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A Proposed Diachronic Revision of Late Quaternary Time-Stratigraphic Classification in the Eastern and Northern Great Lakes Area

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A succession of stratigraphic codes (1933, 1961, 1983) has guided attempts to refine classifications and naming of stratigraphic units for Quaternary deposits of the Great Lakes region. The most recent classifications for the late Quaternary of the Lake Michigan lobe (1968) and the eastern Great Lakes (1972) have been widely used, but later work has created the need for revision. An attempt has been made to integrate the two previous classifications following the diachronic system of the 1983 Code of Stratigraphic Nomenclature. A new nomenclature for the higher, more broadly recognized units was presented in 1997. We here present the diachronic nomenclature for finer subdivisions recognized in the eastern and northern Great Lakes. Following the interglacial Sangamon Episode, the three parts of the Wisconsin Episode are further subdivided as follows: the Ontario Subepisode (former Early Wisconsinan) comprises the Greenwood, Willowvale, and Guildwood phases; the Elgin Subepisode (former Middle Wisconsinan) comprises the Port Talbot, Brimley, and Farmdale phases; and the Michigan Subepisode (former Late Wisconsinan) consists of Nissouri, Erie, Port Bruce, Mackinaw, Port Huron, Two Creeks, Onaway, Gribben, Marquette, Abitibi, and Driftwood phases. Succeeding interglacial time to the present is the Hudson Episode.

Key Words: **Quaternary; diachronic units; stratigraphy; Great Lakes region; Ontario.**

INTRODUCTION

It is over a quarter century since the publication of a late Quaternary time-stratigraphic classification for the eastern Great Lakes–St. Lawrence region (Dreimanis and Karrow, 1972). Subsequent discoveries by numerous workers have shown a growing need for revisions to that classification. We therefore propose a revised classification of time embraced by the last interval of warm climate like the present—an interglaciation—the last glaciation, and postglacial time. This time interval, about 130,000 years in length, is that which the INQUA Working Group on Major Subdivisions of the Quaternary classed informally as late Quaternary time (G. M. Richmond, personal communication, 1988). The present paper extends the diachronic classification of Johnson *et al.* (1997) to finer subdivision for the eastern and northern Great Lakes area centered in Ontario. The finer diachronic subdivision for the Michigan lobe was presented earlier by Hansel and Johnson (1992, 1996).

BACKGROUND

Stratigraphic classification of the Quaternary of Ontario began with Logan *et al.* (1863), who provided a nomenclature for deposits then recognized (Table 1). Use of this nomenclature continued well into the twentieth century. By late in the nineteenth century, work in the midwestern United States came to prominence in the elaboration of Quaternary history. That low-relief and low-latitude area with a relatively dense population provided a sensitive record of glacial fluctuations that allowed recognition of several discrete events of glacier advance and retreat, in part derived from cross-cutting relationships of ice-marginal moraines. To the east, higher relief and more varied bedrock greatly complicated correlation and interpretation of the history. New terms for deposits, events, and

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TABLE 1
Classification of Drift (after Logan *et al.*, 1863)

Shell marl, calcareous tufa, peat
Ochres, bog iron, and manganese ores
Modern alluvions
Algoma sand
Artemisia gravel
Saugeen freshwater clay and sand
Erie clay
Boulder formation or glacial drift

ages derived from the midwestern states were widely used shortly after their publication (Chamberlin, 1895). Coleman (1909) advocated discarding the Logan *et al.* (1863) classification and presented a new one (Table 2) combining some terms from the midwestern states (Wisconsin, Iowan, Illinoian) with local names of deposits, many of the latter of a genetic nature. By 1957, Dreimanis proposed new stratigraphic divisions of the Wisconsin glacial stage along the northern shore of Lake Erie; then it was extended to the Toronto area (Dreimanis and Terasmae, 1958).

The early classifications emphasized deposits, but names for materials, inferred events, and time were commonly interwoven and not clearly separated. Terms were often used interchangeably between what are now regarded as separate categories. Building on Coleman's work, which culminated in his 1933 report on Toronto geology, and current American practice including elaboration by Leighton (1933, 1960), names for rock units proliferated in Ontario from about 1960 on (e.g., Terasmae, 1960; deVries and Dreimanis, 1960; Karrow, 1963, 1967, 1974; Gwyn, 1972). A trend toward finer discrimination and clear distinction between categories of stratigraphic units was embodied in the 1961 code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961).

For most of the past 25 years, there have been mainly two *time-stratigraphic* classifications in use in the Great Lakes region, the Frye and Willman (1960) classification, representing the view from Illinois for the Lake Michigan lobe (Table 3), and the Dreimanis and Karrow (1972) classification, mostly

TABLE 2
Classification of Ontario Drift (after Coleman, 1909)

Nipissing clay, sand, and gravel
Algonquin clay, sand, and gravel
Iroquois clay, sand, and gravel
Warren gravels
Wisconsin moraines and till
Clarke interglacial sands and clays
Iowan till
Toronto Formation
Scarboro beds
Don beds
Illinoian till

TABLE 3
Classification of the Wisconsinan Stage in the Lake Michigan Glacial Lobe (after Frye and Willman, 1960)

Wisconsinan Stage	Valderan Substage
	Twocreekan Substage
	Woodfordian Substage
	Farmdalian Substage
	Altonian Substage

based on the record of the Erie and Ontario lobes in southern Ontario, northwestern Pennsylvania, and southern Quebec (Table 4). Both schemes were found to be quite useful and were the basis for correlation and comparison locally and internationally. Although identified as time-stratigraphic, workers nearly always speak in terms of "early" and "late" (pure time) rather than "upper" and "lower," which are appropriate for chronostratigraphic terminology.

