Géographie physique et Quaternaire

Nature, Origin, and Age Relationships of Landscape Complexes in Southwestern Saskatchewan

Les liens entre Ia nature, l'origine et l'âge des ensembles de paysages du sud-ouest de la Saskatchewan

Beziehungen zwischen Natur, Ursprung und Alter von Landschaftseinheiten in Südwest-Saskatchewan

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Résumé de l'article

On observe six ensembles de paysages dans les régions de Cypress Lake (72F) et Wood Mountain (72G). Les ensembles se distinguent par leur géomorphologie, leur géologie et leurs processus de formation. Les liens entre ces composantes ont servi à déterminer l'âge relatif des paysages. L'ensemble le plus ancien se caractérise par son substratum non englacé et est composé de paysages au stade de la maturité édifiés dans les sédiments du Crétacé supérieur et du Tertiaire. Il a été formé sous les climats arides à semi arides du Tertiaire supérieur par des processus fluviatiles et de solifluxion. Le deuxième ensemble est très semblable, mais comprend, lui, des dépôts glaciaires résiduels dispersés, surtout de nature erratique. Cet ensemble rappelle les mêmes processus de formation, mais il a été englacé au Pléistocène. Le troisième ensemble caractérisé par ses dépôts glaciaires ressemble aux ensembles plus anciens, sauf en ce qui a trait au placage de matériel détritique et à la présence de chenaux de fonte. Ici, les effets de la glaciation du Wisconsinien supérieur se limitent à une érosion par l'eau de fonte, car les dépôts glaciaires semblent antérieurs à cette glaciation. Les trois autres ensembles de paysages se caractérisent, respectivement, par des dépôts glaciaires de première avancée, par des dépôts glaciaires interlobaires et, enfin, par des dépôts glaciaires de dernière avancée. Ces paysages renferment des terrains caractéristiques des milieux de la Prairie englacés au Wisconsinien supérieur.

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NATURE, ORIGIN, AND AGE RELATIONSHIPS OF LANDSCAPE COMPLEXES IN SOUTHWESTERN SASKATCHEWAN*

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ABSTRACT Six landscape complexes are recognized in the Cypress Lake (72 F) and Wood Mountain (72 G) areas of southwestern Saskatchewan. The complexes are recognized by their geomorphology, geology, and processes of landscape formation. The relationships of these components are used to determine the relative ages of the complexes. The oldest complex designated "unglaciated bedrock terrain", consists of mature landscapes developed in Late Cretaceous and Tertiary sediments. It was formed by fluvial and mass wasting processes under Late Tertiary arid to semi-arid climates. A rather similar complex, but with scattered drift residuals — chiefly glacial erratics, is called "bedrock terrain with residual drift". This complex reflects similar Late Tertiary processes of landscape formation but was later affected by Pleistocene glaciation. A complex called "bedrock terrain and drift" resembles the older complexes except for a veneer of drift and local meltwater channels. Here, effects of the Late Wisconsinan glaciation are restricted to meltwater erosion, and the drift appears to predate this glaciation. The other three landscape complexes are: "first advance drift", "interlobate drift" and "last advance drift". These include terrain typical of the parts of the southern prairies covered by the Late Wisconsinan glacier.

RÉSUMÉ *Les liens entre la nature, l'origine et l'âge des ensembles de paysages du sud-ouest de la Saskatchewan.* On observe six ensembles de paysages dans les régions de Cypress Lake (72F) et Wood Mountain (72G). Les ensembles se distinguent par leur géomorphologie, leur géologie et leurs processus de formation. Les liens entre ces composantes ont servi à déterminer l'âge relatif des paysages. L'ensemble le plus ancien se caractérise par son substratum non englacé et est composé de paysages au stade de la maturité édifiés dans les sédiments du Crétacé supérieur et du Tertiaire. Il a été formé sous les climats arides à semi arides du Tertiaire supérieur par des processus fluviatiles et de solifluxion. Le deuxième ensemble est très semblable, mais comprend, lui, des dépôts glaciaires résiduels dispersés, surtout de nature erratique. Cet ensemble rappelle les mêmes processus de formation, mais il a été englacé au Pléistocène. Le troisième ensemble caractérisé par ses dépôts glaciaires ressemble aux ensembles plus anciens, sauf en ce qui a trait au placage de matériel détritique et à la présence de chenaux de fonte. Ici, les effets de la glaciation du Wisconsinien supérieur se limitent à une érosion par l'eau de fonte, car les dépôts glaciaires semblent antérieurs à cette glaciation. Les trois autres ensembles de paysages se caractérisent, respectivement, par des dépôts glaciaires de première avancée, par des dépôts glaciaires interlobaires et, enfin, par des dépôts glaciaires de dernière avancée. Ces paysages renferment des terrains caractéristiques des milieux de la Prairie englacés au Wisconsinien supérieur.

ZUSAMMENFASSUNG *Beziehungen zwischen Natur, Ursprung und Alter von Landschaftseinheiten in Südwest-Saskatchewan.* Sechs Landschaftseinheiten wurden in den Gebieten von Cypress Lake (72 F) und Wood Mountain (72 G) in Südwest-Saskatchewan identifiziert. Die Einheiten unterscheiden sich durch ihre Geomorphologie, Geologie und Prozesse der Landschaftsbildung. Die Beziehungen zwischen diesen Komponenten werden benutzt, um das relative Alter der Einheiten zu bestimmen. Die älteste Einheit, welche sich durch ihr nicht vereistes anstehendes Gestein auszeichnet, besteht aus Landschaften im Stadium der Reife, die sich in Sedimenten der späten Kreidezeit und des Tertiär entwickelt haben. Sie wurde durch fluviale und Masse zerstörende Vorgänge unter den trockenen bis halbtrockenen Klimas des späten Tertiär gebildet. Eine ziemlich ähnliche Einheit, jedoch mit zerstreuten glazialen Ablagerungsrückstanden vor allem erratischer Natur, wird "Gebiet mit anstehendem Gestein und glazialen Ablagerungsrückständen" genannt. Diese Einheit spiegelt ähnliche Prozesse der Landschaftsbildung im späten Tertiär, wurde aber später durch die Vereisung im Pleistozän beeinflußt. Ein Gebiet mit anstehendem Gestein und Ablagerungen gleicht den älteren Einheiten, abgesehen von einem Schleier von Trümmerablagerungen und örtlichen Schmelzwasserkanälen. Hier scheinen die Auswirkungen der spät-Wisconsinischen Vereisung sich auf Erosion durch Schmelzwasser zu beschränken, und die glazialen Ablagerungen scheinen vor dieser Vereisung geschehen zu sein. Die drei anderen Landschaftseinheiten sind: "glaziale Ablagerungen des ersten Vorstoßes", "interlobale glaziale Ablagerungen" und "glaziale Ablagerungen des letzten Vorstoßes". Diese Landschaftseinheiten schließen Formationen ein, die typisch für die im späten Wisconsinum vereisten Teile der Prärien sind.

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INTRODUCTION

GENERAL STATEMENT

A panorama of prairie scenery unique to the Cypress Hills and Wood Mountain uplands of southwestern Saskatchewan includes plateau remnants with north-facing escarpments and southward sloping pediments separated by broad, generally southward trending valleys. Parts of the higher plateaus and steep slopes of the Cypress Hills sustain a substantial cover of pine, spruce and poplar, in contrast to the open grasslands common to other parts of these uplands. Unglaciated plateau remnants found on the highest part (West Block) of the Cypress Hills and the southeastern part of the Wood Mountain Upland are unique to this part of the southern prairies. The uplands form irregular profiles that contrast with the smooth profiles of the surrounding glaciated plains.

Much of the area consists of the glaciated landscapes typical of the southern prairies. However, the Cypress Hills and Wood Mountain uplands were formed mainly by Late Tertiary geomorphic processes and modified somewhat during the Quaternary. The surficial geology maps of the area classify all these surfaces into units on the basis of materials, landforms and inferred origin. Mapping specific landforms resulting from Late Tertiary or Quaternary processes within unglaciated and weakly glaciated landscapes requires more detailed studies than those undertaken to date. Studies by McConnell (1885), Collier and Thom (1918), and Russell (1970) led them to propose a Late Teritary origin for these landscapes, whereas Jungarius (1966, 1967) suggested that the weakly glaciated pediments of the Alberta part of the Cypress Hills formed during the Late Pleistocene.

The author proposes grouping parts of the area dominated by landscapes that formed in similar geologic and geomorphic settings, and by similar processes into "landscape complexes". These criteria are also used to infer relative age differences of six such complexes identified. Beginning with the oldest they are: unglaciated bedrock terrain, bedrock terrain with residual drift, bedrock terrain with drift, first advance drift, interlobate drift, and last advance drift.

The term "pediment" is used frequently in this report in discussions of the bedrock terrain. Most geomorphologists agree that pediments are broad, flat or gently sloping erosion surfaces formed during arid or semiarid climates by processes that included weathering, rill wash, sheet wash and sheet flow (Gary *et al.*, 1972; Twidale, 1976; Garner, 1974). Similar surfaces were also thought to have formed by running water (King, 1953), whereas others (Tricart and Cailleux, 1972) considered vegetation and soil development as major factors in the evolution of pediments.

SOURCE OF INFORMATION

This paper is based largely on information obtained from a study of the surficial geology of the Cypress Lake and Wood Mountain areas in southwestern Saskatchewan during the summers of 1983 to 1990. A particular effort was made to obtain information on the nature of the upland surfaces so as to establish a more rigorous chronologic framework for their development.

Field work included the description and sampling of road cuts, natural exposures, drill holes (10 to 15 m deep) and backhoe trenches. Information for the drift thickness maps came mainly from published maps and reports, along with a large body of unpublished data obtained from government agencies. Published maps and reports based on extensive field and subsurface studies (Frazer *et al.*, 1935; Furnival, 1946; Whitaker, 1965, 1968; Williams, 1929), provided more than adequate information on the bedrock geology and aspects of the physiography of the region. Surficial geology maps of the Cypress Lake (72F) and Wood Mountain (72G) areas on a scale of 1: 250,000 (Klassen, 1991, 1992) provided the bases for establishing the nature of the deposits and deciphering the Late Tertiary to Quaternary history of the region.

PREVIOUS WORK

McConnell's (1885) report on the physiographic and geologic framework of southwestern Saskatchewan provided a sound basis for later studies. It included descriptions of major physiographic units such as the Cypress Hills, Wood Mountain and Swift Current Creek Plateau (Figs. 1, 2) and discussed of the relationship of landscapes to local bedrock and drift thickness. Later studies (Collier and Thom, 1918; Alden, 1924, 1932; Williams, 1929) focused on the physiographic development of the Interior Plains region in Montana and southern Saskatchewan. Alden's proposed framework for the physiographic development of this part of the southern Interior Plains Region was generally accepted and expanded on by later workers. Williams and Dyer (1930), for example, interpreted the successive levels of plateau remnants on the highest parts of the Cypress Hills as part of Alden's (1924) four stage erosional sequence. Alden also suggested that, during Oligocene and Miocene times, coalescing alluvial fans emanating from the Rocky Mountains formed a vast plain and that the main features of the present physiography were shaped largely by fluvial degradation during intervals of uplift and stillstand, beginning during Pliocene time.

The regional surficial deposits maps of southwestern Saskatchewan by Johnston, Wickenden and Weir (1948) provided a sound basis for understanding the role of glaciation in shaping the landscapes of this region. More recently, new information on the surficial geology of the Wood Mountain area was included in an unpublished Ph.D. thesis (Whitaker, 1965). The physiographic divisions outlined in Figure 2 were in part proposed by earlier workers (McConnell, 1885; Williams, 1929; Williams and Dyer, 1930) but are mainly modified from Acton *et al.* (1960).

REGIONAL PHYSIOGRAPHY AND GEOLOGY

The study area lies within the Alberta Plain Division of the Interior Plains Region (Bostock, 1970). The eastern part of the area at about 800 m elevation, marks the beginning of the so-called "third prairie level" (Klassen, 1989) and the gradual rise westward to the Rocky Mountain Foothills Division. Abrupt increases in elevation occur locally around uplands such as the westernmost part of the Cypress Hills which reaches about 1400 m elevation — the highest point of land

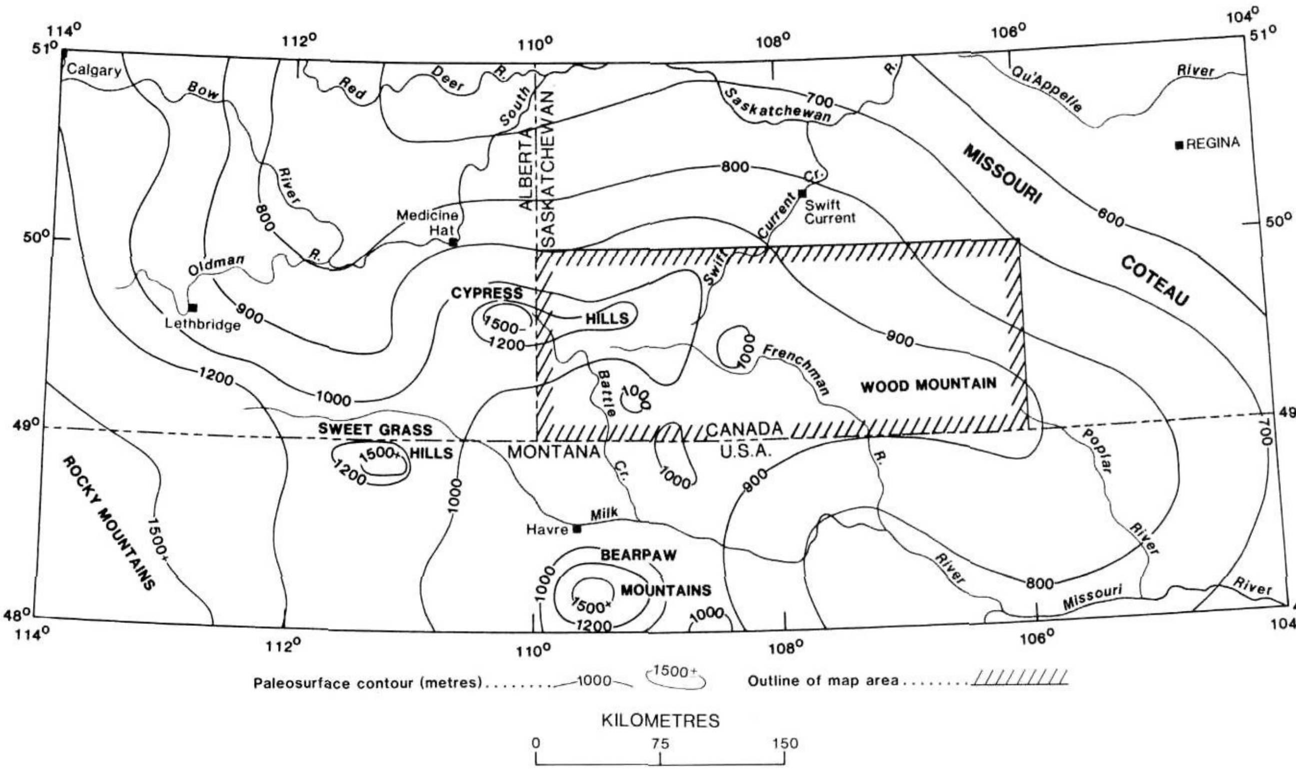

FIGURE 1. Late Tertiary paleosurface of southwestern Saskatchewan, southeastern Alberta, and adjacent Montana. Stretches of modern river valleys along contour reflect glacial diversion. Derived from International Map of the World 1:1,000,000 series; Lethbridge NM-12 and Regina NM-13 map sheets; Dept. of Energy Mines and Resources, Ottawa; 1973 and 1970.

Paléosurface du sud-ouest de la Saskatchewan, du sud-est de l'Alberta et du nord du Montana au Tertiaire supérieur. Certaines portions de vallées modernes le long des courbes reflètent des changements de cours. [Issu de International Map of the World à 1/1 000 000: feuillets NM-12 (Lethbridge) et NM- 13 (Regina); min. de l'Énergie, des Mines et des Ressources, 1973 et 1970.]

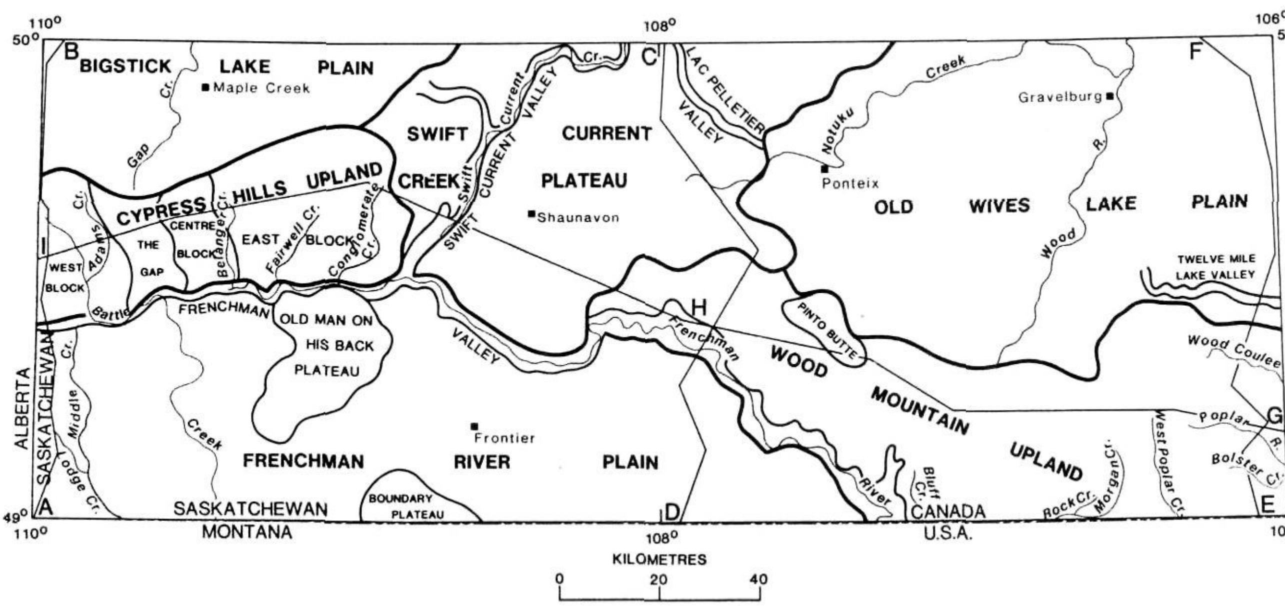

FIGURE 2. Physiographic divisions of the area showing major meltwater channels and present day drainage. Widest dark lines are boundaries of major divisions. Narrower dark lines are boundaries of minor divisions and trace meltwater channels. AB, DC, EF, HG, IH refer to cross-sections shown on Figure 3. Modified from Acton *et al.*, 1960.

