did Dawson and McConnell. They assigned a Kansan age to the lower Laurentide till and thought the upper one to be of early Wisconsin or Illinoian age, Horberg (1952) identified three Laurentide drift sheets in the Lethbridge region of southern Alberta and tentatively correlated them with the Iowan, Tazewell and Cary Substages of the Wisconsin Stage. He considered the "interglacial" beds of previous writers, which he called "Lenzie silt", to be proglacial lake beds deposited in front of the retreating Tazewell or Cary ice sheet. The "Saskatchewan gravels" were believed to be nonglacial in origin and probably of late Tertiary age. Recent work on Pleistocene deposits in southwestern Alberta has been done by Stalker (1962, 1963a, 1963b), who assigns an early Pleistocene age to the "Saskatchewan gravel and sand", recognizes Laurentide and Cordilleran tills of Nebraskan(?), Kansan(?), Illinoian(?), and Wisconsin age, and suggests that the wood-bearing "interglacial" beds, first described by Dawson (1885), are of Yarmouth age.

Calhoun (1906) studied the Pleistocene deposits of northern Montana and concluded that the quartzite gravels—equivalent to Dawson's "Saskatchewan gravels"—were deposited by streams in "pre-Glacial" time, being derived from Tertiary gravels occurring at higher elevations. The fresh morainal topography of the surface Laurentide drift, the amount of post-glacial erosion and degree of weathering led him to believe that this till sheet was of late Wisconsin age. He found some evidence to suggest the presence of an older Laurentide till and also recognized a pre-Wisconsin Cordilleran drift. According to Alden (1932), the oldest till in Montana was deposited by glaciers from the Rocky Mountains in early Pleistocene time. Equivalents of Dawson's "Saskatchewan gravels" were recognized and believed to be pre-Iowan or pre-Illinoian in age, representing either the Sangamon or Yarmouth Stage. Alden comments on the age of the lower Laurentide till as follows (Alden, 1932, p. 69):

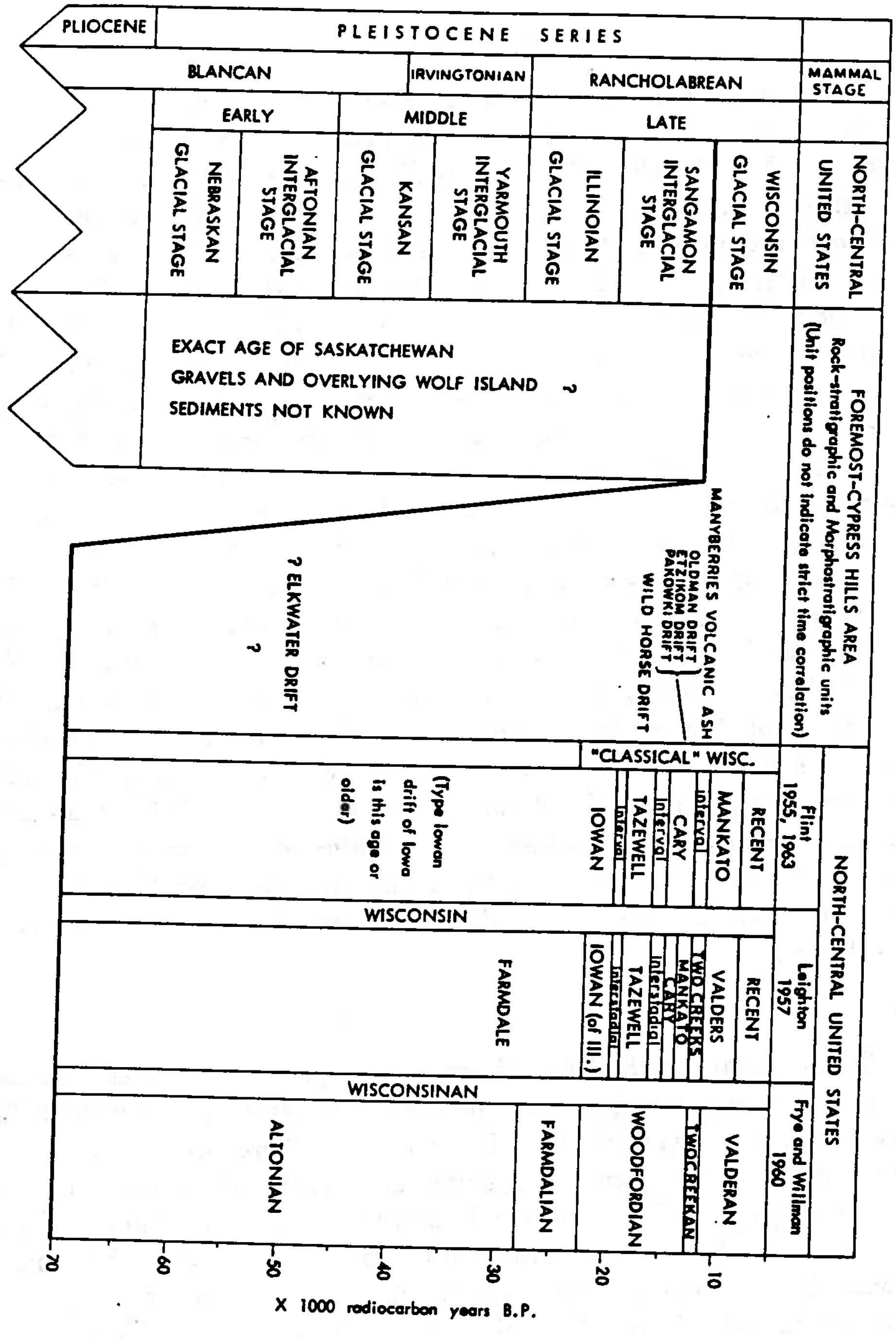


FIGURE 29. Tentative correlation of Pleistocene deposits in southeastern Alberta and north-central United States. Classifications of Wisconsin Stage taken from Frye and Willman (1963) and Lemke et al. *(1965). Age of Cypress Hills loess is not known exactly.*

There seems to be no clear evidence that the Keewatin ice sheet invaded Montana at either the Nebraskan or the Kansan stage of glaciation. Neither is it certainly known that there was extensive development of the Keewatin glacier at the Illinoian stage, when the Labradorean ice sheet extended southwestward over most of Illinois and encroached on southeastern Iowa. After the Sangamon stage of deglaciation, however, there came on a new development and extension of the great Keewatin ice sheet centering in the Hudson Bay region. The ice spread southward across Minnesota into northern Iowa and left a deposit of drift of moderate thickness, which has been regarded as of pre-Wisconsin age but not so old as the Illinoian drift of the Labradorean ice sheet. There are some good reasons, as it seems to the writer, for thinking that the drift found in the Dakotas and in Montana, outside what is regarded as the limit of the Wisconsin drift, is not older than the Iowan drift. It is possible, however, that it is really of Illinoian age.

The Illinoian or Iowan till was subjected to a moderate amount of erosion before the early or middle Wisconsin Laurentide till was deposited on it. In the western part of Montana these Laurentide tills are interbedded with Cordilleran tills.

Local Stratigraphy

General Statement

The stratigraphic column of the Pleistocene deposits in the Foremost-Cypress Hills area is shown in figure 29. The Saskatchewan Gravels and overlying Wolf Island sediments, Cypress Hills loess and Manyberries volcanic ash are all rock-stratigraphic units. The glacial drift sheets, however, are not rock-stratigraphic units as defined by the American Commission on Stratigraphic Nomenclature (1961, Art. 4) because they have been differentiated by their topographic form, geographic position, and inferred geologic history. They are morphostratigraphic units, defined by Frye and Willman (1960, p. 7) as "a body of rock that is identified primarily from the surface form it displays; it may or may not be distinctive lithologically from contiguous units; it may or may not transgress time throughout its extent."

Frye and Willman (1962) took the moraine as the basic unit "and the deposits assigned to it include those of the end moraine that gives it identity, the associated outwash apron, if one exists, and the drift continuing into the associated ground moraine." Clayton (1962, p. 53) considered the basic unit a drift rather than a moraine, and defined a morphostratigraphic unit as "a body of drift that is identified by its surface form and position and consists of all the drift deposited from the glacial ice and associated melt-water of a significant glacial advance."

The establishment of a complete rock-stratigraphic sequence for the Pleistocene deposits of the Foremost-Cypress Hills area is presently not possible because of the limited number of known critical sedimentary parameters in the glacial drift sheets and the scarcity of C-14 dates. Correlation of tills on the basis of lithology alone is still hazardess, hence the glacial drift sheets are here classified into morphostratigraphic units, even though such a scheme does not necessarily embrace all of the drift sheets deposited in the map-area, as some deposits may not crop out at the surface.

Saskatchewan Gravels

For the purpose of this report, the Saskatchewan Gravels are defined as those preglacial* fluviatile sediments that floor the major preglacial valleys and cover the several alluvial terraces below the erosional surface situated at about 4000 feet above sea level (Fig. 8)—a surface probably correlative to the Flaxville level of Collier and Thom (1918). The multiplicity of levels on which these gravels and associated sediments occur (see also Rutherford, 1937, p. 86; Bayrock and Hughes, 1962, p. 17-18; Jensen and Varnes, 1964, p. F28-29) render their subdivision difficult and make it expedient, at present, to group them under one formational name.

McConnell (1886, p. 70c) first described these gravels and named them "South Saskatchewan gravels". Dawson and McConnell (1895, p. 36) later renamed them "Saskatchewan gravels". Since then geologists working in the plains of Western Canada have called these sediments "quartzite river gravels" (Johnston and Wickenden, 1931), "Saskatchewan gravels and sands" (Rutherford, 1937; Westgate and Bayrock, 1964), "Saskatchewan sands and gravels" (Bayrock and Hughes, 1962), and "Saskatchewan gravel and sand" (Stalker, 1963b). The name "Saskatchewan Gravels" is the preferred term; it has priority over the other names and is still in frequent use; it is also the simplest term.

The Saskatchewan Gravels have been widely recognized in the plains of Western Canada and the northern Great Plains of the United States, everywhere lying unconformably upon bedrock and, in most places, covered by glacial drift. In southern Alberta they have been described by McConnell (1886), Dawson and McConnell (1895), and Stalker (1963b); in central Alberta by Rutherford (1937), Bayrock and Hughes (1962), and Westgate and Bayrock (1964); in north-central Alberta by Henderson (1959). The Saskatchewan Gravels floor the major preglacial valleys in Saskatchewan (Christiansen, 1963, p. 51) and have also been recognized in southwestern Manitoba (Elson, 1958, p. 63). In Montana, equivalents have been identified

* In this report the term "preglacial" is used in the sense of "prior to the incursion of the first Laurentide glacier into the map-area".

by Calhoun (1906), Alden and Stebinger (1913), Alden (1932), Smith *et al.* (1959), and Howard (1960). Jensen's (Jensen and Varnes, 1964, p. F28) Wiota gravels are probably correlative with the Saskatchewan Gravels.

In the Foremost-Cypress Hills area, the Saskatchewan Gravels lie unconformably upon Upper Cretaceous rocks and are well exposed in places along the Oldman River Valley and South Saskatchewan River Valley, north of Medicine Hat. These exposures are of the lower (and younger) part of the Saskatchewan Gravels, namely the channel fill in the preglacial valleys. Observed thicknesses range from a few feet to over 30 feet. Other buried preglacial valleys in the map-area are undoubtedly floored with these fluvial gravels and sands. In the southern half of section 25, township 11, range 2 a preglacial terrace, about 2500 feet above sea level, is covered by 10 feet of Saskatchewan Gravels, which lithologically resemble the Cypress Hills conglomerate. The relationship of this terrace to its preglacial valley is best seen from the bedrock high some three miles to the north. Still higher (and older) occurrences of Saskatchewan Gravels are found on the 3200-foot preglacial divide in the southeastern corner of the map-area; in the northwest quarter of township 2, range 3 they crop out at the surface.

The Saskatchewan Gravels vary laterally from deposits consisting entirely of sand to those containing coarse gravel. The pebbles and cobbles of the latter are dominantly quartzite, argillite and chert (the average of two samples, each containing about 1000 stones, was 98 per cent); the remainder consists of arkose, limestone, a green feldspathic porphyry, and bedrock fragments of local derivation. No material from the Canadian Shield is present. Most of the pebbles are red or brown and many are stained by ferric oxide, giving an over-all reddish-brown colour to the sediment. The source region of these gravels and sands lies in part in the Beltian and Paleozoic rocks of the Rocky Mountains to the west (Dawson, 1895; Calhoun, 1906; Alden, 1932; Horberg, 1952) but a significant contribution came from the gravel-capped elevated remnants of the Flaxville and Cypress Hills surfaces (McConnell, 1886; Calhoun, 1906; Alden, 1932; Rutherford, 1937; Colton, 1962; Jensen and Varnes, 1964).

Frost-action (cryogenic) structures (involutions and deranged pebbles) were observed in the Saskatchewan Gravels exposed along the Oldman River Valley (Plate 13). In places these post-depositional structures are overlain by undisturbed Saskatchewan Gravels showing that a cold climate existed in the map-area before deposition of the Saskatchewan Gravels had ceased. Similar frost-action structures have been observed by Westgate and Bayrock (1964) in the Saskatchewan Gravels of central Alberta. They conclude that the uppermost beds were deposited in a periglacial environment.

Divergent views have been expressed as to the age of the Saskatchewan Gravels (see above). Frost-action structures within the low-level preglacial valley fill deposits indicate a Pleistocene age for these younger members. The occurrence of remains of *Mammuthus primigenius* (woolly mammoth) and *Equus* sp., somewhat smaller than the modern *Equus caballus,* at the same horizon likewise denotes a Pleistocene age (see Appendix for stratigraphic sections); the presence of *Mammuthus primigenius* supports the contention that the lower (and younger) part of the Saskatchewan Gravels accumulated in a periglacial environment. A similar faunal assemblage has been found in the Saskatchewan Gravels of central Alberta (Bayrock, pers. comm., 1964) and the equivalent deposits (Wiota gravels) of northeastern Montana (Jensen and Varnes, 1964, p. F28-31). Hibbard comments on the stratigraphic range of *Mammuthus primigenius* as follows (Hibbard *et al.,* 1965, p. 518):

> Two separate stocks of this genus *(Mammuthus)* seem to have entered North America (via the Bering Straits). The later was *M. primigenius,* the Woolly Mammoth, during the Rancholabrean. The earlier was the stock first seen as *Mammuthus haroldcooki* in Kansas and Oklahoma in late Kansan deposits. It may have given rise to all later American species except *M. primigenius.*

The Rancholabrean Mammal Age embraces the Illinoian, Sangamon and Wisconsin Stages (Fig. 29). In North Eurasia, the stratigraphic range of *M. primigenius* is Riss to late Wurm or early Holocene (Zeuner, 1959, p. 334-336; Gromov *et al.,* 1965). This suggests that the youngest beds of the preglacial Saskatchewan Gravels are Illinoian or younger in age. However, this fauna has not been studied closely as yet, and the exact age of the youngest members of the Saskatchewan Gravels must still be regarded as unresolved.

A C-14 date of 29,200 $^{+8100}_{-4000}$ radiocarbon years B.P. (GX-0102) was obtained on wood collected from the preglacial valley fill member of the Saskatchewan Gravels exposed along the South Saskatchewan Valley at NE¼, Sec. 9, Tp. 13, R. 5, just north of Medicine Hat. At this locality sand is the major constituent of the Saskatchewan Gravels, which are overlain by 40 feet of lacustrine sand and silt, 3 feet of till, a thin gravel bed, another 40 feet of lacustrine silt, and 20 feet of massive till. A rerun on this wood, however, gave a date of greater than 36,600 years (GX-0210). The wood giving the finite date is considered to have been contaminated. A similar "greater than" C-14 date was obtained on wood collected from the Saskatchewan Gravels near Edmonton (L. A. Bayrock, pers. comm., 1964). Further, radiocarbon analysis on wood from an intertill deposit near Lethbridge (Fig. 1) indicates that the Saskatchewan Gravels there must be older than 54,500 years (GSC-237).

The above discussion concerns the age of the topographically lower members of the Saskatchewan Gravels specifically, the low-level valley fill deposit. The Saskatchewan Gravels on the higher terraces are clearly older than the valley fill member, and, as defined in this report, the uppermost levels of the Saskatchewan Gravels may well be late Tertiary in age.

Wolf Island Sediments

Wolf Island sediments consist of lacustrine sands, silts, and clays that conformably overlie the Saskatchewan Gravels within the major preglacial valleys but sit directly on bedrock in the tributary preglacial valleys (Plate 13). Along the Oldman River Valley, near Wolf Island (Lsd. 12, Sec. 20, Tp. 11, R. 14), these sediments are laminated and 20 feet thick, but at other places along this valley they have been removed. McConnell (1886, p. 71c) gives a thickness of 150 feet of fine sand and silt above the Saskatchewan Gravels near to where the South Saskatchewan River enters the Red Deer River. The upper part of this stratigraphic unit was deformed when the first Laurentide glacier entered the region.

These sands, silts, and clays accumulated in elongate proglacial lakes that formed along the preglacial valleys when the outlets of their rivers, which then drained northeastwards into Hudson Bay, became blocked by the encroaching Laurentide glacier. As the Wolf Island sediments conformably overlie the Saskatchewan Gravels—there being no evidence of a prolonged break in sedimentation—they are considered to be only slightly younger than the youngest part of the Saskatchewan Gravels.

The presence of fine-grained, laminated sediments above Saskatchewan Gravels has been noted by several workers (Witkind, 1959, p. 19; Smith *et al.*, 1959, p. 135-137; Stalker, 1963b, p. 4; Jensen and Varnes, 1964, p. F29). Stalker's interpretation is the same as that given above. In every case, however, these lacustrine sediments are grouped with the Saskatchewan Gravels. They are treated here as a separate stratigraphic unit so as to emphasize the radical change in depositional environment: the Saskatchewan Gravels were deposited by swiftly flowing streams; Wolf Island sediments accumulated in cold, quiet proglacial lakes.

Surficial Drift Sheets

Five surficial drift sheets (morphostratigraphic units) have been identified in the Foremost-Cypress Hills area. All were deposited by Laurentide glaciers. Their respective end moraines are shown in figure 30, each end moraine representing the approximate outer limit of a significant glacial advance. The drift sheets are informally designated, in order of decreasing age, the Elkwater drift, Wild Horse drift, Pakowki drift, Etzikom drift, and Oldman drift.

LEGEND

Cypress Hills Plateau; unglaciated

Oldman End Moraine (youngest)

Etzikom End and Recessional Moraines

Pakowki End Moraine

Wild Horse End and Recessional Moraines (oldest)

Glacial lineaments

② + Site of geological section described in appendix

A Elkwater drift

B Wild Horse drift-outer limit

C Pakowki drift-outer limit

D Etzikom drift-outer limit

E Oldman drift-outer limit

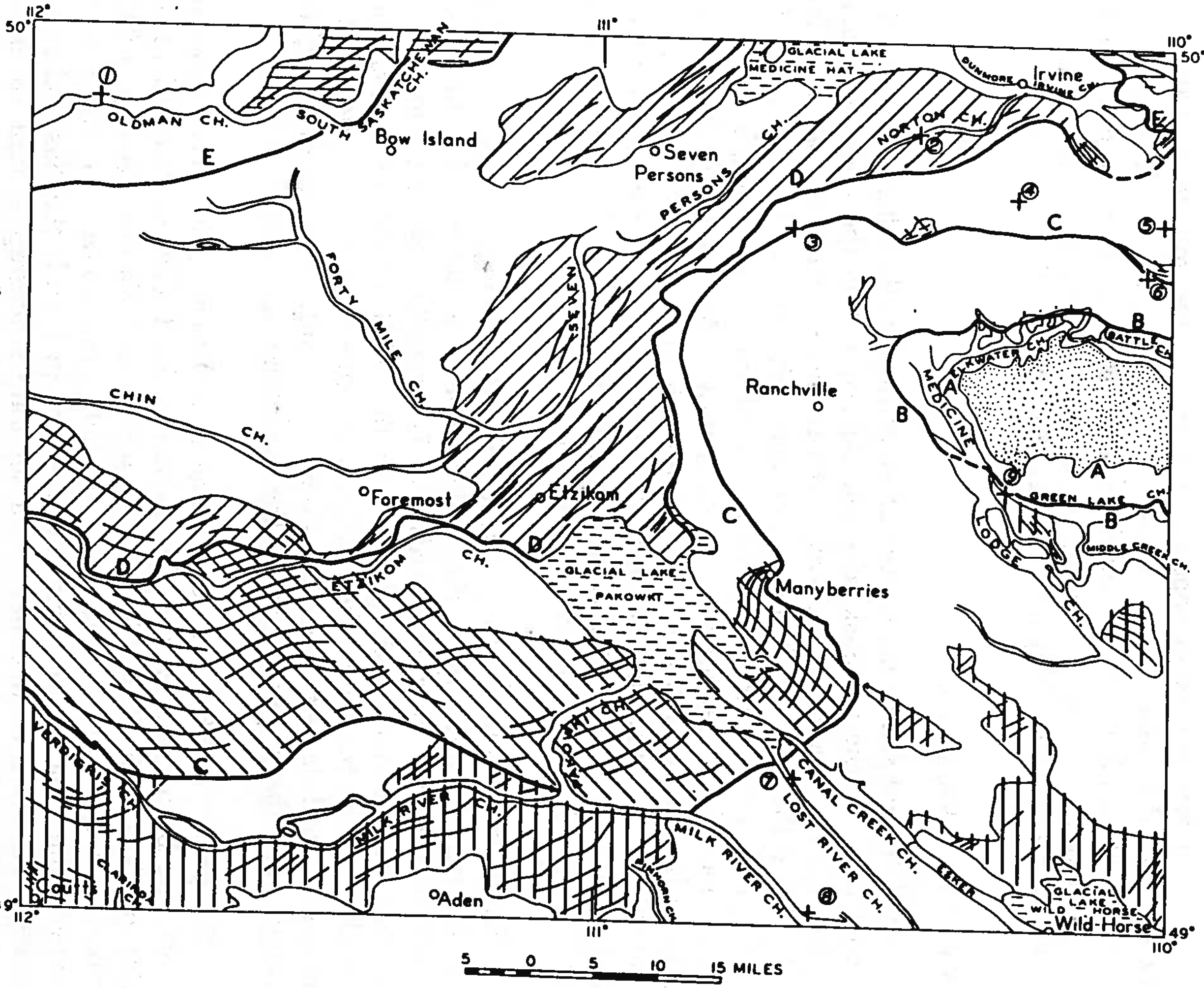


FIGURE 30.
Morphostratigraphic units in Foremost-Cypress Hills area.

