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Abstract

Alloisoleucine/isoleucine (aIle/Ile) ratios obtained from fossil mollusc shells collected at localities in southwestern Ohio and southeastern Indiana, where they occur in silt beds associated with the Whitewater and Fairhaven tills, indicate a pre-Wisconsinan age for these tills, which had previously been thought to be early or middle Wisconsinan.

The aIle/Ile ratios in shells from beneath the buried soil (Sidney soil) and till exposed near Sidney, Ohio, are most similar to values in shells obtained from Illinoian

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sediments at Clough Creek in Hamilton County, Ohio; Mechanicsburg southwest, Illinois; and Trousdale Mine in Vermillion Co., Indiana. The first well-developed weathering profile in the sequence above the implied Illinoian age silt at the Sidney cut, therefore, probably represents Sangamonian, early and middle Wisconsinan weathering. Molluscs from an organic silt, exposed near the base of the Bantas Fork cutbank section, also have aIle/Ile ratios that are similar to those measured in shell recovered from the silt at the Sidney cut and from the silt inclusion in inferred Illinoian till at Clough Creek. These data indicate that the organic silt is pre-Wisconsinan. Therefore, the Fairhaven Till, which overlies the silt at the Bantas Fork locality, could be pre-Wisconsinan and the weathering profile developed in the Fairhaven Till may be correlative with the Sangamon Soil of Illinois.

The New Paris Interstade silt overlies Whitewater Till at the American Aggregates quarry at Richmond, Indiana. Shells from the silt have aIle/Ile ratios that are intermediate between those obtained from inferred Illinoian age sediments at Bantas Fork, Sidney cut, and Clough Creek, and magnetically reversed sediments at Handley Farm, near Connersville, Fayette County, Indiana. These data suggest a pre-Illinoian age for the silt unit and the underlying Whitewater Till.

Introduction

The extent and indeed the very existence of an early Wisconsinan ice advance into southwestern Ohio and southeastern Indiana is still the subject of debate after decades of study (Clark and Lea, 1986). Recent reviews of late Quaternary till stratigraphy along the southern margin of the Laurentide Ice Sheet (Fullerton, 1986; Vincent and Prest, 1987) accept an early Wisconsinan age for the Whitewater and Fairhaven tills on the basis of the position of these tills above a soil or beds interpreted to be Sangamonian in age, and below nonglacial sediments containing wood that yields nonfinite radiocarbon ages (**Fig. 1**).

The sequence of sediments exposed at the Sidney cut, Bantas Fork, and American Aggregates quarry have played an important role in the development of the concept of early Wisconsinan ice deposits in this area. New data obtained from amino-acid epimerization studies of molluscan shell collected from these localities are more compatible with a pre-Wisconsinan placement for these deposits. In this chapter we compare amino-acid data from these sites with values obtained from late Wisconsinan, Illinoian, and pre-Illinoian age sediments within the area (**Fig. 2**) and discuss the significance of these findings with respect to the previous early-Wisconsinan age assigned to these deposits.

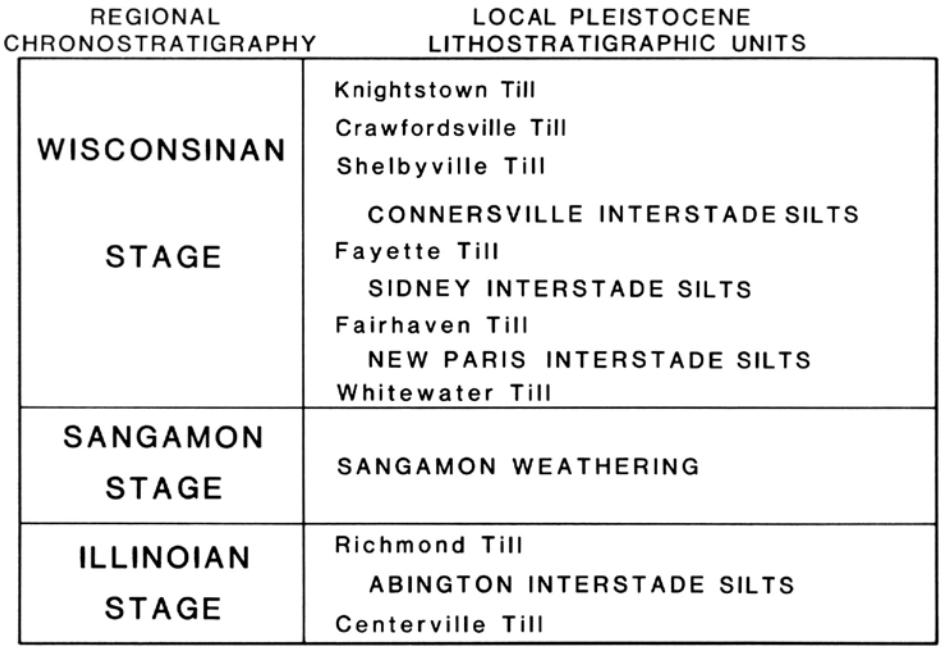

Figure 1. Relation of Pleistocene lithostratigraphic units in southwestern Ohio and southeastern Indiana to regional chronostratigraphic framework (modified from Goldthwait and others, 1981).

