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Chapter 46

Magnetostratigraphy of Quaternary Sections in Eastern Alberta, Saskatchewan and Manitoba

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s0005 46.1. INTRODUCTION

p0005 A record of continental glaciations has been developed from extensive exposures of Quaternary sediments which outcrop along major river valleys in western Canada. Although ages of Late Pleistocene glacial continental events in the study area are relatively well constrained, the age and extent of earlier glaciations are less well defined. Palaeomagnetism, tephras, palaeosols and fossils constrain the timing of some of these glaciations.

p0010 While at least 14 glaciations are recognised in the NW Cordillera of Canada, only about half that number can be documented in the Interior Plains of Canada (Barendregt and Duk-Rodkin, 2011). The magnetostratigraphical record suggests that cold conditions had a very different impact in western Canada than in northwest Canada (Barendregt Au3 and Irving, 1998; Barendregt and Duk-Rodkin, 2011; Duk-Rodkin *et al.*, 2011).

s0010 46.2. STUDY SITES

p0015 The earliest evidence of Laurentide glaciation on the Canadian Prairies occurs in the Medicine Hat, Alberta area, and in the Wellsch Valley, Regina and Saskatoon areas of central and southern Saskatchewan (Fig. 46.1). Of the five sites discussed here, four are composites of multiple sections (Medicine Hat, Alberta, Wellsch Valley and Saskatoon, Saskatchewan and Gillam, Manitoba), and one is derived from a single outcrop (Wascana Creek, near Regina, Saskatchewan). For a number of sites in Saskatchewan where stratigraphic exposures reveal the upper units only, borehole data are used to describe the lower units. The composite sections reported here have been developed from recent work carried out in Saskatchewan, as well as from previously published and unpublished data. Section descriptions are based primarily on magnetostratigraphy, tephrochronology and fossil data and do not provide detailed facies descriptions (these are published in Christiansen, 1968, 1992; Stalker, 1969, 1976, 1982; Stalker and Wyder, 1983). Data presented here highlight extensive pre-Illinoian (pre-Saalian) deposits which are assigned to the (late) Matuyama Reversed Chron and the Brunhes Normal Chron (Fig. 46.2).

46.2.1. Medicine Hat, Alberta s0015

p0020 At least three major till sheets, referred to as the Labuma, Maunsell and Buffalo Lake tills in the early literature, are present in eastern Alberta, and at the Medicine Hat sites. These tills have been correlated on the basis of lithostratigraphical characteristics, to the Saskatoon Group in Saskatchewan (Lower Floral Formation (Fm), Upper Floral Fm, and Battleford Fm, respectively). The Labuma till exhibits a distinctive dark colour, derived from Late Cretaceous shales which were incorporated into the glacial deposits laid down by the first continental glacier to reach the area. It forms the lowermost till at most sections throughout eastern Alberta, and near the outskirts of Medicine Hat, at the Galt Island section (Figs. 46.3 and 46.4) this till is underlain by normally magnetised preglacial sands, silts and clays which contain the Galt Island Tephra (0.43 ± 0.07 Ma; Westgate *et al.*, 1978) as well as late Irvingtonian fossils. (This age of the Galt Island Tephra is considered a minimum age. The tephra has a mineralogical assemblage similar to that of the Wellsch Valley Tephra (0.78 ± 0.04 Ma) and both have a Cascadian source.) The till is overlain by interglacial sediments, which are Sangamon in age, based on dates obtained from organics and fossil bones and teeth (Stalker, 1976). These sediments are assumed to be the equivalent of the interglacial Riddell

f0005 **FIGURE 46.1** Location map of Alberta, Saskatchewan and Manitoba study sites.

Member of the Floral Fm, in Saskatchewan. The interglacial deposits are overlain by three tills, separated in places by intertill beds, some of which are considered to mark interglacial or interstadial conditions. The tills are clearly Wisconsian in age, and the uppermost till can be traced westward across southern Alberta to sites where ^{36}Cl dates on erratics (Jackson *et al*., 1999) and radiocarbon dates on organics and bone have confirmed a Late Wisconsinan age (Stalker, 1969, 1976, 1982; Stalker and Wyder, 1983; Stalker and Vincent, 1993). Further refinement of the post-Sangamon deposits at Medicine Hat into early, middle and late Wisconsian ages has been suggested by previous workers (Stalker, 1976). At Manyberries, Alberta (60 km south of Medicine Hat), glacio-lacustrine sediments deposited by receding ice of the last glaciation contain the 12,000 ^{14}C ka BP Glacier Peak Tephra (Westgate, 1968), further supporting a Late Wisconsinan age for the surface till in southern Alberta.

p0025 All sediments at the Medicine Hat sections (including Au4 Galt Island) are normally magnetised (Barendregt, 1976; Barendregt *et al*., 1977, 1988) and are assigned to the Brunhes Normal Chron. This assignment is supported by tephra and fossil data, as well as stratigraphical correlations with nearby sites at Wellsch Valley, Saskatchewan. Preglacial sediments in the Medicine Hat area are normally magnetised, and based on the Galt Island Tephra and late Irvingtonian fossils found there, are mid to early Brunhes in age (0.78–0.30 Ma; Marine Isotope Stage (MIS) 9–19).

