Proceedings of the Iowa Academy of Science

Volume 62 | Annual Issue Article 33

1955

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Comparisons of Petrographic and Engineering Properties of Loess in Southwest, East-Central, and Northeast Iowa

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Recent studies by the Iowa Engineering Experiment Station have been concerned with basic properties of loess. The objective of the studies is to help solve the problem of stabilization of loess for roads. To date studies have been made on loess from three areas in Iowa, southwest, east-central, and northeast Iowa (Figure 1). Property studies of loess in each area were conducted in two phases: The first phase of study was to sample the loess and determine properties and property variations within each area. Combinations of grid patterns and traverses were used to lay out the sample locations, and samples were taken at various depths at many locations. Systematic areal variations were revealed, and with a grid sampling system, it was found that contour lines could be drawn for various loess properties. These and other data have already been extensively reported on, and the bibliography will be found in references (1), (2), and (3).

The second phase of the research was to select a few C-horizon loess samples for a detailed petrographic and engineering study. These samples were carefully chosen as representative of the loess in each of the three areas. Since the loess varies within an area, samples were selected to represent the range in variations. In the preliminary studies, various loess properties were found to be related; for example, plasticity is proportional to clay content. Therefore, samples for detailed study were checked to see that their properties were consistent with these relationships.

Samples were checked to make sure that in every way their measured properties were average for the ranges represented. In addition, the special samples were so selected as to be spread out geographically. This was done that any hitherto unrecognized variations across an area might be recognized. Geographic separation was partly automatic, since loess properties vary systematically over an area, and samples had to be separated to represent variations within an area. The selection was in part subjective, in that sample locations were chosen to determine the effects of possible different source areas.

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The locations decided on are shown in Figure 1; a qualitative summary of information on these samples is given in Table I. Detailed locations are given in Table II.

In this paper the properties of these different loess samples are compared. Much of the data have been given in separate articles covering each area (1), (2), (3), but no detailed between-area comparisons were made.

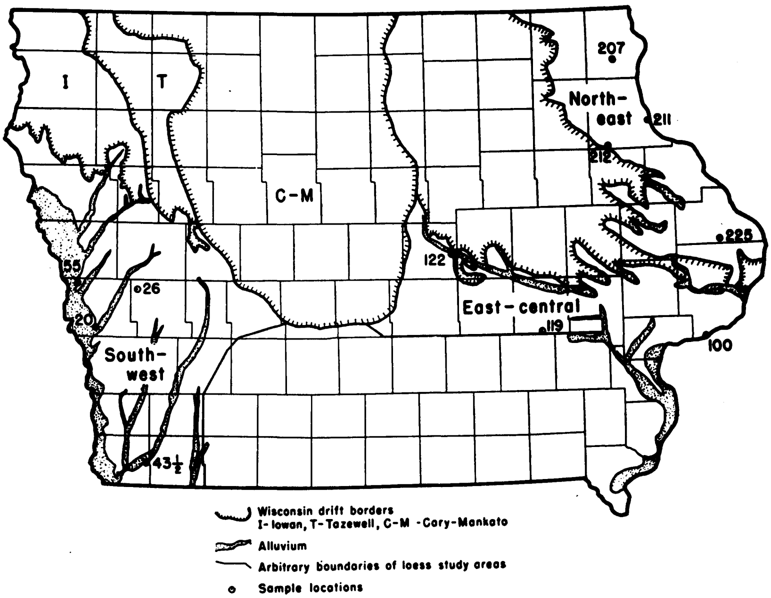


Figure 1. Map of Iowa showing sample locations in three loess areas.

Petrography

Particle Size

Particle size accumulation curves for the selected loess samples are shown in Figure 2. One southwest Iowa sample is moderately high in clay; all other samples are medium or low in clay. Low clay contents are believed to indicate nearness to a source area. Low-clay samples came from near the Missouri, Iowa or Mississippi rivers. Also selected was a medium-clay sample from near the Iowan drift plain. Particle-size curves do not form a criteria to differentiate between loesses of the three different areas.

Clay Composition.

Clay mineral compositions were interpreted from differential thermal analysis, X-ray diffraction, cation exchange capacity and staining. Clay minerals in the various loess samples are believed

Table I.

Descriptions of Loess Samples Selected for Detailed Study.
Leached, moderately plastic samples, are enclosed by the dashed line in the upper right.

Area	Samples			
SW Iowa	55-1 A very friable loess, Bignell in age, from the deep loess area adjacent to the Mo. R. floodplain.	20-2 A typical friable loess of the deep loess area adjacent to the Mo. R. floodplain. Here the total loess thickness is over 100 ft.	26-1 A typical medium-textured loess. Part of the section, including the sample, is leached from the surface. Total loess thickness, 30-40 ft.	43½-1 A typical plastic loess. Total loess thickness, 15 - 20 ft. Leached throughout.
E-Central Iowa	100-8 A very friable loess repersenting limited areas of deep loess W. of and adjacent to the Miss. R. floodplain. Total loess thickness, 38 ft.	122-6 A coarse, friable loess representing deep deposits near the Iowa River floodplain. Total thickness, 50 ft.	119-5 A typical plastic loess. Total thickness, 10 ft. Leached throughout.	
NE Iowa	211-7 A friable loess from deep deposits near the Miss. R. floodplain. Total thickness, 25.5 ft.	225-5 A friable loess from the south-central part of the area. Total thickness, 12 ft.	207-5 A moderately friable loess from the north-central part of the area. Total thickness, 12.5 ft.	212-5 A moderately friable loess from deep deposits near the Iowan drift border. Total thickness, 18.5 ft.