Lithostratigraphy

Whitewater Till (American Aggregates Quarry)

The Whitewater Till has been considered to be the basal unit of the Wisconsinan sequence in this area based upon its position (at some localities) above a weathering profile interpreted to be correlative with the Sangamon soil of Illinois (Gooding, 1963, 1975), and beneath nonglacial sediments that yield nonfinite radiocarbon ages (Goldthwait and others, 1981; Fullerton, 1986; Vincent and Prest, 1987). The Whitewater Till is correlated throughout the Whitewater basin on the basis of its blue-gray color, northwest-trending fabric, and the presence of pink to red-brown till inclusions. The type section for the Whitewater Till is the American Aggregates quarry in Richmond, Indiana, where it rests upon a till with oxidized joints which are interpreted to be the eroded remnant of a formerly more extensive Sangamonian weathering profile (Gooding, 1963). Gooding (1963) introduced the name

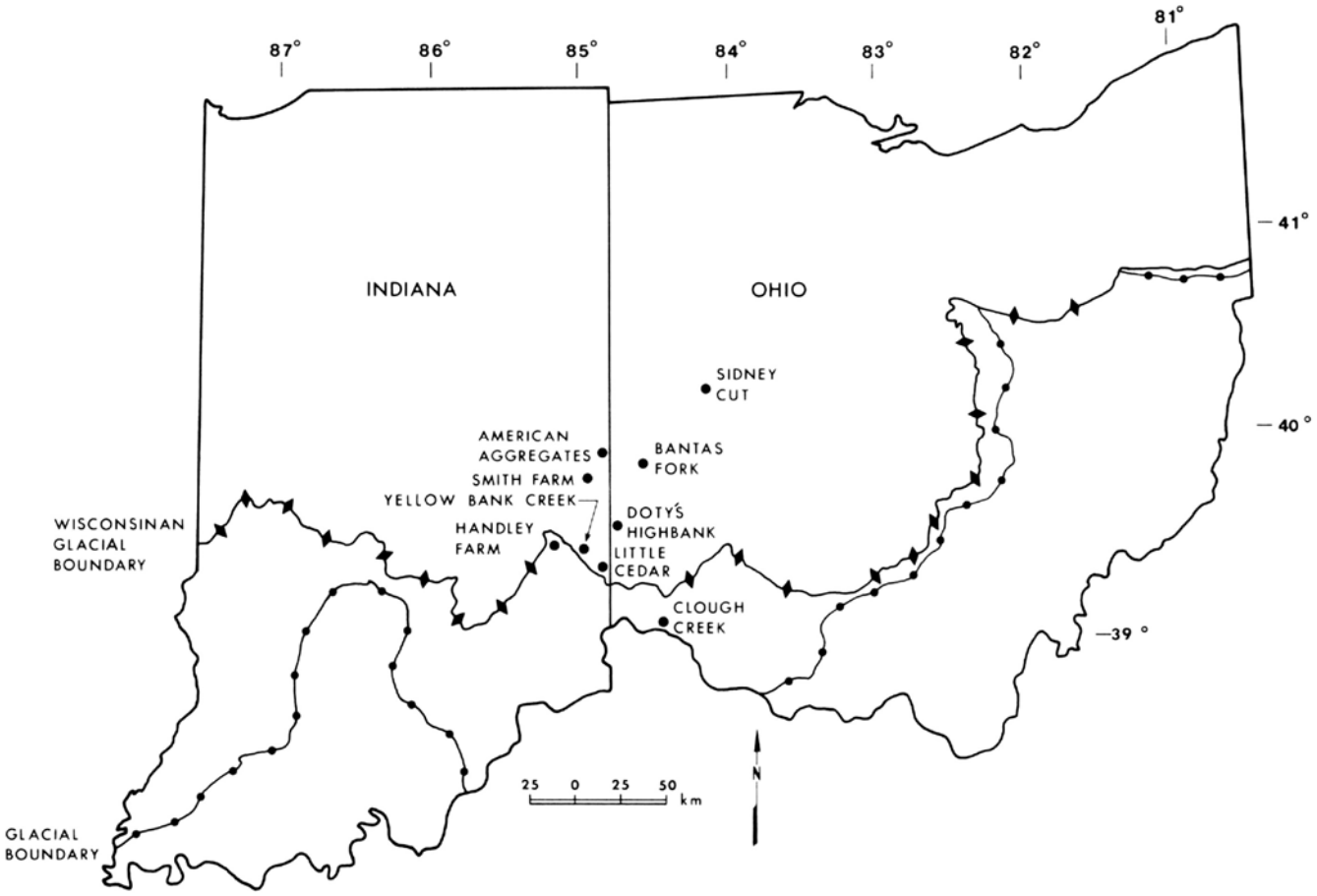

Figure 2. Location map of sites discussed in text relative to the Wisconsinan and pre-Wisconsinan maximum glacial boundaries.

"New Paris Interstade" for the nonglacial organic, calcareous, fossiliferous sediments above the Whitewater Till, and designated the American Aggregates quarry as the type section for the interstadial deposits. Wood samples from the New Paris Interstade unit at that locality have consistently yielded nonfinite ^{14}C ages >40,000 yr B.P. (**Table 1**; Fullerton, 1986). The molluscs used in this study are from the New Paris organic silt unit directly above the Whitewater Till at their type locality (**Fig. 3**).