The *Elkwater drift,* in the map-area, is confined to the Cypress Hills and its immediate vicinity (Fig. 30). For the most part, it lies between 4500 feet and 4100 feet above sea level. The drift is thin, discontinuous, and consists of sporadic patches of glacial gravel and till together with some large erratics, dolomite erratics being conspicuous. Glacial gravels just north of Elkwater (Sec. 30, Tp. 8, R. 2) have the following composition: 87 per cent quartzite pebbles, 9 per cent granitic rocks from the Canadian Shield, and 4 per cent dolomite pebbles. Deformed bedrock at the western end of the Cypress Hills (Sec. 9, Tp. 8, R. 4) indicates that the Elkwater glacier here moved towards the southeast.

The *Wild Horse drift* is present in the southern end eastern portions of the map-area, lying roughly between 4100 feet and 3200 feet above sea level. Till predominates but extensive glacio-fluvial and glacio-lacustrine deposits exist in the southeastern corner of the region. The drift is generally less than 50 feet thick but north of the Cypress Hills it approaches a thickness of 100 feet. The till has a clay-loam to loam texture and its pebble composition, if the soft rock fragments of local origin are excluded, is 50 to 60 per cent dolomite and limestone, with the remainder consisting dominantly of granitic rocks from the Canadian Shield. Just north of the Cypress Hills, the dolomite pebble content increases to 85 per cent. In general, the carbonate pebble content is relatively high in comparison to that of the younger drifts. The drainage is integrated over large parts of the Wild Horse drift but a deranged pattern exists over much of the hummocky morainal tracts where the topography is very rugged and undrained depressions common (Plate 5).

The *Pakowki drift* occupies most of the terrain between Etzikom Coulee and Milk River Valley and covers the western and northern outer slopes of the Cypress Hills Upland (Fig. 30). Its end moraine lies at about 3200 feet above sea level. The drift consists mainly of till that has a loam texture, being somewhat coarser-grained than the Wild Horse till. The drainage is mostly nonintegrated; stream courses are determined by the disposition of the glacial land forms, and undrained depressions are ubiquitous. The topography is rugged for the most part, morainic ridges, knobs, and depressions being sharply defined.

The *Etzikom drift* covers part of the northern half of the map-area. A broad, well-developed end moraine, at about 3000 feet above sea level, marks its outer limit. Till forms the bulk of the drift, but glacio-lacustrine sediments cover part of the surface. Crystalline rocks from the Canadian Shield are much more abundant in the Etzikom drift than in any of the older drifts. They may constitute 70 to 80 per cent of the pebbles in the till, if rocks of local origin are excluded. Values of the ratio, carbonate pebbles to crystalline pebbles from the Canadian Shield, range from 0.2 to 0.9 in the Etzikom drift, but are consistently over 1.0 in the Wild Horse drift. Remarks applied to the Pakowki drift on drainage and morphology equally apply to the Etzikom drift.

The *Oldman drift* occupies the northwestern and northeastern corners of the map-area. Its end moraine lies at an elevation of about 2650 feet and is covered over much of its length by lacustrine sediments. The lithology of the Oldman drift in the northwestern part of the area is similar to that of the Etzikom drift—crystalline rocks and orthoquartzites from the Canadian Shield being predominant—but near the Saskatchewan border the Oldman drift becomes very rich in dolomite; the value of the ratio, carbonate pebbles to crystalline pebbles from the Canadian Shield, is 2:1.* The topography and drainage in the Oldman drift area both have a youthful aspect.

At present only tentative and general statements can be made as to the *age* of these surficial drift sheets. A "classical" Wisconsin age for the Wild Horse and younger drifts is suggested by their fresh-looking morainal topography, slight degree of weathering, abundance of undrained depressions, and poorly integrated to nonintegrated drainage. The presence of three tills younger than 24,500 years at Medicine Hat (Dyck *et al.*, 1965; GSC-205), and the presence of the deformed 12,000-year old Manyberries volcanic ash layer (see below) on the Pakowki drift corroborate this age assignment.

A significant glacial advance across southwestern Saskatchewan and southern Alberta took place approximately 24,000 to 20,000 years ago. This is indicated by three C-14 dates. At Medicine Hat, wood from a peat bed buried by three tills, was dated at 24,490 ± 200 radiocarbon years B.P. (GSC-205). Just north of Leader, Saskatchewan, a soil buried by glacial drift, was dated at 20,000 ± 850 years B.P. (S-176; Christiansen, 1965a), and at Marsden, Saskatchewan, another buried soil was dated at 21,000 ± 800 year B.P. (S-228; *ibid.*). A major glacial advance, therefore, marks the beginning of the "classical" Wisconsin in southern Alberta and southern Saskatchewan—as it does in central and eastern North America (Flint, 1963, figure 2). The Wild Horse drift was most probably deposited during this early "classical" Wisconsin advance. Two C-14 dates (S-173 and S-198; Christiansen, 1965a) in southwestern Saskatchewan show that the youngest drift in the Foremost-Cypress Hills area—the Oldman drift—must be older

* This calcareous till was previously included in the Etzikom drift (Westgate, 1965b), but the elevation of the outer edge of this till is close to that of the Oldman end moraine, suggesting equivalence to the latter.

than 13,000 years. In other words, the Wild Horse, Pakowki, Etzikom, and Oldman drifts most likely all fall within the Woodfordian Substage of Frye and Willman (Fig. 29).

The problem on the age of the Elkwater drift may be summarized as follows: does this drift represent material laid down by a distinctive glacier or is it related to the Wild Horse drift? Information from the Cypress Hills area pertinent to this problem is limited—in part a consequence of the relatively small and discontinuous outcrop area of the Elkwater drift—but evidence from neighbouring areas suggests the former to be true. To the west of the map-area, Stalker (1962) has noted that the glacial drift surrounding the unglaciated Del Bonita Upland, at an elevation of approximately 4100 to 4500 feet, has suffered much more erosion than the topographically lower glacial deposits to the north. In addition, the depth and form of surface weathering, drainage, and absence of buried spillway valleys also distinguish this drift from the lower drift sheets (Stalker, pers. comm., 1963). The similarity in elevation of the highest drift sheet on the Del Bonita Upland to that of the Elkwater drift, together with their geographic proximity, strongly points to an equivalence of these drift sheets. Hence, a time interval of some note probably elapsed before the Wild Horse drift was deposited on to the Elkwater drift.

The Wild Horse drift can be traced southward from the map-area into Montana where its outer edge is marked in places by a youthful-looking end moraine whose local relief occasionally approaches 50 feet. Drainage developed on this drift of Advance 2 (Lemke *et al.*, 1965) is poorly integrated and the ground moraine surface is characterized by numerous undrained depressions. Outside this fresh-looking drift, in Montana, there is another drift sheet (Lemke's Advance 1) upon which surface drainage generally is well integrated. The till is thin or missing in some places; elsewhere it is revealed only by erratic boulders and a few stratified ice-contact deposits (Lemke *et al.*, 1965). The drift of Advance 1, the Elkwater drift, and the highest drift surrounding the Del Bonita Upland, all lie above or beyond the outermost end moraine of the fresh-looking glacial drift (Fig. 31); they all bear witness to long-continued erosion. It seems most probable, therefore, that they are isolated outcrops of the same drift sheet. On the basis of three radiocarbon dates (Lemke *et al.*, 1965, p. 21) Lemke correlates the drift of Advance 1 with the Altonian Substage of Frye and Willman (1960). The age of the Elkwater drift, therefore, is tentatively considered to be post-Sangamon, pre-"classical" Wisconsin, correlating in time with the Altonian of Frye and Willman (Fig. 29).

All of the surface drifts in the Foremost-Cypress Hills area, therefore, are believed to belong to the Wisconsin Stage. Two subsurface Laurentide

Explanation: shaded area—unglaciated by Laurentide ice; ice frontal position 1—outer edge of Elkwater drift and Advance No. 1 drift of Lemke *et al.* (1965); ice frontal position 2 — outer edge of Wild Horse drift and Advance No. 2 drift of Lemke *et al.* (outer front of "classical" Wisconsin drift); ice frontal position 3—outer edge of Pakowki drift; ice frontal position 4 — outer edge of Etzikom drift; ice frontal position 5 — outer edge of Oldman drift; ice frontal position A—regarded by Christiansen (1965a) as 20,000 years old but considered by the writer to be younger—probably the eastward extension of ice frontal position 4 or 5; ice frontal position B—dated as 13,000 years old (Christiansen, 1965a).

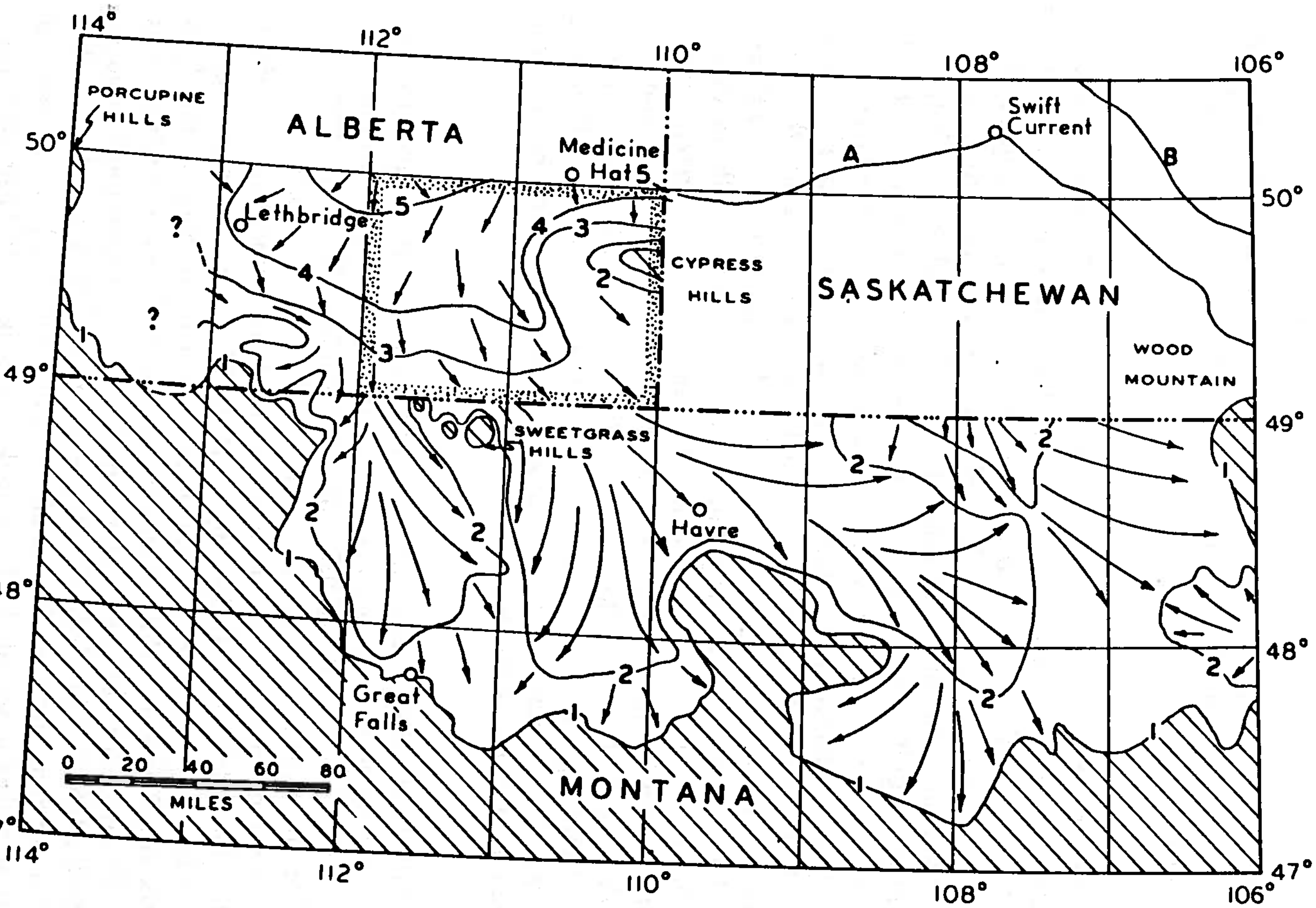


FIGURE 31. ***Directions of ice-movement and significant ice frontal positions in southern Alberta and adjacent areas. Compiled from Horberg (1952), Colton* et al. *(1961), Stalker (1962), Westgate (unpubl. Ph.D. thesis, Univ. Alberta), Lemke* et al. *(1965), and Christiansen (1965a).***

tills near Kipp, however, are older than 54,500 years (Stalker, 1963b; GSC-237), indicating that Laurentide tills of early Wisconsin age or older are present in southern Alberta.

Cypress Hills Loess

A description of the Cypress Hills loess is given in the sections on geomorphology and petrography of the glacial deposits. From the present studies it has not been possible to determine whether the loess was deposited on the Cypress Hills Plateau at the time of the Elkwater or Wild Horse advance.

Manyberries Volcanic Ash

The Manyberries volcanic ash is exposed just south of Manyberries, in Lsd. 14, Sec. 13, Tp. 5, R. 6. It is a 6-inch thick bed, pale greyish orange in colour (10 YR 7/2), contains few detrital contaminants, and grades from a fine sand at the base to a clay at the top (2 per cent fine sand, 93 per cent silt, and 5 per cent clay). The mineralogy is summarized in table 4. The ash bed is covered by 20 to 25 feet of lacustrine sand, silt, and clay and is underlain by 4 feet of lacustrine silt below which occurs 1 foot of outwash gravel and sand, which in turn lies on till. At one place along the section, the dip on the ash bed and adjacent lacustrine sediments suddenly steepens and here the beds are cut by small normal faults (Plate 14). These post-depositional structures indicate that the beds locally collapsed due to the

Table 4. Mineralogy of the Manyberries Volcanic Ash

CONSTITUENT (0.125 to 0.062 mm size fraction)	FREQUENCY PERCENTAGE[1]
Glass (cloudy)	42
Glass (clear)	29
Feldspar (mainly plagioclase)	19
Quartz	5
Hornblende	3
Magnetite	1
Orthopyroxene	1
Garnet	tr
Calcite	tr
Biotite	tr
Refractive index of glass	1.500 - 1.501
Refractive index (n) of hornblende[2]	1.645 - 1.652
Composition of plagioclase feldspar[3]	Andesine ($Ab_{55}An_{45}$)

[1] 300 grains counted.
[2] R. E. Wilcox, pers. comm., 1965.
[3] Calculated from maximum extinction angles of albite twins in sections normal to [010] . n > 1.54.

loss of support at depth, which most probably occurred as a result of the disappearance, by melting, of buried blocks of ice. This suggests that the Manyberries volcanic ash and underlying Pakowki till are approximately contemporaneous. Christiansen (1965b, p. 22), however, has shown that stagnant ice persisted in parts of southwestern Saskatchewan for more than 2000 years. Hence, the Pakowki till may be this order of magnitude older than the Manyberries volcanic ash.

As pointed out by Powers and Wilcox (1964), and Fryxell (1965), volcanic ash layers are sufficiently common and widespread in the Pleistocene and in recent deposits of northwestern United States and adjacent Canada to serve as time-stratigraphic marker horizons provided that they can be identified and correlated. Powers and Wilcox (1964) have developed petrographic techniques for correlation of these ashes, and have recognized two distinct widespread ash layers. The younger ash comes from the extinct Mount Mazama at Crater Lake, Oregon and is about 6600 years old; the other comes from Glacier Peak in the northern Cascade Range of Washington and is about 12,000 years old (Fryxell, 1965).

A sample of the Manyberries ash was submitted to R. E. Wilcox, United States Geological Survey, who identified it as Glacier Peak ash. Wilcox (written communication, 1965) states:

> It (Manyberries volcanic ash) corresponds to Glacier Peak ash in shard habit, presence of numerous microlites, glass refractive index (1.500 - 1.501), phenocryst suite (plagioclase, orthopyroxene, hornblende, and magnetite), and in the refractive index of the hornblende (n_x = 1.645 - 1.652). The microlites, glass index, and hornblende index eliminate any possibility that it could be Mazama ash. Except for the remote possibility that another ash with these characteristics might turn up in this part of the stratigraphic section, its identification as Glacier Peak ash would seem entirely reasonable.

The Manyberries ash, therefore, is about 12,000 years old, but the Pakowki till can not be as young as this for surficial glacial drift in southwestern Saskatchewan, which is definitely younger than any drift in the Foremost-Cypress Hills area, is dated at 13,000 years B. P. (Christiansen, 1965a). This apparent inconsistency is resolved if the ice buried in the Pakowki drift existed for a considerable time. In this case deposition and subsequent collapse of the Manyberries ash would considerably post-date deposition of the Pakowki drift—possibly by some 2000 years (see above). Hence the age of the Pakowki drift is probably about 14,000 to 15,000 years.

PLEISTOCENE HISTORY

Preglacial History

The major features of the present-day topography in southern Alberta and adjacent Montana were formed during the Tertiary and early Pleistocene when numerous changes in the stream regimen were brought about by intermittent phases of regional uplift. Extensive and substantial valley deepening by rejuvenated streams characterized periods of regional differential uplift; aggradation and valley-widening took place during periods of regional stability. Throughout this considerable time interval, a number of major rivers flowed across southern Alberta in an easterly or northeasterly direction (Fig. 9). Their headwaters were situated in the Rocky Mountains to the west and their mouths opened out into Hudson Bay. The coarse traction load of these rivers consisted dominantly of quartzite and argillite pebbles, with some limestone and dolomite. These were derived from the Beltian and Paleozoic rocks in the Rocky Mountains. The Upper Cretaceous sandstones and shales were readily comminuted once they were picked up by these streams.

The product of this, in terms of land forms, is a vertical sequence of benches and alluvial terraces that are mantled with quartzitic gravels; all of these terraces have a regional slope to the east but are locally inclined towards the adjacent valley. Figure 8 shows the major erosional surfaces that are present in the Foremost-Cypress Hills area.

The Saskatchewan Gravels were deposited during the latter part of this early Tertiary-preglacial Pleistocene interval. That the younger beds of the Saskatchewan Gravels are Pleistocene in age is indicated by the faunal assemblage and presence of frost-action structures. Sedimentation of these quartzitic gravels ceased when the outlets of the rivers became blocked by Laurentide ice. At this time, proglacial lakes formed along the preglacial valleys. The Wolf Island sands, silts, and clays accumulated in these cold-water lakes.

Glacial History

Exactly when the first Laurentide glacier entered the Foremost-Cypress Hills area is not known.

