ENGINEERING PROPERTIES AND CLASSIFICATION OF SELECTED SOILS OF LOGAN COUNTY, KANSAS

by

RICHARD DALE DAVIS

B.S., Colorado State University, 1957

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1962

TABLE OF CONTENTS

INTRODUCTION

Soil is the oldest and probably the most used of engineering materials. All engineering structures are built of, through, or are ultimately supported by earth materials, usually soil. The extent to which any civil engineering work renders the service intended depends largely upon the physical properties on which, or of which, it is constructed.

Because of this, soil exploration, sampling, classification, characterization, and mapping have become basic operations which are necessary in all engineering work involving soils. To aid the engineer in this highly important phase of construction investigation, some modern county soil survey reports of the National Cooperative Soil Survey now contain sections containing soil engineering laboratory data and interpretations of agricultural data applicable to engineering. To date, 40 such reports from 23 states containing engineering soils sections have been published.

This study was begun to accomplish four aims: (1) to accumulate soil engineering data for several established and tentative soil series, (2) to compare these data with those from other locations in order to evaluate the soil series as a basic unit for predicting and reporting soil engineering data, (3) to initiate inclusion of an engineering soils section in future Kansas county soil survey reports, and (4) to serve as a guide in the interpretation of agricultural soil surveys for engineering uses.

It is hoped that laboratory data, estimation of properties and behavior, description of each soil, and information regarding climate, geology and geography, will enable an engineer to make sound decisions or recommendations on routine soil engineering problems with a minimum of field work for Logan County, Kansas.

LITERATURE REVIEW

General

The classification of the soil long has been an activity of man. The earliest attempt to classify soil was the work of the engineer Yu during the reign of the Emperor Yao about 4,000 years ago (53).

Very early recognition of soil differences served local and very limited purposes and, while scientifically valid because they dealt with true soil differences, were incomplete. Later systems of classification were based upon features lying outside the soil itself or only partly on the soil characteristics. These systems were based upon geology, physiography, plant ecology, agricultural capabilities, or combinations of these.

About 1870 a new school of soil science was founded in Russia by Dokuchaiev. This school recognized soil as an independent natural body, each soil having a unique morphology reflecting the influences of the variables of vegetation, climate, topography, parent material, and age. This new concept led to a system of classification in harmony with a given soil's morphology and genesis, and is the basis of the National Cooperative Soil Survey in the United States.

The main purpose of soil classification and survey, like that of any other research, is to make predictions. In itself, the random study of soil morphology and behavior does not constitute soil research. The knowledge gained from this study has little prediction value until the characteristics of the soils are cataloged by a system of classification. This classification system, coupled with a soil map, is the basis for reporting the results of research and experience for the soils of a given area.

According to Kellogg (37), soil classification is essential for synthesis and coordination of the results of the method of experimental research and the method of scientific correlation.

A system of soil classification is essential for remembering characteristics, understanding relationships, and developing principles applicable to the whole broad field of soil science. Basic soil classification must delineate kinds of soils sufficiently uniform in their characteristics that one may reasonably expect about the same results from a given use or treatment. It is essential to have soil maps produced when such a classification system is applied to the soils of a given area. With the soil units mapped accurately and named according to a standard system, predictions developed through research are available for application.

According to Aandahl (1) the purpose of soil survey interpretation is to provide people with the best possible information about every acre of soil in a form that is most useful to them. All such interpretations are intended to furnish a better basis for making choices among alternatives in the use and management of soils. It is essential to have some understanding of the objectives for which the soils are to be used before attempting soil survey interpretations.

Aandahl (1) further stated that the function of soil survey interpretation for engineering use is one of providing accurate, complete information on soil character and behavior as an adequate and reliable basis of design and construction and the alternatives possible in using them as construction materials or for foundations.

Stokstad and Humbert (51) also have said that civil engineers must have information concerning the environment of the construction site in question. Since soil types are the product of environmental forces acting on a parent material, they serve to reflect environmental information with respect to climate, natural vegetation, topographic and geographic position, internal and external drainage, and other features.

Engineers are vitally interested in soils information, both factual and interpretative, for soil is the oldest and most used of engineering construction materials. Even before the term "engineer" was coined, it had become necessary for the builder to take at least some visual note of the soil on, of which, or through which he intended to build.

Early engineering soil investigations consisted of sampling soil from holes drilled at specified intervals along the center line of a highway or airfield, with no soil identification or classification attempted until the samples had been subjected to laboratory testing.

Many engineers now have come to recognize the short-comings of soil survey techniques limited to hole drilling and laboratory testing. This method of survey results in rather complete information at the point of collection but gives no information regarding the areal extent of such test information, and very little information regarding the environment at the point of sampling; the data have no prediction value.

Within the past 35 years the science of pedology has been recognized as an important source of information in the study of the engineering uses of soils. Pedology has become important enough in civil engineering that some universities now include a course in a new field called engineering pedology in addition to traditional soil mechanics courses.

As early as 1924, Rose (46) postulated that much of the routine testing of soil could be eliminated once a range of engineering values for a given soil, shown on survey maps, had been established.

The Michigan State Highway Department was the first major engineering establishment to make use of agricultural soil survey (39). In 1925 it began a state-wide study of pavement behavior, the findings of which were correlated with soils identified through soil survey. Two years later (1927) the pedological method was adopted in Michigan for use in making soil surveys and for design of highways. This involved not only field classification of soil profiles but also such occasional sampling and laboratory testing as was necessary to supplement field studies by producing information needed regarding soil properties.

Wright (54) has reported that in 1935 both the American Association of State Highway officials and the American Society for Testing Materials recommended the pedologic method and agricultural soil surveys as a highway soil survey. Olmstead (29) reported in 1948 that nine states were using, and 28 states contemplated the use of pedological maps and methods of soil survey to locate construction materials or to plan and organize soil investigations. Ten years later (1958) a post card survey by Wright (54) indicated that the highway department of 41 states then used or expected to use agricultural soil surveys in the future.

Stokstad (50) has said that soil science can make two very important contributions to the general field of soil surveys for engineering use; first by providing good techniques for the field examination of the soil profile and by providing a well-developed descriptive legend of soil types including a detailed profile description. He has further stated that the pedologists' best contribution to the civil engineers' soil classification problem is made when the former stays completely objective and devotes himself to the characteristics and properties of the soils under study.

Burmister (18) has suggested that there are two steps in the complete engineering classification of any given soil. First, the soil must be identified. To identify soil is to recognize and to establish the identity and individuality of soils as to composition and inherent character.

Identification refers not only to the physical techniques of accurately identifying and naming soils but also to a written report of the individual morphology of the profiles encountered and a written description pertaining to such items as unusual inclusions in a characteristics of the soil (sand lenses, mottling, etc.), topography, typical native vegetation, relation to physiographic site, and other features. Identification should be quantitative, disclosing and describing those inherent characteristics of soils that may dominate and be responsible for the actual behavior under a given set of conditions. Next the soils are classified. To classify soils is to place or arrange them into classes according to a limited number of common qualitive and behavior characteristics of engineering importance.

Burmister (18) stressed that identification is factual information obtained as a result of observed or experimentally determined facts. Engineering classification is a rating of soils, largely interpretative because it is an inference of expected behavior deduced by interpretation of factual information.

When a soil is designated by its classification alone, it loses its identity and individuality and the real soil character can be very roughly known at best. Engineering classification is a broad generalization, not capable of providing sufficiently adequate, accurate, and complete factual and interpretative information regarding the relative dominance of the fundamental behavior characteristics of soils.

According to the Soil Conservation Service (49) at least eight uses may be made of factual and interpretative engineering and agricultural soil information as contained in a soil survey report:

1. For making reconnaissance surveys to allow selection of

sites for engineering structures and to aid in planning detailed soil surveys.

2. To make soil and land use studies that will aid in the selection and development of industrial, commercial, residential, and recreation sites.
3. To make preliminary estimates of runoff and erosion rates for use in designing drainage structures and in designing dams and other soil and water conservation structures.
4. To locate deposits of sand and gravel, borrow areas, rock for crushing, building stone, and to select the best topsoil to use as topdressing for lawns and road embankments.
5. To determine the suitability of soil units for cross-country movements of vehicles and to determine construction equipment needed and the demands to be placed upon it.
6. To correlate performance of engineering structure with soil mapping units and to develop information that will be useful in designing, constructing, and maintaining subsequent structures.
7. To supplement information obtained from other maps, reports and aerial photographs and for the making of soil maps and reports for engineering soil surveys.
8. To furnish information concerning the hazards or useful properties of various soils when used for earth construction, when definite laboratory data are lacking or not available.

Engineering Classification Systems

General. Many schemes for classifying soils into engineering use groups have been proposed but only two are in common use; the Unified Classification System and the American Association of State Highway Officials System, hereafter referred to as AASHO system. Both engineering classifications are based upon three soil properties: (1) particle size analysis, (2) liquid limit, and (3) plastic index.

The particle size analysis of a soil is accomplished by soaking a known weight of a sample in water then washing all the "fines" through a U. S. Standard Number 200 sieve. The material passing this sieve is $<$ .074 mm in diameter and, according to pedological definitions of size limits, includes all of the silt and clay factors as well as about half of the very fine sand fraction. To complete the size analysis, a Bouyoucos hydrometer test may be made upon the whole soil, upon the soil passing the No. 40-inch sieve, or upon the material washed through the No. 200-inch sieve.

The liquid limit is determined on the "soil mortar", that material passing the No. 40-inch sieve, or $<$ .420 mm in diameter. Liquid limit is defined (44) as that water content, expressed as a percentage of the dry weight of the soil, at which the soil mass just begins to become fluid under the influence of a series of standard shocks using an Atterberg apparatus.

The plastic limit is determined upon the same soil material as used previously. Plastic limit is defined (44) as that water content, expressed as a percentage of the dry weight of soil, at which the soil mass ceases to be plastic and becomes brittle, as determined by a procedure for rolling the soil mass into threads one-eighth inch in diameter until it just breaks apart.

The plastic index is the difference between the liquid and plastic limits and represents the range of moisture within which the soil is plastic. A small change in moisture content, such as 5, will change the soil from a semi-solid to a liquid condition. A large plastic index, such as 25, shows that considerable water can be added to the soil before it changes from a semi-solid to a liquid.

American Association of State Highway Officials System. According to Casagrande (19) the AASHO classification system has been adapted from a system originally developed in 1927 to 1929 from research conducted by the Bureau of Public Roads (BPR). It has subsequently been revised once each by the BPR, the Highway Research Board, and the American Association of State Highway Officials. It is an engineering property classification based on field performance of highways, and groups soils of about the same general load-carrying capacity and service into seven basic categories designated A-1 through A-7. The best soils for road subgrade are classified as A-1, grading into the poorest soils classified as A-7.

Due to the wide range in load-carrying capacity of each group, as well as over-lapping of load-carrying capacity between groups, sub-groups and group indices have been devised to approximate within group evaluations.

The Portland Cement Association (44) has given the following brief classification key:

Granular materials (<35% passing No. 200 sieve)

A-1 soils are well-graded[1] mixtures from gravel to sand with nonplastic soil binder[2].

A-1-a soils are gravel, either with or without a well-graded nonplastic binder.

A-1-b soils are sands, either with or without a well-graded nonplastic binder.

A-2 soils are composed of a wide range of granular materials that cannot be classified as A-1 or A-3 because of their fines content, plasticity, or both.

A-2-4 soils are granular materials that have binder characteristics of the A-4 group.

A-2-5 soils are granular materials that have binder characteristics of the A-5 group.

A-2-6 soils are granular materials that have binder characteristics of the A-6 group.

A-2-7 soils are granular materials that have binder characteristics of the A-7 group.

A-3 soils are sands deficient in soil binder and coarse material. Typical are fine beach sands and fine desert dune sands.

Silt-clay materials (>35% passing No. 200 sieve)

A-4 soils are composed predominantly of silt with only moderate to small amounts of coarse material and clay. They are of very common occurrence.

A-5 soils are similar to A-4 soils except they contain such materials as micas and diatoms which produce highly elastic

---

1/ Well-graded indicates that a soil contains a proportionate amount of all size fractions and that no size groups are missing or are dominant. It is the opposite of the geologic and pedologic term "well-sorted", meaning grains are all nearly the same size.

2/ Soil binder is generally considered as the material passing the No. 200-mesh sieve (<.074 mm in diameter).

properties. They are of limited occurrence.

A-6 soils are composed predominantly of clay with moderate to negligible amounts of coarser materials; they are non-elastic.

A-7 soils are composed predominantly of elastic clays.

A-7-5 soils exhibit moderate plasticity indices in relation to liquid limit, and may be highly elastic as well as subject to considerable volume change.

A-7-6 soils exhibit high plasticity indices in relation to liquid limit and are subject to extremely high volume change.

The ASSHO group index rating is obtained by the use of group index charts given by PCA (44) or by the use of a group index formula, as follows:

Group Index = 0.2a + 0.005ac + 0.01 bd;

where:

a = That portion of the percentage passing the No. 200 sieve greater than 35 per cent and not exceeding 75 per cent, expressed as a positive whole number (0 to 40).

b = That portion of the percentage passing the No. 200 sieve greater than 15 per cent and not exceeding 55 per cent (0 to 40).

c = That portion of the numerical liquid limit greater than 40 and not exceeding 60 (0 to 20).

d = That portion of the numerical plastic index greater than 10 and not exceeding 30 (0 to 20).

The group index is given in parentheses after the soil group number. A general evaluation of subgrades in terms of group index is as follows:

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

Whether a soil is "silty" or "clayey" depends upon its plastic index. "Silty" is the term applied to fine materials having a plastic index of 10 or less, and "clayey" is applied to fine material with a plastic index greater than 10.

This classification system has its greatest application in highway and airport investigations and in work concerning the foundations of large, extensive structures. It is commonly used by such organizations and agencies as the Highway Research Board, American Association of State Highway Officials, Bureau of Public Roads, and many state highway departments.

Unified System. According to Casagrande (19) the Unified soil classification system was revised by the Bureau of Reclamation from a 1942 system developed by Casagrande for the Corps of Engineers, and known originally as the Airfield Classification System.

The Unified system recognizes 15 basic soil groups based on textural and plastic qualities and with respect to their performance as engineering construction materials. Under this system soils are divided into three major divisions; (1) coarse-grained soils containing 50 per cent or less of material passing the No. 200 sieve; (2) fine-grained soils with greater than 50 per cent of the material passing the No. 200 sieve, and (3) highly organic soils.

Coarse-grained materials are subdivided into gravels (G) and sands (S), depending upon whether the amount retained or passing the No. 40 sieve (openings 4.76 mm) is dominant. Each subgroup is given a second descriptive letter, depending upon the amount and type of fines or upon the grain size distribution as follows:

W = well graded, P = poorly graded, M = silty, and C = clayey.

Fine-grained soils are divided into silts (M) and clays (C), depending upon their liquid limit and plasticity index. These groups are given a second letter based on whether they have a relatively low (L) or high (H) liquid limit.

Organic soils are designated OL or OH depending upon their compressibility characteristics. Highly organic soils and peats are given the symbol Pt.

This classification system may be used for highway and airport construction, but finds its greatest value in predicting the behavior of soils for foundations of small buildings, embankments, and for soil conservation structures. This is evidenced by the agencies using this system: the Soil Conservation Service, Federal Housing Administration, Corps of Engineers, and Bureau of Reclamation.

Moisture-Density Relations

According to the Earth Manual (17), Proctor showed in 1933 that the dry density of a soil obtained by a given compactive effort depended upon the amount of water contained by the soil during compaction. For any given soil and compactive effort there is one water percentage, called the optimum moisture content, that will result in a maximum dry density of that soil. Water contents both greater and smaller than the optimum value will result in dry densities less than maximum.

Two specifications are used in determining moisture-density relations; the Corps of Engineers test (also known as the AASHO test) and the American Society of Testing Materials test. The former uses slightly more than four and one-half times the force of compaction as the latter test.

According to the Soil Primer (44), the results of the test can be interpreted to give much general information on the load-carrying capacity of soils. This publication has stated that many engineers may interpret moisture-density tests to learn more about the properties of a given soil than from any other one test.

The maximum density of soil gives approximate information on its gradation and texture, including approximate clay and silt content. The shape of the moisture-density curve also gives valuable information showing the influence of water upon the load-supporting capacity of the soil.

Interpretation of Properties and Characteristics from Engineering Classification

As stated previously, the function of soil engineering interpretations is one of providing information of engineering significance about the soils and the alternatives possible in their use and treatment.

With identification by the aid of soil survey reports, maps, and complete profile descriptions, with results of laboratory tests to determine the engineering classification, and with established guides of interpretation established by several Federal agencies, many engineering properties, characteristics, and applications may be predicted.

The Soil Conservation Service, in an Advisory Notice (48) and a Soils Memorandum (49) has set the form of presenting factual information and interpretative information in the engineering sections of soil survey reports. In addition to prescribing such information as map symbols, soil series names, texture, permeability, salinity, and engineering classification and data, the SCS also recommended and set forth a method of estimating the following engineering properties which pertain to conservation and agricultural engineering:

1. Suitability for dikes and levees, as determined by such factors as impermeable layers, permeability rates, water table and flooding, cracking, and shrink-swell potential.

2. Suitability for farm pond reservoirs, as determined by such factors as permeability, rate of seepage, and depth to rock or highly permeable material.

3. Suitability for farm pond embankments, as determined by such factors as soil texture, soil strength and stability, permeability, cracking, and unsuitability due to high organic matter content.

4. Suitability for agricultural drainage, as determined by such factors as permeability, layers which influence the rate of water movement, water table and topographic position and slope.

