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Depositional and Post-Depositional Features in the Late Illinoian and Late Wisconsinan Tills of Massachusetts

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ABSTRACT

Recent pressures on community development in Massachusetts require that the soil parent materials be examined in greater detail than has been done in the past. Up to 50% of the soils in Massachusetts are developed in dense glacial till regionally subdivided into the Lower Till of late Illinoian age and the Upper Till of late Wisconsinan age. Twelve till exposures were investigated to relate common morphological features seen in the tills to soil development, hydrology, and potential impact on land use. Depositional features such as sand layers and lenses, contorted silt/clay beds, and shear planes in the tills act as conduits for rapid water (and potential contaminant) movement. Oxidation along joints and fractures in both the oxidized and unoxidized facies in the Illinoian aged Lower Till suggests water movement and redox reactions are ongoing processes and occur several meters below the surface. There is a noticeable increase in both the amount and degree of development of argillans and redoximorphic features within the solum of soils developed on the oxidized Lower Till. The increased development suggests that much of the morphology of the modern soil is not inherited from the till but is due to pedogenesis. We concluded that the brown matrix, oxidized mineral grains, and increased fissility in the oxidized Lower Till result from postdepositional subaerial weathering and that the oxidized Lower Till appears to represent the remains of the Sangamon C horizon. Redox features also are present in the Upper Till generally occurring at textural transitions in the till. The relatively unweathered deeper portions of the Upper Till contain few to no argillans but argillans are common in the solum of soils developed in the Upper Till. These observations attest to the Holocene pedogenic alteration of the surface tills of all ages in Massachusetts.

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As the scope of soil investigations in the densely populated Northeast extends beyond soil survey work and into the engineering and environmental properties of soils (i.e., on-site disposal, landfill siting, wetlands, etc.) it becomes necessary to look beyond the solum and into the morphological, physical, and chemical properties of the parent materials themselves. This paper explores the applicability of using common soil survey terminology, developed to describe and evaluate the pedogenically altered upper portion of the profile, in description and interpretation of the undisturbed regolith. As an example, we discuss the features in undisturbed Wisconsinan and Illinoian aged tills in Massachusetts and relate their pedological interpretation to potential land use issues such as water quality degradation.

The soils of Massachusetts are developed in a range of Quaternary deposits including glaciomarine, glaciolacustrine, glaciofluvial and glacial till facies. The abundance of till-derived soils has been estimated at 26 to 50% in Massachusetts (Veneman & Bodine, 1982; Lindbo & Veneman, 1989). Glacial till has been defined as a nonsorted, nonstratified deposit homogeneous over large areas (Sugden & John, 1976; Hatheway, 1982), although some investigations have questioned this viewpoint and demonstrated the lateral variability of till over short distances (May & Thomson, 1978; Boulton, 1987; Clark & Hansel, 1989). Morphological features of till impacting both pedogenesis and land use interpretations include: jointing and subsequent preferential water movement, evidence of deep translocation of material, and stratification over both large and small distances.

Over the last decade the nature of dense till/fragipan/paralithic contact identification and its classification in New England has been debated (Calhoun, 1980; Lindbo & Veneman, 1989; Hundley, 1992). The degree of pedogenesis exhibited by till soils is critical in addressing this debate, thus knowledge of parent material is essential. Increased urbanization also requires greater information regarding the till below the soil solum to assure that sound management practices are followed. Unfortunately, the dense and stony nature of the till often precludes their detailed description and interpretation during routine soil survey activities.

The objective of this paper is to evaluate the suitability of standard soil terminology in the description and interpretation of subsolum features. This is accomplished by the description of morphological features typical of the tills in central Massachusetts. Differences between geogenic and pedogenic features will be discussed, along with the implications of morphological interpretations for hydrological and other physical properties.

PREVIOUS WORK

Two distinct tills, Upper Till (late Wisconsinan age) and Lower Till (late Illinoian age) are identified in Massachusetts (Fig. 5–1) (Newton, 1978; Newman et al., 1990). The Upper Till is a sandy, loose diamicton with compact zones or facies. The Lower Till is a compact, loamy textured diamicton with both oxidized and unoxidized facies, containing numerous joints and

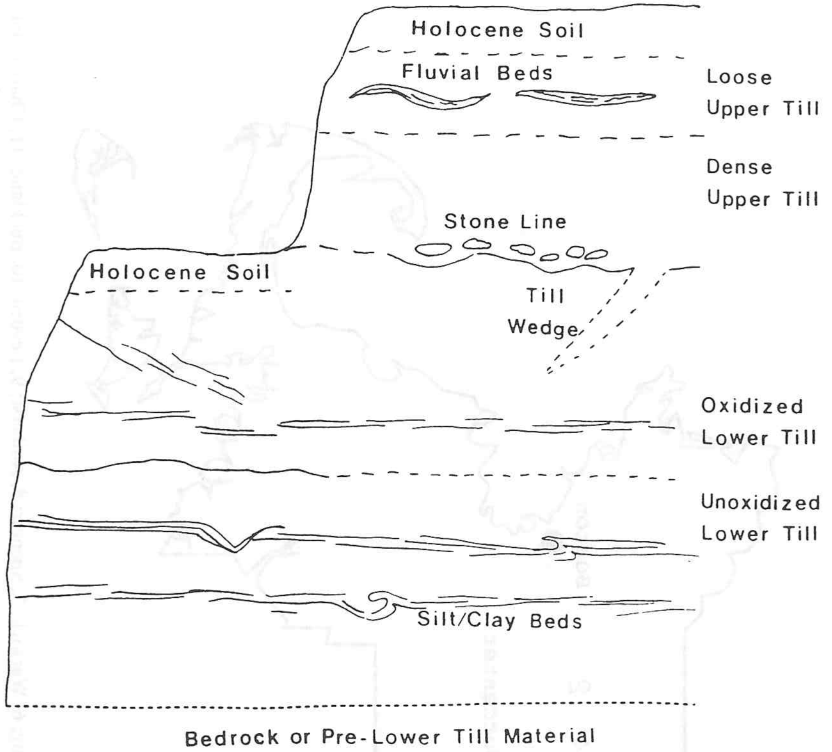

Fig. 5-1. Composite section showing observed features in stratigraphic relation. The diagram is not drawn to scale (Lindbo, 1990).

glaciotectonic features (Pessl, 1966, 1971; Pease, 1970; Newton, 1978; Koteff & Pessl, 1985). The oxidized and unoxidized Lower Till have few compositional or structural differences; however, some minerals in the oxidized facies observed in thin section are more weathered and have Fe-oxide halos that bleed into the matrix, accounting for its browner color. Newman et al. (1990) noted the typically browner coloration and a few argillans in voids and on pedon faces in Boston Harbor drumlins. They concluded the oxidized Lower Till facies is a truncated C horizon of Sangamon age, therefore, some if not all of the argillans in the oxidized Lower Till are inherited. Lindbo and Veneman (1993) observed poorly developed argillans in Cd horizons in oxidized Lower Till, and well-developed argillans in the upper solum of Massachusetts till soils. They concluded the well-developed argillans of the upper solum were formed by modern pedogenic processes.