46.2.2. Wellsch Valley Sections, near Swift Current, Saskatchewan s0020

p0030 Preglacial, glacial and non-glacial deposits of Late Pliocene to Late Pleistocene age near Wellsch Valley, Saskatchewan (Figs. 46.1 and 46.5) have been described from surface exposures and borecores. Preglacial sediments at Wellsch Valley are reversely magnetised (Barendregt *et al*., 1991, 1998a,b) and contain the Wellsch Valley Tephra (0.78 ± 0.04 Ma) as well as early Irvingtonian fossils (Stalker, 1969, 1976, 1982; Szabo *et al*., 1973; Zymela *et al*., 1988; Stalker and Vincent, 1993; Stewart and Seymour, 1996), and therefore the sediments fall within the late Matuyama (1.0–0.78 Ma). These and underlying normally magnetised preglacial sediments are assigned to the Empress Group, which ranges from the late Gauss Normal Chron to the late Matuyama Reversed Chron (Figs. 46.2 and 46.5). The overlying glacial tills (five in total) are all normally magnetised and assigned to the Brunhes Normal Chron. These tills can be correlated to outcrop and borehole records near Regina and Saskatoon based on lithostratigraphical characteristics described in Christiansen (1968, 1992). Overlying the preglacial sediments is the upper till of the Dundurn Formation. This till is recognised through large parts of Saskatchewan. At the Wascana Creek site near Regina (Figs. 46.1 and 46.5), the Dundurn is overlain by glacio-lacustrine sediments containing the Wascana Creek Tephra, which is equivalent to the Lava Creek B Tephra in the American Midwest

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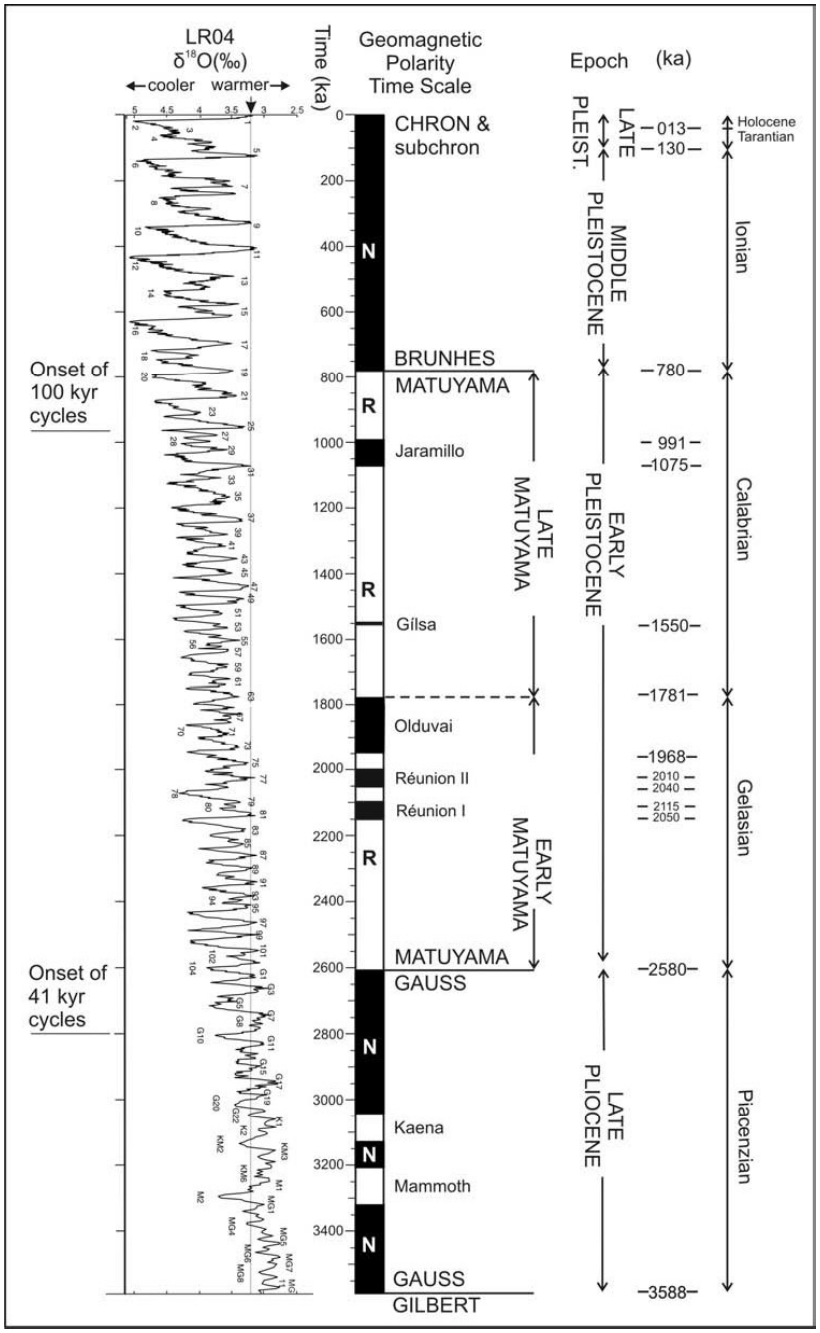

f0010 **FIGURE 46.2** Geomagnetic polarity time scale (Cande and Kent, 1995) for LRO4 benthic $\delta^{18}O$ palaeotemperature profile (Lisiecki and Raymo, 2005). Black/white intervals represent normal/reversed polarity. Marine isotope stages (MIS) are labelled on LR04 (even numbers represent glacials; odd numbers interglacials). MIS numbering scheme follows Ruddiman *et al*. (1986, 1989) and Raymo *et al*. (1989, 1992) from present to MIS 104, and Shackleton *et al*. (1995) in the Gauss Chron. Arrow marks Holocene mean $\delta^{18}O$ (Raymo, 1992).