Frye and Willman (1960) approached the problem of time-stratigraphic classification with newly available radiocarbon dating and attempted to apply the principles of stratigraphy in use for older rocks to those of late Quaternary age. For example, they used adjectival endings consistently for their time-stratigraphic terms (e.g., Wisconsinan instead of Wisconsin, and Valderan instead of Valders) and otherwise adopted more rigor in lithostratigraphy (Willman and Frye, 1970). The 1960 scheme was later extended into Wisconsin with endorsement by the United States Geological Survey (Frye *et al.*, 1968), and new work in the northern Lake Michigan basin led to some modification in terminology by Evenson *et al.* (1976), specifically the substitution of Greatlakean for Valderan as the last substage of the Wisconsinan Stage.

Frye and Willman (1960, p. 4) placed the beginning of their Wisconsinan Stage and their Altonian Substage at the "end of the last major interglacial interval"—"at least 50,000 and per-

TABLE 4
Eastern Great Lakes–St. Lawrence Region Time-Stratigraphic Classification (after Dreimanis and Karrow, 1972)

Late Wisconsin(an)	Driftwood Stadial
	North Bay Interstadial
	Valders Stadial
	Two Creeks Interstadial
	Port Huron Stadial
	Mackinaw Interstadial
	Port Bruce Stadial
	Erie Interstadial
	Nissouri Stadial
Middle Wisconsin(an)	Plum Point Interstadial
	Cherrytree Stadial
	Port Talbot Interstadial
Early Wisconsin(an)	Guildwood Stadial
	St. Pierre Interstadial
	Nicolet Stadial

haps as much as 70,000 radiocarbon years ago.” (Frye *et al.* (1968, p. 14) modified this boundary definition, placing the boundary at the base of the Roxana Silt resting on the Sangamon interglacial soil, and they estimated its age at 75,000 years based on dates reported by Dreimanis *et al.* (1966) from Port Talbot, Ontario. The boundary modifications of Frye *et al.* (1968) were prompted largely by the appearance of the 1961 Code of Stratigraphic Nomenclature, which stimulated more rigorous treatment of nomenclature, such as the basing of time-stratigraphic boundaries on those in the sedimentary record.

Frye and Willman (1960, p. 4) placed the end of the Wisconsinan Stage and Valderan Substage at 5000 yr B.P., followed by a Recent Stage based on the estimated “time since the continental glaciers were dissipated from the North American continent and sea level was stabilized at approximately its present position.” Frye *et al.* (1968, p. 13) modified this boundary definition to “the contact between the Cochrane till and the post-Cochrane deposits in the Ontario, Canada region” with an age of about 7000 yr B.P. Evenson *et al.* (1976, p. 418) retained the definition of Frye *et al.* (1968) for the most part, substituting “glaciolacustrine” for “post-Cochrane.” They further accepted Willman and Frye’s (1970) substitution of Holocene for Recent with a local boundary between Wisconsinan and Holocene at 7000 yr B.P. Karrow (1978) expressed concerns about the resulting two-level classification and the use of the term “Holocene,” recognized internationally as post-Pleistocene time, for a stage of the Pleistocene.

Dreimanis and Karrow (1972) found that the Frye and Willman (1960) classification did not fit well with the history of their area of work in southern Ontario and gave several reasons for devising a separate scheme. Their classification (Table 4), in part influenced by Lüttig (1965), incorporated three levels of time subdivision (stage, substage, stadial/interstadial) with a potential fourth level (phase), compared to the two levels (stage, substage) of Frye and Willman (1960). Their name for the last glacial stage was given as Wisconsin(an), which has confused some readers, but was done to accommodate the differing views at the time of the two authors, one favoring Wisconsin, the other Wisconsinan; it was left for readers to follow their own preference. Privately, they later came to agree on Wisconsinan.

Dreimanis and Karrow’s (1972) Wisconsinan Stage was divided into early and late cold glacial substages and a middle cool, predominantly nonglacial substage, in good agreement with deep-sea core paleotemperature inferences. By then, even more radiocarbon dating control was available and provided refinement on the “interstadial” glacial recessions. Because of space restrictions set by the International Geological Congress organizers, full documentation of the material units (lithosomes) on which time boundaries were based was deferred to a later paper, but that paper was never prepared. This lack of documentation has been the source of some of the subsequent criticisms of the Dreimanis and Karrow (1972) classification. In 1973, Dreimanis and Goldthwait extended this scheme to cover the Huron lobe and Ohio.

The continuing studies of many workers have provided much new stratigraphic information and still more dating control. In 1983, a new North American Stratigraphic Code appeared. It provided a new approach to time classification particularly suited to Quaternary history, where greater time resolution emphasizes diachronism in lithosomes and inferred events. The Code provides for this with diachronic units defined (Article 91, p. 870) as comprising “the unequal spans of time represented either by a specific lithostratigraphic, allostratigraphic, biostratigraphic, or pedostratigraphic unit, or by an assemblage of such units.” As described in the Code (Article 94(c), p. 871), we propose to adopt the terminology in our classification.

Beginning in late 1986, discussions began between Karrow and Dreimanis, and then Johnson, aimed at devising a revised and combined classification for the Great Lakes area. In 1988, A.K. Hansel, Illinois State Geological Survey, circulated a questionnaire to several tens of workers soliciting opinions on time classification. At the 1989 Geological Society of America (GSA) meeting in St. Louis, representatives from several bordering states and Ontario met to discuss possible courses of action. One result was the holding of a Special Session at the North-Central Section meeting of GSA at Toledo in April 1991, at which review papers were presented on dating control and stratigraphy for the Great Lakes states and Ontario. Several discussions were held at other meetings between various groups of interested persons.