METHODS

Site Locations

Three extensive exposures were investigated in detail for till morphology (Fig. 5-2). The first site was located at the Municipal Landfill of Leicester,

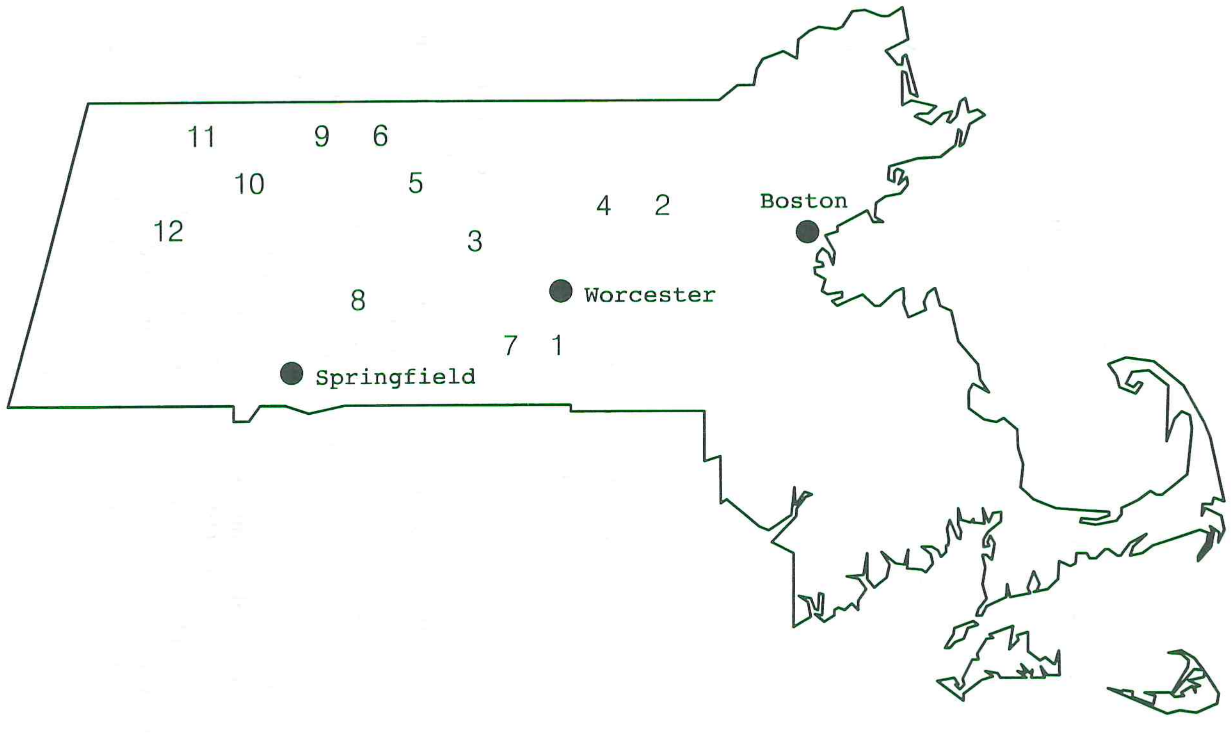

Fig. 5-2. Site locations: 1, Leicester; 2, Ayer; 3, Barre; 4, Lancaster; 5, Erving; 6, Warwick; 7, Spencer; 8, Amherst; 9, Leyden; 10, Buckland; 11, Charlemont; and 12, Savoy.

MA, where approximately 8 m of Lower Till overlain by 3 m of Upper Till were exposed during the investigation. The second site was located in a till strip mine cut into a drumlin in the Pingryville section of Ayer, MA. The headwall exposed a 25-m thick section of Lower Till and an 8- by 3-m thick section of Upper Till on the side of the drumlin. The third site was an exposure of unoxidized Lower Till at a landfill in Barre, MA, a site being strip mined for landfill liner and cover materials. These headwalls were only a few meters high and spatially criss-crossed throughout the site. Numerous faces were exposed thus helping to identify structures within the unoxidized Lower Till, but the oxidized Lower Till and Upper Till were not well exposed at this site. Nine additional, less extensive sites were investigated, illustrating similar features (Fig. 5–2).

Field and Laboratory Procedures

Field descriptions and photographs were taken after a fresh face was exposed. Once described and photographed, bulk soil samples were taken. Oriented blocks of till were removed from the outcrop face for micromorphological examination. Samples were air dried for at least 30 d, and were then impregnated under vacuum with Spurr resin (PolySciences, Warrington, PA) according to the manufacturer's directions. After curing, samples were cut, polished, mounted to frosted glass slides, and ground to about 30 μm. Field orientation was noted during this procedure. Thin sections descriptions followed Brewer (1976).

RESULTS AND DISCUSSION

General Descriptions

The Lower Till is massive and very firm to extremely firm, with colors ranging from gray to dark gray (5Y5/1-4/1 unoxidized facies) to olive to light olive brown (5Y4/3-2.5Y5/4 oxidized facies) (Table 5–1). The contact between the oxidized and unoxidized facies varies from abrupt (0.1–1.0 cm) to diffuse (>50 cm) although an abrupt contact is more common. The rock fragments or clasts are matrix supported and subangular to angular, as are sand and coarse silt observed in thin section. Joints are common in both facies, becoming more closely spaced toward the top of the oxidized facies, leading to well-defined fissility or platy structure (Fig. 5–3). Joints and other structural features are continuous across the facies boundary.

The Upper Till rests conformably upon the oxidized Lower Till. The Upper Till is light yellowish brown to gray (2.5Y6/4-6/1), single grain to massive, and firm to extremely firm. Few light gray (2.5Y7/2) mottles occur at the boundary between lenses of denser till or sandier material. At several locations the lower portion of the Upper Till is more compact than the overlying till. The Upper Till is much stonier than the Lower Till, but clasts are still matrix supported (Fig. 5–4a,b). Clasts in the Upper Till range from round-

Table 5–1. Generalized morphological features of the Upper and Lower Till based on observation from all sites.

