COMPARISONS OF TEXTURE CLASSIFICATIONS OF EARTHY MATERIALS USED BY ENGINEERS AND SOIL SCIENTISTS IN THE UNITED STATES

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ABSTRACT

COMPARISONS OF TEXTURE CLASSIFICATIONS OF EARTHY MATERIALS USED BY ENGINEERS AND SOIL SCIENTISTS IN THE UNITED STATES

by Chwan-chau Wang

Two thousand eight hundred and ninety four soil samples taken from throughout the U.S. have been studied relative to: (1) the possibility of common size class limits desirable for both soil scientists and engineers, (2) the possibility of a revised texture triangle more in accordance with the engineers soil groups, (3) the relationships between liquid limits and USDA textural classes, (4) the relationships between plasticity indices and USDA textural classes, and (5) the possible improvements in correlations of particle size distributions with other properties of fine earth materials by different choices of the silt size range. As far as the silt size class is concerned, the percentage of 0.002-0.074 mm or 0.002-0.1 mm as silt are commonly well correlated with that of the percentage of 0.002-0.05 mm silt. The mean increases in percentage of silt when 0.074 mm or 0.100 mm are the upper silt size limits instead 0.05 mm were 4.9 and 9.2, respectively, according to the study of more than 230 selected samples. The factor 0.89 was proposed to obtain the USDA 0.05-0.002 mm silt from the 0.074-0.002 mm engineers value. It was found that there is usually not much increase in the clay contents in the < 0.42 mm materials, commonly used by engineers for determination of liquid limits and plasticity indices, compared to < 2.0 mm materials used for texture analyses by soil scientists. It is suggested that soils with clay contents larger than 15% and clay activities greater than 0.7 may be considered as having active clays which may serve as a general index to predict the kinds of clay minerals present. Eight AASHO soil groups (or group-complexes), eleven Unified soil groups (or group-complexes), and the significant liquid limit and plasticity index values for engineers have been delineated on the USDA texture triangle. These show pretty good agreement with the delineations separating the USDA textural classes. A revised texture triangle proposed by Whiteside has been tested and it is shown that the proposed revised textural classes correlate better with the AASHO and Unified classes than the current USDA textural classes. A revised diagram for family grouping in the new soil classification system, based on the 0.05-0.002 mm fraction as silt size, is also proposed.

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By

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INTRODUCTION

Soil texture refers to the defined proportions of size groups of individual soil grains in a mass of soil material. Pedologically, it refers to ranges in the proportion of clay (< 0.002 mm), silt (0.05-0.002 mm), and sand (0.05-2.00 mm) in fine earth (< 2.0 mm) materials.

But, if we look back to 1890, soil texture was broader than today's limited meaning. In 1890, Milton Whitney used the term "texture" to include what we call grain-size distribution; soil structure; soil consistence and even organic matter. Gradually but with no clearly defined date, soil consistence, soil structure and organic matter content were expressed as separate terms, and the term "texture" became limited to grain-size distribution alone.

Since soil texture is determined by proportions of various size groups of soil particles, if we use different size-limits for those groups or different textual classification diagrams that define their proportions, we have different soil texture classifications. Today, many sets of size-limits and many texture classification diagrams for mineral soil particles and sediments are used by the soil scientists, the engineers, and the geologists in the United States as well as in the rest of the world. Each set of size-limits was developed by a discipline to fit its own needs largely independent of the other disciplines and some of these were chosen arbitrarily without good reasons for the differentiations.

In the United States there are at least one set of size-limits and two soil classification diagrams used to define the soil groups important to engineers, e.g. the American Association of State Highway Officials (AASHO) soil classification, and the Unified Soil Classification (Corps of Engineers, Department of the Army, and Bureau of Reclamation). Another set of size-limits and another classification diagram is used by soil scientists to define soil texture classes commonly called the USDA system. The geologists commonly use still another set of particle size classes. Therefore, one soil sample may be given various classifications by soil scientists, engineers, and geologists depending on the size-limits set and the classification system used.

In the United States the most disagreement lies in the size-limit of "silt" which is very important and meaningful to each discipline. Soil scientists use 0.05 mm; civil engineers, 0.074 mm; and geologists use 0.063 mm as the upper size-limit for silt. Soil texture classes of soil scientists are now based almost exclusively upon particle size distribution. However, the engineers also use the liquid limit and the plasticity index of the < 0.42 mm fraction, the type of fine in addition to the shape of the grain-size distribution curve, and even organic matter content in their soil classifications. Although the differences in the silt size-limits are not great, they are large enough to be troublesome in communicating and interpreting one another's information. Accordingly, in 1960, the National Technical Work-planning Conference of Cooperative Soil Survey recommended that the feasibility of attaining agreement on one set of grain-size limits be evaluated. The possibility of uniform size class limits, and perhaps eventually a uniform texture classification, is being worked on by a committee on Particle Size and Distributions of the Soil Science Society of America. This committee was appointed in 1963 and several groups of engineers and geologists have agreed to investigate these possibilities with soil scientists. In 1965, a workshop on particle size distribution, the first joint discussion by these professional groups, was held in Columbus, Ohio. It is particularly desired to reach agreement among geologists, engineers, and soil scientists for defining the size-limit of silt. Silt is an important size fraction to soil scientists because it greatly affects available water holding capacity; to engineers because of its unstable property and to both groups because of its relation to frost heaving.

Soil information obtained by soil scientists is valuable to engineers because maps made by soil scientists provide information about soil texture, mineralogy, slope, natural drainage, organic content, and other characteristics. Engineers use of agricultural soil information is becoming more common with the rapidly increasing population and the greater needs for planning and designing of buildings, roads and water-retaining structures.

Highway engineers have probably used soil survey information more than any other non-agricultural technical group. In the development of the new system of soil classification, some soil properties of relevance to engineers have also been taken into consideration for grouping soil series into families (Soil Survey Staff USDA 1960, 1964).

This study, on the basis of USDA size-limits, tries to first relate the USDA soil texture chart to the AASHO and Unified soil classifications (including the liquid limits, and the plasticity indices used by civil engineers); and second to modify the soil texture definition to give more useful and mutually agreeable particle size and texture classes. If this work contributes to the prospects of attaining agreement on a soil texture classification system that is more useful to engineers, geologists and soil scientists and thus facilitates the sharing and supplementing of each other's information, it will not have been in vain.

LITERATURE REVIEW

Size-Limits

Early as 1814, soil particle size class limits had been developed by Wanschaffe in Germany. He used the following size classes and limits:

Size class	Size-limits (mm)
fine gravel	> 2.0
very coarse sand	2-1
coarse sand	1-0.5
medium sand	0.5-0.2
fine sand	0.2-0.1
very fine sand	0.1-0.05
silt	0.05-0.01
fine clay portion	< 0.01

Actually, these size classes correspond closely to the existing USDA system except for the fine clay portion, < 0.01 mm, which is much greater than < 0.002 mm. By his using 0.01 mm as the fine clay upper limit, it is obvious that the concepts of colloids had not been developed at the beginning of the nineteenth century. Later, Hilgard (1893, U.S.A.); Osborne (1887, U.S.A.); Wolf (1891, Germany); Kuhn (1894, Germany); Williams (1895, Russia); Whitney (1896, U.S.A.); Hopkins (1897, U.S.A.) etc. proposed various sets of size-limits for use in agriculture. Simultaneously, Orth (1875); Diller (1898); Udden (1898) etc. also presented several systems of grain size-limits for geologists. Most of these systems were probably based on arbitrary selections of particle size-limits and some were also based on grain shape, cohesion (Williams), and hydraulic value (mm/sec., Hilgard).

Extensive studies of soil properties were made in Sweden in the early part of the twentieth century by Atterberg. Between 1905-1914, he published many papers about the grain size-limits. Atterberg placed the size-limit between sand and silt at 0.02 mm; between silt and clay at 0.002 mm; and between sand and gravel at 2.0 mm. He gave as the reasons for these selections that particles from 0.02-0.002 mm possess good capillarity and allow fast capillary movement of water. Grains finer than 0.02 mm show very high capillarity but the movement of water in the capillaries is retarded. The particles smaller than 0.002 mm exhibit strong Brownian Motion when settling from a water suspension, and show very retarded movement of water in the capillaries. He placed the limit between sand and gravel at 2.0 mm because material larger than this limit possess an insignificant capillarity.

In 1914, Atterberg's particle size-limits were discussed and accepted as an international system by an international commission on mechanical and physical soil investigations; it was adopted by the Agricultural Education

Association of Great Britain in 1927 and became known as the Official British Method in 1928 with a modified velocity of settling scale.

In 1912, engineers set forth to develop their own grain size-limits. Goldbeck (1921); Boyd (1922); Terzaghi (1925); Gilboy (1930, so called M.I.T. System); Hogentogler (1931) etc. proposed several systems which utilized part of Atterberg's limits and part of the limits of a German permanent committee in 1894 with some exceptions. The engineers at that time chose the limits they used because of convenience of separation by the sieve method being used and the portion remaining in suspension after centrifuging.

Meanwhile, Keilhack (1908), and Grabau (1913) proposed two sets of size-limits for geologists. In 1922, Wentworth selected a scale of size-limits for geologists. In 1943, Alling proposed a grade scale for sedimentary rocks. These two systems built up the system of grain sizes proposed by a subcommittee on sediment terminology of the American Geophysical Union in 1947 and now recommended for practicing geologists.

In Agriculture, Shaw and Alexander (1936) reported that soils were divided into silt 0.05-0.005 mm; coarse clay 0.005-0.002 mm; and fine clay or colloid $<$ 0.002 mm groups. Also, Truog, Taylor, Simonson and Week in 1936 recommended changing the lower limit of silt from 0.005 mm to 0.002 mm which corresponded to Atterberg's limit. This limit was adopted by the Soil Science Society of America and the USDA in 1938. The "fine gravel" was further changed to "very coarse sand" in 1947. The following size class limits are now recognized by U.S. soil scientists in what is commonly referred to as the USDA system:

Size class	Size (mm)
gravel	> 2.0
very coarse sand	2.0-1.0
coarse sand	1.0-0.5
medium sand	0.5-0.25
fine sand	0.25-0.1
very fine sand	0.1-0.05
silt	0.05-0.002
clay	< 0.002

In 1947, the civil engineers defined the size limits of gravel and sand on the basis of grain size; sand and silt on grain size and capillarity; and silt and clay on the basis of plasticity. They chose those properties because of their importance in designating size-limits for the practical purposes important to engineers. The limit between sand and silt was put at 0.074 mm (No. 200 sieve); the limit between gravel and sand was placed at 2.0 mm (No. 10 sieve); particles finer than 0.074 mm were called the clay and silt fraction. The American Society for Testing and Materials (ASTM, 1958), and American Association of State Highway Official (AASHO, 1950) used the following limits and made the coarse materials to correspond to the standard sieves used:

Size class	Size limits (mm)	Sieve number
particles larger than (gravel)	2.0	> 10
coarse sand	2.0-0.42	10-40
fine sand	0.42-0.074	40-200
silt	0.074-0.005	
clay	< 0.005	
colloid	< 0.001	

In 1961, the ASTM system renamed its "coarse sand" fraction as "medium sand" and called 4.76-2.0 mm as coarse sand; 76.2-4.76 mm was designated as gravel for the purpose of concrete aggregate.

Atterberg Limits

As mentioned above, the textural classification by engineers is not based entirely on the proportions of particle sizes but also on the plasticity index, and the liquid limit of the fraction finer than 0.42 mm. As a soil material changes in consistency, its engineering properties, e.g. shearing strength and bearing capacity also change. Since consistency varies markedly with water content and degree of base saturation, Atterberg in 1911 suggested two simple tests for determining the moisture content at the upper and lower limits of the moisture range within which a soil exhibits the properties of a plastic solid. He thus established the liquid limit (L.L.), plastic limit (P.L.) and shrinkage limit (S.L.) which are called Atterberg limits or Atterberg constants. The liquid limit is the moisture content at which a soil passes from a plastic to a liquid state, and the plastic limit is the moisture content at which a soil changes from a semisolid to a plastic state. The moisture content at which shrinkage stops is called the shrinkage limit. The plasticity index (P.I.) is defined as the numerical difference between the liquid limit and the plastic limit. Atterberg (1911, 1912) and Terzaghi (1926) have shown that the plasticity index of a soil increases with the increase of clay content. Russell (1926) has reported that the plasticity index is a linear function of the clay content (< 0.005 mm particles). Soils containing less than 15% clay are generally non-plastic. Novak and Hrubes (1936) reported that plasticity and hygroscopicity was proportional to the clay content of the soil material. Gill and Carl (1957) reported that the plasticity index was closely correlated with the specific area ($r = 0.752$) and with the percent of < 0.002 mm clay ($r = 0.870$) of Alabama soils. They also found a high correlation between the plastic index and the sticky point ($r = 0.809$). An intensive study on the relationship of Atterberg limits to some other properties have been worked out by Odell, Thornburn and McKenzie for Illinois soils (1960). They found the correlations between cation-exchange capacity and Atterberg limits were considerably lower than the correlations of each of the Atterberg limits with the percent of organic carbon and the percent of < 0.002 mm clay. The percent of < 0.002 mm clay is highly correlated with the plasticity index (r = 0.959) but very little correlated with the plastic limit (r = 0.239). The addition of silt (0.05-0.002 mm) had very little influence on the correlation coefficients for the liquid limit and the plasticity index. Atterberg (1912) in his original investigations showed that the kind of minerals affect the plasticity. Quartz and feldspar, whose crystals are made up of linked tetrahedra, are non-plastic. On the other hand, kaolinite, talc, muscovite, biotite and others, whose crystal lattices are built up in sheets, are plastic. Bosazza (1941) stated that the plasticity of clay depends on the mineralogical composition as well as on the mechanical analysis. Endell, Loos and Breth (1939) supported Atterberg's study by doing an experiment which showed the plasticity index increased from 0.8 to 29.6 with the decrease of the quartz: kaolinite ratio from 9:1 to 0:1. They also have reported that the nature of exchangeable cation has considerable influence upon soil plasticity. The plasticity index and liquid limit of Na-montmorillonite are 4.7 and 3.4 times greater than those of Ca-montmorillonite.

Gumenskii (1959) also showed that among factors governing the plasticity of clays, the mineral composition, as illustrated by highly plastic montmorillonite; the hydrophyllic clays and kaolinite, is the most important. Pietsh and Davidson (1962) have found that CaO has an influence on the plasticity and compressive strength in Iowa soils.

Plastic limits of all soils examined increased with the addition of small amounts of dolomitic monohydrate of lime up to the lime-fixation point, after which there was little change. Russell (1928) found that the Atterberg limits are a very satisfactory index of the degree of clay accumulation in a soil profile.

Soil Textural Classification System

There are many textural classification systems used by different people in this country and in other nations. In 1911, the first diagrammatic relation between field descriptions of texture and mechanical compositions of soil was drawn by Whitney who used a right-angled triangle on which the percent of clay and silt were represented. Later, an equilateral triangle was used in 1927 by Davis and Bennett of the USDA. The USDA adopted a new procedure of mechanical analysis in 1930, and this change with the new particle size classes, e.g. sand, 2.0-0.05 mm; silt, 0.05-0.002 mm; clay, < 0.002 mm necessitated revision of the texture triangle. This revision was drawn up tentatively in 1945 by James Thorp. This diagram was further modified as the existing USDA textural classification chart in 1949. Marshall (1947) proposed a rectangular texture diagram based on clay content and median size of the non-clay fraction to modify the Council for Science and Industrial Research textural diagram of 1934 in Australia.

The U.S. Corps of engineers and U.S. Bureau of Public Roads Administration (1931) developed their triangular texture classification charts with the size-limits of sand, 2.0-0.05 mm; silt, 0.05-0.005 mm, and clay, < 0.005 mm. The Public Road Administration soil texture classification system was revised twice,in 1942 and 1945. This system became a standard of AASHO in 1945. Its classification system has become widely known and used in highway practice.

The Unified soil classification system was developed by Casagrande in 1952; it is used by both the Corps of Engineers and the U.S. Bureau of Reclamation, USBR. This system also identifies soils according to their size distribution, plasticity qualities and a special chart. The Federal Aviation Agency (FAA) also prepared a soil classification system based on the gradation analysis and the plasticity characteristics of soils in 1948. All of those texture classification systems try to fulfill the particular needs and desires of individual disciplines. The same textural class name may have different meanings and different properties in the different systems. Some soil scientists have tried to modify or simplify their texture charts to make interdisciplinary sharing of information easier. But most of the modified textural classification diagrams were limited to the needs of a particular discipline. Marshall (1947), Beater (1950), Frei (1953, Switzerland), Toogood

(1958, Canada), Saiz del Rio (1960, Spanish), and Elghamry, _et al_. (1962) have reported various revised soil texture classification charts. Loxton (1961) has modified the USDA diagram for the purpose of applying the international particle size-limits to this classification chart in South Africa soils. Pereira and Autunes da Silva (1962) also have made a modification of the USDA diagram based on the international size-limits of soil particles. The factor 0.574 is used to obtain the international silt value from the USDA silt value. Malterre and Alabert (1963, France) have proposed another modified triangular texture diagram for soils and loose rocks.

In 1957, Rieger, _et al_., USDA soil scientists, first generalized the relationship of agricultural texture classes and engineers texture classes. They studied the AASHO soil groups and the Corps of Engineers (CE, Unified) soil groups in relation to the USDA texture classification. Their charts were based on data from some 500 soil samples from 267 soil profiles collected in 20 counties in the eastern half of the United States. Ap horizons and gravelly horizons were excluded. The charts are shown in Figures 7 and 24.

Soil Texture in Relation to Available Moisture

Soil texture markedly influences the available moisture content of soils. The silt fraction, 0.002-0.05 mm for soil scientists and 0.005-0.074 mm for engineers, actually plays an important role. Engelhardt has reported in 1929 that in a homogeneous soil the capillary rise is inversely proportional to the size of the particles. In 1940, Stoeckeler and Aamodt showed that the capillary tension of soil varies with its texture and organic matter content. Botvay (1955) evaluated the capillary rise in sandy soils in the Hungarian plain and found the more clay content in sand soil the higher the capillary rise. Nielson and Shaw (1958) have shown that the correlation of the 15-atm percent was highly significant with clay content but not with silt content. Jamison and Kroth (1958) have studied a large number of predominantly silty soils. They found the available water storage capacity (AWC) increases with the increase of silt content. An increase in clay content decreased AWC in the silty soils but increased AWC in sandy soil of low silt content. In 1959, Bartelli and Peters determined available soil moisture of 31 soil types in Illinois and indicated the silt fraction (0.05-0.002 mm) was highly correlated with the 1/3-atm percent (which approximates field capacity in those soils), but not with the 15-atm percent. In Michigan, the relationship of texture classes of fine earth to readily available water capacity (RAWC) was studied by Franzmeier, Whiteside and Erickson in 1960. They concluded that the USDA classes of texture are more closely related with RAWC values than other textural classes studied. Soils with the higher very fine sand and silt content (0.002-0.10 mm) have high RAWC. The correlations between the texture diagram and the RAWC were improved by combining the very fine sand and silt as one axis of the triangles.

Salter, Berry and Williams (1965, 1966) also studied the influence of texture on the moisture characteristics of soils. They reported that the AWC of a soil was negatively correlated with percent coarse sand and positively correlated with the percent of International fine sand (0.2-0.02 mm) or USDA silt (0.05-0.002 mm) and organic carbon. The AWC of the soils ranged from 0.77 inches/ft. in a sand, to 3.12 inches/ft. in a silt loam, and 3.13 inches/ft. in a peat. Clay soils had approximately 1.95 inches/ft.

EXPERIMENTAL

Material

The test data on 2894 samples used in this study and their grouping into the AASHO and Unified engineering classifications were taken from:

(1) Engineering soil classification for residential development, compiled and edited by the Federal Housing Administration from data prepared by the VPI, the Bureau of Public Roads, and State Highway Departments, Universities and Colleges (1961).

(2) Michigan State Highway Department, testing and research division ,1953, studies of Michigan soils.

(3) The Bureau of Public Roads, studies of soil samples from Michigan ,1955, 1958, 1960, 1961, 1964, 1965 .

Most of those samples (over 90%) came from locations throughout the United States other than Michigan. They represent soils developed in a wide range of unconsolidated materials including sediments over "Red bed," alluvium, colluvium, loess, volcanic ash, and glacial till. The sediments were derived from shale, schist, sandstone, limestone, and granite. Tests data were obtained by those county, or State Highway Departments where the soil samples were located, or

The U.S. Bureau of Public Roads. Mechanical analyses were based on the American Association of State Highway Officials procedure, Designation T 88. The engineering soil classifications were based on the AASHO classification, Designation M145-49, and the Unified soil classification system, Technical Memorandum No. 3-357. Liquid limits and plasticity indices were determined by the ASTM tentative method of Tests, Designations D 423-54T and D 424-54T.

Methods

The particle size analysis data on the materials used were not suitable for use directly in naming texture classes of soils in the USDA system if the results were based in part on the coarse fraction larger than 2.0 mm in diameter. On such samples, the first step was to convert the percent of each size separate to the basis of < 2.0 mm material as 100%. Some samples in which the difference between < 2.0 mm and < 0.42 mm materials was more than 5% were also converted to < 0.42 mm as 100% for checking how much shift would occur on the triangular texture diagram when using the fraction smaller than 0.42 mm (sand, 0.42-0.05 mm) instead of the fraction smaller than 2.0 mm (sand, 2.0-0.05 mm) and for plasticity index, liquid limit, texture relationships. The percent of sand (2.0-0.05 mm or 2.0-0.074 mm or 2.0-0.1 mm); silt (0.05-0.002 mm or 0.074-0.002 mm or

0.1-0.002 mm); and clay (< 0.002 mm) fractions were then calculated for each sample. These analyses for each sample were then plotted on a USDA texture triangle using the appropriate silt size fraction in each of the three cases cited. The AASHO soil classification, the Unified soil classification, the plasticity index or the liquid limit of each sample was then entered beside the plot of each sample on separate copies of the USDA texture diagram. Finally, the author studied the USDA soil texture classification in relation to the (1) AASHO soil classification; (2) Unified soil classification; (3) Other criteria used in engineering classifications (plasticity index, liquid limit, and group indices); and (4) Possible improvements of correlations of particle size distribution with other properties of fine earth materials by choices of silt size ranges. Those separations which are thought to be significant to engineers and soil scientists were drawn on triangular texture diagrams. These, it is hoped will facilitate the communication and interpretation of soil analyses by soil scientists and engineers.

RESULTS AND DISCUSSION

The AASHO Soil Classification in Relation to USDA Soil Texture Classification

Criteria Used in the AASHO Soil Classification

In the AASHO system of soil classification earthy materials are classified into seven basic groups, namely A-1 through A-7, based on their general load bearing capacity; particle size distribution, liquid limit and plasticity index (< 0.42 mm fraction). In recent years, these seven basic soil groups have been further divided into subgroups using a "group index" that was devised to approximate within group evaluations. Group indices range from "0" for the best subgrades to "20" for the poorest. The criteria for the AASHO soil classification are shown in Table 1 and Figure 1.

Distribution of the AASHO Groups on USDA Texture Triangle

Among the 2894 soil samples studied, the number of samples in each AASHO soil group and their percent of the total are summarized in Table 2.

Fig. 1. Charts used in the AASHO soil classification

Chart A. Group index, grain size and P.I. relations

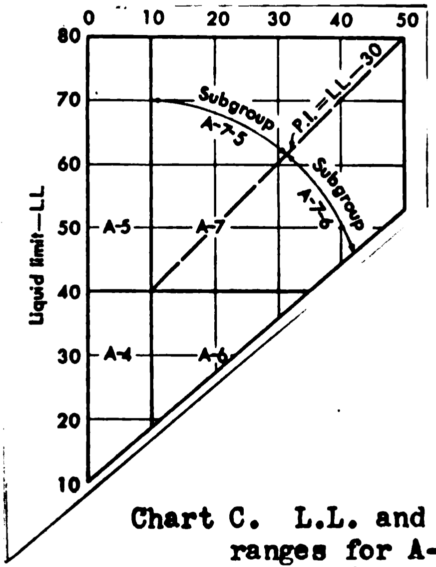


Chart C. L.L. and P.I. ranges for A-4, A-5, A-6, and A-7 subgrade groups.

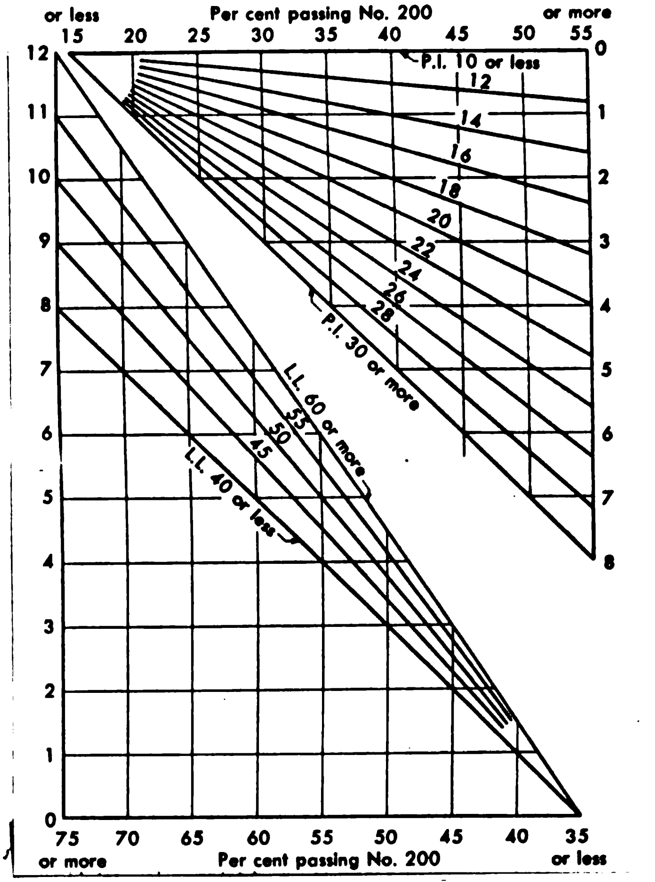


Chart B. Group index, grain size and L.L. relations
Group index equals sum of readings on both vertical scales

Table 1. Classification of highway subgrade materials (with suggested subgroups)

General classification	Granular materials (35 per cent or less of total sample passing No. 200)							Silt-clay materials (More than 35 per cent of total sample passing No. 200)			
Group classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis, per cent passing:											
No. 10	50 max.										
No. 40	30 max.	50 max.	51 min.								
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40:											
Liquid limit				40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.*
Group Index**	0		0	0		4 max.		8 max.	12 max.	16 max.	20 max.

*P.I. of A-7-5 subgroup is equal to or less than L.L. minus 30. P.I. of A-7-6 subgroup is greater than L.L. minus 30 (see Chart C.)

** See Chart A and Chart B.

Table 2. The number of samples in each AASHO soil group and their percentages of all 2894 samples studied.

Soil Group		Number of Samples	Percentage
I.	A-7-6 A-7-5	821	28.37
II.	A-6	607	20.97
III.	A-5	25	0.86
IV.	A-4	916	31.65
V.	A-3	79	2.73
VI.	A-2-4 A-2-5 A-2-6 A-2-7	348 2 26 7	13.24
VII.	A-1-a A-1-b	24 39	2.18
	Total	2894	

The particle size distribution of the samples in these groups (except A-1-a and A-1-b groups) are shown in Figures 2 through 6.

Distribution of the A-7 group on the USDA texture diagram.--Most of the A-7 samples (740 or 90.13%) were distributed, Figure 2, within the area of clay loam, silty clay loam, silty clay and clay on the USDA texture diagram. About one-half of the samples of this group had clay contents (< 0.002 mm) greater than 40%, and the other half usually contained between 20 and 40% clay. The clay loam and silty clay loam areas on the diagram contain most of the samples with less than 40% clay. Only 16 samples (1.95%) of this group show clay contents less than 20% and 13 of these contain 17% or more clay. As shown on Figure 2, no sample of this group had sand (0.05-2.0 mm) contents greater than 63%. Ninety-six percent of the A-7 samples contained less than 45% sand.

