

Dynamics of the Marginal Late Wisconsin Miami Sublobe, Cincinnati, Ohio¹

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ABSTRACT. Physical characteristics and stratigraphic relationships of glacial diamictos in southwestern Ohio have permitted interpretation of local activity and thermal regime of the ice margin beginning at about 19,700 yr BP. At the Sharonville site near Cincinnati, pre-late Wisconsin sediments are overlain by four late Wisconsin lithofacies (three diamictos, one sand and gravel). At the base of the sequence, pre-late Wisconsin sediments are incorporated as blocks and lenses in the overlying diamictos, indicating erosion and entrainment, probably by freezing onto the glacier base. Facies 1 contains sand-filled shear planes and "smudges" of underlying sediments; the diamicton is interpreted to be a deformation till, which indicates a change in basal thermal regime to overall melting. Facies 2 contains blocks of clay, silt, and sorted sand and gravel, and is interpreted to be a subglacial meltout till, which represents deposition from melting, but stagnant, ice. Facies 3 is massive, with variable clast fabrics, and is interpreted to be a sediment flow deposit, reflecting continued marginal melting and recession. The uppermost facies is comprised of poorly sorted sand and gravel, and is interpreted to represent fluvial deposition. Portions of this sequence are stacked at the southern end of the site, and indicate ice-marginal deformation associated with a reactivation of ice with a freezing basal regime in the study area. This sequence indicates at least two periods of active late Wisconsin ice at Sharonville, and a number of fluctuations in basal thermal regime.

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INTRODUCTION

Southwestern Ohio provides a unique opportunity to study glacial sediment sequences at the margin of the southernmost advance of the Laurentide ice sheet (Miami Sublobe). The purpose of this study is to make an interpretation of glacier conditions at this ice margin beginning about 19,700 yrs BP based on sedimentologic, stratigraphic, and structural data. To accomplish this, presented here are descriptions of late Wisconsin sediments at Sharonville, OH, and the stratigraphic relationships of these facies, together with the physical conditions necessary for the formation of each facies. On the basis of these relationships and characteristics, we propose a sequence of changes in glacier activity and thermal regime of the ice-sediment system of the Laurentide ice sheet near its southern margin in Ohio.

Studies of glacial sediments have traditionally been three-part: 1) description of physical characteristics, 2) interpretation of genesis, and 3) interpretation of glacier conditions. Within any single "set" of conditions, however, a variety of deposition processes can occur. Detailed analyses of the structural and textural features within a sedimentologic unit may narrow the number of likely origins for that unit, permitting an interpretation of the genesis. Equally likely, however, is that different genetic processes may produce sediments with common characteristics, making genetic interpretations, in some cases, suspect (Boulton 1968, 1970; Dardis and McCabe 1987).

Shaw (1987) has recently used a two-part approach of: 1) description of physical characteristics, and 2) interpretation of glacier conditions. He demonstrates how physical characteristics within glacial sediments provide

specific clues about the glacier and environmental conditions (i.e., frozen vs. freezing vs. melting thermal regimes; active vs. stagnant ice; subglacial vs. supra- or proglacial) necessary, or responsible, for their formation. This two-part approach emphasizes identification of glacier conditions, and lessens the necessity for interpretation of a specific genesis for each unit. We use here the two-part approach of Shaw (1987), interpreting genesis where possible, to develop a history of changes in marginal thermal regimes and ice activity near Cincinnati, OH.

MATERIALS AND METHODS

Description of the Sharonville Site

The study site is located in Sharonville, OH, approximately 20 km north of downtown Cincinnati, near the southern limit of the late Wisconsin Miami Sublobe (Fig. 1), and outside of the Hartwell Moraine, which is traditionally mapped as the southern limit of late Wisconsin glaciation (Gray et al. 1972). Recently-developed radiocarbon age-control on *in situ* stumps rooted in organic silt (Lowell et al. 1990) indicates that the site was overrun by late Wisconsin ice. The site consists of outcrops in a north-trending stream valley incised into a drift-filled embayment in the bedrock uplands east of Mill Creek Valley. Extensive stream erosion has provided numerous fresh exposures of unconsolidated sediment and bedrock. The units closest to stream level are the best exposed; the upper units remain slumped and covered. Nine of these outcrops have been studied in detail (Fig. 2). These outcrops range from 2-5 m in height, and from 5-15 m in length, and extend laterally over 700 m.

The generalized stratigraphic sequence exposed in the valley includes Ordovician shale and limestone bedrock overlain by both pre-late Wisconsin and late Wisconsin sediments. The bedrock surface within the embayment slopes to the northwest (Fig. 2); strike and dip of the bedrock surface within the embayment, calculated from

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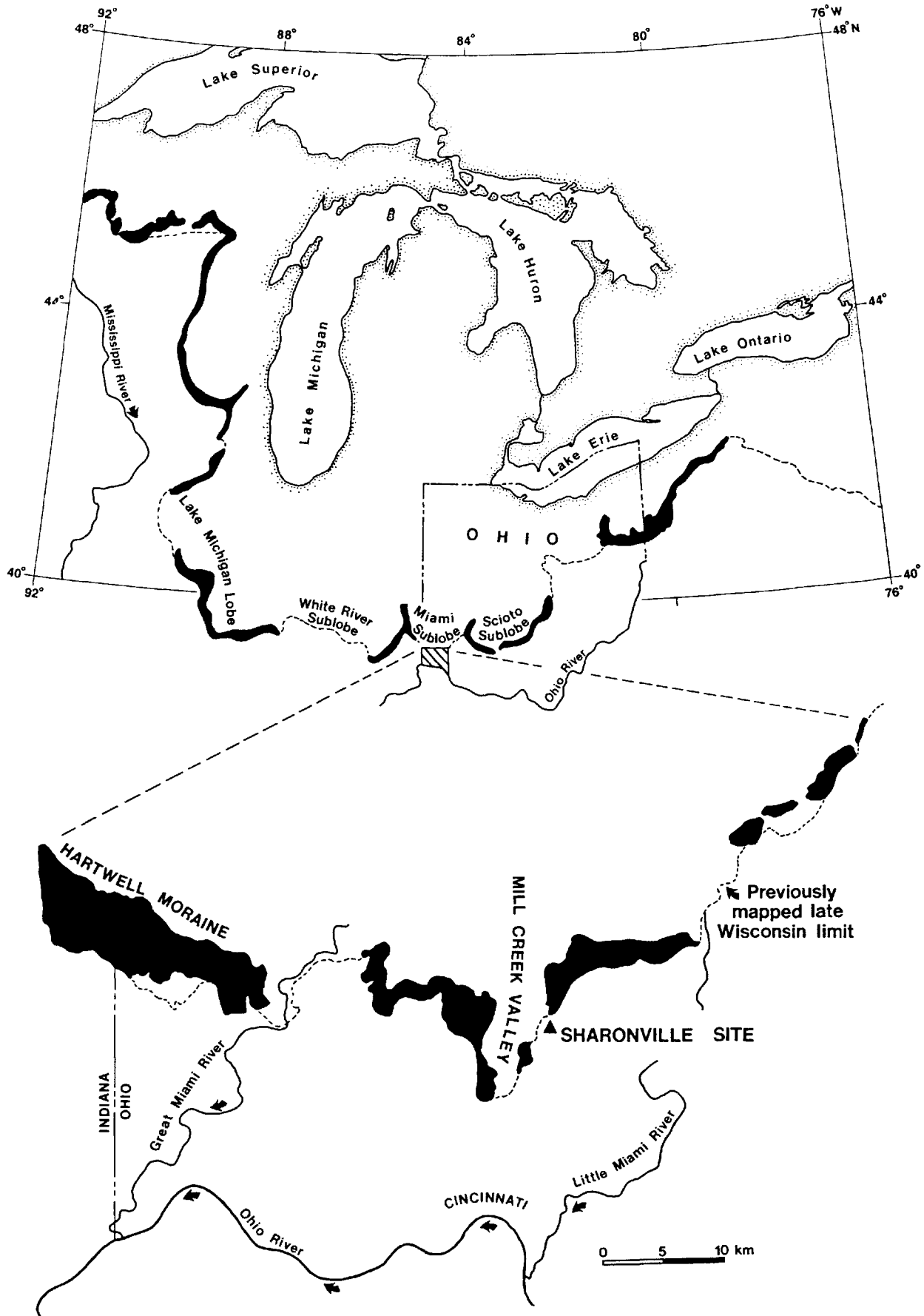


