QUATERNARY GEOLOGIC MAP OF THE REGINA 4° × 6° QUADRANGLE, UNITED STATES AND CANADA

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QUATERNARY GEOLOGIC ATLAS OF THE UNITED STATES

MISCELLANEOUS INVESTIGATIONS SERIES MAP I–1420 (NM–13)

U.S. DEPARTMENT OF THE INTERIOR U.S. GEOLOGICAL SURVEY

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International Map of the World (IMW) Series, 1970
Lambert Conformal Conic Projection

Geology compiled in 1976–85, 1990–2002
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CONTACT

LIMIT OF A GLACIATION, GLACIAL ADVANCE, OR STILLSTAND OF ICE MARGIN—Dashed where inferred; ticks on side of advance

DISTAL MARGIN OF A GLACIOTECTONIC DEPOSIT OR GLACIOTECTONIC STRUCTURE ASSOCIATED WITH A GLACIAL ADVANCE LIMIT—Decoration on side of advance. See symbol IT

LIMIT OF RESIDUAL ERRATIC GLACIAL BOULDERS ON DISSECTED BEDROCK SURFACES—Predominantly map unit xlq; locally, boulders are on or are pressed into gravel deposits of Tertiary age (unit xsh). Most boulders are igneous and metamorphic rocks from the Canadian Shield. Glacial, ice-contact, and glaciofluvial deposits were removed by erosion. Many boulders were transported to the region by ice during one or more late Pliocene continental glaciations

KNOWN OR SUSPECTED GLACIOTECTONIC DEPOSITS OR GLACIOTECTONIC TERRAIN—Bedrock and surficial deposits that were thrust, stacked, and deformed by glacial ice. Chiefly (1) steeply tilted bedrock blocks overlying till and stratified sediments; (2) stacked or imbricated slices of bedrock, till, and stratified sediments forming parallel or concentric ridges; (3) deformed masses of bedrock and surficial deposits characterized by overturned folds; or (4) isolated blocks, isolated irregular masses, or isolated, relatively smooth, nearly equidimensional hills downglacier from source depressions. Some glaciotectonically transported materials are covered by till that was deposited by overriding ice. Thickness 10 to >100 m

CONCEALED (BURIED) GLACIOTECTONIC RAFT OR "MEGABLOCK"—Glaciotectonic deposits as described above. The buried features lack diagnostic surface expression. The largest identified "megablock," in Saskatchewan on eastern margin of quadrangle and in adjacent Winnipeg quadrangle (Fullerton and others, 2000), is exposed as a result of incision of the Qu'Appelle River (Christiansen, 1971a; Sauer, 1978; Aber and others, 1989). Smaller rafts or parts of "megablocks," identified on the basis of test hole and well records, are mapped southwest of Williston, N. Dak., and between Poplar and Medicine Lake, Mont.

WASHBOARD MORAINES, MINOR MORAINES, "ICE-CRACK MORAINES," OR CORRUGATED MORAINE—Chiefly composed of till. Most of the ridges are oriented parallel to vanished ice margins. Local relief of moraines of late Wisconsin age typically is 2–10 m. Moraines of Illinoian age, mapped only in Montana, are very subdued and are conspicuous only from the air. Wild (2003) proposed that the landforms in southwest corner of quadrangle were formed by subglacial floods, not by glacial ice

DIRECTION OF ICE MOVEMENT INDICATED BY STRIATIONS—The southeast-trending striations south of the Missouri River south of Culbertson, Mont., were produced during Illinoian glaciation

ICE-MOLDED OR ICE-SCOURED LANDFORM—Drumlin, rock drumlin, flute, or groove. Long axis of symbol is parallel to direction of ice movement. Wild (2003) proposed that the landforms in southwest corner of quadrangle were formed by subglacial floods, not by glacial ice

ESKER

DUNE FIELD—Mapped in Saskatchewan, in central-western part of quadrangle. Elsewhere, dunes are common or abundant in areas mapped as units ed and eu

PALEOWIND DIRECTION INDICATED BY DUNE ORIENTATIONS—Mapped in Montana east of Medicine Lake

BURIED BEDROCK VALLEYS OF THE ANCESTRAL MISSOURI AND YELLOWSTONE RIVERS—Mapped in southeast quarter of quadrangle

BROCKTON-FROID FAULT ZONE (Colton and Bateman, 1956a; Colton, 1963a and unpub. data; Crone and Wheeler, 2000)—Till has not been observed on bedrock in the axis of the fault zone; apparently, the bedrock there is overlain only by stratified ice-contact and glaciofluvial sediments. The fault zone is the "linear channel" of Witkind - (1959)

LOCATION OF IMPORTANT STRATIGRAPHIC SECTION

NOTE: This map is a product of collaboration of the Saskatchewan Research Council, the North Dakota Geological Survey, and the U.S. Geological Survey, and is designed for both scientific and practical purposes. Maps and map explanations prepared by compilers were combined, integrated, and supplemented by the editor. Map unit letter symbols were revised to a uniform system of classification used for all maps in the Quaternary Geologic Atlas map series. The unit descriptions were prepared by the editor from information received from the compilers and from additional sources listed under "Sources of Information." Illustrations that accompany the map were prepared by the editor and his assistant. The editor is responsible for interpretations of geologic history and the chronologic and stratigraphic framework of Quaternary deposits.

The map units are surface deposits and materials. A complex subsurface stratigraphy in some areas (table 2) is documented by stratigraphic sections (see "Important Stratigraphic Sections"). Bedrock in much of the quadrangle is completely obscured by till and stratified deposits that are products of several glaciations and by sediment deposited during interglacial intervals. Sand and gravel deposits in buried bedrock valleys are important local sources of groundwater; some also are regional surficial aquifers. Residual glacial erratic boulders on some upland bedrock surfaces in Montana and Saskatchewan are interpreted to be vestiges of one or more continental glaciations of late Pliocene age. The Pliocene till was removed by erosion during the long (>1.2 m.y.) interval between the Pliocene and Pleistocene glaciations.

For scientific purposes, the map differentiates Quaternary surficial deposits and materials on the basis of clast lithology or composition, matrix texture or particle size, structure, genesis, stratigraphic relations, engineering geologic properties, and relative age, as shown on the correlation diagram and indicated in the "Description of Map Units." Deposits of some constructional landforms, such as end moraines, are distinguished as map units. Deposits of erosional landforms, such as outwash terraces, are not distinguished, although glaciofluvial, ice-contact, fluvial, and lacustrine deposits that are mapped may be terraced. Differentiation of sequences of fluvial and glaciofluvial deposits at this scale is not possible.

For practical purposes, the map is a surficial materials map. Materials are distinguished on the basis of lithology or composition, texture or particle size, and other physical, chemical, and engineering characteristics. It is not a map of soils that are recognized and classified in pedology or agronomy. Rather, it is a generalized map of soils as recognized in engineering geology, or of substrata or parent materials in which pedologic or agronomic soils are formed. As a materials map, it serves as a base from which a variety of maps for use in planning engineering, land-use planning, or land-management projects can be derived and from which a variety of maps relating to earth surface processes and Quaternary geologic history can be derived.

[Map unit thickness is typical range; in some areas, the map units may be thicker or thinner than the given range]

HOLOCENE

PEAT AND MUCK—Dark-brown or black, fibrous, woody reedsedge or sphagnum peat overlying partly decomposed to well-decomposed peat or clay containing organic residues and comminuted plant material. Peat and muck are in bogs and ice-block depressions along north boundary, in northeast corner of quadrangle. Unmapped deposits elsewhere are included in other map units. Included in swamp deposits (hs) where peat and swamp deposits have not been distinguished. Thickness 1–4 m

HOLOCENE AND LATE WISCONSIN

LOAMY AND CLAYEY SHEETWASH ALLUVIUM1—Pale-yellow, yellowish-brown, olive-brown, brown, olive, yellowish-gray, olive-gray, brownish-gray, gray, or mottled alluvium transported and deposited by unconfined overland flow and rill wash. Typically (1) clay, silty clay, silty clay loam, and clay loam; (2) clay loam, silt, silt loam, and sandy loam; or (3) loamy sand, and sandy loam. Nonstratified to moderately well stratified; poorly to moderately well sorted. Massive, thinly laminated, or with weak horizontal bedding. Disseminated organic matter is abundant in some areas; local buried soils (humic horizons). Fossiliferous (gastropod tests) locally. Fragments of lignite (bedrock) are common. Generally is calcareous and alkaline; saline in some areas. Clast free, with scattered granules and small pebbles, or with stringers, pods, and lenses of granule or pebble gravel. Commonly is interbedded with well-sorted, pebbly, coarse silt and very fine sand. Mixed, intercalated, or interbedded with eolian sand and silt (es, ed) or floodplain and channel alluvium (al) in some places. Clayey alluvium is soft, sticky, and plastic where moist and tough, hard, and blocky where dry. Clay minerals in most areas are predominantly montmorillonite. Granules and pebbles are chiefly local clastic sedimentary rocks and, locally, clinker and ironstone; minor erratic limestone, dolomite, and igneous and metamorphic rocks in glaciated areas. Cobbles and boulders are generally absent. Sheetwash alluvium is in fans and aprons on foot slopes, in glacial diversion channels and sluiceways, in swales and sloughs, and in depressions and other poorly drained areas. Included in other map units in many areas. Includes some alluvial-fan deposits (afj) and inset floodplain and channel alluvium (al) deposited by streams. Also includes some colluvium (caa), till (tlx, tks), and bedrock outcrops. Where sheetwash alluvium directly overlies flood-plain and channel alluvium (al) or lake deposits (lca, lss), commonly it is difficult to distinguish the deposits. Distinction between units wla and cad is arbitrary in some areas. Thickness 1–4 m, locally >10 m

LOAMY AND CLAYEY SHEETWASH ALLUVIUM1 AND LAKE DEPOSITS—Complex map unit of sheetwash alluvium (wla) and older lake clay, silt, and sand (lca, lss). Sheetwash alluvium is chiefly in fans and aprons, overlapping lake deposits along margins of lake basins. Map unit in some areas overlies a thick, complex fill deposit that includes one or more till units. Includes some till (tlx) and inset floodplain and channel alluvium (al). Mapped in Missouri River valley in Montana and North Dakota. Thickness of sheetwash alluvium 1–5 m, locally >10 m; thickness of lake deposits 2–11 m, locally >20 m

FLOOD-PLAIN AND CHANNEL ALLUVIUM—Yellowish-brown, olive-brown, grayish-brown, brown, olive, yellowish-gray, brownish-gray, olive-gray, gray, black, or mottled clay, silt, sand, and gravel. Calcareous or noncalcareous; partly or completely oxidized. Clasts are angular to well rounded. Clast composition reflects composition of other surficial materials and bedrock in the drainage basin. Included in other map units in many areas. Includes some sheetwash alluvium (wla) and alluvial-fan deposits (afj), alluvium beneath low terraces, outwash and ice-contact sand and gravel (gs, gg, kg), lake deposits (lca, lss, lsa), peat and muck (hp), swamp deposits (hs), and bedrock outcrops. Alluvium in some areas is predominantly redeposited outwash, ice-contact deposits, and lake deposits. In some larger valleys, alluvium overlies thick fill deposits of older fluvial, glaciofluvial, and glaciolacustrine deposits and till; fill includes buried landslide deposits in some places. Thickness 1–6 m, locally >20 m