INCREASING CLAY →

Table II.

Locations of Selected Loess Samples

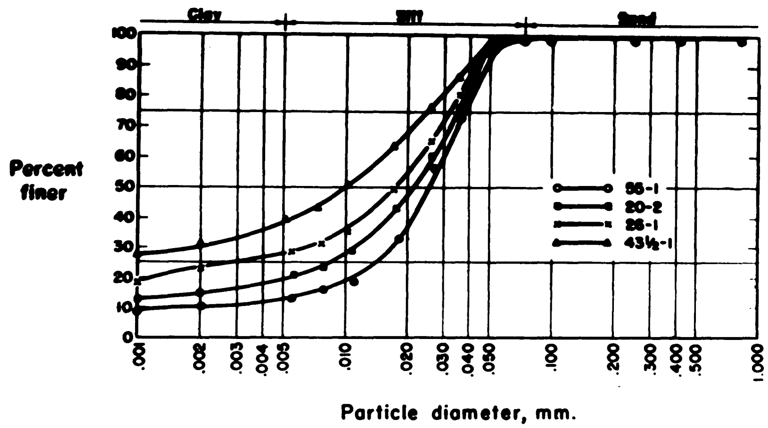
Area	Sample No.	Sampling Depth, ft.	Location
SW Iowa	55-1	2½-3½	Harrison Co. T81N, R44W. SW/c Sec. 8.
	20-2	39-40	Harrison Co. T78N, R43W. NW¼ NE¼ Sec. 15.
	76-1	4-5	Selby Co. T81N, R40W. SW¼ SE¼ Sec. 21.
	43½-1	5-6	Fremont Co. T68N, R40W. NW/c Sec. 36.
E-Central	100-8	25-25½	Scott Co. T77N, R2E. N½ SW¼ Sec. 13.
	122-6	14-14½	Marshall Co. T83N, R17W. NE¼ SE¼ Sec. 3.
	119-5	6-6½	Iowa Co. T78N, R10W. NE¼ NW¼ Sec. 31.
NE Iowa	211-7	17¼-18¼	Clayton Co. T92N, R2W. SE¼ SE¼ Sec. 6.
	225-5	10-10½	Jackson Co. T84N, R4E. SW¼ SE¼ Sec. 19.
	207-5	10-10½	Allamakee Co. T97N, R5W. NE¼ SE¼ Sec. 23.
	212-5	12¼-12 3/4	Clayton Co. T91N, R5W. SE¼ SW¼ Sec. 27.

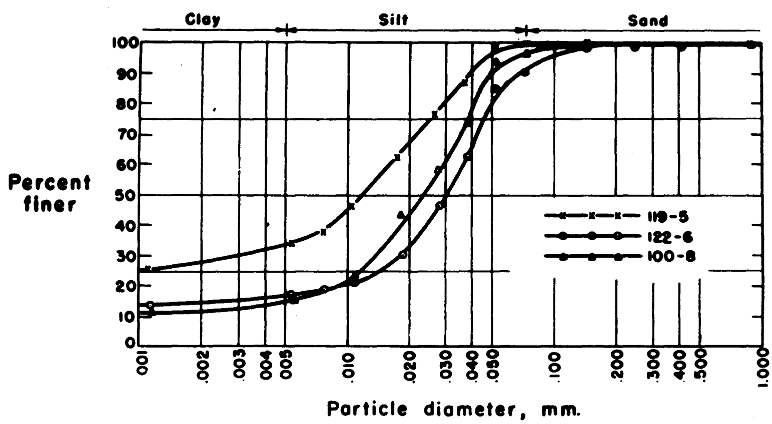
to be essentially the same. The common clay minerals appear to be an intimate mixture of montmorillonite and illite, with montmorillonite predominating. X-ray data show a low, non-uniform glycol expansion suggestive of interlayering. Typical D.T.A. curves are shown in Figure 3. X-ray spectrometor curves are shown in Figure 4. Due to limitations in the methods, accurate quantitative comparisons cannot yet be made.

Silt and Sand Composition.

Grains larger than 5 microns (0.005 mm) were separated into size fractions and examined microscopically. The data for the whole loess samples are presented in Table III.

Figure 2. Particle-size accumulation curves for loess samples from three areas. Top, SW Iowa; center, E-C Iowa; bottom, NE Iowa.


Clay
Silt
Sand
Percent finer
56-1
20-2
26-1
43½-1
Particle diameter, mm.


Clay
Silt
Sand
Percent finer
119-5
122-6
100-8
Particle diameter, mm.

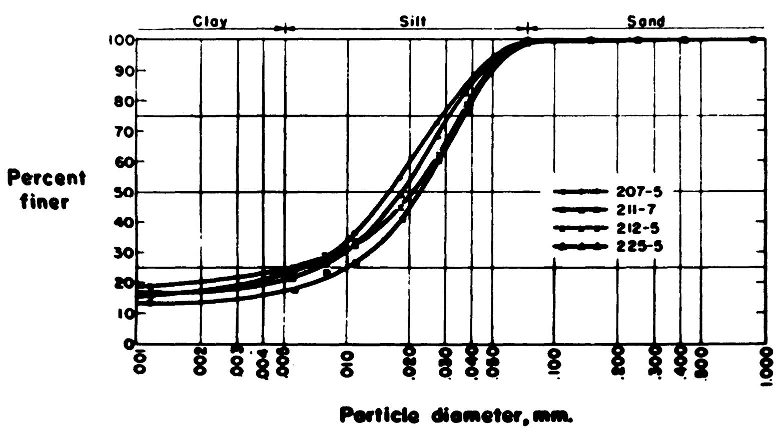

Clay
Silt
Sand
Percent finer
207-5
211-7
212-5
225-5
Particle diameter, mm.

