Remnant Magnetism of Pleistocene Sediments of Indiana

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Abstract

Remnant magnetism of interglacial and intraglacial silt or clay deposits in Indiana, including samples from within and below so-called Kansan till of western Indiana, from intra-Wisconsinan silts of western Indiana, and from Wisconsinan loesses of southern Indiana, reveals that the materials are normally magnetized. This suggests that the Kansan till that has been defined in several often-visited exposures in western Indiana was deposited after about 700,000 years ago, that is, during the Brunhes Normal Polarity Epoch. No evidence has yet been found for inter-Brunhes reversals, such as the Blake, Laschamp, and Puget Reversed Polarity Events.

Normal polarity characterizes silts within and below numerous exposures of a till in west-central Indiana that is an equivalent of the Hillery Till Member, a unit of Kansan age first described in the Danville area of Illinois. At an exposure on Mill Creek in Fountain County, however, organic silts below Kansan and other as yet uncorrelated tills and above thick, highly weathered alluvium atop Lafayette-like gravel are reversely magnetized, and presumably fall within the Matuyama Reversed Polarity Epoch. Reversed polarity also characterizes the laminated fossiliferous lake clays of the Handley Farm section in Fayette County, eastern Indiana. These clays contain a full interglacial pollen profile that has been interpreted as being Yarmouthian in age by R. O. Kapp and A. M. Gooding. Deposits of western Indiana (silts within and below presumed Kansan till), however, are normally magnetized; thus the supposed Yarmouthian interval of western Indiana is most likely of normal polarity. Therefore the clays of the Handley Farm section and an underlying till are probably older than the so-called Kansan of western Indiana.

Introduction

Purpose and Scope of Study

The dating of glacial deposits in Indiana as throughout the Midwest has been of a very relative nature. The drift below the first paleosol below the youngest deposits, the Wisconsinan, has been considered to be the Illinoian drift. The next drift below has been considered to be the Kansan. Because no one has ever proved a fourth distinct drift in Indiana, the Nebraskan Stage has not been recognized in this state. Such a process of counting downward leaves much to be desired, of course, but until recently little recourse has been available. Studies of the physical characteristics of till units will eventually allow detailed rock-unit correlations of units to be made regionally. A detailed rock stratigraphy has been defined in the Danville, Illinois, area (24, 25), and work in progress (2) has now extended recognition of many of these units into western Indiana and has added additional units to the sequence. Petrographic work on tills has been underway for some time in eastern Indiana. (See 16.) Through such studies some tills in west-central Indiana once thought to be pre-Wisconsinan in age are now known to be Wisconsinan; some thought to be Wisconsinan or Illinoian in age are now known to be at least as old as Kansan. At best, however, such rock-stratigraphic correlations only correlate a unit with one or more significant sections elsewhere where paleosols are in place in the stratigraphic section, and where one still counts downward and calls the third major drift the Kansan. Thus, an absolute time scale still remains essential to interpretations made from rock stratigraphy.

Carbon-14 dating methods have aided in identifying and correlating Wisconsinan deposits younger than about 40,000 years. This timespan is an important, but rather insignificant, part of the few-million-year-old glacial age. Unfortunately, we lack in this part of the Midwest any recognizable volcanic ash units of the sort now recognized in relative abundance in the Plains states, where at least five significant ash falls are recognized (3, 4). Indeed, the basic definitions of Kansan and Nebraskan drifts in their type areas are now being scrutinized in the light of this new information, and the Pleistocene record is now seen to extend much farther back in time than was once recognized (3, 4).

We do have available one method of dating our older glacial deposits in a relatively absolute sense. The method is magnetostratigraphy. The orientation of the earth's magnetic field has flip-flopped through time, the last major shift from a reversed state, in which magnetic vectors pointed southward and up in our hemisphere, to a normal state in which magnetic vectors pointed northward and down in our hemisphere, occurring about 700,000 years ago. This date marks the boundary between the Brunhes Normal Polarity Epoch and the preceding Matuyama Reversed Polarity Epoch. (See 7.) *Detrital remnant magnetism* (DRM), that orientation imparted to certain magnetic grains by the earth's magnetic field at the time of their deposition, is a property measurable in sediments. During the past decade a rather detailed time scale of geomagnetic reversals has been outlined. (See 7, 8, 9.) The time scale for the past 4 million years contains four major epochs when magnetic delineation has been dominantly north (with downward inclination) or south (with upward inclination). Numerous shorter events are known within each epoch.

The Brunhes-Matuyama boundary (0.7 million years B.P.) is within the Pleistocene time interval as already determined in studies of continental and oceanic sediments, and the placement of the older Pleistocene deposits in Indiana with respect to the Matuyama reversed and Brunhes normal epochs provides a simple but useful dating reference. This distinction will allow necessary comparisons to be made between old tills in eastern and western Indiana and comparisons to be made to type deposits to the west.

The recognition of reversed events known or suspected within the Brunhes epoch would be of even more specific value in correlation. Evidence for the Blake Reversed Polarity Event (35, see also 28) would be expected in sediments of Sangamonian age. Evidence for the short-lived Laschamp or Puget Reversed Polarity Events might be expected in middle to late Wisconsinan deposits (see 5, 11), although any such events must have been exceptionally short (10).

A principal purpose of this study was to sample intratill and subtill stratified silt and clay deposits from eastern and western Indiana (Fig. 2) in order to place the deposits with respect to the Brunhes-Matuyama boundary. A second purpose was to sample loesses from southwestern Indiana in order to determine whether they record any of the minor events within the Brunhes Normal Polarity Epoch.