Opinions and interest subsequently ebbed and flowed. It became evident that sufficient agreement could not be reached for a single set of terms for the whole Great Lakes area except for the highest levels of time subdivision. A resulting paper (Johnson *et al.*, 1997) (Table 5) proposed a diachronic time and event classification at the episode and subepisode level, including a new episode for postglacial time and new names for subepisodes of the time and events of the last glaciation. Meanwhile, it was agreed that lower levels of classification should be presented separately for parts of the region as was done for Illinois by Hansel and Johnson (1992, 1996). The present paper is a further step in the agreed process.

There has been an attempt to achieve some consensus with the revisions. This was the approach used in preparing the 1983 North American Stratigraphic Code and is in some contrast to the preexisting classifications, which were proposed by individuals largely in isolation. Consensus has, not surprisingly, proven difficult. As Hansel’s questionnaire showed, there is a wide spectrum of opinion on how to proceed, ranging from opposition to any time classification, to maintaining the existing classifications, to indifferent acceptance of any proposal. Any proposed scheme is an experiment, or working hypothesis, as have been the various codes that have been devised. With new findings, later revision will no doubt again become desirable.

TABLE 5
Diachronic Classification for the Great Lakes Region (after Johnson *et al.*, 1997)

Hudson Episode	
	Michigan Subepisode
Wisconsin Episode	Elgin Subepisode
	Ontario Subepisode
Sangamon Episode	

BASIS OF PROPOSED CLASSIFICATION

Nowhere is the stratigraphic record complete (Clague, 1986; Karrow, 1989a), so it must be pieced together from many sites. We want a continuous diachronic time and event classification and must borrow from elsewhere to fill it. Missing sequences (and unrepresented time) at some sites are represented by sediments (and time) at other sites, so as complete a history as is possible has to be built up as a composite. This reality is at odds with the existing Code (NACSN, 1983; Article 91b, p. 870), which states that "a diachronic unit is not extended beyond the geographic limits of the stratigraphic unit on which it is based." Nevertheless, some consensus developed to adopt and adapt diachronic units of the 1983 Code to our purpose. Optimized agreement on unit names used as generally as possible minimizes the creation of new names and shows relationships between different areas.

Our diachronic time and event classification is shown in Table 6 and schematically in a time–distance in Fig. 1. In this paper, all ages are given as noncalibrated ^{14}C years within the nominal 50,000-yr range of the method. There follows below the rationale for each name used in this classification. As in Dreimanis and Karrow (1972) and Johnson *et al.* (1997), the decision to use adjectival endings is an individual one we leave to the reader (see Table 6, note on alternative adjectival endings). The equivalence of the new classification units to others is shown in Table 7, and time–distance diagrams for our region and the Michigan lobe (Johnston *et al.*, 1997) are compared in Figure 2.

Sangamon Episode

Named for the Sangamon soil and Sangamon County, Illinois, this is the time of the last interglaciation or the time of a climate as warm as or warmer than the present (Johnson *et al.*, 1997), and the traditional name is retained. It is principally represented in southern Ontario (at Toronto) by the fluviolacustrine Don Formation (Eyles and Clark, 1988; Karrow, 1990) and in the Hudson Bay Lowland of northern Ontario by the fluvio-paludal Missinaibi Formation (Skinner, 1973). Both formations contain fossils indicating a climate as warm as or warmer than the present. The time span represented and its position in time are undetermined, as it is well beyond the radiocarbon dating range and either other dating methods have been unsuccessful or the results are controversial (Berger and Eyles, 1994; Lamothe *et al.*, 1996, 1998). Correspondence to oxygen isotope substage (0IS) 5e with an age of about 120,000 years is widely accepted. Whether substages 5a–5d are part of "the last interglaciation" is widely debated, with some workers placing them in an "Eowisconsin" interval (e.g., Richmond and Fullerton, 1984). In Ontario, Karrow (1990) and Barnett (1992), and we, herein, favor the narrower span of time, while Fulton, in a Canadian overview, favors the broader (Fulton *et al.*, 1984).

Wisconsin Episode

The time of the last glaciation in North America has long been known as the Wisconsin and the name is retained (Johnson *et al.*, 1997). Named for the state of Wisconsin, it spans the time of glacial activity and cold climates since the last interglaciation. Representative deposits are widespread and complex. The onset of Wisconsin time is undated, but recessions from an early glacier expansion date near 50,000 yr B.P., and major re-expansions at 25,000 yr B.P. followed by recession and disappearance about 6000 yr B.P., have been well documented. The time span generally corresponds to marine oxygen-isotope stages (0IS) 2–4, but it may also include substages 5a–5d (see above).

TABLE 6
Proposed Diachronic Time and Event Classification for the Northern and Eastern Great Lakes Region

Hudson Episode[b]		
Wisconsin Episode[b]	Michigan Subepisode[b]	Driftwood Phase
		Abitibi Phase[a]
		Marquette Phase[a]
		Gribben Phase[a]
		Onaway Phase[a]
		Two Creeks Phase
		Port Huron Phase
		Mackinaw Phase
		Port Bruce Phase
		Erie Phase
		Nissouri Phase
	Elgin Subepisode[b]	Farmdale Phase
		Brimley Phase[a]
		Port Talbot Phase
	Ontario Subepisode[b]	Guildwood Phase
		Willowvale Phase[a]
		Greenwood Phase[a]
	Sangamon Episode[b]	
Illinois Episode[b]		

[a] New names.
[b] Johnson *et al.* (1997).
Note. Alternative terms with adjectival endings for new names would be Greenwoodian, Willowvalian, Guildwoodian, Porttalbotan, Brimlian, Farmdalian, Nissourian, Erian, Portbrucian, Mackinawan, Porthuronian, Twocreekan, Onawayan, Gribbenian, Marquettan, Abitibian, and Driftwoodian.

