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SOIL DEVELOPMENT AND CLAY MINERAL COMPOSITION OF PRE-LATE WISCONSIN TILL UNITS IN NORTHEASTERN CLARK AND SOUTHEASTERN TAYLOR COUNTIES, WISCONSIN

by

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ABSTRACT

Recent mapping of pre-late Wisconsin till units in northeastern Clark and southeastern Taylor Counties has defined the areal and subsurface distribution of four distinct lithostratigraphic units. These till units range in age from possibly Early Pleistocene or Late Pliocene to Late Pleistocene. Three of these units occur at the surface: the Merrill and Bakerville Members of the Lincoln Formation and the Edgar Member of the Marathon Formation. The fourth unit, the Medford Member of the Marathon Formation, occurs only in the subsurface.

In an attempt to infer the relative ages of the geomorphic surfaces, the morphological, physical, and chemical parameters of the till units and selected soils developed on each of the three surficial till units were examined. The types and relative abundance of clay minerals in the soils are poorly related to the age of the underlying parent material. The proximity of several till surfaces of varying ages in this region should provide an excellent opportunity to study the degree of soil development and the intensity of weathering as a function of time.

Within both the soil profiles and the till, the clay minerals do not demonstrate increasing weathering with an increase in the age of the geomorphic surface. Differences in gross clay mineralogy are minimal, with only slight changes in relative species abundance noted. Neither the clay mineralology or the extractable iron oxides show a progression in pedogenic development with time. The duration of weathering is difficult to estimate because the profiles are polygenetic, and the landscape has undergone burial by late Wisconsin loess. The homogeneity in the physical and chemical parameters of these selected soils and till units in north-central Wisconsin is attributed to the presence of permafrost and periglacial conditions during the Pleistocene.

While the evidence for periods of permafrost is well documented at nearby locales, specific examples of periglacial features have eluded workers studying the pre-late Wisconsin surface in Clark and Taylor Counties thus far. Permafrost and periglacial processes presumably dominated much of Wisconsin during not only late Wisconsin time but during previous glacial episodes as well. Solifluction and repetitive freeze-thaw cycles presumably contributed to accelerated hillslope processes that stripped substantial quantities of sediment from the landscape and reworked and homogenized the upper few meters of unconsolidated sediment.

ACKNOWLEDGEMENTS

Just as a ship cannot sail without its crew, this thesis would not have floated without the enlisted help from others. I wish to extend my appreciation to my committee members who included; Dave Mickelson, John Attig, Fred Madison, and Dana Geary. They provided the necessary support and guidance during my tenure as a Masters candidate.

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CHAPTER ONE

INTRODUCTION

Description of the Area

Geographic Setting

The prominent late Wisconsin terminal moraine that traverses Taylor County from southwest to northeast was deposited by ice that retreated approximately 15,000 years ago. The pre-late Wisconsin glacial deposits found beyond the maximum extent of late Wisconsin ice have been collectively referred to as the "Border drifts" or "extra-morainic drifts" by numerous workers (Hole 1943, Stewart 1973, Mode 1976). This thesis examines the relationships between the characteristics of surface soils and the pre-late Wisconsin till surfaces on which they formed.

Samples of both glacial sediment and soil profiles were collected from northeastern Clark and southeastern Taylor Counties in north-central Wisconsin (figure 1.1). The samples were collected within an area bounded by County Trunk O in Clark County on the west, the Clark-Taylor and Marathon County lines on the east, the southernmost late Wisconsin terminal moraine of the Chippewa lobe on the north, and the southern edge of T28N in Clark County on the south.

Previous Geologic Investigations

The origin, age and exact number of pre-late Wisconsin till units

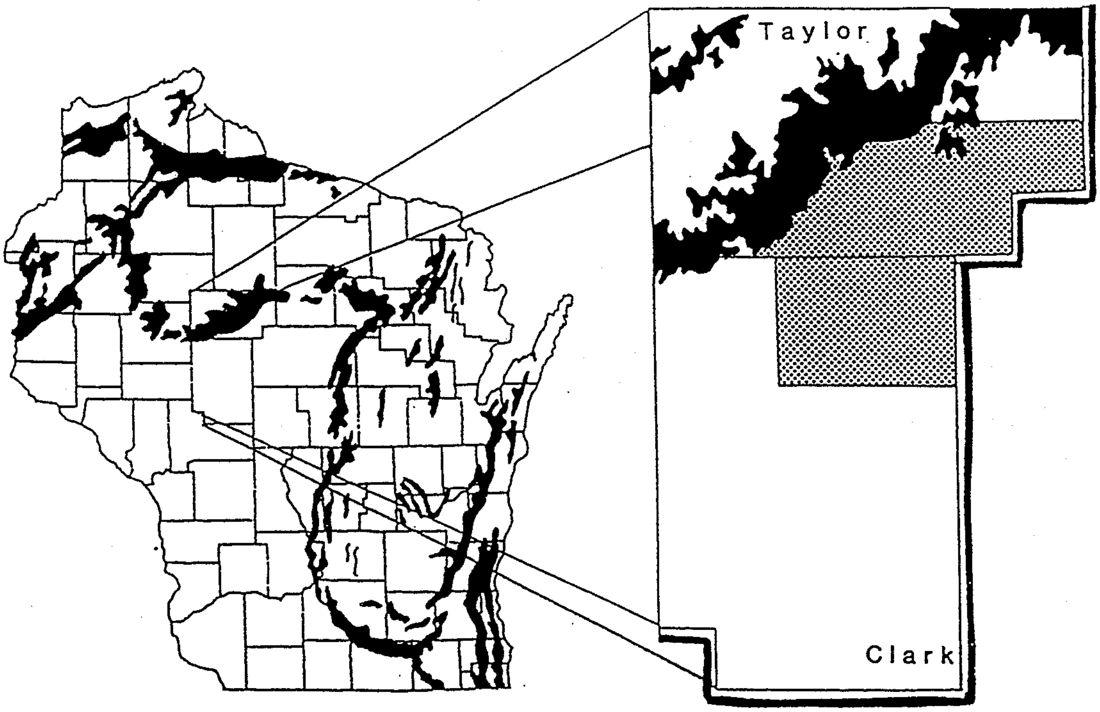


Figure 1.1: Location of the study area with respect to the late Wisconsin moraine system in Wisconsin.

in north-central Wisconsin has been debated for nearly a century. Two investigators (Hole, 1943; Olup, 1969) proposed that the area outside the late Wisconsin end moraines is covered by deposits from a single ice advance. Yet another group (Stewart, 1973; Mode, 1976; Attig and Muldoon, in press) supported the idea of multiple ice advances in north-central Wisconsin. Many ages have been proposed for these deposits. Due to the lack of datable materials such as wood, organic material, carbonate, loess, or paleosols beneath till, geologists have struggled to assign precise ages to the units of this area.

The following is a synopsis of the major studies which have been conducted on the pre-late Wisconsin surface in north-central Wisconsin. A more in-depth discussion of the pertinent literature is contained in Mode (1976) and Ferreira (1980).

The initial geologic investigations of the area were strictly of a reconnaissance nature. One of the first comprehensive geologic surveys that addressed the Quaternary geology in Clark and Taylor Counties was that of Weidman (1907). Weidman initially proposed three drifts and one late Wisconsin unit in north-central Wisconsin (figure 1.2) based on criteria such as the average thickness of the deposit, the degree and depth of subaerial weathering as evidenced by color and clay content of the drift, the presence or absence of swamps and sag and swale topography and the areal extent of each drift unit. The units were named the First, Second, Third and Wisconsin drifts respectively, with the First drift being the oldest. Weidman believed that each

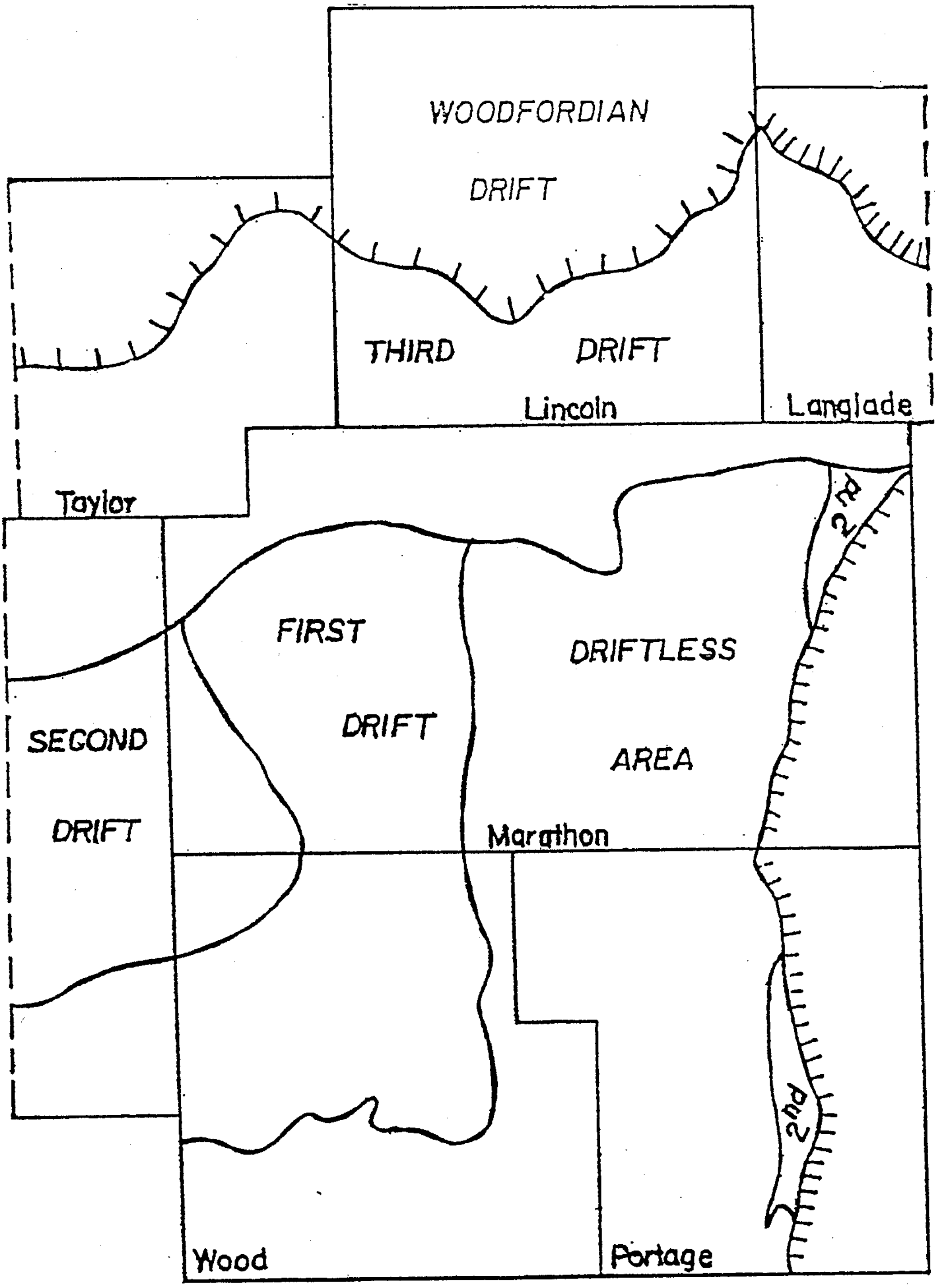


Figure 1.2: Areal distribution of drift units in north-central Wisconsin as mapped by Weidman (from Stewart, 1973).

drift represented a separate ice advance and proposed the following ages for the units:

First Drift:	either pre-Kansan, sub-Aftonian or earlier
Second Drift:	either Kansan or pre-Kansan
Third Drift:	either Iowan or early Wisconsin
Wisconsin Drift:	Wisconsin

Hole (1943) was the first to attempt a detailed quantitative analysis of the pre-late Wisconsin till units. Based on field studies in nine north-central Wisconsin counties, Hole supported an earlier idea (Leverett, 1899) that suggested the existence of only one continuous unit which lay outside the prominent series of end moraines in Wisconsin. Hole called this unit the "Border drift" and believed it to be Wisconsin age (figure 1.3). His conclusion that there is a single Border drift was based on the following reasoning:

1. The thickening of the Border drift from south to north is gradual and irregular. Such thickening could have been produced by the retreat of a single ice mass.
2. There are no Border drift terminal moraines.
3. No till has been found beneath buried soils. Sand silt, and gravel have been encountered beneath the Border drift.
4. Most of the erratics are equally unweathered throughout the Border drift.
5. Red-brown colored drift occurs in the southern Border drift areas as well as in the north. This is another indication that the heterogeneity of the Border drifts does not give evidence of any zonal or regional discontinuities.

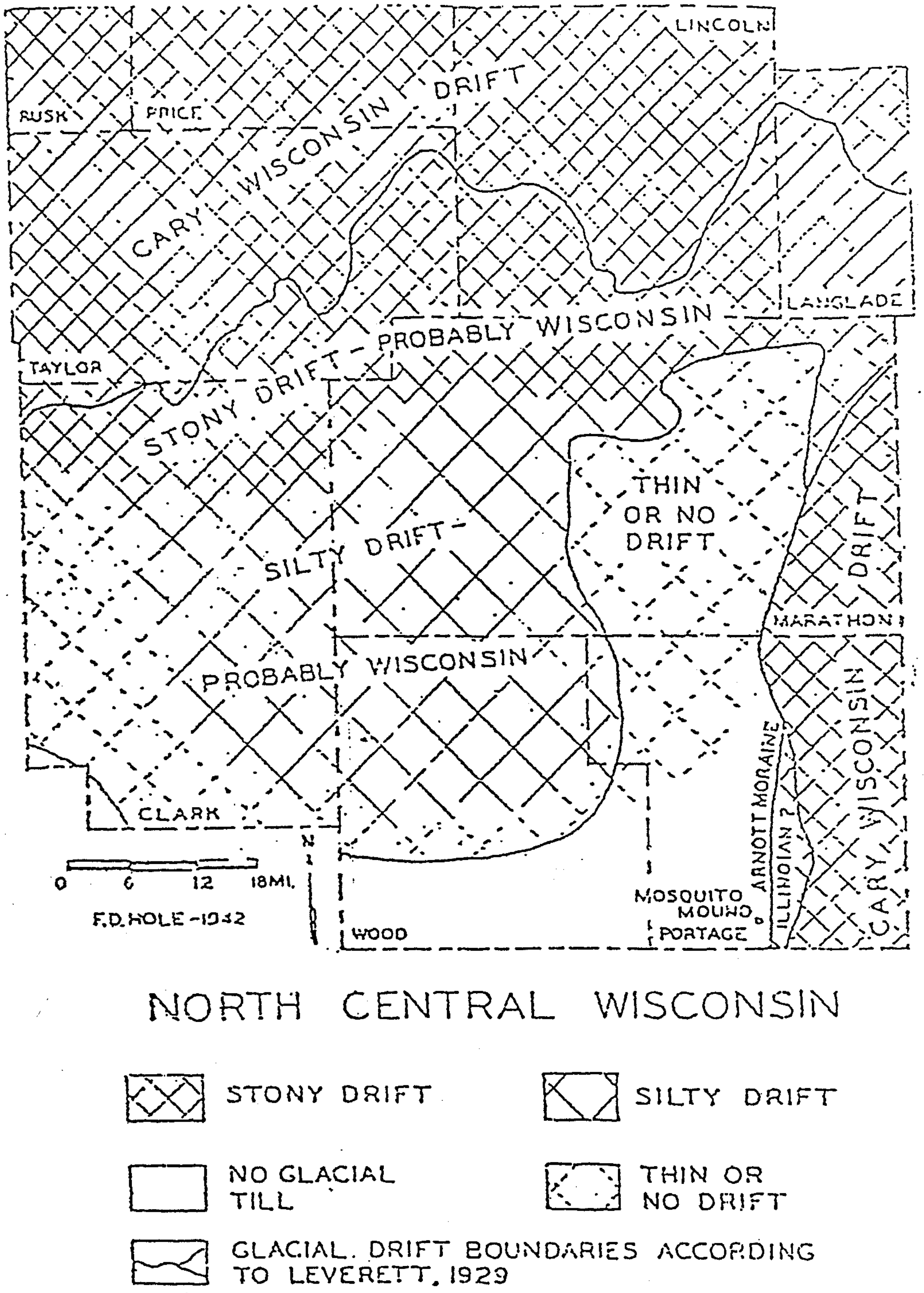


Figure 1.3: Areal distribution of drift units in north-central Wisconsin as mapped by Hole (from Hole 1943).

Olup (1969) sought to petrologically characterize the till of northern Marathon County in an attempt to determine which of the stratigraphic classification schemes proposed by previous workers was correct. Thirty nine till samples were obtained from 2 to 3 foot-deep, hand-dug pits. Based on laboratory analysis of pebble lithology and carbonate content of these samples, Olup concluded that the First, Second, and Third drifts proposed by Weidman (1907) are lithologically the same and should be considered as one continuous surficial till unit. Olup did, however, acknowledge that analysis of the sand, silt, and clay percentages as well as the median grain diameters from samples collected, supported the idea of lithologically distinct till units.

Stewart (1973) further quantified characteristics of till units in Lincoln, Langlade, and northern Marathon Counties (figure 1.4). Primarily using detailed semi-quantitative clay mineral determinations, Stewart concluded that pre-late Wisconsin till could be readily distinguished from late Wisconsin till. Using pebble lithologies and semi-quantitative clay mineralogy, he also demonstrated that distinct differences occur between two pre-late Wisconsin till units (Merrill and Wausau). More recently, Mode (1976) delineated four till units in western Marathon county as well as portions of eastern Clark and northern Wood Counties (figure 1.5). In order of ascending age these are the Wausau, Edgar, Bakerville and Merrill till units. The distribution of these units is similar to that of Weidman's (figure

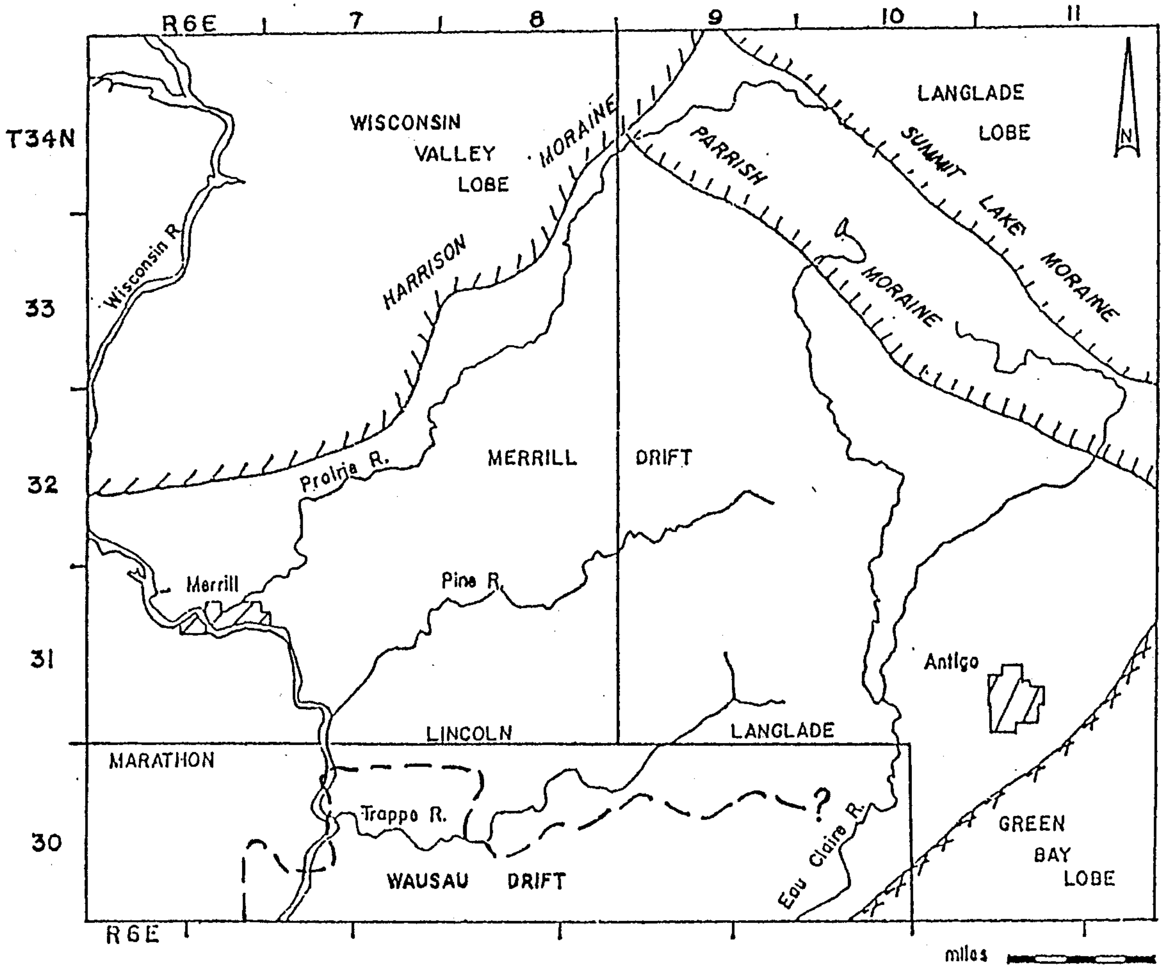


Figure 1.4: Drift distribution in parts of Lincoln, Marathon and Langlade Counties as mapped by Stewart (from Stewart, 1973).

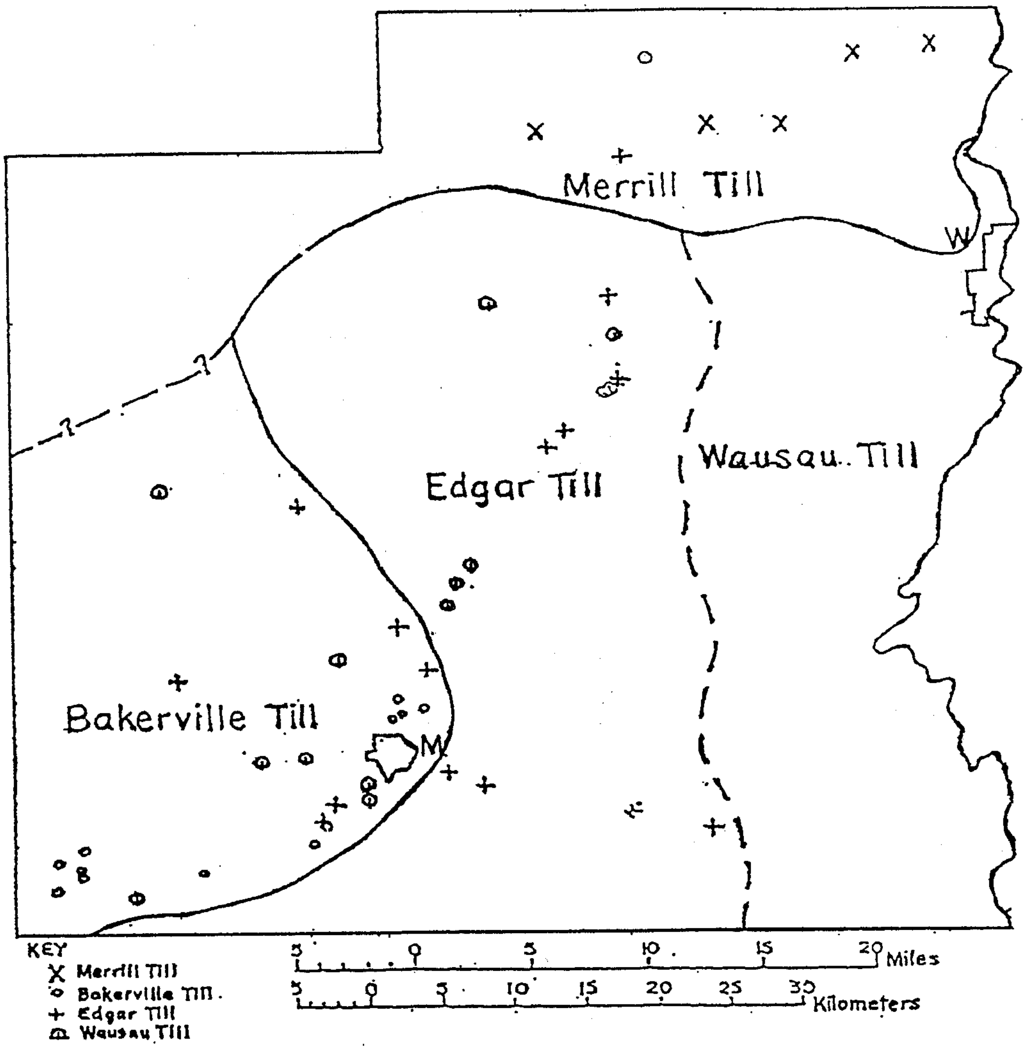


Figure 1.5: Areal distribution of till units and sampling localities in western Marathon County (Mode, 1976).

1.2) and Mode found probable reason to believe that Weidman's First, Second, and Third drifts corresponded to the Edgar, Bakerville, and Merrill till members respectively. Two of these units, the Wausau and the Merrill, had been previously named and described by Laberge and Meyers (1971) and Stewart (1973). The other two units, the Bakerville and Edgar Members were un-named and were first described and informally named by Mode. Mode later formalized the Bakerville Member of the Lincoln Formation and the Edgar Member of the Marathon Formation in the Pleistocene lithostratigraphic framework (Mickelson _et_ _al_., 1984). Based on grain size distribution, clay mineralogy, lithology of the coarse sand fraction, color, and stratigraphic position (table 1.1), Mode was able to show the areal extent of these till units (figure 1.5). Samples collected from the type section of the Bakerville Member and random samples of till of the Merrill Member are strikingly similar (table 1.1). Their grain size distributions are nearly identical, as are the field colors and lithologies of the coarse sand fraction. Although Mode never found the Bakerville and Merrill Members statigraphically juxtaposed in a drill hole, and was doubtful as to their correlation, he chose to consider them as separate lithostratigraphic units based on several subtle differences.

The most recent and comprehensive work on Pleistocene stratigraphy to date in north-central Wisconsin is that of Attig and Muldoon (in press), Muldoon (1987), Attig (in preparation) and Clayton (in press).

Earlier investigations throughout Wisconsin were concerned

Till Name	Thickness (feet)	Color	Depth of carbonate leaching (feet)	Texture (mean-above) (range-below) &	% of local rock and mineral in coarse sand fraction	Clay Minerals (%)					Ice flow direction	Age
						Illite	Kaolinite/ Chlorite	Vermiculite	Smectite	# of Samples		
Merril		darkest - 2.5YR 3/4 majority of samples - 5YR 3/4 lightest - 7.5YR 4/4		sand** - 58 55-56 silt - 30 27-32 clay - 12 7-14	*62 †49-72	65 47-82	9 5-16	13 3-28	13 6-20	5		at least as old as Altonian
Bakerville	‡0-100	darkest - 2.5YR 4/4 majority of samples - 5YR 3/4 to 4/4 lightest - 7.5YR 7/6		sand - 62 51-72 silt - 25 16-32 clay - 13 5-21	62 52-80	53 32-73	8 4-16	14 4-33	25 9-43	15	Northwest and west-northwest	at least as old as Altonian
Edgar	§5-10	darkest - 5YR 4/4 majority of samples - 5YR 4/4 to 5/4	3 to 10 Ave. - 5	sand - 33 23-43 silt - 43 30-58 clay - 24 10-33	56 52-87	44 30-59	6 1-10	17 10-27	33 23-49	17	South-southeasterly	possibly as old as Illinoian
Wausau	5-10	darkest - 5YR 5/4 majority of samples - 7.5YR 4/4 lightest - 10YR 5/4	It is not calcareous	sand - 43 39-47 silt - 34 27-39 clay - 23 18-32	72 68-80	44 19-68	5 3-9	18 6-33	32 11-54	15		possibly as old as Illinoian

*mean; †range; ‡The Marshfield moraine is its great thickness; §But can reach 30 in a low ridge that runs east-southeastward from Marshfield. **sand - 2 - 1/16mm, silt - 1/16mm - 2μ, clay - <2μ

Table 1.1: Summary of the characteristics of till units in Marathon County (Mode, 1976).

solely with quantitatively characterizing the stratigraphic units based on reconnaissance mapping. With detailed mapping (scale 1:100,000) and analysis of drill hole data from both Marathon and Taylor Counties coupled with field observations of stratigraphic relationships, Attig and Muldoon were able to not only further quantify some of the same units that their predecessors had worked with, but were also able to place those units in a more precise lithostratigraphic framework and further define the distribution of the till units.

Muldoon (1987) characterized the Pleistocene lithostratigraphy west of the Wisconsin River in Marathon County using standard Quaternary laboratory methods such as detailed grain size distribution, magnetic susceptibility, Chittick and Munsell color. She also characterized these same four pre-late Wisconsin till units with respect to their hydrogeologic and geotechnical properties using both in field and lab measurements (table 1.2).

Attig and Muldoon (in press), contains a further discussion of the Pleistocene deposits, landforms, and glacial history of Marathon County. The study encompasses the entire county, with a detailed look at deposits ranging in age from early Pleistocene to late Wisconsin. The Wisconsin Geological and Natural History Survey has underway, a systematic county-by-county study and mapping of the Pleistocene geology of Wisconsin. Attig (in preparation) is currently completing a detailed description of the characteristics, distribution, geomorphology and history of the Taylor County Pleistocene materials and

Summary of the Lithostratigraphic Properties of Till Units*

Lithostratigraphic Unit	Number of Samples	Percent Sand	Percent Silt	Percent Clay	Median## Diam. (mm)	Magnet.## Suscept.	Percent Calcite	Percent Dolomite
MARATHON FORMATION								
Undifferentiated	80	38.7	43.8	17.5	.043	$7.3*10^{-4}$	1.1	1.3
Medford Mbr.	23	32.8	47.1	20.1	.023	$1.4*10^{-3}$	1.8	3.3
Edgar Mbr.	197	39.2	42.9	17.9	.039	$1.3*10^{-3}$	1.7	3.0
LINCOLN FORMATION								
Bakerville Mbr.	8	56.7	30.2	13.1	.114	$1.8*10^{-3}$	.6	1.2
Merrill Mbr.	11	49.0	38.5	12.5	.074	$1.3*10^{-3}$	1.0	.8

* The percentages of sand, silt, and clay have been determined for the less-than-2-mm fraction of the sample. The sand fraction includes particles from .0625 to 2 mm, the silt fraction contains particles from .002 to .0625 mm, and the clay fraction contains particles less than .002 mm in diameter.

The values presented for the median diameter and magnetic susceptibility are median values rather than averages because these two parameters are not normally distributed.

Table 1.2: Summary of the lithostratigraphic properties of till units in Marathon County (Muldoon, 1987).

Clayton has mapped the Pleistocene geology of Wood County (in preparation) and Portage County (1986).

Purpose and Scope of Study

The first phase of this investigation focused on the Pleistocene stratigraphy of northeastern Clark and southeastern Taylor Counties. Recently completed Pleistocene mapping in adjacent Marathon County (Attig and Muldoon, in press) and concurrent mapping in Taylor County (Attig, in preparation) has provided detailed descriptions of the lithostratigraphic units as well as a better understanding of the glacial history of the area. This study was done in conjunction with the above in an effort to further the regional correlation of Pleistocene lithostratigraphic units.

I described detailed morphological, chemical, and physical properties of the till units and the soil profiles found on those till units in an attempt to infer or substantiate the relative ages of the various surfaces. As a means of accomplishing this, special emphasis was placed on the clay mineral weathering and transformation sequences in both the till units and selected soils.

Applicability of clay minerals to this study

The study of clay minerals and weathering sequences has been used extensively in geologic and pedologic studies. Because the clay content of a till depends on provenance and weathering since deposition, the relative age of a geomorphic surface can sometimes be deciphered from clay mineral studies. From a pedologic standpoint, clay mineralogy is often used to determine the degree of weathering within a soil profile or to establish the chemical environment within the solum.

Birkeland and Janda (1971) note that studies involving clay mineralogy are potentially most useful to Quaternary stratigraphers if the clay mineral assemblages change with time. Numerous studies in the literature have shown direct correlations between the clay mineralogy observed, either in glacial sediment or soil profiles, and the age of the surface sampled (Stewart, 1973; Razzaq and Herbillon, 1979; Levine and Ciolkosz, 1983). It was hoped that these same principles and observations could be applied in this study.

A logical extension for the site specific studies conducted in Clark and Taylor Counties was to apply the clay mineral trends observed at the local scale to that of a regional synthesis with the hope of discerning meaningful trends in the mineral associations. Ideally this information would enable one to delineate the Pleistocene lithostratigraphy based upon not only clay species differences within the till units themselves but also as evidenced by clay species evolution within the soil profiles. Presumably, the older till surfaces would be characterized by a suite of clay minerals exhibited in both the unoxidized till as well as the soil developed on the surface, that are more advanced in weathering, while glacial sediment and the accompanying soil units comprising the younger surfaces would reflect the relative age of that surface in both the type and relative amount of clay species present.

Clay mineral formation

The clay fraction of sediment analyzed in this study consists of all particles less-than-2-microns in diameter. The phyllosilicates that dominate the clay fraction are generally secondary in nature, and are either derived or inherited from parent materials or are formed within a weathering profile via the alteration and transformation of preexisting minerals. It has been proposed that clay minerals can form by crystallization from solutions (Birkeland, 1984).

Clay minerals will become unstable and begin to decompose when conditions differ from those under which the mineral was originally formed. Environmental changes that could initiate subsequent formation or transformation of new clay species include an alteration of soil drainage conditions, aerial exposure, or the onset of a new climatic regime (Jackson, 1968).

The following general discussion focuses on the description and genesis of the clay minerals that are prevalent in the till units and soil profiles analyzed in the area. Figure 1.6 provides an idealized summary of individual clay species formation.

Conditions of slow permeability, poor drainage, and neutral to slightly alkaline solutions with high K^+ concentrations encourage the formation of micas and mica-type minerals (Keller, 1970). Brady

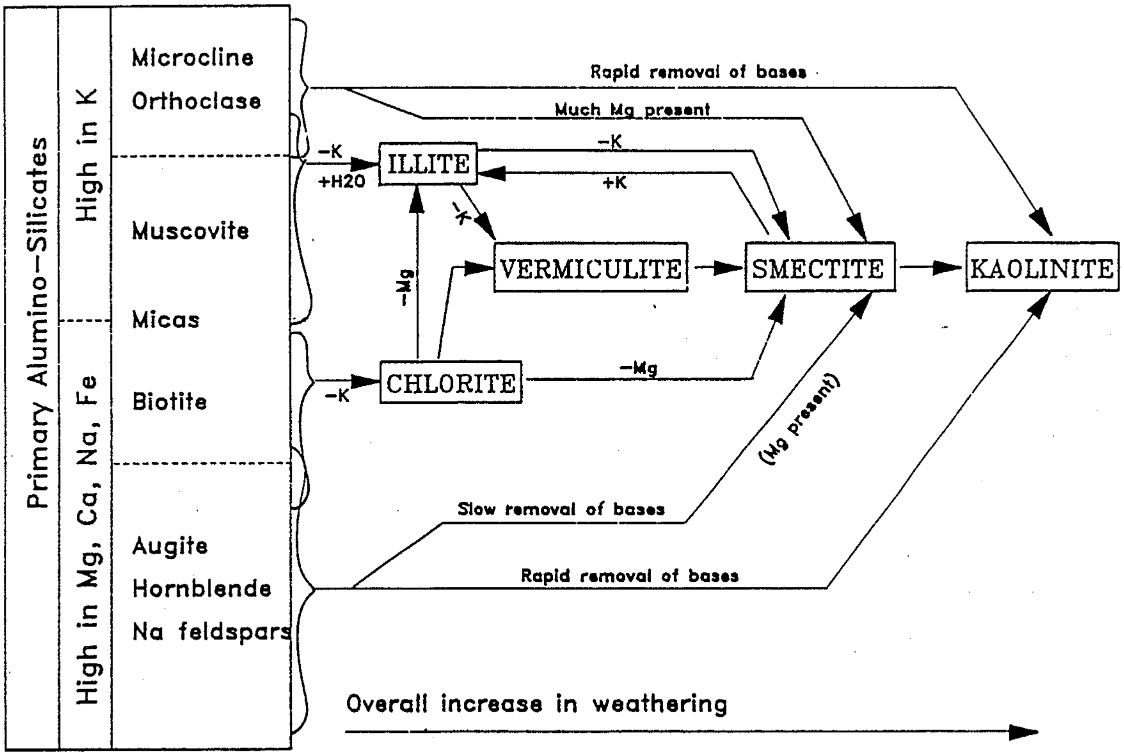


Figure 1.6: Summary of the general conditions for the formation of the silicate clays described in this study (after Brady, 1974).