The *Elkwater glacier* advanced across the map-area and deposited the Elkwater drift probably in early Wisconsin time (Fig. 32). Movement in the Cypress Hills area was to the southeast. At this time the Cypress Hills formed a nunatak about 300 feet high, and the Sweet Grass Hills stood 2000 feet above the ice surface. To the west, the Del Bonita Upland likewise escaped glaciation as did many of the hills along the Rocky Mountain

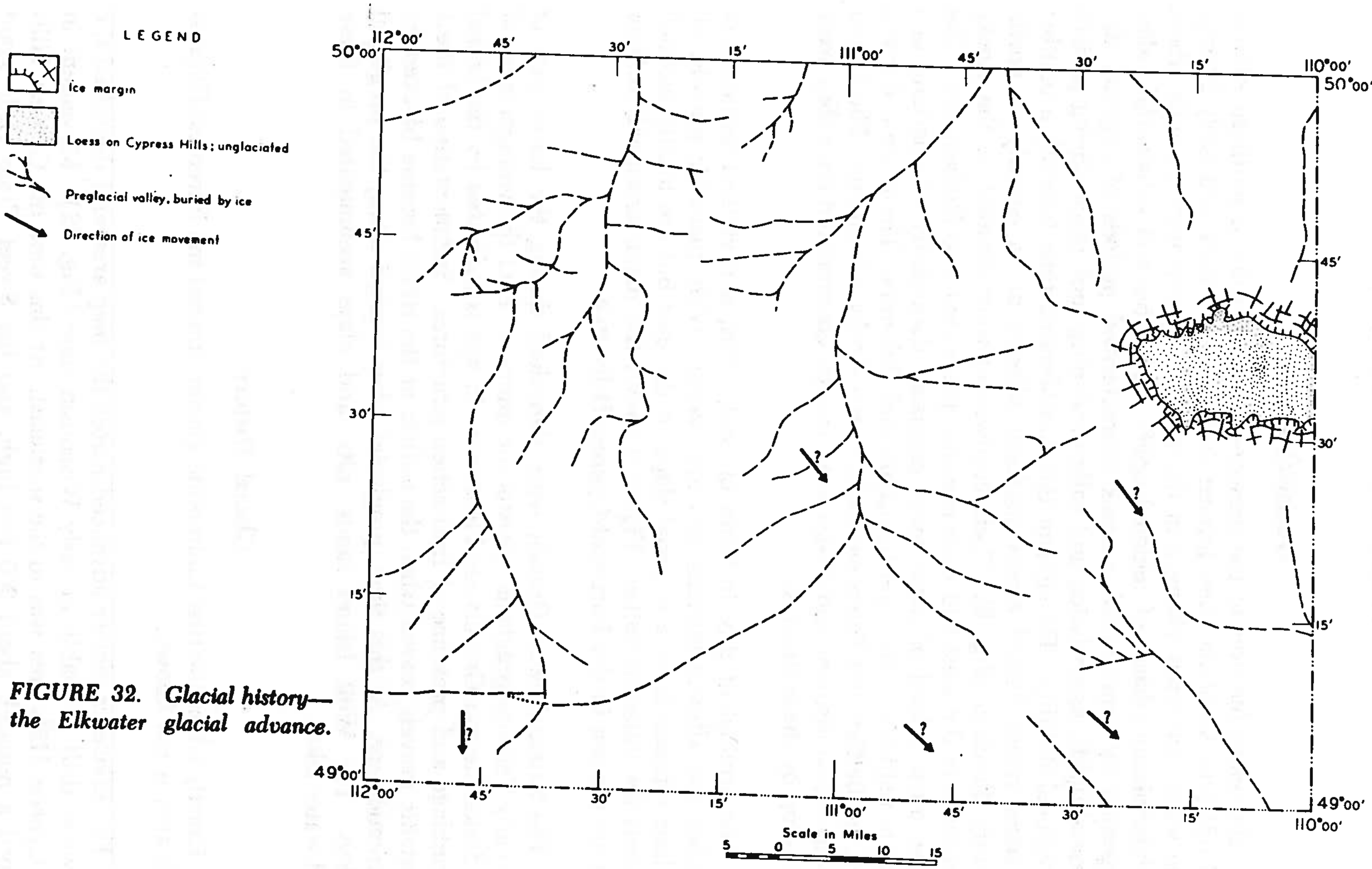
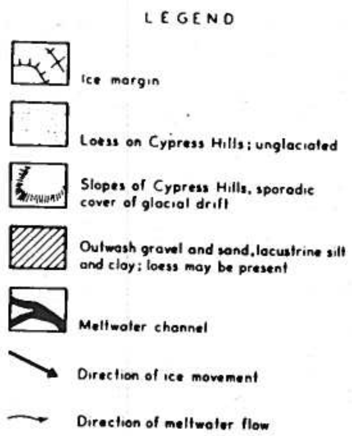


FIGURE 32. ***Glacial history—the Elkwater glacial advance.***



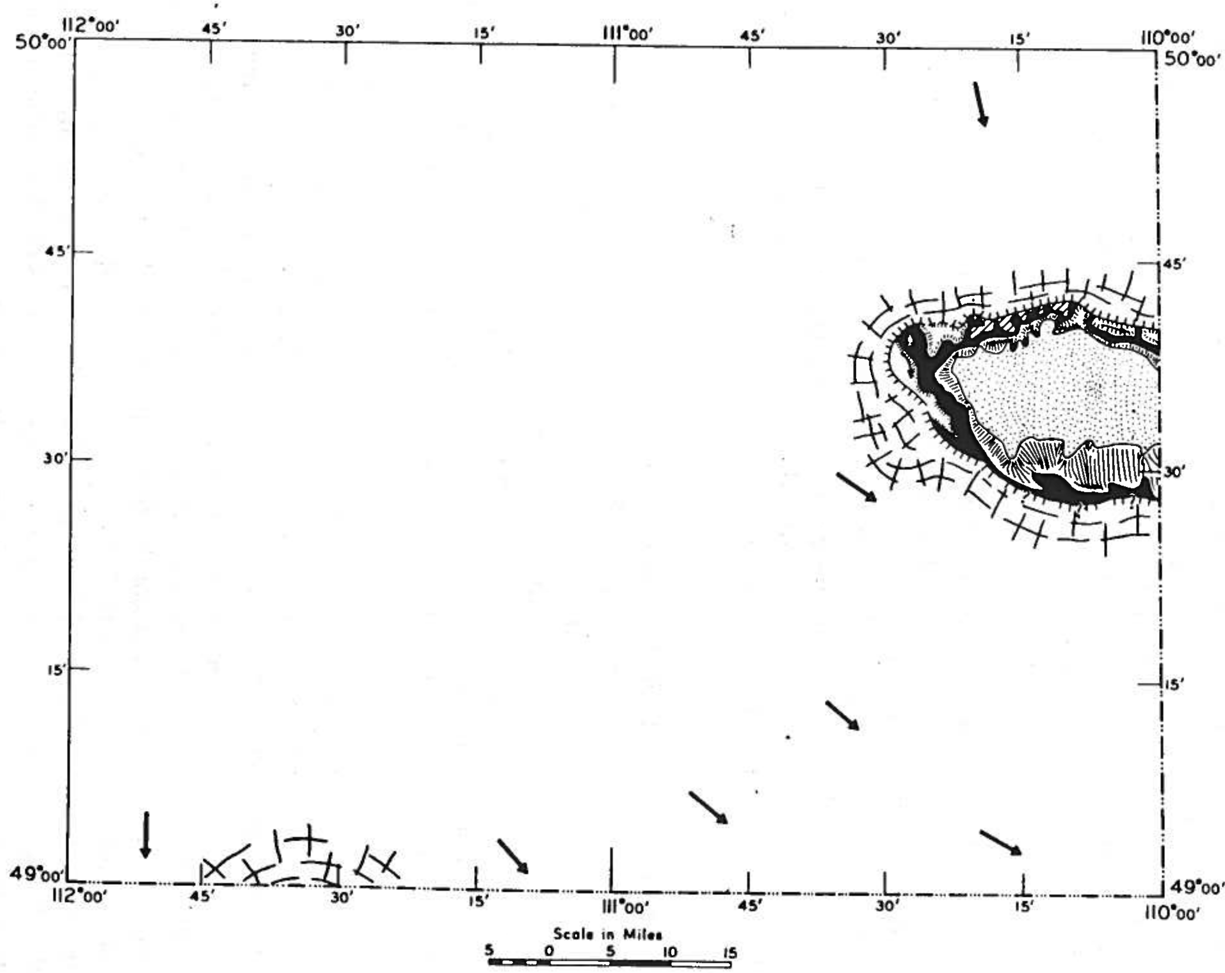


FIGURE 33. Glacial history—the Wild Horse glacial advance.

Foothills belt (Fig. 31). The Elkwater glacier was the most extensive glacier to affect southern Alberta; in Montana the most southerly position it reached is represented by the outer limit of glaciated terrain (Fig. 31). Deformation of the Cypress Hills conglomerate by frost action occurred during this glacial advance.

During ablation of the Elkwater glacier, meltwater channels were formed around the Cypress Hills, the meltwater being conducted to the east and southeast. Elsewhere in the map-area the Elkwater drift has been covered by younger glacial deposits. The precise duration of this interstadial is not known but drainage and morphologic characteristics of the Elkwater drift indicate that an interval of some note had elapsed before the Wild Horse glacier entered the region.

Approximately 24,000 to 20,000 years ago, that is in early "classical" Wisconsin time, the Laurentide ice sheet again moved into southern Alberta. The Wild Horse drift was most probably deposited at this time. The *Wild Horse glacier* flowed across the map-area in a southeasterly direction and moved into Montana as two lobes (Figs. 31, 33). The Cypress Hills loess may have been deposited during this glacial advance, although it is possible that it accumulated during the advance of the earlier Elkwater glacier.

The extent of retreat of the Wild Horse glacier is not known, but complete deglaciation of the plains of western Canada is doubted. The direction of this retreat in the map-area is well recorded by numerous ice-marginal channels and glacial lineaments. In the Cypress Hills area, the glacier receded downslope, and, in the process, successively lower ice-marginal channels were formed which conducted meltwater to the east and southeast. At the same time, the Wild Horse glacier retreated down the northern slope of the Sweet Grass Hills, where initially meltwater drained to the south along consequent meltwater channels (Fig. 30), but later flowed eastwards and southeastwards along the Milk River Ice-Marginal Channel. In the southeastern corner of the area, to the southeast of the preglacial divide that extends from the Cypress Hills to the Sweet Grass Hills, the Wild Horse glacier became stagnant. Meltwater flowed southeastwards across the stagnant ice along ice-walled channels and possibly some subglacial tunnels. Eskers formed in these channels, and, with continued downwasting of the ice surface, they eventually became emergent, impeding the flow of superglacial meltwater which resulted in the formation of Superglacial Lake Wild Horse. Retreat of the glacier northwest of the Medicine Hat Valley led to the formation of a proglacial lake near the present site of Lake Pakowki. During its early stages this lake drained southeastwards along Canal and Lost River channels (Fig. 30), some of the water flowing through the stagnant ice mass in the southeastern corner of the area via the ice-walled channels (Map 29). During recession of the Wild Horse glacier from Montana and the map-area, minor readvances occurred. The lobate end moraine near Wild Horse (township 1, range 1) was deposited during one of these minor readvances.

The next Laurentide glacier that entered the Foremost-Cypress Hills area failed to reach Montana. This glacier deposited the Pakowki drift and flowed across the map-area mainly in a southeasterly direction, but along the southern margin of the glacier, movement was to the south (Fig. 34). The *Pakowki glacier* surrounded the Cypress Hills Upland, and nosed southeastwards across the depression now occupied by Lake Pakowki but did not overtop the adjacent preglacial divide or the Lucky Strike Upland to the west. At this time meltwater again flowed along Milk River and Lost River channels.

As the ice front receded downslope, Glacial Lake Pakowki formed between it and the preglacial divide that joins the Cypress and Sweet Grass Hills. Meltwater drained through successively lower outlets as frontal retreat of the glacier continued. Initially, Glacial Lake Pakowki drained southeastwards via Lost River Channel (about 2950 feet above sea level). With further backwasting of the ice front the glacial waters found a lower outlet, the Pakowki Channel (less than 2900 feet above sea level), which conducted meltwater into Milk River Channel. Later, Etzikom Ice-Marginal Channel contributed a considerable volume of meltwater to Glacial Lake Pakowki, whose waters drained via Pakowki Channel to the Milk River Channel. It was at this time that Milk River Canyon was formed. The buried Granlea Channel (township 8, range 9; Map 29), north of Lake Pakowki, may mark the ice-frontal position at the time of maximum retreat. The position of this channel to the west and east of Granlea is not known precisely, but it probably closely followed the present Chin and Seven Persons channels.

This relatively minor retreatal phase terminated with the entry of the *Etzikom glacier* into the map-area. This glacier flowed in a general south to southwesterly direction, filled the Granlea Channel and part of the Etzikom Channel with glacial drift, and nosed southeastwards across the northern part of Glacial Lake Pakowki Basin (Figs. 31, 35). The general southwesterly flow-direction of the Etzikom glacier is indicated by the configuration of the outer front of the Etzikom drift, orientation of glacial lineaments (Fig. 30), and the distinctive pebble lithology of its drift, namely the relatively high content of crystalline rocks from the Canadian Shield to the northeast.

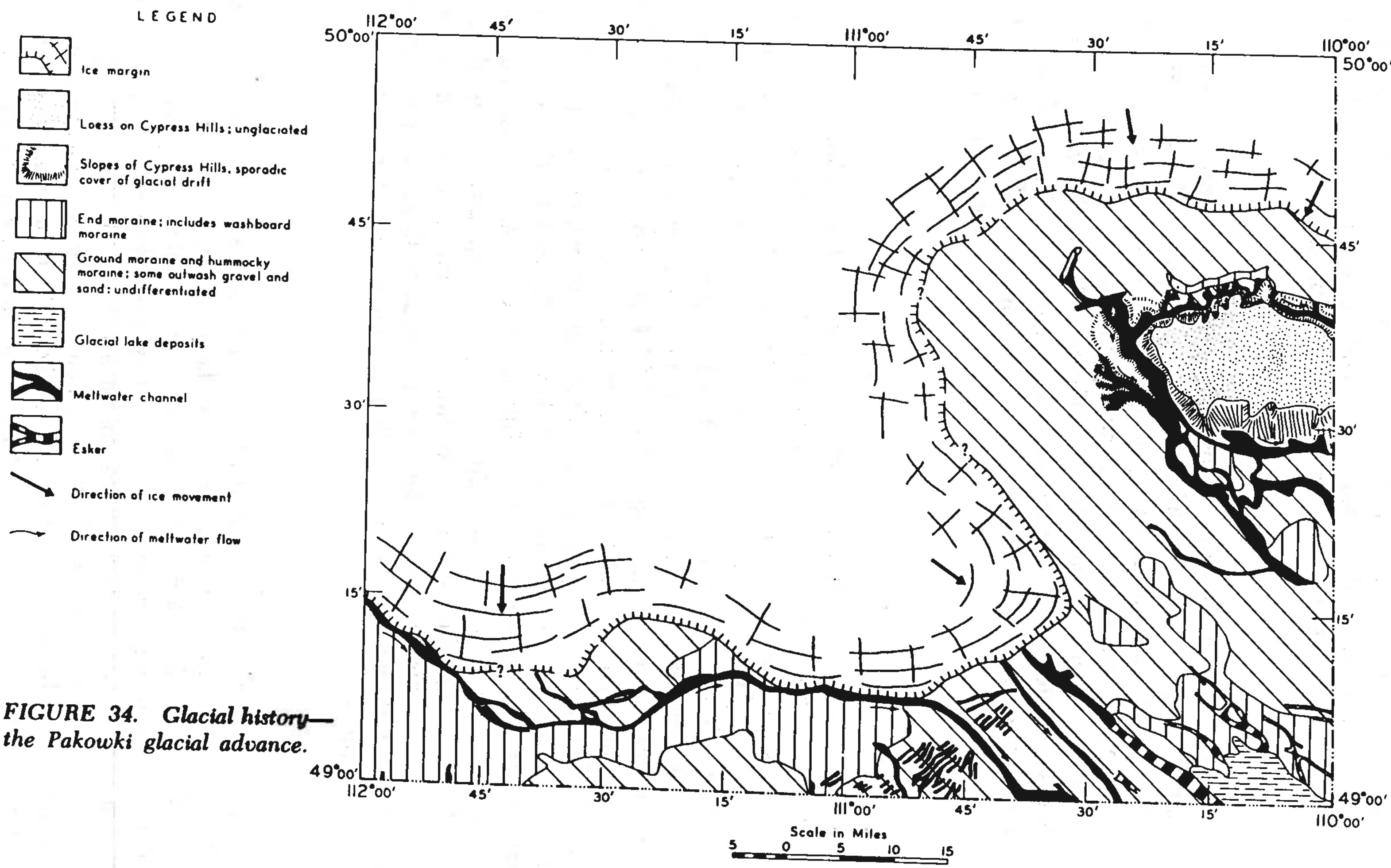


*FIGURE 34. **Glacial history—the Pakowki glacial advance.***

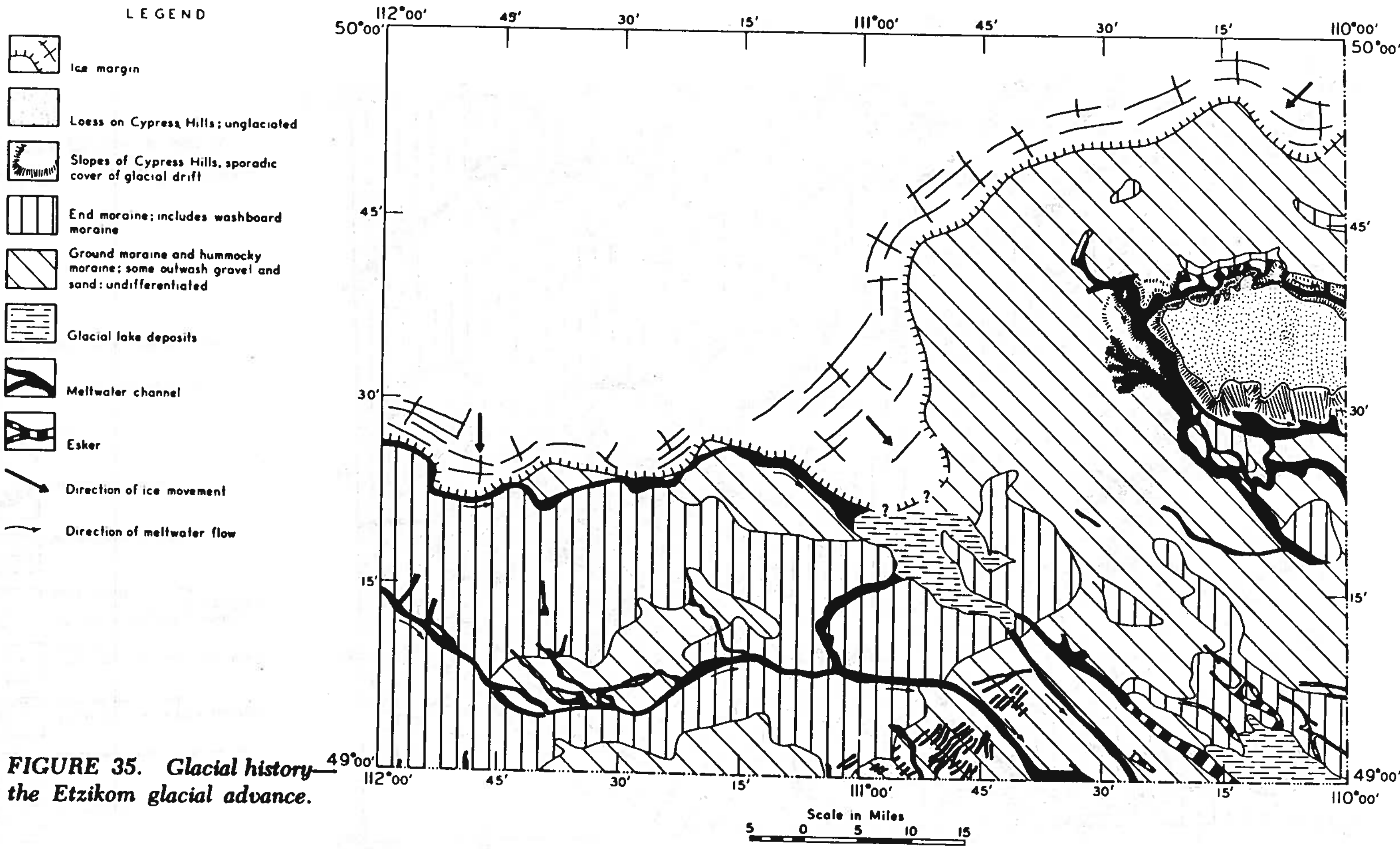


FIGURE 35. *Glacial history—the Etzikom glacial advance.*

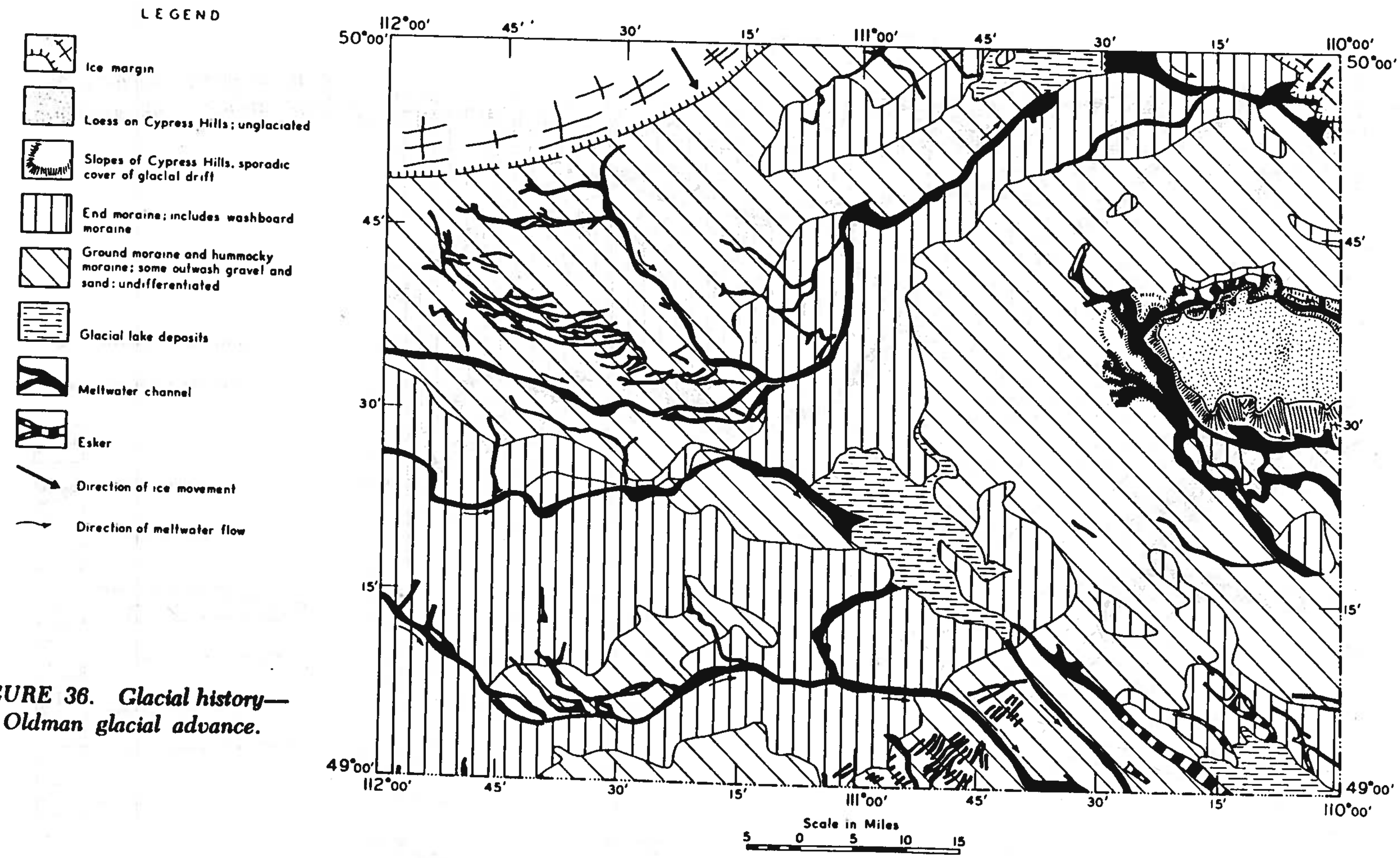


FIGURE 36. Glacial history—the Oldman glacial advance.