5. Suitability for irrigation, as determined by such factors as soil depth, water-holding capacity, permeability, and topography.

6. Suitability for construction of terraces and diversions, as determined by such factors as slope and topography, texture, inhibiting layers, and depth of soil.

7. Suitability for use as waterways, as determined by such factors as erodibility, fertility, slope, and permeability.

The U. S. Army Corps of Engineers (21) has established an interpretative guide for estimating soil engineering properties after classification according to the Unified system. These estimated soil properties pertaining to roads and airfields and to embankments and foundations are as follows:

Pertaining to roads and airfields:

1. Value as a foundation when not subject to frost action
2. Value as a base directly under bituminous pavement
3. Potential frost action
4. Compressibility and expansion
5. Drainage characteristics
6. Compaction equipment needed
7. Dry unit weight (lb/ft^3)
8. Field California Bearing Ratio (lb/ft^3)1/
9. Subgrade modulus (lb/in^3)2/

Pertaining to embankments and foundations:

1. Value for embankments
2. Permeability (cm/sec)
3. Compaction characteristics
4. Maximum unit dry weight (lb/ft^3)
5. Value for foundations
6. Requirements for seepage control

Recently, work has been initiated by the Federal Housing Administration to permit the evaluation of soils with respect to foundations, streets and roads, and other structural, mechanical, and residential site engineering purposes. The Technical Studies Advisory Committee of the National Academy of Sciences recommended that FHA adopt the Unified system with guides of applicable physical characteristics of the fifteen groups of the system.

The Federal Housing Administration contracted with Virginia Polytechnic Institute to develop such guides and with the Bureau of Public Roads to compile and provide engineering test data of representative agricultural soil series.

These guides and test data have been published in 1959 (23) and revised in 1961 (24) and evaluated the following properties of disturbed soils:

1/ California Bearing Ratio (CBR) is a measure of shearing resistance used in design of flexible pavements.

2/ Subgrade modulus (k) is a value of the reaction of the subgrade per unit of area per unit of deformation, used in design of rigid pavements.

1. Workability as a construction material
2. Compaction characteristics
3. Shearing strength when compacted and saturated
4. Compressibility when compacted and saturated
5. Permeability and percolation characteristics when compacted (cm/sec)
6. Corrosion potential
7. Value as a road base when not subject to frost action
8. Value as a road sub-base when not subject to frost action
9. Value as a roadway sub-base when subject to frost action
10. Value as an untreated roadway wearing surface
11. Value as a roadway with surface stabilization with additives
12. Value as a foundation material for low buildings and compacted fill
13. Value as a low berm (less than 6 ft.) for sewage lagoons
14. Value as a compacted earth lining for water storage reservoirs and sewage lagoons
15. Value as a domestic sewage disposal area

In addition, five properties of undisturbed soils at residential building sites are rated according to the various Unified system categories. Since it is most likely that soils to be used for roadways and foundations will be disturbed, only one characteristic of undisturbed soils will herein be evaluated:

1. Value as a domestic sewage disposal area.

Other Engineering Uses of Agricultural Soil Survey

In addition to the manuals which serve to predict engineering behavior of soils on a basis of their engineering classification, much recent literature is in existence which attempts to relate agricultural soil classification to engineering usage, and to serve as guides to the alternatives available for engineering usage.

In 1949, the Highway Research Board published a bulletin (29) containing papers pertaining to the use of agricultural soil surveys by engineers and included a complete list, by state, of all county and special area surveys which had been published from 1918 to 1948. Included with the listings were numerical evaluations (1 through 4) by the USDA of the relative accuracy and value of each survey.

A revision of the above publication in 1957 (31) made the list of completed soil surveys complete up to that time. Other bulletins prepared by the HBR Committee on Surveying, Mapping and Classification of Soils (30, 32, 33, 34) contained other papers concerning interpretation of soils data, geologic and soil surveys in progress, and the listing of names and addresses of state geologists, state soil scientists, and personnel engaged in actual survey work.

In 1959, the Oklahoma Department of Highways issued a comprehensive Soils Manual (43) setting forth a method for making full use of relevant information concerning climate, geology, and soils. The manual contained introductory sections concerning geology, and engineering and pedological soils. It listed the highway engineering characteristics of the major soil series of the state and gave maps of geology, soil problem areas, climate, and 30 well done block diagrams showing the interrelationships among soils, topography, natural vegetation, and geology.

The second section of the manual gave the procedures for identifying the major soils and geologic formations in each of the eight maintenance divisions of Oklahoma. In all cases the pedologic method of identifying soil was used, this related to AASHO engineering classification, and from this, nine predicted characteristics were listed together with laboratory data of four physical tests.

This manual is perhaps the best approach to date of translating information which has been accumulated in one field of work into another field for a different kind of work. It is also noteworthy that it was suggested that soils per se are not the basic cause of highway problems, because the soils themselves are an expression of the totality of the conditions prevailing in any given area. The problems of highways, then, are also problems of the conditions of environment in which the highway is constructed.

Some states, such as Washington, prepare county engineering soil bulletins to be used as supplements to agricultural soil reports and maps. Maytin and Gilkeson (38) have prepared such a bulletin which, after a narrative introduction dealing with use of the bulletin, gave data and interpretations of engineering significance.

Included in climatic data were rainfall intensity-duration-frequency curves, temperature and precipitation data, and freeze data, each of which are given for several stations. Next were listed sources of sand, gravel and other construction materials, and approximations of some engineering characteristics of the major soil series of the county, a brief profile description of each series, including variations and special engineering considerations. Other data were a tabular presentation of each series' typical laboratory data, including Unified and AASHO classification, and finally, aerial photographs of the major soils were shown, helping to illustrate their topographic position, relation to other series, and other factors.

Bartelli(3), in a paper presented to the Soil Conservation Society of America in 1961, discussed the use of agricultural soil surveys in the planning and development of urban-fringe areas. Engineering use and interest in these areas centers around the use of soil for roadways, foundations, and as sewage disposal areas.

The use of soils for sewage disposal and the prediction of the suitability of a given soil for such use from soil surveys has been the topic of two pioneering studies in Virginia and Connecticut. Clayton, et al (20) have found in Fairfax County, Virginia, that after percolation potential was determined for soils representative of a given series, that the information could be projected to other sites of similar soils by using the detailed soil maps as a guide. They have noted that when trunk sewage disposal lines are not available, the size of the building lot for an individual home site and the quality of house built are largely regulated by the type of soil. They also noted that, in general, soils better adapted for agricultural use are the better soils for septic tanks and other engineering uses.

Hill and Shearin (28), have discussed the limitations of the soils of Hartford County, Connecticut, for various engineering uses in urban expansion. They have stated that interpretations of engineering properties from soil surveys are useful in planning and zoning, and in anticipating remedial measures. They have mentioned the conflict between selecting building sites for esthetic values and for engineering properties.

According to Miles and Spencer (40), county engineering soil maps are being prepared for all Indiana counties not having an agricultural soil survey. These maps are prepared using the pedological approach adapted to a limited amount of random sampling and laboratory testing, and upon airphoto interpretation.

Thornburn and Larsen (52), in an investigation of the statistical variation of liquid limit, plasticity index and clay content of the loess-derived soils of DeWitt County, Illinois, showed that certain physical properties can be predicted for soil map units with a reasonable degree of accuracy.

They sampled and tested the major A and B horizon of four major soil series at ten random sites, and made no attempt to limit sampling to modal profile development. The principal objective of the study was to determine the number of profiles which must be sampled in order to characterize each soil series within a specified limit of accuracy. It was concluded that, although the number of samples required would depend upon the variability of the soil horizon, that five profiles of each soil series would characterize each of the three index properties with from 3.0 to 6.5 per cent accuracy 95 per cent of the time, and would reveal significant differences in index properties between soil series derived from identical parent materials.

In a later study, Morse and Thornburn (41), concerned with the problem of extrapolating the data obtained from a few specific locations to cover a vast volume of soil, undertook a further statistical analysis of the engineering properties of the soils of Livingston County, Illinois.

Twelve series, varying in parent material (loess, glacial till, and glacial outwash) were sampled at five random sites.

It was expected that these soils would be more variable than those previously tested in DeWitt County since the C horizons were also sampled and because of variation of the parent material not found in the loessial soils of DeWitt County.

It was found that standard deviation of the mean index values varied with the property measured as well as with the soil series and horizon sampled. In the case of the more uniform loess, samples from each horizon at five sites of a given series again proved to be a sufficient number to define the property limits with a good degree of accuracy. In the case of the more variable till and outwash, the average number of samples required to reach the same accuracy was greatly increased, however for any particular soil type the degree of variability differed with respect to the property being measured.

In view of the inherent variability of index property values, it was decided to determine whether demonstrable differences between similar soil series existed by testing the sample means of one soil series against the corresponding means of another in order to determine whether any pairs of means were significantly different. It was concluded that even with the requirement of 95 per cent probability, soil series do show significant differences in some of their physical properties, and that although pedalogic mapping units are variable, most should be sufficiently unique and accurate to allow engineering usage of a few laboratory tests to be applied over an extensive area.

In a study of the relation of Atterberg limits to other properties of selected Illinois soils, Odell, et al (42) found very close correlation between liquid limit, plastic limit, and plasticity index and per cent of organic carbon, per cent of clay, and per cent of montmorillonite in the clay fraction. This indicated that when the latter three properties are known, that Atterberg limits and associated engineering properties can be estimated quite accurately. Amount of clay and organic carbon were the most important determinants of Atterberg limits. When these properties are known, as they are for many series, it is possible to make reasonably accurate estimates of predictions on the basis of estimated values.

Thus, from these recent studies, the basic nature of pedological soil methods and classification is further demonstrated. It is this basic nature which allows other than agricultural usage of agricultural soil surveys.

MATERIALS AND METHODS

Soils

The soils for this study were collected in Logan County, Kansas. The sites for collection of each series were those at which the series were described in the descriptive legend prepared by the Soil Conservation Service. The ten of the 31 soil series or mapping units recognized in the county which were sampled were: Keith silt loam, Ulysses silt loam, Colby silt loam, Richfield silt loam, Lofton silty clay loam, Promise clay, Bridgeport loam, Manter sandy loam, Dwyer loamy sand, and Likes loamy sand. These series have the complete range of textures found in this county and represent nearly all of the parent materials in the county.

The Keith and Ulysses soils are developed from loessial parent material and comprise nearly 70 per cent of the areal extent of the county's soils. Since these series have widespread development on sites differing in depth of parent material, under slightly different climatic conditions, on varying slopes, and other differing factors, they quite often exhibit profile development differing from that of the modal condition as found in the descriptive legend. For these two series, the major three horizons, generally A, B, and C, were sampled at the site of modal development and at carefully selected sites of minimum and maximum profile development. The purpose in mind was to determine if, for these two soils in this county, the differences within series mapping units was reflected by a concomitant variation in engineering properties and classification.

The Colby and Richfield series, also developed from loess, were sampled for comparisons, but only once each at their modal sites, again represented by the major A, B, and C horizons.

The remaining series were also sampled in three horizons, once each at their modal sites. The Lofton soils are dark colored, noncalcareous Chestnut soils with compacted clay subsoils occurring in upland basins and depressional areas associated with large extents of nearly level Keith soils.

Promise clay is a deep, dark colored Regosol formed in clayey alluvial-colluvial slopes below outcroppings of Pierre shale in the High Plains Region of the county.

The Manter sandy loam is a deep, moderately dark colored, weakly developed zonal soil developed in reworked calcareous sandy deposits of Tertiary and Quartenary materials occurring as elongated ridges in upland positions.

Dwyer loamy sand is a dark, deep, calcareous Regosol formed in reworked Tertiary sands on high terrace escarpments above the flood plain and in upland positions immediately adjacent to the Smoky Hill River.

The remaining two series are alluvial in origin. Likes loamy sand is light colored, moderately deep, calcareous, immature, and is formed in alluvial fans at the termination of upland drainageways that empty into low terraces along the Smoky Hill River Valley.

Bridgeport loam is a light colored, deep, calcareous, weakly developed soil occurring as low terraces and alluvial fans in the Smoky Hill River Valley and as valley sediments in the larger tributaries of this river.

Methods

Several physical and chemical tests were performed on each of the three horizons of the soils from the 14 sites in order to determine their engineering classification and to help to characterize them. These laboratory tests were: (1) organic matter content approximation; (2) determination of pH of saturated soil paste and saturated soil paste extract; (3) determination of soluble salts per liter of saturated soil extract; (4) particle size analysis; (5) liquid limit; (6) plastic limit; (7) optimum moisture content at maximum dry density for selected soils.

Organic Matter. Organic matter content was approximated by a method adapted from Schollenberger (47). Organic matter often affects the plasticity properties of soils sufficiently to influence their classification. Even small amounts of organic matter in collodial form in a clay will result in an appreciable increase in liquid limit without correspondingly increasing its plasticity index. Soils containing even moderate amounts of organic matter are significantly more compressible and less stable than inorganic soils; hence, they are less desirable for engineering use. When determining soil classification according to the Unified system, an estimate of the organic matter content is needed in determining certain border-line classifications and in classifying OL and OH soil groups.

Saturated Soil Paste. Saturated soil paste was made from approximately 250 gm of each soil sample according to the directions given by Jackson (35). The pH of this paste was determined by use of a Beckman pH meter. The soil solution was removed from each saturated sample and the pH determined. The salt content was approximated by determining the conductivity with an Industrial Instruments model RC conductivity bridge.

Particle Size Analysis. The particle size analysis was determined upon each sample in two ways. First, weighed amounts of approximately 200 gm of each soil sample were soaked in water and dispersing agent[1/] for 24 hours. The slurry was washed with tap water over a No. 200-mesh sieve. The material retained on

1/ 15 ml of 1N sodium hexametaphosphate, sold by Fisher Scientific Company under the trade name "Calgon".

this sieve was oven dried, weighed, and passed over a nest of the following sieves: ½ in; Nos. 4, 10, 20, 40, 60, 100, and 200.

From the weight of dry material retained on each sieve, the percentage of each size limit and the amount passing the No. 200-mesh sieve was determined. This test was performed and calculated according to ASTM Designation: D 1140-54 (2).

The Bouyoucos hydrometer analysis was then determined for each soil upon the material passing the No. 10-mesh sieve ($<$2.00 mm). The procedure used was as outlined in ASTM Designation: D 422-54T (2), with the following exceptions: A water bath or constant-temperature room were not employed; the relatively small temperature variations were compensated for by use of a correction factor as given by Bouyoucos (5). Also, rather than correcting the sample weight for hygroscopic water, the samples were oven dried and 50,000 gm of soil weighed for fine-grained samples, with 100.000 gm used in the case of sandy soils.

Hydrometer readings were taken at the following times: 1, 5, 30, 120, 240, and 1440 minutes in order to determine the percentage of soil samller than the following diameters: .05, .02, .005, .002, and .001 mm.

In addition, a check could also be made by this method of the sieving results of the determination of the percentage smaller than the No. 20, 40, 60, 100 and 200-mesh sieves.

Liquid Limit. The liquid limit was determined upon the material passing the No. 40-mesh sieve for each soil sample according to ASTM Designation: D 423-54T, mechanical method (2). The only deviation from the method given was that after initially mixing each soil with water, it was allowed to stand for approximately 30 minutes over water in a closed dessicator before testing.

Plastic Limit and Plasticity Index. The plastic limit was determined upon the same soil material previously used to determine liquid limit, according to ASTM Designation: D 424-54T (2). In all cases a portion of the soil being mixed for the liquid limit test was removed before reaching the liquid limit. Each plastic limit sample was flattened and air dried until its moisture content approximated its plastic limit before being rolled.

Moisture-Density Relations. The moisture-density relations of combined profiles was determined upon certain of the original soil series according to ASTM Designation: D 698-57T, Method A (2). The soil series and depths sampled were:

Ulysses	7-14 inches
Ulysses	20-50 "
Keith	17-41 "
Keith	41-55 "
Lofton	12-30 "
Lofton	40-60 "
Bridgeport	20-46 "
Dwyer	5-40 "
Colby	20-50 "
Promise	8-22 "

Keith, Ulysses, and Colby series were selected because of their wide occurrence in the county; the other series being selected to cover a range of parent materials and textures. Two depths were sampled for Ulysses, Keith, and Lofton series in order to compare the properties of relatively unweathered loessial parent material and to compare the properties of greatly varying horizons within the series. In no case was the surface horizon sampled since variation in organic matter content greatly affects moisture-density relation. In addition, in construction work this horizon is very often discarded, buried beneath other material, or in some instrances, saved for topdressing in the seeding of road embankments and borrow areas. In most cases, parts or all of several horizons were collected in one sample. In construction operations, these layers, unless one or more posesses undesirable characteristics, are mixed.

The only deviation from the ASTM standard was that two instead of one moisture content samples were taken from the compacted soil, one from each end of the plug within the mold. Each damp sample weighed approximately 50 gm.

It should be noted that standard compactive effort (25 blows from 12 inches of a 5.5 lb. hammer on each of 3 layers) was used rather than modified standard compactive effort (25 blows from 18 inches of a 10 lb. hammer on each of 5 layers).

RESULTS AND DISCUSSION

Chemical Tests

The pH determination of the saturated soil paste extract showed one neutral soil (surface horizon of Manter sandy loam), with the other soils being alkaline as expected. The range of pH was from 7.2 to 8.3. The pH determination of the saturated soil paste indicated the soils to be slightly acid to slightly alkaline. In all but seven cases the reading of the extract indicated higher pH than the paste itself. In five cases the paste indicated higher pH values. It is suspected that the cause of difference in the readings is due to differences in soil-water relations.

