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STANDARD PROCEDURES FOR EVALUATION OF QUATERNARY MATERIALS IN IOWA

Edited By
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FOREWORD

An understanding of the engineering and hydrologic properties of Iowa's unconsolidated materials (soils and their parent materials) is fundamental to the success of resource management and land use programs. Standard analytical procedures must be applied to evaluate these materials so that a uniform data base is available to soil scientists, geologists and engineers that utilize the information.

Standardized analytical techniques and standardized descriptive terminology are addressed in this publication. This publication is unique because the topics presented rarely are included within a single reference. The usefulness of this publication is enhanced further by the inclusion of significant applied data.

Stanley C. Grant
State Geologist and Director
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STANDARD PROCEDURES FOR EVALUATION OF QUATERNARY MATERIALS IN IOWA

INTRODUCTION

The Quaternary or unconsolidated materials constitute a very important resource to the State of Iowa. These glacial, wind-blown, and stream-laid sediments cover approximately 97% of the land-surface in Iowa and range in thickness from a few inches to over 600 feet. These are the parent materials for the rich agricultural soils which are the backbone of Iowa's economy. They also constitute an economic resource for the aggregate, brick and tile, and construction material industries. With the widespread nature and great thickness of the Quaternary deposits they also are a major factor in most engineering works. The alluvial deposits and various kinds of buried horizons form important sources of water. Just as important as this, is the role that the various unconsolidated deposits play in influencing water movement into Iowa's important bedrock aquifers. Related to water movement and quality, is the problem of waste disposal. Most waste material in Iowa is disposed of in landfills in Quaternary glacial deposits or loess.

As our resources become more heavily used, the questions of proper resource management becomes more critical. To fully understand the nature of engineering and hydrologic properties and problems in these unconsolidated materials, and for proper understanding and management of the soils developed on these materials it is imperative that their stratigraphy be as fully understood as possible.

To meet this need the Iowa Geological Survey in cooperation with various local, state, and federal agencies and university personnel, most notably the U.S. Geological Survey, Water Resources Division, and the various members of the Iowa Cooperative Soil Survey program, and the Nebraska Conservation and Survey Division, has been conducting investigations into the stratigraphy and related applied properties of Quaternary materials. The stratigraphic relations of these materials are quite complex, and for the purposes of correlating the stratigraphy it is necessary to characterize the properties of the materials so that they may be distinguished from site to site. For the purposes of our investigations the techniques employed have had to meet two basic requirements:

1. That they are inexpensive and relatively simple (don't take too much time) <u>but</u> consistent; so that large numbers of samples can be processed;
2. That they can be used on samples from drill cuttings or cores as well as outcrop; in other words, the analyses must be usable on a small volume of material.

Many techniques have been tried and/or evaluated and discarded. The various procedures outlined here are the standard procedures that have been and continue to be employed in nearly all detailed investigations carried out by the Iowa Geological

Survey. They are presented here for evaluation by those who use the data and hopefully so that these techniques might be used by others working on Quaternary deposits in Iowa. Many other techniques have been used (for example-magnetic susceptibility analyses and multi-element chemical analyses), however, to form a common data base for evaluation it is important that standard techniques be employed with these other analyses. Hopefully, various workers can integrate their approaches so that an expanded and compatible data base emerges for all concerned with the resources of Iowa's Quaternary deposits.

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PART 1. SEMI-QUANTITATIVE ANALYSIS OF CLAY MINERALOGY

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ABSTRACT

The procedure used by the Iowa Geological Survey for the "semi-quantitative" evaluation of clay mineralogy is outlined. The technique is modified from that used by H.D. Glass of the Illinois State Geological Survey. Data is presented on our testing of the consistency of the method and on the effects of weathering on the calculations of relative percentages of clay minerals. With careful, continuous calibration of equipment very repeatable results can be obtained. Repeated analyses of the same samples over time show a standard deviation of the differences between analyses of approximately ± 3%. This is a quick method which is useful in Iowa for stratigraphic characterization of Quaternary deposits.

INTRODUCTION

Various methods of clay mineralogic analyses have proven useful in the characterization of Quaternary materials. One of the most successful and widely used techniques is the "semi-quantitative" analysis employed by Dr. Herbert D. Glass of the Illinois State Geological Survey. We thank Dr. Glass for his help in the initial phases of this project. We also thank Dr. George R. McCormick of the Department of Geology, University of Iowa for his help and assistance.

As of this writing, well over 2,000 samples have been processed by the procedures outlined below. Other reports will deal with the stratigraphic results. This report describes the technique and the results of our testing of its limits and consistency.

SEMI-QUANTITATIVE ANALYSIS OF CLAY MINERALOGY

The semi-quantitative analysis of clay mineralogy was modified from the procedure of Herbert Glass of Illinois State Geological Survey (personal communication, 1975). A dried sediment sample (about 40 grams) is soaked in a 100 ml beaker of distilled water, usually from 4 to 8 hours, until it disaggregates. This disaggregated sample is dispersed for at least 3 minutes in a Soiltest mechanical disperser with about 400 ml of distilled water in a mixing cup. A portion of suspended sample is quickly poured back into its original 100 ml beaker to remove the sand and some of the silt fraction. The sample in the 100 ml beaker is then allowed to settle for 24 hours. The clays in this beaker often flocculate. When this occurs the sample is diluted. A small amount of sodium hexametaphosphate (about as much as can be placed on the end of a toothpick) is also added to the 100 ml beaker to prevent further flocculation. The sample is stirred with a glass rod for about 30 seconds. The settling time before pipetting the less than 2 micron fraction is determined from a nomograph (Jackson, 1974). At the appropriate time, the less than 2 micron fraction is pipetted onto a precleaned petrographic slide labeled with a grease pencil on the bottom side. Enough sample is pipetted onto the slide until the writing on the bottom of the slide can not be read through the water and clay (if too much sample is placed onto the slide, the clay has a tendency to peel after drying). The clay on the slide is allowed to air dry under incandescent lights. Once the clay has dried, the slide is placed in a desiccator with ethylene glycol for at least 24 hours.

For the x-ray analysis, the slide is mounted in a General Electric XRD-5 sample holder and exposed to copper radiation of 1.5418 Angstroms with nickel filtration. The sample is scanned from 2° to 35°. The scan speed used is 2° per minute with the voltage set at 50 KVP with 15 MA. The counting function is set for a logarithmic scale which is calibrated to a range of 10,000 counts full scale. The spectrogoniometer is set up as 1) 1° medium range beam slit, 2) a medium range soller, and 3) 0.2° detector slit.

The maintenance of the 10,000 count full scale is critical for repeatable results. If the full scale is not maintained the results of the percent illite or kaolinite after the Glass method may be seriously in error. In Iowa the clay mineralogy of Pleistocene material is not diverse and with careful control it has been possible to use these techniques for stratigraphic characaterization.

The actual semi-quantitative analysis of clay mineralogy is based on determining the log counts per second (CPS) from a logarithmic baseline curve drawn on the x-ray diffractogram (figure 1). The CPS are taken from the expandable clay or smectite peak (glycolated--5.2° 2θ, 17Å) the illite peak (8.8° 2θ, 10Å), and the kaolinite + chlorite peak (12.4° 2θ, 7.1Å). Using these counts, the relative percentages are calculated as follows:

1. E (expandables) = CPS from baseline to top of peak at 5.2° 2θ (glycolated sample).
2. I (illite) = 3 times CPS from baseline to top of peak at 8.8° 2θ.
3. K (kaolinite + chlorite) = 2 times CPS from baseline to top of peak at 12.4° 2θ.
4. T (total) = E + I + K.
5. % Expandables = (E / T) times 100.
6. % Illite = (I / T) times 100.
7. % Kaolinite + Chlorite = (K / T) times 100.

Values for calcite and dolomite are determined by simply measuring the heights in counts per second (or in mm, Lucas, 1977) of the calcite peak (29.4° 2θ) and dolomite peak (30.9° 2θ) from a linear baseline (fig. 1). These values are recorded as counts per second (CPS) and/or as a calcite/dolomite ratio. The calcite/dolomite ratio is calculated by using the values in CPS or in mm (Lucas, 1977), but the resultant ratio is quite similar.

Two other variables are also measured - the HSI and the DI ratio. The HSI, or heterogeneous swelling index (Frye, Glass, and Willman, 1968, p. 15), is a measure of the height of the 17Å expandable clay (smectite) peak, and can be used as an indication of weathering. The HSI is simply the vertical distance in mm

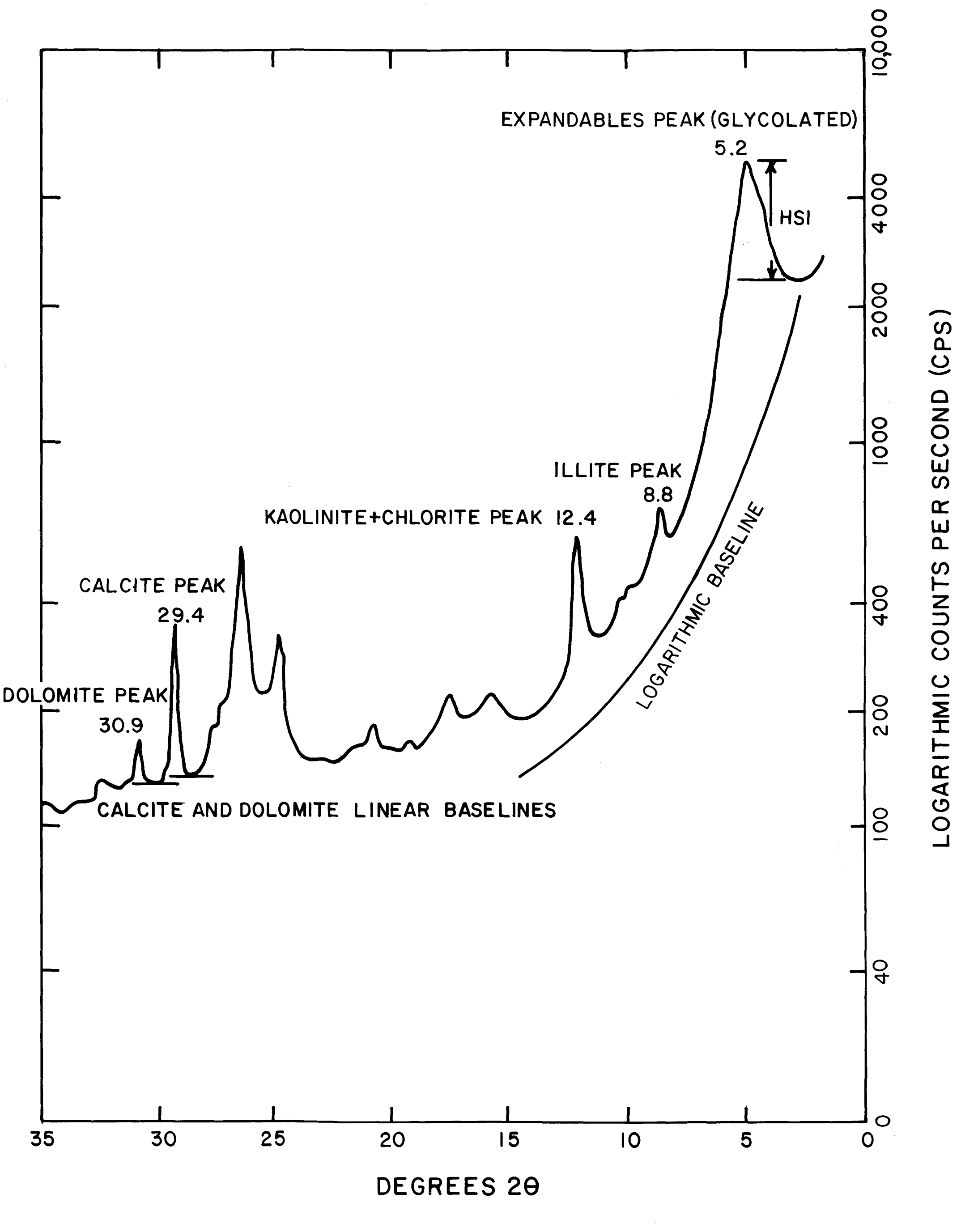

Figure 1. Typical x-ray diffraction trace showing example of baselines used to determine CPS.

from the commencement of this peak to its maximum height (see figure 1). The D.I. ratio, or the diffraction intensity ratio (Frye, Glass, and Willman, 1962) is derived by dividing the x-ray diffraction intensity, in counts per second, (CPS) of the 10Å Illite peak by the CPS of the 7.2Å peak for kaolinite and chlorite. The D.I. ratio may also be used as a measure of weathering (Willman, Glass, and Frye, 1966; Ruhe and Fenton, 1969). The effects of weathering will be discussed in a later section.

EVALUATION AND TESTING

There will justifiably be some skepticism about the validity of the percentages calculated by this method. There is no claim that this method represents a precise measure of the relative percentages of the clay minerals present. The method does represent a relatively rapid and inexpensive method that provides consistent percentages which can be used as a tool for stratigraphic analysis as well as a relative measure of the clay mineralogy. The method has been tried and proven for these purposes in Illinois (Frye, Glass, and Willman, 1963; 1966). Over 2,000 samples have now been processed in Iowa with excellent results.

Much additional testing of the consistency and repeatability of the method has been performed by the authors. Duplicates of the same sample (or in some instances three or four splits of the same sample) were prepared and results compared. For 52 paired samples the standard deviation of the differences between samples was only (sd) = ± 0.76%, for the smectite values.

Further sample testing is continually done by repeatedly analyzing standard samples before and after adjustments and recalibrations of the x-ray equipment itself. For 89 repeated samples over a two year period the standard deviation of the differences between samples was (sd) = ± 3.35%, for the smectite values.

Checks on the consistency and repeatability between operators were also conducted. The drawing of the logarithmic baseline is interpretive and it was not known how much variance might be caused by different operators. For 61 samples calculated by 5 different operators the standard deviation of the differences between samples was (sd) = ± 3.04% for the percentage values of the smectite. This is essentially the same deviation that was found with analyses over time for identical samples. The logarithmic scale minimizes much of the operator variances.

With careful control on the calibration of the equipment it is possible to maintain an expected sample standard deviation of 3 to 3.5%. This can be compared with data from actual stratigraphic sections. Table 1 shows the data from a stratigraphic section of two distinct, unleached, superimposed till deposits. Table 2 shows the data from Wisconsin loess deposits in western Iowa. The data from these multiple samples of actual stratigraphic units show essentially the same magnitude of variation, with a maximum standard deviation of 3.2%. If sample variance can be held within these kinds of limits, the data can certainly be used for site to site stratigraphic characterization and evaluation.

Table 1. Clay mineralogy data for two tills from northeast Iowa.

Strat. Unit	Depth (feet)	Ex.	Ill.	K.&C.			D.	C.
			%		H.S.I.	D.I.	C.P.S.	
Upper Till	61	68	15	17	27	0.61	-	130
	64	66	16	18	26	0.58	-	170
	68	65	16	20	23	0.52	20	120
	72	65	16	19	23	0.54	25	140
	75	63	15	22	27	0.47	-	150
	80.5	61	17	22	24	0.52	-	140
	82	66	16	18	26	0.57	30	80
	mean	64.9	15.9	19.4				
	(s.d.)	2.3	0.7	2.0				
Lower Till	92	46	26	28	14	0.62	-	190
	93	49	22	29	12	0.53	-	200
	93.5	42	28	30	15	0.63	30	220
	94	42	20	32	14	0.42	50	280
	98	46	22	32	17	0.47	30	190
	115	46	22	32	17	0.45	30	120
	117	54	18	28	15	0.42	40	250
	120	50	18	32	17	0.38	50	250
	135	46	22	32	15	0.46	30	190
	140	48	19	33	16	0.38	40	300
	142	49	18	33	17	0.36	50	300
	144	47	19	34	17	0.36	50	300
	145	49	19	32	16	0.39	50	300
	mean	47.2	21.0	31.3				
	(s.d.)	3.2	3.1	1.9				

Table 2. Clay mineralogy for Wisconsin loess site; western Iowa.

Strat. Unit	Depth (inches)	Ex.	Ill. %	K.&C.	H.S.I.	D.I.	D. C.P.S.	C.
Wisconsin Loess	0- 4	76	18	6	25	1.94	-	-
	4- 8	75	18	7	26	1.68	-	-
	8-12	75	18	7	25	1.74	-	-
	12-16	77	16	7	30	1.56	-	20
	16-22	75	19	6	27	2.19	20	-
	22-28	77	16	7	29	1.60	-	-
	35-40	79	15	6	31	1.63	T	T
	40-48	79	14	7	29	1.74	T	20
	56-61	80	14	6	28	1.58	30	30
	71-78	77	15	8	29	1.63	20	T
	85-91	80	15	5	30	2.0	20	50
	Mean	77.3	16.2	6.5				
	(s.d.)	2.0	1.8	0.8				

EFFECTS OF WEATHERING

Most clay minerals are altered by the effects of soil development and weathering. If not understood these alterations can lead to erroneous calculations by the methods here discussed. The nature of these changes on glycolated samples has been investigated and evaluated (Frye, Glass, and Wilman, 1968; Willman, Glass and Frye, 1966), and only the effects pertinent to the calculations of the clay mineral percentages and ratios will be presented.

One of the most apparent effects of weathering on the x-ray diffraction curves is the broadening and rounding of the 17Å expandable clay peak. The peak may become broad and diffuse, because of poor crystallinity - usually in the presence of organic matter or by decreased particle size. The result of this effect on swelling clays has been called heterogeneous swelling material (Willman, Frye, and Glass, 1966). When this "material" is present the calculation of the percentages of clay minerals gives misleading results. As the 17Å peak broadens, with the greater development of this "heterogeneous swelling material," it decreases in height also. This decrease in peak height or intensity (in CPS) produces an apparent decrease in the expandable clays in the percentage calculations, with a concomitant rise in the values of the other clay minerals.

To evaluate these effects Frye, Glass, and Willman (1968) have used the heterogeneous swelling index (H.S.I.) which as defined earlier, is simply a measure of the 17Å smectite peak height. In soil profiles of uniform parent material the smaller the H.S.I., the broader the first order expandable clay peak, and presumably the greater the development of the "heterogeneous swelling material."

These changes can be seen in the x-ray diffraction curves of soil profiles shown in figures 2 and 3. The H.S.I. goes from very low values in the A horizon and increases regularly with depth through the B and into the C horizons. In the Otley silty clay loam (fig. 2) for example, the H.S.I. goes from 0 in the Ap, to 3.0 in the A3, to 14.0 in the B22, 23.0 in the B32 and finally to a relatively stable value of 27.0 in the oxidized and leached upper C horizon.

According to Frye, Glass, and Willman (1968, p. 16): "Diffraction curves that show a decrease in H.S.I. upward through a soil profile should not be used in calculation of clay mineral percentages. The index is significant only in relation to a series of samples in a single profile as a relative estimate of the degree of weathering."

The D.I. (diffraction intensity) ratio can also be used as a relative estimate of alteration. Assuming that kaolinite is generally unaltered, differences in the ratio indicate changes in the proportions of illite and chlorite. An increase in the D.I. ratio upward in the weathering profile indicates the alteration of chlorite -- marked by a decrease in intensity of the 7.2Å peak. Where alteration of illite occurs, as shown by a decrease in intensity of the 10Å reflection, the D.I. ratio will decrease in value.

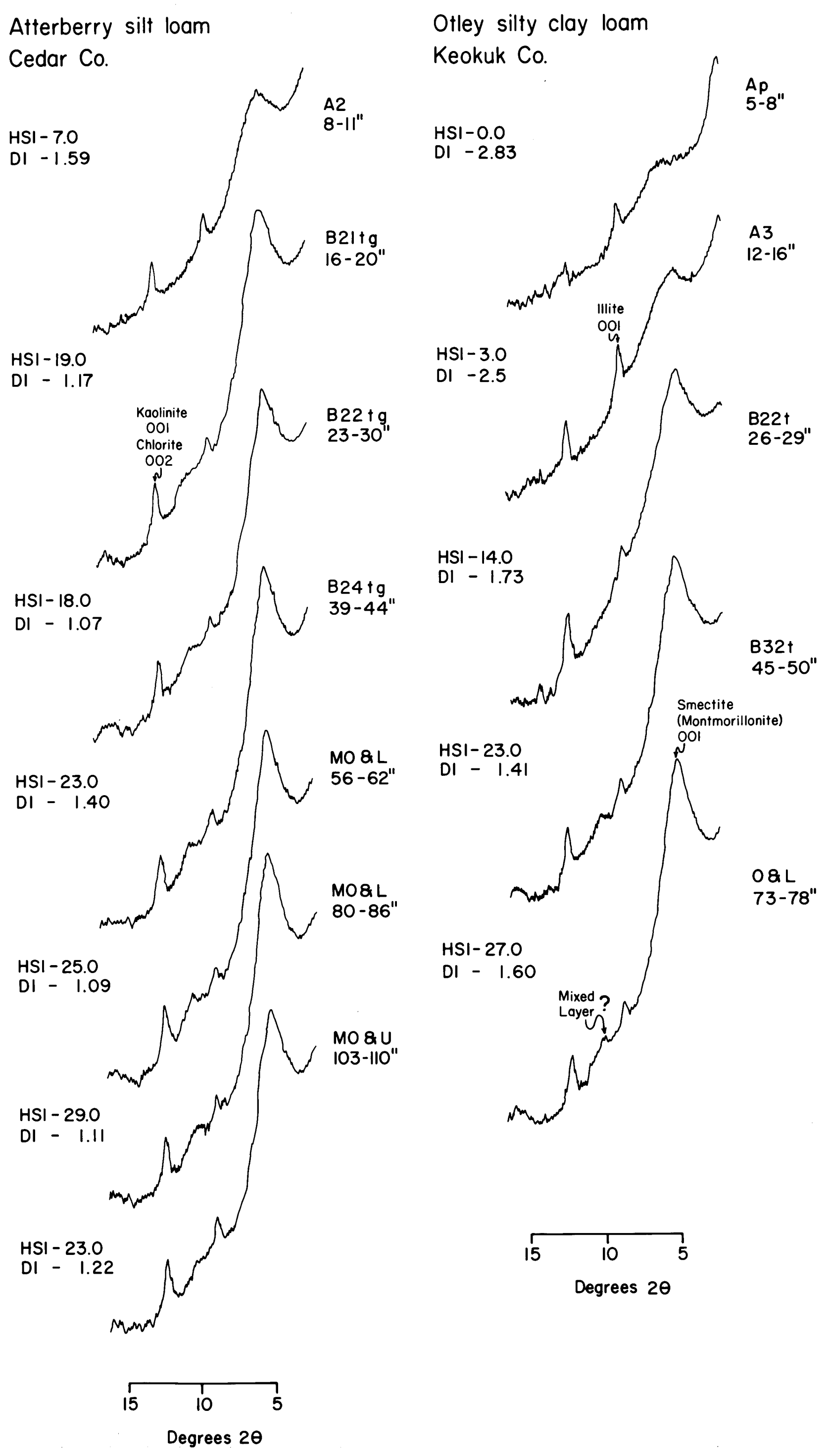

Figure 2. X-ray diffraction traces for two loess-derived soil profiles.

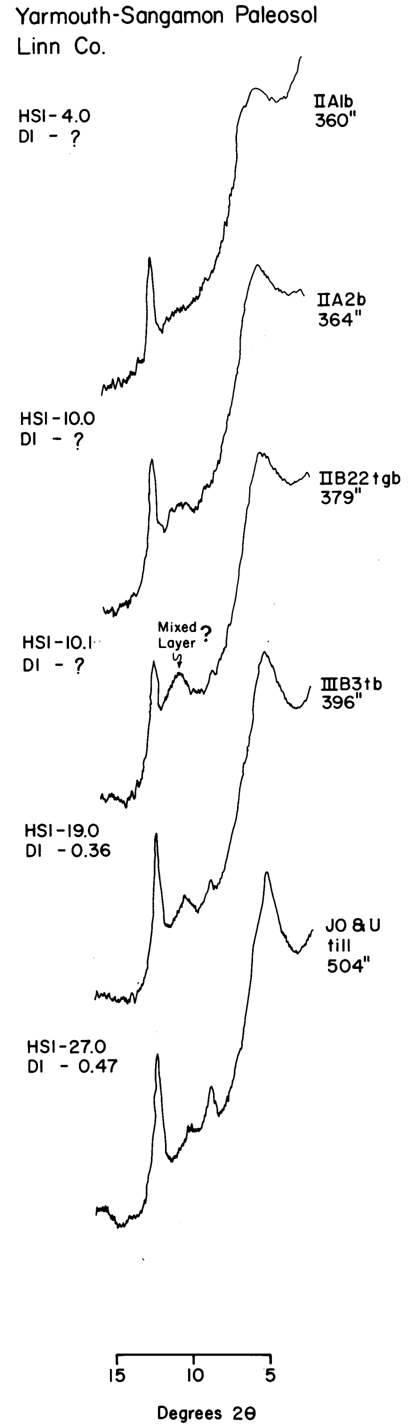

Figure 3. X-ray diffraction traces from a Yarmouth-Sangamon Soil and subjacent till.

Studies of modern surface soils in Iowa have only shown this upward increase in D.I. ratio, presumably because little or no illite is altered. Again, the data on figure 2 shows that the D.I. begins with relatively high values in the A horizon and generally decreases through the B and C horizons. The Otley profile shows the following D.I. values: 2.83 in the Ap, 2.5 in the A3, 1.73 in the B22, 1.41 in the B32, and 1.60 in the upper oxidized and leached C horizon.