The retreatal direction of the Etzikom glacier is recorded by numerous ice-marginal channels and glacial lineaments. Initially, meltwater flowed eastwards along Etzikom Ice-Marginal Channel, debouched into Glacial Lake Pakowki and from here flowed through Pakowki Channel to Milk River Canyon. Contemporaneously, north of the Cypress Hills, meltwater drained to the northeast along Norton Channel (Fig. 30). As the glacier retreated downslope, successively lower ice-marginal channels were formed. When the Chin-Seven Persons-Irvine channel system was formed, all meltwater drained to the east and northeast. Continued backwasting of the glacier to the north and northwest resulted in the formation of Glacial Lake Medicine Hat over the site of the Medicine Hat Valley (township 12, ranges 5 and 6). North of the Chin Ice-Marginal Channel, meltwater from an ablating ice lobe was conducted eastwards along numerous small ice-marginal channels to Forty Mile Channel. With further backwasting of the ice front, a proglacial lake formed in the northwestern part of the map-area (Map 29); its waters later drained via the Forty Mile Channel to Seven Persons Channel. This was a minor retreatal interval.

The Laurentide ice sheet readvanced into the northwestern and northeastern corners of the map-area and deposited the Oldman drift some time before 13,000 years B.P. Movement of the glacier was radial to the margin: it was towards the south and southeast in the vicinity of the South Saskatchewan River, and to the south and southwest in the region north of Taber (Figs. 31, 36). The *Oldman glacier* moved into the northeastern corner of the map-area flowing to the southwest. Here the Oldman till is very rich in dolomite, which was probably derived from the Paleozoic rocks that rim the Canadian Shield southeast of Lac la Ronge, Saskatchewan. This was the last glacier to move into the Foremost-Cypress Hills area.

During ablation of the Oldman glacier, meltwater was ponded in front of the glacier, forming shallow proglacial lakes both in the northwestern and northeastern corners of the map-area. Later, after the glacier margin in the northwestern part of the region had retreated a short distance to the north, meltwater drained eastwards along the Oldman and South Saskatchewan ice-marginal channels. The South Saskatchewan Canyon was formed at this time (Map 29).

ECONOMIC GEOLOGY

Gravel and Sand

Gravel and sand deposits are both abundant and extensive in the Foremost-Cypress Hills area. They are outlined on Map 29 (this report) and six 1 inch to 1 mile maps (Westgate, 1965a). For convenience these deposits are divided into three groups on the basis of age—preglacial, glacial, and postglacial gravel and sand.

Preglacial Gravel

The Cypress Hills Formation, which caps the Cypress Hills, constitutes the largest preglacial gravel deposit in the map-area. A minimum estimate of the gravel reserves in the Alberta portion of the Cypress Hills is 1000 million cubic yards. An overburden of sand and silt is generally present, but seldom exceeds 5 feet in thickness. Minor sandstone lenses are present and the lower part of the deposit is cemented by calcium carbonate. The well-rounded pebbles and cobbles making up the gravels consist dominantly of quartzites (more than 95 per cent), with minor amounts of arkose, chert, and volcanic rocks. The gravel is suitable for most industrial purposes, but, as most of it is coarse, crushing is generally necessary. At present it is being used in the construction and maintenance of local roads.

Similar gravel deposits cover the lower plateaux, mesas, and buttes adjacent to the Cypress Hills. The major preglacial valleys (Figs. 6, 7) are floored by some 10 to 30 feet of preglacial quartzitic gravel, but here the thick overburden of glacial drift precludes economic recovery.

Glacial Gravel and Sand

Glacial gravel and sand deposits are scattered throughout the area. Major deposits, however, are confined to meltwater channels, kames, eskers, outwash plains, and deltas, although some end moraines contain considerable quantities (township 6, range 2; township 9, range 2). The pebbles in these gravels consist mainly of quartzites, granites, limestones, and dolomites with minor amounts of basic igneous rocks and schists.

Postglacial Gravel and Sand

Minor gravel and sand deposits are present along most of the postglacial valleys. They have a composition similar to the glacial gravels.

REFERENCES CITED

Alden, W. C. (1924): Physiographic development of the Northern Great Plains; Bull. Geol. Soc. Am., Vol. 35, p. 385-424.

.... (1932): Physiography and glacial geology of eastern Montana and adjacent areas; U.S. Geol. Surv. Prof. Paper 174, 133 pages.

Alden, W. C. and Stebinger, E. (1913): Pre-Wisconsin glacial drift in the region of the Glacier National Park, Montana; Bull. Geol. Soc. Am., Vol. 24, p. 529-572.

American Commission on Stratigraphic Nomenclature (1961): Code of stratigraphic nomenclature; Bull. Am. Assoc. Petroleum Geol., Vol. 45, p. 645-665.

Barton, R. H. (1962): Differential isostatic rebound—possible mechanism for fault reflection through glacial drift; Bull. Am. Assoc. Petroleum Geol., Vol. 46, p. 2253-2254.

Bayrock, L. A. (1958): Glacial geology of the Alliance-Brownfield district, Alberta; Res. Coun. Alberta Prelim. Rept. 57-2, 56 pages.

.... (1962): Heavy minerals in till of central Alberta; Jour. Alberta Soc. Petroleum Geol., Vol. 10, p. 171-184.

Bayrock, L. A. and Hughes, G. M. (1962): Surficial geology of the Edmonton district, Alberta; Res. Coun. Alberta Prelim. Rept. 62-6, 40 pages.

Breitung, A. J. (1954): A botanical survey of the Cypress Hills; Can. Field Naturalist, Vol. 68, p. 55-92.

Bretz, J. H. (1943): Keewatin end moraines in Alberta, Canada; Bull. Geol. Soc. Am., Vol. 54, p. 31-52.

Calhoun, R. H. H. (1906): Montana lobe of the Keewatin ice sheet; U.S. Geol. Surv. Prof. Paper 50, 62 pages.

Christiansen, E. A. (1956): Glacial geology of the Moose Mountain area, Saskatchewan; Saskatchewan Dept. Mineral Resources Rept. 21, 35 pages.

.... (1959): Glacial geology of the Swift Current area, Saskatchewan; Saskatchewan Dept. Mineral Resources Rept. 32, 62 pages.

.... (1963): Hydrogeology of surficial and bedrock valley aquifers in southern Saskatchewan; Proc. Hydrology Symposium No. 3, Groundwater, Nat. Res. Coun. Can., p. 49-66.

.... (1965a): Ice frontal positions in Saskatchewan; Res. Coun. Saskatchewan, Map No. 2.

.... (1965b): Geology and groundwater resources of the Kindersley area (72-N) Saskatchewan; Res. Coun. Saskatchewan Rept. No. 7, 25 pages.

Clayton, L. (1962): Glacial geology of Logan and McIntosh Counties, North Dakota; North Dakota Geol. Surv. Bull. 37, 84 pages.

Collier, A. J. and Thom, W. T., Jr. (1918): The Flaxville gravel and its relation to other terrace gravels of the Northern Great Plāins; U.S. Geol. Surv. Prof. Paper 108-J, p. 179-184.

Colton, R. B. (1962): Geology of the Otter Creek Quadrangle, Montana; U.S. Geol. Surv. Bull. 1111-G, p. 237-288.

Colton, R. B., Lemke, R. W., and Lindvall, R. M. (1961): Glacial map of Montana east of the Rocky Mountains; U.S. Geol. Surv., Misc. Geol. Investigations, Map 1-327.

Cope, E. D. (1891): On vertebrata from the Tertiary and Cretaceous rocks of the Northwest Territories. 1.—The species from the Oligocene or Lower Miocene of the Cypress Hills; Geol. Surv. Can., Contr. Can. Paleontology, Vol. 3, pt. 1, 25 pages.

Dawson, G. M. (1875): Report on the geology and resources of the region in the vicinity of the Forty-Ninth Parallel from Lake of the Woods to the Rocky Mountains; British North American Boundary Commission, 379 pages, Montreal.

.... (1883): Glacial deposits of the Bow and Belly River Country; Science, Vol. 1, p. 477-479.

.... (1885): Report on the region in the vicinity of the Bow and Belly Rivers; Geol. Surv. Can., Rept. Prog. 1882-83-84, pt. C, 168 pages.

.... (1890): On the glaciation of the northern part of the Cordillera, with an attempt to correlate the events of the Glacial Period in the Cordillera and Great Plains; Am. Geol., Vol. 6, p. 153-162.

.... (1891): On the later physiographical geology of the Rocky Mountain region in Canada, with special reference to changes in elevation and to the history of the Glacial Period; Proc. and Trans. Roy. Soc. Can., Ser. 3, sec. IV, Vol. 8, p. 3-74.

.... (1895): Note on the glacial deposits of southwestern Alberta; Jour. Geol., Vol. 3, p. 507-511.

Dawson, G. M. and McConnell, R. G. (1895): Glacial deposits of southwestern Alberta in the vicinity of the Rocky Mountains; Bull. Geol. Soc. Am., Vol. 7, p. 31-66.

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

Dreimanis, A. (1962): Quantitative gasometric determination of calcite and dolomite by using Chittick apparatus; Jour. Sed. Petrol., Vol. 32, p. 520-529.

Dyck, W., Fyles, J. G., and Blake, W., Jr., (1965): Geological Survey of Canada radiocarbon dates IV; Geol. Surv. Can. Paper 65-4, 23 pages.

Elson, J. A. (1957): Origin of washboard moraine; Bull. Geol. Soc. Am., Vol. 68, p. 1721.

.... (1958): Pleistocene history of southwestern Manitoba; North Dakota Geol. Surv., Misc. Ser., No. 10, p. 62-73.

.... (1961): The geology of tills; Fourteenth Canadian Soil Mechanics Conference, 1960: Nat. Res. Coun. Can., Tech. Memo. No. 69, p. 5-35.

Farvolden, R. N. (1963): Bedrock channels of southern Alberta; *in* Early contributions to the groundwater hydrology of Alberta; Res. Coun. Alberta Bull. 12, 123 pages.

Flint, R. F. (1928): Eskers and crevasse fillings; Am. Jour. Sci., Vol. 15, p. 410-416.

.... (1957): Glacial and Pleistocene geology; John Wiley and Sons, Inc., New York, 553 pages.

.... (1963): Status of the Pleistocene Wisconsin Stage in central North America; Science, Vol. 139, p. 402-404.

Flint, R. F., Colton, R. B., Goldthwait, R. P., and Willman, H. B. (1959): Glacial map of the United States east of the Rocky Mountains; Geol. Soc. Am., New York.

Folk, R. L. (1961): Petrology of sedimentary rocks; Hemphill Publishers, Austin, Texas, 154 pages.

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

Frye, J. C. and Willman, H. B. (1960): Classification of the Wisconsinan Stage in the Lake Michigan glacial lobe; Illinois Geol. Surv. Circ. 285, 16 pages.

.... (1962): American Commission on Stratigraphic Nomenclature note 27—morphostratigraphic units in Pleistocene stratigraphy; Bull. Am. Assoc. Petroleum Geol., Vol. 46, p. 112-113.

.... (1963): Loess stratigraphy, Wisconsinan classification and accretion-gleys in central western Illinois; Illinois Geol. Surv., Guidebook Ser., No. 5, 37 pages.

Fryxell, R. (1965): Mazama and Glacier Peak volcanic ash layers: relative ages; Science, Vol. 147, p. 1288-1290.

Furnival, G. M. (1950): Cypress Lake map-area, Saskatchewan; Geol. Surv. Can. Mem. 242, 161 pages.

Geiger, K. W. (1965): Bedrock topography of southwestern Alberta; Res. Coun. Alberta Prelim. Rept. 65-1, 14 pages.

Gravenor, C. P. (1955): The origin and significance of prairie mounds; Am. Jour. Sci., Vol. 253, p. 475-481.

.... (1956): Air photographs of the Plains Region of Alberta; Res. Coun. Alberta Prelim. Rept. 56-5, 35 pages.

Gravenor, C. P. and Bayrock, L. A. (1955): Use of indicators in the determination of ice-movement directions in Alberta; Bull. Geol. Soc. Am., Vol. 66, p. 1325-1328.

.... (1956): Use of indicators in the determination of ice-movement directions in Alberta; a reply; Bull. Geol. Soc. Am., Vol. 67, p. 1101-1110.

Gravenor, C. P. and Ellwood, R. B. (1957): Glacial geology of the Sedgewick district, Alberta; Res. Coun. Alberta Prelim. Rept. 57-1, 43 pages.

Gravenor, C. P. and Kupsch, W. O. (1959): Ice-disintegration features in western Canada; Jour. Geol., Vol. 67, p. 48-64.

Gromov, V. I., Alekseev, M. N., Vangengeim, E. A., Kind, N. V., Nikiforova, K. V., and Ravsky, E. I. (1965): Possible correlation scheme for the Anthropogen of North Eurasia; a chart presented at the 7th Congress of International Association for Quaternary Research.

Gwynne, C. S. (1942): Swell and swale pattern of the Mankato lobe of the Wisconsin drift plain in Iowa; Jour. Geol., Vol. 50, p. 200-208.

Haites, T. B. (1960): Transcurrent faults in western Canada; Jour. Alberta Soc. Petroleum Geol., Vol. 8, p. 33-78.

Hector, J. (1861): On the geology of the country between Lake Superior and the Pacific Ocean and between the 48th and 54th parallels of latitude; Quart. Jour. Geol. Soc. London, Vol. 17, p. 388-455.

Henderson, E. P. (1959): Surficial geology of Sturgeon Lake map-area, Alberta; Geol. Surv. Can. Mem. 303, 108 pages.

Hibbard, C. W., Ray, D. E., Savage, D. E., Taylor, D. W., and Guilday, J. E. (1965): Quaternary mammals of North America; The Quaternary of the United States: Editors, H. E. Wright, Jr., and D. G. Frey, p. 509-525.

Holmes, C. D. (1947): Kames; Am. Jour. Sci., Vol. 245, p. 240-249.

Hoppe, G. (1952): Hummocky moraine regions, with special reference to the interior of Norbotton; Geografiska Annaler, Vol. 34, p. 1-71.

Horberg, L. (1952): Pleistocene drift sheets in the Lethbridge region, Alberta, Canada; Jour. Geol., Vol. 60, p. 303-330.

.... (1954): Rocky Mountain and continental Pleistocene deposits in the Waterton region, Alberta, Canada; Bull. Geol. Soc. Am., Vol. 65, p. 1093-1150.

Howard, A. D. (1960): Cenozoic history of northeastern Montana and northwestern North Dakota with emphasis on the Pleistocene; U.S. Geol. Surv. Prof. Paper 326, 107 pages.

Jensen, F. S., and Varnes, H. D. (1964): Geology of the Fort Peck area, Garfield, McCone and Valley Counties, Montana; U.S. Geol. Surv. Prof. Paper 414-F, 49 pages.

Johnston, W. A., and Wickenden, R.T.D. (1931): Moraines and glacial lakes in southern Saskatchewan and southern Alberta; Trans. Roy. Soc. Can., Ser. 3, sec. IV, Vol. 25, p. 29-44.

Kendrew, W. G. and Currie, B. W. (1955): The climate of central Canada; Meteorolgical Division, Canada Dept. of Transport, Toronto, 194 pages.

Kupsch, W. O. (1956a): Geology of eastern Cypress Hills; Saskatchewan Dept. Mineral Resources Rept. 20, 30 pages.

.... (1956b): Submask geology in Saskatchewan; First Williston International Symposium, p. 66-75.

Kupsch, W. O. and Wild, J. (1958): Lineaments in the Avonlea area, Saskatchewan; Bull. Am. Assoc. Petroleum Geol., Vol. 42, p. 127-134.

Laprade, K. E. (1957): Dust-storm sediments of Lubbock area, Texas; Bull. Am. Assoc. Petroleum Geol., Vol. 41, p. 709-726.

Lemke, R. W. (1960): Geology of the Souris River area, North Dakota; U.S. Geol. Surv. Prof. Paper 325, 138 pages.

Lemke, R. W., Laird, W. M., Tipton, M. J., and Lendvall, R. M. (1965): Quaternary geology of Northern Great Plains; The Quaternary of the United States: Editors, H. E. Wright, Jr., and D. G. Frey, p. 15-27.

McConnell, R. G. (1886): Report on the Cypress Hills, Wood Mountain, and adjacent country; Geol. Surv. Can., Ann. Rept., Vol. 1, pt. C, p. 1-78.

Meneley, W. A., Christiansen, E. A., and Kupsch, W. O. (1957): Preglacial Missouri River in Saskatchewan; Jour. Geol., Vol. 65, p. 441-447.

Meyboom, P. (1960): Geology and groundwater resources of the Milk River Sandstone in southern Alberta; Res. Coun. Alberta Mem. 2, 89 pages.

Miller, H. (1884): On boulder-glaciation; Proc. Roy. Phys. Soc. Edinburgh, Vol. 8, p. 156-189.

Mollard, J. D. (1957): A study of aerial mosaics in southern Saskatchewan and Manitoba; Oil in Canada, August, 11 pages.

.... (1958): Photogeophysics, its application in petroleum exploration over the glaciated plains of western Canada; Second Williston Basin Symposium, p. 109-117.

Powers, H. A. and Wilcox, R. E. (1964): Volcanic ash from Mount Mazama (Crater Lake) and from Glacier Peak; Science, Vol. 144, p. 1334-1336.

Richter, K. (1932): Die Bewegungsrichtung des Inlandeises, rekonstruiert aus dem Kritzen und Langsachser der Geshiebe; Z. Geshiebeforsch, Vol. 8, p. 62-66.

Russell, L. S. (1948): The geology of the southern part of the Cypress Hills, southwestern Saskatchewan; Saskatchewan Dept. Mineral Resources Rept. 8, 60 pages.

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

Rutherford, R. L. (1937): Saskatchewan gravels and sands in central Alberta; Trans. Roy. Soc. Can., Ser. 3, sec. IV, Vol. 31, p. 81-95.

Schafer, J. P. (1949): Some periglacial features in central Montana; Jour. Geol., Vol. 57, p. 154-174.

Sharp, R. P. (1942): Periglacial involutions in northeastern Illinois; Jour. Geol., Vol. 50, p. 113-133.