Divisions physiographiques de la région montrant les principaux chenaux d'eau de fonte et le réseau de drainage actuel. Les traits plus forts représentent les limites des principales divisions et les traits plus fins, des divisions mineures et le tracé des chenaux d'eau de fonte. Les lettres AB, DC, EF, HG, IH font référence aux coupes de la figure 3 (modifié à partir de Acton et al.*, 1960)* in Saskatchewan. The study area is dominated by a divide that includes major uplands, such as the Cypress Hills and Wood Mountain, punctuated by buttes that form the highest parts (Fig. 1). These major uplands are flanked by extensive glaciated plains and scattered uplands that, in part, are Late Tertiary erosional residuals. The main features of Late Tertiary landscapes are remarkably well preserved over the unglaciated and weakly glaciated parts of the Cypress Hills and Wood Mountain uplands. The adjacent plains, however, were modified by Pleistocene glaciers, and drift commonly masks the lesser features of the preglacial landscapes.

The present South Saskatchewan and Missouri rivers in general follow their ancestral courses in this region. Their basins are separated by a preglacial divide that trends eastward from the foothills of the Rocky Mountains into southern Saskatchewan (Fig. 1). Major shifts from the ancestral drainage can be identified where the modern rivers follow the contours rather than crossing them (Fig. 1). The Late Tertiary surfaces sloped to the north and south from the divide at about 5 m/km. Those surfaces were subsequently dissected by fluvial and mass wasting processes leaving interstream tracts. The higher parts of the uplands and the interstream tracts are underlain by Tertiary gravel, sand and silt, whereas the flanks and valley sides are underlain mostly by Cretaceous silt and clay, which is locally veneered with *in situ* or re-worked Late Tertiary sediments.

The broad, step-like surfaces depicted in Figure 1 appear to have formed by lateral erosion during Late Tertiary time, by rivers that moved from their coarse channel deposits to deepen their valleys in adjacent and more easily erodable bedrock (Stalker, 1973; Klassen, 1989). Remnants of these surfaces form the high parts of the Cypress Hills and Wood Mountain uplands. Nearly flat bedrock surfaces flanking the highest parts of the Uplands are interpreted as pediments or remnants of pediments of regional extent (Fig. 3).

This report infers age relationships of landscape complexes identified on the basis of geology and geomorphology, and the main processes of landscape formation. Its geomorphology is largely descriptive and comprehensive studies of the diverse nonglacial landforms of the uplands were not undertaken.

PHYSIOGRAPHY AND GEOLOGY

Bedrock topography controls the main elements of the physiography, particularly the Cypress Hills, with elevations of between 1100 and 1400 m, and the Wood Mountain Upland, with elevations of between 900 and 1000 m. The higher parts of the Cypress Hills, from west to east, are referred to as the West Block, Centre Block and East Block, and a prominent easterly part of the Wood Mountain Upland is known as as Pinto Butte (Figs. 2 and 3). The plains surrounding the uplands form most of the area. They are between 700 and 1100 m elevation around the Cypress Hills and between 700 and 900 m north of Wood Mountain Upland. Bigstick Lake Plain, Swift Current Creek Plateau, and Frenchman River Plain lie to the north, east and south respectively of the Cypress Hills, and Old Wives Lake Plain is north of Wood Mountain Upland (Fig. 2). The typically flat to gently irregular surfaces of the plains reflect the surface of the bedrock. The drift cover is generally between 5 and 15 m thick, but within buried valleys and hummocky moraines thicknesses exceed 100 m (Fig. 3). Drift is also thick over Old Man on His Back Plateau and Boundary Plateau in the southern part of the Frenchman River Plain (Fig. 2).

Broad, pre-glacial valleys that dissect parts of the uplands form the headwaters of streams such as Battle, Fairwell and Conglomerate creeks in the Cypress Hills and Poplar River in the southeast corner of the Wood Mountain area (Figs. 2, 3). Fairwell and Conglomerate valleys are classic examples of barbed tributaries and reflect the shift of drainage along ancestral valleys into the Frenchman Valley. Frenchman Valley was formed by meltwater flowing east, in side-hill position, across the south slopes of the Cypress Hills. It enters the west part of the Cypress lake area as a shallow trench occupied in part by Middle and Battle creeks. These creeks leave the trench and follow the regional slope to the south (Fig. 2). Frenchman Creek enters the Valley further on where the valley widens to 4 km and deepens to 100 m, and continues eastward to the confluence with Swift Current Creek Valley. Here the valley swings towards Wood Mountain, and thence southward into Montana where it joins the Missouri River. It is widest, about 10 km, where it enters Montana (Fig. 2). Smaller former meltwater channels in the area include a northwest trending tributary of Swift Current Valley, Lac Pelletier Valley in the north-central part, and Twelve Mile Lake Valley across the eastern boundary (Fig. 2). Major preglacial valleys on the southern slopes of the Cypress Hills and Wood Mountain were deepened by glacial meltwater and postglacial erosion. Poplar River valley in the southeastern part forms the largest valley; stretches are more than 10 km from edge to edge, with gently sloping sides and numerous broad tributary valleys.

Most of the plains are underlain by Cretaceous bedrock, whereas Tertiary bedrock is exposed or underlies the drift on upland surfaces and their flanking pediments (Fig. 3). The oldest Cretaceous formation is the Judith River which underlies the thick drift within preglacial valleys in the southeast part of the Frenchman River Plain and in the north part of the Bigstick Plain (Fig. 4). It consists of fine sand, silt and clay. The Cretaceous Bearpaw, a noncalcareous silty clay and clay formation, underlies most of the area beyond the Uplands. The overlying Cretaceous Frenchman, Eastend and Whitemud formations of sand, silt and clay form the south sloping pediments flanking the Cypress Hills and part of the Swift Current Creek Plateau. The Tertiary Ravenscrag Formation, also composed mainly of sand, silt and clay, underlies the slopes adjacent the highest parts of the uplands and the southern part of the Swift Current Creek Plateau (Figs. 3, 4). Gravel and sand of the Late Tertiary Cypress Hills and Wood Mountain formations, typically less than 5 m thick, cap the highest parts of the respective uplands. The gravel of the Cypress Formation consists of well-rounded pebble to boulder sizes of mainly quartzite and a variety of other rock types from the Rocky Mountains and other terrain to the west (McConnell, 1885; Furnival, 1946; Von Hoff, 1965; Leckie and Cheel, 1989). The Wood Mountain Formation consists principally of gravels resembling those of the Cypress

Formation, but the stones are smaller and boulders are absent.

Surficial deposits cover most of the area (Fig. 5) and are mainly drift that forms various types of moraines and glacial lake plains. The drift is derived chiefly from the underlying bedrock, but includes igneous, metamorphic and sedimentary stones brought from the northeast by glaciers from the Shield and its bordering belt of Paleozoic carbonates. The tills consist of roughly equal proportions of sand, silt and clay with minor gravel.

NATURE, ORIGIN AND AGE RELATIONSHIPS OF LANDSCAPE COMPLEXES

UNGLACIATED BEDROCK TERRAIN

Geomorphology and Geology

The unglaciated parts of the area are in the West Block of the Cypress Hills and the southeastern part of the Wood Mountain upland (Fig. 2, 6). The West Block, which includes the eastern part of the extensive Cypress Plain in Alberta,

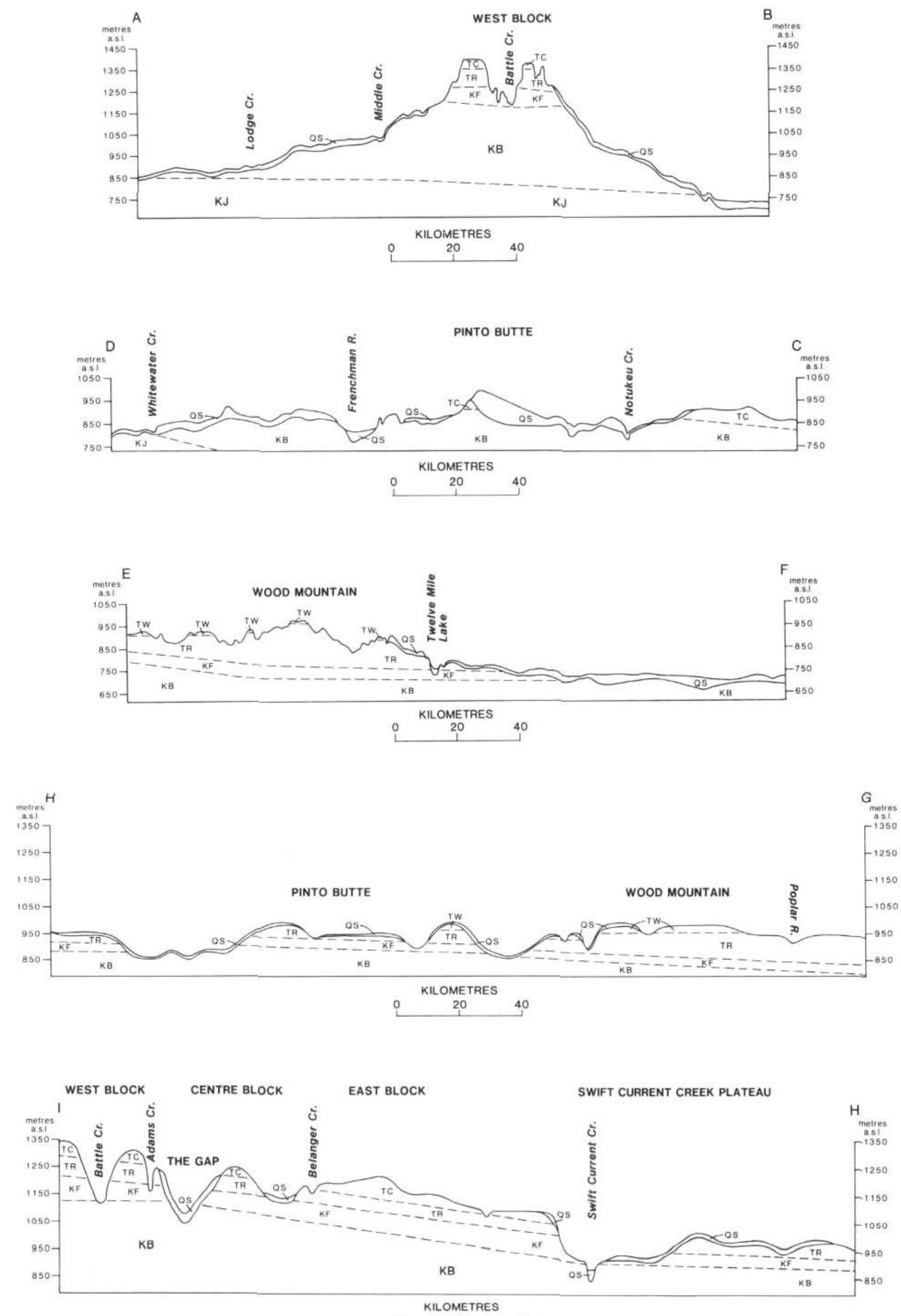

FIGURE 3. Geologic cross-sections (see Fig. 2 locations). QS = Quaternary sediments; TW, TC, TR = Tertiary Wood Mountain, Cypress Hills, Ravenscrag formations; KF = Cretaceous Frenchman, Whitemud, Eastend formations; KB, KJ = Cretaceous Bearpaw and Judith River formations.

Coupes géologiques (localisation à la fig. 2); QS = sédiments quaternaires; TW, TC, TR = formations tertiaires de Wood Mountains, Cypress Hill et Ravenscrag; KF = formations crétacées de Frenchman, Whitemud et Eastend; KB, KJ = formations crétacées de Bearpaw et Judith River.

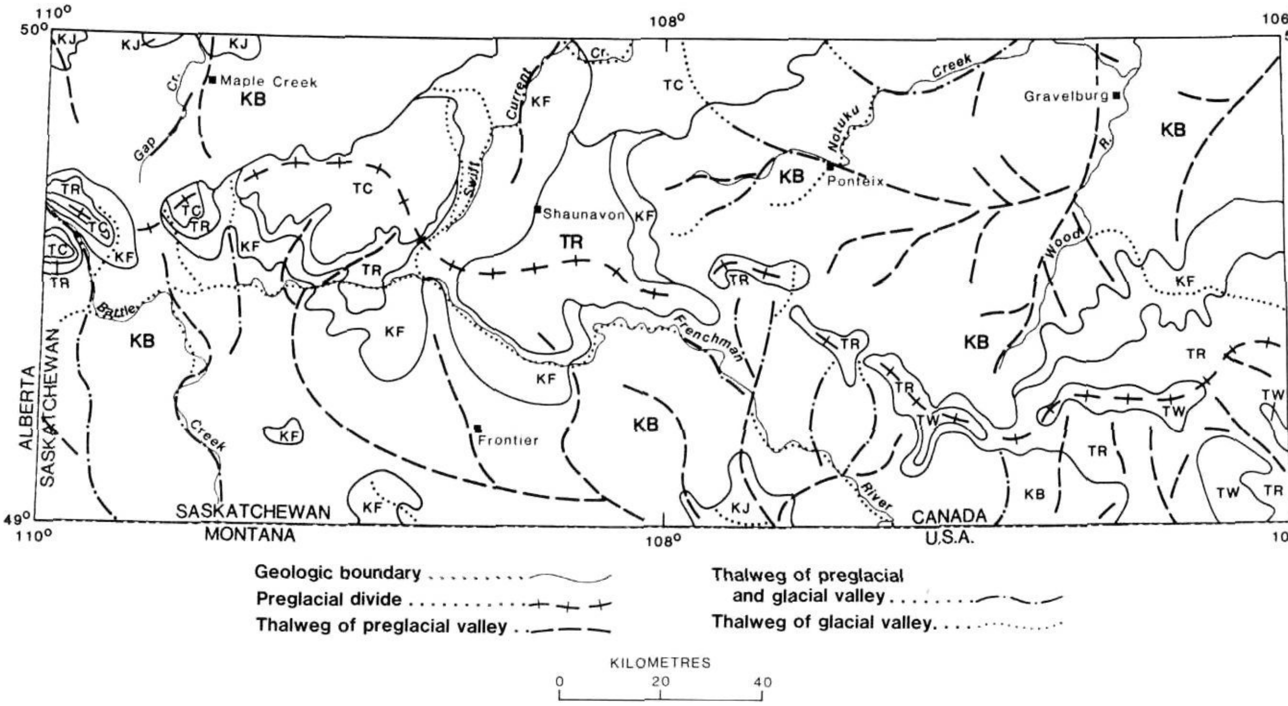

FIGURE 4. Bedrock geology and ancestral valleys in the study area. TW, TC, TR = Tertiary Wood Mountain, Cypress Hills, Ravenscrag formations; KF = Cretaceous Frenchman, Whitemud and Eastend formations; KB, KJ = Cretaceous Bearpaw and Judith River formations (modified from Whitaker, 1967,1976).

Géologie structurale et anciennes vallées de la région à l'étude. TW, TC, TR = formations tertiaires de Wood Mountains, Cypress Hills et Ravenscrag; KF = formations crétacées de Frenchman, Whitemud et Eastend; KB, KJ = formations crétacées de Bearpaw et Judith River (modifié à partir de Whitaker, 1967, 1976).

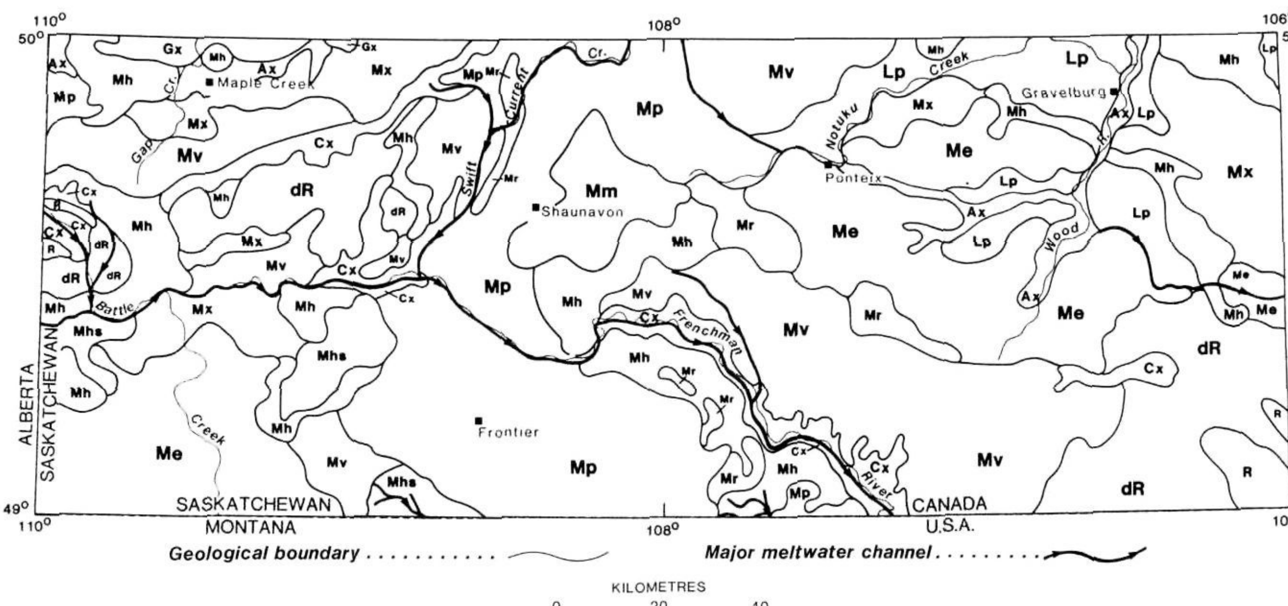

FIGURE 5. Surficial deposits of the study area. Cx = colluvial slope complex; Ax = alluvial complex; Lp = glacial lake plain; Gx = glaciofluvial complex; Mh = hummocky moraine; Mhs = hummocky dead ice moraine; Mr = ridged moraine; Mx = moraine and glacial lake complex; Mp, Mm, Me, Mv = ground moraine (gently irregular, rolling, eroded, patchy); dR = bedrock with scattered erratics; R = unglaciated bedrock (modified from Klassen, 1991, 1992).