Some samples have properties rather unusual for this group. An Ap horizon of Worth stony fine sandy loam derived from glacial till located in Franklin, N.Y., was defined as A-7-5(8) with only 8.2% clay. The L.L. and P.I. of this sample were 46 and 16 respectively. Since the correlation between P.I. and < 0.002 mm clay is pretty high ($r = 0.959 \pm 0.044$), the P.I. of this soil seems to be too high compared to equivalent samples derived from similar

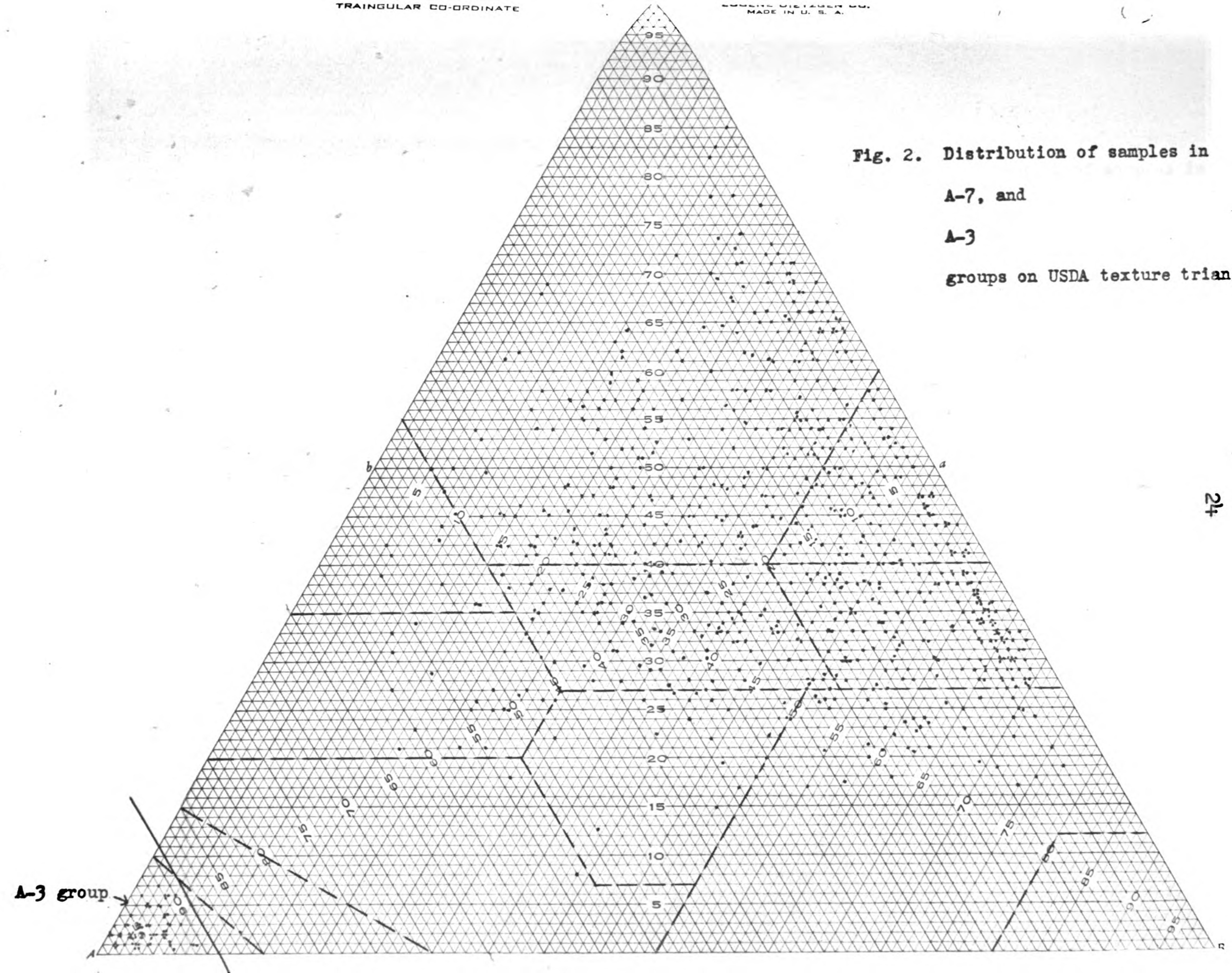


Fig. 2. Distribution of samples in
A-7, and
A-3
groups on USDA texture triangle

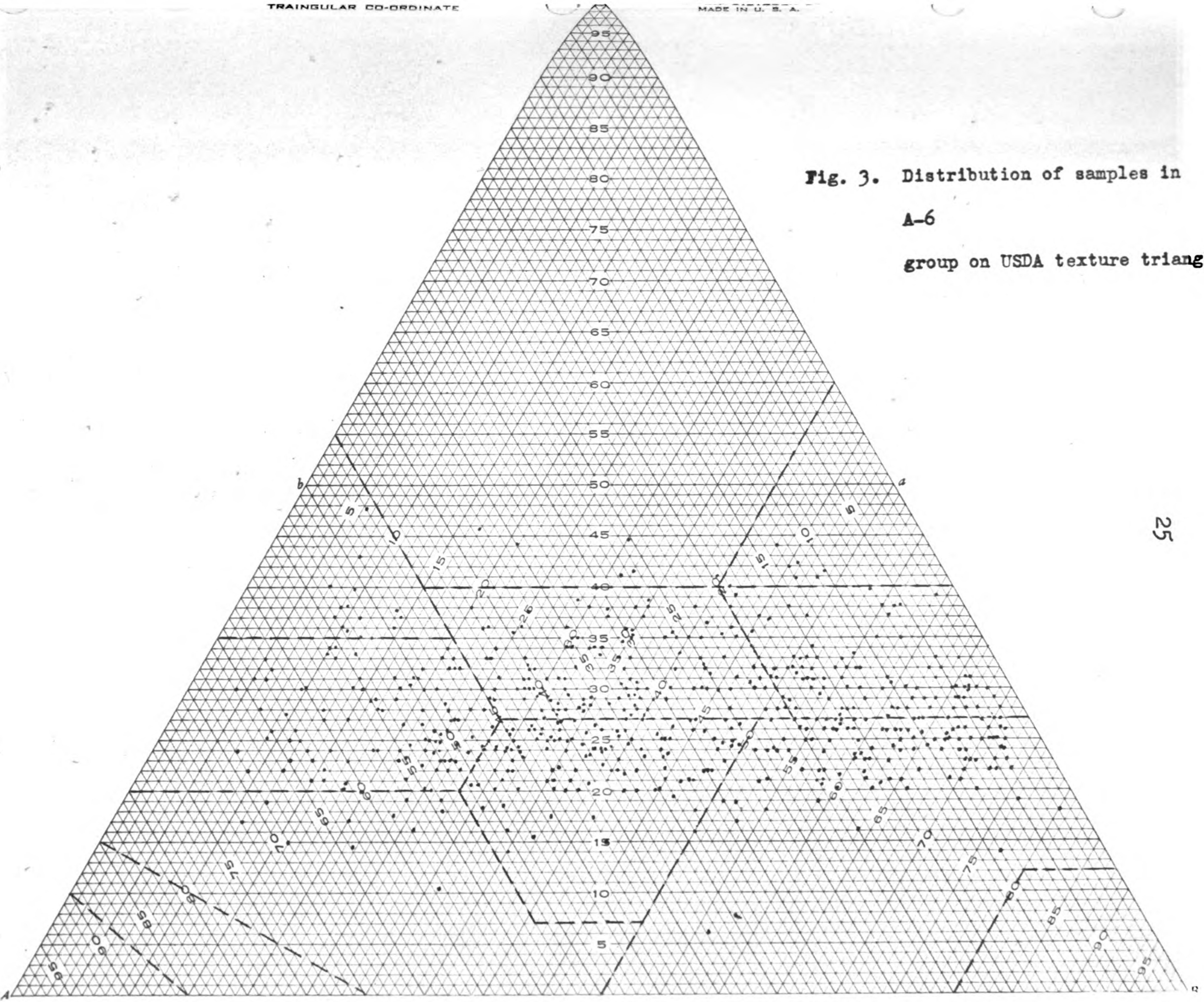


Fig. 3. Distribution of samples in

A-6

group on USDA texture triangle

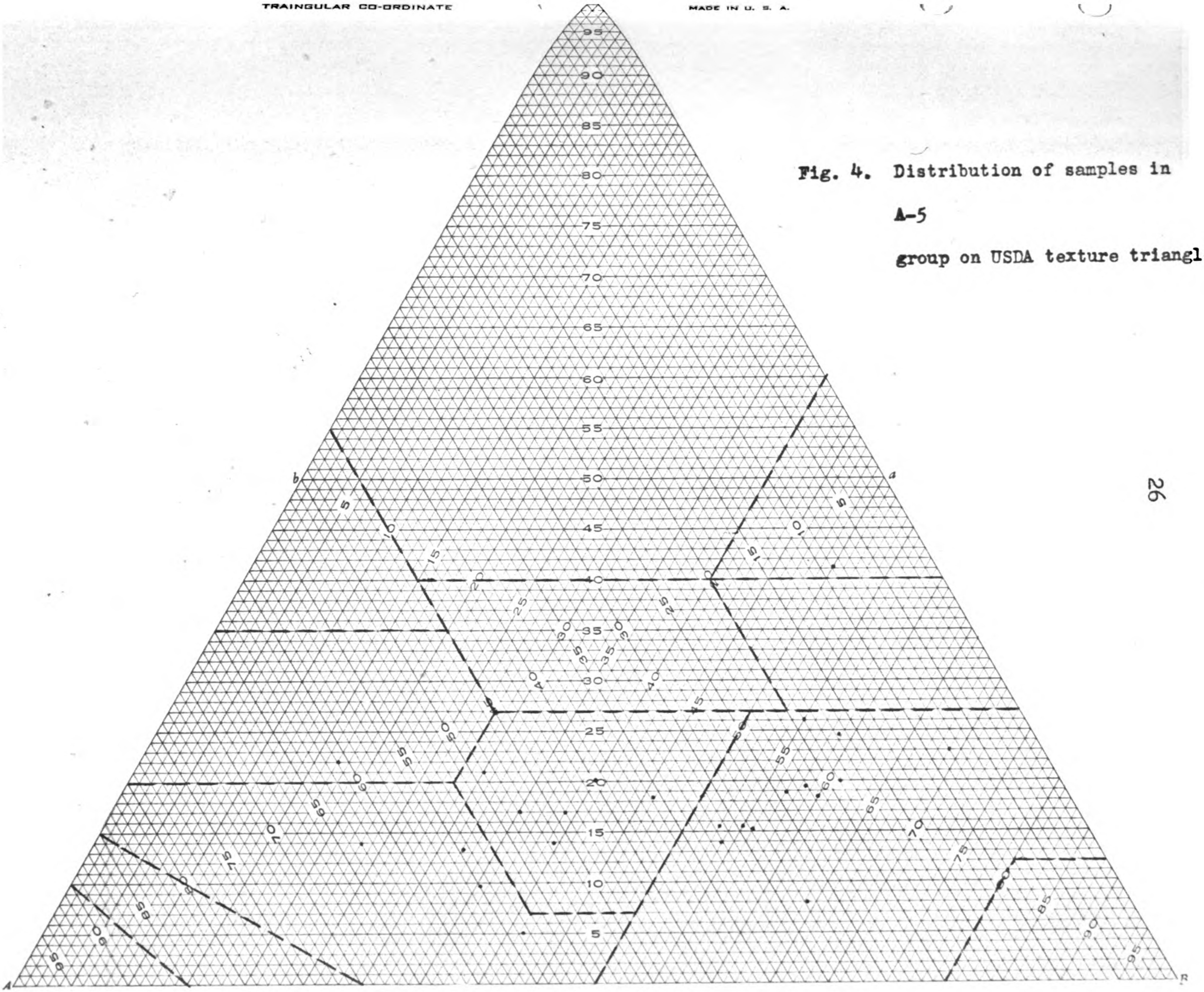


Fig. 4. Distribution of samples in

A-5

group on USDA texture triangle

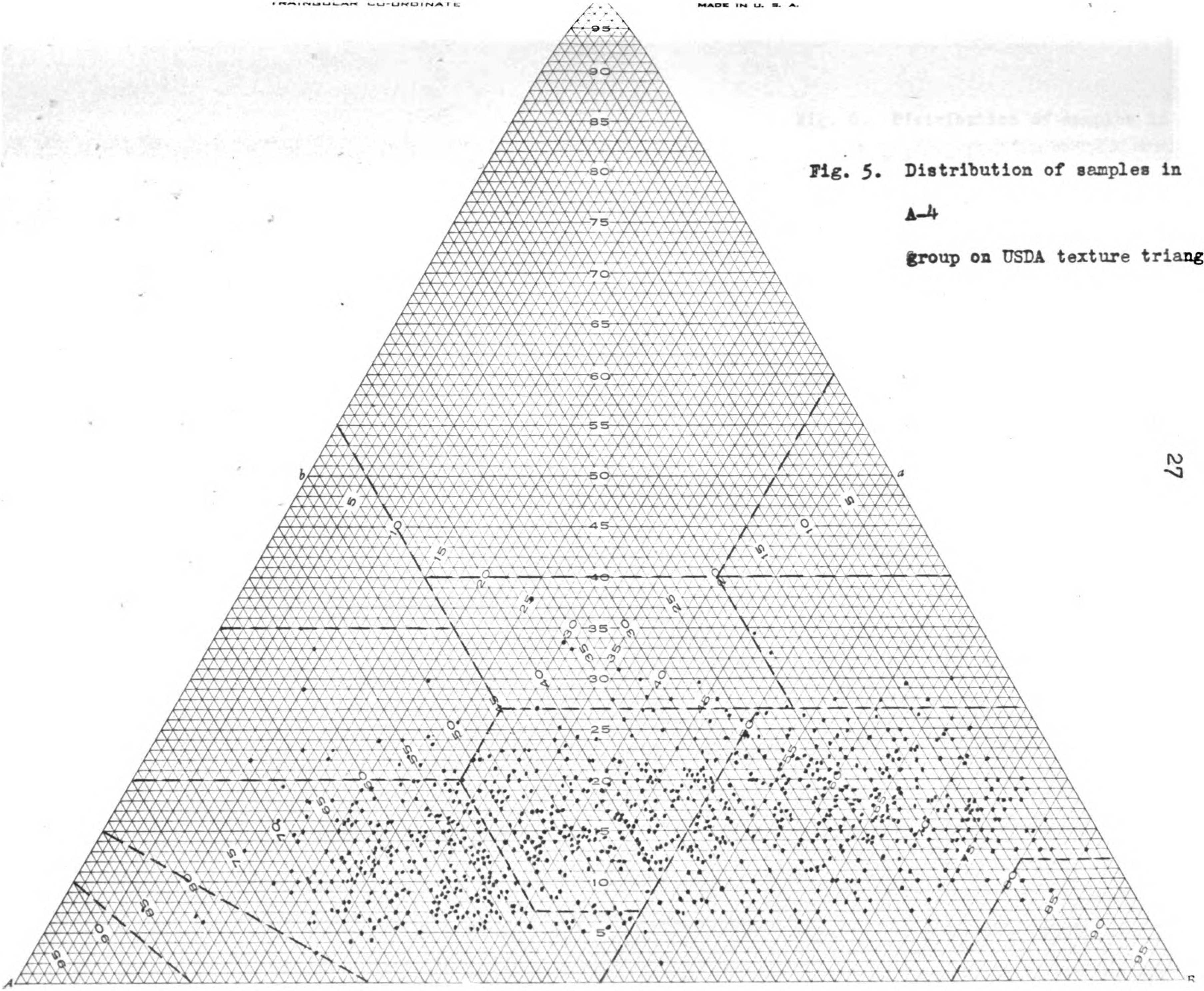


Fig. 5. Distribution of samples in

A-4

group on USDA texture triangle

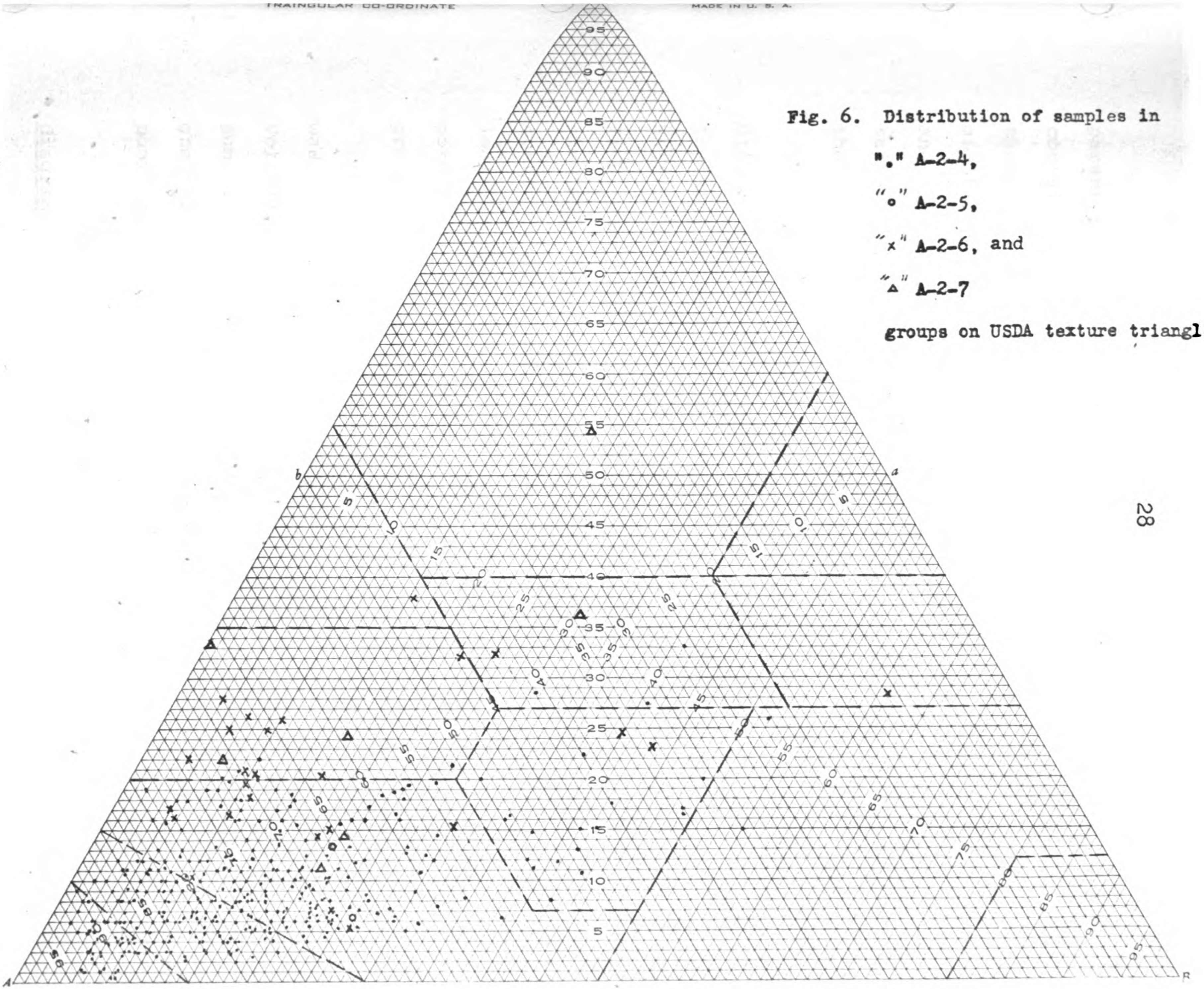


Fig. 6. Distribution of samples in

"•" A-2-4,

"o" A-2-5,

"x" A-2-6, and

"△" A-2-7

groups on USDA texture triangle

parent materials that came from the same location. Samples containing over 40% clay usually had group indices greater than 13, Figure 14. In a few exceptions their group indices might go down to 7. Those samples with clay contents > 40% and lower group indices (< 13) in the A-7 group usually contained relatively high proportions of grain sizes greater than 2.0 mm.

Distribution of the A-6 group on the USDA texture diagram.--91.8% of the 607 A-6 samples were located within the area between 20 and 40% clay and overlapped about one-half of the A-7 samples. The A-6 group covered CL, SCL, SiCL, and the finer parts of the SL, L, and Sil classes on the USDA texture diagram, Figure 3. Only 16 samples had clay content greater than 40%, and only 34 samples contained less than 20%. Twenty-one of the latter contained 17% or more clay. Seventy percent sand is the maximum for this group but most samples contain less than 65%.

The lowest clay content of any sample in this group was 6% with P.I. of 12 and L.L. of 33 in the B, horizon of a Volinia silt loam from Michigan. Group indices of those samples above the 40% clay line in this group are usually greater than 7, and are considered to be "poor" to "very poor" subgrade materials.

Distribution of the A-5 group on the USDA texture diagram.--The A-5 materials are very limited in the samples studied here. They are similar to A-4 samples which will be discussed next, except that their liquid limits are above 40 and their group indices may be up to "12" instead of only up to 8, Table 1. As shown on Figure 4, the A-5 group is usually less clayey than the A-6 or A-7 groups on the USDA texture diagram. One sample of this group was in the silty clay class; one in the sandy clay loam class; one in silt class; and the rest were in the SL, L, and SiL classes on the diagram. Their clay contents usually range from 5% to 27%. Twelve of the 25 A-5 samples were defined as silt loams by the USDA texture triangle. Actually, this group overlaps the A-4 group on the texture diagram.

Distribution of the A-4 group on the USDA texture diagram.--A-4 materials are probably the most common group in the AASHO soil classification. There were 916 A-4 samples in this study, nearly 1/3 of the total. Of these samples, 95.3% were concentrated in SL, L, and SiL textural classes on the USDA diagram, Figure 5. Most samples, 97.2%, of this group had clay contents ranging from 5% to 27% and sand contents of less than 70%. This area also covers all A-5 group samples, with only one exception. A "B horizon" of Tirzah silt loam, from Saluda, S.C. has a clay content of 41%. Those A-4 samples with clay contents > 20%, about 18% of the total number, overlap A-6 samples and some A-7 samples.

Distribution of the A-3 group on the USDA texture diagram.--Although there are only 79 samples of A-3 group in the 2894 samples studied, this group is also common in occurrence and is distributed exclusively in the sand class on the USDA texture diagram, Figure 2. All of those samples show sand fractions greater than 90% with only one exception, the B_3 horizon of Volinia silt loam, Michigan, with 86% sand separates. This group is mostly overlapped by the fine earth fraction from samples of the A-1 group, which commonly contain considerable coarse sand or gravel and are not considered in this study, and partly by the A-2 group.

Distribution of the A-2 groups on the USDA texture diagram.--The four A-2 subgroups were widely distributed on the USDA texture diagram, Figure 6.

(a) A-2-4(0) group: 93% of these samples were located in sand, loamy sand, and sandy loam classes on the diagram. They were mainly distributed in the area with sand fractions from 63% to 92% and clay contents less than 20%.

Many samples, about 1/7 of those in the A-2 group, contain less than 65% sand and are texturally intermingled there with the less silty A-4 and A-5 samples. These samples commonly have a high proportion of gravel content (> 2.0 mm fraction). The lowest sand content was 22.3% in a C horizon of Dellrose cherty silt loam (Alluvial and Colluvial), from Maury, Tennessee. In fact, most of this sample was stones and gravels, the percent passing the No. 10 sieve (< 2.0 mm) was only 27%. About 30 samples of this group, 9% of the total, have been found overlapping with the A-3(0) group discussed above.

(b) A-2-5(0) group: Only two samples of this group were found in the total 2894 samples studied. They were distributed in the middle of the sandy loam class on the texture diagram and fall in the area of A-2-4(0) samples. The A-2-5(0) samples are very similar to A-2-4(0) samples except that they have higher liquid limits (41 or greater).

(c) A-2-6(0-4) group: Ten out of 26 samples of this group were located in SCL; 11 in SL; 2 in L; one each is in the SC, CL, or SiCL class on the diagram, Figure 6. Apparently, those samples having the higher clay contents and the lower sand fractions contained considerable material not passing a No. 10 sieve.

(d) A-2-7(0-4) group: Seven samples of this group were scattered widely in SCL, SL, CL, and C classes on the diagram, Figure 6. By checking the original data, the percentage of particle sizes greater than 2.0 mm in those 7 samples were found to be 0%, 24%, 38%, 66%, 67%, 67%, and 97%. This great variation of particle size distribution resulted in those samples being scattered broadly on the < 2.0 mm diagram.

A diagram showing the generalized relationships of USDA textural classes and AASHO soil groups proposed by Rieger, et al. is shown as Figure 7.

Discussion of Relationships of AASHO Groups of Fine Earth Samples to a Texture Triangle

By looking at the size distributions of the samples in the seven AASHO soil groups, except A-1-a and A-1-b groups, one might have the idea that each AASHO group substantially has its specific pattern on the USDA texture diagram. The dominant groups are A-7, A-6, A-4, and A-2-4(0) classes which make up 94.23% of the samples in this study. In drawing the boundaries to define the AASHO soil classes on the USDA texture diagram, the author first looked over all samples as a whole and observed their general size distributions. Most samples of each of these seven groups, except A-1 group, are generally distributed contiguously on the texture diagrams, Figures 2 through 6. However, gravelly groups of soils probably should be recognized independently of the fine earth texture triangle, as in differentiating gravelly or stoney mapping units. The following discussion is therefore limited to the samples of A-7, A-6, A-5, A-4, A-3, and A-2 groups in the AASHO classification.

The 40% clay line has been used in the USDA texture diagram for separating clay and silty clay from clay loam and silty clay loam. In this study, 49.2% of the A-7 samples

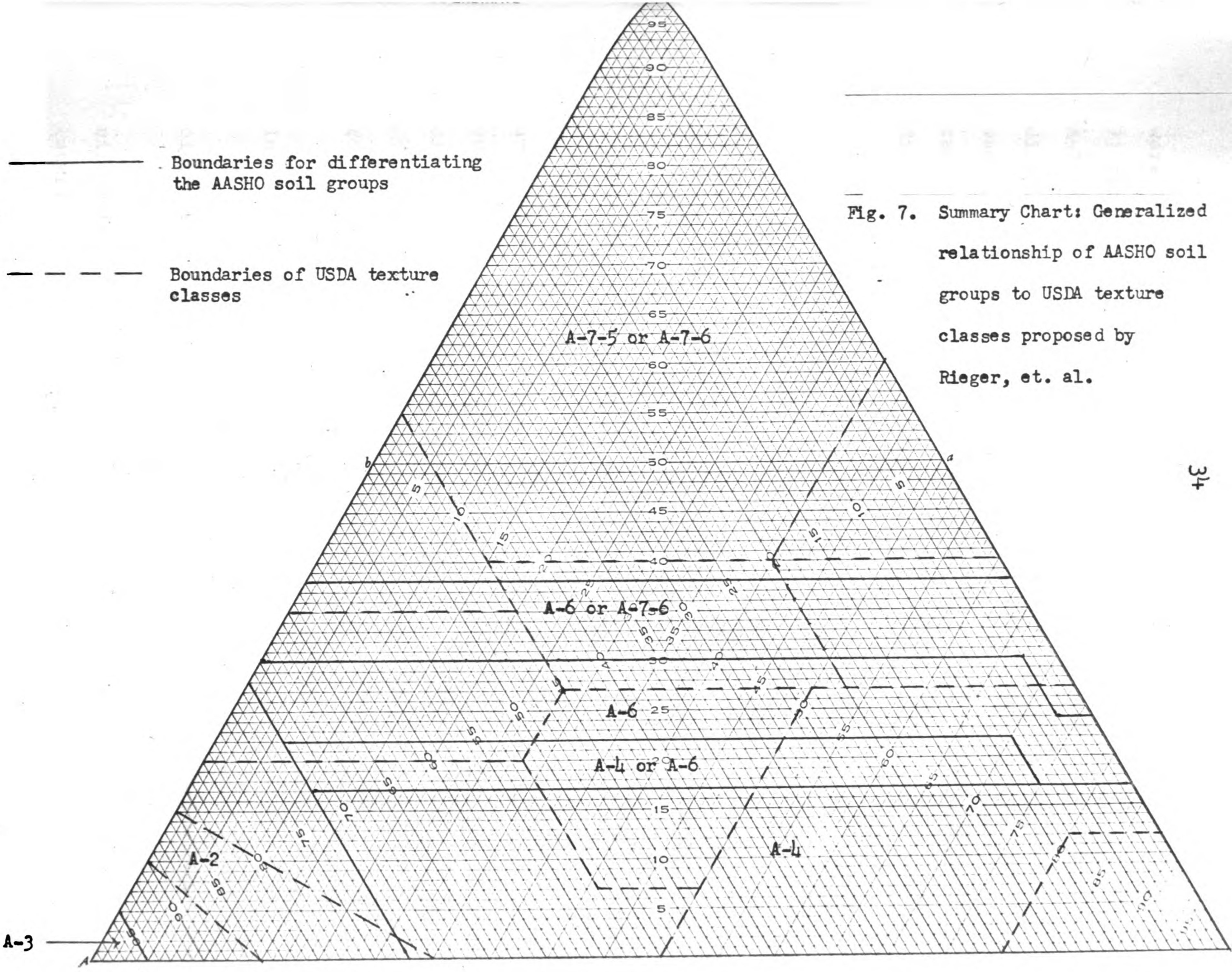


Fig. 7. Summary Chart: Generalized relationship of AASHO soil groups to USDA texture classes proposed by Rieger, et. al.

were located above this line. Rieger, et al. 1957, Figure 7, proposed the 38% clay line for separating the "A-7-5 or A-7-6" groups from the less clayey groups in the AASHO soil classification. By comparing the AASHO classification of samples located above the 40% clay line with the classification of samples above the 38% clay line, the percentage distributions were observed as follows:

Group	> 40% clay, number of samples in study	%	> 38% clay, number of samples in study	%
1. A-7	404	95.72	453	93.20
2. A-6	16	3.8	30	6.17
3. A-5	1	0.24	1	0.21
4. A-4	---	---	1	0.21
5. A-2-7	1	0.24	1	0.21
Total:	422	100.0	486	100.0

From the above data, it is apparent that the A-7 group is the only prominent group distributed above either 40% or 38% clay. The 40% clay line seems to be better for differentiating the more clayey A-7 samples from the less clayey AASHO groups on the diagram than the 38% clay line for the following reasons:

(1) The percentage of A-7 samples to the total samples in the area above the 40% clay line is higher.

(2) The 40% clay line coincides with the line for dividing clay and SiC from CL and SiCL on the USDA texture diagram.

(3) The 40% clay line is better correlated with the significant liquid limit value of "40" (this will be discussed later).

However, only about one-half of the A-7 samples contain more than 40% clay. Within the 20-40% clay range, there were 91.8% of the A-6 samples; 48.8% of the A-7 samples; 18.4% of the A-4 samples; and a few samples of each of the groups A-5, A-2-4, A-2-6, and A-2-7. Since this area represents samples from three major groups, A-7; A-6; and A-4; and various minor groups (representing all together about 40% of the total samples in this study), no single line seems to be possible for separating these groups from each other. Rieger, et al. proposed some group complexes to define the samples within this area, but his dividing boundaries are not clear cut separations. He designated "A-6 or A-7-6"; "A-6"; and "A-4 or A-6" groups between 17-38% clay, with sand fractions less than 72%, Figure 7. In view of the distribution of the 1142 samples located in this 20-40% clay range, Figures 2-6, the author proposes, Figure 9, several revisions of Rieger's diagram.

First: The 65% sand line seems more appropriate for breaking the three less sandy major group complexes from the A-2 groups than does Rieger's 72% sand line for the following reasons:

(1) Within the range of 20-40% clay, the three major groups A-7, A-6, and A-4, representing 98% of all the samples in this area, all have shown sand fractions of no more than 65% with only six exceptions, Figures 2, 3, and 5.

(2) Most of the A-2-6 samples and most of the A-2-4 samples have sand fractions greater than 65%.

Thus, this seems to be a more appropriate boundary for dividing the A-2 groups from the A-4, A-6, and A-7 groups, Figure 6.