Color	Texture, structure, consistence	Description
		Upper Till
2.5Y6/4 (10YR6/4–5Y4/3)	Loamy sand; massive to single grain; firm to very firm, fluvial zones may be loose	Stony, matrix supported rock fragments, rock fragments are subround to subangular, up to 10% rock fragments are grussified, common bands and lenses of graded sand up to 40 cm thick, common pockets of denser material, common bands of silty and sandy material ranging from a few millimeters to tens of centimeters, some have undergone folding and faulting, common silt caps on top of most rock fragments, rare argillans
		Upper Till (dense)
2.5Y6/4 (2.5Y6/2–5Y6/4)	Sandy loam; massive to platy in zones; very firm to extremely firm; hard when dry	Stony, matrix-supported rock fragments, rock fragments are subangular to angular, up to 10% rock fragments are grussified, thin sandy bands may outline plates, common bands of siltier material up to 10 cm thick, these may be contorted, common silt caps, few low chroma mottles may be associated with denser zones
		Lower Till (oxidized facies)
5Y4/4 (10YR5/6–5Y4/2)	Fine sandy loam; platy, becoming massive with depth; very firm to extremely firm	Fissile with dark reddish brown (5YR3/3) ferrans and mangans on plates, common subvertical and subhorizontal joints some with brown (7.5YR4/4) ferrans, few argillans on plates (thin and patchy), in voids, and on some pebbles, rock fragments are matrix supported and are angular to subangular, few discontinuous olive (5Y5/4) sand and clay veins up to 2 cm thick and sometimes clustered in groups of alternating veins up to 40 cm thick, many of these beds are slightly to extremely deformed, the transition between the oxidized facies may be an abrupt change in color
		Lower Till (unoxidized facies)
5Y4/2–5GY4/1	Fine sandy loam to sandy clay loam; massive; very firm to extremely firm	Common to widely spaced joints, common olive gray (5Y5/2) to pale yellow (5Y7/4) sand and clay veins up to 2 cm thick and grouped in alternating bands up to 60 cm thick, groups may be space within 1 m of each other, most beds are extremely deformed, shear planes unrelated to beds may be visible by thin slickensides on their surface, rock fragments are matrix supported and angular to subangular

Fig. 5-3. Platy structure in oxidized Lower Till at Barre (Site 3). Photograph (*a*) approximately 4 m from the surface. Plates commonly are demarcated by mangans and/or ferrans. Knife handle is 10 cm long. Fig. 5-3 continued.

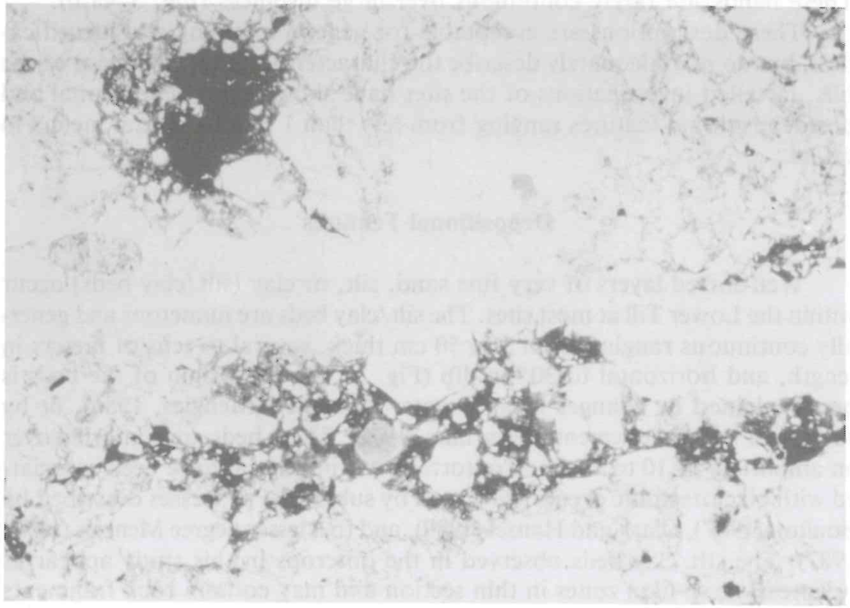

Fig. 5-3. Continued. Photomicrograph (*b*) of a platy structure in oxidized Lower Till at Barre (Site 3). Fig. 5-3 continued on p. 82.

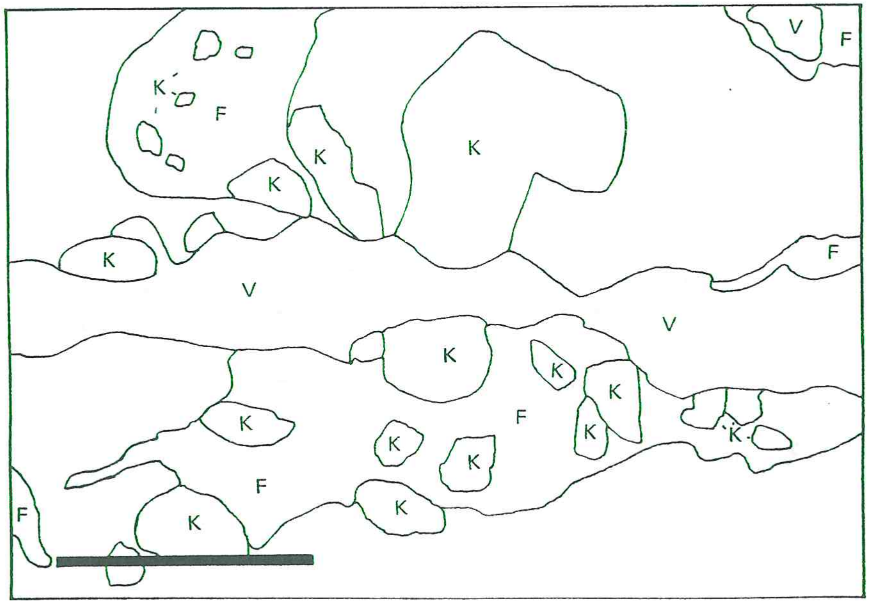

Fig. 5-3. Continued. Schematic (*c*) of a platy structure in oxidized Lower Till at Barre (Site 3) where V = voids, K = skeleton grain, F = ferran/mangan, (bar is 1 mm).

ed to subangular shapes. The Upper Till seems stratified at some sites due to the predominance of different textured bands occurring throughout it. These bands are rarely continuous over large distances (Fig. 5-4a,b).