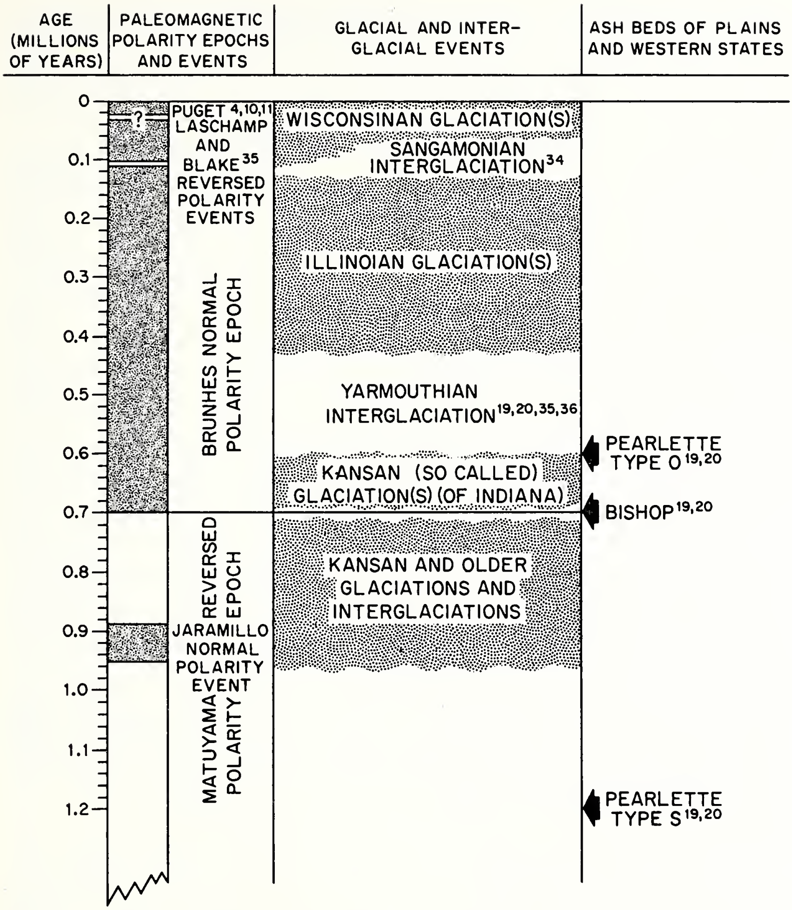


Figure 1. *Diagram illustrating time scale of geomagnetic polarity events of the last million years, glaciations and interglaciations, and positions of ash beds of the western and plains states. Placement of time lines is somewhat speculative. Superscripts indicate source or discussion references. Placement of the so-called Kansan of Indiana is tentative, at best.*

Previous Work

Interest in the use of paleomagnetic data as a regional and world-wide correlation tool was generated by George Kukla (see 27, 28) during his collecting tour of midwestern sections in 1972. His results were presented informally at the American Quaternary Association meetings in Miami, 1972, and at the North-Central Section meeting of the Geological Society of America at Columbia, Missouri, in 1973. Results of magnetic studies in the Danville, Illinois, area (29) indicate reversely magnetized silts beneath Kansan tills but normally magnetized silts between those tills (Tilton and Hillery Till Members of the Banner Formation).

