Chapter 32

Chronology and Extent of Late Cenozoic Ice Sheets in North America: A Magnetostratigraphical Assessment

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p0005 Studies of δ^{18}O and $CaCO_3$ content in cores from the deep ocean, and the presence of ice-rafted debris in cores taken from continental margins, have long suggested that earth's past climate has experienced cold periods, some of which produced extensive glaciation on land. While oceanographers have provided evidence for well over 50 such cold periods in the past 3 million years, many of which clearly point to periods of ice sheet development, the terrestrial records initially suggested only relatively few glaciations. The classic fourfold subdivision of the Pleistocene in both North America and Europe dominated terrestrial Quaternary palaeoclimate studies for many decades.

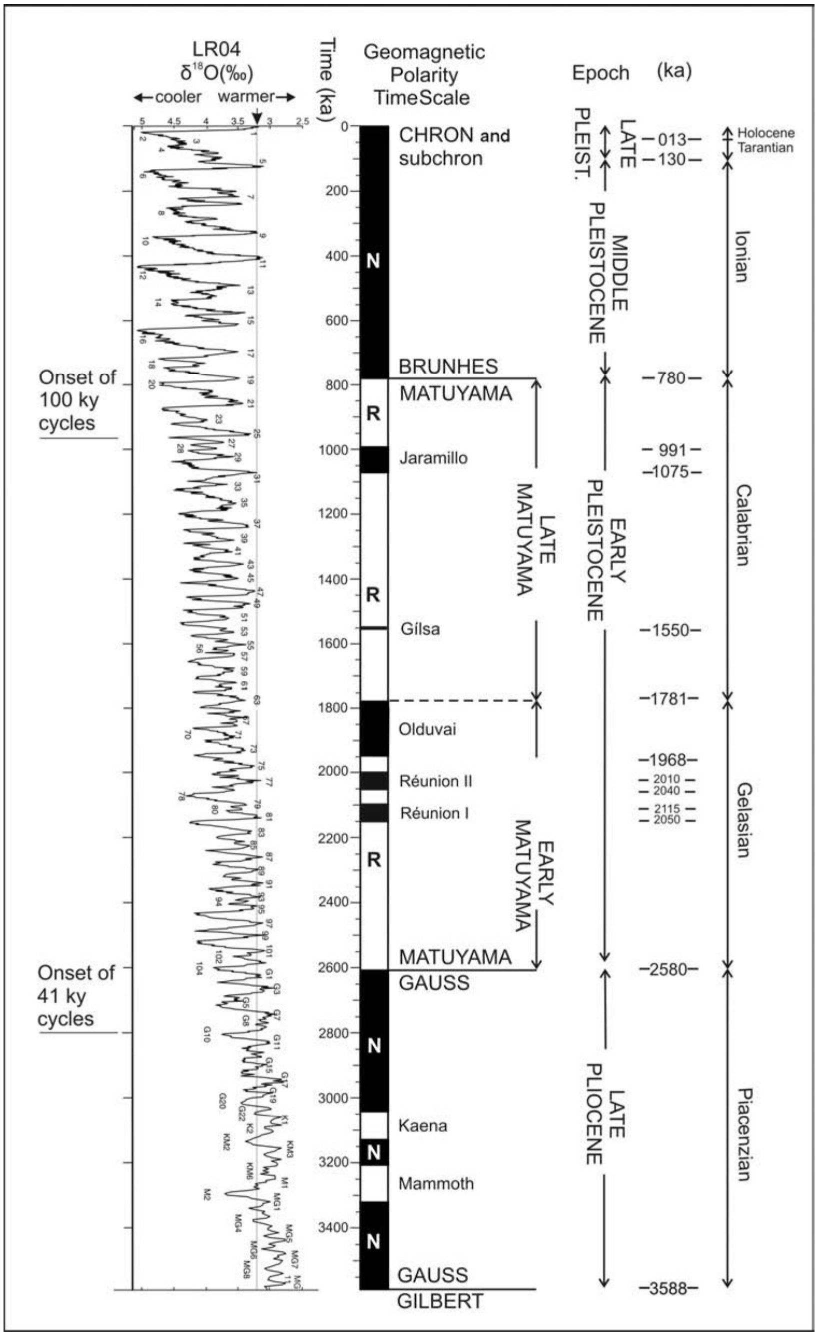
p0010 With the exception of the last major continental (Late Wisconsinan) glaciation, our understanding of the extent and timing of ice sheet development in North America has until recently remained uncertain. With the more widespread use of magnetostratigraphy and detailed mapping of surficial deposits, it has become possible to identify the approximate timing (appearance and disappearance) of ice sheets which pre-date the Late Wisconsinan, and to estimate their approximate spatial extent.