Flood-plain alluvium—Chiefly poorly sorted to well-sorted clay, silty clay, silty clay loam, clayey silt, and silt combined with scattered granules and pebbles; locally, alluvium is loam, sandy clay loam, sandy loam, or fine sand. Moderately to well stratified; commonly has either obscure bedding or pronounced horizontal bedding; weakly laminated in some places. Clay, silt, sand, or gravel lenses or small channel fills of sand and gravel are common. Dense and compact in most places. Clayey alluvium is moderately plastic, soft, and sticky where moist and hard where dry. Textures may vary abruptly, laterally and vertically. Local buried soils (humic horizons). Fossiliferous (gastropod, pelecypod, and ostracode remains, vertebrate remains, wood fragments and plant detritus) in some places. Concentrations of lignite (bedrock) fragments are common in crossbedded sand; lignite fragments as large as 1 cm are present locally. Where flood-plain alluvium directly overlies lake silt and sand (lss) or sheetwash alluvium (wla), in some places it is difficult to distinguish the deposits

Channel alluvium—Chiefly loose, stratified, poorly sorted to well-sorted, pebbly, fine to medium sand and (or) coarse sand and gravel; locally, very poorly sorted sandy shale gravel. Cobbles and boulders are common to abundant in some areas. Generally is crossbedded or has crude horizontal bedding or lenticular bedding; local festoon bedding. Fossiliferous (chiefly vertebrate remains) locally

FLOOD-PLAIN AND CHANNEL ALLUVIUM, SHEETWASH ALLUVIUM,1 AND ALLUVIAL-FAN DEPOSITS—Complex map unit of flood-plain and channel alluvium (al), sheetwash alluvium (wla), and alluvial-fan deposits (afj). Mapped in Saskatchewan in central part of quadrangle. Thickness 0.5–10 m

ALLUVIAL-FAN DEPOSITS—Yellowish-brown, grayish-brown, yellowish-gray, brownish-gray, gray, or mottled clay, silt, sand, and gravel. Generally is calcareous; partly or completely oxidized. Poorly to well stratified; poorly to well sorted. Typically is poorly sorted gravel and pebbly fine sand near fan apex, grading to silt and clay near toe. Clasts are subangular to well rounded; clast composition reflects composition of other surficial deposits and bedrock in the drainage basin. Includes some sheetwash alluvium (wla). Deposits of fan alluvium in many areas are included in flood-plain and channel alluvium (al), sheetwash alluvium (wla), and colluvium (caa). Includes some sheetwash alluvium (wla) and flood-plain and channel alluvium (al). Mapped in Saskatchewan in central part of quadrangle. Thickness 0.5–8 m

ALLUVIUM AND LAKE DEPOSITS—Complex map unit of flood-plain and channel alluvium (al) and lake clay and silt (lca). In central part of quadrangle, thin beds of organic lake clay and silt (lca) and swamp deposits (hs) are interbedded with sodium sulfate (Glauber's salt) in some places. Throughout the quadrangle, streams meander across lake plains and the alluvium is chiefly reworked lake sediment. Alluvium on broad alluvial flats is commonly alkaline. Includes some sheetwash alluvium (wla). Locally, unit is overlain by swamp deposits (hs) 1–3 m thick. Mapped in Saskatchewan. Thickness of alluvium 0.5–3 m; thickness of lake sediment 1–5 m

ALLUVIUM, LAKE DEPOSITS, AND SHEETWASH ALLUVIUM—Complex map unit of flood-plain and channel alluvium (al), lake clay, silt, and sand (lca, lss), and sheetwash alluvium (wla). Mapped in Montana. Thickness 2–20 m

LAKE CLAY AND SILT—Pale-yellow, grayish-yellow, yellowish-brown, olive-brown, grayish-brown, brown, olive, yellowish-gray, brownish-gray, olive-gray, bluish-gray, gray, olive-black, bluish-black, black, or mottled calcareous clay and silt. Well sorted; stratified. Commonly is laminated, locally varved clay and silty clay in lower part; massive or horizontally bedded silty clay and silt in upper part. Upper part is generally clast free; iceberg-rafted granules, pebbles, cobbles, and boulders are common in lower part. Clasts are generally absent on surface. Contains local thin, discontinuous beds, lenses, or stringers of sand or fine gravel; pockets or pods of iceberg-rafted granules and pebbles or isolated rafted erratic cobbles or boulders. Interbedded with sand or fine gravel or with flowtill or till in some areas; local rafted masses of till are 2–3 m in diameter. Graded beds, silt blebs and nodules, or rip-up clasts of till or silt and clay are present locally. Strongly contorted, with load structures and folds, in some places. Generally not faulted; collapse fractures or dessication cracks are common in some places. Commonly oxidized in upper l.5–2.5 m; local iron oxide stains. Soft to very firm; cohesive and compact. Very plastic and sticky where moist and hard where dry. Locally gritty. Dry clay and silt commonly breaks into chips or blocks. Clay minerals are predominantly montmorillonite in most areas; illite is predominant locally. Selenite (gypsum) crystals <6 mm in length are common locally in fractures and are abundant in saline lake sediment. Pelecypod and gastropod tests and secondary calcium carbonate concretions are locally present in upper part. Terraced in some areas; gullies are common adjacent to some larger streams. Clay is susceptible to landslide processes (chiefly slump) in exposures (see unit jea). Most of deposits are off-shore and near-shore deposits of former lakes. Present beneath flat plains and in small basins formerly occupied by glacial and postglacial lakes, and as ice-walled or ice-floored lake deposits in areas of stagnation moraine. Flat to hummocky surface topography on lake plains. Local closed depressions (kettles), 1–9 m deep, are present where sediments were deposited on stagnant or dead ice. Raised rims 0.2–4 m high ring some ice-walled lake deposits in areas of stagnation moraine. Thin and discontinuous in some areas. Overlapped by flood-plain and channel alluvium (al) adjacent to many streams. Includes lake silt and sand (lss) where units lca and lss have not been distinguished. Includes lake sand and gravel (lsa) along margins of some large lake basins and in beaches, bars, and spits that are too small to map at this scale. Includes wave-washed or current-scoured till (tlx) having a thin, discontinuous veneer of lake silt and clay or a lag veneer of sand and gravel. Also includes some ice-contact and outwash sand and gravel (kg, gs, gg), lake delta deposits (ldb), till (tlx), and bedrock outcrops. In some places, unit is overlain by eolian silt and sand (el, es, ed), sheetwash alluvium (wla), alluvial-fan deposits (afj), peat and muck (hp), swamp deposits (hs), and floodplain and channel alluvium (al). Thickness 1–9 m, locally >50 m

LAKE SILT AND SAND—Grayish-yellow, yellowish-brown, grayish-brown, brown, yellowish-gray, olive-gray, brownish-gray, gray, or mottled calcareous silt and sand mixed with minor clay and gravel. Generally is well stratified and well sorted. Typically is horizontally bedded or massive, fine or medium sand containing scattered granules or small pebbles, interbedded or intercalated with massive, bedded or laminated silt containing dropstones; in some areas, unit is chiefly bedded silt and laminated silt and fine sand. Commonly slumped, faulted, and contorted on hillslopes. Fossiliferous (pelecypod and gastropod tests) locally; detrital fragments of lignite (bedrock) are abundant in many areas and are concentrated in crossbeds. Clasts are chiefly rounded erratic limestone, dolomite, and igneous and metamorphic rocks reworked from till. Unit is present beneath flat lake plains and in small basins formerly occupied by glacial and postglacial lakes, and also as ice-walled or ice-floored deposits in areas of stagnation moraine. Deposits are collapsed where sediments were deposited on stagnant or dead ice. Blowouts are common on surface in some places. Thin and discontinuous in some areas. Overlapped by flood-plain and channel alluvium (al) adjacent to many streams. Includes lake clay and silt (lca) where units lss and lca have not been distinguished. Includes lake sand and gravel (lsa) along margins of some lake basins and in beaches, offshore bars, and spits that are too small to map at this scale. Includes some lake delta deposits (ldb), subaqueous density-current underflow-fan deposits (lda), flood-plain and channel alluvium (al), and till (tlx). In many areas, unit overlies lake clay and silt (lca). Locally overlain by peat and muck (hp), swamp deposits (hs), or eolian silt and sand (el, es, ed). Thickness 1–8 m, locally >30 m

LAKE SAND AND GRAVEL—Pale-yellow, brownish-yellow, grayish-yellow, reddish-brown, yellowish-brown, grayish-brown, brown, olive, yellowish-gray, brownish-gray, olive-gray, gray, or mottled, calcareous, very fine to coarse sand, gravelly sand and gravel. Moderately well stratified or well stratified; poorly to well sorted. Unit is typically coarse to medium sand and poorly sorted to well-sorted gravel interbedded with minor silt and clay in uppermost 1–2 m; well sorted, fine to very fine sand and silt (lss) below. Gravel is poorly to well sorted; crudely bedded to well bedded. Sand is generally crossbedded or in thin horizontal beds; local graded bedding or ripple-drift lamination. Grain size typically coarsens upward in thicker and more extensive deposits. In some places, material is interbedded with lake clay and silt (lca), lake silt and sand (lss), till (tlx), or subaqueous debris-flow deposits. Clasts are chiefly subangular to very well rounded granules and pebbles of erratic limestone, dolomite, and igneous and metamorphic rocks reworked from till. Chiefly forms sheet deposits. Includes some lake clay, silt, and sand (lca, lss) and flood-plain and channel alluvium (al). Overlain by eolian sand (es, ed) in some places. Thickness 0.5–4 m, locally >10 m

LAKE CLAY, SILT, SAND, AND GRAVEL—Undivided deposit of lake clay and silt (lca), lake silt and sand (lss), and lake sand and gravel (lsa). Locally overlain by peat and muck (hp), swamp deposits (hs), flood-plain and channel alluvium (al), or eolian silt and sand (el, es, ed). Thickness 1–3 m, locally >10 m

SWAMP DEPOSITS—Brown, bluish-gray, olive-gray, gray, or black muck, mucky peat, and organic residues mixed with fine-grained mineral sediment. Soft to dense and tough; commonly plastic where moist. Obscure horizontal bedding. Locally overlies (1) gray or white marl, a very calcareous, soft, crumbly clay that contains microcrustacean valves, mollusc tests and fragments, and fish fossils; or (2) shelly gyttja, an anaerobic, pulpy, fresh-water mud containing wood and other plant material. Includes peat where peat and muck (hp) and swamp deposits (hs) have not been distinguished. Swamp deposits are in ice-block depressions (kettles) and other depressions, in abandoned meltwater channels, and on clayey lake deposits (lca). Mapped only where extensive; included in other map units. Thickness 1–3 m, maximum >6 m

EOLIAN SILT (LOESS)—Yellow, yellowish-brown, brown, yellowish-gray, brownish-gray, gray, or mottled silt and silt loam; minor, very fine sand. Calcareous; leached where thin. Generally is oxidized throughout. Typically is nonstratified, well-sorted silt; in some places, contains streaks of silty clay or clay or contains scattered granules or small pebbles. Generally is homogeneous, massive, blocky, friable, porous, and weakly compact; stands in nearly vertical faces in exposures. Dry loess commonly has conspicuous columnar joints. Root casts and weakly developed buried soils (humic horizons) are common in some places. Locally fossiliferous (gastropod tests). Basal part is commonly mixed with underlying deposit. Modified by sheet wash and by creep and other mass-movement processes in some places; partly redeposited on some hillslopes. Eolian silt is a mantle of wind-blown sediment that is draped over older deposits and topography. Mapped in Saskatchewan, in central western part of quadrangle; unmapped thin, discontinuous loess overlies other deposits in many areas elsewhere in quadrangle.