Second: The 27% clay line has been used by soil scientists for separating CL and SiCL from L and SiL. In the area of 27-40% clay, nearly 95% of the samples in this study are A-7 and A-6 classes. We thus designate it as an A-7 or A-6 group complex. The A-6 group area proposed by Rieger, *et al*. (Figure 7) partly overlapped with this 27-40% clay range but it actually is composed of a considerable number of samples classified as other than A-6. It was observed that there are 110 A-7 samples (13.4% of total A-7 samples); 103 A-4 samples (11.2% of total A-4 samples); and a few A-5, A-2-6, or A-2-7 samples in his A-6 group area, according to this study.

It thus seems that the separation of an A-6 group would be better taken out of the diagram plotted by Rieger, *et al*. As shown in Figure 5, 97.3% of the A-4 samples were distributed below the 27% clay line. Rieger's 22% clay line for dividing the A-6 group from the underlying groups which were mostly A-4 samples is not suitable because it will keep about one hundred more A-4 samples within this A-7 or A-6 complex area. Consistently, a 27% clay line seems more appropriate for separating the "A-7 ~ A-6" complex group from the less clayey groups.

Third: A 17% clay line, 60% and 72% sand lines below 17% clay content, and 65% sand between 17 and 27% clay would be the most preferable boundaries in differentiating the AASHO soil groups or combinations of groups (complexes) within the area of < 27% clay and < 72% sand with equal concern for each group's distribution. These proposed boundaries and the composition of the resulting groups are shown in Figure 9. The development and testing of these boundaries now requires some discussion and documentation.

The area on the diagram with less than 27% clay and less than 72% sand is probably the most important region for AASHO soil classification. Samples distributed within this area included 50% of all those studied and their composition may be shown as follows:

AASHO Classes	No. of Samples
1. A-7	81
2. A-6	266
3. A-5	24
4. A-4	883
5. A-2-4	119
6. A-2-5	2
7. A-2-6	16
8. A-2-7	4
Total:	1395

In considering all the samples that occur in this area, several separation patterns have been evaluated as to their feasibility for designating the group boundaries. Rieger, et al. proposed a 72% sand line for separating the A-2 group from A-4, A-4 or A-6, and A-6 groups. This is not good for the clay contents greater than 17% as mentioned before and it would be improved there by shifting to a 65% sand content. For those samples below the 17% clay line, the 72% sand line of Rieger is good as a boundary for A-4 soils but unfortunately it will include 32% of the A-2-4 samples within the A-4 soil range, Figures 5 and 6. By drawing a sand line at less than 72% in addition to a 72% sand line where clay contents are below 17%, an area would be created to serve as another complex area for accomodating most of the overlapping A-4 and A-2-4 samples. The 60% sand line was chosen for evaluating the distribution pattern of this A-4 ∿ A-2-4 complex because it seemed to break the A-4 sample distribution between an area of more frequent to less frequent occurrence, Figure 5. The 63% sand line was also tried for comparison with the 60% sand because it seemed appropriate to separate the A-2-6 group from A-4, A-6 ∿ A-4 groups and it also seems to represent a break between an area of more frequent and less frequent A-2-4 occurrence in Figure 6. Three clay percent levels were also selected. Twenty percent clay has been used by soil scientists for dividing SCL from SL; 18% clay has been proposed as a guide for family groupings of soils; and 17% clay was drawn by

Rieger, et al. for dividing an A-4 or A-6 complex from an A-4 group (with sand fractions less than 72%). Comparison of feasibility of these two sand percentages and the three clay percentages as tested by the enclosed sample distribution patterns are given in Table 3.

By observation, the 60-72% sand with < 17% or < 18% clay seemed most appropriate for defining a reasonably homogeneous A-4∿A-2-4 group-complex. However, we need further to check the sample distribution of its adjacent A-7∿A-6∿A-4 complex and A-4 groups before setting the boundary.

In designating horizontal boundaries for separating those samples below 27% clay with sand fraction less than 65% (see Figures 2 through 6), three sample distribution patterns were investigated as in Table 4.

Apparently, the samples in each of these areas are over 95% composed of the three groups: A-7, A-6 and A-4 and about 97% of the A-7, A-6, A-5 and A-4 groups. It apparently doesn't make much difference whether the 20%, 18%, or 17% clay line is used with 65% sand to differentiate these groups. However, the 17% clay line is slightly better because the area delineated includes many more samples with no appreciable loss in homogeneity. Before setting this lower clay limit it is necessary to evaluate the underlying samples, particularly concerning the distribution pattern of the A-4 group.

Table 3. Comparison of **AASHO** group distribution patterns with various clay (< 20, 18, or 17%) and sand (between 60 or 63 and 72%) contents.

Patterns / Soils	(1) < 20% Clay		(2) < 18% Clay		(3) < 17% Clay	
	60-72% sand	63-72% sand	60-72% sand	63-72% sand	60-72% sand	63-72% sand
1. A-6	7	5	5	4	4	4
2. A-5	1	1	1	2	1	2
3. A-4	110	73	105	70	100	68
4. A-2-4	73	67	67	56	59	49
5. A-2-5	2	2	2	2	2	2
6. A-2-6	6	6	4	4	4	4
7. A-2-7	2	2	2	2	2	2
Total	201	156	186	140	172	131
A-4 ∿ A-2-4 samples in area %	91	90	92.4	90	92.4	89.3

Table 4. Comparison of AASHO group distribution patterns with various clay contents (between 20, 18 or 17 and 27%) and less than 65% sand.

Patterns / Groups	Less than 65% Sand		
	(1) 20-27% Clay	(2) 18-27% Clay	(3) 17-27% Clay
1. A-7	65	72	77
2. A-6	227	238	247
3. A-5	5	10	11
4. A-4	158	248	314
5. A-2-4	6	11	15
6. A-2-6	4	4	4
7. A-2-7	1	1	1
Total	466	584	669
For A-7∿A-6∿A-4 samples in each area (%)	96.5	95.5	95.4
For A-7∿A-6∿A-5∿A-4 samples in each area (%)	97.6	97.3	97.0

Samples of the A-5 group were almost all distributed below the 27% clay line and overlapped with the A-4 group, Figure 5. Its average L.L. value is 47, seven more than that of the upper value of the A-4 group. Actually, A-5 samples were rarely found in this study and made up only 0.86% of the total samples. Following in Table 5 are shown the enclosed sample compositions when considering three clay contents as the lower boundary for the A-7 ∿ A-6 ∿ A-5 ∿ A-4 group complex and two sand percentages.

In Table 5, the 17% clay and < 60% sand lines give the most homogeneous A-5 ∿ A-4 group complex.

Before discussing further the data in Tables 3, 4, and 5, let us refer to the other experimental results. The P.I. of "maximum 10" and "minimum 11" are considered as significant values for classifying samples in the AASHO system. Odell, Thornburn, and McKenzie have studied the correlation between < 0.002 mm clay and plasticity indices. They found that the percent < 0.002 mm clay was closely correlated with P.I. and gave the following equation for that relationship: $\hat{Y} = 1.09 + 0.568X_2$ with the correlation coefficient of $r = 0.959 \pm 0.044$, where: $\hat{Y}$ = plasticity index and $X_2 = \% < 0.002$ mm clay. According to their equation, 17% clay will show the estimated P.I. of "10.75," and 18% clay gives "11.31." It seems that 17% clay according to this

Table 5. Comparison of AASHO groups distribution patterns with three clay contents (< 20%, < 18%, or < 17%) and two sand contents (< 60% and < 63%).

Patterns / Groups	(1) < 20% Clay		(2) < 18% Clay		(3) < 17% Clay	
	< 60% sand	< 63% sand	< 60% sand	< 63% sand	< 60% sand	< 63% sand
A-7	16	16	9	9	4	4
A-6	34	36	16	16	11	11
A-5	17	18	12	13	12	12
A-4	618	655	518	550	466	498
A-2-4	32	38	25	31	23	28
A-2-6	1	1	1	1	1	1
Total	718	764	581	620	517	554
For A-4 samples in each area (%)	86	85.7	89.1	88.7	90.0	89.8
For A-5 $\cap$ A-4 samples in each area (%)	88.4	88.1	91.2	90.8	92.4	92.1

equation gives the P.I. value more closely corresponding to the significant value of "maximum 10" and "minimum 11."

In summary, the data in Table 3 indicate that the area of 60-72% sand with < 17% clay is slightly preferable for defining an A-4 $\cap$ A-2-4 group complex; in Table 4, 17% clay is also preferable to designate as the lower boundary for an A-7 $\cap$ A-6 $\cap$ A-5 $\cap$ A-4 group complex; in Table 5, the area with < 60% sand and less than 17% clay is slightly preferable to give the most homogeneous A-5 $\cap$ A-4 group complex. These are the reasons for the proposed boundaries on the texture triangle in the area with < 27% clay and < 72% sand contents.

Continuing now our recommendation for revising Rieger's diagram, Figure 7.

Fourth: In Figures 2 and 6, a 92% sand line may more appropriately be used for dividing A-2-4 samples from A-3 samples than the 95% line suggested by Rieger, et al. The sample distribution in those two areas, A and B, are shown on Figure 8. The purity for the A-2-4 group in the A_1 area is 91.8% and for the A-3 group in the B area is 92.1%.

Fifth: In Figure 8, if the 17% clay line is extended to the 0% silt line, we have the sample distribution shown on Figure 8 for areas A_1 and A_2. The purity of the proposed A-2-4 $\cap$ A-2-6 group complex is 76.4%. This is a little bit low as compared to 91% without extending the 17% clay line to the 0% silt line (Figure 8, A area), but it will give a 91.8% pure A-2-4 group area (Figure 8, A_1 area) in addition to the "A-2-4 ∿ A-2-6" group complex (A_2 area). These subdivisions are recommended.

Proposed Diagram for Designating AASHO Soil Classification on the Basis of the USDA Texture Triangle

In summarizing the above data and discussion, the diagram Figure 9 is proposed for showing the interrelationships among the AASHO soil groups, the particle size distributions of the fine earth fractions of the samples, and the USDA textural classes on a texture triangle. The percentage of purity of each of the groups or group complexes separated by solid lines are also shown in Figure 9, based on the data for the 2831 samples (excluding 63 A-1-a and A-1-b samples) available in this study.

Relationship of other Criteria Used in Engineering Classifications of Fine Earth Materials and Particle Size Distribution

Changes Due to < 0.42 mm Instead of < 2.0 mm Material as Basis for Plotting Plasticity Index and Liquid Limit Measurements

Since the clay fraction (< 0.002 mm) does greatly influence the Atterberg limits of a soil material, it is possible that the position of the liquid limit and plasticity

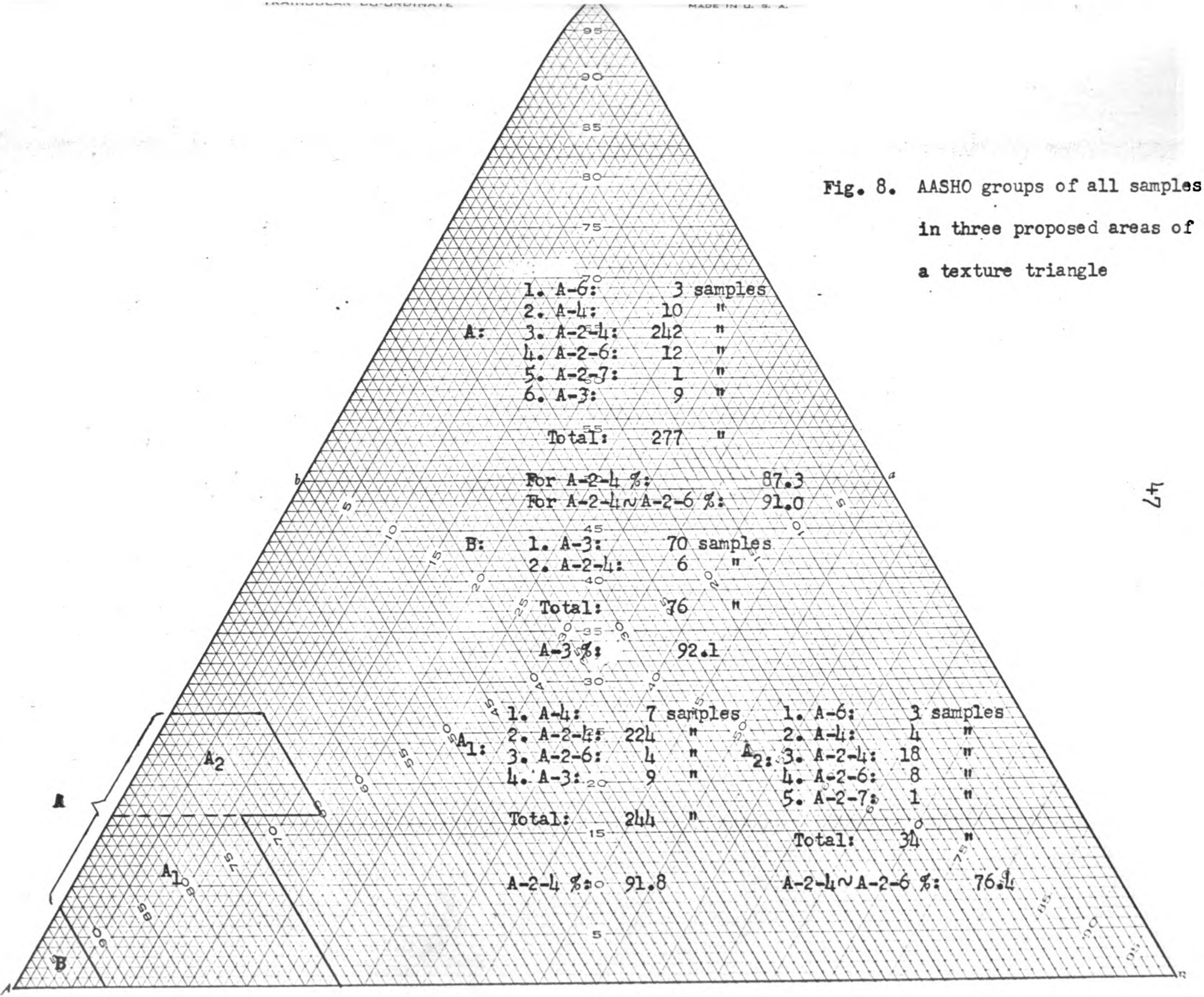


Fig. 8. AASHO groups of all samples in three proposed areas of a texture triangle

A:
1. A-6: 3 samples
2. A-4: 10 "
3. A-2-4: 242 "
4. A-2-6: 12 "
5. A-2-7: 1 "
6. A-3: 9 "

Total: 277 "

For A-2-4 %: 87.3
For A-2-4∾A-2-6 %: 91.0

B:
1. A-3: 70 samples
2. A-2-4: 6 "

Total: 76 "

A-3 %: 92.1

A_1:
1. A-4: 7 samples
2. A-2-4: 224 "
3. A-2-6: 4 "
4. A-3: 9 "

Total: 244 "

A-2-4 %: 91.8

A_2:
1. A-6: 3 samples
2. A-4: 4 "
3. A-2-4: 18 "
4. A-2-6: 8 "
5. A-2-7: 1 "

Total: 34 "

A-2-4∾A-2-6 %: 76.4

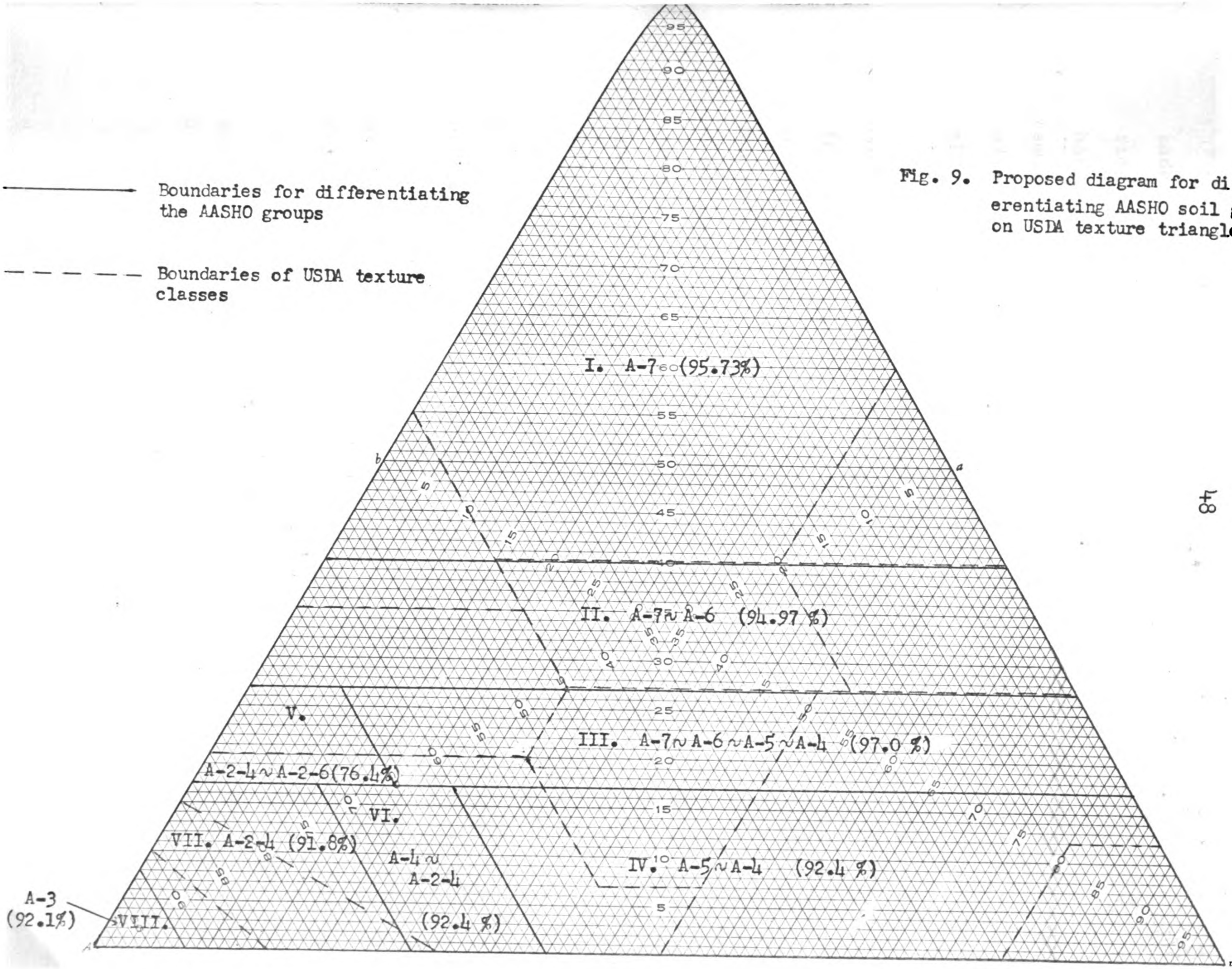


Fig. 9. Proposed diagram for differentiating AASHO soil groups on USDA texture triangle

index values on the texture triangle would be shifted to a significant degree by using a < 2.0 mm instead of a < 0.42 mm basis for plotting the particle size distribution of the samples. The L.L. and P.I. determinations are actually made on the < 0.42 mm material but the USDA texture diagram applies to fine earth < 2.0 mm.

In order to evaluate the change of clay content by converting from the < 2.0 mm fraction to the < 0.42 mm fraction as 100%, 231 Michigan samples were selected from the total 2831 samples (excluding 63 A-1-a and A-1-b samples) throughout the United States. Among these 231 samples, only those samples with a difference greater than 5% between the < 2.0 mm and the < 0.42 mm fractions have been used to calculate the size distributions on the < 0.42 mm base. If the difference between < 2.0 mm and < 0.42 mm fractions is less than 5%, the change of clay content should be quite small when the size distribution is converted from one to the other as a base.

Following is an example to show the conversion of size distributions based on the whole sample, the portion < 2.0 mm and the portion < 0.42 mm as 100%.

Sample	< 7.62	< 2.0	< 0.42	< 0.074	< 0.05	< 0.002	(mm)
Wasepi	100	80	66	26	24	16	(%)
B horizon		100	82	32.5	30	20	
			100	39.4	37.4	24.2	

In this case there was only a 4.2% (24.2-20%) increase in clay by considering the fraction < 0.42 mm as 100% instead of the < 2.0 mm fraction as 100%. In only 98 out of the 231 Michigan samples studied were the differences in content of the < 2.0 mm and the < 0.42 mm fraction greater than 5%. The increase in clay content on these samples averaged 1.85%. The highest and lowest shifts in clay content of those samples were 11.9% and 0.1%, respectively, but only 18 of the 98 samples show shifts in clay content $\geqslant 2.0\%$.

The shifts in position of these Michigan samples on a texture triangle (using 0.074-0.002 mm as silt) are shown with their L.L. values in Figure 10, and with their P.I. values in Figure 11. Arrows connect the points for each sample whose composition was appreciably altered by the shift in base from < 2.0 mm to < 0.42 mm materials. The equation showing the L.L. in relation to clay content (< 0.002 mm) given by Odell, <u>et al</u>. in Illinois is as follows:

Equation (1): $$\hat{Y} = 23.13 + 0.669\ X_1$$

where: $\hat{Y}$ = L.L.

X_1 = clay % (< 0.002 mm)

The average increases in clay of 1.85% would be expected to give an increase of 1.24 in the L.L. on the basis of this equation.

It is noticed that by using the < 0.42 mm fraction as a basis for the clay contents instead of the < 2.0 mm fraction, the expected L.L. of these Michigan samples would be increased by from 0.07 to 8.0 units.

A closer correlation, with $r = 0.854 \pm 0.036$ was found between L.L. value and percent of < 0.002 mm clay by Odell<u>et al</u>. if the percent organic carbon content of the sample and the percent montmorillonite in the clay are also considered. The L.L. value of a soil they found could be estimated quite accurately by the following multiple regression equation:

Equation (2) $\hat{Y} = 11.14 + 4.937\ X_1 + 0.669\ X_2 + 0.112\ X_3$

where: X_1 = % organic carbon

X_2 = % < 0.002 mm

X_3 = % montmorillonite in clay

$\hat{Y}$ = L.L.

Odell, <u>et al</u>. also reported that the inclusion of the percent of silt (0.05-0.002 mm) as an independent variable increased the correlation coefficient for the "plastic limit" (not plasticity index) slightly, but had very little influence on the correlation coefficients for the L.L. and P.I. values.

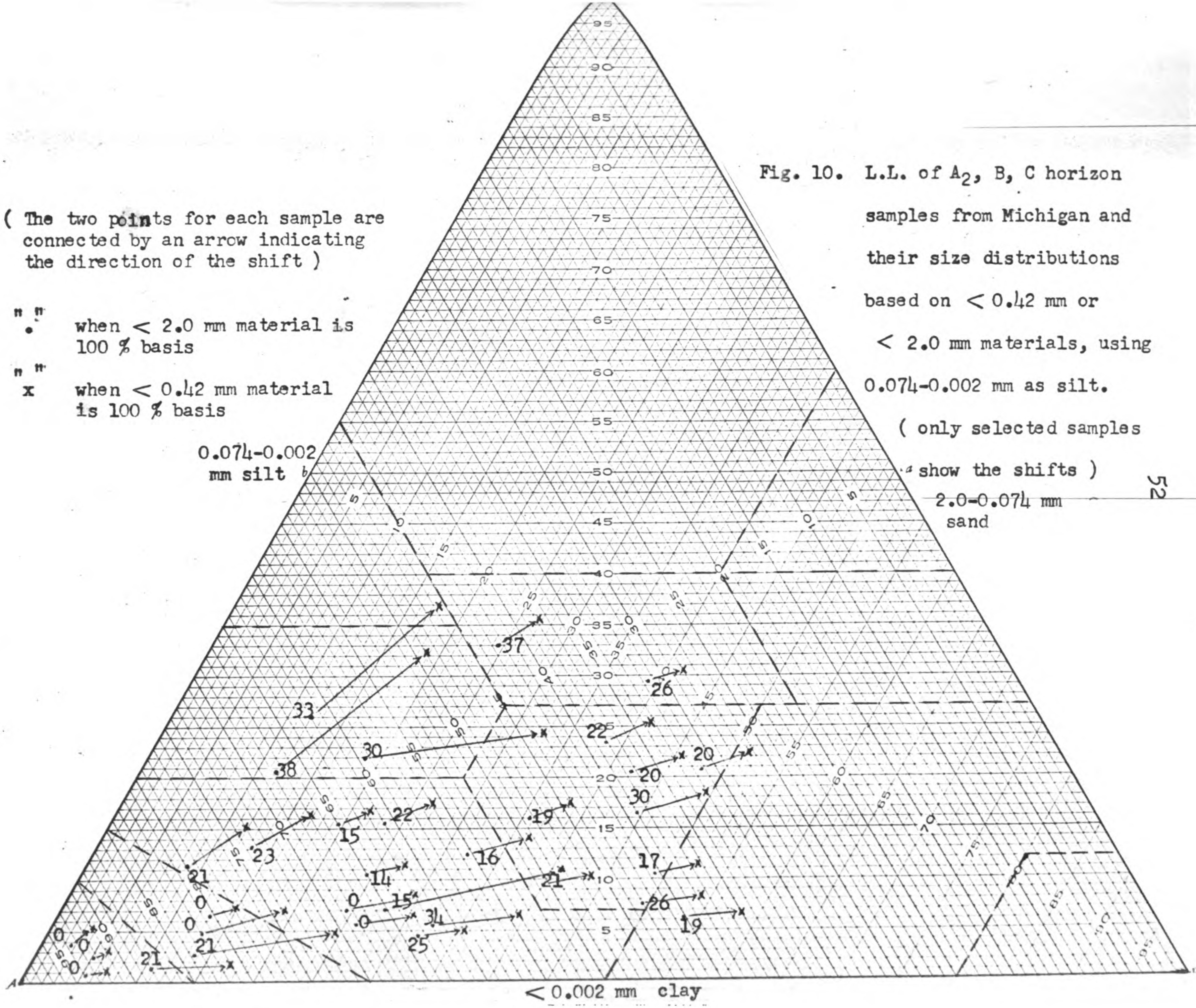


Fig. 10. L.L. of A_2, B, C horizon samples from Michigan and their size distributions based on < 0.42 mm or < 2.0 mm materials, using 0.074-0.002 mm as silt. (only selected samples show the shifts)

(The two points for each sample are connected by an arrow indicating the direction of the shift)

" . " when < 2.0 mm material is 100 % basis

" x " when < 0.42 mm material is 100 % basis

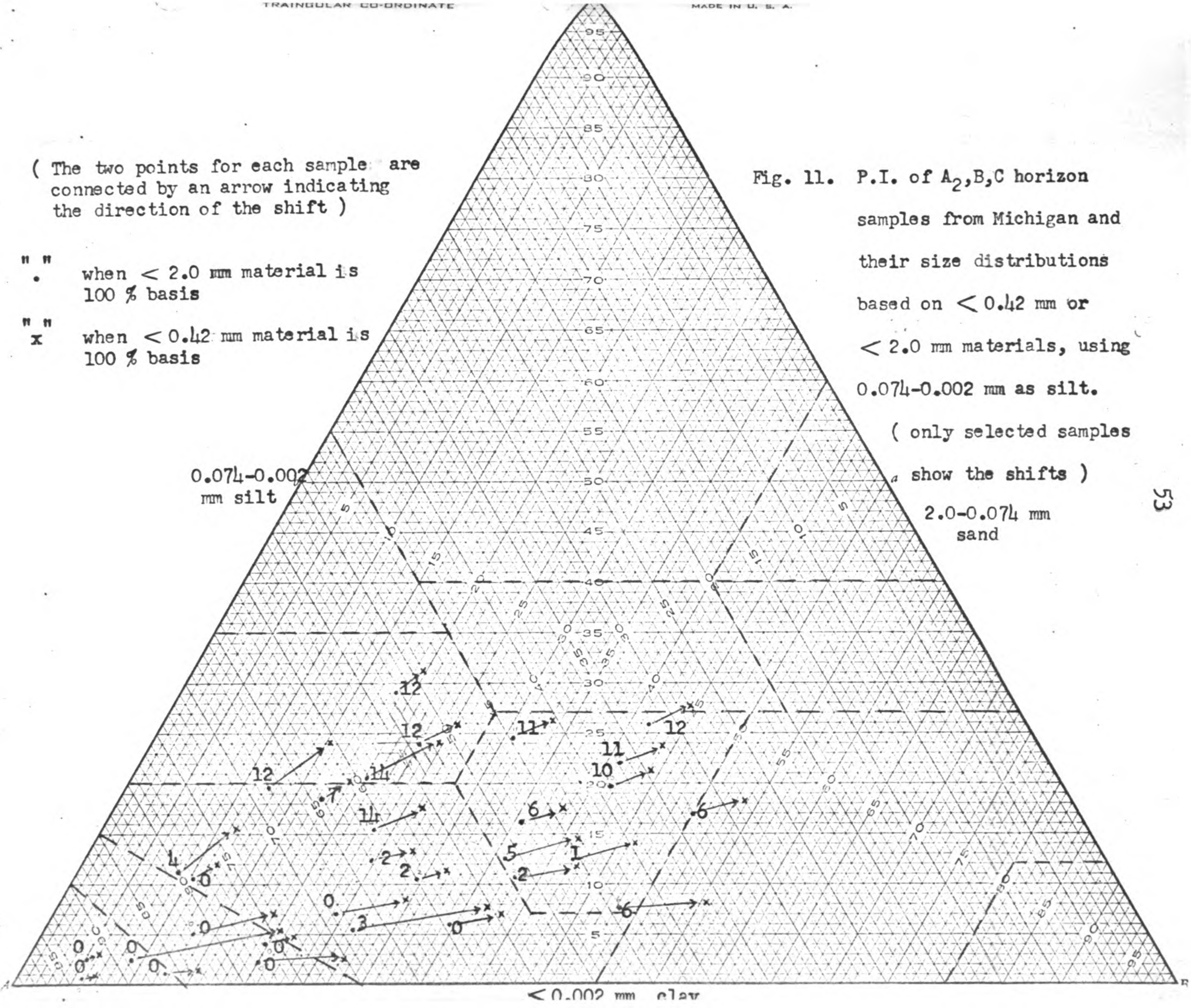


Fig. 11. P.I. of A_2,B,C horizon samples from Michigan and their size distributions based on < 0.42 mm or < 2.0 mm materials, using 0.074-0.002 mm as silt.
(only selected samples show the shifts)

Similarly, the estimated increase in P.I. with the change of clay content resulting from the conversion from the < 2.0 mm base to the < 0.42 mm basis may be calculated using equation (3) given by Odell, et al. as follows:

$$\text{Equation (3)} \qquad \hat{Y} = 1.09 + 0.568 X_2$$

Where: $\hat{Y}$ = plasticity index

$X_2 = \% < 0.002$ mm

The average increase in clay content of 1.85% would be expected to give an increase of 1.05 in P.I. value. By using the maximum and minimum changes in clay content in calculating, the expected values for individual samples would be from 0.06 to 6.7 units according to equation (3).