p0015 With appropriate sampling and analytical techniques, geomagnetic polarity data can be obtained from glacial tills as well as from altered sediments such as palaeosols, to provide a direct assessment of the palaeomagnetism of glacial and interglacial deposits. Such data can be used to assign sedimentary sequences to polarity chrons and subchrons of the global geomagnetic polarity timescale (Fig. 32.1). Where palaeomagnetic data are combined with tephrochronology, palynology and other proxy records of palaeoclimate, magnetostratigraphy affords a robust tool for establishing the timing and extent of glaciations and interglaciations and has substantially enhanced our understanding of Late Cenozoic climate change.

Mapping of surficial geology in northern regions of Canada, as well as remapping of key southern portions of Canada under the NATMAP programme, has provided unique opportunities to study extensive outcrop and bore-core records of glacial and interglacial sediments preserved in pre-glacial valleys, coastal lowlands and interbedded with volcanics. p0020

The work described in this volume points to some of the advances which have been made in dating and modelling of past terrestrial climates. It has been the contribution of magnetostratigraphy in particular, which has provided timelines for glacial and interglacial events of the past 3.0 million years, and facilitated the assignment of sediments to the chrons and subchrons (Fig. 32.1) of the geomagnetic polarity timescale (Barendregt and Irving, 1998; Froese *et al*., 2000; Clague *et al*., 2003; Huscroft *et al*., 2004; Roy *et al*., 2004; Parfitt *et al*., 2005; Nelson *et al*., 2009; Barendregt *et al*., 2010; Mahaney *et al*., 2010). p0025

In 1998, Barendregt and Irving provided a summary of the magnetostratigraphical data for western Canada and the north-western USA (Fig. 32.2). This summary was updated to include new sampling locations (Table 32.1), and new magnetochron/subchron ages of tills, intertill beds, interglacial sediments, palaeosols and pre-glacial sediments were established for sites in NW Canada and are published in Barendregt *et al*. (2011), Duk-Rodkin *et al*. (2011) and Duk-Rodkin and Barendregt (2011, (this volume, see Figs. 49.1–49.3 and 49.23). In these summaries, distribution and extent of ice sheets in western North America are reconstructed, based on some 70 magnetostratigraphical records, and show marked differences between the Matuyama and p0030 Au4



f0005 **FIGURE 32.1** Geomagnetic polarity timescale (Cande and Kent, 1995) for LRO4 benthic δ^{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 represent 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 δ^{18}O (Raymo, 1992).

f0010 **FIGURE 32.2** North American glaciations grouped by polarity chrons.

Brunhes Chrons (Fig. 32.3). 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). 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). 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.

