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THE PRESENCE OF A WINDBLOWN COMPONENT IN MASSACHUSETTS SOILS

A Thesis Presented

By

PETER CRAIG FLETCHER

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
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Department of Plant and Soil Science

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COMPONENT IN MASSACHUSETTS SOILS

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INTRODUCTION

The mode of glacial retreat in Massachusetts provided many widely scattered source areas for windblown sediments. Many soil profiles in the Commonwealth are characterized by a uniform, fine-textured mantle which is distinctly different from the underlying material (Fig. 1). This mantle is believed by soil scientists and geologists to be windblown. In soils lacking a distinct mantle, a windblown component is questionable and its presence is often disputed.

The purpose of this thesis is to study different soil profiles in Massachusetts and establish whether a windblown component is present. A study of the surface textures of quartz sand grains with a scanning electron microscope and cumulative curves plotted from sieved samples will provide the primary data used to establish the presence or absence of a windblown component.

Soil profile studies include soils that have developed in coastal sand dunes, postglacial sand dunes, glacial outwash, thick eolian mantles overlying glacial till, and till soils where a distinct mantle is not evident.

Fig. 1. Photograph of a very fine sandy loam mantle (approximately 34 inches thick) overlying a gravelly coarse sand glacial outwash. This mantle is considered by soil scientists and geologists to be windblown. Note the characteristic color and textural uniformity of the mantle. The abrupt textural transition between the two geologically different sediments is common where the mantle is thick (>18 inches). The photograph was taken in the Town of Mashpee, Barnstable County and the soil is an Enfield very fine sandy loam (coarse-silty over sand or sandy-skeletal, mixed, mesic Typic Dystrochrepts).

CHAPTER I

LITERATURE REVIEW

Deglaciation in Massachusetts

Several ice advances extended completely across New England to or beyond the present south shore. The last glacial ice sheet, the Laurentide Ice Sheet of Wisconsin Age, developed in the highland of eastern Canada (Flint, 1971) and extended southward. The moraines of Nantucket and Martha's Vineyard (Fig. 2.) and the Ronkonkoma Moraine of Long Island mark the furthest position of the ice sheet southward. Radiocarbon dates and correlation with midwestern glaciations date the maximum extent of the last glaciation at 20,000 to 22,000 years ago (Schafer and Hartshorn, 1965).

Following maximum glaciation, the ice front receded from south to north principally by thinning (downwasting) in a wide marginal zone. Stagnation-zone retreat is thought to have been the mode of glacial retreat in New England following the last glaciation (Schafer and Hartshorn, 1965). This is characterized by a zone of stagnant or dead ice, commonly a few kilometers wide, positioned in front of the main ice mass. Where the terrain is rugged, ice remained in valleys long after it had melted from hill tops. Ice-marginal stratified drift was deposited within and beyond the stagnant ice (Schafer and Hartshorn, 1965).

Recessional moraines, marking positions where the ice either stabilized for a time or readvanced, are uncommon in Massachusetts. The Sandwich and Buzzards Bay Moraines of Cape Cod (Fig. 3.) are recessional moraines. Less extensive recessional moraines have been

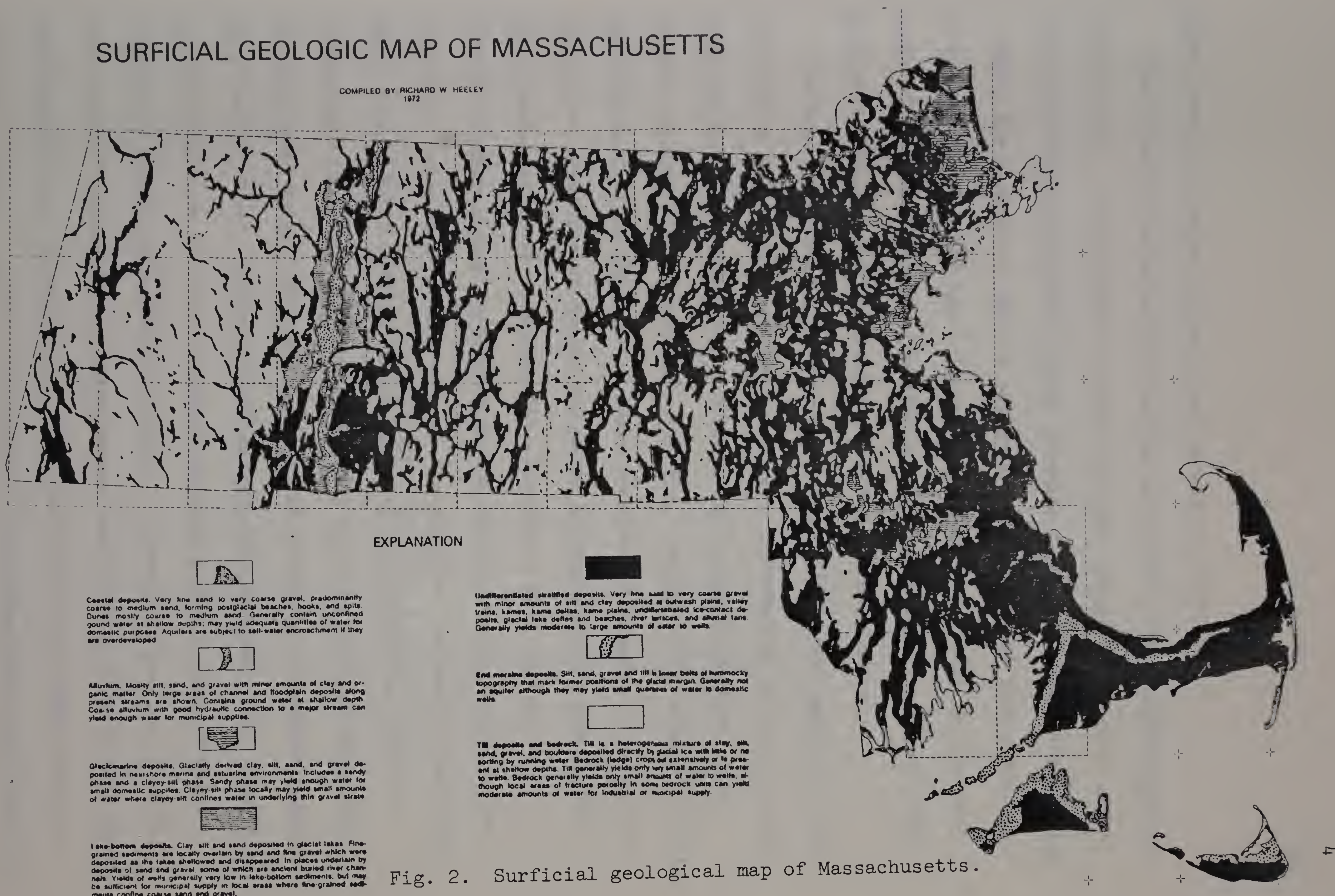


Fig. 2. Surficial geological map of Massachusetts.

mapped south of Boston (Schafer and Hartshorn, 1965).

Many glacial lakes existed during and shortly after deglaciation in Massachusetts. They ranged in size from small ponds to the very extensive glacial Lake Hitchcock, which extended from Rocky Hill, Connecticut to Lyme, New Hampshire, and is believed to have existed from about 13,000 to 10,700 years ago. Its existence coincided with the ice retreat across Massachusetts (Schafer and Hartshorn, 1965) and continued long after the ice retreated across the St. Lawrence River.

During deglaciation, glacial streams deposited vast amounts of outwash beyond the terminus of the ice sheet. Downwasting of the ice sheet also exposed large barren areas of till and outwash deposits. These freshly exposed outwash and till deposits, combined with lacustrine sediments exposed after the glacial lakes drained are thought to have been the source areas for windblown sediments deposited during and shortly after deglaciation in Massachusetts (Hartshorn, 1961; Flint, 1971). Glacial outwash plains, deposited beyond the active ice terminus, are thought to have been primary sources for windblown sediments (Hartshorn, 1961; Flint, 1971). Price (1973) recorded daily ablation rates for present-day temperate glaciers equivalent to 10 to 15 cm of water per day and noted marked diurnal variations in discharge of streams emerging from the ice front. These daily fluctuations in stream flow, accompanied by the deposition of fine sediments, provide a continusouly renewed source for windblown sediments (Joseph H. Hartshorn, personal communication, 1977). Péwé (1951) studied present-day glacial streams in Alaska and described the floodplain as being one to two miles wide, with intricately braided channels and numerous silt-covered bars and cited this as the source for the windblown sediments in that area. Trainer studied the eolian deposits of the Matanuska Valley in Alaska and also cited the bare floodplain of the braided meltwater streams as the primary source of windblown sediments. Rock flour deposited by the streams was considered the source of eolian dust.

Bare till (Fig. 2.) is thought to be a secondary source of windblown sediments (Flint, 1971). Boulton and Dent (1974) described a stony lag surface on recently exposed till near an ice terminus and attributed this to the deflation of silt and fine sand by strong winds blowing from the glacier. Sediments blown from these areas accumulated in areas further from the ice terminus where the wind velocities were less.

Lacustrine sediments (Fig. 3.), commonly exposed to wind activity following rapid draining of the lake, are thought to have been another source for windblown sediments. The lake sediments of glacial Lake Hitchcock are thought to be the primary source of the loess-like mantle deposited just east of the Connecticut Valley.

Establishment of Vegetation on Recently Glaciated Areas

It is generally accepted that nearly all of the windblown sediments deposited in Massachusetts, excluding present-day dune activity along the coastal shores, were deposited during the interim between the disappearance of the glacial ice and the establishment of a nearly complete vegetative cover.

Pollen diagrams collected from central Massachusetts by Davis (1958) were interpreted as indicating a narrow treeless belt along the edge of the retreating ice that was quickly colonized by forest. Migration speed and unstable soil conditions appear to have controlled the early vegetation stages. Pollen and spores attest to an early treeless vegetation. Well drained, sheltered areas are thought to have been the first sites for tree growth. On these sites jack (or red) pine, white (or red) spruce, birch (perhaps shrub birch), oak, and possibly other deciduous trees were thought to have first appeared.

On repeated expeditions to Glacier Bay, Alaska, Cooper (1939) observed three stages of revegetation after recent ice recession. The first stage was a pioneer community of mosses, perennial herbs, and prostrate willows. Next was a willow-alder thicket stage, followed by a climax stage comprised mostly of Sitka spruce.

A striking lack of conformity in the rate of revegetation was noted in several recent studies (Cooper, 1939; Crocker, and Major, 1955; Lawrence, 1958). Areas where there were no significant environmental differences between vegetated and bare areas were often observed. Tisdale, Fosdale, and Poulton (1966) noted distinct vegetation differences on recently deposited moraines and patterns that were still discernable on the oldest moraines; they attributed these to differences in topography, aspect, and soil texture.

Establishment of vegetation on outwash areas is slower than on till areas. Flint (1971) noted the continual disturbance of outwash areas by proglacial streams, while till areas were relatively stable and were first to be colonized by vegetation. Cooper (1939) and Lawrence (1958) also recorded slower development of vegetation on outwash areas. Commonly, wet pits or depressions within outwash areas were crowded with vegetation while adjacent drier areas were often barren.

Studies by Geologists on the Windblown Sediments in Massachusetts

"Evidence for late-glacial eolian activity in Massachusetts is provided by a very widespread layer of windblown sand and silt, by ventifacts in this material (Fig. 3.), by wind-abraded bedrock outcrops, and by stabilized sand dunes" (Hartshorn, 1961, p. 194). Woodworth, in 1899, was the first to suggest that this upper surface layer of sand and silt might be windblown, noting its similarities to loess found in the Midwest. Bryan (1932) recognized the presence of wind-abraded stones within this surface mantle and concluded that it must have been deposited by wind. Smith and Fraser (1935) studied the surface mantle in the vicinity of Boston and by using field relations, mechanical composition, and petrographic characteristics, concluded that it was wind-deposited.

The windblown mantle in Massachusetts is generally too sandy to be called loess (Schafer and Hartshorn, 1965). In southeastern Massachusetts, Hartshorn (1960) described the mantle as being comprised mostly of medium to fine sand and silt. Less extensive areas of loess are found scattered throughout the Commonwealth and are attributed to local source areas of lacustrine sediments.

The occurrence and character of the windblown mantle is dependent primarily upon the extent and character of the source area present at the time of deposition, and the local relief. Schafer and Hartshorn (1965) attribute the nearly ubiquitous nature of the mantle in southeastern New England to the abundance of stratified drift in the area and to the low-lying terrain. Where the relief is greater and the stratified drift is less extensive, the mantle tends to be thinner and less

Fig. 3. Slightly magnified photograph of a wind-abraded granite stone, a ventifact, found in southern Bristol County, Massachusetts. Note the characteristic polished surface, even within concavities. The fluted surface is the result of differential weathering with the harder, more resistant quartz comprising the ridges and crests and the softer, less resistant minerals in the hollowed-out depressions. This ventifact was found in the general vicinity of the Dartmouth study site. Photograph taken by Rino Roffinoli.

extensive. Smith and Fraser (1935) described the windblown mantle in the vicinity of Boston as irregular in thickness and discontinuous in extent, being thin or absent on hill crests and thickest down slope. Hartshorn (1960) described the windblown mantle in the Bridgewater quadrangle as being found nearly everywhere and lacking only on recent alluvium, some areas of lake clays and on some narrow ice-channel fillings.

The thickness of the surface mantle is variable, generally thickest close to and on the leeward side of its source and thinning with distance from the source. The thickness of the mantle in southeastern New England is described as commonly ranging from 3 to 5 feet (Schafer and Hartshorn, 1965). Smith and Fraser (1935) recorded depths ranging from less than one foot to more than five feet. Jahns (1966) and Hartshorn (1967) also recorded thicknesses as great as five feet in the Greenfield and Taunton quadrangles. Smith and Fraser (1935) noted that the lower portion of the mantle is unweathered and is a dull gray color where the mantle is thickest.

Where the mantle is less extensive and thin, severe frost action following the last glaciation is thought to have mixed the thin mantle with the underlying material to form congeliturbate (Hartshorn, 1960, 1967). Thorough mixing with the underlying material is believed to have occurred where the mantle ranges from a few inches to about two feet in thickness; there the soil has taken on the general characteristics of the underlying material (Hartshorn, 1967). Smith and Fraser (1935) noted significant mixing or "dilution" of the windblown sediments with the underlying material where the mantle was thin enough (<18") to fall within the zone affected by soil-churning processes. Boulton and Dent

(1974) studied recently exposed till in Iceland and observed mixing of windblown sediments with the underlying material due to frost heaving. In less exposed vegetated areas, windblown fines were deposited and mixing was not as great.

Ventifacts, wind-abraded and polished stones, are more common to some parts of the Commonwealth than to others. Hartshorn (1976) observed an abundance of ventifacts in southeastern Massachusetts and attributed this to the type of rocks found in the area, noting that the local topography and early postglacial climate must have been conducive to wind work. He also stated that some fragments of every rock type found in the area were wind-abraded. Granite and volcanic rocks were more readily altered by wind abrasion, taking on a "cellophane-like" polish and having a fluted or pitted surface. Very few ventifacts were observed with the classic faceted form of a dreikanter (Hartshorn, 1967, 1976). In the Ware quadrangle, located in central Massachusetts, Mulholland (1974) recognized the presence of an eolian sand mantle over most of the quadrangle but observed no recognizable ventifacts and no wind-abraded bedrock.

Wind-abraded outcrops with flutes or other directional features are not common in New England. Hartshorn (1961), however, studied several outcrops in eastern Massachusetts, Rhode Island and eastern Connecticut. Eight outcrops were abraded by winds from the north or north-northeast and two outcrops indicated a northwest or west direction, characteristic of present wind directions.

Studies by Soil Scientists on the Windblown Soils in Massachusetts

Most of the studies conducted by soil scientists on windblown sediments in Massachusetts and Connecticut have been directed toward soils with distinct eolian mantles, located in the Central Lowland of Connecticut and Massachusetts (Swanson, Shearin, and Bourdeau, 1952; Colby, Light, and Bertinuson, 1953; Ritchie, 1955; Ritchie, Colby, Swanson, and Tamura, 1957; Tamura, Ritchie, Swanson, and Hanna, 1957). Colby, Light, and Bertinuson (1953) discussed the influence of windblown material throughout the Commonwealth and described it as being extensive and widespread but totally lacking in some places. They also stated that it is similar in general character irrespective of the underlying formation, its elevation, or the geographical region in which it is found.

Methods of study used in Massachusetts to identify windblown sediments included textural analysis and mineral analysis. Textural analysis was used in all studies as a method of identifying a windblown mantle. A very low content of coarse material (>2.0 mm), a high content of very fine sand and silt, and a relatively low proportion of clay typifies the windblown mantle found in Massachusetts (Colby, Light, and Bertinuson, 1953). Ritchie (1955) stated that silt is dominant in all of the profiles he studied and that coarse silt (0.05 - 0.02 mm) is dominant over both medium and fine silt (0.02-0 .002 mm).

Mineral analyses by Colby, Light, and Bertinuson (1953) show a uniformity of mineralogy throughout the depth of the mantle, with no significant variations in any important mineral constituent. Some degree of local control was noted in the different physiographic regions within the Commonwealth. Swanson, Shearin, and Bourbeau (1952) conducted mineralogical studies on both a Merrimac and Wethersfield soil profile and used the data to make inferences about the possible source areas of the sediments.

Ritchie (1955) stated that the eolian mantle conforms closely to the pre-depositional topography, filling in depressions and thinning on hill tops. It is thicker on the leeward side of slopes and in depressions, and the thicker and more continuous mantles are found on broad smooth uplands and wide flat terraces. Studies conducted within the Central Lowland of Connecticut and Massachusetts show a progressive thinning of the mantle from its source, the glaciolacustrine and fluvial deposits within the Central Lowland, eastward into the adjacent uplands (Ritchie, Colby, Swanson, and Tamura, 1957; Tamura, Ritchie, Swanson, and Hanna, 1957). A thinning eastward from 3 feet to 18 inches within 3 miles from the source was recorded by Ritchie (1955).

Mantle thicknesses ranging from 0 to 36 inches were noted by Colby, Light, and Bertinuson (1953). Ritchie (1955) described depths as much as 5 feet but found the mantle to be generally 3 feet or less. As the mantle thins, there is increased mixing with the underlying material, causing an increased resemblance, texturally, to the underlying material (Ritchie, 1955). Ritchie, Colby, Swanson, and Tamura (1957) noted that mixing of the underlying material with the mantle was evident in profiles developed in mantles less than 24 inches thick and was most severe in profiles where the mantle is less than 18 inches. A significant trend indicating an increase of particles greater than 2.0 mm, accompanied by higher amounts of sand particles, was evident in mantles as they became thinner (Ritchie, 1955). Tamura, Ritchie, Swanson, and Hanna (1957) recorded the presence of the unstable montorin within thin mantles where natural mixing has occurred and concluded that the mixing was recent, noting that acid soils do not favor the retention of montorin within the soil profile.

Frost action, tree throw, and animal activity have been described as causing most of the mixing within the soil profile. Tamura, Ritchie, Swanson, and Hanna (1957) state that the vegetation determines the depth of mixing and the rate of mixing, referring to tree throw. Stephens (1956) studied a one-acre plot in Harvard Forest and recorded that 14 percent of the surface area was occupied by pits and mounds generated from tree throws. Lyford and MacLean (1966) calculated that roughly half of the surface area of a study site in New Brunswick, Canada, was occupied by mound and pit microrelief and date most of the mounds back to at least as early as the late 1700's.

Lyford (personal communication, 1978) mentioned that movement of silt is possible downward through the soil profile and thought that this dispersion of silt throughout the profile could mask the presence of a thin windblown mantle.

Studies on soil in areas characterized as not having a thick, distinct windblown mantle vary, describing either a thorough mixing of an originally thin mantle with underlying sediments or a soil totally lacking any influence of windblown sediments. Stout (1952) described a loam layer characteristic of most of the soils in the Harvard Forest. The relative uniformity of the loam surface layer, contrasted to the variability of the underlying material, was striking and was interpreted as windblown in origin. Sand, gravel, and larger clasts were distributed throughout this surface layer and this heterogeneity was attributed to mixing with the underlying material.

A study of an 8-acre plot in Harvard Forest by Lyford, Goodlett, and Coates (1962) noted only small isolated pockets of silt at the base of a slope, which were interpreted as possible remnants of an eolian deposit. No silt deposits were observed on the long smooth upper slope nor was the solum any more silty than the underlying till.

Paxton soils in Worcester County were studied by Hill and Gonick (1963); the particle-size distribution of the Paxton profiles was typical of glacial till, showing very little textural change with depth.

In the Agricultural Experiment Station Publication, "Some Morphological, Physical and Chemical Properties of Selected Northeastern United States Soils" (Prince and Raney, 1961), chemical and physical data are listed on some soils in Plymouth, Franklin, and Hampshire Counties. Textural analysis of the soil profiles from this area show a higher concentration of silt in the solum, as opposed to a lower concentration in the substratum. Many of the previously mentioned papers noted a lack of textural profile development due to weathering and attributed finer surface textures to the incorporation of finer textured windblown sediments with the existing sediments. The higher silt content in the solum cannot be interpreted in all situations as the incorporation of windblown silts with the underlying substratum. Other geological and erosional processes could account for the higher silt contents in the solum, but it does suggest a possible wide occurrence of a windblown component in many soils in Massachusetts.

Presently, appreciable erosion or deposition of windblown sediments is confined to the coast and primarily to beach and dune areas. Wind activity inland is noticeable on some unvegetated areas, such as recently plowed fields, gravel pits, and construction sites. Erosion and deposition within these confined areas may be appreciable, but on a state-wide basis, present-day deposition of windblown sediments is thought to be insignificant.

Study of Quartz Sand Surface Textures with a Scanning Electron Microscope

The study of quartz sand surface textures to determine their mode of transport is relatively new and was greatly enhanced by the development and refinement of the scanning electron microscope. The first commercial model was developed in 1965 (Nixon, 1969). The SEM is capable of magnifications ranging from 10X to 100,000X with an average resolution of 50Å (Sandberg and Hay, 1968). The rapid change in magnification, broad depth of field, wide range in specimen positioning, and ease of location make the SEM very suitable for the study of quartz sand surface textures. Studies prior to the development of the SEM were made with a transmission electron microscope; in this technique, casts are made of the sand grain surfaces and examined.

The surface textures of quartz sand grains can be used to determine their mode of transport (Krinsley and Takahashi, 1962; Krinsley and Cavallero, 1970; MacKensie and Gees, 1971; Margolis and Krinsley, 1971; Krinsley and Doornkamp, 1973; Krinsley and Smalley, 1973; Whalley and Krinsley, 1974). The surface morphology of grains from known depositional environments has been studied and various surface features have been related to the different modes of transport. Some features are common to several depositional environments and the combination and abundance of surface features are used to make inferences about the processes involved in their deposition (Krinsley and Doornkamp, 1973). The variability of surface textures on sand grains within a deposit necessitate the study of a representative sample before a satisfactory determination of origin can be made. Krinsley and Doornkamp (1973) consider 15 to 20 grains selected at random to be adequate to study most of the variability present in a single sample. Depending upon the history of a grain, surface features common to different modes of transport may be superimposed upon one another (Margolis and Krinsley, 1971; Krinsley and Doornkamp, 1973). Surface textures of quartz sand grains are resistant to weathering; sediments deposited during the Triassic (Krinsley, Friend, and Klimentidis, 1976) and the Permo-Carboniferous Periods (Krinsley and Smalley, 1972) have been studied and their sedimentary environments determined.

Surface features of sand grains are described by their morphology and may be placed in two broad categories: those related to a mechanical origin and those related to a chemical origin (Margolis and Krinsley, 1974). To facilitate a better understanding of the terminology used in this method of study, individual surface features are described and related, where possible, to a probable genesis.

Features associated with a mechanical origin.

Conchoidal breakage or fracture. Krinsley and Doornkamp (1973,

p. 9) describe this surface feature as "curved irregular depressions or convex elevations which are commonly stepped in a series of shell-like ridges". Ideally they are dish-shaped, but may show varying degrees of irregularity (Margolis and Krinsley, 1974). There is a large variation in the size of conchoidal fractures (Krinsley and Cavallero, 1970). They are most common on large grains more than 500 microns in diameter (Margolis and Krinsley, 1974). Conchoidal fractures have been observed on sand grains from many sedimentary environments: glacial, turbulent subaqueous, eolian, and in laboratory experiments with mechanical fracturing (Margolis and Krinsley, 1971; Krinsley and Doornkamp, 1973; Margolis and Krinsley, 1974; Whalley and Krinsley, 1974). Arc-steps, parallel steps, and sub-parallel steps are terms used to describe the shell-like ridges mentioned above and are thought, in some instances, to relate to cleavage direction (Whalley and Krinsley, 1974).

Upturned plates. Upturned plates are parallel ridges that are irregular in height and oriented in one direction (Krinsley and Doornkamp, 1973; Margolis and Krinsley, 1974; Whalley and Krinsley, 1974). Impacts between large sand grains are thought to produce upturned plates on the fractured portions of the grain surfaces. Upturned plates range in surface relief from several microns to less than 0.1 micron (Margolis and Krinsley, 1974). These ridges are believed to be related to a specific crystallographic direction in the grain (Krinsley and Cavallero, 1970; Margolis and Krinsley, 1971; Krinsley and Doornkamp, 1973; Margolis and Krinsley, 1974). Margolis and Krinsley (1971) refer to these as upturned cleavage plates and state that they may be continuous or discontinuous. They may be jagged or smooth, depending upon silica solution and precipitation (Krinsley and Smalley, 1973; Margolis and Krinsley, 1974). Upturned plates are concentrated on the edges of grains and are not common to depressions (Margolis and Krinsley, 1974).

In a recent paper, Nieter and Krinsley (1976) produced upturned plates on sand-size quartz particles by abrading them with silt-size quartz particles. Krinsley and Takahashi (1962) produced upturned plates on crushed quartz in a wind machine. Willard (1969) observed parallel cleavage plates on quartz that had been fractured by point-loading in a compressive device. Micro-block texture is a term used by Whalley and Krinsley (1974) and is thought to be related to an upturned plate structure that developed in imperfect quartz cleavage.

Flat cleavage surfaces. Krinsley and Doornkamp (1973) state that these are extremely flat areas formed by cleavages parallel to the V and Z faces of quartz and are commonly found on grains of less than 200 microns. Brittle fracture is believed to be predominant in grains greater than about 500 microns, and as the grain decreases in size fracture along cleavage planes becomes more pronounced (Margolis and Krinsley, 1974). Where these flat surfaces meet an edge, there is generally a series of parallel plates (Krinsley and Doornkamp, 1973).

Dish-shaped concavities. Krinsley and Doornkamp (1973) described these as conchoidal chips broken from the surface of eolian sand grains. They are believed to be the result of a single collision during a period of strong winds. Nieter and Krinsley (1976) observed dish-shaped concavities on desert sand surfaces and not on loessial sand surfaces, and concluded that this feature may be a distinguishing characteristic between the two deposits.

Mechanical V-forms. Krinsley and Doornkamp (1973, p. 15) describe these as "V-shaped mechanical depressions that are three-sided, narrowing toward the grain surface; they are chipped into surface expressions of the underlying plate edges." Their size, depth, and density of distribution seem to be related to the energy of the environment in which they were formed (Margolis and Kennett, 1971; Krinsley and Doornkamp, 1973). This surface feature is believed to originate from grain-to-grain collisions (Margolis and Krinsley, 1974) and is characteristic of subaqueous abrasion (Margolis and Kennett, 1971; Krinsley and Doornkamp, 1973).

Straight or slightly curved grooves. Straight or slightly curved grooves are surface features that are commonly associated with mechanical V-forms. The grooves are generally less than 25 microns in length and average about 1 to 5 microns in width. They are generally observed on grains larger than 400 microns in diameter (Margolis and Krinsley, 1974). Straight or slightly curved grooves are believed to form in high-energy subaqueous environments and are seldom observed on grains from other depositional environments. It is felt that they form at higher energies than those associated with mechanical V-forms (Margolis and Krinsley, 1974).