These descriptions are acceptable for general mapping and identification, but do not adequately describe the character (internal variation) of the tills. Detailed investigations of the sites have shown both depositional and postdepositional features ranging from less than 1 mm to several meters in extent.

Depositional Features

Well-sorted layers of very fine sand, silt, or clay (silt/clay beds) occur within the Lower Till at most sites. The silt/clay beds are numerous and generally continuous ranging from 3 to 50 cm thick, several to tens of meters in length, and horizontal to 30° in dip (Fig. 5-5a). The origin of the beds is best explained by changes in pore water dynamics (Menzies, 1986), or by subglacial water movement (Weertman, 1972). These beds are contorted over an amplitude of 10 to 20 cm. Contorted beds in general have been associated with glaciotectonic events or formed by subglacial processes described by Boulton (1987), Clark and Hansel (1989), and to a lesser degree Menzies (1986, 1987). The silt/clay beds observed in the outcrops in this study appear as oriented (varve-like) zones in thin section and may contain rock fragments and till clasts (Fig. 5-5b,c). These beds have little direct impact on pedogenesis, and when observed in the solum their orientation and internal structure

Fig. 5-4. Sand beds, dikes, and fluvial material in the Upper Till at Charlemont (Site 11). Photograph (*a*) is approximately 1.5 m from the surface. The tape is broken into 10-cm increments. Fig. 5-4 continued on p. 84.

(folds, faults, etc.) clearly identify them as geogenic in origin. They may however affect water movement because they are expected to have lower hydraulic conductivities (based on their texture) than the surrounding till. The presence of folds, faults, etc., suggests the beds have a different shear

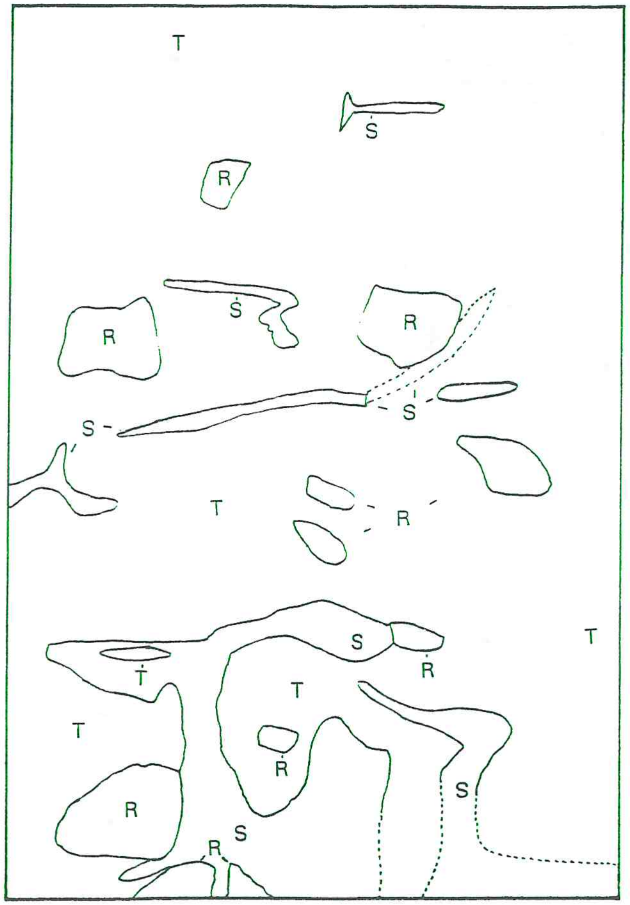

Fig. 5-4. Continued. Schematic (*b*) of photograph (*a*). S = sand bed/fluvial material, R = rock fragments, T = till. Fig. 5-4 continued on p. 85.

strength than the till around them. If the silt/clay beds were as strong or stronger than the surrounding till, the till would contain shear and attenuation features as well. Present in both facies are planes of oriented silt grains, not visible in hand specimens (Fig. 5-6), which represent continuous shearing and deformation where the glacier was sliding and attenuating fine-grained material (Boulton, 1987). There is no oriented clay associated with these features as would be expected if they were pedogenic in origin. These oriented silt planes and silt/clay beds may represent planes of weakness within the till (Linell et al., 1960; Milligan, 1976).

At the Ayer site an extensive medium to coarse sand layer was observed (Fig. 5-7a,b). In this situation, the sand acts as a drain for >20 m of till above it. The layer is not consolidated and would represent a zone of different shear strength and hydrology within the till (May & Thomson, 1978). These features (silt/clay beds, oriented silt layers, and sand layers and lenses)

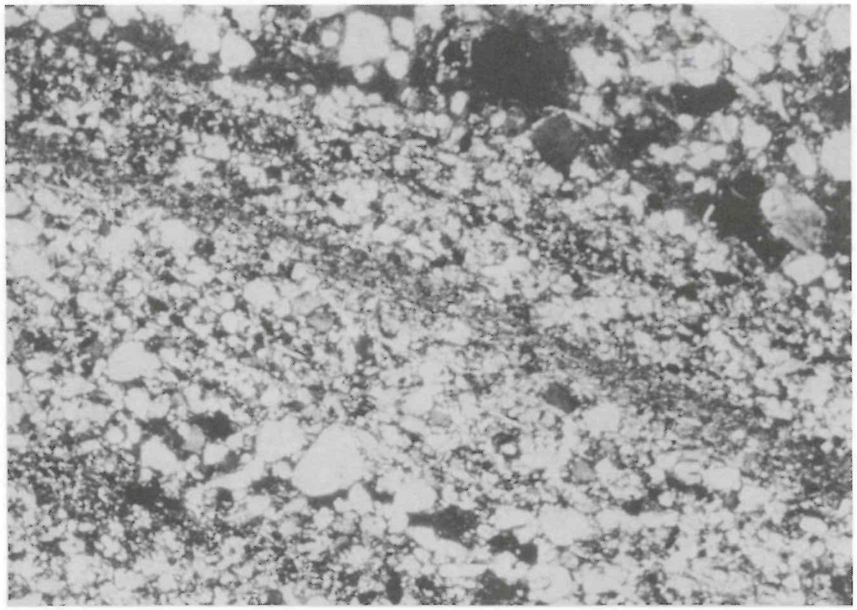

Fig. 5-4. Continued. Photomicrograph (*c*) (plane-polarized light) of graded beds (fluvial) sediment (frame length is 3 mm).

Fig. 5-5. Silt and clay beds (light colored bands) in the Lower Till at Barre (Site 3) (*a*). Rod in center of photo is 1.3 m long. Fig. 5-5 continued on p. 86.