t0005 **TABLE 32.1** Palaeomagnetic Data Sites

Site name	Symbol	Latitude	Longitude	Site name	Symbol	Latitude	Longitude
Port Nelson, Manitoba	T	57.06	−92.61	Danville, Illinois	S	40.15	−87.63
Gillam, Manitoba	T	56.34	−94.71	Minford, Ohio	S	38.89	−82.83
Sundance, Manitoba	T	56.53	−94.07	La Sal Mountains, Utah	S	38.31	−109.24
Henday, Manitoba	T	56.53	−94.18	Sezill Creek, British Columbia	S	57.9	−31.17
Limstone, Manitoba	T	56.52	−94.13	Merrit, British Columbia	S	50.12	−120.78
Echoing River, Manitoba	T	55.3	−92.15	Kelowna, British Columbia	S	49.88	−119.52
Stupart Creek, Manitoba	T	55.5	−93.7	Saskatoon, Saskatchewan	S	52.13	−106.58
Prince Albert, Saskatchewan	T	52.3	−105.77	Worth Point, NWT	S	72.25	−125.5
Smeaton Saskatchewan	T	53.5	−104.82	Duck Hawk Bluffs, NWT	S	71.98	−121.5
Stewart Valley, Saskatchewan	T	50.6	−107.8	Nelson River Bluffs, NWT	S	71.22	−122.5
Wascana Creek, Saskatchewan	T	50.6	−104.82	Morgan Bluffs, NWT	S	72.2	−119.75
Medicine Hat, Alberta	T	50.05	−110.67	West River, NWT	G	69.3	−124.75
Taber, Alberta,	T	49.78	−112.13	Afton, Iowa	G	41.03	−97.13
Bow Island, Alberta	T	49.87	−111.37	David City, Nebraska	G	41.25	−97.13
Calgary, Alberta	T	51.05	−114.08	Yellowstone Park, Wyoming	G	45.07	−110.76
Pincher Creek, Alberta	T	49.48	−113.95	Puget Lowland, Washington	G	47.18	−122.28
Longview, Alberta	T	50.53	−114.23	Fort Selkirk, Yukon	G	62.78	−137.38
Watino, Alberta	T	55.72	−117.62	Katherine Creek, NWT	G	64.95	1127.57
Havre, Montana	T	48.54	−109.68	Little Bear Creek, NWT	G	64.45	−126.75
Greenfield, Iowa	T	41.31	−94.46	Inlin Brook, NWT	G	64.33	−126.62
Thayer, Iowa	T	41.03	−94.05	Mackenzie Delta	G	69.8	−135
Macedonia, Iowa	T	41.19	−95.42	Labrador Sea, NWT	G	55	−51
Glenwood, Iowa	T	41.05	−95.74	Davis Strait, NWT	G	71	−61.5
Le Mars, Iowa	T	42.79	−96.17	Deadman Pass, California	C	37.63	−118.99
Alden, Iowa	T	42.51	−93.38	St. Mary, Montana	C	48.74	−113.43
County Line, Iowa	T	41.85	−95.99	Beazer, Alberta	C	49.12	−113.48
Freemont, Nebraska	T	41.44	−96.49	Tintina Trench, Yukon	C	64.2	−139.2
Wood Valley Road, Kansas	T	39	−95.75	Dawson, Yukon	C	64.06	−139.43
Recumseh, Kansas	T	39.02	−95.55	North Coast, Alaska	C	72	−152
Topeka, Kansas	T	39.03	−95.7	Brooks Range	C	68	−154
Redwood Falls, Minnesota	T	44.54	−95.11	Southern Alaska Mountains	C	63	−148
Mercer, Missouri	T	40.51	−93.52				
Tahltan, British Columbia	T	57.9	−131.17				
Dog Creek, British Columbia	S	51.55	−122.25				
Crescent, Iowa	S	41.37	95.86				

TABLE 32.1 Palaeomagnetic Data Sites—cont'd

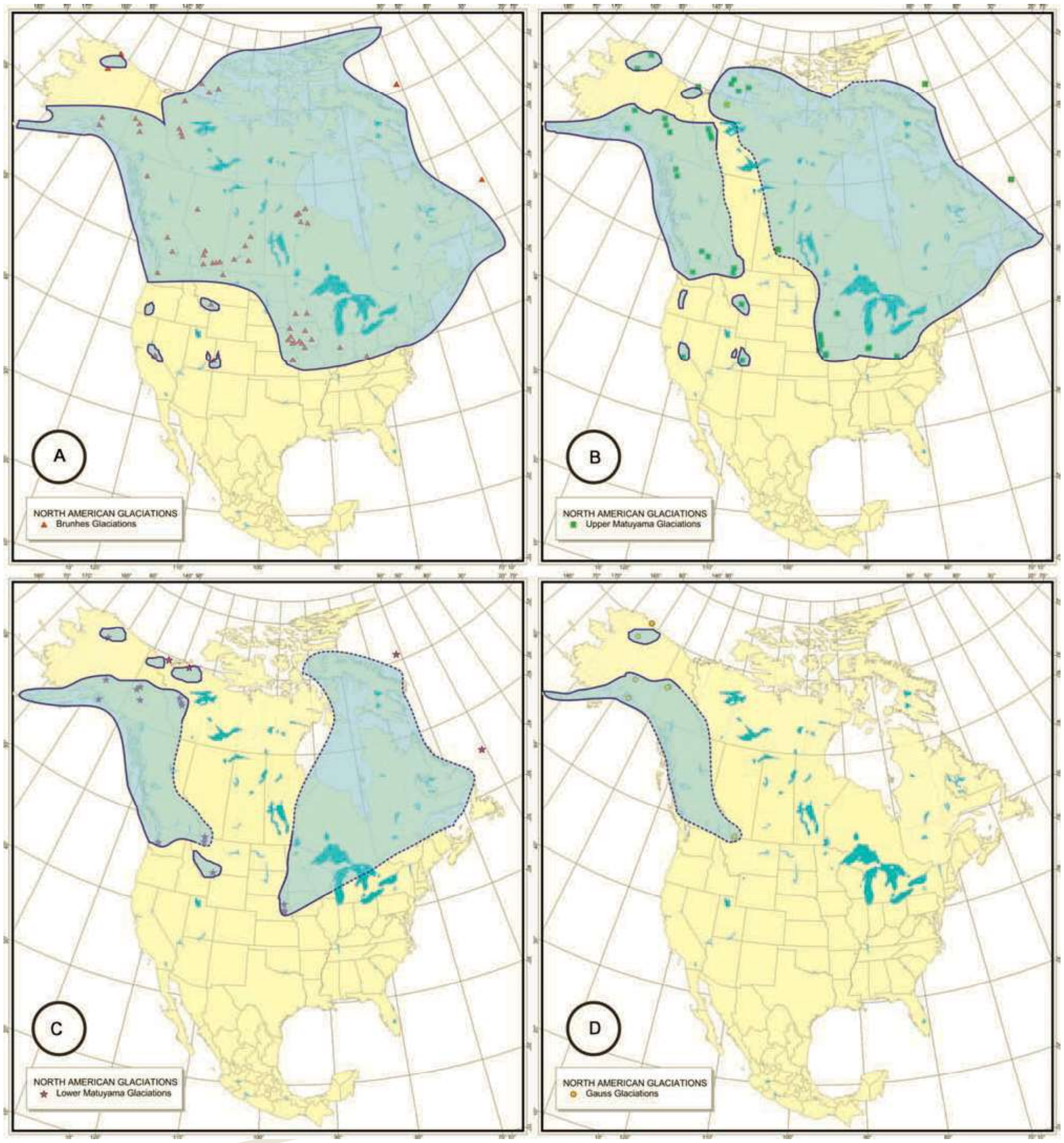
Site name	Symbol	Latitude	Longitude	Site name	Symbol	Latitude	Longitude
Turin, Iowa	S	42.02	−95.97				
Thurman, Iowa	S	40.82	−95.75				
Elk Creek, Nebraska	S	40.2	−96.13				
City-Wide Quarry, Nebraska	S	41.26	−95.93				
Atchison, Kansas	S	39.56	−95.13				
Wathena, Kansas	S	39.76	−94.95				
Hersey, Minnesota	S	44.5	−92.8				
West Lebanon, Indiana	S	40.27	−87.38				