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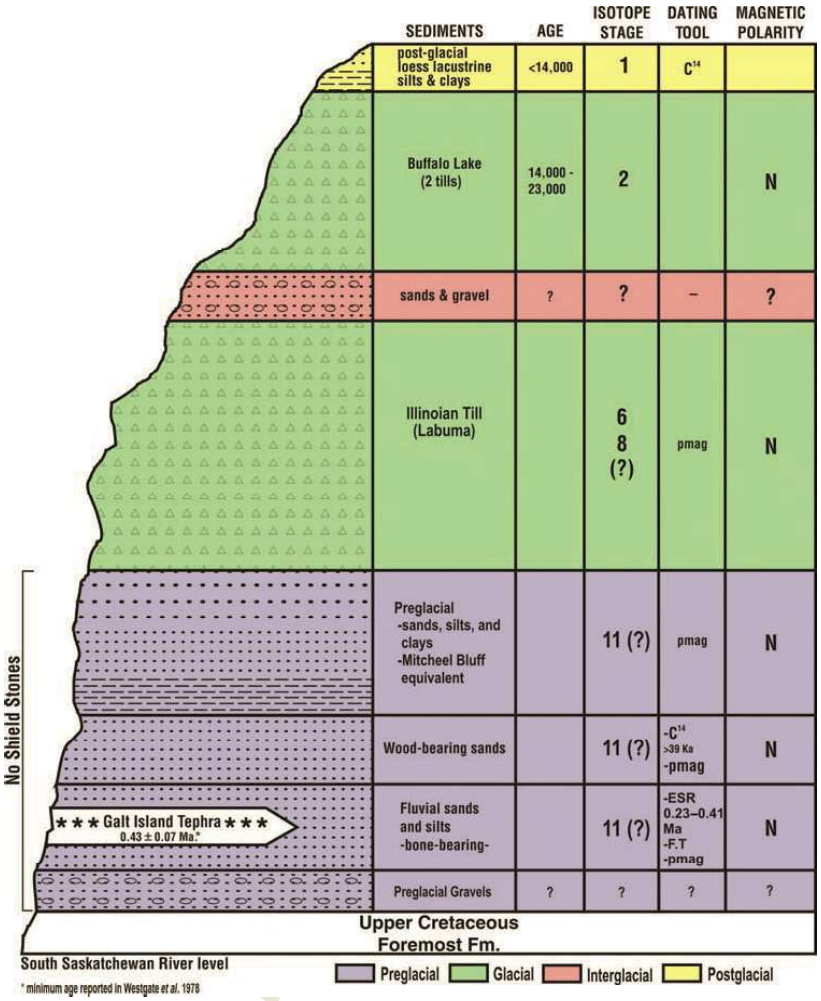

f0015 **FIGURE 46.3** Late Neogene stratigraphy at Galt Island (Redcliff) section near Medicine Hat, Alberta.

(0.639 ± 0.002 Ma; Lanphere *et al*., 2002). The association of the ash with sediments of the Dundurn deglaciation implies that this till was deposited during an MIS 16 glaciation. The Dundurn is overlain by the normally magnetised Warman Fm (MIS 14?) (Fullerton *et al*., 2004) which in turn is overlain by lower and upper tills of the Floral Fm (MIS 6 and 4), and by the Battleford Fm (MIS 2) at the surface.

s0025 46.2.3. Wascana Creek Section and Borecore near Regina, Saskatchewan

p0035 The Wascana Creek Tephra site is located 19 km northwest of Regina, Saskatchewan. Only the upper two-thirds of the Quaternary sediments outcrop along the west bank of the Wascana Creek valley. The lower third has been studied from borecores (Fig. 46.6). Outcrop and borecore records reveal four tills (Mennon, upper till of the Dundurn, Warman and Battleford formations) whose characteristics can be correlated with type sections to the north, near Saskatoon, Saskatchewan. Of note at this site is the presence of the Wascana Creek Tephra (0.639 ± 0.002 Ma; Lanphere *et al*., 2002) within glacio-lacustrine sediments associated with the Dundurn Fm and overlain by the Warman till. This tephra is equivalent to the Lava Creek B Tephra, a Pearlette ash from the Yellowstone area, and is found in a number of localities in the American Midwest. It clearly dates the Upper till of the Dundurn Fm to MIS 16 and points to the

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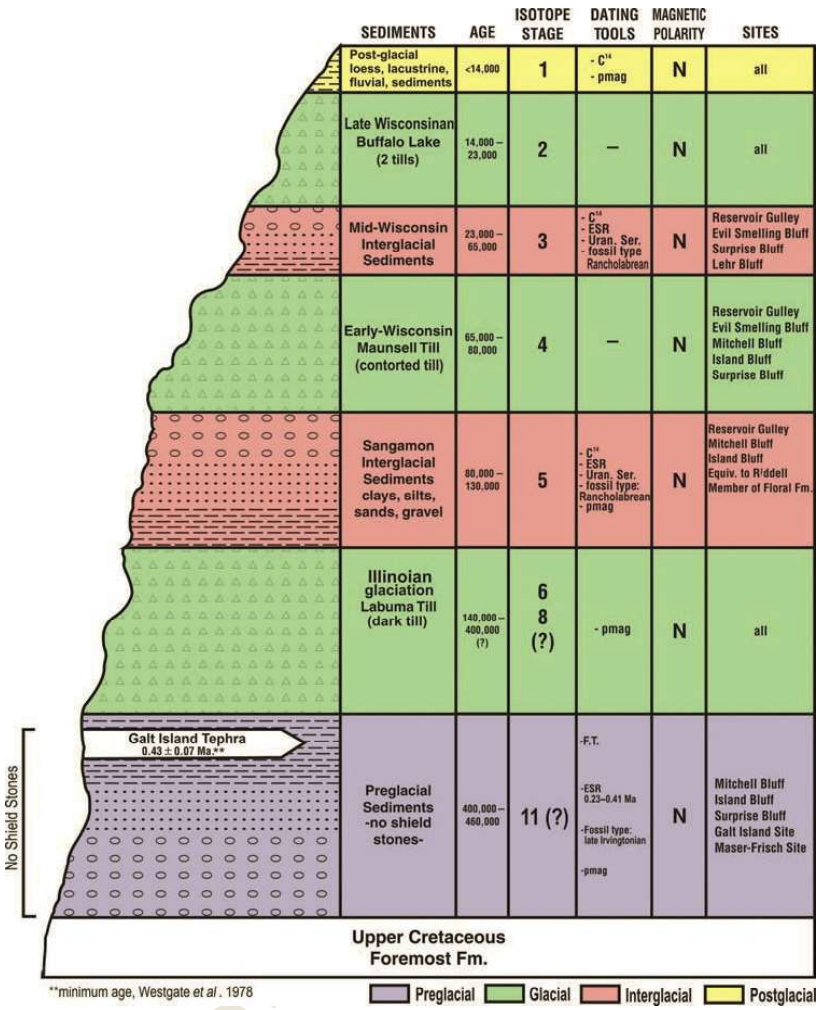

f0020 **FIGURE 46.4** Late Neogene composite stratigraphy at Medicine Hat, Alberta.