Liquid Limit in Relation to Particle Size Distribution and a Texture Triangle

Significant values.--L.L. values of "$\leqslant 40$" and "$\geqslant 41$" have been selected as the significant values in the AASHO soil classification, Table 1. In the Unified soil classification, L.L. "$\leqslant 28$" and "> 28" are used for subdividing the GM and SM groups in coarse-grained soils and a L.L. of "50" for distinguishing between "low" and "high" compressibilities in fine-grained soils, Table 12.

Proposed diagram showing L.L. values on the USDA texture triangle.--Working in reverse from the AASHO soil groups in Figures 2 through 6 for deducing the distribution of L.L. values on the USDA texture diagram. according to the criteria of the AASHO soil classification, the L.L. of A-7, A-5, A-2-7 and A-2-5 groups are all $\geq$ 41; and those of A-6, A-4, A-2-6, A-2-4, and A-3 groups are all $\leq$ 40. With respect to the 40% clay line proposed for designating AASHO soil groups on the USDA texture triangle, 96.2% of the total 422 samples distributed above the 40% clay line showed L.L. $\geq$ 41. It may be concluded that samples with clay contents above 40% usually have L.L. $\geq$ 41. But equation (1) of Odell, et al. gives the clay content of 40% for a L.L. of "50" and of 27% for a L.L. of "41.2." By checking those 1715 samples falling below the 27% clay line, it was found that only 111 samples had L.L. values $\geq$ 41. Thus, nearly 94% of the samples in this study that contained less than 27% clay had L.L. values of "$<$ 40." Fairly consistently then, samples with less than 27% clay may be considered as having L.L. "$\leq$ 40," and samples with greater than 40% clay may be considered as having L.L. "$\geq$ 41."

Between 27 and 40% clay, there were 694 samples; 338 samples showed their L.L. $\geq$ 41 and the other 356 samples have L.L. values of "20-40." In this portion of the texture triangle L.L. determinations are definitely necessary, in addition to particle size distribution, to determine the AASHO classification of the material.

With regard to the Unified system, the 50% clay line may be considered as a dividing line for the L.L. "$>$ 50" and "$\leqslant$ 50." In the area above the 50% clay line, 92% of the samples in this study have L.L. values $\geqslant$ 50.

Observations on 252 selected samples from the U.S.--On the basis of the USDA texture classification, the average L.L. value of each texture class except silt has been evaluated using 252 samples selected from the total of 2894 available. The 252 samples selected are evenly distributed on a USDA texture diagram. The particle size distribution of those selected samples and their liquid limits are shown in Figure 12. The average L.L. value of each USDA texture class except silt is shown as Table 6.

By observation of Table 6, the L.L. values generally decrease from the finest textures as the top to the coarsest textures at the bottom. The inclusion of more silt percent (0.05-0.002 mm) has little influence on the L.L. values, which agrees with the study of Odell, et al. cited above. According to Figure 12, 94.3% of the 65 samples with clay contents greater than 40% showed L.L. $\geqslant$ 41, 93% of total 129 samples distributed below the 27% clay line showed L.L. $\leqslant$ 40. It indicates that the 40% and 27% clay lines still hold true for designating the significant L.L. values for AASHO group of 252 evenly distributed samples on the USDA texture triangle. Between 27-40% clay, there are 58 samples. Of the

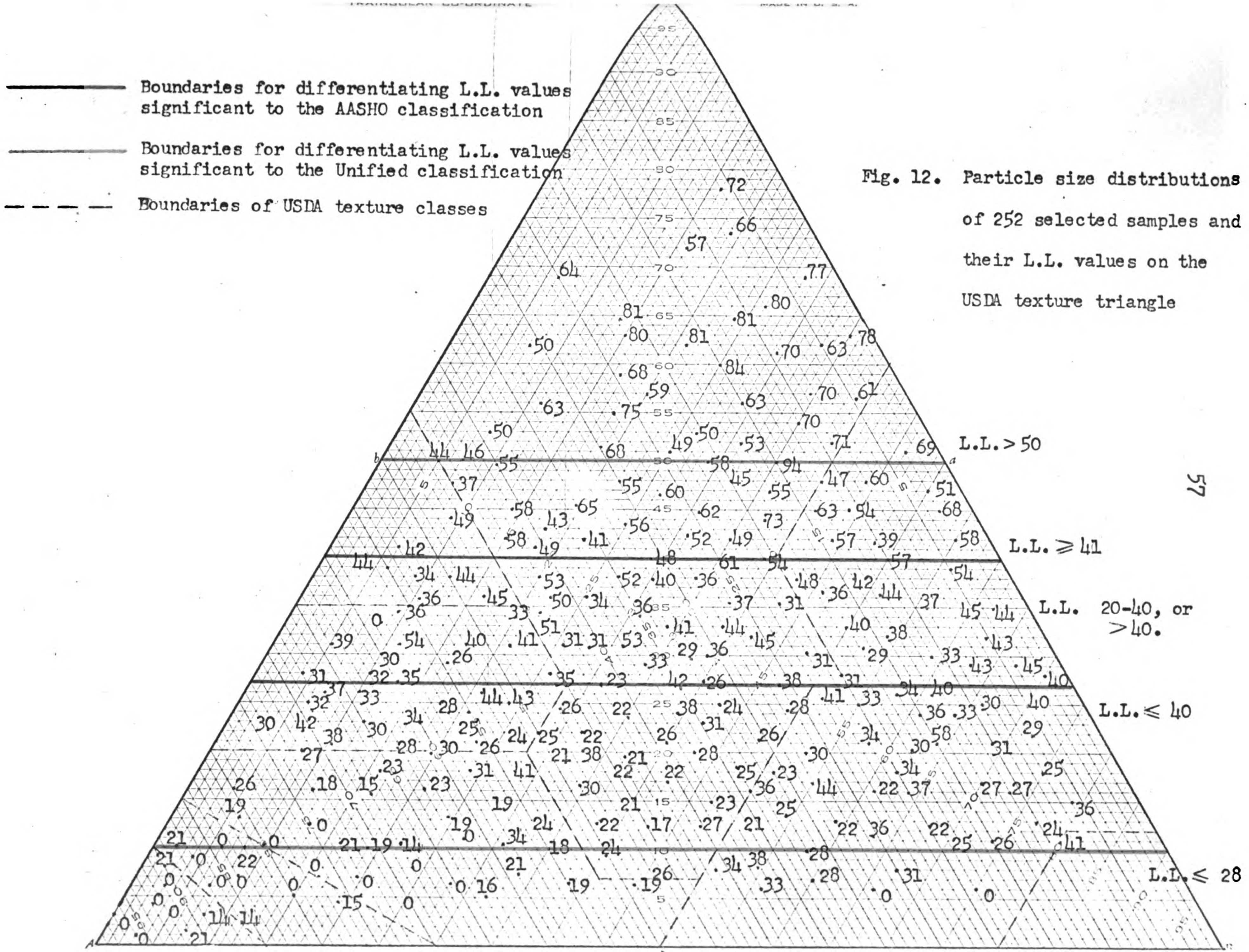


Fig. 12. Particle size distributions of 252 selected samples and their L.L. values on the USDA texture triangle

Table 6. Average L.L. values of 252 selected samples by the USDA texture classes.

Texture Classes	Number of Samples	Average L.L. Values
C	51	61.9
SiC	10	57.6
SC	9	41.6
SiCL	16	41.3
CL	22	38.6
SCL*	30	32.1
SiL*	41	30.3
L	27	26.4
SL*	28	16.1
LS	10	9.1
S*	8	7.0

*Samples with "0" liquid limits are also included in this calculation.

total samples 60.4%; 37.9%; and 1.7% showed their L.L. 20-40; > 40; and < 20, respectively. Thus, 40% and 27% clay lines are drawn for designating AASHO significant values of L.L. ≥ 41 and ≤ 40 on a USDA texture diagram, Figure 12.

Considering the Unified system, the significant values are L.L. > 50, L.L. > 28 and ≤ 28. Tables 6a and 6b are shown to evaluate various clay contents as the boundaries for designating those L.L. values on a USDA texture diagram. From Table 6a, it is observed that the samples with $> 50\%$ clay all have L.L. values > 50. In Table 6b, samples with less clay than any of the clay lines tested have L.L. usually ≤ 28. But the 10% clay line agrees with the line used in the Unified classification and gives the L.L. value of 29, pretty close to 28, according to Odell<s equation (1). Thus, these 50% and 10% clay lines are proposed for designating the Unified significant values of L.L. > 50 and ≤ 28 on the USDA texture diagram, Figure 12.

Plasticity Index in Relation to Particle Size Distribution and a Texture Triangle

Significant values.--The P.I. value "≤ 6," "≤ 10" and "≥ 11" have been used by the AASHO soil classification system (Table 1). The method for using the L.L. and P.I. values for Unified sample identifications is illustrated in the plasticity chart shown in Table 12. A P.I. value of ≤ 6 was chosen for dividing "d" from "u" samples in the GM

Table 6a. Percentages of samples with various clay contents and L.L. values > 50.

Clay (%)	% of Samples with L.L. > 50
> 40 (used in AASHO and Unified classification)	80.0
> 41 (according to Odell's equation, it gives L.L. ≅ 50)	82.2
> 43 (used in Rieger's diagram, Figure 24)	83.6
> 45 (arbitrarily chosen)	89.6
> 50 (used in AASHO and Unified classification)	100.0

Table 6b. Percentages of samples at various clay contents with L.L. values > 28 and ≤ 28.

Clay (%)	% of Samples with L.L. Values	
	> 28	≤ 28
< 9 (according to Odell's equation)	13.3	86.7
< 10 (used in Unified classification)	11.7	88.3
< 15 (arbitrarily chosen)	8.1	91.9
< 17 (used in AASHO and Unified classification)	13.3	86.7

group, and the P.I. < 4, 4-7, and > 7 were used for the groups in the fine-grained soils. The percent < 0.002 mm clay is more closely correlated to plasticity index than to liquid limit as can be seen from the correlation coefficients studied by Odell, et al. ($r = 0.959 \pm 0.044$ for P.I., and $r = 0.854 \pm 0.036$ for L.L.).

Proposed diagram for distribution and designation of P.I. value on a texture triangle.--The theoretical clay boundary for designating the significant P.I. values of "≥ 11" and "≤ 10.5" (or ≤ 10) lies on the 17% line according to equation (3) given by Odell, et al. As mentioned before, 17% clay line was also plotted as a suitable boundary for separating an A-7 $\sim$ A-6 $\sim$ A-5 $\sim$ A-4 group complex from the A-5 $\sim$ A-4 group complex in Figure 9.

By observing the 2894 samples (including the A-1 group), Table 7 shows the choice of various clay percentage lines for delineating the boundaries of significant P.I. values.

In Table 7, it is apparent that for the areas above and below the 20%, 18%, and 17% clay lines the average purities of all samples in the ≥ 11 and ≤ 10 P.I. groups, respectively, are $(87.6 + 94.9)/2 = 91.2\%$, $(81.2 + 96.4)/2 = 88.8\%$, and $(78.4 + 97.5)/2 = 88\%$. If 17% clay line is used, 97.5% of all the samples below this line have P.I. ≤ 10 and 98.1% of all the samples with P.I. ≥ 11 are above this line.

Table 7. Plasticity indices of 2894 samples with particle size distributions in areas delineated by various clay contents on a texture triangle.

Clay Contents (%)	Calculated P.I.	% of P.I. Group Samples in Each of the Areas				% of All Samples in the Areas with P.I. Indicated		
		≥ 11	≤ 10	≤ 6	7-10	≥ 11	≤ 10	≤ 6
≥ 20	12.46	95.4	13.7	2.8	40.8	87.6	12.4	1.9
< 20		4.6	86.3	97.2	59.2	5.1	94.9	76.1
≥ 18	11.31	97.2	22.9	--	--	81.2	18.8	--
< 18		2.8	77.1	--	--	3.6	96.4	--
≥ 17	10.75	98.1	27.6	--	--	78.4	21.6	--
< 17		1.9	72.4	--	--	2.5	97.5	--
≤ 10	6.77	2.7	34.9	48	2.2	0.8	99.2	97.4
≤ 9	6.2	0.3	30.3	--	--	1.0	99.0	--
20-10		4.3	51.3	--	--	7.9	92.1	--
18-10		2.6	42.2	--	--	5.9	94.1	--
17-10		1.8	37.9	--	--	4.6	95.4	--
20-9		4.1	51.6	--	--	7.5	92.5	--
18-9		2.6	44.0	--	--	5.7	94.3	--
17-9		1.8	39.8	--	--	4.4	95.6	--

Even if the 18% clay or 20% clay lines were used these figures would still be 95% or greater. A considerable percentage of samples with P.I. ≤ 10 are above each of these lines but that percentage increases with decreasing clay content from 13.7% for the 20% clay line to 27.6% for the 17% clay line. This criterion would be in favor of the 20% or the 18% clay line instead of the 17% clay line favored here.

As shown in Table 7, the 9% or 10% clay (used with 20%, 18 or 17% clay) doesn't make much difference for designating the area of P.I. ≤ 6. However, the 9% clay line when substituted into Odell's et al. equation (3) will give P.I. value of 6.2. This is closer to the significant P.I. value ≤ 6. It is suggested that the 17% and 9% clay lines might be used as the boundaries for the significant P.I. values of ≤ 10 (or ≥ 11), and ≤ 6 respectively, Figure 13.

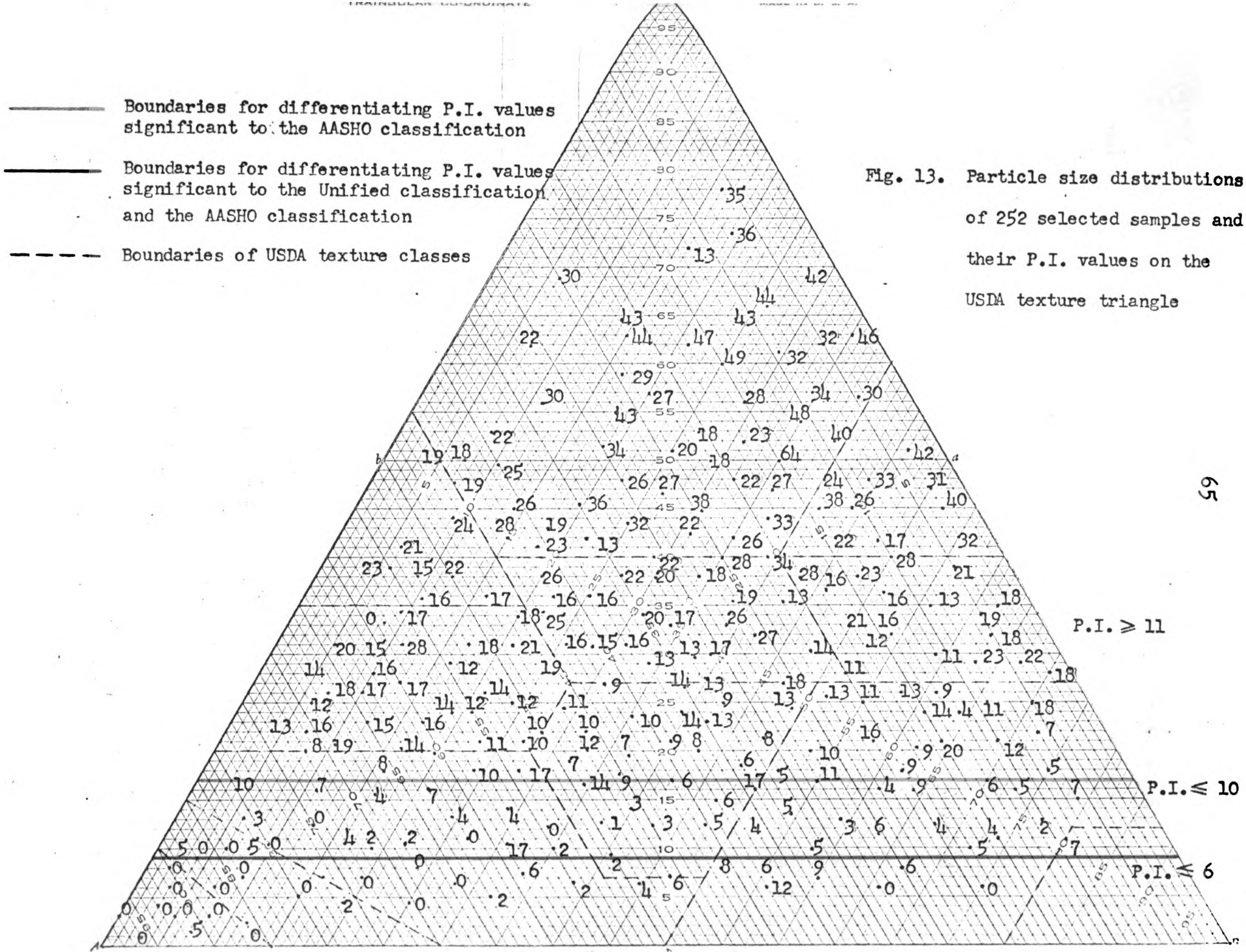
Observations on 252 selected samples from the U.S.--Of 252 samples that have been evaluated as to their P.I. values in relation to USDA texture classes, the average P.I. values of those samples in the USDA texture classes except silt are shown as Table 8. The particle size distribution of these selected samples and their plasticity indices are shown in Figure 13.

In Table 8 the texture classes are listed from finest (most clayey) to coarsest (most sandy) and the average P.I. values decrease in that order.

Table 8. Average P.I. values of 252 selected samples by the USDA texture classes.

Texture Classes	Number of Samples	Average Plasticity Indices
C	51	30.7
SiC	10	30.2
SC	9	19.5
SiCL	16	18.4
CL	22	17.9
SCL	30	15.4
SiL	41	8.3
L	27	8.3
SL*	28	4.5
LS*	10	1.6
S*	8	0.7

*Non-plastic samples are included in these calculations.



Boundaries for differentiating P.I. values significant to the AASHO classification

Boundaries for differentiating P.I. values significant to the Unified classification and the AASHO classification

Boundaries of USDA texture classes

Fig. 13. Particle size distributions of 252 selected samples and their P.I. values on the USDA texture triangle

Table 8a shows the P.I. of samples in areas with various clay contents on the texture diagram in Figure 13.

In Table 8a, it is apparent that for the area above and below the 20% clay line, the average purity of all the samples in the $\geqslant$ 11 and $\leqslant$ 10 P.I. groups is (92.2 + 93.0)/2 = 92.6% which is greater than that of (83.8 + 93.2)/2 = 88.5% for the area above and below the 17% clay line. Of all the samples with P.I. $\geqslant$ 11, 96.2% are in the area above the 20% clay line, and only 93.7% of those samples are above the 17% clay line. Of all the samples with less than 10% clay, 91.2% have P.I. value $\leqslant$ 6 as comparing to only 90% of all the samples below the 9% clay line. Thus, 20% and 10% clay lines would be slightly better than the 17% and 9% to delineate the significant values of P.I. $\geqslant$ 11 or $\leqslant$ 10, and $\leqslant$ 6 on the texture triangle. This agrees with the results from the entire 2894 samples discussed in the previous paragraph when only the P.I. $\leqslant$ 10 group is concerned. Thus, some further improvements of the proposed texture and engineering properties correlations may be possible with further study. The 17% and 9% clay lines suggested in Figure 26 should therefore be considered only as an approximation of these relationships. The 10% instead of 9% clay line would apparently be an improvement. But in the Netherlands (Bakker and Schelling, 1966), they used the 8% clay line for separating the "Lichte Zavel" (light zavel) from the "Zand" (sand). It is interesting that the 10%, 9%, and 8% clay lines are all

Table 8a. Plasticity indices of 252 selected samples with particle size distributions in areas delineated by various clay contents on a texture triangle.

Clay Contents (%)	% of P.I. Group Samples in Each of the Areas				% of all samples in the Areas with P.I. Indicated			
	⩾ 11	⩽ 10	> 6	⩽ 6	⩾ 11	⩽ 10	> 6	⩽ 6
⩾ 20	96.2	14.1	89.7	4.4	92.2	7.8	98.8	1.2
< 20	3.8	84.9	10.3	95.6	7.0	93.0	23.5	76.5
⩾ 17	93.7	31.5	93.5	8.8	83.8	16.2	96.0	4.0
< 17	6.3	68.5	6.5	91.2	6.8	93.2	16.2	83.8
< 10	0.6	35.8	1.6	45.6	3.0	97.0	8.8	91.2
< 9	0.6	31.5	1.6	39.7	3.4	96.6	10.0	90.0

considered to be significant for the soil classification on a texture triangle by these groups.

Distribution of Group Indices of the AASHO Soil Classification on a Texture Triangle

The particle size distribution of 252 samples representative of the particle size distributions of all the samples and their group indices are shown in Figure 14. The AASHO group index rating is obtained by the use of a group index formula based on the particle size gradation, the liquid limit, and the P.I. of the sample, or for rapid determination, by the use of the group index charts A and B in Figure 1. The group index formula is as follows:

$$\text{Group index} = 0.2a + 0.005\,ac + 0.01\,bd$$

where: a = that portion of % passing No. 200 sieve greater than 35% and not exceeding 75%, expressed as a positive whole number (1 to 40)

b = that portion of % passing No. 200 sieve greater than 15% and not exceeding 55%, expressed as a positive whole number (1 to 40)

c = that portion of numerical L.L. greater than 40 and not exceeding 60, expressed as a positive whole number (1 to 20)

d = that portion of the numerical P.I. greater than 10 and not exceeding 30, expressed as a positive whole number (1 to 20).

General evaluation of subgrades in terms of the group index is, according to the PCA, Soil Primer (1956) as follows in Table 9.

Table 9. Evaluation of subgrade materials by group indices.

Excellent:	A-1-a(0)	soils only
Good:	0-1	group indices
Fair:	2-4	group indices
Poor:	5-9	group indices
Very poor:	10-20	group indices

According to the above evaluation, the distribution of the significant group index values of these 252 selected samples are shown on Figure 14.

It is noticed that the 27% clay line (below 42% sand) and the 72% sand line which were significant in differentiating the AASHO soil groups on the texture triangle (Figure 9) are also significant lines for group index groupings. The other boundaries are the 55% sand line for dividing "Fair subgrades" (2-4 group indices) from "Poor subgrades" 15-9 group indices) the 42% sand line and the 27% clay line for dividing "Poor subgrades" from "Very poor subgrades" (10-20 group indices) in Figure 14. The 63% sand line below 20% and the 67% sand line above 20% clay apparently divide "Good subgrades" (0-1 group indices) from "Fair subgrades."

Influence of Clay Activities of Materials with Different Textures on the Properties Important to Engineering

The activity of clays is defined by Yong and Warkentin (1966) as the ratio of the plasticity index to the percentage of clay size particles. The 252 representative samples evenly distributed on the USDA texture triangle, Figure 13, have been evaluated as to their clay activities. The average clay activity value of each USDA texture class is shown in Table 10. Samples with clay contents $<$ 15% are not included in this calculation.

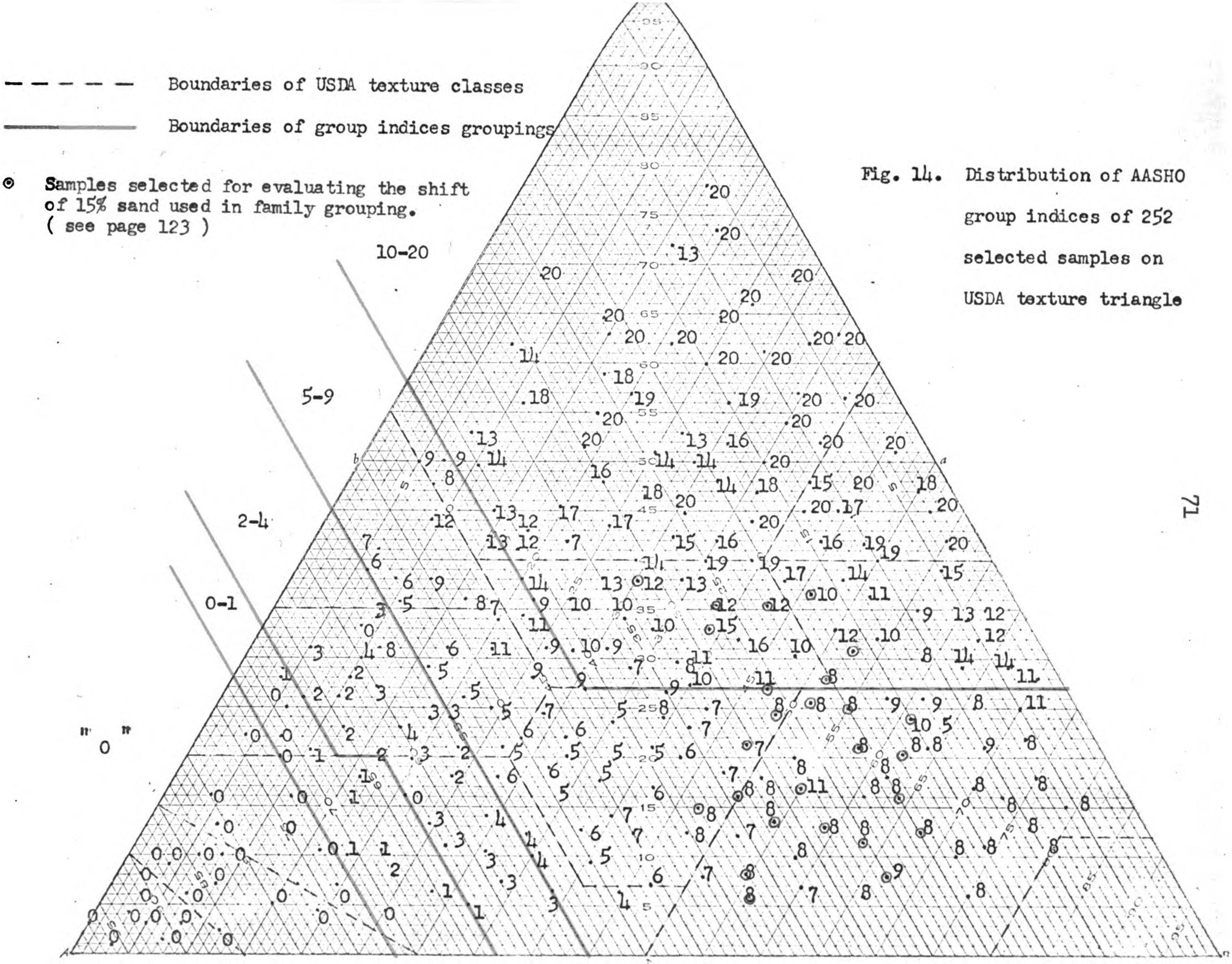


Fig. 14. Distribution of AASHO group indices of 252 selected samples on USDA texture triangle

Table 10. Average clay activity of samples with over 15% clay, in 252 selected samples, by USDA texture classes.

Texture Classes	Number of Samples	Average Clay Activity
C	51	0.58
SiC	10	0.69
SC	9	0.48
SiCL	16	0.55
CL	22	0.54
SCL	30	0.57
SiL	23	0.52
L	21	0.47
SL	8	0.55

It has been shown that the plasticity index varies with the kinds of clay minerals and the kind of exchangeable cation on the clay. Yong and Warkentin cited values for the average clay activities of the common clay minerals as follows: kaolinite - Na, 0.26; kaolinite - Ca, 0.37; illite - Na, 0.27; illite - Ca, 0.50; montmorillonite - Na, 6.03; and montmorillonite - Ca is 1.14 (assuming the clay minerals for which they cited P.I. were 100% clay).

From the above data on clay minerals, samples with clay contents greater than 15% (which are considered as having significant plasticity), and with activities greater than 0.7 may be tentatively defined as having active clays. Thirty-six out of the 252 samples examined have active clays based on these criteria. The size distribution of those samples and their AASHO classifications are shown in Figure 15. The average clay activity values of the samples in each texture class and their average L.L., P.I., and group indices are shown in Table 11. These values may be compared with the average values for the texture classes of the 252 samples in Tables 6, 8, and 10.

