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ILLINOIAN AND WISCONSIN GLACIATIONS IN THE WHITEWATER BASIN, SOUTHEASTERN INDIANA, AND ADJACENT AREAS[1]

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ABSTRACT

Data accumulated in Pleistocene studies since 1955, including pollen analyses and radiocarbon dates, provide a basis for the geologic-climate and time-stratigraphic subdivision and classification of the Illinoian and Wisconsin drift in southeastern Indiana and adjacent areas. Interpretations presented here are based mainly on data from fourteen stratigraphic sections, four of which are described in detail. Type sections are designated and described for newly named stades and interstades in the following classification of the drift of the area:

I. Wisconsin Stage
  A. Tazewell Stade
    1. Bloomington drift
    2. Champaign loess
    3. Champaign drift
    4. Shelbyville loess
    5. Shelbyville drift
  B. Connersville Interstade
  C. Fayette Stade
  D. New Paris Interstade
  E. Whitewater Stade
II. Sangamon Stage
III. Illinoian Stage
  A. Richmond Stade
  B. Abington Interstade
  C. Centerville Stade

INTRODUCTION

Several colleagues and I have been studying the Pleistocene geology of southeastern Indiana and adjacent areas (fig. 1) since 1955. Studies have dealt with (*a*) terraces in the Whitewater basin, (*b*) surficial drift sheets and their associated land forms and soils, (*c*) drift stratigraphy, (*d*) till fabric, texture, and composition, (*e*) pollen analysis of buried soils, and (*f*) analyses of pollen and mollusks from calcareous interstadial sediments and surface bogs (Thorp *et al.*, 1957; Gooding, 1957, 1961; Gamble, 1958; Gooding *et al.*, 1959; Gooding and Gamble, 1960; Kapp and Gooding, 1960, and in press).

More than two hundred drift exposures, mostly in four counties, have been examined in detail in these studies, and a large amount of stratigraphic data has accumulated. Although several criteria for stratigraphic correlation are recognized, problems have existed in correlation between drift lobes in the area. Some recently obtained radiocarbon dates, however, contribute to acceptable stratigraphic interpretations and are consistent with a recognizable succession of Illinoian and Wisconsin drift units. The radiocarbon dates support a plausible correlation of the southeastern Indiana succession with that in southwestern Ohio, elsewhere in Indiana, and in Illinois.

This paper is based especially on fourteen important sections of the drift succession in southeastern Indiana. Four of the sections from which radiocarbon dates have been obtained are described in detail.

SURFACE DRIFT SHEETS

Illinoian drift, and the Wisconsin Shelbyville, Champaign, and Bloomington drift

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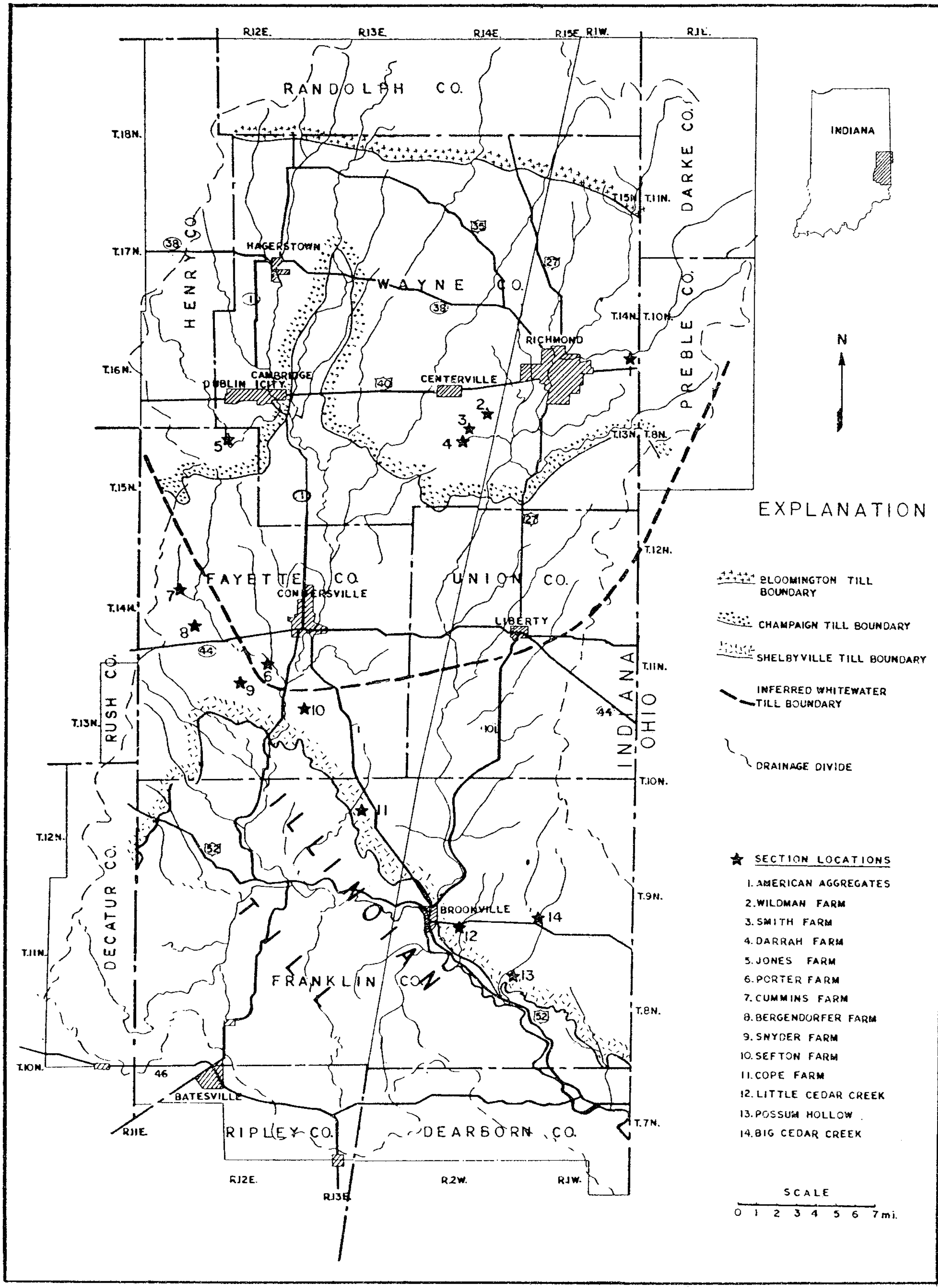

FIG. 1.—Map of Whitewater basin, southeastern Indiana, showing drift sheet boundaries and stratigraphic section locations.

sheets (Leverett and Taylor, 1915, p. 77–122; Malott, 1922, p. 104–108) are areally exposed in southeastern Indiana (fig. 1). Their outer boundaries have been delimited mainly on the basis of characteristic soil associations (Gooding, 1957), although the Wisconsin drift sheets also have outer moraines and other ice-marginal features associated with them in places that agree closely with the soil discontinuities. Detailed mapping of the surficial drift and land forms now in progress is adding details on the Wisconsin drift sheet boundaries and the minor fluctuations of the ice lobes. For purposes of orientation in the present discussion of the Pleistocene stratigraphy, however, only the general boundaries and areal extent of the drift sheets are shown in figure 1.