antiquity of the underlying tills (lower till of the Dundurn and the Mennon). If the latter two tills represent separate glaciations, then the Mennon would be expected to fall in MIS 20 or older and should be reversely magnetised. In fact, recent measurements (Barendregt *et al*., 2007, 2010a) made from borecore sediments at Wascana Creek and Sutherland (see below) indicate that the Mennon indeed falls within the Matuyama Reversed Chron. The Mennon is underlain by reversely magnetised sediments (gravels, clays and sands) of the Empress Formation, and these sediments are probably of the same age as the preglacial sediments at Wellsch Valley (latest Matuyama). Beneath the reversely magnetised sediments of the Empress Formation, at the base of both the Wascana Creek and Sutherland borecores (described below), is an interval of normally magnetised sediments, also assigned to the Empress (Fig. 46.7). This normal interval may be one of the Early Pleistocene normal subchrons within the Matuyama (i.e. Jaramillo or Olduvai), or may be Gauss age (>2.58 Ma).

46.2.4. Sutherland Borecore, Within City Limits of Saskatoon, Saskatchewan s0030

Borecores drilled in the Sutherland district of the City of Saskatoon were collected from the reference sites for the Sutherland Group (Christiansen, 1968). The Sutherland Group (Fig. 46.7) includes all sediments between the p0040

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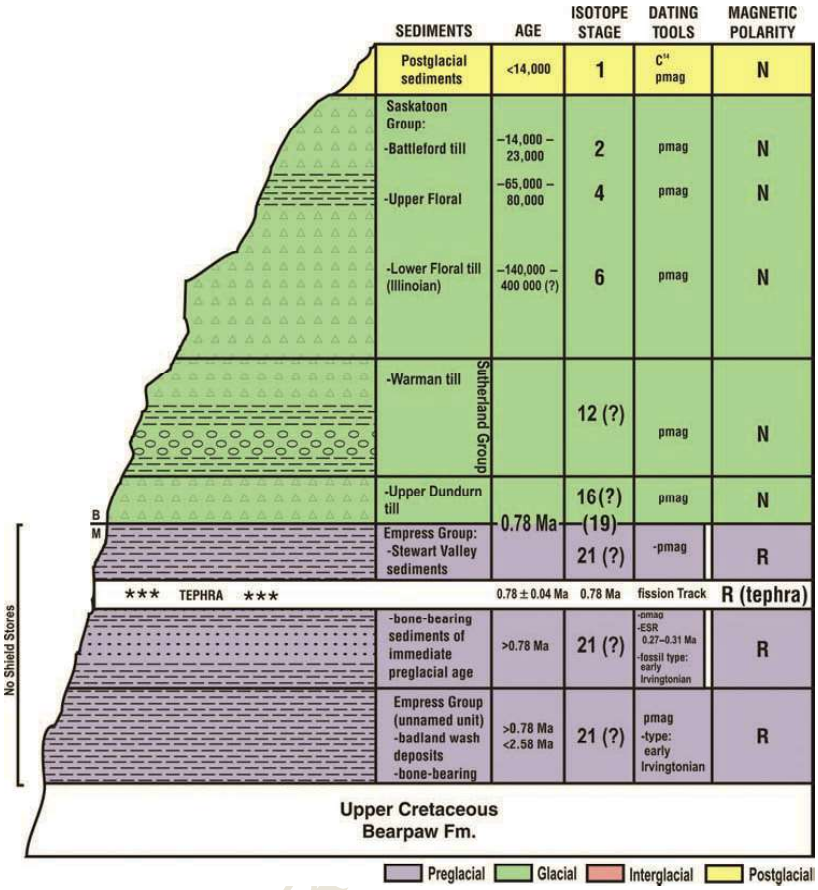


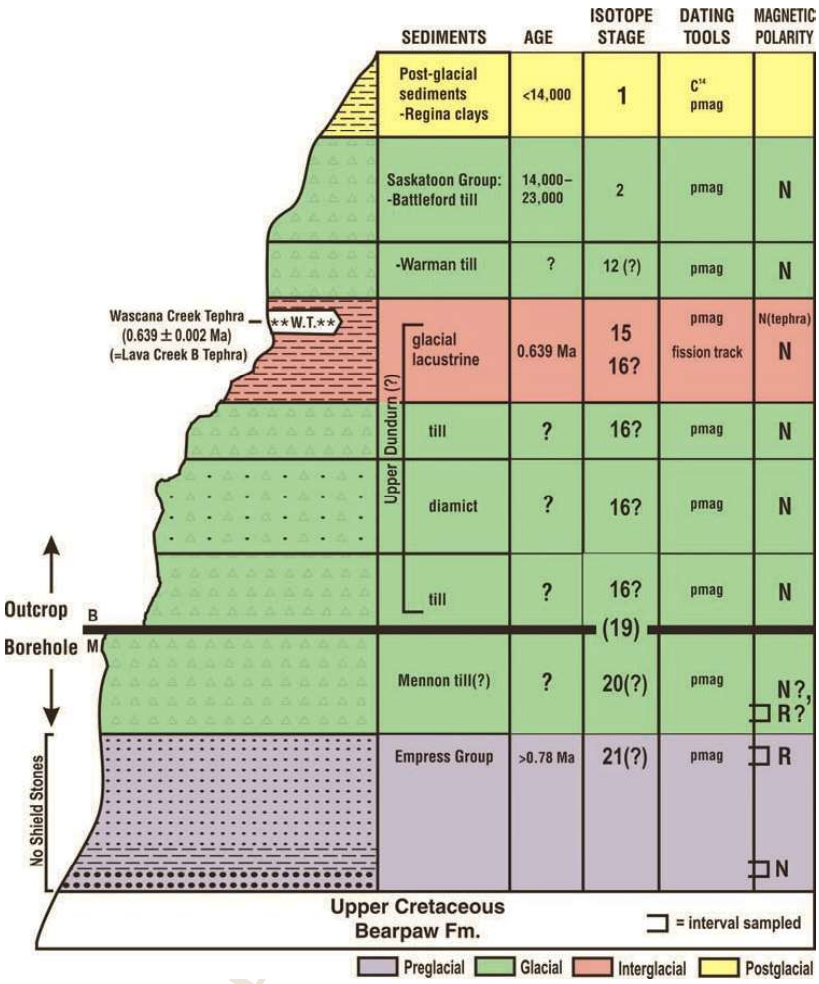
f0025 **FIGURE 46.5** Late Neogene composite stratigraphy from borecores and outcrops at the Wellsch Valley sites, near Swift Current, Saskatchewan.