Thickness generally decreases southeastward. Thickness 0.3–1 m; maximum thickness >3 m

EOLIAN SHEET SAND—Yellow, yellowish-brown, olive-brown, grayish-brown, brown, brownish-gray, gray, or mottled windblown sand in blanketlike deposits; local low dunes. Well stratified; well sorted. Typically is calcareous, loose, homogeneous, massive, fine to very coarse sand with faint bedding or crossbedding. Very friable; slightly hard; subangular blocky structure; not sticky or plastic when moist. Chiefly consists of well-rounded quartz grains; grains are frosted or clear. Contains discontinuous secondary accumulations of calcium carbonate in some places; stained by iron oxides locally. Typically is oxidized to depths >2 m. In some places, contains weakly developed buried soils (humic horizons). Mostly stable, with grass cover; local blowouts. Includes some eolian silt and dune sand (el, ed). Mapped in northwestern part of quadrangle. Thickness 1–3 m

DUNE SAND—Yellow, yellowish-brown, olive-brown, grayish-brown, brown, brownish-gray, gray, or mottled windblown sand in dunes. Generally is calcareous. Typically is loosely compacted, stratified, well-sorted fine to coarse sand. Faint parallel or irregular bedding or pronounced crossbeds; local foreset beds. Chiefly consists of subrounded to well-rounded quartz grains; quartz grains are frosted or clear. Commonly is oxidized to depths >2 m; locally is stained by iron oxides. In some places, contains weakly developed buried soils (humic horizons). Some dunes are irregular hummocks; most are parabolic dunes or elongate blowout dunes. Local relief generally is 2.5–9 m; maximum relief is >15 m. Dunes are mostly stable, with grass cover; local blowouts. Includes some eolian sheet sand (es) and flood-plain and channel alluvium (al). Thickness 1–10 m; maximum thickness >20 m

SLUMP-BLOCK LANDSLIDE DEPOSITS AND EARTHFLOW AND MUDFLOW DEPOSITS—Includes areas of colluvium and sheetwash alluvium (caa) and bedrock outcrops. Individual landslide deposits are too small to map at this scale. Unit includes areas distinguished from unit caa on the basis of the presence of landslide deposits in 5–50 percent of area shown. Includes the "debris-slide" deposits of Klassen (1994)
Slump-block deposits—Masses of bedrock and unconsolidated materials that rotated or slid downslope as a unit, with little or no flow. The physical properties of transported materials are not greatly altered; original textures, stratification, bedding, and sedimentary structures of slumped materials are disturbed but retained. Individual slump-block scarps in some places are >300 m in length; crown scarp displacements generally are <10 m. The length of individual slump deposits generally is 3–70 m, maximum is >600 m. Surface slopes are generally 4–10°, locally more than 20°. Typically the slump-block deposits are composed of jumbled blocks or they form sub-parallel, arcuate, hummocky ridges having 1–15 m local relief, separated by elongate swales and closed depressions. Some older deposits are stabilized by vegetation. In some places, multiple regressive-failure slump-block deposits coalesce to form continuous belts 1–2 km in length, along escarpments or on steep valley sides. Some multiple deposits are reactivated by undercutting of toes by streams. Thickness 3–30 m, locally 60–100 m

Earthflow deposits—Heterogeneous, nonsorted mixtures of clay, silt, and sand containing scattered clasts, that were transported and deposited as a result of slow flow of wet, but not necessarily saturated, disintegrated bedrock and surficial materials. In some areas, most of the deposit is reworked slump-block deposits; in others, deposit is chiefly reworked till, lake deposits, sheetwash alluvium, and (or) colluvium. Deposits commonly are composed of debris derived from gully walls. Deposits typically are in gullies and in fans at mouths of gullies in dissected slump-block deposits or on foot slopes. Thickness 1–5 m, locally >10 m

Mudflow deposits—Heterogeneous mixtures of clay and silt containing scattered clasts, transported and deposited as a result of rapid flow of saturated, unconsolidated materials and disintegrated shale bedrock. Typically, mud-flow deposits are composed of debris washed from exposed shale surfaces or debris derived from collapse of gully walls. Commonly forms fans at mouths of gullies or on foot slopes. Thickness generally 1–5 m

HOLOCENE, LATE PLEISTOCENE, AND MIDDLE PLEISTOCENE

COLLUVIUM,2 SHEETWASH ALLUVIUM,1 AND LANDSLIDE DEPOSITS—Complex map unit on slopes below escarpments, on valley sides, and on eroded uplands. Includes areas of gravelly sand; angular gravel veneers on apronlike "pediment" surfaces; lag sand and gravel over till and (or) bedrock; fan deposits at bases of hillslopes and at mouths of gullies; lag boulder accumulations; sheet-wash- or stream-eroded till or bedrock dissected by deep gullies, ravines, or coulees; very thin disintegration residuum on bedrock; extensive areas of bedrock outcrop, including local badland terrain (Rb). In Montana and North Dakota, locally includes clinker 1–15 m thick (see map unit ckq). In some places, includes deposits similar to those in map unit cad

Colluvium—Yellowish-brown, olive-brown, brown, olive, yellowish-gray, brownish-gray, gray, or mottled debris transported and deposited by mass-movement processes. Calcareous or noncalcareous. Loose to compact. Nonsorted or poorly sorted; nonstratified or faintly stratified. Commonly massive. Where derived from bedrock, colluvium is typically angular and subangular blocks, boulders, cobbles, pebbles, and granules of local bedrock in a clayey to sandy matrix. Where derived from Tertiary sand and gravel or early or middle Pleistocene sand and gravel (see unit xsh), material is typically sand or pebbly sand. Where derived from glacial drift, material is typically boulders, cobbles, pebbles, and granules of erratic limestone, dolomite, and igneous and metamorphic rocks and local bedrock in a clayey to sandy matrix. Three or more buried soils (humic horizons) are locally present in colluvium; lignite (bedrock) fragments are ubiquitous in many areas. Thickness 1–15 m

Sheetwash alluvium—Similar to unit wla. Thickness 0.3–4 m, locally 10 m

Landslide deposits—Similar to unit jea. Thickness 2–20 m

COLLUVIUM,2 SHEETWASH ALLUVIUM,1 AND GLACIOFLUVIAL-FILL DEPOSITS—Complex map unit in meltwater channels and lake sluiceways. Channel sides are sharply defined to indistinct. Some channels and sluiceways are deep, filled trenches; others are shallow, broad flats. In northwestern part of quadrangle, some large meltwater channels and lake sluiceways formed after extinction of glacial lakes; channel

fill deposits are inset into lake sediments (lca, lss), and in some places they were buried by eolian deposits (es, ed). In most other parts of the quadrangle, valley sides are chiefly colluvium, sheetwash alluvium, till, and bedrock outcrops. Large boulders or lag deposits of cobbles and boulders are present on valley sides in some places. In some larger valleys, glaciofluvial sand and gravel (gs, gg, ggi) are present beneath low terraces; two sets of paired terraces are present in some areas. Gullies are common locally on valley sides. In some places, valley floors are marked by elongate, boulder-littered "islands" of till and bedrock surrounded by stratified sediments. Basal part of fill is generally glaciofluvial sand and gravel (gs, gg, ggi) or reworked glaciofluvial deposits. In some fills, lake deposits (lca, lss) overlie glaciofluvial sand and gravel. Locally the fill includes till and associated lake sediment of both late Wisconsin age and pre-Wisconsin age. Flood-plain and channel alluvium (al) is inset into some fill deposits; flood-plain deposits overlap the fill deposits. Sheetwash alluvium commonly overlaps the fill deposits on foot slopes on valley sides; in some places, it mantles most of the fill on the valley floor. Valley floor deposits locally are overlain by swamp deposits (hs). Distinction of units cad, caa, and ggi is arbitrary in some areas. Combined thickness of fill and overlapped alluvium is 1–10 m, locally >30 m
Colluvium—Similar to colluvium in unit caa. Thickness 1–8 m
Sheetwash alluvium—Similar to unit wla. Thickness 1–4 m

LOAMY COLLUVIUM,2 CLINKER,3 TILL, AND SHEETWASH ALLUVIUM 1—Complex map unit in Missouri River valley in Montana. Other areas of colluvium, clinker, till, and sheetwash alluvium elsewhere in Montana and North Dakota are included in units caa and jea

Colluvium—Colluvium derived from clinker generally is rubble of blocks, boulders, cobbles, pebbles, and granules of clinker in a sandy to clayey matrix. Clinker blocks and boulders on the surface commonly are nearly covered by lichens. Colluvium derived from unaltered bedrock and from other surficial deposits is similar to colluvium in unit caa. Thickness 0.3–5 m

Clinker—Pale-red to dark-red, pink, orange, yellow, green, reddish-brown, gray, white, or black sandstone, siltstone, and claystone that was baked and fused in Quaternary time as a result of natural burning of lignite bedrock. Intensity of alteration diminishes upward. Lower part is commonly massive and contains flow structures; bedding and sedimentary structures of original bedrock were destroyed. Contains local slag-like masses with ropy surfaces, or low-density rock with fissures, pores, and pockets resembling scoria. Where the original bedrock was clayey, clinker commonly is massive and hard; it breaks into plates or brittle chips having conchoidal fracture. Upper part typically retains bedding and sedimentary structures of original bedrock; commonly brecciated by collapse caused by removal of underlying lignite; flow structures are absent except in chimneys that project upward. Polygonal columnar jointing is common in some places; breaks in short, columnar fragments or chunky blocks. Clinker is very resistant to erosion; forms ledges and rims on hillslopes or cap rock on hilltops. Burning of lignite occurred at different times in different places. A fission-track age of <50,000 yr was calculated by C.W. Naeser for clinker older than the late Wisconsin till north of the

Missouri River near Culbertson, Mont. (D.A. Coates, written commun., l986). Thickness 2–10 m

Till—Surface till in most places is late Wisconsin in age (tlx). Locally, exhumed till of Illinoian and (or) pre-Illinoian age is exposed. In many places the till was baked and fused with the bedrock when the lignite burned, to form "clinkertill" (Dove, 1922), or clinkered till. Thickness 0.5–1.5 m