ILLINOIAN AND WISCONSIN STRATIGRAPHY

GENERAL STATEMENT

Star symbols in figure 1 mark the locations of the fourteen sections on which the present interpretations of the Illinoian and Wisconsin history of southeastern Indiana are mainly based. Figure 2 shows graphically their stratigraphy and correlation. Although only the American Aggregates and the Wildman, Smith, and Sefton Farm sections will be described in detail, the other sections in figure 2 will be referred to frequently. The Wildman and Darrah Farm sections were described and interpreted originally by Gamble (1958) but are included here because of their importance in the larger picture and because some new stratigraphic units have been recognized as a result of further investigations.

CRITERIA EMPLOYED IN STRATIGRAPHIC DIFFERENTIATION AND CORRELATION

The buried soil in most of the stratigraphic sections (fig. 2) is believed to be the same horizon in all of the sections, on the basis of the similarity of position in stratigraphic sequence with other distinctive drift units which occur in most sections. The depth of weathering, and the nature of the climate during the soil-forming interval as interpreted from pollen data (Kapp and Gooding, 1960, and in press), indicate that the soil was formed during a major interglacial age. It is the writer's judgment that the buried soil is of Sangamon age because no other well-developed buried soil has been found higher in these sections, and the tops of many of the sections are at or near the present upland.

Drift units below and above the Sangamon soil in groups of adjacent sections are correlated with confidence on the basis of the distinctive lithologic characteristics of certain tills, and of organic-rich interstadial sediments in similar stratigraphic sequence both above and below the Sangamon soil (detailed section descriptions and fig. 2).

Earlier uncertainties of correlation of some Wisconsin drift units between groups of sections from the Miami to the East White River lobes (Gooding, 1961) have been reduced by radiocarbon dates.

KEY STRATIGRAPHIC SECTIONS

The following sections described in detail contain radiocarbon dates important in the establishment of the drift succession herein proposed. Special note is to be taken of the Smith Farm section because of the important Sangamon climatic record shown by pollen analysis. The remaining three sections are designated the type sections for the named stades and interstades. The sections are presented in order of their importance to the historical interpretations discussed later.

Wildman Farm section (modification of Gamble's sec. 3, 1958, p. 11–18).—The Wildman Farm section is a composite of three nearby (0.1 mile) exposures along the south bank of a small stream in the NE. ¼, Sec. 33, T. 16 N., R. 14 E., Wayne County, Indiana (see table 1 and sec. 2, figs. 1 and 2).

Smith Farm section (see also Gooding, 1961, p. 111–117).—The Smith Farm section is a composite section from two intermittent stream valleys 100 yards apart which are cut back into the upland in the

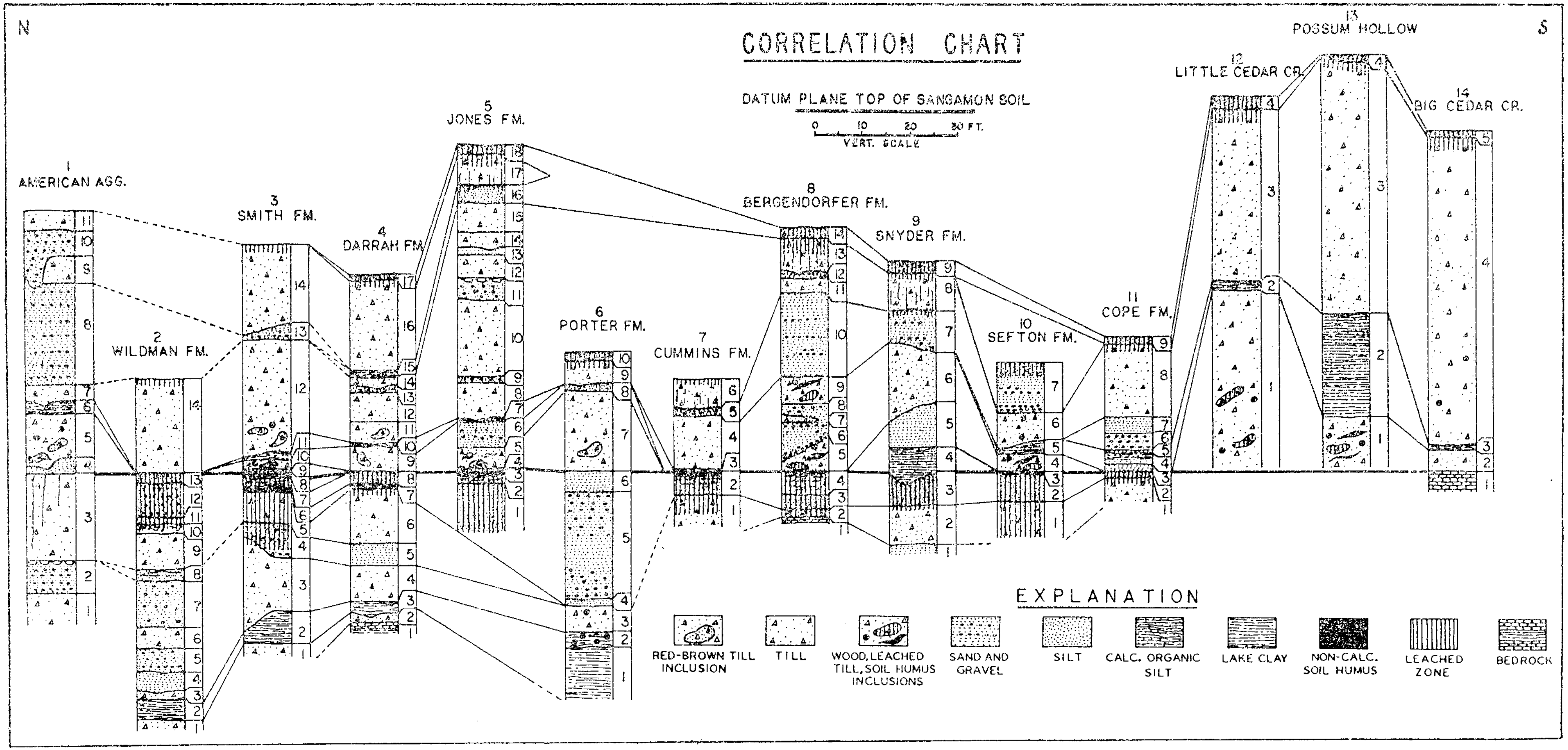

FIG. 2.—Graphic representation of stratigraphic sections, and correlation of stratigraphic units

southern part of the SE. ¼, Sec. 32, T. 16 N., R. 14 E., Wayne County, Indiana (see table 2 and sec. 3, figs. 1 and 2). Although most of this composite section can be found in both adjacent valleys, the buried soil and the drift below it were best displayed and hence described from one valley, while the drift above the soil was best displayed and hence described from the other valley. The buried soil was found at the same elevation in both valleys, so the correlation can scarcely be questioned. The buried soil and various other stratigraphic units described in the Smith Farm section are exposed also along several other intermittent stream valleys within a ½-mile radius of the Smith Farm section.

American Aggregates pit section (see also Gooding, 1961, p. 108–110).—The American Aggregates section was measured in 1959 in the east side of a railroad cut at a gravel quarry operated by the American Aggregates Corporation in the north-central part of Sec. 36, T. 14 N., R. 1 W., at the northeast edge of Richmond, Wayne County, Indiana (see table 3 and sec. 1, figs. 1 and 2).