The organic matter determination revealed that for each of the 14 soils sampled, the organic matter content of the surface horizons was in each case greater than the lower two horizons, as was to be expected. In general, the samdy soils contained less overall organic matter than the heavier soils. Two of the sandy soils showed no measurable organic matter below the surface horizon. The greatest amount of organic matter (2.4%) was found in the surface horizon of Keith silt loam of maximum development. In all cases the second sampled horizon of each soil revealed greater organic matter content than the lowest sampled horizon.

The determination of millequivalents of soluble salts per liter of saturated soil extract revealed generally a fairly low salt content. Salt content was found to vary among soil series and horizons. Results of chemical tests are shown for all soils tested in appropriate columns of Table 1.

Physical Tests and Engineering Classification

Mechanical Analysis. Particle size analyses of the various soils showed the textural differences which gave the series a type designation.

The No. 10 sieve was the first of the sieve series to retain a measurable amount of material in the case of all sampled horizons of Manter sandy loam and Dwyer loamy sand. Hydrometer analyses showed clay contents (particles less than .002 mm) of

Table 1. Summary of selected engineering properties, characteristics, and classification of important soil series of Logan County, Kansas

	Horizon	Depth	Texture (USDA)	% Passing #200 Sieve	% .002 mm diameter (% clay)	L.L.	P.L.	P.I.	O.M.	pH Saturated Paste	pH Saturated Soil Extract	m.eq. salts/l. of Sat. soil Extract	% Water Content at Saturation	Engineering Class. AASHO	Engineering Class. Unified	L.L. Sat. %
Bridgeport	A_1 & A_p	0-18	loam	72	16	27	22	5	1.2	7.4	8.2	6.93	30	A-4(7)	ML-CL	90
(loam)	C_1	18-36	loam	95	24	36	20	16	1.0	7.7	8.1	8.81	44	A-6(10)	ML-CL	82
	C_2	40-46	loam	86	22	33	20	13	.4	7.6	7.8	6.93	38	A-6(9)	ML-CL	87
Colby	A	0-5	silt loam	95	20	31	24	7	2.0	7.2	8.1	7.40	39	A-4(8)	ML-CL	80
(silt loam)	AC	12-24	silt loam	75	32	30	15	15	.7	7.6	7.9	3.85	34	A-6(10)	ML-CL	88
	C	25	silt loam	81	28	31	16	15	.3	7.7	7.9	3.8	36	A-6(10)	ML-CL	86
Dwyer	A_1	0-5	loamy sand	60	5	27	27	0	2.2	7.3	7.6	1.02	29	A-4(5)	ML	93
(loamy sand)	AC	5-12	sand	5	1	(Sl.Pl.(P))		0	0.0	8.2	7.8	3.14	19	A-1b(0)	SP-SM	--
	C	12	sand	9	1	(Sl.Pl.(P))		0	0.0	8.1	7.7	3.34	19	A-3(0)	SP-SM	--
Min. Keith	A_{1p} & A_1	0-8	silt loam	99	26	35	21	14	2.0	7.1	8.0	5.65	42	A-6(10)	ML-CL	83
(silt loam)	B_2	11-15	silt loam	99	32	36	21	15	1.5	7.0	7.7	6.79	49	A-6(10)	ML-CL	74
	B_3	15-34	silt loam	99	30	39	23	16	.7	7.7	7.7	6.18	44	A-6(10)	ML-CL	89
Mod. Keith	A_{1pl} & A_1	0-11	silt loam	99	26	35	24	11	2.0	7.0	7.8	4.60	53	A-6(8)	ML-CL	81
(silt loam)	B_{21}	16-22	silt loam	99	28	39	20	19	1.1	7.1	8.0	4.54	43	A-6(12)	ML-CL	91
	B_{2ca}	32-42	silt loam	99	28	39	20	19	.6	7.6	8.2	5.24	40	A-6(12)	ML-CL	98
Max. Keith	A_1	0-9	silt loam	99	26	36	22	14	2.4	6.2	8.1	5.93	37	A-6(10)	ML-CL	97
(silt loam)	B_2	17-27	silty cl.loam	99	28	39	20	19	1.9	7.0	8.2	4.01	36	A-6(12)	ML-CL	110
	B_{3bl}	27-42	silty cl.loam	99	28	39	21	18	.6	7.5	7.8	8.20	43	A-6(11)	ML-CL	91
Likes	A_1	0-12	loamy sand	20	2	(Sl.Pl.(P))		0	.4	7.6	7.8	7.64	15	A-2-4(0)	SP-SM	--
(loamy sand)	AC	12-30	loamy sand	17	2	(Sl.Pl.(P))		0	0.0	8.0	8.0	3.59	15	A-2-4(0)	SP-SM	--
	C	50	sand	3	1	(Sl.Pl.(P))		0	0.0	8.0	8.1	2.76	18	A-3(0)	SP	--
Lofton	A_p	0-5	silty cl.loam	99	35	32	22	10	1.5	6.0	7.5	4.60	48	A-4(8)	ML-CL	67
(silty clay	B_{22}	8-17	silty cl.loam	99	46	54	21	33	.8	6.4	8.2	5.72	55	A-7-6(20)	ML-CL	98
loam)	BC	43-55	silty cl.loam	99	40	42	21	21	.3	6.8	7.9	6.09	49	A-7-6(13)	ML-CL	86
Manter	A_1	0-6	sandy loam	37	6	23	19	4	1.3	7.2	7.0	6.39	18	A-4(0)	SC-SM	113
(sandy loam)	B_{21}	6-14	sand	34	7	24	19	5	.8	7.0	7.3	4.69	20	A-2-4(0)	SC-SM	112
	C	26-36	sand	40	9	20	19	1	.3	7.6	7.2	4.51	22	A-4(1)	SC-SM	91
Promise	A	0-8	clay	81	42	52	21	31	1.7	7.3	8.1	5.21	43	A-7-6(19)	ML-CL	112
(clay)	AC	8-20	clay	81	46	53	21	32	1.1	7.5	7.4	1.02	43	A-7-6(19)	ML-CL	112
	C	25-35-	clay	85	--	47	22	25	1.1	7.5	7.6	2.6	47	A-7-6(15)	ML-CL	100
Richfield	A_p	0-5	silt loam	99	26	31	21	10	1.4	6.8	8.3	5.6	43	A-4(8)	ML-CL	72
(silt loam)	B_{21} & 22	5-18	silt loam	99	26	37	22	15	1.2	7.3	8.2	3.93	45	A-6(10)	ML-CL	82
	C_{ca}	27-36	silt loam	99	34	38	22	16	.6	7.9	8.0	4.21	45	A-6(10)	ML- CL	85
Min. Ulysses	A_1	0-8	silt loam	98	19	33	23	10	1.5	7.6	8.2	6.29	40	A-4(8)	ML-CL	82
(silt loam)	AC	8-19	silt loam	99	26	36	21	15	.8	7.7	7.8	3.93	42	A-6(10)	ML-CL	86
	C	*30-36	silt loam	99	17	32	23	9	.4	7.7	8.0	4.10	40	A-4(8)	ML-CL	80
Mod. Ulysses	A_1 & A_p	0-5	silt loam	95	20	34	23	11	1.8	7.7	8.3	3.97	40	A-6(8)	ML-CL	85
(silt loam)	B_{21}	5-9	silty cl.loam	93	24	39	20	19	1.5	7.3	8.3	4.08	44	A-6(12)	ML-CL	89
	BC	25-48	silt loam	99	17	30	25	5	.3	7.6	8.0	8.20	38	A-4(8)	ML-CL	79
Max. Ulysses	A_1	0-9	silt loam	99	26	36	22	14	1.5	7.1	8.2	6.98	44	A-6(10)	ML-CL	82
(silt loam)	B_2	9-14	silt loam	99	20	40	21	19	1.2	6.9	8.0	5.55	46	A-6(12)	ML-CL	87
	C	25-30	silt loam	99	20	35	22	13	.6	7.6	7.7	5.24	42	A-6(9)	ML-CL	83

* Depth sampled not extent of whole horizon; all other horizons sampled through entire depth.

these soils to be less than ten per cent. The other two coarse-grained soils show some particles extending into larger size ranges. Likes loamy sand had some particles retained on the No. 4 sieve (greater than 4.76 mm), while Bridgeport loam showed occasional particles greater than one-quarter inch in diameter. Hydrometer analyses of these two soils showed the sampled horizons of Likes to contain an extremely small amount of clay, while the three horizons of the Bridgeport, although having the largest particles of the soils tested, had relatively fewer particles retained on each sieve, but contained substantial amounts of clay.

The Richfield silt loam horizons, like most of the loess-derived soils, showed no material retained on the No. 100 sieve and very little on the No. 200 sieve. All three horizons contained more than 25 per cent clay, most of which was less than .001 mm in diameter.

The Colby silt loam surface horizon contained very little material retained on the No. 200 sieve, while the AC and C horizons contained about 25 and 20 per cent respectively, retained on this sieve. In spite of this, the lower two horizons also contained appreciably more clay than did the surface horizon. The high sand content of the lower two horizons was due to calcium carbonate concretions and to some mixing of loessial parent material with Tertiary outwash sands.

The Lofton silty clay loam contained only occasional, unmeasurable concretions retained on the No. 100 sieve and high clay contents in all three sampled horizons.

The Promise clay contained small amounts of material retained on the larger sieve sizes, but with large amounts of clay in all sampled horizons. The clay content of the C horizon could not be determined by the hydrometer method due to an excessive amount of gypsum which caused flocculation.

Mechanical analyses of the three major horizons of Ulysses silt loam of minimal, modal, and maximal development revealed no material retained on the No. 100 sieve with the exception of a small amount in the case of the upper two horizons of the modal profile. Increasing clay content from minimal through maximal development of all sampled horizons of each profile further reflect stages of genesis. The mean clay content of all three samples from each profile were as follows: minimal, 18.9%, modal, 20.3%, maximal, 23.8%.

Keith silt loam of minimal, maximal, and modal development revealed less than 1 per cent retained on the No. 200 sieve, with the single exception of the surface horizon in the minimal case. Keith soils revealed their greater degree of development (more distinct B horizons and greater depth to calcareous accumulations) than Ulysses soils by overall mean clay content of 27.9% as compared to 21.0% for Ulysses.

However, Keith soils did not reveal clear-cut correlation of clay content with development. Mean clay content of all three horizons sampled for each stage of genesis showed the following: minimal, 29.1%, modal, 27.5%, and maximal, 27.3%. It should be noted that this may be explained by the notation of the horizons sampled. In the case of minimal Keith two B horizons were sampled the layers where greater clay accumulation is expected; while in the maximal case two A horizons were sampled, the layers in which clay is normally at least partially removed.

Complete results of sieve and hydrometer analysis of all three sampled horizons of all 14 soils studied are found in Table 2. Although complete analysis was done by hydrometer, and the results therefore unsuitable for assigning textural names, the percentages of sand, silt, and clay fractions found in this study were quite similar to those which resulted in the assignment of textural names as a result of the pipet method of particle size analysis.

Atterberg Limits. Atterberg limits were determined to the nearest one-tenth per cent of water but, according to convention, were reported to the nearest whole per cent. In the case of non-plastic soils, the liquid and plasticity limits were reported as slightly plastic, temporary (Sl. Pl.(T)), or slightly plastic, permanent (Sl. Pl.(P)), according to the suggested method of Preus, as reported by the ASTM (2). The method estimates the cohesiveness of non-plastic granular soils by the relative strength exerted by thumb and forefinger in order to crush an oven dried ball of sample soil one inch in diameter.

The per cent of water content at saturation when making saturated soil paste was determined. The ratio,

$$\frac{\text{liquid limit}}{\text{saturation per cent}} \times 100$$

was determined in each case as a means of comparing soils and as a means of detecting great errors in the reported liquid limit. It is to be expected that, with the possible exception of very

Table 2. Tabulation of Results of Mechanical Analyses (Hydrometer and Sieve)

Soil	Horizon	Percent Passing Sieve $\frac{1}{4}$"	#4 4.6mm	#10 2.00mm	#20 0.84mm	#40 0.42mm	#60 .250mm	#100 .149mm	#200 .074mm	Per cent Smaller Than (diameter) .05mm	.02mm	.005mm	.002mm	.001 mm
Bridgeport	A_1	96.5	94.5	92.0	88.5	80.2	75.7	73.7	72.5	54.9	29.0	19.6	15.5	12.0
(loam)	C_1		100.0	99.9	99.5	98.7	98.0	97.1	94.9	76.5	52.4	30.5	24.3	19.6
	C_2			100.0	99.9	96.0	90.0	88.0	86.0	84.0	45.0	27.5	22.5	18.6
Colby	A							100.0	94.9	81.5	30.0	24.0	19.5	14.5
(silt loam)	AC			100.0	99.2	90.3	82.1	78.5	75.3	64.2	45.5	36.8	23.0	26.2
	C			100.0	99.0	93.6	88.7	86.4	81.0	65.0	38.0	32.5	27.5	22.5
Dwyer	A_1		100.0	99.5	95.9	78.3	64.9	60.4	59.5	30.5	16.4	9.2	5.2	3.8
(loamy sand)	AC		100.0	99.9	91.8	45.9	16.9	8.2	4.7	2.3	1.8	1.7	1.2	.8
	C		100.0	99.9	96.0	59.4	25.0	13.9	9.4	2.3	1.8	1.7	1.4	.4
Min. Keith	A_1							100.0	98.6	84.5	48.0	31.3	25.5	22.8
(silt loam)	B_2							100.0	99.4	84.5	52.8	38.3	32.5	29.0
	B_3							100.0	99.7	85.0	56.5	37.0	29.5	23.4
Mod. Keith	A_1							100.0	99.1	87.5	51.5	28.3	26.5	22.0
(silt loam)	B_2							100.0	99.7	87.5	51.5	33.4	27.5	24.8
	B_3							100.0	99.7	88.0	52.2	32.5	28.5	24.6
Max. Keith	A_1							100.0	99.4	89.5	50.5	28.9	26.0	23.0
(silt loam)	B_2							100.0	99.5	87.5	49.4	30.0	27.5	24.8
	B_3							100.0	99.6	89.5	50.2	33.7	28.5	24.4
Likes	A_1	100	99.4	98.0	93.6	68.5	38.4	25.4	20.3	10.2	7.4	4.1	2.5	1.2
(loamy sand)	AC	100	99.3	98.9	91.0	60.0	32.8	22.4	17.1	5.5	5.1	4.2	2.4	1.5
	C	100	94.0	93.2	89.2	58.0	11.4	4.3	3.2	2.6	2.1	1.6	.6	.2
Lofton	A							100.0*	99.5	78.5	60.2	42.0	35.2	29.8
(silty clay	B_2							100.0*	99.7	77.0	72.6	55.5	46.5	42.8
loam)	BC							100.0*	99.5	87.5	63.5	48.0	40.5	31.2
Manter	A_1		100.0	99.9	95.1	71.5	50.5	41.8	37.2	16.5	12.5	9.6	6.5	5.0
(sandy loam)	B_{21}		100.0	99.9	96.7	72.9	49.1	39.6	34.3	18.5	12.2	10.5	7.4	6.0
	C		100.0	99.6	97.8	82.4	60.4	48.7	40.0	17.5	14.0	11.8	8.6	6.6
Promise	A			100.0	97.9	88.2	82.2	80.5	78.7	74.0	69.0	49.5	42.5	39.2
(clay)	AC			100.0	97.5	88.9	83.8	82.3	80.6	77.5	66.5	55.0	46.2	41.0
	C			100.0	98.3	91.0	87.4	86.3	85.2	83.5	74.0	54.5	**	**
Richfield	A_1							100.0	98.7	88.2	52.0	31.2	26.5	22.2
(silt loam)	B_{21} & 22							100.0	99.4	87.5	50.5	32.5	26.2	23.0
	C_{ca}							100.0	99.4	87.5	53.5	35.5	33.5	24.2
Min. Ulysses	A_1						100.0	99.0	98.5	83.5	40.0	25.0	19.2	15.4
(silt loam)	AC							100.0	99.3	84.0	45.0	30.0	20.5	17.0
	C							100.0	99.5	85.0	43.2	24.3	17.0	13.0
Mod. Ulysses	A_1 & A_p						100.0	98.0	95.0	76.5	34.0	25.1	19.5	15.8
(silt loam)	B_{21}						100.0	97.0	93.1	75.0	40.0	29.4	24.5	21.2
	BC							100.0	98.9	81.5	38.4	22.5	17.0	11.8
Max. Ulysses	A_1							100.0	98.9	84.5	45.0	30.5	25.5	22.6
(silt loam)	B_2							100.0	99.4	85.0	46.5	30.4	25.5	21.0
	C							100.0	99.5	83.0	47.0	27.0	20.5	14.6

* Occasional particle retained on #100, 60, 40 and 20.
** Flocculation of suspension due to gypsum.

clayey soils, this figure would be less than 100 per cent.

Manter sandy loam horizons revealed the lowest liquid limit of the soils tested, with a very narrow range of plasticity index. The per cent liquid limit/saturated per cent in the top two horizons was excessively large, due probably to the great difficulty in attaining true saturation in sandy soils.

Due to high sand content the lower two horizons of Dwyer loamy sand and all horizons of Likes loamy sand were nonplastic.

Bridgeport loam horizons showed increasing liquid limit and plasticity index with increasing silt and clay content.

Richfield silt loam revealed appreciably higher liquid limit in the lower two horizons than in the surface soil, with the plasticity index of these horizons rising correspondingly.

Colby silt loam horizons showed nearly equal liquid limit in all horizons but with the plasticity index of the lower two horizons slightly over twice that of the surface soil.