The Atterberry silt loam (fig. 2) also shows these trends, but with a little more "noise," which can be expected in the range of natural materials. Some of the variations in the H.S.I. and D.I. which occur in the Atterberry profile in the B horizon and into the mottled-oxidized and leached loess below are included to show that some minor alteration occurs below the solum proper. Often these minor alterations result in a slight increase in the expandable clay percentages in the upper portion of the leached zone versus lower in the profile or especially compared to the unleached material. Table 3 shows the calculated percentages to depth from the Atterberry site, as an example. The percentage values for the solum are shown in parentheses and would not normally be calculated.

On the well-developed pre-Wisconsin age paleosols in Iowa, the weathering and alteration of clay minerals has been more intense than in the surface soils. Unlike the surface soils all of the paleosols investigated show an upward decrease in the D.I. ratio. This indicates the alteration of illite.

Table 3. Clay mineralogy data for an Atterberry silt loam and Wisconsin loess, from Cedar County, Iowa (16 M 15).

Horizon or Zone	Depth (inches)	Ex.	Ill.	K.&C.	H.S.I.	D.I.	D.	C.
			%				C.P.S.	
A2	8- 11	(42)	(41)	(17)	7.0	1.59	-	-
B21tg	16- 20	(75)	(16)	(9)	19	1.17	-	-
B22tg	23- 30	(75)	(15)	(10)	18	1.07	-	-
B24tg	39- 44	(79)	(15)	(6)	23	1.40	-	-
MO & L	56- 62	77	14	9	25	1.09	-	-
MO & L	80- 86	79	13	8	29	1.11	-	-
MO & U	103-110	72	18	10	23	1.22	60	T
D & U	121-127	70	21	9	28	1.56	50	30
O & U	127-133	64	24	12	26	1.38	40	30
O & U	139-147	69	21	10	28	1.45	40	30
D & U	161-167	63	25	12	22	1.45	50	20
U & U	181-185	69	18	13	24	1.08	40	40
U & U	200-206	68	18	14	18	0.90	T	T
U & U	236-241	66	21	13	18	1.13	30	T

Figure 3 shows data from a Yarmouth-Sangamon paleosol (Ruhe, 1967) in Linn County. In the A and upper B horizons of this buried soil this alteration apparently is severe enough that an illite peak is hardly recognizable. Consequently, no D.I. ratio is calculable by these methods. In place of an illite peak is a broad mixed-layer peak between the 7.2Å and 10Å spacings. As the illite peak appears in the lower B horizon, it increases in intensity down into the unleached till below; the D.I. ratio increases systematically with this as well. The mixed-layer peak decreases in intensity simultaneously as the illite increases.

Leached samples often show slightly higher values for expandable clays, but in general the percentages are reasonably representative of the stratigraphic unit. For stratigraphic characterization the unleached materials must be used for consistent and uncomplicated results. Also, the values for dolomite and calcite in the clay fraction are quite useful for characterization and correlation purposes.

NEW METHODS

Although these methods have been consistent and successful for the authors' purposes, the antiquity of the equipment being used necessitates developing a correlatable technique with new equipment. Currently, research is underway to develop a technique for semi-quantitative analyses of clay mineralogy on an automated Philips APD 3501. These techniques are also being adapted for use in Cretaceous deposits in Iowa.

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PART 2. LITHOLOGIC ANALYSIS OF THE 1-2mm SAND FRACTION

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ABSTRACT

Procedures used by the Iowa Geological Survey for the analysis of the lithology of the coarse (1-2 mm) sand fraction are outlined. The data from nearly 1,000 samples in Iowa has shown this to be a useful tool for identification of Quaternary stratigraphic units. Different lithologic parameters appear to be important in different regions of Iowa.

INTRODUCTION

In addition to clay mineralogic analyses, the bulk mineralogy and lithology of the coarse sand (1-2mm) fraction is also a standard analysis used by the Iowa Geological Survey. The 1-2mm sand grains are identified and counted from sieved samples using a binocular microscope. The lithology of the sand fraction has been found to be useful in discriminating different till sheets (Anderson, 1957; Van Zant, 1974), and these counts appear to be more consistent than pebble counts (Anderson, 1957, p. 1431).

PROCEDURE

The 1-2mm sand fraction is separated from the bulk till sample by completely drying 150-200 grams of till, and then allowing this sample to slake or disaggregate by soaking in water in a beaker for about 12-24 hours. In some cases a mechanical disperser and a small amount of sodium hexametaphosphate must be used to disaggregate the till. If possibile this is avoided, because of the possibility of breaking up shale particles. (However, testing of comparative samples of high-shale content tills has not shown any significant differences in the resultant percentages.) If the sample is not completely dried prior to soaking, the till will not slake and nearly always will require some mechanical dispersion.

After disaggregation the sample is wet sieved through standard number 10 and number 18 sieves, and the separated 1-2mm sand fraction is dried in an oven. The sand sample is then split in half and one half is stained in a watch glass with a solution of 0.1 gram alizarine red dye dissolved in a 0.2% mixture of hydrochloric acid for about 1 minute. This procedure is adapted from Dickson (1966), but because the stain can be poured off the sand grains and reused, the time necessary for staining will vary because of slight changes in strength of the acid.

Carbonate rock fragments in the sand fraction turn red, pink, and even violet when stained by this solution. Accordingto Dickson (1966) this staining procedure does not effect dolomite in whole rock samples. However, when staining sand grains that have been glacially abraded and etched by weathering, the dolomite grains react along surficial scratches and pits and take on a small amount of stain and a light shade of red, pink, or violet. X-ray analysis confirmed that the grains were primarily dolomite.

The stain is poured off, and the sample is allowed to dry. The stained sample is then split again to obtain a sample of about 100-150 grains for counting. Counts of this sample size have been found sufficient to provide representative and consistent results (Anderson, 1957).

The sand fragments are identified under a binocular microscope and tabulated using a laboratory counter. Grains are identified as well as possible and tabulated into the following groups:

1. Sedimentary grains:
    a. carbonates
        1. limestone
        2. dolomite
    b. shale
    c. chert - including notes on the color
    d. other - including notes on the lithology, e.g.-coal, sandstone, etc.
2. Quartz-feldspar
3. Igneous and metamorphic grains:
    a. basic
    b. acidic
    c. metamorphic
    d. or simply subdivide into light and dark.
4. Other: pyrite, "graywacke," etc.
5. Unidentified

Carbonate fragments were determined quickly by their color after staining with alizarine red S solution. To subdivide them into "limestone" and "dolomite" the carbonate grains were pushed into 50% (6m) hydrochloric acid. If the grain effervesced rapidly, it was labeled "limestone"; if the grain only evolved a small train of bubbles it was identified as "dolomite." The shale was identified by its physical characteristics. It was soft, usually tabular in shape, and usually gray or green in color.

Percentages of individual categories of lithologies are calculated as well as values for total sedimentary and total crystalline rocks (igneous and metamorphic rocks plus quartz-feldspar). The "other" category is lumped with the appropriate group totals. Unidentified grains, as well as iron and manganese concretions, and secondary carbonates are tabulated but are excluded from the 100-150 grain total for calculations. Limestone and dolomite are usually expressed only as a limestone/dolomite ratio (L/D).

When these total identifications are made the data can be manipulated in various ways depending on what data is significant. In various parts of the state different factors become important. From the analysis of nearly 1,000 samples of various tills in Iowa certain trends are apparent.

In northeast Iowa the most important factors are the L/D ratio, total carbonate, and total sedimentary values. For southeast Iowa these values are also important, as is the presence of small amounts of coal and black shales. In southwest Iowa only the total carbonate and total sedimentary percentages (vs. total crystalline types) are important. In north-central and northwest Iowa total carbonate, shale and other (essentially total crystalline types) are important (Van Zant, 1973, 1974; Lucas, 1977). Figure 1 shows the discrimination of 2 tills in northwest Iowa, based on sand fraction data.

PROBLEMS AND CONSISTENCY

Sand grain identifications can be readily made. The major problem in the past has been distinguishing the carbonates (Anderson, 1957), but the staining procedures used here eliminate this difficulty. Sample splits have been counted by as many as eight different people, using these methods, and the results have always been within a few percent.

There are several problems with internal consistency of data within a single stratigraphic unit from even a single locality. Often when a single sample strongly deviates from the mean values of the unit, it is because of an abnormally high value for quartz and feldspar. This may occur if a small granite pebble disintegrates into sand size components during processing.

Weathering, also may cause problems. In closely spaced samples the uppermost part of the unleached till. deposits often have lower carbonate grain contents than lower in the section. Even though the fine matrix of the till may be calcareous, there seems to be some selective or progressive leaching of the coarser particles, such as in the sand and pebble fraction (Boellstorff, 1973), in the upper part of the "unleached" zone.

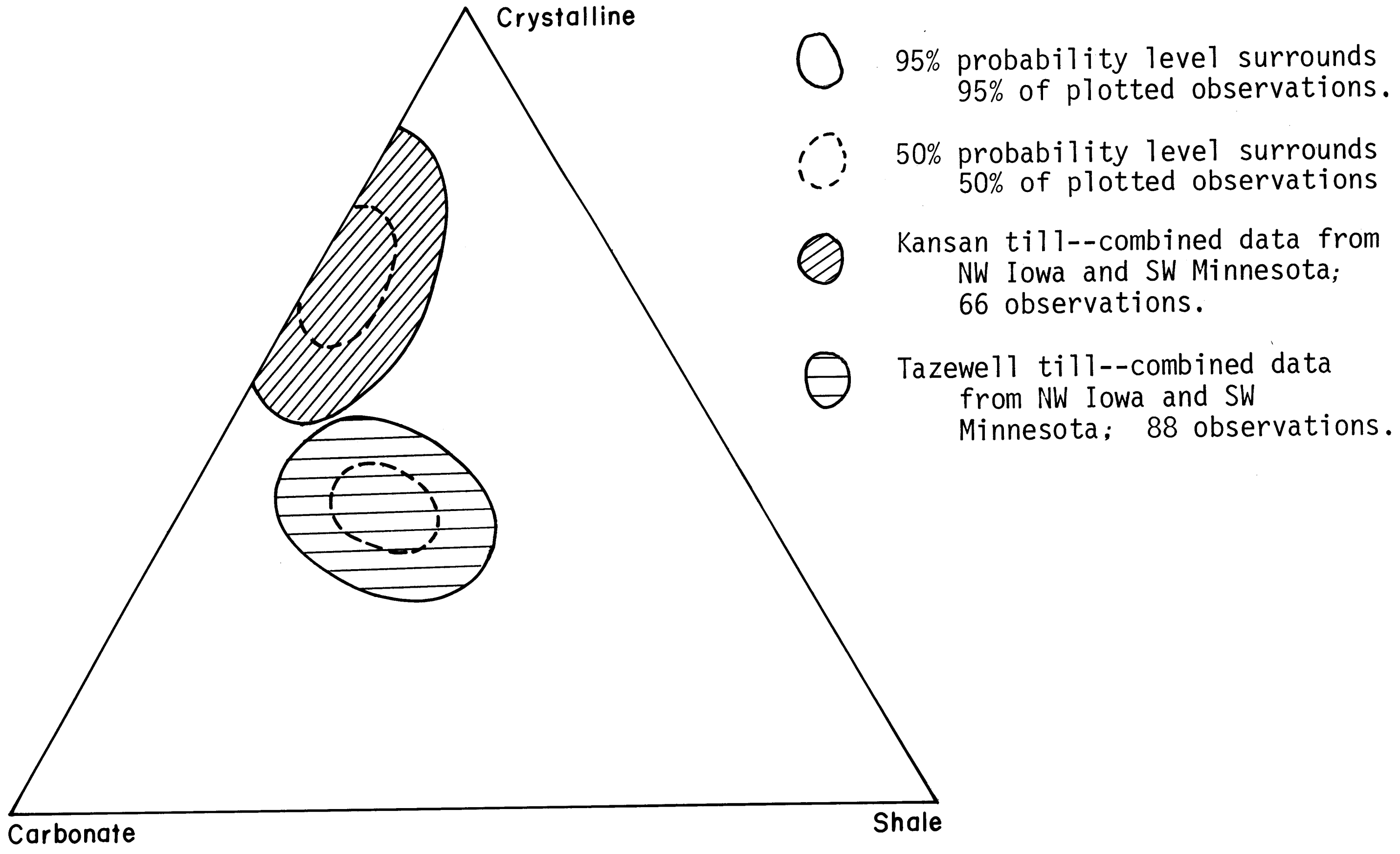

Figure 1. Probability ellipses based on sand fraction lithology data (from Lucas, 1977; Matsch, 1971; Van Zant, 1973).

Calcareous sand and gravel lenses from within a till unit often show lower values for carbonates than the surrounding till matrix, particularly in the oxidized portions of a till unit. This may be caused by the higher permeability of these coarse materials allowing more rapid water movement and possibly more leaching of carbonates to occur.

Another problem may be the incorporation of material underlying the till unit. The lowermost samples of some till units often appear to be diluted by or intermediate in character between the tills own modal characteristics and the character of the underlying material. Again, these effects are more pronounced and more common in the coarse fraction such as the sand and pebble fraction (Boellstorff, 1973) than in the clay fraction. Sampling should be as complete as possible to avoid these problems.

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PART 3. PROCEDURES FOR THE ANALYSIS OF PEBBLE LITHOLOGY, HEAVY MINERALS, LIGHT MINERALS AND MATRIX CALCITE-DOLOMITE OF TILLS[1]

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ABSTRACT

Procedures are outlined for the analysis of till pebble lithologies, heavy and light minerals in the very fine sand fraction, and matrix carbonates. Detailed analyses of several hundred till samples in Nebraska, Iowa, and South Dakota show that heavy mineral and pebble lithology data are useful tools for stratigraphic characterization and correlation. Light minerals are of little value. Only a limited number of heavy mineral species are significant, namely; hornblende, mica, garnet, epidote, and total opaques. The remaining heavy minerals can be lumped as "others," at a great savings in time, with no loss in discrimination. Statistical analyses show that linear combinations of these minerals with total sedimentary and non-sedimentary pebbles is an effective characterization and correlation tool.

SAMPLING

Samples used in the study of glacial deposits in eastern Nebraska and adjacent areas were collected by means of core drilling, hydraulic rotary drilling, auger drilling, and from surface exposures. Although normally samples were continuous in nature, usually only alternate five-foot intervals were analyzed.

The core samples were obtained using a Failing Model-750 drilling rig and a Christensen Diamond Products Company 3½" X 2 1/8" X 10 foot core barrel with split inner tube and face-discharge tungsten carbide core bit. The "up-direction" was

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[1] This research was supported in part by Grant No. DES 74-23535 from the National Science Foundation. Part of this research is from Boellstorff, 1973.

marked on each segment of core prior to wrapping in plastic and boxing for the purpose of subsequent paleomagnetic studies of the core. Most of the samples studied were obtained by coring.

Hydraulic rotary samples were also obtained using a Failing Model-750 rig and a wing bit. Hydraulic rotary drill cuttings were collected continuously during drilling and laid out in stratigraphic succession. The drilling action was stopped every five feet of penetration and all cuttings circulated out of the hole before another five-foot interval was drilled. The position of the changes in drilling action were noted while drilling each five-foot interval. These changes in drilling action are very sensitive to minor changes in lithology such as texture, compactness, and incipient cementation. The position of these changes in drilling action were compared to the description of texture, color, carbonate content, and other features.

Representative cuttings from every five-foot interval or from every change in material, whichever was less, were placed in porous bags and labeled with the test-hole number, legal description, and depth interval. In addition to these samples, pebbles were collected from the till cuttings for each interval.

At the completion of drilling each site, an electric log was made to assist in sample-log analysis.

Sampling with the auger rig followed the principles outlined for hydraulic rotary drilling except the cuttings were retrieved by ramming the auger five feet and then pulling the auger. No electric logs were made for the auger holes because a drilling fluid was not used.

Surface exposures were scraped to remove slumped material, and bulk channel samples, representing five foot intervals or every change in lithology, were taken. From each five-foot interval of till, grains larger than very coarse sand were collected. Usually, at least 100 plus 4-mm sized pebbles were obtained. If a cobble or boulder was encountered, only a chip was taken.

PEBBLE LITHOLOGY

Work currently in progress on till stratigraphy in Nebraska and Iowa indicates that pebble lithologies do not always provide clear discrimination of till units. Studies by Anderson (1957) and Horberg and Potter (1955) suggest that more consistent results might be attained if the analyses were restricted to the 0.5 to 1-inch size grade. Unfortunately, a representative sample of 0.5-1 inch-size pebbles cannot be obtained from drill-holes over a reasonably small depth increment. Therefore, it has been necessary to use the entire >4 mm pebble fraction. The variation in pebble size distribution from sample to sample may interject some noise into the pebble lithology data, but this cannot be avoided.

Procedure

Auger and rotary-drill core samples were air dried, gently crushed, and grains larger than very coarse sand were removed. These pebbles, as well as those collected in the field from surface outcrops and hydraulic rotary cuttings were soaked in a 0.01 N sodium oxalate solution to disperse adhering clay and silt, then wet sieved over the #5 sieve (4 mm). Care was taken at this stage to remove the >4 mm pebbles, such as shale or deeply weathered "granitic" rocks which were fragile. The >4 mm pebbles were then dried and identified with the aid of a binocular microscope. Limestone and dolomite were differentiated by acid reaction and, when necessary, other pebbles were broken to examine fresh surfaces.

The pebbles were placed into classes as shown in Table 1. In part, these classes are arbitrary. For example, pebbles consisting predominantly of quartz and containing a trace or more of mafic minerals were classified as "metamorphic other;" and pebbles consisting predominantly of quartz and containing minor amounts of feldspar were classified as "plutonic." Also, many of the pebbles classified as "granite" are probably of metamorphic origin.

Although the classification scheme may be somewhat arbitrary, it is of little consequence for the purpose of differentiating the tills. The main requirement of the classification is that pebbles be identified in a consistent manner from sample to sample. To check the consistency of identifications, most of the pebble samples were recounted by other geologists. In nearly all cases, the results agreed within a few percent--especially with respect to the major categories.

Results

Numerous graphs showing the relationships between individual pebble classes and combinations of classes were made. As shown in figure 1 this trial and error method of analysis indicates

Table 1. Pebble composition from the tills at City Wide Rock Quarry, Section 1.

		PORTION	PEBBLE COMPOSITION																						
			SEDIMENTARY PEBBLES												METAMORPHIC PEBBLES					"PLUTONIC" PEBBLES					
			Limestone	Dolomite	Calcareous Siltstone	Calcareous Sandstone	Shale	Noncalcareous Siltstone	Noncalcareous Sandstone	Ferrugenous Siltstone	Quartz	Chert	Other	Total Sedimentary	Quartzite	Greenstone	Metawacke	Other	Total Metamorphic	"Granite"	Diorite	Qtz-feldspar	Feldspar	Other	Total "Plutonic"
CITY WIDE ROCK QUARRY - SECTION 1	Upper till	Upper	34.6	0.4	1.1	0.0	0.0	3.7	0.7	0.7	5.9	5.1	0.0	58.2	9.2	2.6	12.1	9.6	33.5	10.7	1.1	1.1	0.4	1.1	14.3
		Middle	33.1	2.3	3.1	1.2	0.6	0.6	1.0	0.4	6.2	5.0	0.0	53.3	10.7	5.0	11.5	5.4	32.6	12.6	0.6	0.4	0.0	0.6	14.2
		Lower	37.3	1.8	3.6	0.9	0.0	0.0	0.9	7.3	4.5	3.6	0.0	60.0	6.4	8.2	9.1	2.7	26.4	10.9	0.9	0.9	0.9	0.0	13.6
			35.0 ±2.2	1.5 ±1.0	2.6 ±1.3	0.7 ±.6	0.2 ±.4	1.4 ±2.0	0.9 ±.2	2.8 ±3.9	5.5 ±.9	4.6 ±.8	0.0 ±.0	55.2 ±4.2	8.8 ±2.2	5.3 ±2.8	10.9 ±1.6	5.9 ±3.5	30.8 ±3.9	11.4 ±1.0	0.9 ±.3	0.8 ±.4	0.4 ±.5	0.6 ±.6	14.0 ±.4
	Middle till	Upper	38.2	4.8	2.9	0.3	0.0	0.3	1.5	4.9	5.0	6.1	0.6	66.2	4.2	2.0	10.1	4.3	20.5	13.6	0.3	0.3	0.6	0.3	15.3
		Middle	45.1	2.9	2.9	1.0	0.0	2.5	0.5	2.0	7.4	3.9	0.0	68.1	1.0	0.5	6.9	10.3	18.6	8.8	0.5	1.5	1.5	1.0	13.2
		Lower	45.1	2.9	2.9	1.0	0.0	2.5	0.5	2.0	7.4	3.9	0.0	68.1	1.0	0.5	6.9	10.3	18.6	8.8	0.5	1.5	1.5	1.0	13.2
			41.7 ±4.9	3.8 ±1.3	2.9 ±.0	0.7 ±.5	0.0 ±.0	1.4 ±1.6	1.0 ±.5	3.5 ±2.1	6.2 ±1.7	5.0 ±1.5	0.3 ±.4	66.2 ±2.8	2.6 ±2.2	1.3 ±1.1	8.5 ±2.3	7.3 ±4.2	19.5 ±1.3	11.2 ±3.4	0.4 ±.1	0.9 ±.9	1.1 ±.6	0.7 ±.5	14.2 ±1.5
	Lower till	Upper	44.3	0.0	3.3	0.0	0.0	1.8	8.2	11.6	4.8	15.7	1.4	91.1	1.9	0.0	2.9	1.0	5.7	1.4	0.0	0.5	1.4	0.0	3.2
		Middle	47.6	0.0	4.8	0.0	0.0	4.8	9.5	11.9	4.8	9.5	0.0	92.9	2.4	0.0	0.0	0.0	2.4	4.8	0.0	0.0	0.0	0.0	4.8
		Lower	59.0	0.0	4.2	0.0	0.0	2.8	2.9	6.8	6.1	14.1	0.0	95.6	0.0	0.5	0.0	0.0	0.5	3.9	0.0	0.0	0.0	0.0	3.9
			50.3 ±7.7	0.0 ±.0	4.1 ±.8	0.0 ±.0	0.0 ±.0	3.1 ±1.5	6.9 ±3.5	10.1 ±2.9	5.2 ±.7	13.1 ±3.2	0.5 ±.8	93.2 ±2.3	1.4 ±1.3	0.2 ±.3	1.0 ±1.6	0.3 ±.6	2.9 ±2.7	3.4 ±1.8	0.0 ±.0	0.2 ±.3	0.5 ±.8	0.0 ±.0	4.0 ±.8
BUTLER COUNTY ASH SITE	Upper till	Upper	29.2	0.0	0.0	0.0	0.0	12.5	0.0	4.2	4.2	0.0	0.0	50.0	0.0	4.2	20.8	8.3	33.3	16.7	0.0	0.0	0.0	0.0	16.7
		Middle	39.6	0.0	0.0	0.0	0.0	9.9	0.0	4.4	5.3	1.7	0.0	60.8	1.0	5.5	14.3	1.9	22.6	11.5	0.0	1.8	0.9	2.7	16.7
		Lower	39.7	0.0	1.0	0.0	0.0	3.8	0.9	1.8	1.9	1.9	0.0	50.9	0.0	4.6	15.9	5.6	26.2	18.4	0.0	4.5	0.0	0.0	22.9
			36.1 ±6.0	0.0 ±.0	0.3 ±.6	0.0 ±.0	0.0 ±.0	8.7 ±4.5	0.3 ±.5	3.5 ±1.5	3.8 ±1.7	1.2 ±1.0	0.0 ±.0	53.9 ±6.0	0.3 ±.6	4.8 ±.7	17.0 ±3.4	5.3 ±3.2	27.3 ±5.5	15.5 ±3.6	0.0 ±.0	2.1 ±2.3	0.3 ±.5	0.9 1.6	18.8 ±3.6
	Lower till	Upper	40.4	8.1	3.0	0.0	1.5	2.1	1.5	1.0	1.0	1.0	0.0	59.5	5.0	4.5	11.0	2.5	23.0	17.6	0.0	0.0	0.0	0.0	17.6
		Middle	36.2	19.3	0.0	0.0	8.5	2.9	1.0	0.0	0.9	4.6	1.0	74.5	1.9	0.0	7.7	0.9	10.6	11.3	1.9	0.9	0.0	0.9	15.0
		Lower	43.0	10.9	0.0	0.0	2.6	0.7	0.0	0.0	5.1	2.6	0.0	64.6	0.0	5.1	3.8	4.4	13.3	22.2	0.0	0.0	0.0	0.0	22.2
			39.9 ±3.4	12.7 ±5.9	1.0 ±1.7	0.0 ±.0	4.2 ±3.8	1.9 ±1.2	0.8 ±.7	0.3 ±.6	2.3 ±2.4	2.7 ±1.8	0.3 ±.6	66.2 ±7.7	2.3 ±2.5	3.2 ±2.8	7.5 ±3.6	2.6 ±1.8	15.6 ±6.5	17.0 ±5.5	0.6 ±1.1	0.3 ±.5	0.0 ±.0	0.3 ±.5	18.2 ±3.7

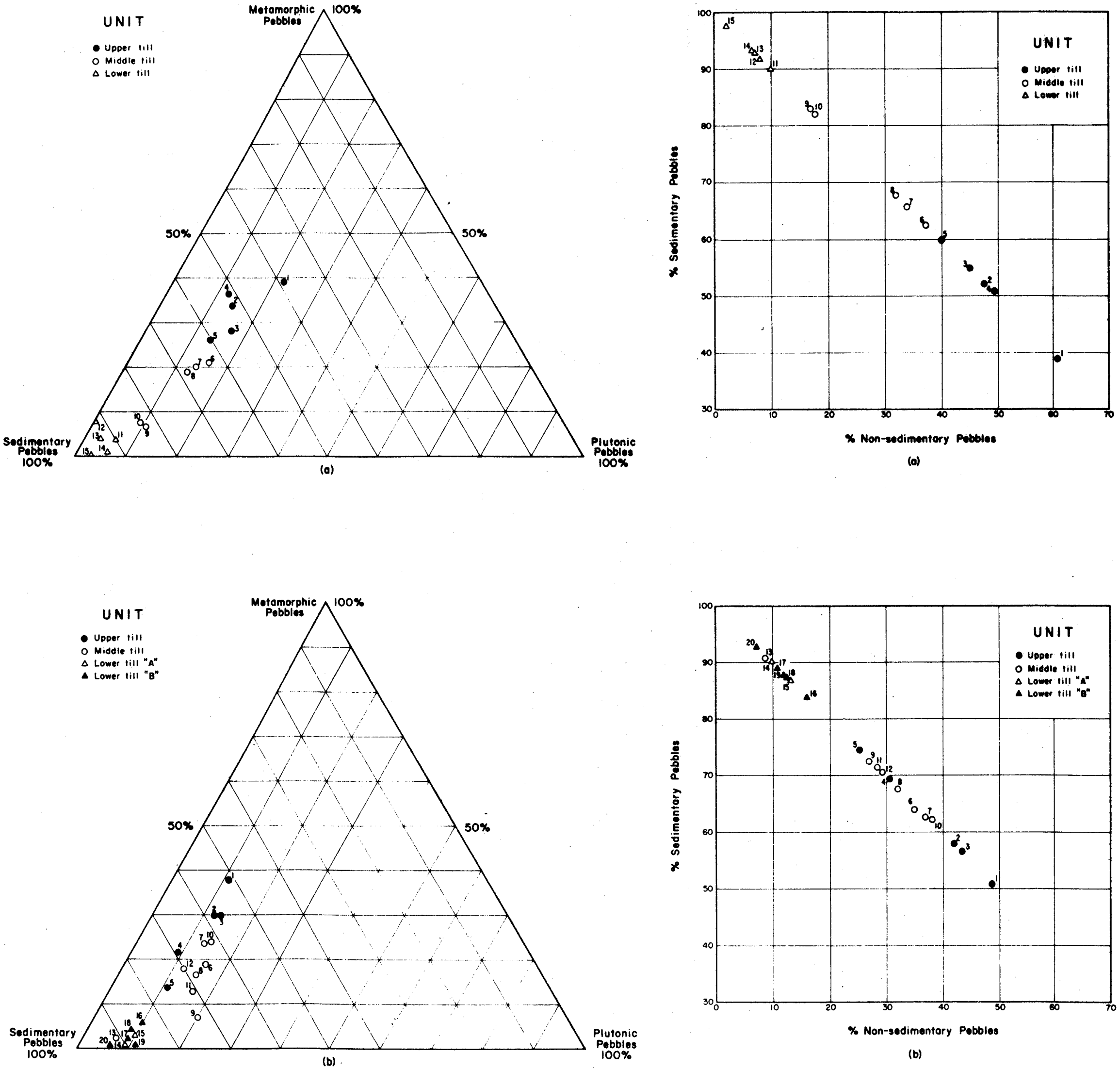

Figure 1. Relationships of sedimentary, metamorphic, and plutonic pebbles from the tills at City Wide Rock Quarry. (a) Section 1, (b) Section 2. The samples are numbered consecutively from top to bottom of the section.