(1974) notes that the simplest derivation of illite is via the slight alteration of one of the other micas such as muscovite, but that illite can also be derived through recrystallization from primary minerals such as potassium feldspar.

It has been universally recognized that micas, illite being one species, weather to 2:1 expandable minerals such as vermiculite and smectite by the loss of potassium interlayers. This transformation within the soil is most readily achieved when the soil pH is low (Douglas, 1977). Because most of the mica minerals in soils appear to be primary minerals inherited from the soil parent materials, they are generally most prevalent in the clay fraction of young, little weathered soils and sediment (Fanning and Keramidas, 1977).

Vermiculite typically is found in conjunction with and is an alteration product of one of the micas and possibly chlorite (figure 1.6). The mica-to-vermiculite transformation depends on strong leaching environments in order to remove the interlayer potassium ions. This situation is typically most prevalent within the A horizon of soil profiles. Vermiculite is considered an unstable, fast-forming, intermediate mineral and will disappear from soils by transforming to smectite (Kittrick, 1973).

Douglas (1977) notes that vermiculite can form in many different environments, and from a wide variety of parent materials, but that for vermiculite to persist for significant periods of time, the normal weathering sequence is:

$$\text{Mica} \longrightarrow \text{vermiculite} \longrightarrow \text{hydroxy-Al}^{3+}\text{-interlayer vermiculite}$$

In soil profiles, these hydroxy-aluminum-interlayer species are more prevalent in the subsoil (B and upper C horizons) while the A and E horizons typically exhibit low aluminum fixation conditions hence smectite tends to dominate the less-than-2-micron fraction (April et al., 1986).

Smectite, of which montmorillonite is one species, is also prevalent in a wide range of environments. Generally smectite formation and preservation are favored by an abundance of exchangeable soluble magnesium and calcium cations, silica enrichment, moisture, slightly acidic medias, and minimal leaching conditions (figure 1.6). As already discussed, the micas may eventually weather to smectites by the loss of K^+ interlayer ions and overall layer charge reductions (Borchardt, 1977).

Kaolinite is probably the most ubiquitous clay mineral found in soils. It is a product of acidic weathering conditions and is the predominant silicate mineral in soils of tropical regions, thus it dominates the profiles of Oxisols and Ultisols (Dixon, 1977). Kaolinite represents a more advanced stage of weathering than any other phyllosilicate (Jackson, 1968). In humid-temperate climates, kaolinite is usually considered to be a relatively stable component with depth and changes little in its relative abundance throughout the profile (Guccione, 1985).

CHAPTER TWO

LITHOSTRATIGRAPHY

Bedrock Geology of the Area

The area straddles the boundary between Precambrian crystalline rock to the north and Cambrian sediment to the south. Within the area, outcrops are rare, and as a result, depth to bedrock was largely inferred from drill hole logs on file at the Wisconsin Geological and Natural History Survey.

The bedrock in the area is lithologically diverse (Brown, 1988; Mudrey *et al*., 1987). The largest continuous exposure of Precambrian rock is found along the Black River. These outcrops contain mainly Archean and Lower Proterozoic metavolcanic rocks, granite, and gneiss that have undergone a complex emplacement history (Maass, 1980). Small inliers of Precambrian granitic rock exist at several localities outside the Black River valley boundary. The Precambrian surface dips gently to the south-southwest beneath a gradually thickening sequence of Cambrian sandstone and shale. Conspicuous sandstone "mounds" are prominent topographic markers on the horizon in central and southern Clark County just to the southwest of the study area.

METHODOLOGY

Field Methods

Field work was begun during the early summer of 1987 and was concluded in the fall of that year. Due to the paucity of outcrops of Pleistocene sediment, nearly all samples were collected from drill holes. Drill hole localities and field notations were plotted on 7.5 minute USGS topographic quadrangles. These locations are included in Appendix I.

Conventional solid stem drilling with a Mobile Drill rig was used to gather samples of subsurface material. A total of 27 drill hole sites were completed. Samples were collected at approximately 1.5 m intervals. In-field characterization of units was minimal. Moist Munsell colors and gross lithologic changes were noted during drilling, saving the remainder of chemical and physical description for the laboratory.

Criteria for the selection of drill sites were; 1.) an upland locality, thereby ensuring that as complete and undisturbed a section as possible was being obtained, 2.) site accessibility and 3.) land owner's permission. Holes were drilled to construct three cross sections; one east-west and two north-south, with drill holes spaced at approximately three-to-four-mile intervals. Figure 2.1 shows the location of drill hole sites which were used to aid in the determination of the Pleistocene lithostratigraphy.

Lab Methods

Laboratory data is summarized in Appendix I. Data was entered into a modified Lotus spreadsheet used routinely by the University of

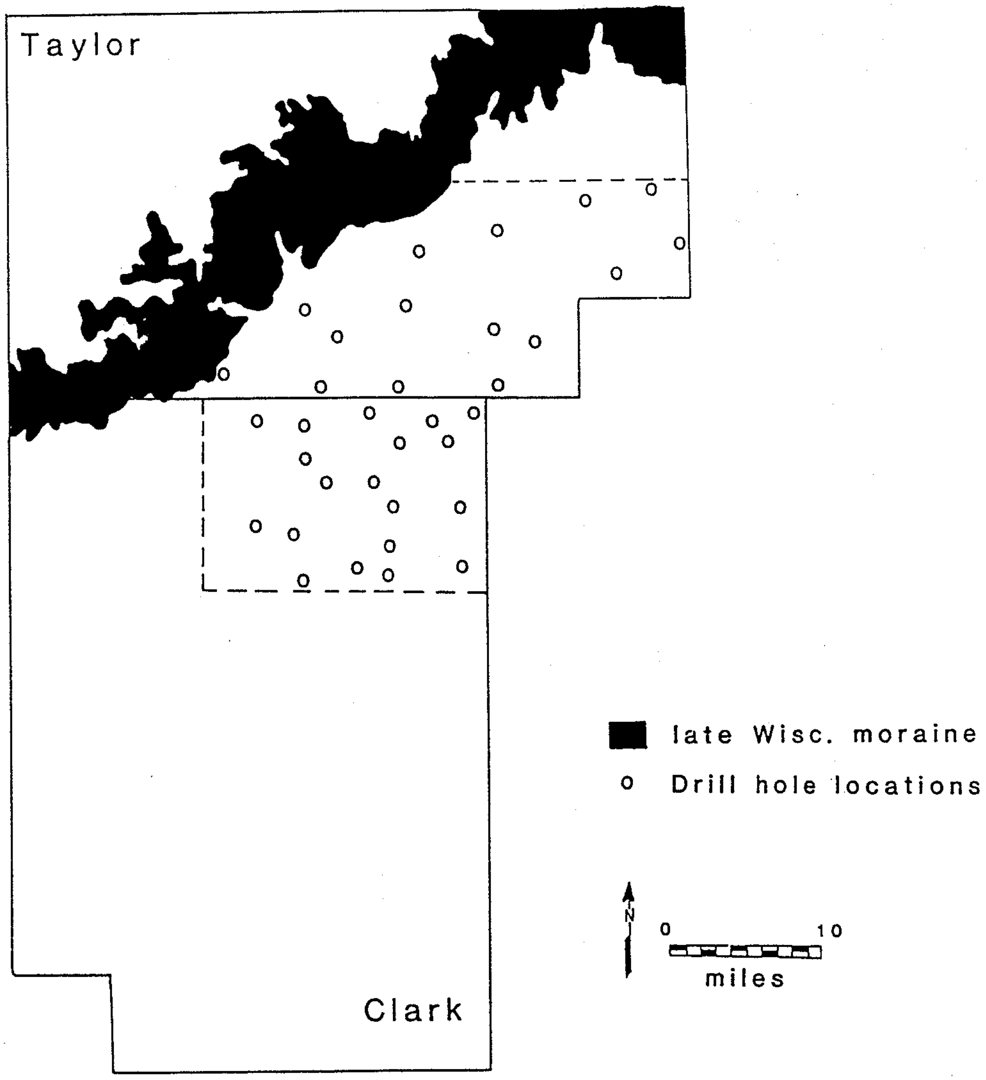


Figure 2.1: Map of sampling localities for lithostratigraphy determination in the area.

Wisconsin--Madison Quaternary laboratory. Detailed drill-hole logs are on file at the Wisconsin Geological and Natural History Survey.

Particle Size

Particle size distribution was determined using the hydrometer method following dispersion with sodium hexametaphosphate and without any pre-treatment for organic matter or iron oxide removal. The particle size classification used in this study differs slightly from that used by the USDA in the clay and silt boundaries, but the same textural terms and textural triangle are used (figure 2.2). The University of Wisconsin Quaternary Lab performs grainsize analysis using 0.05mm as the upper silt size limit while USDA uses 0.063mm as the upper silt boundary. Muldoon (1987) contains a complete description of the entire textural determination procedure.

Calcite and Dolomite content

The percentage of calcite and dolomite contained in the coarse silt fraction was determined gasometrically using a Chittick apparatus as developed by Dreimanis (1962). The reader is referred to Need (1980) for a description of the University of Wisconsin Quaternary Lab's standard method.

Iron

Iron was analyzed by atomic absorbtion using a Perkin-Elmer atomic absorbtion spectrophotometer. Appendix II-A contains a detailed description of the citrate dithionite iron extraction procedure used in

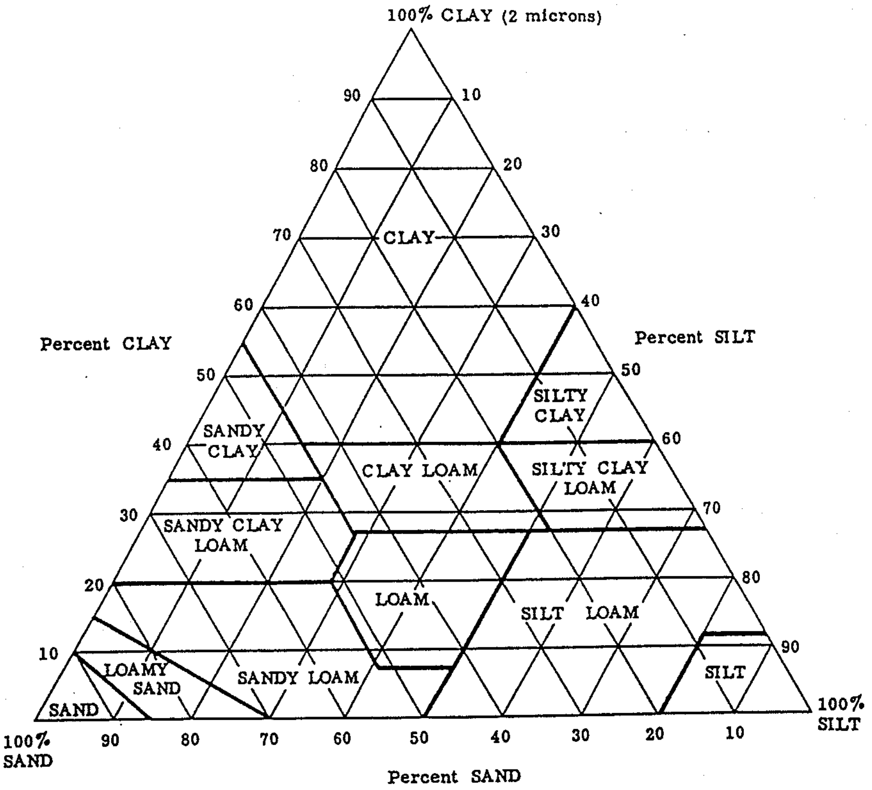


Figure 2.2: United States Department of Agriculture (USDA) textural triangle.

this study. This procedure is essentially that of Holmgren (1967) with a few modifications.

Magnetic Susceptibility

Measurements of the magnetic susceptibility of unconsolidated deposits such as loess and till has been recognized as a valuable diagnostic laboratory tool to aid in characterizing and distinguishing sediments with different provenance. For this reason the method has become a standard procedure in many soil/sediment laboratories. The University of Wisconsin Quaternary Lab's standard magnetic susceptibility technique is documented in Muldoon (1987).

X-Ray Analysis

Sample Preparation

X-ray diffraction analysis was used to semi-quantitatively determine the clay mineral content of samples in an effort to recognise the extent of weathering with depth. All samples that were examined were considered to be representative of one of the three surficial till units mapped in the area.

The clay content of each sample was determined by the hydrometer method. The hydrometer method yields an insufficient quantity of clay to produce infinitely thick, oriented samples, so an alternative separation procedure was used. This method is documented in detail in Appendix II-B.

Numerous workers (Rich, 1965; Whiting and Allardice, 1986; Brindley and Brown, 1980) have documented the necessity of preparing "infinitely thick", homogeneous, oriented samples in semi-quantitative clay determination. A prepared sample with the maximum amount of oriented basal planes lying parallel to the mounting surface results in the most accurate diffraction trace. If the sample is truly infinitely thick, one should observe a negligible increase in net intensity values with a given increase in sample thickness (Brindley and Brown, 1980).

The Clay Minerals Society (1982) workshop syllabus provides an excellent discussion of the merits and pitfalls of various diffractometry preparation techniques for oriented specimens of less-than-2-microns. Brindley and Brown (1980) note that one of the most commonly used mounting techniques, that of sedimentation by gravity onto a glass slide yields excellent orientation, but the slurry is often either too thin and/or too inhomogeneous to provide representative relative intensities. The inhomogeneity is the result of the different settling velocities of the various mineral constituents.

Gibbs (1965) found that both the smear technique onto glass slides and suction of suspended material onto a flat, unglazed, ceramic tile will yield sufficiently thick and homogeneous specimens. The rapid suction technique was chosen for this study because of the apparent ease with which samples could be processed. All washing, acidifying, cation saturating and solvating can be accomplished on the tiles themselves once the suction apparatus is connected to a vaccuum supply. In addition, it has the added advantage over the glass slide technique of allowing the calculation of an exact quantity of sample to apply to the tile, therefore ensuring that an infinitely thick sample is made.

In order to create a sample of sufficient thickness, several parameters need to be considered in the calculations. Rich (1975) tabulated the necessary concentrations of clay (mg cm^{-2}) required to yield the optimum diffraction pattern based on a specified mass absorption coefficient, and a wide range of 2-theta values. Table 1 in Appendix II-B presents the calculated concentrations of clay needed to ensure sufficient clay fraction thickness and table 2 in Appendix II-B shows the necessary amounts of clay-sized material that is needed for the preparation of the infinitely thick tiles.

The clay mineralogy of the less-than-2-micron fraction of 46 samples of relatively unweathered till and 11 samples from soil horizons were analyzed using a Scintag/USA x-ray diffractometer (XRD) with CuKα radiation. Patterns were run at a scan speed of 5° 2θ/min and generally from 3-28° 2-theta using 0.3 and 0.5 divergence slits.

Clay Mineral Determination

Clay minerals in 46 samples were identified by x-ray diffraction: 14 from the Merrill Member, 14 from the Bakerville Member, and 18 from the Edgar Member. The principal species of the less-than-2-micron fraction are from the following groups of phyllosilicates: kaolinite, smectite, vermiculite, and micas. Other crystalline components present include quartz, calcite, feldspars, and miscellaneous iron oxides.

There are numerous classification schemes proposed for the identification of clay minerals. In this study, the clay species were identified using the guides by Jackson (1969), Whitting and Allardice (1986), Brindley and Brown (1980), and the Clay Mineral Society Nomenclature Committee (Bailey et al., 1980).

The criteria used to define, and the laboratory methods used to identify, the various groups are discussed below. These data are then summarized in table 2.1.

Kaolin Group

The minerals of the Kaolin group are classified as 1:1 dioctahedral layered silicates. In oriented samples, well crystallized kaolinite is recognized by a strong, symmetric (001) peak at 7.15-7.2 Å and a harmonic second order reflection at 3.55-3.57 Å. These reflections are stable after solvation and heating below temperatures of approximately 450 C°. Heating above this temperature results in a complete dehydroxylation of the mineral.

The identification of kaolinite in the presence of the mineral chlorite is complicated by the fact that the (001) and (002) reflections of kaolinite overlap with the (002) and (004) reflections of chlorite. There are several means of differentiating the two species. Upon prolonged heating at high temperatures, the kaolinite will become amorphous, whereas if chlorite is present, its 14 Å (001)

Mineral Group	Diffraction Spacing(nm)			
	Treatment (a) Air-dried	Treatment (b) Ethylene glycol	Treatment (c) 350°C heating	Treatment (d) 550°C heating
Kaolinite	0.715 strong .355-.357 v.strong	same as (a)	same as (a) but may lose some intensity	no peaks
Mica (Illite)	0.99-1.01	same as (a) (collapse of expandable minerals enhances 1.0 peak)	same as (a)	same as (a)
Vermiculite	1.4-1.5	1.4-1.42v. strong .70-.71 weak-strong	no 1.4 peaks left, all shifted to 1.0	same as 350°C
Smectite	1.4-1.5	1.68-1.7v. strong	No spacings greater than 1.0	same as 350°C
Chlorite	1.4-1.43wk-strng .70-.71 v. strong .35-.36 v. strong	same as (a)	same as (a) but may lose some intensity	1.4-1.43 intensity increases dramatically .70-.72 absent

Table 2.1: Summary of clay mineral species discussed in this study and the effects of several diagnostic treatments on their diffraction spacings (nm).

peak will be intensified. Distinguishing between these two minerals can also be accomplished by digesting the sample with hydrochloric acid. In this process chlorite is dissolved leaving kaolinite unaffected.

Mica Group

Micas are 2:1 phyllosilicates composed of one octahedral sheet sandwiched between two tetrahedral sheets and bonded by potassium interlayer ions. Illite is one subspecies of the mica family. Illite in magnesium saturated, glycolated, and oriented mounts exhibits a strong characteristic basal (001) reflection at approximately 10 Å (9.8-10.1 Å). This spacing varies little upon heating of the sample. The (002) reflection at 5.0 Å is observable but often weak, while the (003) peak at 3.34 Å coincides with that of quartz. Diffraction patterns typically exhibit a sharp asymmetrical peak at 10 Å if the illite is well crystallized and an asymmetry on the low 2-theta angle side of the 10 Å peak if the illite is hydrated (Droste, 1956).

Vermiculite Group

Vermiculites, like the micas, are 2:1 phyllosilicates consisting of one octahedral sheet and two tetrahedral sheets. This group differs from the micas in being expandable and lacking the potassium interlayer ions. The net negative layer charge is compensated for by the medium-sized cations in the interlayer, typically Mg^{+2} or Ca^{+2}. These cations in turn, are surrounded by hydration shells of water. Differences in the relative intensities of the basal reflections of the expansible lattices depend largely on the interlayer cation present and the degree of hydration. With Mg^{+2} saturation and glycolation, the (001) order peak is at approximately 14 Å.

Removal of the interlayer water molecules by heating results in a temporary collapse of the lattice and yields characteristic basal spacings of 9-10 Å. Walker (1957) has shown that during removal of this interlayer water from hydrated vermiculites, a series of step-wise dehydration phases often occurs before complete collapse of the 14 Å peak to 9-10 Å is attained.

Smectite Group

The term "smectite" is a relatively new term for a group of layered silicates that includes the familiar montmorillonite species. This term was formally adopted by the AIPEA Nomenclature Committee (Bailey, et al., 1980) at the 1971 conference.

The identification of smectite in oriented samples is made based on the readily distinguished (001) order peak of 17 Å after solvation with ethylene glycol or to 18 Å with glycol solvation.

Traditionally, differentiation between vermiculite and smectite species has been accomplished by Mg^{+2} saturation followed by solvation. Following this procedure, smectite will show an increase in intensity of the (001) peak to 17-18 Å, whereas vermiculite will remain stable at

14 Å. Upon heating to temperatures greater than 350 °C the 17 Å reflection will collapse to 10 Å.

Research has shown, however, that the vermiculite-smectite relationship remains an enigma. Work by April _et al_., (1986) suggests that the weathering transformation of vermiculite to smectite is a gradual process resulting in a continuum of clay species exhibiting characteristics intermediate to those of the vermiculite-smectite end members. These intermediate species have been referred to as low-charge vermiculites and high-charge smectites in the literature. In-depth studies of these two minerals is of importance because it has been shown by several researchers (Brindley, 1966; Malla and Douglas, 1987) that erroneous conclusions can be reached when attempting to estimate the abundance of the smectite component in the sample unless very detailed analyses have been done regarding the structural formula. This includes the characterization of parameters such as the layer-charge, the interlayer cations present, and whether the species is tetrahedral or octahedral.

Semi-quantitative calculations

Numerous techniques have been employed to assign actual numerical values to the relative amounts of each clay species present in a sample. Measurement of both peak height and peak area have been traditionally used. Stewart (1973) used peak area ratios in his calculations while Johnson (1984) set up a series of peak height ratios which were a comparison of a given clay mineral's peak height to that of quartz. The Illinois Geological Survey as well as the Iowa Geological Survey (Hallberg _et_ _al_., 1978) use peak height measurements taken from d-spacings at 17, 10, and 7 Å. All of the above patterns were recorded on a logarithmic scale and samples were usually unsaturated with respect to any major cations. Before the advent of computerized x-ray diffraction runs, both peak height and peak area were measured manually from a hand-scribed baseline. These methods are quite subjective and the relative percentages vary considerably depending on who drew the baseline. With the Scintag x-ray diffractometer used in this study, uncorrected, raw peak intensities were measured. These intensities were calculated internally by the computer from a computer derived baseline. All patterns were scaled linearly.

For this study, the relative changes in amounts of clay species with depth were calculated using the semi-quantitative method of Guccione (1985) because preparation techniques between the two studies were similar. Like Guccione's work, this study used Mg^{+2} saturation, clay tiles, and a linear scale on the diffraction patterns. Although all of the pre-treatments were used to aid in the mineral species identification, the relative abundance of each species was estimated only from the Mg-saturated, ethylene glycol solvated patterns. This is a fairly routine practice and insures that an accurate estimation of the amount of expandable clays present in a sample is obtained. Each peak to be quantified was then labelled using the TC9 graphics program on the Scintag diffractometer with respect to peak intensity and d-values.

The intensities at 17, 14, 10, and 7.2 Å were recorded as those of smectite, vermiculite, illite, and kaolinite respectively. The results of heating and glycolation precluded the presence of chlorite in the samples, hence the 7.15 Å peak was considered representative of kaolinite only.

To convert the peak intensity values into relative percentages, the following set of equations were used (Guccione, 1985). The net intensity of illite (I) was multiplied by a reflectivity factor of three and the net intensity of kaolinite (K) by a reflectivity factor of two. The net intensities of the two expandable clay minerals (EXP), smectite and vermiculite, were each mulitplied by a reflectivity factor of one. The raw net intensity value multiplied by the reflectivity value for a given species was then divided by the sum for all four minerals and mulitplied by 100. These calculations are similar to those used by Hallberg _et_ _al_., (1978) with the exception that they do not quantify a 14 Å peak, therefore considering smectite to be the only expandable clay species present.

$$\%\ \text{Expandables} = (\text{Exp}/\text{Exp} + 3\text{I} + 2\text{K}) \times 100$$

$$\%\ \text{Illite} = (3\text{I}/\text{Exp} + 3\text{I} + 2\text{K}) \times 100$$

$$\%\ \text{Kaolinite} = (2\text{K}/\text{Exp} + 3\text{I} + 2\text{K}) \times 100$$

PLEISTOCENE LITHOSTRATIGRAPHY WITHIN THE REGION

The following section is a brief overview of the Pleistocene lithostratigraphic units of northeastern Clark and southeastern Taylor Counties (figure 2.3). Full descriptions of type localities can be found in Mickelson et al. (1984) and Attig et al., (1988).

LINCOLN FORMATION

The Lincoln Formation consists of reddish brown sandy till units and associated outwash sand and gravel. Two members, the Merrill and the Bakerville, have been defined in north-central Wisconsin, and both are exposed at the surface in the area. Based upon two C^{14} dates from organic material overlying till of the Merrill Member, a minimum age of 36,800 radiocarbon years has been proposed for the Lincoln Formation (Stewart and Mickelson, 1976).

Merrill Member

The Merrill Member contains a reddish brown, noncalcareous loam to sandy loam (figure 2.2) till that is the youngest pre-late Wisconsin till unit in Clark and Taylor Counties thus far. It was named and defined to the east-northeast in Lincoln and Marathon County by Stewart (1973) and was later made a formal member of the Lincoln Formation by Mickelson et al. (1984).

Till of the Merrill Member contains clasts of Superior basin origin indicating a north or northwesterly source area. The surface is

FORMATIONS	MEMBERS
Lincoln	Merrill
	Bakerville
Marathon	Edgar
	Medford

Figure 2.3: Summary of the Pleistocene lithostratigraphic units in the area (Mickelson *et al*., 1984 and Attig *et al*., 1988).

the only pre-late Wisconsin surface in north-central Wisconsin to exhibit any glacial topography. A subdued hummocky landscape with numerous wet, poorly drained low areas is evident. Figure 2.4 is a part of the Lublin SE 7.5 minute quadrangle that has been mapped (Attig, in preparation) as till of the Merrill Member at the surface.

The distribution of Merrill till as mapped by Attig and Muldoon (in press) in Marathon County is shown in figure 2.5. The northern part of the county is blanketed by till of the Merrill Member which thickens to the north.

Bakerville Member

Like that of the Merrill Member, till of the Bakerville Member is a reddish brown sandy loam. It too is noncalcareous and contains clasts of Superior basin origin, thereby indicating a north or northwesterly source region. Mode (1976) informally proposed the Bakerville Member as a lithostratigraphic unit. Based on his work done in western Marathon and northern Wood Counties, Mode was the first to remark on the lithologic similiarities between the Bakerville and the Merrill Members. He noted, however, that 35 km separates what otherwise appears to be virtually the same till.

The Bakerville till is best known from the type locality exposure in the Marshfield "moraine" in northwest Wood County. The term Marshfield moraine was first coined by Samuel Weidman (1907) for a topographic ridge that extends from the city of Neillsville in Clark

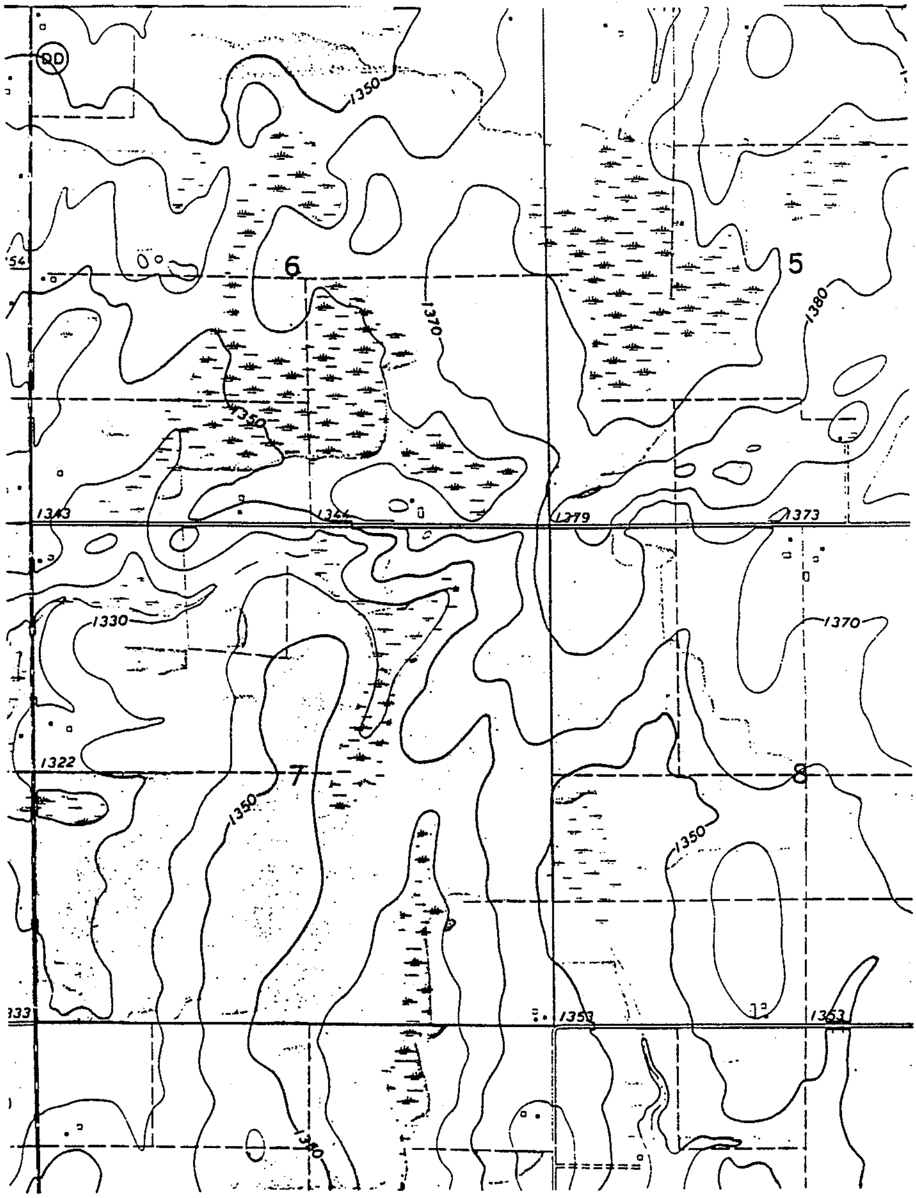


Figure 2.4: Part of the Lublin SE 7.5 minute quadrangle displaying the numerous wet areas and subdued hummocky topography characteristic of the Merrill surface (T30N, R1W).

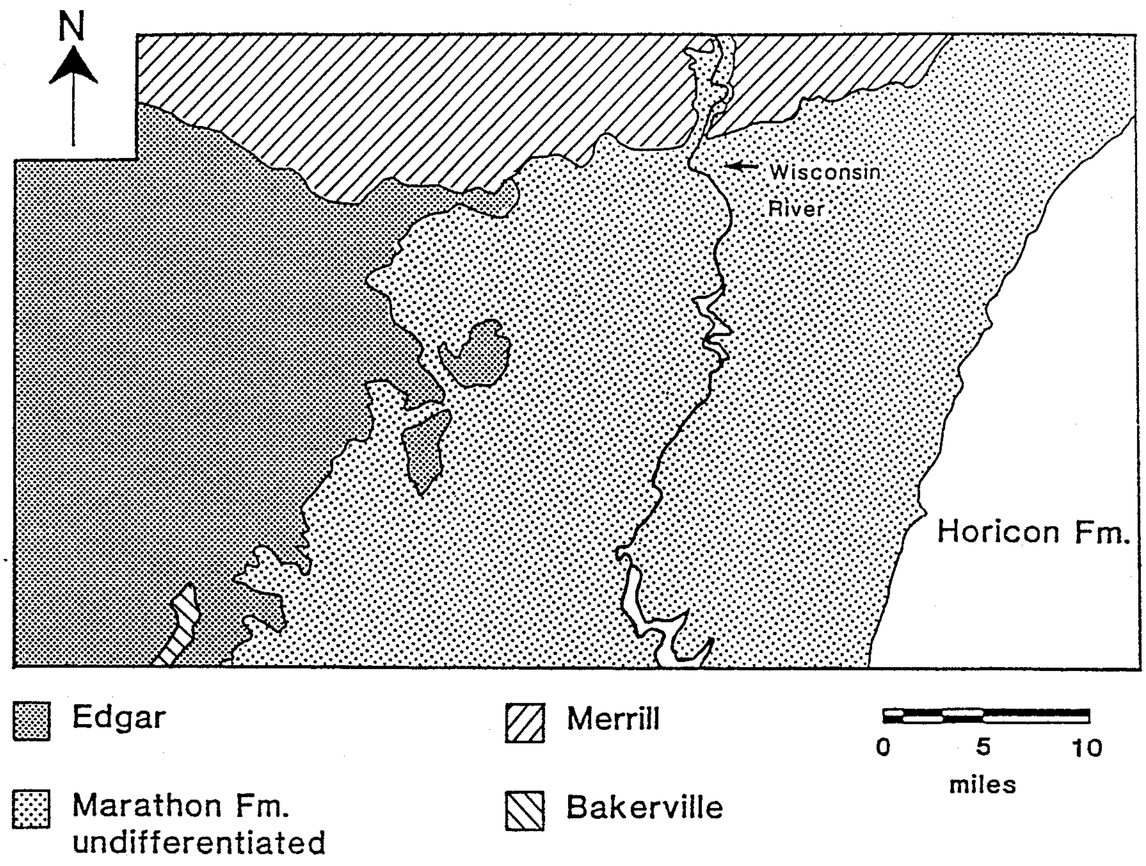


Figure 2.5: Surface distribution of Pleistocene materials in Marathon County (after Attig and Muldoon, in press).

County to just north of the city of Marshfield in Wood and Marathon Counties. Drilling suggests that the ridge is a bedrock high draped with a thick section of both Edgar and Bakerville till members. Attig and Muldoon (in press) and Clayton (in press) have established that the Marshfield moraine is not the terminal position for ice that deposited either the Bakerville or the Edgar Member because patches of both of these two units can be found to the southeast of the feature. Figure 2.6 delineates the extent of Bakerville till mapped in northwestern Wood and southwestern Marathon Counties. Attig (personal communication, 1987) notes that isolated patches of Bakerville sediment can be found to the north of Marshfield in western Marathon County, but that these patches are too small to be mappable at 1:100,000.

MARATHON FORMATION

The Marathon Formation consists of till units, interbedded lake sediment, outwash and organic horizons. This formation is subdivided into three formal lithostratigraphic members. From youngest to oldest these are the Edgar Member, the Medford Member, and the Wausau Member. Two of these members, the Edgar and the Medford occur in the area. Of these two, the Medford is restricted to the subsurface while the Edgar occurs as both a subsurface and a surface unit. The Wausau Member (Muldoon, 1987) is found in Marathon County.