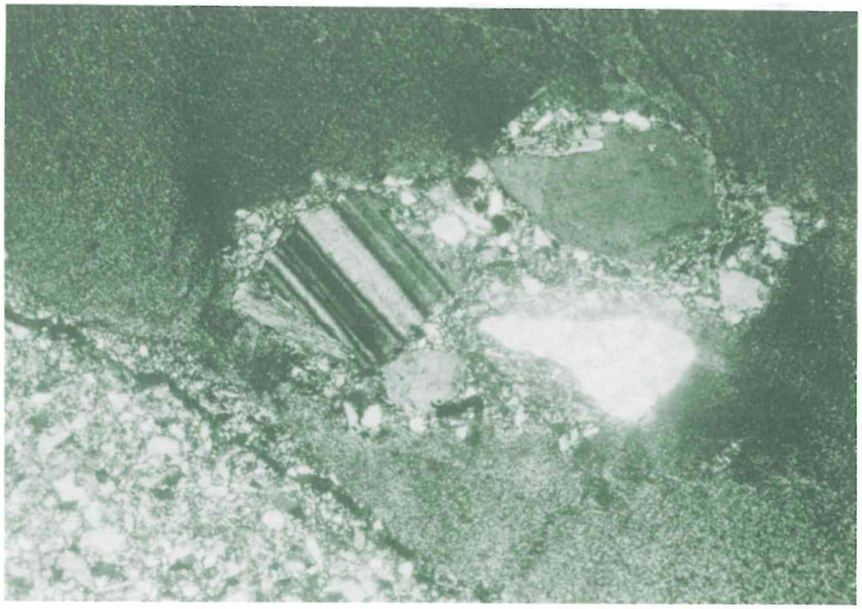

Fig. 5-5. Continued. Photomicrograph (cross-polarized light) (*b*) of a till clast in a clay bed in the Lower Till. Fig. 5-5 continued.

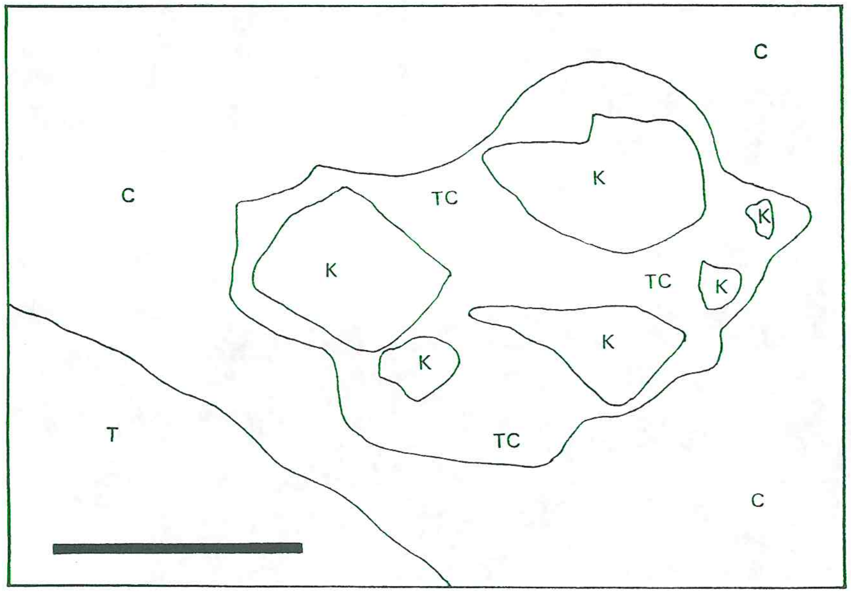

Fig. 5-5. Continued. Schematic (*c*) of photomicrograph (*b*) of a till clast in a clay bed in the Lower Till. K = skeleton grain, C = oriented clay, T = till, TC = till clast (bar is 1 mm long).

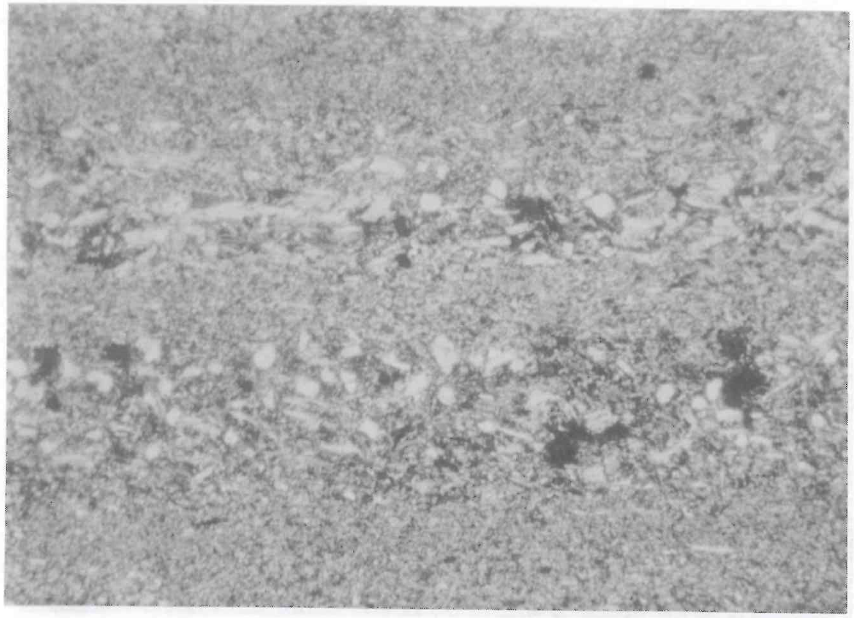

Fig. 5-6. Photomicrograph (cross-polarized light) of oriented silt zone in Lower Till (frame length is 3 mm).