FIGURE 1. Location of the Sharonville site at the southern margin of the Miami sublobe of the Laurentide ice sheet. The site is on the dissected upland east of the Mill Creek Valley. A portion of the Hartwell moraine (the previously-mapped late Wisconsin limit) crosses the valley. Late Wisconsin ice limits after Dyke and Prest (1987), and Gray et al. (1972). (Figure reprinted with permission from *Quaternary Research*, Lowell et al. 1990.)

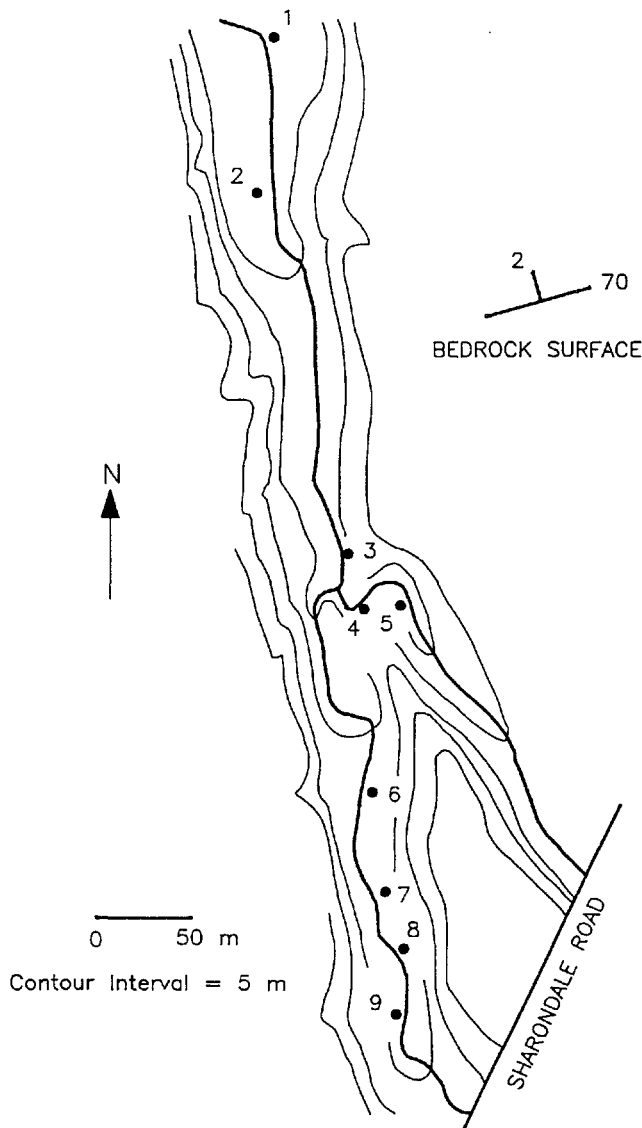


FIGURE 2. Map of stream valley showing locations of studied sections; section numbers correspond to those indicated on Fig. 9 and in Table 3; elevation contours in meters.

subsurface and outcrop data, are $N70^{\circ}E$, and $2^{\circ}NW$, respectively. The pre-Wisconsin sequence, in upward succession, includes: 1) a clay-rich diamicton, the upper 40 cm of which is intensely weathered, and 2) an organic silt bed. The lowermost late Wisconsin unit is a dense clay which overlies the silt (with the dated stumps), and which contains slickensides, and is sheared in the central part of the study area. The subsequent overlying late Wisconsin sediments are the focus of this study. Ice associated with deposition of the sediments may have flowed from the west or northwest (local ice flow into the embayment from the main valley to the west), or from the north (flow from the adjacent uplands to the north into the embayment). In either case, as the ice passed over the study area, it was advancing up a sloping paleosurface, enhancing the compressional forces along the ice margin.

Standard field and laboratory techniques for clast fabric, granulometric analysis, carbonate content, and clast lithologic and shape analysis were utilized in this study (Table 1).

TABLE 1

Summary of methodologies.

Field	
Clast fabric	azimuth and plunge of 25 clasts in diamicton with a minimum a:b axial ratio of 2:1; analyzed using method of Mark (1973, 1974)
Wood orientation	azimuth and plunge of wood incorporated into diamicton; minimum a:b axial ratio of 5:1
Plane orientation	strike and dip of shear and fracture planes within diamictons
Laboratory	
Granulometry	sieve-pipette of Folk (1980); 0.004 and 0.063 mm used as clay-silt and silt-sand boundaries, respectively
Carbonate content	Chittick analysis of <0.063 mm fraction; modified from Dreimanis (1962)
Clay mineralogy	x-ray diffraction analysis of untreated, glycolated, and heated (350° , $550^{\circ}C$) <0.002 mm fraction of matrix
Clast lithology	100 clasts minimum with b-axis dimensions from 16 to 64 mm; identified using a 5X binocular stereoscope
Clast shape	a, b, and c axis dimensions determined; axial ratios plotted on shape diagram of Zingg (1935); also noted were presence or absence of striations and facets on each clast; roundness estimations based on Powers (1953)

Definition of Genetic Terms

The use of genetic terms in the interpretation of tills is an area open to much debate. Lawson (1981, 1982) and Dreimanis (1988) have discussed this matter in terms of sediment deposited by "primary" processes (sediment deposited by direct release from glacial ice with no subsequent disaggregation and resedimentation [Lawson 1981, 1982]), and those deposited by the action of "secondary" processes, such as remobilization and subsequent flow. The importance of distinguishing between primary and secondary processes in the analysis of glacial sequences, and interpretation of depositional environment was emphasized by Lawson (1988). For the present study, we use the term "till" for only those deposits which we believe to have been deposited by primary glacial processes.