Features associated with chemical origin. Margolis and Krinsley (1971) state that chemical features can be found in varying degrees on quartz grains from every environment. Mechanical features may be modified or obliterated by chemical action, leaving the grain surface as either a smooth featureless plane or an irregular etched surface (Margolis and Krinsley, 1974). Moulds indicating the presence of former interpenetrated minerals have been observed in some quartz grain surfaces by Krinsley and Doornkamp (1973).

Due to the complexity and variations of chemical features, only those features which are thought to occur in the study area are described.

Precipitation platelets. Precipitation platelets are one of the earlier phases of silica deposition and are believed to be small areas of redeposited silica on cleavage surfaces. They may also form when small cleavage flakes are cemented to the grain surface by amorphous silica (Whalley and Krinsley, 1974).

Carapace. Whalley and Krinsley (1974, p. 89) describe this surface feature as an "adhering mixture of fragments (usually comminution debris of various kinds) which form a very uneven cover to a grain". Smalley and Cabrera (1970) described adherent material that was observed on the surface of loess particles.

Dissolution and precipitation. Silica dissolution and precipitation can come about in almost any natural environment where very small particles of quartz are present. These particles are extremely reactive and tend to go partly into solution (Smalley, Krinsley, and Vita-Finzi, 1973; Margolis and Krinsley, 1974). Fournier (1960) and Sievers (1962) discuss abrasion solution where abnormally high concentrations of silica were obtained by mechanical abrasion of quartz grains. Once saturation is reached, quartz growth takes place. Krinsley and Smalley (1972) state that abrasion and dissolution/precipitation proceed almost simultaneously.

Precipitation of silica generally smooths the grain surface (Krinsley and Doornkamp, 1973; Smalley, Krinsley, and Vita-Finzi, 1973; Krinsley, Friend, and Klimentidis, 1976). In the later stages of silica precipitation, sharp grain edges may be blunted with deposited silica (Margolis and Krinsley, 1974).

Layered/stepped structure. This feature is similar to upturned plates and is believed to have formed where chemical action was concentrated along traces of cleavage planes (Smalley, Krinsley and Vitz-Finzi, 1973; Margolis and Krinsley, 1974). Upturned plates that are rounded due to solution are difficult to distinguish from these features (Margolis and Krinsley, 1974).

Oriented V-shapes. Grains immersed in sea water for long periods frequently have oriented V-shaped pits (Krinsley and Doornkamp, 1973). Chemical etching by sea water is thought to cause this surface feature (Krinsley and Margolis, 1968). When observed in planar view, these features closely approximate the shape of an isosceles triangle, the angles of which coincide with the angles measured on the prism faces of quartz (Margolis, 1968). Oriented V-shapes occur in sets and range in size from <1 mm to 1,000 mm in diameter (Krinsley and Doornkamp, 1973).

Surface morphology of quartz sand grains associated with wind transport.

The time spent in an active eolian environment, the intensity of the winds, the size of the grain, and the previous history of the grain govern the surface features found on a grain (Krinsley and Cavallero, 1970; Margolis and Krinsley, 1971; Krinsley and Doornkamp, 1973). Sand grains from glacial and periglacial eolian environments are highly variable and generally exhibit eolian surface features superimposed on glacial and glaciofluvial features (Krinsley and Cavallero, 1970; Margolis and Krinsley, 1971). Periglacial eolian sand grains from Long

Island, studied by Krinsley and Cavallero (1970), exhibit eolian features on 90 percent of the grains with 2 to 100 percent of the grain surface being affected.

The mode of wind transport greatly influences the surface morphology of a grain. Larger grains moved by saltation, are characterized by upturned plates, grain rounding (Krinsley and Cavallero, 1970; Margolis and Krinsley, 1971, 1974), and dish-shaped concavities (Krinsley and Doornkamp, 1973). Impacts between large sand grains are thought to produce upturned plates on the fractured portions of grains. Dish-shaped concavities are probably formed during periods of violent abrasion and represent conchoidal chips which have been broken from the surface by a single mechanical event (Krinsley and Doornkamp, 1973). Margolis and Krinsley (1974) observed upturned plates only on the edges of the smaller grains.

Krinsley and Takahashi (1962) abraded crushed quartz in a wind machine. Upturned plates were observed on the edges of abraded grains and were absent in depressions. With time, the grain progressively became more rounded and became nearly perfect spheres.

Precipitation on upturned plates is one of the first stages in silica deposition (Whalley and Krinsley, 1974) and should be evident on some grains. Solution and precipitation are not believed to have a pronounced effect on the surface morphology of sand grains found in the study areas. Particles adhering to the grain surface have been described by Krinsley and Doornkamp (1973) and Smalley and Cabrera (1970).

Surface morphology of quartz sand grains associated with glacial deposition.

Krinsley and Doornkamp (1973) describe quartz sand grains deposited by glacial ice as being very angular, with edges and corners that may be "razor" sharp. All references to glacial ice deposition noted conchoidal fractures on glacially derived grains (Krinsley and Doornkamp, 1973; Margolis and Krinsley, 1974; Whalley and Krinsley, 1974). Conchoidal fracture was most common on larger grains (more than 500 microns), while smaller grains were characterized by flat cleavage surfaces and upturned plates on the grain edges (Krinsley and Doornkamp, 1973).

Whalley and Krinsley (1974) studied glacial sand grains from different positions within the glacier: from superglacial, englacial, and subglacial environments. The variation in surface textures was great, and it was impossible to relate surface morphology to a particular position in the glacier. However, the frequency of fracture textures possibly may be used to distinguish grains that have not been subglacially ground from those that have.

Chemical features that may occur in these sediments include precipitation platelets, carapace, and solution and precipitation (Whalley and Krinsley, 1974).

Surface morphology of quartz sand grains associated with subaqueous deposition. Subaqueous deposition refers to sediments that were abraded and deposited by water, with no distinction between marine and non-marine environments (Krinsley and Doornkamp, 1973). The surface morphology of these subaqueous sediments is governed by the size of the grain and the energy of the environment in which the sediments were deposited (Krinsley and Doornkamp, 1973).

Grains greater than 500 microns generally are irregular in shape and have rounded edges (Krinsley and Doornkamp, 1973; Margolis and Krinsley, 1974). The combination of solution and abrasion is believed to polish sand grains (Margolis and Krinsley, 1971). The most common diagnostic surface feature of subaqueous sediments is the mechanical V-form (Krinsley and Margolis, 1968; Margolis and Kennett, 1971). Straight and curved grooves are also found on subaqueous sediments and are characteristic of high-energy environments (Krinsley and Margolis, 1973; Margolis and Krinsley, 1974). Margolis (1968) observed oriented etch pits on quartz sand grains and associated them with salt-water solution.

SURFACE FEATURE	DEPOSITIONAL ENVIRONMENT		
	GLACIAL	SUBAQUEOUS	EOLIAN
GRAIN SHAPE	Extremely angular, sharp corners and edges.	Irregular in shape, with rounded edges.	Well rounded, without edges.
CONCHOIDAL BREAKAGE	Usually present.	Seldom present.	Seldom present.
UPTURNED PLATES	Generally present, occurring on edges.	Generally present.	Usually present, often occurring on most of the surface.
FLAT CLEAVAGE SURFACES	Usually present.	Seldom present.	Seldom present.
DISH-SHAPED CONCAVITIES	Not present.	Not present.	Usually present.
ORIENTED ETCH PITS	Not present.	Generally present (only associated with sea water).	Not present.
MECHANICAL V-FORMS	Not present.	Generally present (associated with high energy environments).	Not present.

Table 1. Surface features associated with large (>0.2 mm) quartz sand grains deposited within one depositional environment. The descriptive terms usually, generally, seldom and not present refer to the percentage of grains observed with a particular surface feature: usually 80 percent, generally 20 to 80 percent, seldom 0 to 20 percent, not rarely observed.

CHAPTER II

METHODS OF STUDY

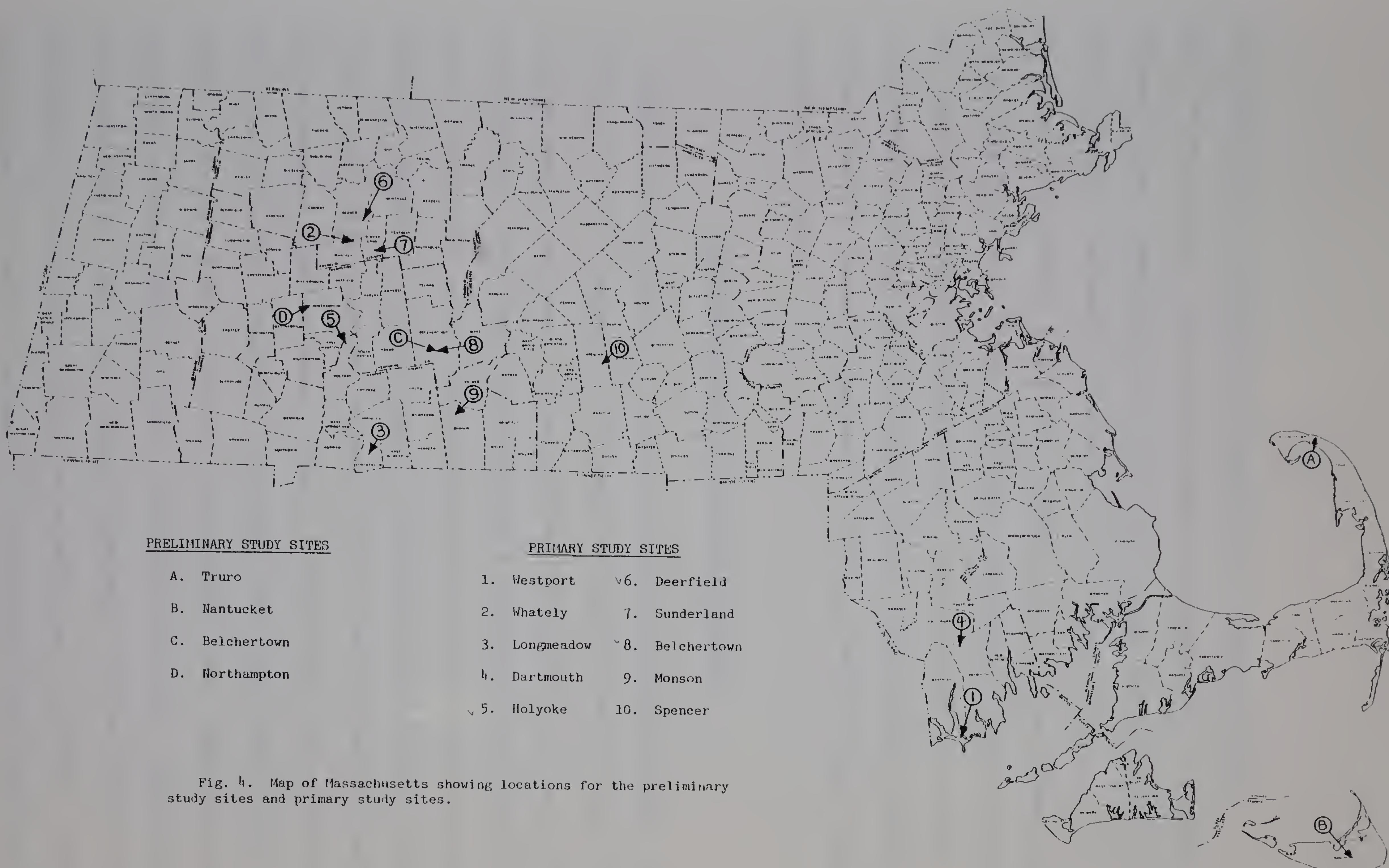
General Procedure

Preliminary studies were conducted using the scanning electron microscope on four representative samples from known depositional environments. Sediments sampled included coastal dune sand, eolian mantle sediments, upper till, and lower till (Schafer and Hartshorn, 1965; Pessel, 1966). The results from these preliminary studies were used to give the author a more complete understanding of the sand-grain surface features described in readings and a working knowledge of the scanning electron microscope.

Ten primary study sites were selected in Massachusetts. These were located throughout the Commonwealth (Fig. 4.) and varied in soil profile development, parent material, and position on the landscape. Soil profile descriptions were written for each study site and a two-pound bag sample was taken from selected horizons for grain-size analysis and scanning electron microscope studies.

Grain-Size Analysis

Grain-size analyses were performed using a modification (Mulholland, 1974) of the A.S.T.M. "Standard Method for Particle-size Analysis of Soils" (A.S.T.M., 1971). Clasts coarser than -2.5ϕ (5.66 mm) were removed from the entire sample by sieving. Material less than -2.5ϕ (5.66 mm) was disaggregated and split to obtain a subsample of appropriate size, 80 to 100 grams. Subsamples were placed in a calgon solution



PRELIMINARY STUDY SITES

A. Truro

B. Nantucket

C. Belchertown

D. Northampton

PRIMARY STUDY SITES

1. Westport
2. Whately
3. Longmeadow
4. Dartmouth
5. Holyoke
6. Deerfield
7. Sunderland
8. Belchertown
9. Monson
10. Spencer

Fig. 4. Map of Massachusetts showing locations for the preliminary study sites and primary study sites.

(2.55 grams/liter) overnight and then mixed in a Hamilton Beach mixer for one minute. The dispersed sample was washed on a 4 ϕ sieve (230-mesh sieve), passing the silt and clay through the sieve into a 1-liter cylinder. The sands collected on the 4ϕ sieve (230-mesh sieve) were dried and sieved at a ½-ϕ mesh interval [-2.0 ϕ sieve (5-mesh sieve) to 4 ϕ sieve (230-mesh) sizes]. The size distribution of the silt and clay fraction was measured by hydrometer. The results of the sieving and hydrometer analysis were processed with the aid of an APL computer program (Robert M. Newton, Department of Geology, Smith College, personal communication, 1977).

Scanning Electron Microscope Studies

Samples were prepared for scanning electron microscope studies using a modification of a procedure established by Krinsley and Doornkamp (1973). A 10-gram sample was placed in concentrated hydrochloric acid and boiled for ten minutes. The sample was then washed thoroughly with distilled water. The clay and part of the silt-size fraction were removed by agitating the sample in a 250-ml beaker of distilled water and then pouring off the liquid plus suspended sediments after a 2-minute settling period. This process was repeated several times. The sand plus silt fraction was then dried and sieved, separating the sample into three particle-size groups: 2 mm to 0.5 mm, 0.5 mm to 0.1 mm, and $<$0.1 mm. Each particle-size group was then examined under a binocular microscope. Quartz grains were identified by their clear, glassy appearance. Fifteen grains from each sample, five from each particle-size group, were selected at random and positioned on a metal specimen plug coated with double sticky tape.

The plug was then positioned in a standard vacuum evaporator with a table that rotated on an eccentric, and gold was evaporated upon the specimen. The specimen was then examined using the scanning electron microscope.

CHAPTER III

RESULTS

Westport Study Site: Soil Profile Description

Soil Type:	Udipsamments, hilly.
Classification:	Udipsamments.
Location:	Town of Westport, Bristol County, Massachusetts. Thirty feet north of John Reed Road at a point 0.9 mile northwest from the intersection of John Reed Road and East Beach Road. Longitude W. 71° 02' 27" Latitude N. 41° 30' 27" Location map (Fig. 5.)
Land Use and Vegetation:	Wooded area - scrub oak, pitch pine, and beach grass.
Physiography:	Coastal sand dune.
Regolith:	Windblown sands.

Horizon	Depth (inches)	Description
A1	0-7	Pale brown (10YR 6/3) fine sand; single grain; loose; few fine roots; clear wavy boundary.
C	7-60	Light gray (5Y 7/1) fine sand; single grain; loose. Sample sieved (Table 2.) and cumulative

Horizon	Depth (inches)	Description
		curve (Fig. 6.) plotted.

Fig. 5. Location of Westport study site. Westport quadrangle map, Massachusetts - Rhode Island, 7.5-minute series (topographic).

WESTPORT STUDY SITE

Particle Size (In Millimeters)	Soil Horizons (Individual Weight Percents)
	C
4.00	0.00
2.83	0.00
2.00	0.00
1.41	0.00
1.00	0.02
0.71	0.03
0.50	0.02
0.35	0.22
0.25	6.08
0.177	49.23
0.125	41.82
0.088	2.80
0.0625	0.11
	100.33

Table 2. Mechanical analysis of samples collected at the Westport study site.

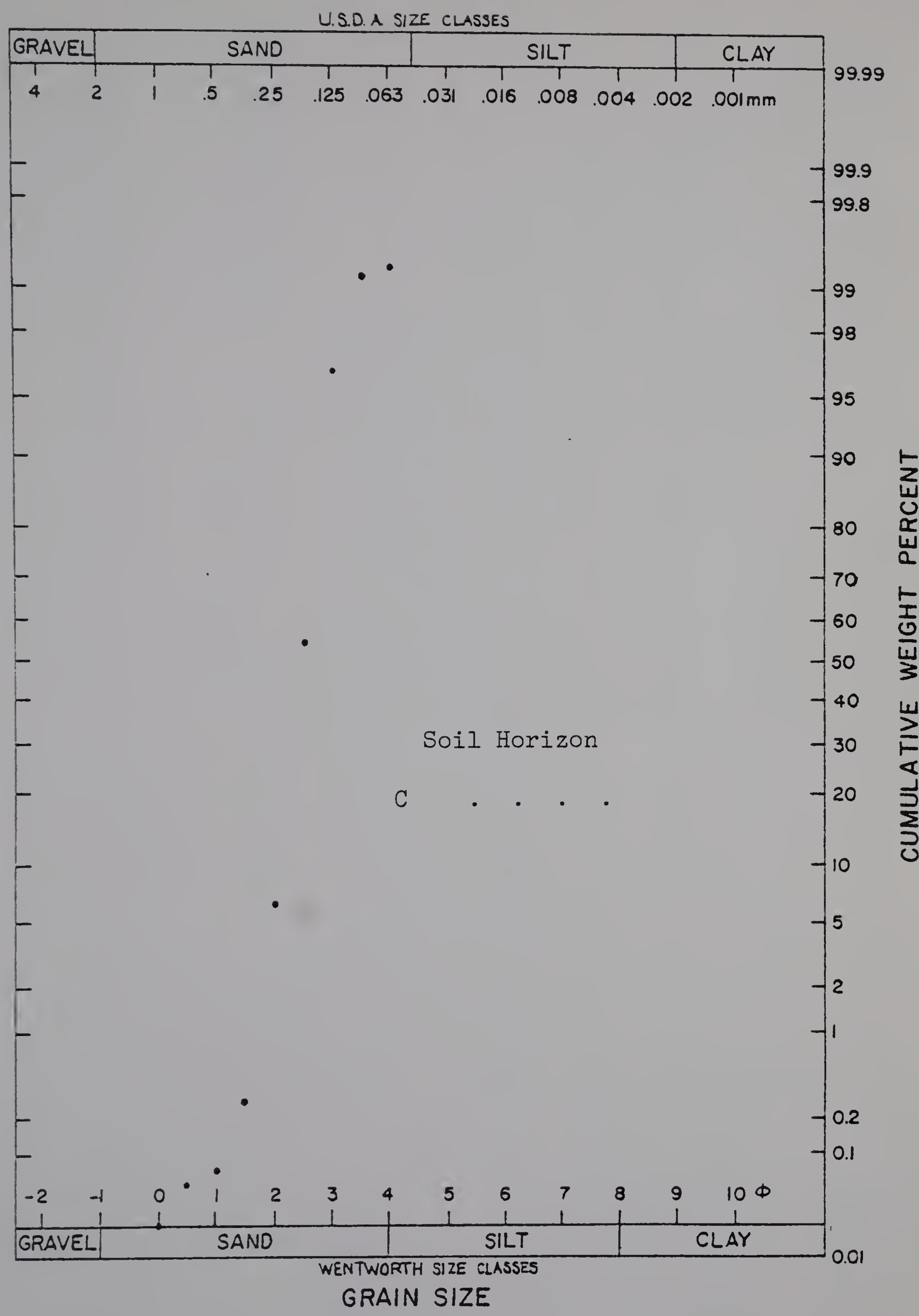


Fig. 6. Cumulative curve of sample collected at the Westport study site.

Table 3. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the C horizon at the Westport study site.

*The descriptive terms few, common, and many refer to the percentage of grains observed with a particular surface feature: few $<$20 percent of the grains, common 20 to 80 percent of the grains, many 80 to 100 percent of the grains.

STUDY SITE Westport | HORIZON STUDIED C

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Sample was not examined.

Medium and fine sand grains: Most grains are subrounded or rounded. Features associated with mechanical origin are confined to certain portions of grains. Chemical weathering seemed to predominate in other areas on grain surfaces.

Very fine sand and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 - 0.5 mm. dia.	0.5 - 0.1 mm. dia.	0.1 - 0.05 mm. dia.
CONCHOIDAL BREAKAGE			
UPTURNED PLATES		Common*- confined to certain portions of the grain.	
FLAT CLEAVAGE SURFACES			
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS			
CARAPACE			
SOLUTION PITS		Common	
SOLUTION/PRECIPITATION		Many - masked other features	
ORIENTED ETCH PITS		Common	

Whately Study Site: Soil Profile Description

Soil Type:	Windsor fine sand.
Classification:	Mixed mesic Typic Udipsamments.
	Note: The soil described at this site is a taxadjunct of the Windsor soil series because the color of the A1 horizon is not within the range in characteristics for the standard series description.
Location:	Town of Whately, Franklin County, Massachusett. Two hundred feet east of Plain Road at a point 0.3 mile southeast from the intersection of Route 116 and Plain Road.
	Longitude W. 72° 20' 54"
	Latitude N. 42° 8' 23"
	Location map (Fig. 7.)
Land Use and Vegetation:	Sand dune with blowouts and stabilized areas of grass.
Physiography:	Postglacial sand dune that is presently active due to the destruction of the protective vegetative cover by human traffic.
Regolith:	Windblown sands.

Horizon	Depth (inches)	Description
A1	0-10	Dark yellowish brown (10YR 4/4) fine sand; single grain; loose, abrupt wavy boundary.

Horizon	Depth (inches)	Description
C	10-25	Light olive brown (2.5YR 5/4) fine sand; brown (10YR 5/3) thin discontinuous bands, thought to be organic stains; single grain; loose; abrupt wavy boundary. Sample sieved (Table 4.) and cumulative curve (Fig. 8.) plotted.
B2b	25-41	Yellowish brown (10YR 5/6) fine sand; single grain; gradual wavy boundary.
Cb	41-48	Light yellowish brown (2.5Y 6/4) fine sand; single grain; loose. Sample sieved (Table 4.) and cumulative curve (Fig. 8.) plotted.

Fig. 7. Location of Whately study site. Mt. Toby quadrangle map, Massachusetts, 7.5-minute series (topographic).

WHATELY STUDY SITE

Particle Size (In Millimeters)	Soil Horizons (Individual Weight Percents)		
	C	B2b	Cb
4.00	0.00	0.00	0.00
2.83	0.00	0.00	0.00
2.00	0.02	0.00	0.01
1.41	0.01	0.02	0.02
1.00	0.05	0.06	0.04
0.71	0.11	0.11	0.13
0.50	0.15	0.20	0.29
0.35	1.13	0.95	1.59
0.25	6.73	5.44	8.13
0.177	29.67	25.31	29.66
0.125	40.95	38.28	36.29
0.088	15.02	16.35	14.08
0.0625	3.73	5.77	4.93
0.077	0.37	1.70	0.82
0.054	0.18	0.87	0.50
0.038	0.09	0.10	0.50
0.027	0.63	0.48	0.50
0.019	0.09	0.97	0.50
0.014	0.09	0.48	0.20
0.010	0.09	0.48	0.30
0.0070	0.27	0.10	0.10
0.0050	0.09	0.39	0.10
0.0035	0.09	0.19	0.10
0.0025	0.09	0.10	0.20
0.0018	0.09	0.10	0.10
0.0014	0.09	0.19	0.10
0.0010	0.18	1.36	0.36
<0.0010	0.00	0.00	0.50
	100.01	100.00	100.05

Table 4. Mechanical analysis of samples collected at the Whately study site.

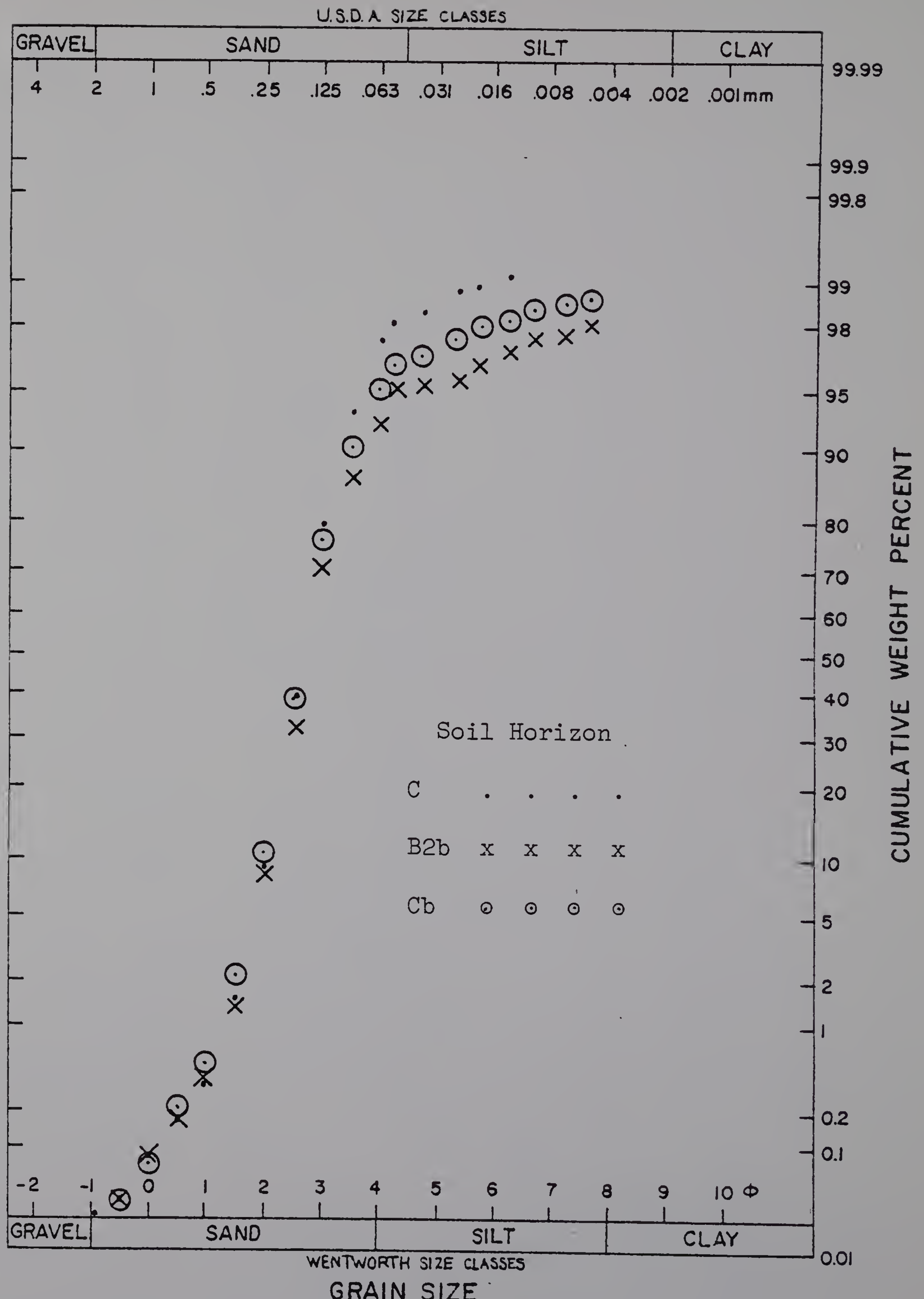


Fig. 8. Cumulative curves of sample collected at the Whately study site.

Table 5. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the Cb horizon at the Whately study site.

STUDY SITE Whately | HORIZON STUDIED Cb

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains are subrounded or rounded in shape. Surface features appear clear and distinct. Edges and corners of grains are chipped.

Medium and fine sand grains: Most grains are subrounded or rounded in shape. Surface features appear clear and distinct. Edges and corners of grains are chipped.