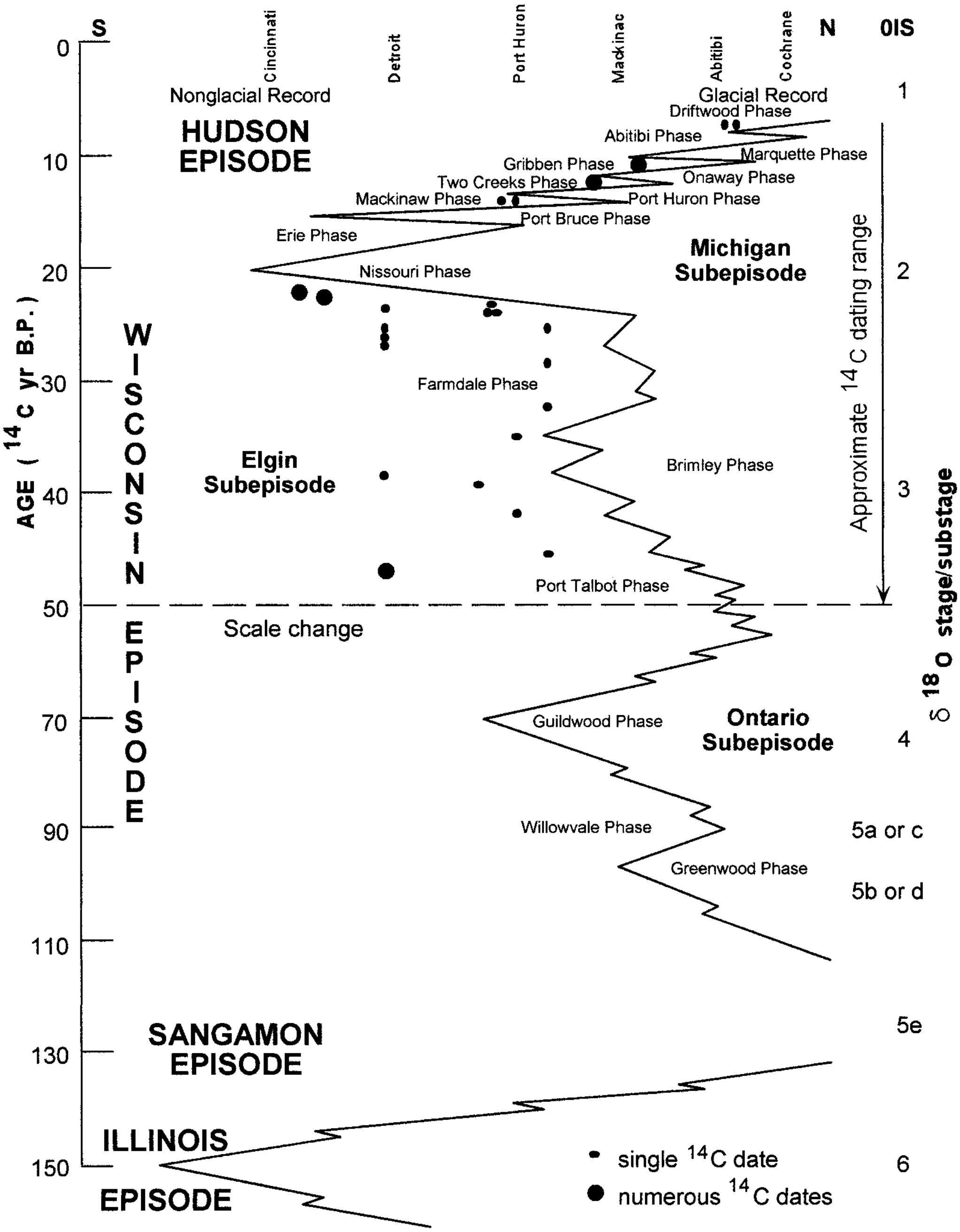

FIG. 1. Time–distance diagram showing a generalized conceptual sketch of late Quaternary history and diachronic time classification for the eastern and northern Great Lakes region. Corresponding oxygen isotope stages (OIS) are shown in the right column.

Ontario Subepisode

This unit is named for southern Ontario (Johnson *et al.,* 1997), where the best record is presently known for this time interval. It is further subdivided into three phases, the Greenwood, Willowvale, and Guildwood, with material referents in the Toronto area (see below). The history it represents is mainly one of cold climates and substantial extent of the continental ice sheet. The Ontario Subepisode replaces the Early Wisconsinan of Dreimanis and Karrow (1972), which was regarded by some as informal or improperly defined because it lacked a specific geographical name; the name Early Wisconsinan Substage is here abandoned. It corresponds to 0IS 4 and perhaps part or all of substages 5a–5d.