preglacial Empress Group and the Saskatoon Group (Illinoian and younger deposits). Results (Barendregt *et al*., 2007) from the first borecore were mixed, with a number of tills yielding incoherent magnetisations and therefore a second core was collected nearby. (Incoherent magnetisation may result from insufficient water content of till slurries at time of deposition, preventing silt and clay-sized ferromagnetic minerals from becoming oriented in the earth's field.) While some of the units produced incoherent results in both cores, the Mennon, upper Dundurn and upper Floral gave good results (Barendregt *et al*., 2007, 2010a). The Mennon (lowermost till in Saskatchewan) is reversely magnetised, while the Dundurn Fm (upper till) and the Floral Fm (upper till) are normally magnetised. Results from the lower till of the Dundurn Fm as well as the Warman and Floral Fm (lower till) were incoherent. Only the lower part of the Empress Fm was sampled, and it is normal.

p0045 Taken together, the records from Wellsch Valley and Wascana Creek, and Sutherland confirm a reversely magnetised till (late Matuyama) at the base of the Quaternary sequence, underlain by preglacial sediments which are likewise reversed, and based on the age and position of the Wellsch Valley Tephra, were probably deposited right up until the first continental (Laurentide) ice sheet arrived in this region of Saskatchewan.

46.2.5. Lower Nelson/Hayes River Area near Gillam, Manitoba s0035

p0050 Thick sequences of both glacial and non-glacial sediments (Fig. 46.8) are exposed where major rivers in the Hudson Bay Lowlands are deeply incised through Quaternary deposits. Four tills have been identified on the basis of provenance, lithological composition, texture and colour. They are, from oldest to youngest: Sundance till, Amery till, Long Spruce till and Sky Pilot till. Sundance till is a sandy granitic till of northwestern (Keewatin) provenance, while



f0030 **FIGURE 46.6** Late Neogene composite stratigraphy from borecore and outcrop records at the Wascana Creek valley site, near Regina, Saskatchewan.

the others are calcareous and of eastern (Labrador) provenance (Dredge and Nielsen, 1987; Roy, 1998).

p0055 Non-glacial beds have been identified between tills at a number of sites and have been correlated on the basis of their stratigraphic position relative to the tills and on palaeoecological criteria. They yield infinite radiocarbon dates, and on the basis of palaeogeographic and palaeoecological constraints, indicate an ice-free Hudson Bay. The top of the oldest till has a 2-m-thick leached zone containing a subarctic pollen assemblage, which is therefore interpreted as a truncated palaeosol. Amino acid racemization studies of shells contained in non-glacial sediments and in the Amery till suggest several marine inundations during the Middle to Late Pleistocene.

p0060 Six sections in the lower Nelson/Hayes River area were selected for palaeomagnetic study. These are Limestone, Henday, Sundance, Port Nelson, Stupart Creek and Echoing Creek. They were chosen because each contains an extensive glacial and non-glacial stratigraphy, which are well preserved in a major preglacial valley system (of Tertiary age). Collectively, the deposits span a considerable amount of time, based on the presence of multiple tills sheets (of differing provenance), the amount of time required to raise and lower sea level by substantial amounts, the considerable thicknesses of interglacial sediments, as well as extended periods of soil development. As no absolute dating techniques could be applied to the older sediments, palaeomagnetic measurements were made to determine whether

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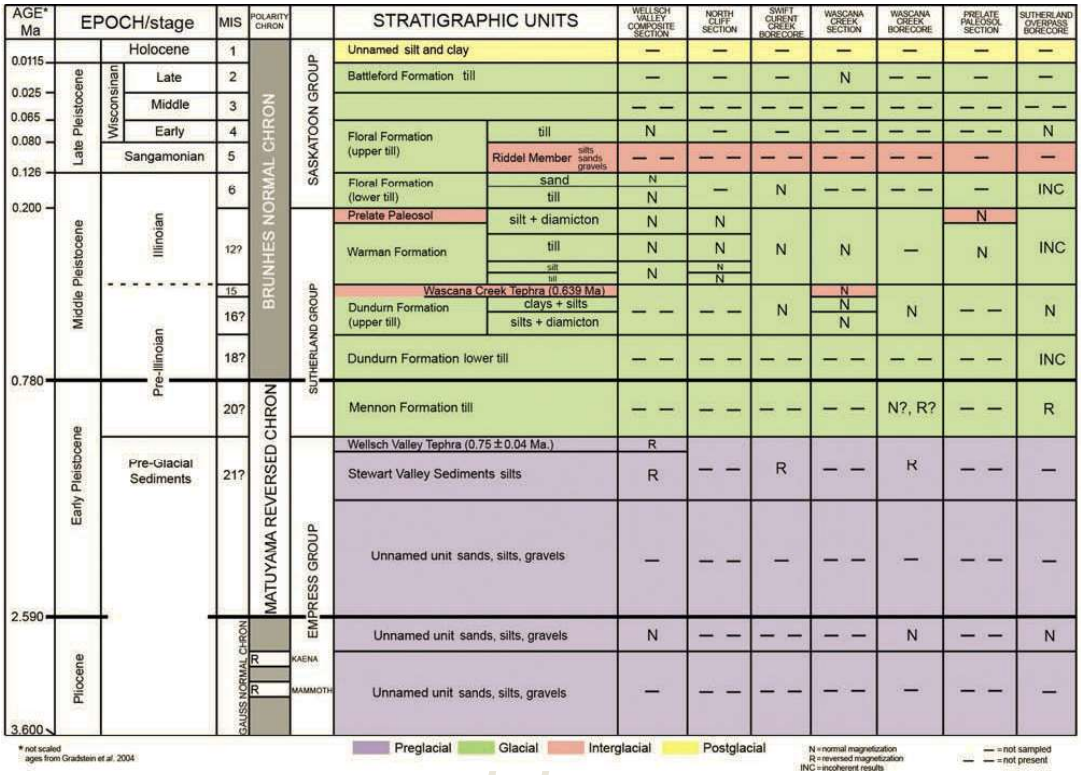