Les dépôts superficiels dans la région à l'étude. Cx = ensemble de dépôts colluviaux: Ax = ensemble alluvial; Lp = plaine de lac glaciaire; Gx = ensemble fluvio-glaciaire; Mh = moraine bosselée; Mhs = moraine bosselée de glace morte; Mr = moraine ondulée; Mx = ensemble de moraine et lac glaciaire; Mp, Mm, Me, Mv = moraine de fond (légèrement irrégulière, ondulée, érodée, inégale); dR = erratiques dispersés sur substratum; R = substratum non englacé (modifié à partir de Klassen, 1991, 1992).

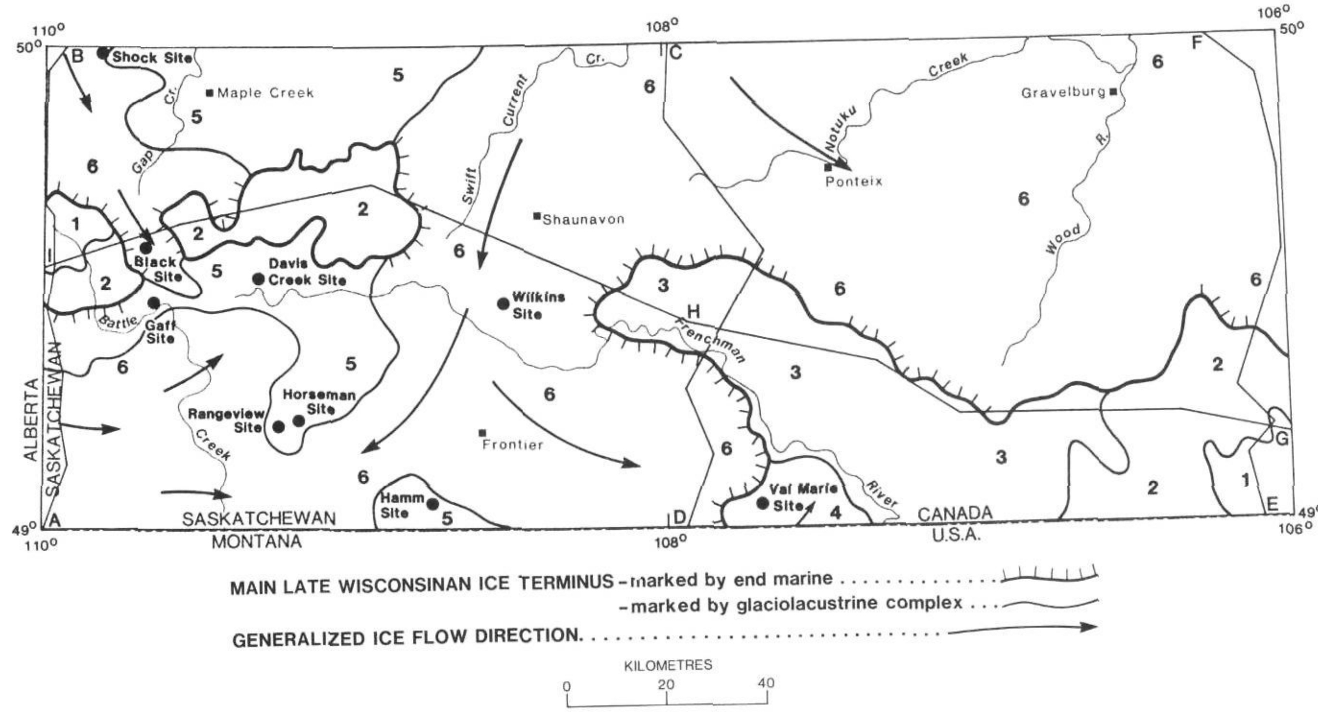

FIGURE 6. Landscape complexes of the Cypress Lake and Wood Mountain areas: 1) unglaciated bedrock terrain; 2) bedrock terrain with residual drift; 3) bedrock terrain with drift; 4) first advance drift; 5) interlobate drift; 6) last advance drift. AB, DC, EF, HG, IH refer to cross-sections shown in Figure 3.

Ensembles de paysages des régions de Cypress Lake et Wood Mountain: 1) substratum non englacé; 2) dépôts glaciaires résiduels sur substratum; 3) dépôts glaciaires sur substratum; 4) dépôts glaciaires de première avancée; 5) dépôts glaciaires interlobaires; 6) dépôts glaciaires de dernière avancée. AB, DC, EF, HG, IH font référence aux coupes de la figure 3.

consists of two Late Tertiary plateau remnants at about 1300 to 1400 m elevation and Battle Creek Valley about 8 km wide and 250 m deep that separates the plateaus (Figs. 3-AB, IH; 7). The surfaces make up only about one third of the 150 km^2 area included in the West Block.

The large valleys and escarpments of the West Block (Fig. 2) are cut in the Cretaceous Bearpaw Formation and overlying Tertiary (Paleocene) Ravenscrag Formation (Fig. 4). The plateau remants are capped by the Cypress Formation, locally cemented into a highly resistant unit (Fig. 8).

The unglaciated part of the Wood Mountain upland (Figs. 9, 10) is the northern limit of the extensive Flaxville Plain in Montana (Alden, 1924). Its surface, at about 900 m elevation, is nearly flat to irregular and slopes southeast at about 3 m/km. It consists of three fairly even parts separated by a dendritic network of broad valleys. These join the trunk valley, about 5 km wide and 80 m deep, occupied by Poplar River and its main tributary, Bolster Creek (Fig. 9). The southern stretch of Poplar River valley has gentle slopes that merge with the pediment surfaces, but near its head in the highly dissected northern part, its walls are much steeper.

The broad valleys are formed in the Ravenscrag Formation and the pediments are underlain by the Wood Mountain Formation. Reworked sediments, derived from both formations during the Quaternary, occur along the valley bottoms and over the gentle slopes of the valley sides. They include sediments (Fig. 11) that Vonhoff (1969) named "Redeposited Wood Mountain Formation".

Main Processes of Landscape Formation

Streams were dominant in forming the landscapes within the unglaciated complex. The unglaciated plains and plain remnants between valleys are low-angle, erosional bedrock surfaces, in places veneered with reworked bedrock detritus, and are pediments as commonly defined (Twidale, 1968; Gary *et al.*, 1972). An example, is the stream dissected Flaxville Plain (Collier and Thom, 1918) between 900 and 1000 m a.s.l. in the Wood Mountain complex. Gecmorphologists generally agree that pediments form in arid and semiarid regions by a combination of processes such as weathering, rill wash, sheet wash and sheet flow (Twidale, 1968). Arid to semiarid climates appear to have prevailed during deposition of the fluvial sediments of the Cypress Hills Formation (Leckie and Cheel, 1989; 1990), although some studies suggest subtropical conditions during deposition of the similar sediments of the Wood Mountain Formation (Holman, 1971; Holman and Tokaryk, 1987). The change from aggrading fluvial regimes to the degrading regimes that formed the pre-Quaternary landscape (Fig. 1) was possibly a combination of regional uplift and a wetter climate, although the former was likely the most important.

Age

Alden (1924, 1932) proposed a chronology for the highest surfaces that was based mainly on fossils. He recognized two former regional surface levels: the highest, named the Cypress Plain or No. 0 bench, formed the plateau remnants of the West Block and was assigned the Oligocene age of the

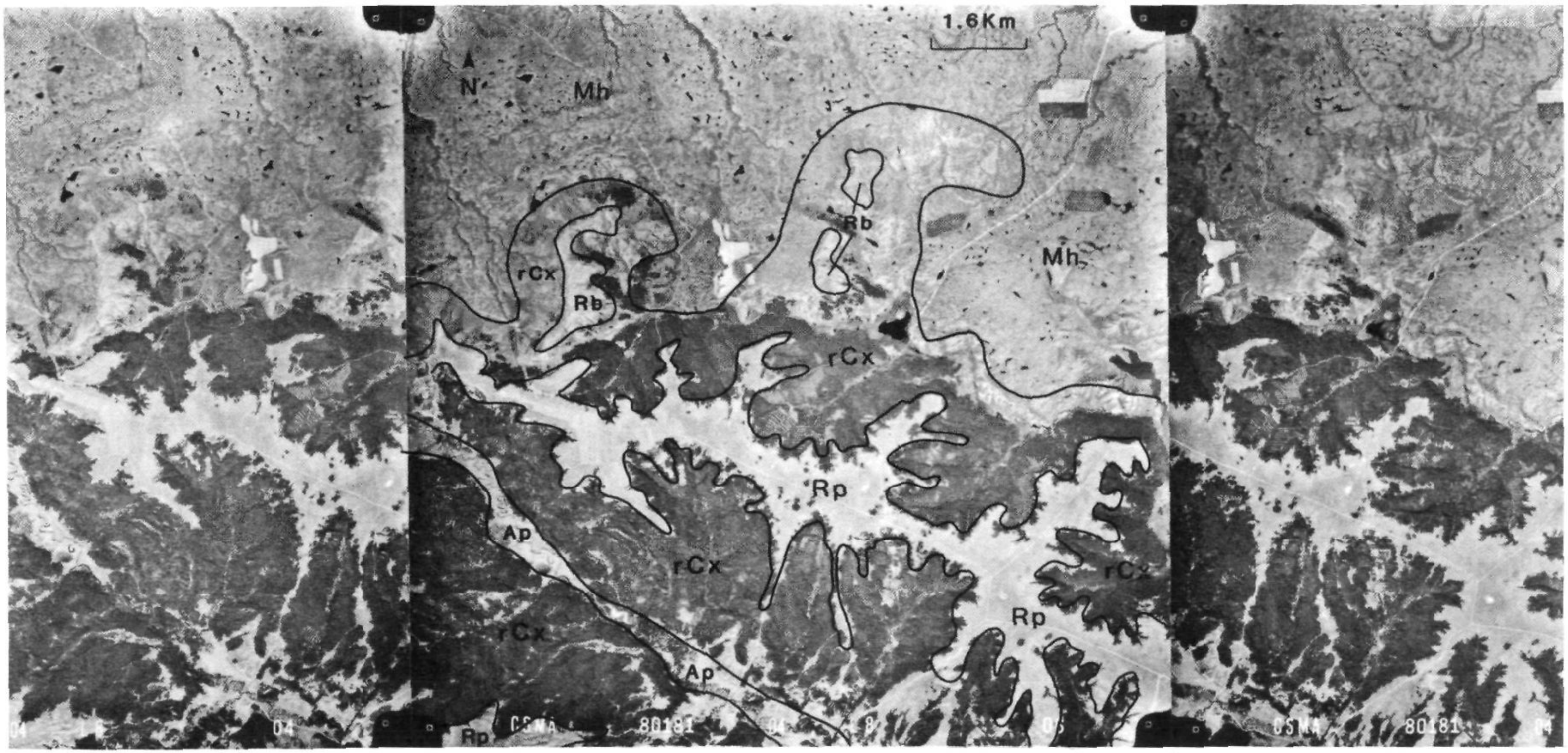

FIGURE 7. Stereo-triplet of West Block showing plateau remnants (Rp), Battle Creek valley with floodplain (Ap), valley walls (rCx), and hummocky moraine (Mh). Harris Lake near centre of photo 06 is in Sec. 20, tp. 8, rge. 29 (49°40'N, 109°54'W). Airphotos CSMA 80181-04-L8-04, 06, 08.

Triplet stéréographique du West Block montrant: vestiges d'un plateau (Rp), vallée de Battle Creek et plaine d'inondation (Ap), versants de vallée (rCx) et moraine bosselée (Mh). Harris Lake près du centre de la photo est à 49°40'N, 109°54'W. Photos aériennes n^{os} 80181-04-L8-04, 06, 08.

FIGURE 8. North-facing escarpment of West Block. Cypress Hills Formation is exposed in foreground, slump ridge in centre, meltwater channel occupied by Adams Lake in centre right, and hummocky moraine beyond. View northwest from SW 1/4 sec. 15, tp. 8, rge. 29 (49°38′40″N, 109°50′50″W). ISPG 2626-139.

Escarpement exposé au nord du West Block. La Formation de Cypress Hills affleure au premier plan, crête d'éboulement au centre, chenal d'eau de fonte occupé par l'Adams Lake au centre droit et moraine bosselée au loin. Vue du sud-ouest vers le nord-ouest (49°38′40″N, 109°50′50″W). ISPG 2626-139.

Cypress Formation cap rock; the lower one, that included the Flaxville Plain, was the No. 1 bench and was assigned the Miocene age of the Wood Mountain Formation. This age framework, based on the assumption that the surfaces approximate the age of the underlying bedrock, has been generally accepted by later workers in southeastern Alberta (Broscoe, 1965; Westgate, 1968), although Jungarius (1966, 1967) considered some surfaces much younger.

The broad valleys of The Gap and Battle Creek, outlined in the profiles across the Cypress Hills (Fig. 3-AB, IH), contrast with the steep-walled and narrow meltwater channels occupied by Adams and Belanger creeks. The difference in the size of the valleys, and also the occurrence of moraine within The Gap between the West and centre blocks, indicates that the broad valleys are much older and most likely of Late Tertiary age as noted by Williams (1929), whereas the narrow channels were cut by glacial meltwater during the Pleistocene and parts are as young as Late Wisconsinan. Similarly, the flat-topped remnants that form the West Block are largely the result of Late Tertiary erosion. They survived the relatively short interval of Quaternary erosion because of elevation, the resistant cap rock and the low gradient of the surface. Mass wasting along the valley walls is, however, slowly encroaching on the surfaces (Fig. 8). The northeastward direction of the slope of the surfaces and the current bedding in the underlying Cypress Hills Formation (Vonhoff, 1965; Leckie and Cheel, 1989), supports the inference that the surfaces are also of Late Tertiary age. Altogether, the geomorphic and geologic evidence does not appear to support the proposal by Jungarius (1966, 1967) that the plateau surfaces formed primarily by mass wasting during the Late Pleistocene.

The size of Battle Creek Valley suggests it is mostly of Late Tertiary age, although valley widening continued during the Quaternary. Goulden and Sauchyn (1986) demonstrated valley widening continued during the Holocene as radiocarbon dates of about 6.2 ka BP (S-2629), 1.7 ka BP (S-2630) and 1.2 ka BP (S-2631)[1] were obtained from beneath landslides along the plateau margins. The fresh scar of a recent landslide can been seen at Police Point just inside the Alberta boundary.

The upper Eocene to middle Miocene age proposed for the Cypress Hills Formation (Storer, 1975; Leckie and Cheel, 1989, 1990) and middle Miocene to upper Miocene (Russell, 1970; Holman, 1971; Holman and Tokaryk, 1987), indicates maximum ages of middle Miocene for the unglaciated parts of the plateau remnants of the West Block and upper Miocene for the unglaciated pediment remnants of the Wood Mountain Upland. Erosion of the unglaciated parts of the West Block during the Quaternary was probably minor and deposition of loess occurred in places (Catto, 1983). Absolute age determinations of 10 million years, from volcanic ash in the Flaxville Formation of northern Montana (Colton *et al.*, 1986), supports the earlier correlation (Russell, 1970) of this formation with Wood Mountain Formation in southwestern Saskatchewan. The "Redeposited Wood Mountain Formation" (Vonhoff, 1969) over parts of the Wood Mountain Upland, likely ranges from Pliocene to Holocene in age.

BEDROCK TERRAIN WITH RESIDUAL DRIFT

Geomorphology and Geology

Scattered erratics are found on some of the bedrock and reworked local bedrock that forms the southern slopes of the Cypress Hills Upland and the southeastern slopes of the Wood Mountain Upland (Fig. 6). The Cypress Hills Upland includes extensive pediments, between about 1100 and 1300 m a.s.l., that slope south at about 8 to 25 m/km. These cover an area of about 225 sq. km in the West Block (Fig. 12), and about 925 km^2 in the Centre and East blocks. The pediments of the West and Centre blocks are crossed by the consequent meltwater channels of Adams and Belanger creeks, which are up to 1 to 2 km wide and 120 m deep; on the other hand, the broad preglacial valleys occupied by Davis, Fairwell and Conglomerate creeks are V-shaped where they head on the East Block. Remnants of meltwater channels occur in side-hill positions along the valley walls. Other meltwater channels, typically less than 1 km wide and up to 20 m deep, begin as hanging valleys at the north margins of the Centre and East blocks, cross the higher parts of the uplands and enter the heads of the ancestral valleys along the zone where the slopes steepen.

Gravel and sand of the Cypress Hills Formation underlie the main pediments of the Centre and East blocks. Stream-dissected surfaces bordering the pediments are underlain mainly by *in situ* and reworked silt and clay of the Bearpaw and younger Cretaceous formations and silt and sand of the Ravenscrag Formation. Igneous and carbonate erratics from the Shield and Paleozoic carbonates to the northeast are scattered on the pediment surfaces and within the valleys.