Lofton silty clay loam horizons showed great variation in liquid limit and plasticity index among the three sampled horizons. This was probably due to the type and nature of the clay fraction as well as to clay per cent. The A horizon contained the least amount of clay and had lowest liquid limit and plasticity index, while the B horizon contained the greatest amount of clay which correspondingly raised the liquid limit and the plasticity index.

Promise clay horizons exhibited the highest liquid limit of the soils sampled. Although these values vary, the plastic limits of the three horizons were nearly equal, giving plasticity values which were only moderately high.

Examination of Atterberg limits values of minimal, modal, and maximal Ulysses silt loam showed that in all cases the middle horizon, the zone of alluviation, had the greatest liquid limit as compared to horizon above and below. The values of liquid limit for these three middle horizons also showed increase, along with increase of clay content, from minimal through maximal development. In all horizons of all three profiles there was no great difference in values of plastic limit. However, the plasticity index was greatest in the middle horizon of the three profiles, the minimal profile having a lower value than the other two, which were equal.

Examination of the Atterberg limits values of minimal, modal, and maximal Keith silt loam showed that for all three profiles the surface horizons revealed liquid limit values nearly equal or slightly lower than the deeper horizons. The lowest horizon of all three profiles showed identical values for liquid limit; the middle horizon of the minimal profile being nearly the liquid limit of the surface, while the middle horizon of the other profiles showed liquid limit values identical with the lowest horizon.

There was little difference in plastic limit values among the Keith soils, and between these figures and those of the Ulysses soils. The plasticity index values of the various horizons of the Keith profiles also reflected great similarity of engineering properties. They followed a pattern identical to that pointed out in discussing liquid limit values of these soils.

<u>Engineering Classification</u>. As may be readily seen by a

comparison of the Unified and AASHO classification systems, the latter, due to greater differentiation of groups and sub-groups and to within-group index numbers, is a much more sensitive indicator of difference in engineering properties than is the former method. For the purposes of this study, significance of difference in engineering properties both among horizons and among profiles has been based upon group and sub-group placings and upon relative difference of index numbers according to the AASHO system. For example, two silty soils may both be classified as ML-CL under the Unified system, while under the AASHO system one may be placed in an A-4(0) grouping and the other may receive a rating of A-6(20); this a very significant difference between the two soils.

The Manter, Dwyer, and Likes series were the only three soils receiving coarse-grained, or sandy (S) designations. All three horizons of the Manter sandy loam were SC-SM under the Unified system, while the AASHO system revealed similarity of the surface and C horizons but a rather significant difference in the middle horizon.

Dwyer loamy sand exhibited a surface horizon classed as ML under the Unified system, while the lower two horizons received the same sandy designation. According to the AASHO system quite significant differences among the three horizons were revealed.

Likes loamy sand revealed identical classifications of the first two horizons under each system. The lower horizon of this profile was found to be significantly different according to both systems.

Bridgeport loam showed engineering properties of the surface soil to be slightly more clayey than the lower horizons according to the Unified system. AASHO classification confirmed the two sampled C horizons to be nearly identical, while a difference was exhibited by the surface horizon.

According to the Unified system all horizons of Richfield silt loam were identical, but again a more silty, less plastic surface horizon was revealed by the AASHO system. Examination of the horizons of Colby silt loam revealed exactly identical results as corresponding Richfield horizons. Although Richfield horizons contained a greater amount of clay than corresponding Colby horizons, engineering properties of the two profiles were made nearly equal by differences in Atterberg limits.

Lofton silty clay loam showed the upper B horizon to be highly compressible clay according to the Unified system, while those horizons above and below had less plastic properties. AASHO system showed the two lower horizons to have uniformly poor engineering properties, while a very significant difference was shown by the surface soil. The Unified system classed the lowest horizon as being less plastic than the two above, while by the AASHO system no significant difference was noticed from the uniformly poor properties.

Comparison of the Unified classification of all three horizons from minimal, modal, and maximal profiles of both Ulysses silt loam and Keith silt loam showed no significant difference among any of these eighteen horizons. However, again the AASHO system has been sufficiently sensitive to detect some minor differences.

According to this system it was seen that the properties of Keith soils show no differences according to the Unified system and but minor differences according to the AASHO system, both within horizons of any profile and among the three profiles. The only variation among the AASHO classification of the 9 Keith horizons was a maximum difference of 4 in the index numbers.

The AASHO system showed that minimal Ulysses surface and C horizons were somewhat less plastic than the AC horizon. In the modal case only the lowest tested horizon displayed less plastic properties. In the maximal case all horizons were of nearly identical classification, and were essentially the same as all Keith horizons and all of the more plastic minimal and modal Ulysses horizons.

A summary of mechanical analysis data, Atterberg limits data, and engineering classification, as well as chemical test data are given in Table 2.

Comparison of Study Results with Data of Other Areas

All of the soil series used in this study are either very extensive in extent or have a wide range of occurrence in the Great Plains states. Particularly important due to wide areal extent are Colby, Ulysses, Keith, and Richfield series. At the present time no accurate estimates of acreages are available for most of these soils. Leadabrand (32), has stated that Keith series in southwestern Nebraska and adjacent parts of Colorado and Kansas covers approximately 5.1 million acres.

Unfortunately, little laboratory information of engineering value is available for these soil series in other states. However, some data have been obtained as a result of the cooperative sampling and testing program of the Physical Research Division, Bureau of Public Roads, Soil Survey, Soil Conservation Service, and the various state highway departments for the following soils in the indicated areas:

1. Bridgeport soils in Dundy County, Nebraska. (8)

2. Ulysses soils in Logan County, Ford County, and Morton County, Kansas; and Beaver County, Oklahoma. (13, 9, 14, 6)

3. Keith soils in Logan County, Kansas; Sharon County, South Dakota; Goshen County, Wyoming; and Hitchcock, Deuel, Dundy, and Kimball Counties, Nebraska. (13, 16, 10, 11, 7, 8, 12)

4. Richfield soils in Ford and Morton Counties, Kansas; Prowers County, Colorado; and Beaver County, Oklahoma. (9, 14, 15, 6)

Comparison of data obtained in this study for Bridgeport loam with five profiles tested from Dundy County, Nebraska, showed a rather wide variation of the characteristics listed in Table 3. However, no one profile or horizon was vastly different from any corresponding profile or horizon. Again, with the AASHO system used as a guide in determining significant differences, all the tested horizons were in either A-6 or A-4 categories, always with fairly large index numbers (between 7 and 10). There was particularly close correlation among the AASHO classification of the Bridgeport soil of this study and the sample numbers 1 and 2 in Nebraska. Due to the number of samples taken in Nebraska,

Table 3. Comparison of properties and classification of Bridgeport soils in various locations.1/

Location	Horizon	Depth	% Passing #200 Sieve	Liquid Limit	Plasticity Index	Engineering Class AASHO	Engineering Class Unified	Density (lb/ft^3)	Moisture Cont. (%)
Bridgeport loam	A_1 & A_p	0-18	72	27	5	A-4(7)	CL-ML		
Logan County,	C_1	18-36	95	36	16	A-6(10)	CL-ML	101	20
Kansas	C_2	40-46	86	33	13	A-6(9)	CL-ML	101	20
Bridgeport loam	A_p	0-8	62	26	8	A-4(5)	CL	115	14
Dundy County,	B_1	8-16	64	29	12	A-6(7)	CL	115	15
Nebraska (No. 1)	C_1	28-39	78	31	13	A-6(9)	CL	116	16
Bridgeport loam	A_p	0-9	67	27	9	A-4(6)	CL	114	14
Dundy County,	B_1	9-15	74	31	13	A-6(9)	CL	113	16
Nebraska (No. 2)	C_p	28-37	93	37	16	A-6(10)	CL	110	18
Bridgeport loam	A_p	0-6	92	31	9	A-4(8)	ML-CL	109	17
Dundy County,	C_2	26-42	93	28	7	A-4(8)	ML-CL	112	16
Nebraska (No. 3)	A_{1b}	42-60	92	27	6	A-4(8)	ML-CL	112	16
Bridgeport loam	A_p	0-7	71	23	4	A-4(7)	ML-CL	116	13
Dundy County,	C_1	19-34	92	30	9	A-4(8)	ML-CL	112	16
Nebraska (No. 4)	C_3	48-60	92	28	7	A-4(8)	ML-CL	112	16
Bridgeport loam	A_p	0-5	90	28	5	A-4(8)	ML-CL	108	16
Dundy County,	C_1	11-23	88	26	2	A-4(8)	ML	110	16
Nebraska (No. 5)	A_{11b}	35-47	88	26	3	A-4(8)	ML	110	15

1/ All data, except from Logan County, from Bureau of Public Roads (8).

the testing has revealed the other three samples to be more silty in nature.

Although these are correlated soils, it may be that further sampling and testing in other locations may reveal a basic difference within Bridgeport soils resulting in establishment of a new series. However, it must be remembered that alluvial soils, because of the basic nature of their parent materials, must of necessity be allowed a wider range of characteristics than other soils; otherwise their classification and delineation would rapidly become impossibly complex and detailed.

As previously discussed, all horizons of the three Ulysses profiles of this study were classified as A-4 or A-6 and with moderately high index numbers according to the AASHO system. The same was generally found to be true of both minimal and modal profiles sampled by BPR in Logan and in Ford Counties, Kansas and modal Ulysses, sample No. 1 in Beaver County, Oklahoma. However, in sample No. 2 from Beaver County, a variation was noted. The profile description made mention of increased clay content with increasing depth and a phase of the normal soil is indicated in the name: Ulysses silt loam, clayey subsoil. Nearly identical classification was observed in corresponding horizons of two profiles sampled in Morton County, Kansas. For both these profiles the description indicated that they were of modal development. However, it was apparent that two profiles had significantly different engineering properties from other profiles indicated as modal. It is probable that they are also clayey subsoil phases of Ulysses. A listing of data of eleven Ulysses soil profiles is given in Table 4.

Fourteen Keith profiles have been collected and classified as to engineering properties by the BPR in four states. As previously discussed, all three horizons from minimal, modal, and maximal profiles in this study received an A-6 AASHO classification. The BPR sample No. 2, collected at the same location as the modal profile for this study, was of identical classification, as was sample No. 1, also described as modal. In the latter two profiles the relatively unweathered loessial C horizon was also tested, and showed less clayey character according to AASHO classification. A "Keith-like" silt loam collected in South Dakota showed classification characteristics similar to the previously discussed Keith profile.

One modal Keith profile from Wyoming, three from two Nebraska counties, and one minimal profile from Nebraska showed a rather significant difference from those previously discussed. In all these profiles the A and C horizons were A-4, while the B_2 horizon in all cases were A-6. These data tend to show a basic difference in parent material or type of weathering since the A horizons have the same engineering properties, reflected in the AASHO classification, as all loessial C horizons which were compared. A definite textural B horizon was indicated by the more plastic property classification. An even more pronounced textural B horizon was indicated in profiles from Hitchcock County, (No. 2) and Deuel County (No. 3), Nebraska. In both these profiles the A and C horizons were placed in the less plastic A-4 grouping.

Three profiles of Keith loam and one of Keith fine sandy

Table 4. Comparison of properties and classification of Ulysses soils in various locations.1/

Location	Horizon	Depth	% Passing #200 Sieve	Liquid Limit	Plasticity Index	Engineering Class. AASHO	Engineering Class. Unified	Max. Dry Density (lb/ft^3)	Optimum Moisture Cont.(%)
Min.Ulysses S.L.	A_1	0-8	98	33	10	A-4(8)	CL-ML		
Logan County,	AC	8-19	99	36	15	A-6(10)	CL-ML		
Kansas	C	30-36	99	32	9	A-4(8)	CL-ML		
Mod.Ulysses S.L.	A_1 & A_p	0-5	95	34	11	A-6(8)	CL-ML		
Logan County,	B_{21}	5-9	93	39	19	A-6(12)	CL-ML	101	22
Kansas	BC & BC_2	25-48	99	30	5	A-4(8)	CL-ML	102	21
Max.Ulysses S.L.	A_1	0-9	99	36	14	A-6(10)	CL-ML		
Logan County,	B_2	9-14	99	40	19	A-6(12)	CL-ML		
Kansas	C	25-30	99	35	13	A-6(9)			
Min.Ulysses S.L.	A_1	0-8	98	37	14	A-6(10)	ML-CL	101	19
BPR Logan Co.,	AC	8-18	99	38	14	A-6(10)	ML-CL	100	20
Kansas (No. 1)	C	18-60	100	35	10	A-6(8)	ML-CL	101	21
Min.Ulysses S.L.	A_1	0-8	98	35	12	A-6(9)	ML-CL	100	18
BPR Logan Co.,	AC	8-19	98	38	13	A-6(9)	ML-CL	98	21
Kansas (No. 2)	C	19-60	100	32	7	A-4(8)	ML-CL	102	20
Ulysses S.L.	A_1	2-9	79	33	11	A-6(8)	CL	103	19
Ford County,	AC	9-17	74	36	13	A-6(9)	ML-CL	102	20
Kansas (No. 1)	C_{cal}	17-38	83	34	13	A-6(9)	CL	105	18
Ulysses S.L.	A_1	0-8	77	34	13	A-6(9)	CL	103	18
Ford County,	AC	8-15	80	35	12	A-6(9)	ML-CL	101	20
Kansas (No. 2)	C_{cal}	15-44	76	32	11	A-6(9)	CL	104	18
Mod.Ulysses S.L.	A_1	0-6	93	40	16	A-6(10)	ML-CL	97	23
Morton County,	B_2	6-15	96	50	27	A-7-6(12)	CL	97	21
Kansas (No. 1)	C_1	32-54	97	43	19	A-7-6(12)	CL	97	19
Mod.Ulysses S.L.	A_1	0-7	93	35	19	A-6(12)	CL	103	18
Morton County,	B_2	7-19	98	45	21	A-7-6(13)	CL	100	22
Kansas (No. 2)	C_1	34-54	99	42	18	A-7-6(12)	ML-CL	101	21
Mod.Ulysses S.L.	A_1	0-10	82	30	9	A-4(8)	ML-CL		
Beaver County,	A_c	10-50	88	39	17	A-6(11)	CL		
Oklahoma (No. 1)	C_{ca}	50-65	85	40	19	A-6(12)	CL		
Ulysses S.L.	A_1	0-9	91	39	14	A-6(10)	ML-CL		
Beaver County,	B_2	9-28	97	51	24	A-7-6(6)	MH-CH		
Oklahoma (No. 2) clayey subsoil	C_{ca}	28-40	93	45	20	A-7-6(13)	ML-CL		

1/ All data, except from Logan County, from Bureau of Public Roads (13, 9, 14, 6).

loam were compared with previous data to determine the effect of texture upon engineering properties and classification. It should be recalled, however, that the textural name applies only to the surface horizon. It was found that the sandy type profile reflects low plasticity throughout its depth.

The loam type Keith profiles, all collected in the same Nebraska county, represent minimal, modal, and maximal development. Increasing degree of development in the form of a textural B horizon is seen in the AASHO classification of these profiles. In each case the A and C horizons had a nonplastic A-4 designation, but the B horizons progressed from A-4 to A-7, from nonplastic to highly plastic. It is probable that high permeability of the loamy surface layers coupled with possible differences in precipitation and age are responsible for the clear-cut differences in this type of Keith.

A compilation of selected properties and classification of the 17 Keith profile types discussed is given in Table 5.