Fairhaven Till (Bantas Fork)

The Fairhaven Till at its type section is exposed in a stream cutbank about 3.2 km (2 mi) north of Fairhaven, Preble County, Ohio, where it

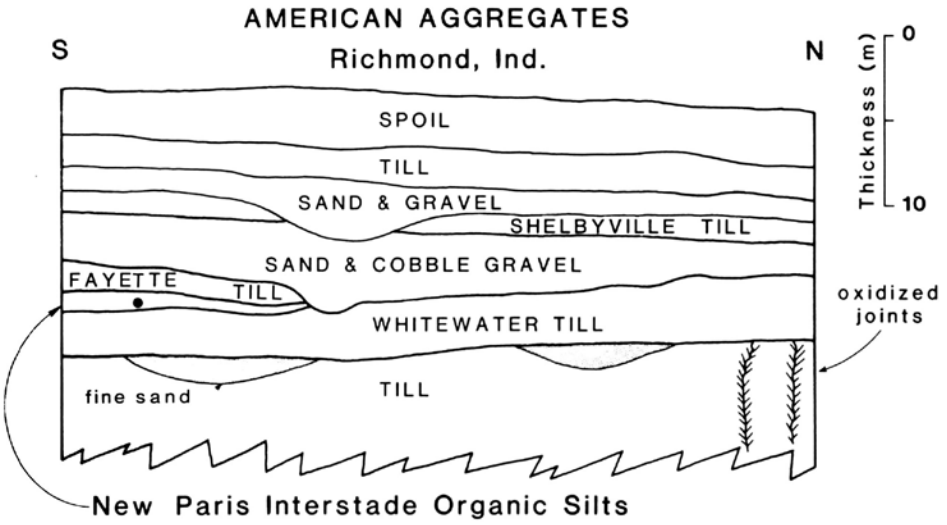

Figure 3. Sketch of stratigraphy at the American Aggregates quarry, Richmond, Indiana. This site is the type section for both the New Paris Interstade and the Whitewater Till. Molluscs were collected from the unit indicated by the black dot (modified from Gooding, 1965).

Table 1. Radiocarbon Age Determinations for Wisconsinan Sites in Ohio and Indiana

Locality	*Laboratory Number*	*Date**	*Source†*
Yellow Bank Creek	DIC-2728	20,020 ± 200-300	1
	Beta-11,550	19,570 ± 220	2
Little Cedar Creek	I-1007	20,290 ± 800	3
Doty's Highbank	W-92	19,980 ± 500	4
	ISGS-761	20,210 ± 260	
	I-10184	20,500 ± 420	
Sidney Cut	W-188	23,000 ± 800	5
	W-356	22,480 ± 800	
Bantas Fork	ISGS-726	44,800 ± 1,700	4
American Aggregates	ISGS-1054	>50,000	2
	L-478B	>40,500	3
Clough Creek	PIT-0512	>45,000	6

* ^{14}C yr B.P. (1950).

† 1 = Miller (1985); 2 = Miller (unpublished); 3 = Gooding (1965); 4 = Goldthwait and others (1981); 5 = Forsyth (1965); 6 = T. Lowell, personal commun. (1989).

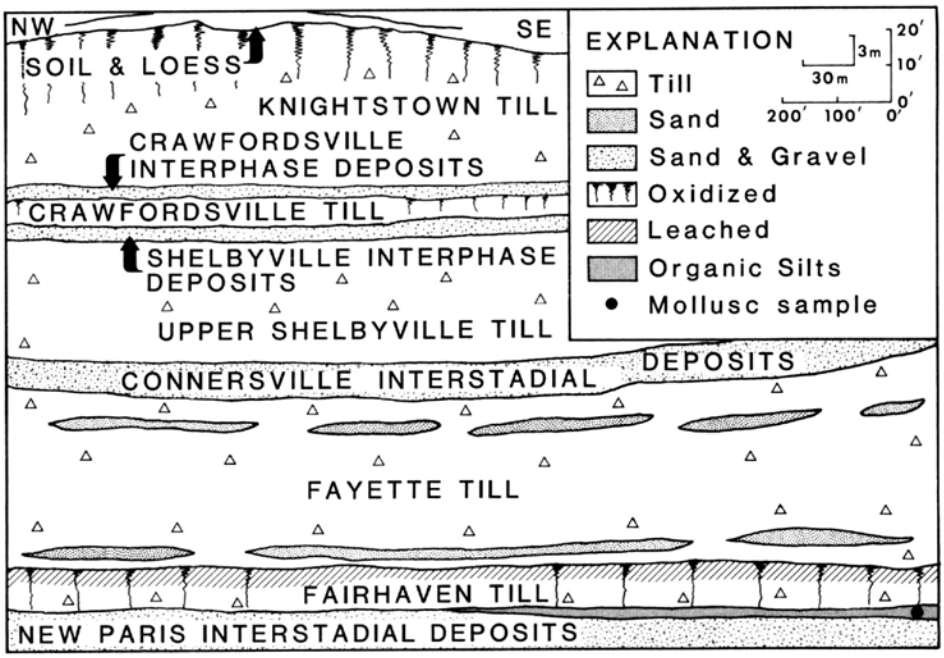

Figure 4. Sketch of stratigraphy exposed in cutbank of Bantas Fork (modified from Goldthwait and others, 1981).

rests upon a discontinuous sand and the Whitewater Till, which has yielded a >45,160 yr B.P. (ISGS—590) age. The Sidney weathering profile has been identified at the top of the Fairhaven Till at this section (Goldthwait and others, 1981).