1. These dates are not included in Table I.

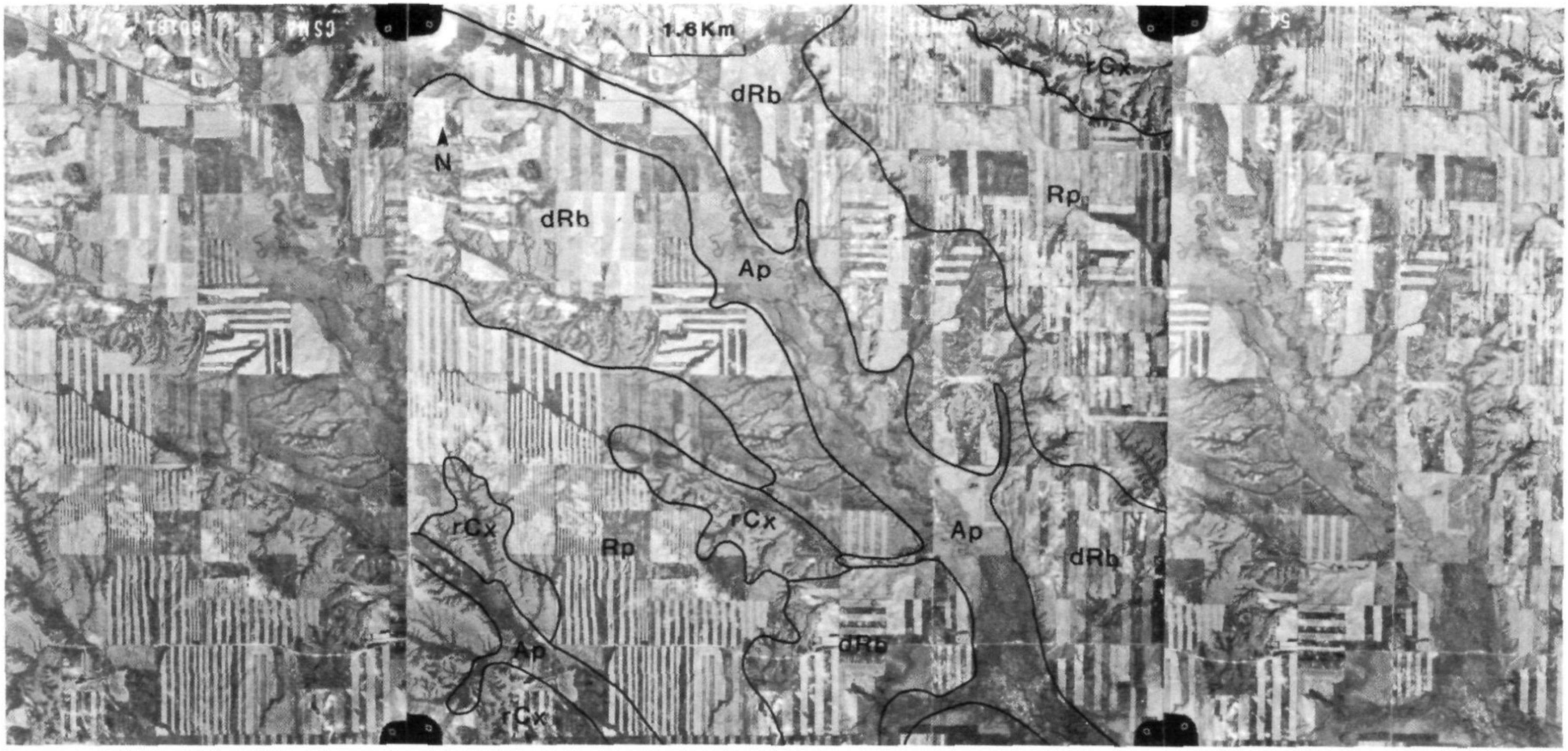

FIGURE 9. Stereo-triplet of southeast part of Wood Mountain area, showing unglaciated bedrock (Rp), gentle slopes (dRb), and alluvial plains (Ap) of Poplar River valley (centre) and Bolster Creek (left corner). Centre of figure is Sec. 22, tp. 2, rge. I (49°08'N, 106°04'W). Airphotos CSMA 80181-06-12-54, 56, 58.

Triplet stéréographique du sud-est de la région de Wood Mountain, montrant le substratum non englacé (Rp), les versants à pente douce (dRb) et les plaines alluviales (Ap) de la vallée de Poplar River (au centre) et de Bolster Creek (coin gauche). Le centre de la figure est à 49°08'N, 106°04'W. Photos aériennes nos 80181-06-12-54, 56, 58.

Local bedrock reworked by fluvial and mass wasting processes and essentially devoid of erratics occurs along the valley sides and valley bottoms.

Some 1500 km² of the eastern part the Wood Mountain Upland consists of bedrock and reworked bedrock with scattered erratics. Broad trunk valleys with gently sloping walls and their tributaries form a radial drainage network separated by interfluves of remnant pediments on the southern slopes of the upland. These valleys are cut deeply into the pediments at about 900 to 1000 m a.s.l. The largest pediment remnant, about 300 km² in area, is flat to gently irregular. It begins about 50 m below a stream-dissected scarp that separates it from the highest pediments (1000 m a.s.l.), and slopes south

FIGURE 10. Unglaciated bedrock terrain and gullied margin of bedrock terrain with residual drift seen below the horizon. Aerial view across the southeast corner of the Wood Mountain area near the International Boundary. ISPG 3761-19.

Le substratum non englacé et, à l'horizon, les marges ravinées du substratum recouvert de dépôts glaciaires résiduels. Vue aérienne à travers la partie sud-est de la région de Wood Mountain, près de la frontière des États-Unis (ISPG 3761-19).

FIGURE 11. Sandstone of Ravenscrag Formation overlain by poorly sorted fine quartzite gravel of the Wood Mountain Formation. Irregular contact is a water scoured surface. Gravel pit in NW 1/4 sec. 12, tp. 6, rge. 4 (49°27'20"N, 106°26'00"W) near the western part of Twelve Mile Lake Valley. ISPG 3304-86.

Grès de la Formation de Ravenscrag recouvert de fins graviers de quartzite mal triés de la Formation de Wood Mountain. La surface décapée par l'eau offre un contact irrégulier. Carrière située à 49°27'20"N, 106°26'00"W, près de la partie ouest de la vallée de Twelve Mile Lake (ISPG 3304-86).

FIGURE 12. Adams Creek meltwater channel in foreground is flanked by the lowest in a series of pediments that are between 1150 and 1200 m elevation. The northernmost remnant of the West Block, at 1330 m elevation, forms the horizon. Aerial view is in the vicinity of sec. 36, tp. 6, rge. 29 (49°31'08"N, 109°46'15"W), about 5 km upstream from its confluence with Battle Creek Valley. ISPG 3761-16.

Au premier plan, chenal d'eau de fonte (Adams Creek) entouré par le moins élevé d'une série de pédiments situés entre 1150 et 1200 m d'altitude. Le vestige le plus septentrional du West Block, à 1330 m, est à l'horizon. Vue aérienne (49°31'08"N, 109°46'15"W), à peu près à 5 km en amont de la confluence avec la vallée de Battle Creek (ISPG 3761-16).

FIGURE 13. Western part of the Killdeer badlands beyond the valley of Morgan Creek (foreground). Aerial view across the badlands (centre) towards the bedrock terrain and drift complex that forms the southern slopes of the Wood Mountain Upland. View is to the northwest in the vicinity of the SW 1/4 sec. 12, tp. 1, rge. 5. (49°01'N, 106°34'W). ISPG 3761-7.

Partie occidentale des badlands de Killdeer au-delà de la vallée de Morgan Creek (au premier plan). Vue vers le paysage caractérisé par ses dépôts glaciaires recouvrant le substratum et qui occupe le versant sud de la haute terre de Wood Mountain. Vue vers le nord-ouest (49°01'N, 106°34'W). ISPG 3761-7.

at 3 m/km. *West Poplar Creek* and its tributaries (Fig. 2) have incised a poorly defined, shallow valley up to 2 km wide across it.

The upland between the pediment remnants is dissected by mature, consequent streams that flow southeast, at gradients of about 3 m/km into Poplar River and Wood Coulee valleys (Fig. 2). The divide between these valleys is marked by gullied ridges with local relief to 50 m, along with scattered remnants of pediments about 150 m above the valley bottoms.

The surfaces within the Morgan Creek - Bluff Creek drainage basin (Fig. 2) are dissected by a dendritic network of valleys and gullies with gradients of about 7 m/km. Gullies extend over virtually all the major interfluves. The Killdeer badlands form a unique landscape in Cretaceous sediments for 50 km^2 along the southwest margin of the main pediment to the east (Fig. 13). There is little residual sediment on the gentle slopes adjoining the bare bedrock hills.

In the northwest part of the Wood Mountain Upland, the surfaces with scattered erratics begin along steep (30 m/km) north-facing scarps below the highest part of the upland and extend northwest and north at gentler slopes (8 m/km). Local relief reaches 60 m along valleys crossing the scarp and 30 m along valleys across the gentler slopes.

Cretaceous silt and clay commonly underlie the low parts of the stream-dissected terrain within the southwestern part of the complex. They display the sharply contrasting colors seen in the Killdeer badlands (Fig. 13). Sediments derived from these formations cover the valley bottoms and parts of the lower slopes. Sand and silt of the Ravenscrag Formation underlies most of the residual drift complex within the Wood Mountain Upland. Sand and gravel of the Wood Mountain Formation and "Reworked Wood Mountain Formation" cap the pediment remnants along the northern margin of the complex. They also form a patchy veneer over the Ravenscrag Formation in the extensive pediments to the south (Fig. 11). The rims and slopes of the adjacent unglaciated pediments were ice marginal zones as indicated by the occurrence of erratics embedded in the rims and buried in slope detritus (Fig. 14). The proportion of strongly weathered to fresh granite boulders seen on these surfaces is substantially higher than on moraine north of the Upland.

Main Processes of Landscape Formation

Much of this complex resembles the unglaciated bedrock complex and was formed by the same processes. The essential difference between the two is the occurrence of glacial erratics within the former. Most erratics, which range in size from large boulders to small pebbles, are considered to be the erosional residuals of drift. Some within the meltwater channels were probably ice-rafted, but this process does not account for those found elsewhere on the pediments.

Periglacial and mass wasting processes modified the pediments, as indicated by cryoturbation structures in the gravels and by wedges of silt deposited along the pediment margins by sheetwash and wind (Vreeken *et al.*, 1989). Studies by Jungarius (1967) on pediments with gradients of about 20 m/km along the southern slopes of the West Block in Alberta, indicated that the veneer of sediment overlying the bedrock in the pediments was deposited by solifluction, sheetwash and streams. This led him to conclude that the pediments were formed mainly by periglacial processes, but other important aspects of the local and regional geomorphology and geology were largely ignored.

Age

The unglaciated and residual drift surfaces are of much the same age. The main pediments of the Centre and East Blocks are underlain by Cypress Hills Formation and therefore have a maximum age of middle Miocene.

Sediments underlying drift at Davis Creek Site along the edge of a pediment some 100 m lower (1044 m a.s.l.) than the loess surfaces on the East Block, have a minimal early Pleistocene age (Vreeken *et al.*, 1989). Williams and Dyer (1930) and St-Onge (1966) speculated that the highest surfaces along the southern slopes of the West Block correlated with the Alden's Flaxville Gravel (No. 1 bench) in Montana. Recent studies (Jensen and Varnes, 1964) appear to confirm the late Miocene or early Pliocene age assigned to these gravels in Montana by Collier and Thom (1918). Paleontologic evidence confirming the correlation has not been obtained from the gravels underlying the highest pediment flanking the West Block. St-Onge (1966) correlated the lower parts of the pediments along Battle and Adams creeks (Fig. 12) with Alden's Nos. 2 and 3 benches, and suggested they developed during the Aftonian and Yarmouthian interglacials respectively.

Fossils from the Wood Mountain Formation indicate that the drift residual pediments of the Wood Mountain upland have a maximum age of upper Miocene (Russell, 1970). The main elements of these landscapes, which consist of

FIGURE 14. Weathered granite erratic buried in quartzite gravel colluvium on gullied slopes (dRb) bordering an unglaciated bedrock plateau (Rp). Location is SW 1/4 sec. 29, tp. 2, rge. 2 (49°09'02"N, 106°14'00"W) in the headwaters of Bolster Creek. ISPG 3304-116.

Bloc erratique de granite altéré enfoui dans des colluvions de graviers de quartzite sur les versants ravinées (dRb) en bordure d'un plateau non englacé (Rp). Source du Bolster Creek à 49°09'02"N, 106°14'00"W. ISPG 3304-116.

pediments and pediment remnants separated by mature drainage networks appear to reflect development during arid to semi-arid climates. The drift residuals on these surfaces, and the meltwater channels across divides, indicate glacial modification, but their main topographic features predate the Quaternary.

Relative ages of parts of landscape complexes may be inferred by comparing the slopes of the pediment surfaces, valley walls and escarpments. The slope gradients tend to increase from oldest to youngest. The gradients of Late Tertiary surfaces (Fig. 1) are between 3 and 5 m/km, like the gradients of most of the pediments in the unglaciated and residual drift complexes. The highest gradients (100 to 250 m/km) are on the sides of meltwater channels and the north-facing escarpments of the uplands, whereas intermediate gradients (10 to 20 m/km) are on the sides of broad valleys and on the highest pediments of the West Block.

A proposed time frame is: (a) Oligocene to Pliocene for the lowest slopes; (b) Pliocene to Early Pleistocene for the intermediate slopes; (c) Late Pleistocene for the steepest slopes. The glacial detritus within the complex indicates that glaciation of this terrain occurred much earlier than glaciation of the till-veneered surfaces to the west, and possibly during the Nebraskan or Kansan stage. The slopes of the West Block studied by Jungerius (1966, 1967) are in the intermediate range, and so it appears unlikely they formed during the Wisconsinan as he suggested.

BEDROCK TERRAIN AND DRIFT COMPLEX

Geomorphology and Geology

This complex covers about 3700 km² within the western part of the Wood Mountain Upland (Figs. 2, 6). Its northern margin is partly along the edge of moraines and the western margin along the Frenchman River valley. Much of this complex is incised by a broadly dendritic pattern of large trunk valleys. The interfluves display narrow, sub-parallel channels trending downslope in the same general direction as the trunk valleys (Fig. 15). The highest parts of the Upland along the northern margin, between 900 and 1000 m a.s.l., form the drainage divide. The major valleys head on the divide, where they form local escarpments and valley walls with gradients up to 20 m/km. The highest parts of the divide are nearly flat, level tracts, which make up most of the eastern part of the complex within the Rock Creek drainage basin. They are bounded by gullied slopes 15 to 50 m high and slope south at 3 to 8 m/km.

A south trending divide, between 900 and 975 m a.s.l., separates Rock Creek basin to the east and Frenchman basin to the west. The divide is a nearly flat, narrow pediment remnant that slopes northeast at about 2 m/km. The terrain within both basins is similar, except for the large, steep-walled valleys and more limited gullying of the interfluves within the Frenchman. The Frenchman valley near the International boundary is about 10 km wide and 170 m deep, with walls sloping at 70 m/km (Fig. 16). The great width of the valley here is partly due to development of an unusually large tributary gully, about 2 km wide and 120 m deep, that heads just 5 km northeast at the divide. Somewhat similar, but much longer, valleys and their tributaries, which head on the main divide to the northeast, form deeply dissected terrain, with isolated erosional remnants along local divides between the valley heads and confluence with Frenchman Valley. Further upstream, some of the tributary valleys from the east are meltwater channels. They rise in the moraine to the north and show trench-like segments 1 to 2 km wide and 50 m deep; some of their tributaries widen considerably near the regional divide. In places their valleys form continuous stretches of gullied slopes with 50 m local relief. The flat, narrow interfluves are crossed by subparallel gullies, 10 to 25 m deep and up to 200 m wide, that trend south and southwest (Fig. 17). These "hanging" gullies predate the cross cutting slopes of the main valleys (Fig. 16).

The main difference in the geology of this complex and that of the residual drift to the east is its patchy veneer of till on the pediment remnants (Fig. 18). The erratic rock types within both complexes are the same as those of the surface tills further north, except that a much higher proportion of granites on the southern complexes are noticeably weathered (Fig. 14). The banks of Rock Creek in the southern part of this complex expose two tills. The upper one resembles the till and diamict that veneers the bedrock elsewhere in this complex.

Main Processes of Landscape Formation

The three landscape complexes of the southern slopes of the Wood Mountain Upland were shaped largely by the same processes. However, the veneer of till over the interfluves of the bedrock terrain and drift complex may have slowed erosion by streams and mass wasting, particulary where they are underlain by the soft, easily eroded Cretaceous silts and clays. Sedimentary structures in some exposures indicate that diamicts were, in places, derived from till and silty clay bedrock by mass wasting (Fig. 18). Mass wasting has formed extensive colluvial fans of silt and clay below the valley walls where the Frenchman valley and its tributaries are incised in the Bearpaw Formation. The process is active on the barren slopes in the Cretaceous bedrock exposed in the Frenchman drainage basin and parts of the Rock Creek basin to the east.