BPR data are available from ten locations for comparison of Richfield soils. It may be seen that, with few exceptions, Richfield horizons follow a pattern of AASHO classification in Kansas, Colorado, and Oklahoma. This pattern showed the surface horizon to have the less plastic A-4 designation while the B and C horizons may be either A-6 or A-7. It might be expected from the amount and type of development that Richfield soils have heavy-textured, more plastic B horizons, but it is somewhat surprising that the C horizons also showed this tendency whereas the C horizons of Keith and Ulysses soils many times had A-4 designations on

Table 5. Comparison of properties and classification of Keith silt loam soils in various locations.1/

Location	Horizon	Depth	% Passing #200 Sieve	Liquid Limit	Plasticity Index	Engineering Class: AASHO	Engineering Class: Unified	Max. Dry Density (lb/ft^3)	Optimum Moisture Cont. (%)
Min. Keith	A_{1p} & A_1	0-8	99	35	14	A-6(10)	CL-ML		
Logan County,	B_2	11-15	99	36	15	A-6(10)	CL-ML		
Kansas	B_3	15-34	99	39	16	A-6(10)	CL-ML		
Mod. Keith	A_{1p1}, A_{1p2}, A_1	0-11	99	35	11	A-6(8)	CL-ML		
Logan County,	B_{21}	16-22	99	39	19	A-6(12)	CL-ML	101	21
Kansas	B_{2ca}	32-42	99	39	19	A-6(12)	CL-ML	102	21
Max. Keith	A_1	0-9	99	36	14	A-6(10)	CL-ML		
Logan County,	B_2	17-27	99	39	19	A-6(12)	CL-ML		
Kansas	B_{3b1}	27-42	99	39	18	A-6(11)	CL-ML		
Mod. Keith	A_p & A_1	0-11	98	37	12	A-6(9)	ML-CL	97	20
BPR Logan Co.,	B_{21}	15-24	99	40	19	A-6(12)	CL	101	19
Kansas (No. 1)	B_{22}	24-33	99	40	17	A-6(11)	CL	99	21
	C	61-76	97	32	8	A-4(8)	ML-CL	102	20
Mod. Keith	A_p & A_1	0-11	98	37	14	A-6(10)	ML-CL	99	20
BPR Logan Co.,	B_{21}	16-22	99	38	16	A-6(10)	CL	101	19
Kansas (No. 2)	B_{22}	22-32	99	38	15	A-6(10)	ML-CL	102	18
	C	53-70	98	32	9	A-4(8)	ML-CL	103	18
Keith-like S.L.	A_p	0-7	86	33	11	A-6(8)	ML-CL		
Sharon County,	B_{23}	19-25	89	34	12	A-6(9)	ML-CL		
South Dakota	C_{ca}	48-65	72	27	6	A-4(7)	ML-CL		
Mod. Keith S.L.	A_{11} & A_{12}	0-8	90	34	10	A-4(8)		100	20
High Alluv. Terr.	B_2	8-19	89	34	11	A-6(8)		104	19
Goshen County	C_1 or C_{ca} & C	36-60	93	34	10	A-4(8)		100	22
Mod. Keith S.L.	A_{1p} & A_{12}	0-9	97	31	8	A-4(8)	ML-CL	104	18
Hitchcock County	B_{21} & B_{22}	9-23	98	37	16	A-6(10)	CL	105	18
Nebraska (No. 1)	C_{ca} & C	33-60	98	29	7	A-4(8)	ML-CL	107	18
Keith S.L.	A_{1p} & A_{12}	0-14	97	30	10	A-4(8)	CL	107	17
Hitchcock County,	B_{21} & B_{22}	14-27	96	42	22	A-7-6(13)	CL	102	21
Nebraska (No. 2)	C_{ca}	33-60	97	28	6	A-4(8)	ML-CL	109	17
heavy subsoil									
Modal Keith S.L.	A_{1p}	0-6	91	30	8	A-4(8)	ML-CL	108	17
Deuel County,	B_{21}	6-12	90	38	17	A-6(11)	CL	106	18
Nebraska (No. 1)	C_{ca}	24-34	90	30	8	A-4(8)	ML-CL	110	17
Mod. Keith S.L.	A_{1p}	0-6	88	28	6	A-4(8)	ML-CL	109	16
Deuel County,	B_{21}	6.11	89	34	11	A-6(8)	ML-CL	107	18
Nebraska (No. 2)	C_{ca}	23-35	88	30	6	A-4(8)	ML-CL	109	17
Max. Keith S.L.	A_{1p}	0-8	84	28	5	A-4(8)	ML-CL	109	16
Deuel County,	B_{21}	13-20	91	41	16	A-7-6(11)	ML-CL	101	21
Nebraska (No. 3)	C_{ca}	30-48	92	30	5	A-4(8)	ML	107	18
Min. Keith S.L.	A_{1p}	0-6	89	30	5	A-4(8)	ML	106	17
Deuel County,	B_2	6.12	88	35	12	A-6(9)	ML-CL	107	18
Nebraska (No. 4)	C_{ca}	12-36	90	30	7	A-4(8)	ML-CL	108	17
Keith Sandy Loam	A_p	0-5	42	21	3	A-4(1)	SM	118	13
Dundy County, Neb.	B_2	10-18	57	27	6	A-4(4)	ML-CL	115	14
(Loess-like Tertiary material)	C_b	42-60	79	27	5	A-4(8)	ML-CL	111	16
Min. Keith Loam	A_{1p}	0-6	80	30	10	A-4(8)	CL	108	16
Kimball County,	B_{21}	11-17	93	41	17	A-7-6(11)	ML-CL	100	21
Nebraska (No. 1)	C_3	41-55	89	26	4	A-4(8)	ML-CL	106	17
Mod. Keith Loam	A_{1p}	0-6	78	30	9	A-4(8)	ML-CL	108	17
Kimball County,	B_{21}	8-14	89	47	24	A-7-6(15)	CL	97	21
Nebraska (No. 2)	C_{ca}	20-29	92	32	8	A-4(8)	ML-CL	103	20
Max. Keith Loam	A_{1p}	0-5	40	22	5	A-4(1)	SM-SC	120	11
Kimball County,	B_{21}	9-14	48	28	10	A-4(3)	SC	114	14
Nebraska (No. 3)	C_2	34-59	46	23	5	A-4(2)	SM-SC	119	13

1/ All data, except from Logan County, from Bureau of Public Roads (13, 16, 10, 11, 7, 8, 12).

similar loessial parent material.

There were three exceptions to the A-4 classification of the A horizon. These results on profile No. 2 from Beaver County, Oklahoma may be explained by the clay loam textural type. They may be explained for profile No. 3 from Prowers County, Colorado, by the presence of a buried B horizon. The B horizon was found to be A-7; and the more plastic properties and classification of the A horizon was probably due to development of this horizon in material which was the textural B horizon of a fossil soil. The A-6 designation of the surface layer in profile No. 2 from Morton County, Kansas, while designated as silt loam type, is probably also due to a buried layer or to an inclusion of a small area of a clayey type of profile within a more prevalent area of silt loam types.

Two exceptions to the plastic designations for C horizons were found. In samples No. 1 and 2 from Prowers, County, Colorado, the lower-most horizons were found to be A-4 types. In both cases, however, the general trend of less plastic surfaces with more plastic B horizon classification was followed.

It was observed that profile No. 1 from Beaver County, Oklahoma, while also designated as clay loam type, exhibited silty A horizon characteristics whereas sample No. 2 reflected its clayey type in its A-6 classification.

A listing of selected properties and classifications for eleven Richfield profiles is given in Table 6.

Table 6. Comparison of properties and classification of Richfield soils in various locations.1/

Location	Horizon	Depth	% Passing #200 sieve	Liquid Limit	Plasticity Index	Engineering Class AASHO	Engineering Class Unified	Max. Dry Density (lb/ft^3)	Optimum Moisture Cont. (%)
Richfield Logan County, Kansas	A_p	0-5	99	31	10	A-4(8)	CL-ML		
	B_{21} & B_{22}	5-18	99	37	15	A-6(10)	CL-ML		
	C_{ca}	27-36	99	38	16	A-6(10)	CL-ML		
Richfield Ford County Kansas (No. 1)	A_p	0-5	97	32	10	A-4(8)	ML-CL	103	19
	B_{22}	11-18	97	45	24	A-7-6(15)	CL	100	18
	C_{ca}	23-43	96	41	18	A-7-6(11)	CL	100	20
Richfield Ford County Kansas (No. 2)	A_p	0-4	82	28	8	A-4(8)	CL	108	16
	B_{22}	9-15	95	42	19	A-7-6(12)	CL	100	20
	C_{ca}	21-40	94	38	18	A-6(11)	CL	103	21
Richfield Morton County, Kansas (No. 1)	A_{12}	3-8	89	29	9	A-4(8)	CL	106	16
	B_2	8-16	94	48	23	A-7-6(15)	CL	95	24
	B_{3ca}	16-28	99	43	18	A-7-6(12)	ML-CL	98	21
	C_1	35-62	99	43	18	A-7-6(12)	ML-CL	97	21
Richfield Morton County, Kansas (No. 2)	A_{1p}	0-5	95	34	11	A-6(8)	ML-CL	101	18
	B_2	5-14	98	54	29	A-7-6(18)	CH	99	23
	B_{3ca}	14-25	99	47	24	A-7-6(15)	CL	97	21
	C_1	34-56	99	44	19	A-7-6(12)	ML-CL	100	21
Mod. Richfield Prowers County, Colo. (No. 1)	A_p	0-3	97	31	9	A-4(8)	ML-CL		
	B_{21}	6-15	96	36	15	A-6(10)	CL		
	C_3	57-116	98	32	9	A-4(8)	ML-CL		
Mod. Richfield Prowers County, Colo. (No. 2)	A_p	0-4	92	30	8	A-4(8)	ML-CL		
	B_{21}	7-12	96	42	18	A-7-6(12)	ML-CL		
	C_3	49-70	98	33	9	A-4(8)	ML-CL		
Richfield Prowers County, Colo. (No. 3) (buried B horizon)	A_p	0-4	90	34	14	A-6(10)	CL		
	B_{21}	6-15	96	48	24	A-7-6(15)	CL		
	C	38-64	98	42	19	A-7-6(12)	CL		
Richfield Prowers County, Colo. (No. 4) light textured B_2	A_p	0-6	94	30	9	A-4(8)	ML-CL		
	B_{21}	8-17	96	42	18	A-7-6(12)	ML-CL		
	C	38-60	97	34	11	A-6(8)	ML-CL		
Richfield clay loam Beaver County Oklahoma (No. 1)	A_1	0-10	77	29	8	A-4(8)	ML-CL		
	B_2	10-20	91	48	23	A-7-6(16)	CL		
	C	42-72	82	40	17	A-6(11)	CL		
Richfield clay loam Beaver County, Oklahoma (No. 2) Modal, Calc. loess	A_p	0-10	97	35	14	A-6(10)	CL		
	B_2	10-50	98	53	25	A-7-6(17)	MH-CH		
	C_{ca}	50-65	96	49	25	A-7-6(16)	CL		

1/ All data, except from Logan County, from Bureau of Public Roads (9, 10, 15, 6).

Optimum Moisture Content and Maximum Dry Density

The optimum moisture content for maximum density was determined for seven of the previously studied soils mapped in Logan County, but only one or two samples incorporating the most important horizons were sampled. These data were determined primarily for practical construction use in the following section, but have been listed in previously cited tables. They will be compared with maximum dry density (standard AASHO method) predicted by tables in Federal Housing Administration Bulletin No. 373 (23) and will be briefly compared with BPR data for Bridgeport, Keith, and Ulysses series.

Both samples of Keith and Ulysses series (modal), and the Bridgeport sample had nearly the same OMC and MDD. The values found for MDD are just midway between the allowable predicted values for ML-CL soils. The Colby sample exhibited a MDD value near the upper allowable limit for a ML-CL soil. This soil had an OMC a little lower than the other ML-CL soils, but the MDD was substantially higher. The reason for this was possibly due to the very high calcium carbonate content, which acts to fill in voids.

Dwyer soil exhibited a relatively large MDD and a very low OMC as would be expected with a sandy soil (SP-SM). Promise clay showed a MDD near the upper limit allowable for CH soils, with correspondingly high OMC.

The two Lofton samples, although of differing Unified classifications, exhibited very similar values for both MCC and OMC.

The upper Lofton sample and the Promise sample, both CH soils, had identical OMC values but the MDD value for Promise was greater by 10 lb/ft^3. It is possible the high gypsum content of this soil served the same function as the calcium carbonate in the Colby C horizon.

A summary of moisture-density data for the soils of this study is given in Table 7. BPR data for moisture-density relations are available for the following soils of this study: Bridgeport, Ulysses, and Keith. These data are shown in Tables 3, 4, and 5 respectively.

The Bridgeport soil showed much less MDD and slightly higher OMC than any of the BPR samples. The reason for this deviation cannot be explained on the basis of only one sample from the study area.

The two samples of modal Ulysses from the study area corresponded very well with both MDD and OMC values of Ulysses from other locations.

The two samples of modal Keith from Logan County, Kansas, exhibited values for MDD and OMC very similar to those of other Keith silt loam profiles found in other locations.

Summary of Results and Conclusions

For all three horizons of the fourteen soil profiles of this study it was generally found that the USDA textural type assigned as a result of laboratory analysis or by field "feel methods" closely agreed with the mechanical analyses of this study.

Several chemical tests were performed upon each of the

Table 7. Optimum moisture content for compacting to maximum dry density for selected soils and depths of Logan County, Kansas soils.

Soil	Depth	Determined Standard AASHO Unit Dry Weight (lb/ft^3)	Optimum Moisture Content (%)	Unified Classi-fication	Predicted Standard AASHO Unit Dry Weight (lb/ft^3)
Modal Ulysses	7-14	101	22	ML-CL	85-120
Modal Ulysses	20-50	102	21	ML-CL	85-120
Modal Keith	17-41	101	21	ML-CL	85-120
Modal Keith	41-55	103	21	ML-CL	85-120
Lofton	12-30	94	26	CH	75-105
Lofton	40-60	96	24	CL	90-120
Bridgeport	20-46	101	20	ML-CL	85-120
Dwyer	5-40	111	8	SP-SM	100-125
Colby	20-50	112	17	ML-CL	85-120
Promise	8-22	104	26	CH	75-105

horizons but no correlation with these results and with engineering properties and classification was apparent, with the possible exception of the effect of organic matter content upon liquid and plastic limit and the resulting classification.

As explained previously, the AASHO classification system results were used, for the purpose of this study, to detect significant engineering property differences between and within profiles. It was found that the three coarse-grained, or sandy soils showed great variation in engineering properties both within and among profiles. This is due primarily to the segregation and layering by wind and water as the coarse parent materials were laid down, but also to the effects of soil genesis and accumulation, removal, transformation, and addition upon sandy materials.

In the more detailed study of Ulysses and Keith silt loam of various degrees of development it was found that very little difference existed between or within any horizon of either series. Only in the surface and C horizons of minimal and modal Ulysses were less plastic properties noted. There were no detected differences within or among Keith profiles.

Results of the characterization of the other loessial series, Colby and Richfield, as well as of the alluvial Bridgeport, revealed close similarity among series and similarity to both Ulysses and Keith. Close correlation was found between the clayey nature and the classification of Promise and Lofton series.

As a result of data obtained, for the county under study it was concluded that the basic nature of pedologic classification was reaffirmed in the light of present classification methods to meet engineering needs. On the basis of the somewhat limited data, it would appear that all the tested loessial profiles were of a quite similar engineering character. It was further concluded that areas designated as either Keith or Ulysses on the soil survey map need not be further delineated as to degree of development. It is assumed that the same would be true of the other loessial soils.

Even though differences existed in surface and C horizons of minimal and modal Ulysses profiles, the difference in the surface is not considered to be important since this layer is thin and of little real importance in construction and is often discarded or buried beneath deeper layer. More study is needed to reach definite conclusions about the importance of the difference between BC and C horizons of modal and minimal Ulysses and C horizons of other loessial horizons.

It may be assumed that other profiles of Lofton and Promise series would not greatly differ from the results of this study. It is stressed that the classifications of the three sandy series may serve as a guide to engineering properties only, for their variability within profiles suggests that their properties may extend over a range just as depths and thicknesses of horizons were found to vary somewhat in field mapping operations.

Moisture-density value determinations for selected horizons of selected soils of the study area showed maximum dry density values within the ranges allowable for their Unified classification. MDD and OMC values obtained in other locations agreed closely with the results of this study, but values for Bridgeport in the study did not agree with the mean found in other areas because of the basic nature of the soil.

SOIL ENGINEERING GUIDE FOR LOGAN COUNTY, KANSAS

General Information and Geography

Logan County is located along the Smoky Hill River breaks in western Kansas, and is in the third tier of counties south of the north border of Kansas and is the second county east of the west border, as shown in the location map, Figure 1. Logan County contains 30 townships from T. 11 S. to T. 15 S., and from R. 32 W. to R. 37 W., and has an area of 1,073 square miles. The county is made up of two natural physiographic areas according to Fly (27). The rough broken lands along the Smoky Hill River and Butte Creek are parts of the area known as the "West Kansas Breaks and Canyon Section of the Breaks and Loess-Bedrock Plains". The smooth, nearly level area of deep soils along the northeast part of the county and in the southwest corner are a part of the "Moist Semi-arid Hardlands Section of the Colorado-Kansas Central High Plains".

According to Fenneman (25), most of Logan County is in the High Plains section of the Great Plains province, but the eastern part falls within the Plains Border section of the same province.

The topography of the county little resembles the flat, almost featureless plains characteristic of the counties adjacent on the north and south. According to Eikleberry, et al (22) the county is characterized by gently rolling divides with steeply sloping topography adjacent to the smaller drainageways. Near the Smoky

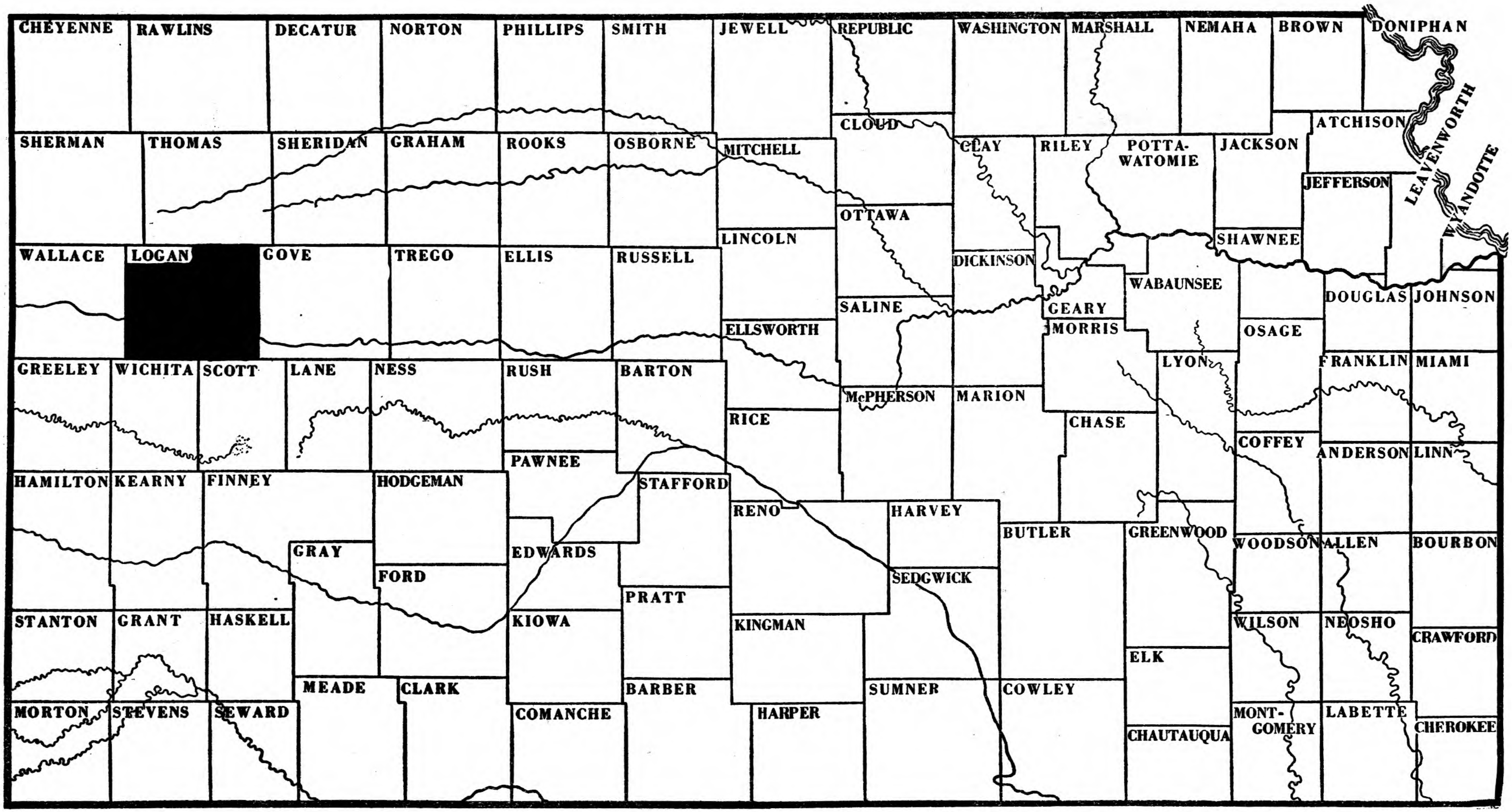


Figure 1. Location map of Logan County, Kansas

Hill River and along its larger tributaries, the slopes are quite steep and the topography is rough and broken. The soils of the upland areas are formed from the weathering of aeolian silts, or loess. The soils along the steep slopes and rough areas are derived chiefly from the weathering of outwash silts and clays from the Ogallala and Pierre formations and from chalk from the Smoky Hill member of the Niobrara formation.