Very fine sand and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 – 0.5 mm. dia.	0.5 – 0.1 mm. dia.	0.1 – 0.05 mm. dia.
CONCHOIDAL BREAKAGE	Common - parallel steps are common.	Common - parallel steps are common.	
UPTURNED PLATES	Many - abundant on rounded grains.	Many - abundant on rounded grains.	
FLAT CLEAVAGE SURFACES			
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Common.	Common.	
CARAPACE	Few.	Common.	

Longmeadow Study Site: Soil Profile Description

Soil Type:	Windsor loamy sand.
Classification:	Mixed mesic Typic Udipsamments. Note: Unusual profile horizon sequence is due to the recent deposition of windblown sediments, C horizon. The source for these sediments is believed to have been an excavated sand pit adjacent to the study site.
Location:	Town of Longmeadow, Hampden County, Massachusetts. Six hundred feet north of Bliss Road at a point 0.3 mile west from the intersection of Bliss Road and Williams Street. Longitude W. 72° 33' 34" Latitude N. 42° 03' 28" Location map (Fig. 9.)
Land Use and Vegetation:	Wooded area - lowbush blueberry, red oak, red maple, and gray birch.
Physiography:	Postglacial sand dune.
Regolith:	Windblown sand.

Horizon	Depth (inches)	Description
O1	1½-0	Non-decomposed organic matter.
C	0-2	Light yellowish brown (2.5Y 6/4) sand; single grain; loose; abrupt wavy boundary.
O1b	2-3	Non-decomposed organic matter.

Horizon	Depth (inches)	Description
Alb	3-6	Dark brown (10YR 3/3) loamy sand; weak fine and medium granular structure; very friable; clear smooth boundary.
B21b	6-11	Dark yellowish brown (10YR 4/4) sand; single grain; loose; gradual wavy boundary.
B22b	11-26	Yellowish brown (20YR 5/6) sand; single grain; loose; gradual wavy boundary. Sample sieved (Table 6.) and cumulative curve (Fig. 10.) plotted.
Cb	26-48	Light yellowish brown (2.5Y 6/4) sand; loose. Sample sieved (Table 6.) and cumulative curve (Fig. 10.) plotted.

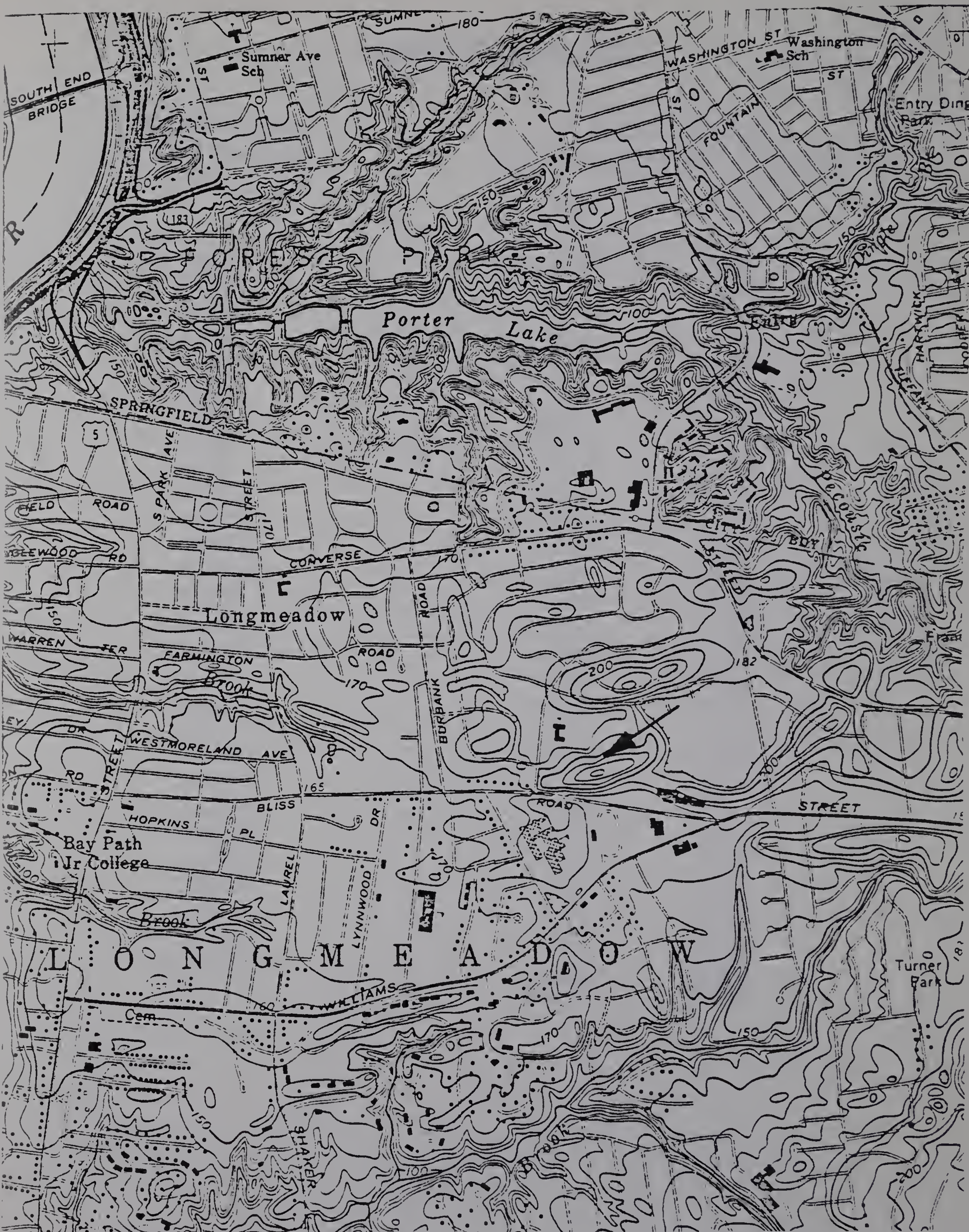


Fig. 9. Location of Longmeadow study site. Springfield South quadrangle map, Massachusetts, 7.5-minute series (topographic).

LONGMEADOW STUDY SITE

Particle Size (In Millimeters)	Soil Horizons (Individual Weight Percents)	
	B22b	Cb
4.0	0.00	0.00
2.83	0.07	0.00
2.00	0.14	0.11
1.41	0.36	0.49
1.00	1.57	2.95
0.71	5.30	8.84
0.50	11.09	14.05
0.35	22.85	24.76
0.25	17.53	19.08
0.177	12.46	12.11
0.125	9.02	7.03
0.088	6.17	4.26
0.0625	5.13	0.41
0.076	2.17	2.58
0.054	0.51	1.11
0.038	0.51	0.33
0.027	0.82	0.11
0.019	0.20	0.11
0.014	0.20	0.11
0.0099	0.72	0.22
0.0070	0.10	0.11
0.0049	0.51	0.11
0.0035	0.31	0.11
0.0025	0.10	0.11
0.0018	0.10	0.11
0.0014	0.20	0.11
0.0010	0.61	0.67
<0.0010	1.23	0.00
	99.98	99.99

Table 6. Mechanical analysis of samples collected at the Longmeadow study site.

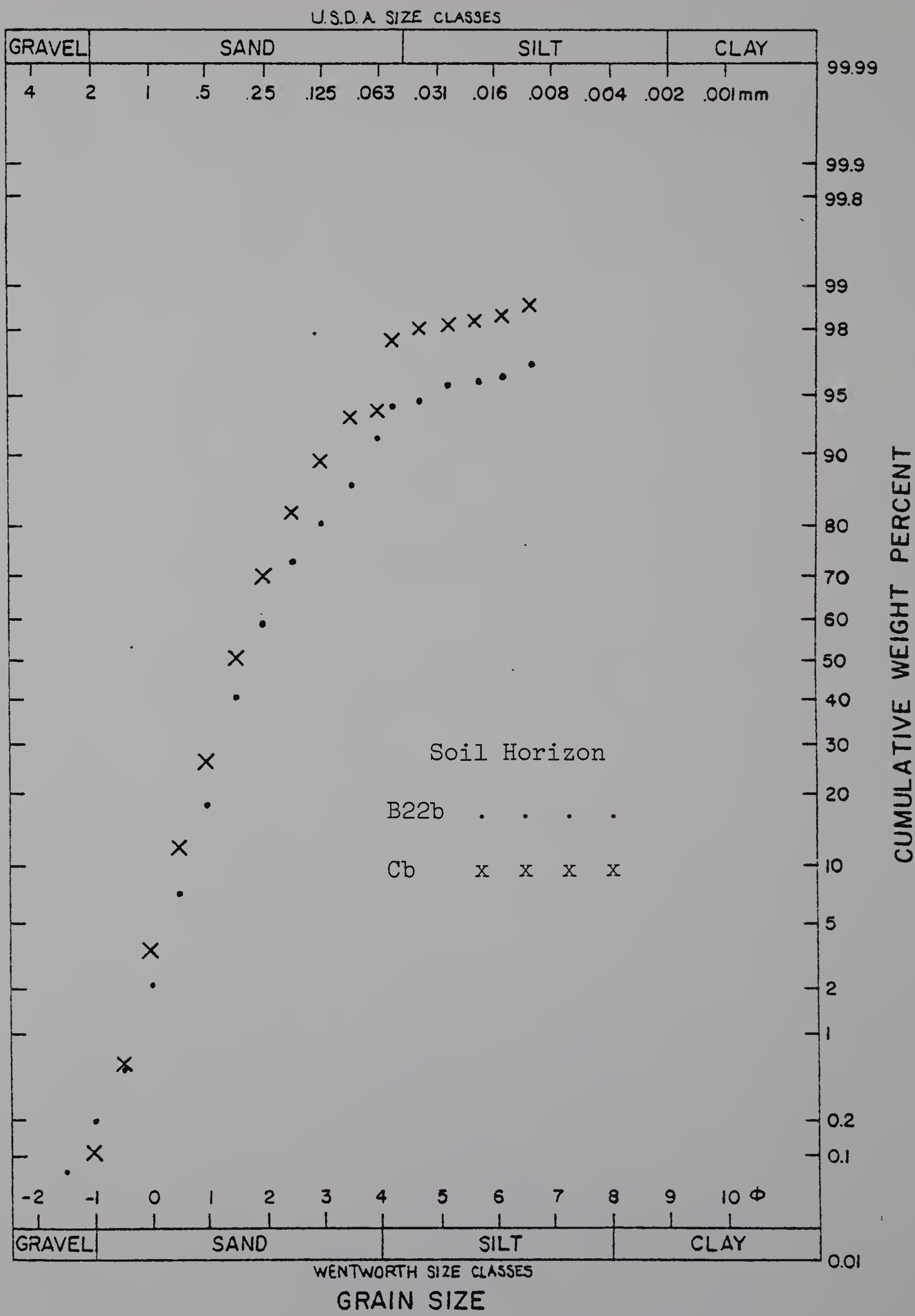


Fig. 10. Cumulative curves of samples collected at the Longmeadow study site.

Table 7. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the Cb horizon at the Longmeadow study site.

STUDY SITE Longmeadow | HORIZON STUDIED Cb

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains are subrounded in shape.
Medium and fine sand grains: Most grains are subrounded in shape, no grains were rounded.
Very fine sand and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 - 0.5 mm. dia.	0.5 - 0.1 mm. dia.	0.1 - 0.05 mm. dia.
CONCHOIDAL BREAKAGE	Few.	Common.	
UPTURNED PLATES	Many - abundant on many grain surfaces.	Many - abundant on many grain surfaces.	
FLAT CLEAVAGE SURFACES			
DISH-SHAPED CONCAVITES	Common.		
PRECIPITATION PLATELETS	Common.	Common.	
CARAPACE			
SOLUTION/PRECIPITATION SMOOTHING	Common - evident on upturned plates.	Common - evident on upturned plates.	

Dartmouth Study Site: Soil Profile Description

Soil Type:	Broadbrook extremely stony very fine sandy loam.
Classification:	Coarse - loamy, mixed, mesic Typic Fragiochrepts.
	Note: The soil described at this site is a taxadjunct of the Broadbrook soil series because the depth to the lithologic discontinuity is too deep and the colors of the A1, A2, B21h, and B23 soil horizons are not within the range in characteristics for the standard soil series description.
Location:	Town of Dartmouth, Bristol County, Massachusetts. Eight hundred feet southwest from the intersection of Albro Avenue and Yellow Hill Road, in a road bank just east of Albro Avenue.
	Longitude W. 71° 02' 49"
	Latitude N. 41° 41' 31"
	Location map (Fig. 11.)
Land Use and Vegetation:	Cut-over area - partridge-berry, sweet fern, lowbush blueberry, scrub oak.
Physiography:	Ground moraine.
Regolith:	Eolian mantle over compact till.

Horizon	Depth (inches)	Description
01	1½-1	Non-decomposed organic matter.
02	1-0	Decomposed organic matter.
A1	0-1	Black (10YR 2/1) loam; weak medium granular structure; very friable; many medium roots; abrupt smooth boundary.
A2	1-1½	Grayish brown (10YR 5/2) loam; massive; very friable; medium roots; abrupt broken boundary.
B21h	1½-2½	Dark brown (10YR 4/3) loam; massive; very friable; many medium roots; clear irregular boundary.
B22	2½-17	Yellowish brown (10YR 5/6) loam; massive; friable; common large roots; gradual wavy boundary. Sample sieved (Table 8.) and cumulative curve (Fig. 12.) plotted.
B23	17-34	Light yellowish brown (2.5Y 6/4) very fine sandy loam; massive; friable; few medium roots; diffuse wavy boundary. Sample sieved (Table 8.) and cumulative curve (Fig. 12.) plotted.
C	34-51	Light olive brown (2.5Y 5/4) very fine sandy loam; common fine distinct yellowish red (5YR 5/6) and light yellowish brown (2.5Y 6/4) mottles; massive; friable; few medium

Horizon	Depth (inches)	Description
		roots; abrupt irregular boundary.
IIC_x	51-60	Light brownish gray (2.5Y 6/2) gravelly fine sandy loam; massive; firm; silt caps are common on the upper surface of coarse fragments and sand beds beneath coarse fragments; vesicular pores were also observed. Sample sieved (Table 8.) and cumulative curve (Fig. 12.) plotted.

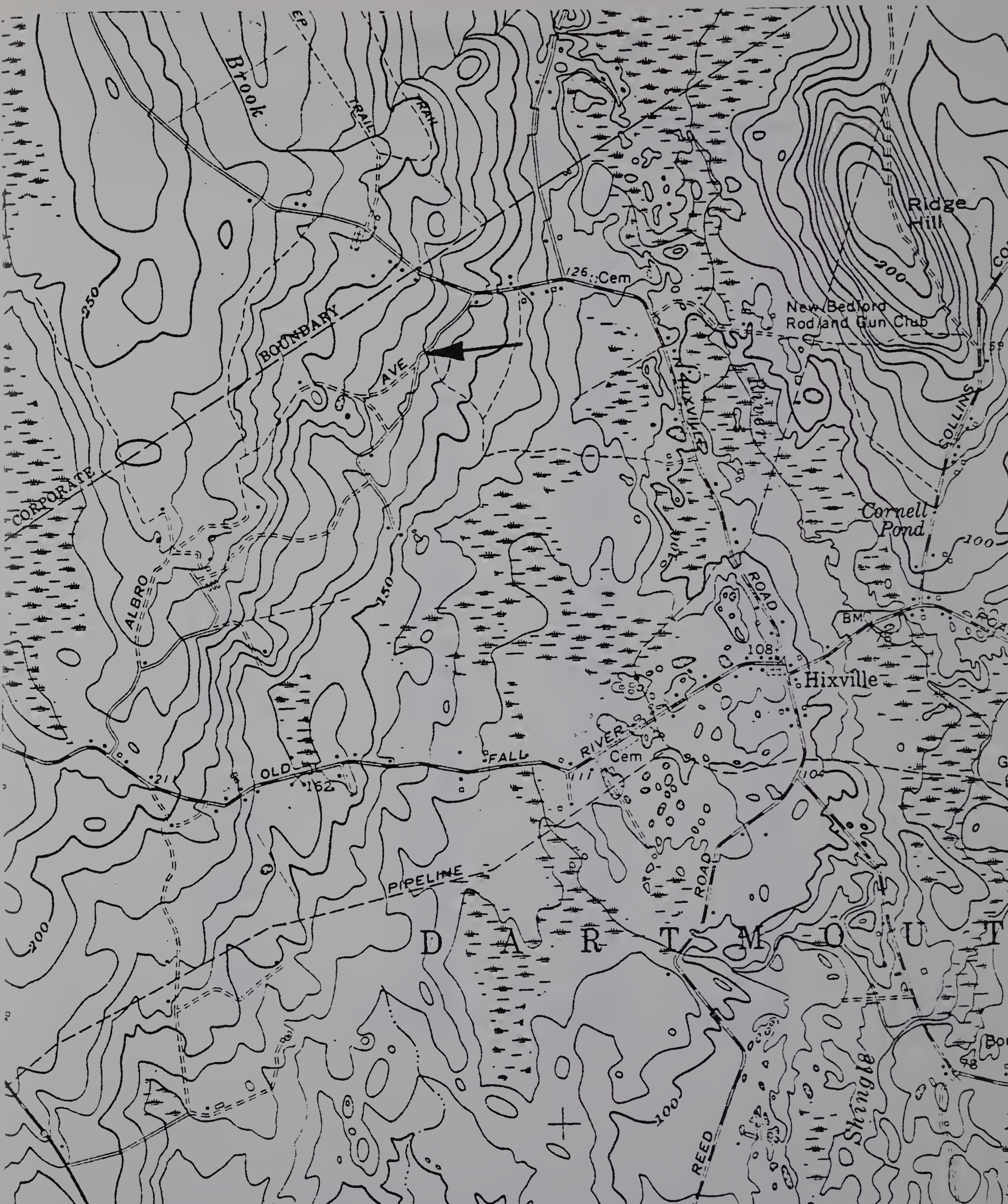


Fig. 11. Location of Dartmouth study site. Fall River East quadrangle map, Massachusetts, 7.5-minute series (topographic).

DARTMOUTH STUDY SITE

Particle Size (In Millimeters)	Soil Horizons (Individual Weight Percents)			
	B22	B23	C	IIC_x
4.00	1.55	0.71	0.00	2.07
2.83	0.79	0.38	0.09	2.07
2.00	1.39	0.83	0.01	3.88
1.41	1.00	0.46	0.03	2.96
1.00	1.38	0.51	0.10	3.43
0.71	1.49	0.64	0.06	3.76
0.50	1.35	0.62	0.06	3.22
0.35	2.02	1.15	0.21	4.28
0.25	2.23	1.59	0.44	3.74
0.177	3.04	2.57	1.05	3.90
0.125	4.26	3.99	3.16	4.23
0.088	5.89	6.07	8.59	4.28
0.0625	11.98	14.66	26.79	6.91
0.056	10.32	12.14	16.33	6.22
0.042	8.92	10.95	14.36	6.63
0.032	10.04	12.05	12.31	7.95
0.024	5.58	7.67	7.18	7.95
0.017	5.58	4.93	3.08	6.63
0.013	3.35	3.29	0.51	3.98
0.0092	2.79	3.29	1.54	3.98
0.0066	2.79	1.64	0.82	1.33
0.0047	2.23	1.64	0.21	2.65
0.0034	1.67	2.74	1.03	0.66
0.0024	1.12	1.10	0.51	0.53
0.0017	0.11	0.22	0.10	0.13
0.0014	0.45	0.66	0.10	0.13
0.0010	1.12	0.22	0.31	1.86
<0.0010	5.58	3.29	1.03	0.66
	100.02	100.01	100.01	100.02

Table 8. Mechanical analysis of samples collected at the Dartmouth study site.

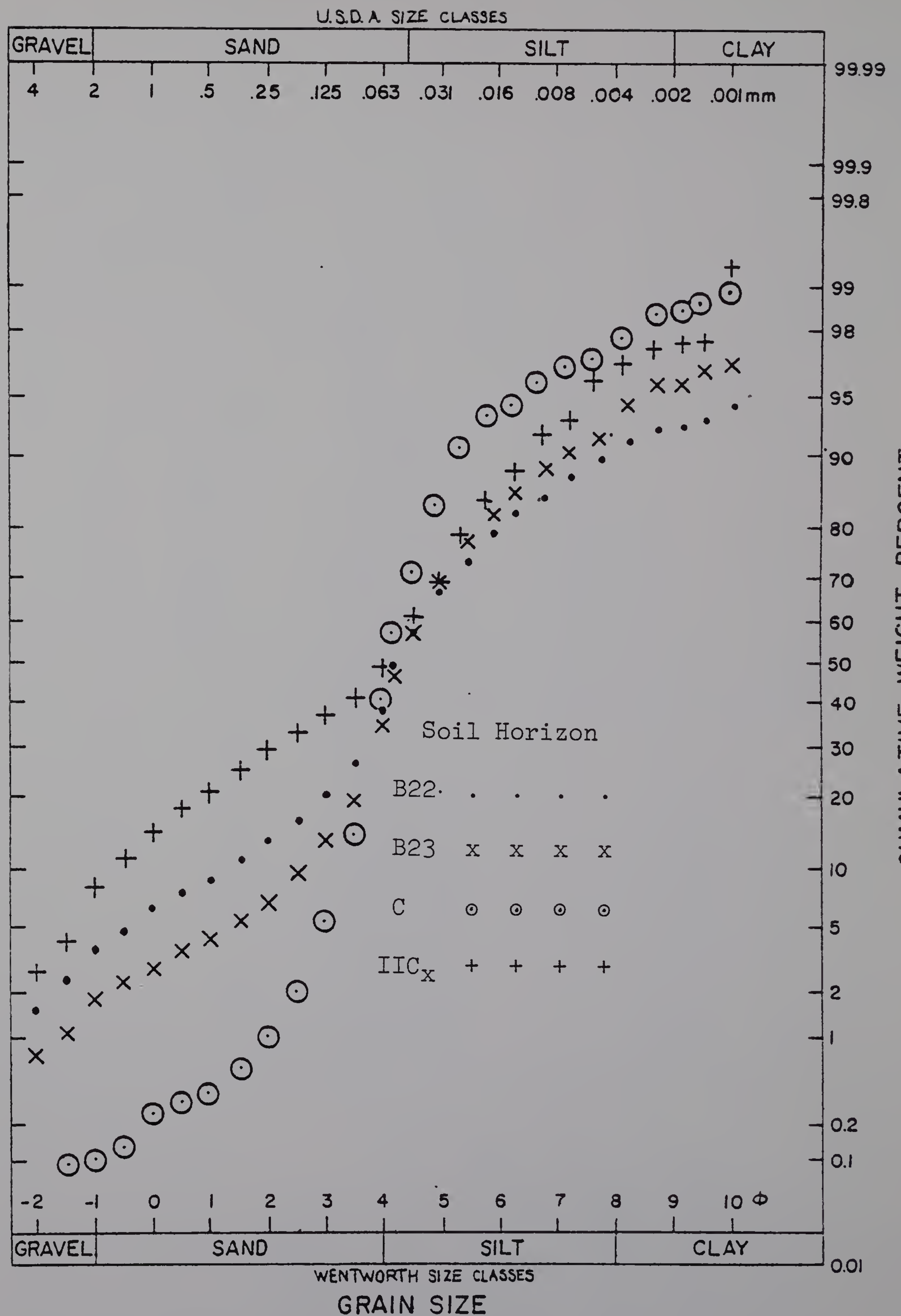


Fig. 12. Cumulative curves of samples collected at the Dartmouth study site.

Table 9. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the B22 horizon at the Dartmouth study site.

STUDY SITE Dartmouth | HORIZON STUDIED B22

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains are subangular in shape, a few grains were rounded. The corners and edges of most grains are rounded.

Medium and fine sand grains: Grain shapes range from subangular to rounded. The surfaces of the well rounded grains are covered with upturned plates.

Very fine sand and coarse silt: Grain shapes range from subangular to rounded. Edges and corners are rounded.

SURFACE FEATURE	GRAIN SIZE		
	2.0 - 0.5 mm. dia.	0.5 - 0.1 m.m. dia.	0.1 - 0.05 mm dia.
CONCHOIDAL BREAKAGE	Many.	Many.	Many.
UPTURNED PLATES	Many - generally found on rounded corners and edges, abundant on rounded grains.	Many - generally found on corners and edges, abundant on rounded grains.	Many.
FLAT CLEAVAGE SURFACES		Few.	Many.
DISH-SHAPED CONCAVITES		Few - found only on rounded grains.	
PRECIPITATION PLATELETS	Many - abundant on some grain surfaces.	Many.	Many.
CARAPACE	Many - depressions of grains.	Many - depressions of grains.	Many - depressions of grains.
SOLUTION/PRECIPITATION SMOOTHING			Common - noticeable on grain edges and upturned plates.

Table 10. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the C horizon at the Dartmouth study site.

STUDY SITE Dartmouth | HORIZON STUDIED C

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Grain shapes range from subangular to rounded.
Medium and fine sand grains: Grain shapes range from subangular to rounded.
Very fine sand and coarse silt: Grain shapes are subangular and subrounded.

SURFACE FEATURE	GRAIN SIZE		
	2.0 – 0.5 mm. dia.	0.5 – 0.1 mm. dia.	0.1 – 0.05 mm. dia.
CONCHOIDAL BREAKAGE	Common - abundant on some grains.	Common - abundant on some grains.	
UPTURNED PLATES	Many - generally found on rounded corners and edges, abundant on rounded grains.	Many - generally found on rounded corners and edges, abundant on rounded grains.	Many - very subdued due to solution/ precipitation.
FLAT CLEAVAGE SURFACES		Few.	Many.
DISH-SHAPED CONCAVITES	Few - found only on rounded grains.	Few - found only on rounded grains.	
PRECIPITATION PLATELETS	Common.	Common.	
CARAPACE		Few.	Few.
SOLUTION/PRECIPITATION SMOOTHING			Common - noticeable on grain edges and up-turned plates.

Table 11. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the IIC_x horizon at the Dartmouth study site.

STUDY SITE Dartmouth | HORIZON STUDIED IIC_x

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains are angular or subangular in shape; one grain was subrounded.

Medium and fine sand grains: Grain shapes range from angular to subrounded. Some grains have glacial surface features while others seem to have eolian features.

Very fine sand and coarse silt: Grain shapes range from angular to subrounded.

SURFACE FEATURE	GRAIN SIZE		
	2.0 – 0.5 mm. dia.	0.5 – 0.1 m.m. dia.	0.1 – 0.05 mm. dia.
CONCHOIDAL BREAKAGE	Many - arc-steps and parallel steps are common on grains.	Many - arc-steps and parallel steps are common on grains.	
UPTURNED PLATES	Few - one subrounded grain with abundant upturned plates was observed.	Common - two grains had abundant upturned plates.	Common.
FLAT CLEAVAGE SURFACES	Common.	Common.	Common.
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Many.	Many.	Many.
CARAPACE			
SOLUTION/PRECIPITATION SMOOTHING			Common - noticeable grain edges and upturned plates.

Holyoke Study Site: Soil Profile Description

Soil Type	Broadbrook extremely stony loam.
Classification:	Coarse - loamy, mixed, mesic Typic Fragiochrepts. Note: The soil described at this site is a taxadjunct of the Broadbrook soil series because the textures of the B22 and IIB3 soil horizons are too coarse and are not within the range in characteristics for the standard soil series description.
Location:	Town of Holyoke, Hampden County, Massachusetts. Nine-tenths of a mile northeast from the intersection of Reservation Road and Smiths Ferry Road, in a borrow pit just east of the access road, which extends to Mt. Nonotuck. Longitude W. 72° 37' 39" Latitude N. 42° 16' 39" Location map (Fig. 13.)
Land Use and Vegetation:	Wooded area - mountain laurel, red oak, hemlock, and black birch.
Physiography:	Thick pocket of compact till in a bedrock area.
Regolith:	Windblown mantle over compact till.