Nonglacial organic sediments containing molluscs and plant remains separate the Whitewater Till from the overlying Fairhaven Till at several sties in this area of Ohio and Indiana (Gooding, 1963; Goldthwait and others, 1981; Fullerton, 1986). At a cutbank along Bantas Fork (**Fig. 4**), the Fairhaven Till rests upon a calcareous, organic-rich silt containing molluscs and wood (New Paris Interstade); the wood has yielded an age of 44,800±1700 yr B.P. (Table 1). The Fairhaven Till here is leached to a depth of up to 75 cm; Goldthwait and others (1981) attributed the leaching to weathering during the Sidney Interstade.

Sidney weathering interval (Sidney cut)

Goldthwait and others (1981) doubted the middle Wisconsinan age implied for the Fairhaven Till by the finite radiocarbon age from Bantas

Fork. They favored a long, nonglacial middle Wisconsinan, the Sidney weathering interval, on the basis of the following: (1) the intensity of the weathering profile developed on the Whitewater Till at several sites in the area south of the southern margin of the Fairhaven Till; (2) the apparent absence of a well-developed weathering profile between the Whitewater and Fairhaven tills at sites where they do occur in superposition; and (3) the observation that Huron-Erie lobe tills of middle Wisconsinan age have not been identified to the north of the study area in Ohio or Indiana.

Goldthwait and others (1981) interpreted the buried soil exposed in a railroad cut south of Sidney, Ohio (Forsyth, 1965), as a consequence of a long middle Wisconsinan interstade, the Sidney weathering interval; the till in which the Sidney soil is developed should be correlative with one of the early Wisconsinan tills of southwestern Ohio and southeastern Indiana.

The few shells available for analysis from the Sidney cut are from a thin, but deeply buried silt (units 2 and 3; La Rocque and Forsyth, 1957), that was formerly exposed about 10 m below the buried soil (**Fig. 5**). Two radiocarbon dates from a log resting on the Sidney paleosol (unit 5, Fig. 5) place an upper limit on the age of the buried soil of about 23,000 yr B.P. (Table 1).

Calibration sites

Amino-acid data from additional sites in the region, where sample age is less equivocal, are included herein for comparison with the data from Bantas Fork, American Aggregates, and the Sidney cut, the three localities at which the interpreted age of the fossil-bearing units are suspect. These additional data include late Wisconsinan samples from Yellow Bank Creek, Little Cedar Creek and Doty's Highbank (Fig. 2). The age of about 20,000 yr B.P. for the fossil molluscs at these sites is based on multiple radiocarbon ages from wood (Table 1). The shells used in this study are from the same units as the radiocarbon-dated wood.

Another collection of shell was made from a cutbank exposure along a tributary of Clough Creek, in southeastern Hamilton County, Ohio. The analyzed molluscs were recovered from a silt inclusion in an unnamed till (**Fig. 6**). An Illinoian age for the till at this site is

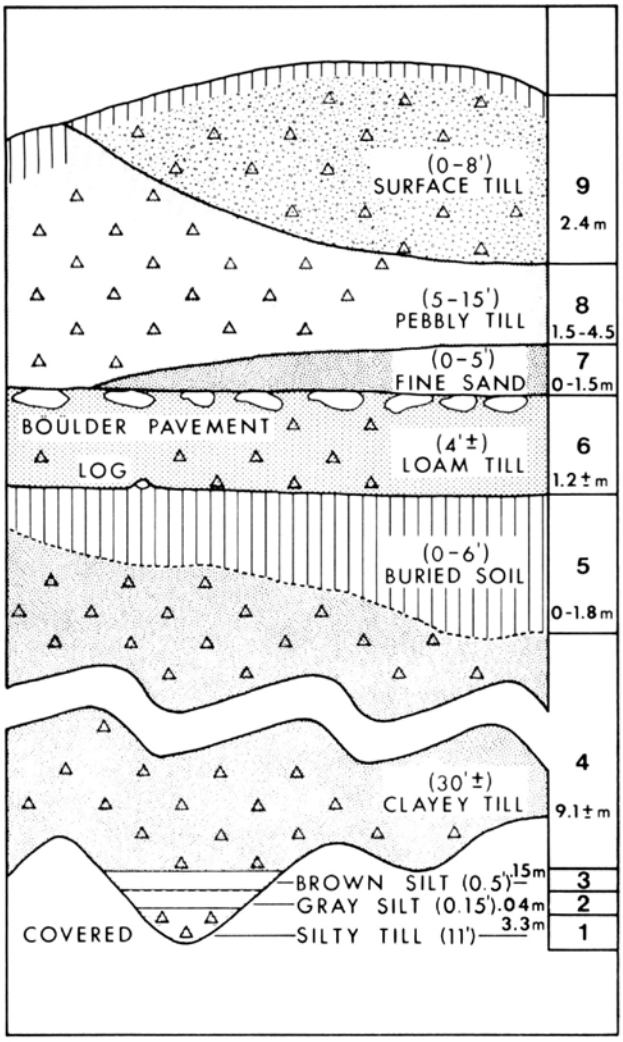

Figure 5. Sketch of stratigraphy as it was formerly exposed at the Sidney Cut. The molluscs used in this study are from units 2 and 3. The Sidney soil is unit 5 (modified from Forsyth, 1965).