Sheetwash alluvium—Similar to wla. Thickness 1–4 m

CLAYEY DISINTEGRATION RESIDUUM,4 COLLUVIUM,2 SHEETWASH ALLUVIUM,1 AND TILL—Complex map unit in southwestern part of quadrangle, south of Missouri River. Includes landslide deposits (jea)

Residuum—Yellowish-brown, olive-brown, grayish-brown, brown, olive, olive-gray, brownish-gray, gray, or mottled, montmorillonitic clay, silty clay, clay loam, or loam. Nonsorted, nonstratified; massive or has faint relict stratification. Loosely con-solidated or compact. Generally is calcareous where not leached. Mildly to strongly alkaline. Plastic, sticky, and slippery where moist; hard and blocky where dry. Iron-oxide stains are common. Residual selenite (gypsum) crystals, fossiliferous calcium-carbonate and ironstone concretions, and redeposited pyrite, marcasite, or siderite crystals are common locally. Shale fragments are common to abundant, particularly in lower part; locally the residuum contains thin layers of platy shale fragments. Thin and discontinuous. Includes extensive areas of bedrock outcrop and badland terrain (Rb). Residual glacial erratic boulders of limestone, dolomite, and igneous and metamorphic rocks are scattered on the land surface. Thickness 0.3–1 m

Colluvium—Similar to colluvium in unit caa. Predominantly angular and subangular fragments of micaceous and bentonitic shale in a clayey matrix. Sandstone and siltstone fragments and granules, derived from local bedrock, and pebbles of erratic limestone, dolomite, and igneous and metamorphic rocks are present where colluvium is derived in part from eroded till. Thickness 0.3–1 m

Sheetwash alluvium—Similar to unit wla. Thickness 0.3–3 m, locally >9 m

Till—Similar to unit tks. Thin and discontinuous. Intensely eroded in most places. Thickness <2 m

QUATERNARY AND TERTIARY

EOLIAN SILT AND SAND—Blanketlike mantle of wind-blown sediment on Tertiary sand and gravel and on residuum overlying the sand and gravel (see unit xsh) in the "driftless area" in the southwest quarter of the quadrangle. Pale-orange, pale-yellow, yellowish-brown, olive-brown, grayish-brown, brown, gray, or mottled, wind-blown silt (loess) and sand. Generally is calcareous; local white or pale-gray filaments, powdery interstitial fillings, or nodules of secondary calcium carbonate. Generally is oxidized throughout. Moderately alkaline. Typically consists of (1) loose, nonstratified, well-sorted, homogeneous, massive silt and very fine to medium sand or (2) silty fine sand containing laminae or thin lenses of silt. Local faint horizontal bedding and crossbedding; vague horizontal color banding is common. Friable; blocky structure is common. Nonsticky, nonplastic. Chiefly subrounded to well-rounded quartz grains; quartz grains are frosted or clear. In some places, includes small fragments of shale and lignite. Locally is stained yellowish brown, reddish brown, or brown by iron oxides. In some places, contains weakly developed buried soils (humic horizons). Modified by bioturbation, cryoturbation, solifluction, and creep. Mostly stable and covered by grass. Included in units xsh and xlq in many places. Thickness 1–3 m

LOAMY DISINTEGRATION RESIDUUM,4 COLLUVIUM,2 AND SHEETWASH ALLUVIUM1—Brownish-yellow, yellowish-brown, olive-brown, grayish-brown, gray, or mottled loam, clay loam, silt loam, and silty clay loam; in some areas, sandy clay loam, sandy loam or loamy sand. Noncalcareous or calcareous; fine seams and soft masses of secondary calcium carbonate are common where sediment is calcareous. Generally is moderately alkaline. Nonsticky or slightly sticky and nonplastic or slightly plastic when moist; slightly hard to hard when dry. Friable. Typically is massive; has prismatic structure or subangular blocky structure. Local reddish-brown, yellowish-brown, or brown iron-oxide stains. Residual concretions of calcium carbonate, limonite, or pyrite are common. In some places, contains fragments of lignite (bedrock). Clay minerals are predominantly montmorillonite in many areas. Modified by bioturbation, cryoturbation, solifluction, and creep. Gullies are common on moderate and steep slopes. Includes extensive landslide deposits (jea). Includes some redeposited sand and gravel containing quartzite clasts as large as 30 cm in diameter (see unit xsh), patchy lag deposits of sand and gravel, and sand and gravel veneers on pediments. Also includes dissected bedrock and badland terrain (Rb). Locally is overlain by discontinuous eolian silt and sand (el, es)

In areas glaciated during late Pliocene time (limit of glaciation is shown on map; see table 2), residual glacial erratic cobbles and boulders of very resistant rocks are scattered on the land surface (Howard, 1960; Klassen, 1992a,b; Fullerton and others, 2004a,b). Most of the limestone and dolomite clasts were removed by weathering processes. Boulders of coarse-grained igneous and metamorphic rocks from the Canadian Shield that were pressed into sand and gravel deposits and that are preserved in colluvium are disintegrated (Klassen, 1992b, 2002). Till deposited during late Pliocene glaciation has not been identified in association with this map unit

Residuum—Derived chiefly in place from mechanical weathering of bedrock or mixed windblown sediment and sheetwash alluvium overlying bedrock. Weathering profile extends into bedrock. Thickness <1 m

Colluvium—Similar to colluvium in unit caa. Where derived from bedrock, clasts are predominantly soft sandstone, siltstone, and claystone. Where derived from sand and gravel, clasts are predominantly quartzite, argillite, chert, and chert conglomerate. Partly cemented by secondary calcium carbonate locally. Thickness 1–4 m

Sheetwash alluvium—Similar to unit wla. Thickness 1–4 m

LOAMY DISINTEGRATION RESIDUUM4—Yellowish-brown, grayish-brown, brownish-gray, or gray, calcareous or noncalcareous clay and silty clay. Soft, slightly sticky, and slightly plastic when moist; hard and flaky when dry. Friable. Generally is massive; sedimentary structures are not preserved; blocky structure is common. Minor iron- and manganese-oxide stains. Root casts are preserved locally. Residuum grades downward to parent material, very calcareous eolian silt and sand that contains lenses and interbeds of secondary calcium carbonate. Parent material in some places is calcrete cap rock. Parent material is the marl unit of the Flaxville formation of Collier and Thom (1918), the Opheim formation of Whitaker (1980) and Patton (1987), and the Ogallala Formation equivalent of Colton and others (1989b). Map unit includes areas of other complex materials and deposits (xsh) and also sheetwash alluvium (wla). In some areas, residuum is overlain by discontinuous wind-blown sand and silt (es, el). Thickness of residuum is 1–5 m. Thickness of parent material is generally 6–8 m, locally >10 m
In areas glaciated during late Pliocene time (limit of distribution of residual erratic boulders is shown on map; see table 2), glacial erratic cobbles and boulders of igneous and metamorphic rocks from the Canadian Shield, and also limestone and dolomite, locally were pressed by ice into the residuum and the parent material of the residuum. Those erratics were preserved because the enclosing sediment was very calcareous and because it was buried subsequently by calcareous eolian sediments. Till deposited during late Pliocene glaciation has not been identified in association with this map unit

SANDY AND LOAMY DISINTEGRATION RESIDUUM4—Grayish-orange, pale-yellow, reddish-brown, yellowish-brown, olive-brown, grayish-brown, brown, yellowish-gray, brownish-gray, gray, or mottled loamy sand, sandy clay loam, sandy clay, loam, and clay loam. Parent material in most places is weathered wind-blown silt and sand of pre-late Wisconsin age that overlies fluvial sand and gravel of Tertiary (Miocene and Pliocene) age. Residuum generally is very calcareous; white masses or nodules of secondary calcium carbonate are common; locally contains carbonate-coated root casts; cemented by calcium carbonate in some places. Generally is strongly alkaline. Poorly stratified or nonstratified; poorly sorted or nonsorted. Commonly is massive; sedimentary structures not preserved. Generally is compact and moderately indurated. Moderately fissile. Angular or subangular blocky structure; minor clay films on ped surfaces. Granular, loose, and friable where very sandy. Silty or clayey residuum is slightly sticky to sticky and slightly plastic to very plastic when moist; hard when dry. Residuum is typically very sandy near base. Scattered, isolated granules and pebbles in upper part of residuum, chiefly well-rounded or very well rounded quartzite, argillite, chert, and chert conglomerate, are products of bioturbation. Multiple buried soils are locally present in the residuum. In some places, a pedogenic composite soil more than 1 m thick is developed in the residuum. Modified by bioturbation, cryoturbation, solifluction, and creep. Residuum grades downward to sand and gravel. Gullies are common in residuum and underlying sand and gravel in some areas. Map unit includes some colluvium; colluvium commonly margins fluvial gravel deposits. Thickness of residuum 1–3 m, locally >8 m

The underlying sand and gravel in Saskatchewan is Wood Mountain Formation; in Montana it is Flaxville Formation and Wiota Gravel. Locally, a buried soil is present

between the fluvial deposits and the residuum. In some places, the long axes of pebbles and small cobbles in gravel are aligned vertically, a product of cryoturbation.
In areas glaciated during late Pliocene time (limit of distribution of residual erratic boulders is shown on map: see table 2), glacial erratic boulders and cobbles in some places were pressed by ice into the sand and gravel or into overlying residuum. Most of the limestone and dolomite clasts were removed by weathering processes. Boulders of coarse-grained igneous and metamorphic rocks from the Canadian Shield are disintegrated (Klassen, 1992b). Till deposited during late Pliocene glaciation has not been identified in association with the map unit.