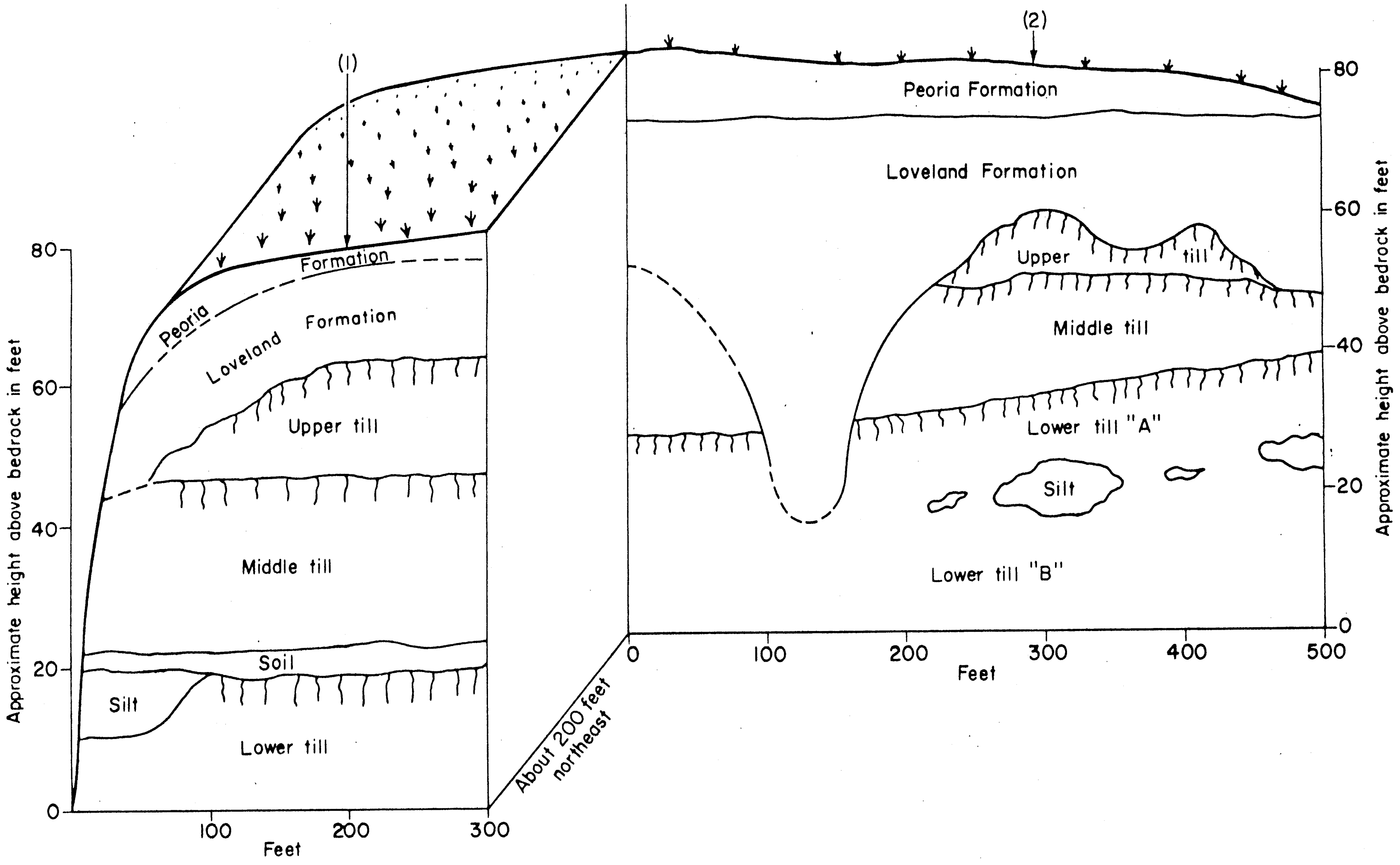

Figure 2. Diagram of sediments exposed on a portion of the north wall of the City Wide Rock Quarry, Sarpy County, Nebraska. (1) Approximate location of measured Section 1. (2) Approximate location of measured Section 2.

relationships of sedimentary, metamorphic, and plutonic classes were useful for differentiating the tills at the City Wide Rock Quarry near Omaha, Nebraska (Fig. 2). The proportion of pebble types in basal samples, collected from within a few feet of the base of a till, is similar to the pebble composition of the underlying till (see fig. 1a, points 9 and 10 and fig. 1b, points 4, 5, and 13). Figure 1 also shows that the proportion of pebble types within each till is similar at sections 1 and 2--especially if the basal samples are disregarded. In addition, the proportion of pebble types in lower till "A" and lower till "B" at section 2 seems to be about the same. Thus, pebble composition serves to differentiate tills at the City Wide Rock Quarry, especially if the basal samples are omitted. Except for these latter samples, there is little overlap in the pebble composition of the tills.

HEAVY MINERAL ANALYSIS

Heavy minerals (specific gravity greater than 2.85) in the very fine sand fraction (0.062-0.125 mm) of glacial deposits are also being evaluated using the standard techniques outlined below.

Procedure

1. About 50 grams of each till sample are air dried and then dispersed in a 0.01N sodium oxalate solution and wet sieved over a number 230 (0.062 mm) sieve.

2. The residue on the sieve is oven dried and the 0.062-0.125 mm sand fraction removed by sieving through number 120 and 230 sieves.

3. Weigh a 1-2cc sample of the 0.062-0.125 mm sand fraction to the nearest 0.001 g. (Weighing the sample is necessary only if the percent "heavies" in the very fine sand fraction is to be determined.)

4. Place in a 50 ml beaker and etch for 20 minutes in 2N HCl; stir occasionally. This removes the carbonates.

5. Dilute with water and decant.

6. Filter and wash with Acetone to hasten drying.

7. Place the sand in a separatory funnel along with Bromoform (Sp. Gr. 2.85). Stir so that the grains are dispersed and let sit until separation is complete. It may be necessary to agitate the floating "cake" several times using a jet of Bromoform from a wash bottle.

8. Tap off heavy minerals: it is often necessary to repeat steps 7 and 8.

9. Rinse "heavies" with Acetone, and allow to dry.

10. Weigh "heavies" to nearest 0.001 g and calculate percent heavies in very fine sand fraction (optional).

11. Drain off light minerals and rinse with Acetone. Dry and save for light mineral analysis (optional).

12. Mount dried heavies on microscope slide with mounting medium such as Lakeside. Try to get even distribution of the grains. Classify 300 grains.

Three hundred grains from each sample were identified using a Leitz ortholux microscope and point count stage. Identifications were based largely on detrital mineral keys of Tickell (1947) with supplementary use of other standard mineralogical references.

Complete identification of heavy minerals was arduous because of the large number of species present. The ice that deposited the tills traveled over sedimentary, metamorphic, and igneous terrains and incorporated deeply weathered to fresh material from each. Thus, ultrastable to unstable minerals from an indeterminate number of rock types occur together in the heavy mineral suite of the tills. Therefore, mineral associations and mineral stability were of little or no aid in identification.

Results

The results of a preliminary heavy mineral study of tills exposed at the City Wide Rock Quarry are shown in Table 2 (Reed, et al., 1966). In this study as many mineral species as possible were identified. This work indicated most of the mineral species were of little value in differentiating the tills. The most diagnostic minerals were hornblende, limonite, hematite, ilmenite, leucoxene, biotite, and garnet. The total percentage of opaque mineral species seems to be as useful as the percentage of individual opaque mineral species for differentiating the tills. Therefore, to facilitate further heavy mineral studies 300 grains per sample were counted and classified as hornblende, biotite, garnet, total opaque minerals, and "others."

As shown in figure 3 the three tills shown in figure 2 are quite distinct with respect to hornblende + biotite + garnet vs. total opaque minerals vs. "others." Note that hornblende + biotite + garnet content increases vertically up the section whereas the opaque minerals content decreases.

Table 2. Results of Preliminary Heavy Mineral Study of Tills at City Wide Rock Quarry - Section 1[1]

	Sample Point[2]	Andalusite	Apatite	Basaltic Hornblende	Beryl	Biotite	Chlorite	Epidote	Garnet	Hematite	Hornblende	Hypersthene	Ilmenite + Magnetite	Kyanite	Leucoxene	Limonite	Monazite	Muscovite	Pyrite	Rutile	Sphene	Spodumene	Staurolite	Topaz	Tourmaline	Zircon	Total Opaques
Upper Till	60	4.0	1.0	0.3	0.0	4.0	0.3	20.7	4.0	3.7	27.7	1.0	8.3	1.3	4.0	11.7	2.0	1.0	0.3	0.0	1.7	0.0	0.0	0.7	1.0	1.0	28.0
	55	4.0	0.3	0.0	0.3	7.0	0.0	16.0	9.0	2.7	29.3	0.0	7.9	3.0	4.0	3.0	6.3	1.3	0.3	0.3	3.3	0.7	0.0	0.0	0.0	1.3	18.0
	49	1.7	1.0	0.0	1.7	2.0	0.3	18.6	7.3	1.0	35.0	2.0	10.3	0.3	3.0	4.4	1.3	0.0	0.7	0.0	4.7	0.7	0.3	1.0	0.7	2.0	19.4
Middle Till	41	4.0	0.7	0.0	1.3	2.7	0.0	16.3	3.0	1.3	26.0	0.3	12.0	1.0	2.7	17.7	4.3	0.3	0.3	0.7	1.7	0.0	1.0	1.0	0.3	1.3	34.0
	32	6.3	0.7	2.0	0.3	5.0	1.7	11.7	5.3	4.0	19.3	0.0	12.0	0.7	4.7	12.3	6.0	1.3	1.0	0.0	3.0	0.0	0.0	1.7	0.0	1.0	34.0
	24	2.0	0.7	0.7	0.0	2.3	0.7	17.3	8.3	5.3	18.0	0.0	16.3	0.7	4.3	13.0	1.0	0.0	1.0	0.7	3.7	0.3	0.7	1.7	0.3	1.0	39.7
Lower Till	16	1.3	0.0	1.0	0.0	1.0	0.7	10.7	6.3	8.3	7.0	1.0	7.3	0.0	8.0	39.3	0.7	1.0	1.7	0.3	3.0	0.0	0.0	0.0	0.3	1.0	64.6
	8	1.7	0.0	1.0	1.0	3.0	0.7	10.0	3.3	6.3	9.7	0.3	11.6	0.7	12.0	28.7	0.3	1.0	1.3	0.0	4.3	0.0	0.0	0.7	0.7	1.7	59.9
	2	0.0	0.3	0.0	0.7	0.7	1.3	13.0	3.7	5.7	9.0	2.0	18.3	0.0	7.7	26.3	2.0	0.0	1.3	0.7	3.7	0.3	0.0	0.0	1.0	2.3	59.3

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[1] All values are percent.
[2] Feet above bedrock.

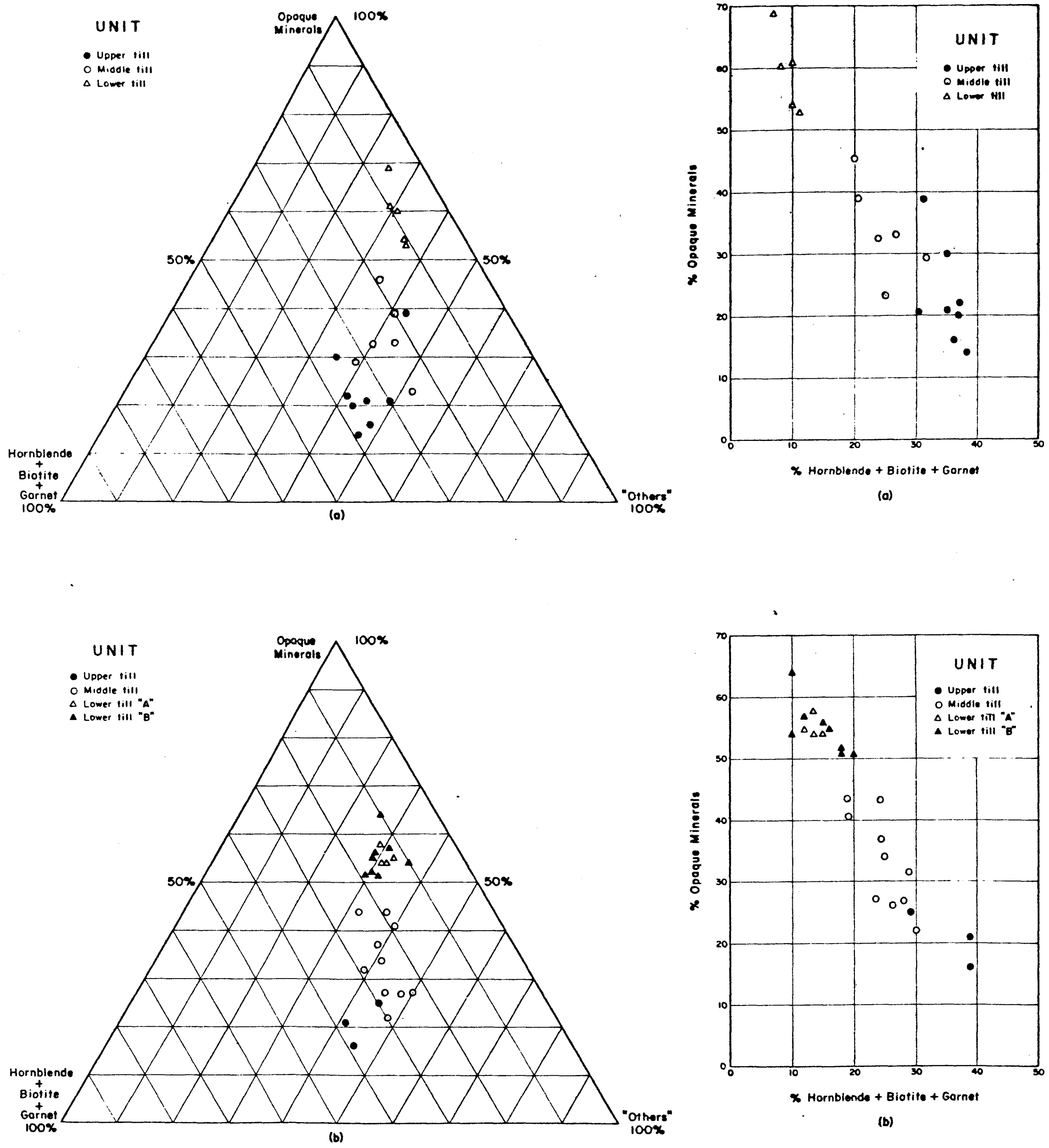

Figure 3. Relationships of selected heavy minerals from the 0.062-0.125 mm sand fraction of the tills at City Wide Rock Quarry. (a) Section 1 (b) Section 2.

A comparison of the triangular plots in figure 3 indicates there is little variation in the proportion of heavy mineral types between the two sections. Also, there does not appear to be a significant difference between lower till "A" and lower till "B" at section 2.

As shown in Table 3 the percent of heavy minerals in the very fine sand fraction is quite consistent--within a sample, within a till at a particular site, and within a till between sites.

In eastern Iowa the percentages for epidote are also valuable for till discrimination.

LIGHT MINERAL ANALYSIS

Light minerals (sp. gr. less than 2.85) in the very fine sand fraction (0.062-0.125 mm) have also been evaluated for their utility in characterizing Quaternary materials in eastern Nebraska.

The percentage, by weight, of light minerals soluble in hydrochloric acid (HCl) was determined for the very fine sand fraction (0.062-0.125 mm) of the tills from the City Wide Rock Quarry (fig. 2). The relative proportions of quartz, potash feldspar, and plagioclase feldspar in the insoluble residue are determined using standard staining and point count procedures. The staining procedure used is that presented by Reeder and McAllister (1956) and outlined below.

Procedure

(For preliminary steps to separate the light minerals, see the Heavy Mineral Procedures outlined above)

Table 3 . Miscellaneous heavy mineral data from the tills at the City Wide Rock Quarry.

City Wide Rock Quarry-Section 1			
	Sample No.	Percent Heavy Minerals[a]	Percent Magnetic Heavies[b]
Upper Till	1	2.3	3.2
	2	2.3	3.2
	3	2.2	3.2
	4	2.2	2.7
	5	2.4	3.6
	6	2.5	3.1
	7	2.2	1.9
	8	2.4	1.0
		2.3 ± .1	2.7 ± .9
Middle Till	9	3.0	0.7
	10	2.4	1.7
	11	2.2	1.0
	12	2.0	2.9
	13	2.4	2.3
	14	2.0	---
		2.3 ± .4	1.7 ± .9
Lower Till	15	1.7	2.3
	16	1.7	2.5
	17	1.4	1.6
	18	1.9	2.4
	19	1.7	2.5
		1.7 ± .2	2.3 ± .4

City Wide Rock Quarry-Section 2			
		Percent Heavy Minerals[a]	
	Sample No.	Trial 1	Trial 2
Upper Till	1	2.2	2.2
	2	2.6	2.6
	3	2.2	2.2
		2.3 ± .2	2.3 ± .2
Middle Till	4	3.1	2.8
	5	3.3	3.3
	6	3.0	3.5
	7	1.9	2.8
	8	2.8	2.6
	9	2.4	2.1
	10	2.5	2.4
	11	2.5	2.5
	12	---	3.1
	13	2.2	2.2
		2.6 ± .5	2.6 ± .5
Lower Till "A"	14	1.8	1.8
	15	2.0	2.0
	16	1.9	1.9
	17	1.7	1.4
		1.9 ± .1	1.8 ± .3
Lower Till "B"	18	1.6	1.7
	19	1.5	1.6
	20	1.5	1.5
	21	1.5	1.6
	22	1.7	1.7
	23	1.7	1.7
	24	1.7	1.9
	25	1.7	1.7
		1.6 ± .1	1.7 ± .1

a. As determined on the 0.062 - 0.125 mm sand fractions.
b. Those removeable with a hand magnet.

1. Weigh the oven-dried "light" mineral fraction of the 0.062-0.125 mm sand to the nearest 0.01 g. Place in a beaker and digest in 1:1 HCl for several hours.

2. Wash contents onto a previously dried and weighed filter paper; wash four times with hot distilled water, oven dry at 100° C for several hours, cool and reweigh.

3. Split out about ½ gram of the residue and etch in 48 percent hydrofluoric acid for about 30 seconds. Use a lead or plastic crucible.

Immediately dilute acid with distilled water and decant liquid. From this point on, the grains may be treated in a glass vessel.

4. Disperse the sample over the bottom of a beaker and soak in a concentrated solution of sodium cobaltinitrite (1 g sodium cobaltinitrite/4 ml distilled water) for one minute.

5. Wash the sample free of the solution with distilled water and decant the liquid. This will take several washings and decantations.

6. Add 10 drops of hematein solution followed by 5 drops of buffer solution to the sodium cobaltinitrite treated sample, and swirl for 2 to 3 minutes. Allow solution to remain in contact with the grains for 5 minutes.

Hematein solution - Dissolve 0.05 g of hematein in 100 ml of 95% ethanol.

Buffer solution - Dissolve 20 g of sodium acetate ($(NaC_2H_3)_2 . 3H_2O$) in 100 ml of distilled water. Add 6 ml glacial acetic acid and dilute the whole to 200 ml with distilled water. This solution is about 0.5N in acidity, and is buffered at pH 4.8.

7. Decant liquid and rinse sample with 95 percent ethanol.

8. Wash twice with acetone and dry.

9. Mount several hundred grains and count 300 using reflected light. Potash feldspar will be yellow, plagioclase feldspar will be various shades of purple with the depth of color increasing from light purple in albite to deep purple in anorthite. Quartz will remain white--usually transparent.

A similar technique has been described by Gross and Moran (1970).

Results

As shown in Table 4 the relative proportions of potash feldspar, plagioclase feldspar, and quartz in the very fine sands of the tills are not clearly diagnostic. The values for the acid soluble fraction look promising but much of the variation appears to be from weathering effects--both leaching and the accumulation of secondary carbonates. Consequently, light mineral analyses have not been continued.

MATRIX CALCITE AND DOLOMITE

The Chittick apparatus used is described by Aleksis Dreimanis in "Quantitative Gasometric Determination of Calcite and Dolomite by Using Chittick Apparatus" (Jour. Sed. Pet., v. 32, no. 3, 1962) and is illustrated in figure 4. The procedure followed is that of Dreimanis with some modifications.

Procedure

Randomly select a reference sample from the bulk air-dried sample--usually an amount to fill a sample bag 3½" x 5". Gently

Table 4. Mineralogy of the "Light" Minerals from the City Wide Rock Quarry - Section 2.

	Sample No.	Weight Percent Acid Soluble[1]	Composition of Residue[2]		
			Potash Feldspar	Plagioclose Feldspar	Quartz
Upper till	1	2.9	0.0	1.0	99.0
	2	1.9	0.3	1.7	98.0
	3	3.1	0.0	0.7	99.3
		2.6 ± .6	0.1 ± .2	1.1 ± .5	98.8 ± .7
Middle till	4	8.8	0.7	0.7	98.4
	5	9.4	0.0	0.7	99.3
	6	8.8	0.0	0.0	100.0
	7	8.7	0.0	0.7	99.3
	8	7.0	0.7	1.0	98.3
	9	7.7	1.0	0.7	98.3
	10	7.3	1.0	1.0	98.0
	11	9.4	1.7	1.3	97.0
	12	28.6	1.7	0.7	97.6
	13	18.4	0.3	0.3	99.4
		11.4 ± 6.9	0.7 ± .7	0.7 ± .3	98.6 ±.9
Lower till "A"	14	12.4	0.0	0.3	99.7
	15	9.6	0.0	0.0	100.0
	16	5.3	0.0	0.3	99.7
	17	4.8	0.0	0.3	99.7
		8.0 ± 3.6	0.0 ± .0	0.3 ± .3	99.8 ±.2
Lower till "B"	18	6.1	0.0	0.3	99.7
	19	5.5	0.0	0.0	100.0
	20	4.6	0.0	0.7	99.3
	21	3.3	0.0	0.0	100.0
	22	3.6	0.3	0.7	99.0
	23	4.9	0.0	0.0	100.0
	24	5.7	0.0	0.0	100.0
	25	4.6	0.0	1.0	99.0
		4.8 ± 1.0	0.0 ± .1	0.3 ± .4	99.6 ±.5

[1] Determined from the .062-.125 mm sand fraction.
[2] Values are percent of residue after acid treatment.