Table III.

Compositions of Loess Samples.

Area	SW Iowa				E-Central Iowa			NE Iowa			
Sample No.	55-1	20-2	26-1	43½-1	100-8	122-6	119-5	211-7	225-5	207-5	212-5
Sand and Silt, $>5\mu$:											
Quartz	41.1	45.0	48.1	41.5	45.2	49.4	50.3	53.8	51.6	50.3	52.8
Dolomite	1.3	1.1	....	....	5.3	1.1	....	2.4	1.8	2.5	1.8
Feldspar	25.7	17.1	15.8	13.9	16.6	17.1	12.0	8.9	7.5	6.8	6.9
Calcite	7.9	10.7	0.9	0.3	15.3	11.7	0.3	12.0	13.4	13.1	8.8
Mica	0.9	0.7	1.6	1.3	0.3	0.2	0.5	2.0	1.8	1.2	1.9
Volcanic Glass	1.8	1.4	0.8	0.4	....	....	....	....	....	....	....
Heavy Minerals	5.6	4.9	4.0	3.1	4.6	4.4	5.1	3.4	2.9	3.2	2.4
Others	0.4	0.4	1.1	0.5	1.3	0.5	0.3	0.5	0.4	0.4	1.0
Clay, $<5\mu$	13.0	20.0	27.8	39.0	12.0	15.8	32.0	17.0	20.6	22.5	24.4

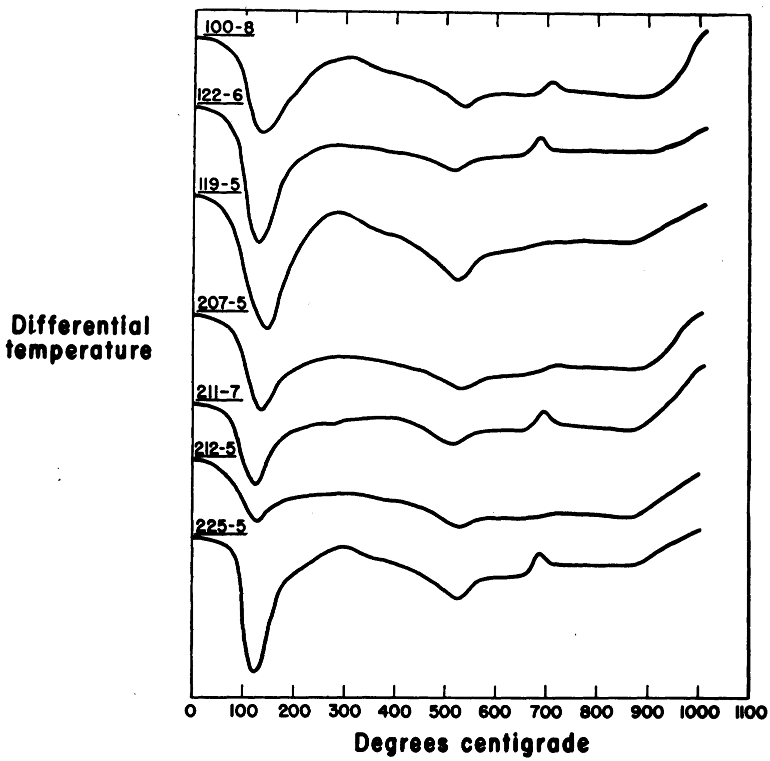


Figure 3. Differential thermal analysis curves for -2μ clay fractions. Pre-humidity, 50%. Exothermic peaks at 700° are unexplained.

In Figure 5 it can be seen that the loess samples from Northeast Iowa are distinctively low in feldspar. In east-central and southwest Iowa, there is a considerable overlapping of feldspar contents. One sample contains almost 10 percent more feldspar than any other; this sample is from one of the few locations of Iowa loess which has been identified as Bignell in age (5).

Perhaps one of the best criteria for recognition of southwest Iowa loess is the presence of minor amounts of volcanic glass. Volcanic glass was not found in samples from east-central and northeast Iowa.

Another strong difference between samples from the three areas was noted: Northeast Iowa samples usually contain more dolomite. The one exception is a high-dolomite sample which occurs in east-central Iowa (100-8) adjacent to the Mississippi River floodplain. It is believed that the occurrence of dolomite may reflect probable source areas; this possibility has been discussed (2).