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f0035 **FIGURE 46.7** Magnetostratigraphic correlation of Saskatchewan outcrop and borehole data from the Wellsch Valley, Wascana Creek and Sutherland sites.

reversely magnetised (Matuyama Chron; 2.6–0.78 Ma) sediments are present in the Hudson Bay Lowlands.

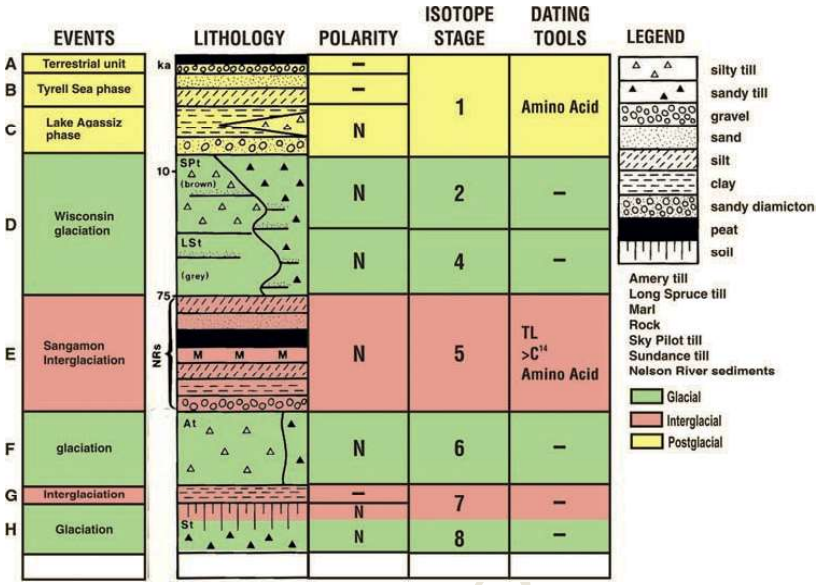
p0065 All units exhibit normal magnetisations (Barendregt *et al*., 2007, 2010b), indicating that the Quaternary record in the Hudson Bay Lowlands can be assigned to the Brunhes Chron (<0.78 Ma) and falls within the Middle to Late Pleistocene age (Fig. 46.2). The magnetostratigraphy of the Hudson Bay Lowlands indicates that Brunhes Chron glaciations occurred repeatedly in this region.

s0040 46.3. DISCUSSION

p0070 The age of North American Interior Plains glaciations is less well constrained than Cordilleran glaciations, both in terms of age and extent (Barendregt and Duk-Rodkin, 2011; Duk-Rodkin and Barendregt, 2011). Only in the American Midwest (Minnesota, Nebraska, Iowa, Kansas and Missouri) have reversely magnetised continental tills been reported (Roy *et al*., 2004; Balco *et al*., 2005). Based on tephra dates, these reversely magnetised glacial sediments fall within the early as well as late Matuyama Reversed Chron (2.60–0.78 Ma). Barendregt *et al*. (2007) reported the results of palaeomagnetic measurements made on borecore samples from south-central Saskatchewan. A single reversely magnetised till (Mennon Fm) can be confidently assigned to the latest Matuyama (MIS 20), based on underlying and overlying tephras. Other than this MIS 20 glaciation, no Early Pleistocene continental tills have been found. To the west, in Alberta, only a single (Late Wisconsinan) glaciation covered most of the province, while areas to the east of the ~700 m contour line saw two or more glaciations. In south-central Saskatchewan, evidence for seven glaciations is reported. Of these, six fall within the Brunhes Normal Chron [one is Late Wisconsinan (MIS 2), one is Early Wisconsinan (MIS 4), one is Illinoian (MIS 6) and three are pre-Illinoian (>0.40 Ma; MIS 14?, 16? and 18?]. The earliest glaciation falls within the latest Matuyama Reversed Chron (> 0.78 Ma; MIS 20), based on palaeomagnetism, tephras and fossil data.

