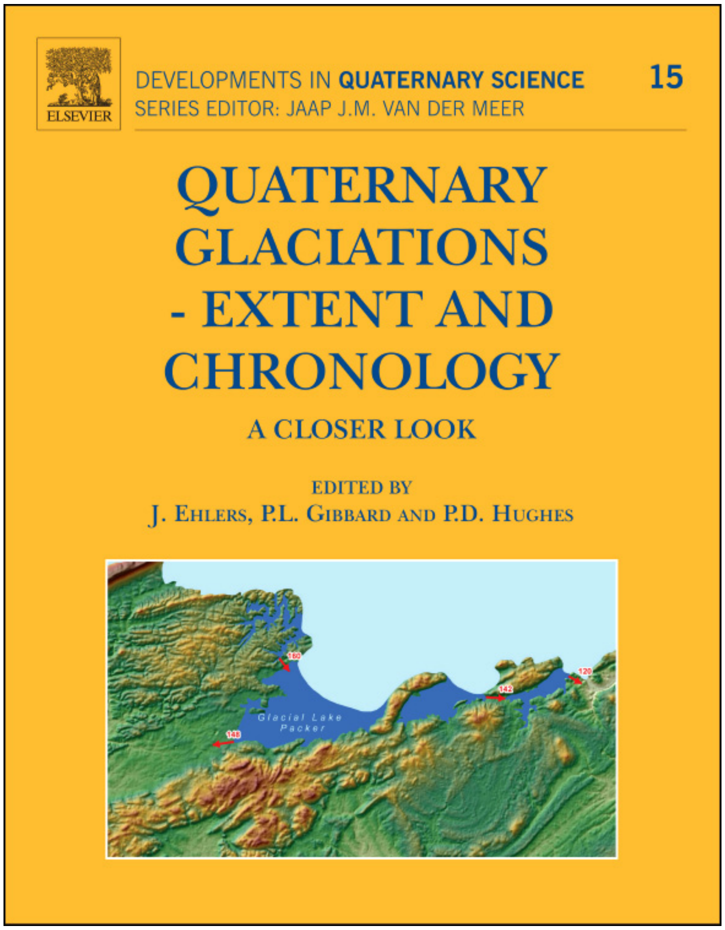

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Chapter 43

Summary of Early and Middle Pleistocene Glaciations in Northern Missouri, USA

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43.1. INTRODUCTION

This chapter summarises recent work on the stratigraphy of glacial sediments at or near the southern limit of North American Pleistocene glaciation in northern Missouri, USA (Fig. 43.1). This stratigraphical sequence records the most extensive advances of the Laurentide Ice Sheet (LIS) during the Early and Middle Pleistocene.

In this chapter, we use "till" in a dual but related sense. The term always indicates a general texture and mode of deposition—a diamicton generated by and deposited from glacial ice. Additionally, the term may refer to lithostratigraphical units that are comprised predominantly of till. We also use the revised Quaternary time scale (Gibbard et al., 2010) for chronological references. Thus, "Early Pleistocene" denotes ages between 2.6 and 0.78 Ma, "Middle Pleistocene" 0.78–0.13 Ma, and "Late Pleistocene" 0.13–0.012 Ma. Finally, many glacial deposits in central North America are commonly referred to by regional stage/episode names. Although the original conception of four Pleistocene glaciations that led to this naming system is obsolete, the terms "Wisconsinan" (referring to the most recent glaciation), "Illinoian" (referring to the penultimate glaciation), and "pre-Illinoian" (referring to all older glaciations) are still in common use, and we use them in this sense here.

Pre-Illinoian glacial deposits of the Midwestern United States are not, in general, well dated, because they are too old for radiocarbon and luminescence techniques. Moreover, they apparently are too old to preserve ice-constructional topography, so ice margins cannot be reconstructed from moraine systems and other landform assemblages. Therefore, the results and interpretations here are generated by (i) observations at numerous isolated exposures, (ii) correlation between these exposures based on quantitative analyses of lithological properties, (iii) palaeomagnetic measurements, and (iv) direct age measurements of individual tills by the cosmogenic-nuclide burial dating technique. We have applied some or all these methods at 30 sections in this study area which expose two or more superposed tills. Of these, 14 preserve three or more tills separated by mature weathering profiles, four expose at least four such tills, and one preserves five tills (the complete stratigraphical sequence).