Tables 10 and 11 show that there are not major differences in average clay activities of samples in the different texture classes or among samples with active clays in the different texture classes. The activities of the clays in the samples with active clays are about 25 to 35%

1. "•" A-7-5
2. "x" A-7-6
3. "Δ" A-6
4. "o" A-2-6
5. "□" A-2-7

(Value in parenthesis represents clay activity)

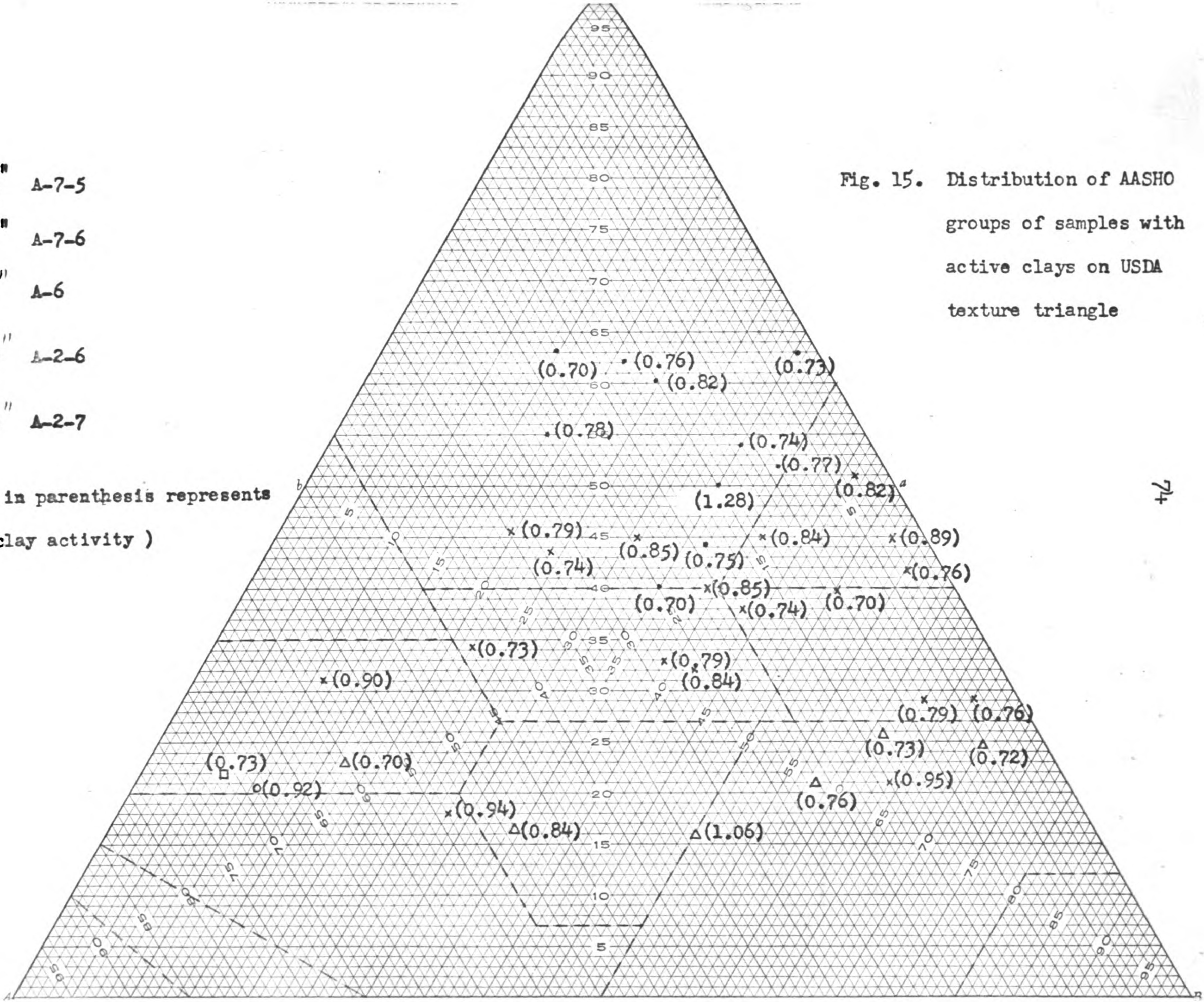


Fig. 15. Distribution of AASHO groups of samples with active clays on USDA texture triangle

Table 11. Average clay activity of the 36 selected samples with active clay by USDA texture classes.

Texture Classes	Number of Samples	Average Clay Activity	Average L.L.	Average P.I.	Average G.I.
C	14	0.80	72	41	19.4
SiC	5	0.80	63	36	19.8
SiCL	3	0.76	45	24	15.0
CL	3	0.78	46	26	14.0
SCL	4	0.81	42	20	3.5
SiL	5	0.84	42	18	11.4
L	1	0.84	30	14	12.0
SL	1	0.94	41	17	6.0

greater than the average clay activities of all the samples in each texture class. Comparing Tables 6 and 8 with Table 11, it found that the average P.I. and L.L. values of samples with active clays are all greater than those of all samples of the same texture class. Since P.I. and L.L. values enter into the group indices they too will be increased in samples with active clays. Obviously, the clay activity is influencing those properties that are significant to the engineering groupings of soils.

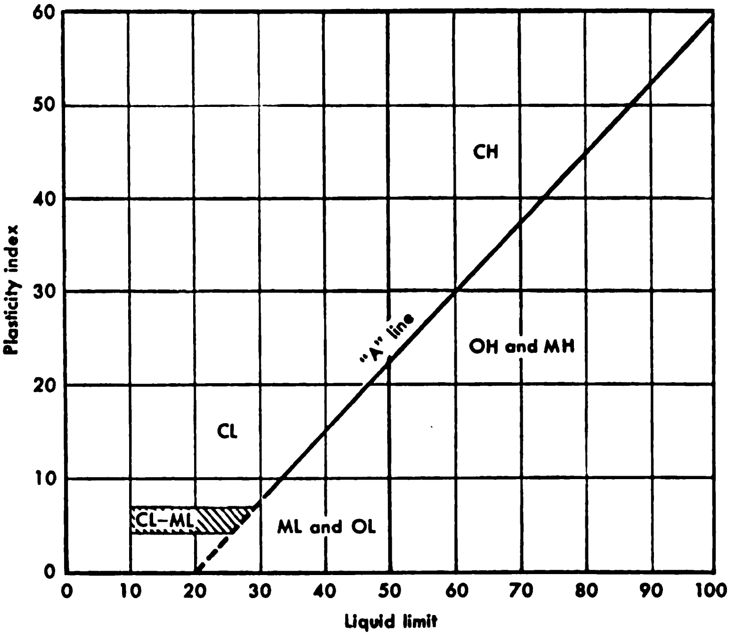
As far as the kinds of clay minerals are concerned, the clay activity may serve as an index to predict approximately the dominant clay minerals of given soil samples. In Yong and Warkentin's citation, it seems that the clay activity range from amorphous dried free oxides is < 0.2; for kaolinite and illite is 0.2-0.7; for undried amorphous materials mixed with montmorillonite, it is 0.7-2.0; and for montmorillonite it is > 1.0. The samples with so-called active clays in this study may thus contain appreciable proportions of amorphous materials or montmorillonite mixed with other clay minerals.

The Unified Soil Classification in Relation to USDA Soil Texture Classification

Criteria Used in the Unified Soil Classification

The Unified soil classification is based on the following properties as outlined in Table 12:

TABLE 12 Unified Soil Classification System

Major divisions			Group symbols		Typical names	Laboratory classification criteria		
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW		Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows: Less than 5 per cent. . . . . GW, GP, SW, SP More than 12 per cent. . . . . GM, GC, SM, SC 5 to 12 per cent. . . . . *Borderline cases requiring dual symbols***	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP		Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM*	d	Silty gravels, gravel-sand-silt mixtures		Atterburg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
				u				
			GC		Clayey gravels, gravel-sand-clay mixtures		Atterburg limits above "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW		Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP		Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM*	d	Silty sands, sand-silt mixtures		Atterburg limits below "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols.
				u				
			SC		Clayey sands, sand-clay mixtures		Atterburg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half of material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	 **Plasticity Chart**		
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL		Organic silts and organic silty clays of low plasticity			
	Silts and clays (Liquid limit greater than 50)		MH		Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH		Inorganic clays of high plasticity, fat clays			
			OH		Organic clays of medium to high plasticity, organic silts			
	Highly organic soils		Pt		Peat and other highly organic soils			

*Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterburg limits; ffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.

**Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. or example: GW-GC, well-graded gravel-sand mixture with clay binder.

(1) percentage of particles within various size limits (including particles < 74.2 mm)

(2) shape of the grain-size distribution curve

(3) plasticity and liquid limits (for fine-grained soils and in GM or SM groups for roads and airfields)

(4) elasticity (MH group)

(5) mineralogical composition (MH group)

(6) organic content (O and P groups)

The criteria for individual groups in the Unified soil classification are shown in Table 12. The number of samples of each of the 26 Unified soil groups available for use in this study are shown in Table 13.

Distribution of the Unified Groups on USDA Texture Triangle

The word "group" is used to suffix the Unified soil classes to distinguish them from the USDA texture classes in this study. For example, "CL" group is an Unified soil class, "CL" refers to the USDA "clay loam" texture. It seems that many Unified soil groups are seldom found in this study. About half of the 26 groups are represented by no more than 6 samples. Figures 16 through 23 show the size distribution of each Unified soil group except the gravel groups (G) on the USDA texture triangle .

(1) Distribution of "silt and clay" groups: These are the most common groups of samples in the Unified soil classification in this study. Nearly 2000 samples, or 70% of the

Table 13. The number of samples in each unified soil group and their percentages of all 2894 samples studied.

"Gravel" Groups	No. of Samples	%	"Sand" Groups	No. of Samples	%	"Silt and Clay" Groups	No. of Samples	%
1. GW	4	0.138	12. SW	1	0.034	20. ML	281	9.71
2. GW-GC	1	0.034	13. SW-SM	6	0.208	21. ML-CL	579	20.0
3. GW-GM	5	0.172	14. SP	27	0.933	22. CL	721	24.91
4. GP	5	0.172	15. SP-SM	94	3.25	23. OL	1	0.034
5. GP-GC	4	0.138	16. SP-SC	2	0.068	24. MH & MH-CH	251	8.682
6. GP-GM	5	0.172	17. SM	384	13.26	25. CH	158	5.46
7. GM	26	0.898	18. SM-SC	140	4.84	26. OH	3	0.104
8. GM-GC	31	1.071	19. SC	144	4.977			
9. GM-SM	3	0.104						
10. GC	17	0.587						
11. GC-SC	1	0.034						
Sum	102	3.52		798	27.57		1994	68.90
			Total Samples:			2894		

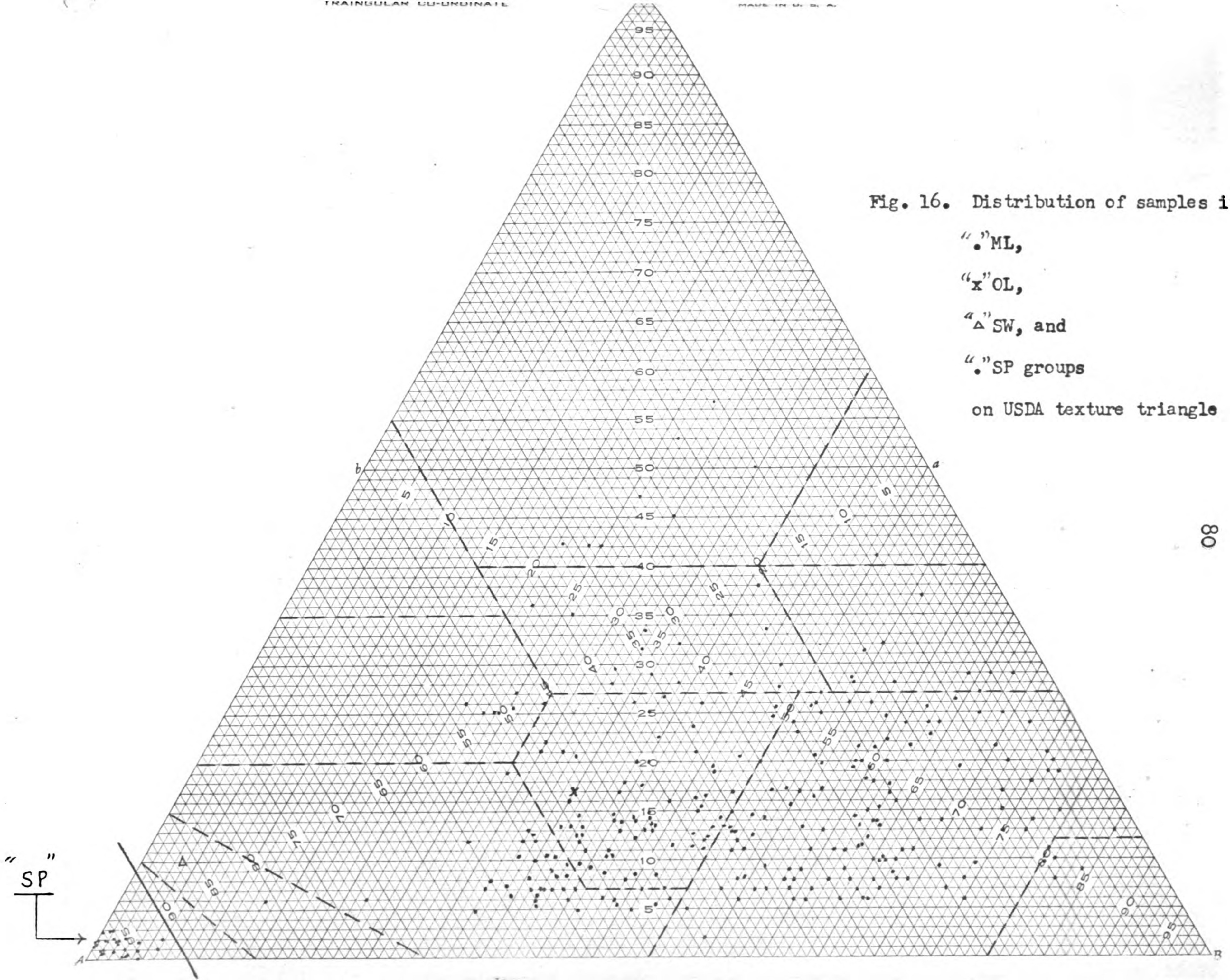


Fig. 16. Distribution of samples in
"•"ML,
"x"OL,
"△"SW, and
"•"SP groups
on USDA texture triangle

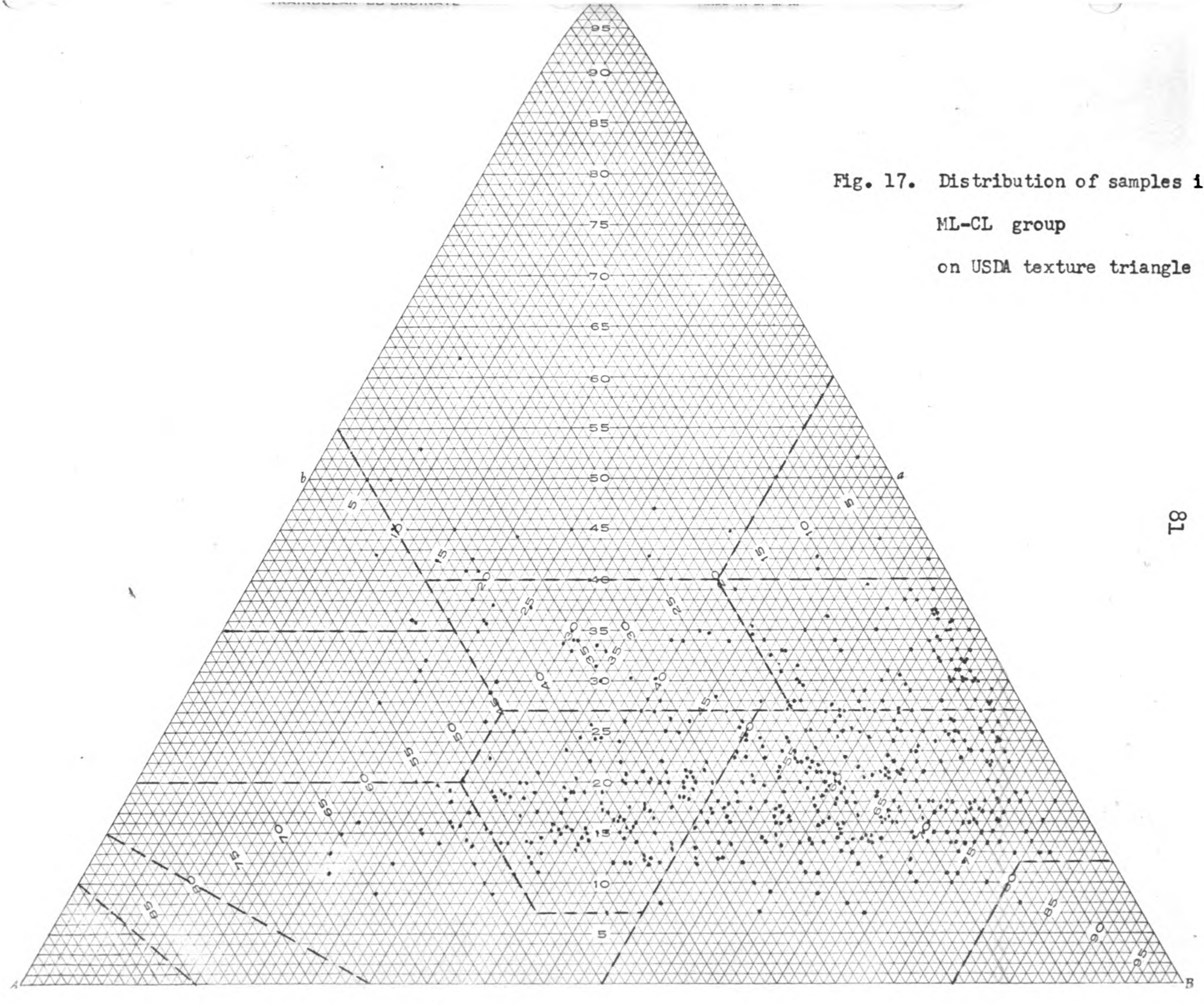


Fig. 17. Distribution of samples **in** ML-CL group on USDA texture triangle

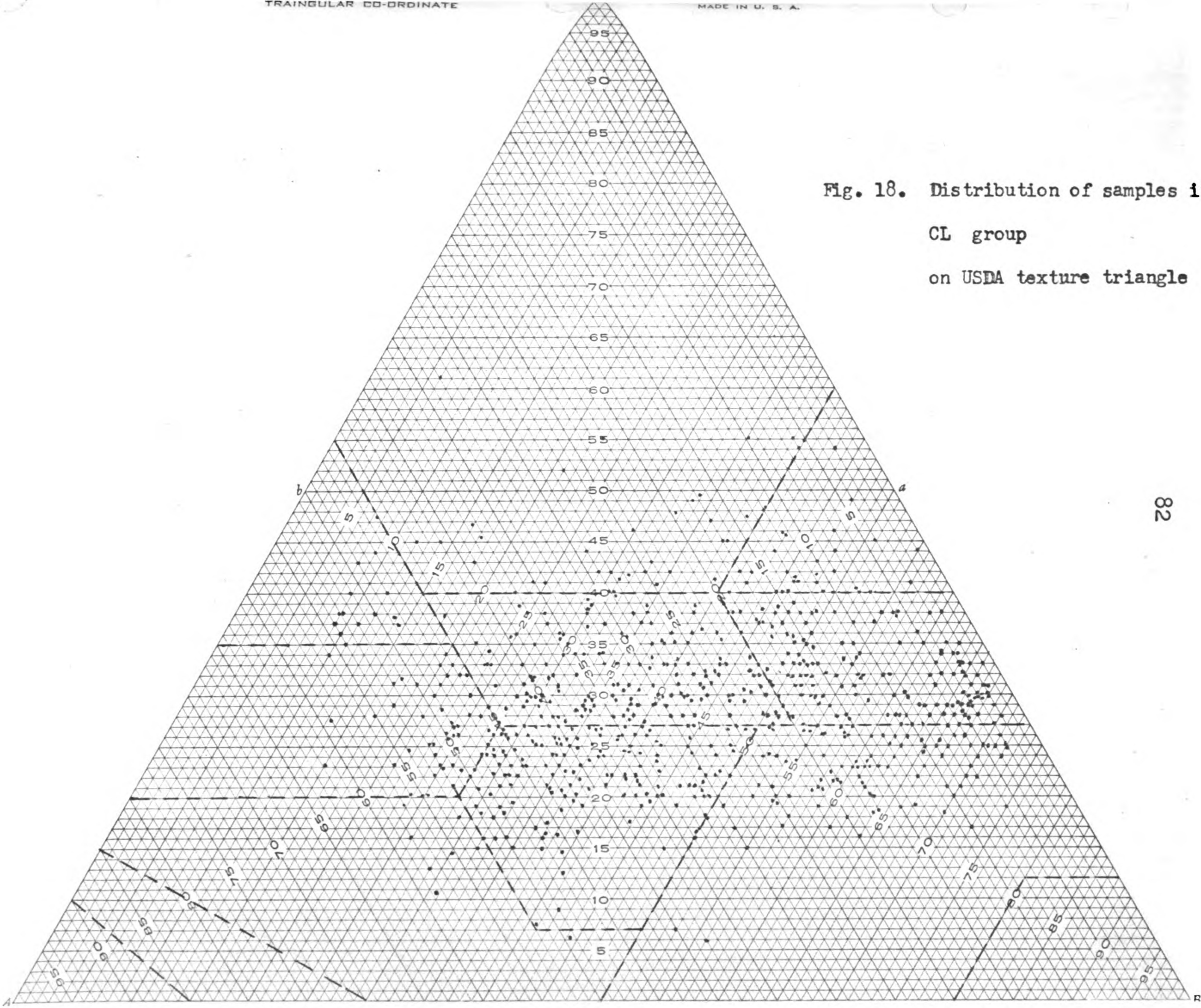


Fig. 18. Distribution of samples **in** CL group on USDA texture triangle

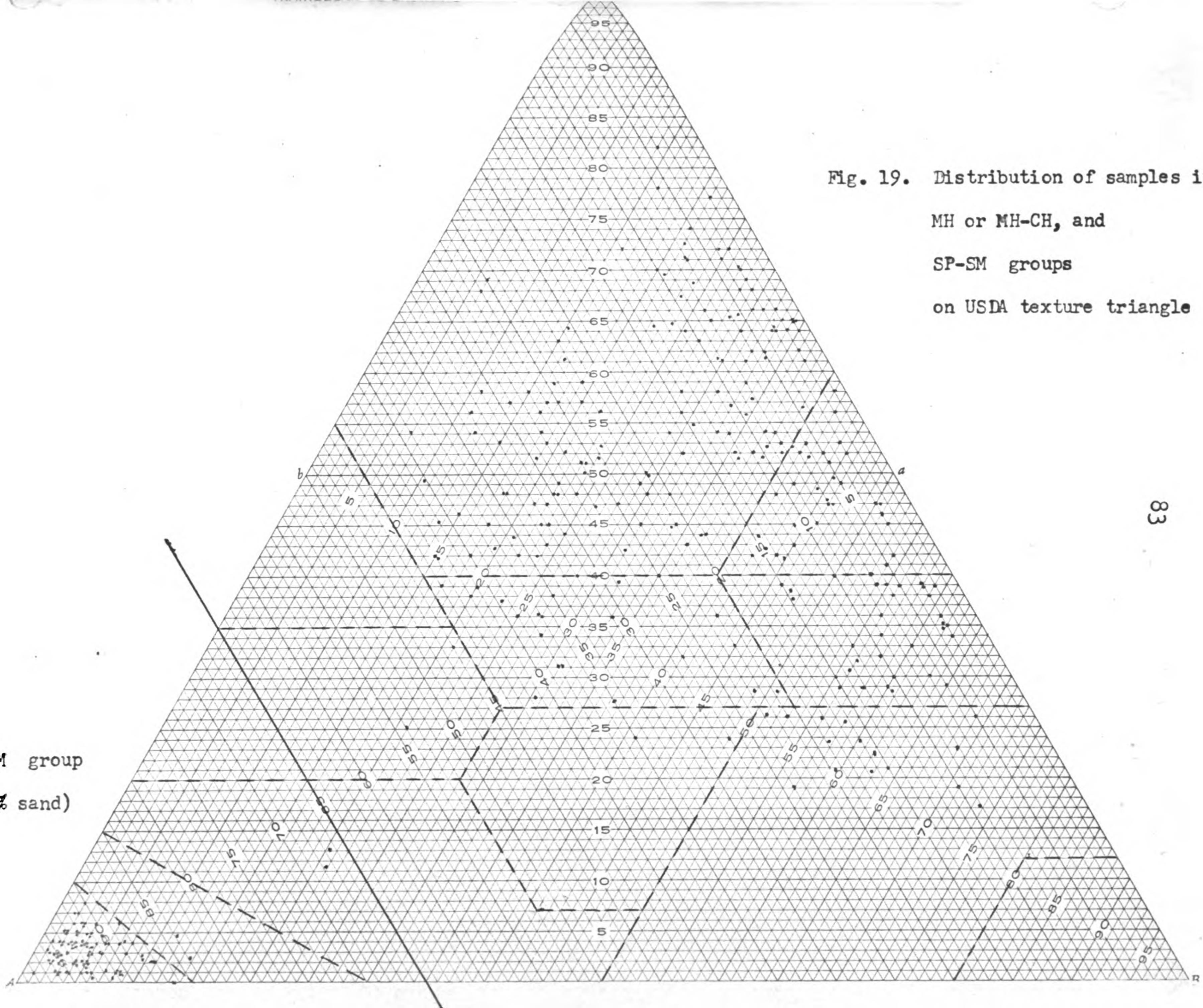


Fig. 19. Distribution of samples in
MH or MH-CH, and
SP-SM groups
on USDA texture triangle

SP-SM group
(> 65% sand)

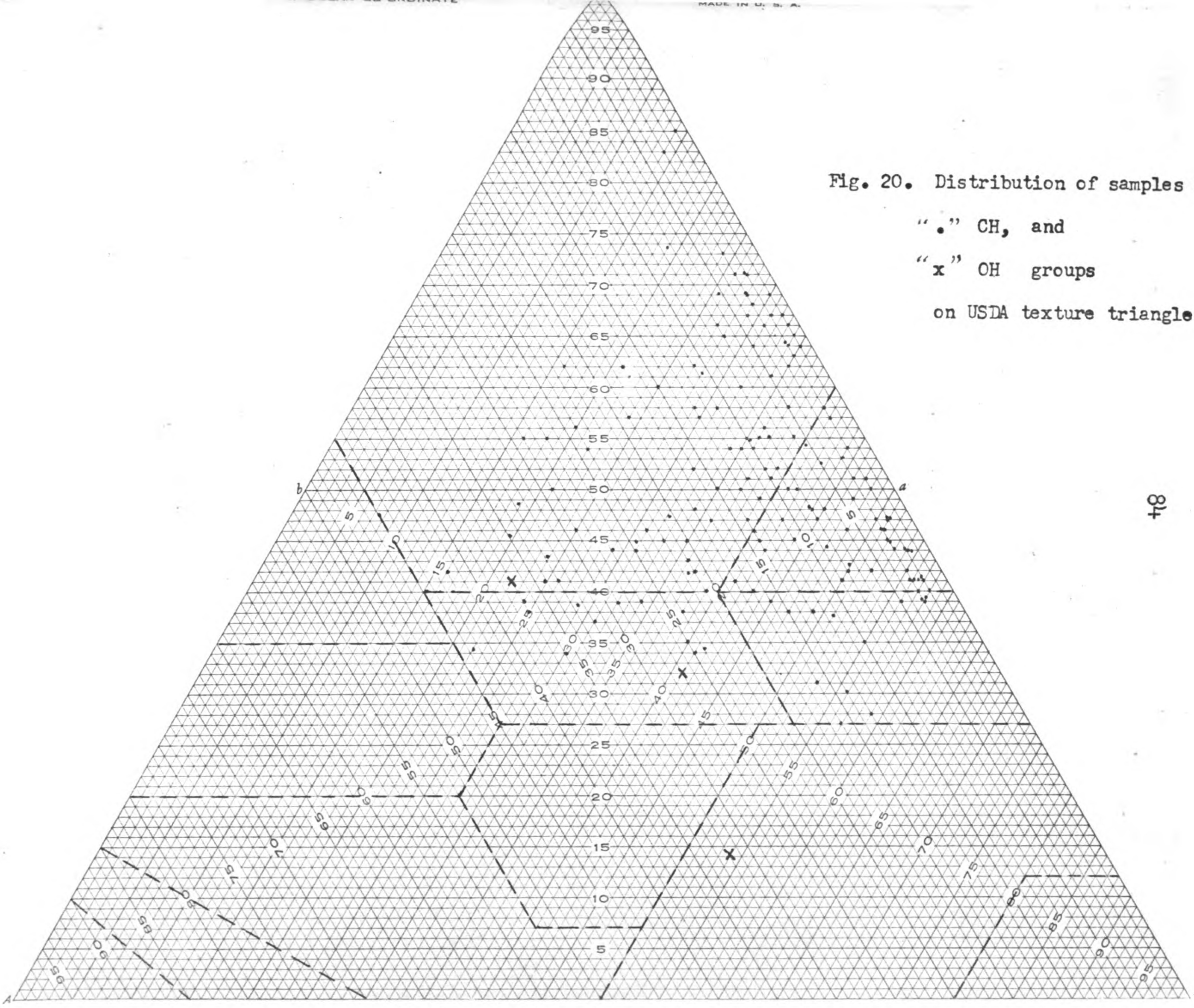


Fig. 20. Distribution of samples **in**
"•" CH, and
"x" OH groups
on USDA texture triangle