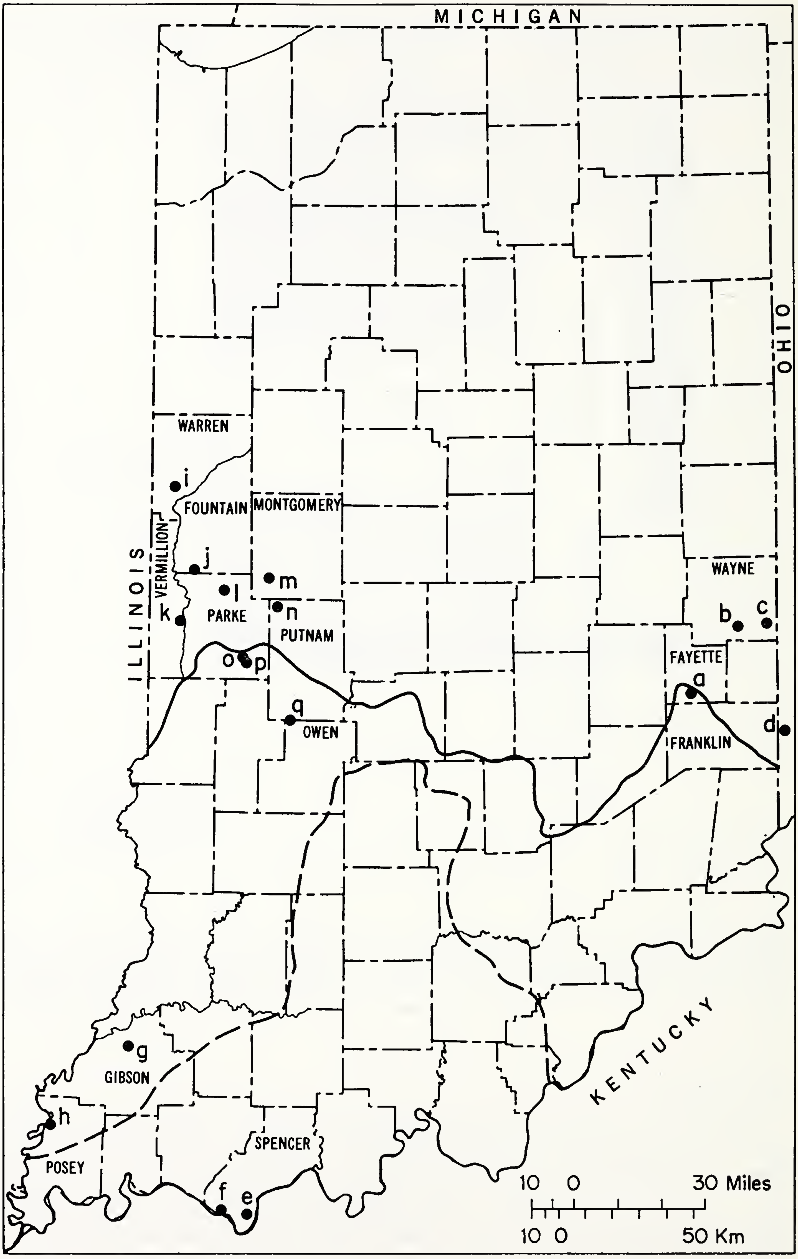


FIGURE 2. *Location of sampling sites for studies of paleomagnetism of Pleistocene deposits in Indiana. Boundaries of Wisconsinan and of older glacial deposits shown by solid and dashed lines, respectively.*

Hoyer (18) found the Minford Silt of southern Ohio to be reversely magnetized. The silts were deposited within the upper Teays Valley when its lower reaches were first blocked by glacial ice and drift.

Principals

Most rocks or unconsolidated sediments exhibit a measurable *natural remnant magnetism* (NRM) owing to the presence in the material of at least small quantities of certain magnetic mineral grains, most commonly iron oxide minerals. This fossil magnetization, or paleomagnetism, is referred to as *detrital remnant magnetism* where it occurs because of alignment of magnetic mineral grains in a sediment, the alignment reflecting the alignment of the grains parallel to the magnetic lines of force at the time of deposition.

The NRM initially measured in sediments consists of a primary DRM, as just described, in addition to various subsequent or secondary magnetization, most importantly *viscous remnant magnetization* (VRM), a relatively weak, or soft, magnetization imposed by the present field. Such secondary magnetization may be removed by cleaning, or partial alternating field demagnetization, as described below. The acquired VRM in samples of the age studied here can be expected to be destroyed by cleaning in fields of a few hundred oersteds. (See 32.) The measurable magnetic properties of a rock sample are the same as those of today's magnetic field and consist of a declination (a horizontal orientation between 0° and 360°) and an inclination (a vertical angle with respect to the horizontal). In central Indiana the present declination is about 1½° east of north and the inclination is about 72° downward to the north. The inclination of DRM exhibited by sediment particles is expected to be somewhat less than true inclination at the time of deposition owing to physical grain interactions during deposition.

Methods

Samples were collected from surface exposures of interglacial and intraglacial silt and clay deposits of west-central and east-central Indiana and from loesses of southern Indiana. Original horizontal or nearly horizontal statification was evident in most sections except those of loess. No evidence of significant deformation was found in any sections sampled. Oriented samples were taken with a block coring device measuring 3 cm x 3 cm x 3 cm and were transferred to plastic cubes in the field. Voids within cubes and tops of cubes were sealed with paraffin, in the field in some instances, to facilitate transfer and laboratory analysis.

Samples were analyzed in a spinner magnetometer having a sensitivity of 10^{-6} cgs. Alternating field (A.F.) demagnetization utilizing a 3-axis tumbler was used to clean samples. Samples were analyzed initially for NRM and for DRM after cleaning in fields of 200 to 400 oersteds. Owing to the diverse nature of the sediments studied, the cleaning fields varied between and within sections. Selected samples were cleaned progressively in fields ranging from 50 to 800 oersteds.

Magnetic vectors were determined for six orientations of the cubes. Vectors averaged for the three axes were plotted stereographically on an equal area net. Down and north hemisphere projections for samples strong enough to withstand A.F. demagnetization through at least 200 oersteds are presumed herein to record normal polarity; up and south hemisphere projections are presumed to record reversed polarity.

Samples that yielded NRM data and withstood some small amount of A.F. demagnetization, or that yielded somewhat spurious results, are listed as probably normal or probably reversed. Samples that were too weak to yield meaningful initial NRM data are listed as indeterminate in the figures. NRM and DRM intensities listed below are averages for the six orientations measured.

Results

Detrital remnant magnetism of both normal and reversed orientation was found in the Pleistocene sediments of Indiana. Intensities of NRM ranged from 0 to more than 100 cgs units. Variations were high between sections and within sections as a function of grain size, weathering, and genesis. Most samples followed relatively smooth A.F. demagnetization curves (Fig. 3) and most were considered stable through cleaning of 400 oersteds; a few samples, however, became unstable after cleaning in as few as 200 oersteds. In general, roughly one-third to one-half of the NRM was removed upon cleaning at 200 oersteds (Fig. 3).

Eastern Indiana

Handley Farm section (NW cor., SE¼ sec. 28, T. 13 N., R. 12 E., Fayette County; Fig. 2a): Units are, in descending order, loess, till of apparent Illinoian age, pro-Illinoian outwash and basal clay, weathered till (variably interpreted as Kansan till or Yarmouthian colluvium), calcareous clay containing a full interglacial pollen sequence, till, and Ordovician limestone.

The main clay section at Handley Farm, that containing a full interglacial pollen profile and that most recently interpreted as of Yarmouthian age (unit 4 of 26), definitely has reversed DRM (Fig. 4). Some samples in the top part of the clay section retain only very weak remnant magnetic properties (Fig. 4), apparently owing to weathering associated with the paleosol atop the thin till directly overlying the clay. Some samples at various lower levels are similarly weak and have nondeterminable or only barely determinable magnetic vectors. Some of these yield definitely southward (reversed) declination but anomalous positive (downward, normal) inclination. The latter are very probably reversed but basically too weak to allow total cleaning of the normal effects of VRM. One stronger sample of initially similar south-down orientation did clean at 200 oersteds to an unquestionably reversed orientation.