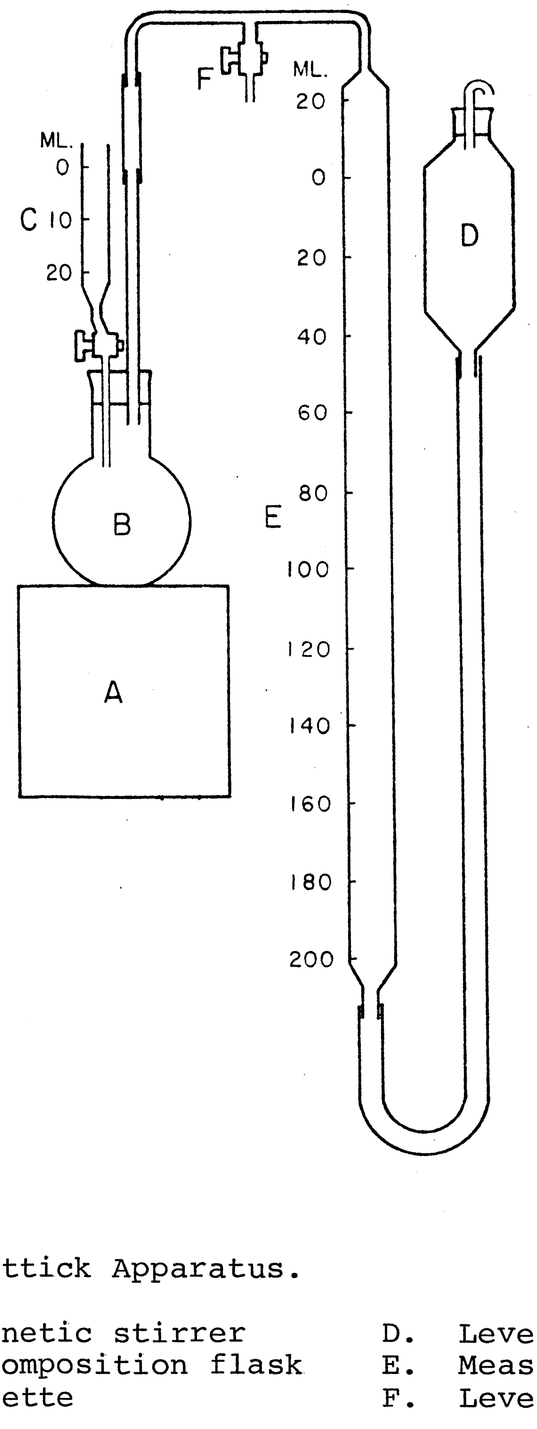

Figure 4. Chittick Apparatus.

A.	Magnetic stirrer	D.	Leveling bulb
B.	Decomposition flask	E.	Measuring burette
C.	Pipette	F.	Leveling stopcock

crush approximately 10 grams of this sample by hand and remove all granules larger than about 1.0 mm. Grind this sample in a mechanical shatter box for 5 minutes and then sieve through a U.S. Standard Sieve No. 200 (200 mesh). The minus 200 mesh fraction (<.074 mm) is used for the Chittick analysis. Two 1.700 gram samples from each interval are analyzed and the average used.

Switch on the magnetic stirrer at least 10 minutes prior to making analyses to insure temperature changes due to the heat produced by the stirrer are constant for all samples. Place 1.700 grams of the minus 200 mesh sample and a magnetic stir bar in a 250 ml decomposition flask and fit the flask onto the apparatus. Fill the pipette to zero with 6N hydrochloric acid. (Make sure no air is trapped in the pipette by the acid). Open by leveling stopcock and level the displacement fluid at 20 ml above zero on the measuring burette by sliding the leveling bulb up or down. This will compensate for the 20 ml of acid which will be added to the sample. Close the leveling stopcock to close the system and then create negative pressure by lowering the leveling bulb approximately 3 ml below the fluid level in the measuring burette. The fluid level in the measuring tube should stabilize above the leveling bulb level. If not, check for leaks in the apparatus. Open stopcock of pipette at time zero and lower the leveling bulb as the CO_2 evolves to maintain negative pressure. Close the stopcock when 20 ml of acid have drained into the decomposition flask (approx. 40 sec.). Read the amount of CO_2 evolved after one minute from time zero by quickly leveling the fluid in the leveling bulb with the fluid in the measuring burette. Then again lower the leveling bulb about 5 cm below the fluid level in the measuring burette in order to maintain negative pressure. As CO_2 is evolved, the leveling bulb will have to be lowered. Take the 20 minute reading in the same manner as the one minute reading. The temperature in the decomposition flask and the barometric pressure should be noted after the last 20 minute reading.

Both the 1 minute and 20 minute CO_2 volume readings must be corrected for room temperature and barometric pressure by applying the appropriate correction factor from Table 5 ("Correction Factors for the Gasometric Determination of Carbon Dioxide," Assoc. of Official Agricultural Chemists, 1950).

The percentages of calcite and dolomite in the sample are then determined by using three charts (figures 5, 6, and 7) based on data obtained by analyzing samples containing known percentages of calcite and dolomite using the procedure just described.

The percent dolomite can be read from figure 5 which is a plot of a known percentage of dolomite against the corrected ml of CO_2 evolved in 20 minutes minus the corrected ml CO_2 evolved in 1 minute. To find the percent dolomite subtract the corrected 1 minute reading from the corrected 20 minute reading and read the percentage of dolomite.

Table 5. Correction factors for temperature and pressure. (From, Methods of Analysis of the Association of Official Agricultural Chemists, 6th ed., 1945, Table 44.3).

Correction factors for the gasometric determination of carbon dioxide.[1]
(Based on sample weighing 1.7000 grams.)

(Multiply the number of ml of gas evolved from 1.7000 grams of sample by the factor that corresponds with existing atmospheric conditions and divide by ten to obtain percentage of carbon dioxide by weight in sample.)

°C.	15.0°	15.5°	16.0°	16.5°	17.0°	17.5°	18.0°	18.5°	
mm.									*inches*
700	0.99194	0.99006	0.98818	0.98573	0.98329	0.98082	0.97835	0.97585	27.56
702	0.99494	0.99300	0.99106	0.98862	0.98618	0.98368	0.98118	0.97868	27.64
704	0.99794	0.99544	0.99394	0.99147	0.98900	0.98653	0.98406	0.98156	27.72
706	1.00094	0.99886	0.99682	0.99435	0.99188	0.98941	0.98694	0.98406	27.80
708	1.00394	1.00183	0.99971	0.99723	0.99476	0.99226	0.98976	0.98726	27.87
710	1.00694	1.00477	1.00259	1.00012	0.99765	0.99512	0.99259	0.99009	27.95
712	1.00994	1.00767	1.00541	1.00294	1.00047	0.99795	0.99541	0.99291	28.03
714	1.01294	1.01061	1.00829	1.00582	1.00335	1.00080	1.99824	0.99576	28.11
716	1.01594	1.01356	1.01118	1.00871	1.00624	1.00368	1.00112	0.99861	28.19
718	1.01894	1.01650	1.01406	1.01156	1.00906	1.00653	1.00400	1.00150	28.27
720	1.02194	1.01949	1.01694	1.01444	1.01194	1.00941	1.00688	1.00435	28.35
722	1.02482	1.02232	1.01982	1.01732	1.01482	1.01229	1.00976	1.00720	28.43
724	1.02771	1.02521	1.02271	1.02021	1.01771	1.01518	1.01265	1.01009	28.50
726	1.03059	1.02809	1.02559	1.02306	1.02053	1.01800	1.01574	1.01291	28.58
728	1.03347	1.03097	1.02847	1.02594	1.02341	1.02088	1.01835	1.01580	28.66
730	1.03635	1.03385	1.03135	1.02882	1.02629	1.02374	1.02118	1.01862	28.74
732	1.03924	1.03674	1.03424	1.03171	1.02918	1.02662	1.02406	1.02147	28.82
734	1.04218	1.03915	1.03712	1.03459	1.03206	1.02950	1.02694	1.02435	28.90
736	1.04506	1.04253	1.04000	1.03744	1.03488	1.03232	1.02976	1.02718	28.98
738	1.04794	1.04541	1.04288	1.04037	1.03776	1.03521	1.03265	1.03006	29.06
740	1.05082	1.04829	1.04576	1.04321	1.04065	1.03806	1.03547	1.03288	29.13
742	1.05371	1.05118	1.04865	1.04609	1.04353	1.04094	1.03835	1.03577	29.21
744	1.05659	1.05403	1.05147	1.04991	1.04635	1.04377	1.04118	1.03859	29.29
746	1.05947	1.05691	1.05435	1.05180	1.04924	1.04665	1.04406	1.04147	29.37
748	1.06235	1.05929	1.05724	1.05418	1.05212	1.04953	1.04694	1.04433	29.45
750	1.06524	1.06218	1.06012	1.05748	1.05494	1.05235	1.04976	1.04715	29.53
752	1.06818	1.06512	1.06306	1.06047	1.05788	1.05527	1.05265	1.05003	29.61
754	1.07106	1.06847	1.06588	1.06330	1.06071	1.05812	1.05553	1.05289	29.69
756	1.07394	1.07135	1.06876	1.06618	1.06359	1.06197	1.05835	1.05571	29.76
758	1.07682	1.07423	1.07165	1.06906	1.06647	1.06386	1.06124	1.05859	29.84
760	1.07971	1.07712	1.07453	1.07191	1.06929	1.06668	1.06406	1.06141	29.92
762	1.08259	1.08050	1.07741	1.07480	1.07218	1.06956	1.06694	1.06430	30.00
764	1.08547	1.08288	1.08029	1.07768	1.07506	1.07244	1.06982	1.06715	30.08
766	1.08841	1.08580	1.08318	1.08056	1.07794	1.07530	1.07265	1.06997	30.16
768	1.09129	1.08868	1.08606	1.08344	1.08082	1.07818	1.07553	1.07285	30.24
770	1.09418	1.09156	1.08894	1.08630	1.08365	1.08100	1.07835	1.07567	30.31
°F	59.0°	59.9°	60.8°	61.7°	62.6°	63.5°	64.4°	65.3°	

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[1] Calculated from 1.976 = weight of 1 liter CO_2 at 0°C, 760 mm pressure and 41° latitude. Formula given by S. W. Parr, *J. Am. Chem. Soc.*, 31, 237 (1909).

Correction factors for the gasometric determination of carbon dioxide.
—Continued.

°C.	19.0°	19.5°	20.0°	20.5°	21.0°	21.5°	22.0°	22.5°	
mm.									*inches*
700	0.97335	0.97085	0.96835	0.96564	0.96294	0.96023	0.95753	0.95509	27.56
702	0.97618	0.97368	0.97118	0.96850	0.96582	0.96311	0.96041	0.95794	27.64
704	0.97906	0.97653	0.97400	0.97132	0.96865	0.96597	0.96329	0.96082	27.72
706	0.98188	0.97938	0.97688	0.97420	0.97153	0.96888	0.96624	0.96371	27.80
708	0.98476	0.98224	0.97971	0.97703	0.97435	0.97173	0.96912	0.96656	27.87
710	0.98759	0.98506	0.98253	0.97988	0.97724	0.97459	0.97195	0.96938	27.95
712	0.99041	0.98788	0.98535	0.98273	0.98012	0.97747	0.97483	0.97227	28.03
714	0.99329	0.99073	0.98818	0.98556	0.98294	0.98032	0.97771	0.97512	28.11
716	0.99612	0.99358	0.99106	0.98844	0.98582	0.98323	0.98065	0.97800	28.19
718	0.99900	0.99644	0.99388	0.99126	0.98865	0.98606	0.98348	0.98083	28.27
720	1.00182	0.99925	0.99671	0.99412	0.99153	0.98894	0.98636	0.98371	28.35
722	1.00465	1.00209	0.99953	0.99694	0.99435	0.99176	0.98918	0.98653	28.43
724	1.00753	1.00497	1.00241	0.99982	0.99724	0.99462	0.99200	0.98932	28.50
726	1.01035	1.00779	1.00524	1.00265	1.00006	1.99746	0.99483	0.99215	28.58
728	1.01324	1.01065	1.00806	1.00547	1.00288	1.00027	0.99765	0.99497	28.66
730	1.01606	1.01347	1.01088	1.00829	1.00571	1.00306	1.00041	1.99781	28.74
732	1.01888	1.01629	1.01371	1.01112	1.00853	1.00588	1.00324	1.00056	28.82
734	1.02176	1.01919	1.01659	1.01497	1.01135	1.00870	1.00606	1.00338	28.90
736	1.02459	1.02200	1.01941	1.01679	1.01418	1.01153	1.00888	1.00620	28.98
738	1.02747	1.02486	1.02224	1.01962	1.01700	1.01435	1.01171	1.00900	29.06
740	1.03029	1.02768	1.02506	1.02244	1.01982	1.01717	1.01453	1.01182	29.13
742	1.03318	1.03056	1.02794	1.02529	1.02265	1.02000	1.01735	1.01464	29.21
744	1.03600	1.03338	1.03076	1.02811	1.02547	1.02279	1.02212	1.01752	29.29
746	1.03888	1.03624	1.03359	1.03094	1.02829	1.02561	1.02294	1.02024	29.37
748	1.04171	1.03906	1.03641	1.03376	1.03112	1.02844	1.02576	1.02306	29.45
750	1.04453	1.04189	1.03924	1.03659	1.03394	1.03126	1.02859	1.02589	29.53
752	1.04741	1.04477	1.04212	1.03944	1.03676	1.03408	1.03141	1.02868	29.61
754	1.05024	1.04759	1.04494	1.04226	1.03959	1.03691	1.03424	1.03150	29.69
756	1.05306	1.05041	1.04776	1.04508	1.04241	1.03973	1.03706	1.03433	29.76
758	1.05594	1.05330	1.05065	1.04797	1.04529	1.04259	1.03988	1.03715	29.84
760	1.05876	1.05612	1.05347	1.05079	1.04812	1.04539	1.04265	1.03992	29.92
762	1.06165	1.05897	1.05629	1.05361	1.05094	1.04821	1.04547	1.04274	30.00
764	1.06447	1.06179	1.05912	1.05644	1.05376	1.05103	1.04829	1.04556	30.08
766	1.06729	1.06462	1.06194	1.05926	1.05659	1.05386	1.05112	1.04839	30.16
768	1.07018	1.06750	1.06482	1.06212	1.05941	1.05668	1.05394	1.05118	30.24
770	1.07300	1.07032	1.06765	1.06424	1.06224	1.05950	1.05676	1.05400	30.31
°F	66.2°	67.1°	68.0°	68.9°	69.8°	70.7°	71.6°	72.5°	

Table 5. con't.

Correction factors for the gasometric determination of carbon dioxide.
—Continued.

°C.	23.0°	23.5°	24.0°	24.5°	25.0°	25.5°	26.0°	26.5°	
mm.									*inches*
700	0.95265	0.95020	0.94776	0.94508	0.94241	0.93973	0.93706	0.93432	27.56
702	0.95547	0.95303	0.95059	0.94788	0.94518	0.94250	0.93982	0.93708	27.64
704	0.95835	0.95585	0.95335	0.95067	0.94800	0.94532	0.94265	0.93988	27.72
706	0.96118	0.95865	0.95612	0.95344	0.95076	0.94808	0.94541	0.94267	27.80
708	0.96400	0.96147	0.95894	0.95626	0.95359	0.95088	0.94818	0.94544	27.87
710	0.96682	0.96429	0.96176	0.95905	0.95635	0.95364	0.95094	0.94820	27.95
712	0.96971	0.96712	0.96453	0.96182	0.95912	0.95644	0.95376	0.95100	28.03
714	0.97253	0.96991	0.96729	0.96461	0.96194	0.95923	0.95653	0.95376	28.11
716	0.97535	0.97273	0.97012	0.96741	0.96471	0.96200	0.95929	0.95655	28.19
718	0.97818	0.97556	0.97294	0.97023	0.96753	0.96482	0.96212	0.95935	28.27
720	0.98106	0.97838	0.97571	0.97300	0.97029	0.96758	0.96488	0.96213	28.35
722	0.98388	0.98120	0.97853	0.97582	0.97312	0.97038	0.96765	0.96488	28.43
724	0.98665	0.98397	0.98129	0.97858	0.97588	0.97314	0.97041	0.96764	28.50
726	0.98947	0.98679	0.98412	0.98141	0.97871	0.97594	0.97318	0.97041	28.58
728	0.99229	0.98961	0.98694	0.98420	0.98147	0.97870	0.97594	0.97319	28.66
730	0.99512	0.99241	0.98971	0.98697	0.98424	0.98147	0.97871	0.97594	28.74
732	0.99788	0.99517	0.99247	0.98973	0.98700	0.98423	0.98147	0.97871	28.82
734	0.00071	0.99799	0.99529	0.99255	0.98982	0.98705	0.98429	0.98165	28.90
736	1.00353	1.00083	0.99812	0.99538	0.99265	0.98985	0.98706	0.98426	28.98
738	1.00629	1.00359	1.00088	0.99815	0.99541	0.99261	0.98982	0.98703	29.06
740	1.00912	1.00643	1.00371	1.00095	0.99818	0.99538	0.99259	0.98976	29.13
742	1.01194	1.00923	1.00653	1.00377	1.00100	0.99820	0.99541	0.99258	29.21
744	1.01471	1.01200	1.00929	1.00643	1.00376	1.00097	0.99818	0.99535	29.29
746	1.01753	1.01482	1.01212	1.00936	1.00659	1.00376	1.00094	0.99809	29.37
748	1.02035	1.01762	1.01488	1.01212	1.00935	1.00653	1.00371	1.00088	29.45
750	1.02318	1.02045	1.01771	1.01492	1.01212	1.00936	1.00659	1.00370	29.53
752	1.02594	1.02321	1.02047	1.01771	1.01494	1.01211	1.00929	1.00644	29.61
754	1.02876	1.02603	1.02329	1.02050	1.01771	1.01483	1.01206	1.00921	29.69
756	1.03159	1.02883	1.02606	1.02326	1.02047	1.01764	1.01482	1.01197	29.76
758	1.03441	1.03165	1.02888	1.02608	1.02329	1.02047	1.01765	1.01477	29.84
760	1.03718	1.03442	1.03165	1.02886	1.02606	1.02323	1.02041	1.01753	29.92
762	1.04000	1.03724	1.03447	1.03164	1.02882	1.02600	1.02318	1.02030	30.00
764	1.04282	1.04003	1.03723	1.03444	1.03165	1.02880	1.02594	1.02306	30.08
766	1.04565	1.04285	1.04005	1.03723	1.03441	1.03156	1.02871	1.02583	30.16
768	1.04841	1.04562	1.04282	1.04003	1.03724	1.03435	1.03147	1.02859	30.24
770	1.05123	1.04844	1.04564	1.04282	1.04000	1.03712	1.03424	1.03136	30.31
°F.	73.4°	74.3°	75.2°	76.1°	77.0°	77.9°	78.8°	79.7°	

Correction factors for the gasometric determination of carbon dioxide.
—Continued.

°C	27.0°	27.5°	28.0°	28.5°	29.0°	29.5°	30.0°	30.5°	
mm.									*inches*
700	0.93159	0.92885	0.92612	0.92332	0.92053	0.91773	0.91494	0.91203	27.56
702	0.93435	0.92161	0.92888	0.92608	0.92329	0.92047	0.91765	0.91476	27.64
704	0.93712	0.93438	0.93165	0.92882	0.92600	0.92320	0.92041	0.91750	27.72
706	0.93994	0.93717	0.93441	0.93158	0.92876	0.92594	0.92312	0.92024	27.80
708	0.94271	0.93994	0.93718	0.93435	0.93153	0.92870	0.92588	0.92297	27.87
710	0.94547	0.94267	0.93988	0.93706	0.93424	0.93141	0.92859	0.92567	27.95
712	0.94824	0.94544	0.94265	0.93982	0.93700	9.93414	0.93129	0.92841	28.03
714	0.95100	0.94820	0.94541	0.94258	0.93976	0.93691	0.93406	0.93115	28.11
716	0.95382	0.95100	0.94818	0.94535	0.94253	0.93964	0.93676	0.93388	28.19
718	0.95659	0.95376	0.95094	0.94809	0.94524	0.94238	0.93953	0.93662	28.27
720	0.95939	0.95655	0.95371	0.95085	0.94800	0.94512	0.94224	0.93932	28.35
722	0.96212	0.95929	0.95647	0.95361	0.95076	0.94788	0.94500	0.94209	28.43
724	0.96488	0.96206	0.95924	0.95638	0.95353	0.95062	0.94771	0.94479	28.50
726	0.96765	0.96482	0.96200	0.95912	0.95624	0.95332	0.95041	0.94750	28.58
728	0.97041	0.96758	0.96476	0.96188	0.95900	0.95609	0.95318	0.95026	28.66
730	0.97318	0.97036	0.96753	0.96464	0.96176	0.95885	0.95594	0.95300	28.74
732	0.97594	0.97309	0.97024	0.96735	0.96447	0.96156	0.95865	0.95578	28.82
734	0.97871	0.97585	0.97300	0.97012	0.96724	0.96429	0.96135	0.95844	28.90
736	0.98147	0.97861	0.97576	0.97288	0.97000	0.96706	0.96412	0.96118	28.98
738	0.98424	0.98138	0.97853	0.97564	0.97276	0.96982	0.96688	0.96394	29.06
740	0.98694	0.98409	0.98124	0.97835	0.97547	0.97253	0.96959	0.96665	29.13
742	0.98976	0.98691	0.98406	0.98115	0.97824	0.97529	0.97235	0.96941	29.21
744	0.99253	0.98967	0.98682	0.98391	0.98100	0.97806	0.97512	0.97215	29.29
746	0.99529	0.99241	0.98953	0.98662	0.98371	0.98076	0.97782	0.97485	29.37
748	0.99806	0.99517	0.99229	0.98938	0.98647	0.98353	0.98059	0.97762	29.45
750	1.00082	0.99796	0.99506	0.99215	0.98924	0.98626	0.98329	0.98032	29.53
752	1.00359	1.00071	0.99782	0.99491	0.99200	0.98903	0.98606	0.98306	29.61
754	1.00635	1.00342	1.00059	0.99738	0.99471	0.99173	0.98876	0.98579	29.69
756	1.00912	1.00624	1.00335	1.00041	0.99747	0.99450	0.99153	0.98853	29.76
758	1.01188	1.00900	1.00612	1.00318	1.00024	0.99724	0.99429	0.99129	29.84
760	1.01465	1.01174	1.00882	1.00588	1.00294	0.99995	0.99700	0.99400	29.92
762	1.01741	1.01450	1.01159	1.00865	1.00571	1.00274	0.99976	0.99673	30.00
764	1.02018	1.01727	1.01435	1.01141	1.00847	1.00547	1.00247	0.99948	30.08
766	1.02294	1.02003	1.01712	1.01418	1.01124	1.00824	1.00524	1.00221	30.16
768	1.02571	1.02280	1.01988	1.01611	1.01394	1.01094	1.00794	1.00491	30.24
770	1.02847	1.02556	1.02265	1.01968	1.01671	1.01371	1.01071	1.00768	30.31
°F	80.6°	81.5°	82.4°	83.3°	84.2°	85.1°	86.0°	86.9°	

Table 5. Con't.

Correction factors for the gasometric determination of carbon dioxide.
—Concluded.