Definitions of terms used in our interpretations below are listed here:

lodgement till – "... deposited by plastering of glacial debris from the sliding base of a moving glacier by pressure melting and/or other mechanical processes." (Dreimanis 1988, p. 43);

deformation till – “. . . weak rock or unconsolidated sediment that has been detached from its source, the primary sedimentary structures distorted or destroyed, and some foreign matter admixed . . .” (Elson 1988, p. 85);

meltout till – “. . . deposited by a slow release of glacial debris from ice that is not sliding or deforming internally . . .” (Dreimanis 1988, p. 45).

For resedimented materials, which may be the result of several secondary processes (Lawson 1979, 1981; Dreimanis 1988), we use the term “**sediment flow deposit**” to describe deposits resulting from those processes. These deposits, while not providing direct information on the glacier itself, may provide information on the local climate and hydrology, as well as other factors affecting the depositional processes (Lawson 1988).

RESULTS

Facies Descriptions

Four facies of late Wisconsin-age sediment are present at the Sharonville site; three of the facies are diamictons, and the fourth facies is sand and gravel. The three diamicton facies have nearly identical textural and compositional characteristics: 1) all are calcareous, sandy, and matrix-supported (Table 2); 2) mean values of clast lithology, shape, and roundness are nearly identical (Fig. 3); and 3) clay mineralogy (illite, chlorite, and kaolinite) of 15 samples is nearly identical.

Each diamicton facies does, however, have unique characteristics that permit assessment of the physical conditions present at the time of deposition. Unique characteristics of each facies are described below.

Facies 1. Low-angle, sand-filled planes distinguish this facies from the others. Spacing between individual planes is 5-10 cm, and individual planes are 0.5-1 cm thick (Fig. 4). These planes generally strike NE-SW (40 to 60° azimuth) and have shallow (7 to 15°) dips to the NW. The sandy planes are undulatory, but they bend to become nearly horizontal in the upper 15-20 cm of the facies, terminating in a well-defined, nearly horizontal plane. Slickensides are observed along these planes, and are oriented at azimuths between 275° and 300°. Wood occurs along the sandy planes, but only as fragments without bark. This wood is oriented NE-SW, and dips in either direction. Two clast fabrics in this unit are to the northwest, and one is to the southwest (Fig. 5a); fabric strength (S_1) values range from 0.60 to 0.70. This facies contains “smudges” (Kruger 1979) of underlying shale bedrock and organic silts, as well as small (2-4 cm high by 8-10 cm long), highly deformed inclusions of the organic silts. Some of these inclusions are augen-shaped. The basal contact of facies 1 with the underlying clays is sharp and unconformable. The upper contact of this facies with facies 2 is abrupt, and is denoted by the nearly horizontal termination of the sandy planes.

Facies 2. Numerous angular, lenticular, and convoluted bodies of sand, silt, clay, and gravel within the diamicton characterize this unit. Their orientation may be vertical, horizontal, or dipping. Within many of these bodies, relict

TABLE 2

Summary of textural analyses (mean and one standard deviation).

Facies	n	Grain Size (%)			
		Sand	Silt	Clay	Carbonate Content
4b	1	97	2	1	—
4a	1	94	5	1	—
3	3	35.9 ± 5.9	59.2 ± 7.0	4.9 ± 2.4	28.7 ± 3.1
2	8	34.6 ± 5.0	60.2 ± 5.1	5.2 ± 4.4	32.8 ± 3.4
1	4	36.1 ± 3.5	56.9 ± 4.3	7.0 ± 3.4	32.5 ± 2.6

bedding and/or laminations are visible (Fig. 6). Like the bodies themselves, this relict bedding exhibits no preferred orientation, but in the silt and clay bodies it may be deformed and contorted, and in many cases parallel to the boundaries of the body itself. Other lenses exhibit both concave-downward morphology and internal laminations, along with vertical grading. This facies contains abundant wood, including logs up to 2 m in length. Nearly all of the wood is circular in cross-section, and some logs retain bark along their lengths. Larger logs (diameter greater than 15 cm) may have sand and gravel drapes over them. Smaller pieces of wood, also circular in cross-section and commonly with bark, are found in sand bodies within the diamicton. Orientations of wood in the diamicton are dominantly NW-SE. Clast fabrics in this facies dip to the northwest, and have the highest fabric strengths of the three facies, ranging from 0.62 to 0.81 (Fig 5b). The lower contact of facies 2 is generally sharp and distinct; the basal 10 cm of facies 2 exhibits a 5 to 8% increase in clay content. The upper contact of facies 2 with facies 3 is transitional and less distinct.

Facies 3. Unlike the previous two, this facies is massive, with neither the shear planes characteristic of facies 1, nor the bodies of sorted material characteristic of facies 2. Small concentrations of clasts (eight to ten clasts) are present, but rare; these clusters are comprised of randomly oriented clasts which are generally not striated. Rare, small, irregular bodies of the underlying organic silt are present. Wood is present in this unit, and may have some bark still attached. Some of the wood is bent, and frayed ends of the wood generally have diamicton matrix injected into them. Clast fabrics in this facies are variable (Fig. 5c). The lower contact of this facies with underlying facies 2 is transitional; the upper contact of this unit was not observed.

Facies 4. This facies consists almost entirely of sand and gravel, with very small amounts of silt and clay. Facies 4 occurs as large lensoid bodies in facies 3 (up to 2 m high and 4 m long; Fig. 7), and occurs as two different sediment types. The first type (facies 4a) is medium to coarse gravel, with lesser amounts of sand, and trace amounts of silt and clay. In general, these lenses have concave-downward upper contacts, and are overlain, at least in part, by facies 3.

The second type (facies 4b) consists of sands overlain by a carbonate-cemented gravel conglomerate. The sands are cross-bedded, and the cross-bedding is truncated at the upper contact with the conglomerate. The sand lenses