Horizon	Depth (inches)	Description
01	3-2	Non-decomposed organic matter.
02	2-0	Decomposed organic matter.
A1	0-2	Dark brown (7.5YR 3/2) loam; moderate fine and medium granular structure; very friable; common medium roots; clear smooth boundary.
B21	2-10	Dark yellowish brown (10YR 4/4) loam; weak; medium subangular blocky structure; friable; many medium roots; gradual smooth boundary. Sample sieved (Table 12.) and cumulative curve (Fig. 14.) plotted.
B22	10-20	Dark yellowish brown (10YR 4/4) sandy loam; weak medium and coarse subangular blocky structure; friable; many coarse roots; gradual wavy boundary. Sample sieved (Table 12.) and cumulative curve (Fig. 14.) plotted.
IIB3	20-27	Brown (10YR 5/3) sandy loam; weak medium and coarse platy structure; friable; many medium roots; clear wavy boundary.
IIC_x	27-60	Brown (7.5YR 5/2) exterior of ped, reddish gray (5YR 5/2) interior of peds, sandy loam texture, interior of peds are finer textured containing more silt and clay, clean fine and medium sands are between peds; strong medium platy structure; firm; roots are

found only in the upper six inches of the horizon and are located between the peds; clasts are rounded reflecting Triassic Conglomerate origin.

Sample sieved (Table 12.) and cumulative curve (Fig. 14.) plotted.

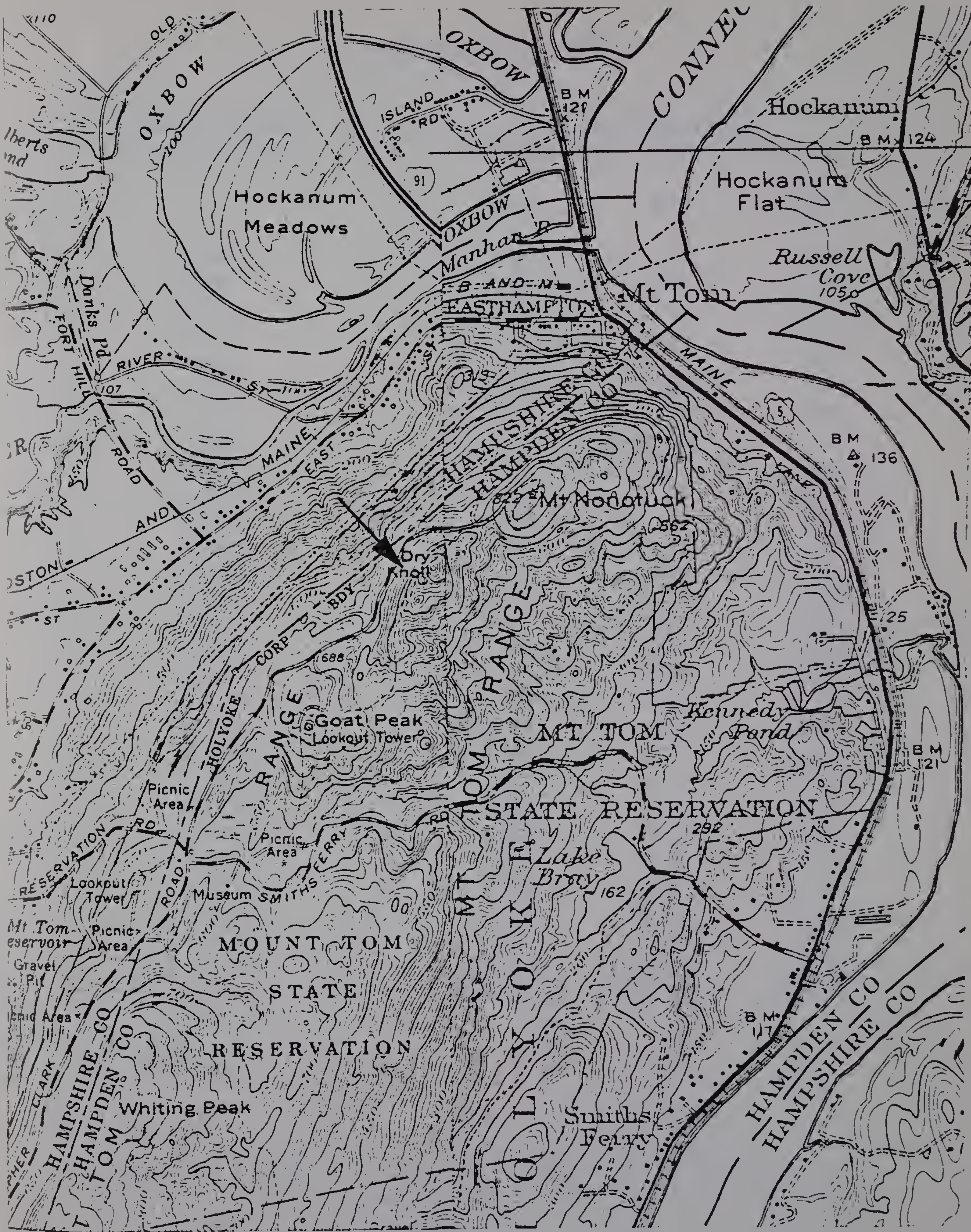


Fig. 13. Location of Holyoke study site. Mt. Holyoke and Easthampton quadrangle maps, Massachusetts, 7.5-minute series (topographic).

HOLYOKE STUDY SITE

Particle Size (In Millimeters)	Soil Horizons (Individual Weight Percents)		
	B21	B22	IIC_x
4.00	0.66	0.33	0.60
2.83	0.37	0.63	1.09
2.00	0.80	1.55	1.32
1.41	0.85	1.33	1.89
1.00	1.71	2.77	3.45
0.71	2.95	4.46	5.63
0.50	3.87	5.72	7.34
0.35	6.37	9.06	11.46
0.25	5.55	7.71	9.41
0.177	5.53	7.56	9.05
0.125	5.49	7.14	8.41
0.088	4.44	5.35	6.15
0.0625	5.52	4.59	5.24
0.062	2.76	3.82	2.36
0.046	6.50	5.43	2.42
0.033	7.59	4.34	2.42
0.024	7.59	5.43	2.42
0.018	5.42	4.34	3.02
0.013	5.43	3.26	2.42
0.0094	3.79	2.71	1.81
0.0067	2.71	2.17	2.42
0.0048	3.25	2.17	1.21
0.0034	0.22	1.09	2.42
0.0024	1.41	1.09	0.97
0.0018	0.33	0.54	0.12
0.0014	1.41	1.09	1.94
0.0010	1.08	1.74	0.60
<0.0010	6.40	2.60	2.42
	100.00	100.02	100.01

Table 12. Mechanical analysis of samples collected at the Holyoke study site.

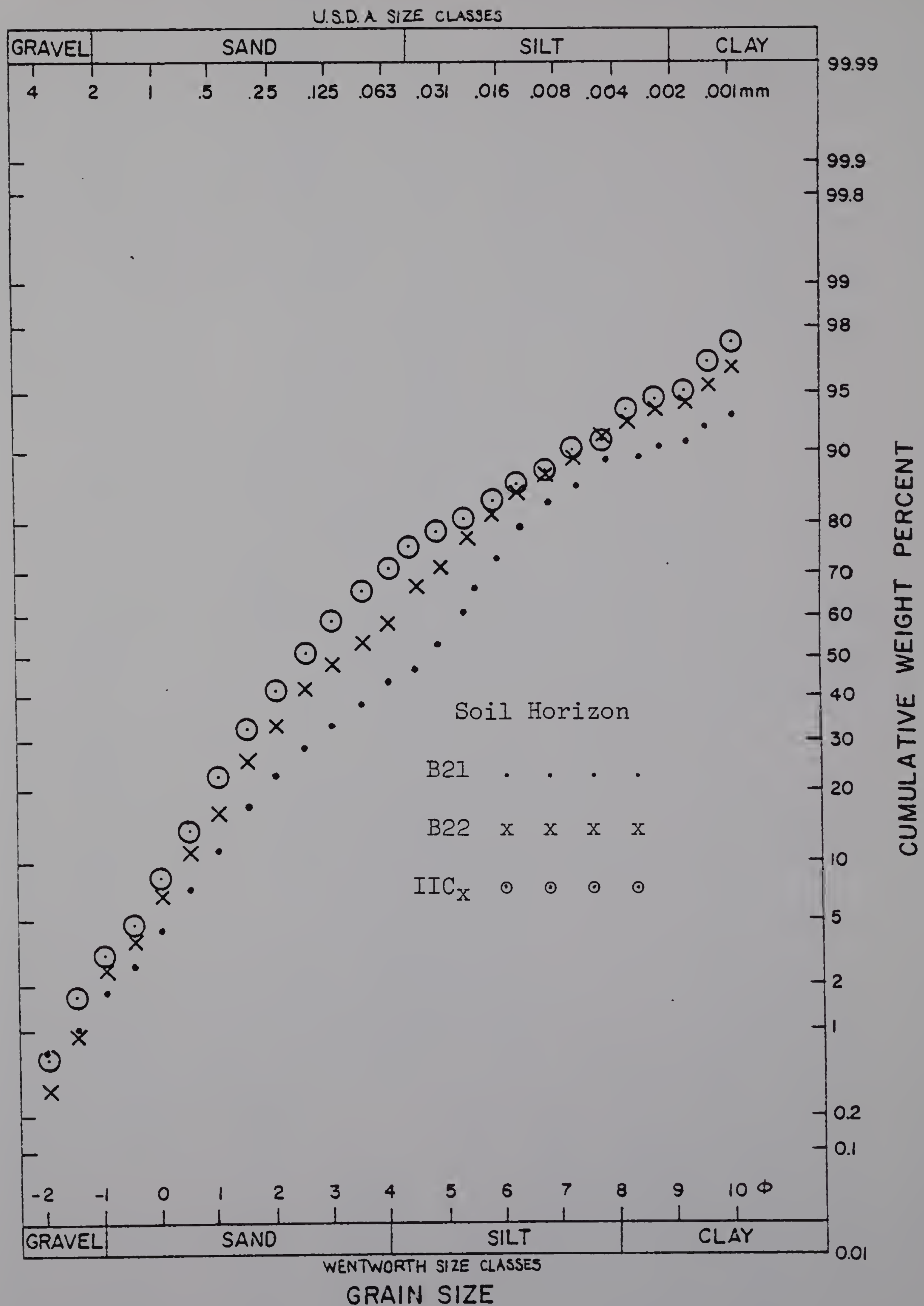


Fig. 14. Cumulative curves of samples collected at the Holyoke study site.

Table 13. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the B21 horizon at the Holyoke study site.

STUDY SITE Holyoke | **HORIZON STUDIED** B21

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Grain shapes range from angular to subrounded.

Medium and fine sand grains: Grain shapes range from angular to subrounded, most grains are subangular or subrounded.

Very fine sand and coarse silt: Grain shapes range from angular to subrounded.

SURFACE FEATURE	GRAIN SIZE		
	2.0 – 0.5 mm. dia.	0.5 – 0.1 mm. dia.	0.1 – 0.05 mm. dia.
CONCHOIDAL BREAKAGE	Many - parallel steps and arc-steps are common.	Common - parallel steps and arc-steps are common.	Common.
UPTURNED PLATES	Common - generally found on rounded corners, edges and sides.	Many - generally found on rounded corners, edges and sides.	Few.
FLAT CLEAVAGE SURFACES		Common.	Many.
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Many.	Many.	Many.
CARAPACE	Few.	Common.	Many.
SOLUTION/PRECIPITATION SMOOTHING	Common - evident on upturned plates and grain edges.	Common - evident on upturned plates and grain edges.	Common - evident on upturned plates and grain edges.

Table 14. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the IIC_x horizon at the Holyoke study site.

STUDY SITE Holyoke | HORIZON STUDIED IIC_x

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains are angular or subangular in shape.
Medium and fine sand grains: Most grains are angular or subangular in shape.
Very fine sand and coarse silt: Most grains are angular or subangular. Some grains seem more weathered than others.

SURFACE FEATURE	GRAIN SIZE		
	2.0 – 0.5 mm. dia.	0.5 – 0.1 mm. dia.	0.1 – 0.05 mm. dia.
CONCHOIDAL BREAKAGE	Many - parallel steps and arc-steps are common.	Many - parallel steps and arc-steps are common.	Few.
UPTURNED PLATES	Few - found on rounded edges and corners of some grains.	Common - found on rounded corners and edges, abundant on some grains.	Few.
FLAT CLEAVAGE SURFACES	Common.	Few.	Common.
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Common.	Many.	Many.
CARAPACE	Few.	Few.	Few.
SOLUTION/PRECIPITATION SMOOTHING	Few.	Few.	Common - more intense on some grains.

Deerfield Study Site: Soil Profile Description

Soil Type:	Hollis very rocky loam.
Classification:	Loamy, mixed mesic Lithic Dystrochrepts.
Location:	Town of Deerfield, Franklin County, Massachusetts. Seven hundred feet west of River Road at a point 0.5 mile northeast from the intersection of Hillside Road and River Road. Longitude W. 72° 34' 26" Latitude N. 42° 29' 34" Location map (Fig. 15.)
Land Use and Vegetation:	Abandoned pasture - pasture grasses and steeple bush.
Physiography:	Bedrock-controlled area.
Regolith:	Eolian mantle over bedrock.

Horizon	Depth (inches)	Description
Ap	0-7	Dark brown (10YR 3/3) fine sandy loam; moderate fine and medium granular structure; friable; many fine roots; abrupt smooth boundary.
B2	7-19	Dark yellowish brown (10YR 4/4) fine sandy loam; massive; friable; many fine roots. Sample sieved (Table 15.) and cumulative curve (Fig. 16.) plotted.
R	19	Bedrock, basalt.

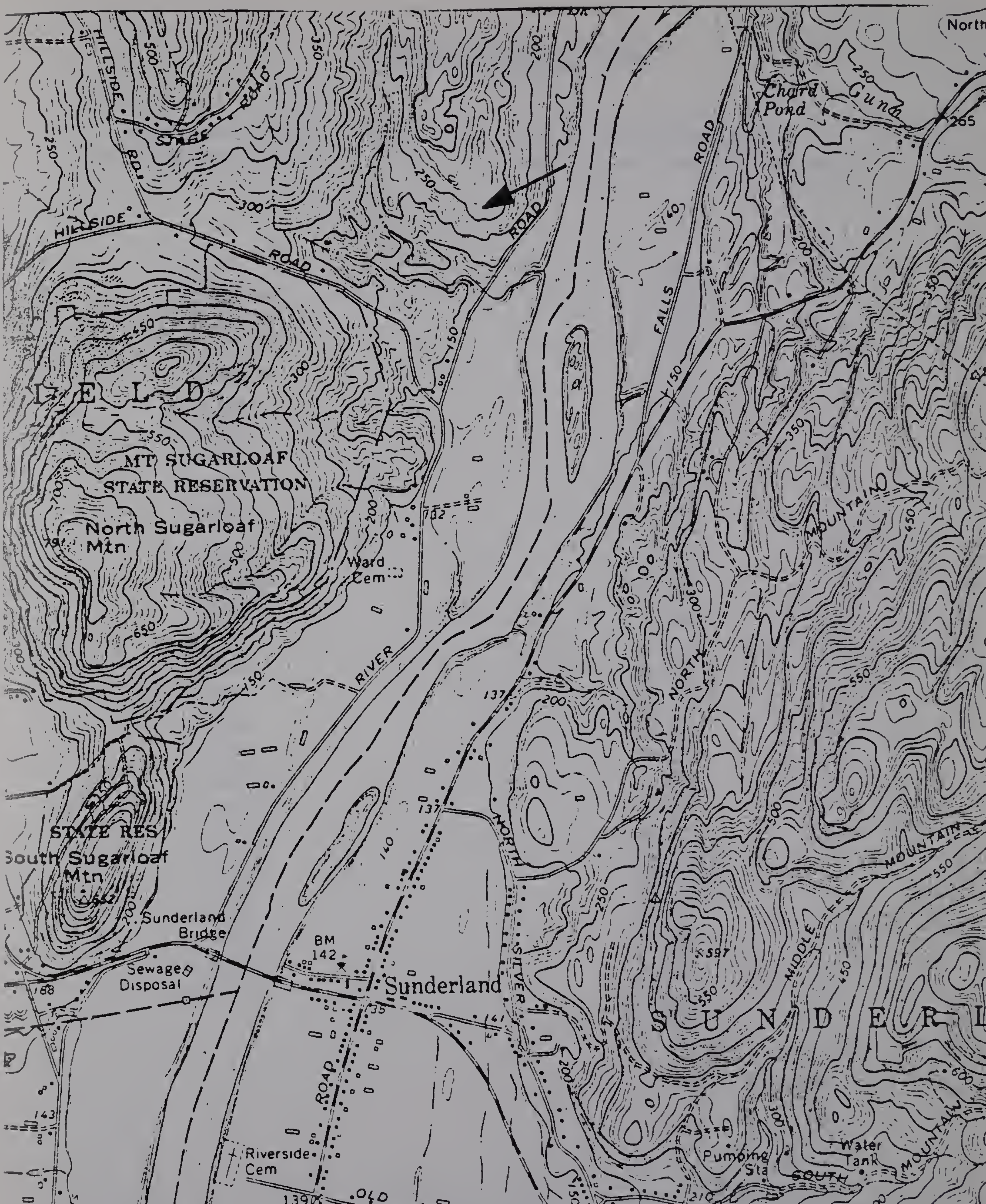


Fig. 15. Location of Deerfield study site. Mt. Toby quadrangle map, Massachusetts, 7.5-minute series (topographic).

DEERFIELD STUDY SITE

Particle Size (In Millimeters)	Soil Horizons (Individual Weight Percents) B2
4.0	2.79
2.83	2.28
2.00	2.38
1.41	1.60
1.00	2.36
0.71	3.09
0.50	3.29
0.35	4.98
0.25	4.30
0.177	4.37
0.125	4.37
0.088	4.11
0.0625	5.94
0.063	5.44
0.046	4.30
0.034	10.02
0.025	7.16
0.018	6.44
0.013	5.01
0.0096	2.86
0.0068	2.86
0.0046	1.43
0.0035	2.15
0.0024	1.43
0.0018	0.14
0.0014	1.29
0.0010	0.14
<0.0010	3.44
	99.97

Table 15. Mechanical analysis of samples collected at the Deerfield study site.

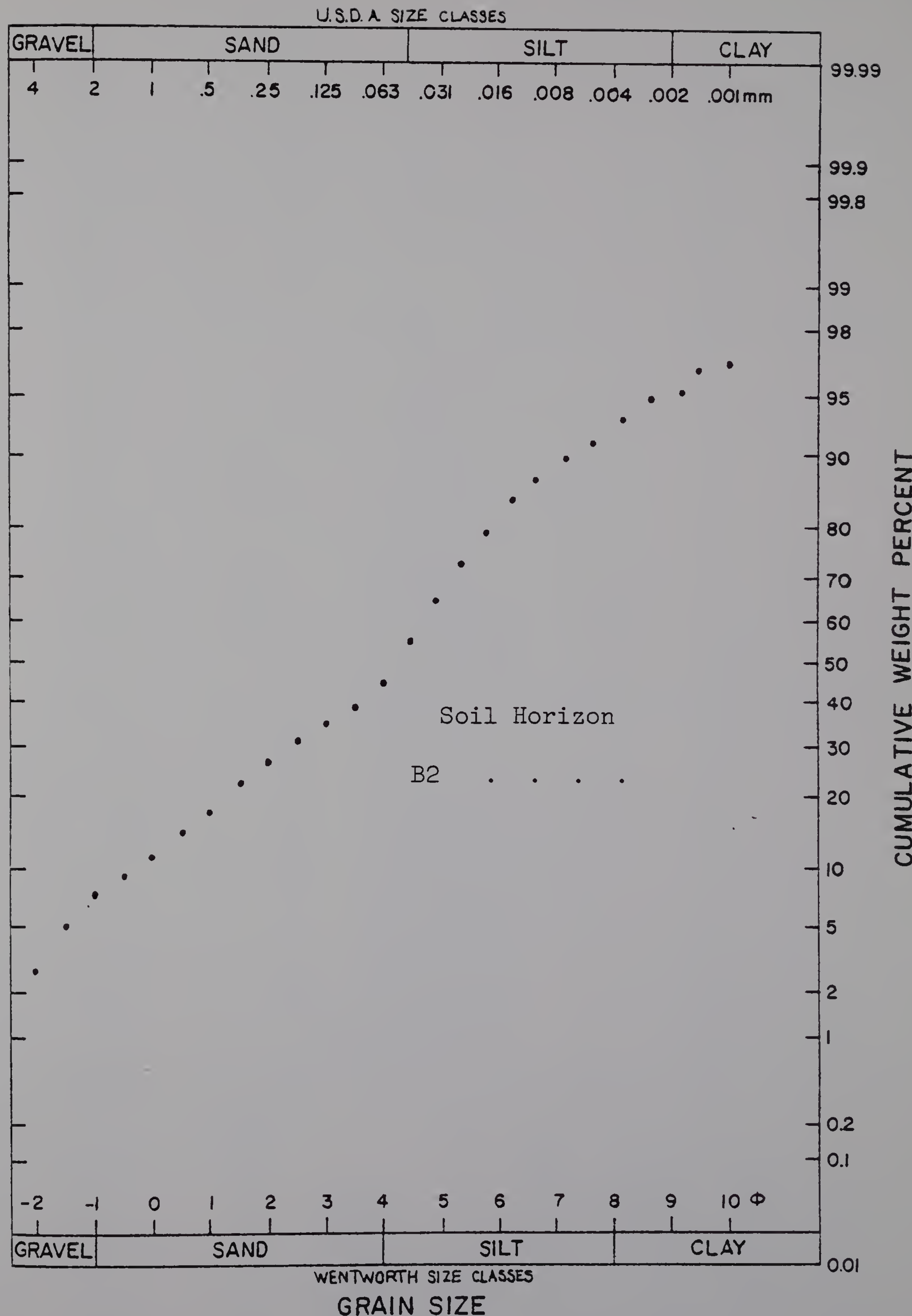


Fig. 16. Cumulative curve of sample collected at the Deerfield study site.

Table 16. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the B2 horizon at the Deerfield study site.

STUDY SITE Deerfield | HORIZON STUDIED B2

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains were subangular or subrounded in shape.
Medium and fine sand grains: Most grains were subangular or subrounded in shape.
Very fine sand and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 - 0.5 mm. dia.	0.5 - 0.1 mm. dia.	0.1 - 0.05 mm dia.
CONCHOIDAL BREAKAGE	Few.	Few.	
UPTURNED PLATES	Many - generally found on rounded corners and edges, abundant on some grains.	Many - generally found on rounded corners and edges, abundant on some grains.	
FLAT CLEAVAGE SURFACES			
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Common.	Many.	
CARAPACE	Few.	Few.	

Sunderland Study Site: Soil Profile Description

Soil Type:	Merrimac fine sandy loam.
Classification:	Sandy, mixed, mesic Typic Dystrochrepts. Note: The soil described at this site is a taxadjunct of the Merrimac soil series because the fine sandy loam surface does not extend below 18 inches, there is a textural discontinuity and the gravel content within the substratum is too low.
Location:	Town of Sunderland, Franklin County, Massachusetts. Six hundred feet west of Route 116 at a point 1/4 mile south from the intersection of Bull Hill Road and Route 116. Longitude W. 72° 32' 58" Latitude N. 42° 27' 52" Location map (Fig. 17.)
Land Use and Vegetation:	Wooded area - white pine, red oak, and white oak.
Physiography:	Glacial lake delta.
Regolith:	Glacial outwash.

Horizon	Depth (inches)	Description
01	2-1	Non-decomposed organic matter.
02	1-0	Decomposed organic matter.
A1	0-1	Very dark gray (10YR 2/1) fine sandy loam; weak fine and medium granular structure;

Horizon	Depth (inches)	Description
		friable; many medium roots; abrupt wavy boundary.
Apb	1-9	Dark yellowish brown (10YR 4/4) fine sandy loam; massive; friable; common medium roots; abrupt smooth boundary.
B21	9-15	Light olive brown (2.5Y 5/4) fine sandy loam; massive; friable; common medium roots; abrupt wavy boundary. Sample sieved (Table 17.) and cumulative curve (Fig. 18.) plotted.
IIB22	15-19	Light olive brown (2.5Y 5/4) gravelly loamy coarse sand; massive; very friable; common coarse roots; abrupt smooth boundary.
IIC	19-40	Light yellowish brown (2.5Y 6/4) coarse sand; single grain; loose; few medium roots. Sample sieved (Table 17.) and cumulative curve (Fig. 18.) plotted.

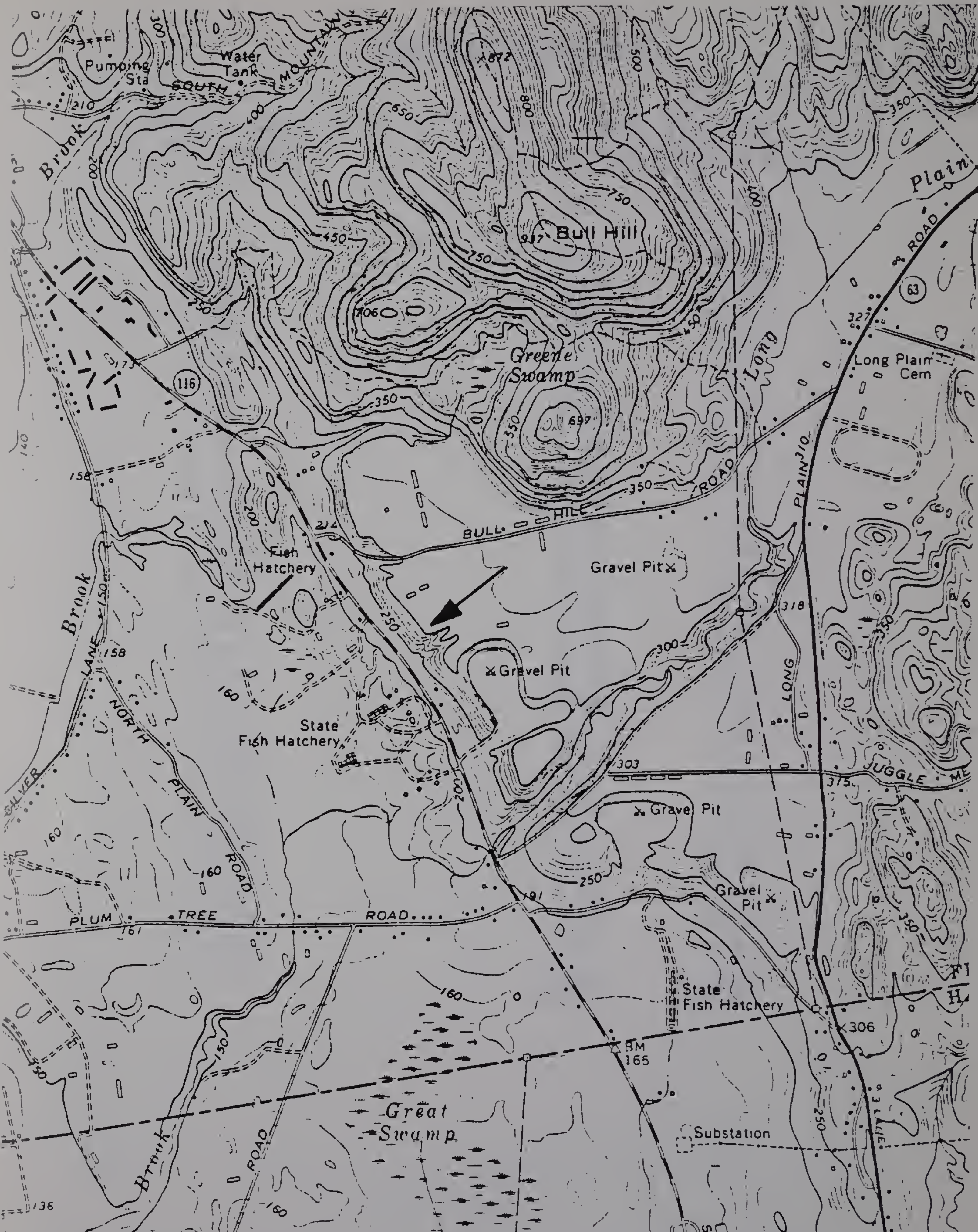


Fig. 17. Location of Sunderland study site. Mt. Toby quadrangle map, Massachusetts, 7.5-minute series (topographic).