The Marathon Formation is comprised of the oldest pre-late Wisconsin deposits in the study area. The type locality for the

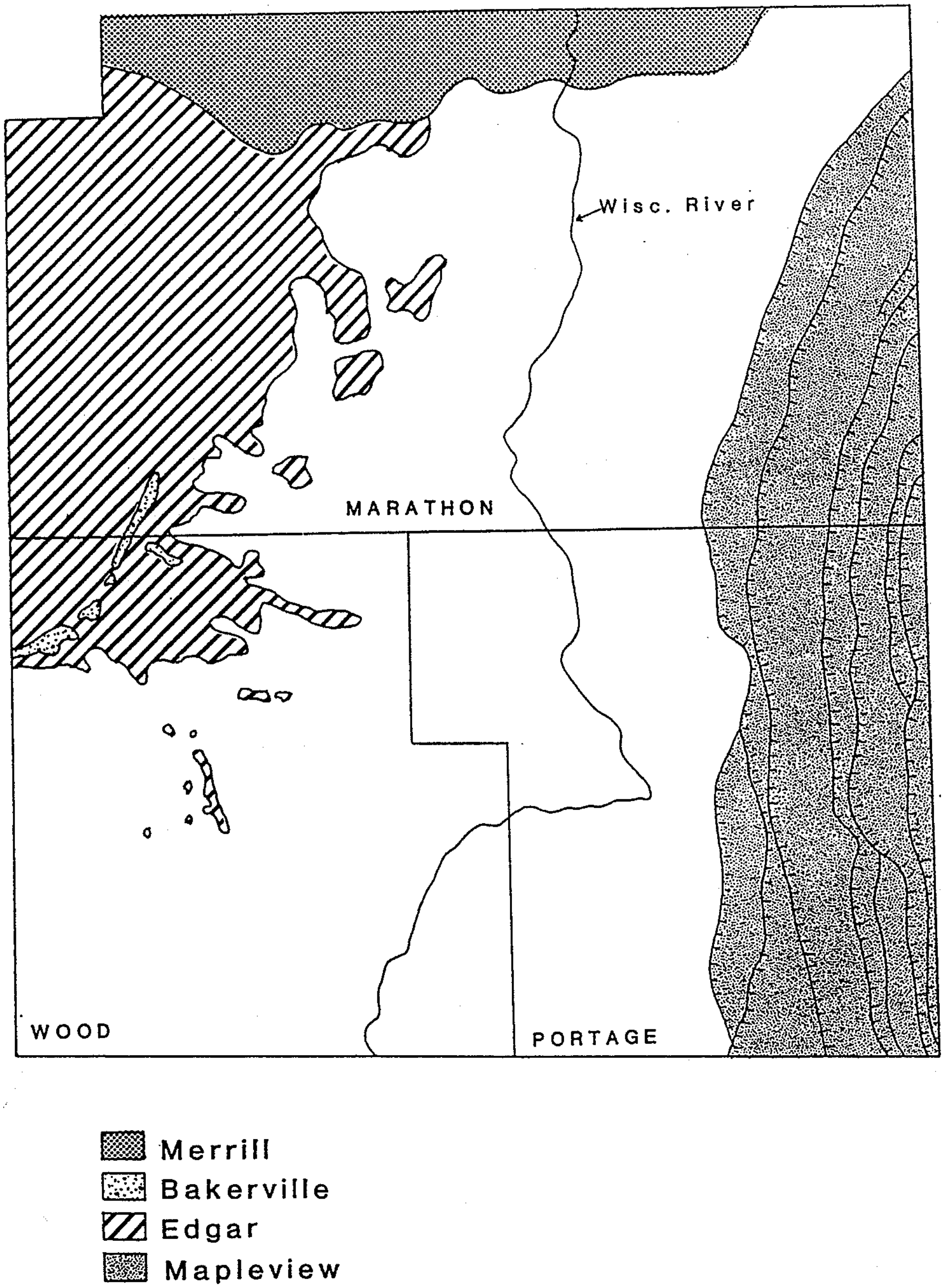


Figure 2.6: Distribution of till units in Marathon County and adjacent Wood and Portage Counties (after Attig and Muldoon, in press).

Marathon Formation is also the reference section for the Wausau Member to the east in Marathon County (Mickelson et al., 1984).

Edgar Member

The Edgar Member is the youngest member of the Marathon Formation. The type locality is located near the village of Edgar in central Marathon County.

Unoxidized till of the Edgar Member is a grayish color at depth in some locales in western Marathon County, and is distinguished by its calcareous nature and relatively silty texture. In addition to its fine texture and calcareous nature, small shale fragments and a few Ordovician fossils led Muldoon (1987) to postulate a source area for the Edgar in the Winnepeg lowlands.

Calcareous sand and gravel lenses as well as organic horizons and lacustrine sediment have been noted in boreholes penetrating the Edgar. Although a formal lithostratigraphic subdivision of the unit has not been made to date, Clayton (personal communication, 1988) postulates that at least 3 subdivisions of the Edgar are evident in northwestern Wood County within the Marshfield moraine. The upper subdivision, although similar in grain size to the material below it, exhibits markedly higher magnetic susceptibility values. The lower two subdivisions cannot be distinguished based on grain size analysis or magnetic susceptibility, but are separated by an organic rich layer. This organic layer within the Edgar till has been reported by Hole

(1943), Muldoon (1987), and this study.

No hint of glacial topography remains in those areas underlain by till of the Edgar Member. Broad, flat, interfluves with well integrated drainage networks characterize the landscape. The area east of Colby typifies this till surface (figure 2.7).

The areal distribution of the Edgar Member in Marathon and adjacent Wood Counties is shown in figure 2.6. Of the landscape east of the Wisconsin River in Marathon County, nearly one half of that is underlain by Edgar sediments. The unit was presumably once more extensive, but has since been stripped from the landscape as evidenced by the thin, ragged eastern boundary of the unit. The Edgar till thickens westward to the Clark-Marathon border and is found stratigraphically below till of the Merrill Member in northern Marathon County (Attig and Muldoon, in press).

Medford Member

The Medford Member has only been found in the subsurface in Marathon and Taylor Counties. Like the till of the Edgar Member, the Medford till in an unoxidized state is dark gray, calcareous, silty, and contains shale fragments. Pebble fabrics measured in the Medford indicate a north-northwest source area. This, coupled with the presence of shale fragments and the calcitic nature of the unit suggests the same source area as that of the Edgar, namely the Winnepeg lowlands in Manitoba (Muldoon, 1987; Attig and Muldoon, in press;

Figure 2.7: Representative Edgar landscape west of Colby, Wisconsin.

Clayton, in press).

The Medford may be correlative with one of two dark gray till units reported in western Wisconsin; the Woodville or Hersey Members of the Pierce Formation (Baker, 1987). Based on reversed paleomagnetic remanence data for the Hersey Member, Baker proposes that the Medford is at least early Pleistocene (730,000 years BP) in age and possibly as old as late Pliocene (2 ma).

Loess Distribution

An extensive blanket of Peoria loess (Lineback *et al*., 1979) covers much of north-central Wisconsin. Much of the loess cover lying beyond the late Wisconsin moraine in Clark and Taylor Counties is considered to have been deposited after the maximum advance of late Wisconsin ice and is thus younger than 14 or 15 thousand years. Thickness varies, but the distribution appears to be a function of distance from the Black River in Clark and Taylor Counties and from the terminal moraine in Taylor County. Loess is typically thickest in areas adjacent to and 4 to 5 miles east of the Black River, which probably served as an important local source of the eolian material. Extensive deposits of loess occur in southeastern Taylor County on the Merrill uplands bordering the outwash plains in front of the late Wisconsin end moraine.

PLEISTOCENE LITHOSTRATIGRAPHY IN CLARK AND TAYLOR COUNTIES

Results and Discussion

Figures 2.11 and 2.12 are used in conjunction with the following section. Three cross sections, 2 north-south and 1 east-west were planned and drilled based on preliminary information obtained from well logs. The location of these sections as well as the resulting subsurface distribution of units is presented in figure 2.12. Figure 2.11 delineates the areal extent of the three surficial units mapped in the study area as well as those units previously mapped in Marathon and Wood Counties.

All laboratory data as well as specific location data are presented in Appendix I. A summary of the mean grain size values as well as magnetic susceptibility and clay mineralogy for each of the three surficial till units is presented in table 2.2.

Merrill Member

Till of the Merrill Member is a reddish brown (5YR 4/6) to brown (7.5YR 4/4-4/6) loam to sandy loam unit. The average grain size distribution for the less-than-2-mm fraction for 21 samples of Merrill till is 50.0% sand, 32.5% silt, 17.5% clay (figure 2.8). This distribution varies little throughout the study area and correlates well with the average grain size distribution of Merrill till in northern Marathon County as reported by Muldoon (1987). For 11 samples, she reports a distribution of 49% sand, 38.5% silt, and 12.5%

Table 2.2

Summary of mean lab data for study area till units

				Magnetic	EXP			
	sand	silt	clay	susceptibility	S	V	Ill	Ka
MERRILL								
					(53)			
Taylor Co.	48.7	34.2	17.1	2.83×10^{-3}	40	13	33	14
+n = 14								
*n = 10								
					(63)			
Clark Co.	51.3	30.9	17.8	1.82×10^{-3}	34	29	25	12
+n = 7								
*n = 3								
BAKERVILLE								
					(56)			
Clark Co.	49.8	30.6	19.6	2.46×10^{-3}	30	26	32	12
+n = 18								
*n = 13								
EDGAR								
Taylor Co.	29.8	41.3	28.9	1.44×10^{-3}	NA		NA	NA
+n = 3								
					(56)			
Clark Co.	43.5	34.4	22.1	1.71×10^{-3}	46	10	28	14
+n = 56								
*n = 18								

* denotes # samples for clay analysis
\+ denotes # samples for grain size analysis (till only)

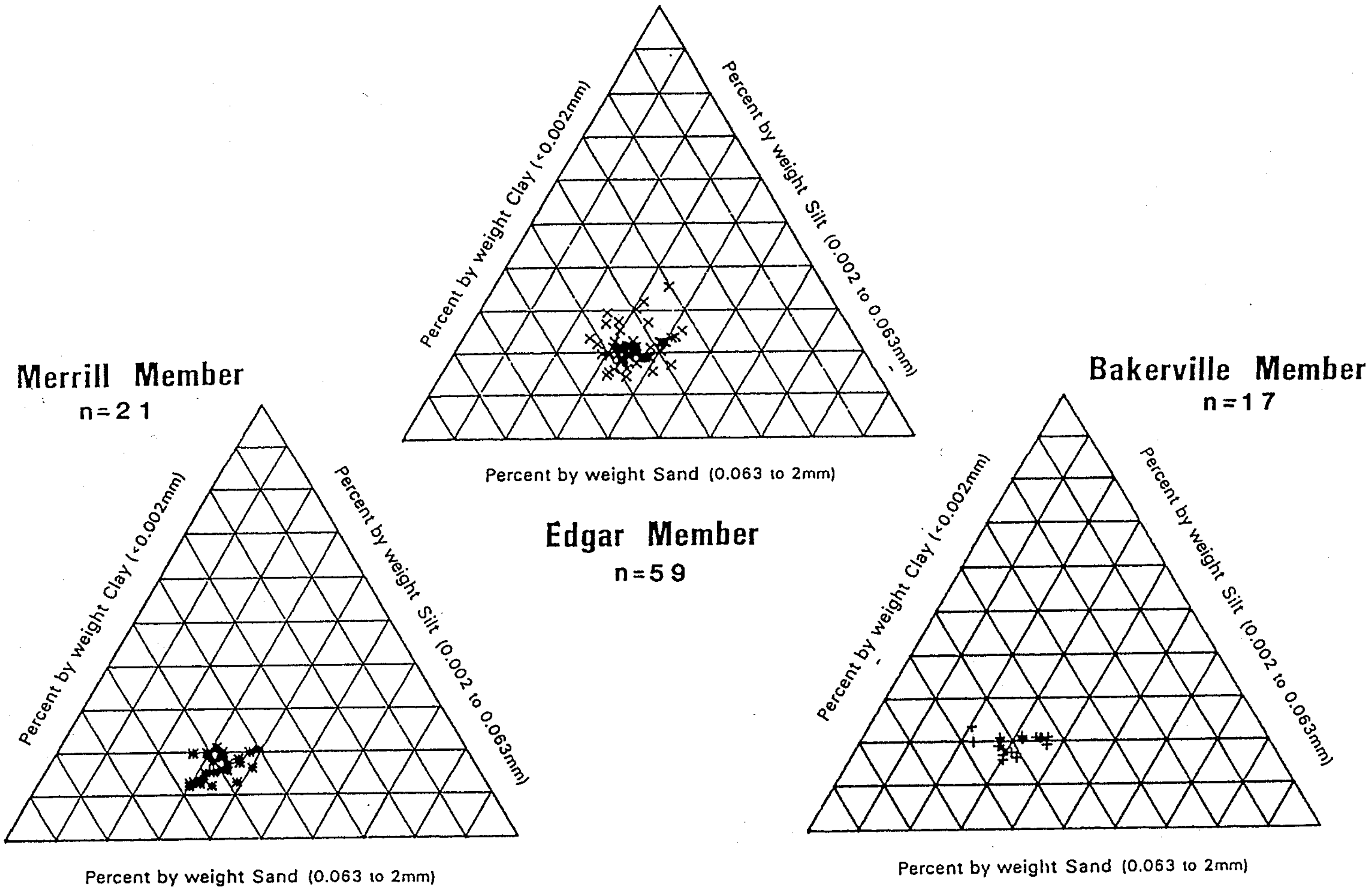


Figure 2.8: Triangular plots of the grain size distribution for the <2-mm fraction only till samples for the three surficial till units mapped in northeastern Clark and southeastern Taylor Counties.

clay (table 1.2). Magnetic susceptibility values range from 5.66×10^{-3} to 1.61×10^{-3} with an average of 2.33×10^{-3} for the 21 samples in Clark and Taylor Counties.

Fourteen samples of Merrill till were analyzed for their clay mineralogy. The till is smectite-rich, with an average percent of 37%. The 17-18 Å smectite peaks are quite sharp, but commonly are asymmetrical with a shoulder at the lower 2-theta values. Vermiculite is detectable in most Mg^{+2} saturated, glycolated samples and typically occurs in slightly less amounts to that of smectite. The combination of these two minerals is referred to as the "expandable" (EXP) portion of the clay mineral assemblage. The relative amounts of expandable clays in samples of Merrill till is different in Clark and Taylor County. Those samples analyzed from Clark County exhibited a greater abundance of expandable clays (63%) than do those samples from Taylor County (53%).

Illite is the second most abundant clay species, averaging 29% for those samples analyzed from the two counties. The relative abundance of kaolinite (7.2 Å) varies little from sample to sample and averages 12% in Clark County and 14% in Taylor County.

Figure 2.9 is a representative diffraction pattern for an unoxidized sample of the Merrill Member (Ck-16-87). The sample is from a depth of approximately 4 m. Four treatments were applied to the sample and the affects of glycolation and subsequent heating are readily observed in this pattern.

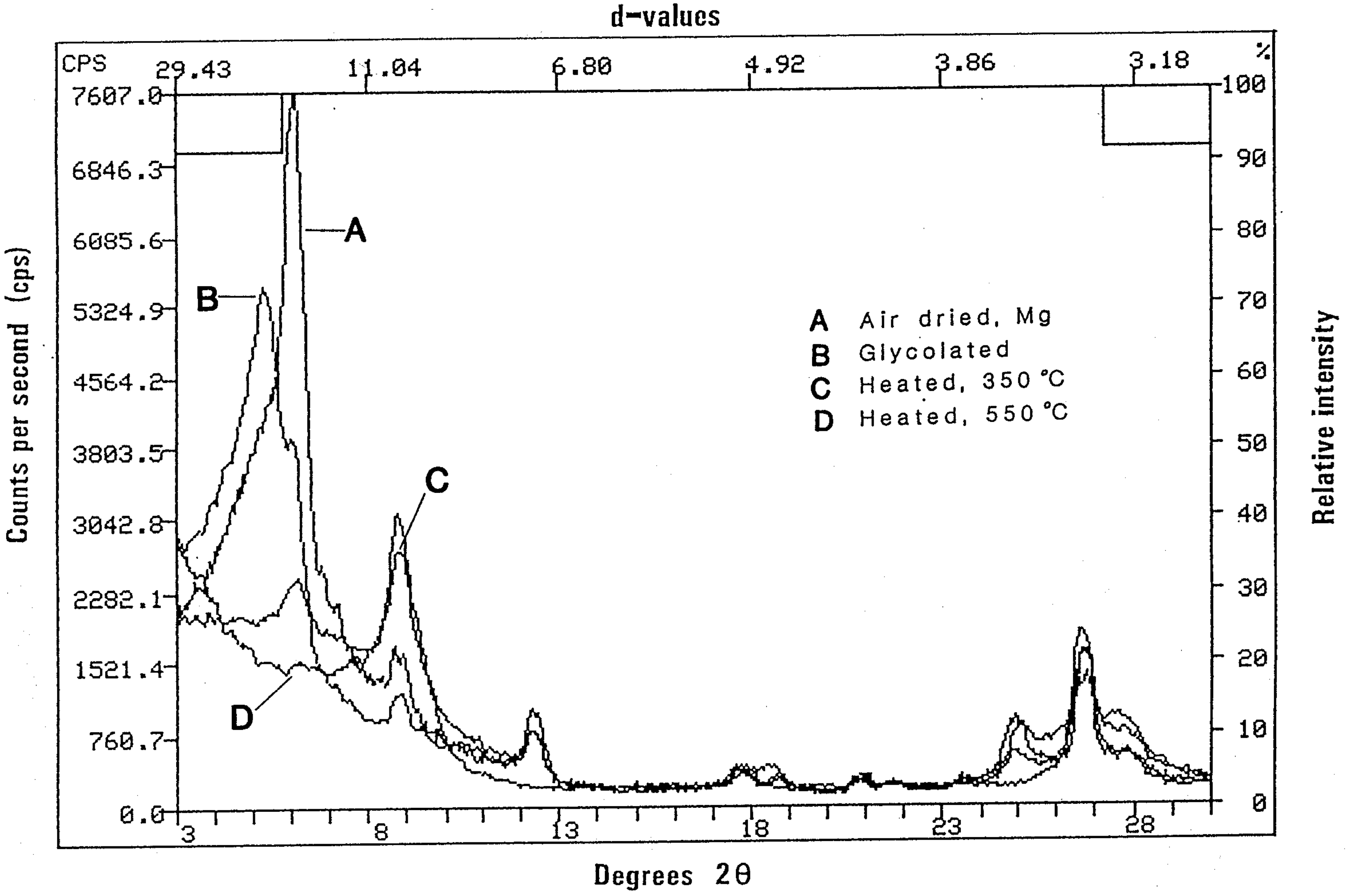
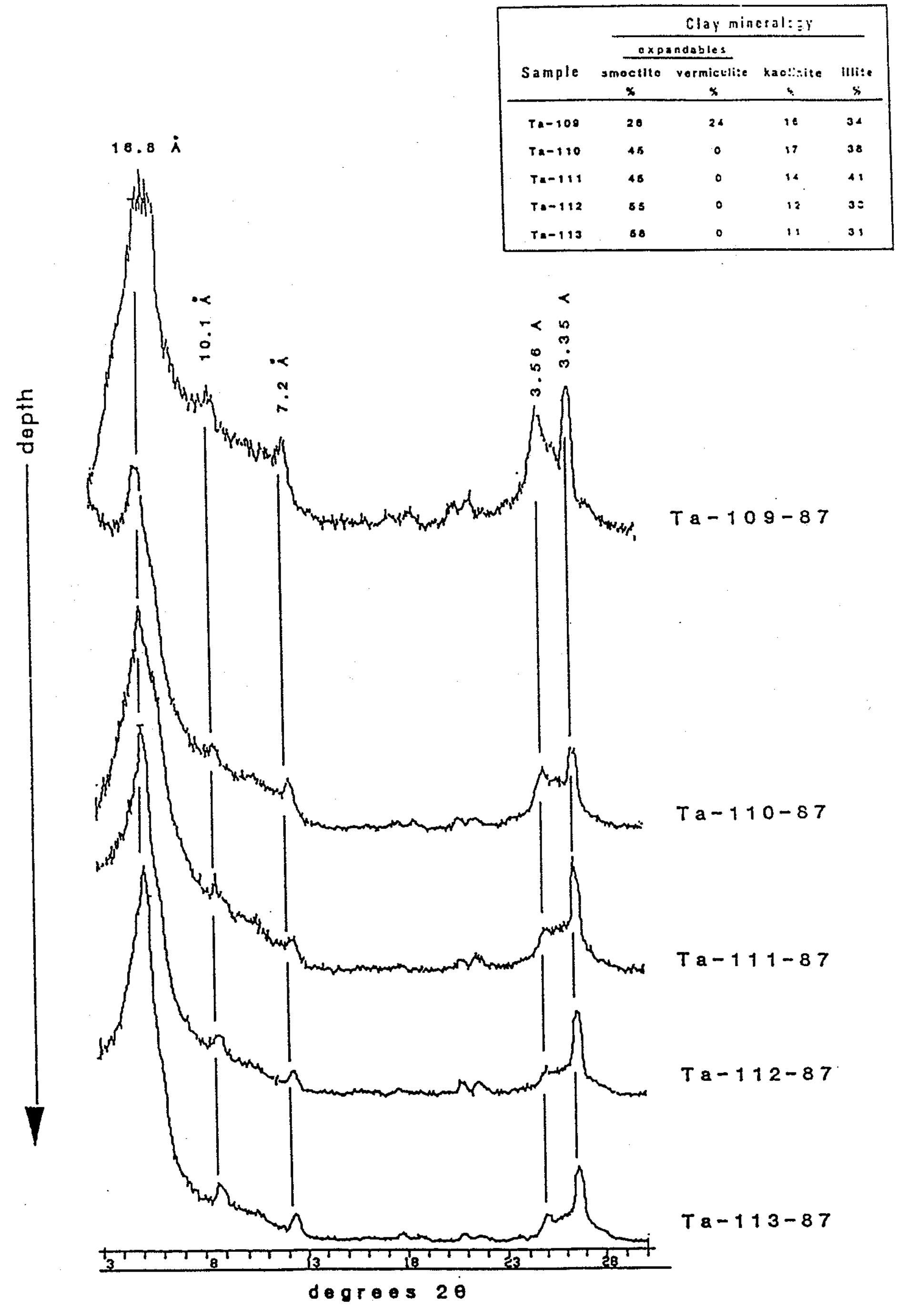


Figure 2.9: Typical oriented diffraction pattern (<2-μm fraction) for unoxidized till of the Merrill Member (Ck-16-87). Sample is from a depth of 4 m.

As previously noted, clay mineralogy is potentially the most useful when it can be used to detect weathering trends. Typically these trends are readily observed as a function of depth. Figure 2.10 depicts the weathering of Merrill till from 2.4 to 8.5 m. The most striking observation is the fact that the clay mineralogy is so homogeneous. The relative abundance of each species is noted on the diagram, and several small overall trends are evident. Both the 001 (7.2 Å) and 002 (3.56 Å) kaolinite reflections decrease in intensity with depth. The relative abundance of kaolinite also follows a similar trend showing a decrease in abundance (16-11%) with depth. Illite (10.1 Å) exhibits a slight overall decrease in relative intensity with depth while the expandables show an increase in relative abundance and crystallinity as exhibited by the sharpness of the peaks. Vermiculite was present but detection was difficult in the glycolated samples. The reported zero values are therefore misleading and more information is garnered from reporting both expandable clays as one value.

The areal distribution of Merrill till is shown in figure 2.11. The unit is the predominant surficial unit outside the late Wisconsin end moraine in Taylor County and covers the northern portion of the study area in Clark County.

All three of the cross-sections in figure 2.12 contain till of the Merrill Member. The unit is thickest in southern Taylor County and thins to the south in northeastern Clark County. Merrill was always found overlying till of the Edgar Member or in direct contact with



Sample	Clay mineralogy			
	expandables			
	smectite %	vermiculite %	kaolinite %	illite %
Ta-109	26	24	16	34
Ta-110	45	0	17	38
Ta-111	46	0	14	41
Ta-112	55	0	12	33
Ta-113	58	0	11	31

Figure 2.10: Weathering profile of till of the Merrill Member. Sample depths are approximately 2.4, 4.0, 5.5, 7.0, and 8.5 m. All patterns are Mg-saturated and solvated with ethylene glycol. Peak positions are labelled in Å.

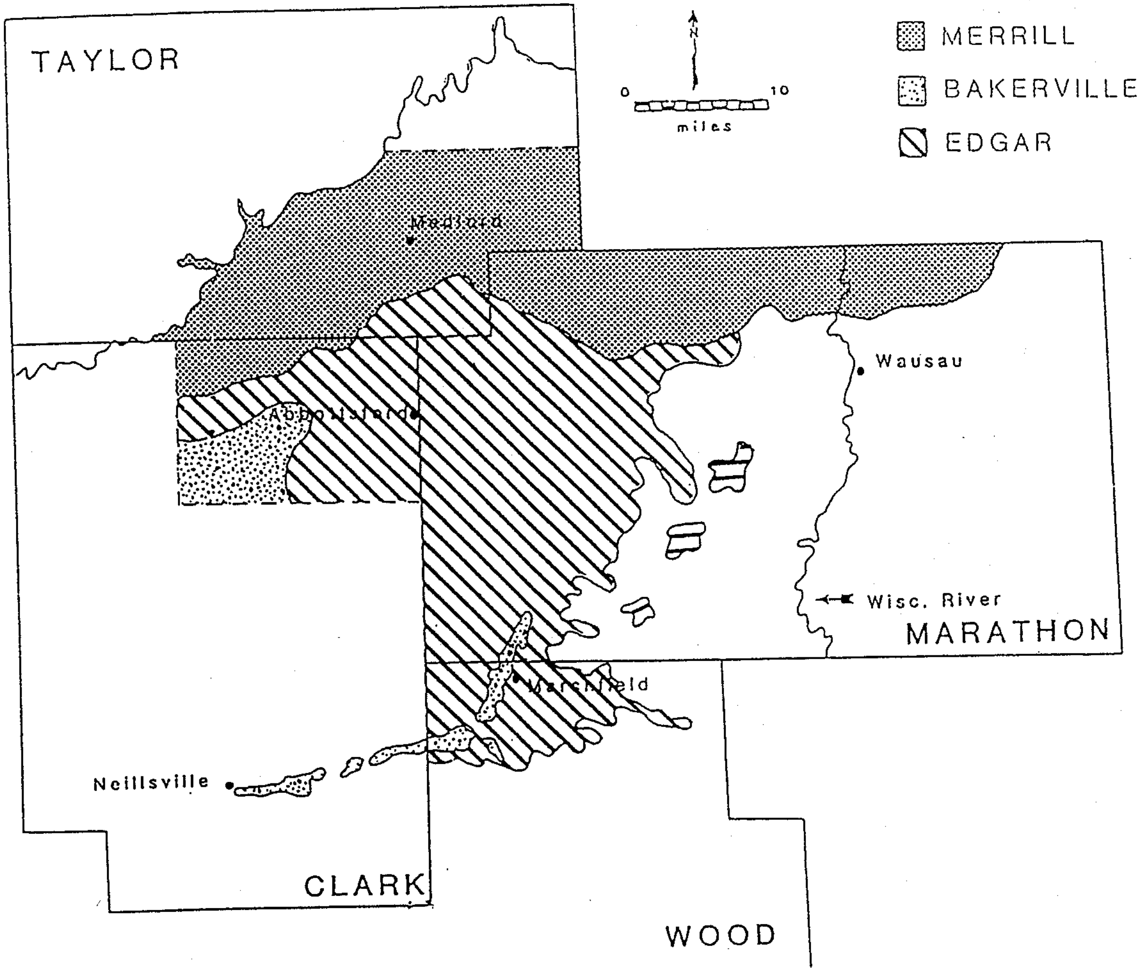


Figure 2.11: Areal distribution of surface till units in northeastern Clark, southeastern Taylor, western Marathon, and northeast Wood Counties (after Attig and Muldoon, in press; Attig, in preparation).

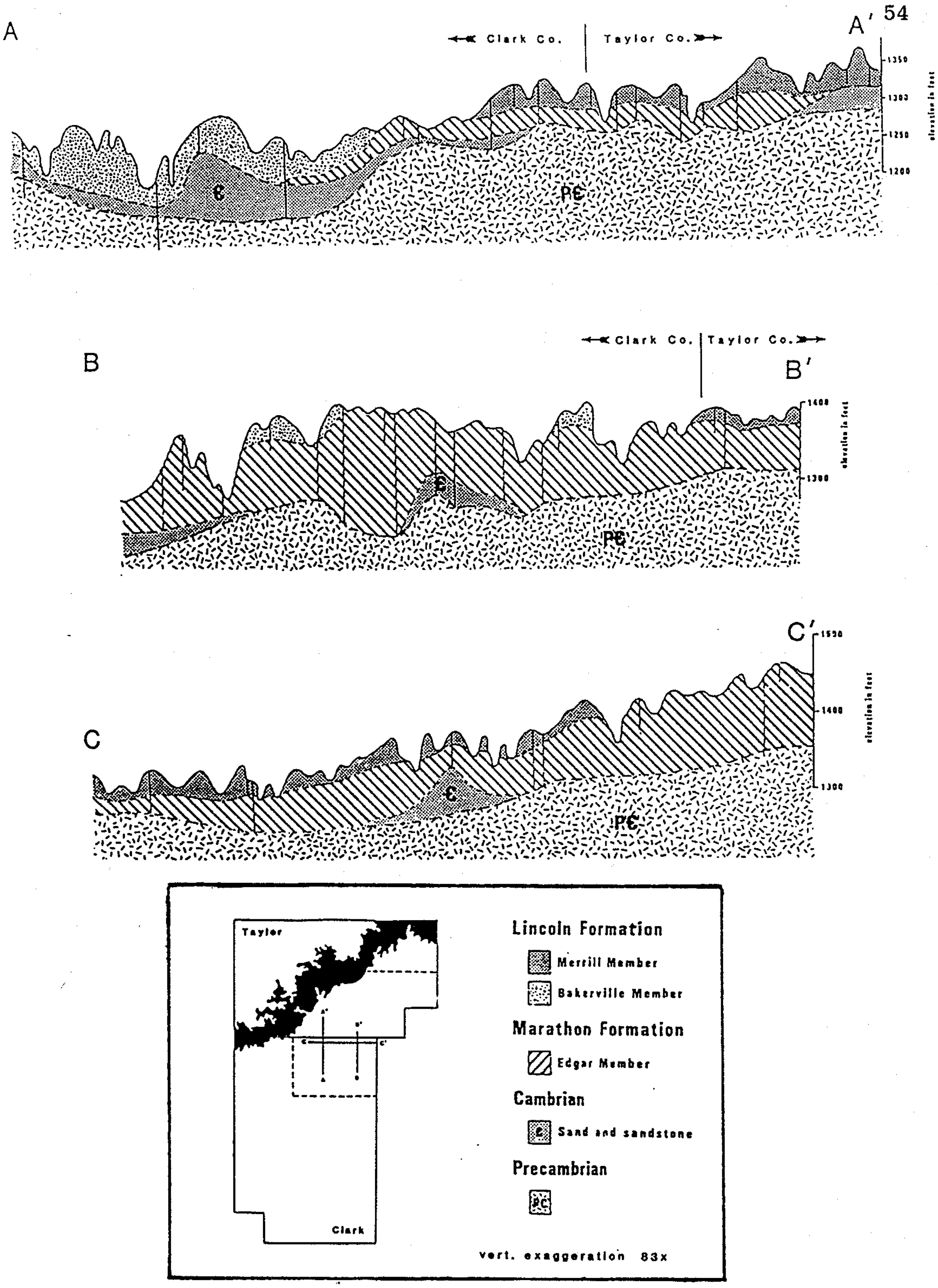


Figure 2.12: Subsurface distribution of the till units in north-eastern Clark and southeastern Taylor Counties. Location of cross sections shown.

Cambrian bedrock (A-A').

As previously noted, the area underlain by till of the Merrill Member is the only pre-late Wisconsin surface that exhibits any remnant glacial topography. Figure 2.13 shows the comparison of poorly drained regions within the study area. The density of these wet areas is highest on that pre-late Wisconsin surface that has been most recently deglaciated.

Bakerville Member

Till of the Bakerville Member is a noncalcareous loam to sandy loam unit. For 17 samples analyzed, the average sand:silt:clay distribution is 49.8%, 30.6%, and 19.6%. These values are similar to those of the Merrill Member within the study area. This grain size distribution is graphically presented in a triangular plot in figure 2.8. The grain size values reported here are slightly different from those of Muldoon (1987) who reported sand:silt:clay averages of 56.7:30.2:13.1 for 8 samples tested.

Two plausible reasons may account for this grain size discrepancy. Although sandstone bedrock is very near the surface in that portion of Clark County mapped as being covered by Bakerville till, the unit is quite thin, and presumably pedogenic processes such as clay illuviation have occurred in much of what is being mapped as Bakerville. This could account for the slightly higher clay content of the unit as compared to those values of Muldoon. The 8 Bakerville samples analyzed

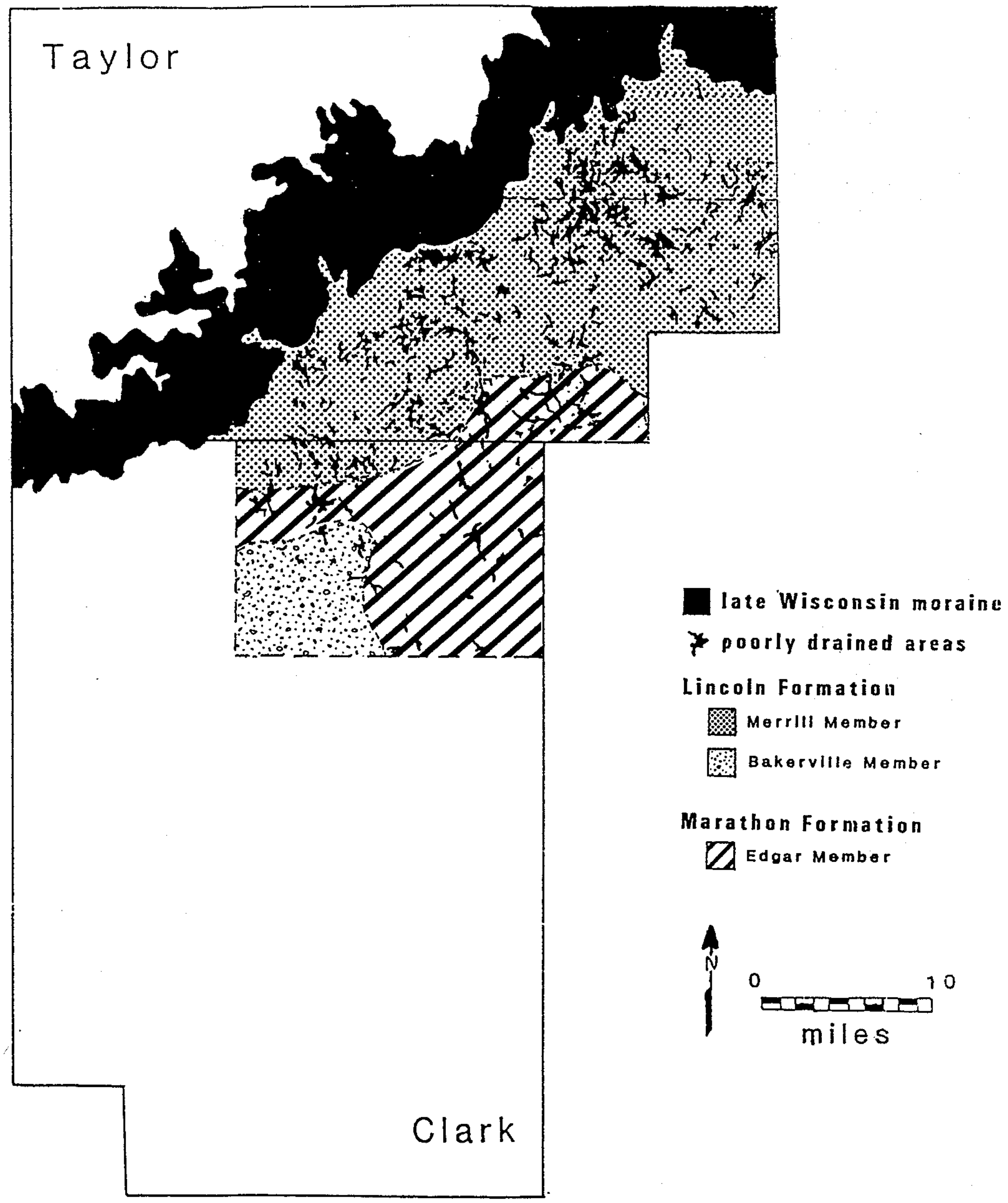


Figure 2.13: Location and areal extent of poorly drained areas within the study area. Till unit boundaries are designated as is the extent of the late Wisconsin glaciation (after Attig, in preparation).

for grain size by Muldoon were from drillholes atop the Marshfield moraine where the till is thicker. The Bakerville at this locality lies stratigraphically above contorted, calcareous sand and gravel of the Edgar Member. These materials could have easily been incorporated into the overriding Bakerville ice thus resulting in more sand in the unit at this locality.