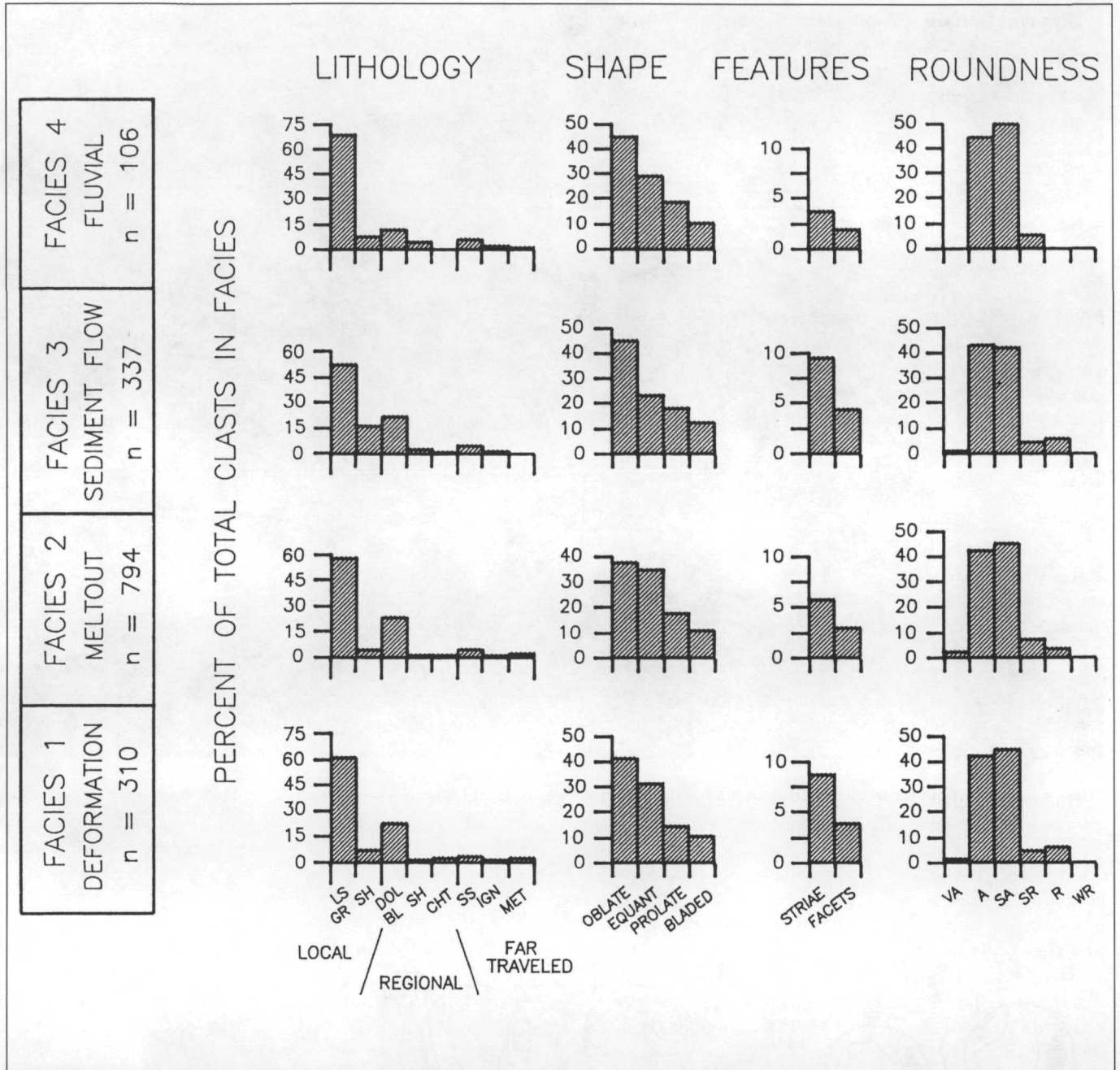


FIGURE 3. Clast characteristics, including lithologic composition, shape, features, and roundness for facies 1, 2, 3, and 4; lithologies include limestone (LS), green shale (GRSH), dolomite (DOL), black shale (BLSH), chert (CHT), sandstone (SS), undifferentiated igneous (IGN), and undifferentiated metamorphics (MET); fossiliferous limestone and calcareous green shale comprise the locally-derived lithologies; dolomite, chert, and black shale are regionally-derived lithologies, and represent a minimum clast transport distance of 45 to 50 km; all other lithologies are distally-derived, and represent a minimum transport distance of 240 km. Roundness categories are very angular (VA), angular (A), subangular (SA), subrounded (SR), rounded (R), and well-rounded (WR).

are less than one meter thick, and range from 2 to 3 m in lateral extent. The conglomerate is 0.35 to 0.45 m thick, and its lateral extent is the same as the underlying sand at all locations.

Transported blocks. In two exposures at the southern end of the study area, the entire assemblage of pre-late Wisconsin sediments (weathered shale bedrock, altered and leached diamicton, organic silt, and massive clay), as well as facies 2 and/or 3, occur as transported blocks, or floes. A key characteristic of this package of sediments is that they have been transported, rotated, and deposited as

a series of imbricate blocks.

At section 7, two blocks are observed; at the contact between the two blocks, weathered shale bedrock (the oldest exposed unit in the valley) overlies the massive diamicton of facies 3 (the youngest observed diamicton in the valley). At section 8 (Fig. 8), the older sediments repeat three times: once as a "partial" sequence (only the weathered shale and organic-rich silt are present), and twice as "complete" sequences (weathered bedrock through facies 2 or 3 diamictons). At each contact between blocks, older sediments are observed to overlie younger sediments.