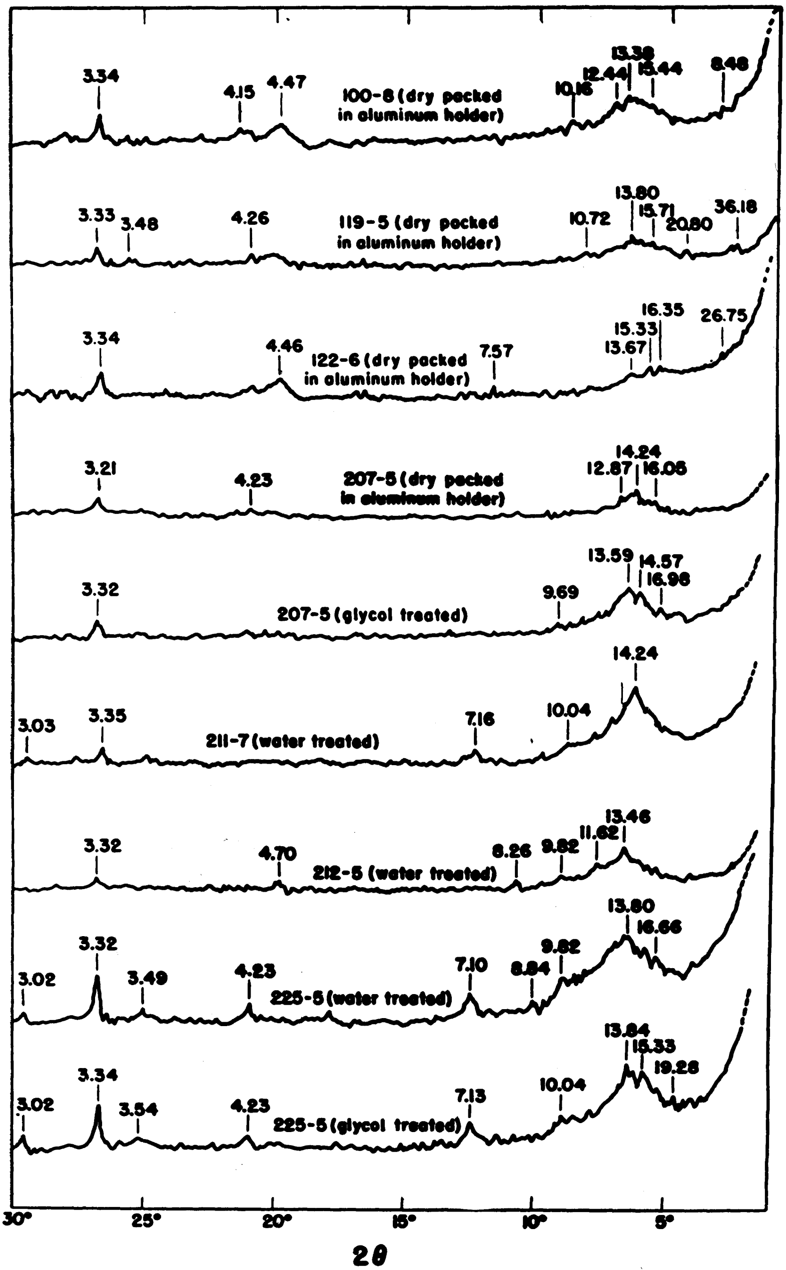


Figure 4. X-ray spectrometer curves for 24μ clay. Numbers written over the reflections indicate Angstrom spacings.

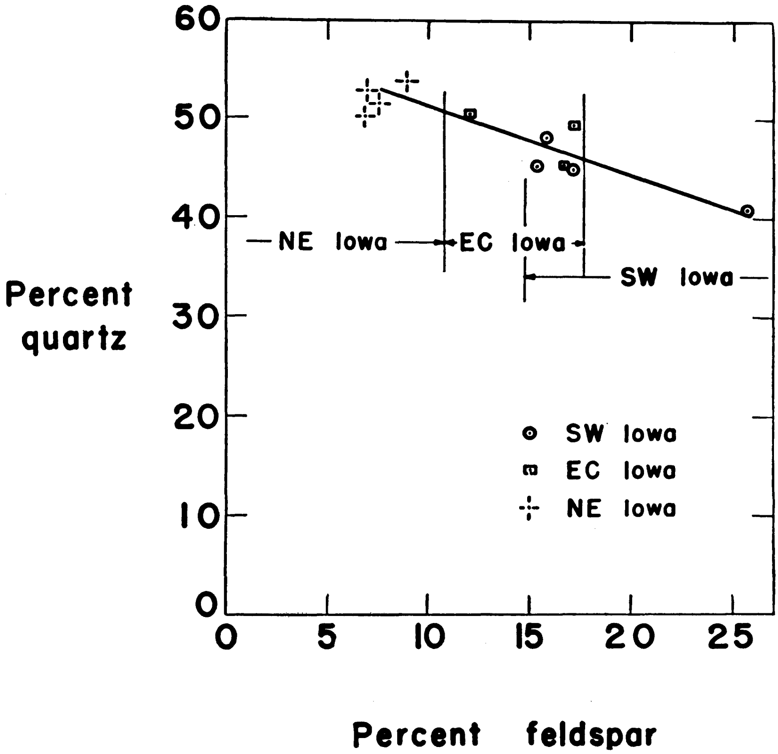


Figure 5. Feldspar and quartz percentages for loess in Iowa.

A more detailed breakdown of the mineralogical compositions is given elsewhere (2), (3), (4). Orthoclase is the dominant feldspar, with traces of plagioclase and microcline usually present. Muscovite is the principle mica; some biotite also occurs. Amphiboles, pyroxenes and iron oxides dominate among the heavy minerals.

Sphericity and Roundness.

The averages of loess grain sphericities in various samples are remarkably uniform, but sphericities tend to be slightly higher in northeast Iowa (Table IV). These samples are also lower in feldspar. Typical histograms showing size distributions of sphericity and roundness are shown in Figure 6. All sphericity histograms are slightly skewed towards the right. The reason for this is not known.

Table IV.