Greenwood Phase

The first phase of the Ontario Subepisode is named after Greenwood Avenue in east-central Toronto, where brickyards formerly operated in the clays of the Scarborough Formation,

TABLE 7
Comparison of Classifications and Units from 1961 and 1983 Codes

1961 Geologic-Time	1961 Time-Stratigraphic	1961 Climate/Event	
1983 Geochronologic	1983 Chronostratigraphic		1983 Diachronic
age	stage	glaciation/interglaciation	episode
subage	substage		subepisode
	stadial/interstadial	stade/interstade	phase
			span
			cline

the material referent. The Scarborough Formation contains cool-climate fossils and is a deltaic body of sediment with lower clay and upper sand members (Kelly and Martini, 1986) deposited in high-level Lake Scarborough, believed to have been formed by glacial blocking of the St. Lawrence Valley outlet of the Lake Ontario basin (Karrow, 1967). The Scarborough Formation rests on the Don Formation, a fluvial and lacustrine deposit containing warm-climate fossils, which is thus interglacial. The new term Greenwood replaces Nicolet Stadial of Dreimanis and Karrow (1972), hereby abandoned, which was based on stratigraphy along the St. Lawrence Valley of southern Quebec. Much subsequent work in this valley has

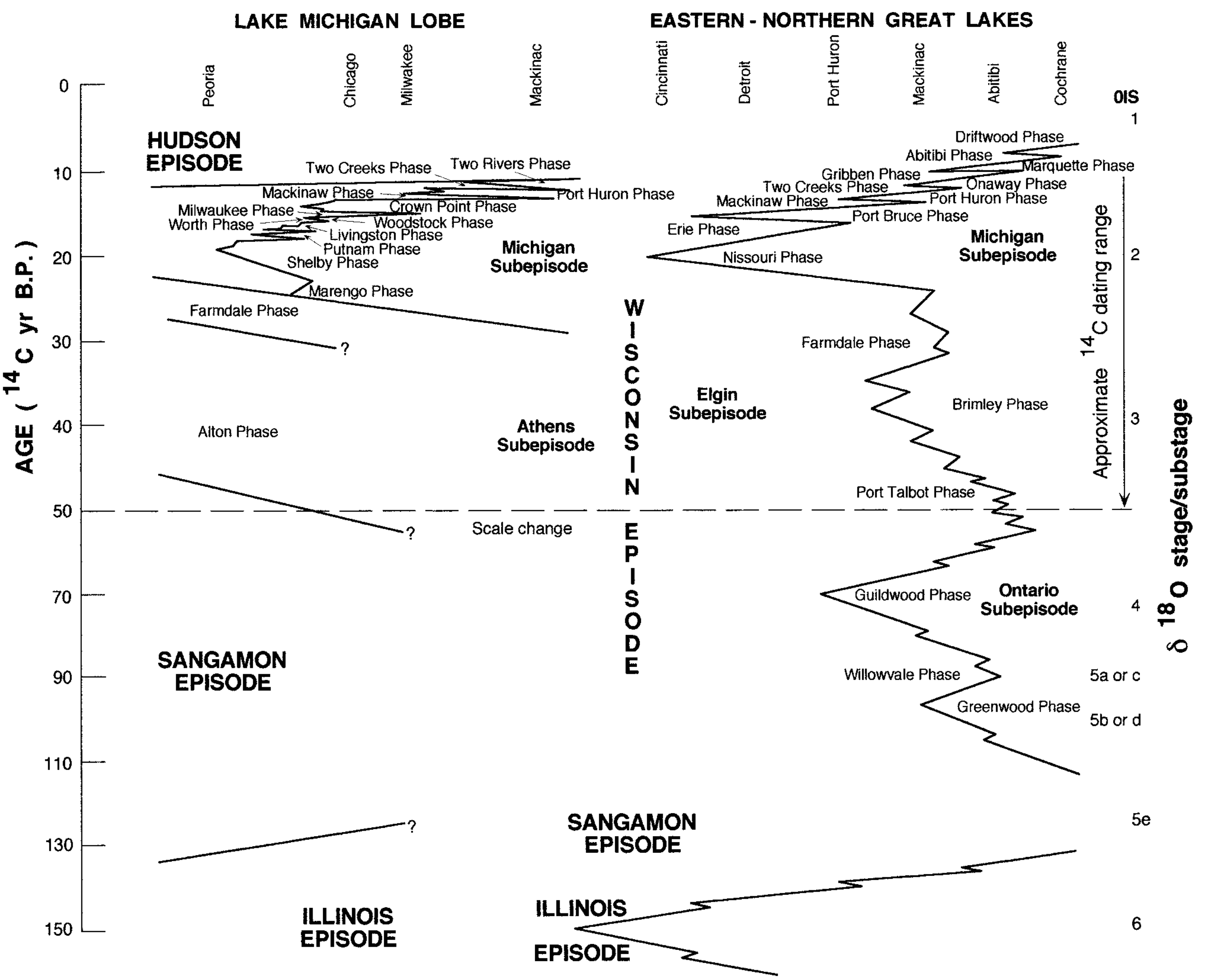

FIG. 2. Comparison of time–distance diagrams for the Michigan lobe (modified from Johnson *et al.*, 1997) and the northern and eastern Great Lakes of the present paper.

led to extensive revision, leaving the age, correlation, and significance of some units uncertain (Lamothe *et al.*, 1992). We have therefore turned to Toronto for a material referent. Correspondence to oxygen isotope substage 5b or 5d is suggested.

Willowvale Phase

The second phase of the Ontario Subepisode is named after Willowvale Park along Bloor Street in west-central Toronto, near the site of former sand pits along Christie and Shaw streets, where channel sands, the material referents, yielded vertebrate fossils (Coleman, 1933). These channel fills are correlated with channel fill gravels at the Don Valley Brickyard named the Pottery Road Formation (Karrow, 1974) and are probably polygenetic. Their formation is interpreted to be associated with lowered water level in the Ontario basin and thus a time of ice retreat (Coleman, 1933; Karrow, 1967), although some sediments may be of glaciofluvial tunnel valley genesis (Sharpe and Barnett, 1985; Hicock and Dreimanis, 1992). This term replaces St. Pierre Interstadial in the classification of Dreimanis and Karrow (1972), and we here abandon that term, for reasons similar to those for the change to Greenwood Phase. However, we still believe the Willowvale correlates with ice-free conditions in the St. Lawrence Valley, perhaps the St. Pierre interval (Les Becquets Interstade of Lamothe *et al.*, 1992). Correspondence to oxygen isotope substage 5a or 5c is suggested.