T, Brunhes Chron magnetizations only (triangles); S, Brunhes and Upper Matuyama Chrons (squares); G, Brunhes and Upper and Lower Matuyama Chrons (stars); C, Brunhes, Matuyama and Gauss Chrons (circles).

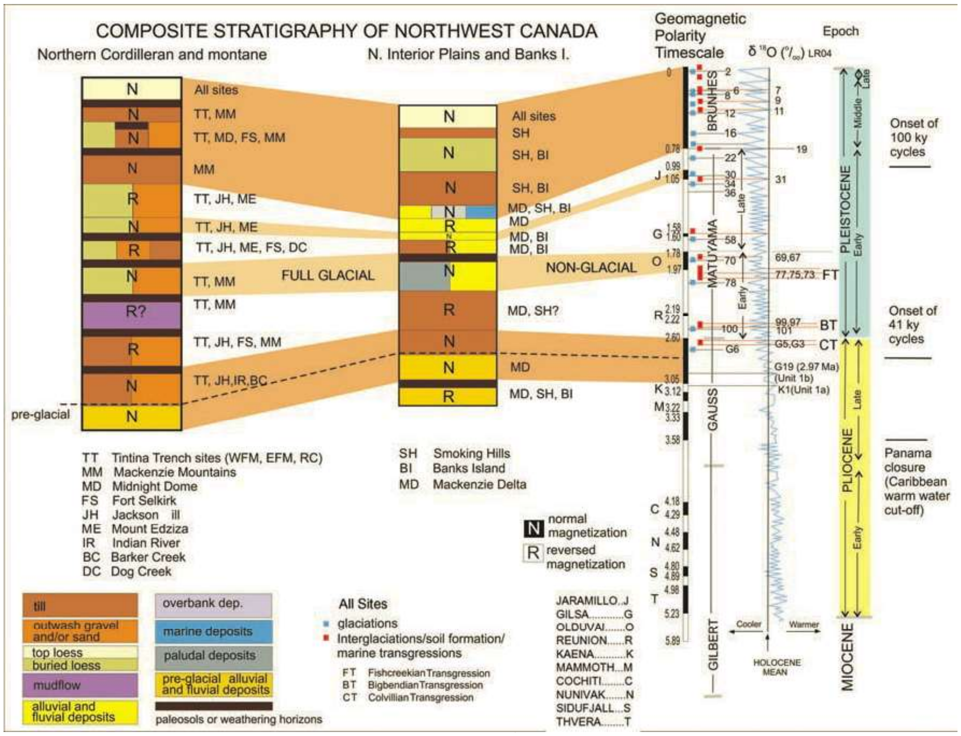
p0035 Data from the Yukon, NWT and Alaska (Fig. 32.4) have led to considerable refinement of the timing of glaciations in NW North America, and provided a better spatial resolution of the extent of some of the ice sheets (Duk-Rodkin *et al.*, 2004, 2010; Barendregt *et al.*, 2010; Duk-Rodkin and Barendregt, 2011). The most complete terrestrial record of Late Cenozoic glaciations is in the Tintina Trench where multiple tills and palaeosols record seven polarity chrons and subchrons, in the Klondike area where loess and glacial gravel sequences record eight polarity chrons and subchrons, and along the Yukon River near Fort Selkirk where Quaternary volcanics and interbedded glacial/interglacial sediments record at least seven polarity chrons and subchrons (Fig. 32.4). Bore-core data from the Mackenzie Delta provide evidence for an early Matuyama glaciation only and contain a record of all polarity chrons and subchrons within the Pleistocene. The West River section on the Horton Plateau (Table 32.1) records at least three polarity chrons, two of which are in tills and one in pre-glacial sediments of probable late Gauss age. Shield stones are absent from all the tills, except for the surface till, and therefore a Horton Plateau-centred ice dome is proposed (Fig. 32.3). This ice dome first developed in the early Matuyama, and was restricted to the local highlands. During the late Matuyama, this ice centre encompassed a considerably larger area and may have reached to Banks Island and merged with the more extensive Keewatin Ice Centre to the south and east. From the late Matuyama Chron onwards, the distribution of ice from the Keewatin Ice Centre became progressively more extensive (Fig. 32.3). Previously published data from the Mackenzie Mountains record five mountain glaciations and one continental glaciation, spanning three polarity chrons and subchrons, and include an extensive palaeosol sequence (Barendregt *et al.*, 1996; Duk-Rodkin *et al.*, 1996), while on Banks Island, four widely separated sites record five glaciations spanning four polarity chrons and subchrons, all post-dating the Olduvai subchron (Barendregt *et al.*, 1998).