All samples tested in the field with dilute HCl were noneffervescent. Laboratory analysis confirmed this with an average total carbonate content of 1.8% for six samples tested.

A total of 5 unoxidized till samples (Hole Ck-538) were analyzed for percent extractable free iron oxides. Values systematically decreased from 1.2% at approximately 4.0 m to 0.5% at 8.5 m (Appendix I). Magnetic susceptibility readings averaged 2.46 x 10^{-3} for 17 samples with values ranging from 5.10 x 10^{-3} to 1.63 x 10^{-3}. Field Munsell colors were consistently a brown (7.5YR 4/4) to a reddish brown (5YR 4/6-4/4) color.

The stratigraphy and lab data for Ck-521-87 are presented in figure 2.14. This drillhole contains a thick sequence of till of the Edgar Member capped by a thin (2.5 m) veneer of Bakerville sediment. A lithologic discontinuity occurs between these two units with the decrease in sand content occurring at 2.5 m below the surface.

For 14 samples of Bakerville that were analyzed for the clay mineralogy, the average clay species distribution was 34% smectite, 23% vermiculite, (57% expandables), 12% kaolinite, and 32% illite. Figure

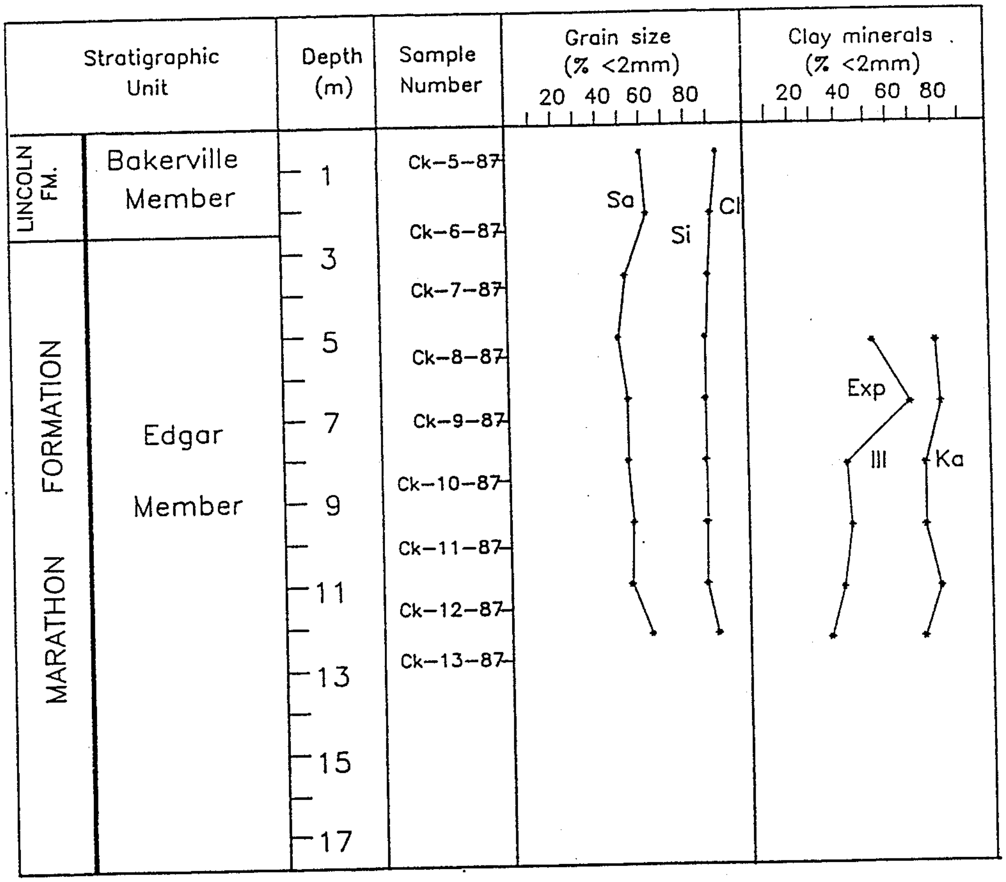


Figure 2.14: Summary of the stratigraphy and laboratory data for a portion of drill hole Ck-521.

2.15 is a characteristic x-ray diffraction pattern for an unoxidized sample (Ck-19-87) of Bakerville taken from a depth of 2.4 m. Aside from the slightly greater peak intensities noted on the Ck-19-87 pattern, the diffraction pattern is nearly indistinguishable from that of the unoxidized Merrill in figure 2.9.

Figure 2.16 is a weathering profile of Bakerville till (Hole Ck-538) from 2.4 m to 8.5 m depth. The same general assemblage of clay species is present as evidenced by the saturated and solvated patterns, notably smectite, vermiculite, illite and kaolinite.

Smectite (17 Å) and vermiculite (14 Å) are the co-dominant clay minerals. These expandable 2:1 minerals exhibit a general increase with depth from 43% at 4 m to 59 % at 7 m below the surface. The expandables then show a drop to 48 % at 8.5 m.

Kaolinite is present in all samples throughout the profile. Weathering is evidenced by the broad, poorly crystallized 7 Å peaks in the upper portions of the profile. The kaolinite peaks are more distinct in the lower portions of the profile where they have been unaffected by subaerial weathering effects. The loss of peak symmetry as indicated by broad ill-defined peaks is characteristics of internal disorganization in the crystal structure or degradation of the mineral due to weathering phenomena (Droste, 1956).

The intensity of the illite peaks also becomes stronger and more symmetrical with depth. Higher in the profile (Ck-123, 124) the illite is characterized by broad asymmetrical peaks probably indicating that

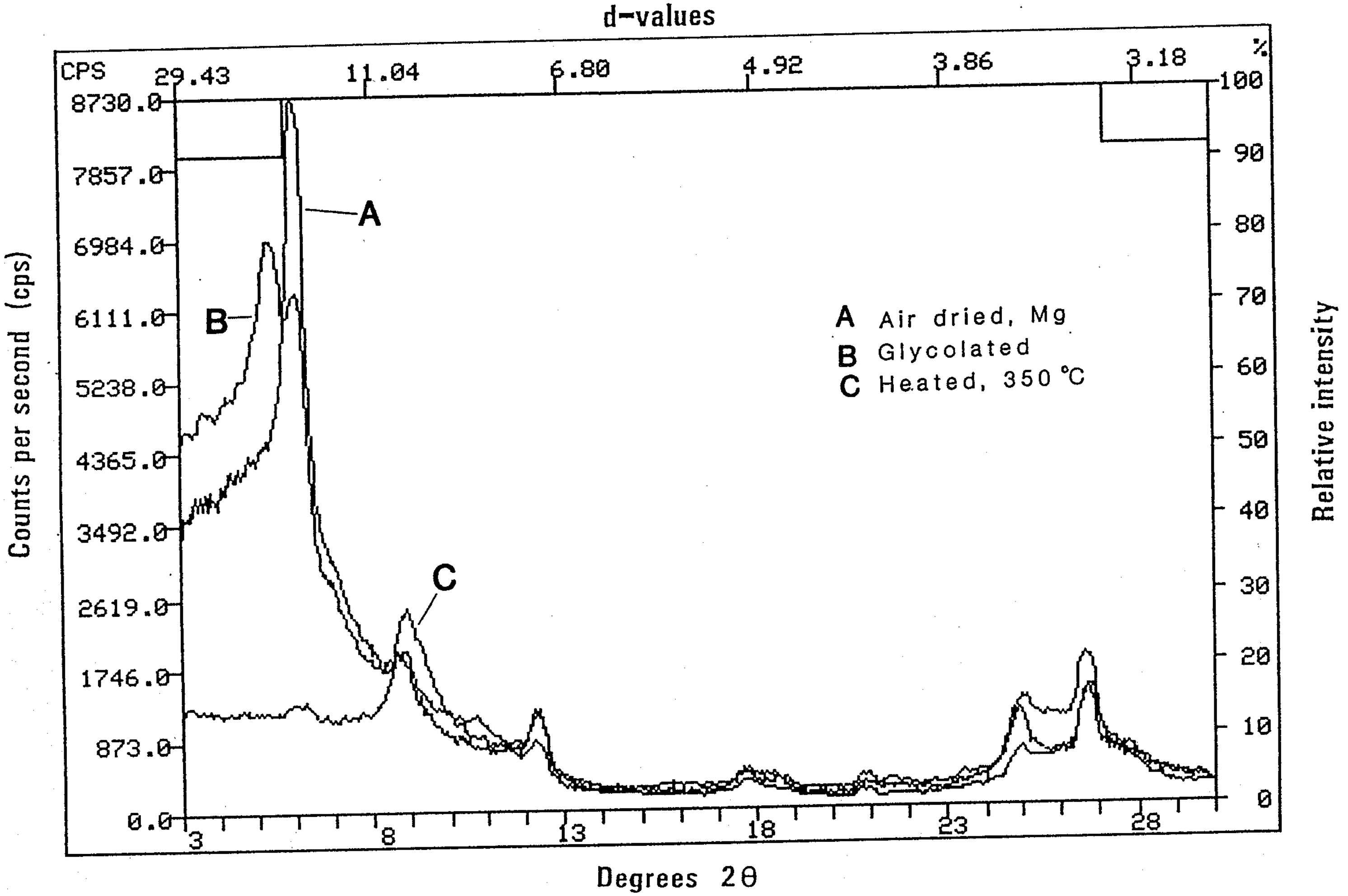
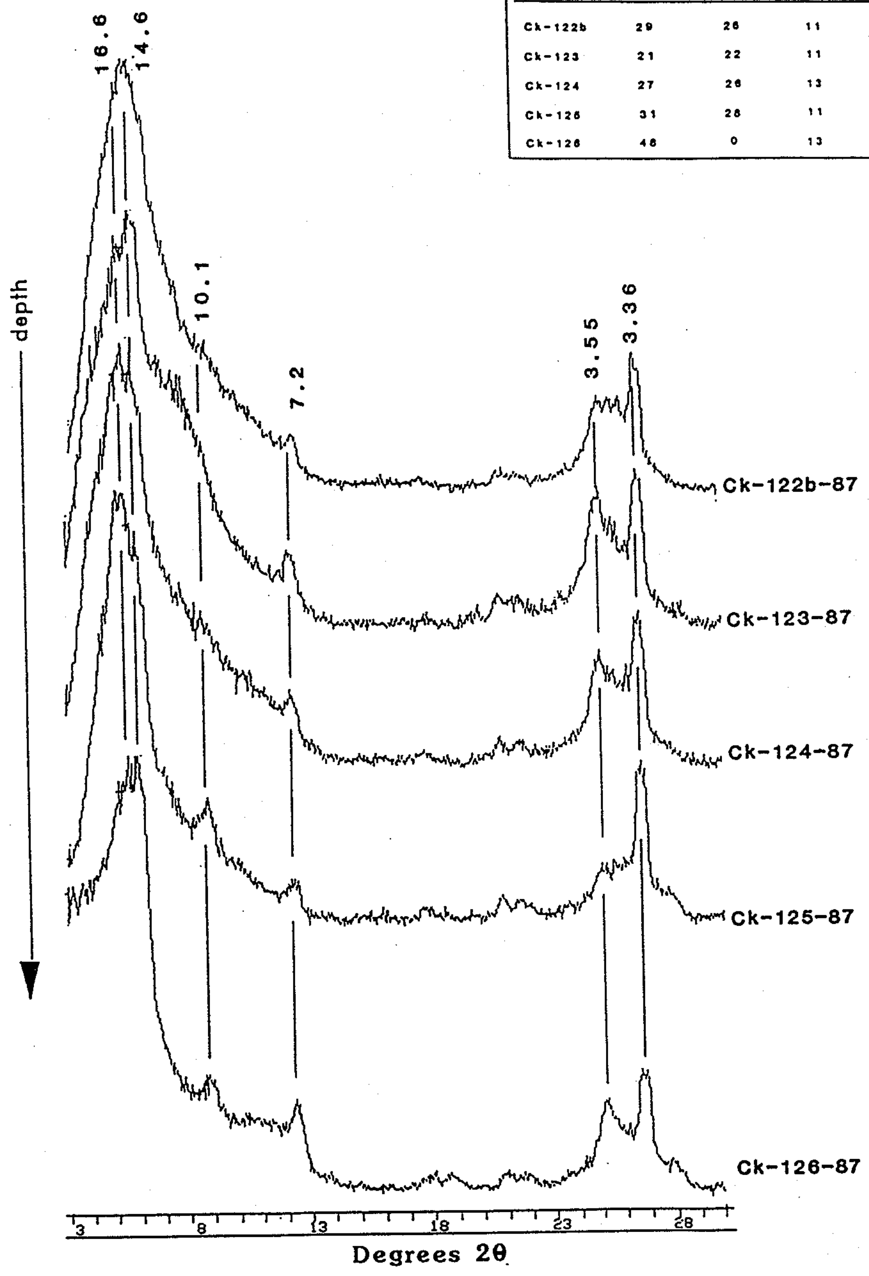


Figure 2.15: Typical oriented diffraction pattern (<2-μm fraction) for unoxidized till of the Bakerville Member (Ck-19-87). Sample is from a depth of 2.4 m.



	Clay mineralogy			
	expandables			
Sample	smectite %	vermiculite %	kaolinite %	illite %
Ck-122b	29	26	11	34
Ck-123	21	22	11	46
Ck-124	27	26	13	34
Ck-125	31	28	11	30
Ck-126	48	0	13	39

Figure 2.16: Weathering profile of till of the Bakerville Member. Sampling depths are approximately 2.4, 4.0, 5.5, 7.0, and 8.5 m. All patterns are Mg-saturated and solvated with ethylene glycol. Peak positions are labelled in Å.

the mineral has undergone some alteration or is in a hydrated state. This is consistent with observations made by Droste (1956).

Till of the Bakerville Member is not present in Taylor County. The unit is mapped at the surface in the southwest corner of the study area in Clark County (figure 2.11). The unit is relatively thin and well records indicate that it overlies Cambrian sandstone as depicted in figure 2.12 (Cross-section A-A'). The majority of the landscape mapped as Bakerville in the study area is bedrock controlled with rolling hills. Presumably for this reason, the Bakerville surface exhibits a better integrated drainage network than that of the older Edgar surface (figure 2.13). Sandstone float is present in roadcuts along County Trunk O in the western edge of the study area. Cross-section B-B' shows scattered patches of Bakerville capping a few of the broad interfluves. The unit is stratigraphically above till of the Edgar Member in these localities.

Edgar Member

Till samples of the Edgar Member vary in color significantly. They range from brown to strong brown (7.5YR 4/4-4/6) in the oxidized zone to gray or reddish gray (10YR 5/1-4/2) in the unoxidized zone. The most common field color is typically of 7.5YR and 5YR hue. These colors are quite similar to those noted for the Bakerville Member.

The Edgar till unit is loam textured with an average grain size distribution of 36.7% sand, 37.9% silt, and 25.5% clay over the entire study area. Figure 2.8 shows a triangular plot of the less-than-2-mm fraction for only till samples of the Edgar Member in the area. The unit is considerably sandier in northeastern Clark County, averaging 43.5% sand, 34.4% silt and 21.1% clay for 49 samples than in southeastern Taylor County where 3 samples yielded a grain size distribution of 29.8% sand, 41.3% silt, 28.9% clay. This is probably a direct reflection of an increase in Cambrian sandstone bedrock in Clark County. Muldoon (1987) reports slightly siltier values to the east in Marathon County. For 197 samples she measured an average distribution of 39.2% sand, 42.9% silt, and 17.9% clay.

The average magnetic susceptibility value for the Edgar is 1.58×10^{-3} with values ranging from 9.83×10^{-4} to 1.24×10^{-3}.

A summary of both stratigraphy and lab data for nearly 18 m of Edgar till is graphically shown in figure 2.17 for drill hole Ck-526. Two distinct discontinuities occur in the profile, both of which are reflected by changes in the grain size distribution. The profile becomes calcareous at 5 to 7 m below the surface. The accompanying change in grain size is toward a more silt and clay rich sample at this depth. From 10 to 11.5 m there is a considerable decline in the amount of sand present (50.9% to 38.4%). The increase in silt and clay possibly represents a thin layer of lacustrine sediment which is characteristic of the Edgar Member.

Figure 2.18 is a second profile in the Edgar till (Ck-536) that exhibits remarkable uniformity with depth of grain size and clay

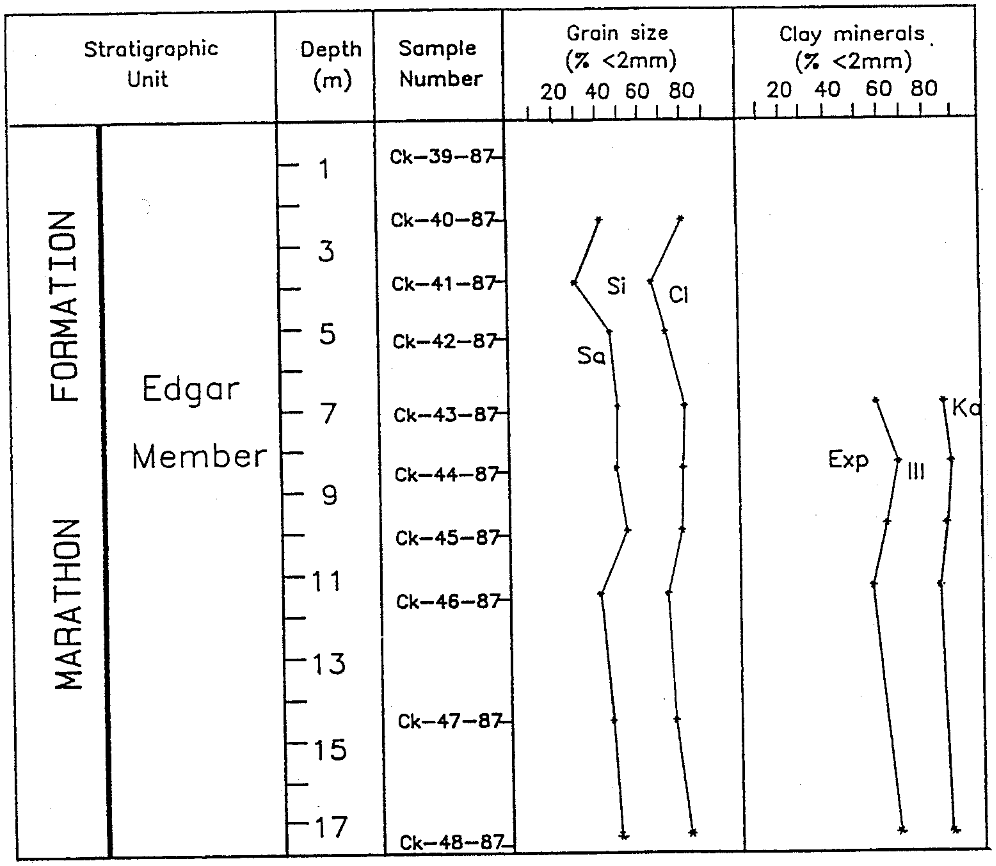


Figure 2.17: Summary of the stratigraphy and laboratory data for a portion of drill hole Ck-526.

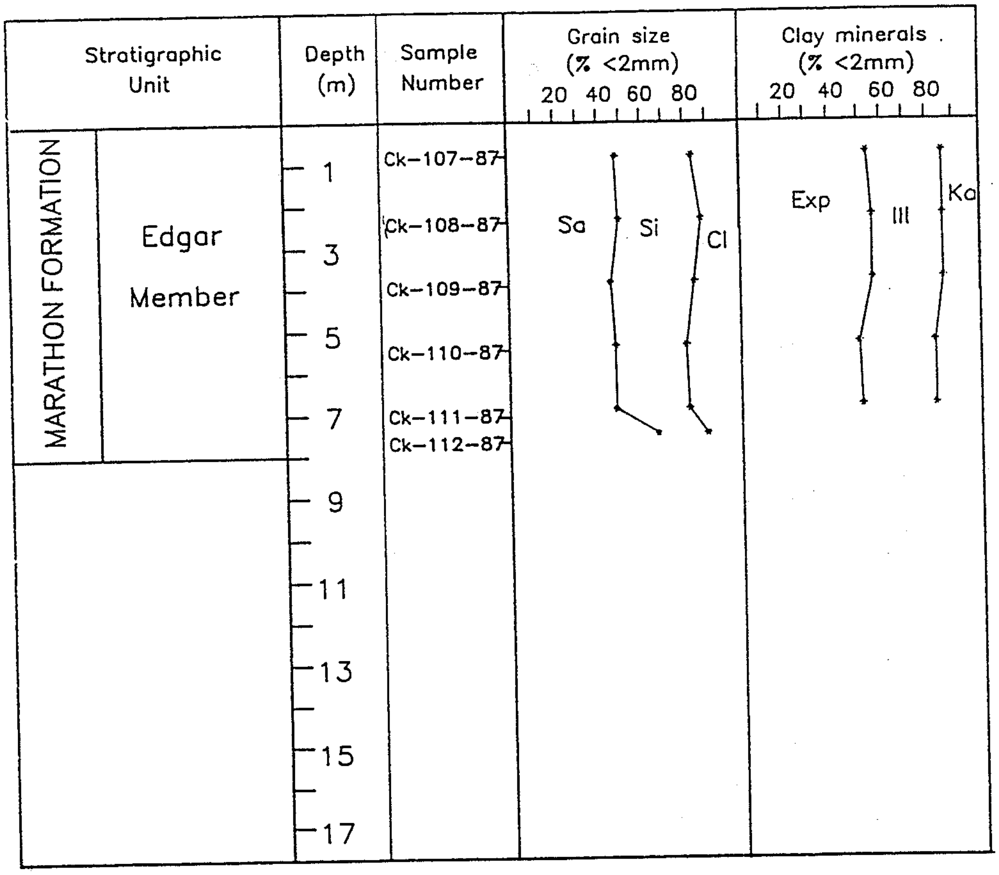


Figure 2.18: Summary of the stratigraphy and laboratory data for a portion of drill hole Ck-536.

mineralogy. Cambrian sandstone was encountered at 8 m which is readily observed by the marked increase is sand percentage at the base of the drill hole.

The clay mineralogy of 18 till samples of Edgar was analyzed. These samples reflect little change from the mineralogy of either Bakerville or Merrill till. Edgar samples contain predominantly 2:1 expandable clays (56%). Smectite is the only expandable clay detectable in many of the samples. Vermiculite was not able to be quantified but is undoubtedly present in minor amounts as evidenced by the step-wise dehydration of the 14 Å peak upon heating. Illite abundance averages 28% and kaolinite 14%.

The saturated-glycolated pattern of unoxidized Edgar till (Ck-44-87) is presented in figure 2.19. The sample is calcareous and was taken from a depth of 8.5 m. Smectite dominates the pattern, exhibiting a well crystallized peak at approximately 17 Å. Vermiculite (14.3 Å) is the co-dominant species. Kaolinite and illite both show some signs of degradation in that the peaks recorded are not well defined. A calcite peak at 3.04 Å attests to the calcareous nature of the sample.

Figure 2.20 depicts the weathering profile of an unoxidized sample of Edgar till. The profile is from 5.5 to 11.5 m and all samples are calcareous. The glycolated patterns are dominated by sharp smectite peaks (17.7 Å). A poorly defined 14 Å shoulder sometimes occurs on the tail of the smectite peak. This is evident in the Ck-9-87 sample.

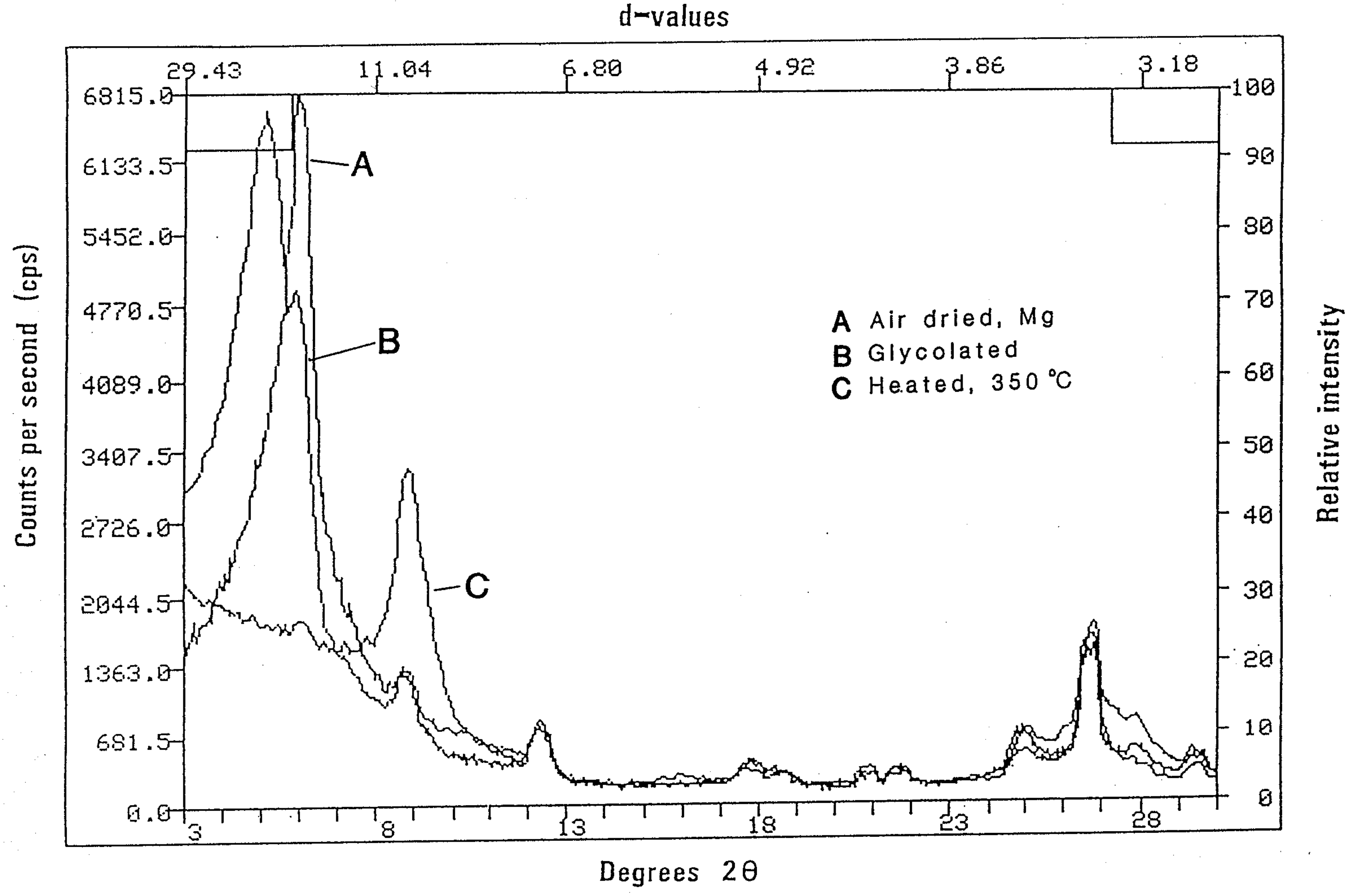
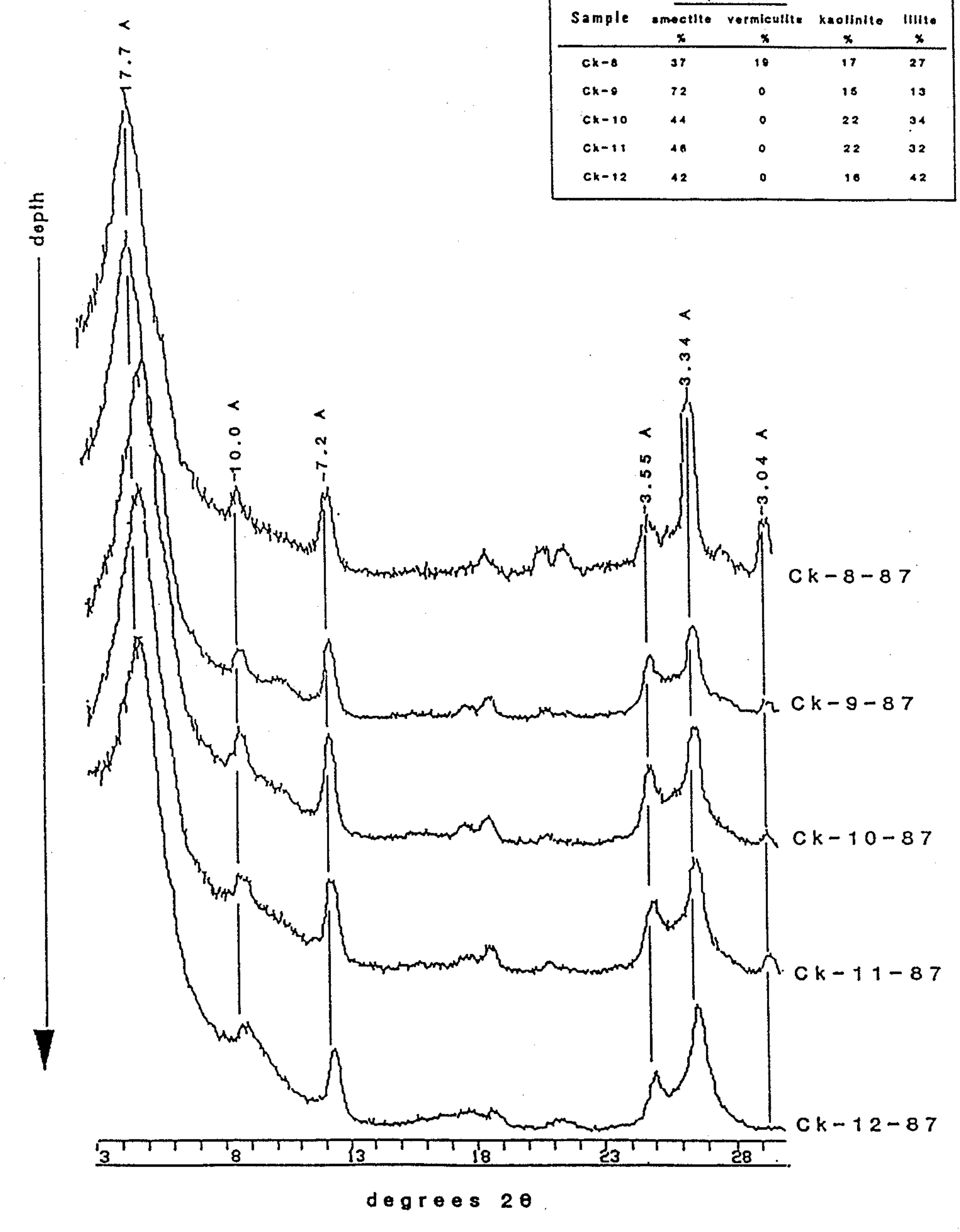


Figure 2.19: Typical oriented diffraction pattern (<2-µm fraction) for unoxidized till of the Edgar Member (Ck-44-87). Sample is from a depth of 8.5 m.



	Clay mineralogy			
	expandables			
Sample	smectite %	vermiculite %	kaolinite %	illite %
Ck-8	37	19	17	27
Ck-9	72	0	15	13
Ck-10	44	0	22	34
Ck-11	46	0	22	32
Ck-12	42	0	16	42

Figure 2.20: Weathering profile of till of the Edgar Member. Sample depths are 5.5, 7.0, 8.5, 10.1, 11.6 m. All patterns are Mg-saturated and solvated with ethylene glycol. Peak positions are labelled in A.

Both the 001- and 002- order kaolinite peaks are well defined and exhibit little alteration with depth. The 10 Å illite peaks become less defined lower in the profile. Quartz (3.34 Å) is present in all samples but is most prevalent in the uppermost pattern and calcite is also present (3.04 Å) in all samples with the exception of Ck-12-87.

In accordance with the predicted weathering of illite to expandable clay minerals, one sees an overall decline in the relative abundance of total expandables (72% to 42%) and an accompanying increase in illite (13% to 42%) with depth. As would be expected, illite is most depleted in those samples closest to the land surface where the most intense weathering has occurred. Kaolinite remains fairly stable throughout the profile with a slight increase detected with depth (17% to 23%).

The thickness of the Edgar till is quite variable. In areas, the till is completely eroded from the landscape or is so severely stripped that it remains only as thin patches. In more complete sections it varies from 7 to 18 m in thickness. Figure 2.12 shows the subsurface distribution and thickness of the Edgar Member. The east-west cross section C-C' shows the Edgar is thickest at the Clark-Marathon border and thins to the west where it is overlain by a fairly continuous cover of Merrill till. The unit also thins to the east in Marathon County (Attig and Muldoon, in press).

Interpretation of the Clay Mineralogy

The data suggest that the clay mineralogy does not vary significantly with the age of the till surface. All glycolated patterns of the three till units analyzed exhibit the same gross mineral assemblages and average relative species abundance (table 2.1). This surprising lack of variation, both as a function of depth and laterally on a regional scale, has several implications.

Comparison to Stewart's values

Because Stewart (1973) was able to convincingly demonstrate that differences exist in the clay mineralogy between the two pre-late Wisconsin till units (Merrill and Wausau), an attempt was made to replicate some of his results. The Merrill Member is the only unit in common between the two studies, hence any direct comparison with the others was not feasible.

The clay mineral methodology differs significantly between the two studies. As previously noted, this study used Mg^{2+} saturated samples to aid in the differentiation and quantification of vermiculite from smectite. This study also used two different heatings (350 °C and 550 °C) and ethylene glycol to solvate. Stewart used both moisture saturated air and dry air in a chamber, glycerol as a solvating media, and no cation saturation. To quantify his mineral percentages, Stewart measured peak area and then set up a series of ratios whereby everything was compared to the 10 A illite peak. The relative percents reported in this study were derived from the Mg-saturated, glycolated patterns using computer generated net peak intensities (Guccione, 1985).