The largest streams in the county are the Smoky Hill River and its tributaries: Chalk, Twin Butte, Hackberry, and Turtle Creeks, and the North Fork of the Smoky Hill River. All streams flow eastward and southeastward at gradients ranging from 14 to 24 feet per mile according to Johnson (36).

The upland plain area, constituting about 35 per cent of the total area of the county, is underlain by Tertiary rocks and slopes slightly south of east from a maximum altitude in Logan County of 3,550 feet to a minimum of 3,000 feet. It includes an area in the northern part of the county that is 15 miles wide at the northeastern corner and tapers to a few miles wide at the northwestern corner of the county. Smaller segments of the upland plain comprise the far southern corner of the county, between Butte and Chalk Creeks, and a narrow strip along the southern border of the county.

River flood plains have a small area in Logan County, most of which are along the Smoky Hill River. Intermediate between the flood plain and the upland plain, dissected surfaces slope gradually to the main valley. Minor tributaries separated from one another by steep valley slopes and rolling divides form belts which are wider on the north side of the Smoky Hill River and Chalk and Twin Butte Creeks than on the south side of these streams.

Cliffs, buttes, and deep, narrow canyons have been cut from rock exposures of Cretaceous chalk of the Niobrara formation along Smoky Hill Valley slopes. In the southeastern corner similar erosion has taken place in the cemented beds of the Ogallala formation.

According to Johnson (36) the average discharge of the Smoky Hill River at Elkader is 57.3 cubic feet per second for the 13 years of record, 1939 to 1952. Maximum discharge during this time was 19,700 cfs on June 11, 1951. During prolonged hot, dry periods there is often very little or no flow in the channel.

Johnson(36), quoting the 1950 U. S. Census, stated that Logan County had a population of 4,206; with 2,731 living in the seven towns of the county. The population density was 3.9 inhabitants per square mile, compared with an average of 24.4 for the state.

The main highways, county roads, streams, and towns of the county are shown in Figure 2, while in Figure 3 is presented a block diagram showing relative relief and drainage.

Climate

The climate of Logan County is semiarid and characterized by abundant sunshine, moderate to low precipitation, considerable wind, low humidity and a high rate of evaporation. Eikleberry, et al (22) quoting U. S. Weather Bureau records stated the mean annual temperature was 54 degrees, absolute maximum was 111 degrees, the absolute minimum was -24 degrees. The mean annual

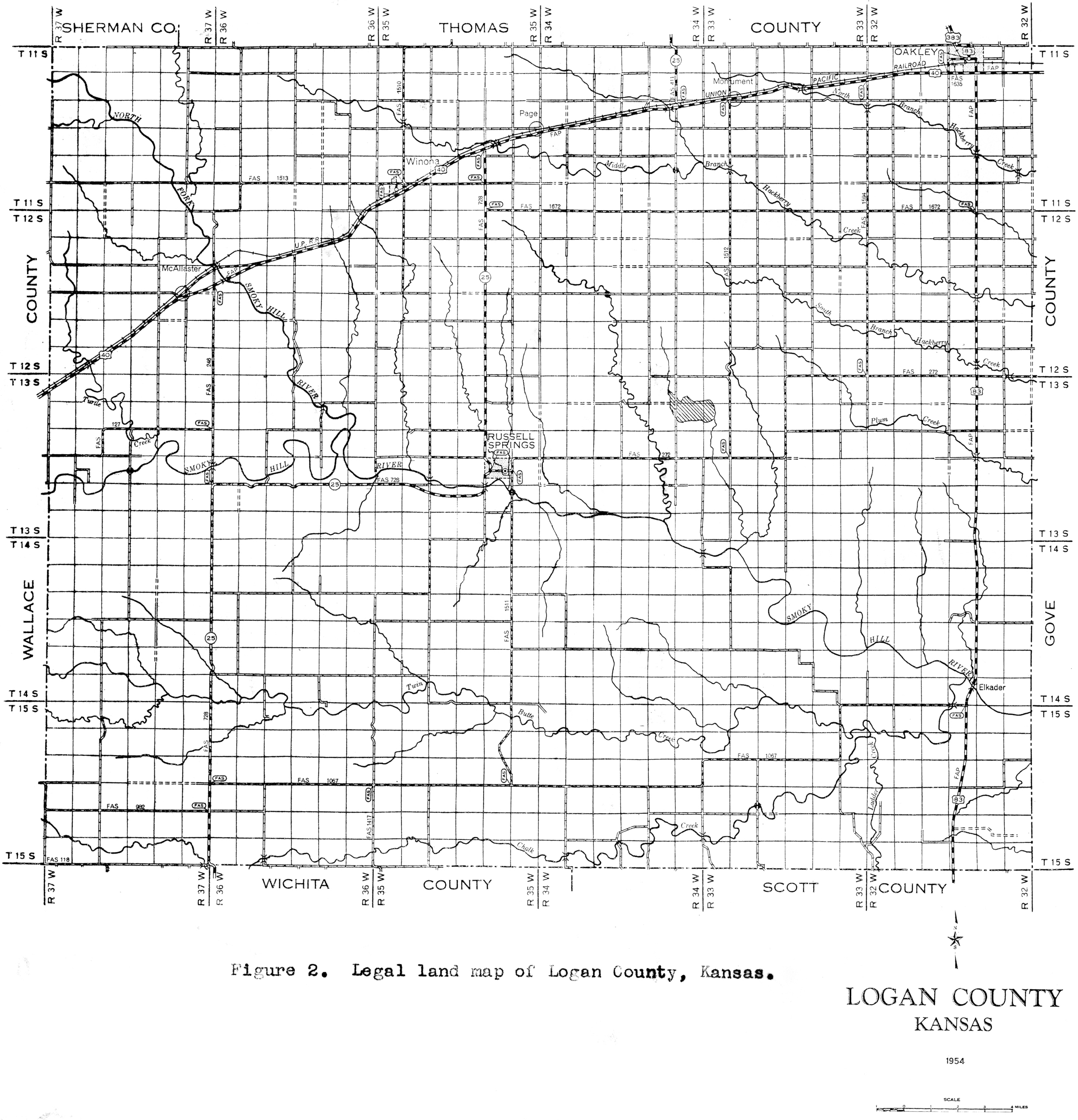


Figure 2. Legal land map of Logan County, Kansas.

LOGAN COUNTY
KANSAS

1954

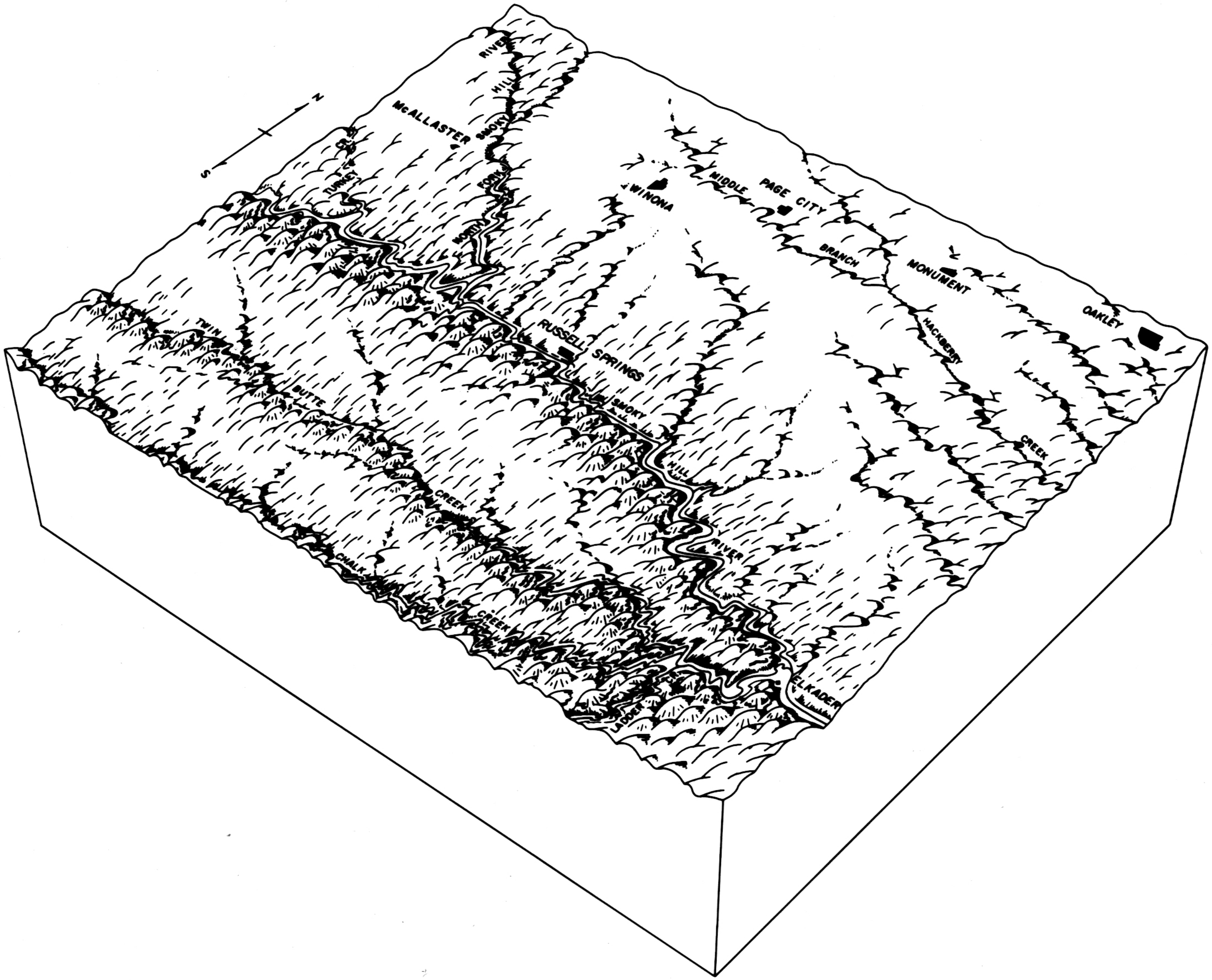


FIGURE 3. TOPOGRAPHY AND DRAINAGE SKETCH OF LOGAN COUNTY (4)

5,P-16,154

precipitation was 19 inches, varying from a maximum of 12 inches to a minimum of 3.3 inches. Seventy-six per cent of the precipitation comes during the average 164 day frost-free period from May through September.

Weather stations in Logan County and type of measurements made are as follows:

Oakley	Precipitation and temperature
Winona	Precipitation
Russel Springs	Precipitation and temperature
Elkader	Precipitation

Climate information of greatest use to engineers includes monthly and annual means of temperature and precipitation and freeze data. These are given for two stations, Oakley in Logan County and Leoti in Wichita County in Tables 8 and 9, from data by Robb (45). The only data available in Logan County are from Oakley. Leoti data are given as being more representative of the climate in southwestern and southern Logan County. Wichita County adjoins Logan County on the south.

Information regarding rainfall intensity, duration, and frequency, of value to conservation and hydrologic engineers, is unavailable for Logan County. However, Flora (26) has stated that the greatest amount of precipitation in 24 hours at Oakley for years of record 1920 to 1945 was 4.52 inches on April 17-18, 1942.

Geology

The rocks exposed in Logan County range in age from Late Cretaceous to Recent. The oldest rocks, occurring in the eastern and central parts of the county along the valley of the Smoky Hill

Table 8. Temperature and precipitation data for Leoti, Wichita County, Kansas, and Oakley, Logan County, Kansas (averages for period 1931-1955. (45)

Month	Leoti, Kansas		Oakley, Kansas	
	Temperature	Precipitation	Temperature	Precipitation
January	29.9	.43	30.5	.54
February	34.0	.45	34.3	.55
March	40.4	.95	40.8	1.29
April	51.7	1.87	52.2	2.09
May	61.3	2.87	61.4	2.93
June	72.1	3.08	72.1	3.49
July	78.5	2.28	78.7	3.10
August	76.8	2.34	77.2	2.45
September	68.3	1.14	68.7	1.42
October	55.8	.95	56.8	1.10
November	40.5	.66	41.5	.67
December	32.31	.42	31.1	.53
Annual Mean	53.5	17.44	53.9	20.16

Table 9. Freeze data for Leoti (Wichita County) and Oakley (Logan County), Kansas.

Town	Freeze Threshold Temperature	Mean Date of Last Spring Frost	Mean Date of First Fall Frost	Mean Days Between Dates	Years of Record--Spring	Number of Occurrences in Spring	Years of Record--Fall	Number of Occurrences in Fall
Leoti	32	05-03	10-07	157	29	29	29	29
	28	04-24	10-18	179	29	29	30	30
	24	04-09	10-27	201	29	29	30	30
	20	04-02	11-04	216	29	29	30	30
	16	03-26	11-12	230	27	27	30	30
Oakley	32	05-05	10-11	159	28	28	30	30
	28	04-19	10-20	184	29	29	29	29
	24	04-08	10-28	203	29	29	30	30
	20	03-31	11-07	221	29	29	30	30
	16	03-25	11-14	235	29	29	29	29

River, are of the Smoky Hill chalk member of the Niobrara formation. The Pierre shale overlies the Niobrara formation and its largest outcrop is in the western and northwestern parts of the county. The Ogallala formation, of Pliocene age, unconformably overlies the Pierre and Niobrara formations except in the Smoky Hill Valley, where it has entirely disappeared due to erosion. The Ogallala crops out over much of the county along stream valleys and at the edges of the upland plains. These plains in turn are mantled by loess of the Sandborn Group.

Colluvial deposits derived from loess and chalk are extensive on the steeper slopes in the Smoky Hill valley and its tributary valleys. Pleistocene sand and gravel also occur here. Small areas of dune sand and alluvium in Turtle Creek and Smoky Hill valleys are the youngest deposits in the county.

Although the oldest formation exposed in Logan County is the Niobrara, Johnson (36) stated that oil and gas test well logs revealed that this formation is underlain by older sedimentary rocks of Mesozoic and Paleozoic age, which in turn rest upon crystalline rocks of Precambrian age. Logs show that the county is underlain by at least 4,500 feet of Paleozoic sedimentary rocks.

During Early and Middle Cambrian time the county was above sea level, but with the coming of Late Cambrian time an interior sea advanced over the area, to persist through Ordovician time. Deposition of extensive calcareous sediments occurred through this submergence.

No rocks of Silurian or Devonian age are known to underlie the county, but during Early Mississippian time limestone and shale were deposited as they were during Pennsylvanian time. Alternating submergence and emergence during early Permian time was accompanied with deposition of rocks. Part of these Permian formations and any Triassic rocks were eroded away before deposition of Jurassic rocks. Marine conditions and depositions continued through Cretaceous time. During early Tertiary Period extensive uplift occurred in the Rocky Mountain area causing deposition on Logan County of complex beds of gravel, sand, silt, and clay.

These deposits filled old stream beds and spread across the divides. Early Pleistocene deposits consisted of silt and sandy clay along and above the present Smoky Hill Valley. Later Pleistocene deposits consisted of a thick mantle of wind-blown silt.

A graphic presentation of the more important geologic formations of the county has been given in Figure 4.

Soils

A total of 32 soil series or mapping units are found in Logan County. A complete listing of these, along with acreages and percentages is given in Table 10. Profile descriptions of the 14 soils studied extensively in this study are found at the end of this section. No detailed soil profile descriptions have been presented for the 22 soils recognized in Logan County which were not extensively studied.