The resulting stratigraphical synthesis is summarised in Fig. 43.2. Glaciogenic sediments in Missouri range in approximate age from 2.4 Ma to 20 ka and span pre-Illinoian to Wisconsinan Stages. However, direct glacial deposits (i.e. till), which record glacial advances into the state, are limited to the Early and Middle Pleistocene. With the exception of distal valley-train outwash in the major river valleys (Mississippi and Missouri Rivers), Wisconsinan and most of the Illinoian Stage deposits are limited to loess. The Illinoian glaciation (during Marine Isotope Stage (MIS) 6) extended ~140 km south of the confluence of the Mississippi and Missouri Rivers but generally in Illinois east of the present Mississippi River valley. Locally, as near St. Louis, the present channel may have been established slightly east of this ice-marginal position. Illinoian till is periodically exposed north of St. Louis in a small area just west of the Mississippi River (Whitfield, 1995). The extent of this till is not known accurately, but it probably extends no farther than a few kilometres west of the Mississippi. With this minor exception, all known till in Missouri is pre-Illinoian in age. Thus, five major pre-Illinoian glaciations in Missouri are recorded by six widely distributed tills that are separated vertically by four mature weathering profiles.

43.2. EARLY WORK IN MISSOURI

Early workers in Missouri largely followed nomenclature and concepts established in neighbouring states. Descriptions of tills were qualitative, and correlations were based

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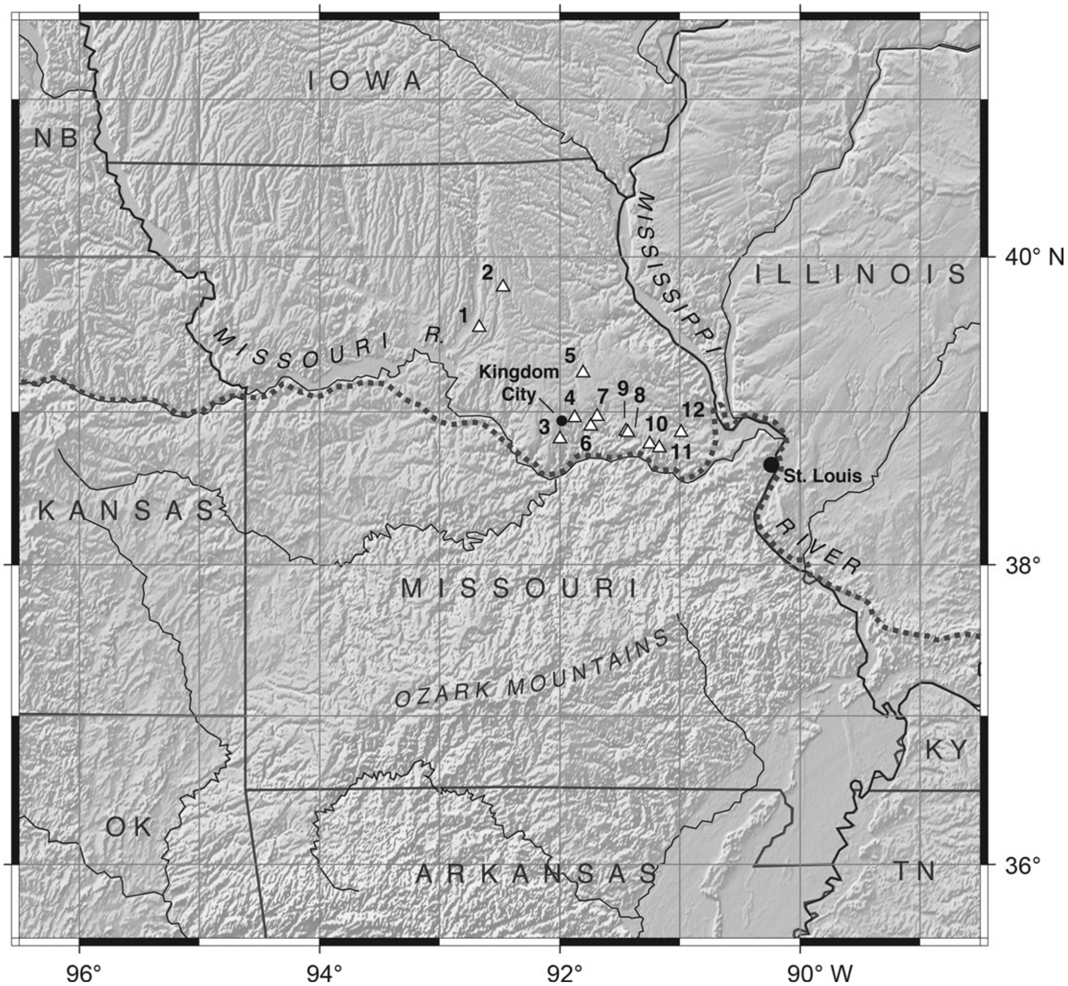