SUNDERLAND STUDY SITE

Particle Size (In Millimeters)	Soil Horizons (Individual Weight Percents)	
	B21	IIC
4.00	0.36	0.00
2.83	0.48	0.00
2.00	1.84	0.12
1.41	1.57	1.00
1.00	3.01	5.23
0.71	4.57	15.25
0.50	4.84	20.73
0.35	6.10	24.34
0.25	4.31	11.19
0.177	3.92	7.17
0.125	3.81	4.93
0.088	4.56	2.50
0.0625	9.27	1.54
0.062	8.29	0.85
0.046	8.15	0.86
0.034	9.31	0.43
0.025	8.15	0.43
0.018	4.66	0.09
0.014	2.33	0.77
0.0097	2.33	0.43
0.0068	1.16	0.43
0.0049	1.16	0.17
0.0035	0.58	0.17
0.0024	1.16	0.09
0.0018	0.58	0.09
0.0014	0.58	0.34
0.0010	0.81	0.43
$<$0.0010	2.10	0.43
	99.99	100.01

Table 17. Mechanical analysis of samples collected at the Sunderland study site.

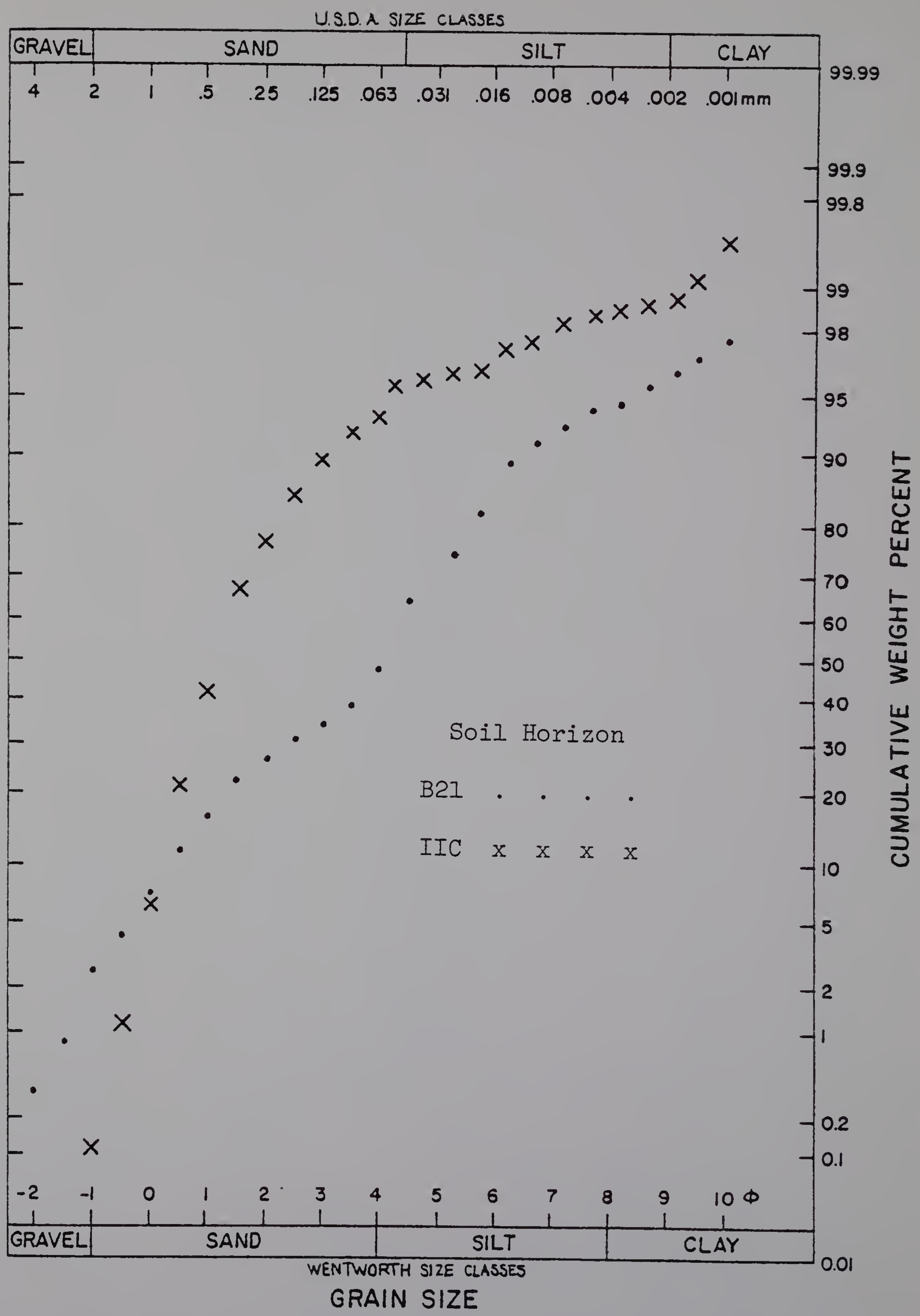


Fig. 18. Cumulative curves of samples collected at the Sunderland study site.

Table 18. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the B21 horizon at the Sunderland study site.

STUDY SITE Sunderland | HORIZON STUDIED B21

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Grain shapes range from angular to subrounded.
Medium and fine sand grains: Grain shapes range from angular to subangular.
Very fine sand and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 – 0.5 mm. dia.	0.5 – 0.1 m.m. dia.	0.1 – 0.05 mm. dia.
CONCHOIDAL BREAKAGE	Many.	Many.	
UPTURNED PLATES	Common - generally found on rounded corners and edges.	Common - found on rounded corners and edges, abundant on portions of some grains.	
FLAT CLEAVAGE SURFACES	Few.	Few.	
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Common.	Common.	
CARAPACE	Common - found in some depressions of grain.	Common - found in some depressions of grain.	

Table 19. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the IIC horizon at the Sunderland study site.

STUDY SITE Sunderland | HORIZON STUDIED IIC

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains are angular or subangular in shape, one grain was subrounded. Edges and corners are chipped, no continuous sharp edges.

Medium and fine sand grains: Grain shapes range from angular to subangular. Edges and corners are chipped, no continuous sharp edges.

Very fine and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 – 0.5 mm. dia.	0.5 – 0.1 m.m. dia.	0.1 – 0.05 mm. dia.
CONCHOIDAL BREAKAGE	Many - arc-steps and parallel steps are common on most grains	Many - arc-steps and parallel steps are common on most grains.	
UPTURNED PLATES	Few - on some rounded edges or corners.	Few - on some rounded edges or corners.	
FLAT CLEAVAGE SURFACES	Few.	Common.	
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Few.	Few.	
CARAPACE			

Belchertown Study Site: Soil Profile Description

Soil Type:	Montauk very stony fine sandy loam.
Classification:	Coarse-loamy, mixed mesic Typic Fragiochrepts. Note: The soil described at this site is a taxadjunct of the Montauk soil series because the color and texture of the B3 horizon are not within the range in characteristics of the standard soil series description.
Location:	Belchertown, Hampshire County, Massachusetts. Just west of the Central Vermont Railroad tracks at a point two hundred feet southeast from the intersection of Jabish Canal and tracks. Longitude W. 72° 23' 15" Latitude N. 42° 15' 09" Location map (Fig. 19.)
Land Use and Vegetation:	Wooded area - white pine, white oak, pitch pine, lowbush blueberries.
Physiography:	Ground moraine.
Regolith:	Possible thin disturbed mantle over compact till (upper till).

Horizon	Depth (inches)	Description
01	3-1	Non-decomposed organic matter, pine needles, and leaves.

Horizon	Depth (inches)	Description
02	1-0	Decomposed organic matter.
A1	0-1	Black (10YR 2/1) fine sandy loam; weak fine and medium granular structure; very friable; many fine roots; small fragments of charcoal; abrupt smooth boundary.
Apb	1-8	Dark brown (10YR 3/3) fine sandy loam; weak fine and medium granular structure; friable; many medium roots; abrupt wavy boundary.
B21	8-14	Yellowish brown (10YR 5/4) fine sandy loam; massive; friable; common medium roots; clear wavy boundary. Sample sieved (Table 20.) and cumulative curve (Fig. 20.) plotted.
B22	14-28	Light olive brown (2.5Y 5/4) fine sandy loam; massive; friable; common medium roots; clear wavy boundary. Sample sieved (Table 20.) and cumulative curve (Fig. 20.) plotted.
B3	28-34	Olive (5Y 5/3) loamy sand; single grain; loose; few fine roots; gradual irregular boundary.
IIC_x	34-48	Olive gray (5Y 5/2) gravelly loamy sand; massive; firm in place; friable when removed; silt caps are common on the upper surfaces of coarse fragments and sand beds

are beneath the coarse fragments.

Sample sieved (Table 20.) and cumulative curve (Fig. 20.) plotted.

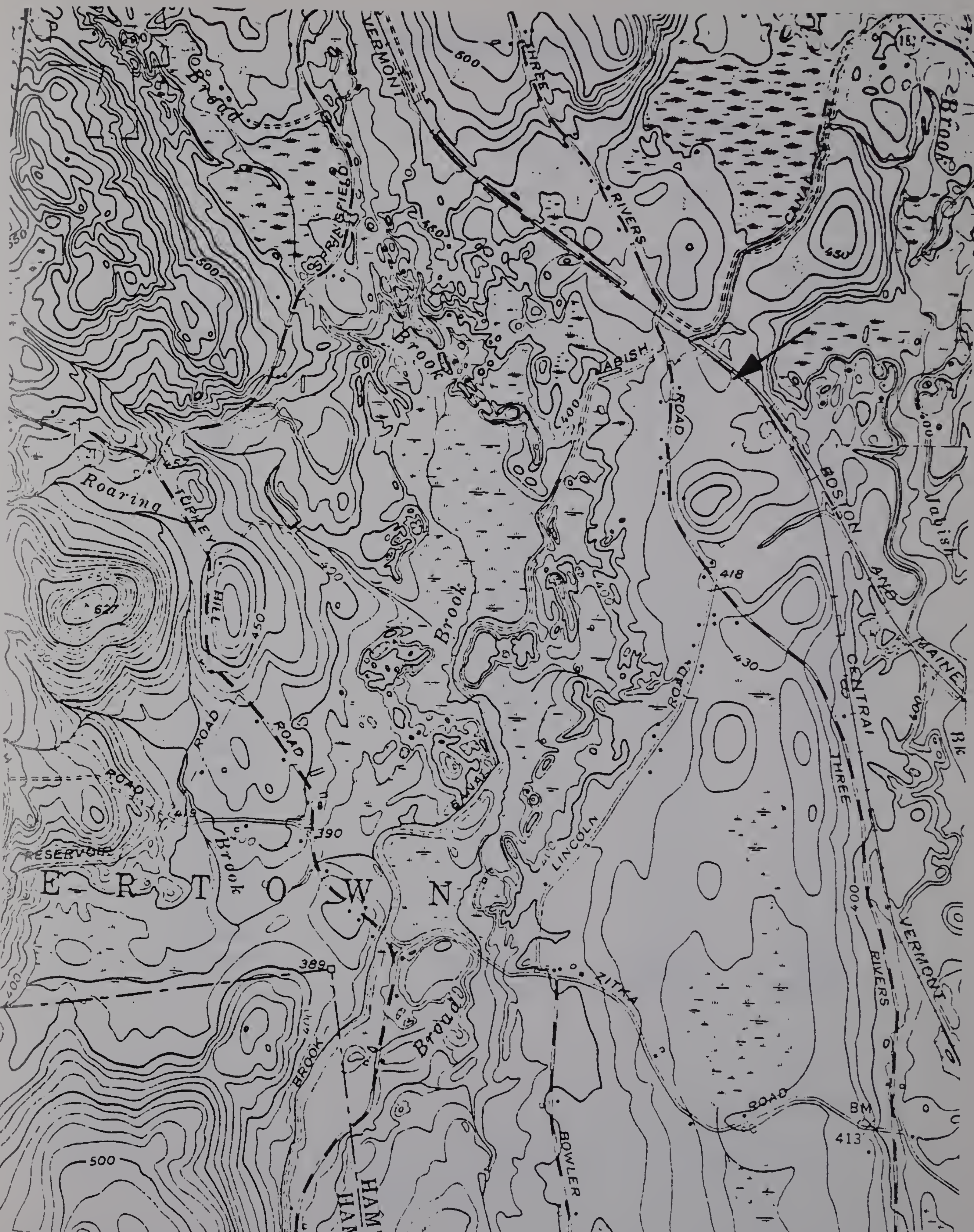


Fig. 19. Location of Belchertown study site. Belchertown quadrangle map, Massachusetts, 7.5-minute series (topographic).

BELCHERTOWN STUDY SITE

Particle Size (In Millimeters)	Soil Horizons (Individual Weight Percents)		
	B21	B22	IIC_x
4.00	1.38	1.02	2.86
2.83	1.94	0.80	2.46
2.00	2.49	1.35	3.96
1.41	1.76	1.29	2.72
1.00	2.23	1.83	3.30
0.71	3.21	2.76	4.28
0.50	3.95	3.79	4.79
0.35	6.49	6.44	7.78
0.25	6.52	6.34	7.79
0.177	7.35	6.89	8.96
0.125	7.80	7.03	9.73
0.088	6.28	5.64	7.72
0.0625	6.43	6.13	6.87
0.062	6.42	6.17	4.03
0.045	4.66	5.80	4.55
0.033	7.26	7.73	3.41
0.024	4.66	6.76	2.84
0.018	4.66	5.80	2.84
0.013	3.11	3.87	2.28
0.0094	3.11	1.93	1.14
0.0067	1.04	1.93	1.14
0.0048	1.04	0.97	1.71
0.0034	1.55	1.45	1.14
0.0024	1.35	1.45	0.11
0.0018	0.10	0.19	0.46
0.0014	0.10	0.29	0.57
0.0010	1.04	0.97	0.57
<0.0010	2.07	3.38	0.00
	100.00	100.00	100.01

Table 20. Mechanical analysis of samples collected at the Belchertown study site.

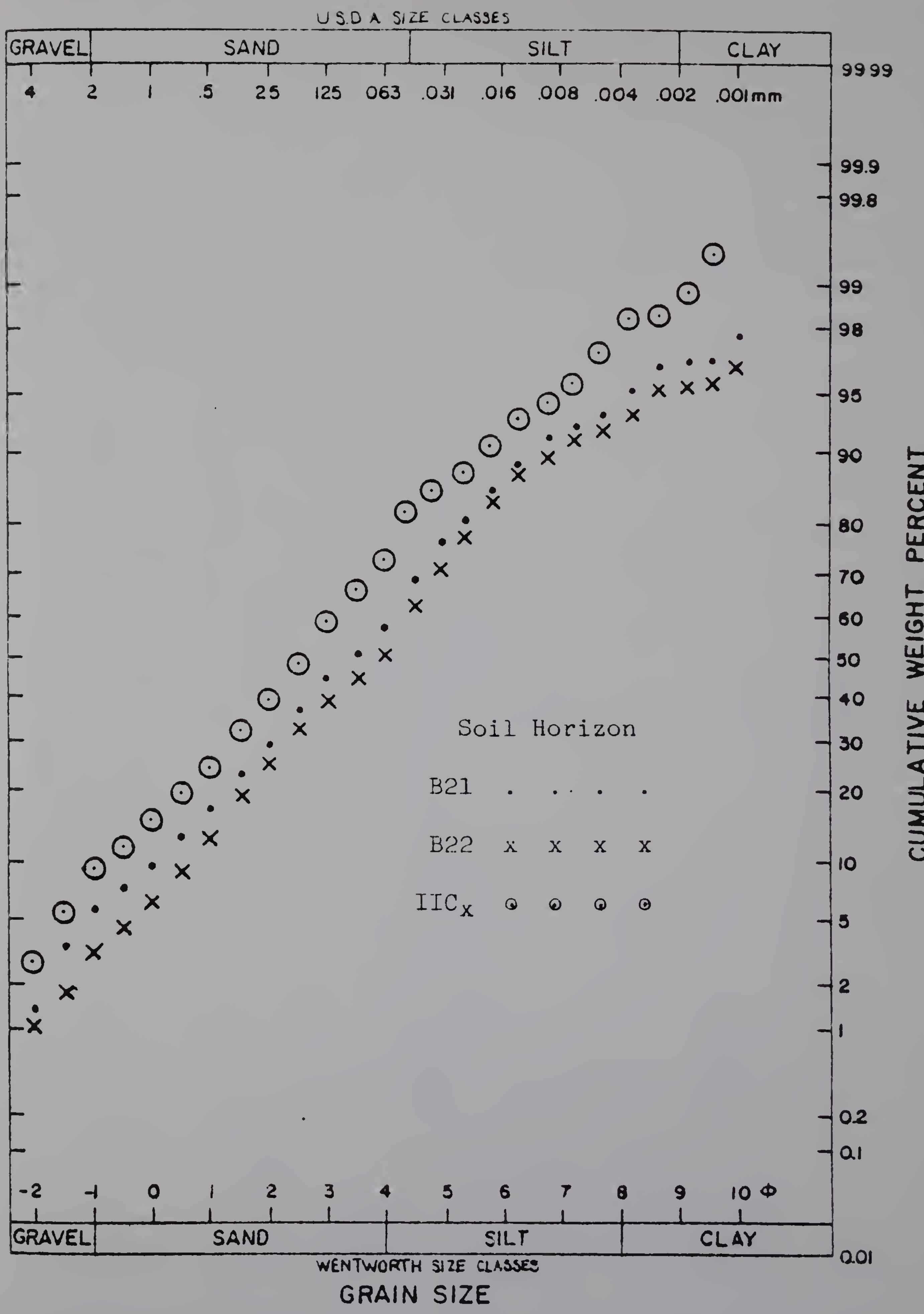


Fig. 20. Cumulative curves of samples collected at the Belchertown study site.

Table 21. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the B22 horizon at the Belchertown study site.

STUDY SITE Belchertown | HORIZON STUDIED B22

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Grain shapes range from angular to subrounded.
Medium and fine sand grains: Grain shapes range from angular to subrounded.
Very fine sand and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 - 0.5 mm. dia.	0.5 - 0.1 m.m. dia.	0.1 - 005 mm dia.
CONCHOIDAL BREAKAGE	Many - parallel steps and arc-steps were common.	Many - parallel steps and arc-steps were common.	
UPTURNED PLATES	Few - edges and corners of some grains.	Common - two subrounded grains had abundant upturned plates.	
FLAT CLEAVAGE SURFACES	Few.	Common.	
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Many.	Many.	
CARAPACE	Common.	Many.	

Table 22. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the IIC_x horizon at the Belchertown study site.

STUDY SITE Belchertown | HORIZON STUDIED IIC_x

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains are angular or subangular in shape. Grains generally had sharp, distinct features.

Medium and fine sand grains: Most grains are angular or subangular, one grain was subrounded.

Very fine sand and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 – 0.5 mm. dia.	0.5 – 0.1 mm. dia.	0.1 – 0.05 mm dia.
CONCHOIDAL BREAKAGE	Many - parallel steps and arc-steps were common.	Many - parallel steps and arc-steps were common.	
UPTURNED PLATES	Few - only on edges and corners of some grains.	Few - only on edges and corners of some grains.	
FLAT CLEAVAGE SURFACES			
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Common.	Common.	
CARAPACE	Few - small amount in some depressions.		
SOLUTION/PRECIPITATION SMOOTHING	Common.	Common.	

Monson Study Site: Soil Profile Description

Soil Type:	Paxton extremely stony fine sandy loam.
Classification:	Coarse loamy, mixed, mesic Typic Fragiochrepts.
Location:	Town on Monson, Hampden County, Massachusetts. Fifty feet north of Hovey Road at a point 0.5 mile west from the intersection of Hovey Road and Bald Peak Road. Longitude W. 72° 20' 54". Latitude N. 42° 08' 23" Location map (Fig. 21.)
Land Use and Vegetation:	Wooded area - lowbush blueberry, red oak, red maple, and American chestnut.
Physiography:	Drumlin.
Regolith:	Compact till.

Horizon	Depth (inches)	Description
01	2½-1	Non-decomposed organic matter.
02	1-0	Decomposed organic matter.
A1	0-2½	Very dark grayish brown (10YR 3/2) fine sandy loam; weak fine and medium granular structure; very friable; many medium roots; abrupt wavy boundary.
B21	2½-10	Yellowish brown (10YR 5/4) fine sandy loam; weak medium subangular block structure; fri-

Horizon	Depth (inches)	Description
		able; many medium roots; clear wavy boundary. Sample sieved (Table 23.) and cumulative curve (Fig. 22.) plotted.
B22	10-20	Light olive brown (2.5Y 5/4) fine sandy loam; weak medium subangular blocky structure; friable; common medium roots; gradual wavy boundary. Sample sieved (Table 23.) and cumulative curve (Fig. 22.) plotted.
C_x	20-44	Olive gray (5Y 5/2) gravelly fine sandy loam; few fine prominent yellowish red (5YR 5/6) and dark brown (7.5YR 4/2) mottles located between peds in the upper portion of the horizon; moderate coarse and very coarse platy structure; firm; few fine roots located between the peds in the upper portion of the horizon; silt caps are common on the upper surfaces of coarse fragments and sand beds are beneath the coarse fragments; vesicular pores are common. Sample sieved (Table 23.) and cumulative curve (Fig. 22.) plotted.

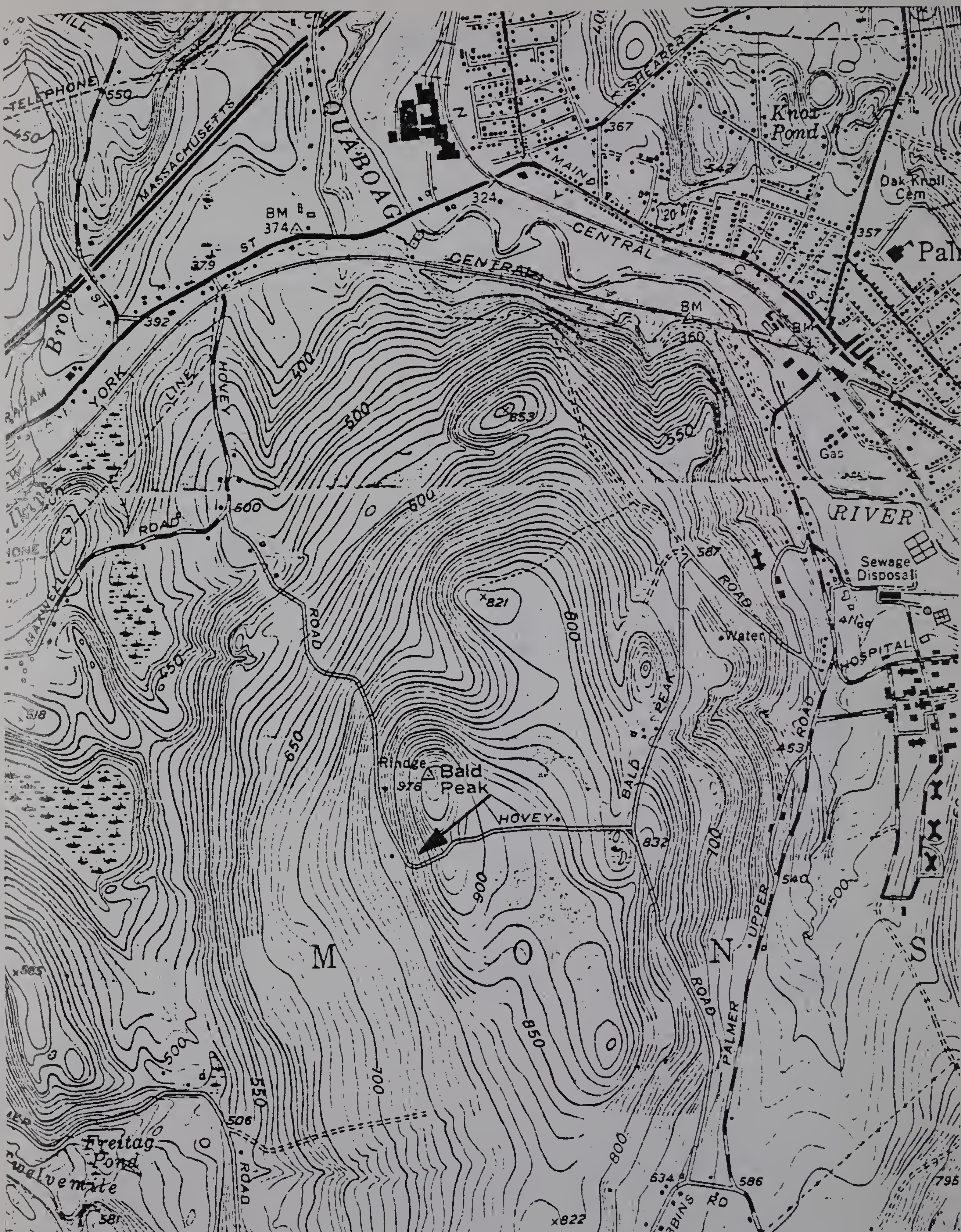


Fig. 21. Location of Monson study site. Palmer quadrangle map, Massachusetts, 7.5-minute series (topographic).

MONSON STUDY SITE

Particle Size (In Millimeters)	Soil Horizons (Individual Weight Percents)		
	B21 and B22	B22	C_x
4.00	8.45	1.01	1.37
2.83	1.90	2.47	1.45
2.00	2.80	2.15	1.80
1.41	1.50	1.81	1.48
1.00	1.71	2.17	2.12
0.71	2.39	3.13	2.86
0.50	2.88	3.35	3.01
0.35	4.93	5.60	4.86
0.25	5.14	5.78	4.92
0.177	6.40	6.95	6.00
0.125	7.91	8.34	7.48
0.0088	6.96	7.36	6.71
0.0625	6.85	7.33	6.91
0.063	5.96	5.58	6.49
0.046	4.28	4.11	4.97
0.033	4.28	5.28	5.53
0.024	5.35	5.28	4.42
0.018	3.21	4.11	4.42
0.013	4.28	4.11	3.32
0.0094	2.67	2.94	3.32
0.0067	2.14	2.94	2.21
0.0048	1.07	1.17	1.11
0.0034	2.14	1.76	2.76
0.0024	0.53	1.76	1.66
0.0018	0.86	0.24	1.11
0.0014	0.11	0.47	1.11
0.0010	0.11	0.47	1.11
<0.0010	3.21	2.35	5.53
	100.02	100.02	100.04

Table 23. Mechanical analysis of samples collected at the Monson study site.