Five representative samples of Merrill till from northeastern Clark and southeastern Taylor Counties were quantified using Stewart's peak area method. Integrated areas were calculated using the Scintag/USA diffractometer and the derived values in turn used to calculate peak area ratios. Since these samples were not originally run under the same conditions as those of Stewart's, two substitutions had to be made. The air dried Mg-saturated patterns were used in place of Stewart's saturated air patterns and the 350 °C patterns were used in place of Stewart's dry air patterns.

Calculations reveal that little difference exists in the average relative percents calculated for the five Merrill till samples from Clark and Taylor Counties using either Stewart's peak area method or the net intensity method (table 2.3A). There is however, a significant difference between the clay mineralogy of the Lincoln and Marathon County Merrill till versus that of the Clark and Taylor County Merrill till when relative percents are determined using only the peak area ratio method of Stewart (table 2.3B). Illite values for instance, are considerably higher in Merrill till from Lincoln and northern Marathon Counties (51%) than from Merrill till to the west in Clark (25%) or Taylor County (33%) while total expandables measured are quite a bit lower (39% vs 53%,63%). Calculated kaolinite values are within 10%. The fact that the mineralogy of the Merrill till appears to be slightly

A

			Expendables	
	Kaolinite	Illite	Vermiculite	Smectite
Peak Area Ratio (Stewart, 1973)	3%	30%	10%	57%
Net Peak Intensity (Guccione, 1985)	12%	29%	17%	42%

B

Merrill till			Kaolinite	Illite	Vermiculite	Smectite
Lincoln-Marathon (Stewart, 1973)	n=23		9%	51%	23%	16%
Clark-Taylor (Sutherland, 1989)	n=10	Ta	14%	33%	13%	40%
	n=3	Ck	12%	25%	29%	34%

Table 2.3: Comparison of calculated relative percentages of clay mineral species present in Merrill till (n=5) from the study area using the peak area ratio method and the net peak intensity method (A). Comparison of Merrill till clay mineralogy in Lincoln and Marathon Counties vs Clark and Taylor Counties (B).

different in the two regions suggests a possible difference in either local bedrock or flow path of the Merrill ice.

The till fabric analysis for 6 sites in Lincoln County (Stewart, 1973) reveals 4 sites in the Merrill till in which ice flow was to the south-southeast. One other site in the Merrill till revealed a well defined ice flow indication from the northeast. If the fabric indicating flow from the northeast is accurate, then the ice travelled over a very different bedrock surface than did Merrill ice with a northwesterly flow component. Ice from the northeast would have travelled over a large area underlain by the Michigamme Slate and related Formations of the Barga Group (Morey _et_ _al_., 1982). Ice from the northwest, however, would have travelled primarily over sandstone, granite, and associated mafic metavolcanic rocks (Morey _et_ _al_., 1982). Perhaps the very different bedrock lithologies influenced the clay mineral constituents present in till of the Merrill Member as seen in the Clark and Taylor area versus that of the Lincoln and Marathon area.

Discrepancies also exist when a comparison is made between the relative percentages derived for each mineral species from the 5 samples of Merrill till from Clark and Taylor Counties using each of the methods described (table 2.4). The peak area ratio method consistently overestimates the amount of smectite in a sample while in 3 out of 5 of the samples, the amount of vermiculite was underestimated. Both kaolinite and illite values were generally within 10% agreement with the exception of sample Ta-126-87. Given these

			Expandables	
	Kaolinite	Illite	Vermiculite	Smectite
		Ck-15-87		
PAR	1%	20%	13%	66%
NPI	11%	24%	31%	34%
		Ta-112-87		
PAR	12%	38%	9%	41%
NPI	12%	33%	0%	55%
		Ta-113-87		
PAR	1%	18%	0%	81%
NPI	11%	31%	0%	58%
		Ta-126-87		
PAR	2%	65%	7%	28%
NPI	15%	27%	29%	29%
		Ta-130-87		
PAR	1%	11%	19%	69%
NPI	13%	29%	26%	32%

PAR =peak area ratio method
NPI =net peak intensity method

Table 2.4: Comparison of calculated relative percentages of clay mineral species present in Merrill till (n=5) samples from northeastern Clark and southeastern Taylor Counties using both the peak area ratio method (Stewart, 1973) and the net peak intensity method (Guccione, 1985).

data, it would seem to indicate that the differences noted in the calculated relative percents are the result of differences in the methodology between the two studies and not the clay mineralogy itself. Perhaps because Stewart did not use any Mg^{2+} saturation in sample preparation, the relative abundance of vermiculite and smectite were not accurately portrayed in the glycolated patterns. Stewart (1973) notes that the high percentage of vermiculite is a distinguishing characteristic of the 26 samples of Border Drift analyzed.

Effects of a periglacial environment

It has been established that permafrost conditions prevailed in much of Wisconsin during late Wisconsin time (Attig, et al., 1987; Black, 1965; Johnson, 1984) and presumably existed during earlier glaciations as well. Black (1961) estimates that permafrost may have existed in Wisconsin from approximately 30,000 to 12,500 years ago. Attig and Clayton (1986) propose that continuous permafrost occurred in the northern part of the state until approximately 13,000 years ago. Florin and Wright (1969) interpret the persistence of buried ice in the St. Croix moraine as an indication of tundra conditions in that area. Although observations of once perennially frozen ground on the pre-late Wisconsin surface in Clark and Taylor Counties are thus far inconclusive, evidence exists that attests to the fact that conditions were conducive to produce permafrost and maintain it in many other parts of the state.

Numerous ice-wedge cast localities as well as patterned ground support this conclusion. Johnson (1984) sites 11 ice-wedge casts in nearby Barron County. The casts are formed in Cambrian sand and sandstone, till, and stream sediment. The vast majority of the sixteen ice-wedge cast localities sited by Black (1961) are in either pre-late Wisconsin sediments or the Driftless Area of the state. In a study of the Chippewa moraine complex Cahow (1976) attributed intensively frost-rived quartzite on the eastern end of Flambeau Ridge and a series of poorly developed ice-wedge casts and involutions in a road cut to be periglacial in origin.

Ventifacts in Chippewa County (Cahow, 1976) and Barron County (Johnson, 1984) are fairly common. Johnson (1984) notes that all ventifacts in Barron County occur on surfaces older than approximately 20,000 years and that although the ventifacts were not necessarily formed under permafrost conditions they are of similar age as the ice-wedge casts in the county.

Accelerated hillslope movement due to solifluction or congelifluction, and repeated freeze-thaw cycles of the till and soil were probably common occurrences in the landscape over much of northern and north-central Wisconsin during both pre-late and late Wisconsin glaciations. Solifluction is favored by an impermeable substratum, such as frozen ground, which limits the downward movement of percolating water. The process is most effective where melting ice layers weaken the sediment and provide excess water which in turn reduces the internal friction and cohesion of the sediment and flow is induced (Williams, 1957, 1959). Solifluction is the most common periglacial process taking place on every slope, and every surface in excess of 2° slope (Jahn, 1975). Frost action and solifluction commonly occur in conjunction with each other (Washburn, 1980). Deformation of sediment as a result of these periglacial conditions would result in a homogenization and reworking of the upper few meters of landscape materials.

Differentiation of oxidized Edgar till from till of the Bakerville Member is difficult in northeastern Clark County. The difficulty is compounded by the fact that not only is the Bakerville till generally stripped and hence less than 3 m thick, but loess has also been incorporated into both units. The combination of an extensively reworked loess/till mixture and formerly active accelerated hillslope processes and stripping of the upland surfaces would offer one explanation for the uniformity of till and soil characteristics. If this is the case, then it is of little surprise that all three of the till units exhibit not only the same gross clay mineral assemblages, but also in nearly the same proportions.

CHAPTER THREE

SOILS

Introduction

The advent of pedostratigraphy is a relatively new addition to the field of Quaternary studies and within the last quarter of a century, the use of soils as relative age indicators has gained popularity (Birkeland, 1978; Morrison, 1967,; Vreeken, 1984). Soil stratigraphy, or pedostratigraphy, is an all encompassing term for several methods that use weathering profiles to aid in the subdivision and/or correlation of Quaternary sediments. The use of paleosols and weathering zones were formally introduced as distinct stratigraphic units to the American Stratigraphic Code (ACSN, 1961) and have since been useful in Quaternary investigations in the glaciated Midwest (Follmer, 1978; Willman _et al_., 1966) as well as the western mountainous regions (Shroba and Birkeland, 1983). One aspect of pedostratigraphy involves the use of soils as relative age indicators. By noting trends in the morphological and chemical properties within a soil profile a rough estimation of the degree of soil development can be derived.

The soil forming factors originally proposed by Jenny (1941) are climate, parent material, vegetation, organisms, topographic position, and time. The basic premise in this portion of the study was based on the assumption that if climate, vegetation, and position in the landscape were considered constant, then any relative differences in soil development could be attributed to differences in time and parent material. The detailed grain size analyses done in conjunction with the Pleistocene lithostratigraphic portion of this study have suggested that sufficient mixing of the upper few meters of till and loess has occurred, thus blurring any effects of time from a soil genesis standpoint. Therefore, all differences in pedogenic development in those profiles chosen to study, is believed to be due to a combination of both differences in parent material lithology as well as time.

Previous work in north-central Wisconsin

There were several early reconnaissance soil surveys organized by the Wisconsin Geological Survey in the early 1900's in north-central Wisconsin. Weidman (1903) was the first to publish a comprehensive report in which he recognized 14 soil types in the north-central portion of the state. Weidman did not designate any particle size limits for the two soil separates (sand and clay) he used in his classification scheme.

Kellogg (1930) recognized Gray Brown Forest, Podsol, and Prairie soils as three generalized types of soils in Wisconsin (figure 3.1). He also realized that many of those profiles encountered in the central part of the state did not fit into any of these three categories. Kellogg classified these as "Transitional" soils because the profiles contained characteristics seen in the Gray Brown Forest soils to the

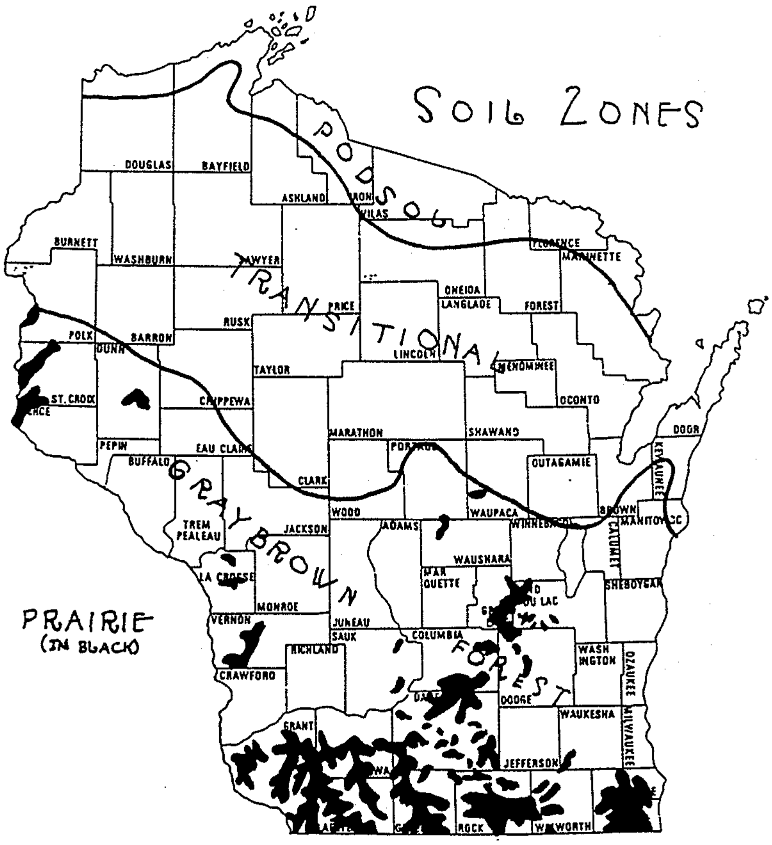


Figure 3.1: Generalized sketch of soil zones in Wisconsin (Kellogg, 1930).

south as well as genetic similarities to the Podsols to the north.

With the revised Soil Taxonomy (1975), most of Kellogg's Gray Brown Forest soils now are known as Alfisols and the Podsols as Spodosols. Those soils found within the Transitional zone are typically suborders of either the Alfisol or the Spodosol order. Along a traverse from the Alfisol region northward in the state, profiles are progressively more deeply leached and have thicker albic horizons.

Within the area, the majority of the transitional soils are classified as Alfisols and more specifically, Glossoboralfs, due to the tongues of albic material that grade downward into the argillic (Bt) horizon. Figure 3.2 is a representative profile of the Glossoboralfs of the area taken in the wall of a small gravel pit near the Clark-Taylor County line.

Ranney (1966) conducted detailed work on the genesis of these Typic Glossoboralfs with an emphasis on the formation of the albic tongues and mechanisms of clay translocation within the profiles. Mineralogical analysis of the silt fraction indicated that in the upper B horizon, the albic material and the surrounding B material had similar coarse:fine silt ratios, therefore suggesting that the tongues could have formed in situ via eluviation of clay from the B horizon itself. Lower in the B horizon however, the albic tongues consistently have different coarse:fine silt ratios than the surrounding B material. Ranney suggests this indicates that the translocation of silt and sand has been involved in the formation of the lower sections of the albic

Figure 3.2: Glossoboralf exposed in a gravel pit wall near the Clark-Taylor County line.

tongues.

Regional Distribution of Soil Series

Soil Associations

The soils of Clark and Taylor Counties have been grouped into generalized soil associations by SCS field scientists (figures 3.3 and 3.4). A soil association map is a geographic assemblage of soils found within a landscape. Each of the spatial areas delineated on figures 3.3 and 3.4 consists of one or more major soil series and at least one minor soil series. The delineated polygon is then named for the major soil that predominates in that landscape. It is important to note that the soils within any given association may very well occur in another association, but sometimes in a different position in the landscape.

These association maps are useful because they give a general idea of the groupings of soils within a county and can ideally be used to infer the texture of parent materials from which they are derived. With this in mind, it is interesting to note the similarities between the two association maps and figure 2.11 which shows the areal distribution of till units in both the study area and adjacent Marathon and Wood Counties. The boundary between areas 1 and 7 in the southeast portion of Taylor county corresponds quite well to the Merrill-Edgar boundary on figure 2.11. Likewise, in northeastern Clark County, the

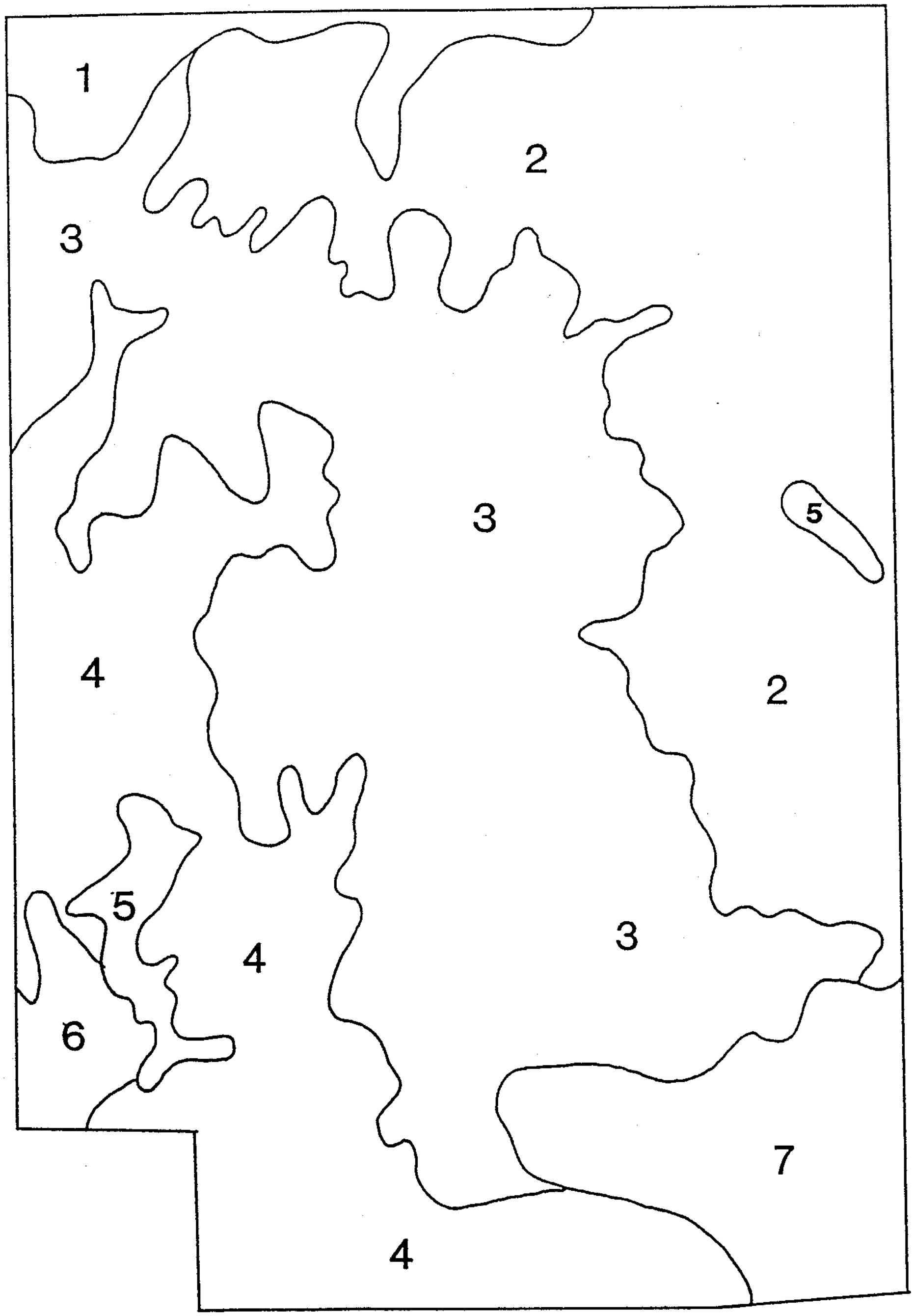


Figure 3.3: Soil association map of Clark County (SCS, 1987).

Soil Associations of Clark County

1. Freeon-Amery-Auburndale Association

   Nearly level to moderately steep, well drained to poorly drained, loamy and silty soils on ground and end moraines

2. Withee-Loyal-Marshfield Association

   Nearly level and gently sloping, somewhat poorly drained and poorly drained, silty soils, on ground moraines

3. Loyal-Kert-Withee Association

   Nearly level to moderately steep, well drained to somewhat poorly drained, silty soils on ground and end moraines and on low uplands underlain by sandstone interstratified with shale

4. Ludington-Elm Lake-Fairchild Association

   Moderately deep, nearly level to sloping, moderately well drained to poorly drained, loamy and sandy soils on low uplands underlain by sandstone interstratified with shale

5. Cathro-Markey-Seelyville Association

   Nearly level, very poorly drained, mucky soils on floodplains and on depressions of moraines

6. Eleva-Meridian-Otterholt Association

   Nearly level to steep, somewhat excessively drained and well drained, loamy soils on stream terraces, valley slopes and ridges underlain by sandy deposits, or sandy residuum and sandstone

7. Vesper-Kert Association

   Nearly level and gently sloping, somewhat poorly drained and poorly drained, silty soils on low uplands underlain by sandstone interstratified with shale

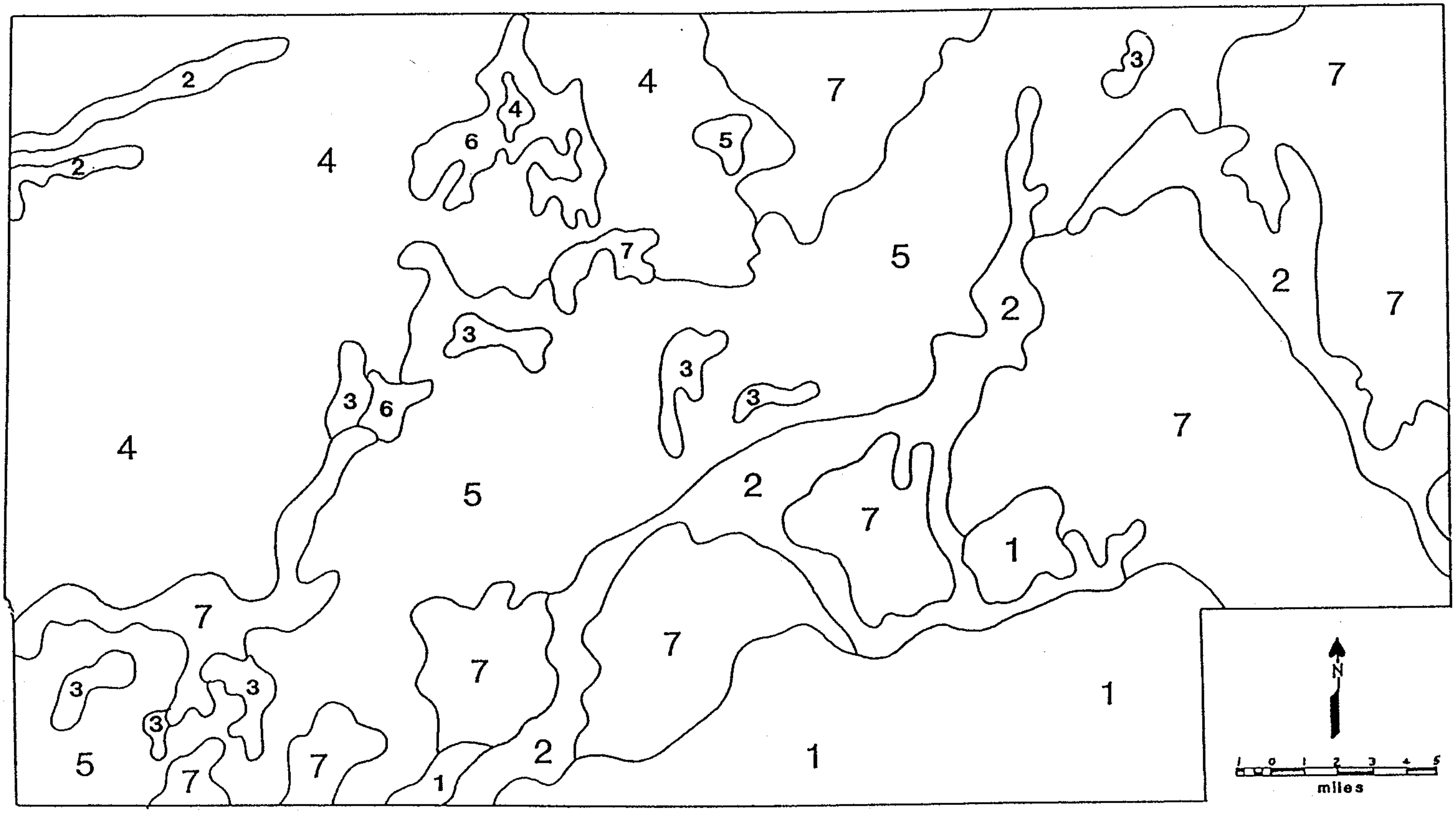


Figure 3.4: Soil association map of Taylor County (SCS, 1988).

Soil Associations of Taylor County

1. Withee-Marshfield Association

   Nearly level to gently sloping, somewhat poorly to poorly drained soils formed in moderately deep silt loam over loam glacial till

2. Antigo-Brill-Poskin Association

   Nearly level to gently sloping, moderately deep to deep, well to somewhat poorly drained silt loam soils over sandy and gravelly outwash

3. Campia-Crystal Lake-Comstock Association

   Nearly level to moderately steep, well to somewhat poorly drained, deep silty lacustrine soils

4. Almena-Auburndale-Barronnett Association

   Nearly level to gently sloping, somewhat poorly to poorly drained deep silty soils over sandy loam glacial till. Barronnett is over silts

5. Amery-Goodman-Pence Association

   Rolling to steep moraine. Thin to moderately deep silty and loamy soils over sandy loam glacial till. Pence is over sandy, gravelly, cobbly outwash

6. Peat (deep)

   Includes moss and sedge peats, mucky peats and mucks over 48 inches thick

7. Santiago-Freeon-Freer Association

   Nearly level to sloping, well to somewhat poorly drained soils formed in moderately deep silt loam over sandy loam glacial till

Merrill-Edgar boundary mimics that of the areas 1 and 2 while the Bakerville distribution is reflected by the area designated 3 on the Clark County association map.

Association 2 in Clark County and Association 1 in southeastern Taylor County have been referred to colloquially as the "Withee landscape" of north-central Wisconsin. This landscape is part of a larger contiguous area characterized by silty upland soils in the northern portion of the state (Hole, 1976). The Withee landscape is characterized by nearly level to undulating topography covered with 1 to 2 m of loess. Several of the upland soil series mapped in this landscape in places exhibit extremely deep, well developed profiles with thick argillic horizons and well developed structure. These sites are not common, and attempts to predict where they occur in the landscape have failed thus far. SCS unofficially recognizes a "deep Withee" and a "shallow Withee" soil in Clark County (Lorenz, personal communication, 1988).

Profile Ck-545 from this study is one example of these deep soils. The soil mapped at this locality is the Loyal silt loam. The solum is developed in Bakerville till. This site was first observed in the summer of 1987 when a gas line trench was dug. The wall of the trench revealed a deep, highly mottled soil with coarse prismatic structure in the argillic horizon, thick cutans and prominent silans. Prisms extracted from the pit wall were approximately 0.35 m in length. A core taken a few meters from the trench was analyzed in the lab. The particle size distribution of the less-than-2-mm fraction of a sample from the 2Bt2 horizon has 44% clay. This is considerably more clay translocation than other profiles of the same series.

A second deep, strongly developed profile is evident in a wall of the Lewer gravel pit in Wood County. Once again, a thicker than average argillic horizon and well developed pedogenic structure are evident in the profile. In both of these cases, the strong grade of structure, the greater than average clay translocation, and the well developed pedological features suggest a moderately strong phase of soil development compared with surface Holocene soils.

Generalized Profile Morphology

The three soil series chosen for detailed analysis were the Withee, Loyal, and Almema silt loams. These three series are deep, somewhat poorly drained soils that developed in late Wisconsin loess and the underlying till on the broad uplands covering much of the landscape of north-central Wisconsin. The Withee series is developed in approximately 0.38 to 0.76 m of loess over acidic till and has its Bt horizon in both materials. The Almema soil has a 1.02 to 1.52 m loess cap over acid sandy loam till. The Bt horizon of the Almena is entirely within the silt loam portion of the profile (SCS, 1987). The Loyal Series is a moderately well drained version of the Withee.

The profiles were all disturbed as evidenced by the Ap horizon.

Beneath the humus layer were silty, bleached E horizons which graded into loamy or sandy loam subsoils. The profiles were naturally strongly acidic, with pHs ranging from approximately 4.5 in the A horizons to 5.5 or 6.5 in the subsoil (SCS, 1967).

These soils are all Glossoboralfs and by definition exhibit tongues of albic material in the argillic horizons. Although these tongues are not evident in the cores that were sampled, evidence of the albic material was seen in the silt eluviation and prominent silans occurring deep within several pedons.

The Withee and Almena Series have a seasonally high water table with moderately low permeability in the subsoil hence prominent high chroma mottles are evident throughout the solum.

METHODOLOGY

Field Methods

A hydraulically operated truck mounted Giddings probe was used to obtain all soil profiles. Lengths (1.2 m) of hollow, thin walled, aluminum tubing were pushed into the soil one at a time and extracted until parent material (C horizon) was reached. The contents of each extracted tube were carefully extruded into foil-lined transport trays (figure 3.5). Each segment was then tightly wrapped and labelled for transport back to the lab.

A total of twelve pedons were sampled, seven of which were then

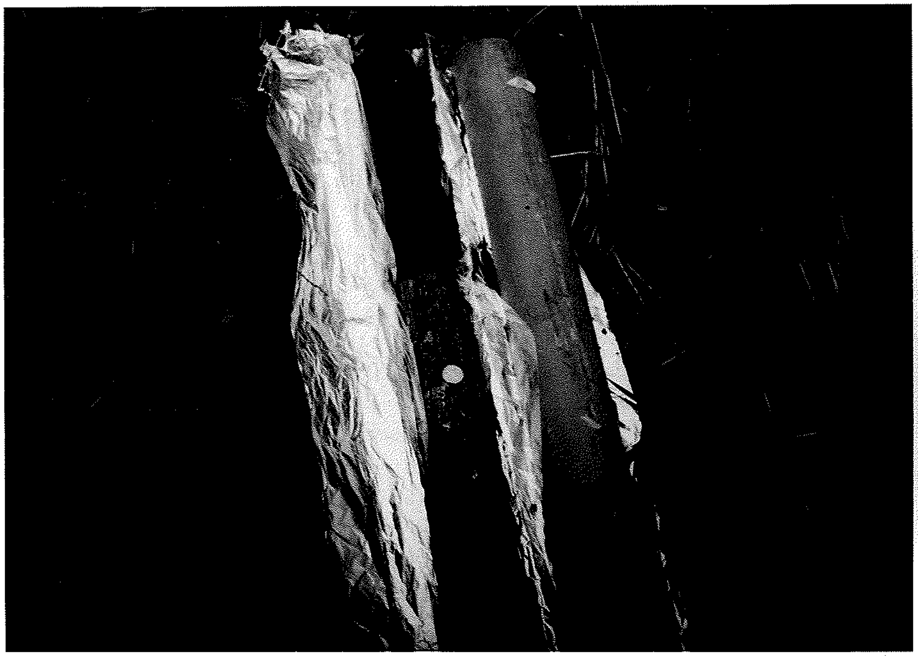


Figure 3.5: Soil core taken with Giddings apparatus. Core is 1.2 m in length.

analyzed in detail in the laboratory (figure 3.6). The analyzed profiles included two pedons each of the Withee (Ta-290, 292), Almena (Ck-546, 543) and Loyal (Ck-541, 545) soil series as well as one unmapped site (Ck-544). All twelve sites sampled were upland, poorly drained sites and were either at or near a drill hole used for studying till stratigraphy. This was to ensure that parent material from that profile would be fully characterized.

Laboratory Methods

Once in the lab, the cores were split lengthwise and fully described using the standard definitions and nomenclature of the USDA Soil Conservation Service (SCS) as revised in 1975 (Soil Survey Staff, 1975). Detailed core descriptions are included in Appendix III. Samples were retrieved from each horizon and stored for future analysis. All selected samples were analyzed for grain size distribution, magnetic susceptibility, and percent extractable free iron oxide. A subset of these samples was then selected for clay mineral determination. All physical and chemical data for the seven profiles analyzed in this study are given in Appendix IV.

Field/Lab Color

All field colors noted in the descriptions are reported as moist Munsell colors taken under artificial light with hand samples from each horizon. Lab colors are Munsell colors which are noted at the one hour

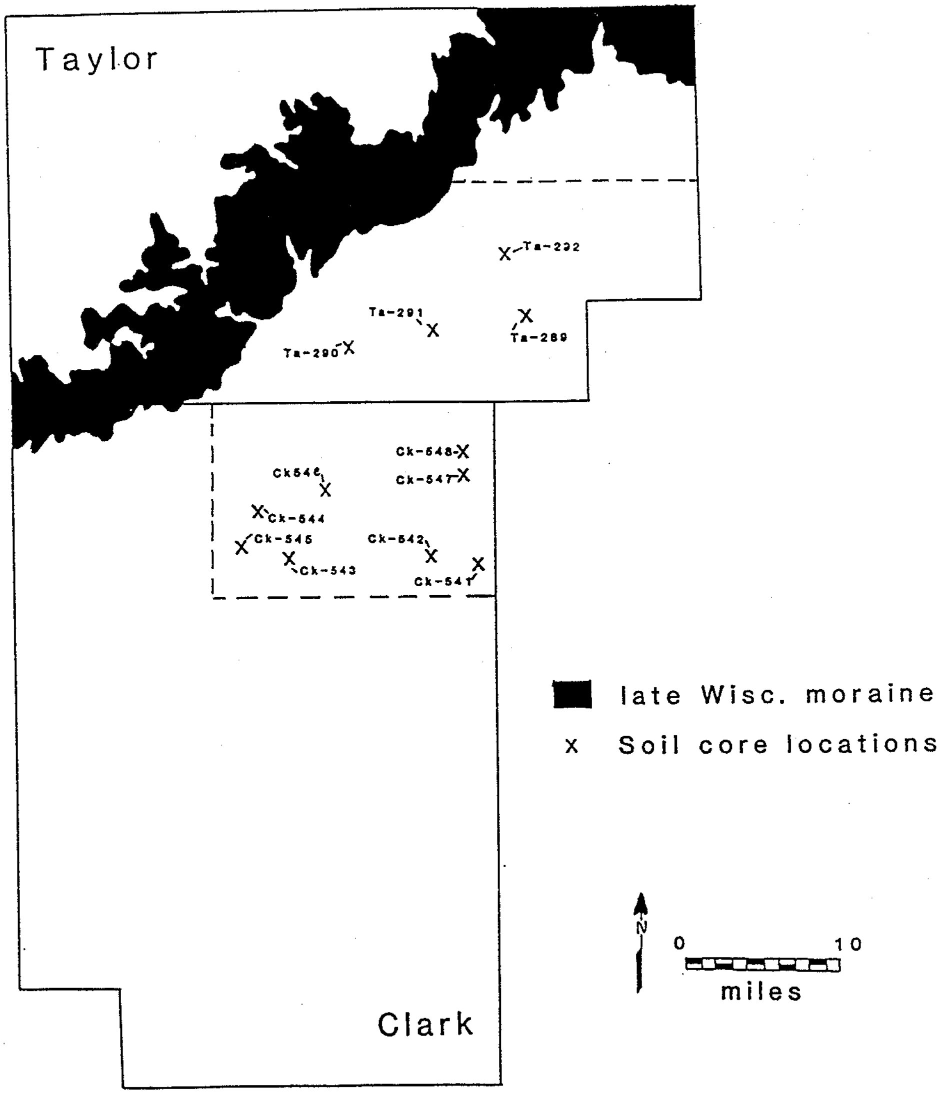


Figure 3.6: Map of sampling locations for soil stratigraphy in the study area.

hydrometer reading and are the color of the clay and silt suspended fraction.

Iron oxide

The same extraction procedure was used for all of the soil samples as was used for the bulk till samples. This was nearly the same procedure as specified by Holmgren (1967). A detailed outline of the analysis is included in Appendix 1-A.

Clay mineralogy

X-ray diffraction patterns of the total clay fraction (less-than-2-micron) were obtained with a Scintag/USA diffractometer using CuKα radiation. The goniometer speed was 5°/min. and divergence slits of 0.2 and 0.1. All patterns were scanned from 3 to 30° 2-theta. Three pre-treatments were done for each sample; air-dried and Mg^{2+} saturated, glycolated and Mg^{2+} saturated, and heating of the air-dried samples. The detailed procedures for the preparation of tiles is given in Appendix I-B.

All semi-quantitative estimations of clay species were done using the diffraction patterns from the Mg^{2+}-saturated, ethylene glycolated tiles. The semi-quantitative methodology is discussed in Chapter 2.

Grain size distribution

The hydrometer method was used for particle size analysis using the standard procedure of the University of Wisconsin--Madison's

Quaternary Laboratory. Muldoon (1987) has a complete description of the methods. The samples were not pre-treated for organic matter or iron oxide removal prior to dispersal and subsequent analysis. All sand, silt, clay percentages for the less-than-2-mm fraction were calculated using the Quaternary Laboratory's TILLPRO spreadsheet program.