FIGURE 43.1 Location Map. Triangles show locations of important sections (Table 43.1); appended numerals correspond to those in Table 43.1. The dashed line is the (composite) southern margin of glaciation. In Illinois, this line shows the limit of Illinoian (MIS 6) advance; in Missouri and Kansas, this line represents the southern boundary of multiple pre-Illinoian glaciations. "NB" denotes Nebrasksa.

on their position relative to any observed weathering profile, with the assumption that only one such profile occurred within the pre-Illinoian glacial sequence. Apparently, no sections ever exposed more than one weathering profile, and early workers in Missouri followed the now obsolete North American framework of two pre-Illinoian till sheets, consisting of "Kansan" till overlying the older "Nebraskan" (Shipton, 1924; Holmes, 1942; Heim, 1961). This twofold division of "Kansan" and "Nebraskan" influenced perceptions and interpretations of glacial sediments in Missouri into the 1980s. Hallberg (1986, p. 13), in summarising the state of knowledge for Missouri at that time, could only state that "at least two pre-Illinoian tills have been recognised".

Following publication of *The Stratigraphic Succession in Missouri* in 1961 (Koenig, 1961), the Missouri Geological Survey placed little emphasis on glacial and Quaternary sediments. Nevertheless, by the 1970s, various authors had recognised and described (mostly in informal field guides) three or more tills in direct superposition at multiple sites in Missouri (Guccione et al., 1973; Allen and Ward, 1974).

Guccione (1983) introduced an informal lithostratigraphical framework for glaciogenic sediment in Missouri. The present lithostratigraphical nomenclature has grown from Guccione's work with later additions and restrictions by Tandarich (1992) and Rovey and Kean (1996); formation names were formalised by Rovey and Tandarich (2006).

43.3. STRATIGRAPHY AND LITHOLOGIES

Six tills can be recognised and correlated over large portions of northern Missouri (Fig. 43.1, Table 43.1; Rovey and Tandarich, 2006; Balco and Rovey, 2010). These six tills represent five major glaciations, based on the presence of four mature weathering profiles with argillic B horizons developed atop individual tills. Two of the tills are not separated by a significant weathering horizon and appear to