°C	31.0°	31.5°	32.0°	32.5°	33.0°	33.5°	34.0°	34.5°	35.0°	
mm.										*inches*
700	0.90912	0.90620	0.90329	0.90082	0.89735	0.89432	0.89129	0.88821	0.88512	27.56
702	0.91188	0.90894	0.90600	0.90303	0.90006	0.89703	0.89400	0.89091	0.88782	27.64
704	0.91459	0.91165	0.90871	0.90576	0.90282	0.89976	0.89671	0.89362	0.89053	27.72
706	0.91735	0.91441	0.91147	0.90847	0.90547	0.90241	0.89935	0.89627	0.89318	27.80
708	0.92006	0.91712	0.91418	0.91118	0.90818	0.90512	0.90206	0.89897	0.89588	27.87
710	0.92276	0.91982	0.91688	0.91388	0.91088	0.90782	0.90476	0.90168	0.89859	27.95
712	0.92553	0.92256	0.91959	0.91659	0.91359	0.91053	0.90747	0.90438	0.90129	28.03
714	0.92824	0.92529	0.92235	0.91932	0.91629	0.91323	0.91018	0.90706	0.90394	28.11
716	0.93100	0.92803	0.92506	0.92203	0.91900	0.91594	0.91288	0.90976	0.90665	28.19
718	0.93371	0.93078	0.92776	0.92474	0.92171	0.91865	0.91559	0.91247	0.90935	28.27
720	0.93641	0.93344	0.93047	0.92744	0.92441	0.92135	0.91829	0.91517	0.91206	28.35
722	0.93918	0.93618	0.93318	0.93015	0.92712	0.92412	0.92100	0.91785	0.91471	28.43
724	0.94188	0.93897	0.93606	0.93294	0.92982	0.92676	0.92371	0.92056	0.91741	28.50
726	0.94459	0.94159	0.93859	0.93556	0.93253	0.92944	0.92635	0.92323	0.92012	28.58
728	0.94735	0.94435	0.94135	0.93830	9.93544	0.93215	0.92906	0.92591	0.92276	28.66
730	0.95006	0.94706	0.94406	0.94103	0.93800	0.93488	0.93176	0.92861	0.92547	28.74
732	0.95282	0.94979	0.94676	0.94373	0.94071	0.93759	0.93447	0.93132	0.92818	28.82
734	0.95553	0.95250	0.94947	0.94644	0.94341	0.94034	0.93718	0.93403	0.93088	28.90
736	0.95824	0.95521	0.95218	0.94915	0.94612	0.94300	0.93988	0.93670	0.93353	28.98
738	0.96100	0.95797	0.95494	0.95188	0.94882	0.94570	0.94259	0.93941	0.93624	29.06
740	0.96371	0.96068	0.95765	0.95459	0.95153	0.94841	0.94529	0.94211	0.93894	29.13
742	0.96647	0.96341	0.96035	0.95730	0.95424	0.95112	0.94800	0.94482	0.94165	29.21
744	0.96918	0.96615	0.96312	0.96003	0.95694	0.95382	0.95071	0.94750	0.94429	29.29
746	0.97188	0.96885	0.96582	0.96273	0.95965	0.95653	0.95341	0.95020	0.94700	29.37
748	0.97465	0.97159	0.96853	0.96544	0.96235	0.95925	0.95606	0.95288	0.94971	29.45
750	0.97735	0.97429	0.97124	0.96815	0.96506	0.96191	0.95876	0.95558	0.95241	29.53
752	0.98006	0.97703	0.97400	0.97088	0.96776	0.96461	0.96147	0.95826	0.95506	29.61
754	0.98282	0.97976	0.97671	0.97359	0.97047	0.96732	0.96418	0.96097	0.95776	29.69
756	0.98553	0.98247	0.97941	0.97629	0.97318	0.97003	0.96688	0.96367	0.96047	29.76
958	0.98829	0.98521	0.98212	0.97900	0.97588	0.97273	0.96959	0.96638	0.96318	29.84
760	0.99100	0.98794	0.98488	0.98176	0.97865	0.97547	0.97229	0.96908	0.96588	29.92
762	0.99371	0.99065	0.98759	0.98443	0.98135	0.97817	0.97500	0.97176	0.96853	30.00
764	0.99647	0.99338	0.99029	0.98717	0.98406	0.98088	0.97771	0.97447	0.97124	30.08
766	0.99918	0.99609	0.99300	0.98988	0.98676	0.98356	0.98053	0.97714	0.97394	30.16
768	1.00188	0.99880	0.99571	0.99259	0.98947	0.98629	0.98312	0.97986	0.97659	30.24
770	1.00465	1.00156	0.99847	0.99532	0.99218	0.98897	0.98576	0.98252	0.97929	30.31
°F	87.8°	88.7°	89.6°	90.5°	91.4°	92.3°	93.2°	94.1°	95.0°	

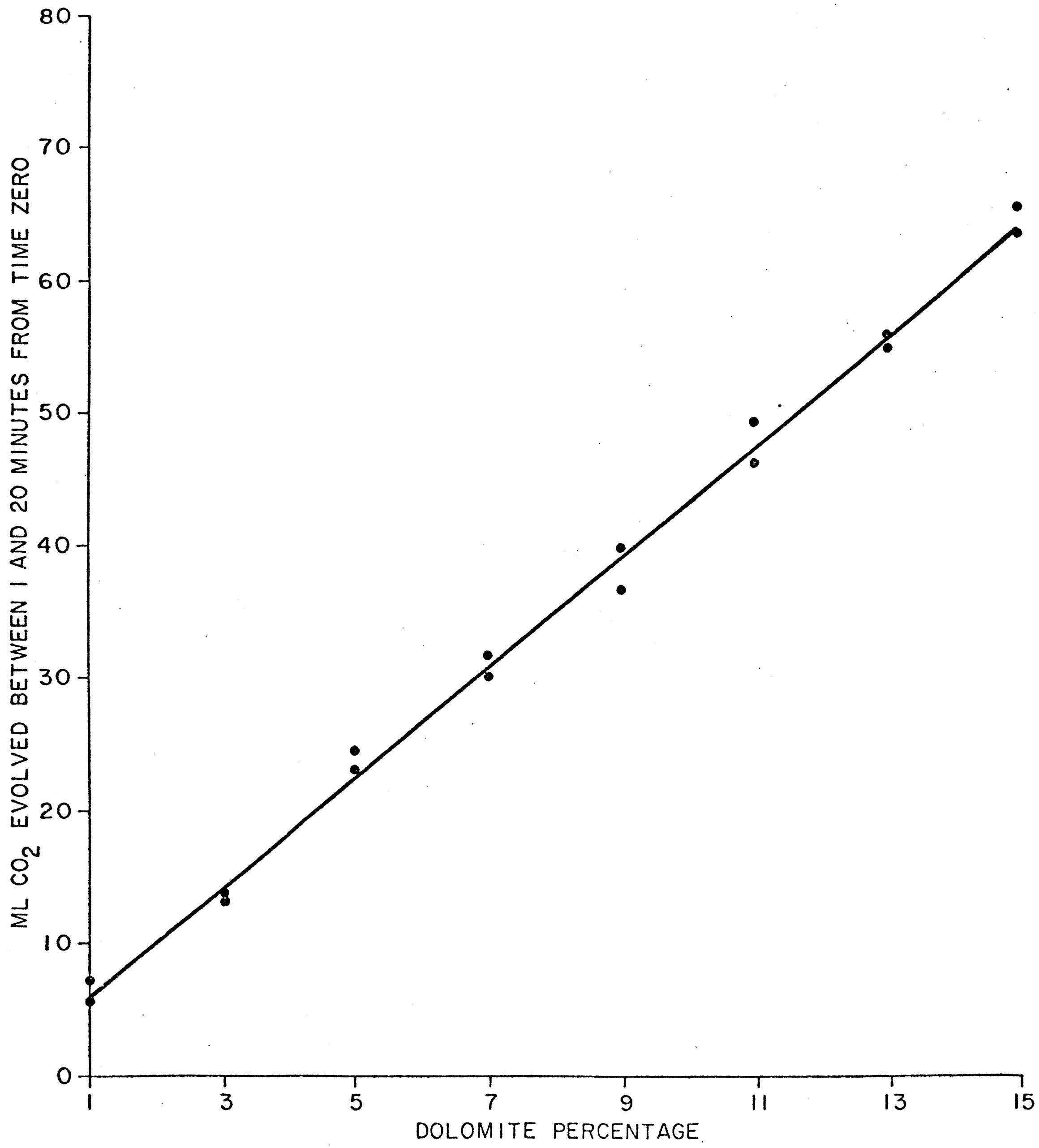

Figure 5. Percentage of dolomite versus CO_2 evolved between 1 and 20 minutes from time zero by 1.700 g of minus 200 mesh material reacting with 20 ml of 6N hydrochloric acid. CO_2 volume corrected for temperature and pressure. See text for explanation of how to use this chart.

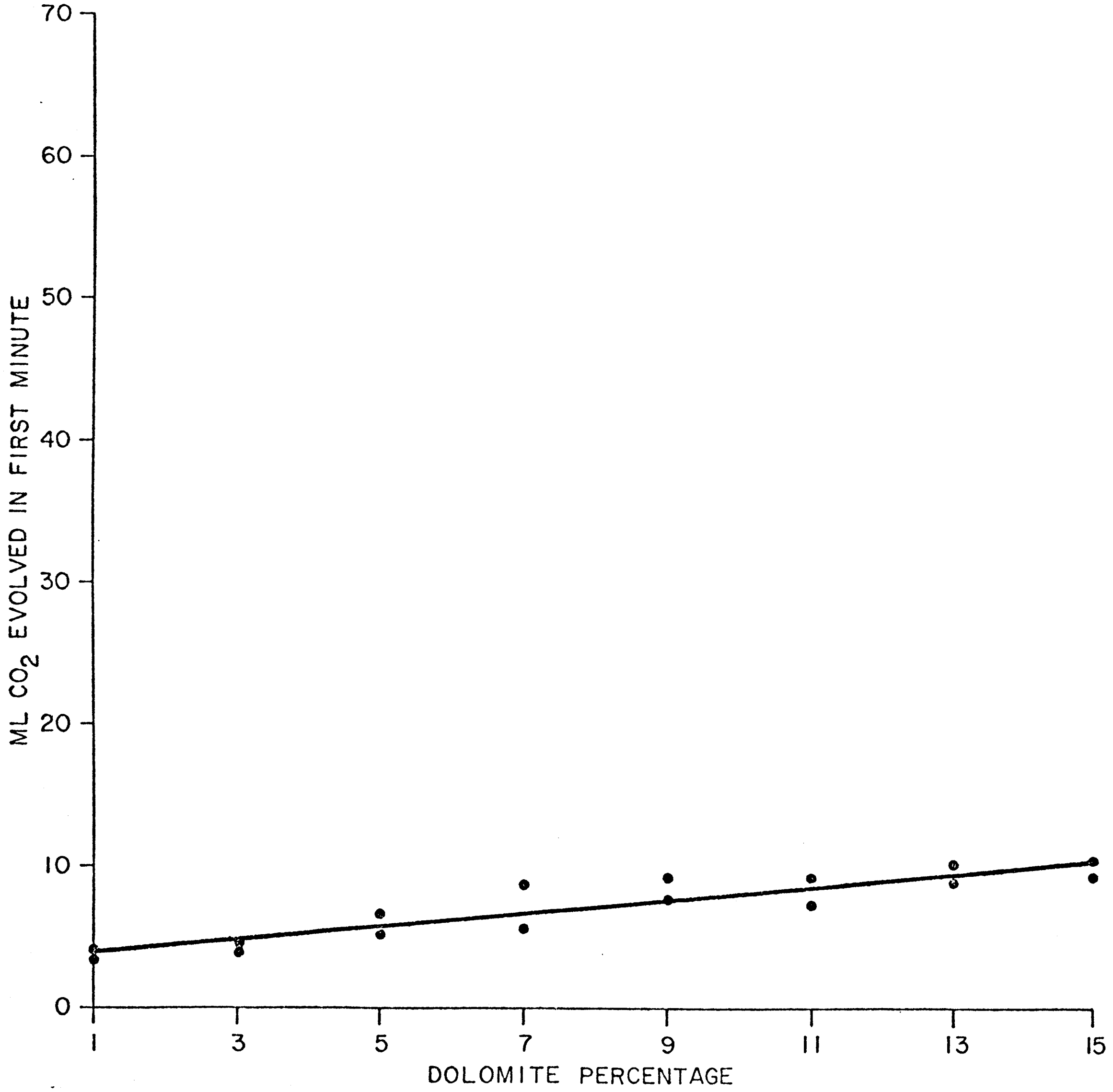

Figure 6. Corrected ml of CO_2 evolved in the first minute from 1.700 g of minus 200 mesh material reacting with 20 ml of 6N hydrochloric acid, versus percentage of dolomite CO_2 volume corrected for temperature and pressure. See text for explanation of how to use this chart.

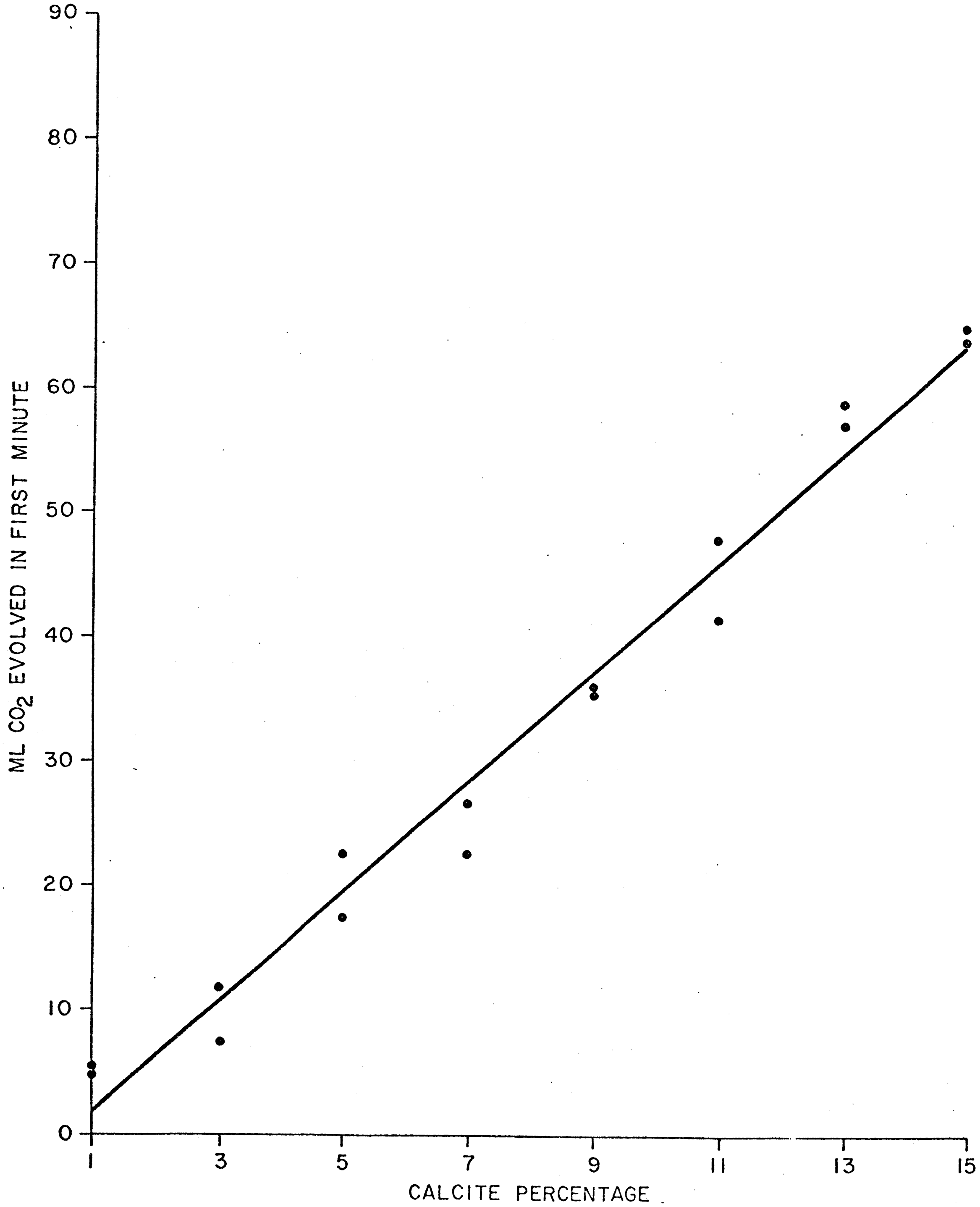

Figure 7. Percentage of calcite versus CO_2 evolved in first minute by 1.700 g of minus 200 mesh material reacting with 20 ml of 6N hydrochloric acid. See text for explanation of how to use this chart.

This percentage of dolomite is then used on figure 6 to determine the corrected ml of CO_2 evolved from any dolomite in one minute. Figure 6 is a plot of known percentages of dolomite versus the corrected ml of CO_2 evolved from the known samples in 1 minute. Subtract the value for the ml of CO_2 evolved by the dolomite in 1 minute from the corrected total 1 minute reading to find the ml CO_2 evolved by the calcite alone in 1 minute. Using this corrected ml CO_2 evolved by the calcite in 1 minute read the percentage of calcite directly from figure 7 which is a plot of known percentages of calcite versus the corrected ml CO_2 evolved in one minute.

All the necessary data is recorded on a chart as shown in Table 6.

The Chittick carbonate values have not been of great value in till characterization in southwestern Iowa and Nebraska. Preliminary work indicates they will be very useful in eastern and north-central Iowa however.

Locality ____________________

Analyst ____________________ Date ____________________

Sample Interval	°C	Press	Corr. Factor	R_1	CR_1	R_{20}	CR_{20}	$CR_{20}-CR_1$	% Dol	% Cal	Total

Table 6. Table for recording Chittick data.

SUMMARY

Investigations of till lithology and mineralogy in Nebraska and Iowa have indicated that pebble lithology and heavy mineral data are useful for stratigraphic characterization. Only a limited number of heavy minerals are significant, namely: Hornblende, mica, garnet, epidote, total opaques. The remaining minerals can be lumped as "others" at a great savings of time, with no loss in discrimination. Light mineral analyses are of little value.

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More detailed investigations and analyses currently in progress, of hundreds of till samples from Nebraska, Iowa, and South Dakota show similar results (Boellstorff, 1977). The application of various statistical techniques (graphical analysis, analysis of correlation coefficients, various forms of factor analysis, principal components analysis) has shown that linear combinations of the pebble and heavy minerals provide a good tool for correlation of stratigraphic units. The following combinations are the most significant discriminators:

1. Percent hornblende plus mica plus garnet, plus non-sedimentary pebbles; versus
2. Percent total opaque heavy minerals plus sedimentary pebbles.

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PART 4. PARTICLE-SIZE ANALYSIS BY THE IOWA STATE UNIVERSITY SOIL SURVEY LABORATORY*

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ABSTRACT

Standard procedures for particle-size analysis for the Iowa Cooperative Soil Survey and Iowa Geological Survey investigations are outlined. Data are compiled to show how estimates and transformations may be made between the different particle-size classification schemes used by soil scientists, geologists, and engineers.

INTRODUCTION

Standard particle-size analysis is carried out for the Iowa Cooperative Soil Survey program at the Iowa State University Soil Survey Laboratory. These procedures and this laboratory are also used for particle-size analysis for geologic investigations of the Iowa Geological Survey.

Standard soils analyses are run using the U.S.D.A. particle-size classification: sand less than 2.0 mm, greater than 0.05 mm; coarse silt 0.05 mm to 0.020 mm; fine silt 0.020 to 0.002 mm; clay less than 0.002 mm (2 micrometers, μm). For geological analysis, 0.062 mm is used as the sand-to-silt break. This allows for more detailed sediment fractionation and statistical analysis, using the geometric progression of particle size fractions of the Wentworth (1922) scale as

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Table 1. Particle-size fraction classification.

	Equivalent diameter	
Class	mm	micrometers (μm)
Gravel	>2.0	>2000
Very coarse sand	2.1	2000-1000
Coarse sand	1-0.5	1000-500
Medium sand	1.5-0.25	500-250
Fine sand	0.25-0.125	250-125
Very fine sand	0.125-0.062	125-62
Very coarse silt	0.062-0.031	62-31
Coarse silt	0.031-0.016	31-16
Medium silt	0.016-0.008	16-8
Fine silt	0.008-0.004	8-4
Very fine silt	0.004-0.002	4-2
Clay	<0.002	<2

(after Ruhe, 1969)

modified by Ruhe (1969). This classification is shown in Table 1. All textures are named using the U.S.D.A. textural classification shown in figure 1.

PROCEDURES

Particle-size analysis is performed using the method of Kilmer and Alexander (1949) with slight modifications. A step-by-step procedure follows:

Grind the air-dry samples to pass a 2-mm sieve. Save all particles that will not pass through the sieve. Put approximately 10 gm of soil from each sample into a small beaker to be oven dried at 105-110°C for several hours. Take the oven-dried soil samples and place them in a desiccator to cool. After cooling, weigh out exactly 10.00 gm into a Pyrex 8 oz baby bottle. Organic matter will interfere with the analysis of the mineral particle sizes. To digest the organic matter, add approximately 100 ml of distilled water

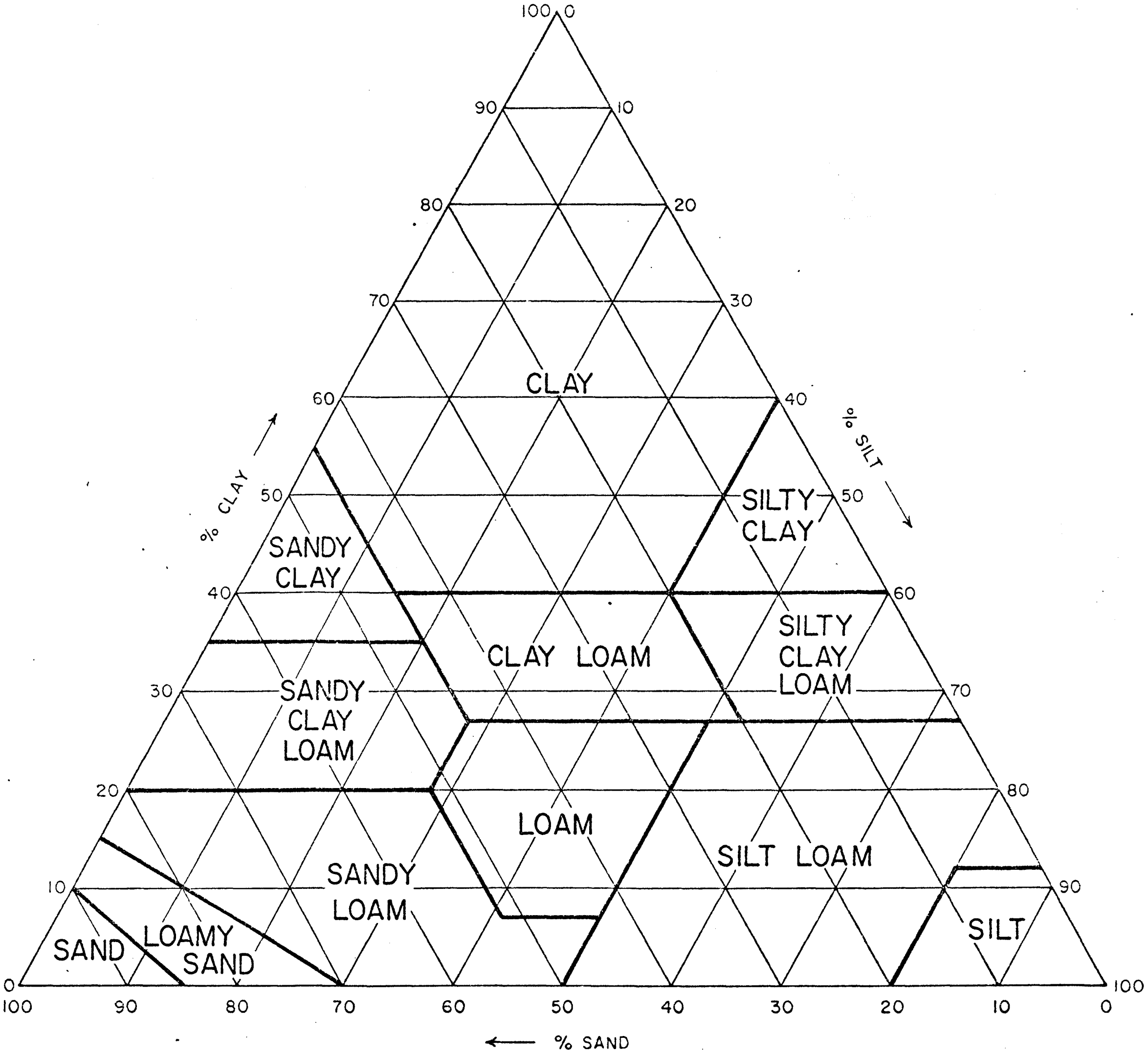

Figure 1. U.S. Dept. of Agriculture textural classification.

to the bottle and then approximately 5 ml of 1-percent acetic acid solution. Next add approximately 10 ml of hydrogen peroxide to each bottle and cover with a 2-in.(5cm) watch glass. Let the solution sit for several hours or overnight. Add approximately another 50 ml of distilled water and set each bottle in a sand bath on a hot plate; boil until about 50 ml of water has been evaporated. Remove each bottle from the hot plate and allow the particles to settle out. If the supernatant liquid is green or very dark brown, add another dose of acetic acid and peroxide and repeat the boiling process. Two digestions should be adequate except for soils exceptionally high in organic matter. Add exactly 10.00 ml of Calgon solution to each bottle, stopper with a #7 rubber stopper, and shake in a reciprocating shaker overnight, to disperse the sample.

Place a large metal funnel into the mouth of a 1000-ml graduated cylinder and place the appropriate sand sieve (50 or 62 μm) in the funnel. Pour the soil solution through the sieve into the graduated cylinder making sure a quantitative transfer occurs. Wash the soil particles that stay on the sand sieve around the surface of the sieve gently with distilled water up to the 1000-ml mark on the cylinder. Make sure all particles that will go through the sieve are washed through. Take the sand sieve from the funnel and wash the sand into a 50 ml beaker tared to the nearest mg.

Stir the cylinder with a plunger described by Day (1965). At the appropriate time and depth, pipette a measured aliquot containing particles $\leq 20\mu m$, and later $\leq 2\mu m$, from the cylinder and into a 50 ml beaker tared to the nearest 0.1 mg. Settling times and depth of aliquoting can be obtained from Tanner and Jackson (1947). An automatic pipette apparatus is described by Day (1965).

Dry the beakers containing the three particle size fractions in a 110° C oven overnight. Transfer the beakers to a desiccator to cool. When they are cool, weigh the beakers containing the clay ($\leq 2\mu m$) and fine silt ($\leq 20\mu m$) fractions to the neraest 0.1 mg. Weigh the beaker containing the sand fraction (2-0.05 mm) to the nearest mg.

Calculations

Let $A = \dfrac{1000 \text{ ml}}{\text{ml in pipette}}$ Let $B = \dfrac{\text{oven dry wt. of 10 ml of Calgon solution}}{(A)}$

Let C= (net wt. of $\leq 2\mu m$ particles) - (B)

Let D= (net wt. of $\leq 20\mu m$ particles) - (B)

Let E= net wt. of 2-0.05 mm particles

Let F= wt. of original sample

$$\%\text{clay } (\leq 2\mu m) = \frac{(C)\ (A)\ (100)}{(F)}$$

$$\%\text{ fine silt } (20\text{-}2\mu m) = \frac{(D-C)\ (A)\ (100)}{(F)}$$

$$\%\text{ sand } (2\text{-}0.05 \text{ mm}) - \frac{(E)\ (100)}{(F)}$$

% coarse silt (50-20μm) = sum of the three other fractions subtracted from 100.0%

Reagents

1% acetic acid solution: dilute 10 ml of concentrated acetic acid to 1 liter with distilled water.