With the description of the morphology of each series is found the exact legal description of the location where it was collected, and other pertinent data concerning range of

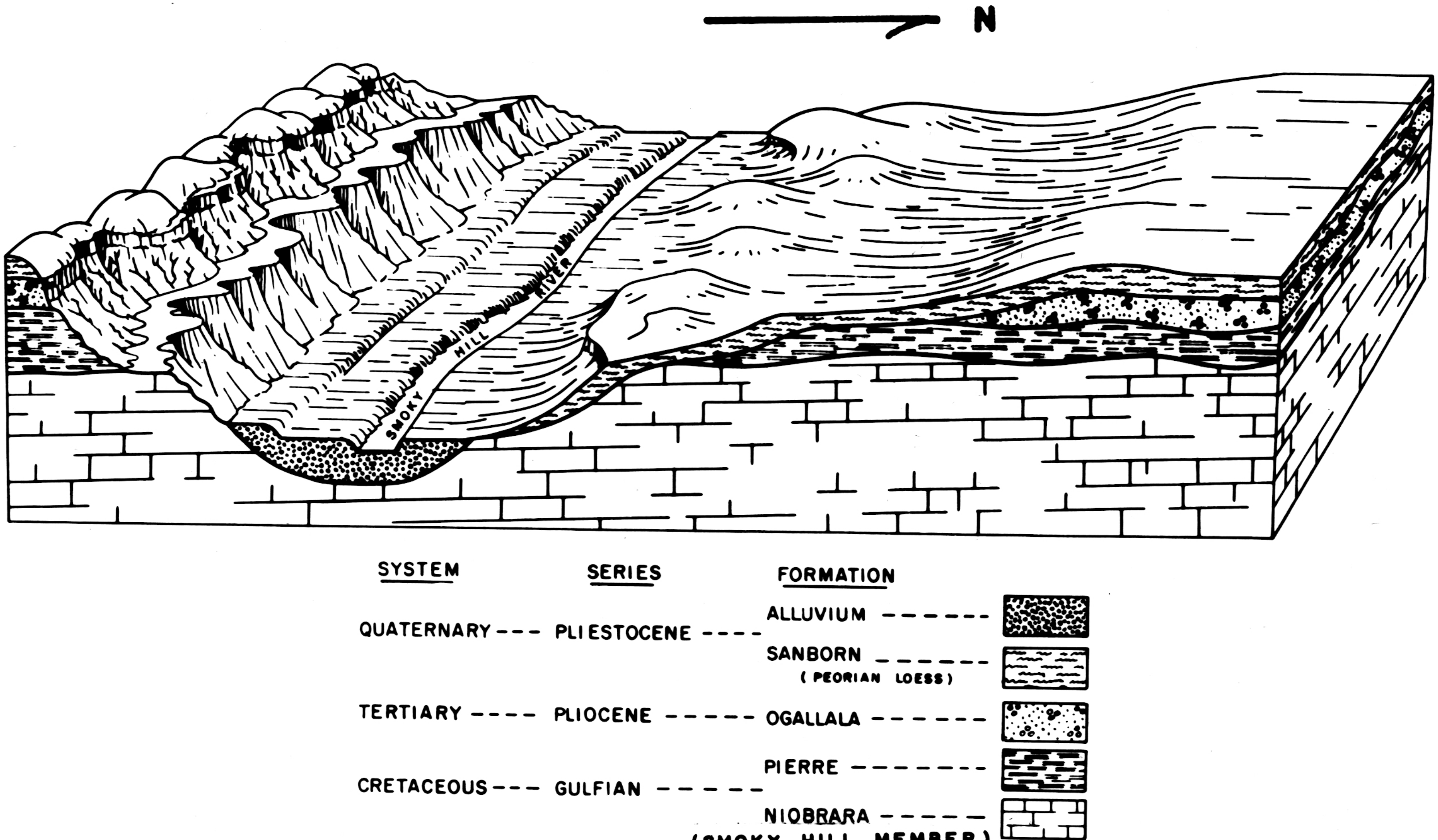


FIGURE 4. SCHEMATIC DIAGRAM OF THE MAJOR OUTCROPPING GEOLOGIC FORMATIONS OF LOGAN COUNTY THAT CONTRIBUTE PARENT MATERIAL FOR SOILS (4)

Table 10. Approximate acreage and proportionate extent of the soils mapped in Logan County, Kansas. (4)

Soil	Area Acres	Extent Per cent
Active dunes	124	(1)
Alluvial land	7,485	1.1
Berra silt loam	7,195	1.1
Bridgeport loam	11,941	1.7
Colby silt loam, 3 to 5 per cent slopes	1,509	.2
Colby silt loam, 5 to 12 per cent slopes	68,094	9.9
Dwyer loamy fine sand	1,464	.2
Elkader silt loam, 0 to 1 per cent slopes	1,179	.2
Elkader silt loam, 1 to 3 per cent slopes	5,053	.8
Elkader silt loam, 3 to 5 per cent slopes	8,652	1.3
Elkader silt loam, 5 to 12 per cent slopes	9,861	1.4
Gravelly broken land	3,398	.5
Keith silt loam, 0 to 1 per cent slopes	133,583	19.5
Keith silt loam, 1 to 3 per cent slopes	12,303	1.8
Las loam	2,282	.3
Las Animas sandy loam	2,054	.3
Likes loamy sand	541	(1)
Lincoln soils	2,360	.3
Lismas clay	10,673	1.6
Loamy broken land	10,121	1.5
Lofton silty clay loam	913	.1
Lubbock silt loam	1,393	.2
Manter fine sandy loam, 1 to 3 per cent slopes	1,097	.2
Manter fine sandy loam, 3 to 5 per cent slopes	509	(1)
Nio silt loam	16,775	2.5
Oelrichs silty clay loam	1,356	.2
Orman clay	1,005	.1
Otero fine sandy loam	3,539	.5
Potter soils	8,539	1.3
Promise clay, 1 to 3 per cent slopes	790	.1
Promise clay, 3 to 5 per cent slopes	533	(1)
Randall clay	1,088	.2
Richfield silt loam, 0 to 1 per cent slopes	11,313	1.6
Rough broken land, Nio material	2,151	.3
Sweetwater clay loam	263	(1)

(continued on next page)

Table 10. (continued)

Ulysses silt loam, 0 to 1 per cent slopes	97,193	14.2
Ulysses silt loam, 1 to 3 per cent slopes	148,072	21.6
Ulysses silt loam, 3 to 5 per cent slopes	43,954	6.4
Ulysses silt loam, 3 to 5 per cent slopes, eroded	8,380	1.2
Ulysses silt loam, 5 to 12 per cent slopes eroded	2,520	.4
Ulysses silt loam, 5 to 12 per cent slopes	25,924	3.8
Volin silt loam	3,677	.6
Volin-Solonetz Complex	329	(1)
Weskan silt loam	2,613	.4
Sub-total	683,798	99.60
Other areas, not mapped in detail	2,922	.4
Total	686,720	100.0

(1) Less than 0.1 per cent

characteristics, physiography of soil location, drainage, relation to other soils, and other facts. Figure 2 may be referred to when locating exact points of occurrence and sampling.

In order to help persons unfamiliar with the soils of Logan County to gain insight into their topography and relation to other soils, seven aerial photographs have been presented in Plates 1 through 7. These photographs have been taken directly from field mapping sheets prepared by the Soil Conservation Service and each shows two sections, 2 square miles (1,280 acres), at a scale of 4 inches per mile. The legal description and significance of each photograph, including symbols, is found for each photograph on its facing sheet.

For the ten soil series of this study 39 engineering factors and uses have been interpreted from determined properties and classification in Tables 11 through 14; pertaining to roads and airfields, embankments and foundations, agriculture engineering and conservation, and to disturbed soils at residentail building sites, respectively. It is felt that the column headings of the uses being evaluated are self-explanatory.

It is warned that the names of the soils given are not necessarily the correlated names, and these could be changed as more is learned about these soils in other areas. The names will become final with publication of the Logan County soil survey report or with final correlation by the Soil Conservation Service.

It is not intended that this report will eliminate the need for on-site sampling and testing for design, construction, and maintenance of specific engineering works. Rather, the interpretations in this guide and the soil survey report for Logan

County should be used primarily in planning more detailed field, and perhaps laboratory, investigations to determine the properties and characteristics of the soil at the proposed site of the engineering work.

Even in the case of soils with determined properties and classification, the information presented herein should be used only as a guide of general conditions and to aid the engineer in gaining knowledge of the general sorts of soils and soil properties with which he will be dealing.

Interpretations have been made for the various soils directly from the published guides and standards referred to in a previous section. In the case of estimating properties for disturbed soils at residential sites from the Unified classification one change has been made. Federal Housing Administration has used a numerical notation, 1 through 15, 1 being used for the group or groups considered most desirable, while higher numbers up to 15 indicate desirability decreasing with magnitude of the numbers. For the purposes of this guide, the FHA numbers have been divided into the following groups:

1-3	Excellent
4-6	Good
7-9	Fair
10-12	Poor
13-15	Very poor or not suitable (NS)

More specific information concerning any of the soils of Logan County may be found in the SCS soil survey report (4).

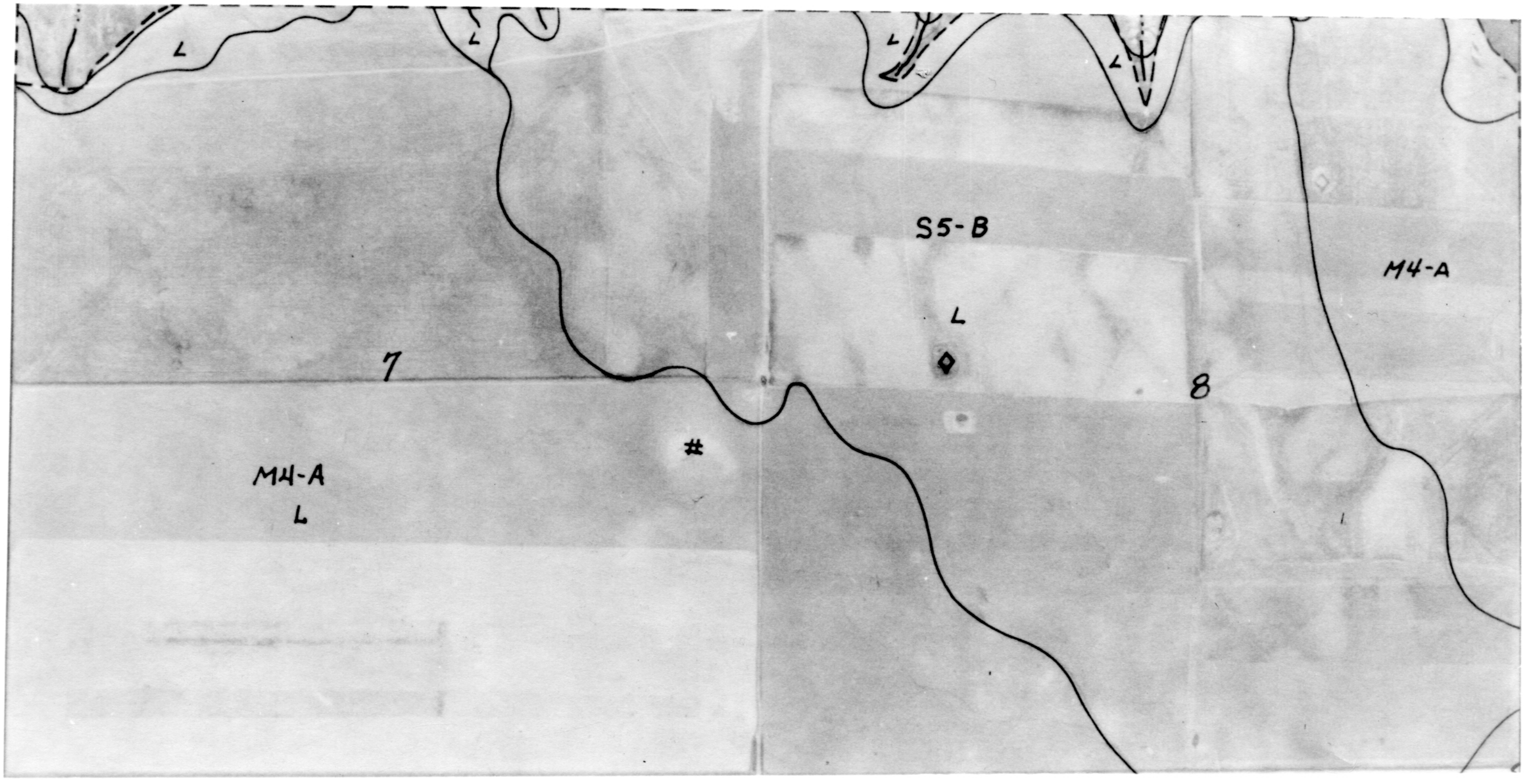
Figures 3 and 4, Table 10, and the seven following plates were provided by the Soil Conservation Service and full credit is due this agency for all drawing, mapping, photography, and calculations.

EXPLANATION OF PLATE I

Sections 7 and 8, T 14 S, R 36 W.

Keith silt loam, M-4, found on nearly level (0-1% slope) upland positions in this instance, found associated with Manter fine sandy loam, S5B, on long, narrow convex ridges which slope from 2½ to 3%.

PLATE I



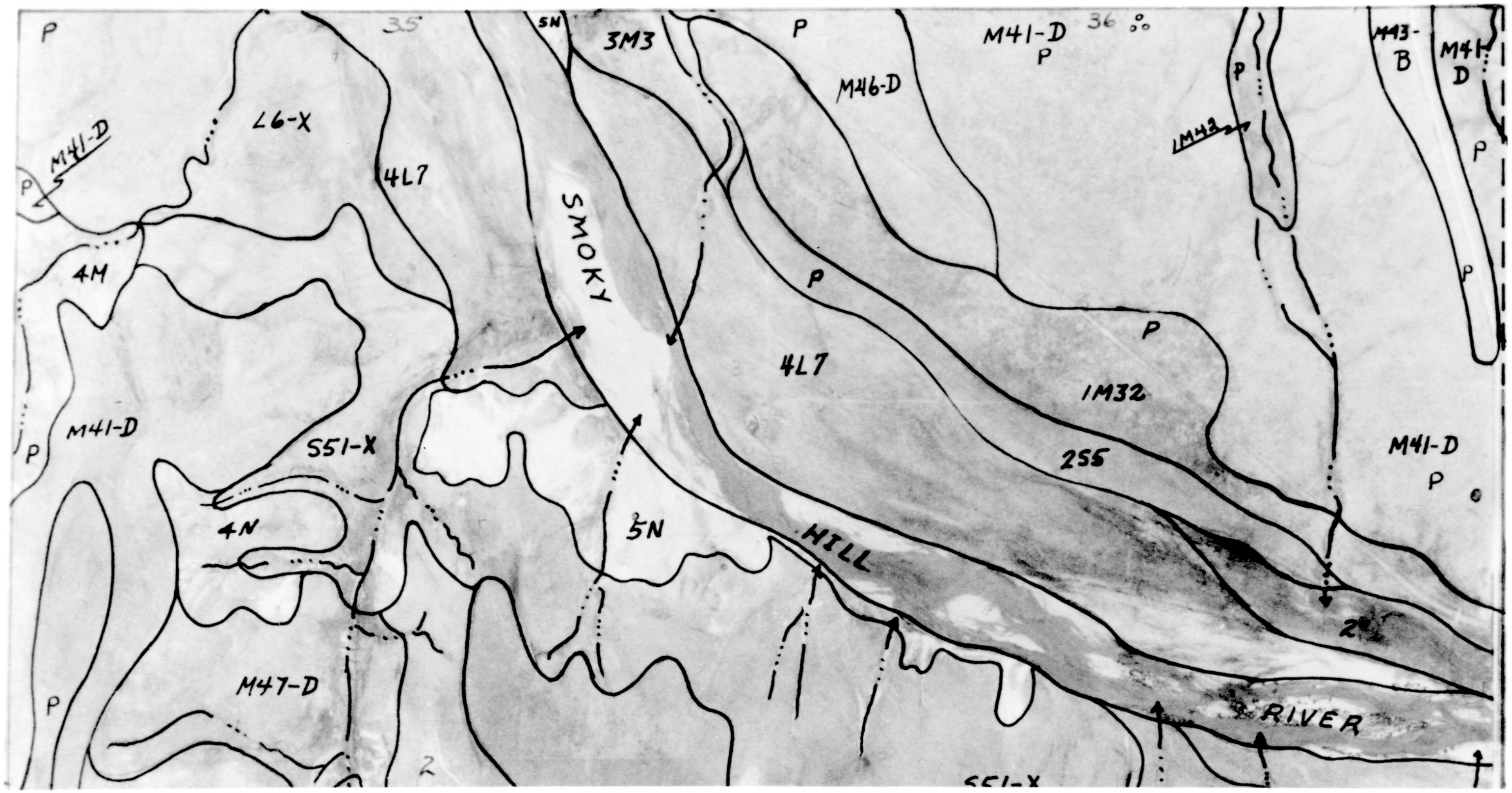
EXPLANATION OF PLATE II

S½ Sections 35 and 36, T 13 S, R 34 W, and
N½ Sections 1 and 2, T 14 S, R 34 W.

Dwyer loamy fine sand, L6-X, formed in wind reworked calcareous sand above the flood plain of the Smoky Hill River and extending to upland positions; associated with Colby silt loam, M41-D.

A band of Lincoln loamy sand, 4L7, is shown on the level flood plain adjacent to, and north of, the river. To the south of the river is seen a small area of Rough broken land, Nio material, 5N, consisting of deep canyons and steep bluffs eroded in Niobrara chalk, Smoky Hill member.