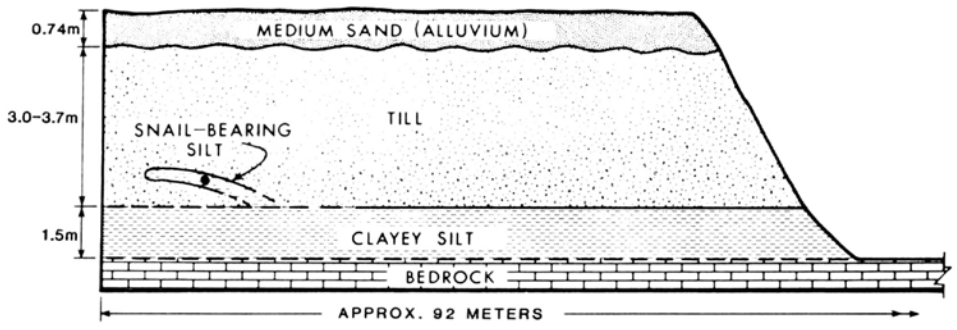

Figure 6. Sketch of stratigraphy exposed at tributary of Clough Creek, in southeastern Hamilton County, Ohio. Molluscs from this site were recovered from the silt inclusion (solid black circle).

inferred from: (1) its location, 20 km south of the Hartwell Moraine (the mapped late Wisconsinan till boundary) and within an area of Ohio that has been mapped as Illinoian drift (Goldthwait and others, 1961); (2) the depth of carbonate leaching of this till unit at other localities in the area—the leaching is at least 40% deeper south of the Wisconsinan till boundary than on the surface till to the north; (3) lithologic differences between the surface tills north and south of the Hartwell Moraine (Brockman, unpublished data); and (4) *Fossaria* shells from silt included in the till that have aIle/Ile ratios similar to values obtained from shells of the same taxon from Illinoian sediments of the Glasford Formation and Petersburg Silt of Illinois and Indiana (see aIle/Ile values for shells from the Trousdale Coal Mine and Mechanicsburg southwest in **Table 2**).

A small collection of *Catinella* shell from Illinoian (Abington Interstade) sediments exposed at Smith Farm was analyzed (unit 2 in Gooding, 1963, Table 2).

Molluscs studied from the Handley Farm locality (**Fig. 7**) were collected from a clay unit exposed on the floor of the creek (unit 3 of Kapp and Gooding, 1974). Magnetic studies of the laminated clay overlying unit 3 at that locality suggest that it was deposited during the Matuyama Reversed Polarity Chronozone (Bleuer, 1976) and therefore is older than 740 ka (Izett and Wilcox, 1982).

Aminostratigraphy

Substantial literature documents the successful application of amino-acid data from fossil mollusc shell to the solution of Quaternary stratigraphic problems (Wehmiller, 1982; Bradley, 1985). Studies by McCoy (1987), Scott and others (1983), Miller and others (1987), and Clark and others (1989) have demonstrated the stratigraphic utility of the epimerization of isoleucine in nonmarine molluscan shells.

The rate of isoleucine epimerization is dependent on the molluscan taxon involved and is sensitive to temperature. The temperature history and age of most samples, however, are usually unknown. Aminostratigraphy permits direct use of amino acid epimerization ratios as indicators of relative age, usually within a limited geographic region where close proximity permits the assumption that the sites in question have had similar temperature histories (Wehmiller, 1982).

Table 2. Summary of alle/Ile Total Acid Hydrolysate Ratios

Locality	*AGL* Number*	*Taxon*	*Number Analyzed †*	*Hydrol*	*Standard Deviation*
Yellow Bank Creek	262	*Stenotrema*	3	0.060	± 0.008
	435	*Catinella*	2	0.071	± 0.020
	437	*Fossaria*	1	0.054	
	442	*Fossaria*	1	0.047	
Little Cedar Creek	383	*Stenotrema*	3	0.049	± 0.008
	311	*Catinella*	2	0.080	± 0.002
Doty's Highbank	364	*Catinella*	2	0.051	± 0.004
	444	*Catinella*	1	0.053	
Clough Creek	642	*Fossaria*	3	0.17	± 0.01
	714	*Fossaria*	3	0.16	± 0.02
Bantas Fork	123	*Catinella*	3	0.19	± 0.02
	713	*Catinella*	2	0.22	± 0.01
Sidney Cut	785	*Succinea*	1	0.22	
	786	*Stenotrema*	1	0.19	
	787	*Catinella*	1	0.23	
Trousdale Coal Mine (Vermillion County, Indiana)	639	*Fossaria*	3	0.20	± 0.02§
Mechanicsburg, S.W. (Sangamon County, Illinois)	580	*Fossaria*	2	0.20	± 0.01**
Smith Farm	1352	*Catinella*	2	0.33	±0.01
American Aggregates	125	*Catinella*	2	0.50	± 0.01
	715	*Catinella*	2	0.50	±0.02
	1016	*Catinella*	3	0.53	±0.06
	1017	*Fossaria*	3	0.46	± 0.01
Handley Farm	1177	*Succinea*	2	0.78	±0.01
	1178	*Catinella*	1	0.84	

* AGL = Amino Acid Geochronology Laboratory, University of Massachusetts.