Hydrogen peroxide: Use 27-30% strength technical grade.

Calgon solution: Dissolve 38 gm of Calgon and 8 gm of sodium carbonate in 1 liter of distilled water.

Notes on the Procedure

The excess oven-dry soil not used in the procedure should not be returned to the original sample container. The soil's chemical and physical properties have been altered by oven drying.

If the fine silt fraction is not needed, the first pipetting can be omitted.

After the beaker containing the sand particles is weighed, the sand can be sieved through a nest of sieves to determine the various sand size fractions.

It is necessary to leave the desiccator lid slightly ajar for about 15 minutes after hot beakers are transferred to it to facilitate pressure equilibrium.

It is important that the oven-dry beakers containing the clay and fine silt particles do not absorb moisture from the atmosphere while being weighed. A 50-ml beaker of desiccant placed in the weighing chamber of the analytical balance eliminates this problem.

To facilitate the addition of the distilled water to the baby bottles, concentric lines can be drawn on the bottles with a felt-tipped pen at 100-and 150-ml volumes.

The boiling time of the solution is judged by the evaporation of the solution from the 150 ml line down to the 100-ml line. It does not matter if boiling continues for a longer period of time as long as the solution does not boil dry.

For soils having a combination of extremely high organic matter and calcium carbonate contents, it is necessary to use 20 ml of Calgon solution to insure adequate dispersion. Adjustments must be made in calculations.

The settling time for the clay fraction at a pipette depth of 10 cm can be cut in half if the pipette depth is cut in half also.

"Quality Control"

Standard samples are run continuously with other samples to check consistency over time in the laboratory or to check performance between operators. A large volume of uniform loess material is used as the standard. When first used the standard is run numerous times to establish its particle size distribution. The present loess standard has a mean clay content (N=14) of 33.3% with a standard deviation of ±.51%. As an example of the quality control over time, 54 analyses of the loess standard over a period of six months show a mean clay content of 33.6%, a standard deviation of ±1.04%, and a total range of 32.6 to 35.2%. The coefficient of variation (standard deviation/mean= % variation) is only 3%, which is excellent for any procedure.

Another aspect of procedures has been tested. Some glacial till samples in Iowa have abundant shale particles in the sand and gravel fraction. The possibility existed that the physical grinding of samples might have several effects such as:

1. Crushing small shale pebbles into sand-sized grains, increasing the measured sand content;
2. Crushing sand-sized shale particles into smaller sand-sized or even silt-sized particles, creating error in these measurements.

To test this, duplicate till samples were analyzed; one sample was ground, and the duplicate sample was allowed to slake and disaggregate in water with no grinding. The results are shown in Table 2 . From the data presented in Table 2, no significant differences were found in total sand content, the sand fractions, or silt and clay percentages between the two techniques. Sample 5 was unusual in that it showed a 25.4% difference in sand content, but, the unground portion had a fine silt lens inclusion, which accounts for the large discrepancy. For the remaining 14 samples, in 9 cases the ground sample showed slightly higher total sand contents, and in the other 5 cases the unground samples had higher values for sand. For these samples the mean difference in total sand content (% unground sample sand - % ground sample sand) was - 0.29%. The ground samples did have a tendency to have more sand, but the difference is not significant.

TABLE 2. Comparison of Mechanical Analysis Data for ground and unground till samples.

		Mechanical Analysis %				Sand Sizes %						DT%
Sample No.		Sand 2-.062 mm	Co. Silt .062-.020	Fi Si .020-.002	Clay .002	1.0-2.0	0.5-1.0	0.25-0.5	0.125 0.25	0.062-0.125	0.053-0.062	(U-G)
1	G	39.9	16.5	17.2	26.4	3	6	12	11	8	2.4	-0.7
	U	39.2	17.6	17.2	26.0	2	5	13	11	8	2.6	
2	G	36.5	18.7	18.9	25.9	1	4	12	11	8	2.6	-1.10
	U	35.4	17.9	19.6	27.1	2	4	11	10	8	2.6	
3	G	34.1	17.4	20.7	27.7	2	5	11	9	7	2.2	-0.5
	U	33.6	17.9	21.3	27.2	1	5	11	10	7	2.5	
4	G	37.9	19.0	22.6	20.6	2	7	12	9	8	2.4	2.6
	U	40.5	19.3	21.5	18.7	2	5	10	14	9	2.9	
5	G	48.7	9.7	16.9	24.7	5	8	22	9	5	1.9	-25.4
	U	23.3	19.2	31.0	26.5	1	3	6	6	7	3.0	
6	G	43.6	16.3	18.8	21.3	2	6	14	13	9	2.5	0.3
	U	43.9	15.6	19.5	21.0	3	6	15	12	8	2.7	
7	G	44.1	16.5	18.8	20.6	3	7	14	12	8	2.4	0.6
	U	44.7	16.4	18.6	20.3	3	7	14	12	9	2.6	
8	G	44.8	16.2	18.9	20.0	4	7	14	12	8	2.7	-1.8
	U	43.0	16.4	19.9	20.7	2	6	14	13	8	2.6	
9	G	37.1	19.1	21.2	22.6	2	6	11	10	8	2.6	-1.0
	U	36.1	18.1	22.3	23.5	2	5	11	10	8	3.4	
10	G	44.3	16.6	18.0	21.1	2	6	15	12	9	2.8	-1.70
	U	42.6	16.4	18.0	23.0	2	6	14	13	8	2.9	
11	G	43.9	13.4	12.2	30.4	2	5	15	13	9	2.2	-1.9
	U	42.0	11.0	14.2	32.8	2	5	14	12	9	2.0	
12	G	46.2	15.6	16.6	21.6	2	6	14	14	10	2.4	1.2
	U	47.4	15.1	15.8	21.7	2	6	15	14	10	2.4	
13	G	46.0	16.1	17.1	20.7	2	6	15	13	10	2.2	-0.2
	U	45.8	15.9	16.5	21.8	3	6	15	13	9	2.3	
14	G	43.4	15.7	17.9	23.0	1	5	14	14	9	2.3	-0.6
	U	42.8	16.1	18.2	22.9	1	5	15	13	9	2.4	
15	G	34.1	17.5	21.2	27.2	1	5	11	9	8	2.5	0.8
	U	34.9	17.3	21.1	26.7	1	5	10	9	8	2.2	

G=data for ground sample
U=data for unground, or water-slaked sample
*DT=difference in total sand content; % Unground-% Ground

PARTICLE-SIZE CLASSIFICATION

Unfortunately there is no single scheme of particle size or textural classification used between the various disciplines involved with unconsolidated materials. Pedologists define sand sizes as less than 2.0 mm and greater than 0.05 mm diameter particles and clay as less than 0.002 mm. Some engineering particle-size classifications define sand as less than 2.0 mm but greater than 0.074 mm, and clay is defined as less than 0.005 mm. Geologists often use the geometrical progression described earlier where the sand-to-silt break is $\frac{1}{16}$ mm (0.062 mm) and clay is finer than $\frac{1}{256}$ mm (0.004 mm).

Some statistical data have been compiled to facilitate comparisons and trasformations between these textural classifications. The most important difference is in the definition of the clay sizes, because the amount of clay influences many important characteristics of the sediment. There are several concurrent problems in this regard. The various textural classes use 0.002, 0.004, and 0.005 mm particle size to define the upper limit of the clay-size fraction. The usual methods for measurement vary as well. The pipette method previously outlined is standard for 0.002 mm clay measurement for pedologic and some geologic analyses. The hydrometer method is used in engineering and some geologic analyses of 0.004 and 0.005 mm clay. Standard hydrometer methods are outlined in AASHTO Designation T88-57 or ASTM D422-63. Comparative data are therefore needed between methods as well as between textural classification differences. Duplicate samples were run by both pipette and hydrometer method to relate the differences in clay content.

Data are presented for till and loess materials only. These two materials (and closely related materials) make up about 66% of the surficial materials of the state.

In the subsequent discussion, the following symbols will be used:

X002 = % clay less than 0.002 mm by pipette method
Xh002 = % clay less than 0.002 mm by hydrometer
X004 = % clay less than 0.004 mm by hydrometer
X005 = % clay less than 0.005 mm by hydrometer

Loess Data

Handy (1973) presented the conversion data for loess shown in figure 2. His data show that

1. $X002 = 0.81X005 - 0.666$

   $r = 0.99$; a close approximation is $X002 = 0.8X005$

2. $X004 = 0.93X005 - 1.16X002$

Till Data

Data for 24 duplicate samples of till, 3 samples of till-derived sediments, and 3 paleosol samples were used to calculate the following conversion data. Some samples with high clay contents could not be shown on the following figures. The data were regressed both ways and thus the best fit equations are not directly reversible. Figure 3 shows the data for X002 to X005:

1. $X002 = 0.91X005 - 4.8$
2. $X005 = 0.88X002 + 11.5$

   $r = 0.89$

Figure 4 shows the data for X002 to X004:

1. $X002 = 0.94X004 - 3.0$

2. $X004 = 0.90X002 + 7.8$

$r = 0.92$

For comparison, figure 5 shows the data between X002 and Xh002 (.002 mm clay calculated from hydrometer data):

1. $X002 = 0.99Xh002 - 1.5$ or $X002 = Xh002 - 1.5$
2. $Xh002 = 0.88X002 + 5.0$

$r = 0.93$

Sand Fraction Data

The transformation of sand-fraction classifications is not as critical as the clay-fraction data. Data for 41 glacial till samples show that the difference between 0.05-mm sand and 0.062-mm sand averages 2.5% (see Table 2 for example). The difference between 0.062-mm sand and 0.074-mm sand averages 2.7%. Thus, to convert data using %0.062 mm to %0.05 mm simply add 2.5% to the sand content and subtract this amount from the coarse silt or total silt fraction for an estimate.

This conversion is not as easily done for loess. The total sand content and the sand-size fractionation vary with proximity to the source of the loess. The total sand content is generally so low, however, (1-4%) that this transformation is not critical. Some comparisons have been made, and data from 18 eastern Iowa loess samples showed an average difference of 1.1% between 0.05 and 0.062 mm sand content. No figures were compiled for 0.074-mm sand.

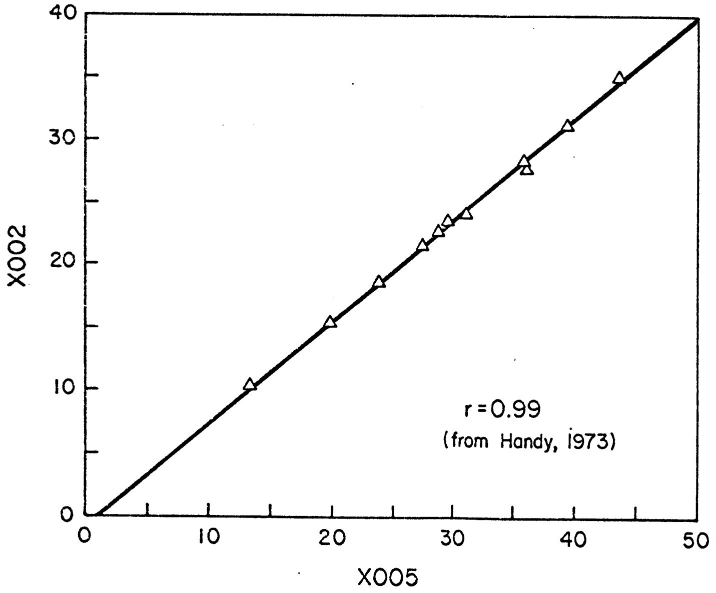

Figure 2. X002 vs. X005 for Loess.

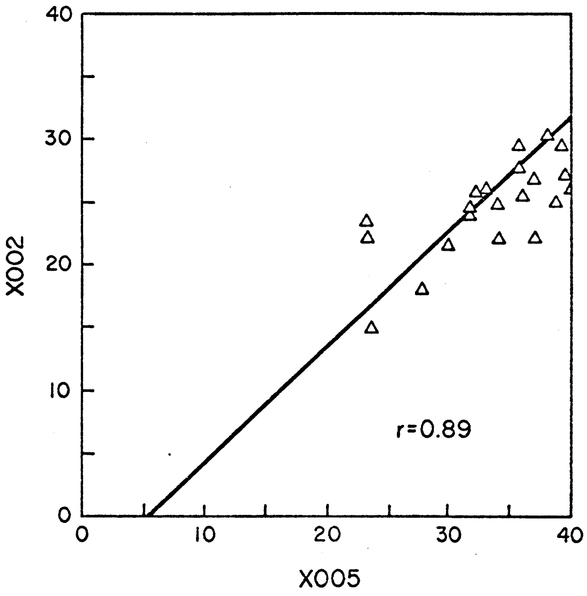

Figure 3. X002 vs. X005 for Till.

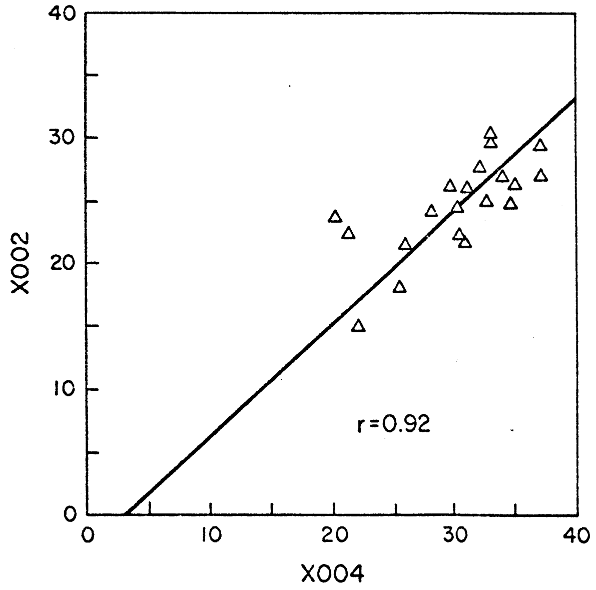

Figure 4. X002 vs. X004 for Till.

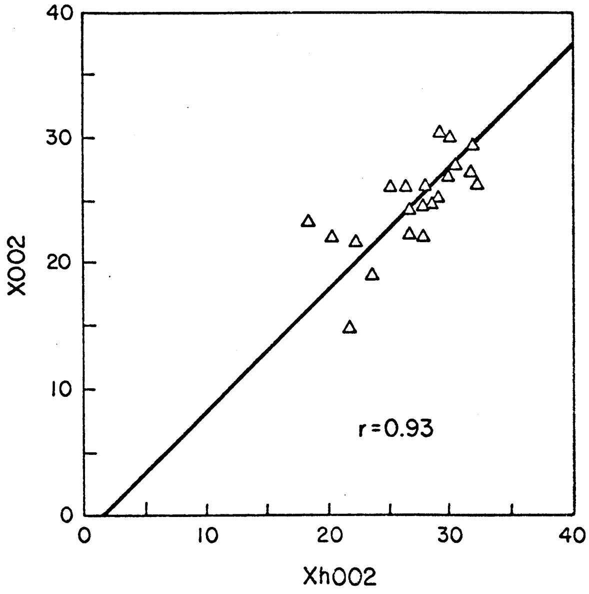

Figure 5. X002 vs. Xh002 for Till.

Figures 2-5. Percent 0.002 mm (x002) clay from pipette method (vertical axis) versus percent 0.005 (x005), 0.004 (x004), and 0.002 (xh002) mm clay by hydrometer method (horizontal axis). Regression equations given in text; correlation coefficients (r values) shown on graph.

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PART 5. STANDARD WEATHERING ZONE TERMINOLOGY FOR THE DESCRIPTION OF QUATERNARY SEDIMENTS IN IOWA

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ABSTRACT

Weathering zone terminology is the "shorthand" phrases or symbols used to describe Quaternary sediments, exclusive of solum or paleosolum. It is just as important to standardize descriptions of materials, as it is to standardize laboratory techniques, because all lab data are inextricably linked to the description of the materials.

Standard weathering zone terminology is quantified in terms of specific associations of moist Munsell colors, iron segregations, and the presence or absence of carbonates. The basic terms are: oxidized, deoxidized in loess, reduced in till, unoxidized; leached and unleached; with modifiers to indicate severe mottling, secondary carbonates, and jointing (in till). Symbol abbreviations and their order are also specified.

There are conceptual problems with these terms because deoxidized, reduced, and unoxidized are not synonymous with a reduced chemical state. Chemical data document differences in the distribution of iron oxides, and also show a progressive increase in the amount of ferrous iron as colors change from oxidized to unoxidized. As long as these relations are understood the color-related "oxidation" terms are useful descriptive tools.

Various lines of research indicate that weathering zones are related to hydrologic conditions. Research is continuing in this area.

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INTRODUCTION

"Weathering zone" terminology refers to the shorthand phrases which are used to describe Quaternary sediments in terms of their color and the presence or absence of soluble carbonate minerals. In Iowa this terminology is used to summarize the description of material below the solum (A and B horizons). For soil descriptions, modern, relict, or buried, standard descriptive terminology and nomenclature are used (Soil Survey Staff 1951, 1975). Horizon designations such as A1, A2, B22t, B23g, etc., form a standard shorthand notation to convey to the informed reader what the properties of that horizon are, when it is not possible to present a full description. Weathering zone terminology provides a short-hand for C horizon materials.

Wherever possible, detailed descriptions should be provided. This is often not practical, especially in publications. Thus, the proper use of these shorthand descriptors is imperative. Just as it is important to standardize our methods of analyses to provide comparative laboratory data, it is perhaps more important to begin with a standard description of the material-- because all our data eventually are related to this.

It also is important to understand fully the nature of weathering zones. Very abrupt contacts between these zones may coincide with stratigraphic breaks. However, the more gradual transitions between these zones in natural progression should not be confused with stratigraphic boundaries.

Historical Development

Weathering zones in unconsolidated sediments have been described on the basis of the presence or absence of carbonates and interpreted oxidation states (from color).

The terminology of weathered zones in Quaternary deposits in Iowa has a long history (Kay, 1916b; Kay and Pearce, 1920; Kay and Apfel, 1929, p. 162). In other areas of the Upper Mississippi Valley numbers have been applied to designate weathering zones (Leighton and MacClintock, 1930). More recently, mineral zonations have been successfully used to differentiate weathering zonation (Frye, Glass, and Willman, 1962, 1968; Kleiss and Fehrenbacher, 1973). The standard terminology discussed in this paper concentrates on simple terms that can be applied by field observations. Table 1 shows the references for the first detailed use of various terms in Iowa.

Carbonate Status - Leached and Unleached Zones

Smith (1942), Hutton (1947), Frye and Leonard (1952, p. 129), and others have shown that loess particles were originally deposited in a calcareous matrix. Similar assumptions have been made for till deposits in Iowa (Kay, 1916b; Kay and Pearce, 1920; Kay and Apfel, 1929; Kay and Graham, 1943). Therefore, the terms leached and unleached provide utility for descriptive purposes. The zones are determined by the usual simple test for a reaction with dilute hydrochloric acid. Only the presence or absence of the more soluble bases, calcium and magnesium carbonates, are described by these terms.

Table 1. Reference to initial use of weathering zone terms in Iowa.

OL - oxidized and leached (Kay and Apfel, 1929, p. 109).
OU - oxidized and unleached (Kay and Apfel, 1929, p. 109).
DL - deoxidized and leached (Kay and Graham, 1943, p. 170; Ruhe, 1954b).
DU - deoxidized and unleached (Ruhe, 1954b).
UU - unoxidized and unleached (Kay and Apfel, 1929, p. 109).

The leaching process commences with the removal of carbonates. The process involves the reaction of carbon dioxide with water, forming carbonic acid within the sediment matrix. This in turn reacts with the carbonate minerals releasing the highly mobile calcium ion and forming bicarbonate.

The rate of leaching is a complex process and is dependent on a series of physical and chemical parameters (Ruhe, 1969a, p. 8). For example, increases in the carbon dioxide partial pressure on the soil solution will increase the hydrogen ion concentration and the rate of carbonate solution (Krauskopf, 1967, p. 108).

Oxidation Zones

The use of oxidation states to describe characteristics of soils and their parent materials was introduced by Russell (1889, p. 15) in his study of soils from a variety of rock formations in the southeastern United States. The terms oxidation and deoxidation were introduced by Van Hise (1904, p. 204, 461-573) in his classical treatise regarding the belt of weathering. He discussed oxidation states in terms of the chemical status of iron.

Oxidation in sediments relates to the state of aeration. Oxidized sediments exist in an environment where the oxygen supply is high and/or the oxygen supply exceeds the biological oxygen demand. In the oxidation process of unconsolidated sediments, iron is the most commonly oxidized element (Carroll, 1970, p. 113). The oxidation of iron, from the ferrous to the ferric state, in the weathering of common rock-forming minerals disrupts the electrostatic neutrality of the crystal lattice. This disruption allows for the collapse of the crystal lattice and promotes an additional weathering process, in the presence of oxygenated water; it allows for the formation of an oxide, Fe_20_3 (hematite), or hydrous oxides such as $Fe_20_3.H_20$ (goethite), and $2Fe_20_3.3H_20$ (limonite). The oxidation of manganese is more complex because of the number of oxidation states it processes. However, manganese is readily weathered to an oxidized form in an aerated environment. The products of manganese oxidation are dark brown or black.

Reduction or deoxidation occurs in an environment where the oxygen supply is limited or the biological oxygen demand is high. This process occurs where the sediments are in an environment of saturation or near-saturation. The occurrence of these moisture regimes is related to either permanent or temporary high water tables and the presence of organic materials and microorganisms. In a deoxidized environment the iron is reduced to a highly mobile ferrous form (Cate, 1964). The ferrous iron may be lost from the sediments if there is a net movement of the ground water. If, on the other hand, the ferrous iron remains in the sediment matrix it may move into crevices or channels within the sediment and be oxidized or remain in the matrix and react with sulfides in the reduced state.

An unoxidized state occurs, in theory, when the sediment matrix has not been exposed to oxygen or oxygenated waters. In the unweathered common rock-forming minerals the iron exists in the ferrous state.

The matrix colors of sediments have generally been related to the state of oxidation and the chemical status and distribution of iron. The oxides or iron have optical properties that may be determined by the distance between iron atoms. These properties are a function of the allochromatic nature of the iron compound. For example Fe_2O_3, hematite, has an iron-iron distance of 2.88Å and has a red color (Pauling, 1960, p. 438). The hydrated iron oxides, such as goethite and limonite tend to be lighter in color. A reduced form of iron, iron sulfide, has an iron-sulfide distance of 2.27 Å and has a very light color (Pauling, 1960, p. 248). The bluish and dark gray colors of ferrous oxides are evidently the result of iron existing in two valence states in the reduced form (Mason and Berry, 1968, p. 111). Color is not then a true guide to oxidation states because color is dependent on chemical subdivisions, minor impurities, the distribution of these secondary iron compounds within the matrix, as well as the degree of hydration Krauskopf, 1967, p. 108). This will be discussed in later sections also.

As discussed previously, field studies in the Upper Mississippi Valley region and especially in Iowa have made use of terms that have presumed a relationship between color and oxidation states. In these studies the color ranges for the oxidized zone include reddish-brown, yellowish-brown, and olive brown (Kay and Pearce, 1920; Kay and Apfel, 1929; Kay and Graham, 1943; Ruhe, 1954b; Ruhe, Prill, and Riecken, 1955; Ruhe, 1969a). Fenton (1966) defined the matrix of the oxidized zone as having hues of 2.5Y or redder with values of 3 or higher and chroma of 2 or higher. Gray mottlings could make up 10 to 40% of the matrix.

The color range for the matrix of the deoxidized zone has been centered on a gray or light gray hue (Kay, 1916; Ruhe, 1954b; Ruhe et al., 1955; Ruhe and Scholtes, 1956; Daniels, Simonson, and Handy, 1961; Fenton, 1966; Ruhe, 1969a). Fenton (1966) defined the colors of the deoxidized matrix. His criteria required that at least 60% of the sediment matrix contain hues of 2.5Y and 5Y having values of 5 and 6 with chroma of 1 and 2. Segregated iron exists in the deoxidized zone in the form of concretions and tubules. The color of these segregations would be similar to the colors observed in the matrix of the oxidized zone (Fenton, 1966).

The colors observed for an unoxidized matrix include dark gray, dark greenish gray, greenish gray, green, blue, and bluish gray (Kay, 1916; Kay and Pearce, 1920; Kay and Apfel, 1929; Kay and Graham, 1943; Ruhe, 1954b; Ruhe and Scholtes, 1956; Daniels et al., 1961; Fenton, 1966; Ruhe, 1969a). Fenton (1966) defined the colors of the unoxidized matrix to include hues of 5Y, 5GY, 5BG, and 5G having values of 4 and 5 with chroma of 0 and 1. Segregation of iron into nodules or tubules does not occur in the unoxidized zone.

The actual chemical status of iron in the oxidation zones has been studied only recently. Oxidized zones have free iron oxide contents, determined chemically by extraction with sodium hydrosulfite and expressed as an oxide, which varies from 1.5 to 3.5% (Ruhe, 1969a, p. 49). Extraction of free iron oxide by the sodium dithionite-sodium citrate method (Holmgren, 1967) from oxidized zones in loess has yielded values from 0.8 to 1.7% (Fenton, 1966; Huddleston, 1969; McKim, 1972). In the oxidized zone, the ferrous iron content expressed as an oxide varies from 1×10^{-4} to 5×10^{-4}% (Daniels, et al., 1961).