Wiota Gravel of late Pliocene(?) age beneath till of pre-Illinoian (middle Pleistocene) age on some low-altitude bedrock erosion surfaces in Montana contains rare reworked granules, pebbles, and small cobbles of granite, pegmatite, gneiss, and other igneous and metamorphic rocks from the Canadian Shield (Jensen, 1951a; Witkind, 1959; Colton, 1962; Jensen and Varnes, 1964). Most of the fluvial gravel is nonglacial in origin and is much older than the overlying till. The reworked erratic clasts were derived from glacial and glaciofluvial deposits that were eroded during an interval of ≈1.4 million years between late Pliocene and middle Pleistocene continental glaciations (table 2). Reworked glacial erratics have not been observed in older, higher altitude (middle and late Pliocene?) deposits of Wiota Gravel or in gravel of the older Flaxville Formation (Miocene and early Pliocene). Indurated "calcrete" till or colluvium beneath middle Pleistocene till in Montana (see "Important Stratigraphic Sections," #36) is interpreted to be late Pliocene in age. A cobble of pink granite from the Canadian Shield was extracted from the base of the till or colluvium. Empress Group fluvial and lacustrine deposits that are older than the early Pleistocene Wellsch Valley tephra (table 2; see "Important Stratigraphic Sections," #11, Jaw Face exposure) in Saskatchewan contain rare redeposited glacial erratics. The erratics here are interpreted to have been reworked from late Pliocene glacial, glaciofluvial, and glaciolacustrine deposits. Glacial, glaciofluvial, and glaciolacustrine deposits of late Pliocene age are expected to be preserved only in upland areas where they overlie Tertiary fluvial deposits. All of the late Pliocene surficial deposits in lowland areas were removed by erosion prior to Quaternary glaciation

LATE WISCONSIN

LOAMY TILL—Sediment deposited directly by glacial ice. Pale-yellow, grayish-yellow, yellowish-brown, olive-brown, grayish-brown, brown, brownish-olive, olive, yellowish-gray, brownish-gray, olive-gray, bluish-gray, gray, or mottled calcareous clay loam and loam; in some areas, clay, silty clay, silty clay loam, silt loam, sandy clay, or sandy loam. Locally very gravelly; where till directly overlies shale bedrock, matrix in some places is >90 percent shale fragments. In some places, interbedded with, intercalated with, or contains lenses, pods, and stringers of clay, silt, sand, or gravel. Generally nonstratified; nonsorted or very poorly sorted. Locally has weak horizontal layers where ice margin fluctuated in a lake. Commonly massive; cohesive and friable. In some areas, gritty or mealy; crude fissility. Loosely compact or compact, but not hard. Sandy till is loose to firm; silty till firm. Clayey till is soft, slightly sticky to sticky, and slightly plastic to plastic when moist; hard and blocky when dry. Dry till in some places breaks into small angular flakes and plates that have sharp edges. Parting is typically irregular or prismatic. Clay minerals are predominantly montmorillonite in many areas, predominantly illite or kaolinite locally. Widely spaced, weakly developed joints are common; in some places, joint surfaces are coated by powdery calcium carbonate or gypsum, or both. Locally weakly stained by iron or manganese oxides. Selenite (gypsum) crystals 1–3 mm long are present on some joint surfaces. Fragments of lignite (bedrock) are ubiquitous in till in Montana and North Dakota. Nearly pebble free to very pebbly; cobbles and boulders are rare to abundant. In Montana and North Dakota, boulders typically are more abundant in till of late Wisconsin age than in older subsurface or exhumed tills; also, average diameter of boulders is larger than that in older tills. Pebbles are chiefly subangular to rounded erratic limestone and dolomite; less abundant erratic igneous and metamorphic rocks from the Canadian Shield. Where thin and derived from local bedrock, pebbles are chiefly angular to subrounded shale, siltstone, and soft sandstone; where derived from Tertiary gravel, pebbles are predominantly quartzite, argillite, chert, and chert conglomerate. Cobbles and boulders are predominantly subangular to well-rounded, erratic granite, pegmatite, gneiss, schist, diorite, and other igneous and metamorphic rocks from the Canadian Shield; less abundant erratic limestone and dolomite from Canada. Largest erratic boulders are >5 m in diameter. Clasts of older till and clasts of lignite (bedrock) as large as 2 m in diameter are locally included in till. Glaciotectonic blocks or rafts of shale tens or hundreds of meters in length are locally included in till. Generally unstable; moves by creep on hillslopes; slumps in exposures. Thin and discontinuous in many areas in Montana and North Dakota; includes exhumed till of Illinoian and (or) pre-Illinoian age that is exposed at the surface. Includes some unmapped glaciotectonic deposits (symbol IT), flowtill, and landslide deposits (jea). Includes extensive areas of till modified by waves and currents in glacial lakes, with a surface litter of cobbles and boulders or discontinuous cover of lake clay, silt, sand, and gravel (lca, lss, lsa). Includes some lake delta deposits (ldb), lake density-current underflow-fan deposits (lda), outwash and ice-contact sand and gravel (gs, gg, kg), flood-plain and channel alluvium (al), and bedrock outcrops. Locally overlain by sheetwash alluvium (wla), lake clay, silt and sand (lca, lss, lsa), eolian sand and silt (el, es, ed), peat and muck (hp) or swamp deposits (hs)

Ground-moraine deposits—Integrated drainage; flat, rolling, or undulating surface topography. Includes collapsed supraglacial sediment (stagnation moraine) having <3 m of relief. Includes till in minor moraines, washboard moraines, or corrugated moraine. Maximum slope angles are generally less than 4°. Thickness 0.5–2 m; maximum thickness >15 m

Flood-scoured till—Broad till surfaces eroded by catastrophic glacial lake outburst floods. Includes erosional remnants of surface till, exhumed older till, erosional remnants of outwash sand and gravel (gs, gg), flood deposits (aqa), and bedrock outcrops. Local long surface flutes or grooves parallel to flood flow (Meneley, 1972). Boulder pavements or isolated lag boulders 1–3 m in diameter are present on surface in some places; maximum diameters of largest boulders generally decrease downstream. Boulders were derived from till and other deposits eroded by floods. Includes local sand and (or) gravel deposits 1–4 m thick; local mantle of massive cobble gravel as thick as 3

m. Small channel scars are common on eroded surfaces; local braided or anastomosing channel scars. Surface till thickness □0.5–5 m

End-moraine deposits—Broad, long belts of hummocky or undulating ridges or belts of narrow, discontinuous, sharply defined ridges oriented parallel to vanished ice margins. Closed depressions and lag cobbles and boulders are common on surface. Relief in some places is 30–50 m. Till end moraine deposits locally are replaced laterally by kame-moraine deposits (ke) that are included in unit. In some areas, boundaries between end-moraine deposits and stagnation-moraine or ground-moraine deposits are transitional and contacts are arbitrary. Thickness 6–20 m, locally >30 m

Stagnation-moraine deposits—Broad areas of hummocky or knob-and-kettle collapsed topography lacking distinct, continuous ridges oriented parallel to vanished ice margins. Nonintegrated or poorly integrated drainage; lakes, ponds, and marsh-filled sloughs and depressions are common. Ice-block depressions (kettles) are common in many areas. Relief is >3 m; locally >40 m. Slope angles are generally less than 4°. Includes collapsed glacial sediment (till and flowtill), ice-walled and collapsed supraglacial lake clay, silt, sand, and gravel (lca, lss, lsa), and collapsed outwash and ice-contact sand and gravel (gs, gg, kg). Glacial, glaciolacustrine, glaciofluvial, and alluvial sediments were redeposited by mass movement (flow and sliding) as a result of melting of buried ice for several thousand years after initial deglaciation. In some areas, boundaries between stagnation-moraine deposits and ground-moraine or end-moraine deposits are transitional and contacts are arbitrary. Thickness 6–20 m, locally >50 m

KAME-MORAINE DEPOSITS—Ice-contact gravel, sand, and minor silt similar to unit kg (description of unit kg applies). Comprises end moraines and interlobate moraines: broad, gently sloping ridges or aligned hummocks and hills (kames) of sand and gravel separated by other deposits. Relief is generally 5–10 m, locally 30 m. Sand and gravel in some places are replaced laterally by till (tlx) that is included in map unit. Parts of some kame moraine deposits southwest of Regina, Sask., are partly covered by eolian sand (es, ed); extensive deposits northwest, north, and northeast of Regina are veneered by lake clay and silt (lca). In some areas, deposits were modified by waves and currents in glacial lakes; ice-block depressions (kettles) are common where deposits were not modified. Includes outwash sand and gravel (gs, gg). Thickness 5–l5 m, locally >30 m

ICE-CONTACT SAND AND GRAVEL—Sediment deposited on or against glacial ice; sediment collapsed when ice subsequently melted. Pale-yellow, brownish-yellow, grayish-yellow, reddish-brown, yellowish-brown, olive-brown, grayish-brown, brown, olive, yellowish-gray, olive-gray, brownish-gray, gray, or mottled, calcareous sand and gravel and minor silt. Textures vary abruptly, laterally and vertically. Locally, unit is predominantly boulder or cobble gravel; in some places, it is pebbly silt and fine sand. Sand and gravel commonly is interbedded with, or contains lenses, inclusions, or clasts of, clay, silt, till, or flowtill. Poorly to well sorted; poorly to well stratified; irregularly bedded to well bedded; beds are discontinuous laterally. Faults, folds, and slump and collapse structures are common. Gravel is locally cemented by iron oxides or secondary calcium carbonate in zones; intense iron-oxide stains on some clasts. Clasts are angular to well rounded; composition is similar to that of clasts in associated till. Typically, shale clasts are much less abundant than in associated till; resistant erratic clasts are more abundant. Fragments of lignite (bedrock) are common in many areas. Present in kames, kame terraces, kame deltas, eskers, and ice-fracture fillings; some eskers are indicated on the map. Topography is typically hummocky to knobby, or forms isolated mounds or hills; in some places, hills are irregular in shape. The surface is locally flat. Commonly pitted with ice-block depressions (kettles). Boulder litters locally are present on surface. Relief is generally 3–15 m, locally 50 m. In some areas, deposits were modified by waves and currents in lakes; ice-contact deposits are overlain by discontinuous lake clay, silt, sand, and gravel (lca, lss, lsa). Distinguished from kame-moraine deposits (ke) arbitrarily in some areas. Included in outwash sand and gravel (gs, gg) in some areas. Includes some kame-moraine deposits (ke), kame-delta deposits, and lake-delta deposits (ldb). Also includes some outwash sand and gravel (gs, gg), lake clay, silt, sand, and gravel (lca, lss, lsa), inset flood-plain and channel alluvium (al), till (tlx), glaciotectonic deposits (symbol IT), and bedrock outcrops. Overlain by till or flowtill as thick as 5 m locally; in some areas, overlain by eolian silt and sand (el, es, ed), swamp deposits (hs), or peat and muck (hp). Thickness 1–10 m, locally >35 m

OUTWASH AND ICE-CONTACT SAND AND GRAVEL—Complex map unit of outwash sand and gravel (gs, gg) and ice-contact sand and gravel (kg). Relief generally is 3–10 m. Includes inset flood-plain and channel alluvium (al). Locally overlain by eolian silt and sand (el, es, ed) or swamp deposits (hs). Thickness 1–6 m, locally >10 m

OUTWASH SAND—Sediment deposited in meltwater streams. Pale-yellow, brownish-yellow, yellowish-brown, brown, yellowish-gray, brownish-gray, gray, or mottled, calcareous fine to coarse sand or silty sand containing scattered pebbles and small cobbles. Local beds of granule or pebble gravel or lenses or thin beds of silt. Poorly to well stratified; poorly to well sorted. Bedding is predominantly planar; cut-and-fill crossbeds are common. Clasts are subangular to well rounded. Clast composition is similar to that of outwash sand and gravel (gg) and till (tlx) in same area. Present beneath terrace remnants and outwash plains and as meltwater channel fills. Surfaces are generally smooth; locally pitted with ice-block depressions (kettles). Includes inset flood-plain and channel alluvium (al). Locally overlain by eolian silt or sand (el, es, ed). Mapped in Saskatchewan in east half of quadrangle; included in outwash sand and gravel (gg) where units gs and gg have not been distinguished. Thickness 1–6 m