† Number of separate preparations analyzed.

§ Sample is from a slit between the Smithboro Till (Glasford Formation) and Hillery Till (Banner Formation).

** Sample is from silt in Glasford Formation.

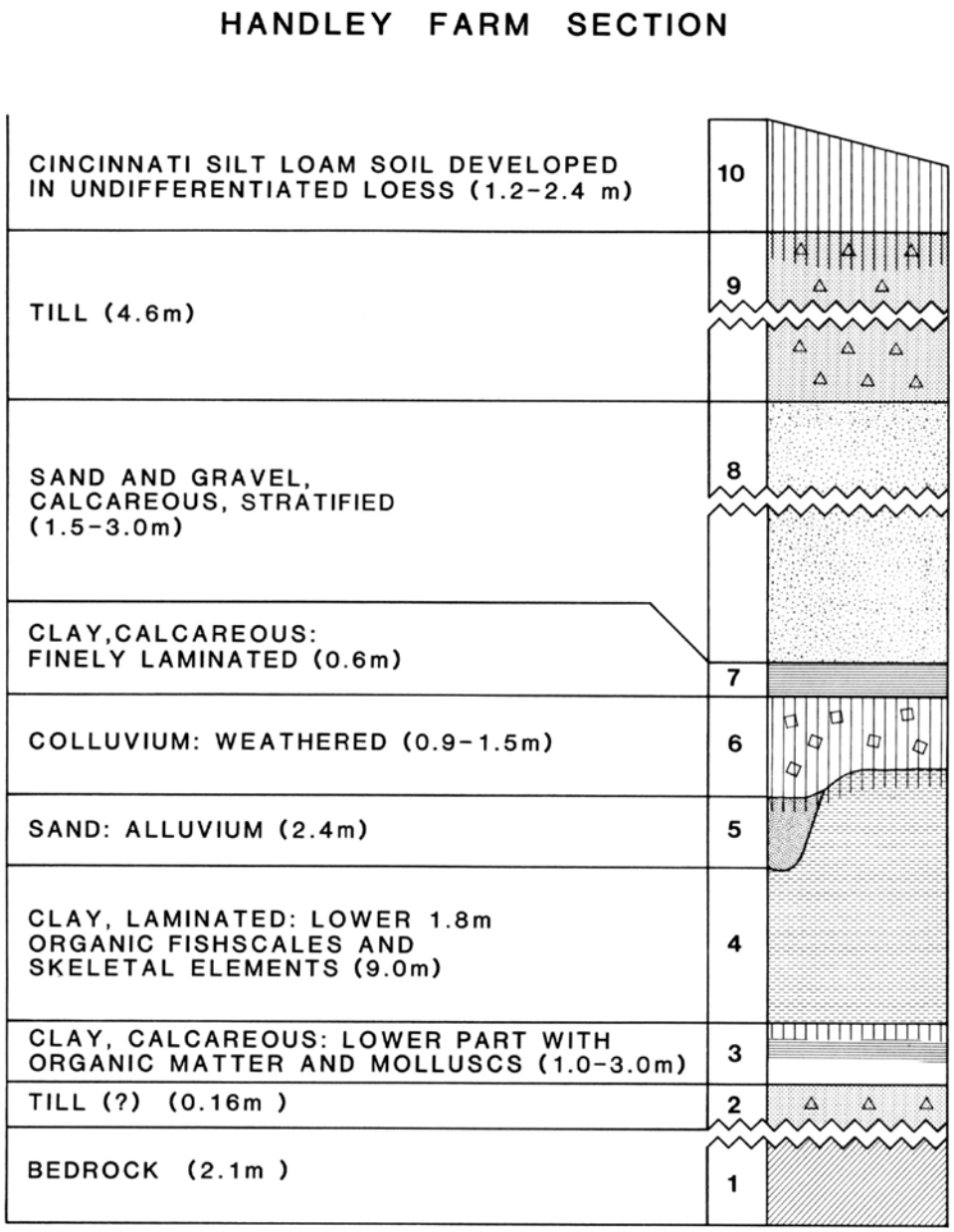

Figure 7. Sketch of stratigraphy at Handley Farm. The mollusc samples are from unit 3 (modified from Kapp and Gooding, 1974).

Within the limits of the study area, highest and lowest mean annual temperatures differ by only 2.2 °C. (Armington, 1941; Fisher, 1941). For the amino acid data reported here, therefore, it is assumed that discordant aIle/Ile ratios between samples of the same taxon are due to differences in age.

Laboratory methods

Shells from four taxa of molluscs (*Fossaria, Stenotrema, Catinella,* and *Succinea*) from a total of nine sites in southwestern Ohio and southeastern Indiana (Fig. 2, Table 1) have been analyzed at the University of Massachusetts Amino Acid Geochronology Laboratory (AGL).