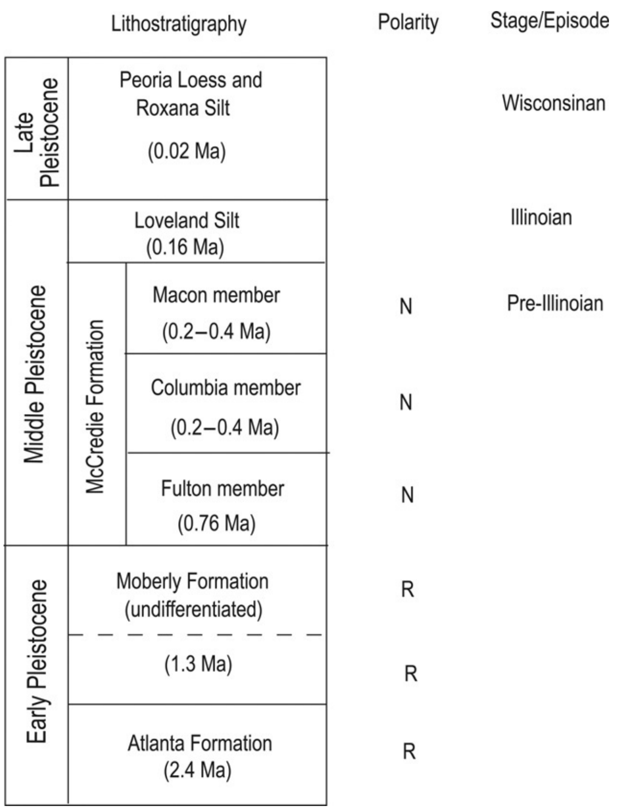

FIGURE 43.2 Stratigraphy of Glaciogenic Sediment in northeast Missouri. The Roxana and Loveland Silts are mostly loess; the McCredie, Moberly, and Atlanta Formations are mostly till. Members within the McCredie Formation are informal. Approximate ages are given for each stratigraphical unit; see the text for a discussion of these ages and error limits. "N" denotes normal magnetic polarity; "R" reversed.

represent closely spaced ice advances during a single glacial episode. The six tills are grouped into three formations that are recognisable in the field by visual characteristics.

Laboratory characteristics of each till are summarised in Table 43.2. These averages are most representative within the western portion of the study area (Sections 1–9, Fig. 43.1) where the complete stratigraphical sequence was first recognised (Rovey and Kean, 1996). More recently, the Missouri Division of Geology and Land Survey completed a drilling transect between St. Louis and Kingdom City (Fig. 43.1). These results showed that the same stratigraphical sequence is present in the easternmost portion of Missouri as well, and individual tills display the same relative differences in lithology. Nevertheless, analysis of these cores has defined an east–west gradient in some lithological parameters. Tills within the McCredie and Moberly Formations become sandier to the east, and they also contain more igneous-rock fragments within the coarse-sand fraction. The clay mineralogy within these two formations also grades eastwards to compositions with a lower percentage of expandable clay.

The oldest till (Atlanta Formation) is rarely preserved, but it is recognised by a very cobbly texture with a high proportion of sedimentary to igneous clasts. In some cases, a highly weathered residual lag between bedrock and the Moberly Formation is assigned to the Atlanta Formation, based on the presence of erratic lithologies.

The younger Moberly and McCredie Formations have a lower concentration of clasts but a much higher proportion of igneous and metamorphic lithologies. The Moberly Formation usually is the first till above bedrock, and it generally has a higher concentration of organic materials (wood, charcoal, and coal) than the overlying McCredie Formation. The high organic content within the Moberly renders it much more resistant to oxidation than the other tills, and the Moberly is the only till which commonly retains a significant unoxidised zone.

Recently, we recognised two tills with nearly identical lithology within the Moberly Formation (Balco and Rovey, 2010). However, these two tills can be distinguished only where they are in direct superposition and separated by interbedded fluvial/lacustrine sediment and/or a weak weathering profile, marked mainly by a concentration of redox features typical of relatively short (interstadial not interglacial) surface exposure.

The three members of the McCredie Formation represent distinct glaciations, as they are separated vertically by mature weathering profiles. Nevertheless, they are lumped within a single formation, because each one cannot always be indentified unambiguously in the field without any stratigraphical context. The (lower) Fulton member is quite distinct, however, based on laboratory parameters. The Fulton has the finest clay-rich texture and also contains a much lower percentage of crystalline rock fragments in the coarse-sand fraction. The youngest (Macon) member generally is preserved in stable landscape positions along interfluves. Even in this position, however, the Macon usually is highly weathered throughout its entire thickness, which precludes an adequate lithological characterisation. Based on three occurrences in the northern portion of the study area, the unaltered Macon till has a sandier texture than the other tills within the McCredie Formation, and it also has a lower percentage of expandable clay minerals (Table 43.2).