Sefton Farm section (see also Gooding, 1961, p. 121–124).—The Sefton Farm section is located in a creek bank cut in a terrace in the SW. ¼, NE. ¼, Sec. 13, T. 13 N., R. 12 E., east of the west fork of the Whitewater River near Nulltown, Fayette County, Indiana (see table 4 and sec. 10, figs. 1 and 2).

ILLINOIAN AND WISCONSIN DRIFT SUCCESSION IN SOUTHEASTERN INDIANA

ILLINOIAN STAGE

Illinoian ice advanced and melted back over southeastern Indiana several times, as recorded by tills separated by outwash sands and gravels, and possibly thin aeolian silts in places, occurring below the Sangamon

TABLE 1

Unit	Thickness (Feet)	Description
		Wisconsin Stage
14	18.0	Till—calcareous, oxidized to buff color. Top 1 foot leached (surface soil).
		Sangamon Soil and Illinoian Stage
13	2.0	Sand—non-calcareous, mostly quartz grains stained light yellowish-brown. Layer of limonite concretions near bottom. Chunks of underlying unit 12 included in this unit.
12	7.0	Gravel—non-calcareous, mostly siliceous minerals stained yellowish-brown (oxidized). Upper 6 inches especially iron-rich.
11	1.0	Silt—and clay, non-calcareous, yellowish-brown (oxidized), stratified.
10	1.5	Silt—and sand, yellowish-brown (oxidized); upper 1 foot non-calcareous, lower 0.5 foot calcareous with a few scattered mollusks. Entire unit strongly involuted (see Gamble, 1958, fig. 4, p. 14).
9	7.0	Till—calcareous, buff (oxidized).
8	2.0	Silt—and clay, calcareous, yellowish-brown (oxidized), mildly involuted.
7	9.0	Sand—and fine gravel, calcareous, yellowish-brown (oxidized), crossbedded.
6	4.0	Till—calcareous, gray (unoxidized), contains wood.
5	4.0	Gravel—calcareous, gray (unoxidized) to buff (oxidized).
4	4.0	Silt—calcareous, gray (unoxidized), stratified.
3	0–2.0	Till—calcareous, gray (unoxidized).
2	4.0	Silt—calcareous, gray (unoxidized), mildly involuted, contains abundant finely divided plant remains, pollen, larger pieces of wood, and mollusks.
1	1.0	Till—calcareous, gray (unoxidized). Continues beneath creek bottom.

soil in the Wildman, Smith, and Darrah Farm sections. A calcareous, organic-rich silt between Illinoian tills in these sections records an interval of ice retreat that was long enough for some vegetation and mollusks to become established. The absence of weathering phenomena and the cold-climate character of the flora (Kapp and Gooding, in press) and fauna (table 5) in the calcareous, organic-rich silt, suggest that the retreat interval was short and that Illinoian ice probably remained in the area not far to the north. The calcareous, organic-rich silt is judged, however, to record a significant break within the Illinoian stage that must have been due to climatic factors that affected a wider region than the Whitewater basin, and therefore should be considered as representing an Illinoian interstadial event. The till below the interstadial organic-rich silt, consisting of till units 1, 1, and 2 in the Wildman, Smith, and Darrah Farm sections,

TABLE 2

Unit	Thickness (Feet)	Description
		Wisconsin Stage
14	18.0	Till—calcareous, contains lenses of sand and silt. Upper 10 feet buff (oxidized), top 18 inches leached (surface soil). Lower 8 feet gray (unoxidized).
13	1–3.0	Sand—and fine gravel, calcareous, brightly stained with limonite and manganese oxide. Zones of weak cementation in places.
12	24.0	Till—calcareous, upper 6 feet buff (oxidized), contains limonite-stained sand lenses, and shows weak convolutions. Lower 18 feet gray (unoxidized) and contains in the lower part inclusions of a red-brown till, pieces of wood, and thin streaks of gray, calcareous silt.
11	0–1.0	Silt—calcareous, gray (unoxidized), contains "peaty" plant remains, twigs, and mollusks. Traced along valley side zone changed to yellowish-brown sand with a layer of plant remains and mollusks on top.
10	1–2.0	Till—calcareous, gray (unoxidized), contains inclusions of red-brown till and wood, L-479A, >43,000.
9	0.2	Clay—calcareous, gray (unoxidized), infiltrates unit below.
		Sangamon Soil and Illinoian Stage
8	1.3	Silt—and fine sand, non-calcareous, black, very rich in finely divided plant remains and pollen (soil humus). L-479B, >37,500.
7	2–3.0	Silt—and fine sand, non-calcareous, gray, contains finely divided plant remains and pollen.
6	0.9	Silt—non-calcareous, black, very rich in finely divided plant remains and pollen (soil humus). L-479C, >35,000.
5	6.0	Till—non-calcareous, upper 4 feet grayish-green and very clayey (gumbotil), lower 2 feet yellowish-brown and weakly cemented with limonite (a hard pan). (Determined by auger.)
4	1–6.0	Sand—Determined by auger. Where sand was 6 feet thick it was leached 5 feet, with $CaCO_3$ cementation at bottom of leached zone. 40 feet downstream an auger hole revealed 1 foot of sand completely leached, with leaching extending $1\frac{1}{2}$ feet into underlying till.
3	16.0	Till—calcareous, gray (unoxidized), except at second auger hole above where overlain by 1 foot of leached sand. Leaching here goes $1\frac{1}{2}$ feet into this till. At bottom of zone of leaching in this till is a 3–4 inch limonite "hardpan" layer at transition to underlying calcareous till.
2	2–6.0	Clay—and silt, calcareous, gray, stratified, has weak convolutions, contains finely divided plant remains and mollusks. Traced laterally, this unit changes to sand in places.
1	2.0	Till—calcareous, gray (unoxidized). Continues beneath creek bottom.

TABLE 3

Unit	Thickness (Feet)	Description
		Wisconsin Stage
11	2–4.0	Till—calcareous, buff (oxidized). Surface soil stripped from top.
10	4.0	Sand—and gravel, calcareous, limonite-stained.
9	5.0	Till—calcareous, buff (oxidized).
8	20.0	Sand—and cobble gravel, calcareous, some cementation at top. Strong limonite and manganese oxide staining toward bottom.
7	3–4.0	Till—calcareous, gray (unoxidized), contains sand lenses. Top few inches yellowish-brown (oxidized). Top is an irregular erosional surface and till is completely truncated in places.
6	1–2.0	Silt—and fine sand, calcareous, stratified, gray to black, contains finely divided plant remains, pollen, twigs, and mollusks. Unit traced for several hundred feet on both sides of railroad cut. L-487B, >40,500; I-587, >38,000.
5	10.0	Till—calcareous, brownish-gray (unoxidized), blocky. Contains inclusions of calcareous red-brown till and pieces of wood.
4	0–3.0	Silt—and fine sand, calcareous, gray (unoxidized), stratified.
		Illinoian Stage
3	17.0	Till—calcareous, tough, gray (unoxidized) except for several inches parallel to deeply penetrating joints which are oxidized and cemented with limonite. Basal portion of till contains many white to bluish-gray angular chert cobbles. Striations made by the glacier on boulder pavement below trend S. 23°W.
2	6.0	Sand—and fine gravel, calcareous, stratified, brightly stained with limonite and manganese oxide. Boulder pavement at top.
1	5.0	Till—calcareous, gray (unoxidized). Continues beneath creek bottom.