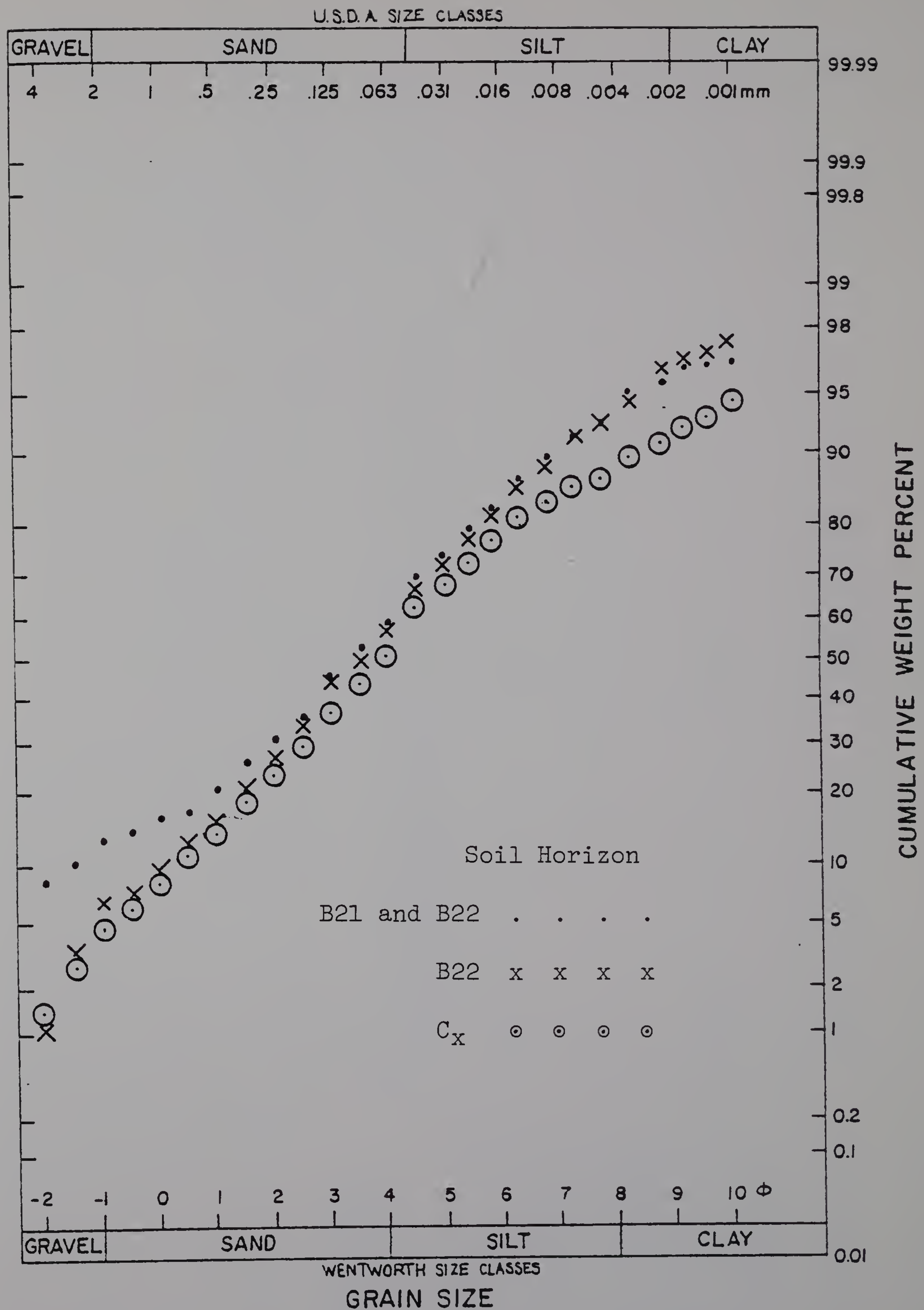


Fig. 22. Cumulative curves of samples collected at the Monson study site.

Table 24. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the B21 and B22 horizon at the Monson study site.

STUDY SITE Monson | HORIZON STUDIED B21 & B22

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains are angular or subangular in shape. Edges and corners are chipped on many grains.

Medium and fine sand grains: Most grains are angular or subangular in shape. Some grains appear to be highly weathered.

Very fine sand and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 - 0.5 mm. dia.	0.5 - 0.1 mm. dia.	0.1 - 0.05 mm dia.
CONCHOIDAL BREAKAGE	Many.	Many.	
UPTURNED PLATES	Few - on some corners.		
FLAT CLEAVAGE SURFACES	Few.	Few.	
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Many.	Many.	
CARAPACE	Many - found in depressions of grain.	Many - found in depressions of grain.	
SOLUTION/PRECIPITATION SMOOTHING	Common.	Common.	

Table 25. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the C_x horizon at the Monson study site.

STUDY SITE Monson | HORIZON STUDIED C_x

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains are angular or subangular in shape. Intense weathering is evident on portions of some grain surfaces.

Medium and fine sand grains: Most grains are angular or subangular in shape.

Very fine sand and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 – 0.5 mm. dia.	0.5 – 0.1 mm. dia.	0.1 – 0.05 mm. dia.
CONCHOIDAL BREAKAGE	Many.	Many.	
UPTURNED PLATES	Few - on some grain corners and edges.	Few - on some grain corners and edges.	
FLAT CLEAVAGE SURFACES	Common.	Common.	
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Common.	Many.	
CARAPACE	Few.		
SOLUTION/PRECIPITATION SMOOTHING	Common.	Common.	

Spencer Study Site: Soil Profile Description

Soil Type:	Paxton extremely stony fine sandy loam.
Classification:	Coarse loamy, mixed mesic Typic Fragiochrepts.
Location:	Town of Spencer, Worcester County, Massachusetts. Twelve hundred feet west along the high tension lines from Greenville Road and two hundred feet south from the high tension lines. Longitude W. 71° 57' 14" Latitude N. 42° 13' 26" Location map (Fig. 23.)
Land Use and Vegetation:	Wooded area - red oak, red maple, black cherry, white pine.
Physiography:	Drumlin.
Regolith:	Compact till.

Horizon	Depth (inches)	Description
01	2½-½	Non-decomposed organic matter.
02	½-0	Decomposed organic matter.
A1	0-5	Very dark grayish brown (10YR 3/2) fine sandy loam; moderate medium granular structure; very friable; abrupt wavy boundary.
B21	5-12	Dark yellowish brown (10YR 4/4) fine sandy loam; weak medium subangular blocky structure; clear smooth boundary.

Horizon	Depth (inches)	Description
		Sample sieved (Table 26.) and cumulative curve (Fig. 24.) plotted.
B22	12-19	Olive brown (2.5Y 4/4) fine sandy loam; weak medium and coarse subangular blocky structure; friable; clear wavy boundary. Sample sieved (Table 26.) and cumulative curve (Fig. 24.) plotted.
B23	19-29	Light olive brown (2.5Y 5/4) fine sandy loam; weak medium and coarse subangular blocky structure; friable; clear wavy boundary.
C_x	29-48	Light olive brown (2.5Y 5/4) exterior of peds; olive brown (2.5Y 4/4) interior of peds; fine sandy loam; segregated sand between peds; few medium distinct strong brown (7.5Y 5/6) mottles; moderate medium and coarse platy structure; firm; vesicular pores. Sample sieved (Table 26.) and cumulative curve (Fig. 24.) plotted.

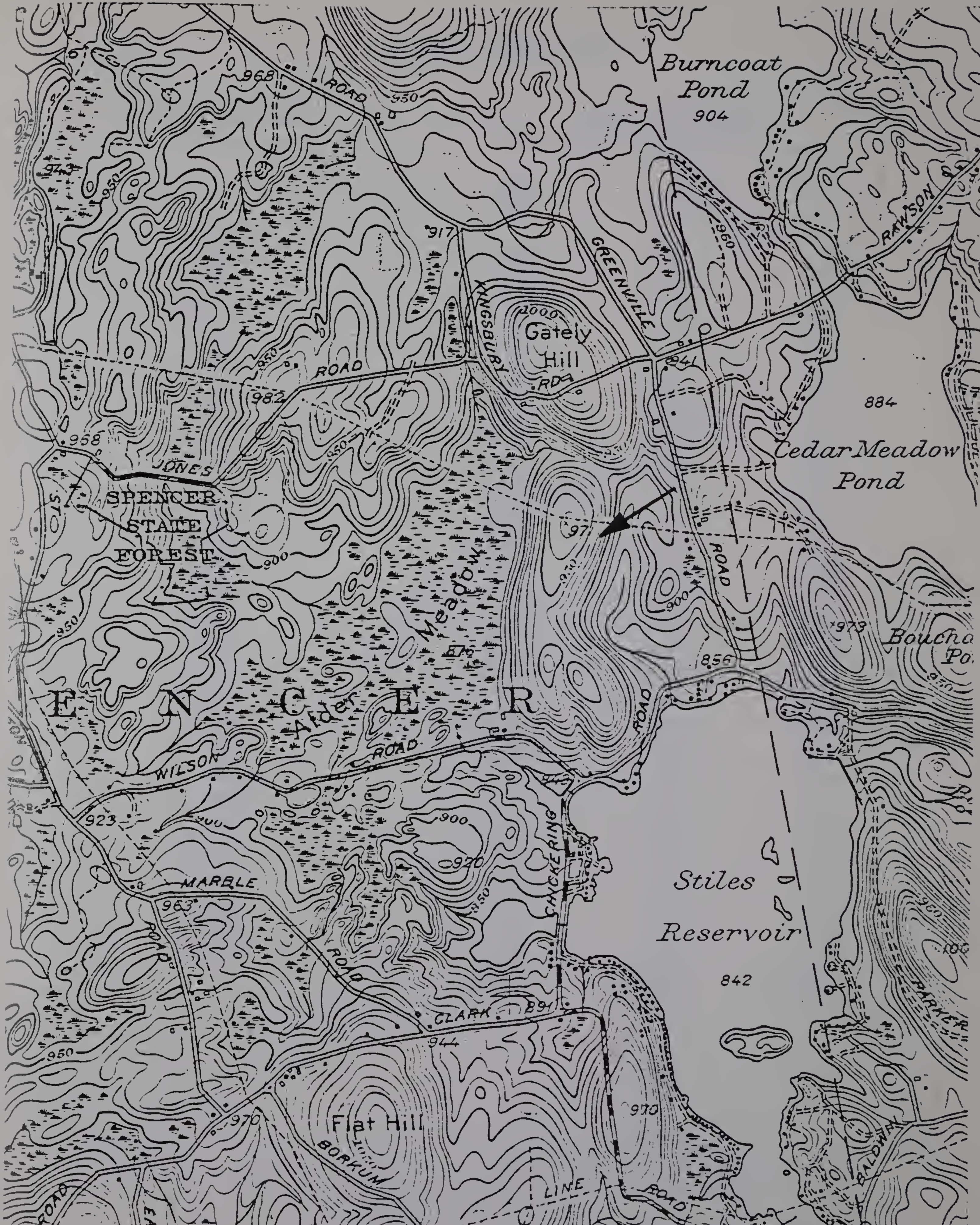


Fig. 23. Location of Spencer study site. Leicester quadrangle map, Massachusetts, 7.5-minute series (topographic).

SPENCER STUDY SITE

Particle Size (In Millimeters)	Soil Horizons (Individual Weight Percents)		
	B21	B22	C_x
4.00	2.07	1.91	1.19
2.83	1.49	1.17	1.26
2.00	1.82	2.18	2.23
1.41	1.45	1.35	1.91
1.00	2.25	2.24	2.72
0.71	2.87	2.67	3.26
0.50	2.87	2.88	3.38
0.35	4.65	4.78	5.23
0.25	5.07	5.20	5.44
0.177	6.62	6.70	6.85
0.125	8.18	8.16	8.36
0.088	7.10	7.14	7.09
0.0625	7.14	6.92	6.96
0.064	7.00	4.62	4.89
0.047	4.22	5.26	3.46
0.034	3.52	3.95	4.61
0.024	4.93	3.95	3.46
0.018	4.22	4.60	4.61
0.013	2.82	3.29	3.46
0.0094	3.52	3.95	2.31
0.0067	2.82	1.97	2.31
0.0048	2.11	2.63	2.31
0.0034	2.11	1.97	1.15
0.0024	1.83	2.63	2.31
0.0018	0.28	1.32	0.58
0.0014	2.68	1.32	1.15
0.0010	0.99	1.84	1.96
<0.0010	3.38	3.42	5.54
	99.99	100.02	99.99

Table 26. Mechanical analysis of samples collected at the Spencer study site.

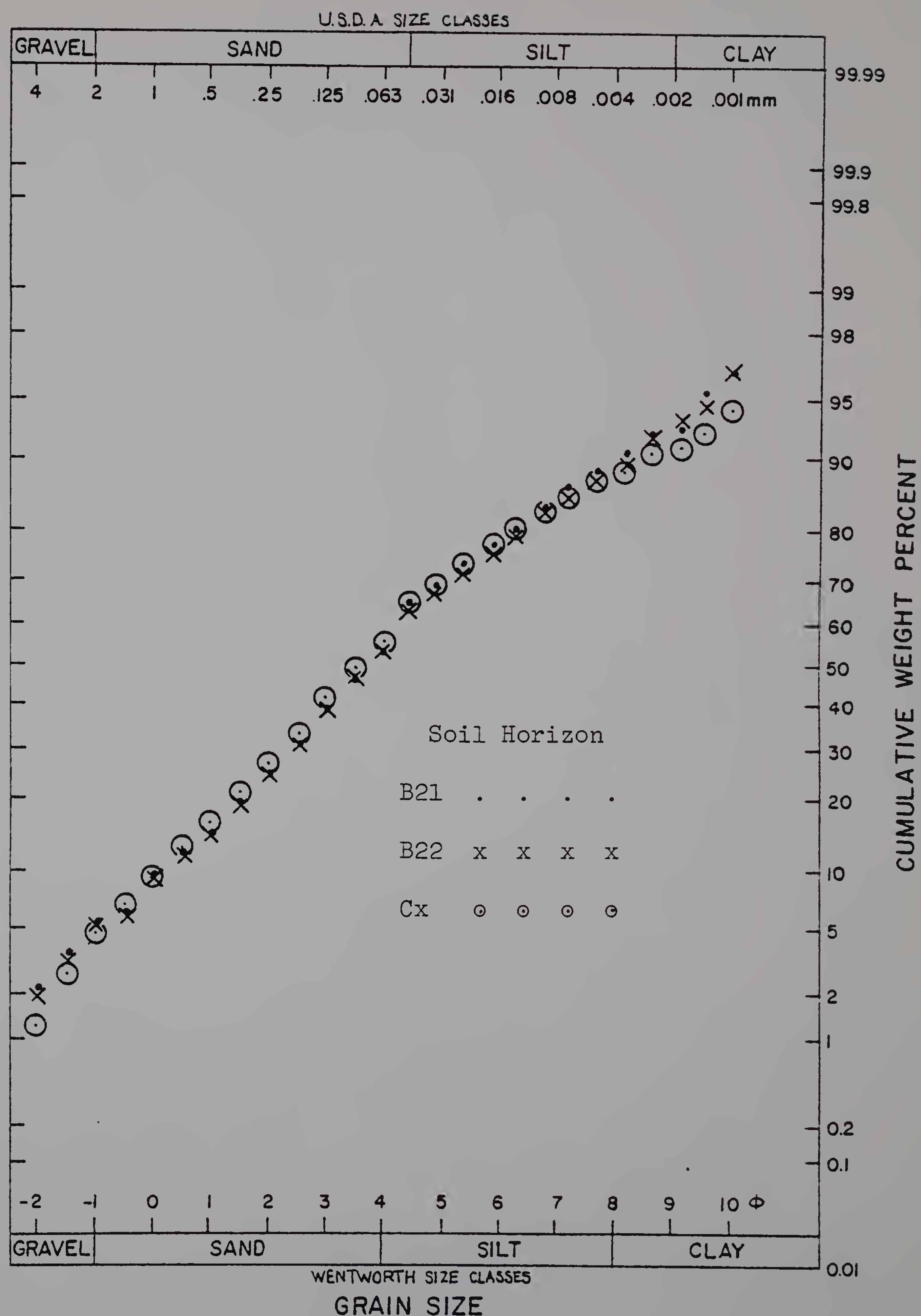


Fig. 24. Cumulative curves of samples collected at the Spencer study site.

Table 27. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the B21 horizon at the Spencer study site.

STUDY SITE Spencer | HORIZON STUDIED B21

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains were angular or subangular. Sides of some grains seem highly weathered and have carapace adhering to them.

Medium and fine sand grains: Most grains were angular or subangular. Sides of some grains seem highly weathered.

Very fine sand and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 – 0.5 mm. dia.	0.5 – 0.1 m.m. dia.	0.1 – 0.05 mm dia.
CONCHOIDAL BREAKAGE	Many - parallel steps and arc-steps were common.	Many - parallel steps and arc-steps were common.	
UPTURNED PLATES	Common - on some rounded edges and corners.	Few - on some rounded edges and corners.	
FLAT CLEAVAGE SURFACES	Few.	Few.	
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Many.	Many.	
CARAPACE	Many - not restricted to depressions, found covering sides of some grains.	Many - not restricted to depressions, found covering sides of some grains.	
SOLUTION/PRECIPITATION SMOOTHING	Common.	Common.	

Table 28. Quartz grain surface characteristics observed during SEM viewing of a sample collected from the C_x horizon at the Spencer study site.

STUDY SITE Spencer | HORIZON STUDIED C_x

GENERAL CHARACTERISTICS OF GRAINS

Very coarse and coarse sand grains: Most grains are angular or subangular in shape. Sides of some grains seem highly weathered and have carapace adhering to them.

Medium and fine sand grains: Most grains are angular or subangular in shape. Sides of some grains seem highly weathered and have carapace adhering to them.

Very fine sand and coarse silt: Sample was not examined.

SURFACE FEATURE	GRAIN SIZE		
	2.0 – 0.5 mm. dia.	0.5 – 0.1 mm. dia.	0.1 – 0.05 mm. dia.
CONCHOIDAL BREAKAGE	Many - parallel steps and arc-steps were common.	Many - parallel steps and arc-steps were common.	
UPTURNED PLATES	Few - on some rounded corners and edges.	Few - on some rounded corners and edges.	
FLAT CLEAVAGE SURFACES	Few.	Few.	
DISH-SHAPED CONCAVITES			
PRECIPITATION PLATELETS	Many.	Many.	
CARAPACE	Few.	Few.	
SOLUTION/PRECIPITATION SMOOTHING	Few.	Few.	

Fig. 25. SEM photograph of a coarse sand grain taken from the eolian mantle (120X). Note the rounded shape of the grain, upturned plates covering most of the grain surface except in depressions, and the dish-shaped concavities. Sample collected from the B horizon at the preliminary study site on Nantucket Island.

Fig. 26. SEM photograph of a very coarse sand grain taken from the eolian mantle (80X). Note the subrounded shape and upturned plates on the rounded corners and edges. Conchoidal fractures and flat cleavage surfaces are also present. Sample collected from the B horizon at the preliminary study site on Nantucket Island.

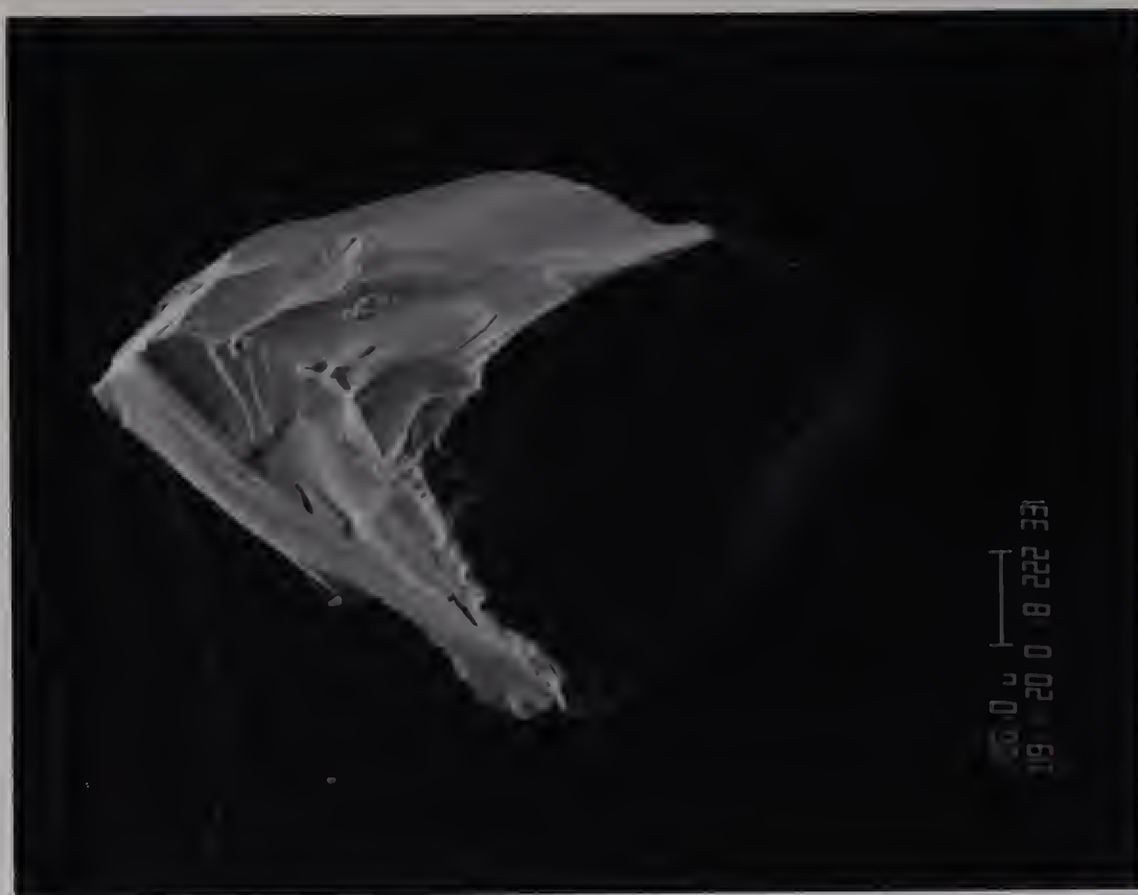
Character display, lower left of each photo. Top line, left to right: total line length expressed in microns, micron line. Bottom line, left to right: magnification factor, magnification multiplier, gun KV, working distance in mm, reference counter, photo counter.

Fig. 27. SEM photograph of a coarse sand grain taken from the eolian mantle (400X). Note the rounded surface and smoothing of upturned plates due to the solution and precipitation. Mechanical V-forms denote prior subaqueous environment. Sample collected from the B horizon at the preliminary study site on Nantucket Island.

Fig. 28. SEM photograph of a coarse sand grain taken from a coastal sand dune (110X). Note the rounded shape of the grain, the upturned plates covering most of the grain surface and the dish-shaped concavity. Sample collected from the C horizon at the preliminary study site in Truro.

Fig. 29. SEM photograph of the surface of a sand grain taken from a deposit of upper till (600X). Note carapace in the depression and precipitation platelets cemented to the grain surface. Sample collected from the B horizon at the preliminary study site in Belchertown.

Fig. 30. SEM photograph of a coarse sand grain taken from a deposit of upper till (90X). Note the sharp angular shape of the grain. Arc-steps, conchoidal fractures and flat cleavage surfaces are present on the grain surface. Sample collected from the C_x horizon at the preliminary study site in Belchertown.



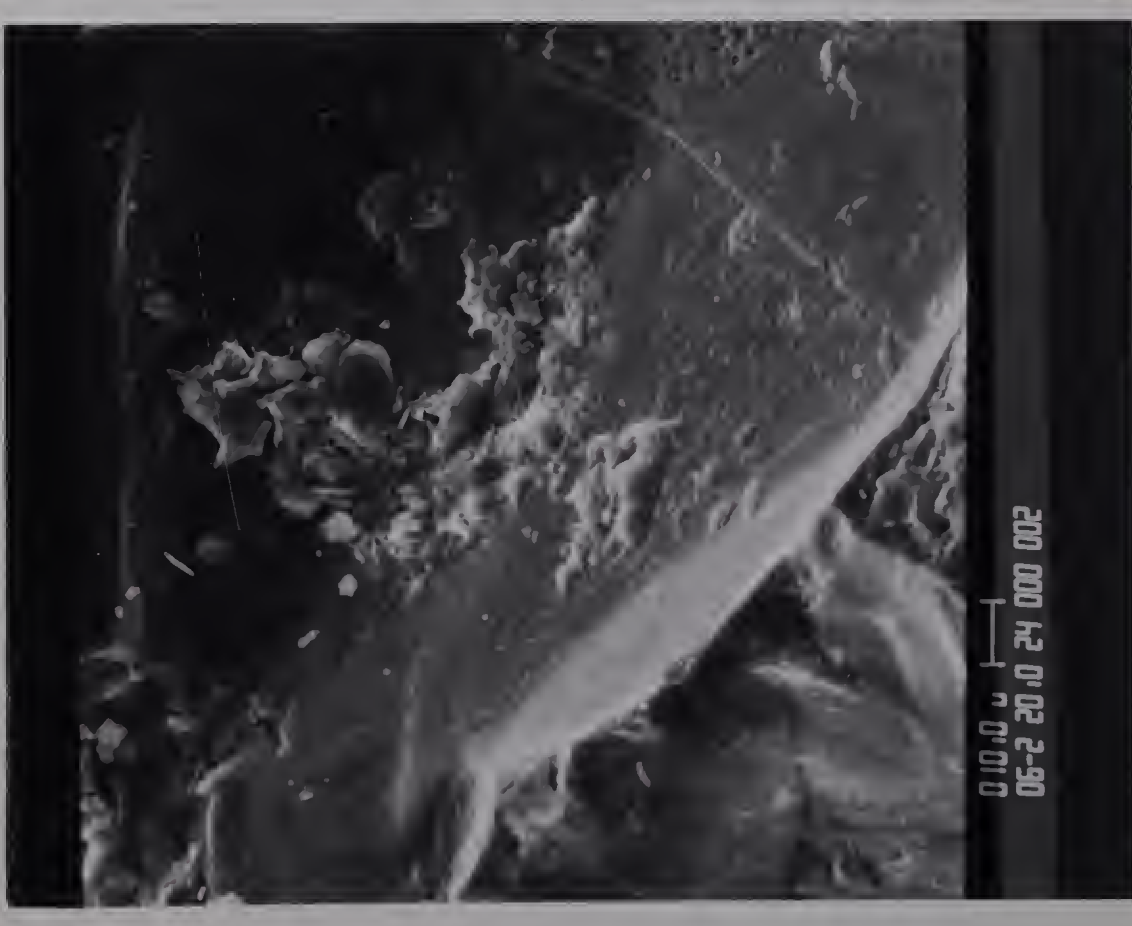


Fig. 31. SEM photograph of a very coarse sand grain taken from a deposit of lower till (70X). Note the angular shape of the grain. Sample collected from the C_x horizon at the preliminary study site in Northampton.

Fig. 32. SEM photograph of the surface of a sand grain taken from a coastal sand dune (1,400X). Note oriented etch pits and solution/precipitation smoothing of the grain surface. Sample collected from the C horizon at the Westport study site.

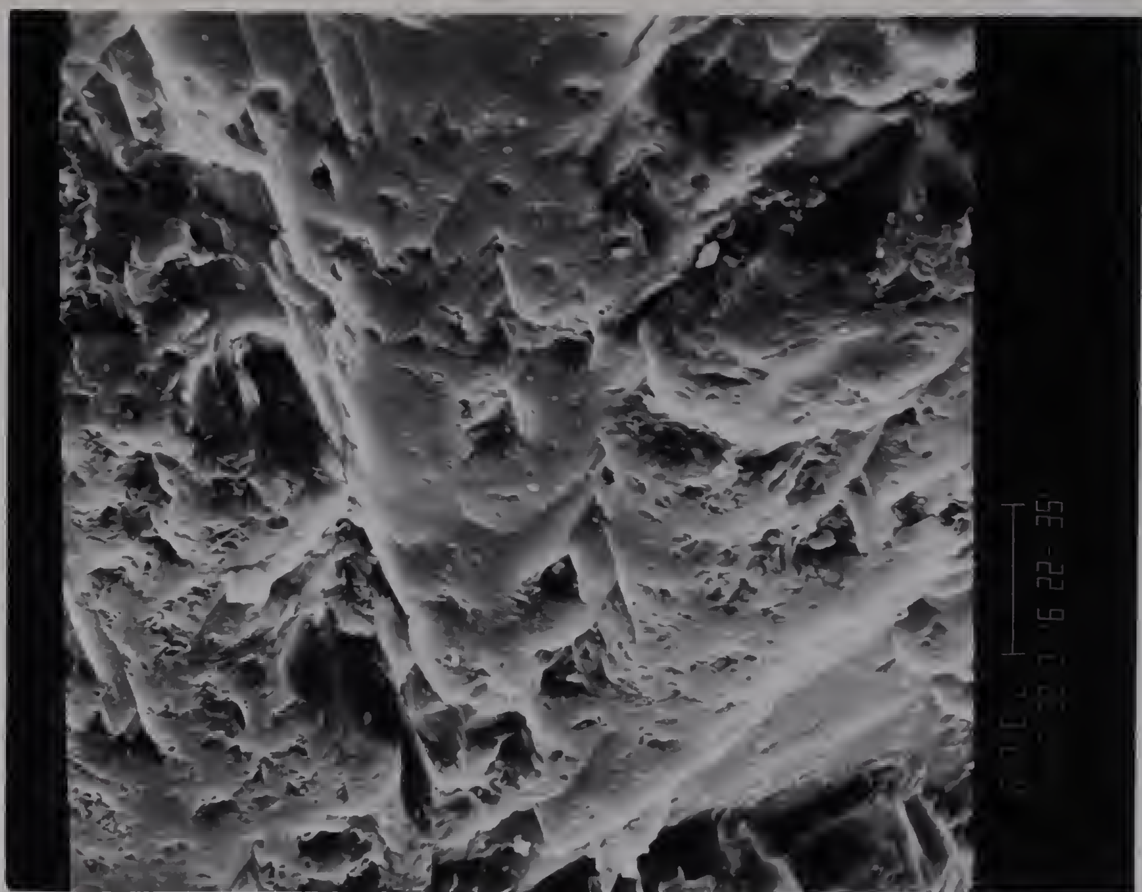


Fig. 33. SEM photograph of the surface of a sand grain taken from a coastal sand dune (500X). Note solution/precipitation smoothing of the grain surface and layered/stepped structure. Cavity in grain may represent area of intense weathering. Sample collected from the C horizon at the Westport study site.