Tills within the McCredie Formation have been left as informal members (Rovey and Tandarich, 2006) due to several factors. Among these reasons is some uncertainty in correlating the Macon member among sections. "Macon" is generally applied to a highly weathered till above a discrete weathering profile atop the Columbia member. Thus, superposition, without supporting lithological characterisation, is the only criterion used for its assignment in these cases, and multiple tills of different ages could be lumped within the same stratigraphical unit.

TABLE 43.1 Important Sections in Northeast Missouri

Section/location Till unit	Polarity	Age (Ma)	Reference
1. AECI Pit—S.26, T55N, R16W: 39°32.50′N, 92° 40.17′W			
Columbia			Rovey and Kean (1996), Rovey (1997), Rovey and Kean (2001)
Fulton	N		
Moberly	R		
2. SMS92a (core)—S.28, T78N, R14W: 39°48.15′N, 92° 28.45′W			Balco and Rovey (2010), Rovey and Kean (1996)
Macon			
Columbia		0.31 ± 0.50	
Fulton			
Moberly			
3. FU02 (core)—S.24, T47N, R10W: 38°49.30′N, 92°00.00′W			Balco and Rovey (2010), new
Fulton	N	0.84 ± 0.11	
upper Moberly	R		
lower Moberly			
4. Harrison Pit—S.1, T48N, R9W: 38°57.53′N, 91° 52.42′W			Rovey and Kean (1996), Rovey and Kean (2001)
Columbia			
Fulton	N		
Moberly	R		
5. Blum/Sieger Pit—S.33, T52N, R8W: 39°14.88′N, 91° 48.36′W			Balco and Rovey (2010), Rovey (1997), Rovey and Kean (2001), Balco and Rovey (2008)
Macon		0.21 ± 0.18	
Columbia	N		
6. Prairie Fork (core)—S.30, T48N, R7W: 38°54.24′N, 91° 44.58′W			Balco and Rovey (2010), Balco and Rovey (2008), new
Macon		$\leq 0.18 \pm 0.15$	
Columbia		0.21 ± 0.16	
Fulton			

7. WB 19 (core)—S.3, T48N, R7W: 38°57.84′N, 91°41.22′W			Balco and Rovey (2010)
Fulton			
upper Moberly			
lower Moberly		1.31 ± 0.09	
8. Johnson/Deeker Pit—S.2, T47N, R5W: 38°52.20′N, 91° 27.10′W			Rovey and Kean (2001), new
Columbia			
Moberly	R		
Atlanta	R		
9. Musgrove Pit/NF06 (core)—S.1&2, T47N, R5W: 38°51.80′N, 91° 26.10′W			Balco and Rovey (2010), Balco et al. (2005), Rovey and Kean (2001), Rovey et al. (2006), Balco and Rovey (2008), Rovey and Balco (2010)
Columbia		0.74 ± 0.06	
Moberly	R	1.31 ± 0.15	
Atlanta	R	2.48 ± 0.15	
10. Pendleton Pit—S.33, T47N, R3W: 38°47.28′N, 91° 15.11′W			Balco and Rovey (2010), new
Fulton	N		
Moberly	R(?)		
Atlanta	R	2.28 ± 0.16	
11. Polston Pit—S.7, T49N, R3W: 38°45.79′N, 91° 10.45′W			new
Atlanta	R		
12. WL3 (core)—S.14, T46N, R1W: 38°51.78′N, 90° 59.40′W			Balco and Rovey (2010), Balco and Rovey (2008)
Fulton		0.80 ± 0.06	
upper Moberly			
lower Moberly			

This table includes all sections in northeast Missouri with palaeomagnetic and/or age control. Numerals correspond to those in Fig. 43.1; some nearby sections are lumped together, as they cannot be plotted separately at this scale. The lithostratigraphy of till units is shown in Fig. 43.2. Any section with previously unpublished data pertaining to palaeomagnetism or burial dates is denoted by "new."