Guildwood Phase

The third and last phase of the Ontario Subepisode retains the name used by Dreimanis and Karrow (1972) for this time of ice advance in the Ontario basin, but their term Guildwood Stadial is here abandoned. The Guildwood Phase is named after a housing development in Scarborough near Lake Ontario, where glacial and glaciolacustrine sediments of the Sunnybrook Drift occur at or near the surface on the glacial Lake Iroquois terrace (Karrow, 1967, 1969). Sunnybrook Drift is the material referent for this unit, and it indicates the existence of the Laurentide ice sheet extending through the Ontario basin at that time. Hicock and Dreimanis (1992) recognize three members, representing glaciolacustrine, glacial, and glaciolacustrine sedimentation, respectively. Dreimanis (1987, 1992) has suggested that glaciolacustrine sediment of Tyrconnell Formation member B (north-central Lake Erie) may be correlative. It probably corresponds to 0IS 4.

Elgin Subepisode

This, the second subepisode, is named after Elgin County (Johnson *et al.,* 1997), located along the central north shore of Lake Erie south of London, Ontario, where the classic Port Talbot and Plum Point interstadial sediments were described by Dreimanis *et al.* (1966). Other sites of comparable radiocarbon age, such as the Haight site near new Sarum (Barnett *et al.*, 1996), have subsequently become known in the county as well. The material referents are members C and D of the Tyrconnell Formation at Bradtville (Dreimanis, 1987) and the next youngest alluvial deposits at the Haight site (Barnett *et al.*, 1996).

The Elgin is a time of significant ice retreat and moderated climate (at least to forest-tundra vegetation; Berti, 1975) when apparently much of southern Ontario was substantially free of glaciers, interrupted only by limited ice advances in the Ontario basin. It replaces the term Middle Wisconsinan Substage of Dreimanis and Karrow (1972), here abandoned, because it lacked a specific geographical term and its status as a formally defined unit was questioned by some. It probably corresponds to 0IS 3. Only the last half or two thirds is within the normal radiocarbon dating range. The Elgin Subepisode is subdivided into three phases, the Port Talbot, Brimley, and Farmdale.

Port Talbot Phase

This first phase of the Elgin Subepisode is named after Port Talbot on the north shore of Lake Erie, the source of the name for the Port Talbot Interstadial (Dreimanis *et al.*, 1966; Dreimanis and Karrow, 1972), terminology which is here abandoned. The deposits of this time at the stratotype section include lacustrine and organic sediments, with many radiocarbon dates of about 43,000–48,000 yr B.P., (Dreimanis, 1982, 1987, 1992), referred to as Tyrconnell Formation member C, which is the material referent. Correlative deposits at Toronto are identified as the lower member of the Thorncliffe Formation (Karrow, 1967, 1974). Nonglacial sediments at several other interstadial sites in southwestern Ontario are believed to represent the same interval and events (Karrow, 1989b).

Brimley Phase

The second phase of the Elgin Subepisode is represented by lithosome referents in the Scarborough Bluffs sequence, Seminary Till, middle member Thorncliffe Formation, and Meadowcliffe Till, a glacial, glaciolacustrine, and glaciofluvial sequence indicating at least two readvances of the Ontario ice lobe (Karrow, 1967). The name Brimley comes from Brimley Avenue, whose southern extension provides access to the shore of Lake Ontario at the foot of Scarborough Bluffs. Its descent to lake level follows the former Seminary Ravine, which used to be a standard visiting site for examining the Bluffs stratigraphy. The term Brimley Phase replaces Cherrytree Stadial of Dreimanis and Karrow (1972), which was based on a locality, sediments, and an inferred ice advance event in northwestern Pennsylvania that are no longer considered valid (Braun, 1996). Thus, the extent of ice advance is now considered to be restricted to the Lake Ontario basin and to be less than formerly thought. The term Cherrytree Stadial is hereby abandoned. The time interval represented is that between the radiocarbon-dated preceding Port Talbot Phase and the following Farmdale Phase (see below), i.e., between 48,000–43,000 and 39,000–23,000 yr B.P.

Farmdale Phase

The third and final phase of the Elgin Subepisode is named from the Farmdale type locality in Illinois and replaces the term Plum Point Interstadial of Dreimanis and Karrow (1972), which is hereby abandoned. This name was originally used by Leighton to designate a glacial substage based on loess derived from outwash of a related ice advance (Leighton, 1958). Reconsideration of the significance of associated weathering, peat, and wood resulted in the term being applied to a time of ice retreat (Farmdalian of Frye and Willman, 1960). The age equivalence of nonglacial sediments known widely across the Great Lakes area has been well established by radiocarbon dating, 39,000–23,000 yr B.P. in the eastern Great Lakes region, with the succeeding southward glacier advance well documented, particularly in Illinois (Kempton and Gross, 1971) and Ohio (Goldthwait, 1958). Local sediment referents in Ontario include the upper member of the Thorncliffe Formation at Toronto. The Illinois name is adopted because of priority (Frye and Willman, 1960).

Michigan Subepisode

Named for the state of Michigan, centrally located in the Great Lakes area (Johnson *et al.*, 1997), this subepisode embraces the Late Wisconsinan of Dreimanis and Karrow (1972), and their term is hereby abandoned. This is also the time of glaciation formerly referred to by some as "classical Wisconsin" (Flint, 1957). Material referents embrace numerous named surface and near-surface tills and associated meltwater deposits (see below). It is fully within the range of radiocarbon dating and corresponds to 0IS 2, a time of cold climate and extensive continental glaciation.