Sample preparation involved repeated sonification and washing in purified water, followed by dissolution and hydrolysis in 6N HCl for 22 h at 110 °C under a nitrogen atmosphere. The aIle/Ile ratios in the total acid hydrolysate were determined by cation-exchange liquid chromatography. The results of our analyses of the Interlaboratory Comparison (ILC) samples (Wehmiller, 1984) were given in Miller and others (1987). Recent analyses of these standards have yielded comparable results and are not reproduced here.

When sample size permitted, three separate preparations and analyses were made for the total hydrolysate. The number of shells used for each preparation varied with the size of the individuals being analyzed. Smaller individual shell size usually results in greater variance between separate preparations from the same site. Replicate preparations and analyses of shells from a single locality are generally within 10% of their mean value. The results of these analyses are summarized in Table 2 and **Figure 8**.

Results

The epimerization ratios for the four genera used in this study (*Succinea, Catinella, Stenotrema,* and *Fossaria)* show significant differences for samples from the same lithostratigraphic units (Table 2, Fig. 8). The ratios suggest that *Succinea* and *Catinella* epimerize faster than *Stenotrema* and *Fossaria.* Direct comparison of ratios must consider the relative racemization rates.

The aIle/Ile hydrolysate ratios for the 22 samples analyzed in this study are plotted by locality and genus in Figure 8. The lowest aIle/Ile ratios (all less than 0.10) are found in shells collected from late Wisconsinan deposits at Dotys Highbank, Yellowbank Creek, and Little Cedar Creek (group 1, Fig. 8).

A second grouping of ratios includes samples of (1) *Fossaria* from inferred Illinoian silt at Clough Creek; (2) *Stenotrema, Catinella* and

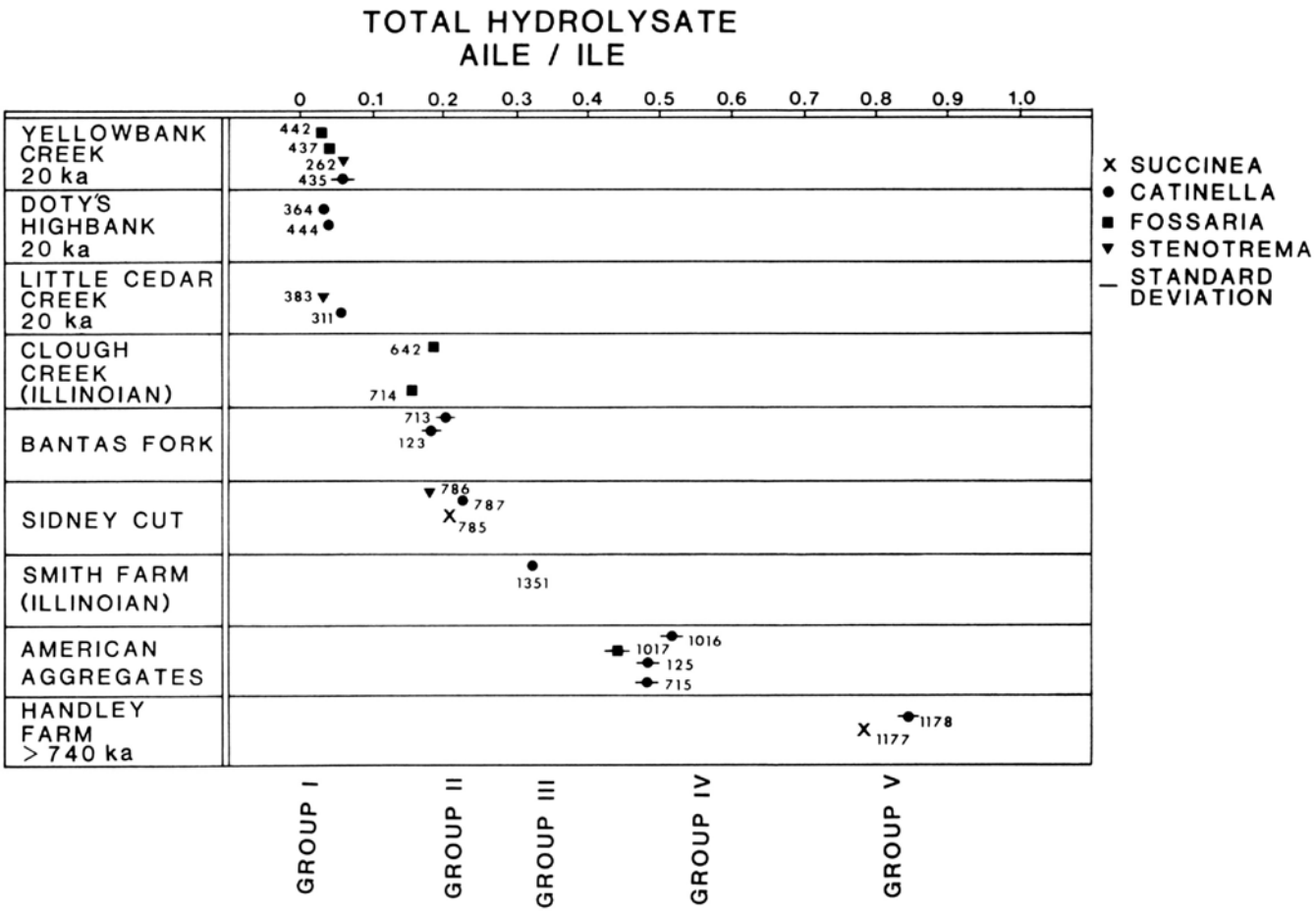

Figure 8. Plot of total Hydrolysate values for *Fossaria, Catinella, Succinea* and *Stenotrema* from nine localities in southwestern Ohio and southeastern Indiana.