Average Sphericities of Silt Grains in Loess Samples.

Area	Sample No.	Average Sphericity*
SW Iowa	55-1	0.76
	20-2	0.76
	26-1	0.76
	43½-1	0.77
E-Central Iowa	100-8	0.76
	122-6	0.76
	119-5	0.76
NE Iowa	211-7	0.79
	225-5	0.77
	207-5	0.79
	212-5	0.78

$$*\text{Sphericity} = \frac{\text{Intermediate Diameter}}{\text{Maximum Diameter}}$$

Surface Area.

Since compositions were determined in each size fraction, surface areas may be calculated. Spherical grain shapes are assumed; since the average sphericity is nearly constant, the error in different samples should be practically constant. The surface areas of various minerals should be more important for chemical stabilization than are the actual mineral percentages. The relationship between surface area and grain size can be seen by comparing Figures 7 and 8: Surface areas are higher in finer sizes. Mineral surface areas for various samples are summarized in Table V; their significance is discussed later.

Chemical Tests.

Cation exchange capacity is one of the best indicators of clay minerals; cation exchange capacity plotted against clay content is shown in Figure 9. The southwest Iowa and northwest Iowa samples show the same relation to clay percentage, indicating a probable similarity in clay mineral composition. The east-central Iowa cation exchange capacities are low and do not fall on the same straight line. This may indicate less montmorillonite and more illite in the east-central Iowa samples.

Table V.

Calculated Non-Clay Mineral Surface Areas in the Loess Samples, sq. cm/gm

Area	SW Iowa				E-Central Iowa			NE Iowa			
Sample No.	55-1	20-2	26-1	43½-1	100-8	122-6	119-5	211-7	225-5	207-5	212-5
Quartz	410	502	520	647	552	407	588	549	584	669	516
Feldspar	241	177	187	236	218	170	167	96	94	81	85
Calcite	81	110	11	8	218	138	7	153	200	206	118
Dolomite	16	12	....	....	56	10	....	25	22	33	22
Volcanic Glass	21	12	9	4	....	....	....	....	....	....	....
Heavy Minerals	53	42	62	62	56	42	78	36	34	43	28
Mica and Others	10	7	23	11	30	9	14	22	29	18	28
Total	842	862	812	968	1130	776	854	881	963	1050	797

Chemical determinations of organic matter show less than 0.2 percent in most samples. Sulphates and chlorides are present only in trace amounts or are absent. The free iron content is usually less than one percent. The pH of calcareous loess is slightly basic; the pH of leached loess is near neutral. These data are practically the same for samples from all three areas — no differences are shown.

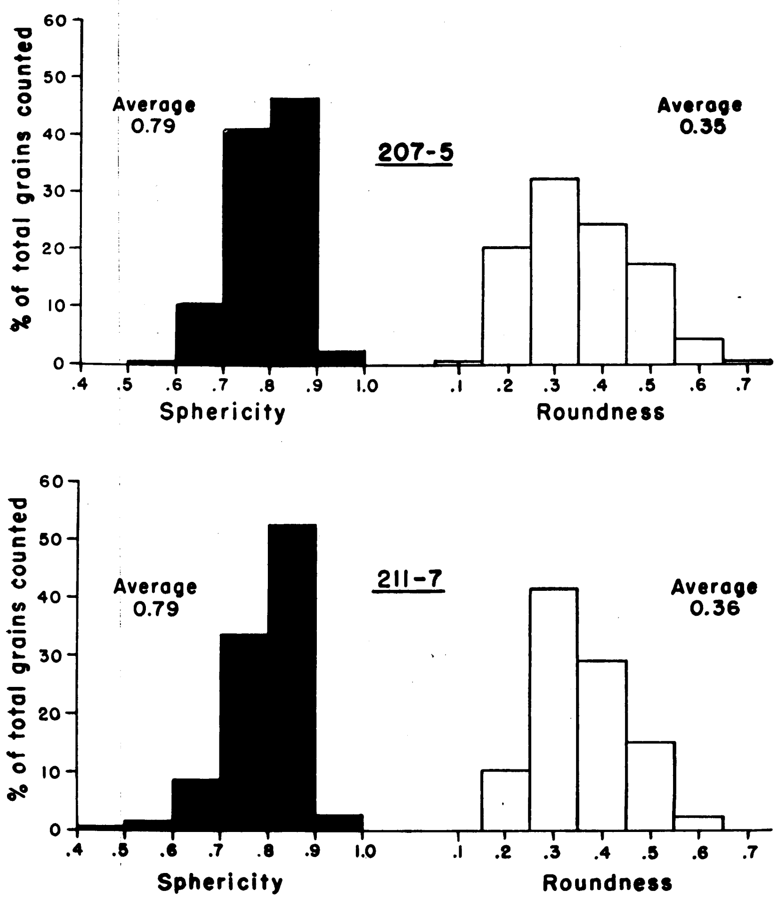


Figure 6. Histograms showing grain sphericity and roundness in two loess samples.

Engineering Properties

Prediction with Soil-Cement.

Studies with soil-cement have indicated that reactivity of Southwest Iowa loess may be related to quartz surface area (3). Also, reactivity appears to be greatly reduced by clay, probably because much of the clay occurs as coatings on the silt grains. An empirical (and tentative) Reactivity Index was devised to express these two relationships. Indexes calculated for the various samples are shown in Table VI, along with soil-cement results for loess from southwest Iowa. Reactivity was indicated by large strength gain through a severe weathering test. From Table VI, it would be expected that most of the loess in Northwest Iowa would be reactive, and the localized dolomitic loess deposits in east-central Iowa along the Mississippi River would be reactive. Of course, this is as yet unknown; further research with soil-cement should show if it is true.