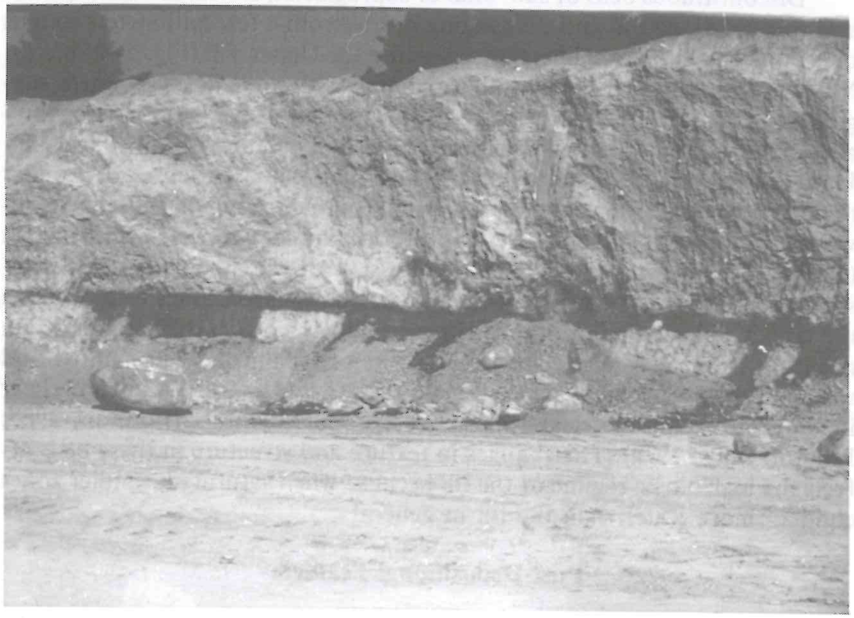

Fig. 5-7. Sand layer at Ayer (Site 2) (*a*). The layer is identified by the water seeping from it appearing darker in the photograph. Fig. 5-7 continued on p. 88.

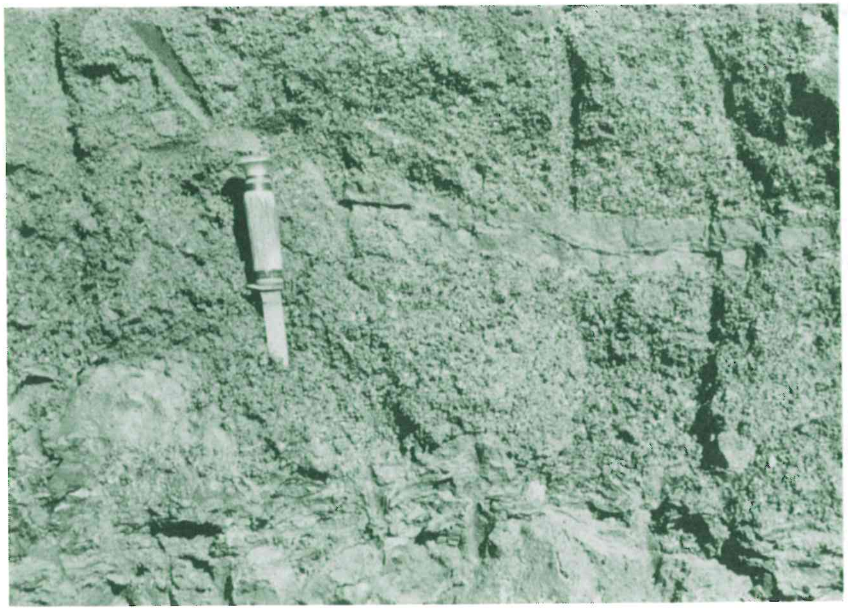

Fig. 5–7. Continued. Detail of the sand layer (*b*), note the fine-grained dikes crossing it.

are common and need to be considered when determining geotechnical and hydrologic properties (Milligan, 1976; May & Thomson, 1978; Prudic, 1982).

Discontinuous beds of sub- and/or supraglacial, fluvial sediment (lenses and veins of fine sand and silt ranging in size from a few millimeters to tens of centimeters thick) are interspersed within the Upper Till (Fig. 5–4a,b,c,d). Many of these are well-sorted, subhorizontal, with some fining upwards suggesting that the Upper Till's internal structure was formed in part by sub- and/or supraglacial meltwater action (Shaw, 1983; Shaw & Kvill, 1984; J.H. Hartshorn, 1987, personal communication). Laminated lenses of sandier material suggest either deposition directly by meltwater or subsequent reworking by meltwater soon after deposition, and may represent meltout till (Drake, 1971; Newton, 1978; Koteff & Pessl, 1985; Dreimanis, 1989). Small-scale (approximately 1-m) folded, faulted, and sheared zones also occur in the Upper Till. Folded or draped zones are likely postdepositional in origin resulting from dewatering and collapse of the sediment. The faulted and sheared beds are probably depositional in origin due to attenuation and shear in water-saturated materials below the ice/debris contact (Boulton, 1987; Boulton et al., 1974). The changes in texture and structure in these beds affects the hydrologic regime of the till because when saturated, sandier zones conduct more water than the till in general.

Post-Depositional Features

The Upper and Lower Tills contain numerous morphological examples of ongoing and inherited postdepositional weathering and water movement.

The most obvious postdepositional feature of the Lower Till is the brown color and fissile nature of the oxidized facies. Mineral grains (hornblende and garnet, in particular) are oxidized and stain the matrix (Fig. 5-8). Individual plates found below the solum and extending 3 to 4 m into the oxidized facies commonly are coated with ferrans and/or mangans (Fig. 5-3a,b,c). Determining whether the color and fissility were modern or inherited was based on two observations. First, a glaciotectonically overturned section first described by Newton (1978) in western Massachusetts has the unoxidized facies stratigraphically above the oxidized facies. The morphology of the overturned oxidized facies in this section is similar to the oxidized facies observed elsewhere (Newton, 1978). Second, the clay mineralogy from the overturned section and normal sections elsewhere in the state indicate the oxidized facies is more highly weathered than either the unoxidized facies or the Upper Till in general (Newton, 1978; Lindbo, 1990; Newman et al., 1990). The oxidized facies must have developed during the last interglacial, therefore, the color and fissility are most likely the remnants of a Sangamon paleosol (Newman et al., 1990). Fissility and coated plates are seen infrequently in the modern solum (Lindbo & Veneman, 1993). If they are present they may have argillans or siltans superimposed on the ferrans and mangans, indicating clay and silt illuviation are the dominant pedogenic processes occurring today.