OUTWASH SAND AND GRAVEL—Sediment deposited in meltwater streams. Pale-yellow, brownish-yellow, grayish-yellow, reddish-brown, yellowish-brown, olive-brown, grayish-brown, brown, olive, yellowish-gray, brownish-gray, olive-gray, gray, or mottled, calcareous sand, pebbly sand, and gravel; locally, the deposit is pebbly sand and silt. Poorly to well sorted; poorly to well stratified. Stratification typically is (1) horizontal beds of well-sorted sand, (2) pebbly sand with ripple-drift, cut-and-fill, planar, or trough crossbeds, or (3) interbedded pebbly sand and pebble, cobble, or boulder gravel. Local lenses or beds of silt and clay; local boulder beds; local clasts or blocks of till or flowtill. Textures generally coarsen in downstream direction in valley train deposits. Clasts are subangular to very well rounded; size of largest clasts generally decreases in downstream direction in valley train deposits. Clast composition is generally similar to that of local till; locally predominantly shale or predominantly redeposited quartzite, argillite, chert, and chert conglomerate derived from Tertiary gravel and early and middle Pleistocene gravel. Boulders and large cobbles are predominantly subangular to subrounded, reworked glacial erratics (limestone, dolomite, granite, pegmatite, gneiss, schist, diorite, and other igneous and metamorphic rocks). Fragments of lignite (bedrock) are abundant in many areas. Clasts in some places are intensely stained by iron oxides or manganese oxides; gravel is locally cemented by secondary calcium carbonate. Present beneath outwash plains, as valley trains, in fans and aprons, beneath terrace remnants, as delta topset beds, and as melt-water channel fills. Surfaces are smooth, undulating, or gently rolling; locally pitted with ice-block depressions (kettles). Some surfaces are marked by braided or anastomosing channel scars. In some places, includes some till (tlx), ice-contact sand and gravel (kg), lake-delta deposits (ldb), inset flood-plain and channel alluvium (al), or bedrock outcrops. In some areas, deposits were modified by waves and currents in lakes and the outwash sand and gravel is overlain by lake clay, silt, sand, and gravel (lca, lss, lsa). Locally overlain by eolian silt and sand (el, es, ed), swamp deposits (hs), or peat and muck (hp). Thickness 1–6 m, locally >15 m

Some of the sand and gravel mapped as outwash possibly is early postglacial alluvium. Precipitation and runoff were greater than at present for several thousand years after initial glaciation, and glacial, ice-contact, glaciofluvial, and glaciolacustrine sediments were eroded and redeposited as alluvial fills. The surface morphology, lithology, and sedimentary structures of the deglacial outwash and early postglacial alluvium are similar, and the deposits have not been distinguished on published maps

ALLUVIUM—Yellowish-brown, grayish-brown, brown, brownish-gray, gray, or mottled, calcareous gravel and sand beneath terrace remnants in Saskatchewan in east half of quadrangle. Poorly sorted; poorly stratified. Generally cobbly and bouldery. Clasts are predominantly reworked from till. Alluvium in the Qu'Appelle River valley probably was deposited soon after drainage from glacial Lake Regina was diverted eastward; the Qu'Appelle River subsequently was incised deeply into the alluvium, older sediments, and bedrock. Where the apparent thickness of the deposit is >6 m, alluvium commonly overlies older fill deposits. Locally, gravel is a lag deposit on till or bedrock. Thickness 1–6 m

FLOOD DEPOSITS—Yellowish-brown, olive-brown, grayish-brown, brown, olive, yellowish-gray, olive-gray, brownish-gray, gray, or mottled calcareous sand and gravel deposited by a catastrophic glacial-lake outburst flood. Sediments in some areas were deposited by braided or anastomosing streams; sand and gravel bars are common between channels. In other areas, the outer (higher) and inner (lower) flood-bar deposits form terraces. The upper part of flood bar deposits is commonly firm to compact, plane-bedded sand and gravel; lower part is poorly sorted, massive sand containing very large boulders. Locally, some boulders enclosed in flood deposits are till or lignite (bedrock). The inner channel-bar deposits are commonly homogeneous, firm to compact, matrix-supported, very poorly sorted, plane-bedded, pebbly cobble gravel containing boulders as large as 3 m. Indistinct tabular cross stratification or horizontal beds present are locally. In some places, cobbles and boulders are imbricated. Boulders are common on some outer bar surfaces; absent on most inner bar surfaces. Thickness of inter-channel flood deposits is 1–2 m; thickness of outer flood-bar deposits is 1–6 m; thickness of inner flood-bar deposits generally is >15 m

FLOOD DEPOSITS AND FLOOD-SCOURED TILL—Braided- or anastomosing-channel flood deposits and intervening areas of current-scoured till or intervening streamlined hills of till or bedrock
Flood deposits—See unit aqa
Flood-scoured till—See unit tlx

CATASTROPHIC-FLOOD FAN DEPOSITS—Subaerial-fan deposits produced by a channeled, catastrophic, glacial-outburst flood (Kehew and Teller, 1994). Brownish-yellow, yellowish-brown, olive-brown, grayish-brown, brown, olive, brownish-gray, olive-gray, gray, or mottled, calcareous sand and gravel. Poorly sorted to well sorted; poorly stratified to well stratified. Typically consists of boulder, cobble, and pebble gravel at fan apex, grading to sand at toe. Local concentrations of boulders on surface; systematic decrease in diameters of largest boulders from apex to toe. Predominantly pebble and cobble gravel at depth. Fan lobes are locally margined by boulder berms 10 m high. Clasts were derived predominantly from till eroded from the lake-spillway channel upstream from the fan. Surface is smooth, irregular, or hummocky; isolated ridges and boulder armors on surface. Local ice-block depressions (kettles) were produced by melting of ice blocks transported and buried during the flood. Relief is generally 5–10 m. In some places, fan deposits are overlain by eolian silt and sand (el, es, ed). Mapped in Saskatchewan. Thickness 2–10 m, locally >12 m

DELTA SAND AND GRAVEL—Brownish-yellow, yellowish-brown, olive-brown, grayish-brown, brown, olive, brownish-gray, olive-gray, gray, or mottled, calcareous clay, silt, sand, and gravel. Moderately to well sorted; moderately to well stratified. Bottomset beds typically are upward-thickening rhythmite beds of fine sand, silt, and clay. Foreset beds commonly are ripple-laminated or planar-bedded, coarse to fine sand and silt. Topset beds typically are (1) well-sorted coarse sand and gravel, (2) moderately well sorted gravelly sand, or (3) planar-bedded, trough-crossbedded, or ripple-laminated fine or medium sand. Grain size of topset beds varies abruptly, laterally and vertically. Topset and foreset beds in some places are partly cemented by secondary calcium carbonate. Boulders are common in some deposits. Clasts are subangular to well rounded; clast composition is similar to that of till in same area. Closed depressions (kettles) on surfaces of some deposits were produced by melting of buried ice blocks. Some small delta deposits are included in outwash sand and gravel (gs, gg) and lake silt, sand, and gravel (lss, lsa). Locally includes inset floodplain and channel alluvium (al). Locally overlain by eolian silt and sand (el, es, ed), thin till (tlx), or flowtill. Mapped in Saskatchewan. Thickness 3–10 m, locally >18 m

LAKE DENSITY-CURRENT UNDERFLOW-FAN DEPOSIT—Pale-yellow, grayish-yellow, yellowish-brown, brown, brownish-gray, olive-gray, gray, or mottled, calcareous silt, sand, and gravel. Well stratified; generally well sorted. Chiefly laminated silt and very fine sand interbedded with thin layers of clay or fine to coarse sand. Average grain size decreases from top to bottom and toward axis of lake basin. Foreset beds are absent; basal sediments commonly are clay, but are not delta bottomset beds. Silt and sand are crossbedded or horizontally bedded; ripple-drift lamination is common. Clasts are mixed rocks derived from surficial deposits and bedrock that were eroded by catastrophic-flood drainage into a glacial lake. In some places, underflow-fan deposits are overlain by shore and near-shore lake silt, sand, and gravel (lss, lsa) deposited by waves and currents after deposition of the underflow-fan sediments. Fan deposits and shore and near-shore silt, sand, and gravel in some places are overlain by eolian silt and sand (el, es, ed). Mapped in northeast corner of quadrangle. Thickness 3–20 m, locally >30 m

ILLINOIAN

LOAMY OR SANDY LOAMY TILL—Sediment deposited directly by glacial ice. Pale-yellow, grayish-yellow, yellowish-brown, olive-brown, grayish-brown, brown, brownish-olive, olive, yellowish-gray, brownish-gray, olive-gray, gray, or mottled clay loam, loam, or sandy loam; in some areas, unit is silty clay loam, sandy clay, or sandy clay loam. Generally nonstratified; nonsorted or very poorly sorted. In some places, interbedded with, or contains lenses, pods, and stringers of, clay, silt, sand, or gravel. Weak horizontal layers are present locally where ice margin fluctuated in a lake. Commonly massive; cohesive and friable. Crudely fissile. Generally compact or very compact; resists penetration by pick or shovel. Clayey till is slightly sticky to very sticky and slightly plastic to plastic when moist, hard and blocky when dry. Dry till in some places breaks into small, irregular pieces; commonly it breaks through granules and small pebbles. Parting is typically crudely irregular or prismatic. Platy structure is present locally. Clay minerals are predominantly montmorillonite in many areas, predominantly illite or kaolinite locally. Widely spaced polygonal joints in some areas. In some places, joint surfaces are coated by seams of secondary calcium carbonate, or by powdery calcium carbonate or gypsum. Selenite (gypsum) crystals 1–4 mm long, or clusters or crusts of crystals, are present on some joint surfaces. Stains, flecks, or scales of iron and manganese oxides are common on joint and parting surfaces. Fragments of lignite (bedrock) are common. Generally oxidized throughout where thin. Nearly pebble free to very pebbly; cobbles and boulders are rare to abundant. Clasts in many areas are predominantly granules and pebbles. In Montana, boulders in general are less abundant in till of Illinoian age (tks) than in till of late Wisconsin age (tlx). Pebbles are predominantly subangular to rounded erratic limestone and dolomite; igneous and metamorphic rocks from the Canadian Shield are less abundant. Where till is thin and derived from local bedrock, pebbles are chiefly angular to subrounded shale, siltstone, and soft sandstone; where derived from Tertiary gravel or early or middle Pleistocene gravel, pebbles are predominantly quartzite, argillite, chert, and chert conglomerate. Cobbles and boulders are predominantly subangular to well-rounded erratic granite, pegmatite, gneiss, schist, diorite, and other igneous and metamorphic rocks from the Canadian Shield; erratic limestone and dolomite are less abundant. Largest erratic boulders are >3 m in diameter. Clasts of till of pre-Illinoian age and clasts of lignite (bedrock) are locally included in till. Vertical repetitions of till and gravel beds in some exposures in Montana apparently are products of glaciotectonic stacking. Integrated drainage; flat, rolling, or undulating surface topography. Maximum slope angles are <4°.