TABLE 4

Unit	Thickness (Feet)	Description
		Wisconsin Stage
9	10.0	Sand—grading down to cobble and boulder gravel, calcareous except for top 3 feet which are leached (surface soil). Boulders are mostly flat slabs of local Ordovician limestone.
8	6–8.0	Sand—and pea gravel, calcareous, yellowish-brown (oxidized), formed probably as sub-ice channel fill into underlying till, contains numerous pieces of wood in lower part.
7	5.0	Till—upper 1 foot buff (oxidized), lower 4 feet gray (unoxidized). Contains sand and gravel pockets and many pieces of wood.
6	0–2.0	Silt—calcareous, dark gray to black, contains plant remains and mollusks. Top is "peaty," with mosses, and several logs, one of which is a stump 8 inches in diameter believed to be in place. I-610, 20,000 ± 500.
5	3–8.0	Till—calcareous, gray (unoxidized), contains inclusions of non-calcareous black soil humus, pieces of wood, and olive-green, very clayey, leached till (gumbotil).
		Sangamon Soil and Illinoian Stage
4	0.5	Silt—non-calcareous, black, rich in finely divided plant remains (soil humus).
3	4.0	Clay—silty, non-calcareous, grayish-green. Upper 2 feet exposed above creek bottom, lower 2 feet and all underlying units determined by auger.
2	6.5	Till—non-calcareous, mottled grayish-green to olive-green, very clayey (gumbotil).

respectively, is thus considered to represent an Illinoian glacial stade, here called the Centerville glacial stade, after Centerville, Indiana, the town nearest the type area where the above sections are located.

The Illinoian interstadial deposit, represented by the calcareous, organic-rich silt (Wildman Farm unit 2, Smith Farm unit 2, Darrah Farm unit 3, and Porter Farm unit 2), is here named the Abington interstadial, after the village of Abington, Indiana, about 3 miles south of the first three sections.

The deposits between the younger overlying Illinoian tills record a recessional event during which some local erosion and deflation (e.g., boulder pavement at top of unit 2, American Aggregates section), silt accumulation (loess?), and immigration of a few snails occurred (unit 10, Wildman Farm section; also in small nearby section described by Wayne, 1955, p. 31). These features are not found in other sections, however, and would seem to record a much shorter and probably more local recession and short readvance of Illinoian ice, probably during its general retreat from the area. At the present time, therefore, all Illinoian drift above deposits of the Abington interstadial, as defined above, is considered to belong to one recessional stade, here named the Richmond glacial stade, after Richmond, Indiana, the largest town in the vicinity.

Since the stratigraphic relationships between the deposits representing the Centerville stade, Abington interstade, and Richmond stade of the Illinoian stage are most clearly demonstrated in the Wildman Farm section, it is designated the type section for these subdivisions in the type area.

Although data are inconclusive, further investigation may show that till of the Centerville stade does not extend as far south as the outermost Wisconsin till boundary, at least in the western part of the Whitewater basin. The Illinoian till extending to the Ohio River Valley in this area therefore may belong entirely to the Richmond stade.

TABLE 5

MOLLUSCAN SPECIES*

Species	A	B	C	D
Fresh-water species:				
Valvata tricarinata (Say)	×	......	......	......
Gyraulus altissimus (F. C. Baker)	×	......	......	......
Pisidium sp.	×	......	......	......
Fossaria parva (Lea) (*Lymnaea parva* of others)	......	×	×	......
Land species:				
Succinea gelida (F.C. Baker)	......	×	×	×
S. ovalis (Say)	......	......	×	......
Vertigo morsei (Sterki)	......	×	......	......
V. elatior (Sterki)	......	×	×	×
V. *alpestris oughtoni* (Pilsbry)	......	......	×	×
Pupilla muscorum (Linnaeus)	......	......	×	×
Columella alticola (Ingersoll)	......	......	×	×
Discus cronkhitei (Newcomb)	......	......	......	×
Stenotrema leai (Binney)	......	......	......	×
Vallonia pulchella (Müller)	......	......	×	×
V. excentrica (Sterki)	......	......	×	×
Euconulus fulvus (Müller)	......	......	×	......

* Identified by Nave and La Rocque from (*A*) Illinoian Abington interstadial deposit in Smith Farm section (unit 2); (*B*) New Paris interstadial deposit in American Aggregates section (unit 6); (*C*) Connersville interstadial deposit in Sefton Farm section (unit 5); and (*D*) Connersville interstadial deposit in Little Cedar Creek section (unit 2).

SANGAMON STAGE

Buried soils of Sangamon age are known at several localities in the Whitewater basin, and in most cases the soils are of the humic-gley type.[2] The abundance of such buried Sangamon humic-gley soils, and their widespread occurrence in the Whitewater basin, indicates that large upland areas of the Illinoian surface remained poorly drained during Sangamon time. Peaty soil humus, silt, and sand appear to have accumulated slowly in two of these poorly drained sites (Smith and Darrah Farm sections) essentially from the time the surface was exposed with the last meltback of Illinoian ice until the sites were buried by the overriding Wisconsin glacier. Successive accumulations in the Smith and Darrah Farm sections preserve pollen which gives what is believed to be essentially a complete record of the vegetation and climate of the region during the ice-free time, the rich humus layers in the Smith Farm section (units 6 and 8) having been deposited during the colder climatic periods at the beginning and close, respectively, of the ice-free interval (pollen data presented in Kapp and Gooding, in press).

The upper part of the Sangamon soil profile at several other sites farther south in the basin (see fig. 2) is very silty and contains streaks of finely divided organic matter in places. Pollen is sparse in the silty upper portion of these soils, however, and those grains present are badly ruptured and fragmented, making identification difficult in most cases.

The silty upper portion of these soils is interpreted to be largely weathered loess because (1) the silty zone in many of the sections is similar in thickness and texture, as would be expected if it were a loess blanket, and (2) the pollen grains which are identifiable are largely coniferous throughout the silty zone, suggesting a cold climate during deposition. Although the apparent absence of deciduous pollen in the top of these soils might suggest an early Wisconsin age for the silty upper layer, the following points tend to favor the interpretation that the silt was deposited around the retreating Illinoian ice front: (1) no organic material has been found between the silty layer and the underlying weathered till; (2) the degree of weathering appears to be gradational through the silty zone into the underlying till; and (3) the exposed Illinoian drift beyond the Wisconsin till boundary has a generally pebble-free surficial layer 5 or more feet thick which must be weathered Illinoian loess in part. Thus, Illinoian loess, generally thicker toward the south, is believed to be present in the Whitewater basin. Probably it was derived in part from Illinoian outwash deposits in shallow channels above present valley bottoms (Gooding, 1957, p. 26) and also, in the southern part of the basin, from Illinoian outwash in the Ohio River Valley. Colluviation after loess deposition does not appear to have been an important process during Sangamon time at most sites in the southern part of the Whitewater basin.