RESULTS AND DISCUSSION

The soil properties commonly used as indicators of progressive development with increasing age of the parent material include sequence and thickness of the soil horizons, development of red color especially in the B horizon, increase in clay content of the B horizon, iron oxide trends, and the degree of clay mineral alteration (Shroba and Birkeland, 1983; Birkeland, 1984).

A comparison of the B horizon colors for the soils studied revealed no progressive increase in rubification with time. The profiles also displayed little variation in either horizon sequence or thickness (Appendix III). Therefore, this portion of the study focused on the last three development indices as potential relative age indicators.

Iron Oxides

There are several specific laboratory tests performed to extract iron oxides from soils. An acid oxalate extraction removes the amorphous hydrous oxide forms of iron. Pyrophosphate extractions remove the oganically bound iron component and the citrate-dithionite or citrate-bicarbonate-dithionite extraction removes the majority of the total free iron from the sediment (Mahaney _et al_., 1984).

The ratio of acid oxalate to citrate-dithionite extractable iron is often used as a relative indicator of soil age. This ratio should decrease with an increase in soil age. Alexander (1984) analyzed the above in a chronosequence of well drained Quaternary soils developed on eight stream terraces along the Truckee River in the Sierra Nevada Mountains and found that extractable iron ratios showed an increase in the first several thousand years of soil development and then decreased to a constant value within a few hundreds of thousand years.

Because the bulk of the extractable iron can be removed by one citrate-dithionite or citrate-bicarbonate-dithionite extraction, the simpler of the two procedures (citrate-dithionite) was chosen to help substantiate the relative ages of the soils sampled. One should ideally see an increase in the mean iron content in the B horizon of a soil with an increase in age since presumably the longer oxidation, podzolization and other pedogenic weathering phenomena occur, the more iron will be released and distributed within a given profile (Birkeland, 1984). Birkeland (1984) notes that although the amount of free iron in soils is time-dependent, the rate of accumulation or depletion is also related to the bioclimate. Birkeland found for instance, that 100,000 years of pedogenesis in the cold, arctic climate of Baffin Island has had little effect on the iron trends in soils there.

The two profiles developed on the Merrill till surface (Ta-292, 290) exhibit an average iron oxide content of 1.05% and .86% respectively for the entire Bt horizon. The three profiles examined from the Bakerville surface (Ck-544, 545, 546) record average extractable iron values of .83%, 1.23%, and 1.07% for the Bt horizon and those profiles (Ck-541, 543) from the oldest surface, that of the Edgar Member, show average Bt horizon iron values of 1.16% and .96% (table 3.1). These data do not support the idea that soils formed in till of the Edgar Member are older than those profiles formed in till of the Bakerville Member, which in turn are older than profiles formed in till of the Merrill Member.

Levine and Ciolkosz (1983) have demonstrated that an increase in extractable iron oxide content of soils and the movement of the zone of maximum iron oxide accumulation deeper in the profiles, are distinct trends of soil formation through time. These same trends however, are not obvious in this study.

Most of the profiles exhibit the same general trend with measured iron values lowest in the surface horizons and subsequently increasing with depth. This is not surprising, for the A, E, and BE horizons are the zones of eluviation, hence leaching of iron, aluminum and silica is expected. The extractable iron content consistently shows a subsurface maximum in the B horizon for all pedons. In some pedons this maximum

IDENTITY						MUNSELL (Field)	STRATIGRAPHIC INDICATORS								GRAINSIZE PERCENTAGES(< 2mm)		
							Clay mineralogy (in percent)										
County (code)	Sample no.	Year	Sample depth (cm)	Horizon	Drill hole no.	Hue value/ chroma	expand.	illite	chlor. +kaol.	verm.	smec.	Fe % Citrate- Dith.	Textural Class	Soil Series	Percent sand (2.0 to 0.0625mm)	Percent silt (0.0625 to 0.002mm)	Percent clay (<0.002 mm)
CK	145	87	20-25	E	545	10YR5/3						0.65	si		3.98	88.79	7.23
CK	130	87	55-65	Bt1	545	10YR5/2						1.08	sicl	Loyal	13.90	57.86	28.24
CK	131	87	80-90	2Bt2	545	10YR5/1						1.35	c		19.06	37.18	43.76
CK	146	87	20-30	E	544	10YR6/2						1.30	si		3.32	81.87	14.82
CK	132	87	70-80	Bt1	544	10YR5/2						0.82	sil		14.09	67.66	18.26
CK	133	87	100-110	2Bt2	544	7.5YR4/6						0.83	l	?	51.14	31.42	17.43
CK	147	87	220-230	2C	544	7.5YR4/4						0.84	l		45.06	45.46	9.48
CK	148	87	22-32	E	541	10YR5/4	64	21	15	38	26	0.90	sil		11.41	78.91	9.68
CK	134	87	55-63	Bt1	541	10YR4/1						1.12	sicl	Loyal	18.85	48.97	32.19
CK	135	87	71-81	2Bt2	541	7.5YR4/4	61	24	15	39	22	1.11	l		38.50	36.44	25.06
CK	149	87	95-105	2Bt3	541	7.5YR4/4	71	23	13	41	30	1.24	sl		60.38	25.69	13.93
CK	150	87	23-29	E	546	10YR6/2	57	24	19	30	27	0.79	si		7.93	80.62	11.45
CK	136	87	47-57	Bt1	546	7.5YR4/4	59	24	17	37	22	1.10	l		38.40	37.86	23.73
CK	137	87	62-72	2Bt2	546	7.5YR4/4	58	25	17	39	19	1.12	l	Almena	46.63	32.54	20.84
CK	138	87	86-96	2Bt3	546	7.5YR4/4						0.99	l		42.74	37.12	20.14
CK	139	87	240-250	2C	546	7.5YR4/6						0.82	l		42.26	39.82	13.92
CK	143	87	20-30	E	543	10YR5/2						0.72	si		3.73	88.80	7.48
CK	144	87	50-60	Bt1	543	10YR6/2						1.08	sil		9.66	73.59	16.75
CK	140	87	67-77	2Bt2	543	7.5YR5/2						0.97	sil	Almena	14.67	70.86	14.47
CK	141	87	85-95	2Bt3	543	5YR4/3						0.82	sil		25.78	64.84	9.39
CK	142	87	158-168	2C	543	7.5YR4/4						0.54	l		44.92	42.84	12.24
TA	132	87	40-50	Bt1	292	10YR5/4						0.90	sil		22.19	59.09	17.92
TA	133	87	65-75	2Bt2	292	5YR4/4						1.01	scl	Withee	49.10	26.99	23.91
TA	140	87	85-95	2Bt3	292	5YR4/4						1.24	l		49.17	34.85	15.98
TA	138	87	14-24	E	290	10YR5/3	60	24	16	32	28	0.66	si		7.84	84.31	7.85
TA	134	87	34-44	BE	290	10YR5/3	52	28	20	26	26	0.70	sil		15.56	63.69	20.76
TA	135	87	56-66	Bt1	290	10YR5/2						0.91	l		30.08	48.87	21.06
TA	136	87	123-133	2Bt2	290	7.5YR4/4	69	21	10	36	33	0.88	l	Withee	48.45	35.26	16.29
TA	139	87	151-161	2Bt3	290	7,5YR4/4	69	19	12	30	39	0.80	l		47.46	43.80	8.73
TA	137	87	228-238	2C	290	7.5YR4/6	69	20	11	37	32	0.88	l		46.93	35.63	17.44

Table 3.1: Summary of the physical and chemical properties for the soil profiles analyzed in the study.

is in the Bt1 (Ck-543, Ta-290) while others show a maximum in the 2Bt2 horizon (Ck-545, 546) or 2Bt3 horizon (Ck-541, Ta-292). The data do not indicate that with increasing age, the zone of maximum iron accumulation is found deeper in the profile. The fact that the upper portion of the solum of all of these profiles is developed in late Wisconsin age loess has probably masked any expected iron trends.

Figure 3.7 contains the extractable iron data plotted as a function of depth for profile Ta-290. Free iron within the profile was less than 1%. A maximum of .91% Fe_2O_3 was attained in the Bt1 horizon at approximately 0.6 m. with values leveling off to .88% Fe_2O_3 in the 2Bt2 and 2C horizons. The acidic nature of the E and BE horizons has caused iron to be leached from the profile.

The iron distribution in pedon Ck-541 is shown in figure 3.8. Total extractable iron values are greater than those for Ta-290. Values increased from .90% Fe_2O_3 in the surface soil to 1.24% in the 2Bt3 horizon.

Grain size distribution

The textural data are summarized in table 3.1 for the horizons that were sampled. The particle size data for all pedons examined supports the morphological evidence for an abrupt lithologic discontinuity at the base of the E hoizon. The upper part of the profiles contain more silt because they are loess derived. The silt content of these horizons ranges from 79% to 89% whereas in the loam

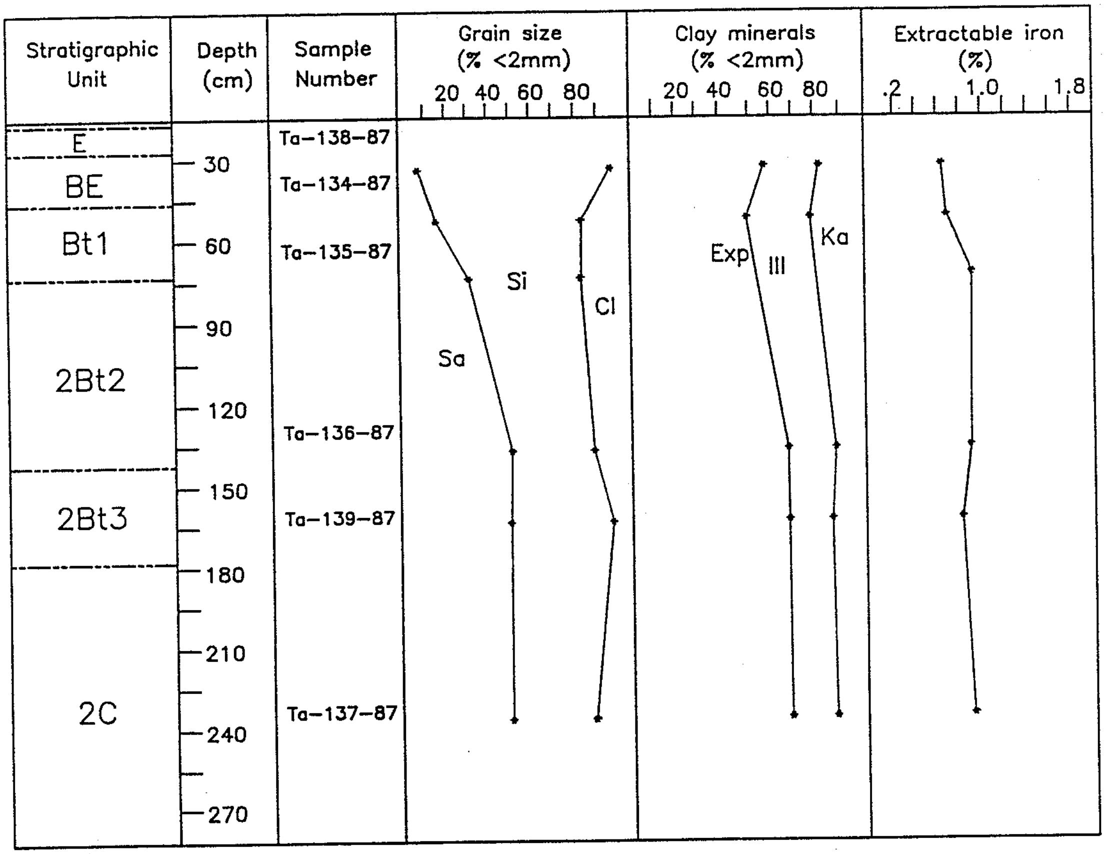


Figure 3.7: Summary of selected laboratory data for pedon Ta-290-PG.

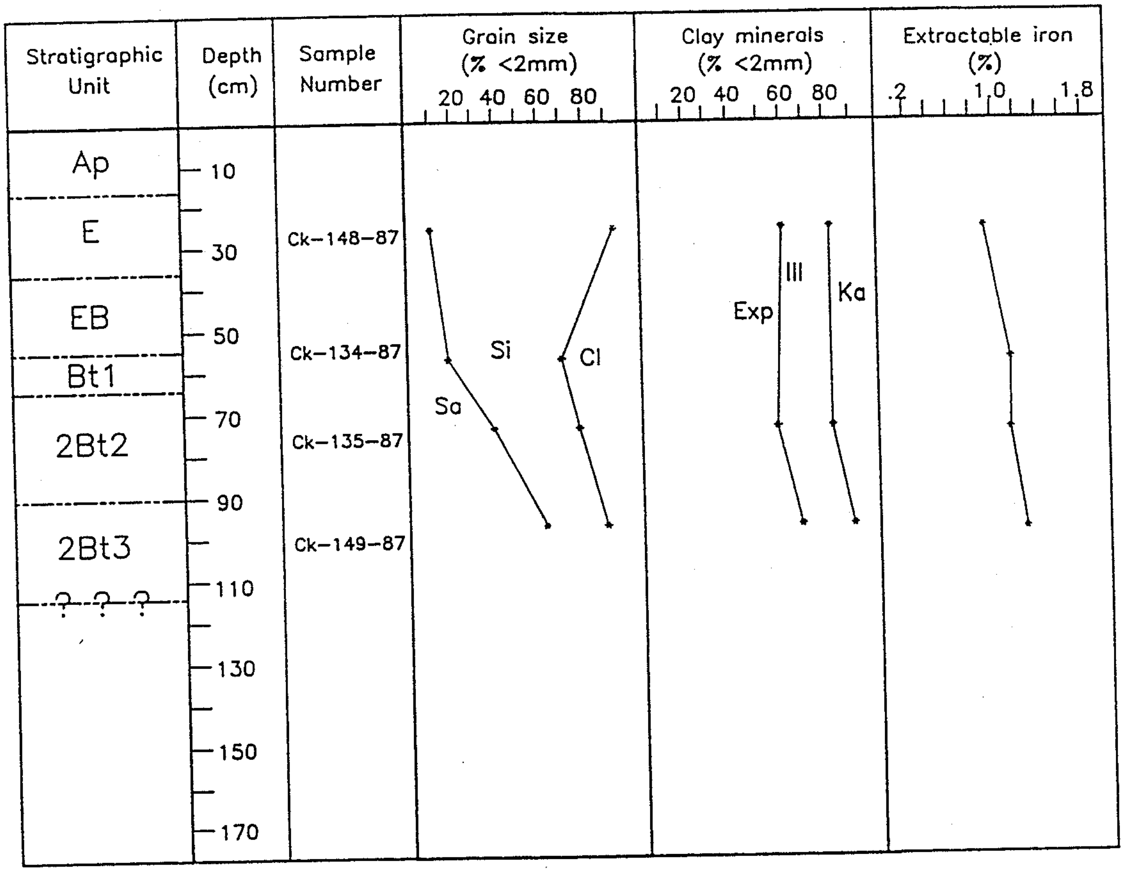


Figure 3.8: Summary of laboratory data for pedon Ck-541-PG.

textured subsoils it ranges from 31% to 49%.

The amount of sand increases with depth. Sand ranges from 3% to 11% in the E horizons to a fairly constant 29% to 42% in the subsoil and parent material.

The particle size data clearly indicate an enrichment in clay in the Bt horizons. This increase in clay with depth is associated with the presence of clay skins on the surface of peds. The discussion of clay distribution warrants special attention and will, therefore, be covered in the next section.

Clay content

Most moderately well to well developed soils are characterized by a relatively low clay content in the A and C horizons and more clay generally in the upper B horizon (Birkeland, 1984). Pedogenic clay accumulation is primarily a function of time. Ideally clay content increases with depth in the amount of translocated clay. Total clay content therefore, is often used as a rough estimate of soil age. In a study of soil development in till of various ages in northeastern Pennsylvania, Levine and Ciolkosz (1983) found that an increase in total clay content, higher fine:total clay ratios, and the depth and thickness of the argillic horizon are useful indicators of the degree of development in soils.

Direct comparison of Bt horizons from different regions must take into account climatic variations. In general, an increase in the temperature and humidity will result in greater clay accumulation within a soil profile (Birkeland, 1984).

The average total clay content for the argillic horizons (table 3.1) in each of the two profiles developed on the Merrill surface (Ta-292, 290) is 46% and 58% respectively with total Bt horizon thickness' of approximately 0.55 m. The three profiles developed on the Bakerville surface (Ck-544, 545, and 546) show average Bt thickness' of 0.40, 0.45 and 0.49 m. Total clay contents for these argillic horizons average 36%, 72%, and 65%. The two soils sampled from the Edgar surface (Ck-541, 543) exhibit average total clay contents of 71% and 41%. The Bt horizons for these two profiles are approximately 0.50 and 0.45 m respectively. These values do not exhibit a steady accumulation of total clay with time as expected.

The majority of the soils have clay maxima in the Bt1 horizon with clay content ranging from 17% to 32% of the total less-than-2-mm fraction. This trend is consistent with data from other studies (Birkeland, 1984; Harlan _et_ _al_., 1977).

In profile Ck-541 (figure 3.8), the clay content reaches a maximum of 32% in the Bt1 horizon, and decreases to nearly 14% in the underlying parent material, which is till of the Edgar Member. The maxima in clay (21%) for profile Ta-290 sampled on the Merrill surface in Taylor County (figure 3.7) occurs slightly deeper in the profile.

Allan and Hole (1968) found that eluviation of clay from a loess cover was an important factor in the genesis of the argillic horizon in a series of Hapludalfs in southeastern Wisconsin. Harlan et al., (1977) were unable to correlate the clay contents of observed argillic horizons with a change in loess thickness in the landscape. The same appears to be true in Clark and Taylor Counties. There is however, a tendency for the clay contents of the argillic horizons to be greater in the moderately well drained Loyal profiles (71% and 72%) than in the somewhat poorly drained Withee and Almena profiles (41% to 65%).

Clay mineralogy

The clay mineralogy of three pedons was examined in detail. The calculated percentages of clay species present are included in table 3.1. The results from the Mg-saturated and glycolated x-ray diffraction traces of the less-than-2-micron fraction show that the clay mineral assemblage in each of the pedons is comprised of expandables + illite + kaolinite. Vermiculite is generally the more abundant of the two expandable species. Subsequent heat treatments at both 350 °C and 550 °C precluded the presence of chlorite within the profiles.

The clay mineralogy of the Loyal pedon (Ck-541) which is developed on the Edgar surface, is dominated by vermiculite which ranges from 38% in the E horizon to 41% in the 2Bt3 horizon (figure 3.9). Smectite is the co-dominate expandable species which exhibits a slight increase in relative abundance from 26% in the E horizon to 30% in the 2Bt3. The 2:1 expandables clays show an overall increase from 64% to 71% with

	Clay mineralogy			
	expandables			
Sample	smectite %	vermiculite %	kaolinite %	illite %
Ck-148	26	36	16	21
Ck-134	25	29	22	24
Ck-135	22	39	15	24
Ck-149	30	41	13	23

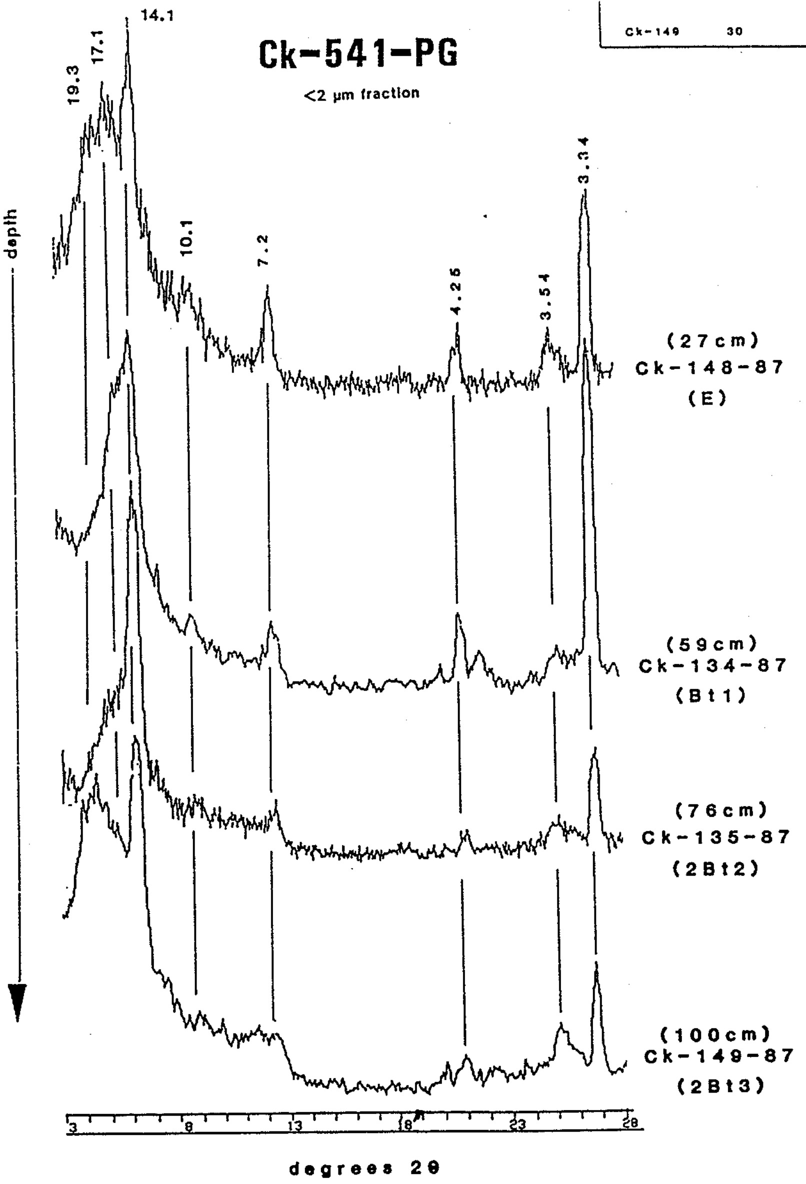


Figure 3.9: Oriented x-ray diffraction pattern of the <2-µm fraction from soil profile Ck-541-PG. All patterns are glycolated and Mg^{2+} saturated. Peak positions are given in Å.

depth. The distribution of kaolinite within the profile is nearly constant, with a slight drop in abundance in the lower portion of the solum. Illite also is a relatively stable component of the profile and varies little with depth. Quartz is quite abundant in the E and Bt1 horizons presumably as a result of the substantial leaching of the loess mantle. Minor quantities of feldspar are also present. Kaolinite (7.01 Å) decreases in intensity and crystallinity with depth as evidenced by the broad based peaks in the 2Bt2 and 2Bt3 horizons. Vermiculite (14 Å) produces consistently sharp peaks throughout the profile. The E and 2Bt3 horizons contain what is interpreted to be either smectite in various hydration states or a man-made aberration. D-spacings range from 17 to 19 Å for this species on these two patterns.

The Withee soil sampled from the Merrill surface in Taylor County (Ta-290) is not readily distinguished from that of the Loyal profile based on the clay mineralogy (figure 3.10). Again, the dominant species of the less-than-2-micron fraction is vermiculite with lesser amounts of smectite. There is a slight increase in expandables with depth, with values ranging from 60% in the E horizon to a consistent 69% in the subsoil and parent material. Kaolinite decreases from a high of 20% in the BE horizon to 11% in the subsoil. The 7 Å kaolinite peaks become progressively less distinct with depth as do the 10 Å illite peaks. Smectite and vermiculite are the sharp 17 and 14 Å peaks respectively.

	Clay mineralogy			
	expandables			
Sample	smectite %	vermiculite %	kaolinite %	illite %
Ta-138	28	32	16	24
Ta-134	26	26	20	28
Ta-135		-NA-		
Ta-136	33	36	10	21
Ta-139	39	30	12	19
Ta-137	32	37	11	20

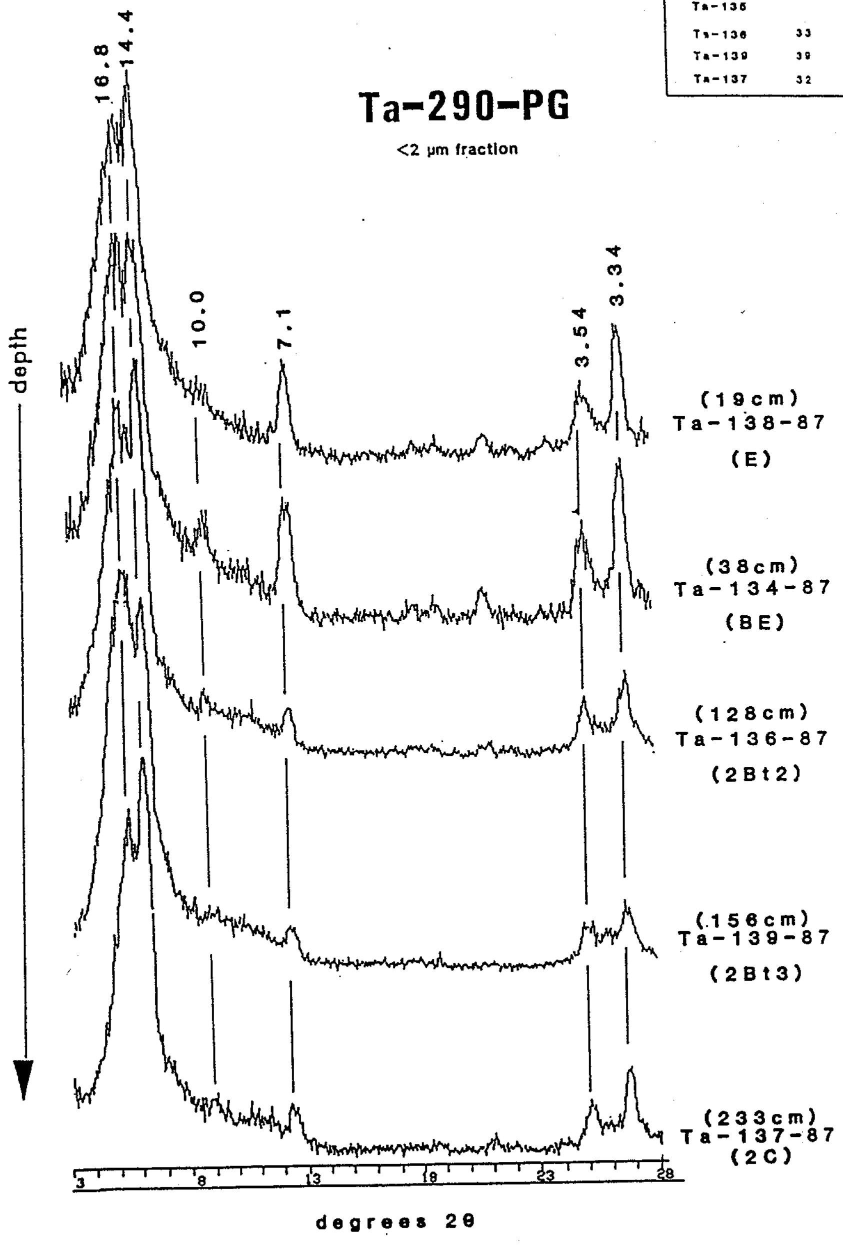


Figure 3.10: Oriented x-ray diffraction pattern of the <2 -µm fraction from soil profile Ta-290-PG. All patterns are glycolated and Mg^{2+} saturated. Peak positions are given in Å.

Samples from only three horizons of Ck-546 were analyzed for their clay mineralogy. This profile is the Almena Series and is developed on what is believed to be the Bakerville till surface. The mineral assemblage of the clay fraction is vermiculite rich in all 3 horizons. An overall increase in vermiculite is present with 30% in the E horizon, 37% in the Bt1 and 39% in the 2Bt2. Smectite and illite are nearly equal, with smectite showing a slight decrease in abundance with depth. Kaolinite abundance is constant with depth but the relative abundance of kaolinite for Ck-546 is greater than for either Ck-541 or Ta-290.

The clay mineral assemblage of the soils differs slightly from that of the unoxidized till samples analyzed, by the presence of more vermiculite and on average, less 10 Å illitic clay. Relative abundances of illite tend to decrease substantially in the lower sola when compared to the parent material thus suggesting a weathering front above the till. The interpretation of the clay mineralogy of the soils is complicated by the fact that Wisconsin age loess has been mixed into the subsoil thereby incorporating less weathered material into the profile.

As previously noted, research (April et al., 1986; Ransom et al., 1988) has shown that smectite and vermiculite identification is difficult. These two 2:1 species are often considered to be a continuum with the idealized end members exhibiting diagnostic characteristics which make identification a relatively simple task.

Many of these properties were discussed previously in Chapter 1. There is however, a series of smectite-vermiculite phases that display properties that are intermediary to those of the end members and differ primarily in the total layer charge.

Vermiculite in soils commonly contains hydroxy-Al interlayers (Ransom et al., 1988; April et al., 1986). This Al3+ fixation then prevents the complete collapse of the (001) 14 Å peak to 10 Å upon heating as well as complete solvation (April et al.,1986). The degree of Al3+-fixation in the interlayer sites is greatest within both the B and C horizons and either low or absent in the E and BE (April et al., 1986). These observations are evident in the soil horizons analyzed in this study (data not shown). Nearly complete collapse of the 14 Å spacing to 10 Å occurred in those horizons that have experienced some degree of eluviation such as the E and BE horizons sampled. This is in contrast to the step-wise, progressive collapse of vermiculite during heating in samples taken deeper in the profile. Only after prolonged (>2 hours) heating at temperatures near 550 °C was a complete shift to 10 Å observed in those samples from the lower B and C horizons.

Evidence and effect of permafrost conditions

Past climatic regimes played an active role in shaping the landscape of northern Wisconsin. In particular, permafrost and periglacial processes presumably dominated much of this portion of the state during not only late-Wisconsin time but during previous glacial episodes as well. While the evidence for a cryogenic period are well documented in nearby locales (see discussion in Chapter 2), specific examples of ice-wedge casts, patterned ground, and other periglacial features have eluded workers in Clark and Taylor Counties thus far. Probably the difficulty in differentiation of the upper few meters of the Bakerville and Edgar till units is the result of considerable reworking and mixing of the upper few meters of till and loess due to former active periglacial processes. The evidence for periglacial processes is much more subtle in light of pedogenesis.

Olson and Ruhe (1979) attributed mixing between loess and underlying paleosols to cryoturbation, bioturbation, wind-winnowing, and other near-surface processes. Using both macro and micromorphological evidence, Habecker (1988) concluded that soils adjacent to the study area in Taylor County, have been affected by permafrost activity. Macroscopic evidence includes the coincidental occurrence of platy structure, sheaths of silty material around larger grains, and vesicular porosity. In addition, microscopic features attributed to cryoturbation are evident in thin sections. These features include silt coatings superimposed on clay coatings and disrupted clay coatings. All three of the macromorphologic features were evident in the profiles examined from northeastern Clark and southeastern Taylor Counties.

CONCLUSIONS

The following interpretations concerning the Pleistocene deposits and soils in northeastern Clark and southeastern Taylor Counties appear to be valid.

1. Four pre-late Wisconsin till units have been identified in northeastern Clark and southeastern Taylor Counties. Three of these, the Merrill and Bakerville Members of the Lincoln Formation, and the Edgar Members of the Marathon Formation, are surficial units while the fourth, the Medford Member of the Marathon Formation, occurs only in the subsurface. The Medford Member was not encountered in Clark County and more work needs to be done to determine the subsurface distribution of this unit.

2. Differentiation of the three surficial units was based on laboratory parameters as well as stratigraphic relationships. The Merrill Member was easily characterized by its reddish-brown hue, noncalcareous matrix and sandy loam texture. The Edgar Member is calcareous at depth, but where it is leached of carbonates, the unit is difficult to distinguish from the weathered, thin cover of Bakerville till.

3. Expandable clay minerals are the most abundant species in the till units of the study area. When both smectite and vermiculite were identifiable in Mg-saturated, glycolated samples, smectite tended to be

the more abundant of the two species. Illite is the second most prevalent component and small amounts of kaolinite are present in all of the bulk till samples.

4. Expandable clay minerals were also the most abundant species in the soil profiles. Of the two 2:1 species identified, vermiculite was the more abundant. Kaolinite and illite as well as quartz and feldspar were present in all samples.

5. Clay mineralogy did not prove to be a reliable parameter for distinguishing between the identified till units.

6. The pedons of Loyal, Withee, and Almena series examined in this study belong to similar catenary sequences. All profiles are somewhat poorly drained, upland sites developed in late Wisconsin loess and underlying till. The polygenetic nature of the soils as well as the fact that profiles are genetically complex, has made meaningful interpretations of clay mineral weathering trends difficult. Differences in gross mineralogy are minimal and profiles differ only slightly with respect to changes in the relative percents of the clay species despite the fact that they developed on till units of presumably widely separated ages and very different provenance.

7. The homogenization and reworking of the upper few meters of glacial sediment and incipient soil profiles during late-Wisconsin time is presumably a result of permafrost and periglacial activity. Evidence for episodes of permafrost activity are well documented in northern Wisconsin on both late-Wisconsin and pre-late Wisconsin

surfaces, several sites of which occur in the vicinity of the study area.

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APPENDICES

Appendix I: Tillpro Module I data for till samples

Appendix II: Analytical Methods
  - A. Citrate-Dithionite extractable iron oxide procedure
  - B. Clay separation technique and preparation of oriented <2-μm samples
  - C. Scintag XRD operation parameters for clay mineral analysis

Appendix III: Detailed soil profile descriptions

Appendix IV: Tillpro Module I data for soil profiles

APPENDIX I

TILLPRO Module I data for Pleistocene lithostratigraphy

All data obtained in the University Wisconsin Quaternary lab is tabulated in a program designed by Bill Simpkins (1986 & 1988) and is entitled "TILLPRO". TILLPRO uses either Symphony or Lotus 1-2-3 as its' software. Some data entered into the spreadsheet modules entails the use of codes specifically designed for the lab's use. The following series of codes are specifically designed to be used in conjunction with TILLPRO modules. Appendix II and Appendix III contains a modified version of INPUT1 from the program. For a complete reference to the documentation to TILLPRO the reader is referred to Muldoon (1987).

I. County Code

COUNTY	CODE
Clark =	Ck
Taylor =	Ta

II. Lithostratigraphic Unit

LITHO. UNIT	CODE
Marathon Formation	MA
Edgar Member	Ed
Medford Member	Mf
Lincoln Formation	LN
Merrill Member	Mr
Bakerville Mbr.	Bk

III. Type of material and/or inferred genesis

MATERIAL	CODE
Undifferentiated	99
Subglacial till	1
Supraglacial till	2
Till, Undiff.	3
Outwash sand/gravel	4
Lacustrine	5
Loess	6
Modern alluvium	7
A horizon	8
B horizon	9
E horizon	10
C horizon	11

Rock	12
Organic mat'l	13
Paleosol, undiff.	14
Eolian sand	15
Debris-flow sed.	16
Residuum	17

IV. Collector of sample

COLLECTOR	CODE
A. Sutherland	24

V. Sample Source

SOURCE	CODE
Auger/drill hole	1
Split spoon or Shelby tube	2
Roadcut	3
Pit or Quarry	4
Shoreline bluff	5
Stream cut	6
Excavation	7
Landfill (grab)	8
Hand auger	9
Railroad cut	10
Other/unknown	99

APPENDIX I - LOCATIONS AND STRATIGRAPHIC DATA (CLARK CO.)