Smith, J. F., Jr., Witkind, I. J., and Trimble, D. E. (1959): Geology of the lower Marias River area, Chouteau, Hill, and Liberty Counties, Montana; U.S. Geol. Surv. Bull. 1071-E, p. 121-155.

Sproule, J. C. (1939): The Pleistocene geology of the Cree Lake region, Saskatchewan; Trans. Roy. Soc. Can., Ser. 3, sec. IV, Vol. 33, p. 101-109.

Stalker, A. MacS. (1956): Surficial geology, Beiseker, Alberta; Geol. Surv. Can. Paper 55-7, map with marginal notes.

.... (1960): Ice-pressed drift forms and associated deposits in Alberta; Geol. Surv. Can. Bull. 57, 38 pages.

.... (1961): Buried valleys in central and southern Alberta; Geol. Surv. Can. Paper 60-32, 13 pages.

.... (1962): Surficial geology, Lethbridge (east half), Alberta; Geol. Surv. Can. Map 41-1962.

.... (1963a): Surficial geology of Blood Indian Reserve, No. 148, Alberta; Geol. Surv. Can. Paper 63-25, 20 pages.

.... (1963b): Quaternary stratigraphy in southern Alberta; Geol. Surv. Can. Paper 62-34, 52 pages.

.... (1965): Pleistocene ice surface, Cypress Hills area; Alberta Soc. Petroleum Geol., 15th Annual Field Conference Guidebook, Pt. 1, Cypress Hills Plateau, p. 116-130.

Stalker, A. MacS. and Craig, B. G. (1956): Use of indicators in the determination of ice-movement directions in Alberta, Canada; a discussion; Bull. Geol. Soc. Am., Vol. 67, p. 1101-1104.

Westgate, J. A. (1965a): The surficial geology of the Cypress Hills area, Alberta; Res. Coun. Alberta Prelim. Rept. 65-2, 6 maps, 6 pages.

.... (1965b): The Pleistocene stratigraphy of the Foremost-Cypress Hills area, Alberta; Alberta Soc. Petroleum Geol., 15th Annual Field Conference Guidebook, Pt. 1, Cypress Hills Plateau, p. 85-111.

.... (in press): Age and origin of the Cypress Hills Plateau surface in Alberta; a discussion; Geographical Bulletin.

Westgate, J. A. and Bayrock, L. A. (1964): Periglacial structures in the Saskatchewan gravels and sands of central Alberta, Canada; Jour. Geol., Vol. 72, p. 641-648.

Wickenden, R.T.D. (1931): An area of little or no drift in southern Saskatchewan; Trans. Roy. Soc. Can., Ser. 3, sec. IV, Vol. 25, p. 45-47.

.... (1937): Age relations of glacial deposits in southeastern Alberta and southwestern Saskatchewan (abs.); Proc. Roy. Soc. Can., Ser. 3, Vol. 31, p. cxliii.

Williams, M. Y. (1929): The physiography of the southwestern plains of Canada; Trans. Roy. Soc. Can., Ser. 3, sec. IV, Vol. 23, p. 61-79.

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

Wilson, J. T., Falconer, G., Mathews, W. H., and Prest, V. K. (1958): Glacial map of Canada; Geol. Assoc. Can., Toronto.

Witkind, I. J. (1959): Quaternary geology of the Smoke Creek, Medicine Lake, Grenora area, Montana and North Dakota; U.S. Geol. Surv. Bull. 1073, 80 pages.

Wyatt, F. A. and Newton, J. D. (1926): Soil survey of the Medicine Hat sheet; Univ. Alberta, College of Agriculture, Bull. 14, 76 pages.

Wyatt, F. A., Newton, J. D., Bowser, W. E., and Odynsky, W. (1941): Soil survey of Milk River sheet; Univ. Alberta, College of Agriculture, Bull. 36, 105 pages.

Yule, U. G. and Kendall, M. G. (1958): An Introduction to the Theory of Statistics; Griffen and Company Ltd., London, 701 pages.

Zeuner, F. E. (1959): The Pleistocene Period; Hutchinson and Co. Ltd., London, 447 pages.

APPENDIX

Stratigraphic Sections

Section 1. North bank of Oldman River, north of Wolf Island, in Lsd. 12, Sec. 20, Tp. 11, R. 14.

	Thickness (feet)
Glacial drift (Pleistocene):	
Sand and silt, rusty yellow, stones present in upper part	30
Till, dark greyish brown	5
Till, buff to light brown, unconsolidated; exposure poor	80
Bentonitic shale, grey (U. Cretaceous?)	5
Till, dark greyish brown, compact	35
Interbedded till and sand	10
Till, grey, compact	5
Sand, well-sorted, glaciofluvial; upper part contorted	15
Wolf Island sediments (Pleistocene):	
Clay and silt, dark brown, some beds pink; varved, upper part contorted	10
Saskatchewan Gravels (Pleistocene):	
Gravel and sand; lower part dominantly gravel, upper part sand with thin gravel beds; frost action structures in upper part	15
Foremost Formation (Upper Cretaceous):	
Shale	15+

Section 2. North bank of Gros Ventre Creek in Lsd. 2, Sec. 14, Tp. 11, R. 4.

		Thickness (feet)
Glacial drift (Pleistocene):		
Till, buff to light brown, stony; interbedded with few thin silt and sand beds		12.0
Interbedded till and glaciofluvial materials:		
Sand, horizontally bedded	1.5	
Till, brown, compact	3.0	
Sand and silt, horizontally bedded	1.8	
Till, grey to buff	0.9	
Clay	0.1	
Sand and silt	1.0	
Gravel	0.2	
Silt	0.7	
Till, grey, compact	0.5	
Sand with inclusions of till; contorted	9.0	18.7
Till, dark grey, compact		4.5
Bearpaw Formation (Upper Cretaceous):		
Shale		10.0+

Section 3. Composite section of exposures along east and west banks of Bullshead Creek in Lsd. 15, 16, Sec. 31, Tp. 9, R. 5.

	Thickness (feet)
Glacial drift (Pleistocene):	
Till, brown, stony; good columnar jointing	30
Till, grey; good columnar jointing	30
Sand, cross-bedded; slightly deformed	3

Wolf Island sediments (Pleistocene):	
Silt, yellow to ochre, bedded; slightly deformed	15
Interbedded silt and clay; deformed (Plate 13)	12
Bearpaw Formation (Upper Cretaceous):	
Shale and bentonite	2+

Section 4. East bank of Ross Creek in Lsd. 13, Sec. 18, Tp. 10, R. 2.

Glacial drift (Pleistocene):	**Thickness (feet)**
Sand, silt and clay	2
Till, buff to light brown; contains flame-shaped inclusions of lower dark till	35
Till, dark greyish-brown, compact; contains lens of nonglacial quartzitic gravel near base	20
Bearpaw Formation (Upper Cretaceous):	
Shale with large ironstone concretions	50+

Section 5. East bank of Mackay Creek in Lsd. 10, Sec. 1, Tp. 10, R. 1.

Glacial drift (Pleistocene):	**Thickness (feet)**
Till, light brown	20
Till, light brown; contains numerous flame-shaped inclusions of dark brown till; in places overlain by outwash sand	40
Till, dark brown	15+

Section 6. West bank of Mackay Creek in Lsd. 6, Sec. 23, Tp. 9, R. 1.

Glacial drift (Pleistocene):	**Thickness (feet)**
Till, light brown; (to south grades laterally into fossiliferous lacustrine sand, silt, clay and marl)	4
Sand and gravel, glaciofluvial	13
Till, dark brown, compact	9
Wolf Island sediments (Pleistocene):	
Fine sand, silt and clay with occasional pebbles; upper part deformed	15+

Section 7. Northeast bank of Canal Creek in Lsd. 16, Sec. 31, Tp. 2, R. 5.

Glacial drift (Pleistocene):	**Thickness (feet)**
Silt	7
Gravel and sand, glaciofluvial	2
Till, compact	5
Sand, minor till inclusions	4
Till, minor sand inclusions	15+

Section 8. North bank of Milk River in Lsd. 13, Sec. 4, Tp. 1, R. 5.

Glacial drift (Pleistocene):	**Thickness (feet)**
Sand, minor gravel, inclusions of till	6
Till, dark brown; iron oxide cementation along joints	7-15

Oldman Formation (Upper Cretaceous):

Sandstone and siltstone	4+

Section 9. East bank of Thelma Creek in Lsd. 5, Sec. 25, Tp. 6, R. 3.

Glacial drift (Pleistocene):	**Thickness (feet)**
Sporadic glacial erratics on surface	0-1
Flaxville Formation? (Miocene to early Pliocene):	
Quartzitic gravels; deformed by frost action	5
Bearpaw Formation (Upper Cretaceous)	
Sand, rusty yellow	10
Shale with numerous sandstone dykes, some 8 feet wide	50+

Section 10. West bank of Ross Creek in Lsd. 5, Sec. 23, Tp. 11, R. 3.

Glacial drift (Pleistocene):	**Thickness (feet)**
Till, buff to light brown, stony, massive	20
Till, greyish buff, interbedded with thin sand beds	20
Till, greyish brown, compact, massive Compare with Section 2.	15+

Section 11. North bank of South Saskatchewan River in NE¼, Sec. 9, Tp. 13, R. 5.

Glacial drift (Pleistocene):	**Thickness (feet)**
Till, dark greyish brown	20
Sand and silt, yellow	40
Gravel, glaciofluvial	1
Till, grey	5
Wolf Island sediments (Pleistocene):	
Clay, grey	2
Silt, some sand	40
Saskatchewan Gravels (Pleistocene):	
Mainly sand, large-scale festoon bedding; contains partly carbonised twigs with a radiocarbon age of greater than 36,600 years (GX-0210)	30+

Section 12. West bank of South Saskatchewan River in SW¼, Sec. 17, Tp. 13, R. 5.

Glacial drift (Pleistocene):	**Thickness (feet)**
Sand and silt	10
Gravel, bouldery in places, glaciofluvial	1
Sand, cross-bedded, glaciofluvial	30
Interbedded gravel and sand; with: (a) Camelid, about the size of the modern camel; fragmentary lower part of left scapula, (b) *Equus* sp., about the size of *E. caballus;* fragment from skull, (c) *Mammuthus primigenius*, fragments of molar	15

Wolf Island sediments (Pleistocene):

Silt 3

Saskatchewan Gravels (Pleistocene):

Gravel, minor sand; with:

(a) *Mammuthus primigenius*, incomplete, moderately worn premolar,

(b) *Equus* sp., right astragalus, about 10% smaller than *E. caballus* 10

Foremost Formation (Upper Cretaceous):

Shale .... 5+

Section 13. East bank of South Saskatchewan River at SE¼, Sec. 5, Tp. 14, R. 5.

Glacial drift (Pleistocene):

	Thickness (feet)
Sand and silt, lacustrine	10
Till, yellowish-brown, silty; contains gravel inclusions	20
Silt	6
Till, dark-brown, massive	5
Interbedded silt and till	5
Till, dark greyish-brown; some silt and gravel beds present	50
Sand and silt, possibly alluvium, with fragmentary bird bones*	6
Sand, minor gravel, and a peat bed; with: (a) Artiodactyl, possibly *Cervus* sp., fragment of left ramus of lower jaw with very worn 4th premolar and 2nd and 3rd molars, (b) *Equus* sp., smaller than *E. caballus;* left calcaneum, (c) *Equus* sp., smaller than modern *E. caballus;* left scapula, incomplete	70
Gravel, glaciofluvial	3

Wolf Island sediments (Pleistocene):

Silt, yellow; lowermost beds darker colour; with *Equus* sp., about 10% smaller than *E. caballus;* left metatarsal 10

Saskatchewan Gravels (Pleistocene):

Sand, minor gravel 6

Foremost Formation (Upper Cretaceous):

Shale .... 10+

---

* In Westgate (1965b) *Bison occidentalis?* was recorded from this horizon. Two radiocarbon dates on the bones indicate that this material is of recent age, and therefore intrusive (1500 ± 70 years B.P., S-222, carbonate fraction: 1760 ± 70 years B.P., bone collagen).

Selected Drill-Hole Logs

Location				Description	Depth (feet)
Lsd.	Sec.	Tp.	R.		
13	8	2	14	Till	0-60
				Gravel	60-85
				Sandstone (bedrock)	85-150
4	15	2	13	Till	0-45
				Gravel	45-60
				Blue shale (bedrock)	60-75
2	25	3	15	Sand	0-73
				Gravel	73-90
3	4	4	15	Till	0-145
				Gravel	145-150
				Sandstone (bedrock)	150-190
4	28	1	13	Till	0-80
				Fine gravel	80-100
				Sandstone (bedrock)	100-120
13	6	1	13	Till	0-70
				Gravel	70-75
				Till?	75-90
				Gravel	90-105
				Sandstone (bedrock)	105-120
14	32	6	13	Brown till	0-35
				Sand and gravel	35-40
				Blue till	40-88
				Shale (bedrock)	88-105
16	19	7	13	Till	0-40
				Gravel	40-44
				Till	44-190
				Sandstone and shale (bedrock)	190-210
15	23	6	13	Brown till	0-120
				Blue till	120-250
13	8	7	12	Brown till	0-90
				Blue till	90-200
16	19	7	12	Brown till	0-45
				Blue till	45-195
				Shale (bedrock)	195-210
15	9	6	12	Brown till	0-65
				Blue till	65-130
				Gravel	130-180
				Shale (bedrock)	180-210
5	23	6	12	Brown till	0-70
				Blue till	70-150
				Gravel	150-165

Location Lsd.	Sec.	Tp.	R.	Description	Depth (feet)
12	7	6	11	Brown till	0-55
				Blue till	55-250
16	33	6	11	Till	0-50
				Fine gravel	50-60
				Till	60-140
				Shale (bedrock)	140-165
4	25	11	10	Till	0-20
				Sand	20-35
				Till	35-105
5	28	10	10	Brown till	0-30
				Blue till	30-105
				Shale (bedrock)	105-130

Locations of Samples Referred to in Text

Sample Number	Location Lsd.	Sec.	Tp.	R.
561	12	28	6	4
3261	13	28	8	4
4961	6	23	9	1
7361	4	3	10	4
7761	11	3	10	3
9761	12	34	9	1
4262	2	18	10	5
3663	10	18	10	2
3763	5	23	11	3
3963 (i)	2	14	11	4
3963 (ii)	2	14	11	4
4063	13	15	12	5

PLATE 1.

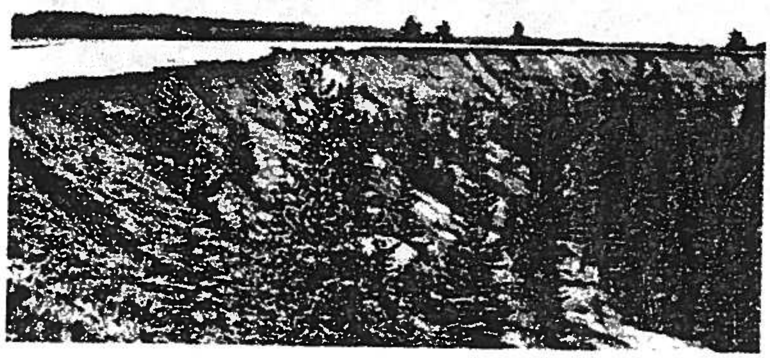


FIGURE 1. The Cypress Hills Plateau, south of Elkwater. The Cypress Hills conglomerate and overlying loess are well exposed here.

FIGURE 2. Looking westward along Chin Coulee in Sec. 11, Tp. 7, R. 13. This ice-marginal channel is a mile wide and about 200 feet deep.

PLATE 2.

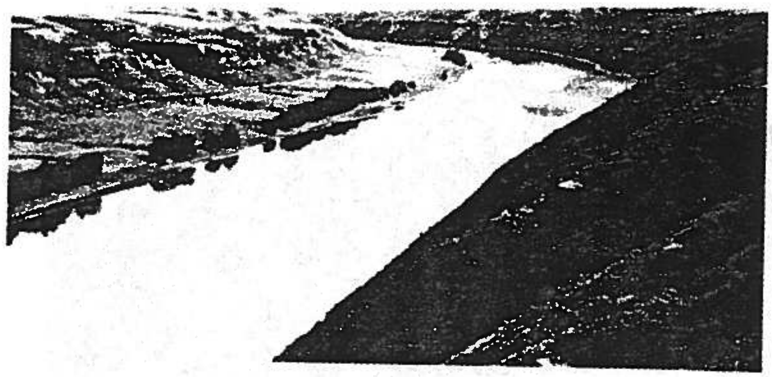


FIGURE 1. *Looking eastwards along South Saskatchewan Canyon (Lsd. 8, Sec. 12, Tp. 11, R. 13), which is over a mile wide and more than 300 feet deep. The Foremost beds are exposed along the valley sides.*

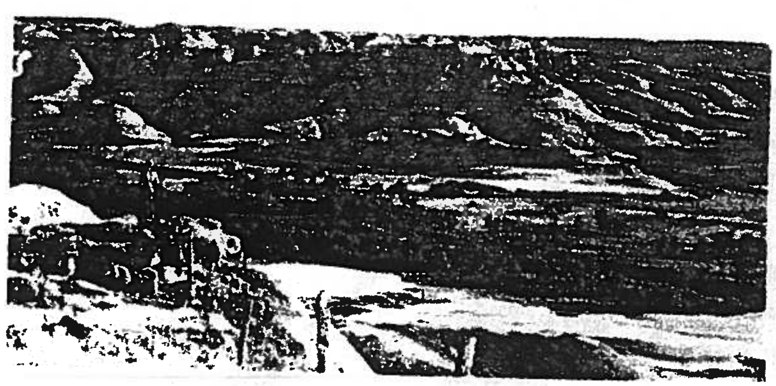
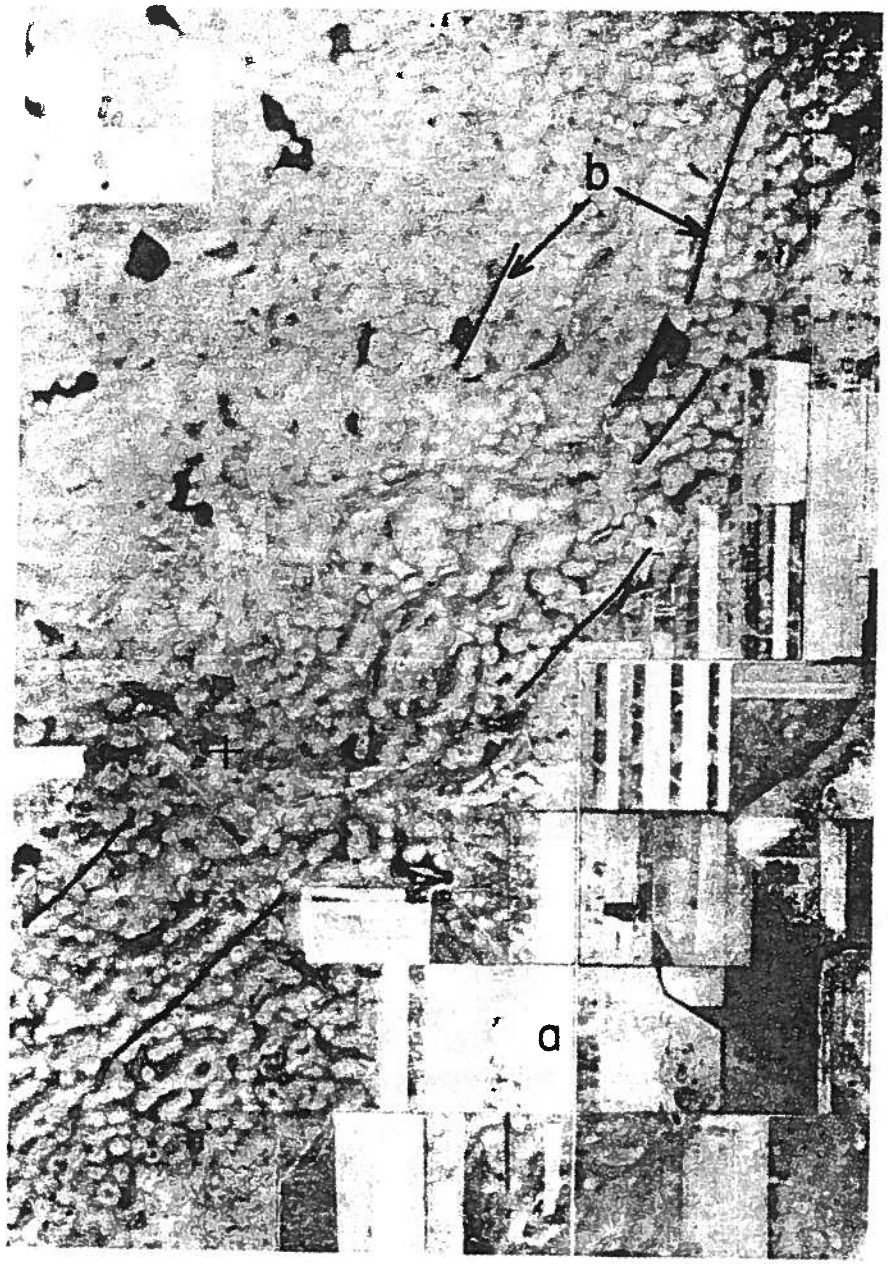


FIGURE 2. *Milk River Canyon in Sec. 9, Tp. 2, R. 6, is over a mile wide and more than 400 feet deep. The Oldman and underlying Foremost beds are exposed along the dissected valley sides.*

PLATE 3.