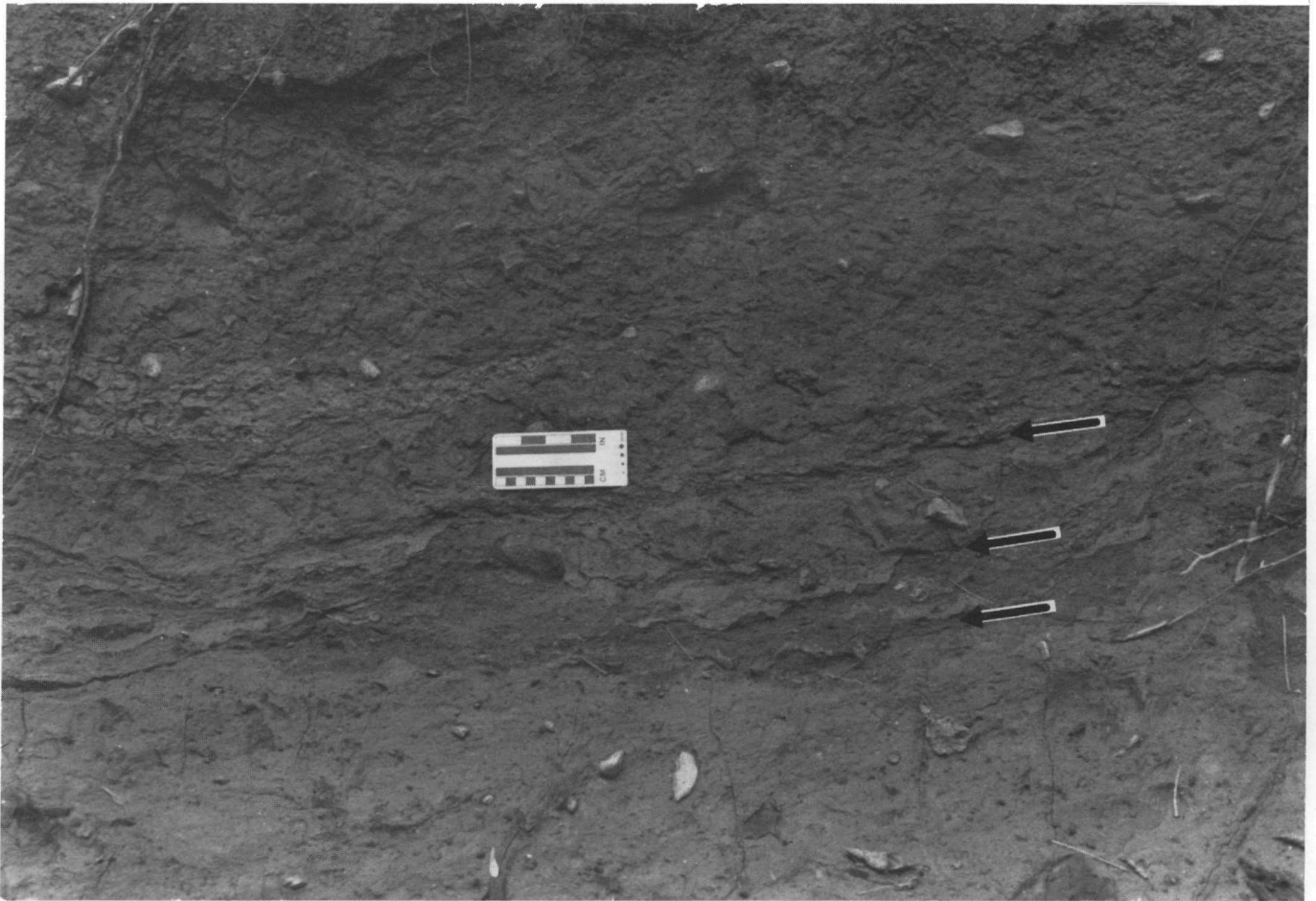


FIGURE 4. Facies 1, with shear planes (arrows); note unshered nature of overlying Facies 2.

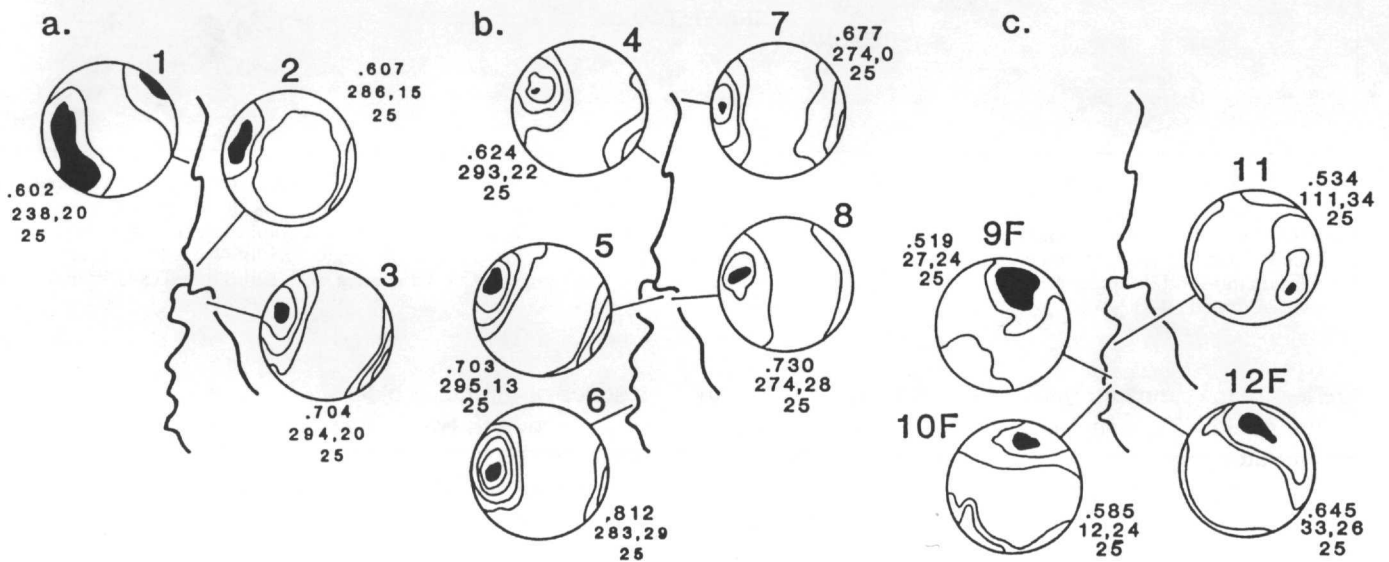


FIGURE 5. Clast fabrics for each facies: a) Facies 1; b) Facies 2; c) Facies 3; circles represent clast orientation projected onto the lower hemisphere of an equal area net; numbers on the upper portion of each circle refer to fabric numbers shown on Fig. 10 ("F" next to fabric number denotes fabric taken from a stacked section; numbers on the lower side of each circle represent the fabric strength (S_i ; 0 = random, 1 = uniform), azimuth and plunge of the mean vector (V_i), and number of clasts (n). Contour interval is 2 standard deviations, with black areas representing the maximum deviation from random. Measures after Lawson (1979).



FIGURE 6. Sand and gravel lens in facies 2; note bedding preserved within this lens.

The contacts between these sequences have strikes between 0 and 35° azimuth. Clast fabrics from facies 3 diamicton within the stacked sequences (Fig. 5; fabrics 9, 10, 12) are all to the northeast.

Composite Stratigraphy

Stratigraphic relationships observed at four sections in the central and southern portions of the valley (Fig. 9; Table 3, sections 5-8) were used to construct a composite stratigraphy for the site (Fig. 10). These sites were used because they contain the best exposures of multiple unit sequences. Pre-late Wisconsin sediments observed in a trench at section 5 were *in situ*, and are the oldest units. Also at section 5, massive clays, and facies 1 and 2 form the base of the late Wisconsin sequence. At section 6, approximately 80 m south of section 5, facies 2, 3, and 4a were found; these sediments represent the next portion of the sequence. At sections 7 and 8, the incorporation of facies 3 in the blocks of transported sediments indicates that this transport/deformation occurred after facies 3 deposition. Eight of the nine sections are capped by Recent alluvium.

Interpretation of Glacier Conditions and Diamicton Genesis

Pre-late Wisconsin sediments. Angular blocks of these sediments within the diamicton facies provide information about the first late Wisconsin advance over the site. The

organic silt blocks in the overlying facies indicate that the substratum was probably initially unfrozen, and was subjected to erosion by net basal freezing associated with the overriding of active ice (Weertman 1961; Shaw 1971, 1987; Boulton 1979; Wickham and Johnson 1981). This occurred prior to, or contemporaneous with the deposition of the parent material for facies 1. The paucity of blocks of the pre-late Wisconsin diamicton or bedrock in the overlying diamictons suggests that the depth of incorporation was restricted to the organic silt horizon. The angular nature of these blocks suggests transport as frozen blocks, and may be the result of brittle fracture.