Four of five samples of the calcareous clay overlying the weathered till and main clay (unit 7 of 26) yielded no results. This is attributed to the poor condition, the apparently modern root-disturbed nature of the available exposure. One sample yielded possibly normal DRM vectors, but sufficient cleaning was impossible.

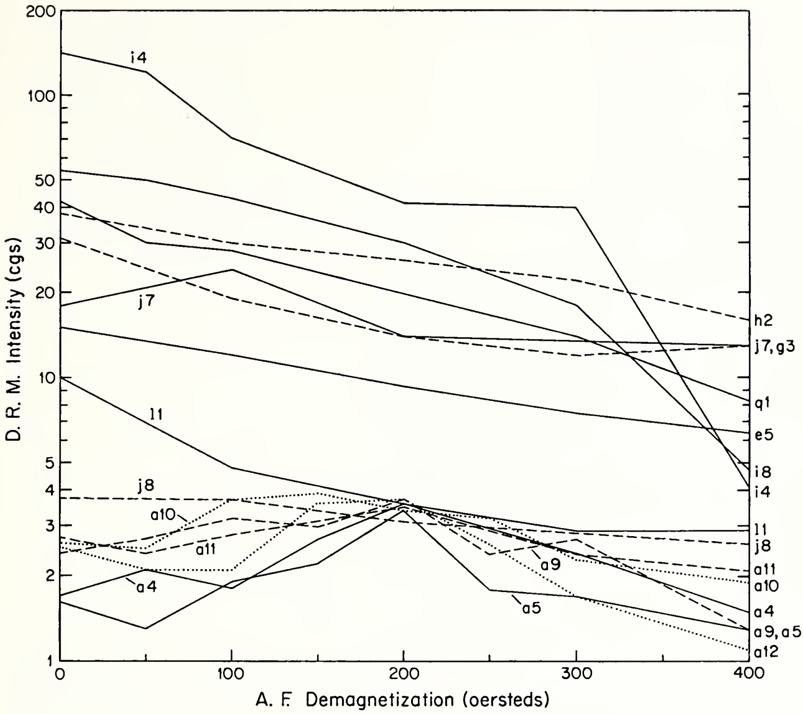


FIGURE 3. *Variation of detrital remnant magnetism intensity with stages of alternating field demagnetization of representative strong samples of interglacial and intraglacial silts and clays of west-central Indiana, loesses of southern Indiana, and the Handley Farm section of eastern Indiana. All samples are normal, except those from sections a and j, which are reversed. Samples numbered from top down in referenced figures: a, main clay, Handley Farm section (fig. 4a); e, loess, section 2 of Ray (33) (fig. 5e); g, loess, Patoka section (fig. 5g); h, loess, New Harmony section (fig. 5h); i, silt, Redwood Creek section (fig. 6i); j, silt, Mill Creek section (fig. 6j); l, silt, Lusk Chapel section (fig. 6l); m, silt, Liberty School section (fig. 6m); q, silt, Cagles Mill section (fig. 6q).*

Alternating field demagnetization curves (Fig. 3) for the samples from the main clay at Handley Farm are markedly different from those obtained for most other samples. Remnant magnetic intensity is actually increased in almost all samples with demagnetization to 200 oersteds, apparently reflecting the subtraction of the normal viscous remnant magnetic vector component, that component imposed upon the sediment by the field of the past 0.7 million years.

Kapp and Gooding (26) reported the presence of a till unit beneath the clays. If a till is, indeed, present in this position, it is older than the so-called Kansan till and Yarmouthian soil of western Indiana (considering the paleomagnetic data presented below that show the interglacial clays to be pre-Yarmouthian).

During a short visit to the site in October, 1975, with H. H. Gray and J. Bassett, an auger hole was drilled to bedrock beneath the central part of the exposure. No obvious till was encountered in this hole.

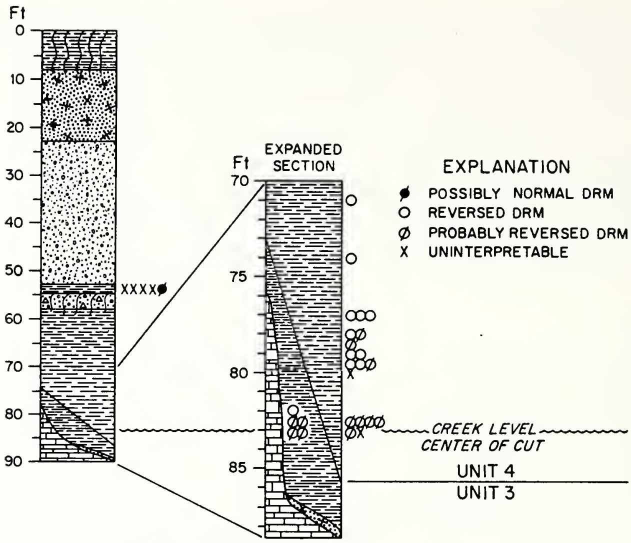


FIGURE 4. *Detrital remnant magnetism determined for clays of the Handley Farm section (15, 26), southeastern Indiana; NW cor., SE ¼ sec. 28, T. 13, N., R. 12 E.; (fig. 2a).*

Rather, the lake clays grade downward into a sandy basal zone rich in local shale granules. Heavy mineral analysis of this basal material yielded small quantities of fine and very fine sand-sized heavies, mostly tourmaline, zircon, and garnet, a seemingly nonglacial assemblage. The overlying clay, however, contains a relatively high percentage of amphiboles, including a few large fresh hornblende grains, although only about 20 grains were obtained from a 300-grain sample (John Bassett, personal communication). These fresh grains may indicate a till source nearby, stratigraphically below the interglacial clay deposit. Kapp and Gooding (26) reported some pollen evidence of colder climate in the basal clay. Intraglacial stratified deposits have been described within till considered to be of Kansan age in eastern Indiana; however, the exposures are no longer available.