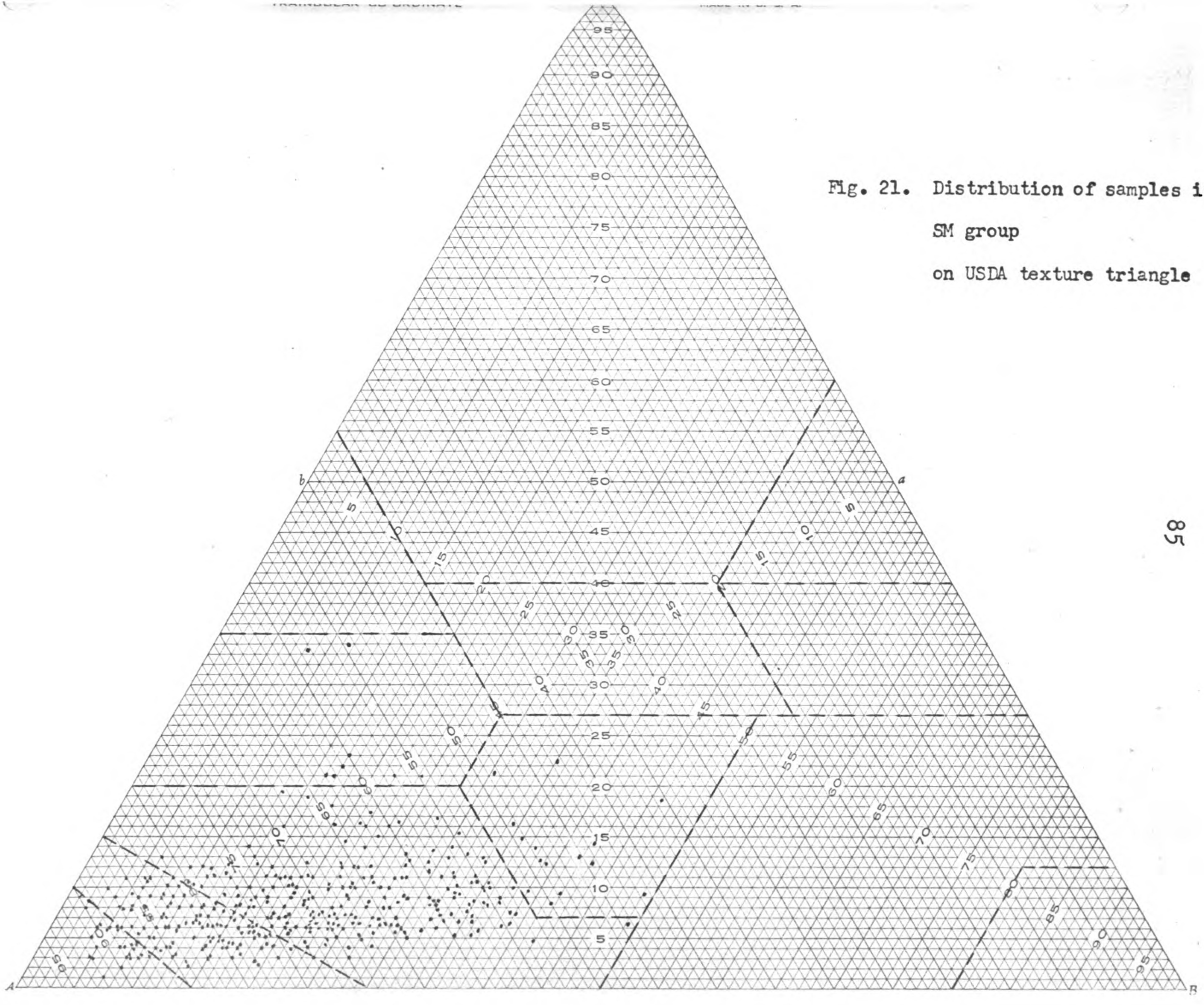


Fig. 21. Distribution of samples in
SM group
on USDA texture triangle

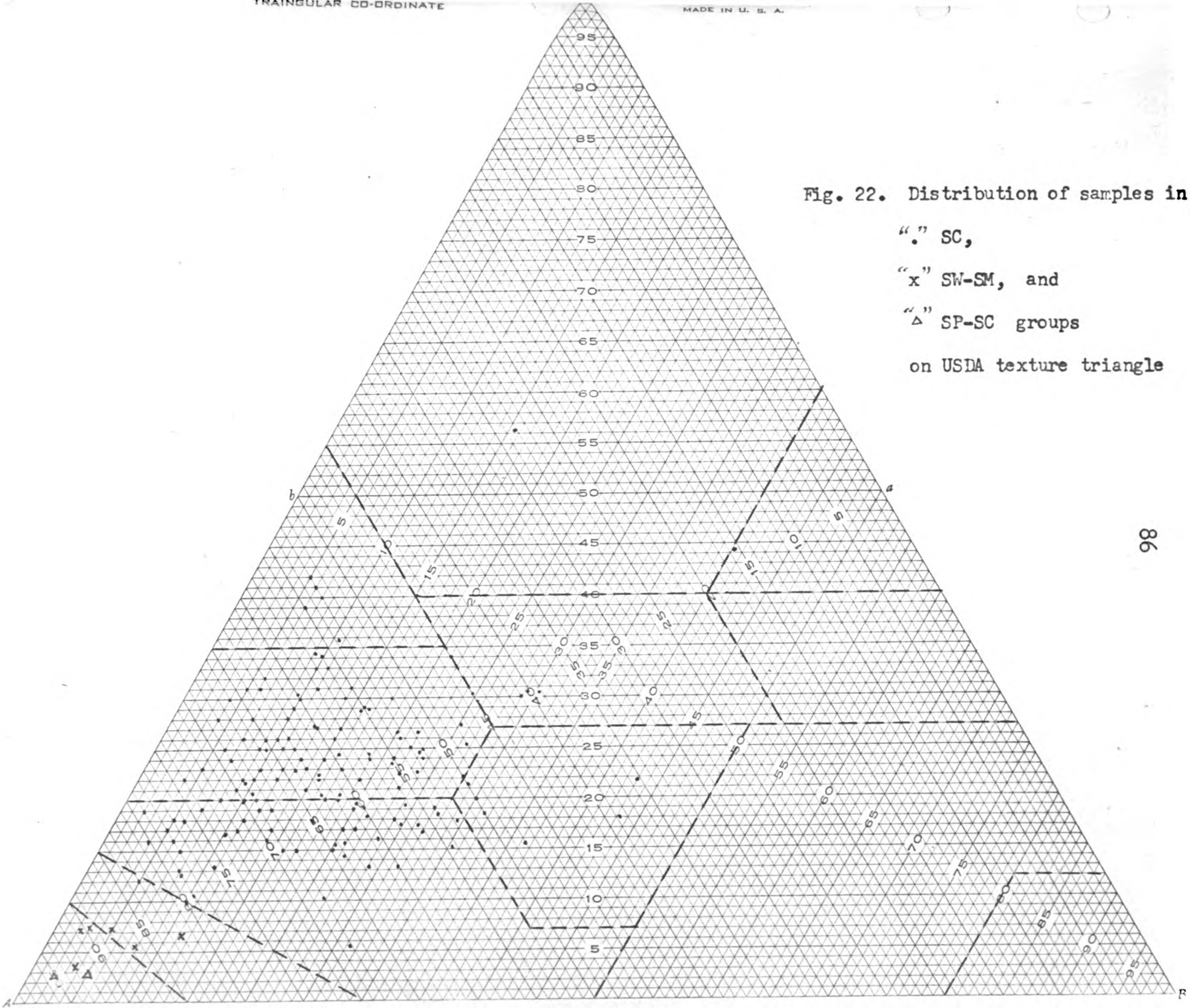


Fig. 22. Distribution of samples in
"." SC,
"x" SW-SM, and
"△" SP-SC groups
on USDA texture triangle

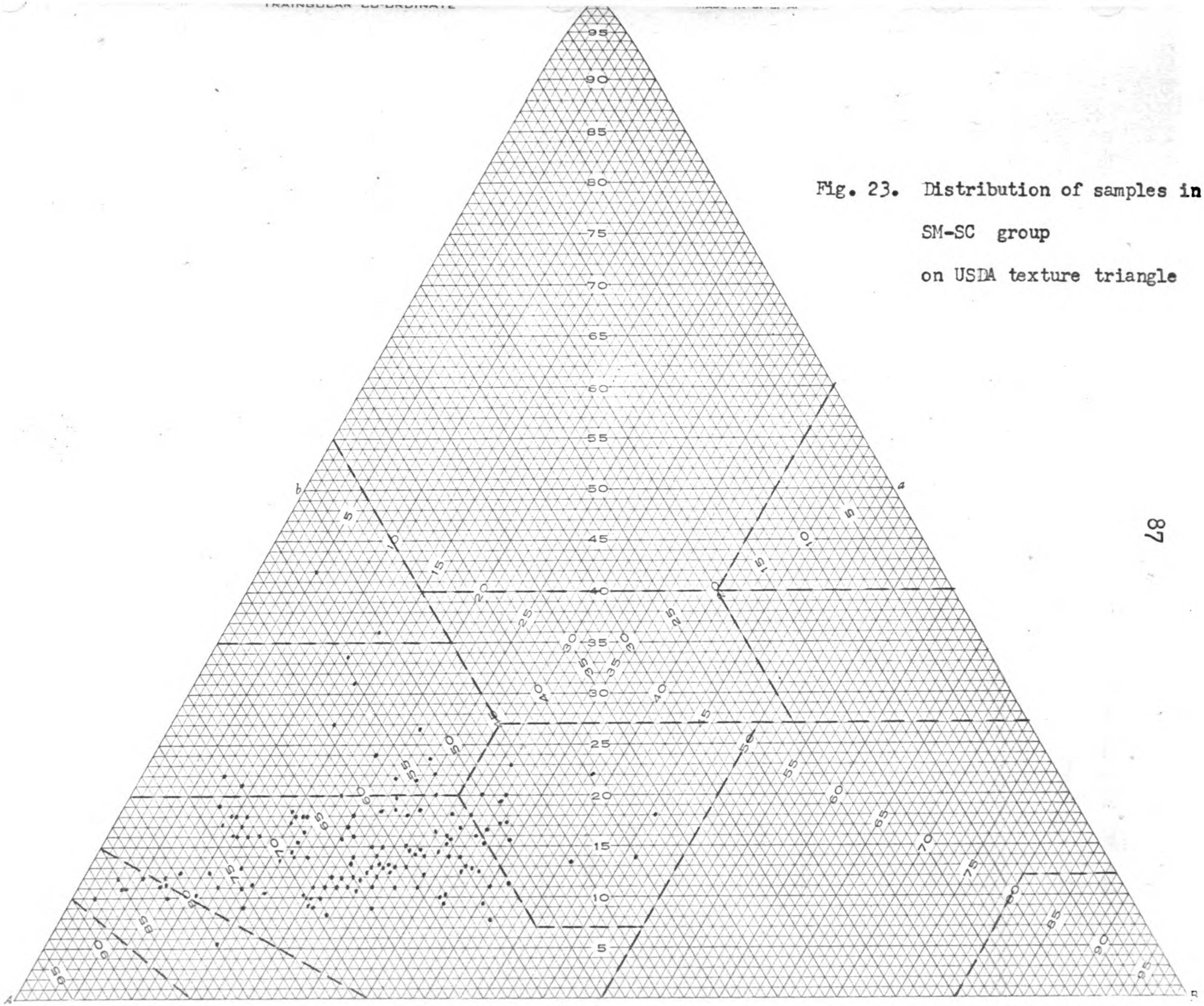


Fig. 23. Distribution of samples in
SM-SC group
on USDA texture triangle

total studied, fall into the 7 subgroups. The OL and OH subgroups are rarely represented in these samples. The distribution of the other five subgroups are shown separately in Figures 16, 17, 18, 19, and 20.

(a) ML group: Most samples were located within SiL, L, and the siltier portion of SL textural classes. Figure 16.

The clay content of this group is usually less than 27%. The 52% sand line would be a suitable boundary for separating this group from the adjacent SM and SC groups.

(b) ML-CL group: This is an intermediate group between the ML and CL groups. Actually, as pointed out by Decker, this consists of ML or CL materials.* Five hundred seventy nine such samples are included. They are distributed mostly within the L, SiL, and SiCL texture classes, Figure 17. More samples of this group overlapped the ML group than the CL group. The particle size distribution pattern of the ML-CL group is broad in the area of clay contents between 10% and 40%, and with sand contents less than 55%.

(c) CL group: This is the most numerous Unified soil group in this study. It includes 721 samples nearly one-fourth of all the samples studied. Their size distributions, Figure 18, are chiefly in the area of CL or SiCL, the more clayey parts of L or SiL, the less sandy parts of

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*Personal communication under date of August 19, 1966.

the SCL or SC, and the less clayey parts of the SiC or C texture classes. Of the samples of this group, 87.3% were distributed within the 17-40% clay range.

(d) MH and MH-CH groups: These groups, not differentiated in this study and subsequently referred to here as MH, differ from the ML and CL groups in having L.L. greater than 50. The 251 samples, Figure 19, are located chiefly within the clay, silty clay, clay loam, silty clay loam, and the less clayey portion of the silt loam texture classes. Of the samples in these groups, 92.8% have clay contents of greater than 27% and sand fractions of less than 45%.

(e) CH group: This group is very similar to the MH group in properties except that the CH group contains more consistently finer materials than the MH group. All samples are distributed above the 27% clay line principally above 40% clay line and have sand contents of less than 44%.

(2) Distribution of "S (sand)" groups: Eight "S" groups including a total of 798 samples are represented in this study, Figures 16, 19, 21, 22, and 23. These groups are predominantly composed of the SP (Figure 16), SM (Figure 21), and SC (Figure 22) groups , with two intergrades between them (SP-SM, Figure 19) and (SM-SC, Figure 23). These five groups account for 95.48% of the total "S" samples. Most samples of the SM group are distributed in the central parts of the LS and SL texture classes, Figure 21. Seventy-five

percent of the samples of the SM-SC group are located within the more clayey portion of the SL texture class, Figure 23. The distribution of the SC group is broader than the foregoing group, Figure 22. Most of the SC group covers the area of the SCL and the more clayey part of the SL texture classes, Figure 22. Figure 16 and Figure 19 indicate that almost all of the SP and SP-SM groups fall within the sand textural class.

Discussion of Relationships of Unified Groups of Fine Earth Samples to a Texture Triangle

Rieger, et al. in the Soil Conservation Service, USDA, proposed a diagram showing the generalized relationship of the Unified soil classification to the USDA textural classes in 1957. It is shown here as Figure 24.

Examining the data in Figures 16 through 23, and looking at the criteria for the Unified soil classification system, Table 12, the 26 Unified soil groups identified among the 2894 soil samples seem too numerous. Actually, most of the samples are in a much smaller number of groups. The 10 groups of fine earth considered here include 96% of all the samples (Figures 16 through 23, include 2782 samples). Rieger, et al. proposed a diagram, Figure 24, with 10 Unified soil groups (or group complexes). Revision of this diagram based on the much larger number of samples on which data are now available is considered next.

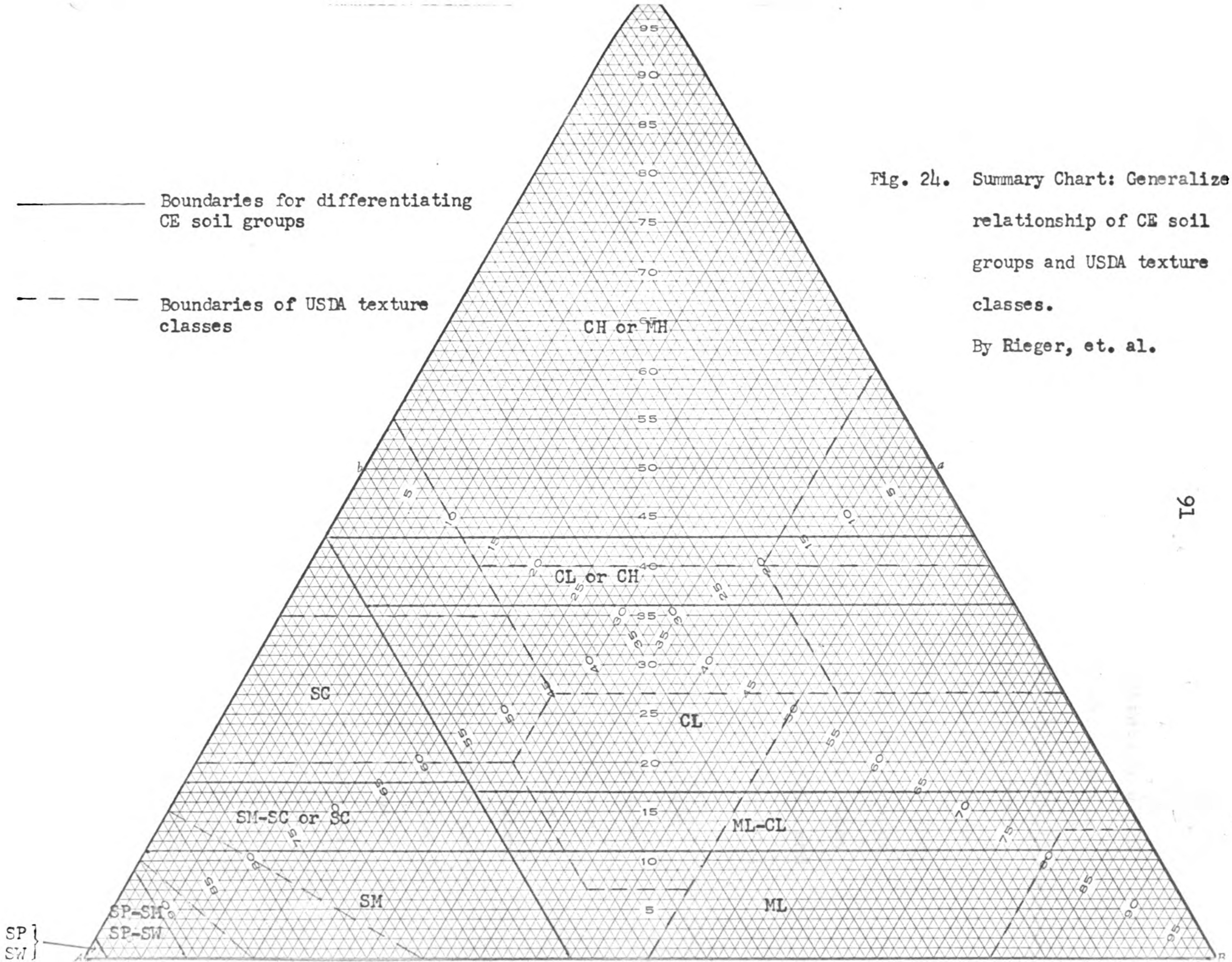


Fig. 24. Summary Chart: Generalized relationship of CE soil groups and USDA texture classes.

By Rieger, et. al.

Rieger plotted a 43% clay line for separating a "CH or MH" group from the less clayey groups. Checking this with a 50% clay line which is correlated with L.L. value 50, according to Odell *et al.*; a 40% clay line which has been used in the AASHO soil classification; and a 45% clay line in addition to Rieger's 43% clay line, it is found that in the area above the 40% clay line the "CH, MH, and MH-CH" groups made up 75.1% of the samples; above the 43% clay line, they account for 83.3%, above 45% clay line, they are 86.32%; and above 50% clay they are 92% of the samples. This is shown as area I in Figure 25.

In considering the underlying groups, 35% and 40% clay lines were evaluated in addition to the 36% clay line used by Rieger, *et al.*, Figure 24. Reasons for these are the possible significance of the 35% clay line in family grouping as suggested in the new soil classification system Soil Survey Staff, 1964, Supplement, and because of the significance of the 40% clay line in the proposed diagram for the AASHO soil classification, Figure 9, and in the USDA texture triangle. These comparisons are shown in Table 14.

From Table 14, it is indicated that the 40-50% clay range would better be defined as a "MH ∿ CH ∿ CL" group-complex (MH includes MH and MH-CH), because these kinds of samples represent 85.78% of the samples in that area. This is area II in Figure 25.

Table 14. Comparisons of Unified group distribution patterns in various clay ranges of 35-50%, 36-50% and 40-50%.

Unified Groups	35-50% Clay	36-50% Clay	40-50% Clay
1. MH(& MH-CH)	88	83	65
2. CH	84	82	65
3. CL	147	123	57
4. ML-CL	47	36	19
5. ML	10	9	7
6. SC	6	5	3
7. SM-SC	2	1	1
8. OH	1	1	1
% MH ∨ CH ∨ CL samples in each area	82.86	84.70	85.78

Rieger's "CL" group area, 17-36% clay, actually is represented by more than 1000 samples in this study. In addition to many CL samples, Figure 18, this area also includes a larger number of ML, ML-CL, and MH samples (plus samples of other groups), Figures 16, 17, and 19 respectively. The lower boundary of this group used by Rieger is 17% clay. This line agrees with the line plotted for differentiating the A-7 ∼ A-6 ∼ A-5 ∼ A-4 group complex from the A-5 ∼ A-4 group complex in the AASHO soil classification diagram, Figure 9. By evaluating the distribution pattern of CL, ML-CL, ML, and MH groups represented in this area, the best combinations of those groups are designated in Figure 25 as:

III. CL ∼ ML-CL ∼ ML ∼ MH;
IV. CL ∼ ML-CL ∼ MH;
and V. CL ∼ ML-CL ∼ ML group complexes.

The percentages of all the samples in those areas that are in the groups or group complexes named are 96.7%, 92.7%, and 92% respectively. The 27% clay line, as an upper limit of most of the ML and the lower limit of most of the MH samples (in the loam texture range) is apparently significant to the USDA and the AASHO classifications.

Further, in the diagram proposed by Rieger, <u>et al</u>., the ML-CL group, Figure 24, doesn't seem appropriate. As shown in Figures 16 and 17, there were 169 "ML-CL" and 179 "ML" samples distributed below the 17% clay line. They overlap pretty well between 5 and 17% clay. It is hard to separate the ML-CL group from the ML group by any designated texture boundary. Therefore, a "ML-CL∿ ML" group complex is proposed for area VI in Figure 25. The sandy boundary of that complex and the purity of this group-complex so defined are 52% and 87.4% respectively.

Although the 57% sand line is a good boundary for separating the "SC" group from Rieger's "CL" group, his 18% clay line as a lower limit for the SC group, Figure 24, would include more SM-SC samples, Figure 23, with the SC group than if a lower limit of 20% clay was used. In evaluating the boundaries for delineating the SC group, the distribution patterns shown in Tables 15 and 16 have been studied.

From Tables 15 and 16, 20-40% clay or 17-40% clay both with sand contents of > 65% seem to give the best boundaries for designating a homogeneous SC∿SM-SC group complex. But using sand contents of > 57%, > 60%, or > 65% will greatly decrease the purity of its adjacent group complexes, such as CL∿ML-CL∿ ML∿ MH, etc., and include many fewer samples. Also if 18% and 17% clay lines were used as lower limits for this group, it would involve more samples of the SM-SC group in the SC∿ CL group complex. SM-SC makes up only 10% of this SC∿CL∿SM-SC group complex. The 20-40% clay lines with > 52% sand are proposed to designate

Table 15. Some limits of sand and clay contents examined as possibilities for relating the Unified soil groups to a texture triangle.

Combinations Unified groups		20-40% Clay			
		> 52% Sand	> 57% Sand	> 60% Sand	> 65% Sand
SM	(384)*	8	5	3	--
SM-SC	(140)	11	4	2	2
SC	(144)	75	50	41	18
ML	(281)	1	--	--	--
ML-CL	(579)	1	--	--	--
CL	(721)	18	2	1	--
MH or CH	(409)	1	--	--	--
Total samples		115	61	47	20
% SC		65.2	81.96	87.2	90.0
% SC ∪ SM-SC		74.8	88.5	91.5	100.0
% SC ∪ CL ∪ SM-SC		90.4	**	**	**
% SC ∪ CL.		80.9	**	**	**

*Numbers in parenthesis are the total of samples of each group in this study.

**CL is represented by only 1 or 2 samples, so, it should not be considered in those areas.

Table 16. Some limits of sand and clay contents, other than in Table 15, examined as possibilities for relating the Unified soil groups to a texture triangle.

Combinations	18-40% Clay				17-40% Clay			
Unified groups	> 52% sand	> 57% sand	> 60% sand	> 65% sand	> 52% sand	> 57% sand	> 60% sand	> 65% sand
SM (*)	10	8	6	2	12	9	7	2
SM-SC	24	13	8	7	31	20	15	12
SC	88	63	52	25	98	69	57	28
ML	2	--	--	--	2	--	--	--
ML-CL	5	--	--	--	6	--	--	--
CL	21	2	1	--	21	2	--	--
MH or CH	1	--	--	--	1	--	--	--
Total samples	151	86	67	34	171	100	79	42
% SC	51.6	73.2	77.6	73.5	57.3	69	72.1	66.6
% SC ∼ SM-SC	74.2	88.4	89.5	94.1	75.4	89	91.1	95.2
% SC ∼ CL	72.2	**	**	**	69.6	**	**	**
% SC ∼ CL ∼ SM-SC	88.1	**	**	**	87.7	**	**	**

*, **See footnote to Table 15.

the boundaries for a SC ∿ CL group complex as area VII in Figure 25.

The SM-SC group is mostly distributed within the range between 10 and 20% clay and 50 to 92% sand, Figure 23. A large number of samples of the SM group and quite a few samples of the SC group are also included in that area, Figures 21 and 22. It is suggested that this area, VIII in Figure 25, be designated as a SM-SC ∿ SM ∿ SC group complex with a purity of 85.5% rather than as a "SM-SC or SC" group which has been proposed by Rieger, et al.

The SM group samples, Figure 21, usually contained less than 15% clay and from 52 to 90% sand. Although many samples of this group have been kept in the overlying group complex (SM-SC ∿ SM ∿ SC), SM samples still represent about 83% to the total samples in the area with < 10% clay and 52 to 90% sand, area IX in Figure 25.

The area between 91 and 98% sand, Rieger, et al., Figure 24, designated as a complex of the SP-SM and SP-SW groups. In this study, no "SP-SW" group sample was found among a total of 2894 samples. The SP group, it seems can better be separated from the SP-SM group at 96% sand, instead of 98% sand as shown by Rieger, et al. These SP-SM and SP areas are shown as X and XI in Figure 25. Only one sample of the SW group was found in this study, but it fell in the SM-SC ∿ SM ∿ SC group complex. It therefore seems, based on this study, that the area with greater than 96% sand will be better designated as the "SP" group, rather than as a "SP and SW" group complex as proposed by Rieger, et al.

A Proposed Diagram for Relating the Unified Soil Classification to the USDA Texture Triangle

According to the study of the 26 Unified soil groups identified in this study, only nine fine earth groups (or group complexes) were common in occurrence, i.e. ML; ML-CL; CL; MH & MH-CH; CH; SP-SM; SM; SM-SC; and SC groups. For convenience in grouping these samples and showing their particle distribution patterns, eleven groups and group complexes are shown on a USDA texture triangle as Figure 25.