Facies 1. The sandy planes are interpreted to be shear planes; these shears, together with the highly deformed inclusions of the underlying organic silt reflect the deformed nature of this unit. Deposition of this facies, and its subsequent deformation may have been contemporaneous with a change from frozen/freezing to melting basal conditions associated with still-active ice. Deformation of the underlying clays supports the idea of a frozen (freezing) to basal melting transition (Boulton 1972b, Hansel et al. 1987, A. Dreimanis pers. comm.), and a thawing of the underlying sediments. Shearing, such as that noted in this facies, has been interpreted by Boulton et al. (1974) to be an ice-marginal process. Orientations of the shear planes, interpreted to be dipping upglacier (Hicock and Dreimanis 1985), and the slickensides along the planes, indicate a

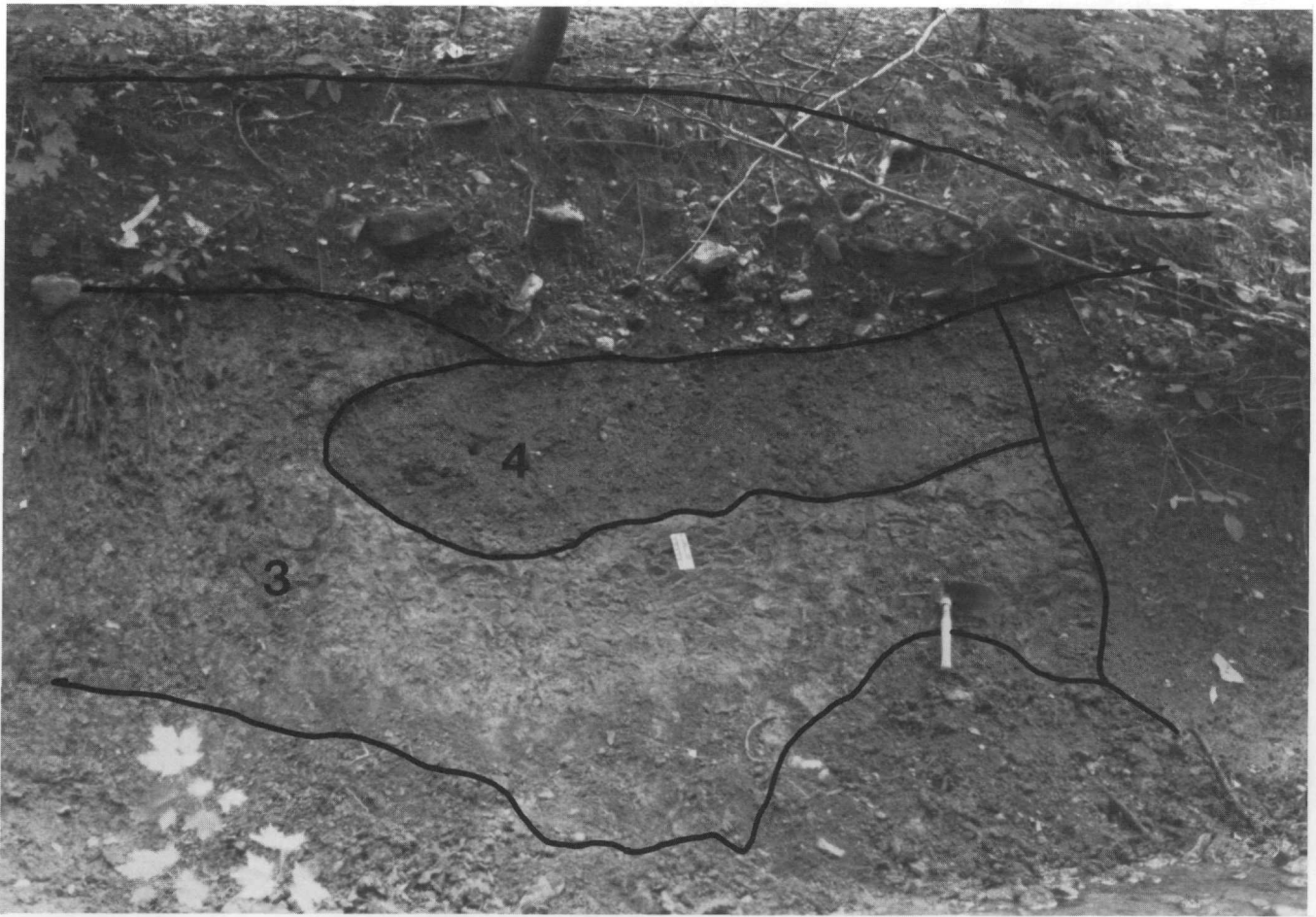


FIGURE 7. Facies 4 sand and gravel inset in facies 3 at section 6; at left end of facies 4 (central portion of photo), the sands are overlain by facies 3; in the middle and at the right end, the upper portion of facies 4 has been removed by erosion, and is overlain with Recent alluvium.

possible ice flow direction from the northwest. Two of the fabrics support this flow direction.

Characteristics of this diamicton, as described above, are consistent with those reported by previous workers for subglacially deposited tills (e.g., Boulton 1970; Kruger and Marcussen 1976; Kruger 1979; Broster et al. 1979; Dreimanis 1982, 1988). Because of the highly deformed nature of the diamicton, we interpret this facies to be a deformation till. This facies may correspond to the "deforming bed till" of Alley et al. (1987).

Facies 2. The undeformed, or slightly deformed nature of blocks of organic silt, sand and gravel, and clay in this facies indicates that their transport and deposition probably occurred while the blocks were still frozen (Aber 1985, Shaw 1985), and under conditions of very little shear stress. These characteristics are consistent with deposition associated with inactive ice, and represent a transition from active, melting ice to inactive (or stagnant) melting ice. Subsequent release of the blocks could have been by: a) supraglacial deposition in a sediment flow deposit, b) supraglacial meltout, or c) subglacial meltout. Clast fabrics in this unit, generally to the northwest, support the notion of ice flow from the northwest, as discussed above in facies 1.

Undeformed laminations in drapes over logs, and consistent clast fabrics over several hundred meters of

lateral exposures (J. Shaw pers. comm., Haldorsen and Shaw 1982, Bouchard et al. 1984, Van der Meer et al. 1985) suggest a meltout, rather than flow, origin; channel-form sand and gravel lenses are likely englacial or subglacial in origin and favor subglacial meltout for deposition of this facies (Boulton 1972b). We therefore interpret this facies to be a subglacial meltout till.

Paul and Eyles (1990) have discussed some theoretical conditions governing the formation and preservation potential of meltout till, and conclude that these tills require any basal shear stress to be below the yield strength of the sediment, and pore water pressures within the sediment to be below the level necessary to induce fluidization. Because these are rare conditions, they also conclude that meltout tills must likely form a very small part of the preserved glacial record, and are likely to be very restricted in thickness. Although Paul and Eyles (1990) conclude that basal and englacial debris concentrations are far too low to permit accumulation of thick sequences of meltout till, other workers (e.g., Boulton 1970, 1972a) have reported debris concentrations with the potential to produce meltout tills at least 5 m thick.