Recent work in NW Canada has pointed to the importance of tectonics and proximity to open oceans for the development of ice centres (Barendregt *et al.*, 1998; Duk-Rodkin *et al.*, 2004, 2010). The timing of uplift and erosion in the Wrangell/St Elias Mountains, and the Continental Divide (Mackenzie and Selwyn Mountains), appears to have been an important controlling factor in the distribution of moisture supply and the build-up of ice masses in NW Canada. Likewise, periods of low-amplitude variation in benthic δ^{18}O appear to have seen little or no ice cover in the interior of the North American continent, as suggested by the lack of glacial sediments during these intervals of time (see Fig. 49.24 in Duk-Rodkin and Barendregt (2011, this volume). p0040

In the absence of absolute dating tools, magnetostratigraphy affords a valuable means of assigning terrestrial ice age deposits to the geologic timescale and, most importantly, allows a correlation to be made with the more complete marine record. The distribution of past ice sheets and their timing will undoubtedly be better defined with future magnetostratigraphical work. p0045



f0015 **FIGURE 32.3** Proposed maximum ice distribution during late Gauss, early and late Matuyama and Brunhes polarity Chrons (modified from Barendregt and Irving, 1998; Barendregt and Duk-Rodkin, 2004).



f0020 **FIGURE 32.4** Correlation of glacial/interglacial events based on a composite stratigraphy developed from multiple sites in the Northern Cordillera, the Northern Interior Plains and Banks Island. The sites included here are discussed in Duk-Rodkin *et al*. (2010) and identify glaciations (blue squares) as well as interglacial and pre-glacial sediments containing palaeosols and/or pollen (red squares). See Fig. 32.1 for legend of geomagnetic polarity timescale and composite δ^{18}O LR04 marine isotopic record. The Gauss and Brunhes normal chrons are highlighted in medium brown, and Olduvai and Jaramillo normal subchrons in light brown.

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Abstract

This paper summarises the advances which have been made in the magnetostratigraphic assessment of glacial and interglacial events of the past 3.0 million years, to facilitate the assignment of sediments to the Chrons and subchrons of the geomagnetic polarity timescale. In the absence of absolute dating tools, magnetostratigraphy affords a valuable means of assigning terrestrial ice age deposits to the geologic timescale, and most importantly, allows a correlation to be made with the more complete marine sedimentary record, where oxygen isotopic data also provide a robust paleotemperature record.

Keywords: Magnetostratigraphy, North American glacial record, marine isotopic record, Cordilleran and continental glaciations, Late Cenozoic and Late Neogene glaciations

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