Table VI.

Possible Soil Cement Reactivity of Various Loess Samples

Sample No.	Area	Calculated Reactivity Index*	Known Reactivity†
207-5	NE	555	
100-8	E-Cent.	535	
211-7	NE	500	
225-5	NE	497	
20-2	SW	422	Reaction
55-1	SW	388	Somewhat reactive
212-5	NE	371	
122-6	E-Cent.	368	
26-1	SW	306	Very slightly reactive
119-5	E-Cent.	261	
43½-1	SW	54	Not reactive

*RI=Spec. Surf. (in sq. cm/gm)—0.01 x (percent clay)^3.
†Indicated by strength *gain* during severe weathering test.

Plasticity.

Plasticity is related in part to clay content, as shown in Figure 10. The engineering classification of the samples by the Bureau of Public Roads method is shown in the same graph. A-6 and A-7-6 C-horizon samples are only found away from the major rivers. The A-6 sample from Northeast Iowa was taken adjacent to the Iowan drift border, but not near any major outwash stream. Near large rivers the loess is usually the more friable A-4.

Proctor Density; C.B.R.

The Proctor density is the soil density obtained with a standard compactive effort. An optimum moisture content gives a maximum Proctor density which appears to be related to sand content, particle shape, and clay. The optimum moisture is increased by an increase in clay, due to water retention by the clay. Samples low in clay have a very critical optimum moisture content, probably due to the uniform particle size.

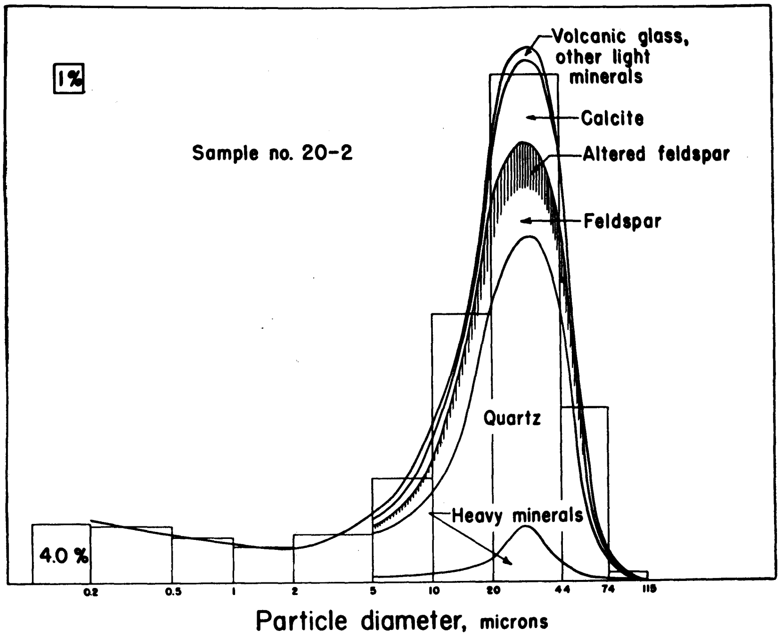


Figure 7. Diagram showing percentages of minerals in various size fractions of a loess sample.

The California Bearing Ratio is a penetration measurement of compacted soil; it is expressed as a percent comparison to rolled stone. C.B.R. values are related to the compacted density, as shown in Figure 11. The highest C.B.R. value is for an East-Central Iowa sample (122-6) containing about 10 percent fine sand. This sample also has a high C.B.R. after soaking. The second highest value is for a northeast Iowa sample (225-5) with almost no sand and moderate clay. This sample compacts to a higher density than a southwest Iowa sample (20-2) with the same percent of clay, and it does so with less moisture. The southwest Iowa sample is consistently coarser and contains slightly less clay — yet it has a lower C.B.R. There are a number of possible explanations, none of which seem to apply consistently to all samples. In fact, wide variations have been found in the compactibility of different hatches of sample 20-2. The size gradation curves show no wide variations. The only relatively unmeasured variable is the clay. Two things are not known about the clay, an accurate, quantitative, mineralogical composition, and an accurate *measure* of how the clay occurs in the loess — whether as particles, aggregates, or as coatings.