The Sangamon soil in the Wildman Farm section appears to have developed entirely in sands, gravels, and silts, probably in a terrace situation. Its physical characteristics are those of a fairly well-drained soil, similar to the Park soil on loess-mantled outwash terraces beyond the outermost Wisconsin till boundary (Gooding, 1957, p. 26–28; Rogers *et al.*, 1950). The strongly convoluted silt (unit 10) in the Wildman Farm section (Gamble, 1958, p. 14) indicates that deposition stopped briefly after the last Illinoian ice melted from this location. The overlying sand and gravel units probably were deposited shortly thereafter, as the thickness of the zone of leaching through these materials is 10 feet. The soil is truncated, however, so the original depth of leaching, before truncation by the overriding Wisconsin ice, was still greater. It may have been nearly the same as the depth of leaching shown by Park soils on existing remnants of exposed Illinoian outwash terraces beyond the outermost Wisconsin till boundary. Park soils are leached on the order of

[2] Humic-gley soils are mineral soils of swamps and marshes, with organic-rich surface horizons and reduced gray and brown mottled subsoils. Humic-gley soils may develop in any parent material and embrace a wide range of textures. Those that have a high clay content and very deep weathering in glacial till are "gumbotils."

eighteen feet (Gooding, 1957; Rogers *et al.*, 1950).

In the American Aggregates section, the overriding Wisconsin ice almost completely removed the Sangamon soil, leaving only highly oxidized and cemented joints which penetrate deep into the Illinoian till (unit 3). These features suggest that the soil here may have been on a fairly well-drained site.

The dominance of preserved buried Sangamon soils of the humic-gley type over better-drained soil types is due, of course, to the location of the former in poorly drained flats and shallow depressions on the Illinoian surface. The completeness of several of these buried Sangamon humic-gley soils, some with leaf and twig litter, and moss polsters apparently *in situ*, at the soil surface (Smith, Jones, Cummins, Bergendorfer, Snyder, and Sefton Farm sections), indicates that the soil surface must have been covered by meltwater ice over which the Wisconsin glacier advanced.

RADIOCARBON DATES

Radiocarbon dates from two sections on Sangamon soil materials, including the uppermost humic zone in the Smith Farm section which pollen data suggest accumulated during the building of the Wisconsin ice, are as follows: Smith Farm unit 8, bulk sample of humic material, L-479B > 37,500; Smith Farm unit 6, bulk sample of humic material, L-479C > 35,000 (Olson and Broecker, 1961, p. 144). Darrah Farm unit 8, soil humus and wood, L-414 > 41,000 (Olson and Broecker, 1959, p. 12).

WISCONSIN STAGE

WHITEWATER DRIFT

The basal Wisconsin till lying on the Sangamon soil in sections in the upper part of the Whitewater basin (American Aggregates, and Smith, Darrah, Jones, and Porter Farm sections) contains inclusions of a distinctive calcareous, red-brown till (color ranges from 2.5YR 5/4 dry, 2.5YR 4/4 wet, to 5YR 6/4 dry, 5 YR 4/4 wet; Munsell color notations) and is overlain by an organic-rich interstadial deposit.

Till containing the calcareous, red-brown till inclusions is known at several other sites in the upper Whitewater basin, where it also contains inclusions of non-calcareous, black soil humus and olive-green leached till, indicating that the ice that deposited it overrode the Sangamon soil in approaching these locations as well. The calcareous, red-brown till inclusions are found occasionally as small streaks in the next younger till, but rarely in other tills. Abundant and sometimes massive chunks and streaks of it are so characteristic of the basal Wisconsin till in the upper part of the basin that they are considered to be a criterion for its identification and correlation. This till with red-brown inclusions, so far known only in the upper Whitewater basin of southeastern Indiana, and its associated fluviolacustrine deposits, are named the Whitewater drift. The American Aggregates section (figs. 1, 2, and section description) is designated the type section in the type area of Wayne and Fayette counties in the upper part of the Whitewater basin.

OUTER BOUNDARY OF BURIED WHITEWATER DRIFT

In the Porter Farm section, where the Sangamon soil is absent, the Whitewater till with red-brown inclusions contains also abundant, large, thick-shelled, warm-climate snails and clams (*Pleurocera canaliculatum* (Say), *Campeloma ponderosum* (Say), *Lioplax subcarinate occidentalis* (Pilsbry), *Lithasia armigera* (Say), *Amblema peruviana* (Lamark), *Elliptio* sp. cf. *E. dilatatus* (Rafinesque) (identified by Nave and La Rocque, written communication), presumably picked up by the Whitewater Wisconsin glacier from stream sediments of Sangamon age. The abundance and undeformed condition of the mollusks suggests that they were picked up by the ice from the near vicinity just before the ice stagnated. Otherwise, it would seem that such fragile shells would have been crushed and destroyed in the load environment of the glacier.

That the Wisconsin ice that deposited the

Whitewater till stopped about the Porter Farm site is indicated further by the fact that (1) the Whitewater till with red-brown inclusions is not present in the Cummins, Bergendorfer, or Snyder Farm sections to the south (fig. 2), in each of which the Sangamon soil is entirely intact beneath Wisconsin till, and (2) the organic-rich interstadial deposit, which overlies the Whitewater till in sections to the north, lies directly on the Sangamon soil in the Snyder Farm section $1\frac{1}{2}$ miles southwest of the Porter Farm section (fig. 1). Thus, it seems possible to establish fairly accurately the buried outer boundary of the Whitewater till sheet in Fayette County. The buried boundary is drawn eastward across Union County more tentatively on the basis of the presence or absence of the Whitewater till with red-brown inclusions in other known sections (fig. 1).

COMPOSITION, SOURCE, AND SIGNIFICANCE OF RED-BROWN TILL INCLUSIONS IN WHITEWATER TILL

Gamble (1958, p. 28) reported that the red-brown color of the calcareous till inclusions in Whitewater till in the Darrah Farm section seems to be due to their being composed of a large quantity of ground-up hematitic quartz sandstone and siltstone, as pebbles and cobbles of these rock types occur commonly in the inclusions. I have observed also that in wet-sieve mechanical analysis of these calcareous till inclusions, the red-brown color in the disaggregated fine sand and silt size ranges washes away, showing that the coloration is due entirely to hematitic clay coatings on the mineral grains. In places, however, the calcareous red-brown inclusions consist mainly of clay, suggesting that at least some of them may be from lake clays (see Murray, 1953, p. 151–154, for explanation of red color of Valders till).

Both the Erie and Superior-Michigan basin areas contain hematitic bedrock which has been responsible for distinctive colors of certain drift units in other areas. Hematitic shale, siltstone, and sandstone rocks derived from the Silurian Queenston Shale and Grimsley Sandstone in the Erie basin are probably responsible for the purplish-brown color of a till in western Ontario (Dreimanis and Packer, 1959, p. 22; Dreimanis, written communication).

The hematitic lake clays believed by Murray (1953) to be responsible for the red color of the Valders till were derived from hematitic Precambrian rocks of the Superior and upper Michigan basins.

The red-brown color of the Winnebago drift of northwestern Illinois (Shaffer, 1956; Frye and Willman, 1960, p. 5), and the distinctive "pinkish" color of Leighton's Farmdale loess (Leighton, 1960, p. 535) also may be from hematitic rocks and/or lake clays in the Lake Superior and upper Lake Michigan basins (Leighton, written communication).