We propose that the embayment setting of the Sharonville site is an area with high potential for both the formation and preservation of meltout till for the following reasons: 1) presence of extensive sand and gravel aquifers

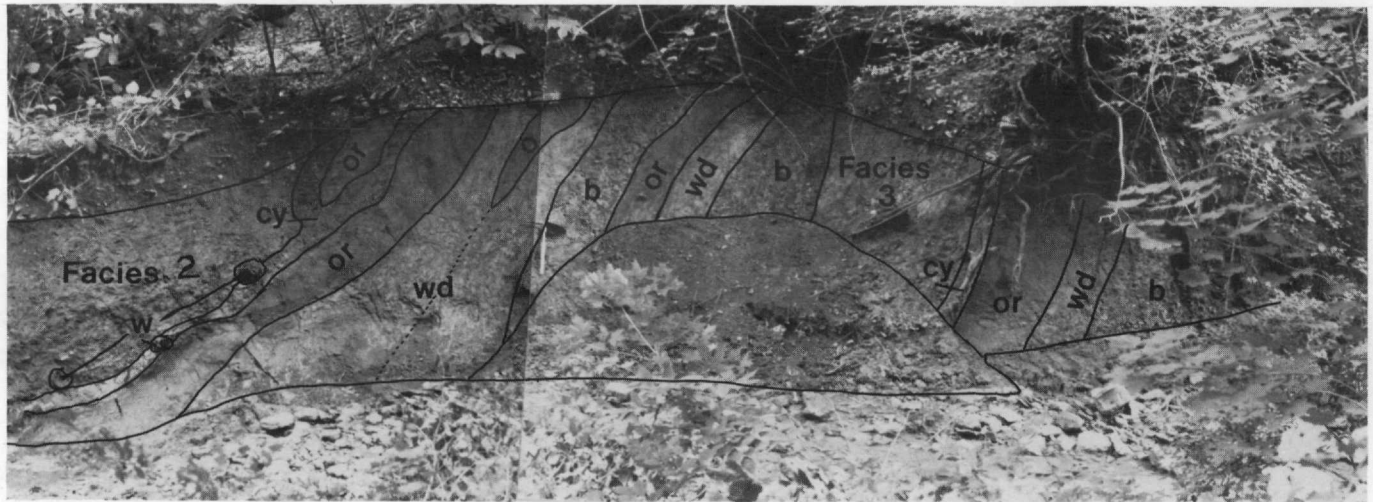


FIGURE 8. Photograph and facemap of section 8, with stacked, transported sediment blocks; Facies 2 and 3 diamictons indicated; other materials labeled: wood (w), bedrock (b), weathered diamicton (wd), organic silt (or), clay (cy).

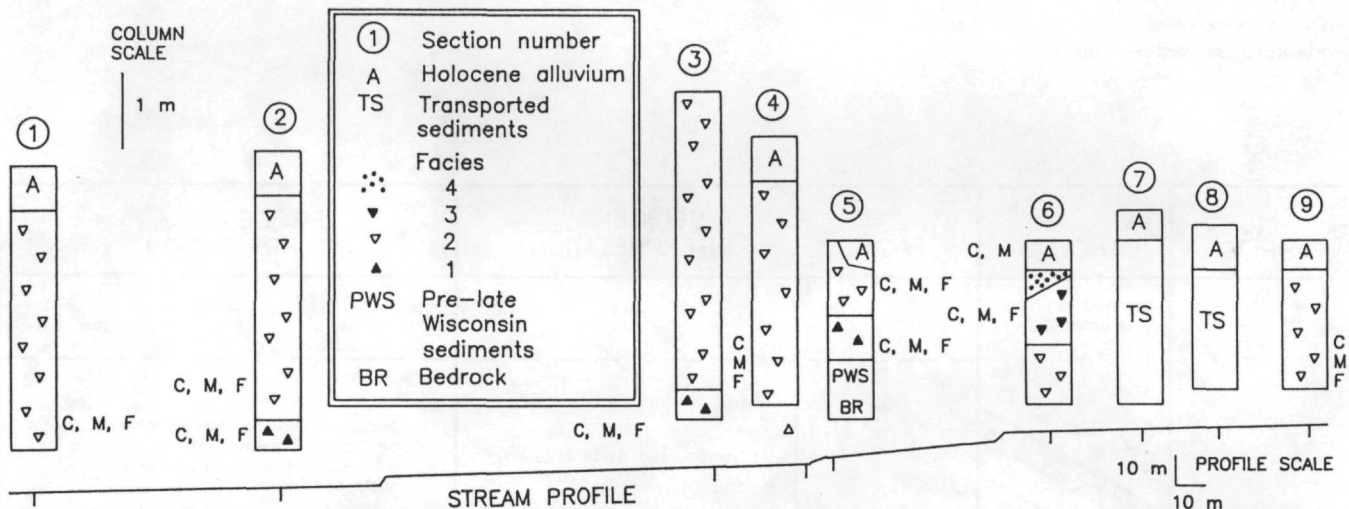


FIGURE 9. Geographic distribution of the observed facies; numbers above each column correspond to section numbers on Fig. 2; "C" denotes clast sample, "M" denotes matrix sample, and "F" denotes the location of a clast fabric.

in the major valley (Mill Creek) located upglacier from the study site; these aquifers, over 1,500 m wide, and in some places in excess of 15 m thick (Bernhagen and Schaefer 1946), were probably capable of draining substantial quantities of subglacial meltwater, thereby keeping overall pore water pressures reduced, and relative sediment shear strength high; and 2) very gentle slope of the substrate, providing little gradient to initiate flow. Our interpretation of stagnant ice at the time of deposition, if correct, serves to reduce or eliminate shear stress from active ice. Likewise, deposition in a subglacial setting would reduce the likelihood of flow.

Facies 3. This facies is massive, with no unique identifying characteristics. Melting conditions are required for deposition by supraglacial and subglacial sediment flow, as well meltout and lodgement; the fundamental difference is whether the ice is active or inactive at the time of deposition. The characteristics within this facies, as described above, allow us to interpret this unit as being

deposited under melting conditions, probably in an ice-marginal setting.

Facies 4. The morphology of these bodies, especially facies 4a, indicates little or no truncation of their upper contacts with facies 3, and suggests deposition in a subglacial fluvial setting, reflecting continued melting conditions. The stratigraphic position of the sands and gravels indicates that they were deposited contemporaneously with facies 3.

Transported blocks. Imbricate, stacked megablocks of sediments have been reported by numerous authors (e.g., Kupsch 1962; Moran et al. 1980; Aber 1985; Aber and Lundqvist 1988; and references therein). These studies have identified common characteristics likely to favor such stacking. These features include: 1) ice flow upslope, 2) compressional ice flow, 3) active ice flowing over a freezing- or frozen-bed marginal zone, 4) pre-existing planes of weakness in the bed, and 5) decreased shear strength in the sediments caused by elevated pore water

TABLE 3

Facies occurrence and distribution.

Age	Facies	Section									Maximum Thickness (m)
		1	2	3	4	5	6	7	8	9	
Recent	Alluvium	*	*		*	*	*	*	*	*	—
Late Wisconsin	4b					*					—
	4a						*				—
	3						*	S	S		2.0
	2	*	*	*	*	*	*			*	3.5
	1		*	*		*	*				0.5
	Clay					*		S	S		0.4
Pre-Late Wisconsin	Org. Silt					*			S	S	1.3
	Wthd Diam.					*			S	S	0.9
	Bedrock					*			S	S	—

*—indicates presence of facies at indicated section
 S—indicates a "stacked" section