Unit sampled	DRM Orientation	NRM Intensity
Unit 7 of Kapp and Gooding (26), clay above paleosol in colluvium	Normal? (1 of 5 samples)	0-1.4 cgs
Units 4 and 3 of Kapp and Gooding (26), main clays	Reversed (10 of 25 samples)	0-2.7 cgs

All other units sampled in eastern Indiana are of intra-Wisconsinan silts. These were not sampled in detail, and most relate to sections recently described by Gooding (17).

Darrah Farm section (14, 13) (not diagrammed; SE¼NE¼ sec. 5, T. 15 N., R. 14 E., Wayne County; fig. 2b):

Unit sampled	DRM Orientation	NRM Intensity
Unit 15 of Gooding (14, fig. 2), unit 12 of Gamble (13, fig. 5), silt between Wisconsinan tills	Normal (1 sample)	27 cgs

Forest Hills Country Club section (17) (not diagrammed; NW¼ NW¼ sec. 15, T. 13 N., R. 1 W., Wayne County; fig 2c):

Unit sampled	DRM Orientation	NRM Intensity
Intratill silt presumed to mark position of Sidney Interstadial of Gooding (17, p. 1000-1009)	Normal (2 samples)	11 cgs

New Paris, Ohio, Waterworks section (17) (not diagrammed; SW cor., sec. 21, T. 9 N., R. 1 E., Preble County, Ohio; fig. 2d):

Unit sampled	DRM Orientation	NRM Intensity
Soil of Sidney Interstadial of Gooding (17, p. 1000-1009)	Normal (2 samples)	17-28 cgs
Silt of New Paris Interstadial of Gooding (17, p. 994-1000)	Normal (2 samples)	6.1-6.8 cgs

Southern Indiana

The loess members of the Atherton Formation of southern Indiana are normally magnetized. Samples were taken from sections in Gibson, Posey, and Spencer Counties in southern Indiana (fig. 2, e-h) containing loess units identified by Ray (33) as the Peoria, Farmdale (=Roxana Silt of Illinois), and Loveland or the Peoria overlying undifferentiated loess (21, probably Roxana equivalent) (fig. 5). The sections sampled were: e, section 2 of Ray (33, p. 66), NW¼SW¼ sec. 9, T. 8 S., R. 6 W.; f, section 7 of Ray (33, p. 61), NW¼SW¼ sec. 4, T. 8 S., R. 7 W.; g, Patoka section of Johnson (21, p. 195-196), center of SE¼ sec. 26, T. 1 S., R. 11 W.; h, New Harmony section of Johnson (21, p. 201-202; see also 12, p. 29, and 31, pl. 2A), NW¼SW¼ sec. 1, T. 5 S., R. 14 W.

Unit sampled	DRM Orientation	NRM Intensity
Peoria Loess Member (4 sections)	Normal (8 of 9 samples)	0-47 cgs
Farmdale Loess Member (4 sections)	Normal (8 of 9 samples)	0-32 cgs
Loveland Loess Member (1 section)	Normal (1 sample)	30 cgs