Although the source of the hematitic quartz sandstone cobbles in the red-brown till inclusions in the Whitewater till has not yet been determined petrologically, the following facts suggest that they came from the Superior-Michigan basin: (1) fabric data at several places from the Whitewater till show a northwest to southeast direction of ice flow; (2) the basal Wisconsin till lying on the Sangamon soil south of the tentative buried Whitewater till boundary in eastern Franklin County (Sefton, Cope, Little Cedar Creek, Possum Hollow, and Big Cedar Creek sections, figs. 1 and 2) has a northeast to southwest fabric and *does not* contain red-brown till inclusions; (3) red-brown till inclusions have not been observed in drift in adjacent southwestern Ohio; and (4) later definite Erie lobe tills in the area do not contain significant amounts of hematitic rock types. Thus, the present evidence suggests that the Whitewater till was deposited by a Patrician Superior-Michigan basin ice lobe, rather than by a Labradorean Erie ice lobe, as were later tills of the area. Presumably, the red-brown inclusions in the Whitewater till are from an older, post-Sangamon, Superior-Michigan basin drift which does not extend as far south as the Whitewater basin.

RADIOCARBON DATES

Radiocarbon dates on wood from the Whitewater drift, with pertinent comments, are as follows.

L-477B, > 41,000, Jones Farm section (Olson and Broecker, 1961, p. 144): Wood from thin calcareous silt (unit 4) lying on humus (unit 3) of Sangamon soil and beneath Whitewater till (unit 5; see fig. 2). The calcareous silt (unit 4) is interpreted as pro-Whitewater glacial rock flour. The wood sample was thought possibly to be from vegetation growing at the time the Whitewater ice moved over the area. It is possible, however, that the wood sample may have been washed from the underlying peaty deposit of Sangamon age.

L-479A, > 43,000 Smith Farm section (Olson and Broecker, 1961, p. 144): Wood from Whitewater till (unit 10). "The above age is for humic acid extracted from the wood. The alkali-treated wood gave an age of 33,600 ± 2800. As a check on the latter age, an untreated portion of the wood is currently in process" (Olson and Broecker, 1961).

Although the above dates in themselves do not prove conclusively that the Whitewater till was deposited more than 41,000 radiocarbon year ago, dates reported later on the overlying organic-rich interstadial deposit give them credibility.

NEW PARIS INTERSTADIAL DEPOSIT

As has been mentioned, the Whitewater till in several sections (American Aggregates, and Wildman, Smith, Darrah, and Jones Farm sections) is overlain by a calcareous organic-rich, interstadial deposit, which is largely silt in texture. The nearly identical silty texture of the deposit at all sites suggests that the material is of common origin and may be largely loess deposited in moist sites on the Whitewater till surface. The interstadial deposit contains north-temperate and boreal mosses, arctic herbaceous pollen, sparse coniferous pollen and wood fragments (Kapp and Gooding, in press), and mollusks (table 5). The molluscan data from this deposit in the American Aggregates section (unit 6) are interpreted by Nave and La Rocque (written communication) as follows: *Vertigo morsei* and *V. elatior* are land snails that exist today in wet or moist situations. *Succinea gelida* is a land snail limited to Pleistocene deposits. *Fossaria parva* is a fresh-water pulmonate which is common in wet, marshy places, generally out of water. *Vertigo morsei* and *F. parva* have a rather widespread distribution, but *V. elatior* is confined now to more rigorous climatic zones in northern latitudes and occurs only in mountainous areas south of Canada. This suggests that the environment represented by the post-Whitewater interstadial deposit at the American Aggregates site was a wet, poorly drained area when the climate was considerably colder than at the present time.

The lack of weathering phenomena and the nature of the organic materials in the interstadial deposit overlying Whitewater till indicate that the retreat interval during which the sediment was deposited was relatively short and cold. The ice probably existed not far to the north. However, the widespread occurrence of the deposit in the Whitewater basin, and the fact that plants and animals were able to get established, suggest that it records a significant event probably related to a climatic condition that effected the ice front over a wide area beyond the Whitewater Valley. Thus, it is considered to represent a significant break within the Wisconsin and is here named the New Paris interstadial, after New Paris, Ohio, which lies 1½ miles northeast of the American Aggregates type section.

RADIOCARBON DATES

Radiocarbon dates on the New Paris interstadial deposit are as follows.

L-478B, > 40,500, American Aggregates section: Wood from organic-rich New Paris interstadial deposit (unit 6) which lies on Whitewater till (unit 5). "Humic acid was isolated from two separate pieces of the wood sample. Both the humic acid portions were found to have measurable carbon-14, giving apparent ages of 31,800 ± 2500, and

23,100 ± 1500" (Olson and Broecker, 1961, p. 144).

I-587, > 38,000, American Aggregates section (date unpublished previously): Wood collected 5 inches from the top of 2-foot-thick organic-rich New Paris interstadial deposit (unit 6).

FAYETTE DRIFT

South and southeast of the tentative boundary of the buried Whitewater till (fig. 1) another till without inclusion of the distinctive red-brown till lies on the Sangamon soil and is in turn overlain by a calcareous, organic-rich, interstadial deposit (Sefton Farm, Little Cedar Creek, Possum Hollow, and Big Cedar Creek sections, fig. 2). Till fabric data at a few places suggest that the ice that deposited this till in the eastern part of the Whitewater basin moved over the area from the northeast.

Since only one calcareous, organic-rich interstadial deposit has been observed in the buried pre-Shelbyville Wisconsin drift in all known sections in the Whitewater basin, I concluded originally (Gooding, 1961) that the Whitewater till to the north, with a NW. to SE. fabric, and the basal Wisconsin till with a NE. to SW. fabric in southern Fayette and eastern Franklin counties, probably were deposited by two essentially contemporaneous ice lobes, and that the interstadial deposits which overlie these tills must be equivalent over the area. As will be seen, however, recently obtained radiocarbon dates show the basal Wisconsin till and overlying interstadial deposit in Franklin and southern Fayette counties to be younger than the Whitewater till and overlying New Paris interstadial deposit in sections to the north. The Sefton Farm section, which shows best the younger Wisconsin till (unit 5) and overlying interstadial deposit (unit 6), on the Sangamon soil (see Gooding, 1961, p. 121–124), is taken as the type section for these Wisconsin drift units. This Wisconsin till and its associated stadial deposits are named the Fayette drift, after Fayette County, Indiana.

In southeastern Fayette and eastern Franklin counties (see fig. 1), the buried Fayette till boundary is essentially coincident with the surface Shelbyville till boundary. Its exact boundary farther west is not known, although, as will be indicated later, evidence suggests that buried Fayette drift exists at several localities in central Indiana, one of which is near Rushville, Indiana, about 20 miles due west of the Sefton Farm section. The basal Wisconsin till on completely intact Sangamon soil in the Cummins and Bergendorfer Farm sections in west-central Fayette County (see figs. 1 and 2) is thought to be probable Fayette drift.