Aligned knobs, closed and linear ridges in hummocky end moraine. Lacustrine sediment (a) covers part of the moraine. The till is more than 100 feet thick, and some of the glacial lineaments are shown (b).
Location: townships 6 and 7, range 8.
Reference Number: 160-4909
2172-91
All the vertical air photographs have a scale of 1:40,000 and are oriented so that north is at the top of the page, unless otherwise indicated.

PLATE 4.

Small ice-marginal meltwater channels excavated in ground moraine. They are approximately 300 feet wide and about 10 feet deep.
Location: township 8, range 13.
Reference Number: 160-4911
2194A-78

PLATE 5.

Elkwater drift (a), loess-covered Cypress Hills Plateau (b), and Wild Horse drift (c). Hummocky disintegration moraine is well illustrated in Wild Horse drift area. Here the local relief is greater than 25 feet and the till is more than 60 feet thick.
Location: township 8, range 3.
Reference Number: 160-4912
2194A-50

PLATE 6.

FIGURE 1. *Ridged end moraine east of Lake Pakowki. Till ridges are the most conspicuous element. The till varies from 20 to 50 feet thick.*
Location: township 4, ranges 5 and 6.
Reference Number: 160-4905
1998-82

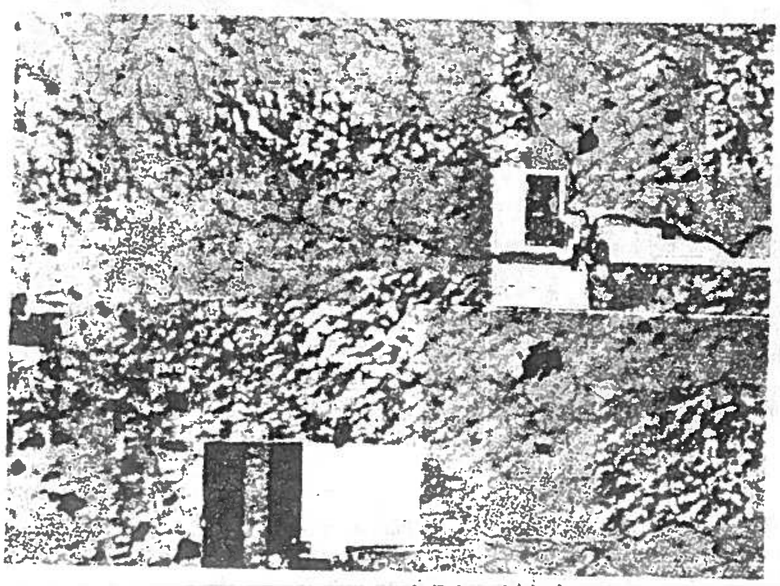


FIGURE 2. *Washboard moraine north of Seven Persons. Transverse till ridges are up to 10 feet high and 100 to 300 feet apart. The till is more than 50 feet thick.*
Location: township 11, range 7.
Reference Number: 160-4916
1926-109

PLATE 7.

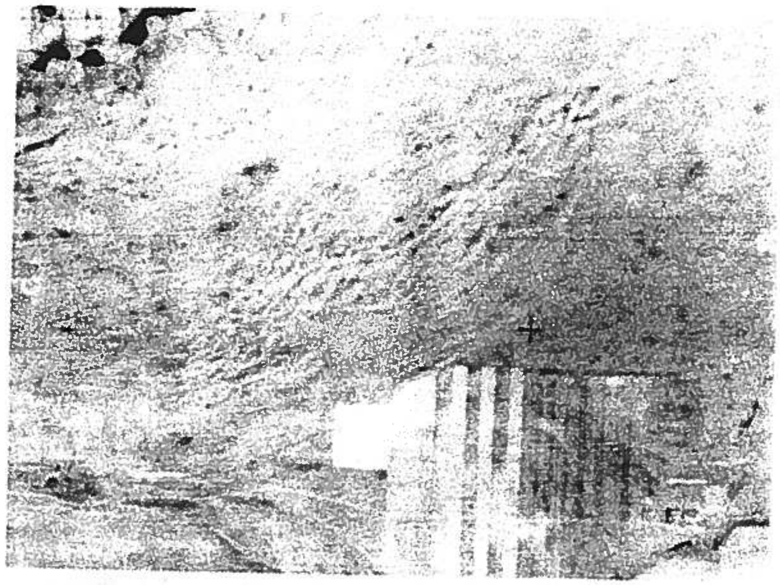


FIGURE 1. Linear disintegration ridges along the northwestern shore of Lake Pakowki, composed of gravel and sand. The ridges parallel the former margin of stagnant glacier.
Location: township 5, range 8.
Reference Number: 160-4907
2456-42

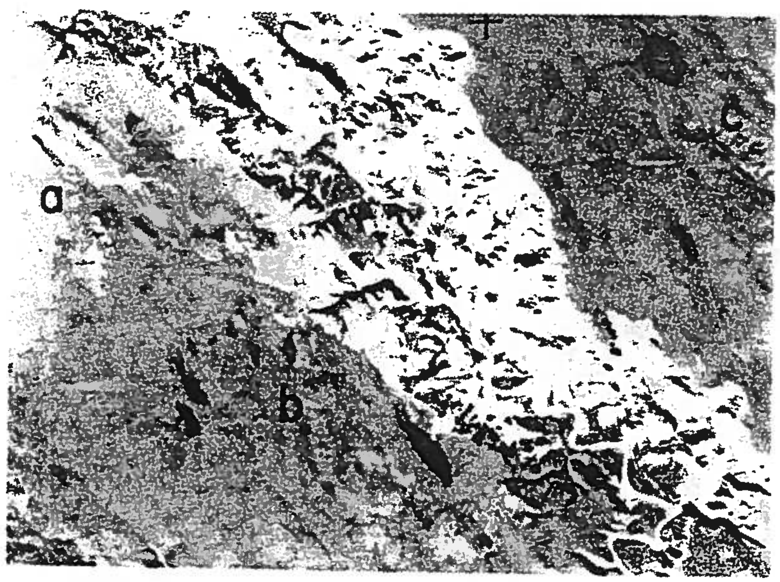


FIGURE 2. Drumlins (a), about 50 feet high and composed of gravel and sand; associated with ice-contact features—kames (b) and an esker (c). Lost River flows across the area.
Location: township 1, range 4.
Reference Number: 160-4901B
2191-143

PLATE 8.

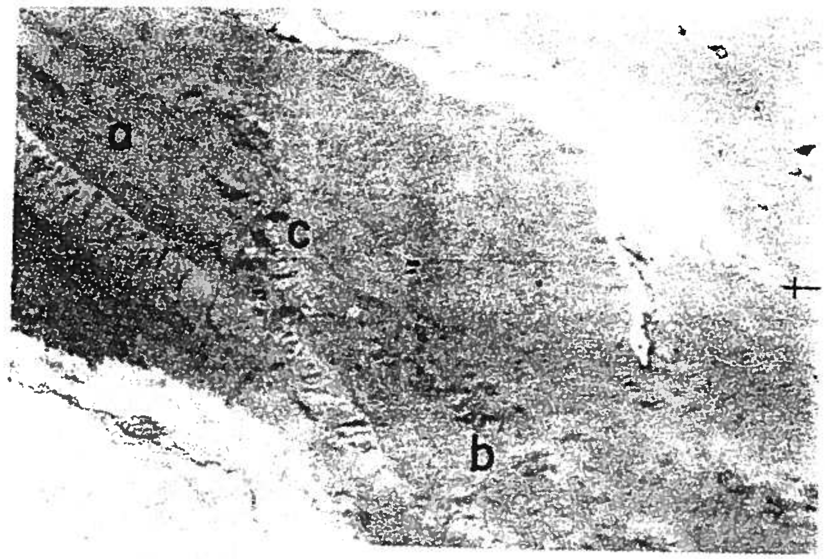


FIGURE 1. A relatively straight esker (a) oriented parallel to the direction of ice movement and pitted by kettles (b) and a channel (c). The last-named was formed by a superglacial stream. This esker is more than 12 miles long, approximately a mile wide in places, and rises 50 feet above the surrounding prairie level.

Location: township 1, range 3.

Reference Number: 160-4901B

2191-145

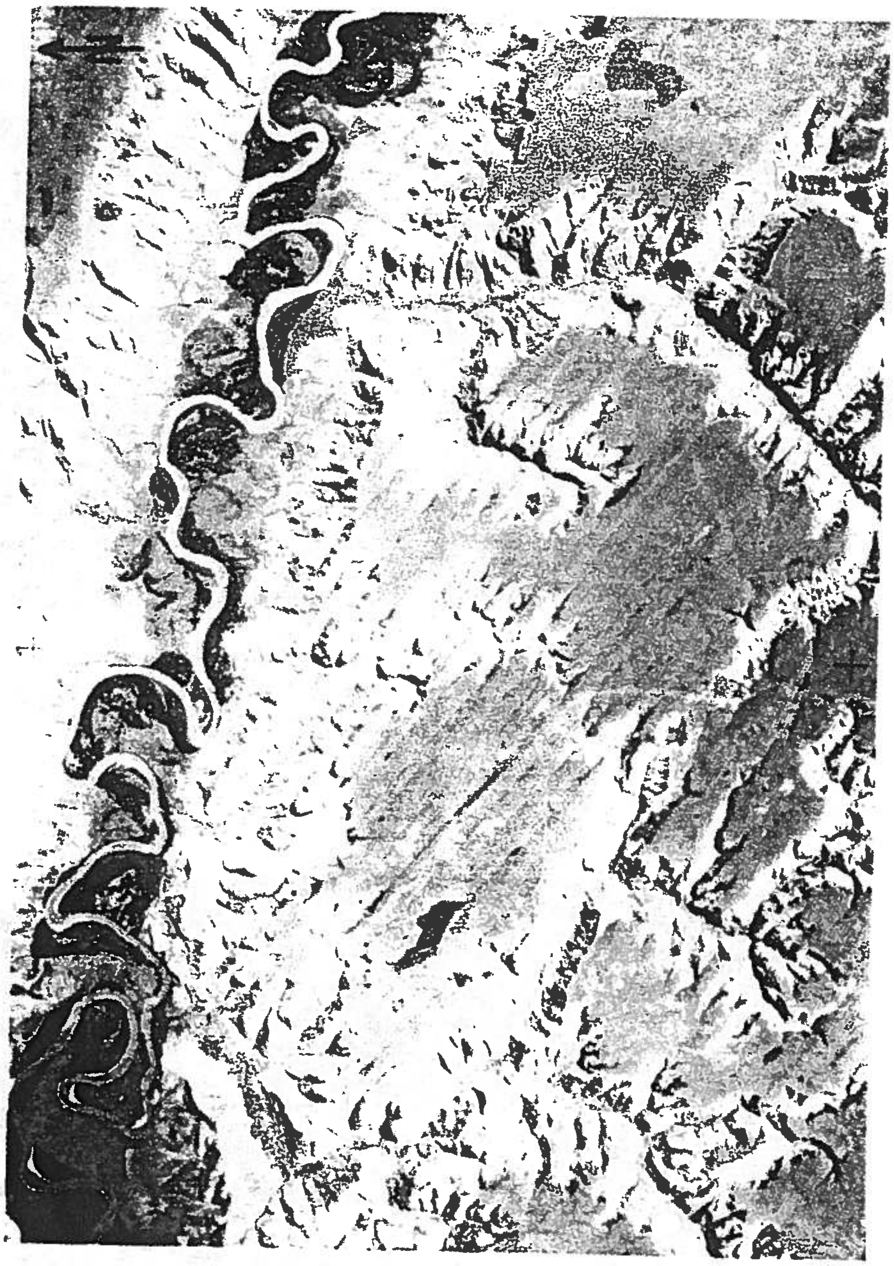
FIGURE 2. A sinuous esker (a), lying on hummocky moraine (b). Note the tonal contrast between the gravel and sand of the esker and the till of hummocky moraine.

Location: townships 1 and 2, range 2.

Reference Number: 160-4901

2273-111

PLATE 9.



Flutings in bedrock south of Milk River Canyon. The drift thickness varies from 0 to 15 feet. The dissection of the land by streams south of the Milk River largely post-dates the formation of the Milk River Canyon. Notice how the flutings have controlled the orientation of some tributary valleys.
Location: township 2, range 7.
Reference Number: 160-4902
1998-146

PLATE 10.

FIGURES 1, 2. Three feet of loess on the Cypress Hills conglomerate, whose uppermost beds have been deformed by frost action. Involutions and the vertical attitude of the long axes of pebbles are well shown in figure 2. Location: Lsd. 12, Sec. 9, Tp. 8, R. 3.

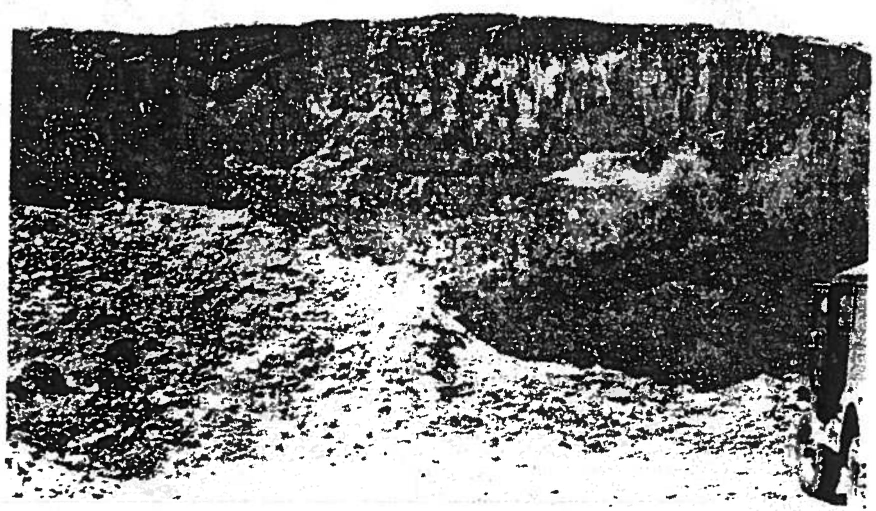


FIGURE 3. Eight feet of Cypress Hills loess on deformed beds of the Cypress Hills conglomerate. (This section has now been destroyed). Location: Lsd. 8, Sec. 25, Tp. 8, R. 2.

PLATE 11.

FIGURE 1. Lobate sheets of sand with superimposed dunes (a) overlying ground moraine (b) east of Lake Pakowki. The sandy area is now stabilized by grasses, shrubs and trees, although some dunes have been reactivated locally.
Location: township 5, ranges 6 and 7.
Reference Number: 160-4907
2456-46

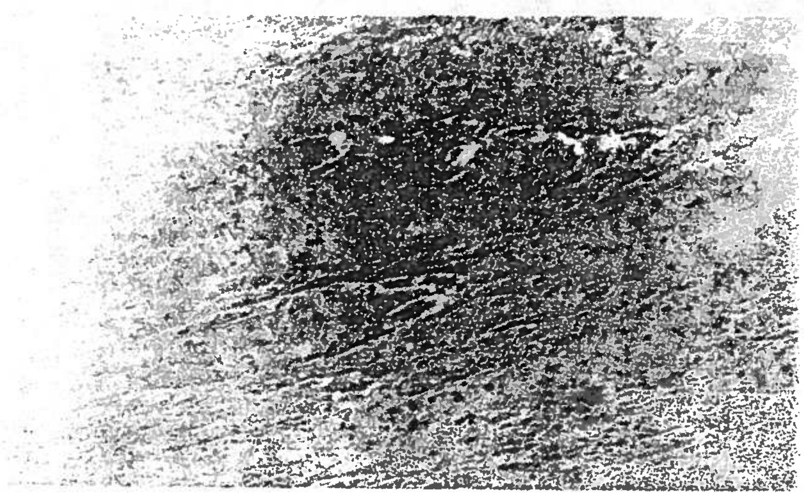
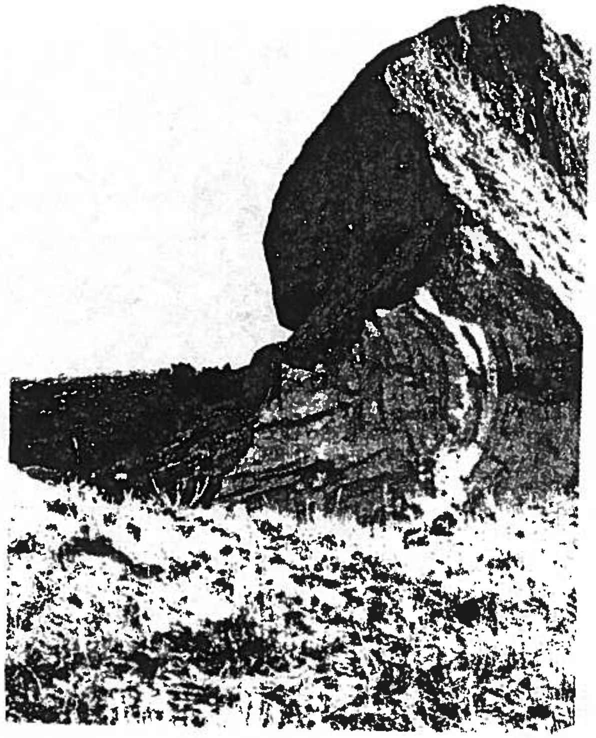
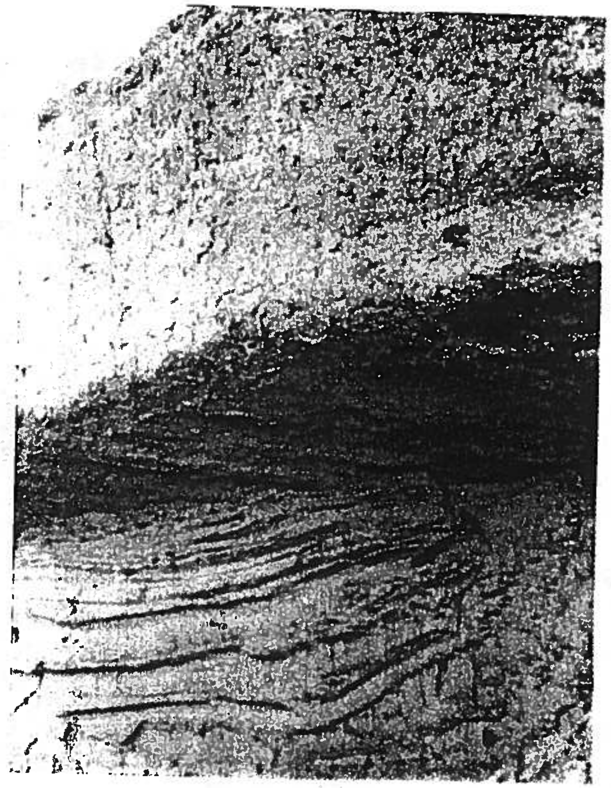


FIGURE 2. Parabolic dunes, south of Oldman River, developed by west-southwesterly winds. Lacustrine sand overlies till in this area.
Location: township 11, range 14.
Reference Number: 160-4915
2060-9

PLATE 12.

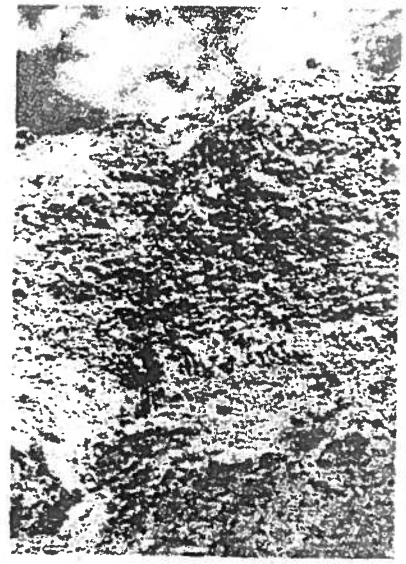




FIGURES 1, 2. Deformed sands overlain by Oldman till. Ice movement to the southeast is indicated by the overturned fold in the sands (Fig. 1) and by linear sole marks, which parallel the direction of ice movement, on the Oldman till (Fig. 2).

Location: Lsd. 1, Sec. 1, Tp. 12, R. 11.

PLATE 13.



FIGURES 1, 2. Frost action structures in the Saskatchewan Gravels exposed along the Oldman River Valley: an involution (Lsd. 12, Sec. 20, Tp. 11, R. 14) (Fig. 1); a horizon of deranged pebbles whose long axes are now in a vertical position (Lsd. 6, Sec. 23, Tp. 11, R. 15) (Fig. 2).