46.4. CONCLUSIONS s0045

p0075 In 1998, Barendregt and Irving provided a summary of the magnetostratigraphical data for western Canada and the



f0040 **FIGURE 46.8** Late Neogene composite stratigraphy of Hudson Bay Lowland near Gillam, Manitoba.

northwestern USA. In these summaries, distribution and extent of ice sheets in western North America are reconstructed, based on some 70 magnetostratigraphic records, and show marked differences between the Matuyama and Brunhes Chrons (see Fig. 46.3 in Barendregt and Duk-Rodkin, 2011, Chapter 32). During the Matuyama Chron, ice appears to have been largely absent from large areas of the southern prairie provinces in Canada and the adjacent states of Montana and North Dakota, as well as from much of the Arctic Islands. In the Late Matuyama a modest Keewatin ice centre formed, delivering ice as far distant as Banks Island, North West Territories (NWT) and south-central Saskatchewan. In contrast, the Labrador/Hudson Bay ice centre delivered ice as far south as Kansas during both the Early and Late Matuyama (Roy *et al*., 2003; Balco *et al*., 2005). During the Brunhes Chron, ice caps appear for the most part to have been far more extensive than in the Matuyama, and only in the southern Midwestern states did Brunhes-age ice not reach previous limits. During the last major glaciation (Late Wisconsinan), ice cover was continuous from Atlantic to Pacific, with Cordilleran and Keewatin ice sheets in contact in western Alberta, and along the eastern margin of the Mackenzie Mountains in the NWT.

REFERENCES

Au5

Balco, G., Stone, J.O.H., Mason, J., 2005. The first glacial maximum in North America. Science 307, 222.

Barendregt, R.W., 1976. A detailed geomorphological survey of the Pakowki-Pinhorn Area, Southeastern Alberta. Ph.D. Dissertation, Department of Geography, Queen's University, 275 pp.

Barendregt, R.W., Duk-Rodkin, A., 2011. Chronology and extent of late Cenozoic ice sheets in North America: a magnetostratigraphic assessment. In: Ehlers, J., Gibbard, P.L., Hughes, P.D. (Eds.), Quaternary Glaciations—Extent and Chronology. Part IV: A Closer Look. Elsevier, Amsterdam.

Barendregt, R.W., Irving, E., 1998. Changes in the extent of North American ice sheets during the late Cenozoic. Can. J. Earth Sci. 35, 504–509.

Barendregt, R.W., Stalker, A.MacS., 1978. Characteristic magnetization of some Middle Pleistocene sediments from the Medicine Hat Area of Southern Alberta. Geological Survey of Canada Paper, 78-1A, pp. 487–488.

Barendregt, R.W., Vincent, J.-S., 1990. Late Cenozoic paleomagnetic record of Duck Hawk Bluffs, Banks Island, Canadian Arctic Archipelago. Can. J. Earth Sci. 27, 124–130.

Barendregt, R.W., Foster, J.H., Stalker, A. MacS, 1977. Paleomagnetic remanence characteristics of surface tills found in the Pakowki-Pinhorn area of southern Alberta. Geological Survey of Canada Paper, 77-1B.

Barendregt, R.W., Churcher, C.S., Stalker, A. MacS, 1988. Stratigraphy, paleomagnetism and vertebrate paleontology of Quaternary preglacial sediments at the Maser-Frisch Site, southeastern Alberta. Geol. Soc. Am. Bull. 100, 1824–1832.

Barendregt, R.W., Thomas, F.F., Irivng, E., Baker, J., Stalker, A. MacS, Churcher, C.S., 1991. Stratigraphy and paleomagnetism of the Jaw Face section, Wellsch Valley site, Saskatchewan. Can. J. Earth Sci. 28, 1353–1364.

Barendregt, R.W., Irving, E., Christiansen, E.A., Sauer, E.K., Schreiner, B.T., 1998a. Stratigraphy and Paleomagnetism of Late

Pliocene and Pleistocene sediments from Wellsch Valley and Swift Current Creek areas, southwestern Saskatchewan, Canada. Can. J. Earth Sci. 35, 1347–1361.

Barendregt, R.W., Vincent, J.-S., Irving, E., Baker, J., 1998b. Magnetostratigraphy of Quaternary and Late Tertiary sediments on Banks Island, Canadian Arctic Archipelago. Can. J. Earth Sci. 35, 147–161.

Barendregt, R.W., Duk-Rodkin, A., Enkin, R.E., Baker, J., Christiansen, E., Naeser, N.D., et al., 2007. New magnetostratigraphic data from central Saskatchewan, and from the Horton Plateau, Mackenzie District, NWT: evidence for Matuyama Chron glaciations in the Interior Plains of Canada. In: XVII I NQUA Congress, Cairns, Australia, 28 July–3 August, 2007.

Barendregt, R.W., Enkin, R.J., Christiansen, E.A., Westgate, J.A., 2010a. Magnetostratigraphy of Wascana Creek, Swift Current Creek and Sutherland bore-cores: evidence for an extensive Pleistocene glacial record from southern and central Saskatchewan. Can. J. Earth Sci. (in preparation).

Au6 Barendregt, R.W., Dredge, L., Nielsen, E., Enkin, R., Verosub, K., 2010b. Paleomagnetism of Quaternary sediments along the Nelson River, near Gillam, Manitoba. Can. J. Earth Sci. (in preparation).

Cande, S.C., Kent, D.V., 1995. Revised calibration of the geomagnetic timescale for the Late Cretaceous and Cenozoic. J. Geophys. Res. 100 (B4), 6093–6095.

Christiansen, E.A., 1968. Pleistocene stratigraphy of the Saskatoon area, Saskatachewan, Canada. Can. J. Earth Sci. 5, 1167–1173.

Christiansen, E.A., 1992. Pleistocene stratigraphy of the Saskatoon area, Saskatchewan, Canada: an update. Can. J. Earth Sci. 29, 1767–1778.

Churcher, C.S., Stalker, A. MacS, 1988. Geology and vertebrate paleontology of the Wellsch Valley site, Saskatchewan. unpublished manuscript.

Dredge, L.A., Nielsen, E., 1987. Glacial and interglacial stratigraphy, Hudson Bay Lowlands, Manitoba. In: Biggs, D.L. (Ed.), Geological Society of America Centennial Field Guide. North Central Section 3, 43–46.

Duk-Rodkin, A., Barendregt, R.W., 2011. The glacial history of Northwestern Canada. In: Ehlers, J., Gibbard, P.L., Hughes, P.D. (Eds.), Quaternary Glaciations—Extent and Chronology. Part IV: A Closer Look. Elsevier, Amsterdam.