IDENTITY					SOURCE			LOCATION							MUNSELL COLOR		TILL STRATIGRAPHIC INDICATORS											GRAINSIZE PERCENTAGES(< 2mm)		
																	Clay mineralogy (in percent)						Carb. cont. (Wt. percent)							
County (code)	Sample no.	Year	Litho-strat. unit (code)	Mat. (code	Coll. of samp. (code	Sample source (code)	Sample depth (m)	Drill hole no.	1/4 1/4 1/4	1/4 1/4	1/4	Sec.	Tnshp.	Range	(Field) Hue value/ chroma	(Lab) Hue value/ chroma	expand.	illite	chlor. +kaol.	verm.	smec.	Mag. susc. (dim. units)	calc.	dolo.	total carb.	C/NC	% Fe	Percent sand (2.0 to 0.0625mm)	Percent silt (0.0625 to 0.002mm)	Percent clay (<0.002 mm)
CK	1	1987			24	4	0.45		SE	NE	NE	17	28N	1E	7.5YR4/4	7.5YR5/8						2.35E-03				NC		41.90	46.22	11.88
CK	2	1987			24	3	0.45		NE	SW	NW	14	29N	1E	7.5YR4/4	7.5YR6/6						2.40E-03				NC		50.75	33.08	16.17
CK	3	1987			24	7	0.45		SE	SE	SE	35	29N	1E	7.5YR4/6	10YR6/6						5.99E-04				NC		37.72	41.34	20.94
CK	4	1987			24	4	0.45		SE	SW	NE	29	27N	1W	7.5YR4/4	7.5YR6/6						1.44E-03				NC		49.64	31.46	18.90
CK	5	1987	LNBk	3.0	24	1	0.91	521	SE	SW	SE	15	29N	1E	7.5YR4/6	7.5YR6/6						1.98E-03				NC		50.93	32.72	16.35
CK	6	1987	LNBk	3.0	24	1	2.44	521	SE	SW	SE	15	29N	1E	7.5YR5/6	7.5YR6/6						1.12E-03				NC		53.18	27.78	19.04
CK	7	1987	MAEd	3.0	24	1	3.96	521	SE	SW	SE	15	29N	1E	10YR4/6	10YR6/6						1.03E-03				NC		43.49	35.97	20.54
CK	8	1987	MAEd	3.0	24	1	5.49	521	SE	SW	SE	15	29N	1E	10YR5/1	10YR7/4	56	27	17	19	37	1.73E-03	4.3	9.7	14.0	C		40.14	37.92	21.94
CK	9	1987	MAEd	3.0	24	1	7.01	521	SE	SW	SE	15	29N	1E	2.5YR4/2	10YR7/4	72	13	15	0	72	1.41E-03	2.9	2.5	5.4	C		44.04	33.72	22.25
CK	10	1987	MAEd	3.0	24	1	8.53	521	SE	SW	SE	15	29N	1E	2.5YR4/2	10YR6/4	44	34	22	0	44	1.63E-03	3.4	2.4	5.9	C		43.68	33.93	22.39
CK	11	1987	MAEd	3.0	24	1	10.06	521	SE	SW	SE	15	29N	1E	2.5YR4/2	10YR6/4	46	32	22	0	46	1.36E-03	3.8	1.9	5.8	C		45.73	31.91	22.36
CK	12	1987	MAEd	3.0	24	1	11.58	521	SE	SW	SE	15	29N	1E	10YR4/2	5YR5/4	42	42	16	0	42	1.30E-03	3.8	3.9	7.7	C		44.53	32.94	22.53
CK	13	1987	MAEd	17.0	24	1	12.80	521	SE	SW	SE	15	29N	1E	10YR5/2	10YR5/4	36	41	23	0	36	8.14E-04	3.8	2.4	6.2	C		53.14	28.52	18.34
CK	14	1987	LNMr	3.0	24	1	0.91	522	SW	SW	NW	7	29N	1W	5YR4/4	7.5YR6/6						3.00E-03	0.0	0.5	0.5	NC		47.47	30.79	21.74
CK	15	1987	LNMr	3.0	24	1	2.44	522	SW	SW	NW	7	29N	1W	7.5YR4/4	7.5YR6/6	65	24	11	31	34	2.59E-03				NC		53.71	31.94	14.35
CK	16	1987	LNMr	3.0	24	1	3.96	522	SW	SW	NW	7	29N	1W	7.5YR4/4	7.5YR6/6	66	23	11	31	35	2.59E-03	-0.3	0.5	0.5	NC		52.55	31.48	15.97
CK	17	1987	LNMr	3.0	24	1	5.49	522	SW	SW	NW	7	29N	1W	5YR4/4	7.5YR6/6	59	28	13	26	33	5.20E-03	-0.5	0.0	0.0	C		50.07	30.23	19.70
CK	18	1987	LNBk	3.0	24	1	0.91	523	NW	NW	NE	32	29N	1W	5YR4/6	7.5YR6/6						2.77E-03				NC		56.18	20.34	23.48
CK	19	1987	LNBk	3.0	24	1	2.44	523	NW	NW	NE	32	29N	1W	5YR4/6	7.5YR6/6	61	28	11	29	32	2.63E-03				NC		52.25	27.78	19.97
CK	20	1987	MAEd	5.0	24	1	3.96	523	NW	NW	NE	32	29N	1W	10YR5/3	2.5YR7/4						4.31E-04				NC		4.39	70.51	25.10
CK	21	1987	MAEd	3.0	24	1	5.18	523	NW	NW	NE	32	29N	1W	7.5YR4/4	10YR6/4						3.33E-03				NC		42.90	34.99	22.11
CK	22	1987	MAEd	3.0	24	1	0.91	524	SW	SW	NW	2	28N	1E	7.5YR4/6	7.5YR6/6						1.55E-03				NC		43.77	35.63	20.59
CK	23	1987	MAEd	3.0	24	1	2.44	524	SW	SW	NW	2	28N	1E	7.5YR4/6	7.5YR6/6						1.70E-03				NC		42.55	41.21	16.24
CK	24	1987	MAEd	3.0	24	1	3.96	524	SW	SW	NW	2	28N	1E	7.5YR4/4	10YR6/6						1.53E-03				NC		38.21	44.00	17.80
CK	25	1987	MAEd	3.0	24	1	5.49	524	SW	SW	NW	2	28N	1E	7.5YR4/6	10YR6/6						1.19E-03				NC		49.88	33.34	16.78
CK	30	1987	MAEd	9.0	24	1	0.91	525	SE	NW	SW	22	28N	1W	7.5YR4/6	10YR6/6						1.65E-03	-0.5	1.5	1.5	NC		36.78	34.53	28.69
CK	33	1987	MAEd	3.0	24	7	1.22		SW	SW	SW	17	28N	2W	7.5YR4/6	7.5YR6/6						8.62E-04				NC		37.63	34.50	27.87
CK	34	1987			24	1	0.45		NE	SW	SW	19	28N	1W	5YR4/4	7.5YR6/6						1.92E-03				NC		42.71	36.98	20.31
CK	35	1987			24	1	0.45		SE	SW	SE	19	27N	2W	7.5YR4/6	10YR6/6						4.55E-04				NC		70.52	17.80	11.69
CK	36	1987			24	1	0.45		SW	NW	NW	8	28N	2W	5YR4/6	10YR8/4						6.48E-04				NC		64.40	26.46	9.14
CK	37	1987	MAEd	3.0	24	4	0.45		SW	SE	SW	17	28N	1E	7.5YR4/4	7.5YR6/8						1.39E-03				NC		34.04	41.54	24.42
CK	40	1987	MAEd	9.0	24	1	2.44	526	SE	SE	SE	25	28N	1W	10YR4/3	7.5YR6/6						1.10E-03	0.5	21.7	22.2	NC		40.66	37.19	22.15
CK	41	1987	MAEd	3.0	24	1	3.96	526	SE	SE	SE	25	28N	1W	5YR4/4	7.5YR7/6						8.38E-04				NC		29.38	34.31	36.31
CK	42	1987	MAEd	3.0	24	1	5.18	526	SE	SE	SE	25	28N	1W	5YR4/4	10YR6/6						1.46E-03				NC		44.50	25.29	30.21
CK	43	1987	MAEd	3.0	24	1	7.01	526	SE	SE	SE	25	28N	1W	5YR4/3	7.5YR6/6	60	28	12	0	60	1.65E-03	0.5	3.0	3.5	C		47.47	30.52	22.02
CK	44	1987	MAEd	3.0	24	1	8.53	526	SE	SE	SE	25	28N	1W	5YR4/3	10YR6/6	69	22	9	32	37	1.56E-03	0.5	4.0	4.5	C		46.49	30.17	23.34
CK	45	1987	MAEd	3.0	24	1	10.06	526	SE	SE	SE	25	28N	1W	5YR4/4	7.5YR6/6	64	25	11	27	37	1.94E-03	0.0	9.9	9.9	C		50.93	24.87	24.21
CK	46	1987	MAEd	3.0	24	1	11.58	526	SE	SE	SE	25	28N	1W	7.5YR5/4	10YR7/4	58	28	14	21	37	1.67E-03	1.0	5.5	6.4	C		38.41	30.57	31.02
CK	47	1987	MAEd	3.0	24	1	14.63	526	SE	SE	SE	25	28N	1W	5YR4/3	10YR7/6	59	26	14	24	35	1.77E-03				C		43.31	29.56	28.13
CK	48	1987	MAEd	3.0	24	1	17.68	526	SE	SE	SE	25	28N	1W	5YR4/3	10YR6/6	69	21	10	26	43	1.48E-03	1.8	3.0	4.8	C		45.41	32.02	21.57
CK	50	1987	LNBk	6.0	24	1	2.44	527	NE	NE	NE	24	28N	1W	7.5YR4/4	7.5YR6/6	54	32	14	0	54	1.70E-03	-0.5	0.0	0.0	NC		39.35	39.37	21.29
CK	51	1987	LNBk	3.0	24	1	3.96	527	NE	NE	NE	24	28N	1W	5YR4/6	7.5YR6/6	63	21	16	29	34	2.04E-03	-0.5	2.1	2.1	NC		43.70	35.40	20.90
CK	52	1987	LNBk	3.0	24	1	5.49	527	NE	NE	NE	24	28N	1W	5YR4/4	10YR6/6	68	22	10	31	37	1.63E-03	0.0	0.5	0.5	NC		47.64	31.75	20.61
CK	53	1987	MAEd	17.0	24	1	8.53	527	NE	NE	NE	24	28N	1W	5YR4/6	7.5YR6/4						1.63E-03	1.8	3.2	5.0	C		38.87	33.21	27.92
CK	54	1987	MAEd	17.0	24	1	10.06	527	NE	NE	NE	24	28N	1W	5YR5/3	7.5YR7/4						1.60E-03	0.5	2.5	3.0	C		30.65	38.41	30.94
CK	55	1987	MAEd	17.0	24	1	10.97	527	NE	NE	NE	24	28N	1W	7.5YR5/4	10YR7/4						2.01E-03	1.9	7.9	9.8	C		29.68	36.73	33.58
CK	56	1987	MAEd	6.0	24	1	0.91	528	SW	SW	SW	10	28N	2W	7.5YR4/4	7.5YR6/6						6.47E-04	0.0	1.0	1.0	NC		28.43	39.91	31.66
CK	57	1987	MAEd	3.0	24	1	2.44	528	SW	SW	SW	10	28N	2W	7.5YR4/4	7.5YR6/6						1.96E-03				NC		35.01	31.18	32.82
CK	58	1987	MAEd	3.0	24	1	3.96	528	SW	SW	SW	10	28N	2W	7.5YR3/4	7.5YR6/6						2.20E-03				C		46.05	26.31	27.63
CK	59	1987	MAEd	3.0	24	1	5.49	528	SW	SW	SW	10	28N	2W	7.5YR4/4	7.5YR6/6						2.30E-03				C		44.10	29.85	26.05
CK	60	1987	MAEd	3.0	24	1	7.01	528	SW	SW	SW	10	28N	2W	7.5YR5/4	7.5YR7/4						2.66E-03				C		50.16	27.07	22.77
CK	61	1987	MAEd	3.0	24	1	10.06	528	SW	SW	SW	10	28N	2W	7.5YR5/4	7.5YR6/6						1.87E-03				C		50.45	29.99	20.46

APPENDIX II - LOCATIONS AND STRATIGRAPHIC DATA (CLARK CO.)

IDENTITY County (code)	Sample no.	Year	Litho-strat. unit (code)	Mat. (code	SOURCE Coll. of samp. (code	Sample source (code)	Sample depth (m)	LOCATION Drill hole no.	1/4 1/4 1/4	1/4 1/4	1/4	Sec.	Tnshp.	Range	MUNSELL COLOR (Field) Hue value/ chroma	MUNSELL COLOR (Lab) Hue value/ chroma	TILL STRATIGRAPHIC INDICATORS Clay mineralogy (in percent) expand.	illite	chlor. +kaol.	verm.	smec.	Mag. susc. (dim. units)	Carb. cont. (Wt. percent) calc.	dolo.	total carb.	C/NC	% Fe	GRAINSIZE PERCENTAGES(< 2mm) Percent sand (2.0 to 0.0625mm)	Percent silt (0.0625 to 0.002mm)	Percent clay (<0.002 mm)
CK	62	1987	MAEd	3.0	24	1	13.11	528	SW	SW	SW	10	28N	2W	7.5YR5/4	10YR7/4						2.04E-03				C		49.00	30.15	20.84
CK	63	1987	LNBk	3.0	24	1	0.91	529	SW	SW	SW	18	29N	1E	5YR4/6	5YR6/6	64	24	12	30	34	1.75E-03	0.5	1.6	2.1	NC		47.45	31.29	21.26
CK	64	1987	LNBk	3.0	24	1	2.44	529	SW	SW	SW	18	29N	1E	5YR4/6	7.5YR6/6	46	42	12	0	46	1.98E-03	0.0	0.5	0.5	NC		44.83	34.20	20.96
CK	65	1987	MAEd	5.0	24	1	3.96	529	SW	SW	SW	19	29N	1E	10YR6/4	10YR7/6						9.59E-04	2.0	5.9	7.9	C		15.31	49.69	35.01
CK	66	1987	MAEd	5.0	24	1	5.49	529	SW	SW	SW	18	29N	1E	10YR5/4	10YR7/4						1.03E-03	3.9	9.4	13.3	C		18.82	47.89	33.29
CK	67	1987	MAEd	5.0	24	1	7.01	529	SW	SW	SW	18	29N	1E	10YR5/4	10YR7/4						1.20E-03				C		18.16	50.29	31.55
CK	68	1987	MAEd	5.0	24	1	10.06	529	SW	SW	SW	18	29N	1E	10YR5/4	10YR7/4						6.95E-04				C		18.91	48.71	32.38
CK	69	1987	MAEd	3.0	24	1	13.11	529	SW	SW	SW	18	29N	1E	10YR5/3	10YR7/4	59	28	13	26	33	8.87E-04				C		41.44	39.05	19.51
CK	70	1987	LnBk	3.0	24	1	0.91	530	NW	NW	NW	31	28N	1W	5YR4/4	7.5YR5/6						2.66E-03				NC		51.97	27.15	20.88
CK	71	1987	MAEd	3.0	24	1	2.44	530	NW	NW	NW	31	28N	1W	5YR4/4	7.5YR7/6						2.82E-03				NC		45.62	32.54	21.84
CK	72	1987	MAEd	3.0	24	1	3.96	530	NW	NW	NW	31	28N	1W	7.5YR4/6	7.5YR6/6						1.79E-03				NC		43.26	34.64	22.10
CK	73	1987	MAEd	5.0	24	1	5.49	530	NW	NW	NW	31	28N	1W	7.5YR4/6	7.5YR7/6						7.18E-04	2.4	1.0	3.4	NC		13.40	64.58	22.02
CK	74	1987	MAEd	3.0	24	1	7.01	530	NW	NW	NW	31	28N	1W	7.5YR4/6	7.5YR7/6						1.98E-03				C		45.29	34.65	20.06
CK	75	1987	MAEd	3.0	24	1	8.53	530	NW	NW	NW	31	28N	1W	7.5YR4/6	7.5YR6/6						1.96E-03				C		43.36	35.30	21.35
CK	76	1987	MAEd	3.0	24	1	10.97	530	NW	NW	NW	31	28N	1W	7.5YR4/6	7.5YR6/6						1.94E-03				C		47.70	33.30	19.00
CK	77	1987	LNBk	3.0	24	1	0.91	531	NE	NE	NE	13	28N	2W	7.5YR4/6	7.5YR6/6						1.70E-03				NC		44.20	34.97	20.83
CK	78	1987	LNBk	3.0	24	1	2.44	531	NE	NE	NE	13	28N	2W	5YR3/4	7.5YR7/6	64	27	9	29	35	3.12E-03	-0.3	0.2	0.2	NC		51.37	31.14	17.49
CK	79	1987	LNBk	3.0	24	1	3.96	531	NE	NE	NE	13	28N	2W	5YR4/4	7.5YR6/6	56	28	16	27	29	2.20E-03	0.0	1.0	1.0	NC		57.56	22.39	20.05
CK	83	1987	MAEd	3.0	24	1	0.91	532	NW	SW	SW	19	29N	1W	7.5YR4/6	7.5YR6/6						1.15E-03				NC		36.58	40.22	23.20
CK	84	1987	MAEd	3.0	24	1	2.44	532	NW	SW	SW	19	29N	1W	7.5YR4/6	7.5YR6/6						1.67E-03				NC		46.75	33.89	19.36
CK	85	1987	MAEd	3.0	24	1	3.96	532	NW	SW	SW	19	29N	1W	7.5YR5/4	7.5YR6/6						1.55E-03				NC		47.29	35.80	16.91
CK	86	1987	MAEd	17.0	24	1	5.49	532	NW	SW	SW	19	29N	1W	5YR3/4	5YR5/6						5.99E-04	2.9	1.0	3.9	NC		25.32	30.76	43.92
CK	87	1987	MAEd	17.0	24	1	7.01	532	NW	SW	SW	19	29N	1W	7.5YR4/6	7.5YR7/6						3.59E-04	2.9	8.9	11.8	NC		22.00	41.32	36.68
CK	895	1987			24	9	0.91		SW	SW	SW	14	30N	1E		7.5YR6/6						2.04E-03				NC		50.27	32.38	17.35
CK	90	1987	LNMr	3.0	24	1	2.44	533	NE	NE	NW	10	29N	2W	7.5YR4/6	7.5YR6/6						1.61E-03				NC		49.70	31.77	18.53
CK	91	1987	LNMr	3.0	24	1	3.96	533	NE	NE	NW	10	29N	2W	7.5YR4/6	10YR5/6						3.74E-03				NC		55.92	30.26	13.82
CK	93	1987	LnMr	3.0	24	1	0.91	534	SW	SE	SW	2	29N	1W	5YR4/6	7.5YR7/6						2.25E-03				NC		49.93	29.48	20.59
CK	94	1987	MAEd	3.0	24	1	2.44	534	SW	SE	SW	2	29N	1W	5YR4/6	7.5YR6/6						2.06E-03				NC		37.77	39.06	23.17
CK	95	1987	MAEd	3.0	24	1	3.96	534	SW	SE	SW	2	29N	1W	7.5YR4/4	7.5YR6/6						1.63E-03				NC		43.50	37.09	19.42
CK	96	1987	MAEd	3.0	24	1	5.49	534	SW	SE	SW	2	29N	1W	7.5YR4/4	7.5YR7/6						1.13E-03				C		45.54	34.79	19.67
CK	97	1987	MAEd	17.0	24	1	7.01	534	SW	SE	SW	2	29N	1W	10YR5/4	10YR7/4						8.87E-04	7.8	5.4	13.2	C		19.27	48.75	31.98
CK	98	1987	MAEd	17.0	24	1	10.06	534	SW	SE	SW	2	29N	1W	10YR5/3	10YR7/4						1.95E-03	5.4	5.9	11.2	C		25.83	46.04	28.13
CK	100	1987	MAEd	3.0	24	1	0.91	535	NE	SE	NW	9	29N	1E	5YR4/6	7.5YR6/6						1.58E-03				NC		42.79	33.74	23.47
CK	101	1987	MAEd	3.0	24	1	2.44	535	NE	SE	NW	9	29N	1E	5YR4/4	7.5YR7/6						2.13E-03				NC		47.07	34.01	18.92
CK	102	1987	MAEd	3.0	24	1	3.96	535	NE	SE	NW	9	29N	1E	7.5YR4/4	7.5YR6/4						1.48E-03				NC		38.56	40.44	21.00
CK	104	1987	MAEd	3.0	24	1	7.01	535	NE	SE	NW	9	29N	1E	7.5YR4/4	7.5YR6/6						2.06E-03				NC		52.04	32.58	15.38
CK	105	1987	MAEd	3.0	24	1	8.53	535	NE	SE	NW	9	29N	1E	5YR4/6	7.5YR6/6						2.01E-03				C		49.01	30.74	20.24
CK	106	1987	MAEd	3.0	24	1	10.06	535	NE	SE	NW	9	29N	1E	5YR5/3	7.5YR6/4						2.10E-03				C		51.23	32.60	16.17
CK	107	1987	MAEd	3.0	24	1	0.91	536	SW	SE	SW	1	29N	1E	7.5YR4/6	7.5YR5/6	56	32	12	0	56	4.31E-04				NC		47.37	33.96	18.68
CK	108	1987	MAEd	3.0	24	1	2.44	536	SW	SE	SW	1	29N	1E	5YR4/6	7.5YR7/6	58	30		0	58	9.83E-04	3.0	1.5	4.5	NC		48.40	36.65	14.95
CK	109	1987	MAEd	3.0	24	1	3.96	536	SW	SE	SW	1	29N	1E	5YR4/6	7.5YR7/6	58	30	12	0	58	1.68E-03	4.4	1.0	5.4	C		44.73	37.05	18.21
CK	110	1987	MAEd	3.0	24	1	5.49	536	SW	SE	SW	1	29N	1E	5YR4/4	7.5YR6/6	52	32	16	0	52	2.71E-03	4.0	3.5	7.5	C		46.45	31.49	22.06
CK	111	1987	MAEd	3.0	24	1	7.01	536	SW	SE	SW	1	29N	1E	5YR4/6	7.5YR6/6	53	31	16	0	53	2.68E-03	4.5	2.5	7.0	C		46.41	32.65	20.94
CK	112	1987	MAEd	17.0	24	1	7.62	536	SW	SE	SW	1	29N	1E	10YR4/2	7.5YR6/6						4.12E-03	3.4	2.0	5.4	C		64.95	21.45	13.60
CK	113	1987	MAEd	3.0	24	2	1.22	537	NW	NW	SW	26	28N	1E	7.5YR4/6	7.5YR6/6						2.03E-03	2.0	1.0	2.9	NC	0.8	36.98	39.77	23.25
CK	114	1987	MAEd	3.0	24	2	1.83	537	NW	NW	SW	26	28N	1E	7.5YR4/6	7.5YR6/6						1.92E-03	2.4	2.0	4.4	NC	0.6	41.65	38.60	19.75
CK	115	1987	MAEd	3.0	24	2	2.44	537	NW	NW	SW	26	28N	1E	7.5YR4/4	7.5YR6/6						1.61E-03	4.4	1.5	5.9	NC	0.6	32.02	42.09	25.89
CK	116	1987	MAEd	3.0	24	2	3.05	537	NW	NW	SW	26	28N	1E	7.5YR4/4	10YR6/6						1.61E-03	2.9	1.0	3.9	NC	0.4	34.93	40.86	24.21
CK	117	1987	MAEd	4.0	24	2	3.73	537	NW	NW	SW	26	28N	1E	7.5YR4/4	7.5YR6/6						2.42E-03	2.4	1.5	3.9	NC	0.5	52.79	28.79	18.42
CK	118	1987	MAEd	3.0	24	2	4.57	537	NW	NW	SW	26	28N	1E	10YR5/4	10YR6/6						1.24E-03				NC	0.6	37.39	39.29	23.32
CK	119	1987	MAEd	4.0	24	2	5.49	537	NW	NW	SW	26	28N	1E		2.5Y6/8						1.63E-03				NC		94.06	5.94	0.00
CK	120	1987	MAEd	4.0	24	2	6.10	537	NW	NW	SW	26	28N	1E		10YR6/6						8.63E-04				NC		97.83	1.73	0.44

APPENDIX I - LOCATIONS AND STRATIGRAPHIC DATA (CLARK CO.)

++ IDENTITY					+ SOURCE			LOCATION							MUNSELL COLOR		TILL STRATIGRAPHIC INDICATORS											GRAINSIZE PERCENTAGES(< 2mm) +		
++ County (code)	Sample no.	Year	Litho-strat. unit (code)	Mat. (code	+ Coll. # of samp. + (code	Sample source (code)	Sample depth (m)	Drill hole no.	1/4 1/4 1/4	1/4 1/4	1/4	Sec.	Tnshp.	Range	(Field) Hue value/ chroma	(Lab) Hue value/ chroma	Clay mineralogy (in percent) expand.	illite	chlor. +kaol.	verm.	smec.	Mag. susc. (dim. units)	Carb. cont. calc.	(Wt. percent) dolo.	total carb.	C/NC	% Fe	Percent sand (2.0 to 0.0625mm)	Percent silt (0.0625 to 0.002mm)	Percent clay (<0.002 mm) +
CK	121	1987	MAEd	3.0	24	2	9.14	537	NW	NW	SW	26	28N	1E	7.5YR4/4	7.5YR5/6						1.58E-03				NC		42.41	38.02	19.57
CK	122b	1997	LNBk	3.0	24	2	2.44	538	SW	SW	SW	10	28N	2W	7.5YR4/4	10YR6/6	55	34	11	26	29	1.65E-03				NC	0.7	42.48	36.47	21.05
CK	123	1987	LNBk	3.0	24	2	3.96	538	SW	SW	SW	10	28N	2W	7.5YR4/4	7.5YR6/6	43	46	11	22	21	5.10E-03				NC	1.2	43.61	37.14	19.25
CK	124	1967	LNBk	3.0	24	2	5.49	538	SW	SW	SW	10	28N	2W	7.5YR4/4	10YR6/6	53	34	13	26	27	4.43E-03				NC	0.8	53.34	29.72	16.94
CK	125	1987	LNBk	3.0	24	2	7.01	538	SW	SW	SW	10	28N	2W	5YR4/4	7.5YR6/6	59	30	11	28	31	2.47E-03				NC	0.6	52.56	29.17	18.27
CK	126	1987	LNBk	3.0	24	2	8.53	538	SW	SW	SW	10	28N	2W	5YR4/6	7.5YR6/6	48	39	13	0	48	2.58E-03				NC	0.5	53.88	30.26	15.86

APPENDIX I - LOCATIONS AND STRATIGRAPHIC DATA (TAYLOR CO.)

++ IDENTITY					+ SOURCE		LOCATION								MUNSELL COLOR		TILL STRATIGRAPHIC INDICATORS								GRAINSIZE PERCENTAGES(< 2mm)		
County (code)	Sample no.	Year	Litho-strat. unit (code)	Mat. (code)	+ Coll. + of + samp. + (code	Sample source (code)	Sample depth (m)	Drill hole no.	1/4 1/4 1/4	1/4 1/4	1/4	Sec.	Tnshp.	Range	(Field) Hue value/ chroma	(Lab) Hue value/ chroma	Clay mineralogy (in percent) expand.	illite	chlor. +kaol.	verm.	smec.	Mag. susc. (dim. units)	C/NC	%Fe	Percent sand (2.0 to 0.0625mm)	Percent silt (0.0625 to 0.002mm)	Percent clay (<0.002 mm)
TA	101	1987	LnMr	6	24	1	0.91	283	SW	NW	NW	16	30N	1W	10YR4/4	10YR6/8						1.25E-03	NC	0.84	13.80	65.19	21.01
TA	102	1987	LnMr	3	24	1	2.44	283	SW	NW	NW	16	30N	1W	5YR4/4	7.5YR6/6						2.18E-03	NC	0.81	41.55	37.75	20.70
TA	103	1987	LnMr	3	24	1	3.96	283	SW	NW	NW	16	30N	1W	7.5YR4/6	7.5YR6/6						1.87E-03	NC	0.78	39.37	39.40	21.22
TA	104	1987	LnMr	3	24	1	5.49	283	SW	NW	NW	16	30N	1W	7.5YR4/4	10YR5/8						2.04E-03	NC	0.66	44.53	36.36	19.11
TA	105	1987	LnMr	3	24	1	7.01	283	SW	NW	NW	16	30N	1W	7.5YR4/4	7.5YR6/6						1.82E-03	NC	0.56	48.07	35.47	16.46
TA	108	1987	LnMr	6	24	1	1.22	284	NW	NW	SW	6	30N	1W	7.5YR4/6	7.5YR6/6						1.44E-03	NC		34.21	46.18	19.61
TA	109	1987	LnMr	3	24	1	2.44	284	NW	NW	SW	6	30N	1W	7.5YR4/6	10YR6/6	50	34	16	24	26	4.58E-03	NC		52.72	26.83	20.45
TA	110	1987	LnMr	3	24	1	3.96	284	NW	NW	SW	6	30N	1W	7.5YR4/6	10YR5/6	45	38	17	0	45	2.85E-03	NC		47.56	32.56	19.87
TA	111	1987	LnMr	3	24	1	5.49	284	NW	NW	SW	6	30N	1W	7.5YR4/4	10YR6/8	45	41	14	0	45	2.85E-03	NC		52.82	34.33	12.85
TA	112	1987	LnMr	3	24	1	7.01	284	NW	NW	SW	6	30N	1W	7.5YR4/4	7.5YR6/6	55	33	12	0	55	1.99E-03	NC		50.87	33.04	16.09
TA	113	1987	LnMr	3	24	1	8.53	284	NW	NW	SW	6	30N	1W	7.5YR4/4	7.5YR6/6	58	31	11	0	58	2.47E-03	NC		54.93	31.70	13.37
TA	114	1987	LnMr	6	24	1	0.91	285	NW	SW	NW	32	30N	1W	10YR4/3	7.5YR6/4						2.73E-03	NC		38.94	45.20	15.86
TA	115	1987	LnMr	3	24	1	2.44	285	NW	SW	NW	32	30N	1W	7.5YR4/4	10YR6/6						2.11E-03	NC		46.88	32.47	20.66
TA	116	1987	LnMr	3	24	1	3.96	285	NW	SW	NW	32	30N	1W	5YR4/6	10YR7/6						2.37E-03	NC		44.62	37.11	18.27
TA	117	1987	LnMr	3	24	1	5.49	285	NW	SW	NW	32	30N	1W	5YR4/4	10YR6/6						2.83E-03	NC		42.79	40.13	17.07
TA	118	1987	MaEd	3	24	1	7.01	285	NW	SW	NW	32	30N	1W	10YR4/4	10YR7/6						2.99E-03	NC		34.50	47.73	17.77
TA	119	1987	MaEd	3	24	1	8.53	285	NW	SW	NW	32	30N	1W	2.5YR3/4	7.5YR6/6						3.83E-04	NC		24.88	42.38	32.74
TA	120	1987	MaEd	3	24	1	10.06	285	NW	SW	NW	32	30N	1W	2.5YR3/6	7.5YR6/8						9.35E-04	NC	1.22	30.03	33.78	36.19
TA	123	1987	LnMr	3	24	1	0.91	286	NW	SW	SE	13	31N	3E	5YR3/4	7.5YR5/6						3.36E-03	NC		48.75	34.68	16.57
TA	124	1987	LnMr	6	24	1	0.91	287	NW	NW	SW	29	31N	3E	10YR4/4	7.5YR6/6						2.59E-03	NC		30.83	53.15	16.01
TA	125	1987	LnMr	3	24	1	2.44	287	NW	NW	SW	29	31N	3E	10YR5/4	10YR6/6	58	26	16	30	28	4.03E-03	NC		47.52	38.82	13.66
TA	126	1987	LnMr	3	24	1	3.96	287	NW	NW	SW	29	31N	3E	5YR4/4	7.5YR6/6	58	27	15	29	29	4.63E-03	NC		47.19	33.26	19.55
TA	127	1987	LnMr	3	24	1	4.72	287	NW	NW	SW	29	31N	3E	5YR4/4	7.5YR6/6	55	31	14	25	30	4.03E-03	NC		47.12	34.85	18.03
TA	128	1987	LnMr	6	24	1	0.91	288	NW	NE	NE	1	31N	2E	2.5YR3/4	7.5YR5/8						2.95E-03	NC		34.70	42.18	23.12
TA	129	1987	LnMr	3	24	1	2.44	288	NW	NE	NE	1	31N	2E	5YR4/4	5YR6/6	59	28	13	22	37	3.38E-03	NC		54.49	31.47	14.04
TA	130	1987	LnMr	3	24	1	3.96	288	NW	NE	NE	1	31N	2E	5YR4/6	7.5YR6/6	58	29	13	26	32	4.43E-03	NC		56.82	29.71	13.48
TA	131	1987	LnMr	3	24	1	5.49	288	NW	NE	NE	1	31N	2E	5YR4/6	7.5YR6/6	48	38	14	0	48	5.66E-03	NC		57.32	29.92	12.76

APPENDIX II-A

Citrate-Dithionite Extractable Iron

Principle: The citrate-dithionite iron technique extracts the bulk of the total free iron in a given sample. This is primarily in the form of various oxides acting as cements or grain coatings. With this technique, sodium dithionite serves to reduce and remove iron from the sample. Sodium citrate aids in the extraction and buffering of the solution to a pH >6.5 thereby preventing decomposition of the dithionite. (Olson, 1965).

Equipment:
wash bottle with deionized water
funnels
filter paper (#42 Watman 11cm)
clean 250ml wide mouth jars with lids
reciprocating sample shaker
rubber gloves
80 mesh screen
clean 250ml narrow mouth jars with lids
Atomic Absoption spectrometer
analytical balance
clean Nalgene storage bottles

Reagents:
Sodium citrate powder ($Na_3C_6H_5O_7.2H_2O$)
Sodium dithionite powder ($Na_2S_2O_4$)
Flocculating agent (.2% in water); for example MgCl: add 2g MgCl salt to 1 liter deionized water. It easiest to bring the salt into solution by using a magnetic stirrer instead of shaking manually for hours.

Procedure:

A. Iron extractions:

1. Place 1-5g* air dried sample (ground to pass an 80 mesh sieve) into a 250ml wide mouthed glass jar. Record weight precisely. *Use 4-5g of the sample if it is low in iron oxides.

2. Add 2g Na dithionite and 20-25g Na citrate powder to the sample.
3. Add 118ml deionized water and screw the cap on tightly. Shake vigorously for a few minutes manually in order to completely suspend the sample.
4. Secure the capped glass jars containing sample solutions in the reciprocating shaker andshake overnight approximately 10 hours).
5. Transfer the suspensions to individually labelled 250ml volumetric flasks or jars. You may wish to work under a hood from this point on since the extraction vapors are strong.
6. Add 5 drops of the flocculating agent, cap, and shake vigorously for 30-60 seconds. Bring the solution to volume, shake again and allow to settle for 1 hour.
7. Filter the supernatant through ashless filter paper into a Nalgene bottle and keep stored in the refrigerator.

B. Standards and Dilutions:

1. Prepare a minimum of 3 iron standards ranging from 0 mg/l Fe (blank) to beyond the expected concentration of the highest sample concentration to be run. The standard concentrations should be more or less uniformly

spaced over the entire range.

2. Concentration range of samples: As with all AAS work, for best results the ratio of the most concentrated sample to the least concentrate should not exceed 10 and should preferably be about 5. If the ratio does exceed 10 then the samples should be diluted. In this study for example, all sample extractions were run at 1:10 dilutions.