TABLE 43.2 Chronological, Magnetic, and Lithological Properties of Tills in Northeast Missouri

			Clay Mineralogy				Texture				Sand-fraction: Lithology			
Age (Ma)	Polarity	Unit	*E*	*I*	*K+C*	(n)	*Sa*	*Si*	*Cl*	(n)	*Q+F*	*C+C*	*I+M*	(n)
0.2–0.4	N	Macon	48	23	29	(3)	37	34	29	(3)	61	29	10	(3)
0.2–.04	N	Columbia	54	23	23	(8)	34	34	32	(8)	60	30	10	(8)
0.76	N	Fulton	53	25	22	(6)	26	37	37	(7)	60	36	4	(7)
1.3	R	Moberly	39	34	27	(7)	28	41	31	(7)	53	40	7	(7)
2.4	R	Atlanta	16	49	35	(4)	18	46	36	(4)	16	82	2	(4)

Values within each category are normalised percentages taken from Rovey and Tandarich (2006); these values are means of individual averages at various sites. See Rovey and Tandarich (2006) for procedures, definitions, and site-specific values. Ages for tills are based on the cosmogenic-nuclide burial dating method; see text and Balco and Rovey (2010) for a summary of age measurements and error limits. Rovey and Kean (2001) and Rovey et al. (2006) summarise palaeomagnetic measurements.
Abbreviations: E, expandable clay minerals; I, Illite; K + C, kaolinite + chorite; Sa, sand; Si, silt; Cl, clay; Q + F, quartz + feldspar; C + C, carbonates + chert; I + M, igneous + metamorphic rock fragments; (*n*) is the number of sites.

43.4. CHRONOLOGY

Prior to the recent advent of the cosmogenic-nuclide burial dating method, only indirect age control could be applied to the pre-Illinoian till sequence in Missouri. The youngest till (Macon member) is present beneath the Loveland Silt (Rovey, 1997), which is widely distributed regionally and has a well-established age of ~160 ka at its base (MIS 6). Thus, the entire sequence of Pre-Illinoian till in Missouri must be older than ~160 ka.

The Matuyama/Bruhnes boundary is a widespread datum between Early and Middle Pleistocene deposits throughout the midwestern United States (Rovey and Kean, 2001; Roy et al., 2004). Therefore, the palaeomagnetic remanence of these tills and intertill sediments also provides some age control. Specifically, the reversed remanence of the Moberly and Atlanta Formations (Rovey and Kean, 1996, 2001; Rovey et al., 2006) restricts their age to the Early Pleistocene, >0.78 Ma. The normal depositional remanence within the McCredie Formation, combined with its stratigraphical position beneath Illinoian (MIS 6) sediment, restricts its age to the Middle Pleistocene (0.78–0.13 Ma).

Cosmogenic-nuclide burial dates recently have provided additional age control on the till sequence in Missouri. General aspects of cosmogenic-nuclide dating are summarised in Granger (2006); specific procedures and methods for these till sections are given in Balco and Rovey (2008). Results to date are summarised in Balco et al. (2005), Rovey and Balco (2010), and Balco and Rovey (2010).

The Atlanta till has been dated at two sites (Fig. 43.1, Table 43.1) approximately 20 km apart with excellent consistency. Ages of 2.28 ± 0.16 and 2.48 ± 0.15 Ma agree and yield an error-weighted mean of 2.42 ± 0.14 Ma, which is indistinguishable in age from the first major pulse of isotopically light meltwater in the Gulf of Mexico (Joyce et al., 1993) and the first sustained occurrence of ice-rafted debris in the North Atlantic Ocean (Raymo et al., 1989). The Atlanta Formation appears to record the first major Quaternary expansion of the LIS into central North America.