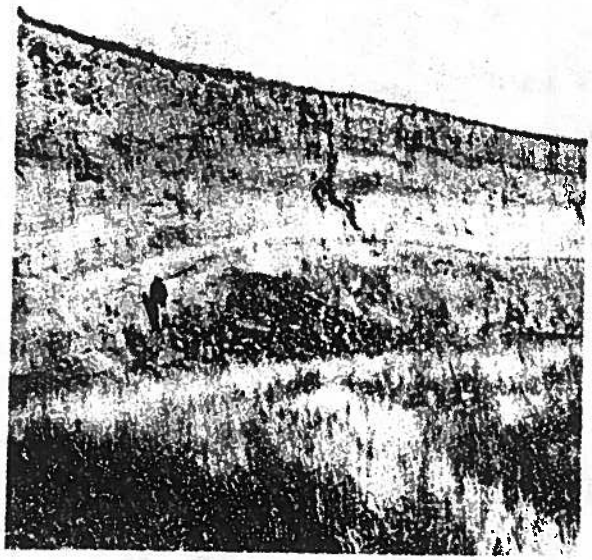
FIGURE 3.

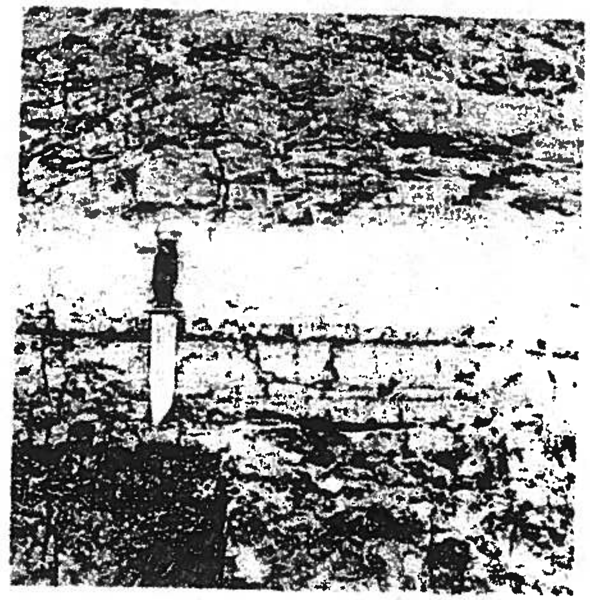
FIGURE 4.

FIGURE 3. Wolf Island sediments, consisting of interbedded sands, silts, and clays, deposited in a proglacial lake that occupied Bullshead Creek preglacial valley just prior to glaciation of the area. These lacustrine sediments were deformed by the overriding glacier. (Hammer gives scale). Location: Lsd. 16, Sec. 31, Tp. 9, R. 5.

FIGURE 4. Three distinctive till sheets exposed in Lsd. 5, Sec. 23, Tp. 11, R. 3. These three tills can be traced westwards along Gros Ventre Creek for a distance of 8 miles.

PLATE 14.

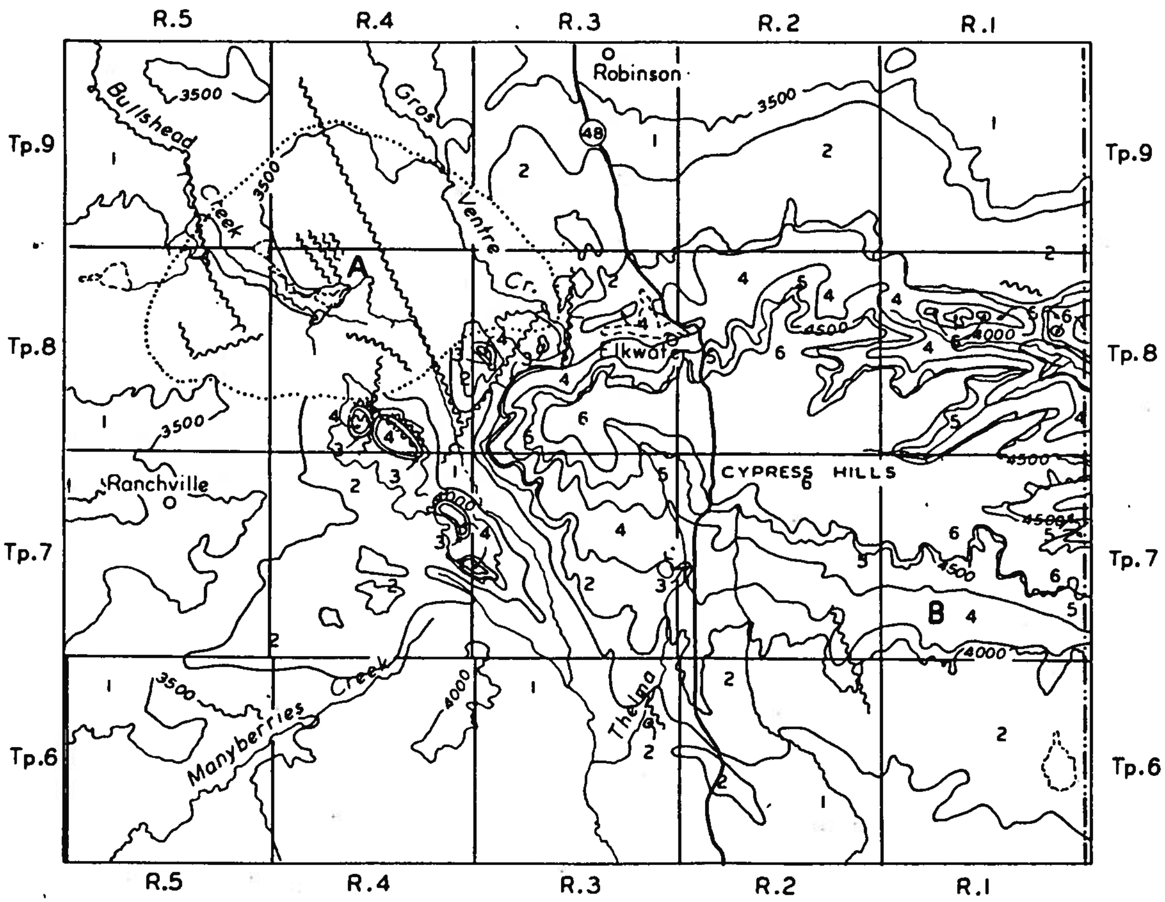




FIGURES 1, 2. Manyberries volcanic ash—a 6-inch thick ash bed overlain by 25 feet of lacustrine sand, silt, and clay. Till is exposed at the foot of the cliff. Note the sudden steepening of the dip on the lacustrine beds immediately above the ash layer (Fig. 2).
Location: Lsd. 14, Sec. 13, Tp. 5, R. 6.

INDEX

FIGURE 4. Geological map of the Cypress Hills.



To accompany Research Council Bulletin 22,

by J. A. Westgate

LEGEND

TERTIARY

Oligocene

6 — CYPRESS HILLS FORMATION: conglomerate; sandstone; some thin bentonite beds.

Paleocene

5 — RAVENSCRAG FORMATION: grey sandstone; red, green and grey clays; some bentonite beds.

CRETACEOUS

4 — FRENCHMAN FORMATION: grey, buff-weathering sandstone.

3 — BATTLE AND WHITEMUD FORMATIONS: black, bentonitic shale and volcanic ash; light grey, greenish-grey and brown clays.

2 — EASTEND FORMATION: grey sandstone, shale; coal seams.

1 — BEARPAW FORMATION: dark grey shale; sandstone, bentonite beds.

Geological boundary; approximate ...

Geological boundary; assumed ......

Fault ....

Scale in Miles

5 4 3 2 1 0 5

After L.S. Russell, 1940, G.S.C. maps 566A, 567A: slightly modified after L. Lindoe (written communication in 1963); T.B. Haites and H. van Hees, 1962, Jour. Alberta Soc. Petrol. Geol., vol. 10, no. 9; and fieldwork by J.A. Westgate during the period 1961-1963.

Note 1. This is an area of highly disturbed beds. At point A, a series of N.W.-S.E. aligned thrust faults bring the Alberta Shale to the surface; a vertical movement of over 3000 feet. This deformation is probably due to emplacement of an igneous body at depth, probably synchronous with the Sweetgrass intrusions in Montana.

Note 2. Along the southern slope of the Cypress Hills (B) the upper-most 50 feet of strata have been deformed by movement, under gravity, on underlying clay beds - e.g. Battle and Whitemud Formations.

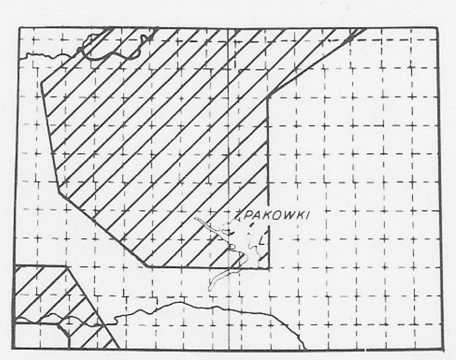
LEGEND

Contour, bedrock surface 2500

Thalweg of preglacial valley ....

Preglacial drainage divide ....

Bedrock topography by J.A. Westgate, 1964

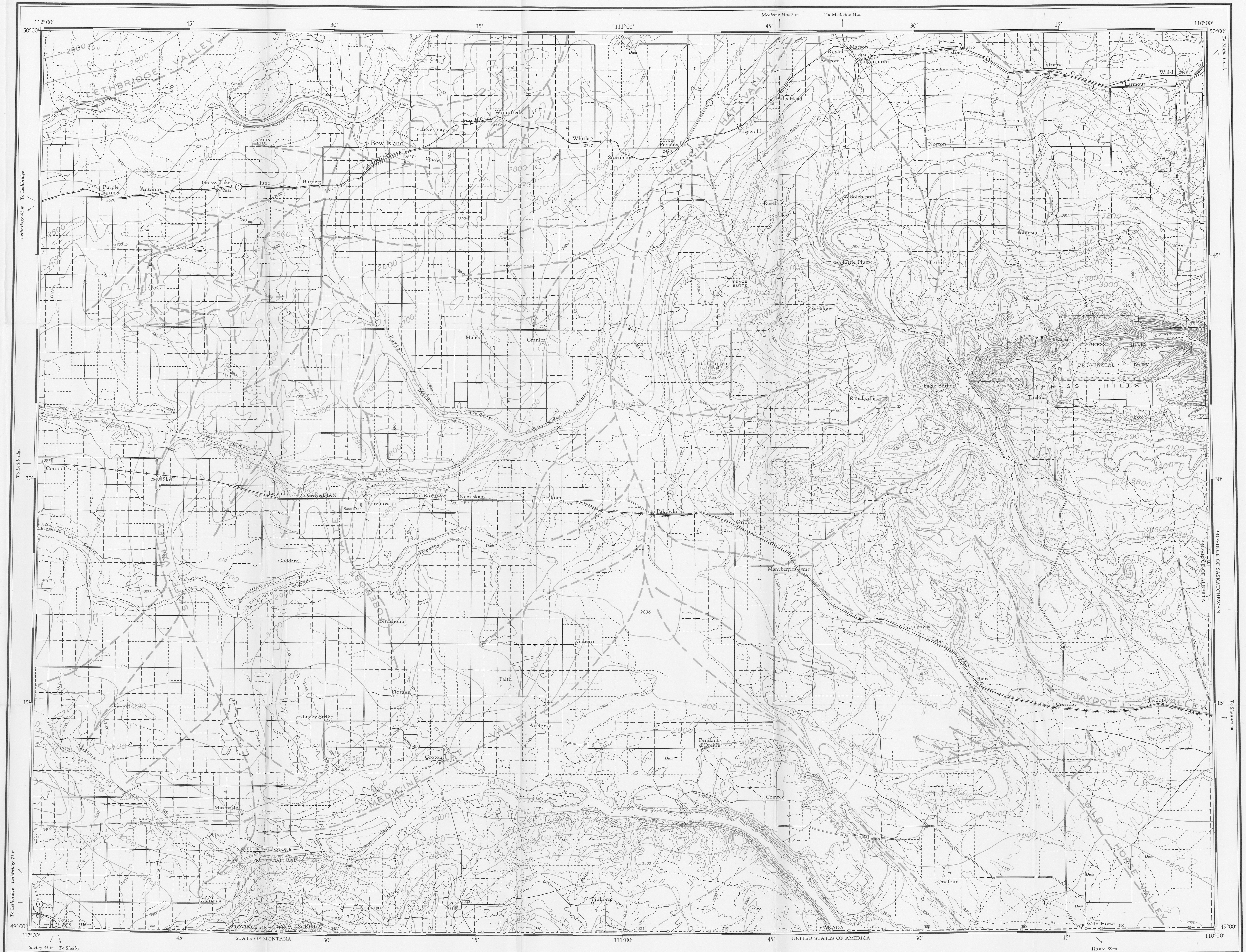


Reliability of bedrock contours

Shaded areas: — excellent to good control; data mainly from seismic shot-hole logs; bedrock surface spot heights spaced one mile apart or less over most of this area

Unshaded areas: — fair to poor control; contours drawn up from data obtained in the field, supplemented by limited information from seismic shot-hole logs, and water wells

FIGURE 6. Bedrock topography of the Foremost-Cypress Hills area, Alberta.

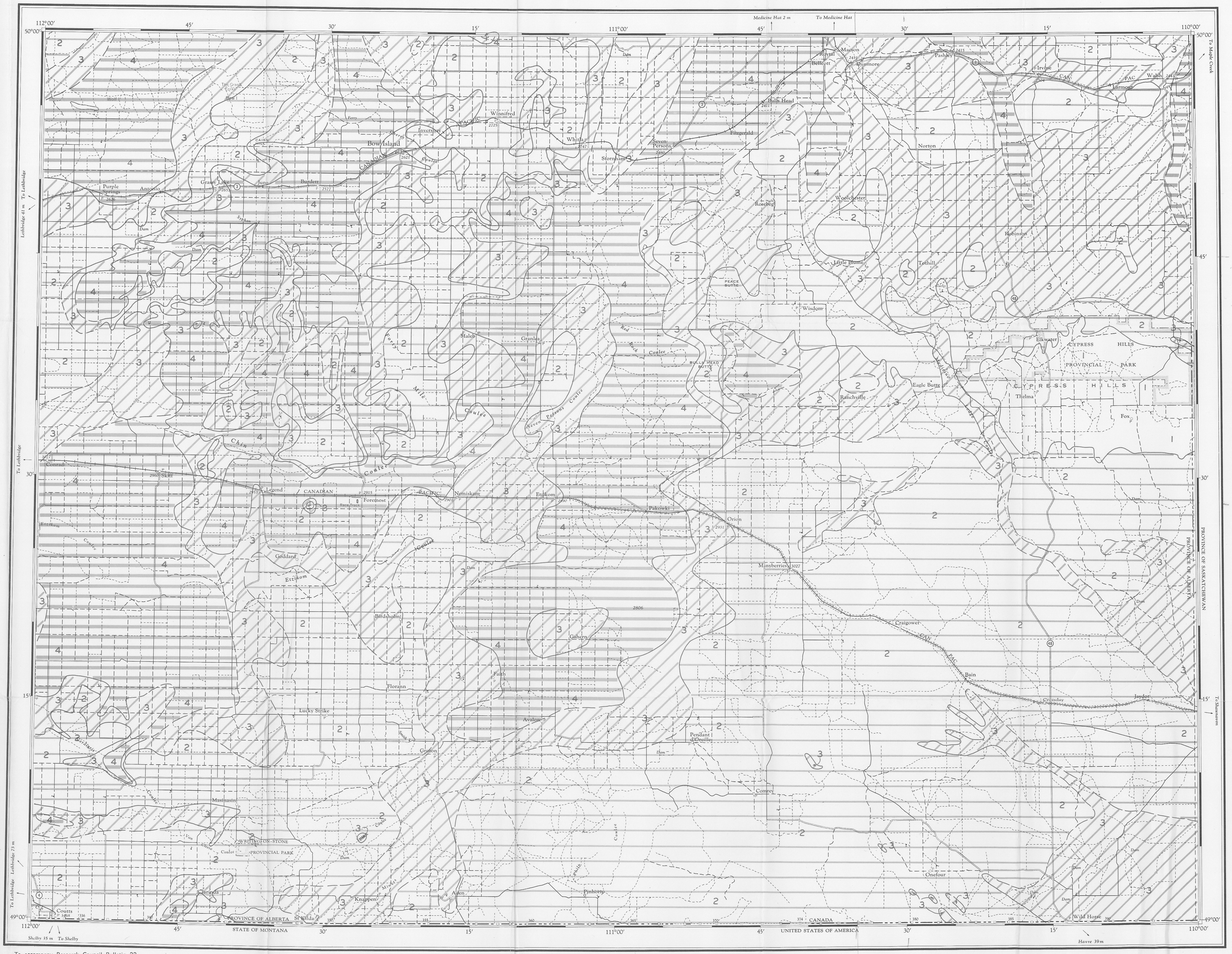


To accompany Research Council Bulletin 22, by J. A. Westgate

Scale 1:250,000
1 Inch to 4 Miles Approximately

Miles 5 0 5 10 15 20 Miles

Kilometres 5 0 5 10 15 20 25 30 Kilometres



LEGEND

4	Glacial drift more than 100 feet thick
3	Glacial drift 50–100 feet thick
2	Glacial drift 0–50 feet thick
1	Cypress Hills Plateau: unglaciated; some loess, generally less than 5 feet thick

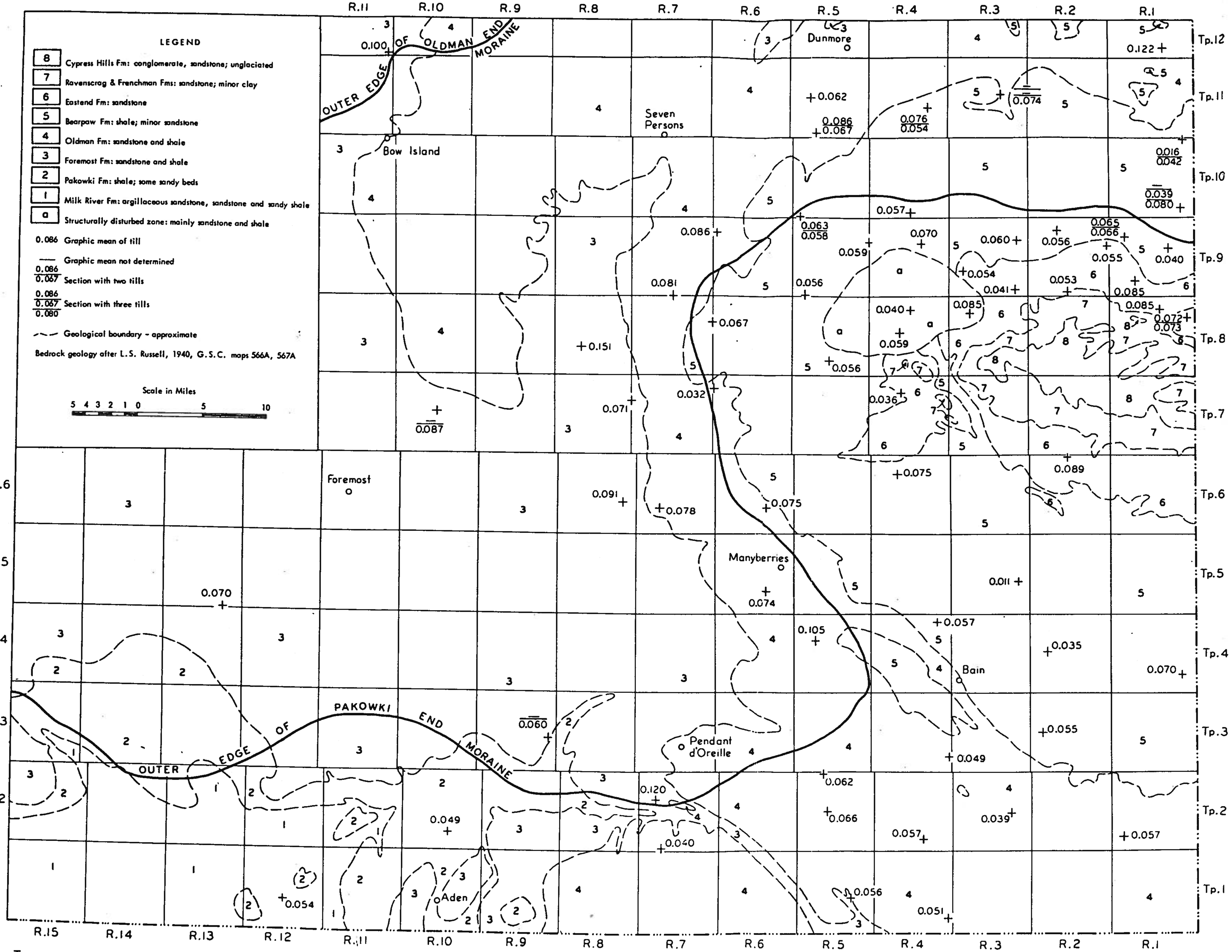
Boundary, fairly well defined ....