Fig. 34. SEM photograph of the surface of a sand grain taken from a postglacial sand dune (800X). Note the upturned plates and carapace adhering to the grain surface. Sample collected from the Cb horizon at the Whately study site.

Fig. 35. SEM photograph of the surface of a sand grain taken from a postglacial sand dune (1,000X). Note the upturned plates ending in parallel steps. Sample collected from the Cb horizon at the Whately study site.

Fig. 36. SEM photograph of a coarse sand grain taken from a postglacial sand dune (120X). Note the rounded upper portion of the grain and the abundance of upturned plates on this surface. Sample collected from the Cb horizon at the Whately study site.


100.0 μ
12-1 20.0 16 222 3:2


010.0 μ
10-2 20.0 15 222 3:3

Fig. 37. SEM photograph of the surface of a sand grain taken from a postglacial sand dune (800X). Note the upturned plates and carapace adhering to the grain surface. Sample collected from the Cb horizon at the Longmeadow study site.

Fig. 38. SEM photograph of a coarse sand grain taken from a postglacial sand dune (90X). Note the subrounded shape of the grain and upturned plates covering most of the grain surface. There is a dish-shaped concavity on the upper portion of the grain. Sample collected from the Cb horizon at the Longmeadow study site.

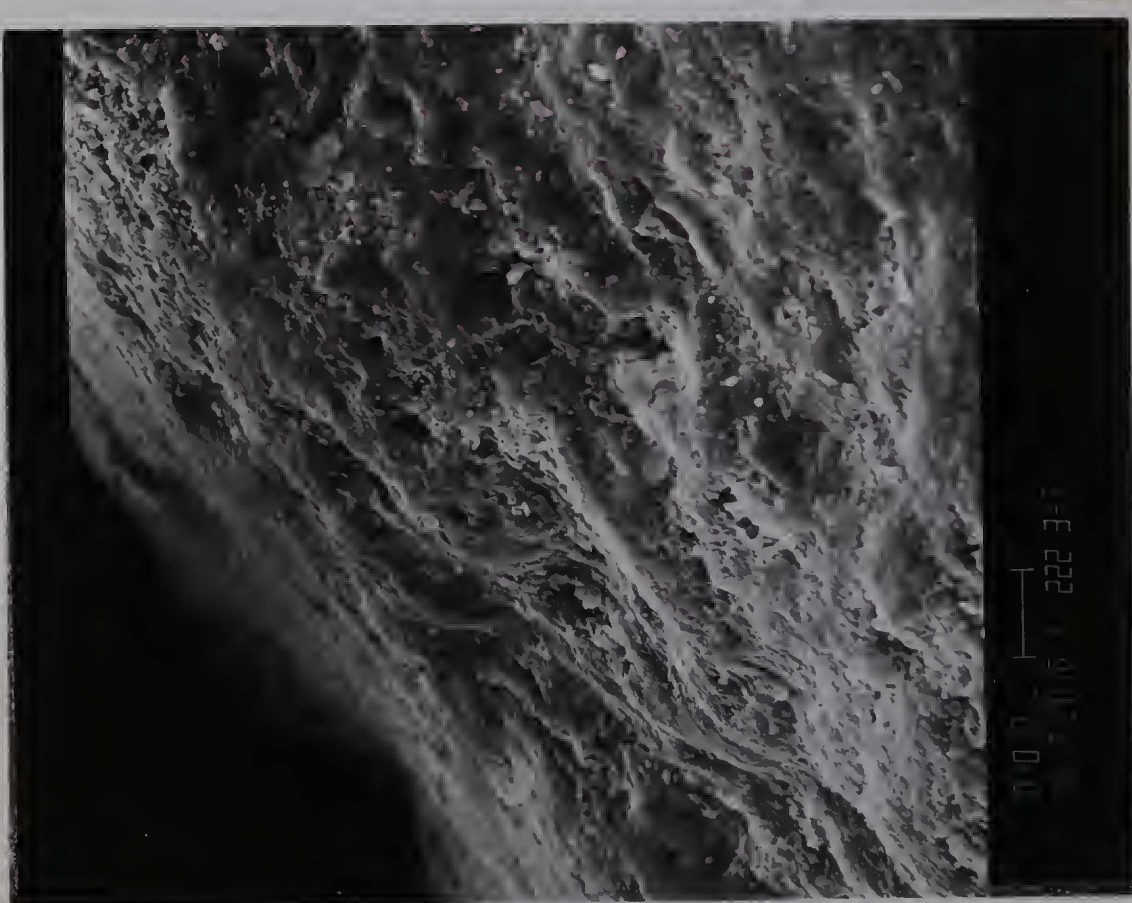


Fig. 39. SEM photograph of a coarse sand grain taken from a postglacial sand dune (100X). Note subangular shape of grain, conchoidal breakage, and rounded corners and edges with upturned plates. Sample collected from the Cb horizon at the Longmeadow study site.

Fig. 40. SEM photograph of a fine sand grain taken from an eolian mantle (200X). Note the upturned plates on some rounded corners and edges. Carapace can be seen in most of the depressions. Sample collected from the B22 horizon at the Dartmouth study site.

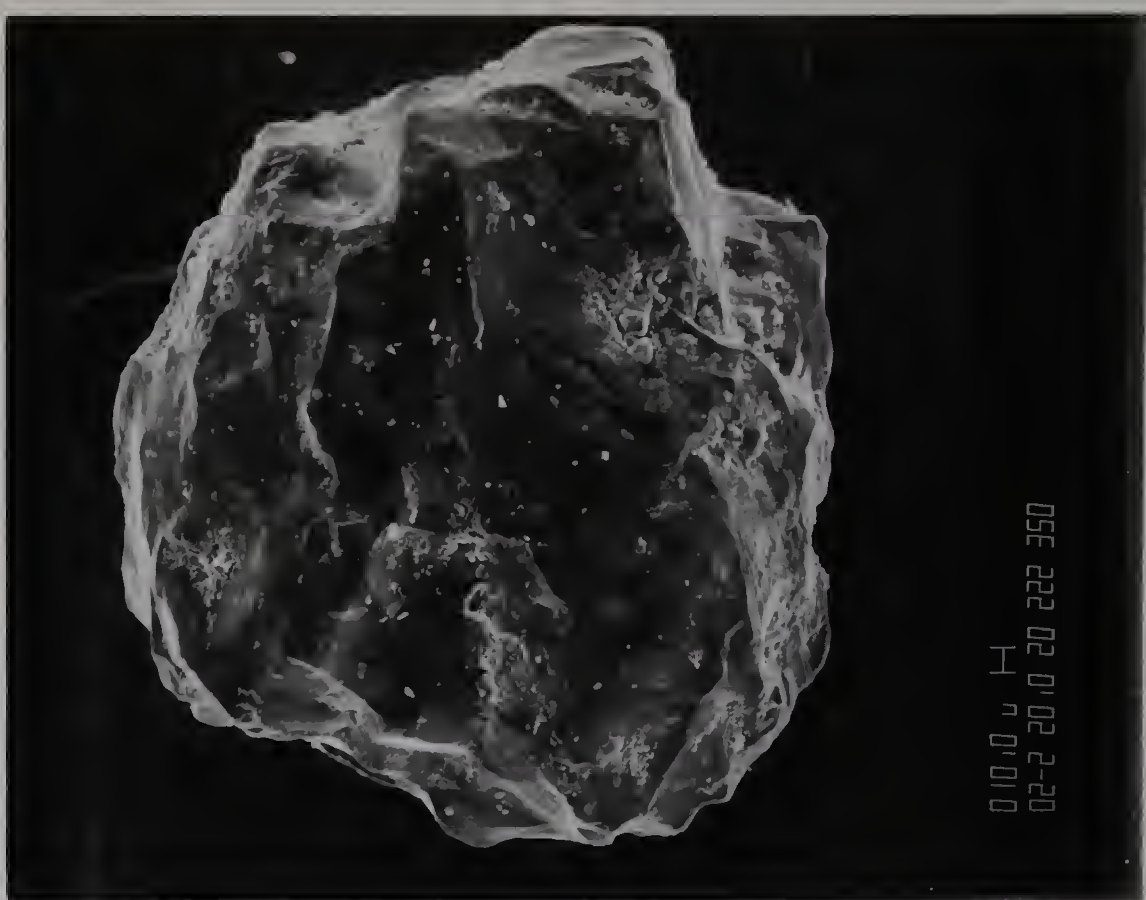
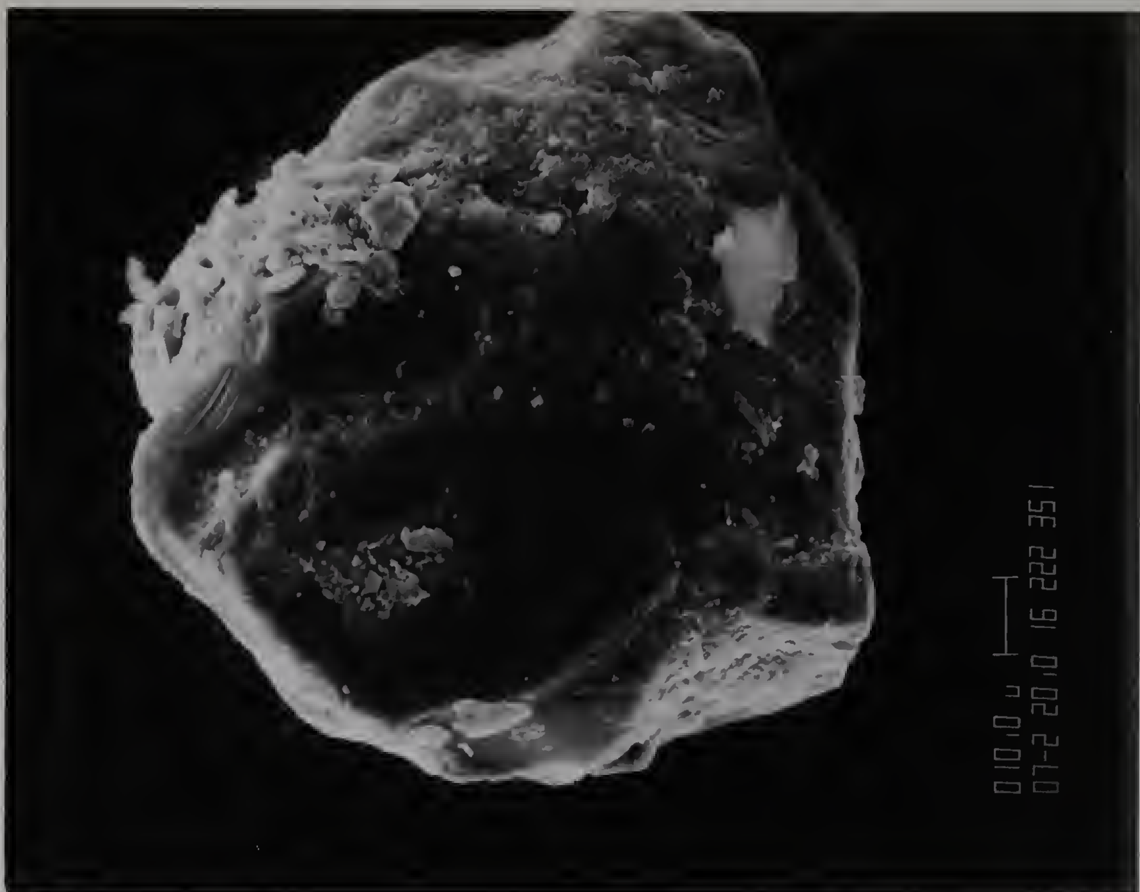


Fig. 41. SEM photograph of the surface of a sand grain taken from an eolian mantle (1,000X). Note carapace in depressions. Sample collected from the B22 horizon at the Dartmouth study site.

Fig. 42. SEM photograph of a fine sand grain taken from the eolian mantle (700X). Note the flat cleavage surface and the rounded edges and corners with upturned plates. Solution/precipitation smoothing is evident on the upturned plates and most of the grain edges. Carapace can be seen adhering to the grain surface. Sample collected from the B22 horizon at the Dartmouth study site.



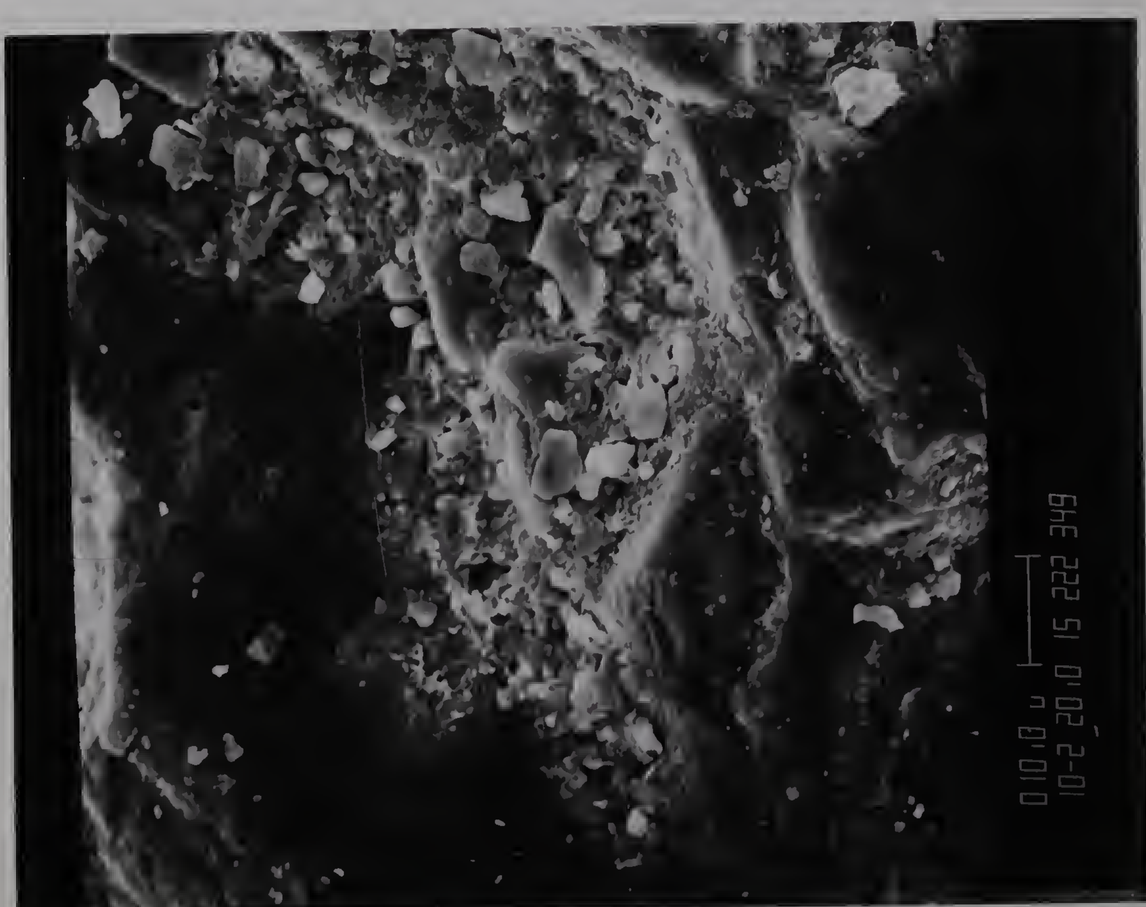


Fig. 43. SEM photograph of a coarse sand grain taken from the eolian mantle (130X). Note the rounded shape of the grain and upturned plates covering most of the grain surface. Sample collected from the C horizon at the Dartmouth study site.

Fig. 44. SEM photograph of a very fine sand grain taken from the eolian mantle (700X). Note the flat cleavage surface, parallel steps and upturned plates. Surface features have been subdued due to solution/precipitation smoothing. Sample collected from the C horizon at the Dartmouth study site.

Fig. 45. SEM photograph of a coarse sand grain taken from the upper till (90X). Note sharp angular shape and parallel steps. Sample collected from the IIC_x horizon at the Dartmouth study site.

Fig. 46. SEM photograph of the surface of a sand grain taken from the eolian mantle (1,000X). Note smoothing of upturned plates due to solution/precipitation. Sample collected from the B22 horizon at the Holyoke study site.

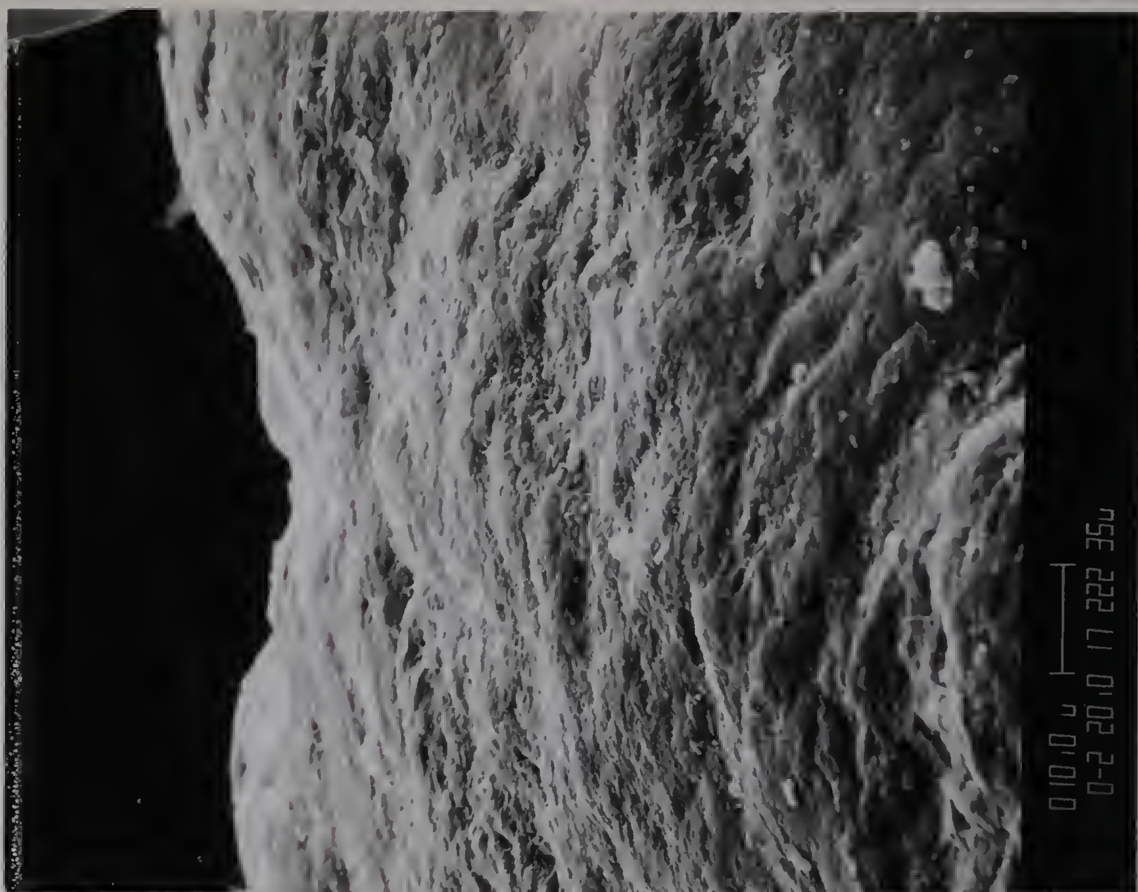
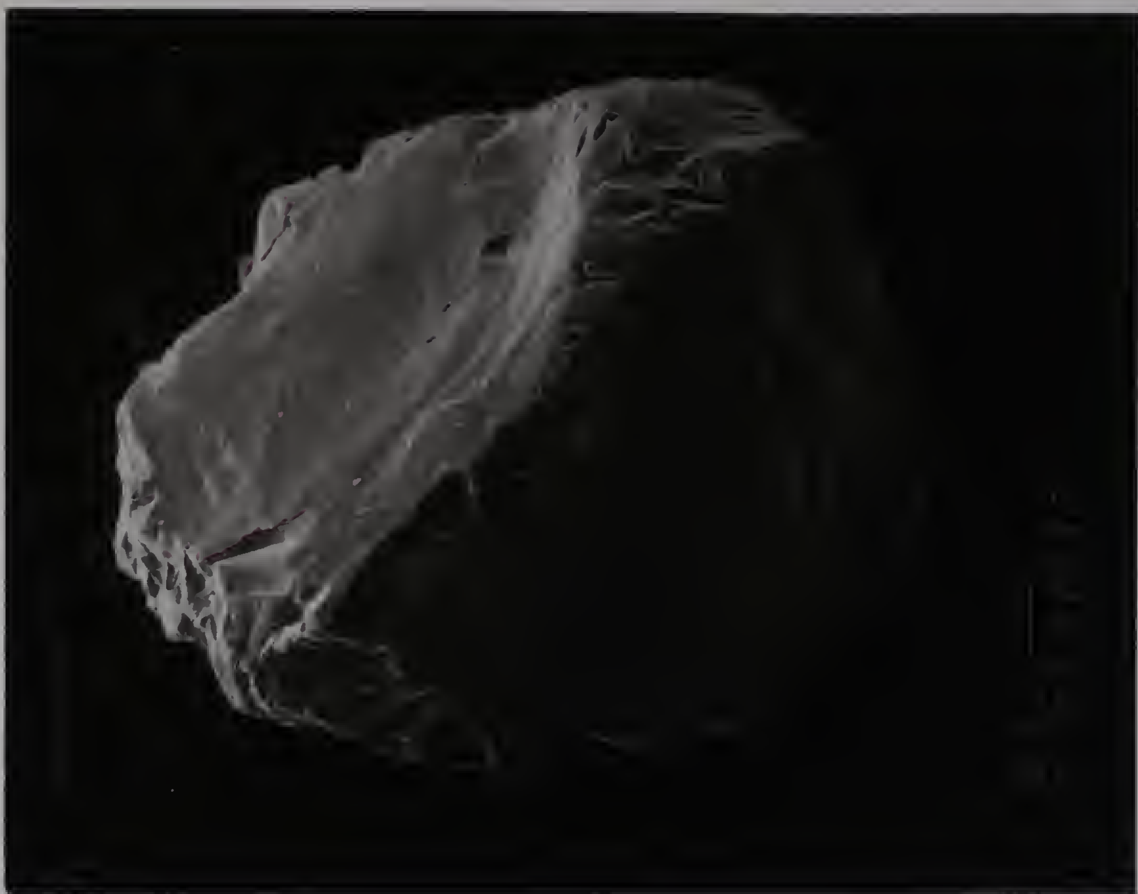


Fig. 47. SEM photograph of the surface of a sand grain taken from a glacial lake delta (500X). Note upturned plates on rounded corner and carapace adhering to the grain surface. Sample collected from the B22 horizon at the Sunderland study site.

Fig. 48. SEM photograph of a coarse sand grain taken from a glacial lake delta (70X). Note conchoidal breakage on corners and edges of grain. Sample collected from the C horizon at the Sunderland study site.



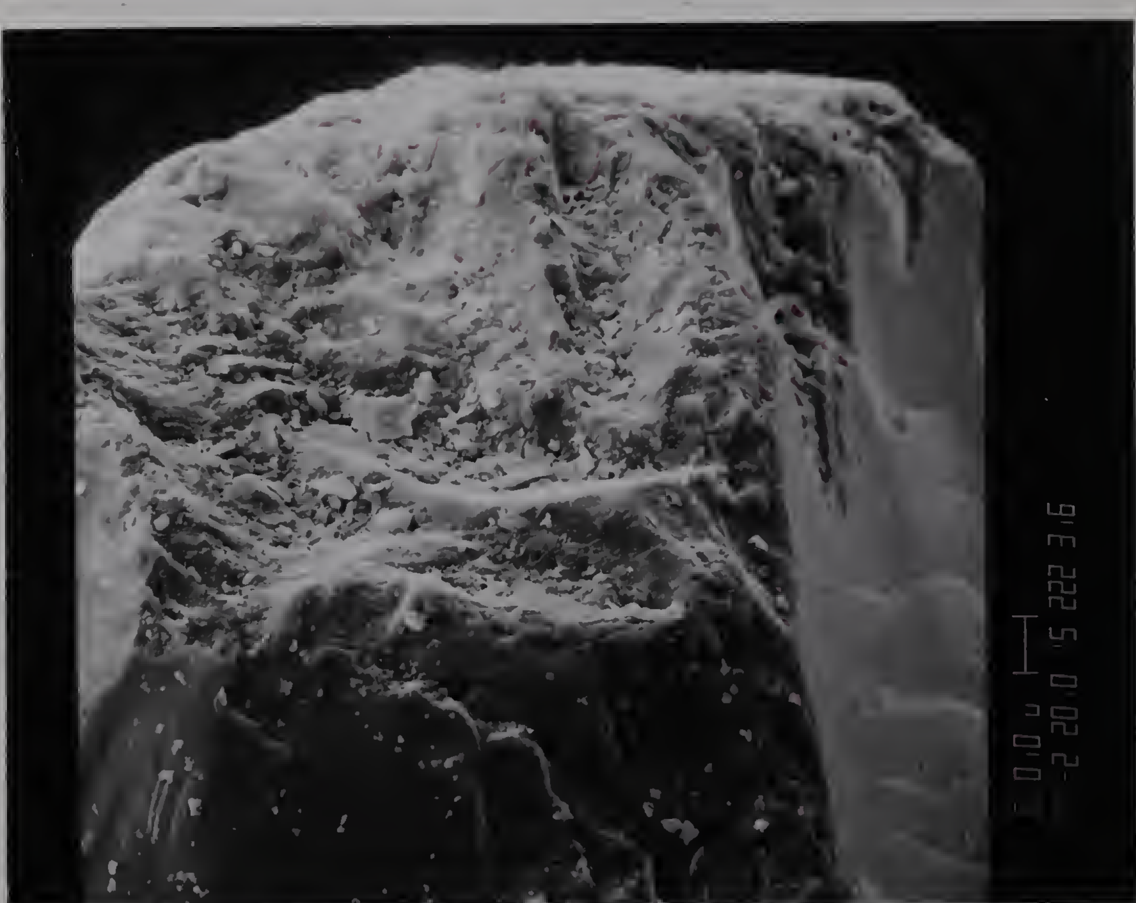


Fig. 49. SEM photograph of a coarse sand grain taken from a glacial delta (100X). Note upturned plates on some rounded corners and conchoidal breakage. Sample collected from the C horizon at the Sunderland study site.

Fig. 50. SEM photograph of the surface of a sand grain taken from a deposit of upper till (800X). Note the parallel steps and carapace adhering to the grain surface. A limited amount of smoothing due to solution/precipitation is evident. Sample collected from the IIC_x horizon at the Belchertown study site.