Age

The maximum possible age of these surfaces is upper Miocene, which is the age of the Wood Mountain Formation underlying the highest parts of the Upland. The till surfaces of the interfluves are much younger than the surfaces of the interfluves within drift residual complex to the east. The side-hill position of much of the Frenchman Valley west of the complex indicates its glacial origin and a radiocarbon date of 11,460 BP (S-2932) from wood near the base of the fill suggests that most of the Frenchman Valley formed during Late Wisconsinan deglaciation about 15 ka (Christiansen and Sauer, 1988). However, the large tributaries that head on the divide and enter the southern part of the valley from the east, are not meltwater valleys (Fig. 16). They also are mostly of Late Wisconsinan and Holocene ages, but the valleys and segments of valleys that follow regional slope, which compare in size to ancestral valleys farther east, may be older. The greater size of some of these tributaries also reflects high

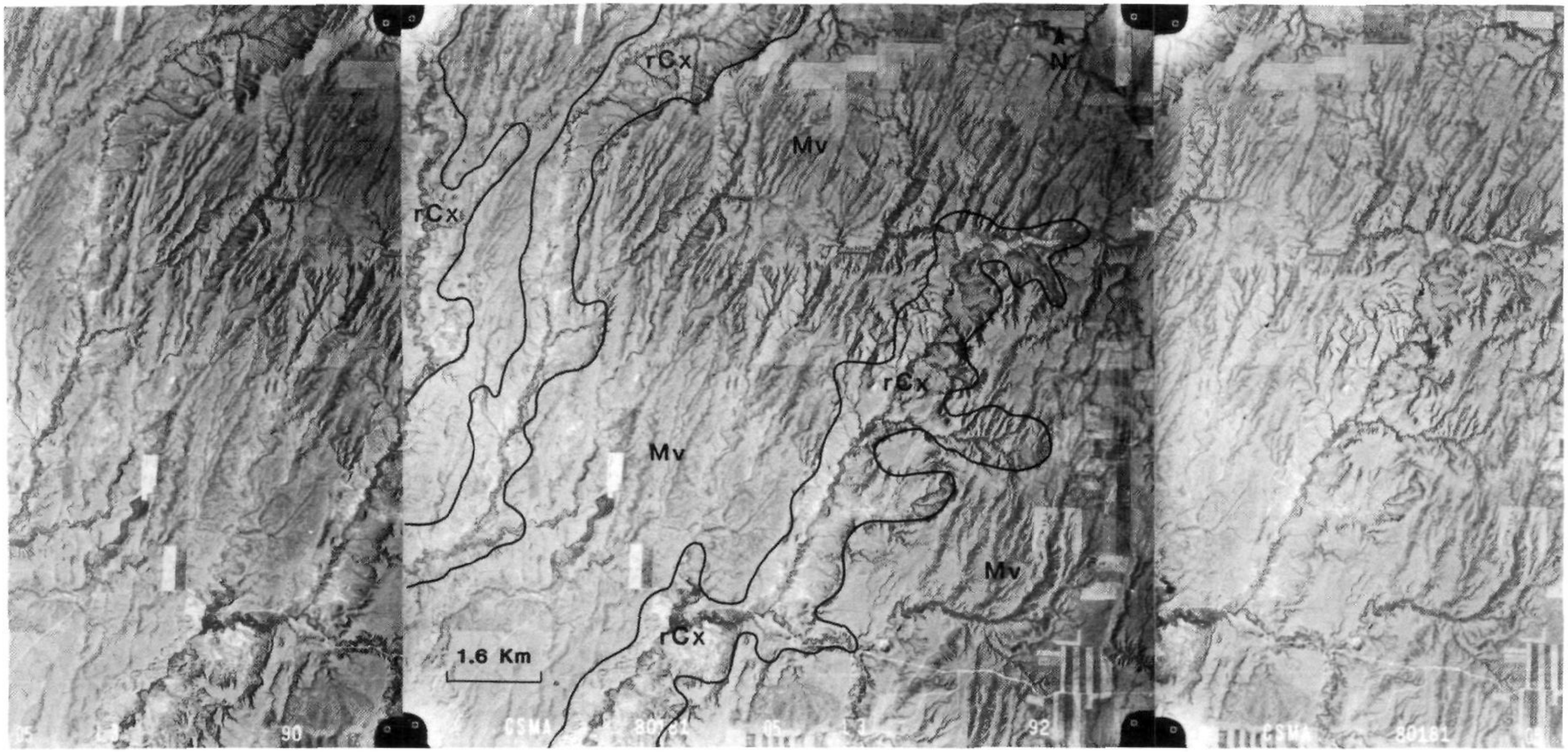

FIGURE 15. Stereo-triplet of bedrock terrain and drift complex over the southern slopes of the Wood Mountain Upland. Note intricate drainage network and ongoing stream capture by headward erosion of consequent gullies (upper centre of photo). Centre of photo 92 is in sec. 14, tp. 3, rge. 10 (49°12'N, 107°15'W). Airphotos CSMA 80181-05-L3- 90, 92, 94.

Triplet stéréographique du paysage caractérisé par ses dépôts glaciaires recouvrant le substratum sur le versant sud de la haute terre de Wood Mountain. Noter le réseau de drainage enchevêtré et les cours d'eau capturés par érosion régressive de ravins conséquents (centre supérieur). Le centre de la photo est à 49°12'N, 107°15'W. Photos aériennes n^{os} 80181-05-L3-90, 92, 94.

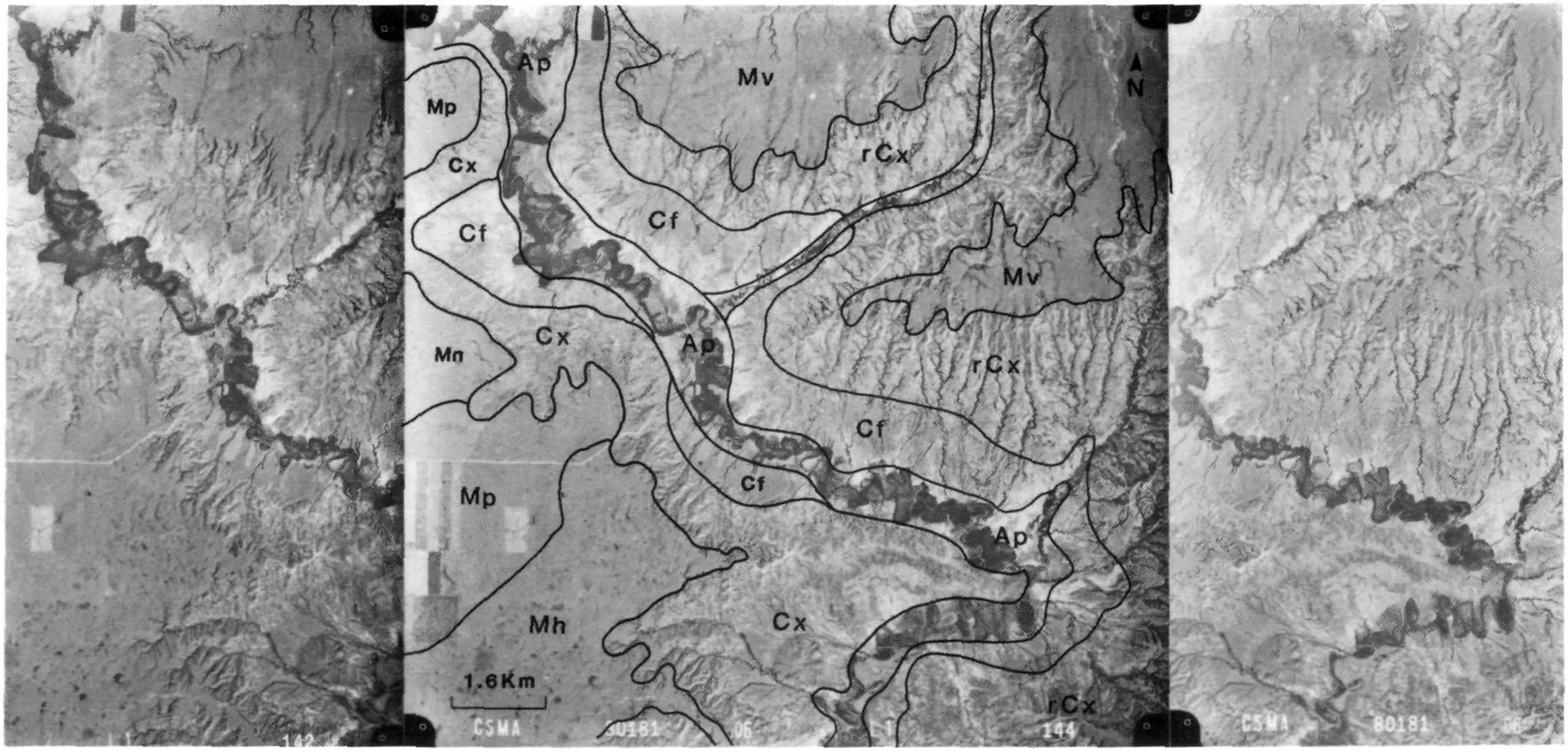

FIGURE 16. Stereo-triplet of Frenchman Valley near the International Boundary. Surfaces beside the valley include high relief (Mh) and low relief (Mn) hummocky moraine, gently irregular (Mp) or patchy (Mv) ground moraine; surfaces within the valley include slopes in bedrock (rCx), colluvial fans (Cf) and alluvial plains (Ap). Centre of photo 144 is sec. 19, tp. I, rge. 9 (49°03′N, 107°19′W). Airphotos CSMA 80181-06-LI-142, 144, 146.

Triplet stéréographique de la vallée de Frenchman River près de la frontière des États-Unis. Les terrains autour de la vallée sont composés de moraines bosselées élevées (Mh) et basses (Mn), de moraines de fond légèrement irrégulières (Mp) ou inégales (Mv); à l'intérieur de la vallée, versants rocheux (rCx), cônes colluviaux (Cf) et plaines alluviales (Ap). Le centre de la photo est à 49°03′N, 107°19′W. Photos aériennes n^{os} *80181-06-LI-142, 144, 146.*

FIGURE 17. A gully typical of the features that form the subparallel pattern on interstream tracts in the bedrock terrain and drift complex of Wood Mountain Upland (see Fig. 15). View is north (upslope) from NE 1/4 sec. 9, tp. 4, rge. 11 (49°17'25"N, 107°25'05"W). ISPG 3304-42.

Ravin caractéristique du réseau subparallèle de ravins qui traversent le paysage caractérisé par ses dépôts glaciaires recouvrant le substratum de la haute terre de Wood Mountain (fig. 15). Vue du nord-est vers le nord (amont) (49°17'25"N, 107°25'05"W). ISPG 3304-42.

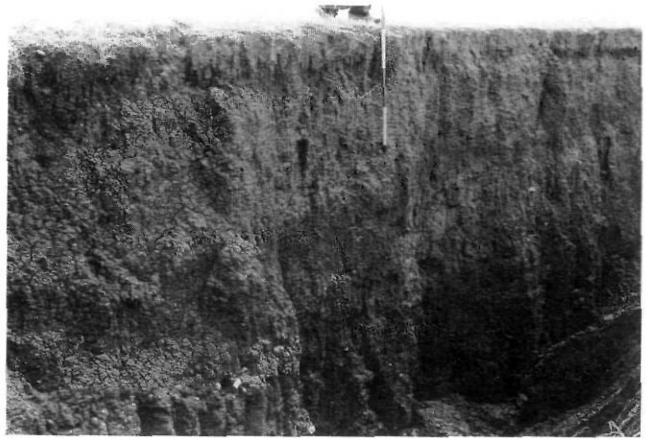

FIGURE 18. Clay loam till with columnar structure overlain by 2 m of clayey diamict. Contact is marked by a stone line in the lower left of photo. Exposure is behind a fresh slump block along the east edge of Frenchman Valley SW 1/4 sec. 24, tp. 1, rge. 10 (49°03'10"N, 107°14'10"W). Scale is in feet. ISPG 3098-37.

Till d'argile limoneuse comprenant des structures colonnaires recouvert de 2 m de diamicton argileux. Le contact est souligné par une ligne de pierres à la partie inférieure gauche. La coupe est située derrière un bloc d'éboulement récent le long de la bordure est de la vallée de la Frenchman River (49°03'10"N, 107°14'10"W). Échelle en pieds. ISPG 3098-37.

rates of erosion due to the steep slopes in weak Cretaceous sediments and the absence of a protective cap of Tertiary gravels.

The interfluves between the steep-walled valleys in the Frenchman drainage resemble the gullied surfaces grading into the valley bottoms within the Rock Creek drainage east of the local divide, which indicates they are of much the same age. The sub-parallel channels across the interfluves of the former predate the widening of the valleys, whereas interfluves of the latter are integrated with the system of major valleys. These relationships and the steep valley walls common to the Frenchman drainage indicate that the last strong glaciofluvial erosion was restricted to it. Its chief cause was Late Wisconsinan meltwater, although much erosion of the valley walls and infilling of valleys by stream and mass wasting processes also occurred during the Holocene.

This complex was glaciated much later than the residual drift complex as indicated by the occurrence of till on the pediments within the former. A major stillstand of Late Wisconsinan ice is marked by end moraines around the northwest part of the complex. An age of either Early Wisconsinan or Illinoian is proposed for the till surfaces because the higher proportion of weathered to unweathered granites seen on its surfaces, as compared to the Late Wisconsinan till surfaces north of the Wood Mountain Upland. Also, the nature of the till surfaces and landforms within the complex, as discussed in the preceding paragraph, suggest effects of the Late Wisconsinan glaciation were restricted to meltwater erosion.

FIRST ADVANCE DRIFT

Geomorphology and Geology

This complex of hummocky moraine and ground moraine covers about 400 km² between the Frenchman Valley and a belt of end moraine to the northwest (Fig. 19). Meltwater channels up to 1 km wide and 40 m deep begin at the distal margin of that end moraine (Fig. 19 -Mr), and cross the complex to join a main valley to the south across the International boundary. The hummocky moraine belts consist of aligned to non-aligned, steep-sided hummocks and depressions with 5 to 15 m local relief (Fig. 20). They are separated by flat to gently irregular tracts of ground moraine.

The drift is thick and covers sandy to silty shale of Judith River and Bearpaw formations. The former underlies the surficial deposits in a large buried valley and its tributaries, and the latter underlies the surficial deposits elsewhere (Fig. 4). The surficial deposits are about 15 m thick in the southeast corner along the Frenchman Valley, but reach 60 m within the buried valley.

The hummocky and ground moraine is formed of till similar in composition to surface tills elsewhere in the region (Fig. 21). The percentage of granite stones, however, is much smaller than the 10 to 30 percent found in the till of the moraine to the west. This results in a 1 to 2 ratio of granites to quartzites on the surfaces within this complex, in contrast to a 2 to 1 ratio on the surfaces of the former.

Surficial deposits of silt, sand, clay and gravel are found mostly in meltwater channels occupied by misfit, ephemeral streams. Massive deposits of clay and silt, 4 to 12 m thick, overlie the till in the hummocky moraine depressions (Fig. 22).

Main Processes of Landscape Formation

Glaciers and associated processes formed the landscapes within this complex. The hummocky moraine is an ice marginal deposit, whereas the intervening tracts of ground

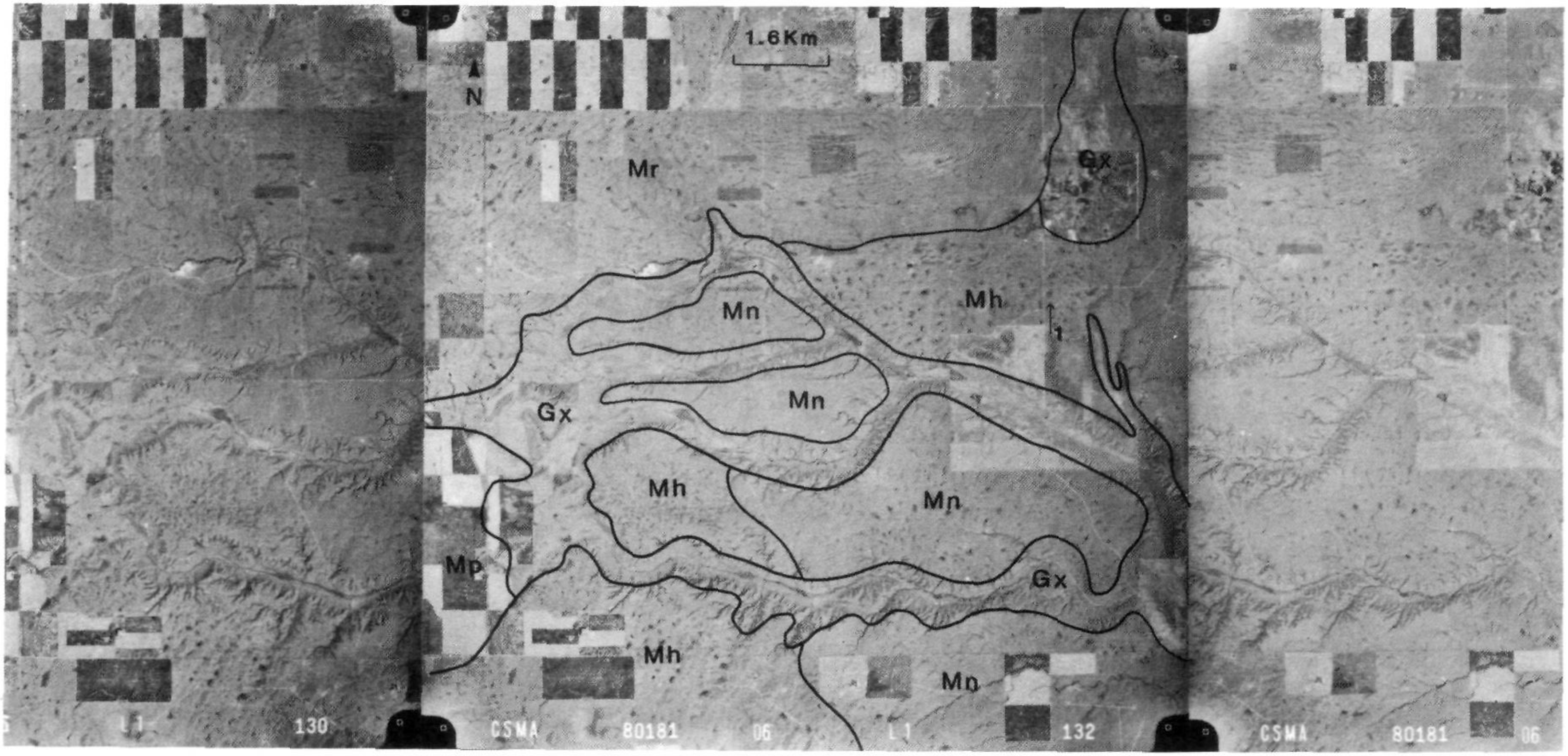

FIGURE 19. Stereo-triplet of morainic terrain including ridged moraine (Mr) and ground moraine (Mp) of the last Late Wisconsinan advance, and hummocky moraine of the first advance (Mh, Mn). Meltwater channels and outwash (Gx) from the last advance cross the latter. Centre of photo 132 is sec. 23, tp. 1, rge. 14 (49°03'N, 107°46'W). Airphotos CSMA 80181-06-L1-130, 132, 134.

Triplet stéréographique de terrain morainique comprenant des moraines ondulées (Mr) et des moraines de fond laissées au cours de la dernière avancée glaciaire au Wisconsinien supérieur et des moraines bosselées de la première avancée (Mh, Mn). Chenaux de fonte et épandage fluvioglaciaire (Gx) de la dernière avancée sillonnent la région. Le centre de la photo est à 49°03'N, 107°46'W. Photos aériennes n^{os} 80181-06-L1-130, 132, 134.