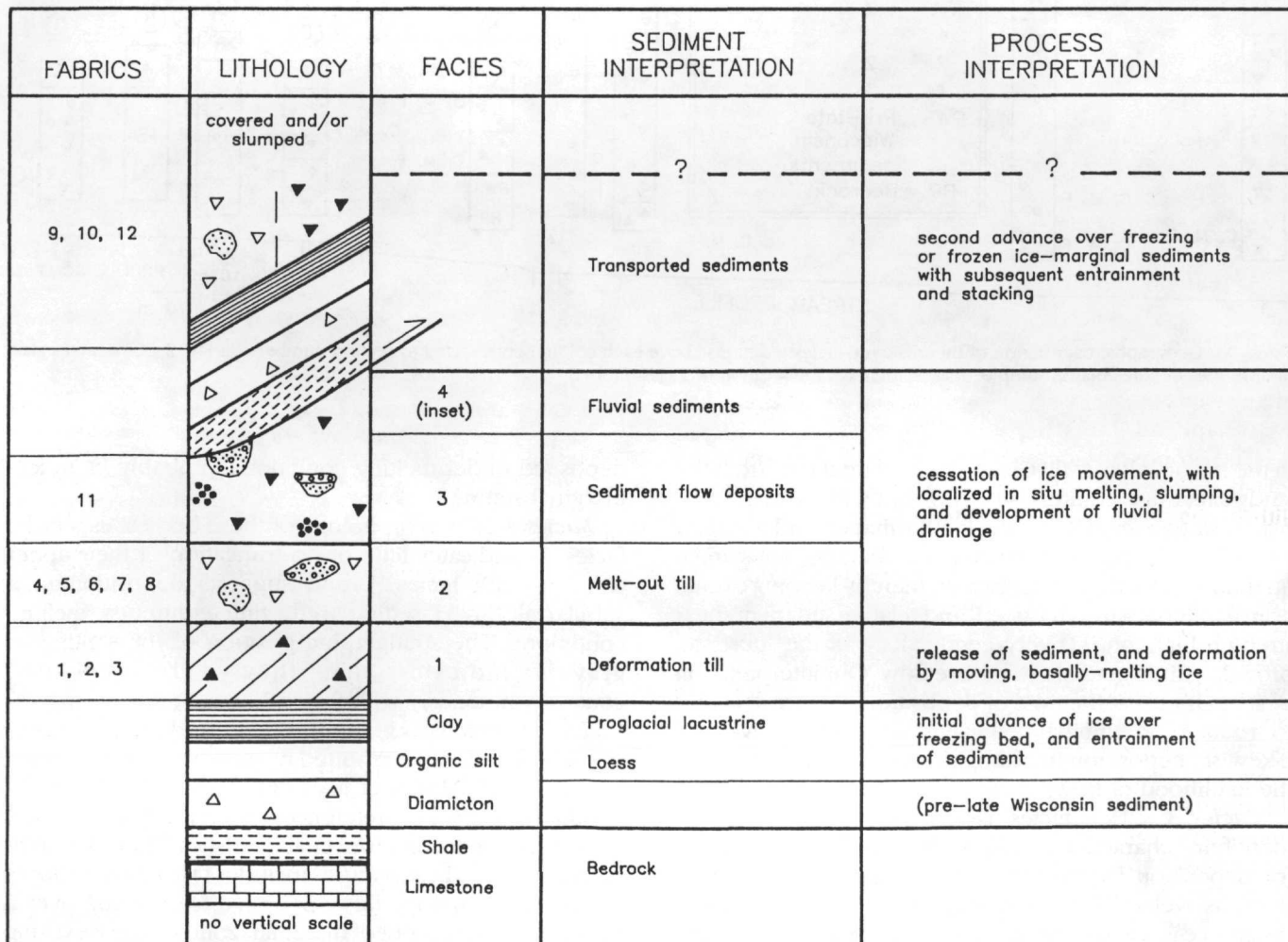


FIGURE 10. Composite stratigraphic sequence, including interpretation of sediment genesis and processes; positions of clast fabrics noted.

pressure. The first two factors are readily applicable to this site because of the geomorphic setting and interpreted ice flow direction. Factor 3 is consistent because it is near the terminus of the late Wisconsin advance, and ice flow may have been over a freezing or frozen bed. Weathered, highly fissile shale bedrock is the basal unit affected by the stacking; the fissility of the shale is consistent with the fourth factor. Moreover, the unweathered bedrock is likely less permeable than the overlying weathered bedrock and unlithified sediments, and may act to promote localized zones of high pore water pressures, consistent with factor 5. The mechanism discussed above has been termed "glacial-thrust" (Moran et al. 1980), or "ice-thrust."

The youngest unit obviously affected by the stacking is facies 3; therefore, the interpreted reactivation of ice flow over the site had to have occurred after deposition of facies 3 from stagnant ice. We interpret the stacking at Sharonville to be the result of ice-marginal deformation processes associated with reactivation of ice in the embayment.

DISCUSSION AND CONCLUSIONS

On the basis of sedimentologic, structural, and stratigraphic data, we are able to reconstruct a sequence of changes in the activity and basal thermal regime of the ice at this site, beginning at about 19,700 yr BP. The interpreted sequence of glacier conditions, from oldest to youngest, is:

- 1) active ice flow over a freezing bed (entrainment of pre-late Wisconsin sediments);
- 2) basally-melting, active ice (facies 1 deposition and deformation);
- 3) melting, inactive ice (facies 2, 3, and 4 deposition);
- 4) active ice flow over a freezing bed ("thrusting" and stacking of megablocks of ice-marginal sediment); and
- 5) melting, inactive ice (deposition of megablocks).

It is important to note that the thermal "zones" described in previous sections are generally margin parallel, and may be quite narrow (e.g., Kupsch 1962; Moran et al. 1980; Wickham and Johnson 1981).

The proposed sequence lends itself to the formulation of two hypotheses to account for the origin of the lithofacies and associated deformation. The primary difference between the two hypotheses lies in the cause for ice stagnation responsible for facies 2 and 3 deposition. In the first hypothesis, the observed stratigraphic sequence reflects only changes in the character of the ice lying within the bedrock embayment. In this hypothesis, ice within the embayment became detached from the main, still-active ice mass in the Mill Creek Valley, and stagnated, resulting in deposition of facies 2 meltout till and facies 3 sediment flow sediments. After some time, ice within the embayment again became active, mobilizing older sediments. This hypothesis is testable by description of the presence or absence of similar sequence of changes in the activity and basal thermal regime at sites outside of the embayment. If this sequence is not observed elsewhere, the changes in the nature of the ice may be restricted to a small area, and likely represent only a reactivation of

locally stagnant ice. It must be emphasized that it is the sequence of changes in ice behavior, not the specific sedimentary sequence, that must be identified to test the hypothesis.

In the second hypothesis, facies 2 and 3 represent regional cessation of ice movement and subsequent melting. Entrainment and transport of older sediments represents regional reactivation of ice, and implies regional changes in boundary conditions of the glacier. This hypothesis is testable by additional study across the Miami Sublobe.

We offer the following site-specific and general conclusions: 1) sedimentologic, structure, and stratigraphic data from a glacial sequence at the southern margin of the Miami sublobe of the Laurentide ice sheet reflect a sequence of ice advance – stagnation/recession – readvance, beginning about 19,700 yr BP; 2) these data also indicate complex changes in the thermal regime of the ice at a marginal setting; 3) the sediments reflect active, subglacial deposition at a site outside of the traditionally-mapped late Wisconsin limit; and 4) preservation of a significant thickness of meltout till may be attributed to a specific set of local geologic and geomorphic conditions.

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