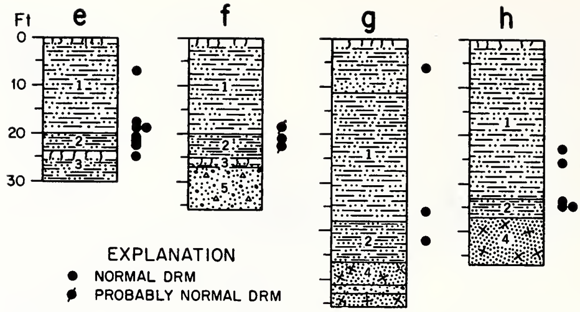


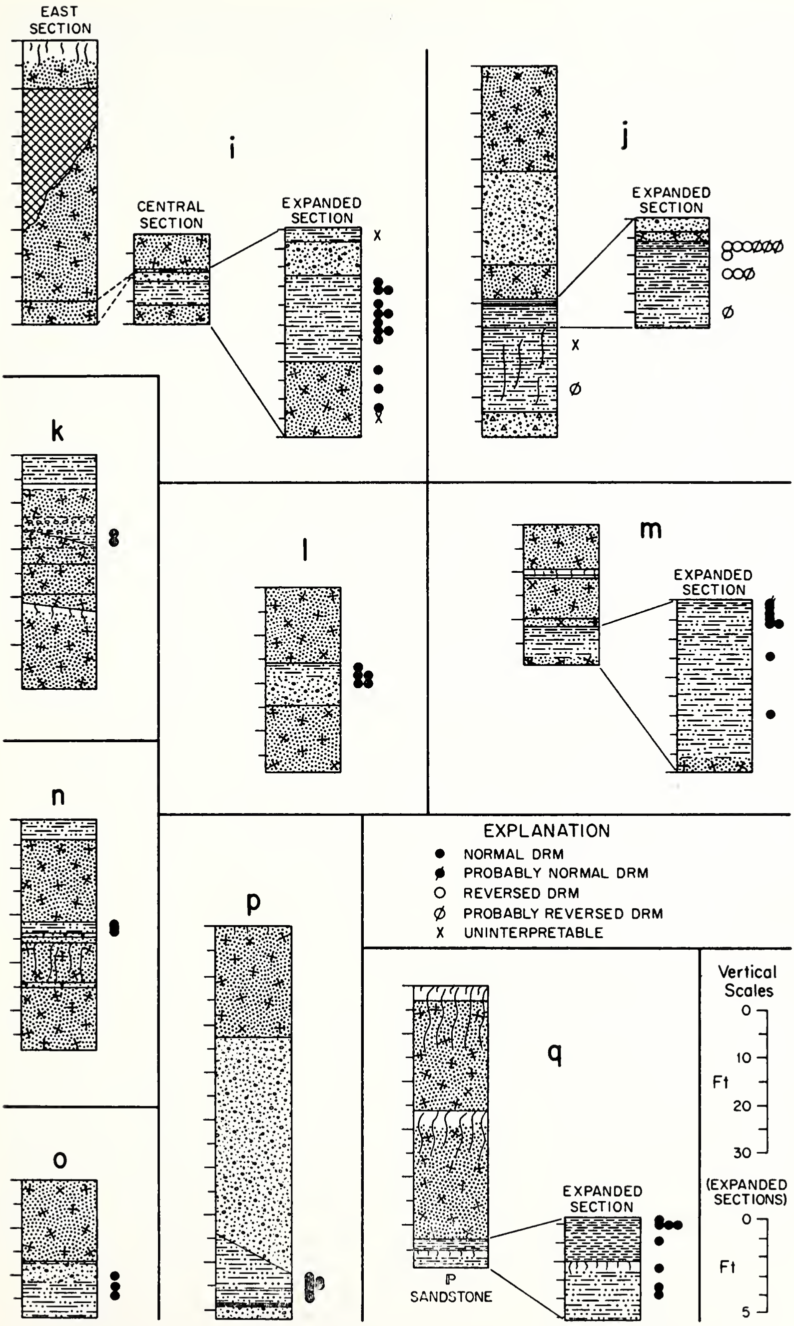
FIGURE 5. *Detrital remnant magnetism determined for loesses of the Atherton Formation of southern Indiana. In descending order the units are* (1) *Peoria Loess Member,* (2) *Farmdale Loess Member (=Roxana Silt of Illinois), (3) Loveland Loess Member, (4) till of Illinoian or greater age, or (5) Luce Gravel of Ray (33). Section locations (see fig. 2):* e, *section 2 of Ray (33);* f, *section 7 of Ray (33, p. 61); g, Patoka section of Johnson (21, p. 195-196);* h, *New Harmony section of Johnson (21, p. 201-202).*

West-central Indiana

Redwood Creek section (SE¼NW¼SE¼ sec. 27, T. 21 N., R. 9 W., Warren County, on south cutbank of eastward-flowing tributary to Redwood Creek): Section diagrammed is composite of low section containing silt beds and larger multiple till section downstream (east) (fig. 2i). Several tills, including equivalents of the Tilton and (or) Hillery Till Members (Banner Formation) of the Danville, Illinois, area, and a basal, peculiarly red and clayey till possibly equivalent to the Harmattan Till Member of the Banner Formation of that same area, overlie silt containing organic debris and snails, which in turn overlies gleyed till-colluvial material (fig. 6i). The lower material is noncalcareous and contains some evidence of subaerial weathering. The lowest material is most probably a correlative of the Hegeler Till Member (Banner Formation) in Illinois (22). It contains a distinctly glacial heavy mineral suite, which has characteristics of a Lake Michigan Lobe source (low garnet-epidote ratio). The silt and material below are normally magnetized.

The normal polarity of these materials is somewhat problematical. Silts thought to be stratigraphically above the Hegeler Till Member at Danville are reversed. (See 23, 29.) Additional rock-stratigraphic study is needed to resolve this inconsistency. Pollen and snail analyses (to interpret inter glacial vs. intraglacial magnitude) of the silt at

FIGURE 6. *Detrital remnant magnetism determined for inter- and intra-glacial silts and clays in sections in west-central Indiana. Section locations (see fig. 2): i, Redwood Creek section; j, Mill Creek section; k, Hillsdale section; 1, Lusk Chapel section; m, Liberty School section; n, Russellville Quarry section; o, West Mansfield section; p, Raccoon Creek section; q, Cagles Mill section.*


EAST SECTION
CENTRAL SECTION
EXPANDED SECTION
i
j
EXPANDED SECTION
k
l
m
EXPANDED SECTION
n
o
p
EXPLANATION
NORMAL DRM
PROBABLY NORMAL DRM
REVERSED DRM
PROBABLY REVERSED DRM
X UNINTERPRETABLE
q
EXPANDED SECTION
P SANDSTONE
Vertical Scales
0
10
Ft
20
30
(EXPANDED SECTIONS)
0
Ft
5

Redwood Creek would be useful in defining the time lapsed between deposition of the probable Hegeler till and the overlying tills.

Unit sampled	DRM Orientation	NRM Intensity
Silt over sand over main silt	? (1 sample)	3.2± cgs
Main silt	Normal (10 samples)	2.2-136 cgs
Lower till-like material (Hegeler till?)	Normal (3 of 4 samples)	2.6-4.4 cgs

Mill Creek section (NW¼NW¼SE¼ sec. 32, T. 18 N., R. 8 W., Fountain County, cutbank on south side of Mill Creek; fig. 2j): Several tills, as yet not studied in detail, overlie a thin sticky clay which in turn overlies a massive silt containing snails, oxidized in its upper half, and organic matter in the topmost part. This overlies thick highly weathered silty clay which in turn overlies brown Lafayette-like chert gravel (fig. 6j). (One or more of the overlying tills is very probably Kansan in age.) The clay, silt, and underlying weathered unit all are reversely magnetized.