FIGURE 20. A depression, named the Val Marie site, within hummocky moraine of the first advance. Looking northwest across a depression located in NW 1/4 sec. 21, tp. 1, rge. 13 (49°03'29"N, 107°41'38"W). ISPG 3304-127.

Dépression, appelée le site de Val Marie, dans la moraine bosselée de la première avancée. Vue vers le nord-ouest (49°03'29"N, 107°41'38"W). ISPG 3304-127.

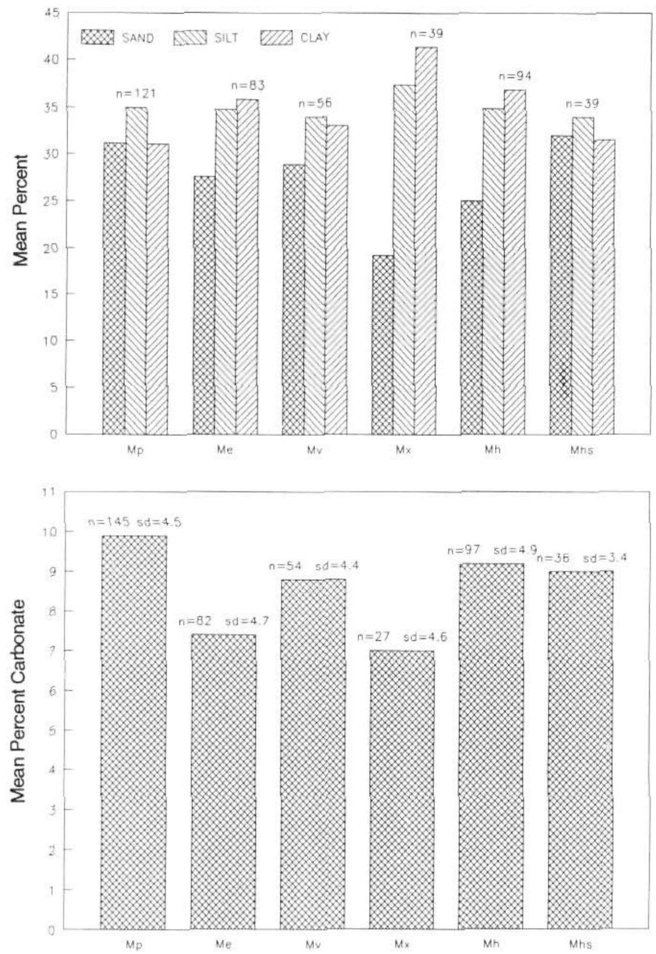

FIGURE 21. Textural characteristics (upper graph) and carbonate contents of the silt fraction (lower graph) of tills and diamictons associated with morainic map units in the Cypress Lake and Wood Mountain areas. See Figure 5 for explanation of letter symbols.

Structure (diagramme supérieur) et teneurs en carbonates de la fraction silteuse (diagramme inférieur) des tills et des diamictons associés aux unités morainiques des régions de Cypress Lake et Wood Mountain (signification des ensembles de lettres à la fig. 5).

moraine appear to be mainly of subglacial origin. The channels across the complex (Fig. 19) were excavated by meltwater from the glacier that formed the belt of end moraine along the channel heads.

Postglacial erosion, mainly by mass wasting and streams, formed fans and terraces within the valleys and gullies along the valley edge. Hummocky moraine depressions are underlain by fine sediments over till (Fig. 22). These sediments were carried into ponds by sheetwash and wind during the Holocene. The ground moraine surface commonly has patches of gravelly lag and shallow blow-outs, indicating stronger wind action than on similar surfaces farther west.

Age

It is proposed that this complex was not covered by the last advance of a Late Wisconsinan ice lobe from the northwest. The terminus of this lobe was along the northwest margin of the complex (Fig. 19). An earlier advance of Late Wisconsinan ice from the southwest may have resulted in the difference between the surface till in this complex and the one to the northwest.

Radiocarbon dates of about 10 ka (Fig. 22; Table I-ref. nos. 6, 7) and a pollen profile (Klassen, in preparation), on sediment over till in a hummocky moraine depression (Val Marie site), support the inference of a Late Wisconsinan age for the till surfaces.

INTERLOBATE DRIFT

Geomorphology and Geology

Three separate areas of interlobate drift occur within the Cypress Lake area (Fig. 6). The most extensive covers about 1750 km² north of the Centre and East blocks. It includes mainly hummocky terrain with 5 to 20 m relief and local patches of flat to gently rolling terrain (Fig. 5). Most valleys are about 1 km wide and 25 m deep, and they trend downslope towards the north and northeast across the glaciated terrain. Another area of hummocky dead ice moraine covers about 1300 km² along the Frenchman Valley to the west and the Old Man on His Back Plateau (Figs. 2, 23, 24). The moraine has up to 30 m local relief and the higher relief parts commonly include flat-topped features Stalker (1960) called "moraine plateaus" (Figs. 25, 26). The smallest area of hummocky dead ice moraine has 5 to 20 m local relief and covers about 250 km² in the northernmost part of the Boundary Plateau (Figs. 2, 5). A network of meltwater channels with a trunk valley up to 2 km wide and 30 m deep, in part filled by hummocky moraine, trends southeast across the complex.

The interlobate complex is formed of drift from 30 to 90 m thick that consists of till and bedded to massive glacial lake and stream silt, sand, clay, diamicts and gravel. Till composition resembles that of the tills elsewhere in the region (Fig. 21), except for the till north of the Upland, which has a carbonate content about 5 % higher than the till south of the Upland.

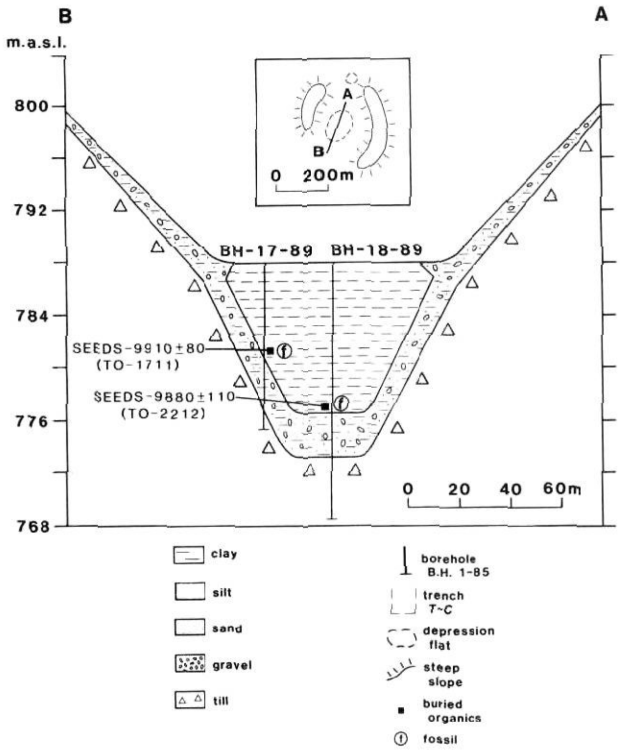

FIGURE 22. Stratigraphic cross-section of the Val Marie site (Fig. 20). See Table I for details on radiocarbon dates.

Coupe stratigraphique du site de Val Marie (fig. 20) (datations au tabl. I).

The area north of the Cypress Hills includes large tracts of hummocky glacial lake silt and sand along with tracts of hummocky moraine and outwash (Fig. 5). Silt bluffs up to 50 m high mark the courses of postglacial valleys that were cut across the hummocky terrain. Where the streams cross glacial lake basins beyond the steep Upland slopes, they have formed broad alluvial flats underlain by silt and clay up to 15 m thick (Fig. 5). The hummocky dead ice moraine south of the Cypress Hills consists of mostly till, although in local basins and on moraine plateaus the till is capped by both massive and varved silt and clay (Figs. 25, 26, 27). Glaciofluvial sand and gravel occur within and beside meltwater channels across the Boundary Plateau.

Main Processes of Landscape Formation

The landscapes within the complex developed mainly as a result of ice stagnation combined with ponding of glacial meltwater. Most of the hummocky to gently irregular glacial lake basins north of the Cypress Hills (Fig. 3) appear to be deltaic sediments deposited in a lake that in part innundated stagnant ice. The lake was impounded between the Upland and ice lobes to the north. Outwash north of the area (David, 1981) grades into deltaic deposits where meltwater entered the lake. Patches of hummocky moraine within the complex likely formed along the retreating ice margin before formation of the lake. Sandy parts near the transition from coarse outwash to silty deltaic sediments display stabilized to active dunes. Most of the valleys in the area are postglacial, although parts in sidehill positions along the upper slopes are meltwater channels.

Landscapes south of the Cypress Hills Upland formed under deglaciation conditions similar to those to the north. Hummocky dead ice moraine formed during proglacial ponding and ice stagnation over the Old Man on His Back and Boundary plateaus. The plateaus separated ice flowing east and northeast around the western part of the Cypress Hills from ice flowinq south and southeast around the eastern part (Fig. 6). Postglacial sediments from 4 to 8 m thick, mainly of sheetwash silt and clay, were deposited in depression ponds (Figs. 27, 28).

Age

The oldest radiocarbon dates from postglacial sediments in hummocky moraine depressions within the two complexes south of the Upland and from sediments in the complex north of the Upland are in the 14 to 10 ka age range (Figs. 27, 28, Table I- ref. nos. 1, 2, 4, 8). The last glaciation of the complex therefore was probably of Late Wisconsinan age. Glacial features formed during retreat from the limit of the first Late Wisconsinan advance, marked by the highest drift around the Cypress Hills Upland, and the last advance and retreat. Much of the lake sediment found north and south of the Cypress Hills Upland was probably deposited over stagnant ice of the last readvance. The infilling of meltwater channels on the Boundary Plateau by hummocky moraine may have occurred at the same time.

The Late Wisconsinan Frenchman Valley (Christiansen and Sauer, 1988) was a spillway that drained proglacial lakes south of the Upland. The presence of the Mazama ash of about 6.6 ka (David, 1970) within low terraces, along with radiocarbon dates of 3.5 to 6.6 ka from the banks of modern channels (Table I — ref. nos. 17, 18, 19) indicate deposition of the valley fill ended by the middle Holocene. The channel network of the Boundary Plateau complex opens into a belt of ground moraine which forms a re-entrant bordered by extensions of the hummocky moraine of the Boundary Plateau in Montana (Colton *et al.*, 1961). The ground moraine is considered to be of Illinoian age and the bordering hummocky moraine to be of Late Wisconsinan age (R.B. Colton, United States Geological Survey, personal communication, 1986). However, the positions of the moraines and the meltwater channels, indicates the ground moraine may have been exhumed by Late Wisconsinan meltwater.

The valleys north of the Cypress Hills Upland are mostly of Holocene age, as indicated by their consequent positions on the slopes and by radiocarbon dates of 7 and 3.6 ka from channel banks (Table I — ref. nos. 21, 22). Modern streams occupy valley segments in sidehill positions along the higher parts of both the Upland slopes and consequent valleys. The meltwater that excavated those segments flowed eastward along the ice margin during final deglaciation.

LAST ADVANCE DRIFT

Geomorphology and Geology

This drift complex covers about 22,000 km^2 or about 70 % of the area. It consists mainly of ground moraine and glacial

TABLE I

Radiocarbon from post-till sediments in the Cypress Lake and Wood Mountain areas

Reference Number	Laboratory Number	Date (Years B P)	Material	Landscape Setting (elevation)	Location	Comments
1	TO 310	14 340 ± 100	Peat	Hummocky moraine depression ca. 1000 m	Robsart (Horseman site) 49°13′20″N, 109°10′40″W	Lower zone of peat bed 4 to 5 depth in sediments 8 m thick abvoe till (ref. 1)
2	GSC 4270	10 000 ± 130	Peat	Hummocky moraine depression ca. 1000 m	Robsart (Horseman site) 49°13′20″N, 109°10′40″W	Middle zone of peat bed 4 to 5 m depth in sediments 8 m thick above till (ref. 1)
3	GSC 4098	9500 ± 80	Wood	Hummocky moraine depression ca. 1000 m	Robsart (Horseman site) 49°13′20″N, 109°10′40″W	Middle zone of peat bed 4 to 5 m depth in sediments 8 m thick above till (ref. 1)
4	GSC 4266	10 200 ± 140	Peat	Hummocky moraine depression ca. 1000 m	Robsart (Horseman site) 49°13′20″N, 109°10′40″W	Upper zone of peat bed 4 to 5 m depth in sediments 8 m thick above till (ref. 1)
5.	TO 216	12 630 ± 80	Shells	Hummocky moraine plateau ca. 930 m	Loomis (Ham site) 49°04′05″N, 108°45′20″W	Depth of 2.5 m in sandy loam sediments along plateau margin (ref. 1)
6	TO 1711	9910 ± 80	Seeds	Hummocky moraine depression ca. 780 m	Val Marie site 49°03′30″N, 107°41′50″W	Depth of 6 m in clayey loam sediments near till contact
7	TO 2212	9880 ± 110	Seeds	Hummocky moraine depression ca. 780 m	Val Marie site 49°03′30″N, 107°41′50″W	Depth of 12 m in clayey loam sediments near till contact
8	GSC 4675	13 900 ± 340	Shells	Hummock silt knoll ca. 830 m	Fleming Creek 49°49′20″N, 109°29′00″W	Depth of 2 m in silty glaciolacustrine sediments
9	TO 694	13 120 ± 80	Shells	Hummocky silt knoll ca. 830 m	Fleming Creek 49°49′20″N, 109°29′00″W	Depth of 2 m in glaciolacustrine sediments
10	TO 201	8590 ± 100	Shells	Hummocky moraine depression ca. 1130 m	The Gap (Black site) 49°37′00″N, 109°43′00″W	Depth of 3 m in silty loam 7 m thick above till
11	S 2932	11 460 ± 250	Wood	Frenchman valley bottom ca. 800 m	Val Marie 49°13′N, 107°44′W	Depth of 36 m in valley fill 44 m thick (ref. 2)
12	S 2911	9225 ± 330	Wood	Frenchman valley bottom ca. 975	Cypress Lake 49°29′N, 109°22′W	Depth of 13 m in valley fill 50 m thick (ref. 2)
13	S 2820	7395 ± 590	Wood	Frenchman vallen bottom ca. 900 m	Shaunavon 49°24′N, 108°36′W	Depth of 25 m in valley fill 80 m thick (ref. 2)
14	S 2819	3800 ± 165	Wood	Frenchman valley bottom ca. 900 m	Shaunavon 49°24′W, 108°36′W	Depth of 5 m in valley fill 80 thick (ref. 2)
15	S 2821	7245 ± 580	Wood	Frenchman valley bottom ca. 880 m	Climax 49°20′N, 108°25′W	Depth of 15 m in valley fill 80 m thick (ref. 2)
16	S 2930	3440 ± 165	Wood	Frenchman valley bottom ca. 880	Climax 49°20′N, 108°24′W	Depth of 5 m in valley fill 80 m thick (ref. 2)
17	GSC 4325	4340 ± 60	Shells	Frenchman valley bench ca. 950 m	Near confluence with Conglomerate Creek 49°29′55″N, 109°02′50″W	Depth of 4 m in sandy loam exposed in cutbank across bench 9 m above river level
18	S 2893	3970 ± 80	Bone	Conglomerate valley bench ca. 950	Near confluence with Frenchman River 49°30′30″N, 109°02′30″W	Depth of 1 m in silty loam 8 m above creek bottom
19	S 2892	6570 ± 95	Bone	Battle valley terrace ca. 1080 m	Fort Walsh 49°31′00″N, 109°51′15″W	Depth of 4 m in silty loam 8 m above creek bottom
20	S 2908	9120 ± 250	Organic detritus	Meltwater channel bottom ca. 1230 m	Harris Lake 49°40′05″N, 109°54′00″W	Depth of 10 m in silty clay bottom sediments (ref. 3)
21	GSC 4422	7270 ± 80	Wood	Gap valley colluvial fan ca. 800 m	Near the Weir 49°51′05″N, 109°35′25″W	Depth of 9 m below fan surface
22	TO 100	3600 ± 80	Bone	Gap valley bench ca. 785 m	The Weir 49°51′33″N, 109°35′00″W	Depth of 2 m in sandy alluvium overlying till 7 m above creek bottom

References: (1) Klassen and Vreeken, 1987; (2) Christiansen and Sauer, 1988; (3) Sauchyn, 1990.