The contact between oxidized and unoxidized till may be abrupt, although some brown (5YR3/4) Fe-oxide staining is common along the joints

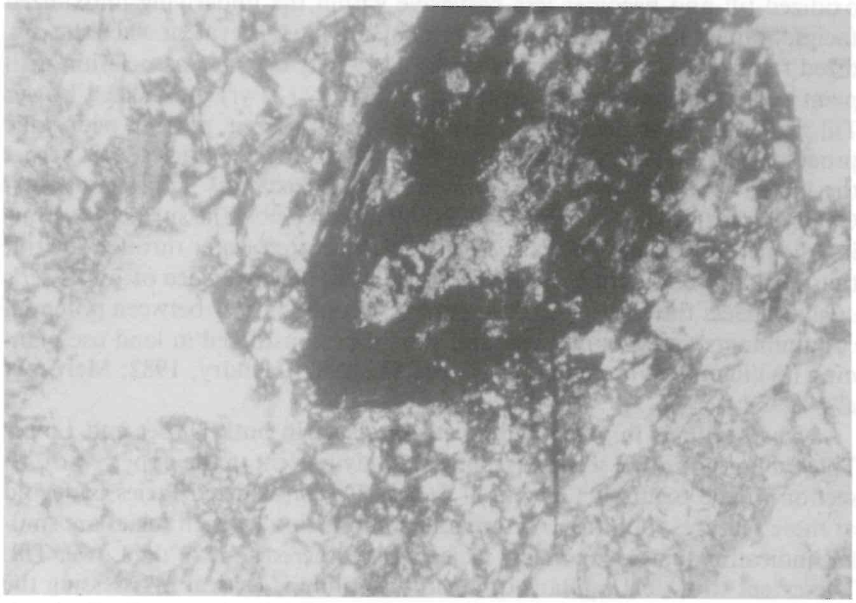

Fig. 5-8. Photomicrograph (plane-polarized light) (*a*) of an oxidized garnet grain in the oxidized Lower Till. Fig. 5-8 continued on p. 90.

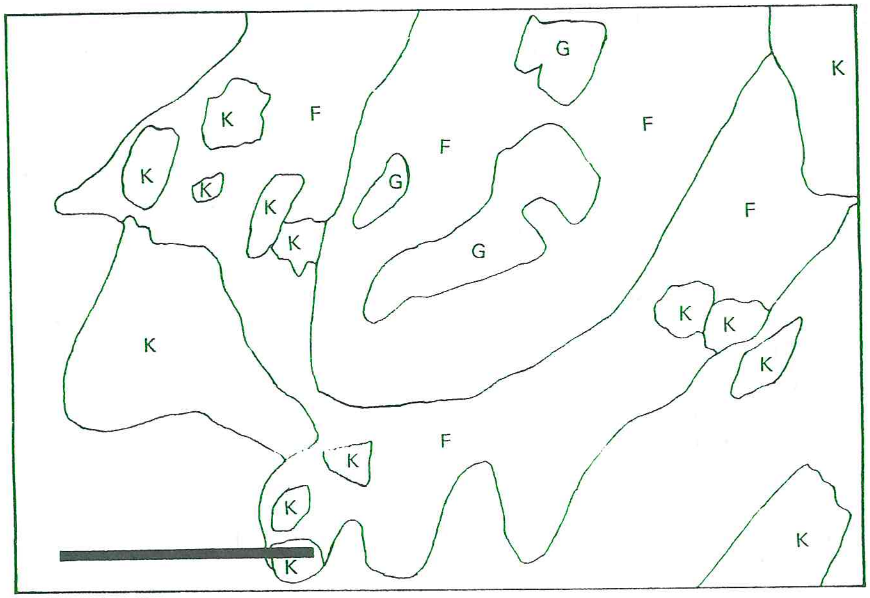

Fig. 5–8. Continued. Schematic (*b*) of photomicrograph (*a*) of an oxidized garnet grain in the oxidized Lower Till where K = skeleton grain, G = garnet, F = ferran (bar is 1 mm long).

between the unoxidized and oxidized facies. The staining along joints represents postdepositional subaerial weathering, and is common within the oxidized till and becomes less pervasive within the underlying unoxidized facies. Stained joints are generally vertical and most prevalent when the oxidized facies is only a few meters thick. They may occur in association with plant roots that have grown in freshly exposed (1–2 yr) unoxidized Lower Till material. The oxidation apparently results from present pedogenic processes since it is superimposed on other features in the facies, cuts across the facies boundary, and is associated in some instances with plant roots. Oxidation features may be present several meters below the surface illustrating the depth to which joints are conducting aerated water through the till, thus limiting the filtering nature of the subsoil. The presence of joints seriously impacts the ability of till to act as a proper barrier between potential contaminants and groundwater and should be considered in land use planning (Williams & Farvolden, 1967; Prudic, 1982; Hendry, 1982; Melvin et al., 1992).

Few argillans in voids and on pedon faces in both Upper and Lower Till (Cd horizons) are seen. Argillans are only present in the upper 1- to 2-m section of the oxidized Lower Till facies. The unoxidized facies is devoid of these features, but the structure and composition of both facies are similar, indicating that the oxidizing facies is a weathered zone of the Lower Till. The extent to which argillans occur in the solum is critical in assessing the degree of pedogenesis. The lower solum (Bt and Btx horizons) of soils developed from oxidized Lower Till may contain an order of magnitude more

Fig. 5–9. Photograph (*a*) of a silt cap in the Upper Till. Knife handle is 10 cm long. Fig. 5–9 continued on p. 92.

argillans than the Cd horizons. The solum of Upper Till soils behaves similarly (Lindbo & Veneman, 1993). The few argillans present in the till (Cd horizons) and the common well-developed argillans in the solum indicate a substantial pedogenic alteration of both tills.

The Upper Till is less oxidized than the oxidized Lower Till. Thin high chroma bands occur within the Upper Till adjacent to sandier beds or lenses. These represent localized oxidation due to changes in hydraulic conductivity. The high chroma bands are found up to 3 m below the surface, indicating the extent of water movement and potential translocation of material.

The common occurrence of silt caps on rock fragments in the Upper Till further indicates the importance of water movement (Fig. 5–9). Hypotheses describing the formation of silt caps include: syndepositional processes that concentrate fines adjacent to clasts (Newton, 1978), immediate postdepositional migration of fines out of the surface layers (Boulton & Dent, 1974), or freeze-thaw activity associated with permafrost (van Vliet-Lanoë, 1985; Fitzpatrick, 1987). Silt caps drape the upper surfaces of clasts and in extreme cases silt may coalesce and have been observed on bedrock (S. Bodine, 1986, personal communication). The preferred orientation strongly suggests a postdepositional origin; if formed syndepositionally, a more random orientation would be expected. Silt caps, while having little impact on land use interpretations, do, however, indicate the importance of illuviation in the formation of Upper Till soils.