Unfortunately, knowledge of the position of the magnetically reversed silt beneath tills and above deeply weathered alluvium of possible Tertiary age has no immediate usefulness. Pollen and snail studies of this silt, however, could add much useful information. The presence, for instance, of a fauna or a flora indicative of a cool climate would relate the reversely magnetized silt to a preceding glaciation or would relate it closely in time to the overlying till, most likely the latter.

Unit sampled	DRM Orientation	NRM Intensity
Clay overlying silt	Reversed (3 of 6 samples)	0-4.8 cgs
Organic silt	Reversed (3 of 5 samples)	1.4-7.7 cgs
Weathered silty clay	Reversed? (1 of 2 samples)	0-1.3 cgs

Hillsdale section (SE¼SW¼NE¼ sec. 34, T. 16 N., R. 9 W., Vermillion County, borrow pit north of U.S. Highway 36; fig. 2k): Thin loess and a possible thin cap of loam till of the Wedron Formation overlie a thick sequence of pinkish loam tills, separated by or including numerous stone lines. A thin organic and snail-rich silt occurs within the pinkish tills, which are probably equivalent of Hillery till of eastern Illinois. The till overlies a thin greenish clayey till, possibly an equivalent of Harmattan till of eastern Illinois (24), which in turn here overlies a till containing an apparent truncated paleosol, indicated by oxidation and marked nodular and vein-fill carbonate deposition (fig. 6k). The organic silt is normally magnetized.

Unit sampled	DRM Orientation	NRM Intensity
Silt within till	Normal (2 samples)	22-23 cgs

Lusk Chapel section (SE¼NW¼NW¼ sec. 22, T. 17 N., R. 7 W., Parke County, lower of two road cut sections, southwest side of 50 East Road, at north boundary of Turkey Run State Park; (fig. 2*l*): A calcareous silt and sand unit is present within a faintly pink-tinged loam till (fig. 6*l*) in two road cut exposures. The till is probably equivalent to the Hillery till (Kansan) of eastern Illinois (24). The silt is magnetically normal.

Unit sampled	DRM Orientation	NRM Intensity
Silt bed within till	Normal (5 samples)	8.3-10 cgs

Liberty School section (SW cor., sec. 5, T. 17 N., R. 5 W., Montgomery County, stream-cut bank; fig. 2m): The Liberty School section (fig. 6m) has been interpreted as containing Wisconsinan and Illinoian tills, Yarmouthian organic-rich stratified noncalcareous alluvium, and a basal till (40, p. 33-34). I do not believe that the basal material in this section is a till, which is not to say that a till may not occur stratigraphically below. Johnson and others (24) have suggested on the basis of physical properties that the reddish till considered to be Illinoian by Wayne is, rather, the equivalent of Hillery till (Kansan) of eastern Illinois. I agree with this correlation. Thus, the basal silts and clays at Liberty School, which are normally magnetized, are probably intra- or pre-Kansan in age.

Unit sampled	DRM Orientation	NRM Intensity
Stratified silt and clay, basal 8+ feet of section	Normal (6 of 8 samples)	1.5-34 cgs

Russellville Quarry section (SE¼SE¼NW¼ sec. 8, T. 16 N., R. 5 W., Putnam County, west wall of quarry; fig. 2n): The surface till of the Trafalgar Formation overlies an organic and snail-rich silt dating 21,000 ± 200 radiocarbon years B.P. (ISGS-387). Beneath are additional tills and a paleosol (fig. 6n). The silt is normally magnetized.

Unit sampled	DRM Orientation	NRM Intensity
Silt beneath surface till	Normal (3 samples)	11-16 cgs

West Mansfield section (NE¼SE¼NE¼ sec. 7, T. 14 N., R. 6 W., Parke County, borrow pit exposure on north side of county road; fig. 2o): A loam till overlies 10 to 15 feet of interstratified sand and silt (fig. 6o). The till has not been studied in detail, but it probably is the equivalent of the Butlerville Till Member (Illinoian) of the Jessup Formation at the Cagles Mill section in Putnam County. The silt is normally magnetized.

Unit sampled	DRM Orientation	NRM Intensity
Silt units beneath till	Normal (3 samples)	3.6-17 cgs

Raccoon Creek section (NE¼SW¼NW¼ sec. 18, T. 14 N. R. 6 W., Parke County, cutbank on south side of Big Raccoon Creek; fig. 2p):

This section on Raccoon Creek west of Mansfield was used by Wayne (39, p. 75) as a reference section for the Jessup and Atherton Formations. A single till, considered to be the Butlerville of Illinoian age, overlies gravel, sand, silt, and a highly compacted basal peat (braunkohle of Wayne (39) (fig. 6p), the latter considered to be of Yarmouthian age. No criterion exists, other than its occurrence as a surface till in an area supposedly underlain by Illinoian till, to assign an Illinoian age to the till or a Yarmouthian age to the lowest sediment. No rock-stratigraphic work has been done in this area. The silt is normally magnetized.

Unit sampled	DRM Orientation	NRM Intensity
Gray finely laminated silt and clay	Normal (8 samples)	1.9-23 cgs
Dark stratified silt immediately overlying highly compacted peat	Normal (2 samples)	23-24 cgs

Cagles Mill section (Cataract Lake spillway, SE¼SE¼NW¼ sec. 13, T. 12 N., R. 5 W., Putnam County, section at east end of north side of spillway cut; fig. 2q): The Cagle Loess Member of the Atherton Formation, a massive silt containing snails and organic material in its top part, immediately underlies a thin clay, two distinct tills, and two major paleosols (fig. 6q). The tills have been interpreted as Illinoian and Kansan in age (38, 39, 40). The Cagles Mill section was one of several in the Midwest sampled by George Kukla in 1972. Results of his sampling, as presented informally in Columbia, Missouri, in 1973, showed the unit to have normal DRM. His finding has been verified in this study (fig. 6q). Rock-stratigraphic work has not yet allowed the tills of this section to be compared with other tills in western Indiana.