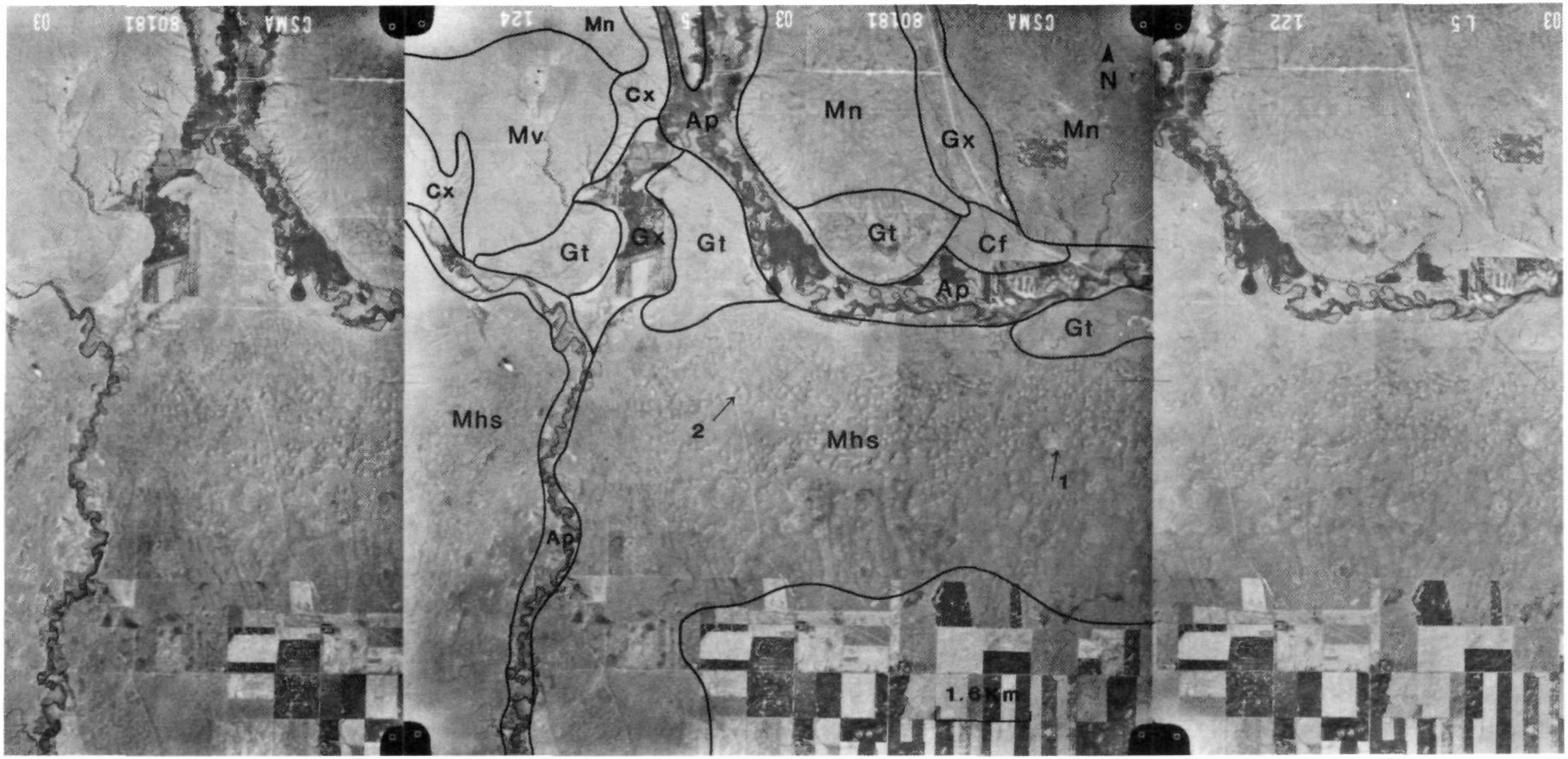

FIGURE 23. Stereo-triplet of part of the interlobate drift complex along the west to east stretch of the Frenchman Valley spillway near the Alberta boundary. The complex includes hummocky dead ice moraine (Mhs), hummocky moraine (Mn) and glaciofluvial deposits (Gt, Gx) within the valley. The upper segment of Middle Creek (Ap) in the western part of the photo and lower segment of Battle Creek (Ap) are within the main spillway. Arrows 1 and 2 locate a moraine plateau (Fig. 25) and excavated depression (Gaff Site) respectively. Centre of airphoto 124 is sec. 14, tp. 5, rge. 29 (49°23'N, 109°48'W). Airphotos CSMA 80181-03-L5-122, 124, 126.

Triplet stéréographique du paysage caractérisé par ses dépôts interlobaires le long de la portion est-ouest du canal de trop plein de la vallée Frenchman, près de la frontière de l'Alberta. L'ensemble comprend: moraine bosselée de glace morte (MhS), moraine bosselée (Mn) et dépôts fluvio-glaciaires (Gt, Gx) à l'intérieur de la vallée. Le segment supérieur de Middle Creek (Ap) (vers la gauche) et le segment inférieur de Battle Creek (Ap) font partie du canal principal. La flèche 1 identifie un plateau morainique (fig. 25) et la flèche 2, une dépression creusée (site de Gaff). Le centre de la photo est à 49°23'N, 109°48'W. Photos aériennes n°s 80181-03-L5-122, 124, 126.

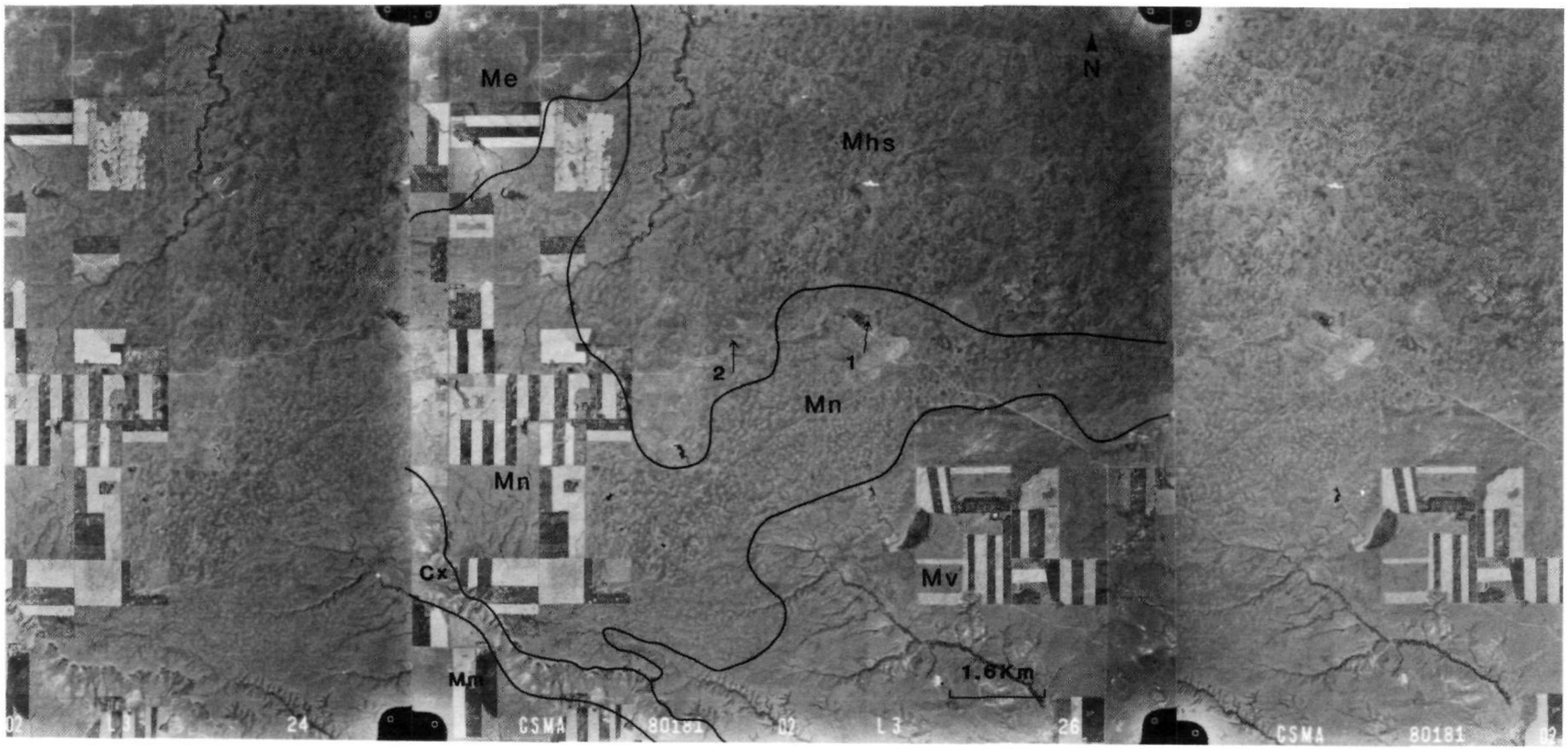

FIGURE 24. Stereo-triplet of part of the interlobate drift complex on the Old Man on His Back Plateau. Hummocky dead ice moraine (Mhs) and hummocky moraine (Mn) make up the complex flanked by ground moraine (Me, Mm, Mv) and the southwest-facing plateau scarp (Cx). Arrows 1 and 2 locate the Horseman and Rangeview sites respectively. Centre of airphoto 26 is Sec. 16, tp. 3, rge. 24 (49°13′N, 109°11′W). Airphotos CSMA 80181-02-L3-24, 26, 28.

Triplet stéréographique du paysage caractérisé par ses dépôts interlobaires sur le Old Man on His Back Plateau. La moraine bosselée de glace morte (Mhs) et la moraine bosselée (Mn) constituent l'ensemble entouré par la moraine de fond (Me, Mm, Mv) et l'abrupt du plateau exposé au sud (Cx). Les flèches 1 et 2 identifient les sites de Horseman et de Rangeview, respectivement. Le centre de la photo est à 49°13′N, 109°11′W. Photos aériennes nos 80181-02-L3-24, 26, 28.

FIGURE 25. Hummocky dead ice moraine south of Battle Creek. Looking north towards the West Block which forms the horizon. Surface in the foreground is the edge of a moraine plateau (Fig. 26) located in NW 1/4 sec. 18, tp. 5, rge. 28 (49°23′20″ N, 109°45′30″W). ISPG 2519-8.

Moraine bosselée de glace morte au sud de Battle Creek. Vue vers le nord du côté du West Block, à l'horizon. La surface au premier plan constitue la bordure d'un plateau morainique (fig. 26) (49°23′20″N, 109°45′30″W). ISPG 2519-8.

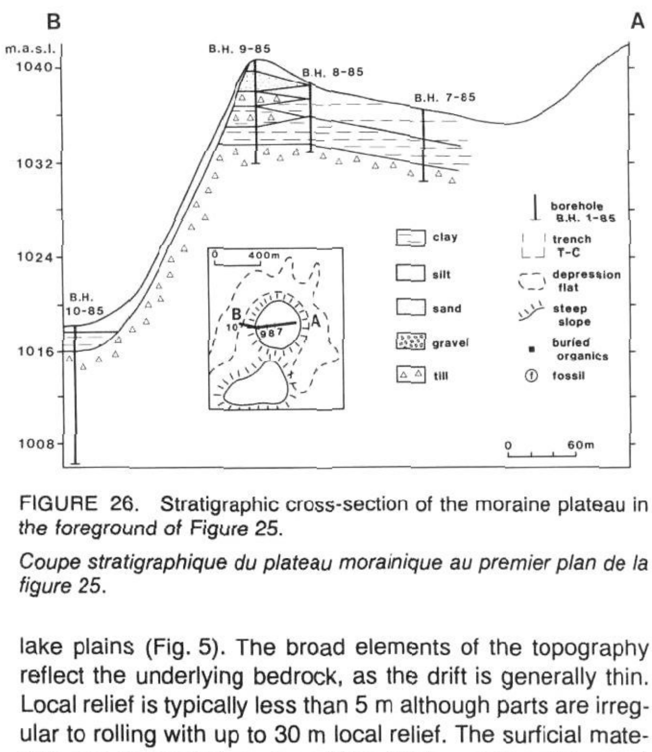

FIGURE 26. Stratigraphic cross-section of the moraine plateau in the foreground of Figure 25.

Coupe stratigraphique du plateau morainique au premier plan de la figure 25.

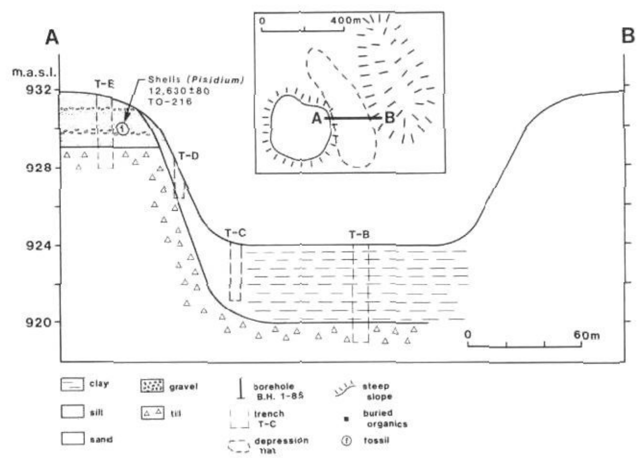

FIGURE 27. Photo (ISPG 2482-26) of the Ham Site viewed northeast from the margin of a moraine plateau (foreground) across a depression in hummocky dead-ice moraine of the Boundary Plateau. Stratigraphic cross-section of the Ham Site located in NW 1/4 sec. 28, tp. 1, rge. 21 (49°04′05″N, 108°45′30″W). Radiocarbon date listed in Table I.

Photo (ISPG 2482-26) du site de Ham vue du nord-est à partir de la bordure du plateau morainique (premier plan) au-delà d'une dépression dans la moraine bosselée de glace morte du Boundary Plateau. La coupe stratigraphique du site Ham est à 49°04′05″N, 108°45′30″W (datation au tabl. I).

lake plains (Fig. 5). The broad elements of the topography reflect the underlying bedrock, as the drift is generally thin. Local relief is typically less than 5 m although parts are irregular to rolling with up to 30 m local relief. The surficial materials are generally less than 15 m thick over the plains, but thicknesses of more than 100 m occur within buried valleys and the belts of hummocky and ridged moraine.

Parts of the ground moraine are bordered by or enclose belts of hummocky moraine, ridged moraine, and meltwater valleys. Ground moraine forms vast stretches of flat to gently undulating or rolling plains south of the Cypress Hills and on the northern slopes of the Wood Mountain Upland. Drumlins trending south-southwest occur just east of the East Block and subdued grooves trending southeast mark the ground moraine surface south of the east trending segment of Frenchman Valley. Glacial lake plains merge with ground moraine plains along the north slopes of Wood Mountain Upland and extend over much of the north-central part of the Wood Mountain area (Fig. 5).

Belts of hummocky moraine and ridged moraine, mostly between 2 and 5 km wide, and with 5 to 30 m local relief, occur within or separate this complex from other complexes. The largest tract of hummocky moraine occurs in The Gap between the West and Centre blocks of the Cypress Hills Upland (Fig. 5), and extensive ridged moraine forms the south-facing slope of Pinto Butte of the Wood Mountain Upland (Fig. 29). Ridges in the hummocky moraine are randomly oriented, but in the ridged moraine they commonly parallel the trend of the moraine belt.

The major valleys in side hill positions adjacent to the East Block described earlier (Fig. 2) are meltwater channels now occupied by the misfit Frenchman River (Fig. 30) and Swift

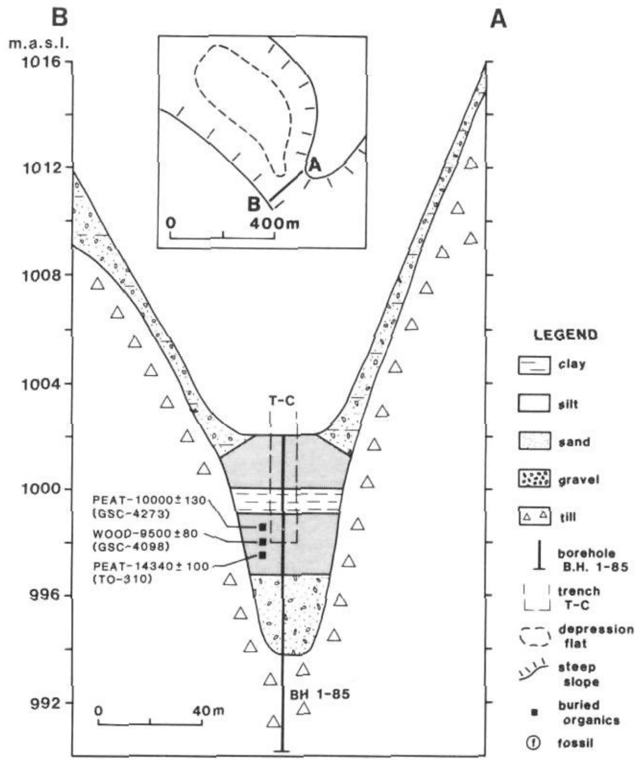

FIGURE 28. Stratigraphic cross-section of the Horseman site within a depression in hummocky moraine of the Old Man on His Back Plateau (see Fig. 24). Radiocarbon dates listed in Table I.

Coupe stratigraphique du site de Horseman à l'intérieur d'une dépression dans la moraine bosselée du Old Man on His Back Plateau (fig. 24) (datations au tabl. I).

Current Creek. Lac Pelletier in the northwest corner of the Wood Mountain area and Twelve Mile Lake along the north facing slopes of the easternmost part of the Wood Mountain Upland (Fig. 2) are within segments of former meltwater channels. These valleys are 2 to 3 km wide, 50 to 100 m deep, and have gradients of about 1 m per km. Smaller valleys typically less than 1 km wide and 25 m deep, are mostly in consequent position across ground moraine and lake plains, although short stretches of the valleys are in sidehill positions.

The moraine types are mainly till and the lake plains mainly stratified silt and clay (Fig. 5). Diamicts along with silt and clay and local occurrences of sand and gravel, occur within and between the moraines and lake plains.

Two tills are commonly exposed along valleys or penetrated in shallow boreholes within the ground moraine plains in the southern part of the Cypress Lake area. There are commonly less than 5 % erratics and local stones, and their matrix is a silty loam with the carbonate content of the silt mainly between 7 and 13 % (Fig. 21b). The lower till is compact and jointed, whereas the upper is looser, contains sand lenses, and has more erratics. The contact between them typically is gradational and does not show evidence of subaerial weathering or biota. The upper till, typically several metres thick, is locally absent. The ground moraine of the Swift Current Creek Plateau (Figs. 2, 5) includes patches of massive silt of eolian or lacustrine origin within shallow depressions in the till. However, erosion of the ground moraine in the western part of the Frenchman River Plain has produced discontinuous patches of lag sand and fine gravel over the till.

Tracts of ground moraine north and south of the Centre Block, and near the lake basins in the northeastern part of the Wood Mountain area (Fig. 5 — Mx), consist of till and intercalated glacial lake sediments. The lake sediments are bedded to massive silt, clay and diamicts with a lower carbonate content (Fig. 21) than in the ground moraine.

The glacial lake plains include both low relief hummocky plains underlain mainly by silt and sand with minor clay, and flat to gently irregular plains underlain mainly by silt and clay (Fig. 5 — Ln, Lp). The sediments are more than 15 m thick within the central parts of larger basins and less than 5 m in the small basins.

The hummocky moraines (Fig. 5 — Mh, Mn) consist mostly of till similar to that in most ground moraines. The ridged moraine, however, also includes slabs and stringers of local bedrock intercalated with till (Fig. 31).