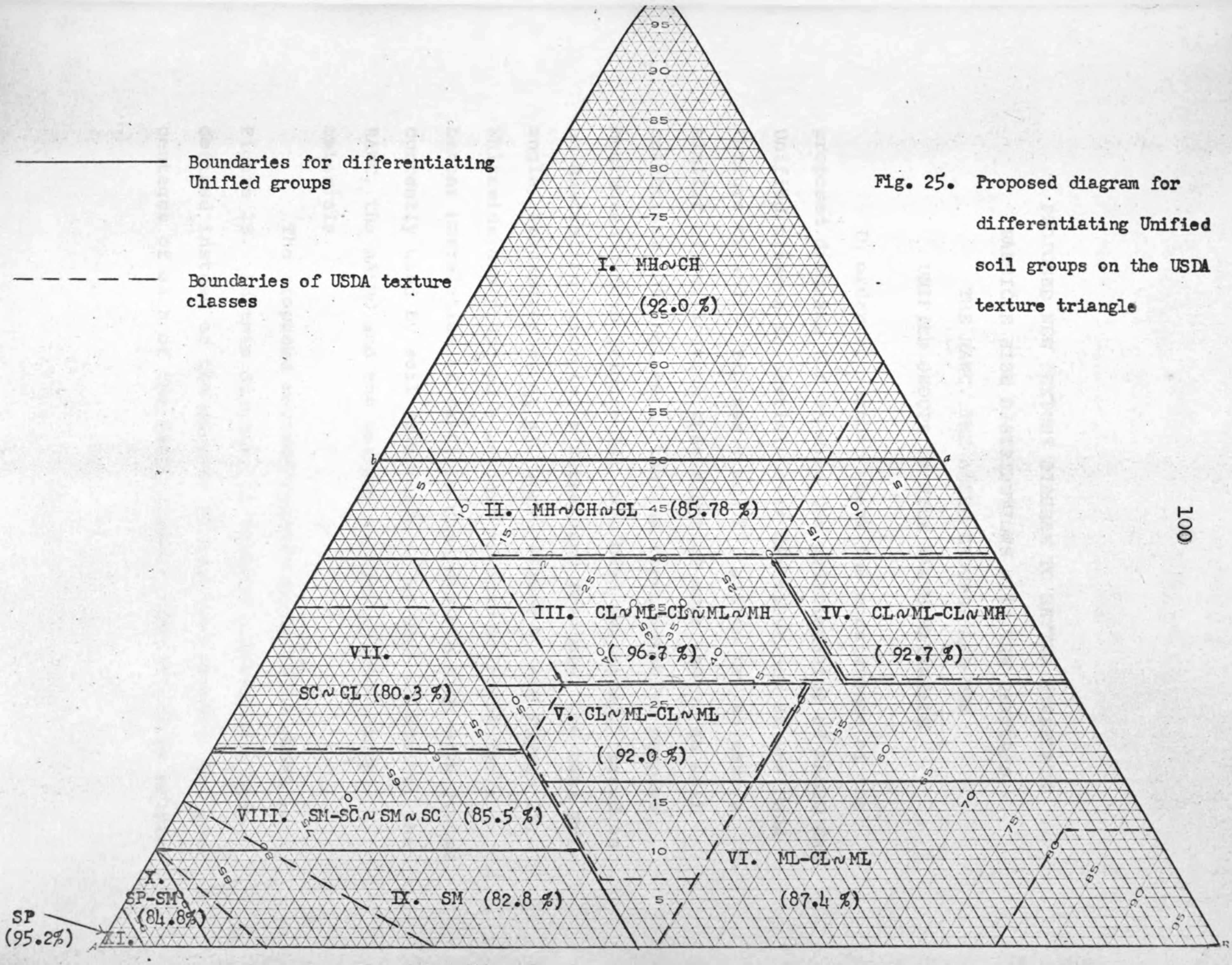
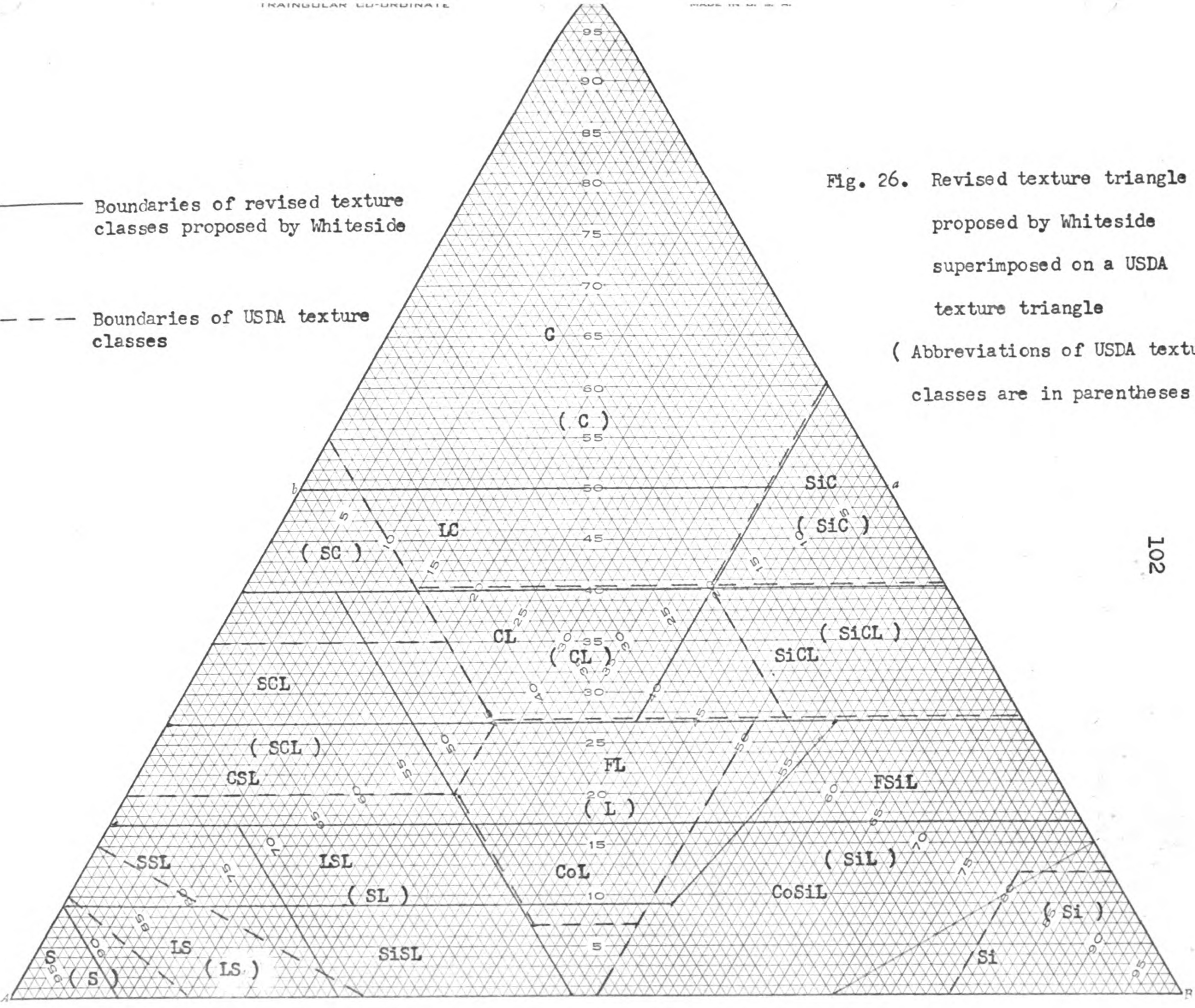


Fig. 25. Proposed diagram for differentiating Unified soil groups on the USDA texture triangle

PROPOSED NEW TEXTURE DIAGRAM TO BETTER CORRELATE PARTICLE SIZE DISTRIBUTIONS WITH THE TEXTURES, THE RAWC, THE AASHO GROUPS, AND THE UNIFIED GROUPS OF FINE EARTH MATERIALS

In order to further check the consistence of the proposed diagrams for showing the relationships of AASHO and Unified classes to particle size distributions on the USDA texture triangle, Figures 9 and 25, and to try to test a similar classification that might be more useful to soil scientists and engineers, the 252 representative samples mentioned before (Figure 14) have been evaluated. Based on an Australian Triangle, a Netherland Triangle, the USDA Triangle, Franzmeier's, et al. work, Figure 9, and Figure 25, Whiteside has proposed a revised texture triangle for a better correlation of particle size distribution with groups currently used by soil scientists in several countries, the RAWC, the AASHO and the Unified classes of fine earth materials.

The proposed revised texture triangle is shown in Figure 26. In this diagram, 17 texture classes have been defined instead of the current 12 texture classes. The percentages of each of the AASHO classes represented by samples



—— Boundaries of revised texture classes proposed by Whiteside

— — — Boundaries of USDA texture classes

Fig. 26. Revised texture triangle proposed by Whiteside superimposed on a USDA texture triangle (Abbreviations of USDA texture classes are in parentheses)

in each of the texture classes in the current triangle and in the proposed revised texture triangle are shown in Table 17. The percentages of each of the Unified groups represented by samples in each of the texture classes in the current texture diagram and the proposed revised texture triangle are shown in Table 18.

Comparisons of USDA Texture Diagram and a Revised Texture Diagram with the AASHO Groupings of Samples

From Figure 9 and Table 17, items a, it appears that the 40% clay line is a significant boundary for differentiating the A-7 group from the less clayey groups. Of clay samples, C, 70.6% are in the A-7-5 group and 29.4% of clay samples are in A-7-6 group. Eighty percent of SiC and 66.6% of SC samples are also in the A-7-6 group. In the revised texture diagram (Figure 26), items b in Table 17, samples in the C area are 93.9% in the A-7-5 group and 6.1% in the A-7-6 group. Thus it is apparent that the 50% clay line is a significant boundary for separating the A-7-5 group from the A-7-6 group as well as differentiating C area from LC area. The SiC remains unchanged, and the samples in the added LC class are 95% in the A-7 group which is composed of 27% of A-7-5 and 68% of A-7-6 groups.

The 20-40% clay range which includes SiCL, CL and parts of SCL and SC textures in Figure 9 has been defined as an A-7∿A-6 group-complex. This is also appropriate

Table 17. Percentages of samples of various textures, in the **USDA** texture diagram (a) and in an revised texture diagram (b), that belong in the various **AASHO** groups.

AASHO Texture			A-7-5	A-7-6	A-6	A-5	A-4	A-3	A-2-4	A-2-6	A-2-7
C	(51)	a	70.6	29.4	-	-	-	-	-	-	-
	(33)	b	93.9	6.1	-	-	-	-	-	-	-
SiC	(10)	a	10.0	80.0	10.0	-	-	-	-	-	-
	(10)	b	10.0	80.0	10.0	-	-	-	-	-	-
SC	(9)	a	-	66.6	33.4	-	-	-	-	-	-
LC	(22)	b	27.2	68.2	4.6	-	-	-	-	-	-
SiCL	(16)	a	5.0	51.25	43.75	-	-	-	-	-	-
	(21)	b	4.74	42.86	52.4	-	-	-	-	-	-
SCL	(30)	a	10.0	3.33	46.67	-	10.0	-	3.33	23.34	3.33
	(12)	b	8.33	8.34	75.0	-	-	-	-	8.33	-
CL	(22)	a	13.63	22.73	63.64	-	-	-	-	-	-
	(23)	b	13.05	30.43	56.52	-	-	-	-	-	-
SiL	(41)	a	2.43	4.88	24.4	2.44	65.85	-	-	-	-
FSiL	(15)	b	6.66	6.67	46.67	-	40.0	-	-	-	-
CoSiL	(22)		-	-	4.6	4.6	90.8	-	-	-	-
L	(27)	a	-	3.7	25.9	-	70.4	-	-	-	-
FL	(25)	b	4.0	8.0	24.0	-	64.0	-	-	-	-
CoL	(9)		-	-	22.22	-	77.78	-	-	-	-
SL	(28)	a	3.57	-	7.14	-	43.21	-	46.08	-	-
CSL	(19)	b	10.53	-	31.58	-	15.79	-	5.26	31.58	5.26
LSL	(10)		-	-	10.0	-	50.0	-	40.0	-	-
SiSL	(6)		-	-	-	-	66.67	-	33.3	-	-
SSL	(10)		-	-	-	-	-	-	100.0	-	-
LS	(10)	a	-	-	-	-	-	10.0	90.0	-	-
	(9)	b	-	-	-	-	-	11.1	88.9	-	-
S	(8)	a	-	-	-	-	-	62.5	37.5	-	-
	(6)	b	-	-	-	-	-	83.33	16.67	-	-

(a) Existing **USDA** texture classes; (b) proposed revised texture classes, Figure 26. Figures in parentheses represent the number of samples.

Table 18. Percentages of samples of various textures, in the USDA texture diagram (a) and in a revised texture diagram (b), that belong in the various Unified groups.

Texture		Unified	MH ∼ CH *	CL	ML-CL	ML	SC	SM	SM-SC	SP-SM	SP
C	(51)	a	76.47	7.84	11.77	3.92	-	-	-	-	-
	(33)	b	81.82	-	15.15	3.03	-	-	-	-	-
SiC	(10)	a	90.0	10.0	-	-	-	-	-	-	-
	(10)	b	90.0	10.0	-	-	-	-	-	-	-
SC	(9)	a	-	44.44	22.22	-	33.34	-	-	-	-
LC	(22)	b	59.1	22.5	9.2	4.6	4.6	-	-	-	-
SiCL	(16)	a	6.25	56.25	37.5	-	-	-	-	-	-
	(21)	b	4.76	66.68	28.56	-	-	-	-	-	-
SCL	(30)	a	-	20.0	-	6.67	66.67	3.33	3.33	-	-
	(12)	b	-	8.33	-	-	83.34	8.33	-	-	-
CL	(22)	a	18.18	72.72	4.55	4.55	-	-	-	-	-
	(23)	b	17.4	69.55	8.7	4.34	-	-	-	-	-
L	(27)	a	-	44.44	37.03	18.53	-	-	-	-	-
FL	(25)	b	-	52.0	36.0	12.0	-	-	-	-	-
CoL	(9)		-	22.22	33.33	44.45	-	-	-	-	-
SiL	(41)	a	2.43	24.39	43.9	29.28	-	-	-	-	-
FSiL	(15)	b	6.67	46.67	33.33	13.33	-	-	-	-	-
CoSiL	(22)		-	9.2	49.4	41.4	-	-	-	-	-
SL	(28)	a	-	7.14	7.14	10.72	10.72	42.85	21.43	-	-
CSL	(19)	b	-	5.26	5.26	5.26	73.7	-	10.52	-	-
LSL	(10)		-	10.0	10.0	10.0	-	40.0	30.0	-	-
SiSL	(6)		-	-	-	33.33	-	66.67	-	-	-
SSL	(10)		-	-	-	-	10.0	50.0	40.0	-	-
LS	(10)	a	-	-	-	-	-	80.0	10.0	10.0	-
	(9)	b	-	-	-	-	-	88.9	-	11.1	-
S	(8)	a	-	-	-	-	-	25.0	-	50.0	25.0
	(6)	b	-	-	-	-	-	-	-	66.67	33.33

(a) Existing USDA texture classes; (b) proposed revised texture classes, Figure 26.

*Includes MH, MH-CH and CH groups.

Figures in parentheses represent the number of samples.

because all of the SiCL and CL texture samples are either defined as A-7-5 and A-7-6 or A-6 groups, and 60% of the SCL samples are classified as A-7 and A-6 groups. In the revised texture diagram, Figure 26, the samples in the SCL texture are more homogeneous. Seventy-five percent are in the A-6 group (item b) as compared to 47% earlier (item a), and only two other groups (A-7 and A-2-6) are represented instead of five other groups as previously. The A-4 group in Figure 9 is mainly composed of SiL, L, and parts of SL and SCL. As seen in Table 17, items a, 66% of the SiL samples, 70% of the L samples, and 43% of the SL samples are in the A-4 group. In the revised texture diagram, samples in the L texture are similar to those in the current L texture. However, while the fine silt loam, FSiL, samples remain a complex mainly of A-4 and A-6, as previously, they are now more nearly evenly divided among the two. In the new coarse silt loam texture, CoSiL, the samples are 90% in the A-4 texture, as compared to only 66% previously.

Samples in the sandy loam, SL, texture in Figure 9 are over 89% in the A-4 and A-2-4 groups, in about equal proportions, along with some A-6 and A-7 samples. In the revised texture diagram, Figure 26, the former SL, and LS texture classes, with parts of the SCL and S texture classes are subdivided into 5 texture classes. The resulting sandy-sandy-loam, SSL, and LS are predominantly (100% and 80%, respectively) in the A-2-4 group as the LS was previously.

The loamy sandy loam, LSL, and the silty sandy loam, SiSL, are composed largely of samples in the A-4 and A-2-4 groups as the SL was earlier. The samples in the clayey sandy loam, CSL, are 63% in the A-6 and A-2-6 groups. This is apparently the most heterogeneous texture class in the proposed revision insofar as the AASHO groups are concerned.

The A-3 group is entirely in the sand texture class on the current texture triangle, Figure 2, but over one-third of the samples in that area are also in the A-2-4 group, Table 17. In the revised texture diagram only one-sixth of the S samples are in the A-2-4 group and the remainder are in the A-3 group.

Comparison of the USDA Texture Diagram and a Revised Texture Diagram with the Unified Groupings of Samples

From Table 18 item a, and Figure 25, it is noticed that the major inclusions of USDA texture classes in the MH∿CH group complex are clay, and the parts of the SiC, and SC with clay contents greater than 50%. Seventy-six percent of the clay, C, samples and 90% of the SiC samples were in the MH∿CH groups (which actually include MH, MH-CH, and CH groups), Table 18. In the revised texture diagram, Figure 26, the number of samples in those Unified groups are similar in the corresponding C and SiC areas, Table 18. In the less clayey groups not more than 20% of the samples (18% of the CL texture) are in the MH∿CH group.

The 40-50% clay range in Figure 25 was defined as a MH∿CH∿CL group complex and covered SC, C, and SiC texture classes. In Table 18, 44.4% of the SC texture samples, item a, are in the CL group. In the revised texture diagram, samples in the LC texture class were 59% in the MH∿CH group complex.

The SiCL texture class was defined as a "CL∿ML-CL ∿MH" group complex in Figure 25. A check of Table 18, item a, shows that 100% of the SiCL samples are classified as MH∿CH, CL, and ML-CL groups, with most samples (56%) in the CL group. In the revised texture diagram, the enlarged SiCL texture class includes the same Unified groups, Table 18, item b, but the percentage of samples in the CL group is increased to 66%.

As shown in Table 18, item a, 72.7% of the CL texture class samples were in the CL group in the Unified classification. In the revised texture diagram, the CL texture class has a similar composition, Table 18, items a and b respectively.

The samples in the L texture class are in the ML-CL, ML, and CL groups. That is also the order of their decreasing percentages, Table 18, items a. In the revised texture diagram, the L is subdivided into a fine loam, (FL), and a coarse loam, (CoL), texture classes. The same Unified groups occur in each of these texture classes, but in the FL the CL group is the most common (52%) while in the CoL the

ML group is most common (44%) and the CL group is least common (22%).

Similarly, the current SiL texture class contains samples mainly in the ML-CL (44%), ML (29%) and CL (24%) groups. After subdivision in the revised diagram the fine silt loam, (FSiL), is composed of CL (47%), and ML-CL (33%) while in the coarse silt loam, (CoSiL), the ML-CL (49%) and ML (41%) groups predominate.

The SL texture class, Table 18, item a, currently includes samples of the SM (43%), SM-SC (21%), SC (11%), and ML (11%) groups. It is thus the most heterogeneous texture class in terms of engineering groups commonly included. In the revised texture diagram, the SL and LS classes with portions of the SCL and S classes have been subdivided into 5 texture classes. The proposed loamy sandy loam, (LSL), and loamy sand, (LS) classes are similar in composition to the earlier SL and LS classes, Table 18 items a and b. The other 3 texture classes however, are apparently different in composition and more homogeneous than the current SL texture class. The samples in the clayey sandy loam (CSL) class are 74% in the SC Unified group; those in the sandy-sandy loam (SSL) class are chiefly in SM (50%) and SM-SC (40%) groups; and those in the silty sandy loam (SiSL) are chiefly in the SM (67%) and ML (33%) groups.

The present sand texture (S) includes mainly samples in the SP-SM (50%), SP (25%) and SM (25%) groups. In the revised texture diagram only the SP-SM (67%) and SP (33%) groups are represented, Table 18 items a and b, respectively.

Conclusions on Correlations of Textures, AASHO Groupings and Unified Groupings

While the limited number of samples in some texture classes makes it impossible to be precise as to their ranges in composition, the 252 samples studied in these comparisons, Tables 17 and 18, have shed considerable light on the subject. All but one of the texture classes (SCL for AASHO, and SL for Unified) currently used by soil scientists in the United States are composed predominantly (90% or more) of samples from one or two AASHO groups or one, two or three Unified groups (items a in Tables 17 and 18). In five of the eleven texture classes tested (silt was not represented in the samples studied) two-thirds or more of the samples are in one AASHO class or Unified group. The general relationship between the current texture classes of soil scientists and the classifications of fine earth materials (< 2.0 mm) by engineers is thus quite evident.

The proposed revised texture triangle for fine earth materials (< 2.0 mm) has 17 classes, Figure 26. This may be compared to 15 groups in the Unified system for fine earth material (excluding "G" groups*) Table 12, 8 in the AASHO System (excluding A-1-a and A-1-b classes*) Table 1, and 12

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*Neither organic soils such as peats and mucks or gravels are considered in this study.

in the present USDA texture triangle. However, it should be pointed out that 4 subdivisions in the sandy loam, loamy sand and sand texture classes are commonly used today, based on the predominant sand sizes present. Thus, coarse, medium, fine, and very fine sand sub-classes are possible in each of the 3 texture classes. This would add 9 sub-classes to the 12 classes (if the medium sand groups are counted first as representative of the classes) giving 21 texture separations commonly recognized at present by soil scientists for material < 2.00 mm in diameter. Whether the sand sizes are correlated with the differences in the AASHO groups and Unified groups in this part of the triangle has not been studied here. It should also be mentioned that engineers also commonly subdivide their soil groups in practice. The AASHO group designations are commonly supplemented at present by addition of A-7-5 and A-7-6 subgroups and by addition of a "group index" number in parentheses after the class designations. The Unified SM group is subdivided into "d" and "u" subgroups, for roads and air fields, based on the Atterberg limits. In view of these current practices in classifying fine earth materials the 17 proposed texture classes seem to be a reasonable number, if they prove useful in classification of fine earth materials. However, they need further evaluation by both engineers and soil scientists. If they prove useful where laboratory data are available (to use in making the classification) then they still need testing to determine if they can be consistently differentiated in the field.

The evidence in the Tables 17 and 18, items b compared to items a, indicate that the revised texture triangle is an improvement over the current texture diagram as judged by the degree of correlation of the proposed texture classes with the AASHO and the Unified groups.

These improvements have been cited in detail in the discussions of Tables 17 and 18. More generally, in nine of the sixteen revised texture classes examined, or 56%, two-thirds or more of the samples are in the same Unified group, as compared to five of the current eleven classes tested, or 45%. In ten of the sixteen revised texture classes examined, or 62%, two-thirds or more of the samples are in the same AASHO class, as compared to five of the current eleven classes tested, or 45%.

In general the current and the revised texture classes correlate somewhat better with the AASHO than with the Unified groups. But, the possibility that a single texture diagram might be useful to both soil scientists and engineers, in conjunction with the other properties of fine earth materials important to their uses for various purposes, seems to warrant further attempts to devise a mutually agreeable texture diagram.

POSSIBLE IMPROVEMENTS OF CORRELATIONS OF PARTICLE SIZE DISTRIBUTIONS WITH OTHER PROPERTIES OF FINE EARTH MATERIALS BY DIFFERENT CHOICES OF THE UPPER SILT SIZE LIMIT

Changes Resulting from the Difference Between 0.05 mm and 0.074 mm as Upper Silt Size Limit

As discussed before, the silt separate is important to both soil scientists and engineers, but its upper size limit differs between those disciplines. In the above sections, the engineer's soil classification systems, the P.I., the L.L. and the "group indices" have been studied in relation to the USDA texture classification. The soil textural classes are based on 0.05 mm as the upper silt size limit, which is only 0.024 mm smaller in diameter than the limit of 0.074 mm commonly used by engineers. The following discussion is to show what changes might result from the difference between 0.05 mm and 0.074 mm as the upper silt size limit. Two hundred twenty seven Michigan soil samples representing horizons in the Humic gley, Gray Brown Podzolic and Podzol great soil groups were used from the 2894 samples in this study to evaluate these changes.

Correlation Between 0.05-0.002 mm and 0.074-0.002 mm Silt Percentages

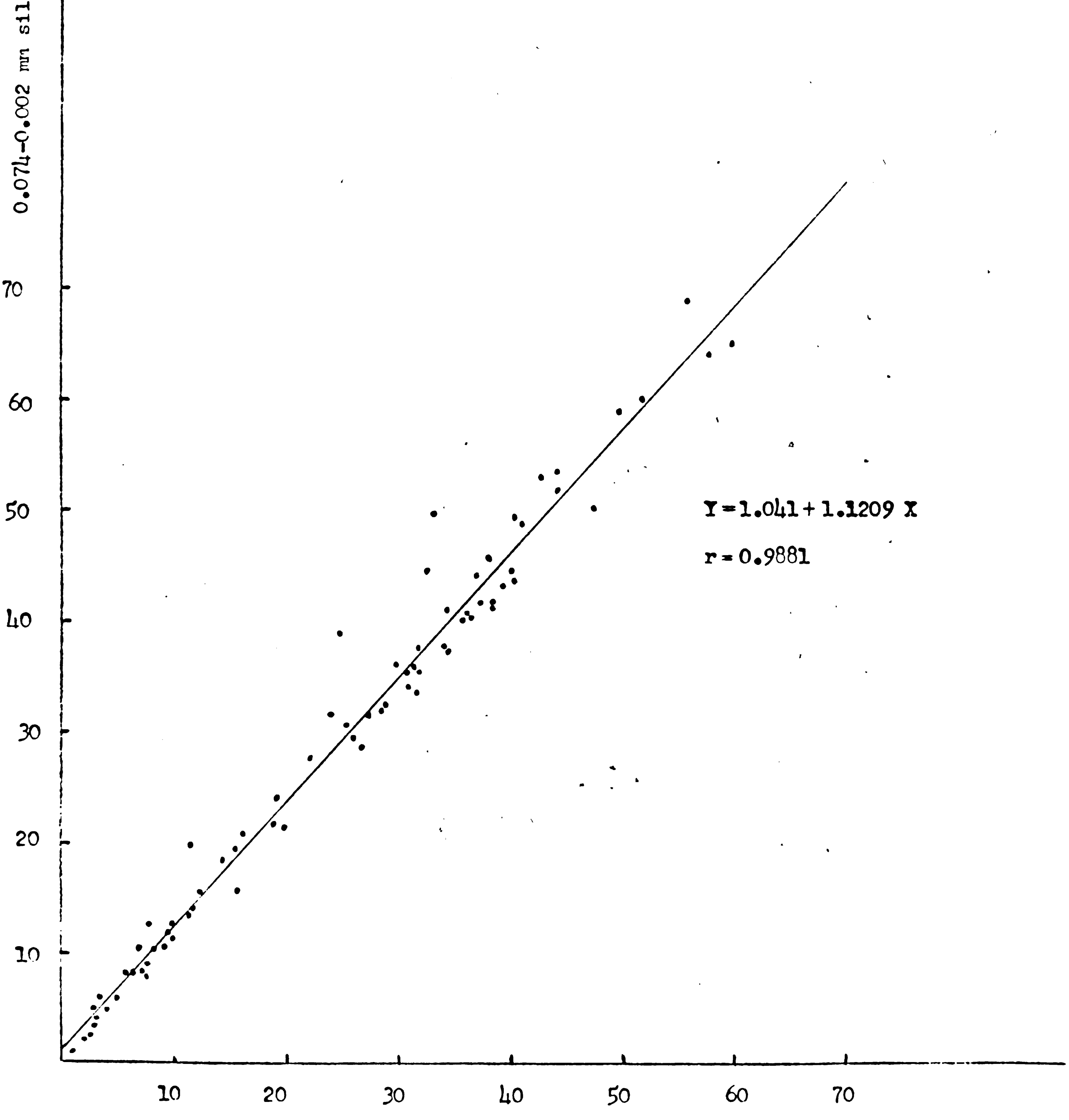
In this study, correlations were made between the percent silt when using 0.05 mm and 0.074 mm size limits as the upper size limit for silt. Samples from each of the 3 great soil groups were divided into surface horizons (Ap, or A_1) and subsurface (A_2, B, or C) horizons and each of these six groups of samples were studied separately. One of those correlations is shown in Figure 27.

As far as the upper silt size limit is concerned, the data in Figure 27 indicate that it should not make much difference whether 0.05 mm or 0.074 mm are chosen as the upper silt size limit. They are closely correlated with each other as indicated by a high correlation coefficient of greater than 0.95 in each of the six groups of samples studied. But the limit used does influence the position of a particular sample on the soil texture classification triangle and the correlation of the texture classes with the RAWC percent and other properties of the soil samples which will be discussed later.

The Shift in Percentage of Silt with Change in the Upper Silt Size Limits

In the particle size distribution of any sample, the percent of clay would not be changed by the choice of 0.05

Fig. 27. Relationship of 0.074-0.002mm and 0.05-0.002 mm silt in Gray Brown Podzolic subsurface (A_2, B, C) horizons from Michigan (75 samples represented)



mm, 0.074 mm, or 0.1 mm as the upper silt size limit. The percentage of silt would be increased when 0.074 mm or 0.1 mm is used as the upper silt size limit in comparison with the percentage of silt using the 0.05 mm limit. The average increases in percentage of silt with a change from 0.05 mm to 0.074 mm as the upper silt size limit are shown in Table 19, for three Michigan great soil groups by surface (Ap, A_1) and subsurface (A_2, B, C) horizons.

The average increase of silt in the surface horizons is a little bit greater than that in the subsurface horizons, Table 19. This may be due to:

(1) the fine silty fraction in the Ap horizon, with the clay fraction, may be washed out of the surface down into the A_2, B, and C horizons. The relative or percentage decrease or increase, respectively, of silt percent between the larger (o.074 mm - 0.002 mm) and the smaller (0.05-0.002 mm) silt fraction shifts less for the larger fraction. Thus where decreases are involved (in the surface) the differences widen, and where increases are involved (in the subsurface) the differences narrow;

(2) disruption of coarse soil particles in the Ap horizon due to frost action or cultivation, forming coarse silt, or very fine sand, may be relatively more intensive than that in subsurface horizons; or

(3) organic matter in the surface horizons may tend to aggregate fine silt or clay particles into coarse silt

Table 19. Average differences in % of silt, when shifting from 0.05 to 0.074 mm as the upper size limit of silt in six groups of Michigan soil horizons samples.

Soil Groups	Horizons	Number of Samples	Average % Difference Between Contents of 0.05-0.002 mm and 0.074-0.002 mm silt
Humic Gley	Ap, A_1	16	+ 5.7
	A_2, B, C	44	+ 4.3
Gray Brown Podzolic	Ap, A_1	26	+ 5.9
	A_2, B, C	75	+ 3.7
Podzol	Ap, A_1	17	+ 5.0
	A_2, B, C	49	+ 4.7
Total and Average		227	+ 4.88

aggregates that are not dispersed as well as in the surface horizons that are higher in organic matter.

The average increase in silt percent in the six groups of soil horizon samples, Table 19, is 4.88% or about 5%. A factor of "0.89" might be used for converting the percent of 0.074-0.002 mm into percent of 0.05-0.002 mm as the silt size. The reverse conversion requires a factor of 1.12 as indicated by the equation of the line in Figure 27. For example, in the AASHO soil classification system, engineers define the silt-clay materials as having more than 35% of the total sample passing the No. 200 sieve ($<$ 0.074 mm). If samples on this borderline contain no particles $>$ 2.0 mm in diameter, then using 0.05 mm as the upper silt size limit, the $>$ 35% criteria would approximately change to $>$ 31% (35% x 0.89) where no clay was present on the base of the texture triangle and remain at 35% where no silt was present along the left side of the texture triangle, Figure 9. Similarly, the separation of fine grained materials with more than 50% passing the No. 200 sieve in the Unified classification would show on the texture triangle as having greater than 50% clay on the left side of the triangle and more than 44.5% silt along the base of the triangle, Figure 25.

Changes in the USDA Texture Classes

Among the 227 samples studied, 19% of the samples would have changed their USDA texture classes with the change of the upper silt size limit from 0.05 mm to 0.074 mm, using the present texture class boundaries. Some sandy loam soils changed to loam texture, some loam soils changed to silt loam texture, etc. Some shift in the boundaries on the texture triangle would be needed to avoid so many of these changes if the upper silt size limit was changed to 0.074 mm or 0.100 mm. With respect to the texture differences in relation to soil moisture content, the RAWC doesn't change much with the change of texture from sandy loam to loam. But the average RAWC may increase 50% with the change of texture from loam to silt loam and another 35% with the change from silt loam to silt. A better correlation between the 0.074-0.002 mm silt content and the RAWC would be anticipated, as with a shift to the 0.10-0.002 mm silt as explained next.

Changes Resulting from the Difference Between 0.05 mm and 0.1 mm as the Upper Silt Size Limit

Franzmeier, Whiteside and Erickson (1960) studied the correlation of the size range 0.10-0.002 mm (which is more closely correlated with RAWC than the 0.05-0.002 mm silt size) with RAWC in a texture diagram using 0.1 mm as the upper silt size limit. They drew equal RAWC lines on that texture diagram. In the new soil classification system, the 0.10-0.002 mm fraction has also been used as the silt fraction for family grouping in its guide triangle. Using 0.10 mm as the silt upper limit apparently has advantages in correlation with RAWC and as a basis for soil family groupings.