The Moberly Formation has been dated at two sites approximately 25 km apart, both of which yielded ages of 1.31 Ma with a weighted error limit of 0.089 Ma. Thus, the age of the Moberly is firmly established within the latter portion of the Matuyama Chron.

Three cosmogenic-isotope dates for the Fulton member of the McCredie Formation (Fig. 43.1, Table 43.1) range from 0.74 to 0.84 Ma, with an error-weighted mean of 0.80 ± 0.04 Ma. This mean age is nearly coincident with, but slightly older than, the Matuyama/Bruhnes boundary at 0.78 Ma. Nevertheless, the detrital remanent magnetisation within the Fulton (both till and proglacial-silt facies) is consistently normal, meaning that the true age must be younger than this datum, most likely within MIS 18 (0.71–0.76 Ma, Lisiecke and Raymo, 2005).

Cosmogenic-nuclide burial dating using the ^{10}Be–^{26}Al nuclide pair (as used here) is not well suited for events younger than about 0.5 Ma (Balco and Rovey, 2008), and the relative uncertainty in dates younger than this age increases dramatically. Thus burial dates on the two youngest tills within the McCredie Formation (Macon and Columbia) are relatively imprecise. One analysis for the (younger) Macon member gives an age of 0.21 ± 0.17 Ma, while a second gives a maximum age of ≤0.18 ± 0.15 Ma. Two dates for the subjacent Columbia member are 0.21 ± 0.16 and 0.31 ± 0.5 Ma. Thus, the burial ages indicate that these two tills are younger than ~0.5 Ma but yield little further information. As discussed above, these tills predate the 0.15–0.135 Illinoian glaciation, so they were most likely deposited during MIS 8 (~0.25 Ma), 10 (~0.35 Ma), or 12 (~0.45 Ma). This implies that the youngest pre-Illinoian tills in central North America may predate the Illinoian glaciation by only one or two 100,000-year glacial-interglacial cycles, a much shorter time interval than previous assessments (e.g. Richmond and Fullerton, 1986), which are mostly based on the development of weathering profiles. This issue remains to be investigated in more detail.

43.5. GLACIAL BOUNDARIES

Early workers recognised that the pre-Illinoian till sheets do not preserve ice-constructional topography and associated moraine systems. Thus, landforms are of little use in reconstructing ice margins and till-sheet boundaries. Accordingly, various workers produced different interpretations of ice margins within Missouri, but all such reconstructions were based on the old twofold concept of "Nebraskan" followed by "Kansan" glaciation (e.g. Holmes, 1942; Flint, 1957). By the 1960s, a consensus was reached that the composite southern boundary of pre-Illinoian glaciations is nearly coincident with the modern Missouri River valley (e.g. Heim, 1961), and this consensus has endured to the present (Middendorf, 2003). In the eastern portion of the state that boundary is well defined by the common preservation of till along interfluves to within a few kilometres of the valley; we are unaware of any *bona fide* examples of till south of the Missouri River. Reworked erratics within fluvial sediment (Rubey, 1952; Heim, 1961) a few kilometres south of this border may indicate that one or more early glaciations reached a terminus slightly farther south. Nevertheless, the Missouri River is a close approximation to the southern limit of glaciation in eastern Missouri.

In the western portion of the state (west of the "big bend" in the Missouri River, Fig. 43.1), the glacial boundary is more problematic, but most published maps depict it as being a few kilometres to several tens of kilometres south of the Missouri River (Heim, 1961; Middendorf, 2003). Again, till exposures are common just north of the Missouri River valley, but none to our knowledge has been found to the south. Placement of the glacial boundary south of the Missouri River in this area apparently is based on the presence of isolated erratics, but criteria for this placement are vague.