Stream and mass wasting sediments are found in the large misfit valleys. Fill up to 75 m thick is found within the lower stretches of Frenchman Valley and upper segment of Swift Current Valley. It consists mainly of sand, silt, clay, and reworked bedrock and till. In the smaller valleys the fill is much thinner, commonly less than 15 m thick. Wood River and its tributaries, in the north-central part of the Wood Mountain area, are flanked by broad alluvial flats where the streams meander across glacial lake plains. Much of the alluvium is thin and consists of reworked lake sediments.

Main Processes of Landscape Formation

The ground moraine consists mainly of till formed directly by lodgement beneath active ice and by ablation from stagnant ice. Late glacial and postglacial lacustrine, colluvial, fluvial and eolian processes have modified its surfaces in places and left discontinuous fine sediment veneers and coarse lag deposits. The ground moraine (Mx) with intercalated units of till and glaciolacustrine sediments formed through ice ablation combined with meltwater ponding beneath the ice and along the ice margin. The flat glacial lake beds (Lp) of silt and clay were deposited beyond the ice margin; sandy to gravelly sediments were deposited along the basin margin, and the low hummocky lake plains (Ln) either formed over stagnant ice or reflect pre-existing topography.

Hummocky moraine (Mh) and ridged moraine (Mr) peripheral to the ground moraines and lake plains are lateral or end moraines in the traditional sense. The ridged moraine, common to glaciated terrain around the up-ice peripheral zones of prairie uplands, reflects glacial thrusting under certain ice regimes (see Klassen, 1989).

The large valleys of Frenchman River and Swift Current Creek formed as meltwater channels that drained the extensive proglacial lakes around the Cypress Hills nunatak, and carried meltwater during deglaciation. The Frenchman Valley across the "interlobate complex" and Swift Current Creek Valley along the margin of the East Block formed as ice

FIGURE 29. Stereo-triplet of ridged moraine (Mr) flanked by eroded (Me) and patchy (Mv) ground moraine north of Pinto Butte. Centre of airphoto 234 is sec. 25 tp. 7, rge. 13 (49°34'N, 107°40'W). CSMA 80181-02-L7-232, 234, 236.

Triplet stéréographique d'une moraine ondulée (Mr) entourée par une moraine de fond érodée (Me) et irrégulière (Mv) au nord de la butte Pinto. Le centre de la photo est à 49°34'N, 107°40'W. Photos aériennes nos 80181-02-L7-232, 234, 236.

FIGURE 30. Frenchman Valley and exposure of Ravenscrag Formation sandstone (foreground). Looking south from Ravenscrag Butte in the NW 1/4 sec. 30, tp. 6, rge. 22 (49°30'05"N, 108°57'10"W). Steepest parts of the valley walls are in bedrock and colluvial benches form gentle slopes toward the modern channel. ISPG 2626-45.

Vallée de la Frenchman River et coupe de la Formation de grès de Ravenscrag (au premier plan). Vue vers le sud à partir de la Ravenscrag Butte située à 49°30'05"N, 108°57'10"W. Les versants les plus abrupts font partie du substratum et les colluvions forment les versants plus doux du côté du chenal actuel. ISPG 2626-45.

FIGURE 31. Ice thrust bedrock exposed in ridged moraine northwest of Pinto Butte in the NE 1/4 sec. 32, tp. 8, rge. 14 (49°41'40"N, 107°52'40"W). ISPG 3304-9.

Fragments de poussée glaciaire mis à nu dans la moraine ondulée au nord-ouest de la Pinto Butte à 49°41'40"N, 107°52'40"W (ISPG 3304-9).

marginal channels as indicated by their side-hill positions. The trench of Frenchman Valley across the Frenchman River Plain (Fig. 2) possibly began as a supraglacial or subglacial extension of the ice marginal stretches of the Frenchman and Swift Current valleys (see Vreeken, 1991). This stretch, although lateral to the regional slope, follows a shallow sag in the surface, which may have initiated the spillage eastward from the impounded glacial lakes.

Mass wasting deposits make up most of the sediments along the lower parts of the large valleys. These are commonly incised by the modern channels or form divides within the upper reaches; notable examples of the latter are found along Frenchman Valley, west of Cypress Lake, where Battle Creek is diverted southward, and also along Swift Current Valley just north of its confluence with Frenchman Valley where the creek is diverted northeast along the main valley.

Age

The landscapes within this complex include the youngest drift of the area. The oldest radiocarbon date obtained was 14 ka from peat in a hummocky moraine depression (Fig. 28; Table I, ref. no. 1), and compares with the oldest ages of 12 to 14 ka obtained from the interlobate complexes (Table I, ref. nos. 5, 8, 9). Maximum radiocarbon ages in the 9 ka range were obtained from shells and organic detritus in sediments overlying hummocky moraine in The Gap and in a meltwater channel bordering the moraine (Table I, nos. 10, 20). The radiocarbon dates, however, provide only minimal ages, as is evident from the differences of about 4 ka in dates from sediments in similar stratigraphic settings in hummocky moraines. The relative and absolute chronologies lead to the inference that the landscapes within this complex date from the final phases of Late Wisconsinan ice recession in this region about 15 ka.

Most of the fill within the Frenchman and Swift Current valleys and their main tributaries was deposited between about 11 and 4 ka as indicated by radiocarbon dates (Table I, ref. nos. 11, 17, 18) and the occurrence of the 6.6 ka Mazama ash in fans and terraces bordering the modern flood plains. The formation of these features and cutting by modern streams to depths of up to 6 m across parts of the features, occurred durinq the last 4 ka.

SUMMARY AND CONCLUSIONS

Landscapes in the area are classified as: (1) unglaciated bedrock terrain, (2) bedrock terrain with residual drift, (3) bedrock terrain with drift, (4) first advance drift, (5) interlobate drift, (6) last advance drift. This classification and the proposed chronology of landscape evolution is based on the dominant geomorphic and geologic components and processes that shaped the landscapes.

The surfaces of the upland landscapes were shaped largely by Late Tertiary fluvial and mass wasting processes and those of the surrounding plains were further shaped by processes associated with glaciation. Relative ages of the complexes on the uplands are inferred by comparing gradients of the main surfaces. The proposed time frame is Late Tertiary for surfaces with the lowest gradients (about 3 to 5 m/km), Late Tertiary to early Quaternary for surfaces of intermediate gradients (10 to 20 m/km) and late Quaternary for surfaces with gradients of 100 to 250 m/km.

The unglaciated bedrock terrain of the Cypress Hills and Wood Mountain uplands consists mainly of remnants of ancient plateaus and pediments separated by broad valleys and their tributaries. The plateaus and pediments were formed chiefly by streams and mass wasting during the Late Tertiary (Miocene to Pliocene), as these surfaces generally have low slopes. During the Quaternary they were modified by mass wasting and stream erosion that enlarged pre-existing valleys and in places cut new ones.

The bedrock terrain with residual drift on the Cypress Hills and Wood Mountain uplands is similar to the unglaciated bedrock terrain, except for glacial erratics (residual drift) scattered on the surface or buried in colluvium. The pediment surfaces of the Wood Mountain Upland have low gradients but pediments on the Cypress Hills have low and intermediate gradients. The intermediate gradients may result from fluvial and mass wasting processes during the Quaternary. The drift residuals are considered deposits of a glaciation as old as early Pleistocene.

Bedrock terrain with drift occurs on the southern slopes of the Wood Mountain Upland. The landscapes here resemble the unglaciated and residual drift complexes, except for much strong dissection by valleys and gullies and a veneer of till and colluvial detritus on the pediment remnants. Surface gradients are low on the pediment surfaces and intermediate to high along valley walls and escarpments. Pre-Late Wisconsinan valleys were enlarged and new valleys cut during the Late Wisconsinan. It appears that this complex was glaciated before the final Late Wisconsinan advance, and possibly during Early Wisconsinan or Illinoian time. Most of Frenchman Valley and some of its tributaries within this complex were excavated by Late Wisconsinan meltwater. Headward erosion by Holocene streams and mass wasting continued to expand a radial network of small valleys and gullies.

Late Wisconsinan glacial features dominate the complexes designated as first advance drift, interlobate drift and last advance drift. They include vast expanses of ground moraine and glacial lake plains interspersed with belts of hummocky and ridged moraine. The Late Wisconsinan age assigned to these surfaces is based mainly on radiocarbon dates on material obtained from postglacial sediments. Final deglaciation occurred about 15 ka.

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REFERENCES

Acton, D.F., Clayton, J.S., Ellis, J.G., Christiansen, E.A. and Kupsch, W.O., 1960. Physiographic divisions of Saskatchewan as established by Saskatchewan Soil Survey in co-operation with Geology Division. Saskatchewan Research, Council and Geology Department, University of Saskatchewan. Map, 1:1 520 640 scale.

Alden, W.C., 1924. Physiographic development of the Great Plains. Bulletin of the Geological Society of America, 35: 385-424.

—— 1932. Physiography and glacial geology of eastern Montana and adjacent areas. United States Department of the Interior, Geological Survey Professional Paper 174, 133 p.

Bostock, H.S., 1970. Physiographic regions of Canada. Geological Survey of Canada, Map 1254A (1:500 000 scale).

Broscoe, A.J., 1965. Geomorphology of the Cypress Hills-Milk River Canyon area, Alberta, p. 74-84. *In* R.L. Zell, ed., Alberta Society of Petroleum Geologists. 15th Annual Field Conference Guidebook, Part 1, Cypress Hills Plateau, 288 p.

Catto, N.R., 1983. Loess in the Cypress Hills, Alberta, Canada. Canadian Journal of Earth Sciences, 20: 1159-1167.

Christiansen, E.A. and Sauer, E.K., 1988. Age of the Frenchman Valley and associated drift south of the Cypress Hills, Saskatchewan, Canada. Canadian Journal of Earth Sciences, 25: 1703-1708.

Collier, A.J. and Thom, Jr. W.T., 1918. The Flaxville gravel and its relationship to other gravels of the northern Great Plains. United States Geological Survey Professional Paper 108: 179-184.

Colton, R.B., Naeser,N.D. and Naeser, C.W., 1986. Drainage changes in eastern Montana and western North Dakota during Late Cenozoic time. Geological Society of America Abstracts with Programs, 39th Annual Meeting Rocky Mountain Section, 18, (5): 347.

David, P.P., 1964. Surficial geology and ground water resources of the Prelate area (72K), Saskatchewan. Ph.D. thesis, McGill University, Montréal, 329 p.

—— 1970. Discovery of Mazama ash in Saskatchewan, Canada. Canadian Journal of Earth Sciences, 7: 1579-1583.

Frazer, F.J., McLearn, F.H., Russell, L.S., Warren, P.S. and Wickenden, R.T.D., 1935. Geology of southern Saskatchewan. Canada Department of Mines, Bureau of Economic Geology, Geological Survey, Memoir 176, 137 p.

Furnival, G.M., 1946. Cypress Lake map-area, Saskatchewan. Canada Department of Mines and Resources, Bureau of Geology and Topography, Geological Survey Memoir 242: 161 p.

Garner, H.E., 1974. The origin of landscapes. Oxford University Press, New York, 734 p.

Gary, M., McAfee, R., Jr. and Wolf, C.L., 1974. *Glossary of Geology*. American Geological Institute, Washington, D.C., 799 p.

Goulden, M.R. and Sauchyn, D.J., 1986. Age of rotational landslides in the Cypress Hills, Alberta-Saskatchewan. Géographie physique et Quaternaire, 40 (3): 239-248.

Holmam, J.A., 1971. Climatic significance of giant tortoises from the Wood Mountain Formation (Upper Miocene) of Saskatchewan. Canadian Journal of Earth Sciences, 8: 1148-1151.

Holman, J.A. and Tokaryk, T.T., 1987. A new specimen of giant land tortoise (*Geochelone* sp.) from the Wood Mountain Formation (Middle Miocene) of Saskatchewan. Canadian Journal of Earth Sciences, 24: 2572-2574.

Jensen, S.F. and Varnes, H.D., 1964. Geology of the Fort Peck area, Carfield, McCone and Valley counties, Montana. United States Geological Survey Professional Paper 414F.

Johnston, W.A., Wickenden, R.T.D. and Weir, J.D., 1948. Surface deposits of southwestern Saskatchewan. Geological Survey of Canada, Paper 48-18 (consists of two maps scaled 1 inch to 6 miles).

Jungerius, P.D., 1966. Age and origin of the Cypress Hills plateau surface in Alberta. Department of Energy Mines and Resources (Canada). Geographical Bulletin, 8 (4): 307-318.

—— 1967. The influence of Pleistocene climate changes on the development of polygenetic pediments in the Cypress Hills area, Alberta. Department of Energy Mines and Resources (Canada), Geographical Bulletin, 9 (3): 218-231.

King, K.C., 1953. Canons of Landscape Evolution. Geological Society of America Bulletin, 64: 721-752.

Klassen, R.W., 1989. Quaternary geology of the southern Canadian Interior Plains, p. 97-174. *In* R.J. Fulton, ed., Chapter 2 of Quaternary Geology of

Canada and Greenland, Geological Survey of Canada, Geology of Canada, no. 1 (also Geological Society of America, The Geology of North America, v. K-I), 839 p.

——— 1991. Surficial geology and drift thickness, Cypress Lake (72F) Saskatchewan. Geological Survey of Canada, Map 1766A (1:250 000 scale).

——— 1992. Surficial geology and drift thickness, Wood Mountain (72G) Saskatchewan. Geological Survey of Canada, Map 1802A (1:250 000 scale).

——— (in press). Moraine plateaus: Relicts of stagnant ice in southwestern Saskatchewan. *In* R.W. Barendregt, ed., Proceedings of Palliser Triangle Mosaic and Temporal Aspects of a Region Conference, Lethbridge, Alberta, University of Calgary Press.

Klassen, R.W. and Vreeken, W.J., 1987. The nature and chronological implications of surface tills and post-till sediments in the Cypress lake area, Saskatchewan. *In* Current Research, Part A, Geological Survey of Canada Paper 87-1A, 111-125.

Leckie, D.A. and Cheel, R.J., 1989. The Cypress Hills Formation (Upper Eocene to Miocene): A semi-arid braidplain deposit resulting from intrusive uplift. Canadian Journal of Earth Sciences, 26: 1918-1931.

——— 1990. Nodular silcretes of the Cypress Hills Formation (upper Eocene to middle Miocene) of southern Saskatchewan. Sedimentology, 37: 445-454.

McConnell, R.G., 1985. Report on the Cypress Hills, Wood Mountain and adjacent country. Geographical and Natural History Survey of Canada Annual Report, lc-85c.

Russell, L.S., 1970. The great Saskatchewan mouse mine. Rotunda (Royal Ontario Museum), 3 (1): 16-24.

Sauchyn, D.A., 1990. A reconstruction of Holocene geomorphology and climate, western Cypress Hills, Alberta and Saskatchewan. Canadian Journal of Earth Sciences, 27: 1504-1510.

Stalker, A. MacS., 1960. Ice-pressed drift forms and associated deposits in Alberta. Geological Survey of Canada Bulletin 57, 38 p.

——— 1973. Surficial geology of the Drumheller area, Alberta. Geological Survey of Canada, Memoir 370, 122 p.

St-Onge, D.A., 1966. Cypress Hills east area, Saskatchewan. *In* Mélanges de Géographie, ed. M.O. Tulippe, Université de Liège, 72-79.

Storer, J.E., 1975. Middle Miocene mammals from the Cypress Hills, Canada. Canadian Journal of Earth Sciences, 12: 520-522.

Tricart, J., and Cailleux, A., 1972. Introduction to geomorphology. Longman Group Ltd., London, 295 p.

Twidale, C.R., 1968. Pediments, p. 817-818. *In* R.W. Fairbridge, ed., The Encyclopedia of Geomorphology, Reinhold Book Corporation, New York, 1295 p.

——— 1976. Analysis of landforms. John Wiley and Sons, Australasia Pty. Ltd. Toronto, 572 p.

Vreeken, W.J., 1991. The southern Swift Current Plateau (Saskatchewan): A subglacial-meltwater erosion surface. Geological Association of Canada Annual Meeting Toronto, Program with Abstracts, 16: A129.

Vreeken, W.J., Klassen, R.W. and Barendregt, R.W., 1989. Davis Creek silt, an Early Pleistocene or Late Pliocene deposit in the Cypress Hills of Saskatchewan. Canadian Journal of Earth Sciences, 26: 192-198.

Vonhof, J.A., 1965. The Cypress Formation and its reworked deposits in southwestern Saskatchewan, p. 142-161. *In* R.L. Zell, ed., Alberta Society of Petroleum Geologists, 15th Annual Field Conference Guidebook, Part 1, Cypress Hills Plateau, 288 p.

——— 1969. Tertiary gravels and sands in the Great Canadian Plains. Ph.D. thesis, University of Saskatchewan, Department of Geological Sciences, 279 p.

Westgate, J.A., 1968. Surficial geology of the Foremost-Cypress Hills area, Alberta. Research Council of Alberta Bulletin 22, 122 p.

Whitaker, S.H., 1965. Geology of the Wood Mountain area (72-G), Saskatchewan. Ph.D. thesis, University of Illinois, Urbana, 95 p.

——— 1967, Geology and groundwater resources of the Wood Mountain area (72-G), Saskatchewan. Saskatchewan Research Council Geology Division, Map No. 5 (1:250 000 scale).

——— 1976. Geology and groundwater resources of the Cypress area (72-F), Saskatchewan. Saskatchewan Resarch Council Geology Division, Map No. 22 (1:250 000 scale).

Wickenden, R.T.D., 1931. An area of little or no drift in southern Saskatchewan. Transactions of the Royal Society of Canada, Third Series, 25, Section 4: 45-47.

Williams, M.Y., 1929. The physiography of the southwestern plains of Canada. Transactions of the Royal Society of Canada, Third Series, 23, Parts 1 and 2, Section 4: 61-79.

Williams, M.Y. and Dyer, W.S., 1930. Geology of southern Alberta and southwestern Saskatchewan. Canada Department of Mines, Geological Survey, Memoir 163, 160 p.