Nissouri Phase

This, the first unit of the Michigan Subepisode, continues the concept of Dreimanis and Karrow's (1972) Nissouri Stadial, named after Nissouri Township in Middlesex County, Ontario, but the term Nissouri Stadial is here abandoned. Coarse-textured till of the Catfish Creek Drift (deVries and Dreimanis, 1960; Karrow, 1988) is the material referent and is widely recognized in southwestern Ontario as being the deposit of the main advance of the ice to the maximum reached near the Ohio River. Correlative till, typically silty or sandy, is widely recognized in nearby states (e.g., Kent Till of Ohio; White, 1960).

Erie Phase

The second phase of the Michigan Subepisode is a nonglacial interval represented by lacustrine sands and clays of the Malahide Formation (Mörner and Dreimanis, 1973; Dreimanis, 1987) that separate coarse-textured Catfish Creek Drift from overlying fine-textured Port Stanley Drift. The latter contains, and is interbedded with, much glaciolacustrine clay and silt that accumulated in the Erie basin (the source of the name Erie) during a time of ice recession, interpolated to be about 16,000 yr B.P. The term Erie Interstadial of Dreimanis and Karrow (1972) is hereby abandoned, but the name and concept are continued in the modified terminology.

Port Bruce Phase

The name Port Bruce is taken from the community of that name on the north-central shore of Lake Erie and follows the usage of Port Bruce Stadial of Dreimanis and Karrow (1972), but the latter term is here abandoned. The material referents are the Port Stanley Drift of the Erie lobe and Tavistock and Rannoch tills of the Huron lobe (Karrow, 1993), which are mostly fine-grained multiple till layers believed to have formed by incorporation of glaciolacustrine clay and silt (Erie Phase) during widespread advance of the Erie and Huron lobes. Most of the surface glacial deposits in southwestern Ontario were formed during this time and correlative deposits are widespread in the nearby northern United States, e.g., Hiram Till of Ohio (White, 1960).

Mackinaw Phase

An interval of ice retreat and predominantly nonglacial sedimentation is named for Mackinaw City, Michigan. It marks a time of lowered water level in the Lake Michigan basin because of ice retreat sufficient to allow eastward drainage through the Straits of Mackinac (Monaghan and Hansel, 1990) and probably the Fenelon Falls outlet in Ontario. Its age was originally taken from the oldest date on the Cheboygan (Michigan) bryophyte bed (Farrand *et al.*, 1969), thought to mark this glacial recession. However, re-excavation and redating of that site has led to a revised younger age, so it is no longer considered representative of this phase (Larson *et al.*, 1994). Through an error, the Mackinaw and Milwaukee phases became interchanged in Hansel and Johnson (1996) and Johnson *et al.* (1997). The correct placement in Illinois is for the Milwaukee Phase to separate the Woodstock and Crown Point phases, and for the Mackinaw Phase to be between the Crown Point and Port Huron phases, equivalent to its position between the Port Bruce and Port Huron phases of Ontario.

In Ontario, unnamed sediments serve as the referents for this phase. They include: sediments of glacial Lake Arkona and others between Port Stanley Drift and Wentworth Till and beyond the limit of the Wentworth Till, exposed in Lake Erie bluffs near Long Point with an age of about 13,300 yr B.P. (Barnett, 1984; Warner and Barnett, 1986); Wentworth Till; and sediments between Wentworth Till and Halton Till (and their correlatives), including early sediments of glacial Lake Whittlesey. In the southeastern Huron basin, a single date on a spruce log near the base of St. Joseph Till (Port Huron advance) of 13,100 $\pm$ 110 yr B.P. (GSC-2213: Gravenor and

Stupavsky, 1976) also represents this time of ice recession and lowered lake level prior to Lake Whittlesey. The designation Mackinaw Interstadial, of Dreimanis and Karrow (1972), is hereby abandoned, but the concept and source name are retained.

Port Huron Phase

A prominent series of moraines and related tills marks a substantial readvance of the ice to the Port Huron moraine (Wyoming moraine of Ontario) and its correlatives in Michigan and Wisconsin, dated at close to 13,000 yr B.P. (Hansel and Johnson, 1992). In the "thumb" of the lower peninsula of Michigan, Eschman (1978) identified the sediment of the Port Huron moraine as the Jeddo Till.

Ontario material referents for this phase are the St. Joseph Till (Huron lobe; Cooper, 1979), Kettleby Till (Georgian Bay–Simcoe lobe; Gwyn, 1972), and Halton Till (Ontario lobe; Karrow, 1963). The Port Huron Stadial of Dreimanis and Karrow (1972) is here abandoned. This ice advance in Ontario blocked eastward Trent Valley and Niagara area drainage and diverted raised lake outflow such as Whittlesey, westward across Michigan to the restored Glenwood phase of Lake Michigan and south through the Chicago outlet.

Two Creeks Phase

The Two Creeks forest bed, exposed at its type section on the shore of Lake Michigan in eastern Wisconsin, has long been known to mark an ice retreat of the Lake Michigan lobe and lowered water level in that basin. It has been dated numerous times and is often used as a source of radiocarbon laboratory reference samples. Its average age (wood) is 11,850 yr B.P. (Broecker and Farrand, 1963). With the redating of the Cheboygan bryophyte bed (average of four new dates: 11,825 yr B.P.) as equivalent in age, the ice recession and spread of vegetation is now recognized into northeastern lower Michigan and the northwestern Huron basin (Larson *et al.*, 1994).

Material referents in Ontario have not yet been identified for certain, but they would probably include some earlier sediments of glacial Lake Algonquin, generally covered by later sediments of that lake.