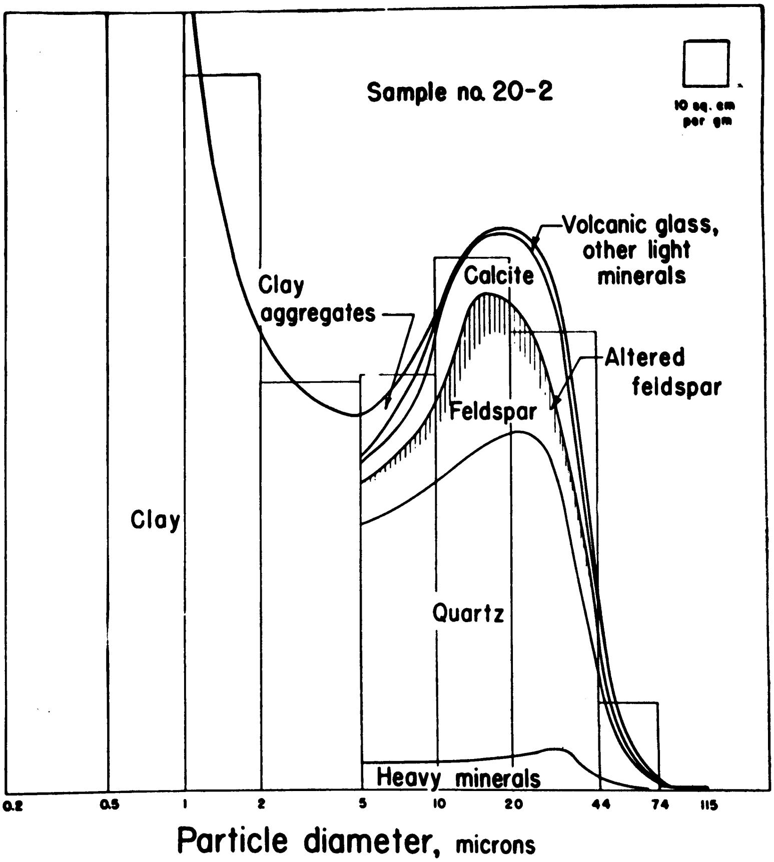


Figure 8. Diagram showing surface areas of minerals in various size fractions of a loess sample.

Clay-silt relationships have been noted and visually estimated with the use of the microscope, for some of the samples. In general, most of the clay grains are adhering to the larger silt grains, partially coating the silt. Estimations for percent coverage ranged from 15 to 40 percent for various samples, the higher values being for samples higher in clay. Superficial examinations indicate that Northeast Iowa samples with the exception of No. 211-7 have a higher percentage of clay coatings than do southwest Iowa samples with the same percent clay. The clay may serve as lubrication, allowing more compaction, or it may more efficiently aid cohesion. Thus 225-5, with the same percent clay as 20-2, appears to have more clay as coatings, possibly making compaction easier and giving a C.B.R. It should be noted that 225-5 shows a much greater loss of C.B.R. on wetting.

Other anomalies shown in Figure 11 are as difficult to explain. Samples 119 and 212, high in clay, compact to a high density but have a low C.B.R. Is this due to a higher clay occurrence as coating? One B-horizon sample high in clay, compacts to a low density but has a relatively high C.B.R. More clay as aggregates, less as coatings? These questions cannot easily be answered, especially since standard methods of mechanical analysis are designed to destroy the natural aggregation of the clay. It is apparent that new methods are needed if the C.B.R. is to be predicted.

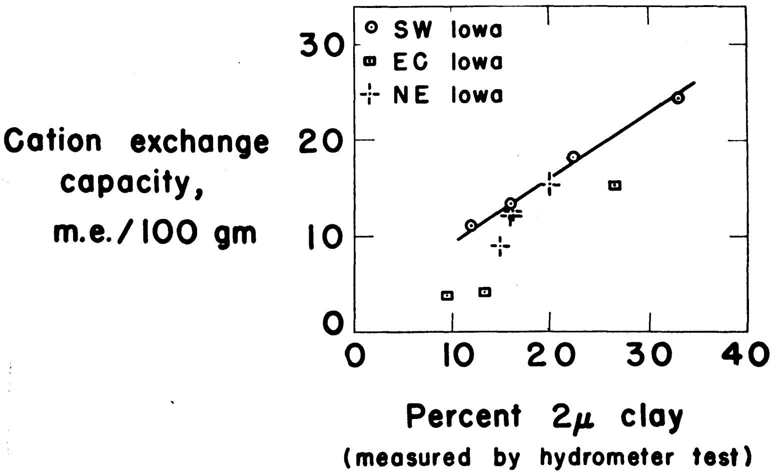


Figure 9. Cation exchange capacity of whole loess samples related to their clay content.

Conclusions

1. There are no unique features of particle-size that would show from which of the three study areas any sample had come.

2. Clay mineral compositions qualitatively are believed to be the same. The principal clay minerals appear to be an interlayered mixture of montmorillonite and illite. Quantitative differences have not been measured.

3. Compositions of loess, silt, and sand show three distinctive features:

   a. Northeast Iowa samples are distinctively low in feldspar, running from 5 to 10 percent. The single Bignell loess sample is distinctively high in feldspar, containing 25 percent. East-central samples and other southwest samples are in between.

   b. Southwest Iowa loess samples contain volcanic glass. Northeast and east-central Iowa samples do not.