Data for free iron oxide and ferrous iron in deoxidized matrices are also available (Daniels, et al., 1961). These results were obtained from samples in deoxidized zones of both loess and till from western and central Iowa. Their results indicated that the reduced iron content is low in the deoxidized zone, ranging from 1 to 5×10^{-4}% for the gray sediment matrix. However, the gray matrix of the deoxidized zone yielded low ferric oxide values, also. These values were in the range of 0.3 to 0.6%. The free iron-oxide content of the vertical tubules or pipestems, which were segregated in the deoxidized zone, varied from 9 to 26%. Free iron oxide values (sodium dithionite-sodium citrate) of 0.4% were reported for the gray sediment matrix in samples form deoxidized loess from east-central Iowa

(Fenton, 1966). Daniels, et al., (1961) reported ferrous iron values for the unoxidized zone ranging from 4×10^{-4} to 2.3×10^{-1}%. Free iron oxide values from the same samples varied from 0.1 to 0.6%. They also reported that the color of the unoxidized sediment changed upon exposure to the air. Free iron oxide values of 0.4% were reported for the matrix of unoxidized loess from east-central Iowa (Fenton, 1966, p. 201).

These data present a dilemma for oxidation terminology in that deoxidized and even unoxidized are not wholly synonymous with reduced. The deoxidized matrix colors are more a function of low total free iron than the presence of abundant ferrous iron.

The change in color from oxidized through unoxidized does show a progressive increase in the amount of ferrous iron present, though. Data in figures 1 and 2 show the amount of ferrous iron as a percentage of total dithionate extractable iron, plotted versus Munsell color. Figure 2 contains data from Daniels et al. (1961) and from the present study, from soil and sediment samples. Data in figure 1 are from Bradbury, Graham, and Ruhe (1977) from soils and sediments which have been submerged under a reservoir. Because of submergence, these soils are being altered, the free iron compounds are being reduced, and the colors are moving toward the "unoxidized" colors. As the colors shift from 10YR to 2.5Y to 5Y, N, 5GY, and 5G-5BG, the percentage of ferrous iron does indeed increase.

There are other conceptual problems with the oxidation terminology. The concept of the unoxidized zone (being that the

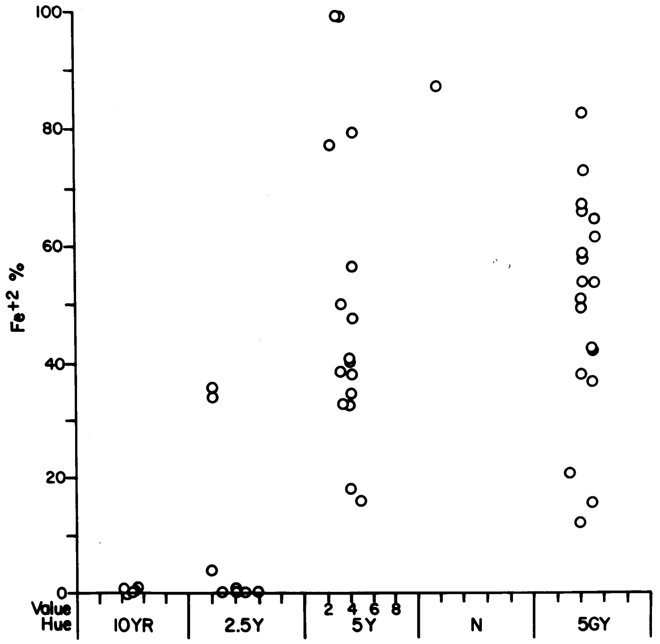


Fig. 1. After Bradbury, Graham and Ruhe (1977)

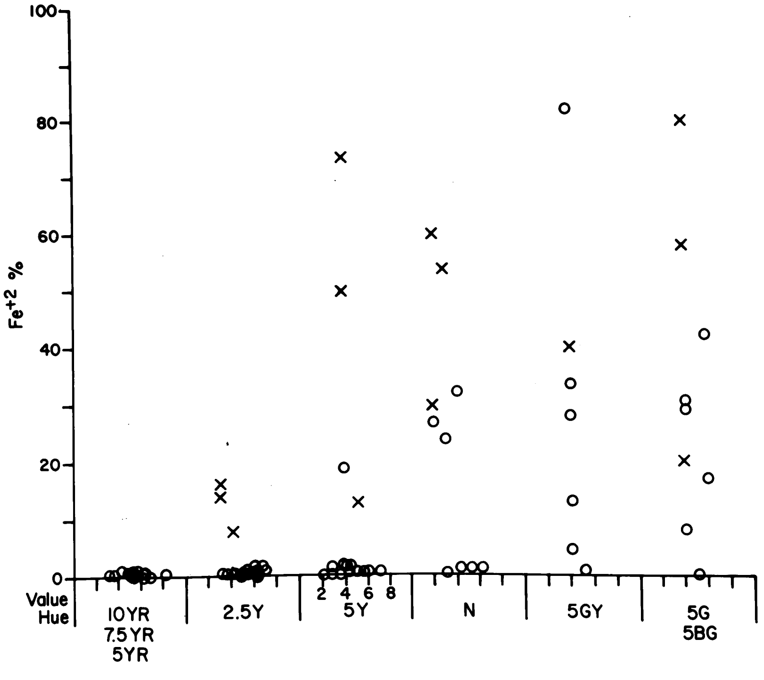


Fig. 2. 0-Data from Daniels, et. al. (1961); x- this study.

Figures 1 and 2. Ferrous iron content as a percentage of total dithionite extractable iron versus Munsell soil or sediment color (value and hue).

sediment matrix has never been exposed to oxygen or oxygenated waters) may be applicable to till deposits; till being deposited from ice as a wet slurry. However, this concept isn't really appropriate for loess. Loess, being a wind-blown sediment, was certainly in an oxidized state while in transport in the atmosphere. Certainly it may have been (and was) deposited into a poorly drained environment, which produced the unoxidized zones in loess that we see today. But originally these deposits must have been oxidized.

Even though the oxidation terms do not wholly fit with their historical concepts, the chemical data do support the relative chemical status between the zones. All the zones have about the same range of free iron, on the bulk level. As we progress from oxidized to deoxidized, or especially the reduced zone in till deposits (described in the next section), to unoxidized, the relative amount of ferrous iron increases (up to 90% of total free iron or greater). Also, the deoxidized zone, as it implies, does show the effects of the mobilization and movement of iron compounds. The light gray matrix has very low reduced iron values but mainly exhibits low total free iron. The iron, outside silicate mineral structures is concentrated into secondary segregations of ferric oxides, such as mottles, tubules (pipestems), and nodules.

TERMINOLOGY

In the past, the same terms (Table 1) have been applied to loess, till, and other sediments. The deoxidized criteria for loess are not wholly appropriate for till and added descriptors are also necessary. Two sets of terminology will therefore be presented here. The numerical values for color refer to moist Munsell colors as determined on fresh samples. If samples are allowed to dry in the laboratory, they may change color irreversibly (Daniels, et al., 1961).

As discussed, there are conceptual problems with the use of "oxidation" terms, inferred from sediment colors. Miller (1974) discussed the possible replacement of these terms with color-related connotative names: "brunambric" for oxidized; "pallic" for deoxidized, and "glaucic" for unoxidized. However, we have chosen to retain the use of the classical "oxidation" terms, in spite of their technical misconceptions, because of their long historical usage. When the conceptual problems and the nature and distribution of the iron compounds are understood, the color-related oxidation terms can be useful descriptive tools.

Loess

Standard symbols, terms, and their defined use for loess are:

First Symbol - color reference.

O - oxidized; 60% of matrix has hues of 2.5Y or redder, values of 3 or higher, and may have segregation of secondary iron compounds into mottles, tubules, or nodules.

D - deoxidized; 60% of matrix has hues of 10YR, 2.5Y, and/or 5Y, values of 5 and 6, and chromas of 1 or 2 with segregation of iron (ferric oxides) into tubules (pipestems) or nodules.

U - unoxidized; matrix has hues of 5Y, 5GY, 5GB, and 5G, values of 4, 5, or 6, and chromas of 1 or less (except 5Y 6/1 is deoxidized), with no segregation of iron into tubules or nodules. May include hues of N or values of 3 or less with the presence of zones with abundant organic matter; these are often described as organic bands.

<u>Second Symbol</u> - leached or unleached state.

U - unleached; primary carbonates present.

L - leached; no carbonates detectable (with dilute HCl).

L2 - leached; primary carbonates absent, secondary carbonates present.

<u>Modifier Symbols</u> - when used precedes first symbol.

M - mottled; refers to zones containing 20-50% contrasting mottles.

<u>Examples</u>: OL - oxidized, yellowish brown or strong brown matrix, and leached.

UU - unoxidized, dark greenish gray matrix and unleached.

MOL - mottled, oxidized - yellowish brown or strong brown matrix with gray mottles, leached.

MDU - mottled, deoxidized - grayish brown matrix with strong brown pipestems and strong brown mottles, unleached.

Till

Standard symbols, terms, and their defined use for till are:

First Symbol - color reference

O - oxidized; 60% of matrix has hues redder than 2.5Y (ex.- 10YR, 7.5YR); hues of 2.5Y, with values of 5 or higher, but including 2.5Y 4/4; may have segregation of secondary compounds into mottles, tubules, or nodules, etc.

R - reduced; 60% of matrix has hues of 2.5Y, with values of 3 or less, hues of 2.5Y, with value of 4, with chromas of 2 or less; hues of 5Y, N, 5GY, 5G, 5BG, and 5G, values of 4 or higher (usually values in this zone are 5 or higher). Colors in this zone are nearly always mixed as weak mottles, diffuse blends of color, or as discrete bands. Discrete vertical bands of reduced colors may occur for some distance adjacent to joints. These bands may eventually grade into uniform unoxidized material. In this zone there may be considerable segregation of secondary iron compounds (with oxidized colors) into mottles, nodules, or sheets along cleavage planes, or joints.

U - unoxidized; matrix uniform; has hues of 5Y and N, values of 5 or less, 5GY, 5G, 5BG, 5G, with values of 6 or less; with no segregation of iron compounds into mottles, nodules, etc.

Second Symbol - if used

J - jointed, describes the presence of well-defined vertical joints in the till; joints often show oxidized and reduced colors, often have coatings or rinds of secondary iron-oxides; occasionally other secondary minerals such as calcite or gypsum.

Second or Third Symbol - leached or unleached state; same as for loess.

U - unleached.

L - leached.

L2 - leached of primary carbonates, but secondary carbonates present.

Modifier Symbols - when used precede first symbol, as with loess.

M - mottled; zones with 20-50% contrasting mottles; when used with the unoxidized zone designation it infers 20% or less mottles of reduced colors.

Examples: JRU-jointed reduced unleached-mixed olive (5Y4/4 and 5Y4/3) and very dark grayish brown (2.5Y 3/2), with common gray (5Y5/1) and light olive brown (2.5Y 5/4) mottles; prominent vertical joints, with 1 cm strong brown (7.5Y 5/8) segregations along the joint; unleached.

JUU - jointed, unoxidized, unleached-uniform dark greenish gray (5GY 4/1) matrix, with few thin vertical joints, which have mottled light olive brown (2.5Y 5/6) and olive gray (5Y 5/2) faces, and a 3 cm rind of greenish gray (5GY 5/1); unleached.

MUL - mottled, unoxidized, leached - dark greenish gray (5GY 4/1) matrix with few, small gray (5Y 5/1) mottles; leached.

Other Materials

Other materials, such as alluvium, lacustrine sediments, etc., can also be described by these terms. Dependent upon the texture and density of these materials the terms for loess or till may be more appropriate.

Discussion

As with any system of classification of natural entities, the boundaries between these "pigeonholes" are very transitional. Table 2 shows a vertical sequence of weathering zone abbreviations that might be encountered in a transitional but complete sequence in loess or till. The subdivisions and color "quantification" of these zones have evolved from numerous descriptions of outcrops and core-samples from depths of 5 to 400 feet. As with any classification, judgements must be made on transitional samples.

Table 2. Vertical sequence of weathering zones that might be encountered in a complete transitional sequence.

Loess	Till
OL	OJL
OL2	MOJL
MOU	MOJL2
MDU	MOJU
DU	MRJU
UU	RJU
	MUJU
	UJU
	UU

The deoxidized zone terms have been replaced by the reduced zone in till deposits primarily because this intermediate zone exhibits a much wider range of colors in till than in the loess. Also, the secondary segregations of iron in till generally do not occur as the thin tubules or pipestems that are so classically a trait of deoxodized loess.

There is also a great deal of overlap in the Munsell colors defined for the reduced and unoxidized till zones. These zones are often much more transitional than the deoxidized and unoxidized zones in loess. As expressed in their definitions, the reduced zone usually has higher values and chromas than the unoxidized zone. Another typical characteristic is that the reduced zone is highly variegated, and may have oxidized segregations such as mottles, nodules, and joint coatings. By contrast, the unoxidized zone is very uniform, except possibly along narrow bands adjacent to vertical joints.

Another difference between the till and loess terms is that values of 2 and 3 are allowed in the unoxidized till but not in unoxidized loess. When values this low are encountered in loess (ex. N2/0, 5Y 3/1), they occur as "organic bands" within the unoxidized zone, and are described as such. In till, organic material can be incorporated to impart these dark colors but it generally does not occur as distinct bands and obviously does not have the same significance as in the loess. Consequently, these colors are lumped in the unoxidized zone. Problems also arise in deoxidized loess. Where organic bands or the basal loess paleosol occur in deoxidized loess, they often exhibit 10YR, or 2.5Y hues, with 4/2 value and chroma. These are sometimes mistakenly described as oxidized. As shown by McKim (1972) these 4/2 colors reflect the increase in organic carbon content and should be noted as organic bands also.

The jointed modifier in till is also of significance. Joints affect the hydrologic and engineering properties of till. Work in progress suggests that they also influence stream valley development. Joints are significant features and should be part of a complete description.

SIGNIFICANCE OF WEATHERING ZONES

A great deal of research is in progress concerning the nature of weathering zones. Some pertinent hydrologic observations can be summarized here.

Drainage classes of soils have historically been separated using color criteria and degree of mottling. Well drained soils have red (or YR) hues, analogous to the oxidized zone; poorly and very poorly drained soils show strong mottling and gleyed hues, like the deoxidized zones. Figure 3 shows a statistical summary of several thousand monthly observations of water table conditions, taken over a period of several years, from all over Iowa. These observations document the color-related interpretations of drainage conditions.

Similar relations can be shown in regard to weathering zones below the soil profiles, as well. Ruhe (1969b) and Worcester (1973) have shown that as the Wisconsinan loess systematically thins away from the Missouri River in southern Iowa,

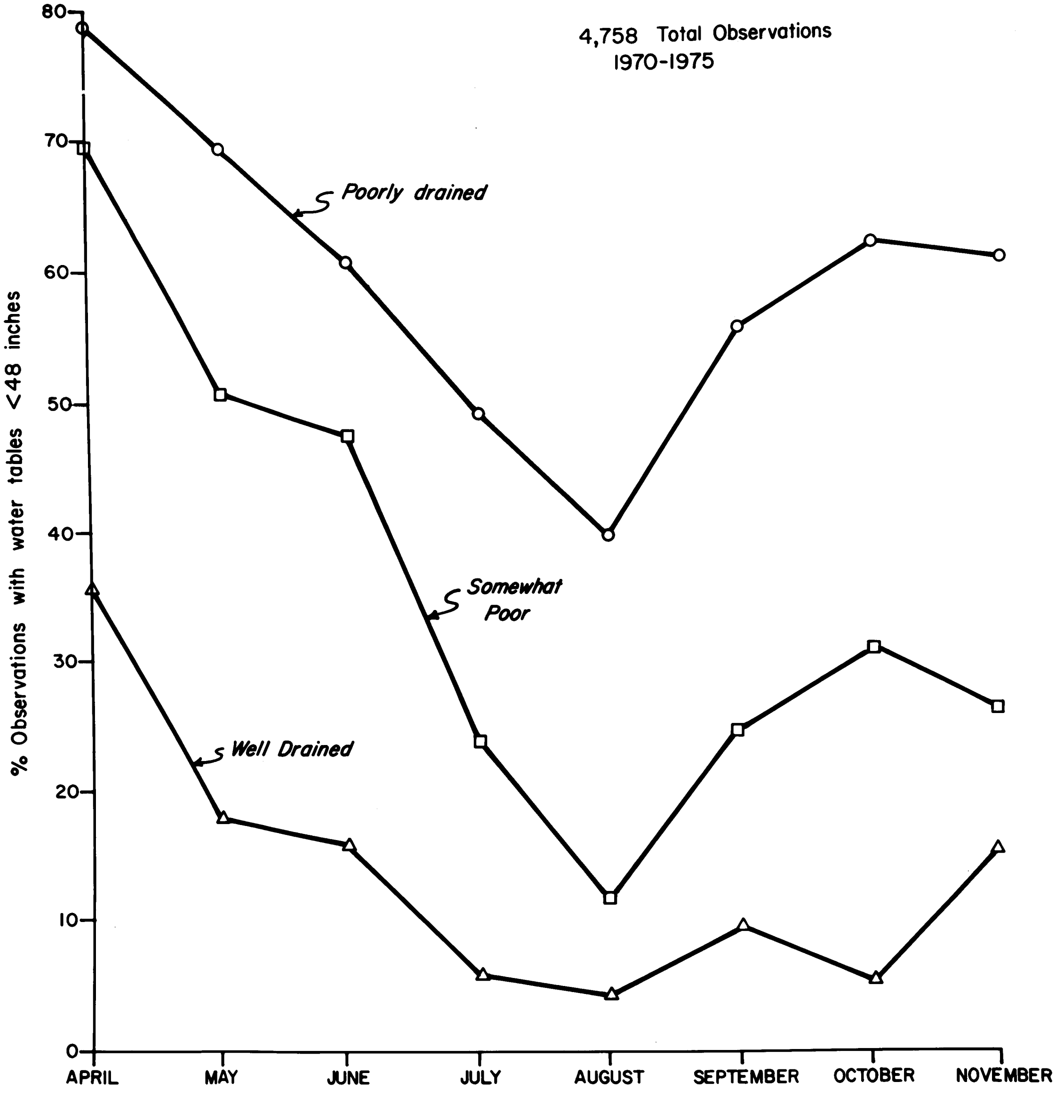


Figure 3. Water table observations (1970-1975) summarized by soil drainage class.

the water table, which is perched on the underlying Yarmouth-Sangamon paleosol, comes progressively closer to the land surface. This water table rises, in a relative sense, as the loess thins and the deoxidized zone gets closer to the surface in response.

As examples of these relations, figures 4 and 5 show interfluve and divide transects in Marion County (Girgus, 1976). These cross-sections show the relationships of the high, low, and average water table recorded from July 1974 through September 1975. This study and others indicate that the deoxidized colors occur in zones of fluctuating water table conditions-- being saturated long enough to reduce and mobilize iron compounds, yet these zones are unsaturated long enough to allow migration and crystallization of the iron compounds in secondary segregations of ferric oxides-- such as the pipestems. Also, as the iron oxides become more segregated, the percentage of gray fabric increases, and the aeration porosity decreases (McKim, 1972).

Figures 6 and 7, from Girgus' study, show that relationships between water table conditions and more subtle features such as depths to yellowish brown mottles and depths to gray mottles and colors can also be described.

For the past four years, bulk density and field moisture contents have been measured during investigations of engineering properties of loess and till. The samples range from 6 to 88 feet in depth. From these data the percent saturation can be calculated. As these data have been collected from sites all

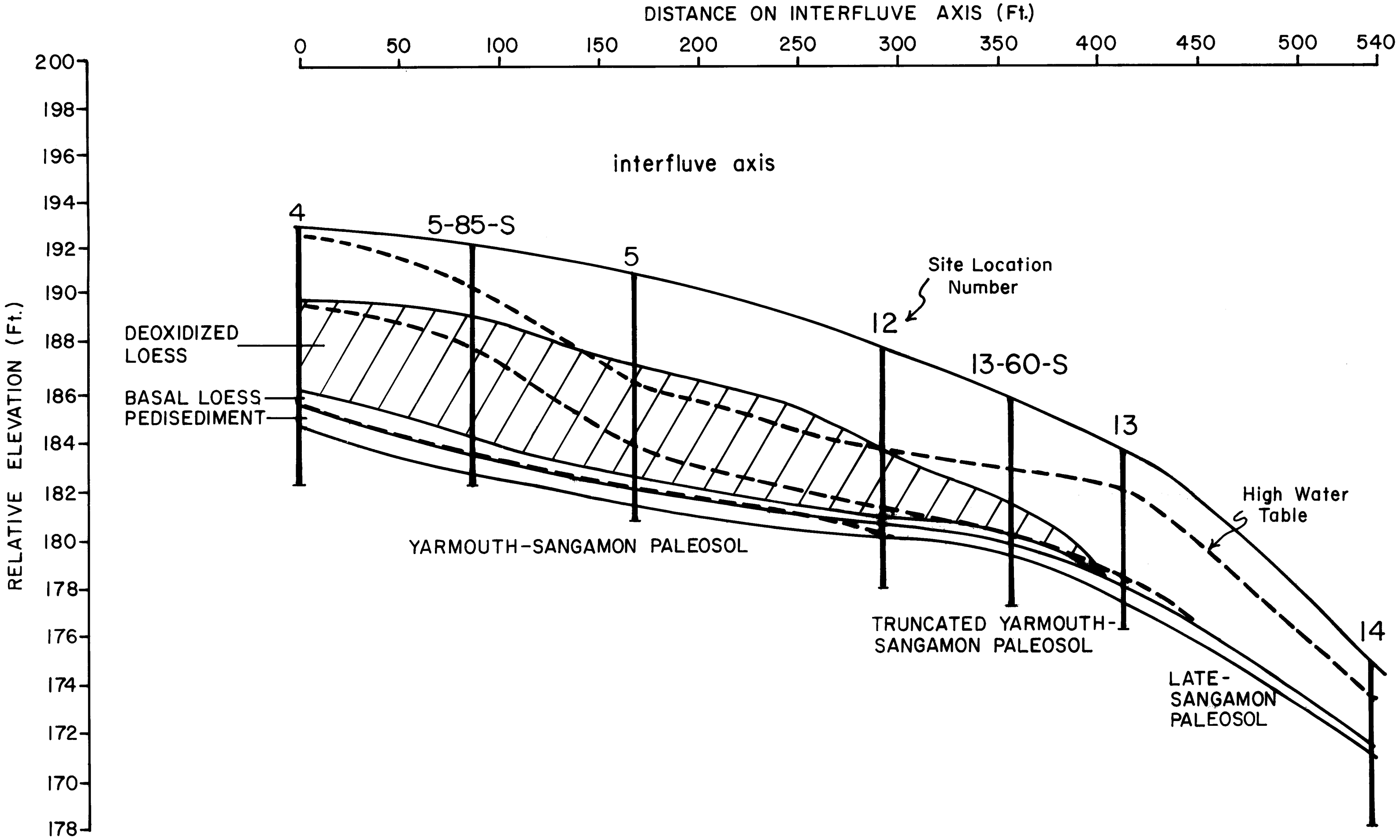


Figure 4. Weathering zones in loess along interfluve axis in Marion County, Iowa in relation to high, average, and low water table levels (dash lines) for water year 1974 (after Girgus, 1976).