To study the relationship of 0.05 mm and 0.10 mm as the upper silt size limit, the 252 selected samples evenly distributed on the USDA texture diagram, Figure 13, have been used to: evaluate the changes of their size distribution in the texture triangle; the boundaries of the USDA texture classes on a triangle using 0.100-0.002 mm as silt; and to show the boundaries of a revised texture triangle on a texture triangle using the 0.100-0.002 mm fraction as silt.

The percentage of < 0.100 mm material in each sample was obtained from the accumulative curve of its particle size distribution. The analyses of the samples using these silt limits and their previous texture classes were then plotted on a texture triangle.

Correlation of 0.05-0.002 mm and 0.100-0.002 mm Silt Percentages

It was found that the average percentage of silt would be increased by 9.2% when 0.100 mm is used as the upper silt limit instead of 0.05 mm. The relationship of the percentage of 0.05-0.002 mm to the 0.100-0.002 mm silt is shown in Figure 28.

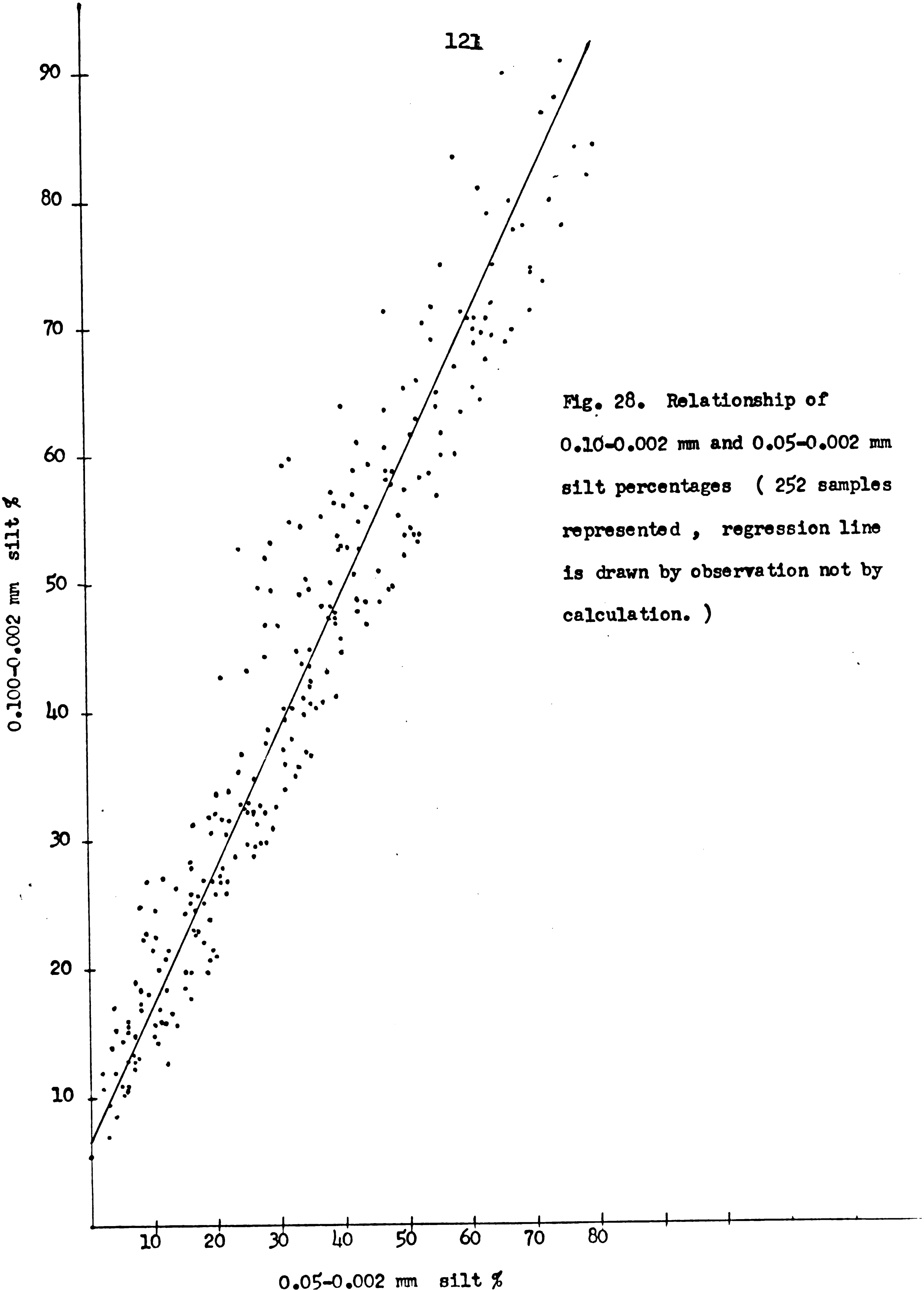


Fig. 28. Relationship of 0.10-0.002 mm and 0.05-0.002 mm silt percentages (252 samples represented , regression line is drawn by observation not by calculation.)

A Texture Diagram Based on 0.100-0.002 mm Silt

The clay boundaries for delineating the USDA texture classes are all the same when 0.1 mm is used as the upper silt size limit as when 0.05 mm is used as the upper silt size limit. But by drawing boundaries differentiating these 252 selected samples into the same texture classes they represent on a USDA texture diagram when they are plotted on a texture triangle using 0.100-0.002 mm (instead of 0.05-0.002 mm) as silt the USDA texture boundaries were transferred to a texture triangle based on 0.100 mm as the upper silt size limit. These are the solid line in Figure 29. These boundaries were also checked against key values expected from the relationship between the 0.05-0.002 and 0.100-0.002 mm silt fractions shown in Figure 28. If these 252 selected samples were plotted using 0.100-0.002 mm as silt instead of the 0.05-0.002 mm on the USDA texture triangle, which is still on the 0.05 mm silt basis (dashed lines in Figure 29), 80% samples, or 31.6% of the total selected samples would have changed their textures to more silty classes. When the transposed texture boundaries are used to determine the texture of these samples, only 11.1% of them had changed in texture. Of these 5.9% became more silty and 5.2% became less silty.

These USDA texture classes are also shown as solid lines on a texture triangle using 0.100-0.002 mm as silt in

Figure 30. Comparing these solid boundaries with the dashed line boundaries proposed by Franzmeier et al., it is found that boundaries between L and SiL, CL and SiCL, C and SiC were shifted 3%, 4% and 4% left respectively, and boundaries between L and SL, SL and LS, LS and S were shifted a little bit to the right. The new boundaries, solid lines in Figure 30, are believed to be a more precise transformation of the USDA texture diagram onto a triangle using 0.100-0.002 mm as silt. A transformation of the proposed revised texture triangle, Figure 26, onto this base is shown as the solid lines in Figure 31.

Revised Texture Boundaries for Family Groupings of Soils

In view of the significance attached to the 15% sand line for family groupings in the new soil classification system (Soil Survey Staff, SCS, USDA Supplement in 1964, Chapter 6-2a), the position of this separation on the USDA texture diagram using 0.05-0.002 mm as silt needs to be established for transferring experiences based on that diagram into the new classification system. By checking the samples within ± 5% of the 15% sand line and below 40% clay on Figure 29, it is found that the 26 samples within that area occur on the USDA texture diagram, Figure 14, as shown by the encircled points in that diagram between 16 to 38% sand. The 25 to 27% sand line, at 40% and 0% clay respectively, divides those 26 samples into equal groups. It was thus drawn as a solid line for separating the loamy family from the silty family, as proposed by the Soil Survey Staff in the 1964 Supplement, as shown in Figure 32. The other boundaries proposed for separating families in the 1964 supplement are also shown as solid lines in Figure 32. The dashed lines in that figure are proposed revised boundaries for family groupings, based on the 0.05-0.002 mm fraction as silt size and the studies reported here.

The proposed revised boundaries for family groupings are based on the lines which were used for the AASHO and Unified classification (associated with the significant boundaries for L.L. and P.I. values), and the revised texture triangle proposed by Whiteside. The 40% clay is a significant boundary used for the AASHO, Unified and the USDA (texture) classification (Figure 9,   and Figure 25). Thus, it is better to designate this line for dividing clayey families from loamy families instead of the 35% used by Soil Survey Staff, SCS, USDA in 1964. The 50% clay line is significant for dividing the A-7-5 group from A-7-6 group, Table 17, and to the Unified classification for separating the MH$\sim$CH group complex from the MH$\sim$ CH$\sim$CL group complex, Figure 25. This is also in agreement with the 50% clay line used in the Netherland to differentiate "Zeer and Matig, Zware-Klei" (very to moderately heavy clay, Bakker and

Schelling, 1966). However, the range between it and the 40% clay line seems too small to divide the fine clayey family from very fine clayey family for all purposes. Until a clay line above 50% clay is proven to be significant for this division, we are tentatively using the 40% clay only for separating the clayey families from the loamy families, Figure 32. The 17% clay line, used in Figure 9 and Figure 25 for the AASHO and Unified classification on the texture triangle, approximates the significant P.I. value of 10.75 (or maximum 11 and minimum 10) which is used for the AASHO classification. This 17% clay line seems a little better to use as a boundary for separating fine loamy and fine silty families from coarse loamy and coarse silty families than the 18% clay line used by the Soil Survey Staff, SCS, USDA in 1964. The 17.5% clay line used in the Netherlands (Bakker and Schelling, 1966) agrees well with either of these.

The proposed revised boundaries for dividing fine loamy and coarse loamy families from fine silty family and coarse silty family are based on the boundaries designated in the revised texture diagram, Figure 26, for differentiating the texture classes of SiSL from CoSil; CoL from CoSiL; FL from FSiL and SiCL; and CL from SiCL. This should be a more meaningful separation in relation to available water holding capacities and frost heaving phenomena than the nearly constant sand content line proposed by the Soil Survey Staff (SCS, USDA, 1964).

The line used for separating the sandy family from the coarse loamy family is based on the lines for differentiating the texture classes of LS from SSL and SiSL, Figure 26. This is apparently a more significant separation for engineering purposes than the earlier proposals.

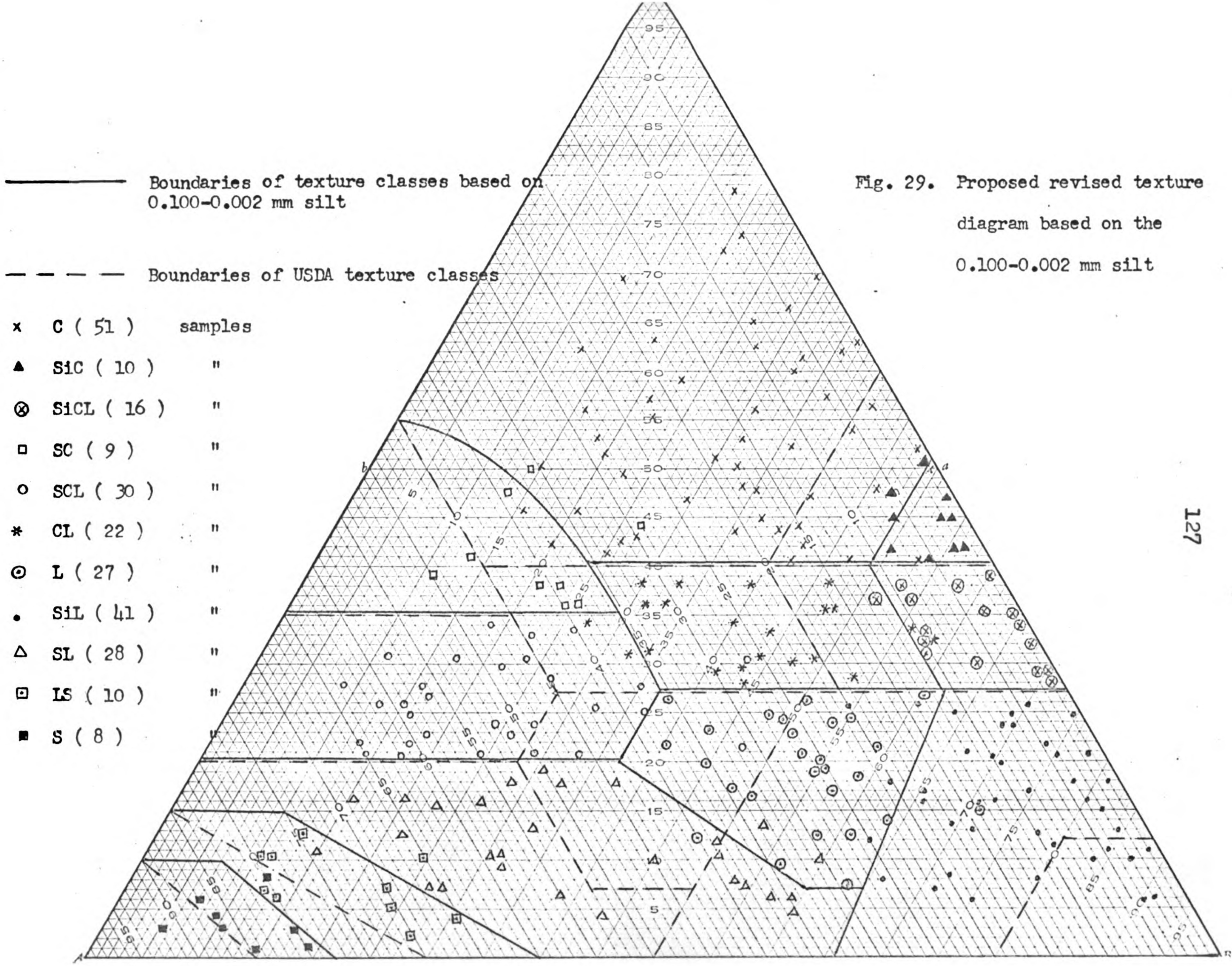


Fig. 29. Proposed revised texture diagram based on the 0.100-0.002 mm silt

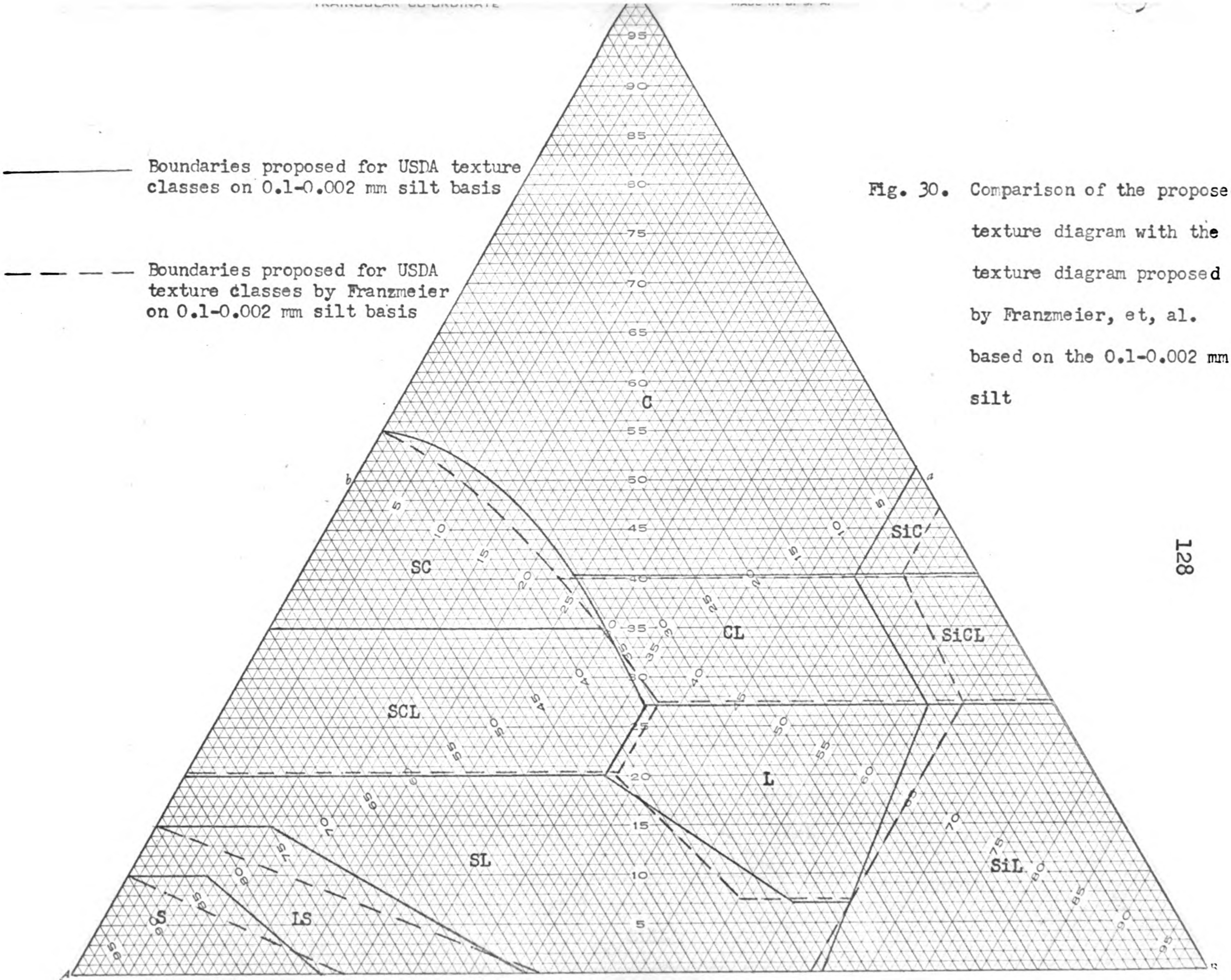


Fig. 30. Comparison of the proposed texture diagram with the texture diagram proposed by Franzmeier, et, al. based on the 0.1-0.002 mm silt

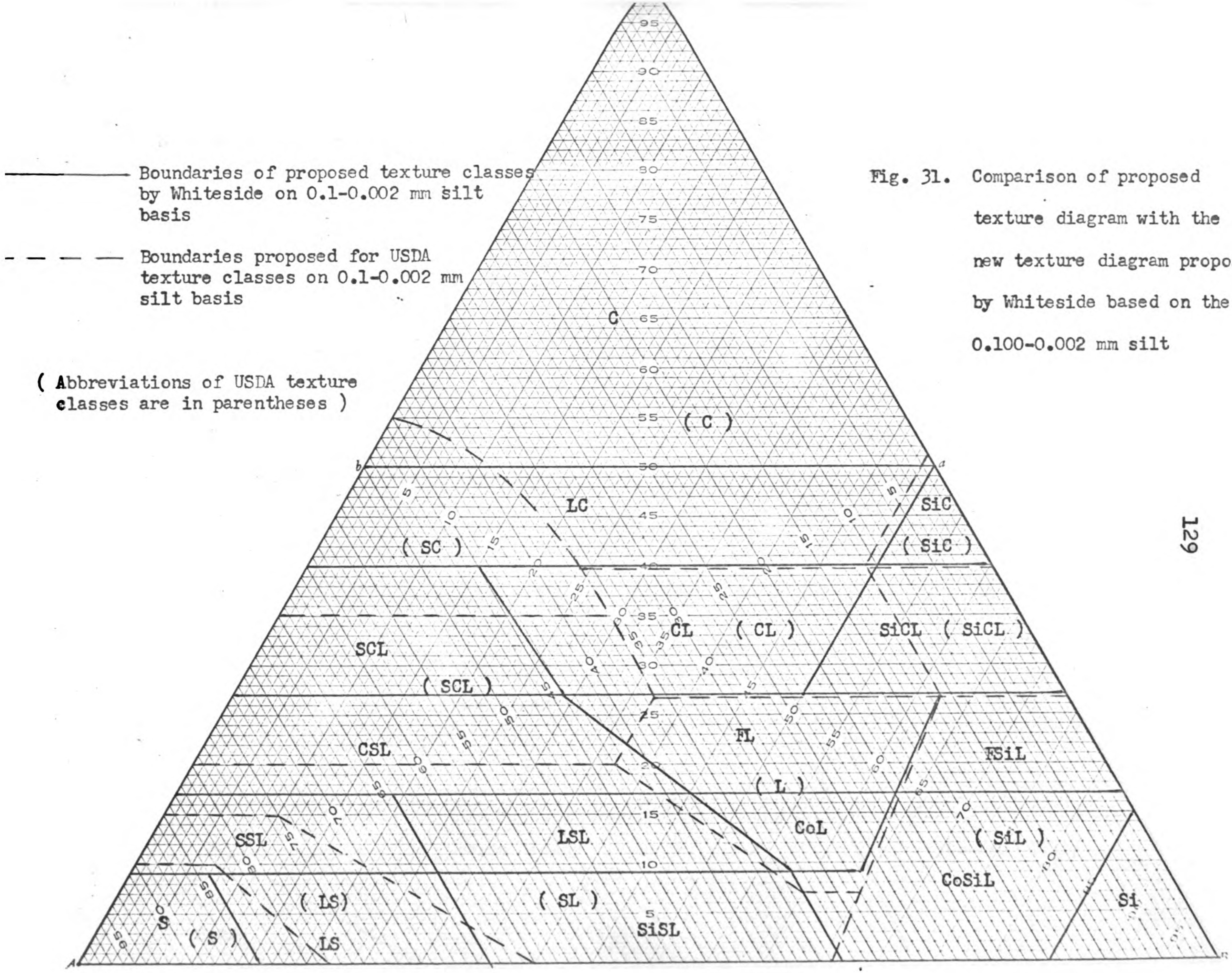


Fig. 31. Comparison of proposed texture diagram with the new texture diagram proposed by Whiteside based on the 0.100-0.002 mm silt

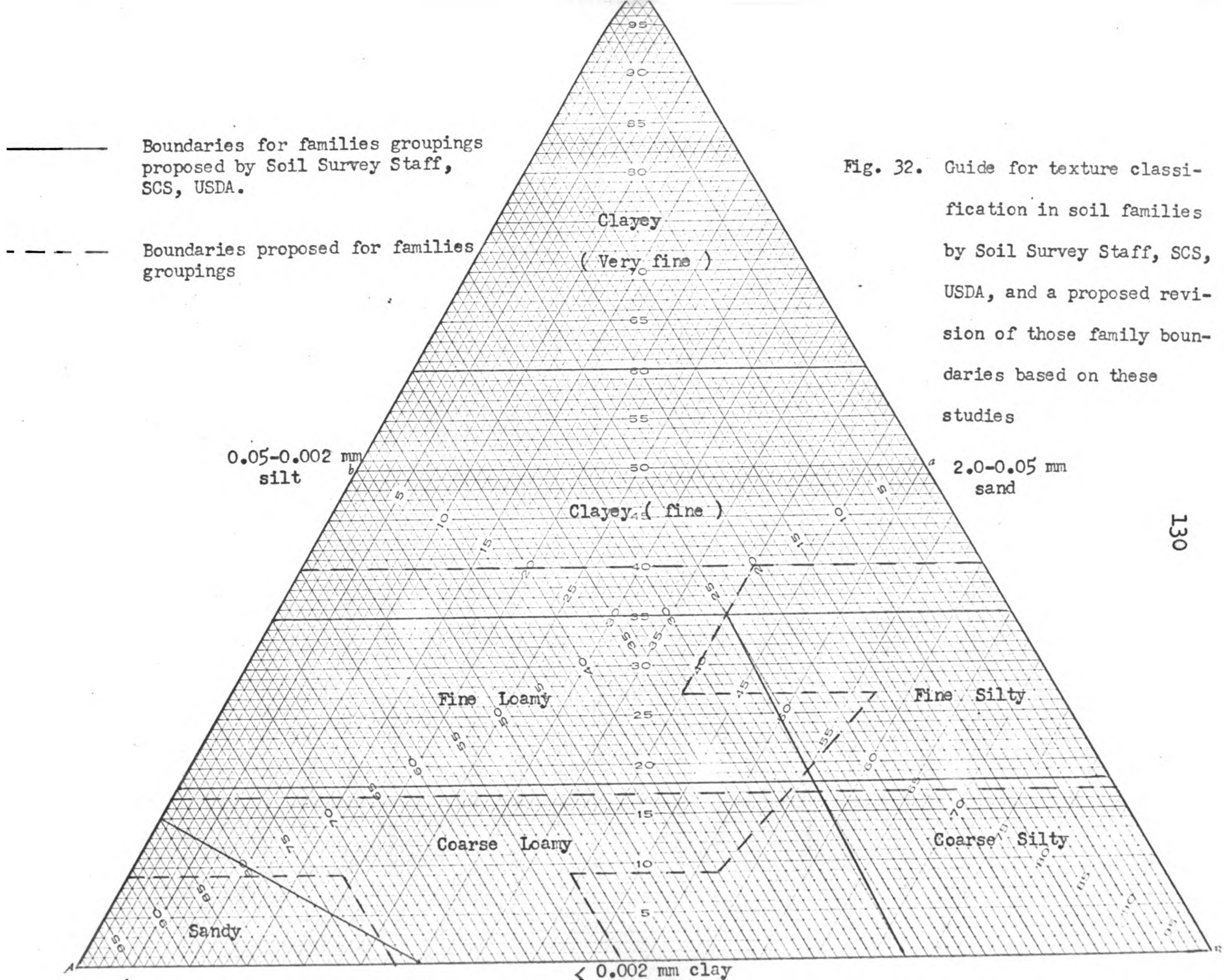


Fig. 32. Guide for texture classification in soil families by Soil Survey Staff, SCS, USDA, and a proposed revision of those family boundaries based on these studies

CONCLUSIONS

In discussing the possibility of common size class limits desirable for both soil scientists and engineers, emphasis usually is laid on the size limits of $<$ 3 in - 2.0 mm, 2.0 mm-0.05 mm, $<$ 0.42 mm, $<$ 0.074 mm, and 0.05-0.002 mm fractions. The clay fraction, $<$ 0.005 mm, cited by engineers is little used by them. As far as the silt size class is concerned, a pretty close correlation, with average correlation coefficient of 0.95, was found between the percentage of 0.074-0.002 mm and 0.05-0.002 mm silt in 231 selected Michigan soils. The average increases in percentage silt between 0.074-0.002 mm and 0.100-0.002 mm compared to 0.05-0.002 mm were 4.9 and 9.2 respectively. The factor 0.89 was proposed to obtain the USDA 0.05-0.002 mm silt from the 0.074-0.002 mm engineers value.

By checking with those 231 Michigan samples, it does not usually make much difference whether the clay content in the $<$ 2.0 mm or in the $<$ 0.42 mm size fractions is used in plotting the liquid limit and plasticity index determinations. The increase in clay content only averaged 1.85% with the conversion from the $<$ 2.0 mm fraction to the $<$ 0.42 mm fraction as the 100% base. The difference in the clay contents was very small unless the 2.0-0.42 mm fraction was greater than 5%.

On the basis of 0.05 mm as the upper silt limit, the AASHO soil groups, Unified engineers soil groups, plasticity indices, liquid limits, and AASHO group indices were plotted on the USDA texture triangle. Eight AASHO soil groups (or group complexes), five group indices, and eleven Unified soil groups (or group complexes) have been delineated on the USDA texture diagram. Several boundaries between classes in those groupings have shown pretty good agreement with those separating the USDA texture classes. All delineations on these diagrams have been carefully adjusted so that more than 80% of the samples in each area agree with the proposed designation of that area.

Using the USDA particle size classes, (2.0-0.05 mm: sand; 0.05-0.002 mm:silt; and < 0.002 mm:clay) five triangular texture diagrams were proposed to show the AASHO soil groups, the Unified soil groups, the plasticity indices, the liquid limits, and the group indices of fine earth materials (< 2.0 mm) in relation to the USDA texture classes. These diagrams may provide a basis for improved interpretations and communications of fine earth classification between soil scientists and engineers. The particle size distributions of A-1-a and A-1-b groups of AASHO and "Gravel" group of Unified soil samples were not shown on these diagrams. They were distributed pretty widely within the fine to coarse texture classes on the USDA texture diagram. It is obvious that the gravel fraction of 2.0-76.2 mm which is used by engineers for grouping those materials have more influence on designating those soil groups than the difference between 0.074 mm and 0.05 mm as upper limits of the silt size fraction or the kinds of clay minerals present. It also indicates that to find a uniform soil texture classification system for use by soil scientists and engineers, it will first be necessary to agree on the upper and lower size-limits of the samples considered so our analyses and the calculation of the results are uniform. Before acceptance of uniform particle size limits among soil scientists and engineers, no common system of soil texture classification for use by all is possible. The first step to attempting to set a uniform grain size limit is to define a common upper size limit to be used in soil texture classification by each discipline and an uniform method for particle size analyses by all groups.

On 252 representative samples selected from the total 2894 samples, clay activities (defined as the ratio of the plasticity index to the percent clay by Yong and Warkentin) have been evaluated. It is suggested that samples with clay activities greater than 0.7 and containing more than 15% clay may be considered as containing active clays. The average clay activities of the selected samples were calculated. Samples with active clay had appreciably higher L.L. values and P.I. values than other samples of the same texture. These increases also result in higher group indices for such samples. All of these properties influence engineering classification of fine earth materials. The magnitude of the clay activity of a soil may serve as a general index to predict the kinds of clay minerals present.

Two hundred fifty-two samples evenly distributed on the USDA texture triangle have also been studied to test the consistence of the proposed diagrams for correlating the AASHO and Unified groups with the USDA texture classes. The boundaries designated for grouping those engineering soil groups on the USDA texture triangle were commonly consistent with the USDA textural classes boundaries. In comparisons of the current USDA texture classes and revised texture classes proposed by Whiteside (based on better correlations of particle size distributions with texture classes in Australia and the Netherlands, RAWC, ASSHO groups and Unified groups), it is shown that the proposed revised texture classes correlates better with the AASHO and Unified texture groups than the current USDA texture classes, Tables 17 and 18.

Since a 0.100-0.002 mm silt fraction gives better correlations with the RAWC and the new soil family groupings now being developed by soil scientists in several countries, a transformed USDA texture diagram based on the 0.100-0.002

mm silt fraction has been proposed by Franzmeier, Whiteside, and Erickson. This texture diagram was slightly revised based on the study of the 252 representative samples. The revised texture diagram was also transferred to a texture diagram using the 0.100-0.002 mm as silt.

Based on the relationships deduced in this study, the nearest equivalent separation of the silty family groups in the new classification system on the current texture diagram was delineated. Revised family textural groupings are suggested based on the results of these studies.

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