RADIOCARBON DATES

I-611, > 40,000, Cummins Farm section (data unpublished previously): Wood sample appeared to be the stump of a small tree which was growing on the Sangamon soil surface at the time the site was overridden by Fayette ice. The wood sample was surrounded by gray, highly calcareous silt (unit 3) interpreted to be pro-Fayette glacial rock flour. If the interpretation of the occurrence of the wood sample is correct, the Fayette drift would seem to be bracketed by radiocarbon dates of >40,000 and 20,000 ± 500, the latter date from the overlying interstadial deposit discussed below. It is possible, however, that the small stump was washed in from surrounding Sangamon deposits and therefore may not date the advance of Fayette ice.

CONNERSVILLE INTERSTADIAL DEPOSITS

As mentioned above, the Fayette drift in southern Fayette and eastern Franklin counties is overlain by a calcareous, organic-rich interstadial deposit in several sections (Sefton, Cope, Little Cedar Creek, Possum Hollow, and Big Cedar Creek sections). The deposit is indistinguishable in itself from the Illinoian Abington and Wisconsin New Paris interstadial deposits and is believed to be largely loess deposited in a moist environment.

A coniferous pollen assemblage of spruce, pine, fir, and north-temperate mosses, has been identified from this interstadial deposit in the Sefton Farm and Little Cedar Creek sections (Kapp and Gooding, in press). Mollusks from this unit in these sections, identified by Nave and La Rocque, are listed in table 5. The fauna consists exclusively of land snails. *Vallonia pulchella* and *V. excentrica*, *Euconulus fulvus*, and *Succinea ovalis* are presently rather widespread forms common in debris in moist situations near water or in humid forests. *Succinea gelida* is an extinct Pleistocene form. *Pupilla muscorum* is especially abundant in rocky, limestone areas with accumulations of rock powder and soil. *Vertigo elatior*, *V. alpestris oughtoni*, *P. muscorum*, and *Columella alticola* all have a present distribution limited to colder climates of Canada and mountainous areas farther south. A wet, boggy, calcareous environment in a climate considerably colder than the present is suggested (Nave and La Rocque, written communication).

This interstadial deposit overlying the Fayette drift is considered to represent a climatically controlled retreat interval and is named the Connersville interstadial, after Connersville, Indiana, near the type Sefton Farm section.

RADIOCARBON DATES

I-610, 20,000 ± 500, Sefton Farm section unit 5 (date unpublished previously): The dated sample was wood, collected from near the top of the calcareous, organic-rich Connersville interstadial deposit.

A sequence of Wisconsin drift units identical to the succession in southern Fayette and eastern Franklin counties, Indiana, occurs over the Sangamon soil in southwestern Ohio. The suggested correlation (Forsyth, 1961, p. 59) of Wisconsin drift in these nearly areas now seems substantiated by the above radiocarbon date of 20,000± 500 on the Connersville interstadial deposit. Radiocarbon dates of 18,750 ± 300 (W-738) on organic matter from the interstadial deposit, and of 19,100 ± 300 (W-724) on wood from the base of the overlying till, have been reported from the Hamilton, Ohio, cut (Durrell, 1961, p. 89).

A radiocarbon date of 20,000 ± 800 (W-598) is reported on one of several occurrences of an interstadial silt containing plant remains and mollusks between two tills at several places in central Indiana (Wayne, 1955, 1956, 1957; Thornbury and Wayne, 1957). The earlier suggestion (Gooding, 1961, p. 102) that the central Indiana interstadial silts might correlate with a silt between Shelbyville and Champaign tills in the Whitewater basin (discussed later) appears to be wrong.

The Connersville interstadial deposit is now recognized and correlated by radiocarbon dates from central Indiana, across southwestern Indiana, into southwestern Ohio.

TAZEWELL STADIAL

Although the stratigraphic data in the Whitewater basin show distinct Shelbyville and Champaign till sheets separated by a thin loess deposit, the following lines of evidence suggest that the ice oscillations that formed them and the Bloomington drift occurred in rather rapid succession: (1) the close parallelism of the interlobate boundaries of the Shelbyville and Champaign till sheets suggests a close relationship in time between the ice lobes that deposited them; (2) the differences in depth of leaching between the Russell soils (leached 3–5 feet) on the Shelbyville surface and the Miami soils (leached 20–30 inches) on the Champaign surface seem to be related more to variations in thickness of the loess mantles than to a significant age difference (Gooding, 1957); (3) terrace data (Gooding, 1957) suggest that blocks of Shelbyville ice were buried by Champaign valley train fill, partly exhumed by Bloomington meltwater scouring, and only later melted to form kettles; (4) radiocarbon dates show a close relationship in time between the drifts in Illinois (Frye and Willman, 1960) with which the Shelbyville, Champaign, and Bloomington drift units in the Whitewater basin have been correlated; and (5) plants and mullusks, which would be expected in an interstadial deposit, are sparse to absent in the Shelbyville loess where it has been observed buried beneath Champaign till.

The presence of a few mollusks in buried Shelbyville loess at a few localities a short distance inside the Champaign till border and the greater area of exposure of the Shelbyville till surface suggest that the Shelbyville-Champaign retreat interval was longer than the Champaign-Bloomington retreat interval. Neither, however, appears to record events significant enough to be considered interstadial.

Shelbyville drift.—Shelbyville drift forms the outermost Wisconsin till boundary in the Whitewater basin and crops out over all of Union County, most of Fayette County, and parts of Franklin and Wayne counties (fig. 1). The interlobate nature of the till boundary and till fabric data show the drift to have been deposited by two ice lobes, the east flank of the East White River lobe radiating from the northwest, and the west flank of the Miami lobe from the northeast.

Detailed mapping (in progress) shows several belts of weak retreatal moraines over the exposed Shelbyville surface, especially in Fayette County, suggesting frequent fluctuations of the Shelbyville ice front, particularly in the East White River lobe. Stratigraphic data in several Fayette County sections show several tills separated by sand, gravel, and silt units. The number of till units varies from section to section, however, and must record brief, local oscillations of the Shelbyville glacier. There is no indication of important time breaks between these tills, and fabric data are essentially the same for the different Shelbyville tills in each section.

A loess blanket averaging 2–4 feet in thickness lies on the Shelbyville surface in both the Miami and East White River lobes. The loess was derived from both the Shelbyville and Champaign valley trains which were formed down the drainage ways of the East and West Forks of the Whitewater River (Gooding, 1957). Correlation of valley trains in the East and West Forks of the Whitewater River and the uniformity in thickness of loess and degree of weathering on the Shelbyville surface over the area indicate that the East White River and Miami Shelbyville ice lobes in the area were essentially contemporaneous.

At several localities north of the Champaign till boundary (Darrah and Jones Farm sections, and others) Shelbyville loess occurs beneath the Champaign surface till. In some places it contains a few mollusks but so far has not yielded pollen. Fossiliferous Shelbyville loess beneath Champaign till thus seems to record a brief meltback of Shelbyville ice before readvance of the Champaign ice. Shallow excavation of Shelbyville valley trains occurred during melting of Shelbyville ice and before the readvance of Champaign ice.

No radiocarbon dates are yet available from Shelbyville and younger drift in the Whitewater basin. The similarity of radiocarbon dates on the Connersville interstadial deposit, however, to a date on wood from Shelbyville till in Illinois (19,200 ± 700, W-187) would seem to confirm the Shelbyville age, heretofore assigned tentatively, for the surface drift overlying the Connersville interstadial deposit in the Whitewater basin and adjacent areas.