Unit sampled	DRM Orientation	NRM Intensity
Stratified clay atop Cagle Loess Member	Normal (5 samples)	13-41 cgs
Cagle Loess Member	Normal (3 samples)	10-14 cgs

Conclusions

The reversely magnetized main clay unit of the Handley Farm section of eastern Indiana is probably older than most of the presumed Kansan tills of western Indiana and eastern Illinois. Therefore, it is not likely of Yarmouthian age (at least as that age has been defined for western Indiana) as interpreted by Kapp and Gooding (26); rather, it is much older. Although the Brunhes Normal Polarity Epoch is known to contain several relatively short reversed events in its latter part (fig. 1) (which postdate deposition of any of the sediments in the Handley Farm section), and although additional reversed events may well be found in the future, Cox (8, p. 100) has shown statistically that "a stratigrapher will incur at most a 4-percent risk of being wrong if he concludes that a reversely magnetized deposit has an age greater than 0.7 million years."

The thin weathered till immediately overlying the clays at Handley Farm is probably the equivalent of one of the several tills of Kansan age already described in eastern Indiana (15). Gooding (15) originally interpreted this material as a Kansan till, but later (26) he interpreted it as a late Yarmouthian colluvial deposit. The weathering extending through the till and into the underlying clay could, indeed, represent Yarmouthian weathering as Kapp and Gooding noted (26, p. 231). The presence of a till beneath the lake clays is presently very questionable in my mind—and of very great importance. If a till is, indeed, present beneath the magnetically reversed clays, it would be the oldest till known in Indiana. Classically, it would have to be termed Nebraskan; however, considering the present state of uncertainty as to the identity of the type Kansan and Nebraskan and the recent revelations of the presence of many old type drifts (3, 4) I can only conclude that it is older than the Yarmouthian paleosol and so-called Kansan drift of western Indiana. If the main clay deposit is truly preglacial (for this area), in its own tributary to the preglacial Kentucky River (a northward-flowing tributary to the Teays (37)), then it might be a correlative of the Minford Silt of southern Ohio. The Minford Silt, an upstream backwater deposit formed when the trunk valley of the Teays was first blocked, is reversely magnetized (18).

Spot samples of the Peoria and Farmdale Loess Members of southern Indiana are all normally magnetized; no evidence of a reversed event was found. The Farmdale loess is relatively thin in Indiana sections, and neither it nor the Peoria was sampled continuously or in sufficient detail. Magnetic studies of thick type sections in Illinois might be profitable, however.

Conclusions regarding other sections in eastern and western Indiana must be considered very tentative at this time. Many of the sections reported here were not sampled in sufficient detail. More continuous sampling through the glacial section in the Midwest and some definitive analysis of the type Kansan and Nebraskan deposits in the Plains are necessary. (See 3, 4.) The normal polarity associated with so-called Kansan deposits here most likely records deposition after about 0.7 million years ago during the Brunhes Normal Polarity Epoch rather than during a normal event within the earlier Matuyama Reversed Polarity Epoch. This is supported by the lack thus far of any evidence of a reversed polarity period stratigraphically above these magnetically normal so-called Kansan sediments and by normal polarity associated with the youngest, but not necessarily the older of the so-called Kansan deposits of the Plains (John Boellstorff, personal communication regarding unpublished work by George Kukla).

The normal polarity associated with the so-called Kansan drift of western Indiana is wholly expectable in light of Kukla's original unpublished work and that of Kukla et al. (29).

If the dating of uppermost Kansan and Yarmouthian deposits in the Plains states given by 0.6-million-year-old type O Pearlette ash (see discussion in 6, p. 216) is assumed for the Midwest as well, Kansan time, as we know it in the Midwest, represents a rather miniscule part of the Pleistocene Epoch, although that time span is no more miniscule than that of the Wisconsinan Age (fig. 1). It is unlikely that such tills as the Cedar Ridge Till of the Wind River Mountains, which occur *below* the 0.7 million-year-old Bishop Ash Bed (1, 34), or tills called Kansan in the Plains that are as old as 1.2 million years can be correlative with so-called Kansan till of our part of the Midwest.

The Cromerian interglacial stage of northern Europe reportedly contains the Brunhes-Matuyama 0.7-my boundary. (See discussion in 6.) A similar major interglacial episode might exist in North America, and various correlations (6, table 3; 3, 4) that place the Yarmouthian Age as spanning a large interval of time centered on that same 0.7-my boundary are certainly logical. However, the relationship may well be more complicated than this, and the probable 0.7-million-year-old so-called Kansan of the Midwest could be equivalent to only a very late portion of what has been called the Kansan or even the Yarmouthian elsewhere, or perhaps it could be equivalent even to what has been called Illinoian in places. Certainly the understanding is confused at this point.

A gross framework of the magnetostratigraphy of Indiana's glacial deposits has been provided herein, into which new examples of old drift deposits may be fitted. However, considering the incomplete sampling of many of the units reported herein, the absence of available and known correlative parallel sections to sample, and the overall lack of suitable consistency checks (see discussion in 30), the conclusions reached herein are at best tentative. Even so, I suggest that magnetostratigraphy combined with detailed petrographic study of tills is the only means of defining the glacial stratigraphic succession in this area. Past regional and trans-Atlantic correlations of glacial and interglacial stages are of questionable validity, and no firm basis for correlation will exist until further stratigraphic, ash-dating, and magnetic work is done in the Plains states and elsewhere.

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