Table 5–1 serves as a basic field guide for identifying tills in the uplands of Massachusetts. The internal structures observed are dominated by sub-

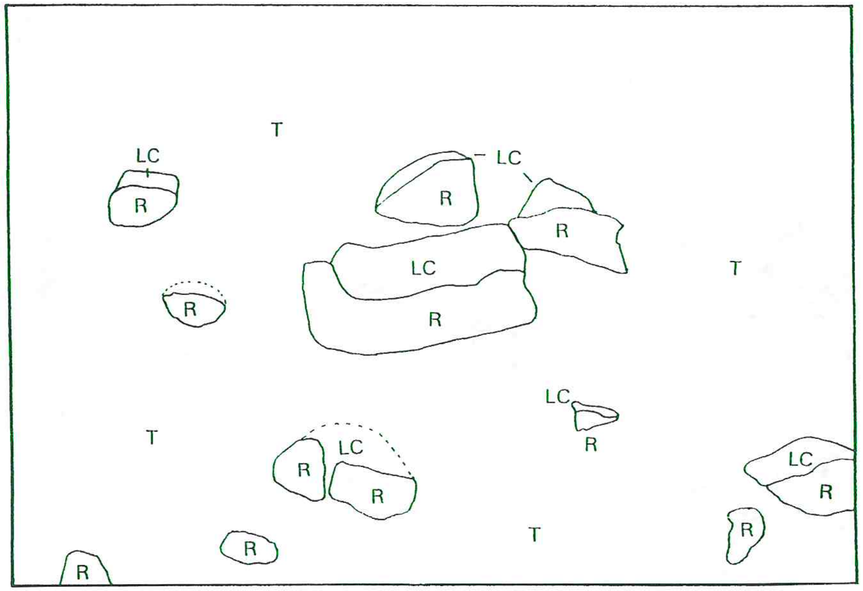

Fig. 5-9. Continued. Schematic (*b*) of photograph (*a*) where LC = silt cap, R = rock fragment, T = till. Fig. 5-9 continued.

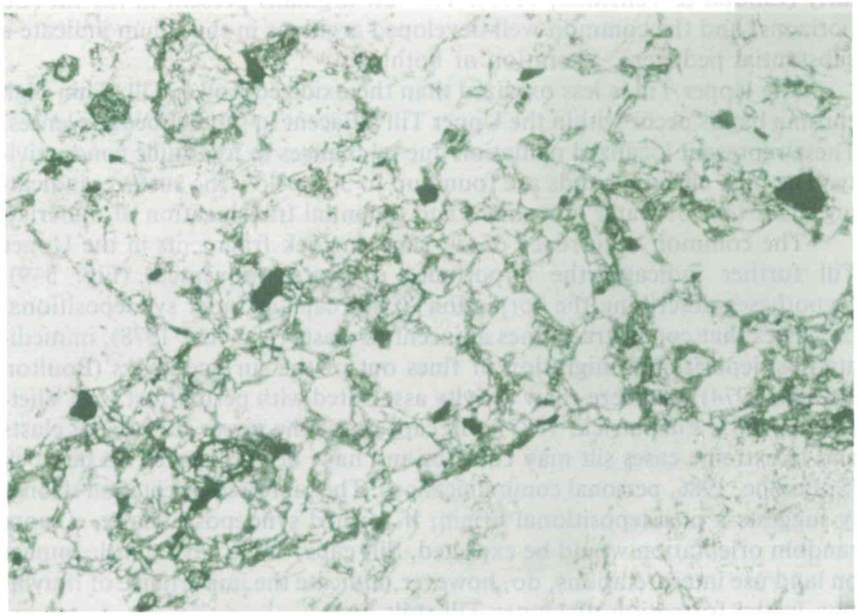

Fig. 5-9. Photomicrograph (plane-polarized light) (*c*) of a silt cap in the Upper Till. Fig. 5-9 continued on p. 93.

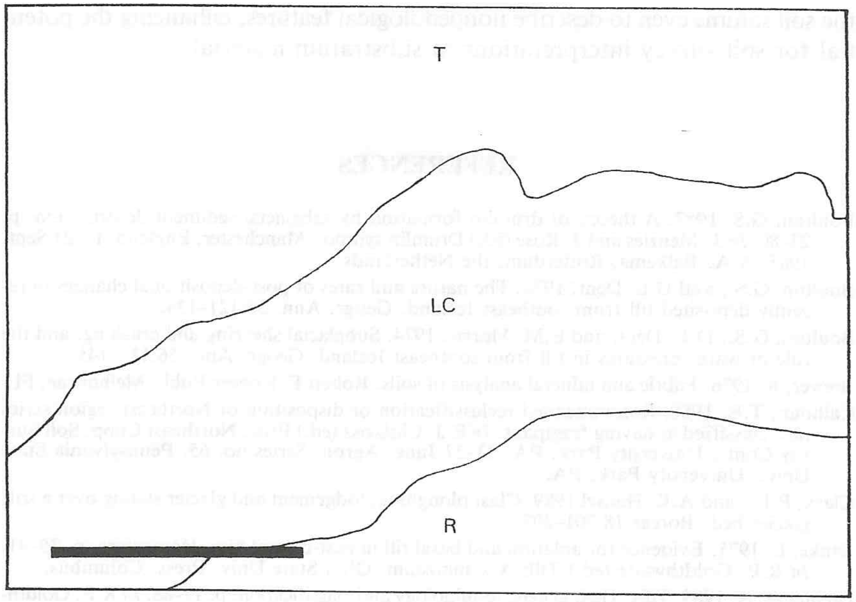

Fig. 5-9. Continued. Schematic (*d*) of photomicrograph *c* where LC = silt cap, R = rock fragment, T = till. Bar is 1 mm long.

glacial shearing and deformation as evidenced by shear-oriented silt grains and deformation features (dragged and folded silt/clay beds, contorted beds, and till shadows around clasts). Layers of sandier sediment having different engineering and hydrologic properties than the surrounding till also are present. Nearly ubiquitous, they should be considered in any development on areas underlain by till. They are depositional features and should not be confused with pedogenic features. Postdepositional weathering of minerals in the Lower Till accounts for the observed color of the oxidized facies. Apart from the greater degree of weathering the unoxidized and oxidized facies appear to be of the same lithology. Joints, both with and without coatings, are common in the Lower Till. They may compromise the inherent low hydraulic conductivity of the till. Graded beds and crossbeds are common in the Upper Till indicating the importance of fluvial action in the depositional history of the Upper Till. Silt caps are a common postdepositional feature.

This paper described typical features of glacial tills as observed within and below the soil solum, and postulated on their impact on pedogenesis, hydrology, and engineering properties. The inherent variability of the features observed suggest random testing is insufficient to characterize the properties of the till. This has significant implications if we want to extend soil survey information below the depth of the solum. Further research should address quantifying the effects of these features on a soil/site specific basis. This data will enhance our understanding of tills and till-derived soils. This paper also shows that common soil survey terminology can be used below the soil solum, even to describe nonpedological features, enhancing the potential for soil survey interpretations in substratum material.

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