Succinea from a silt beneath the weathering profile and till at the Sidney cut; and (3) *Catinella* from the organic silt near the base of the section at Bantas Fork (group II, Fig. 8). The range of aIle/Ile values within this group are partly due to differences between the faster epimerizers *Succinea* and *Catinella* versus the slower epimerizers *Fossaria* and *Stenotrema*. As a group, these aIle/Ile ratios are significantly higher than the values obtained from the known late Wisconsinan samples.

Succinea and *Catinella* from unit 3 at Handley Farm yield the highest total aIle/Ile ratios (group V, Fig. 8) for any of the study sites. These high values are consistent with the magnetically reversed signature of unit 3 at this site.

Catinella from the type section of the New Paris Interstade at the American Aggregates quarry yield aIle/Ile ratios (group IV, Fig. 8) that are intermediate between the values obtained for this taxon from unit 2 at Smith Farm (group III, Fig. 8) and unit 3 at Handley Farm.

Discussion

The aIle/Ile ratios of shell from beneath the buried soil and till exposed in the Sidney cut (Fig. 5) are most similar to shell values obtained from sediments of interpreted Illinoian-age exposed at Mechanicsburg southwest, Trousdale Coal Mine, and Clough Creek. Molluscs from the Sidney cut are thus thought to be coeval with these fossil-bearing Illinoian silt units. The first well-developed weathering profile in the sequence above the Illinoian silts at the Sidney cut, therefore, may include the Sangamonian weathering interval.

Molluscs from the organic silt exposed near the base of the Bantas Fork cutbank section also have aIle/Ile ratios that are similar to those measured in shell recovered from (1) the silt at the Sidney Cut; (2) the silt inclusion in Illinoian till, at Clough Creek; (3) the Mechanicsburg southwest site; and (4) the Trousdale Coal Mine locality. The amino-acid data suggest that the organic silt at Bantas Fork is pre-Wisconsinan, and that the 44,800 ± 1700 yr B.P. age on wood collected from the same unit as the snails is too young. On the basis of this interpretation, the Fairhaven Till at this locality should be pre-Wisconsinan, and the buried soil developed in the Fairhaven Till (Fig. 4) probably represents weathering that took place during Sangamonian, early and middle Wisconsinan time.

AIle/Ile ratios for shell from the organic silt that overlies the Whitewater Till at the American Aggregates quarry suggest a much greater age for that unit than the sampled horizons at Bantas Fork, the Sidney cut, or the Smith Farm. Although the ratios are lower than those obtained for *Succinea* and *Catinella* from magnetically reversed sediments at Handley Farm, the aIle/Ile ratios are higher than shell values obtained from known Illinoian sediments at sites in Indiana and Illinois (Miller and others, 1988). On the basis of these aIle/Ile values, the calcareous organic silt at the American Aggregates quarry is interpreted to be pre-Illinoian.

Table 3. Summary of Pleistocene Stratigraphy in Study Area

Wisconsinan Stage	Knightstown Till Crawfordsville Till Shelbyville Till Fayette Till
Wisconsinan-Sangamonian	Sidney weathering interval; unit 5 at the Sidney Cut
Illinoian Stage	Fairhaven Till at Bantas Fork; silt and till at Clough Creek; units 1, 2, 3, and 4 at Sidney cut; unit 2 at Smith Farm
Pre-Illinoian	New Paris organic silt at American Aggregates quarry Whitewater Till and pre-Whitewater till at American Aggregates quarry Pre-Whitewater till; unit 2 at Handley Farm

Conclusions

The amino-acid data obtained during this study suggest the following interpretations that are summarized in **Table 3**.

1. If the Fairhaven and Whitewater tills are pre-Wisconsinan, then the basal Wisconsinan till in the area is the late Wisconsinan Fayette Till.
2. The Sidney weathering interval developed in the unit 4 till at the Sidney cut probably represents the last interglacial as well as early and middle Wisconsinan weathering, as does the Sangamon soil at many places in its type area of Sangamon County, Illinois.
3. The Fairhaven Till at Bantas Fork, the till at Clough Creek, and the unit 4 till that overlies the mollusc-bearing silt at the Sidney cut probably were deposited by a late Illinoian ice advance into the area.
4. The hydrolysate ratios obtained from the Sidney cut and Bantas Fork molluscs suggest that they are approximately coeval with the fossil-bearing silt inclusion at Clough Creek, and are probably younger than the Illinoian Abington Interstade.
5. The Abington Interstade is represented by the shells from unit 2 at Smith Farm.

6. *Catinella* from the organic silt at the American Aggregate quarry yield aIle/Ile ratios that indicate that this unit is younger than the magnetically reversed sediments at Handley Farm but is probably pre-Illinoian.
7. The Whitewater Till at its type section, in this interpretation, probably represents an early-middle Pleistocene ice advance into the area.
8. The oldest Pleistocene fossils in the area are represented by material from unit 3 at the Handley Farm section.

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