Onaway Phase

The Two Creeks forest bed of Wisconsin was overridden by the rapidly advancing Lake Michigan lobe, which deposited reddish clay-rich till initially identified as the Valders Till. Reinterpretation of the stratigraphy in eastern Wisconsin led to differentiation of the overlying till as the Two Rivers Till, and the event and related time were changed from the Valderan of Frye and Willman (1960) to the Greatlakean of Evenson *et al.* (1976). Meanwhile, Burgis and Eschman (1981) mapped deposits of the equivalent ice advance into northeastern lower Michigan, which they called the Onaway advance. Although Hansel and Johnson (1992) chose a new name, Denmark Phase, for this time interval, they later substituted Two Rivers Phase, named after the superjacent till at the Two Creeks type section. To be consistent and not use lithostratigraphic names for diachronic units, we have chosen instead to adopt the Michigan name Onaway Phase in our nomenclature.

Equivalent deposits in Ontario have not been identified. The limit of glacial advance trends eastward into Lake Huron from Michigan and should logically extend across the Bruce Peninsula and east of Georgian Bay, where glacial deposits are thin and discontinuous. The Valders Stadial of Dreimanis and Karrow (1972) is here abandoned.

Gribben Phase

In the upper peninsula of Michigan, the Lake Gribben forest bed, dated at approximately 10,000 yr B.P. (Drexler *et al.*, 1983, Lowell *et al.*, 1999), marks forest growth just prior to the last advance of the Lake Superior lobe. Following the provisions of the Stratigraphic Code regarding choice of geographic names (Article 7a, p. 852) we omit the word Lake from the name, as did Drexler *et al.* (1983), and designate it as the Gribben Phase.

No equivalent material referents have been identified in Ontario but should be expected to occur east of Lake Superior. This area is largely unmapped and is part of the higher relief Precambrian Shield terrain, where sediments are patchy and discontinuous. This phase is equivalent to the early to middle part of the North Bay Interstadial of Dreimanis and Karrow (1972), terminology which is here abandoned.

Marquette Phase

The last advance of the Lake Superior lobe, which ended the Gribben Phase, is referred to as the Marquette advance (Clayton and Moran, 1982; Drexler *et al.*, 1983), and we adopt this term for the diachronic unit Marquette Phase. Material referents are the unnamed deposits of the Grand Marais moraine of Michigan. The advance and retreat must have been rapid, and the time span represented can only be a few centuries about 10,000–9500 yr B.P.

Lowell *et al.* (1999), following Saarnisto (1974), correlate the Marquette ice margin position at the Grand Marais moraine of northern Michigan with the discontinuous Cartier moraine of Ontario (Boissoneau, 1968), and they further suggest it marks the Younger Dryas event in Ontario. Much uncertainty in such correlations makes them still tenuous. This phase is equivalent to a later part of the North Bay Interstadial of Dreimanis and Karrow (1972), terminology which is here abandoned.

Abitibi Phase

This phase, the second to last of the Michigan Subepisode, is named from Lake Abitibi, in northeastern Ontario. Its material referents are the lacustrine sediments of glacial Lake Barlow-Ojibway, the Barlow-Ojibway Formation (Hughes, 1965), which are widespread across northern Ontario. These sediments were deposited during widespread glacier retreat from and north of the Superior and Huron basins. This phase corresponds to the latest part of Dreimanis and Karrow's (1972) North Bay Interstadial, a term which never came into widespread use and is here abandoned.

Driftwood Phase

This, the last phase of the Michigan Subepisode, is named after Driftwood, west of Cochrane in northern Ontario. The material referent is the Cochrane Till (Prest, 1993), formerly Cochrane Formation of Hughes (1965). This till represents the last known major ice advance of the Laurentide ice sheet and is recognized across northern Ontario south of Hudson Bay, and into northwestern Quebec. The term is equivalent to the Driftwood Stadial of Dreimanis and Karrow (1972) and that term is here abandoned.

Hudson Episode

Postglacial time is embraced by the Hudson Episode, named after Hudson Bay, around which unnamed marine (Tyrrell Sea), fluvial, and paludal sediments were formed after stagnation, retreat, and breakup of the ice sheet. Through isostatic uplift and regression of the Tyrrell Sea, fluvial and paludal environments replaced marine, and that succession continues today. This name was used briefly by Leighton (Hudsonian) to designate his latest of three Wisconsin substages, but it was formally withdrawn and renamed Mankato (Leighton, 1958). Dreimanis and Karrow (1972) did not deal with postglacial time, while the usage of Frye and Willman (1960), Frye *et al.* (1968), Willman and Frye (1970), and Evenson *et al.* (1976) of Recent and Holocene has already been described. The Hudson Episode corresponds to the European chronostratigraphic term Flandrian, which is the name of the stage equivalent to Holocene Epoch. Both Flandrian and Holocene are defined with fixed lower boundaries at 10,000 ^{14}C yr B.P., in contrast to the diachronous boundary between the Wisconsin and Hudson episodes, which varies from near 20,000 ^{14}C yr B.P., at the southern limit of ice advance near the Ohio Valley, to less than 8000 ^{14}C yr B.P. in northern Ontario (Dredge and Cowan, 1989).

SUMMARY

Classification of geological time is an ever-evolving process. In this paper we have proposed a revised subdivision of time and events since the penultimate glaciation, or about the last 130,000 years of earth history. The proposed time classification builds on the recent proposal of Johnson *et al.* (1997) and provides further or finer diachronic subdivisions for the eastern and northern Great Lakes area centered on Ontario. A deliberate attempt was made, where appropriate, to use terminology similar to that used in previous time-stratigraphic classifications in order to provide continuity and to ease the transition into the proposed system. The rationale behind the selection of all terms used in the proposed diachronic classification has been presented. With new findings, revision will no doubt again become desirable.

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