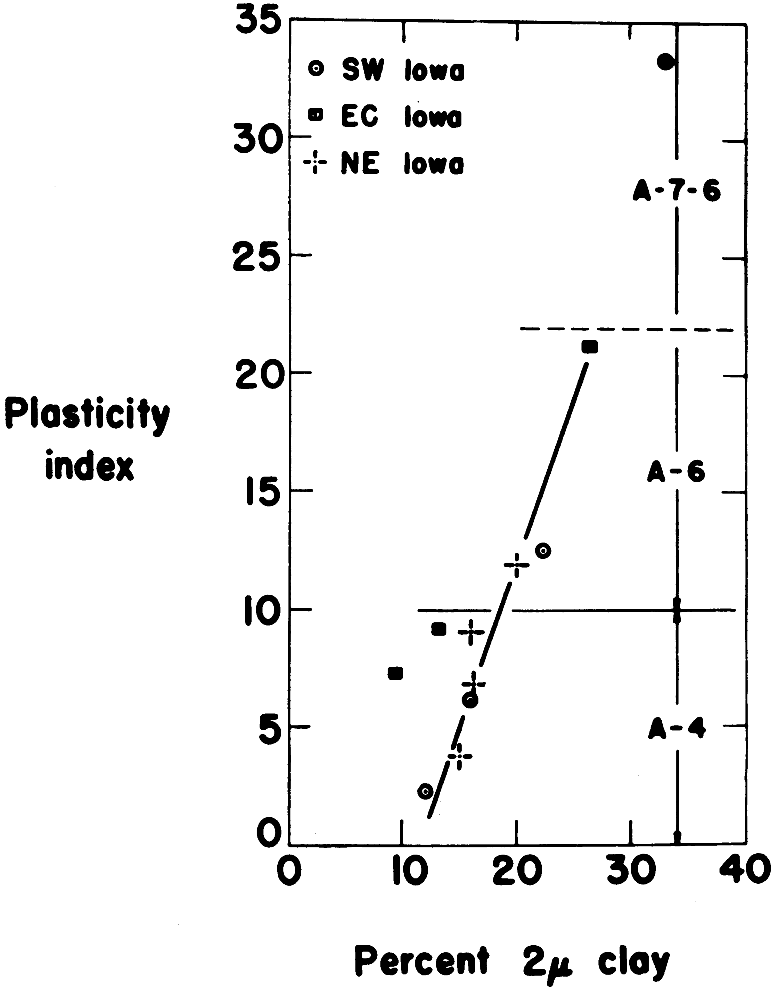


Figure 10. Plasticity index related to clay content. An engineering soil classification of the samples is shown at the right.

c. Northeast Iowa samples contain slightly more dolomite than do other samples. The one exception from near the Mississippi River is an east-central Iowa sample which is very high in dolomite.

4. Sphericities of various samples are very nearly the same but tend to be slightly high in northeast Iowa, perhaps because of the lower percentage of feldspar and the higher percentage of quartz.

5. Cation exchange capacity is related to clay content. East-central Iowa samples have a low cation exchange capacity relative

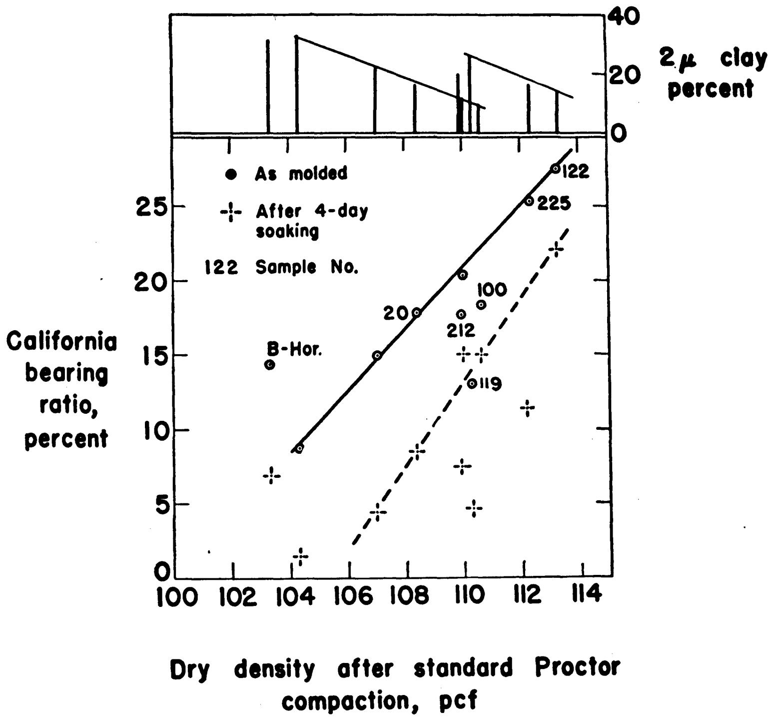


Figure 11. California Bearing Ratio related to compacted density. There are two points for each sample, since the C.B.R. is lowered by soaking. Graph at the top shows the clay content of each sample.

to their clay content. They, therefore, may contain less montmorillonite. This is the only indication of a clay difference.

6. Silt mineral surface areas have been calculated, and on the basis of an empirical formula, predictions have been made for soil-cement. The predictions may not be valid due to uncertain effects of the clay (see below). If they are valid, northeast Iowa samples and the dolomitic east-central Iowa sample should react well in soil-cement.

7. The California Bearing Ratio is usually related to compacted soil density. Almost identical samples were found to be widely variant in compaction. This and other C.B.R. anomalies cannot be explained without a difference in clay. Partial observations indicate that this may be largely a difference in disposition of the clay rather than a difference in clay mineral.

Acknowledgment

The subject matter of this report was obtained as part of the research being done under Project 283-S of the Engineering Experiment Station of Iowa State College. This project entitled, "The

Loess and Glacial Till Materials of Iowa; an Investigation of Their Physical and Chemical Properties and Techniques for Processing Them to Increase Their All-Weather Stability for Road Construction", is being carried on under contract with the Iowa Highway Research Board and is supported by funds supplied by the Iowa State Highway Commission and the U.S. Bureau of Public Roads.

The writers are also indebted to Dr. C. J. Roy, Geology Department, Iowa State College, for the X-ray analyses, and to the Ames Laboratory, U.S. Atomic Energy Commission, for use of x-ray equipment. Also to Dr. T. Y. Chu and J. B. Sheeler, Iowa Engineering Experiment Station, and to others whose researches contributed much to the substances of this paper.

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