Includes minor moraines or washboard moraines that are conspicuous only from the air (shown on map). Generally stable on hillslopes; till in natural exposures (such as stream cuts) and artificial excavations does not slump readily. Thin and discontinuous in many areas. Till mapped in Saskatchewan and in much of Montana generally is a thin veneer on interfluves between major and minor streams; intervening material is colluvium, sheetwash alluvium, and landslide deposits (wla, jea, caa) and bedrock outcrops. Gullies are common on hillslopes. Surface is intensely deflated in many areas. Discontinuous lag deposits of granules and pebbles are common on till surfaces; lag cobbles and boulders are widely scattered on till surfaces and on bedrock surfaces. In Montana, till of Illinoian age is generally thick and continuous where it and older till of middle Pleistocene age overlie gravel of Tertiary age or early or middle Pleistocene age. Map unit includes exhumed till of pre-Illinoian age exposed at the surface. Includes some outwash sand and gravel (ggi), flood-plain and channel alluvium (al), Tertiary nonglacial sand and gravel (see unit xsh), and bedrock outcrops. Locally overlain by sheetwash alluvium (wla), eolian silt and sand (el, es, ed, eu), or unmapped lake deposits of Illinoian age and (or) late Wisconsin age. Thickness 0.3–3 m; maximum thickness >10 m

OUTWASH SAND AND GRAVEL—Sediment deposited in meltwater streams. Pale-yellow, brownish-yellow, reddish-brown, yellowish-brown, olive-brown, grayish-noncalcareous coarse sand, pebbly sand, and gravel. Poorly to well sorted; poorly to well stratified. Typically consists of interbedded pebbly sand and pebble, cobble, or boulder gravel. Lenses of silt and clay are present locally; local boulder beds. Clasts are subangular to very well rounded. Clast composition generally is similar to that of till in same area; locally, predominantly redeposited quartzite, argillite, chert, and chert conglomerate derived from gravel of Tertiary to middle Pleistocene age (see unit xsh). Boulders and large cobbles are predominantly subangular to subrounded, reworked glacial erratics (limestone and dolomite; granite, pegmatite, gneiss, schist, diorite, and other igneous and metamorphic rocks). Clasts in some places are intensely stained by iron and manganese oxides. Mapped deposits are fills in melt-water channels. Distinction between outwash sand and gravel (ggi) and colluvium, sheetwash alluvium, and glaciofluvial-fill deposits (cad) is arbitrary in some areas because exposures on channel floors are lacking. Surfaces are smooth or undulating. Includes some till (tks), inset flood-plain and channel alluvium (al), colluvium (caa, cad), and bedrock outcrops. Commonly overlain by sheetwash alluvium (wla) or eolian silt and sand (el, es, eu). Thickness 1–4 m, locally >6 m

PRE-ILLINOIAN MIDDLE PLEISTOCENE

LAKE SILT AND SAND—Sprole Silt of Colton (1963a,f). Pale-yellow, yellowish-brown, grayish-brown, yellowish-gray, brownish-gray, gray, or mottled, generally calcareous silt, sand, and clay. Generally well sorted; moderately well stratified to well stratified. Lignite (bedrock) fragments are common. Lower part is predominantly thin-bedded or laminated silt and clay containing scattered granules and pebbles; in some places it is silt and sand interbedded or intercalated with bedded or laminated silt and fine sand. Upper part is generally weakly bedded or massive silt and fine or medium sand containing scattered granules, pebbles, and small cobbles. Locally folded and deformed by overriding ice. Clasts are predominantly redeposited quartzite and chert derived from gravel of Tertiary to middle Pleistocene age (see unit xsh); includes rare rafted erratic igneous and metamorphic rocks from the Canadian Shield or erratic limestone or dolomite. Poorly exposed. Lake sediment overlies bedrock or Wiota Gravel (early and middle Pleistocene?) and is overlain by till of middle Pleistocene age (see table 2). Thickness 10–20 m, locally 30 m

The sediment was deposited in the (now buried) paleovalley of the Missouri River (shown on map). It was deposited in a lake that was dammed in the paleovalley during the earliest Pleistocene glaciation in the Poplar-Brockton region in Montana, when the ice sheet blocked the ancestral valleys of the Missouri and Yellowstone Rivers (Fullerton and others, 2004a,b). At its maximum extent, the lake possibly was 95 km long and 17 km wide. Damming of the lake caused the initial diversion of the Missouri and Yellowstone Rivers eastward through the Charbonneau Sag in North Dakota (in the Big Horn Mountains 4° × 6° quadrangle south of this quadrangle). A lake in the Yellowstone River valley was contemporaneous (and, at least briefly, confluent) with the lake in the Missouri River valley. The basal lake sediments in the Yellowstone Valley have normal remanent geomagnetic polarity (see table 2).

DISSECTED BEDROCK (BADLANDS)—Predominantly dissected, barren bedrock eroded by sheet wash and sheet floods. Erosional topography typically is narrow-crested or rounded bedrock ridges or isolated, rounded bedrock hills. Erosional landforms are separated by narrow, steep gullies and ravines graded to broader valley floors. All minor streams are intermittent; sediments are transported chiefly during cloudbursts and flash floods. Many hill slopes are steeper than 40°. Hillslopes steeper than 20° are predominantly bedrock, and there is little or no vegetation cover. Slopes between 8° and 20° in some places have a thin, discontinuous, grass-covered mantle of colluvium. Slopes more gentle than 8° in some places are covered by fans and aprons of sheetwash alluvium (wla) or small deposits of alluvial-fan sand and gravel (afj). Flood-plain and channel alluvium (al) is inset into sheetwash alluvium and bedrock on broader gully and ravine floors. Includes some colluvium (caa). Mapped in one area in Saskatchewan, in southwest quarter of quadrangle. Many areas of badlands in Montana and North Dakota are included in other map units (caa, xcg, xlq)

Figure 1. Regional ice flow in southern Alberta, southern Saskatchewan, Montana, and northwestern North Dakota. The Illinoian glaciation was the most extensive Pleistocene continental glaciation on most of the glaciated plains in Montana (Fullerton and others, 2004a,b). During maximum Illinoian glaciation (A), regional ice flow in southwestern Saskatchewan was southward into Montana. Ice flowed westward between the Sweetgrass Hills nunataks in Montana and the Cypress Hills (West Block) nunatak in Alberta and Saskatchewan. The Central Block and East Block of the Cypress Hills were glaciated. Westward ice flow in Alberta north and northeast of Glacier National Park was blocked by a large piedmont lobe of coalesced mountain valley-glacier ice in the valleys of the Oldman, Waterton, Belly, and St. Mary Rivers. Ice from a subordinate dispersal center flowed southwestward, west-southwestward, and westward through southwestern Manitoba, southeastern Saskatchewan, and northwestern North Dakota into Montana. The areal distributions and clast compositions of the deposits of the two

documented pre-Illinoian Pleistocene continental glaciations in Montana indicate that the regional pattern of ice flow during the maxima of both of those pre-Illinoian glaciations was similar to that during the Illinoian glaciation (A), and it was very different from the regional flow during maximum late Wisconsin glaciation (B).

During maximum late Wisconsin glaciation, ≈20,000 14C yr B.P. (≈23,360 CAL yr B.P.1), regional ice flow was west-southwestward and southwestward from southwestern Manitoba into northwestern North Dakota and northeastern Montana (B). Regional ice flow in southernmost Saskatchewan was west-southwestward and westward into Montana and eastern Alberta. The predominant northeastern ice dispersal center was (1) a Patrician center south or southwest of Hudson Bay in Canada (Tyrrell, 1914; Johnston, 1935) or a modeled dome in that general region (Clark and others, 1996, 1997); (2) a "Hudson dome" in the southwestern part of Hudson Bay (Dyke and others, 1982; Hughes, 1985, 1987); or (3) a "Hudson ice divide" southwest of Hudson Bay (Dyke and Prest, 1987b). The flow was not from a distant dispersal center in Quebec or Labrador (Shilts, 1980, 1982, 1985; Veillette and others, 1999) or from an "ancestral Keewatin" ice divide depicted by Dyke and Prest (1987b). Ice from a subordinate Keewatin dispersal center west of Hudson Bay was forced far westward in Canada, and coalesced Keewatin ice and "Cordilleran" ice from the Rocky Mountains (Dyke and Prest, 1987a,b) flowed southeastward from central Alberta into Montana. Southeastward regional flow of ice from central Alberta into Montana occurred only during late Wisconsin glaciation. The regional ice flow pattern in B is incompatible with reconstructions of Laurentide ice sheet flow during maximum late Wisconsin glaciation by Dyke and others (1982), Fisher and others (1985), Hughes (1987), Dyke and Prest (1987a,b), and Andrews and Fulton (1987).

Later than ≈17,000 14C yr B.P. (≈19,856 CAL yr B.P.), the northeastern dispersal center collapsed and regional ice-flow patterns changed markedly (Fullerton and others, 1995, 2000, 2004a,b). The ice thinned and stagnated on uplands, and active ice margins in lowlands retreated rapidly. The positions of ice domes, ice divides, and ice saddles in Canada shifted (Shilts, 1980, 1982, 1985). The Keewatin center subsequently became the predominant ice-dispersal center for Laurentide glaciation in southeastern Alberta, southern Saskatchewan, southwestern Manitoba, northeastern Montana, and northwestern North Dakota (C).

A regional Keewatin-source glacial readvance in Alberta, Saskatchewan, Manitoba, Montana, North Dakota, Minnesota, South Dakota, and Iowa culminated 14,000±100 14C yr B.P (≈16,310 CAL yr B.P.) (table 1; also see Fullerton and others, 1995, 2000, 2004a,b). The regional ice flow in C is similar to a reconstruction by Dyke and Prest (1987a, 1987b); it is incompatible with a reconstruction of Laurentide ice flow ≈14,000 14C yr B.P. by Hughes (1987). Reconstructions of ice flow during maximum late Wisconsin glaciation by Dyke and others (1982) and Andrews and Fulton (1987) depicted regional flow directions ≈14,000 14C yr B.P., not regional ice flow during maximum glaciation ≈20,000 14C yr B.P. (≈23,360 CAL yr B.P.).

Ice-surface topography in the Regina 4° × 6° quadrangle during maximum late Wisconsin glaciation was reconstructed by Mathewes (1974). That reconstruction was based on (1) inferred directions of ice flow and (2) inferred distances of sites from the glacial limit.

Those directions and distances are not supported by stratigraphic, sedimentologic, or geomorphic evidence in the Regina quadrangle and adjacent quadrangles, and the reconstruction is not reliable.