C. Flame Atomic Absorption Spectrophotometer: (Perkin-Elmer)

1. Install an iron hollow cathode lamp in the lamp holder. Be sure that the current knob is turned completely counter-clockwise.
2. Turn on power.
3. Set lamp current setting as specified on the lamp.
4. Set the wavelength knob to correct setting (used 271.9nm).
5. Set slit width (used 3).
6. Align the lamp with the control knobs located on the top and side of the lampholder so as to attain the greatest deflection.
7. Fine tune the wavelength.
8. Adjust the gains in order to maximize the beam.
9. Turn on the air and acetylene and adjust flow rates
10. Ignite the flame.

11. Aspirate a sample of deionized distilled water.
12. Aspirate a standard and fine tune the burner head until a maximum response in the flame is reached.
13. Can now begin running the unknowns.
14. Use 3 10 second interpretations for each sample/standard.
15. Aspirate deionized distilled water between each unknown and record.
16. Check the full set of standards after every 10 unknowns in order to monitor any machine drift.
17. Record all data on strip chart.

Calculations: Using the average absorbance readings from the AA analysis one can calculate mg iron in each unknown. This can be accomplished by either calculating a regression equation for absorbance as a function of concentration and time or by manually plotting absorbance vs. concentration for each standard and then using the prepared standard curve to read off the sample concentrations. Regression analysis with the aid of a computer is by far the quickest method. Once parts per million is calculated, the iron content of any given sample is as follows:

$$\text{\% Fe in sample} = \frac{\begin{array}{c}\text{250 x dilution factor x} \\ \text{ppm Fe in sample soln - ppm in blank soln}\end{array}}{\text{sample wgt.(g) x 10,000}}$$

Additional Remarks:

1. Be sure to do a thorough job in grinding the samples before the extraction procedure since this will increase the efficiency of the iron extraction.
2. The filtration step is very slow. It is not imperative to recover every last drop of supernatant. 50-60ml will be more than sufficient for analysis in the AA since only 15-20ml will be actually used in the dilution and aspiration steps.
3. As with any lab standard method, it is very important that you remember to make up a blank for every batch that is run. Don't forget this!
4. Sample solutions will need to be diluted so that they are in the correct range for the AA. If you are unfamiliar with this, seek out a qualified water chemist.
5. All of these samples were run on the AA within 24 hours after the extractions were completed. No matrix modifictions were made. As a result, the pH of the solutions changed significantly within the ensuing 48-72 hours. If you plan on storing the extract solutions for any length of time prior to the AA work you may wish to either acidify the solutions or buffer them with bicarbonate in order to avoid any spurious results. (see Jackson, 1958).

Further Reading:

Holmgren, G.G.S., 1967, A rapid citrate-dithionite extractable iron procedure, Soil Science Society Am. Proc. 31:210-211.

Olson, R. V., 1965, Iron, in A. Klute (ed), Methods of soil analysis, Part II, Agronomy 9:311-312. Am. Soc. of Agron., Madison, Wi.

Mehra, D.P., and M.L. Jackson, 1960. Iron oxide removal from soils and clays by a dithionite citrate system buffered with sodium bicarbonate. Clays and Clay Minerals, Seventh Conference, Permagon Press, London, pp. 317-327.

Appendix II-B

Clay Separation Technique and Preparation of Oriented <2-μm Samples

Principle: The use of porous ceramic tiles and a suction apparatus allows for relatively rapid preparation of oriented x-ray diffraction (XRD) samples. The use of tiles and a vacuum system offers the advantage of being able to a.) add a known amount of clay to the tile surface hence ensuring sufficient thickness and b.) saturate with various cation solutions and solvate all on the same tile thereby eliminating the need to prepare many tiles for the same sample.

Equipment:

Porous ceramic tiles (Fisher Scientific Supply)
Suction apparatus (built to specifications as per Singer and Janitzky, 1986)
Muffle furnace
Eye droppers (1 and 2ml size)
vacuum source (wall unit or pump)

Reagents:

Magnesium chloride saturated solution in a wash bottle
HCl, pH 3.5 stored in a wash bottle
Ethylene glycol or glycerol
1:1 ethylene glycol-water solution
HCl 6N
Deionized water in a wash bottle

Procedure:

A. Preparation of ceramic mounting tiles

1. Each 6 x 6" unglazed ceramic tile is rough cut into 25 smaller tiles measuring 3 cm^2 using a large rock saw.
2. The 3 cm^2 tiles are then trimmed and smoothed by wet-

grinding on an electric grinder using #220 grit to a tile thickness of approximately 3 mm.

3. Once the desired measurements are met, the tiles are rinsed with tap water and placed in a shallow petri dish filled with warm 6N HCL. Allow the tiles to soak until all of the abrasive grit has disappeared.
4. Rinse the tiles well with deionized water and allow to dry.

B. Clay separation technique

1. Run a standard particle size procedure and calculate the clay percentage in a standard sized lab sample.
2. Based on the clay percentage in the total sample, weigh out enough bulk sample to ensure an adequate amount of clay fraction to perform several diagnostic tests. Table I lists suggested weights of bulk sample needed to obtain 400mg of <2µm fraction.
3. Record the weighed sample and place in a screw cap 200 ml glass jar. As per standard procedure, disperse the samples with 5 ml of sodium hexametaphosphate (60g/liter concentration) and 100 ml deionized water. Although dispersal was deemed a neccessity for these samples, an attempt was made to minimize the effects of this chemical pre-treatment. Recent studies (Omueti and Lavkulich, 1988) have questioned the suitability of Na pyrophosphate

% CLAY IN SAMPLE	WEIGHT NEEDED
7.5	80.0
10	53.3
12.5	40.0
15	32.0
17.5	26.7
20	22.9
22.5	20.9
25	17.8
27.5	16.0
30	14.5
32.5	13.3
35	12.3
37.5	11.4
40	10.7
42.5	10.0
45	9.4
47.5	8.9
50	8.4
52.5	8.0
55	7.6
57.5	7.3
60	7.0
62.5	6.7
65	6.4
67.5	6.2
70	5.9

Table 1: Suggested sample weights needed to obtain 400 mg of <2 µm clay from a 20 ml aliquot drawn from a 200 ml sample suspension (Leigh, 1988).

or Na hexametaphosphate as a dispersing agent for soils whose clay mineralogy is to be determined. This research has shown that soils which contain 2:1 phyllosilicates will exhibit "new" peaks other than those actually present when subjected to XRD analysis.

4. Transfer the samples to labelled 250 ml beakers and bring to a 200 ml volume with deionized water.
5. Stir the samples with a glass rod taking care to suspend all of the material.
6. Allow to settle for 2 hours.
7. Pipette a 20 ml volume of the <2µm clay particles from the top 2 cm of solution. Store this aliquot in a labelled plastic snap cap vial.
8. Extract an additional 5 ml aliquot at the same time and place it in a 50 ml beaker. Record the weight of the beaker + sample.
9. Oven dry the 5 ml aliquot overnight and re-weigh the beaker + sample. You can now calculate the exact concentration (mg/ml) of the <2µm fraction in each aliquot.

<u>example:</u> A = (beaker = 26.85g)

beaker + 5 ml sampl (wet)	B ↓ beaker + 5ml sampl (dried)	A–B		
32.13g	26.96g	0.11g	$\frac{110\text{mg}}{5\text{ml}}$	$\frac{22\text{mg}}{\text{ml}}$

C. Clay mounting technique

1. Based on the calculated clay concentrations, a known volume is extracted from the 20 ml aliquot taken in step B7 so as to yield an infinitely thick sample. Using a mass absorption coefficient of 30 and a maximum 2-theta angle of 30° then the amount of clay needed per tile for 99% of the observed diffraction to be produced is approximately 20 mg/cm^2. See Table 2 and refer to Rich (1975) for the full explanation of the governing equation and its variables.
2. Uncork several holes on the suction apparatus and place labelled dry tiles over the holes. At least 2 tiles should be made per sample; obviously the number will increase depending on the number of saturating and solvating techniques planned. Before applying the clay to the tiles, turn on the vacuum and make sure that the tiles are seated properly and that no leaks occur in the suction.
3. Wet the tiles with deionized water. Check to see that the vacuum pressure is high enough to pull the water through the ceramic quickly.
4. Apply the calculated amount of clay to the tile with an eye dropper, being sure to coat the tile evenly.
5. For this study, 2 tiles were prepared for each sample.

	Mass absorption coefficient						
20	30	40	50	75	100	200	250
Degrees	mg/cm^2						
			95% of the Observed Diffraction				
10	4.5	3.4	2.7	1.8	1.4	0.7	0.5
20	8.7	6.5	5.2	3.5	2.6	1.3	1.0
30	12.9	9.7	7.8	5.2	3.9	1.9	1.6
40	17.1	12.8	10.2	6.8	5.1	2.6	2.0
50	21.1	15.8	12.7	8.4	6.3	3.2	2.5
60	25.0	18.7	15.0	10.0	7.5	3.7	3.0
80	32.1	24.1	19.2	12.8	9.6	4.8	3.8
			99% of the Observed Diffraction				
10	6.7	5.0	4.0	2.7	2.0	1.0	0.8
20	13.3	10.0	8.0	5.3	4.0	2.0	1.6
30	19.9	14.4	12.9	7.9	6.0	3.0	2.4
40	26.2	19.7	15.8	10.5	7.9	3.9	3.2
50	32.4	24.3	19.5	13.0	9.7	4.9	3.9
60	38.4	28.8	23.0	15.4	11.5	5.8	4.6
80	49.3	37.0	29.6	19.7	14.8	7.4	5.9
			99.9% of the Observed Diffraction				
10	10.0	7.5	6.0	4.0	3.0	1.5	1.2
20	20.0	15.0	12.0	8.0	6.0	3.0	2.4
30	29.8	22.3	17.9	11.9	8.9	4.5	3.6
40	39.4	29.5	23.6	15.7	11.8	5.9	4.7
50	48.7	36.5	29.2	19.5	14.6	7.3	5.8
60	57.6	43.2	34.5	23.0	17.3	8.6	6.9
80	74.0	55.5	44.4	29.6	22.2	11.1	8.9

Table 2: Concentrations of clay on a tile surface needed to produce 95%, 99%, and 99.9% of the observed diffraction. Concentrations are calculated for a range of 2 and mass absorption values (Rich, 1975).

Tile A was saturated with respect to Mg^{2+} ions and then air dried before being x-rayed. Tile B was saturated with Mg^{2+} ions and solvated with ethylene glycol before being analyzed. After the air dried analysis, tile A was subjected to one or more heating tests and then rexrayed.

6. Wash both tiles three times with HCl (pH 3.5) being sure to wait for all of the excess liquid to draw through the tile before re-applying the next wash of HCl. This step will help prevent the precipitation ofmagnesium hydroxides.
7. Wash both tiles with 1N Mg^{2+} chloride solution 4 times.
8. Wash the tiles 4 times with deionized water applying suction continuously and waiting for each drawdown before reapplication.
9. Tile A is complete after step 8 but tile B needs to be solvated. To accomplish this, a 1:1 ethylene glycol-water solution is applied to the tile and drawn through via the vacuum. It was found that solvating the sample directly on the tile in addition to exposing the tile to EG vapors overnight, helped to ensure complete solvation.
10. Disengage the vacuum and carefully remove the tiles. Place the unsolvated tiles in a shallow covered tray to dry . A dessicator tended to dry

the samples to quickly thus causing them to peel. Place the solvated/saturated tiles in a glycolator with 2-3" of EG in the bottom. Place the entire glycolator in an oven and heat at 60 °C overnight.

11. X-ray the air dried and solvated tiles as per instructions in Appendix I-B. Once all of the air dried samples are x-rayed, place them in a preheated muffle furnace and heat for 1 hour at 350 °C. X-ray immediately to avoid any rehydration of expandables.
12. Re-heat the air dried tiles at 550 °C for 2 hours and x-ray immediately.

<u>Further Reading:</u>

Singer, M.J., and Janitzky, P., 1986, Field and Laboratory Procedures Used in a Soil Chronosequence Study. USGS Bulletin 1648. U.S. Government Printing Office, Washington.

Hallberg, G.R., Lucas, J.R., and Goodman, C.M., 1978. Semiquantitative analysis of clay mineralogy Part I in Standard Procedures for the Evaluation of Quaternary Materials in Iowa. Iowa Geological Survey Technical Information Series #8. Iowa City, pp. 5-21.

APPENDIX II-C

Scintag X-ray diffractometer Operation parameters for clay mineral analysis

This is intended as a brief step-by-step procedure guideline for the operation of the Scintag x-ray diffractometer (XRD) as it was used in this study.

1. Check to make sure that the correct voltages are programmed. If you don't see the following: 45KV and 40MA on the front readout panel you will need to enter these values. To do so, first push the KV pad and then push "45" on the number pad. Press enter and the XRD will automatically dial in this value. Then push MA, 40, and enter.

2. Open the XRD hood and take off all jewelry.

3. Take a look at the two calibrated vernier dials on the front of the platform. Note both the theta and 2-theta angles.

4. You should always verify these angles with the computer since there stands a good chance that it thinks it's at some other locality. To do this, press the DA5 program key after you see the "x-ray " prompt. At the "ready" prompt, type in "OA" (output angles). The theta and 2-theta angles on the screen should match those on the dials of the XRD. If by chance they don't, type in "SA" (set angles) and manually type in the theta and 2-theta angles which you read off the dials.

5. To test your ability at coordinating the computer with the XRD, tell the VAX to "DM" (drive motors). It will ask you for the

specific angles you wish to drive to. Enter these and 2-theta values along with zeros for chi and phi values. Press "enter." The XRD will automatically swing to the programmed values. Once again double check your work by verifying the angles. Match the screen output with a quick visual check. You should now be ready to run a pattern.

6. Place your slide in the spring mount and insert the appropriate divergence slits. Both 0.1/0.2 and 0.3/0.5 pairs of slits were tried and it was found that the best pattern with the maximum intensity beam on the tile was with the 0.3/0.5 slits. Close the hood door.

7. You will still be in the DA5 program; which you will always begin with. There are two sub-routines in this program.

a.) <u>step scan</u>: during this scan type, the goniometer is driven to each specified position whereby diffraction data is collected for a specified length of time. This is the traditional method of data aquisition.

b.) <u>fast scan</u> : this is the cost common scan used at the higher scan speeds. Unlike the step scan mode which collects data only at discreet settings of the goniometer, the FS allows you to collect data while the goniometer is moving to the next position by performing an integration over each step.

8. Type in "FS" and then hit the enter key.

9. The program will now require several inputs. The order they will appear is:

a.) "enter file name" -- ex: Ta-290.GLY

b.) "enter title of sample" -- ex: AD (air dried)
GLY (glycolated)

c.) "multi-range continuous scan?" -- ex: 0 (no)

d.) "scan type?" type 0 and by default a normal scan will be run; in other words a 2:1 ratio will be kept between the 0 and 20 angles.

e.) "starting angle" -- ex: 3° 2-theta

f.) "stopping angle" -- ex: 30° 2-theta

g.) "chopper increment?" this is the number of degrees over which the scan is integrated. Scintag recommends a 0.5 default value.

h.) "scan rate" this is the rate at which the data will be collected. ex: 5°/min. The computer will tell you how long the scan will take given the parameters you've keyed in.

i.) "real time plot?" You will need to play with this value since it will vary from sample to sample. A typical value used for this study was 2000 cps. Don't worry if the graph is scaled incorrectly since this will be compensated for in another program.

j.) You don't want to spin the sample, use a chart recorder, oscillate it, power down the generator after the run, or output the data to a terminal. Type in "0" for each of these parameters.

k.) The scan will now begin. Two files are created under the DA5 program run and will be appended with either ".rd" (raw data) or ".da" (data aquisition). If you run into any problems, "control C" will dump the program and take you back to the $ prompt whereby you can enter DA5 again and input new values. Once the scan is completed press "by" to exit the DA5 program.

If you wish to output the raw data you'll need to move on to the graphics program (TC9). This program is all menu driven with a set of cross hairs on the screen. Upon entering TC9, the Scintag color wheels logo will appear on the screen. Hit CR to get to the main menu. Most clay work will be run under a "normal display" therefore enter "1". You will then be asked for the file name you wish to display. More often than not you will want to display the raw data ".rd" file created during the initial run in DA5. Be sure to therefore append your file name with the ".rd" extension. For example: CK-46gly.rd.

If you opted to use either peak intensities or peak heights for semi-quantitative mineral estimations, you will need to label all desired peaks on your solvated sample pattern. Be sure to have the cross-hairs positioned at the apex of the peak or you will be recording erroneous peak intensities. Once labelling is complete, move the cross-hairs off the screen and print out the pattern for further measurements and/or reference.

APPENDIX III

Detailed Soil Profile Descriptions

SITE: Ta-292-PG

LOCATION: T31N R1E SESESE sec. 13 (Medford Quad)

SOIL SERIES: Withee

SAMPLED BY: Andrea Sutherland and David Leigh

METHOD: Truck mounted hydaulically operated Giddings auger

DESCRIBED: in lab 12/12/87

Depth (cm)	Horizon	Description
0-24	Ap	10YR 3/2 v. dk grayish brown silt loam; moderate medium granular parting to weak medium subangular blocky; friable; noneffervescent; fine rootlets visible; gradual boundary.
24-37	EB	10YR 5/3 brown silt loam; moderate medium platy; medium common 7.5YR 5/6 prominent mottles; friable; noneffervescent; common fine rootlets; gradual boundary.
37-52 (Ta-132-87)	Bt1 (40-50cm)	10YR 5/4 yellowish brown silt loam; moderate medium subangular blocky parting to moderate medium platy; friable; noneffervescent; few fine rootlets; clear boundary.
52-80 (Ta-133-87)	2Bt2 (65-75cm)	5YR 4/4 reddish brown sandy loam; moderate medium subangular blocky; noneffervescent; friable; few pebbles present (1-5cm wide); argillans; gradual boundary.
80-105 (Ta-140-87)	2Bt3 (85-95cm)	5YR 4/4 reddish brown pebbly loam; moderate coarse subangular blocky; thick argillans; noneffervescent;

friable.

SITE: Ta-290-PG

LOCATION: T30N R1W SWNWNW sec.16 (Lublin SE Quad)

SOIL SERIES: Withee

SAMPLED BY: Andrea Sutherland and David Leigh

SAMPLING METHOD: Truck mounted hydraulic Giddings auger

DESCRIBED: in lab 12/12/87

Depth (cm)	Horizon	Description
0-5	A	10YR 3/2 very dark grayish brown silt loam; moderate fine granular; very thick root mat; friable; clear boundary.
5-26 (Ta-138-87)	E (14-24cm)	10YR 5/3 brown silt loam; strong coarse platy; noneffervescent; friable; gradual boundary.
26-46 (Ta-134-87)	BE (34-44cm)	10YR 5/3 brown silt loam; moderate medium subangular blocky parting to weak medium platy; common fine faint 7.5YR 4/6 mottles; friable; noneffervescent; diffuse boundary.
46-74 (Ta-135-87)	Bt1 (56-66cm)	10YR 5/2 grayish brown loam; moderate medium subangular blocky parting to weak medium platy; common medium prominent 7.5YR 4/6 mottles; friable; noneffervescent; clear boundary.
74-143 (Ta-136-87)	2Bt1 (123-133cm)	7.5YR 4/4 brown-dark brown loam; moderate coarse subangular blocky; argillans and mangans present; noneffervescent; friable; gradual boundary.
143-178 (Ta-139-87)	2Bt2 (151-161cm)	7.5YR 4/4 brown-dark brown loam; moderate coarse subangular blocky; numerous small pebbles; friable; noneffervescent; gradual boundary.

178-240+ (Ta-137-87)	2C (228-238cm)	7.5YR 4/6 strong brown loam; weak coarse subangular blocks becoming massive with depth; firm; noneffervescent.

SITE: Ck-545-PG

LOCATION: T28N R2W SWSWSW sec. 17 (Lombard Quad)

SOIL SERIES: Loyal

SAMPLED BY: Andrea Sutherland and David Leigh

SAMPLING METHOD: Truck mounted hydraulic Giddings core apparatus

DESCRIBED: in lab 12/14/87

Depth (cm)	Horizon	Description
0-19	Ap	10YR 3/2 very dark grayish brown silt loam; moderate fine subangular blocky; noneffervescent; friable; clear boundary.
19-25 (Ck-145-87)	E (20-25cm)	10YR 5/3 brown silt loam; moderate fine platy; noneffervescent; friable; gradual boundary.
25-46	EB	10YR 6/2 light brownish gray ped exterior silt loam; moderate medium subangular blocky; many medium prominent 7.5YR4/6 mottles; friable noneffervescent; clear boundary.
46-70 (Ck-130-87)	Bt1 (55-65cm)	10YR 5/2 grayish brown ped exterior and 7.5YR 4/6 ped interior silty clay loam; weak medium prismatic parting to strong medium subangular blocky; prominent silans coating ped faces; noneffervescent; friable; gradual boundary.
70-93 (Ck-131-87)	2Bt2 (80-90cm)	10YR 5/1 gray clay; moderate medium subangular blocky parting to weak angular blocky; prominent silans and argillans on ped faces; firm consistence; noneffervescent; clear boundary.
93-151	BC	7.5YR 4/4 brown to dark brown sandy loam; moderate medium sub-

angular blocky; prominent argillans
and some manganese staining; firm;
noneffervescent.

SITE: Ck-544-PG

LOCATION: T28N R2W NWNWSE sec. 4 (Lombard quad)

SOIL SERIES: currently unmapped

SAMPLED BY: Andrea Sutherland and David Leigh

SAMPLING METHOD: truck mounted hydraulic Giddings core apparatus

DESCRIBED: in lab 12/15/87

Depth (cm)	Horizon	Description
0-19	Ap	10YR 3/2 very dark grayish brown silt loam; weak medium subangular blocky parting to moderate fine granular; friable; many fine rootlets; noneffervescent; abrupt boundary.
19-31 (Ck-146-87)	E (20-30cm)	10YR 6/2 light brownish gray silt with common medium distinct 7.5YR 5/6 mottles; moderate medium platy; friable; noneffervescent; clear boundary.
31-54	EB	10YR 5/2 grayish brown heavy silt loam with many coarse prominent 7.5YR 5/6 mottles; moderate medium subangular blocky parting to weak medium platy; friable; noneffervescent; few cobbles present; clear boundary.
54-95 (Ck-132-87)	Bt1 (70-85cm)	10YR 5/2 grayish brown silt loam matrix with many medium distinct 10YR 5/6 and 5/8 mottles; moderate medium angular blocky; friable; noneffervescent; few argillans; many fine vesicular pores; clear boundary.
95-140 (Ck-133-87)	2Bt2 (100-110cm)	7.5YR 4/6 strong brown loam; moderate medium subangular blocky;

		friable; noneffervescent; numerous small pebbles; few argillans; gradual boundary.
140-250+ (Ck-147-87)	2C (220-230cm)	7.5YR 4/4 brown to dark brown loam; moderate medium subangular blocky grading to massive with depth; firm; noneffervescent; from 180-208 cm is a 2.5YR 3/4 dark reddish brown sandy clay loam inclusion of different till.

SITE: Ck-541-PG

LOCATION: T28N R1E NENENW sec. 26 (Abbotsford Quad)

SOIL SERIES: Loyal

SAMPLED BY: Andrea Sutherland and David Leigh

SAMPLING METHOD: Truck mounted hydraulic Giddings core apparatus

DESCRIBED: in lab 12/10/87

Depth (cm)	Horizon	Description
0-17	Ap	10YR 3/2 very dark grayish brown silt loam; moderate medium granular; friable; noneffervescent; many very fine roots; abrupt bound-ary.
17-37 (Ck-148-87)	E (22-32cm)	10YR 5/4 yellowish brown silt loam with few fine faint 10YR 5/6 mottles; strong medium-coarse platy; friable; noneffervescent; clear boundary.
37-54	EB	10YR 5/2 grayish brown silt loam matrix with common medium distinct 10YR5/8 mottles; strong medium subangular blocky parting to moderate medium platy; noneffervescent; friable; clear boundary.
54-64 (Ck-134-87)	Bt1 (55-63cm)	10YR 4/1 dark grayish brown silty clay loam with few fine faint 10YR 4/6 mottles; strong medium angular blocky parting to moderate medium platy; noneffervescent; friable; abundant thick argillans; clear boundary.
64-90 (Ck-135-87)	2Bt2 (71-81cm)	7.5YR 4/4 dark brown loam; moderate medium subangular blocky; friable; noneffervescent; thick argillans from 63-72 cm; very pebbly matrix; gradual boundary.

90-114 (Ck-149-87)	2Bt3 (95-105cm)	7.5YR 4/4 dark brown sandy loam; moderate medium subangular blocky; noneffervescent; friable; very pebbly.

SITE: Ck-546-PG

LOCATION: T29N R1W SWNWNE sec. 31 (Owen Quad)

SOIL SERIES: Almena

SAMPLED BY: Andrea Sutherland and David Leigh

SAMPLING METHOD: Truck mounted Giddings core apparatus

DESCRIBED: in lab 12/15/87

Depth (cm)	Horizon	Description
0-23	Ap	10YR 3/2 very dark grayish brown silt loam; moderate fine granular; noneffervescent; friable; many fine roots; abrupt boundary.
23-29 (Ck-150-87)	E (23-29cm)	10YR 6/2 light grayish brown silt with common medium distinct 7.5YR 5/6 distinct mottles; strong medium platy; many fine visicular pores; common fine rootlets; friable; noneffervescent; clear boundary.
29-47	EB	10YR 5/2 grayish brown heavy silt loam with common distinct 7.5YR 4/5 and 4/6 mottles; friable; argillans; many fine rootlets; clear boundary.
47-58 (Ck-136-87)	Bt1 (47-57cm)	7.5YR 4/4 loam with few fine destinct 7.5YR 5/6 mottles; moderate medium subangular blocky; thick 10YR4/2 argillans; few silans; common very fine rootlets; friable; abrupt boudary.
58-76 (Ck-137-87)	2Bt2 (62-72cm)	7.5YR 4/4 brown to dark brown loam; moderate medium subangular blocky; firm; numerous small igneous pebbles; thick argillans; noneffervescent; clear boundary.

76-110 (Ck-138-87)	2Bt3 (86-96cm)	7.5YR 4/4 brown to dark brown loam; moderate coarse subangular blocky; firm; noneffervescent; numerous small pebbles; gradual boundary.
110+ (Ck-139-87	2C (240-250cm)	7.5YR 4/6 reddish brown loam; few large distinct 5YR 5/6 mottles; weak coarse subangular blocky becoming massive with depth; firm.

SITE: Ck-543-PG

LOCATION: T28N R2W NWNWSE sec. 23 (Owen Quad)

SOIL SERIES: Almena

SAMPLED BY: Andrea Sutherland and David Leigh

SAMPLING METHOD: truck mounted hydraulic Giddings core apparatus

DESCRIBED: in lab 12/18/87

Depth (cm)	Horizon	Description
0-20	Ap	10YR 4/2 dark grayish brown silt weak fine subangular blocky parting to weak fine platy; fine fibrous roots common; friable; abrupt boundary.
20-30 (Ck-143-87)	E (20-30)	10YR 5/2 grayish brown silt with many medium prominent 10YR 5/6 and 5/8 mottles; moderate medium platy; very friable; fine fibrous roots common; clear boundary.
30-48	EB	10YR 6/2 light brownish gray silt with common medium prominent brownish yellow 10YR6/6 and common fine prominent strong brown 7.5YR 5/6 mottles; moderate medium thin platy parting to weak fine subangular blocky; very friable; few fine fibrous roots; clear boundary.
48-62 (Ck-144-87)	Bt1 (50-60)	10YR 6/2 light brownish gray silt loam with common medium prominent 7.5YR 5/6 and 5/8 strong brown mottles; strong coarse subangular blocky parting to moderate coarse platy; friable; silans common on ped faces; clear boundary.
62-78 (Ck-140-87)	Bt2 (67-77cm)	7.5YR 5/2 brown silt loam matrix with common medium prominent 5YR5/6

		and 5/8 yellowish red mottles; moderate medium angular blocky with many distinct argillans; few faint silans; firm; clear boundary.
78-101 (Ck-141-87)	2Bt3 (85-95cm)	5YR 4/3 reddish brown silt loam with common medium faint yellowish red 5YR 4/6 mottles; strong coarse angular blocky parting to weak fine platy; firm; few faint argillans; gradual boundary.
101-231+ (Ck-142-87)	2C (158-168cm)	7.5YR 4/4 brown to dark brown loam with few medium distinct 7.5YR 5/6 strong brown mottles; weak coarse subangular blocky becoming massive at depth; firm; few faint argillans and silans present; <5% pebbles present.

APPENDIX IV

Modified Tillpro Module I
Soil profile data

APPENDIX IV - LOCATIONS AND LABORATORY DATA FOR SOIL PROFILES

IDENTITY County (code)	Sample no.	Year	Sample depth (cm)	Horizon	LOCATION Drill hole no.	1/4 1/4 1/4	1/4 1/4	1/4	Sec.	Tnshp.	Range	MUNSELL (Field) Hue value/ chroma	COLOR (Lab) Hue value/ chroma	TILL STRATIGRAPHIC INDICATORS Clay mineralogy (in percent) expand.	illite	chlor. +kaol.	verm.	smec.	Fe % Citrate-Dith.	Mag. susc. (dim. units)	Textural Class	Soil Series	GRAINSIZE PERCENTAGES(< 2mm) Percent sand (2.0 to 0.0625mm)	Percent silt (0.0625 to 0.002mm)	Percent clay (<0.002 mm)
CK	145	87	20-25	E	545	SW	SW	SW	17	28N	2W	10YR5/3	10YR5/6						0.65	1.45E-04	si		3.98	88.79	7.23
CK	130	87	55-65	Bt1	545	SW	SW	SW	17	28N	2W	10YR5/2	10YR7/4						1.08	5.03E-04	sicl	Loyal	13.90	57.86	28.24
CK	131	87	80-90	2Bt2	545	SW	SW	SW	17	28N	2W	10YR5/1	10YR6/4						1.35	6.47E-04	c		19.06	37.18	43.76
CK	146	87	20-30	E	544	SW	SW	SE	4	28N	2W	10YR6/2	10YR6/6						1.30	2.28E-04	si		3.32	81.67	14.82
CK	132	87	70-80	Bt1	544	SW	SW	SE	4	28N	2W	10YR5/2	10YR7/4						0.82	5.99E-04	sil	?	14.09	67.66	18.26
CK	133	87	100-110	2Bt2	544	SW	SW	SE	4	28N	2W	7.5YR4/6	10YR6/6						0.83	1.77E-03	l		51.14	31.42	17.43
CK	147	87	220-230	2C	544	SW	SW	SE	4	28N	2W	7.5YR4/4	7.5YR5/6						0.84	2.06E-03	l		45.06	45.46	9.48
CK	148	87	22-32	E	541	NE	NE	NW	26	28N	1E	10YR5/4	10YR5/6	64	21	15	38	26	0.90	1.92E-04	sil		11.41	78.91	9.68
CK	134	87	55-63	Bt1	541	NE	NE	NW	26	28N	1E	10YR4/1	10YR6/6	54	24	22	25	29	1.12	6.47E-04	sicl	Loyal	18.85	48.97	32.19
CK	135	87	71-81	2Bt2	541	NE	NE	NW	26	28N	1E	7.5YR4/4	7.5YR6/6	61	24	15	39	22	1.11	2.25E-03	l		38.50	36.44	25.06
CK	149	87	95-105	2Bt3	541	NE	NE	NW	26	28N	1E	7.5YR4/4	7.5YR5/6	71	23	13	41	30	1.24	3.28E-03	sl		60.38	25.69	13.93
CK	150	87	23-29	E	546	NE	NE	NW	26	28N	1E	10YR6/2	10YR6/6	57	24	19	30	27	0.79	3.36E-04	si		7.93	80.62	11.45
CK	136	87	47-57	Bt1	546	NE	NE	NW	26	28N	1E	7.5YR4/4	7.5YR6/6	59	24	17	37	22	1.10	1.39E-03	l		38.40	37.86	23.73
CK	137	87	62-72	2Bt2	546	NE	NE	NW	26	28N	1E	7.5YR4/4	10YR6/6	58	25	17	39	19	1.12	1.68E-03	l	Almena	46.63	32.54	20.84
CK	138	87	86-96	2Bt3	546	NE	NE	NW	26	28N	1E	7.5YR4/4	7.5YR5/6						0.99	2.56E-03	l		42.74	37.12	20.14
CK	139	87	240-250	2C	546	NE	NE	NW	26	28N	1E	7.5YR4/6	7.5YR6/6						0.82	2.27E-03	l		42.26	39.82	13.92
CK	143	87	20-30	E	543	NW	NW	SE	23	28N	2W	10YR5/2	10YR6/4						0.72	2.40E-04	si		3.73	88.80	7.48
CK	144	87	50-60	Bt1	543	NW	NW	SE	23	28N	2W	10YR6/2	10YR5/6						1.08	8.63E-04	sil		9.66	73.59	16.75
CK	140	87	67-77	2Bt2	543	NW	NW	SE	23	28N	2W	7.5YR5/2	10YR6/6						0.97	9.83E-04	sil	Almena	14.67	70.86	14.47
CK	141	87	85-95	2Bt3	543	NW	NW	SE	23	28N	2W	5YR4/3	7.5YR6/6						0.82	1.70E-03	sil		25.75	64.84	9.39
CK	142	87	158-168	2C	543	NW	NW	SE	23	28N	2W	7.5YR4/4	7.5YR6/6						0.54	2.64E-04	l		44.92	42.84	12.24
TA	132	87	40-50	Bt1	292	SE	SE	SE	13	31N	1E	10YR5/4	10YR6/6						0.90	6.95E-04	sil		22.19	59.89	17.92
TA	133	87	65-75	2Bt2	292	SE	SE	SE	13	31N	1E	5YR4/4	10YR6/6						1.01	1.13E-03	scl	Withee	49.10	26.99	23.91
TA	140	87	85-95	2Bt3	292	SE	SE	SE	13	31N	1E	5YR4/4	7.5YR5/6						1.24	1.58E-03	l		49.17	34.85	15.98
TA	138	87	14-24	E	290	SW	NW	NW	16	30N	1W	10YR5/3	10YR5/4	60	24	15	32	28	0.66	4.31E-04	si		7.84	84.31	7.85
TA	134	87	34-44	BE	290	SW	NW	NW	16	30N	1W	10YR5/3	10YR6/6	52	28	20	26	26	0.70	6.23E-04	sil		15.56	63.69	20.76
TA	135	87	56-66	Bt1	290	SW	NW	NW	16	30N	1W	10YR5/2	10YR6/6						0.91	5.75E-04	l		30.08	48.87	21.06
TA	136	87	123-133	2Bt2	290	SW	NW	NW	16	30N	1W	7.5YR4/4	7.5YR5/6	69	21	10	36	33	0.88	1.20E-03	l	Withee	48.45	35.26	16.29
TA	139	87	151-161	2Bt3	290	SW	NW	NW	16	30N	1W	7.5YR4/4	7.5YR5/6	69	19	12	30	39	0.80	1.29E-03	l		47.46	43.80	8.73
TA	137	87	228-238	2C	290	SW	NW	NW	16	30N	1W	7.5YR4/6	7.5YR6/6	69	20	11	37	32	0.88	1.69E-03	l		46.93	35.63	17.44

APPROVED: David M Mickelson

NAME: David M. Mickelson

DATE: 3/20/89