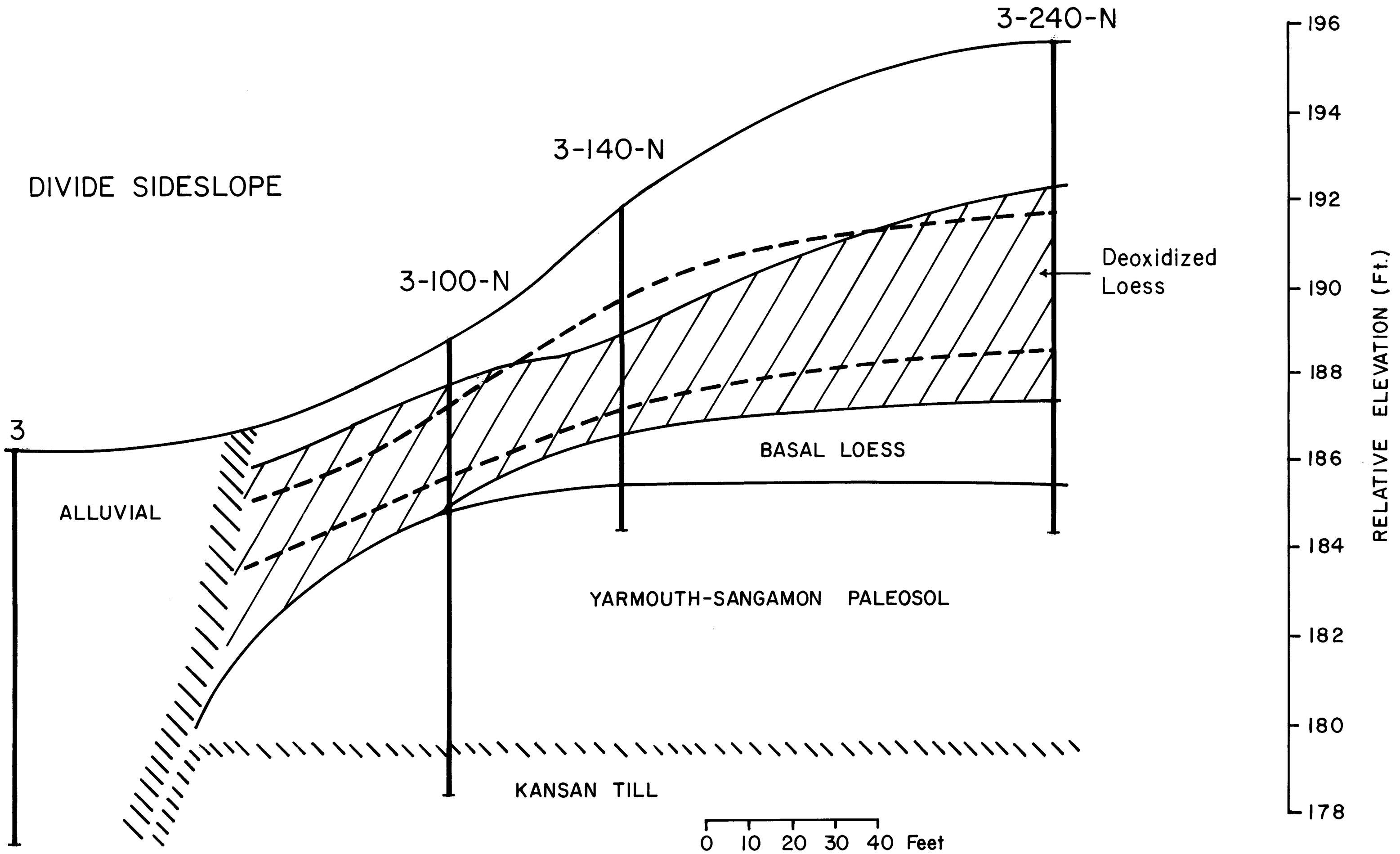
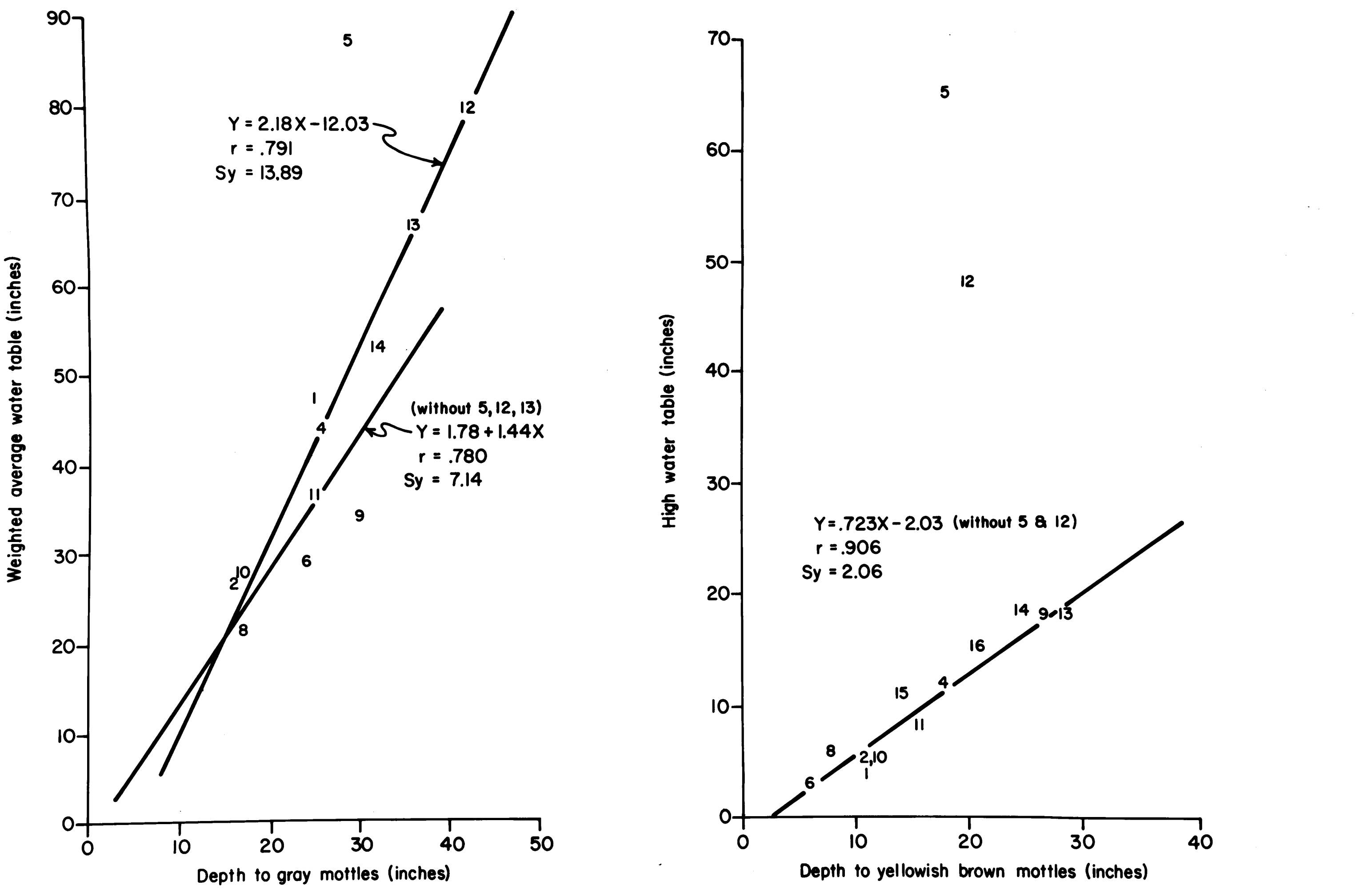


Figure 5. Weathering zones in loess along divide sideslope in Marion County, Iowa, in relation to high and low water tables during summer and fall of 1975 (after Girgus, 1976).



Figures 6 and 7. Relationship between water table levels and depths to soil mottles in Marion County study area (after Girgus, 1976).

over Iowa during all seasons but mid-winter, they form a statistical sampling of conditions similar to the water table data in figure 3. These data are summarized in figure 8 by weathering zones. These measurements also support the relations between hydrologic regime and weathering zones. The modal class of percent-saturation increases from 60-70% for oxidized zones; to 80-90% for mottled oxidized; to 90-97% for deoxidized; 90-100% for reduced; and 97-100% for jointed unoxidized till and for unoxidized till and loess. As would be expected, the range of percent saturation observed decreases from oxidized to unoxidized, indicating more permanent saturation in the unoxidized zone. In the unoxidized zones, only 21% of the observations were less than 100% saturated. Of these, 18% were either mottled-unoxidized or samples from Yarmouth-Sangamon paleosols that were included in the data.

Figure 9 shows a summary plot of the percent saturation at 1/3 bar moisture content. If we make the general assumption that 1/3 bar moisture approximates field capacity, then the percentage of saturation at the mode of field capacity (70-80%) for medium density till (1.68-1.82 g/cc) is between the modes for the oxidized and mottled-oxidized zone measurements (fig. 8). This seems to indicate that oxidized conditions can be obtained even without much desiccation below field capacity. Conversely, figure 9B shows that modal field capacity for heavy textured (45-61% clay) Yarmouth-Sangamon paleosols and a few samples of high-density till (1.92-1.98 g/cc) is 90-97% of saturation. Even where these deposits are exhumed by erosion in a relatively

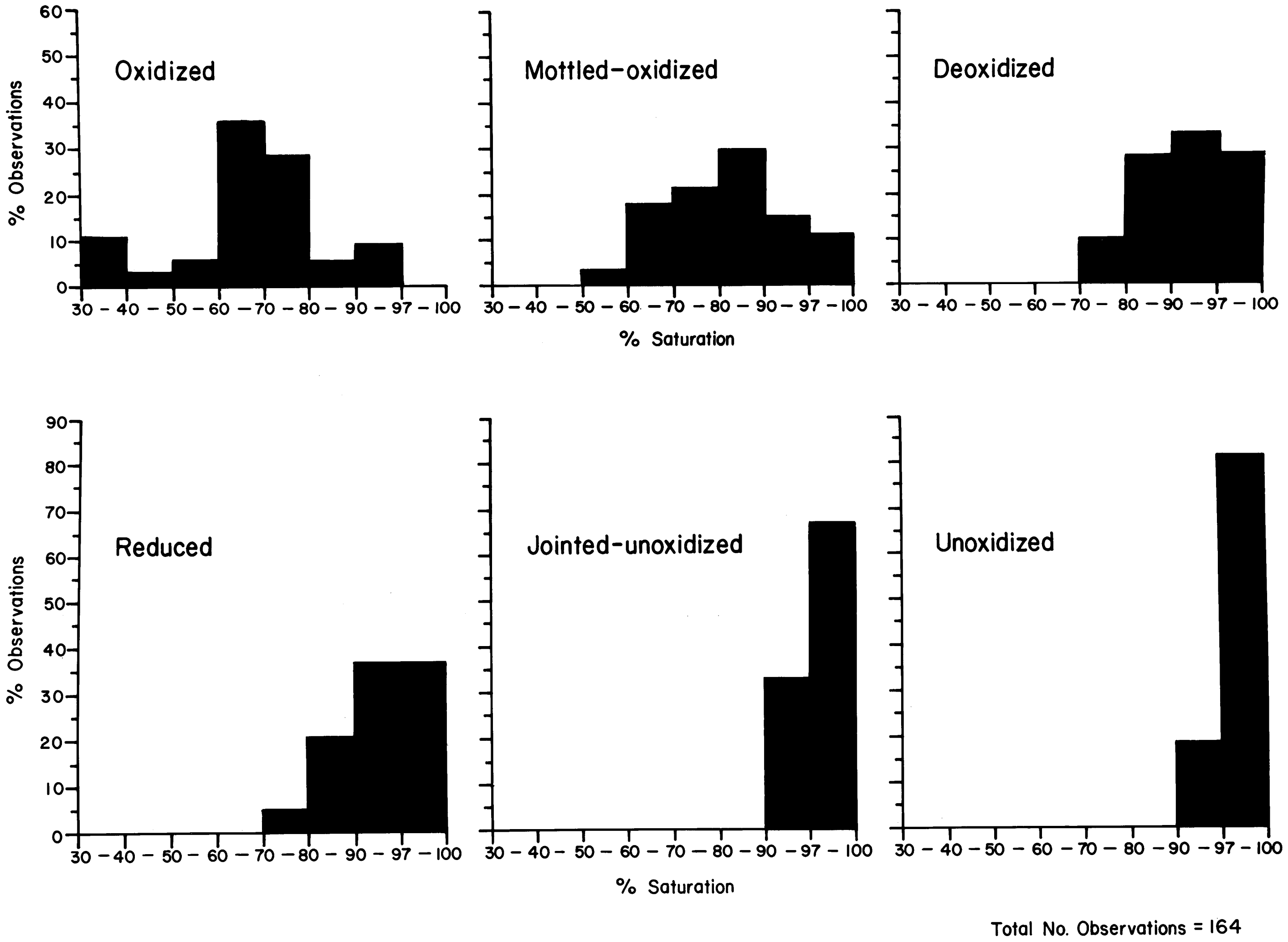


Figure 8. Histograms of percentage of saturation, categorized by weathering zone for loess, till, and a few paleosol samples.

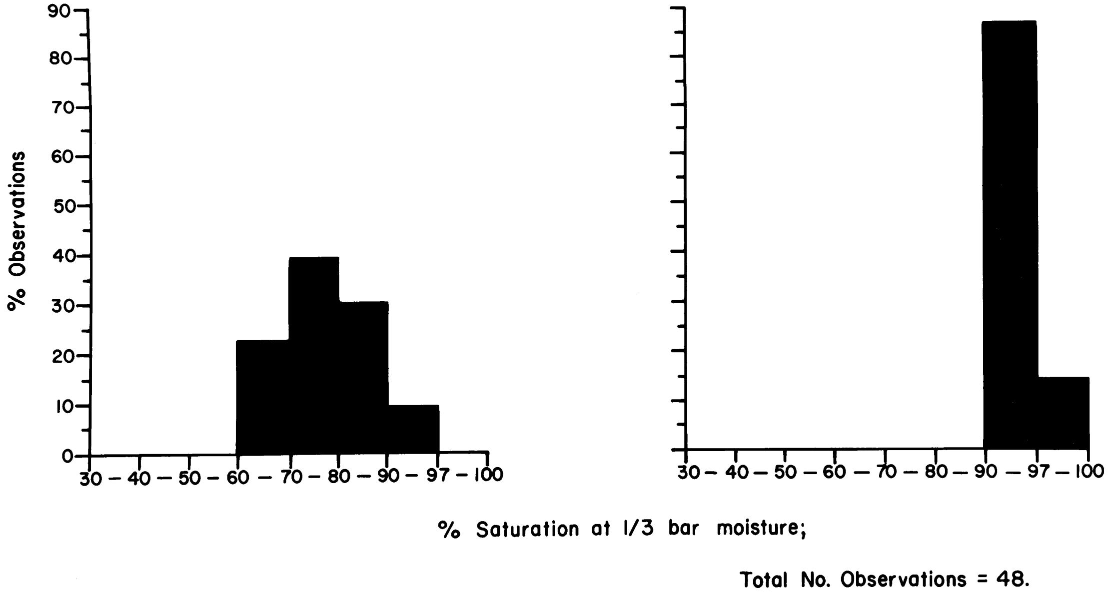


Figure 9. Histograms of percentage of saturation at 1/3 bar moisture contents (field capacity) for medium density till (left) and high density tills and clay to silty clay paleosols.

well-drained environment, they have maintained their reduced to unoxidized colors. The reason may be that when drained to field capacity these materials are still 90-97% saturated and there is essentially no aeration porosity to allow oxidation.

Figure 10 shows a transect through a till landscape in Buchanan County. The diagram shows the stratigraphy and the abbreviations for the weathering zones. The water table observations were taken in late summer of 1977, after 2 years of drought conditions when many water levels were at record lows. Even at this time the water table is encountered in the very bottom of the jointed-unoxidized zone. The interesting point of this site is that the land surface crosscuts the stratigraphic units; the water table, as expected, tends to parallel the land surface. The weathering zones in turn parallel the land surface and the water table -- regardless of the stratigraphic units.

Enigma of the Deoxidized Zone

All the available evidence points to consistent relationships between hydrologic conditions and weathering zones. Research continues to further document these relationships.

Certain problems still exist with our understanding of the deoxidized zones in loess. In general, in thick loess sequences overlying very low permeability Yarmouth-Sangamon paleosols, the deoxidized zone occurs as a transition zone above unoxidized loess. This seems to be a result of the fluctuation of the

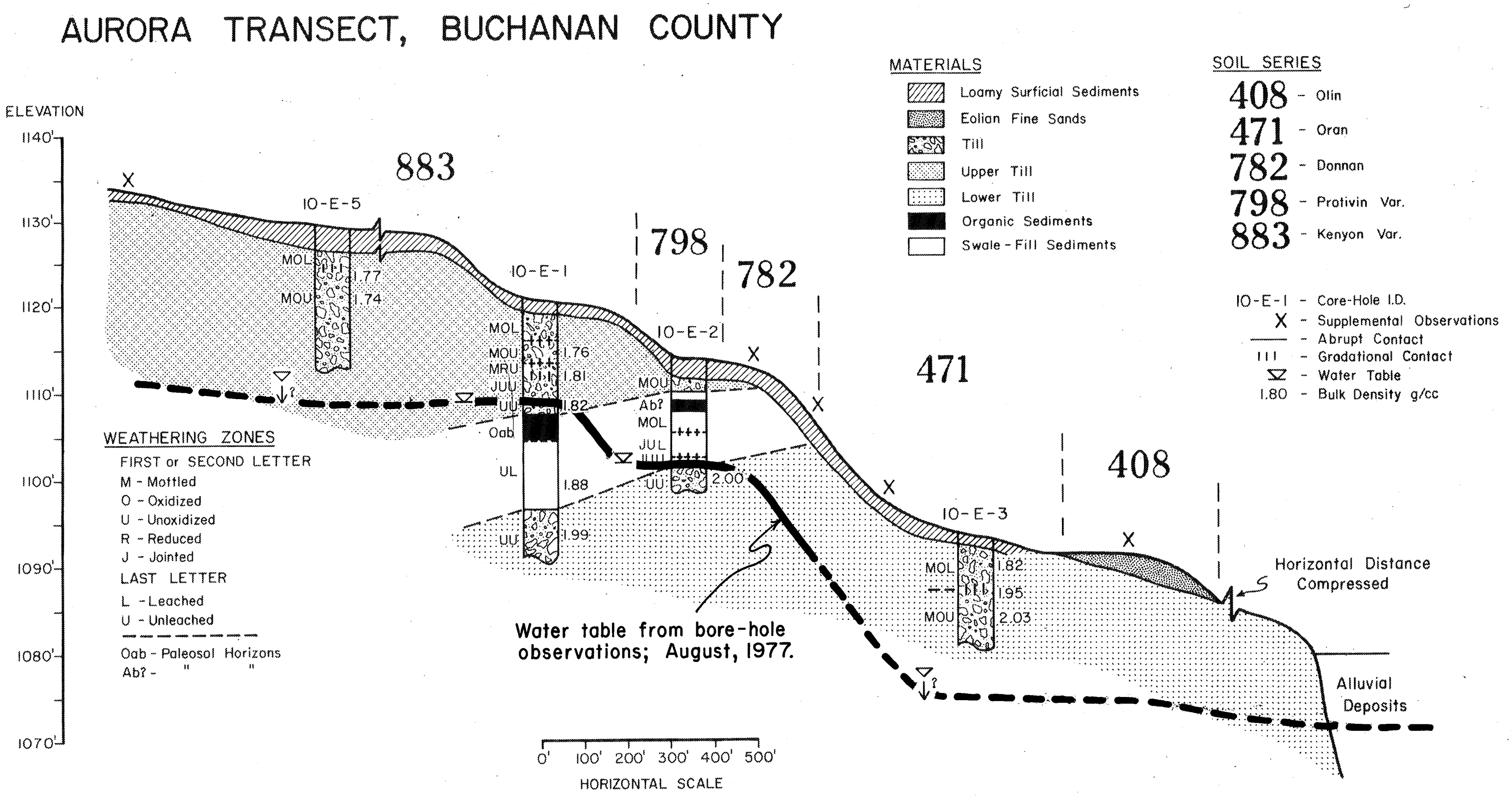


Figure 10. Low-water table observations in relation to hillslope transect, stratigraphy, and weathering zones in till and intertill deposits. Note discordance of the stratigraphy to the land surface, but concordance of water table, weathering zones, and the land surface.

water table in the deoxidized zone over the permanently saturated unoxidized zone. In thin loess sequences where the water table may fluctuate throughout the entire thickness of loess, there may be no appreciable unoxidized zone (such as in figs. 4 and 5). In these areas, the deoxidized zone may be exhumed on side slopes, where Holocene hillslope erosion has eroded the loess to expose the deoxidized material in what is now a well-drained environment.

The deoxidized zone may also occur as the basal weathering zone where the loess overlies the Late Sangamon soil or glacial till on erosion surfaces and narrow interfluves. In these positions water is only perched temporarily at the lithologic contact with the underlying less permeable till or paleosols.

In eastern Iowa deoxidized zones may also occur "perched" between oxidized zones where deoxidized loess overlies oxidized eolian sand. The likely explanation is that moisture tension perches water in the smaller pores of the finer-textured loess versus the larger pores of the coarser textured sand. Water is held up by tension in the finer pores until enough head is developed to overcome this tension and then the water can flow into the larger pores in the sand. Neutron probe data (fig. 11) support this interpretation. Similar situations were documented by Vreeken (1968).

In western Iowa, however, deoxidized loess occurs between oxidized loess with no apparent difference (as with the sand zone above) to cause perching of water. This has been interpreted as a relict condition caused by once higher water tables

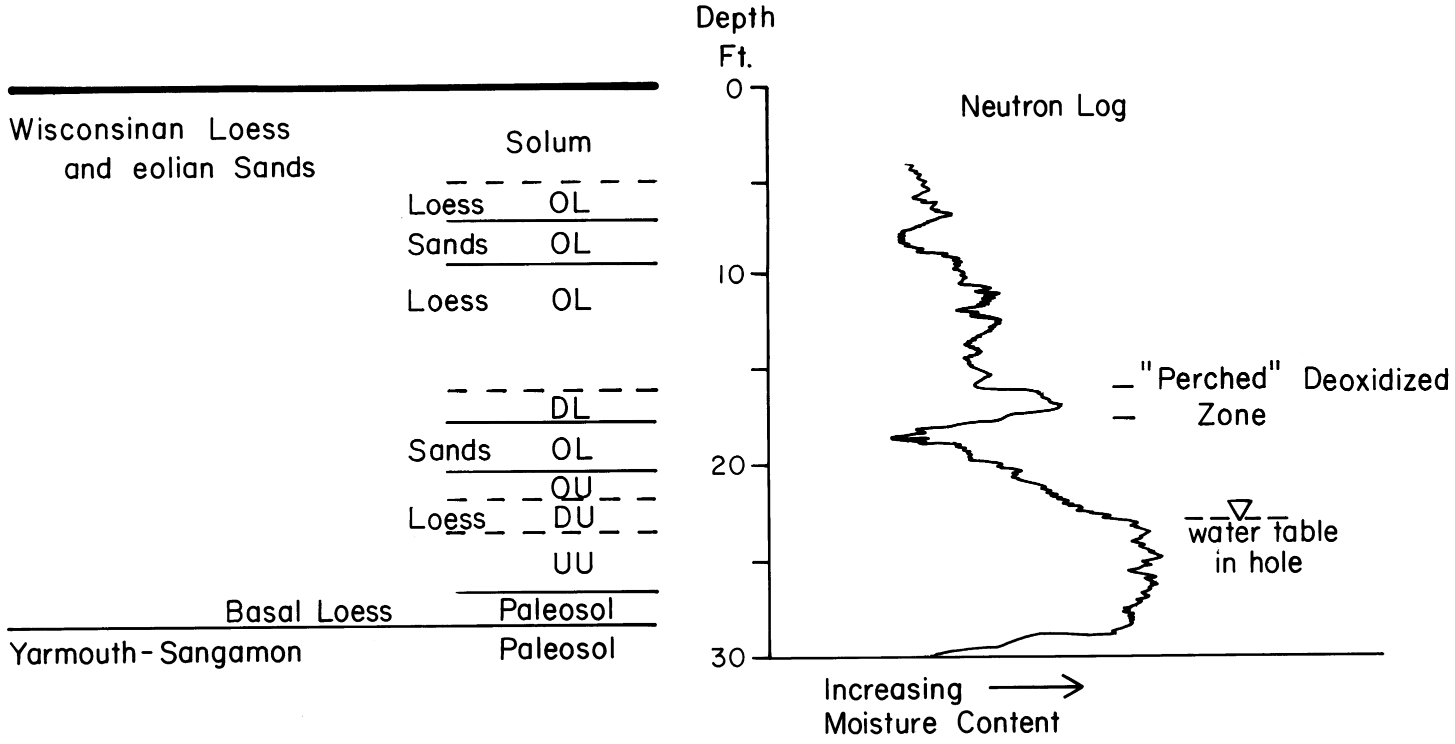


Figure 11. Loess stratigraphy, weathering zones, and neutron probe curve from Linn Co., Iowa. The neutron log shows increased moisture content in a "perched" deoxidized zone.

(Ruhe, et al. 1955). It isn't clear, though, why the underlying loess is oxidized. Work currently in progress (Ross, et al. 1976) shows that the deoxidized loess has a higher proportion of small voids, and consequently has a higher percentage saturation at field capacity, than the related oxidized loess. This situation needs further investigation.

SUMMARY

Weathering zone terminology is composed of "shorthand" phrases or symbols used to describe Quaternary sediments in terms of their color and the presence or absence of soluble carbonates. These terms are used for the materials below the soil profile where full descriptions are not possible or are not necessary. It is just as important to standardize descriptions of materials as it is to standardize laboratory data because all data are eventually linked to the description of the material. It is also important to understand fully the nature of weathering zones. Very abrupt contacts between these zones may coincide with stratigraphic breaks. However, the more gradual transitions between these zones in natural progression should not be confused with stratigraphic boundaries.

The standard weathering zone terminology presented here is a quantification and modification of classical terms that can be applied in the field. These classical terms are based on: (1) the presence or absence of carbonates (unleached vs. leached), by the simple test for a reaction with dilute hydrochloric acid; and (2) a color-related "oxidation" term.

The classical "oxidation" terms oxidized, deoxidized, and unoxidized present conceptual and technical problems because deoxidized and unoxidized are not wholly synonymous with a reduced chemical state. Deoxidized colors, for example, are more a function of low total free iron than the presence of abundant ferrous iron. Also, the concept of unoxidized, indicating never having been oxidized is certainly not appropriate for loess.

Chemical data do show that, as colors change from oxidized, to deoxidized in loess, or reduced in till, to unoxidized there is a progressive increase in the amount of ferrous iron present.

When the conceptual problems and the nature and distribution of the iron compounds are understood, these color-related oxidation terms can be useful descriptive tools.

With this in mind, standard terminology is defined and quantified in terms of specific moist Munsell colors and iron segregations, and the presence or absence of carbonates. The basic terms are: oxidized, deoxidized in loess, reduced in till, unoxidized, leached and unleached; with modifiers to indicate mottling, secondary carbonates, and jointing in till. Symbol abbreviations and their sequence are also specified.

Just as mottling and gleyed colors are indications of drainage and water table conditions in soils, abundant research indicates that weathering zones are related to hydrologic conditions. In general, the deoxidized and reduced zones are marked by fluctuating water tables and saturated conditions. Unoxidized zones are related to nearly permanent saturation. Research continues to investigate these relationships.

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