Sauer and others (1993a, p. 431) calculated thicknesses of overriding ice during glacial maxima at several sites in southern Saskatchewan. They concluded, "There is no apparent relationship between calculated maximum ice thickness and the measured preconsolidation pressures [of specific till units and intertill clay units at those sites]. In all cases, the maximum [calculated] ice thicknesses are much greater than the thickness of ice required for consolidation." Crude calculation of maximum ice thickness at a specific site during a specific glaciation requires construction of an ice-surface profile along the ice-flow path from the site to the glacial limit. Construction of an ice-surface profile requires knowledge of the distance from that site to the glacial limit along the ice flow path, and also the altitude of the ice margin at the glacial limit for that flow path at the time of maximum loading by ice. The distances from the sites in Saskatchewan to limits of glaciation in Montana and North Dakota (Sauer and others, 1993a, p. 427 and table 6) were not measured along ice-flow paths from the sites in Saskatchewan. The ice-flow paths at each site during each glacial maximum were different, as were the distances from the sites to the glacial limits. Figure 1 illustrates striking contrasts between ice-flow paths during maximum Illinoian glaciation and those during maximum late Wisconsin glaciation. The flow paths from most of the sites studied by Sauer and others (1993a,b) to the glacial limits are not known for any of the glacial maxima, and the basal shear stress (1 bar) used in the calculations by Sauer and others (1993a) was much too high. Reliable ice-thickness data currently cannot be calculated for comparison with preconsolidation-pressure data from stratigraphic units at the sites in Saskatchewan.

1Rank terms of formal stratigraphic units are capitalized (for example, "Battleford Formation"); rank terms of informal stratigraphic units are not capitalized (for example, "Perch Bay till"). See "Important Stratigraphic Sections."

2Sidereal ages younger than 25,000 yr are calibrated (CAL) ages. Conventional 14C ages (in parentheses) were calibrated to the 230Th/234U time scale of Bard and others (1990a,b, 1998) using the linear equation in Bard and others (1998): CAL age = 1.168 (14C age). Older age controls are (1) 40Ar/39Ar and K/Ar ages of the Lava Creek Tuff and Lava Creek B airfall tephra (footnote 10); (2) 40Ar/39Ar ages and astronomically tuned ages of paleomagnetic polarity reversals (footnote 14); and (3) the astronomically tuned marine oxygen-isotope time scale (Martinson and others, 1987; Bassinot and others, 1994; Berger and others, 1994; Chen and others, 1995) and the astronomically tuned Mediterranean sapropel time scale (Hilgen, 1991; Hilgen and others, 1993; Lourens, Antonarakou, and others, 1996; Lourens, Hilgen, and others, 1996). The astronomically tuned Quaternary time scale and the 40Ar/39Ar geomagnetic polarity time scale are internally consistent (Berggren, Hilgen, and others, 1995; Berggren, Kent, and others, 1995). Radiocarbon ages in the stratigraphic columns are conventional (uncalibrated) ages.

3Included in map unit tlx.

4A regional glacial readvance culminated ≈14,000±100 14C yr B.P. (table 1, fig. 1). The regional ice-flow pattern during maximum late Wisconsin glaciation (≈20,000 14C yr B.P.) and during marginal recession from that maximum was markedly different from ice flow during the later regional readvance and subsequent deglaciation (Fullerton and others, 2004a,b).

5The Riddell and Saskatoon sites, containing the “Sangamon” Riddell local fauna (Christiansen, 1968b, 1969b, 1992; Lammers, 1968; Pohorecki and Wilson, 1968; SkwaraWoolf, 1980, 1981; Skwara and Walker, 1989), are ≈21 km north of the Regina quadrangle. The Riddell member of the Floral Formation, which contains the fossiliferous sediments, has been traced southward into the Regina quadrangle on the basis of test hole records (see “Important Stratigraphic Sections”). Electon-spin resonance ages for a fossil tooth ranged from 99 ka to 195 ka, depending on the uranium uptake model used to calculate the age (Schwarcz and Zymela, 1985; Zymela, 1986; Zymela and others, 1988).

6Included in map unit tks.

7The Markles Point till was deposited by northern-source ice that flowed southward across the Wood Mountain upland in Saskatchewan to the Malta–Glasgow–Fort Peck region in Montana, and then eastward to the Wolf Point–Poplar region in the Missouri River valley. The Kisler Butte till was deposited by northeastern-source ice that flowed west-southwestward and southwestward from southwestern Manitoba and southeastern Saskatchewan into northwestern North Dakota and northeastern Montana. Ice from the two dispersal centers coalesced in Montana (Fullerton and others, 2004a,b). The Kisler Butte till in Montana and the till of the Horseshoe Valley Formation (Fulton, 1976) or unit E (Salomon, 1974, 1976) in McKenzie County, N. Dak., are laterally continuous.

8See “Important Stratigraphic Sections,” #17.

9The weathered zone in till of the Warman Formation is the most intensely developed weathered zone in the subsurface tills in southern Saskatchewan. It represents a weathering interval of ≈400,000 yr duration prior to Illinoian glaciation.

10The “Wascana Creek ash” in Saskatchewan is the Yellowstone-source Lava Creek B tephra (Westgate and others, 1977; Izett and Wilcox, 1982). It was deposited in ponds on stagnant ice during the deglaciation associated with deposition of the upper till member of the Dundurn Formation (“Important Stratigraphic Sections,” #15). North of Glendive, Mont. (Izett and Wilcox, 1982), 70 km south of the Regina quadrangle, the normal-polarity, airfall Lava Creek B tephra was deposited in a pond or lake that was dammed by an alluvial fan in an abandoned deglacial melt-water channel. That channel earlier was incised into the upper unit of the Archer till (Fullerton and others, 2004a,b). Published 40Ar/39Ar ages of the source-area Lava Creek Tuff are 600±10 ka and 610±10 ka (Obradovich and Izett, 1991), 602±2 ka (Gansecki and others, 1998), and 639±2 ka

(Lanphere and others, 2002). 40Ar/39Ar ages for the airfall tephra are 660±10 ka and 670±10 ka (Izett and others, 1992), 630±15 ka (Gansecki and others, 1998), and 635±7 ka (Lanphere and others, 2002). The weighted mean of the most reliable K/Ar ages for the tuff is 617±4 ka (Obradivich, 1992). The Rockland tephra stratigraphically overlies the Lava Creek B tephra (Sarna-Wojcicki and others, 1985; Rieck and others, 1992). The 40Ar/39Ar age of the Rockland ash bed is 614±8 ka (Lanphere and others, 1999). Therefore, that age is a minimum age for the Lava Creek B tephra. The preferred 40Ar/39Ar age of the Lava Creek B tephra is 639±2 ka (Lanphere and others, 2002). That age is adopted here.

11The upper unit of the Perch Bay till in Montana, the upper unit of the Archer till in Montana, and the till of the Medicine Hill Formation (Fulton, 1976) or unit B (Salomon, 1974, 1976) in McKenzie County, N. Dak., are laterally continuous. The intense weathering of those tills reflects a weathering interval of nearly 500,000 yr prior to Illinoian glaciation. The upper unit of the Archer till is older than the Lava Creek B tephra (footnote 10), not younger as inferred by Fullerton and Colton (1986).

12A calcic paleosol(?) in weathered till of the Mennon Formation ("Important Stratigraphic Sections," #9) is older than the upper till member of the Dundurn Formation and younger than the lower till member of the Mennon Formation. Its stratigraphic relation to the lower till member of the Dundurn Formation and the upper till member of the Mennon Formation is not known. A paleosol(?) also is developed in the intensely weathered upper till member of the Mennon(?) Formation at the Wellsch Valley site ("Important Stratigraphic Sections," #11). In a test hole 1.5 km north of the Regina quadrangle, a weathered zone in the lower till member of the Dundurn Formation is overlain by the unoxidized upper till member of the Dundurn Formation (Christiansen and Sauer, 1998).

13Two pre-Illinoian Pleistocene continental glaciations are known to be represented by till in Montana and North Dakota. Other pre-Illinoian glaciations possibly are represented by till in the buried valleys of the ancestral Missouri and Yellowstone Rivers (Fullerton and others, 2004a,b). Tills of the Warman and Mennon Formations were identified in the fill in the buried Missouri River valley less than 2 km north of the International Boundary ("Important Stratigraphic Sections," #27), indicating that laterally equivalent subsurface tills probably are present in extreme northeastern Montana and extreme northwestern North Dakota.

The "Sturgeon Bay till" of Fullerton and Colton (1986) at that time (1986) was interpreted to have reversed remanent geomagnetic polarity. It is a compositional facies of the lower unit of the normal-polarity Perch Bay till. Reanalysis of paleomagnetic data for the till samples by Mark Hudson indicated that the "Sturgeon Bay" till has normal remanent polarity. Both units of the Perch Bay till were deposited by ice that flowed southward across the Wood Mountain upland in Saskatchewan to the Malta-Glasgow-Fort Peck region in Montana, and both of the Archer till units were deposited by ice that flowed west-southwestward and southwestward from southwestern Manitoba and southeastern Saskatchewan into northeastern Montana.

"Early Archer" glaciation was not extensive in Montana. The lower unit of the Archer till is known to be present in the fill in the buried valley of the ancestral Missouri River (see map). Laterally equivalent (unnamed) till that is indistinguishable from till of the Medicine Hill Formation is present in the buried valleys of the ancestral Missouri and Yellowstone Rivers in North Dakota. The “early Archer” ice and the “early Perch Bay” ice did not coalesce in the Missouri River valley in Montana; glacial Lake Sprole was dammed between the two ice lobes (see description of map unit llg). In contrast, “late Archer” glaciation was extensive. The ice margin advanced at least as far south as Glendive, Mont., in the Yellowstone River valley, and the “late Archer” ice and “late Perch Bay” ice coalesced in the Missouri River valley in the Regina quadrangle.

14An 40Ar/39Ar age of ≈778 ka (Renne and others, 1994; Pringle and others, 1995; Tauxe and others, 1996) for the Matuyama-Brunhes geomagnetic polarity reversal is the same as the astronomically tuned age for that reversal calculated by Tauxe and others (1996). An 40Ar/39Ar age of ≈992 ka (Tauxe and others, 1992) for the Jaramillo-Matuyama reversal is the same as the astronomically tuned age assigned to that reversal by Berger and others (1994). An estimated 40Ar/39Ar age of ≈1.11 Ma, constrained by limiting ages, was assigned to the Matuyama-Jaramillo reversal by Izett and Obradovich (1992, 1994); an astronomically tuned age of ≈1.073 Ma was assigned to that reversal by Berger and others (1994), and an astronomically tuned age of ≈1.07 Ma was assigned to it by Shackleton and others (1990), Hilgen (1994), and Chen and others (l995). Astronomically tuned ages of ≈1.785 Ma and ≈1.942 Ma were assigned to the Olduvai-Matuyama reversal and the Matuyama-Olduvai reversal, respectively, by Lourens, Antonarakou, and others (1996).

15Stratigraphic, paleontologic, paleomagnetic, and chronologic data from the Wellsch Valley site are presented in “Important Stratigraphic Sections” (#11). The reversed-polarity Stewart Valley sediments here are interpreted to be older than the Jaramillo Normal-Polarity Subchron and younger than the Olduvai Normal-Polarity Subchron (older than ≈1.11 Ma and younger than ≈1.785 Ma).
16The Pliocene-Pleistocene boundary is defined at the Vrica boundary stratotype section in Italy (Aguirre and Pasini, 1985; Partridge, 1997; Suc and others, 1997; Mauz, 1998). The astronomically tuned age of that boundary is ≈1.806 Ma (Lourens, Hilgen, and others, 1996).

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