Champaign drift.—The Champaign till boundary in the Whitewater basin also is interlobate (fig. 1) closely paralleling the Shelbyville boundary. Till fabric data agree with moraine orientations, indicating that the Champaign till was deposited in the area by both the East White River and Miami ice lobes. Whereas the Shelbyville ice seems to have fluctuated considerably, producing several till units with intercalated sand, gravel, and silt layers, especially in the East White River lobe, the Champaign ice appears to have advanced uniformly, leaving essentially one relatively thin till in the area (Darrah and Jones Farm sections).

A valley train was developed down the East and West Forks of the Whitewater River with the Champaign advance (Gooding, 1957), and a mantle of loess about 1 foot thick was blown from this surface onto the uplands during the retreat of Champaign ice.

Although no radiocarbon dates are available on the sparse organic matter from the buried Shelbyville loess or the Champaign till by which the time of Champaign ice advance could be compared with the event in Illinois, the stratigraphic position of this till, above what now seems more conclusively to be Shelbyville drift, supports the previous tentative correlation with the Champaign drift of Illinois.

Bloomington drift.—The wide, massive, Bloomington morainic complex lies roughly east-west across northern Wayne and southern Randolph counties (fig. 1). This moraine established the present headwater divide between the Whitewater basin and the adjacent West White River and Miami drainage basins.

Although all of the stratigraphic sections reported in this paper are south of the Bloomington moraine, and therefore do not contain Bloomington till, other evidence suggests a definite, but minor, stratigraphic separation of this till from the Champaign drift.

The Bloomington till is known to be somewhat more clayey than earlier Wisconsin tills in the area. Geomorphological data (Gooding, 1957) suggest that the retreat interval was brief, precluding the possibility of the high clay content of the Bloomington till having been derived from a distant source. Distribution of pro-Champaign outwash in Wayne County (Gooding, 1957) suggests that the drainage divide was essentially in its present position during Champaign time. Hence, the clayey composition of Bloomington till might be due to the acquisition of lake clays that accumulated a short distance to the north during a short retreat of Champaign ice.

The Bloomington till surface has little or no loess. Because of poor drainage, however, the Bloomington till surface is characterized by rather extensive but shallow, pond-laid clay deposits.

The stratigraphic position of the Bloomington drift in this area agrees with the earlier tentative correlation of this drift with the Bloomington drift of Illinois, as indicated originally by Leverett and Taylor (1915).

LEACHED CLAY-ENRICHED ZONES

Gooding *et al.* (1959) and Gooding and Gamble (1960) presented evidence leading to the conclusion that leached, clay-enriched zones in outwash gravel, sand, and silt which lie beneath calcareous till, widespread in southwestern Ohio and southeastern Indiana, are not remnants of a paleosol of regional extent but are downward extensions of the B horizons of present surface soils through cracks and joints in the overlying calcareous till. These zones have been observed at various stratigraphic levels in the drift of the area wherever there is good drainage through jointed surface till underlain by permeable sand, gravel, or silt.

The leached, clay-enriched zones in sands, gravels, or silts beneath the surface tills in the Jones, Cummins, Bergendorfer, and Snyder Farm sections (see fig. 2) all show evidences of being extensions of the surface soils. Hence, they have no stratigraphic value. For detailed discussions of the nature and origin of these pseudo-paleosols, the above references should be consulted.

STRATIGRAPHIC AND HISTORICAL SUMMARY

Figure 3 shows the general areal and stratigraphic relationships, and table 6 the geologic-climate and time-stratigraphic classification of the Illinoian and Wisconsin drift units in the Whitewater basin of southeastern Indiana.

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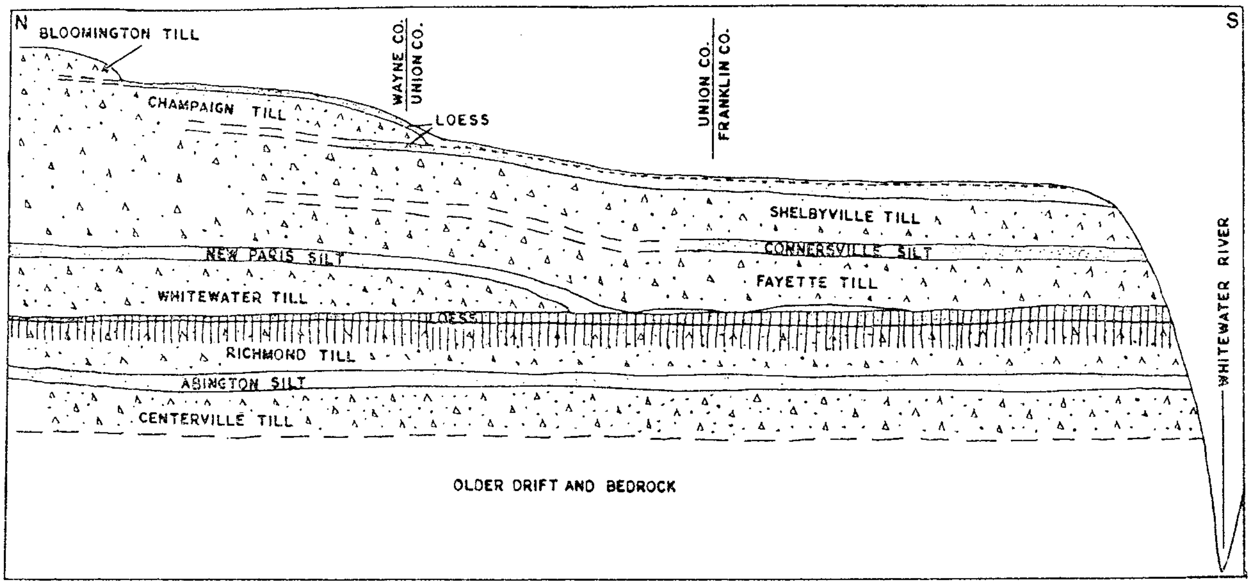

FIG. 3.—Idealized diagram showing areal and stratigraphic relationships between Illinoian and Wiscon sin drift units in the Whitewater basin, southeastern Indiana. Great vertical exaggeration.

TABLE 6

ORDER OF SUCCESSION AND CLASSIFICATION OF ILLINOIAN, SANGAMON, AND WISCONSIN UNITS IN THE WHITEWATER BASIN, SOUTHEASTERN INDIANA

	Units	Radiocarbon Dates
Wisconsin glacial stage:		
Tazewell Stade	Bloomington drift; Champaign loess; Champaign drift; Shelbyville loess; Shelbyville drift	. . . .
Connersville Interstade	Connersville organic-rich sediments	I-610, 20,000±500
Fayette Stade	Fayette drift	I-611, >40,000
New Paris Interstade	New Paris organic-rich sediments	I-587, >38,000 L-478B, >40,500
Whitewater Stade	Whitewater drift	L-479A, >43,000 L-477B, >41,000
Sangamon interglacial stage:	Weathered materials and organic deposits	L-479B, >37,500 L-479C, >35,000 L-414, >41,000
Illinoian glacial stage:		
Richmond Stade	Loess; Richmond drift	. . . .
Abington Interstade	Abington organic-rich sediments	. . . .
Centerville Stade	Centerville drift	. . . .

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