A few reports (e.g. Aber, 1999) have interpreted subtle topographic features and drainage patterns as moraine ice-margin positions in Missouri. Allen (1973) traced curvilinear features on satellite imagery of northeast Missouri and also interpreted these as degraded moraines. However, if these features do represent moraines, they would have to be recessional, because they do not coincide with any till boundaries; all six tills recognised in Missouri (Figs. 43.1 and 43.2) have been found within ~15 km of the Missouri River valley. Therefore, the Missouri River seems to be a good approximation to the ice margin of all the pre-Illinoian glaciations that reached Missouri. Advances farther south of this location may have been prevented by a reversal in the slope of the bedrock topography. The Missouri River channel coincides nearly exactly with the southern margin of the Ozark Dome, and the general bedrock-surface elevation rises rapidly southwards of this location. If a series of thinning ice margins advanced to this boundary, such a reversal could focus the terminus of successive glaciations at nearly the same latitude.

43.6. CORRELATION AND FUTURE WORK

Now that the Pleistocene glacial stratigraphy of northeast Missouri is established, an obvious question for future research is that of the correlation between the Pleistocene section in Missouri and those elsewhere in glaciated central North America. In particular, an informal lithostratigraphy is well established for pre-Illinoian tills northwest of Missouri in western Iowa and eastern Nebraska. The till sequence in these states has some age control based on palaeomagnetic remanence (Easterbrook and Boellstorff, 1984; Roy et al., 2004) and fission-track dates of interbedded tephras (Boellstorff, 1978a,b). Moreover, the stratigraphical, lithological, and palaeomagnetic sequence there is similar to that in northeast Missouri (Rovey and Kean, 1996, 2001; Rovey et al., 2006); three normal-polarity tills overlie three tills with reversed magnetic remanence. The oldest of these reversed-polarity deposits (the "C-Till" of Boellstorff) locally includes a second lower till which likely records a minor ice-margin fluctuation, but this unit generally is represented by a single till.

These observations suggest several possible correlations between the two sequences. First, the oldest glacial deposit in the Nebraska–Iowa sequence is a highly weathered till that at one site underlies tephra dated at ~2 Ma (Boellstorff, 1978a,b; Hallberg, 1986). This till may correlate with the Atlanta Formation in Missouri, but it has not been directly dated. Second, two younger reversed-polarity tills with nearly identical lithology overlie, at one site, a tephra within unweathered silt with a fission-track age of ~1.3 Ma. As these two tills also have similar lithology to the Moberly Formation in Missouri, it is possible that they correlate with the Moberly.

However, available chronological information does not support a one-to-one correlation between the three normal-polarity tills in Nebraska/western Iowa and the three till members of the McCredie Formation in Missouri. Two of the normal-polarity tills in Nebraska/western Iowa are older than a tephra dated at ~0.6 Ma (Boellstorff, 1978a,b). However, the cosmogenic-nuclide burial ages described above indicate that only one of the normal-polarity tills in Missouri is older than this datum. This difference could be explained, if the Middle Pleistocene till sequence is more complex than currently recognised. Specifically, stratigraphical observations in Iowa, Nebraska and Missouri show unambiguously that *at least three* normal-polarity tills are present; however, due to the fragmentary and scattered nature of the exposures and similarity in composition among some normal-polarity tills, it is not possible to prove that *no more than three* such tills are present. Thus, there may be more than three normal-polarity tills within the Iowa–Nebraska sequence, and in Missouri as well.

43.7. SUMMARY AND CONCLUSIONS

Major expansions of the LIS to $\sim 39°$ latitude occurred at about 2.4 and 1.3 Ma during the Early Pleistocene. Another major glaciation reached this same latitude at $\sim$ 0.76 Ma during the Middle Pleistocene shortly after the Matuyama/Bruhnes transition. This episode was followed by at least two more expansions of the LIS to the same position between about 0.2 and 0.4 Ma. Other dating techniques for tills to the north in Nebraska and Iowa have shown that at least two glaciations reached at least as far south as 41° latitude between 0.6 and 0.78 Ma, whereas only one till within this age range is known from Missouri. The relationship between these till sequences and other Early and Middle Pleistocene sections in the region could, in the future, be constrained by cosmogenic-nuclide burial dating of additional glacial sections.

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