Fullerton, D.S., Colton, R.B., Bush, C.A., 2004. Limits of mountain and continental glaciations east of the continental divide in northern Montana and northeastern North Dakota, USA. In: Ehlers, J., Gibbard, P.L. (Eds.), Quaternary Glaciations—Extent and Chronology. Part II: North America. Elsevier, Amsterdam.

Jackson, L.E., Jr., Phillips, F.M., Little, E.C., 1999. Cosmogenic ^{36}Cl dating of the maximum limit of the Laurentide Ice Sheet in southwestern Alberta. Can. J. Earth Sci. 36, 1347–1356.

Lanphere, M.A., Champion, D.E., Christiansen, R.L., Izett, G.A., Obradovich, 2002. Revised age for tuffs of the Yellowstone Plateau volcanic field—assignment of the Huckleberry Ridge Tuff to a new geomagnetic polarity event. Geol. Soc. Am. Bull. 114, 559–568.

Au2

Lisiecki, L.E., Raymo, M., 2005. A Pliocene–Pleistocene stack of 57 globally distributed benthic δ^{18}O records. Paleoceanography 20, PA1003. doi:10.1029/2004PA001071.

Raymo, M.E., 1992. Global climate change: a three million year perspective. In: Kukla, G.K., Went, E. (Eds.), Start of a Glacial, Nato ASI Series, Series I, Global Environmental Change 3, 207–223.

Raymo, M.E., Ruddiman, W.F., Backman, J., Clement, B.M., Martinson, D.G., 1989. Late Pliocene variation in Northern Hemisphere ice sheets and North Atlantic Deep Water circulation. Paleoceanography 4, 413–446.

Roy, Martin, 1998. Pleistocene stratigraphy of the Lower Nelson River Area: implications for the evolution of the Hudson Bay Lowland of Manitoba, Canada. Unpublished M.Sc. Thesis, Université de Quebec a Montreal, 220 pp.

Roy, M., Clark, P.U., Barendregt, R.W., Glasmann, J.R., Enkin, R.J., Baker, J., 2004. Glacial Stratigraphy and Paleomagnetism of late Cenozoic deposits of the north-central United States. Geol. Assoc. Am. Bull. 116, 30–41.

Ruddiman, W.F., Raymo, M.E., McIntyre, A., 1986. Matuyama 41,000-year cycles; North Atlantic Ocean and northern hemisphere ice sheets. Earth Planet. Sci. Lett. 80, 117–129.

Ruddiman, W.F., Raymo, M.E., Martinson, D.G., Clement, B.M., Backman, J., 1989. Pleistocene evolution of Northern Hemisphere climate. Paleoceanography 4, 353–412.

Shackleton, N.J., Hall, M.A., Pate, D., 1995. Pliocene stable isotope stratigraphy of site 846. Proc. Ocean Drill. Prog. Sci. Results 138, 337–353.

Stalker, A. MacS, 1969. Alberta report II: sections near Medicine Hat. Geological Survey of Canada, Paper, 69-26, 28 pp.

Stalker, A. MacS, 1976. Quaternary stratigraphy of the Southwestern Prairies. In: Mahaney, W.C. (Ed.), Quaternary Stratigraphy of North America. Hutchinson and Ross Inc., Stroudsberg, Pennsylvania, Dowden, pp. 381–407.

Stalker, A., 1982. Ice age deposits and animals from the southwestern part of Great Plains of Canada. Geological Survey of Canada, Miscellaneous Report, 31, (wall chart).

Stalker, A. MacS, Vincent, J.-S., 1993. Quaternary; subchapter 4K in Sedimentary Cover of the Craton in Canada. In: Stott, D.F., Aitken, J.D. (Eds.), Geological Survey of Canada, Geology of Canada, No. 5. pp. 466–482 (also Geological Society of America, The Geology of North America, v. D-1).

Stalker, A. MacS, Wyder, J.E., 1983. Borehole and outcrop stratigraphy compared with illustrations from the Medicine Hat area of Alberta. Geol. Surv. Can. Bull. 296, 28 pp. and maps.

Stewart, K.M., Seymour, K.L. (Eds.), 1996. Palaeoecology and Palaeoenvironments of Late Cenozoic Mammals: Tributes to the Career of C.S. (Rufus) Churcher. University of Toronto Press, Toronto, Canada 521 pp.

Szabo, B.J., Stalker, A. MacS, Churcher, C.S., 1973. Uranium-series ages of some Quaternary deposits near Medicine Hat, Alberta, Canada. Can. J. Earth Sci. 10, 1464–1469.

Westgate, J.A., 1968. Surficial geology: foremost-Cypress Hills area, Alberta. Alberta Res. Counc. Bull. 22, 120. Au8

Westgate, J.A., Christensen, E.A., Boellstorff, J.D., 1977. Wascana Creek Ash (Middle Pleistocene) in southern Saskatchewan: characterization, source, fission track age, paleomagnetism and stratigraphic significance. Can. J. Earth Sci. 14, 357–374.

Westgate, J.A., Briggs, N.D., Stalker, A. MacS, Churcher, C.S., 1978. Fission-track age of glass from tephra beds associated with Quaternary vertebrate assemblages in the southern Canadian Plains. Geol. Soc. Am. Abstr. 10, 514–515.

Zymela, S., Schwarcz, H.P., Grun, R., Stalker, A. MacS, Churcher, C.S., 1988. ESR dating of Pleistocene fossil teeth from Alberta and Saskatchewan. Can. J. Earth Sci. 25, 235–245.

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Abstract
This paper summarises the continental (Laurentide) glacial history of the northern Interior Plains of Canada (Alberta, Saskatchewan, and Manitoba) using magnetostratigraphy, tephrochronology, and paleosol data collected at type sections. The use of borecores for retrieval of oriented till samples for paleomagnetic analysis, is discussed.

Keywords: Laurentide glaciations, glacial tills, paleomagnetism, Yellowstone and Cascadian tephras

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