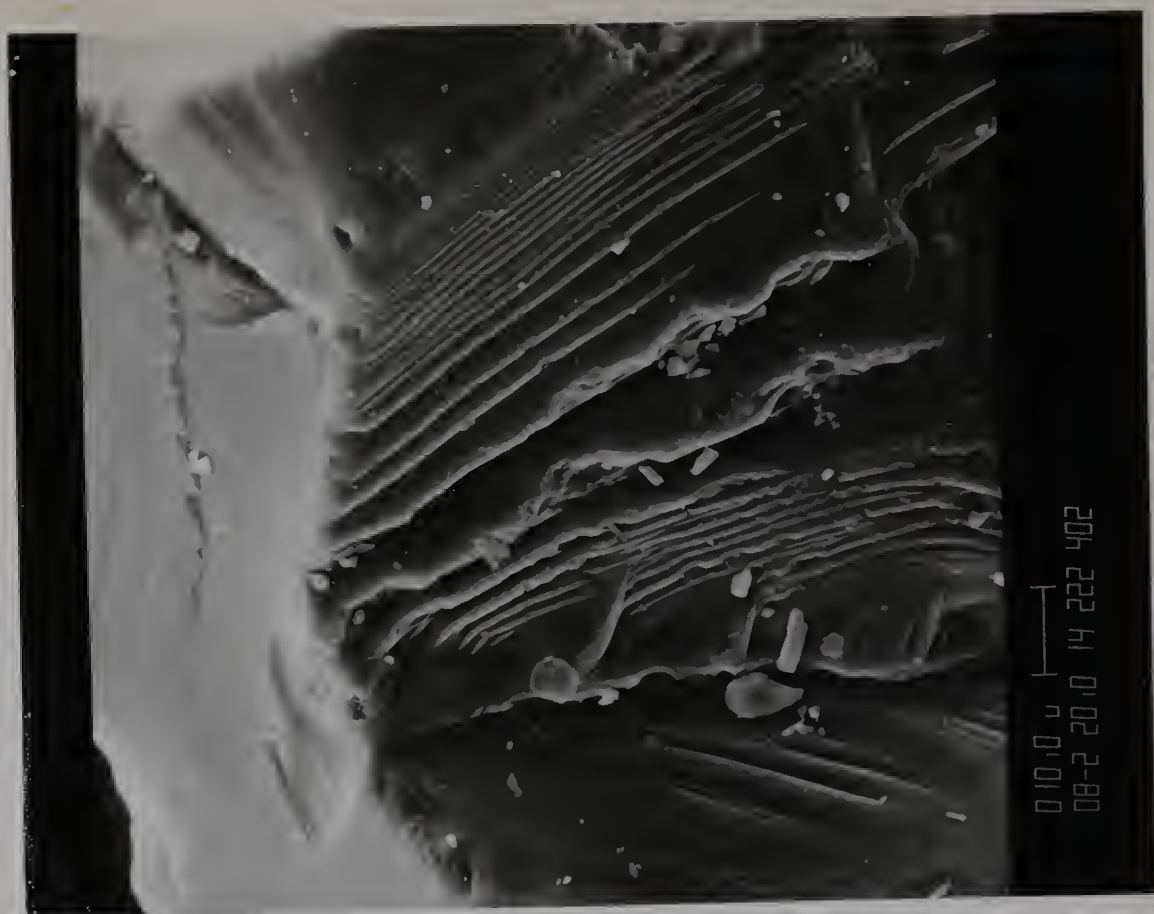

010.0 u
08-2 20.0 14 222 402

Fig. 51. SEM photograph of the surface of a sand grain taken from a deposit of upper till (150X). Note the conchoidal breakage and the upturned plates on rounded edges and corners. Sample collected from the IIC_x horizon at the Belchertown study site.

Fig. 52. SEM photograph of the surface of a sand grain taken from a deposit of lower till (700X). Angular depressions are thought to be molds indicating the former presence of other minerals that had interpenetrated the quartz surface. Sample collected from the B21 and B22 horizon at the Monson study site.

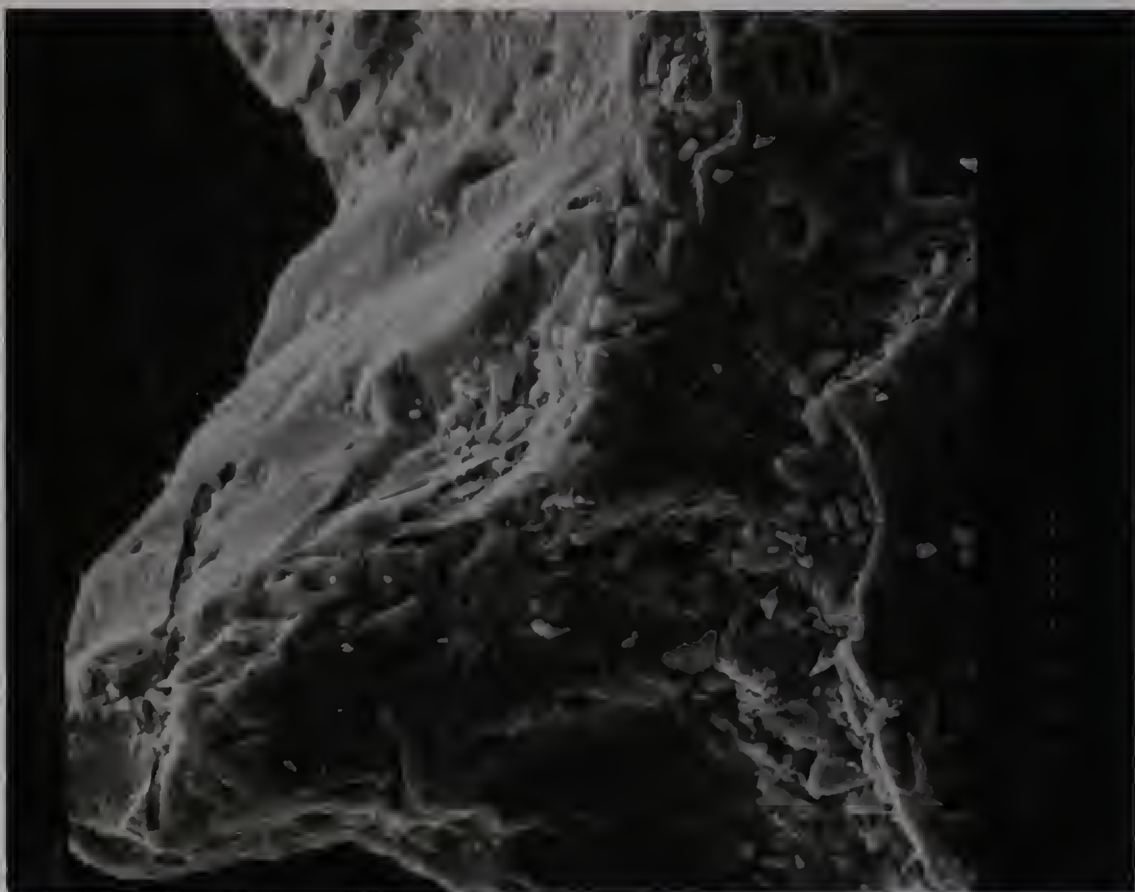
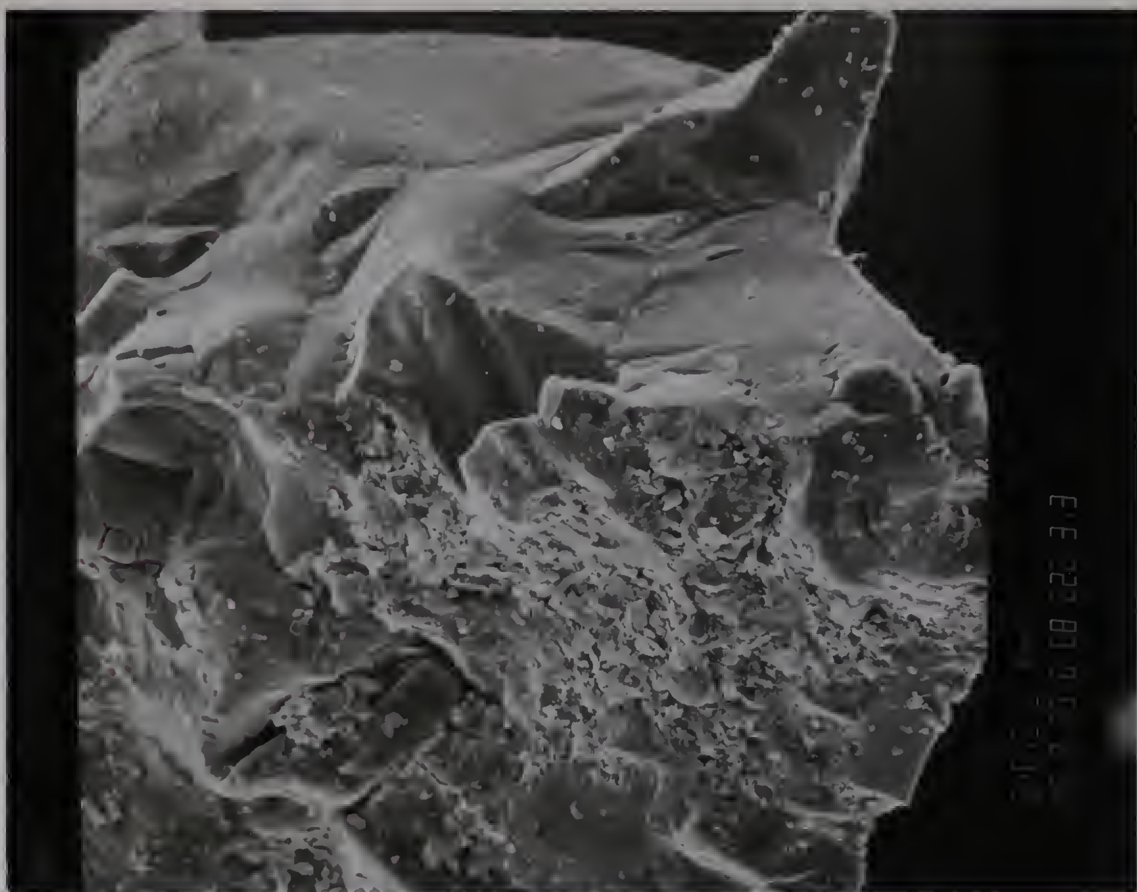


Fig. 53. SEM photograph of the surface of a sand grain taken from a deposit of lower till (100X). Note the sharp, angular shape of the grain and the abundant conchoidal fractures. Sample collected from the C_x horizon at the Monson study site.

Fig. 54. SEM photograph of the surface of a sand grain taken from a deposit of lower till (300X). Note carapace adhering to one side of the grain while the other side is almost free of carapace. Sample collected from the B21 horizon at the Spencer study site.



CHAPTER IV

DISCUSSION

Preliminary Study Sites

Samples collected from the preliminary study sites were considered to be representative samples of coastal dune sand (Truro preliminary study site), eolian mantle sediments (Nantucket preliminary study site), upper till (Belchertown preliminary study site), and lower till (Northampton preliminary study site). The surface textures of quartz sand grains taken from the above samples were viewed using a scanning electron microscope. A favorable comparison was observed between the surface features viewed on the sand grains collected from the different depositional environments (Fig. 25., 26., 27., 28., 29., 30., 31.) represented by the preliminary study sites (Fig. 4.) and the reference material reviewed prior to SEM work. Observations made on the preliminary study site samples were used as a reference for the studies done on the primary study sites.

Quartz sand grains collected from the preliminary study sites in Truro and on Nantucket Island (Fig. 4.) have surface textures that are characteristic of wind-transported grains. Earlier studies describe the surface textures of large quartz sand grains associated with wind deposition as being characterized by upturned plates, rounding of the grain (Krinsley and Cavallero, 1970; Margolis and Krinsley, 1971, 1974), and dish-shaped concavities (Krinsley and Doornkamp, 1973). All of these features were observed on most of the grains collected from the above preliminary study sites.

Surface textures observed on quartz sand grains collected from the preliminary study sites in Northampton and Belchertown (Fig. 4.) are characteristic of grains deposited by glacial ice. Krinsley and Doornkamp (1973) described sand grains associated with deposition by glacial ice as being very angular, having conchoidal fractures and flat cleavage surfaces. Arc-steps and parallel steps have also been observed on glacially derived grains (Whalley and Krinsley, 1974). Some of these features were observed on all of the grains collected from the Northampton and Belchertown preliminary study sites.

Primary Study Sites

Primary study sites were selected to show varying degrees of influence by windblown sediments. For this reason, the results from the particle-size analyses and SEM viewing varied significantly and each individual site is discussed separately rather than collectively.

Westport Study Site. The study site is located (Fig. 5.) on a vegetated coastal sand dune. The soil profile described at the site is within the range in characteristics for the soil great group, Udispamments.

Textural analysis (Table 2.) of a sample collected from the C horizon shows a very high concentration of fine sand, about 93 percent of the total sample.

A cumulative curve (Fig. 6.) plotted from the above textural analysis is characteristic of dune sand, having a single large saltation population with very small traction and suspension populations (Visher, 1969).

The surface textures of medium and fine quartz sand grains collected from the C horizon were examined using a SEM (Table 3.; Fig. 32., 33.). Most grains were subrounded or rounded in shape (Powers, 1953). Both mechanical and chemical features were observed on the grains, often occurring on the same grain but on different portions of the grain surface. Upturned plates were found on some grains. Solution/precipitation smoothing was observed on most grains and often masked other surface features. Oriented etch pits, solution pits, and layered/stepped structures were observed on some grains. The SEM studies were interpreted as showing surface features derived from two modes of transport, subaqueous and eolian. The subaqueous features are more pronounced, and are attributed to the close proximity of the site to the beach and the short distance traveled in an eolian environment.

The site location, soil profile, textural analysis and cumulative curve show deposition within an eolian environment.

Whately Study Site. The study site (Fig. 7.) is located on an active sand dune of postglacial origin which has been reactivated due to the destruction of the protective vegetative cover. The soil profile described at this site is a taxadjunct of the Windsor soil series.

Textural analyses (Table 4.) of samples collected from the C, B2b, and Cb soil horizons show a high concentration of fine sand, about 80 percent for each horizon.

The cumulative curves (Fig. 8.) plotted from the above textural analyses closely coincide with one another and are characteristic of dune sand, having a single large saltation population with small traction and suspension populations (Visher, 1969).

The surface textures of very coarse, coarse, medium and fine quartz sand grains collected from the Cb horizon were examined using the SEM (Table 5; Fig. 34, 35, 36.). Most grains were subrounded or rounded in shape (Powers, 1953). The edges and corners of the grains were chipped, commonly having upturned plates. Upturned plates were observed on many grains, covering most of the grain surface on the rounded grains. The surface features were clear and distinct, indicating minimal smoothing due to solution/precipitation. Carapace and precipitation platelets were observed on some grains. The SEM studies showed surface features derived from several modes of transport: eolian, glacial, and subaqueous. Eolian features were evident on most grains and predominant on some grains, often partly obliterating surface features derived from previous deposition environments.

The site location, soil profile, textural analyses, cumulative curves, and SEM studies all show deposition within an eolian environment.

Longmeadow Study Site. The study site (Fig. 9.) is located on a post-glacial sand dune. The soil profile described at the site is within the range in characteristics for the Windsor soil series.

Textural analyses (Table 6.) of samples collected from the B22b and Cb soil horizons show a concentration of medium sand, about 40 percent, with about 65 percent of the sample within the 0.71 mm to 0.177 mm size range.

The cumulative curves (Fig. 10.) plotted from the above textural analyses closely coincide with one another and are characteristic of dune sand, having a single large saltation population with small traction and suspension populations (Visher, 1969).

The surface textures of very coarse, coarse, medium, and fine quartz sand grains collected from the Cb horizon were examined using the SEM (Table 7.; Fig. 37., 38., 39.). Most grains were subrounded in shape; no grains were rounded (Powers, 1953). Conchoidal breakage and dish-shaped concavities were observed on some grains. Upturned plates were observed on many grains, covering most of the grain surface on some grains. Precipitation platelets and solution/precipitation smoothing were observed on some grains. The SEM studies showed surface features derived from several modes of transport: eolian, glacial, and subaqueous. Eolian features were evident on most grains and predominated on some grains, often obscuring surface features derived from previous depositional environments.

The site location, soil profile, textural analyses, cumulative curves, and SEM studies all show deposition within an eolian environment.

Dartmouth Study Site. The study site (Fig. 11.) is located in an area of ground moraine blanketed with a thick, distinct, fine textured mantle. Where the soil profile was described, the mantle was 51 inches thick and the light olive brown color of the C horizon is thought to be that of unoxidized eolian sediments. The transition between the very fine sandy loam mantle and the underlying gravelly fine sandy loam till is abrupt and irregular. The soil profile described at this site is a taxadjunct of the Broadbrook soil series.

Textural analyses were done on samples collected from the B22, B23, C, and IIC_x soil horizons (Table 8.). Significantly higher concentrations of very fine sand and coarse silt were recorded in the B22, B23, and C horizons, as opposed to a rather uniform textural distribution in the IIC_x horizon.

The cumulative curves (Fig. 12.) plotted from the above textural analyses illustrate the different degrees of sorting found within the different horizons. The C horizon is the best sorted, and its cumulative curve is characteristic of an eolian mantle. The IIC_x horizon is not as well sorted, and its cumulative curve is characteristic of a glacial till.

The surface textures of very coarse sand grains through coarse silt size grains, collected from the B22, C, and IIC_x horizons were examined using the SEM (Tables 9., 10., 11.; Fig. 40., 41., 42., 43., 44., 45.). Grains collected from the B22 and C horizons were subangular to rounded in shape (Powers, 1953). Upturned plates were observed on the rounded corners and edges of many grains, and covered most of the grain surface on the rounded grains. Dish-shaped concavities were observed on some grains. The SEM studies were interpreted as showing surface features derived from the two modes of transport, eolian and glacial. Features of the subaqueous environment are difficult to differentiate from incipient eolian features and glacial till features, and may be present. Eolian features were evident on most grains and predominant on some grains, often obscuring surface features derived from previous depositional environments.

Grains collected from the IIC_x horizon were mostly angular or subangular in shape (Powers, 1953). Many grains had conchoidal breakage and arc-steps. Upturned plates were observed on some of the grains, and covered most of the grain surface of a few rounded grains. The few rounded grains found in the IIC_x horizon are thought to have either moved down through the profile or were mixed with the underlying till. Other than the few rounded grains, SEM studies clearly indicated surface textures related to direct glacial deposition.

The soil profile, textural analyses, cumulative curves, and SEM studies done on samples collected from the B22 and C horizons all strongly indicate deposition within an eolian environment. Studies done on the sample collected from the IIC_x horizon indicate deposition by glacial ice.

Holyoke Study Site. The study site (Fig. 13.) is located on a thick pocket of compact till in a bedrock area with many rock outcrops. A fine textured mantle overlies the compact till. The soil profile described at this site is a taxadjunct of the Broadbrook soil series.

Textural analyses (Table 12.) were done on samples collected from the B21, B22 and IIC_x horizons. There were higher concentrations of silt in the B21 and B22 horizons, as opposed to lower concentrations within the IIC_x horizon. However, no significantly high concentrations of particles were recorded within any of the individual sieve intervals and the particles were distributed rather uniformly throughout the sieve intervals within the silt and very fine sand size ranges.

The cumulative curves (Fig. 14.) plotted from the above textural analyses illustrate the relatively even distribution of particles in the sample, showing only a slight increase in the concentration of coarse silt in the B21 horizon.

The surface textures of very coarse sand grains through coarse silt size grains, collected from the B21 and IIC_x horizons, were examined using the SEM (Tables 13., 14.; Fig. 46.). Grains from the B21 horizon ranged in shape from angular to subrounded and were generally more rounded than the grains examined from the IIC_x horizon. Upturned plates were observed on a greater percentage of grains collected from the B21 horizon and were generally located on the rounded corners and edges. The SEM studies showed surface features derived from two modes of transport, eolian and glacial. Similar surface features were observed in both horizons, but features characteristic of an eolian environment, mainly upturned plates, were more prevalent in the B21 horizon.

The soil profile, textural analyses, cumulative curves, and SEM studies indicate the presence of a windblown component that has been mixed with the underlying glacial till.

Deerfield Study Site. The study site (Fig. 15.) is located in an area of shallow soils underlain by bedrock. A thin (19 inches thick) fine textured mantle overlies the bedrock. The soil profile described at the site is within the range in characteristics for the Hollis soil series.

A textural analysis (Table 15.) was done on a sample collected from the B2 soil horizon. A slightly higher concentration of coarse silt was recorded, with the remaining particles distributed rather evenly throughout the textural range.

The cumulative curve (Fig. 16.) plotted from the above textural analysis illustrates the even distribution of particles in the sample, showing only a slight increase in the concentration of coarse silt.

The surface textures of very coarse, coarse, medium, and fine quartz sand grains were examined using the SEM (Table 16.). Most grains were subangular or subrounded in shape (Powers, 1953). Upturned plates were observed on many grains, generally on rounded corners and edges. A few grains had upturned plates covering most of the surface. The results from SEM studies strongly indicate deposition within an eolian environment.

The site location, soil profile, textural analysis, and cumulative curve support the SEM findings, but are inconclusive if studied separately.

Sunderland Study Site. The study site (Fig. 17.) is located near the outer edge of a glacial lake delta. A fine textured mantle is present and some mixing with the underlying glacial outwash is apparent. The soil profile described at this site is a taxadjunct of the Merrimac soil series.

Textural analyses (Table 17.) were done on the B21 and IIC soil horizons. An increase in very fine sand and coarse silt was detected in the B21 horizon. The remaining particles were distributed rather evenly throughout the textural range. The concentration of coarse and medium sands in the C horizon is the result of sorting by water.

The cumulative curves (Fig. 18.) plotted from the above textural analyses illustrate the concentrations of sediments found in both horizons.

The surface textures of very coarse, coarse, medium, and fine quartz sand grains, collected from the B21 and C horizons, were examined using the SEM (Tables 18., 19.; Fig. 47., 48., 49.). Very coarse and coarse sand grains studied from the B21 horizon ranged in shape from angular to subangular. Medium and fine sand grains from the B21 horizon and the grains examined from the C horizon were angular to subangular in shape (Powers, 1953). Upturned plates were observed on some of the grains taken from the B21 horizon and a few of the grains collected from the C horizon. When present on a grain, the upturned plates were generally found on the rounded corners and edges. SEM studies indicate incipient eolian surface features, as shown by the more frequent occurrence of upturned plates in the B21 horizon.

None of the data studied separately are conclusive as to the origin of the sediments found in the solum. Studied collectively, all of the data indicate the presence of a possible windblown component that was mixed with the underlying coarse sediments.

Belchertown Study Site. The study site (Fig. 19.) is located in an area of ground moraine. A fine textured mantle overlies a light colored, gravelly loamy sand till. The soil profile described at the site is a taxadjunct of the Montauk soil series.

Textural analyses (Table 20.) were done on samples collected from the B21, B22, and IIC_x soil horizons. The silt content in both the B21 and B22 horizons was higher, averaging about 30 percent, than that found in the IIC_x horizon, about 18 percent. Sand size grains were distributed rather uniformly throughout each horizon and the concentrations were similar between the different horizons.

The cumulative curves (Fig. 20.) plotted from the above textural analyses illustrate the rather uniform distribution of particles within individual horizons and the textural similarities between the horizons. A slight rise in the curve in the B21 and B22 horizons represents the higher concentration of silt.

The surface textures of very coarse, coarse, medium, and fine quartz sand grains collected from the B22 and IIC_x horizons were examined using the SEM (Tables 21., 22.; Fig. 50., 51.). Grains were more rounded in the B22 horizon ranging in shape from angular to subrounded, as opposed to angular and subangular shaped grains found in the IIC_x horizon. Upturned plates were more common on the grains viewed from the B22 horizon. Generally upturned plates were only observed on the rounded edges and corners of grains taken from both horizons. Two medium sand grains observed from the B22 horizon had abundant upturned plates covering most of the grain surface. SEM studies were interpreted as showing surface features derived from two modes of transport, eolian and glacial. Similar surface features were observed in both horizons but features characteristic of an eolian environment, mainly upturned plates, were more prevalent in the B21 horizon.

Studied collectively, all of the data indicate the presence of a possible windblown component that was mixed with the underlying coarse sediments.

Monson Study Site. This study site (Fig. 21.) is located on a drumlin in an area of compact lower till. There was no evidence of a surface mantle and the solum and substratum had similar textures. The soil profile described at the site is within the range in characteristics for the Paxton soil series.

Textural analyses (Table 23.) were done on samples collected from the B21-B22, B22, and C_x soil horizons. There were no concentrations of particles within any of the horizons and they were distributed throughout the textural range. The textural similarity between the three horizons was striking.

The cumulative curves (Fig. 22.) plotted from the above textural analyses illustrate the rather uniform distribution of particles within the individual horizons and the textural similarities between the horizons.

The surface textures of very coarse, coarse, medium, and fine quartz sand grains from the B21-B22 and C_x horizons were examined using the SEM (Tables 24., 25.; Fig. 52., 53.). Most grains viewed from these horizons were angular or subangular in shape (Powers, 1953). No significant differences in mechanical surface features were observed between the B21-B22 and C_x samples. Many grains had conchoidal breakage and some grains had flat cleavage surfaces. Upturned plates were observed on only a few grains and were generally observed on rounded corners and edges. Only surface features associated with deposition by glacial ice were observed in both horizons. No evidence of eolian activity was observed. The significance of carapace adhering to many grains in the B21-B22 horizon and few grains in the C_x horizon is not understood.

All of the data collected show strong similarities between the solum and the substratum, with no evidence of any windblown component present.

<u>Spencer Study Site</u>. This study site (Fig. 23.) is located on a drumlin

in an area of compact lower till. There was no evidence of a mantle, and the solum and substratum have similar textures. The soil profile described at the site is within the range in characteristics for the Paxton soil series.

Textural analyses (Table 26.) were done on samples collected from the B21, B22, and C_x soil horizons. There were no concentrations of particles within any of the horizons and the grains were distributed throughout the textural range. The textural similarity between the three horizons was striking.

The cumulative curves (Fig. 24.) plotted from the above textural analyses illustrate the rather uniform distribution of particles within the individual horizons and the textural similarities between the horizons.

The surface textures of very coarse, coarse, medium, and fine quartz sand grains were examined from the B21 and C_x horizons using the SEM (Tables 27., 28.; Fig. 54.). Most grains viewed from both horizons were angular or subangular in shape (Powers, 1953). No significant differences in mechanical surface features were observed between the B21 and C_x horizons. Many grains had conchoidal breakage and a few grains had flat cleavage surfaces. Upturned plates were observed on a few grains and were generally observed on rounded corners and edges. Some grains, from both horizons, appear to be more chemically weathered on some portions of the grains. Only surface features associated with deposition by glacial ice were observed in both horizons. No evidence of eolian activity was observed. The significance of carapace adhering to many grains in the B21 horizon and a few grains in the C_x horizon is not understood.

All of the data collected show strong similarities between the solum and the substratum, with no evidence of any windblown component present.

CHAPTER V

CONCLUSIONS

As indicated in previous studies, the presence, amount, and character of windblown sediments in Massachusetts soils vary throughout the Commonwealth. The coastal dune (Westport study site) and the postglacial dunes (Longmeadow and South Deerfield study sites) were the most characteristic of eolian sediments studied, and both the cumulative curves and the quartz sand surface textures were diagnostic of windblown sediments. Where the eolian mantle was thick and relatively little mixing had occurred with the substratum (Dartmouth study site), the data were also conclusive and clearly indicated deposition within an eolian environment. Areas where the mantle was thin and less distinct (Holyoke, Deerfield, Sunderland, and Belchertown study sites), the data were less diagnostic and indicated a windblown component mixed with the substratum. Data collected from areas with no evidence of a mantle (Monson and Spencer study sites) indicated that the surface soil was developed from the underlying substratum, and no windblown component was detected in the testing.

Both the cumulative curves and surface textures of the quartz sand grains proved to be very satisfactory methods for detecting a windblown component in the soil. Scanning electron microscope studies of the surface textures were more definitive where the windblown sediments were mixed with the underlying substratum.

It is felt that more conclusive statements and more interpretations could have been made about the surface textures of the quartz sand grains if a larger number of samples were examined and more time was available for the use of the scanning electron microscope. SEM research on the surface textures of quartz sand grains deposited by meltwater streams is lacking. Due to the importance of outwash deposits as source areas for the windblown sediments in Massachusetts, additional research is needed to make more valid comparisons.

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