Boundary, approximate ....

FIGURE 7. Drift thickness in the Foremost-Cypress Hills area, Alberta.

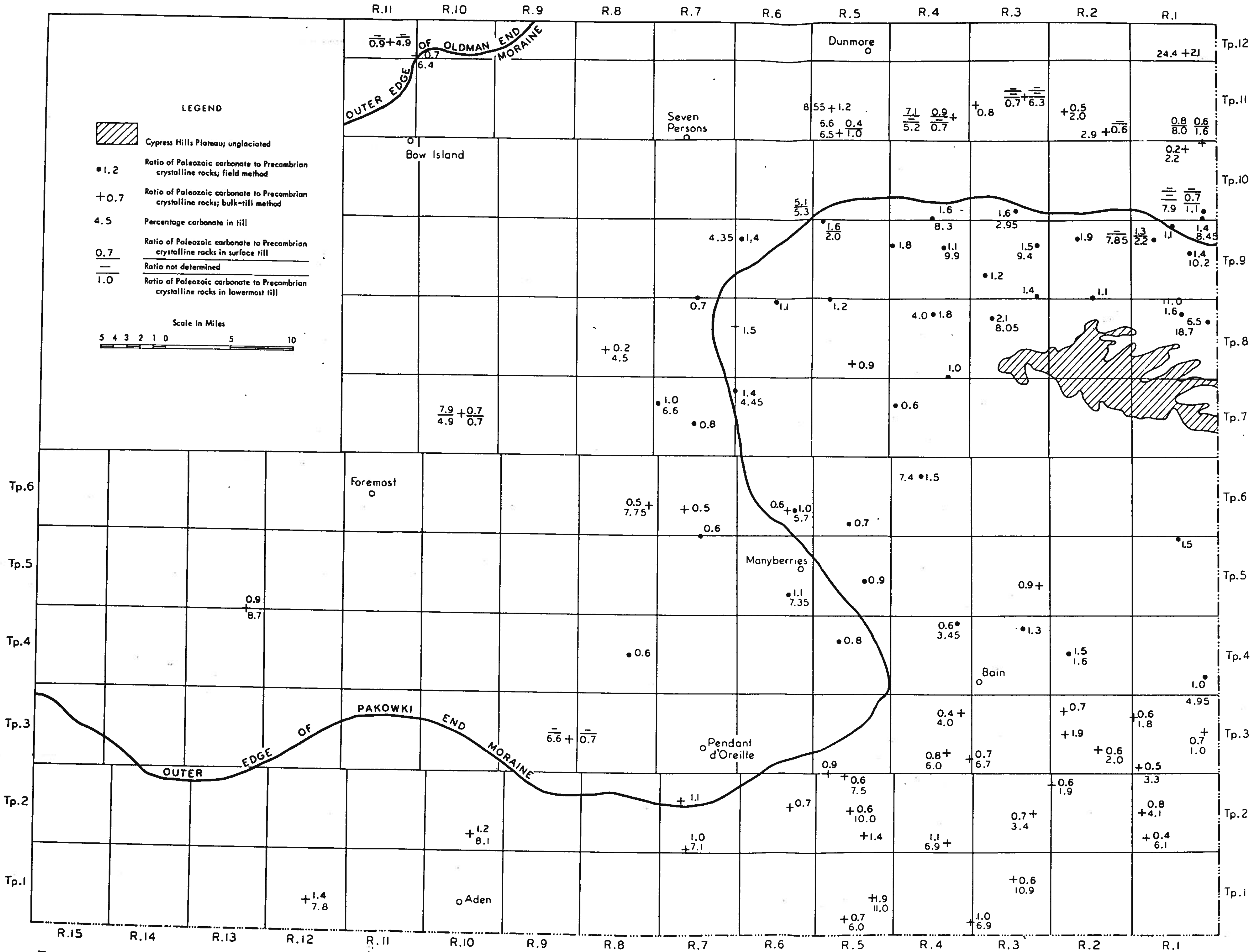
To accompany Research Council Bulletin 22,
by J. A. Westgate

Scale 1:250,000
1 Inch to 4 Miles Approximately
Miles 5 0 5 10 15 20 Miles
Kilometres 5 0 5 10 15 20 25 30 Kilometres



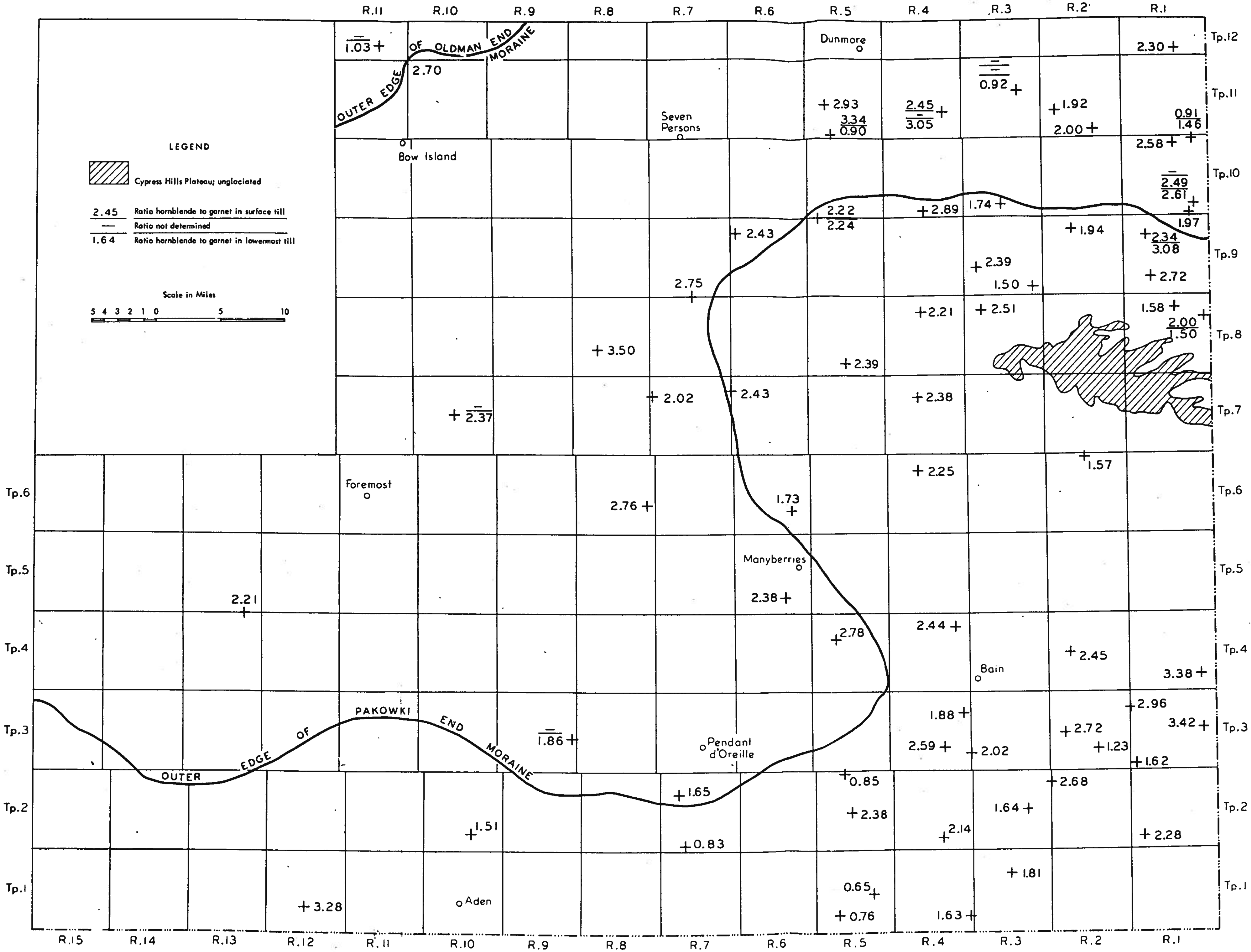
To accompany Research Council Bulletin 22, by J. A. Westgate

FIGURE 20. Textural variation of tills in the Foremost-Cypress Hills area with respect to the underlying bedrock.



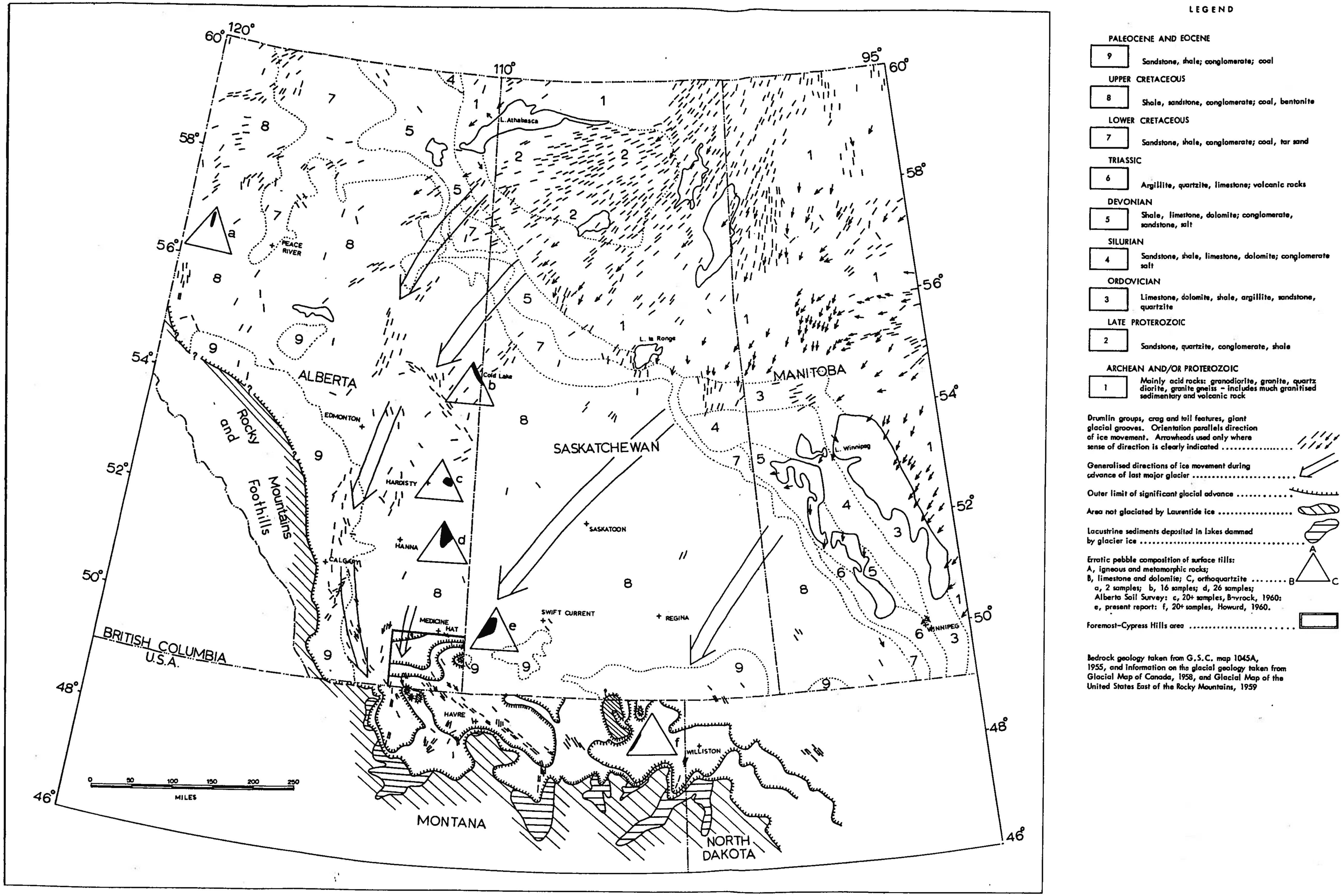
To accompany Research Council Bulletin 22,
by J. A. Westgate

FIGURE 23. Comparison of ratio values of Paleozoic carbonate to Precambrian crystalline pebbles in tills, with percentage carbonate in till matrix.



To accompany Research Council Bulletin 22,
by J. A. Westgate

FIGURE 24. Ratio of hornblende to garnet in tills of the Foremost-Cypress Hills area.



To accompany Research Council Bulletin 22,
by J. A. Westgate

FIGURE 28. Regional directions of ice movement, erratic pebble composition of tills, and bedrock geology of the Western Plains of Canada and contiguous parts of the United States.

RESEARCH COUNCIL OF ALBERTA

LEGEND

QUATERNARY

RECENT

18 — Aeolian deposits: *sand and silt; parabolic dunes; blow outs.*

PLEISTOCENE AND RECENT

17 — Eroded slope: *mainly bedrock; some colluvium; extensive slumping. (Also present along meltwater channels and recent valleys but not indicated on map.)*

PLEISTOCENE

GLACIO-LACUSTRINE

16 — Lacustrine sediments: *sand, silt and clay; thin, generally less than 10 feet thick; till in places.* 16a, *lacustrine silt over hummocky and ridged end moraine.*

15 — Lacustrine sediments: *sand, silt and clay; some gravel; in places covered by recent lacustrine sediment and alluvium.* 15a, *deltaic sediments: gravel and sand.*

GLACIO-FLUVIAL

14 — Undifferentiated outwash gravel, sand and till: *bedrock exposed in places.*

13 — Outwash and alluvium: *gravel and sand; some silt.*

12 — Outwash: *gravel and sand on Cypress Hills Formation; large Laurentian erratics present, including dolomite.*

11 — Meltwater channel sediments: *gravel, sand, silt and clay; terraces present and lower parts covered by recent alluvium, colluvium and lacustrine sediment.*

10 — Eroded plains: *in parts scoured by meltwater; till, gravel, sand, silt and clay; bedrock exposures common; extensive badland.*

9 — Esker: *gravel and sand.*

8 — Kame: *gravel and sand.*

AEOLIAN

7 — Loess: *unconsolidated sand, silt and clay overlying bedrock; generally less than 5 feet thick; slightly deformed by frost action; bedrock exposures common on southern slope of Cypress Hills; unglaciated.*

GLACIAL

6 — Bedrock upland veneered with till: *some gravel and sand in places.*

5 — Patches of glacial drift: *includes Laurentide erratics; resting on bedrock.*

4 — Hummocky and ridged end moraine: *mainly till; some gravel and sand; aligned knobs, linear and closed disintegration ridges; large to medium local relief.*

3 — Washboard moraine: *mainly till; aligned ridges; small local relief - less than 10 feet.*

2 — Hummocky disintegration moraine: *mainly till; knobs, closed and linear disintegration ridges; large to medium local relief.*

1 — Ground moraine; *mainly till - unsorted rocks, sand, silt and clay; patches of lacustrine and outwash sand, silt and clay; local relief less than 10 feet.*

Geological boundary, definite

gradational, approximate

Buried channel (glacial)

Postulated direction of meltwater flow

Direction of ice movement as determined by petrofabric analysis: a, *uppermost till;* b, *lowermost till;* c, *grooves on bottom of uppermost till*

Drumlin or drumlinoid ridge: direction of ice movement indicated by arrow

Fluting: the staff parallels direction of ice movement

Glacial lineaments: dominant orientation parallels former positions of ice front

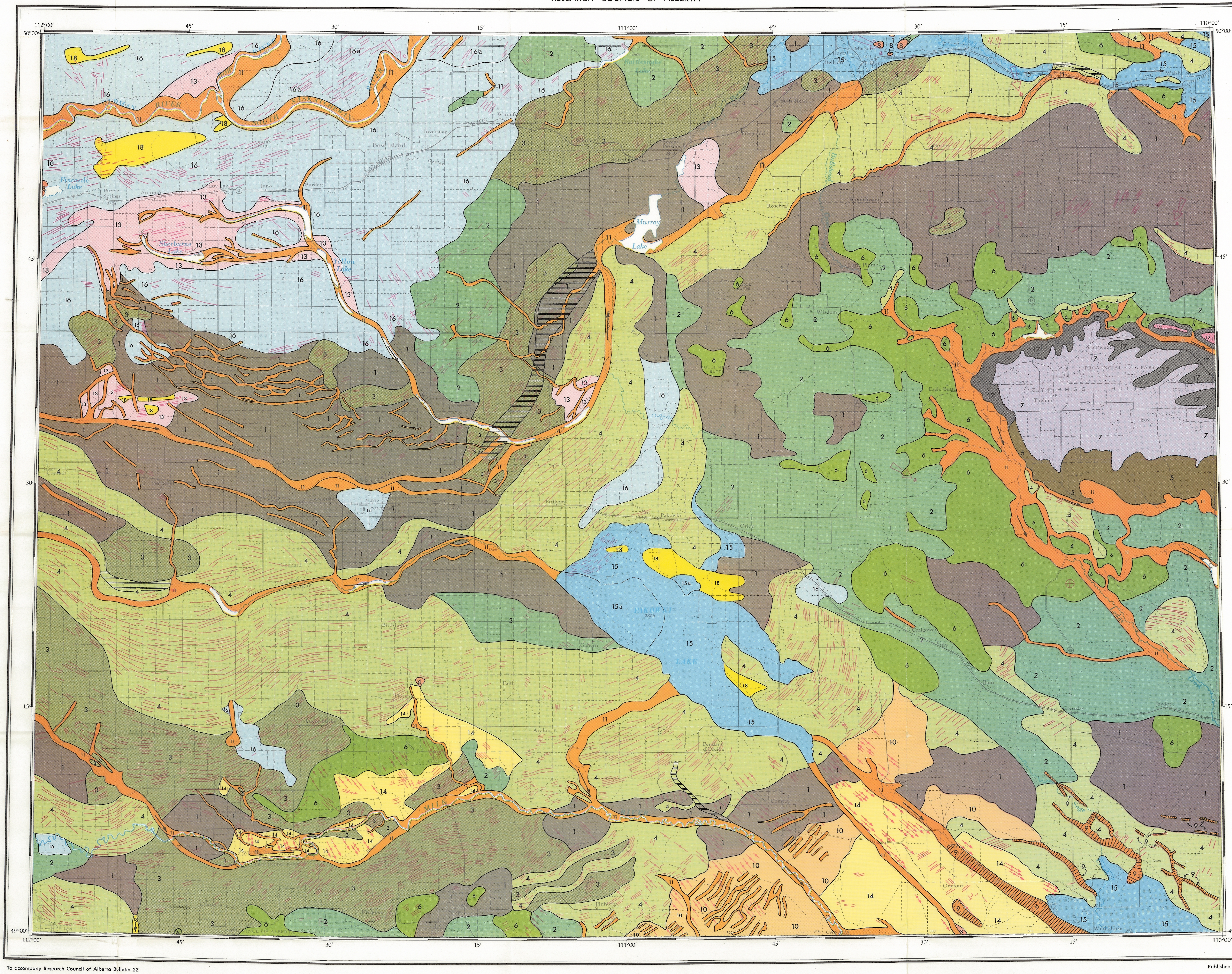
Site of large erratic blocks of Cypress Hills conglomerate

Limit of glacierization

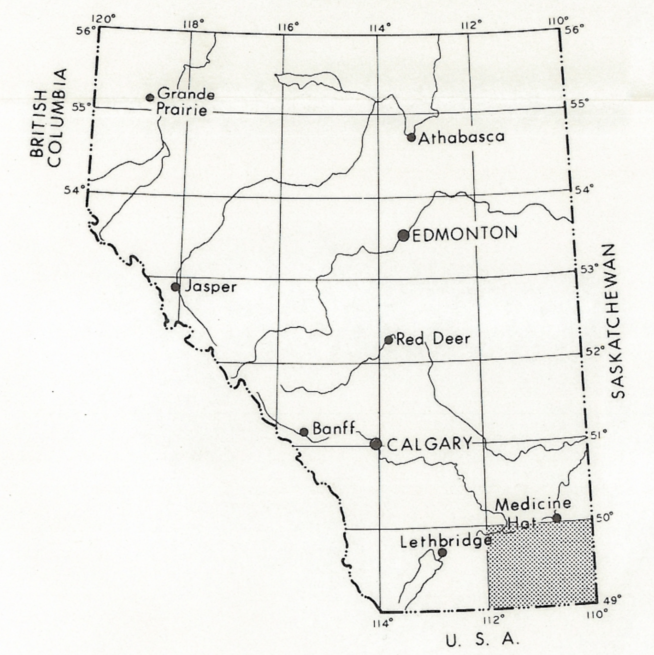
Geology by J. A. Westgate 1961-63.

Base map by Department of Energy, Mines and Resources, Ottawa.

Balance of map construction by the Technical Division, Department of Lands and Forests, Edmonton, Alberta.



INDEX MAP



To accompany Research Council of Alberta Bulletin 22

Published 1968

MAP 29

Surficial Geology

FOREMOST — CYPRESS HILLS

WEST OF FOURTH MERIDIAN

ALBERTA

Scale 1:250,000

1 Inch to 4 Miles Approximately

Miles 5 0 5 10 15 20 Miles

Kilometers 5 0 5 10 15 20 25 30 Kilometers