PLATE II



P
35
5N
3M3
P
M41-D
P
36
M43-B
M41-D
L6-X
M41-D
P
4L7
M46-D
1M43
P
SMOKY
4M
P
P
4L7
P
1M32
M41-D
P
S51-X
255
M41-D
P
4N
5N
HILL
M47-D
P
2
RIVER

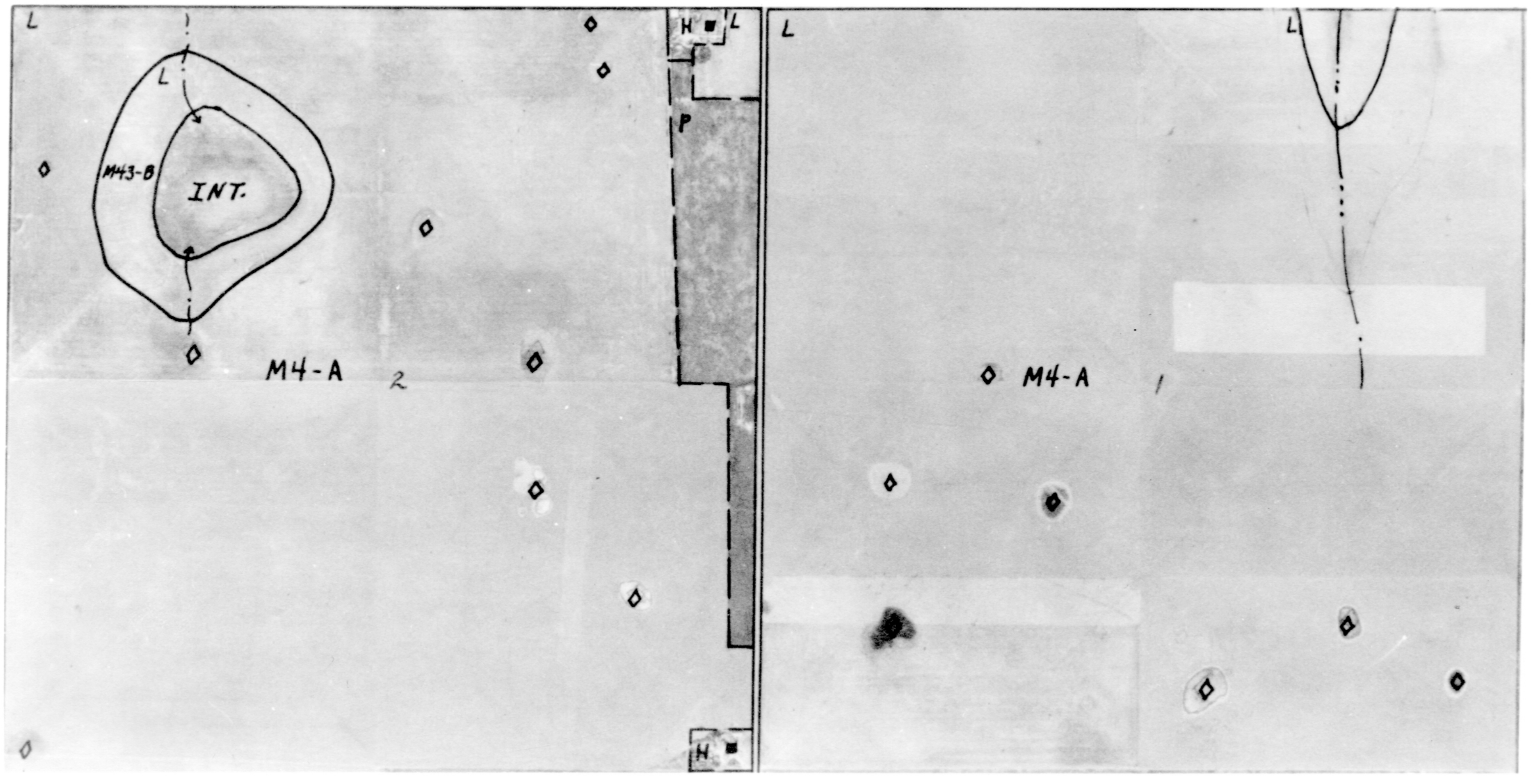
EXPLANATION OF PLATE III

Sections 1 and 2, T 12 S, R 34 W.

Nearly featureless expanses of Keith silt loam, M4-A, typical of northern portions of Logan County.

An approximately ten acre area of Lofton silty clay loam, Int. (intermittent lake), is shown surrounded by a slightly sloping band of Ulysses silt loam, M43-B. Smaller depressions of Lofton of less than five acres are indicated by diamonds.

PLATE III



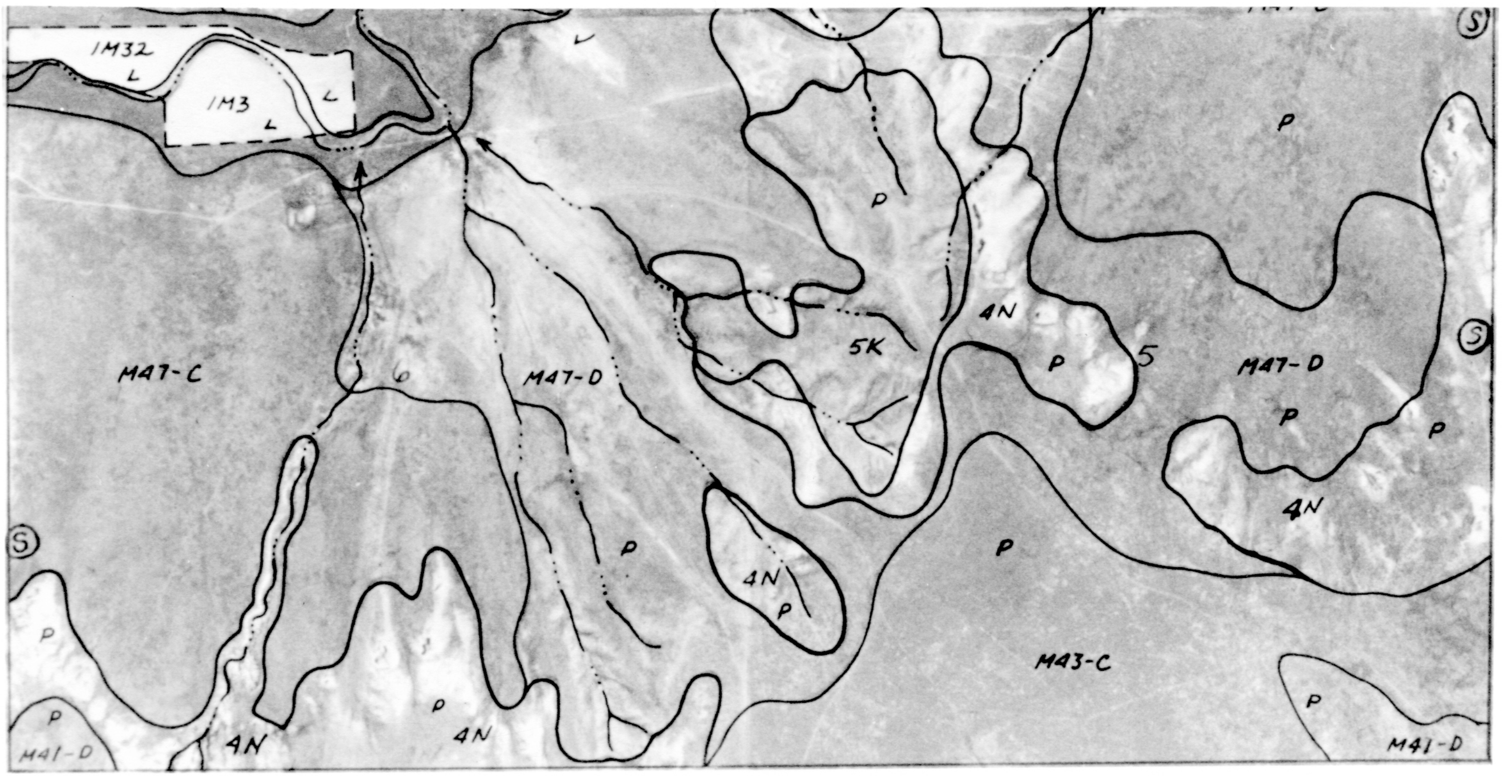
EXPLANATION OF PLATE IV

Sections 5 and 6, T 15 S, R 35 W.

Extensive areas of Berra silt loam, M47-C and M47-D, are shown formed on colluvial-alluvial slopes beloe Nio soils, 4N, and chalk outcrops.

An area of Lismas clay, 5K, is shown in typical position on narrow, steep drainageways cut into Pierre shale exposures.

PLATE IV



EXPLANATION OF PLATE V

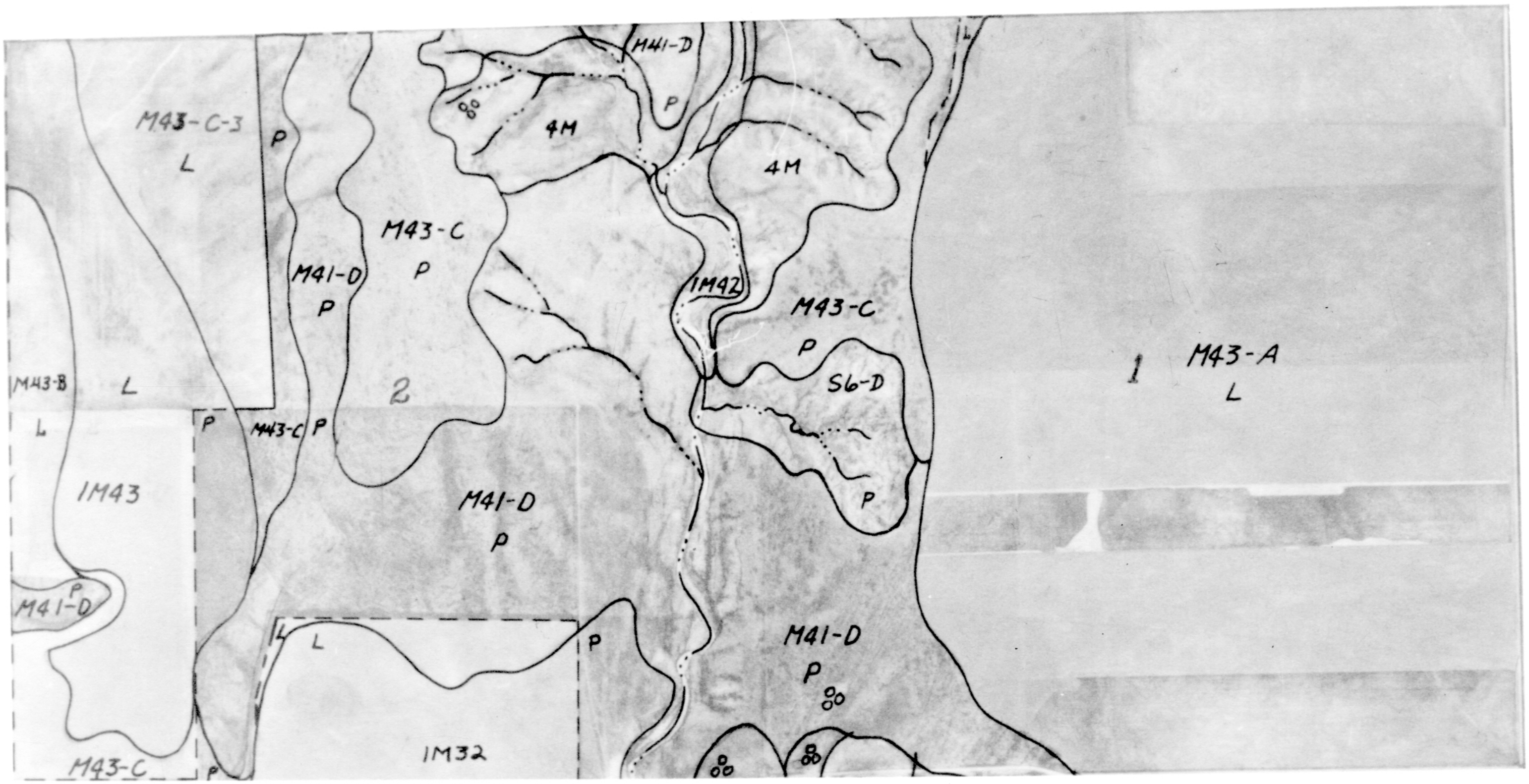
Sections 1 and 2, T 13 S, R 36 W.

A large level area of Ulysses silt loam is shown to the right, while to the left are associated areas of Ulysses on steeper slopes, M43-C and M43-C-3, and Colby, M41-D, slope to the Smoky Hill River, a short distance to the south.

Also in the steeper area are found Loamy broken land, 4M, and Gravelly broken land, S6-D, with the small drainage bottoms mapped as loamy Alluvial land, 1M42.

Bridgeport loam, 1M32, is shown mapped on a low terrace just north of the river channel.

PLATE V

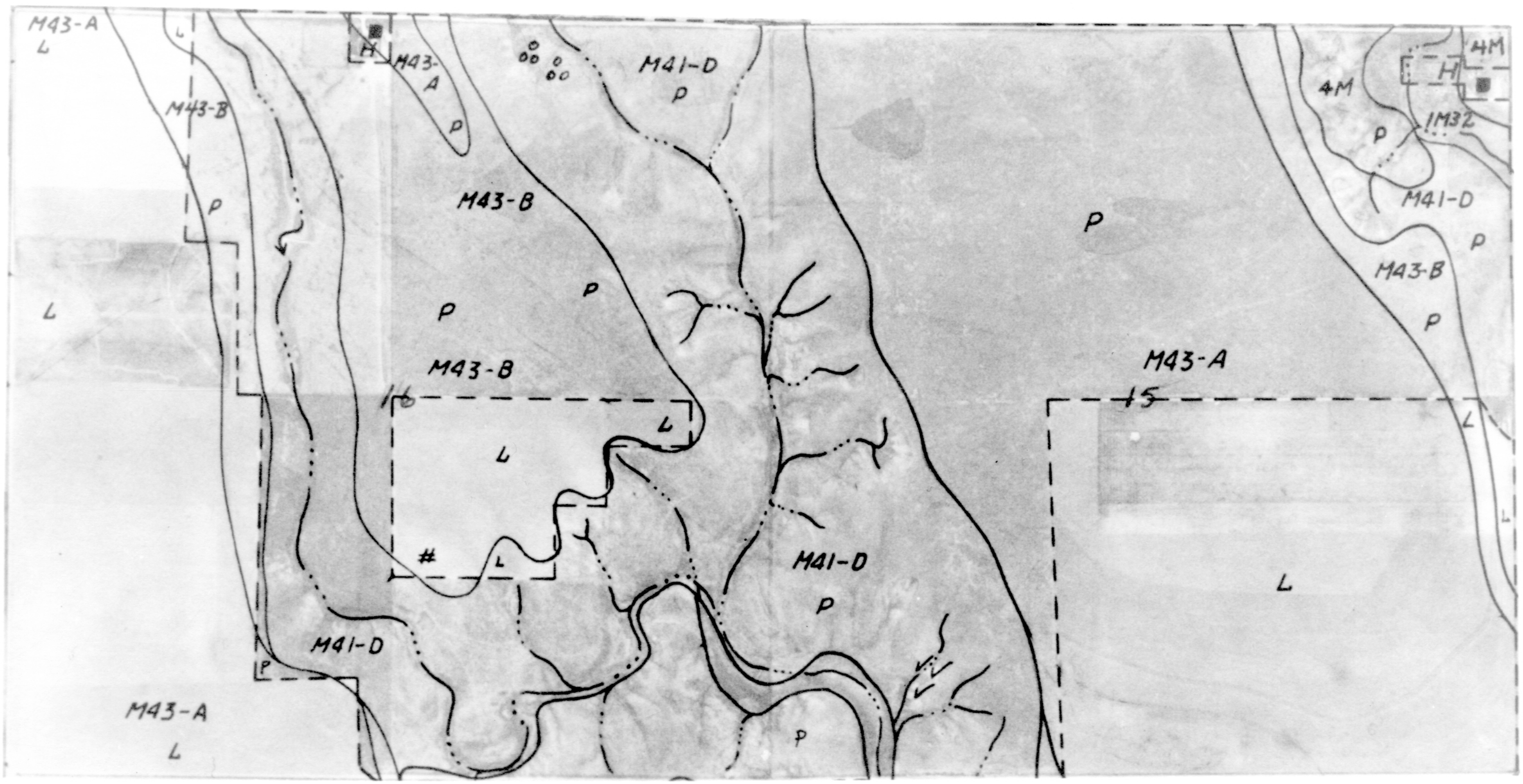

M43-C-3
L
P
M43-C
P
M41-D
P
2
M41-D
P
4M
4M
1M42
M43-C
P
S6-D
P
1
M43-A
L
M43-B
L
P
M43-C
P
1M43
P
M41-D
M41-D
P
L
L
P
1M32
M41-D
P
M43-C
P

EXPLANATION OF PLATE VI

Sections 15 and 16, T 14 S, R 34 W.

A typical association of Ulysses silt loam, M43-A and M43-B, and Colby silt loam, M41-D, as found extensively in the eastern part of Logan County south of the river.

PLATE VI



M43-A
L
M43-B
P
H
M43-A
P
M41-D
P
M43-B
P
P
L
M43-B
16
L
L
#
L
M41-D
P
M43-A
L
M41-D
P
P
P
M43-A
15
L
4M
H
4M
P
IM32
M41-D
P
M43-B
P
L

EXPLANATION OF PLATE VII

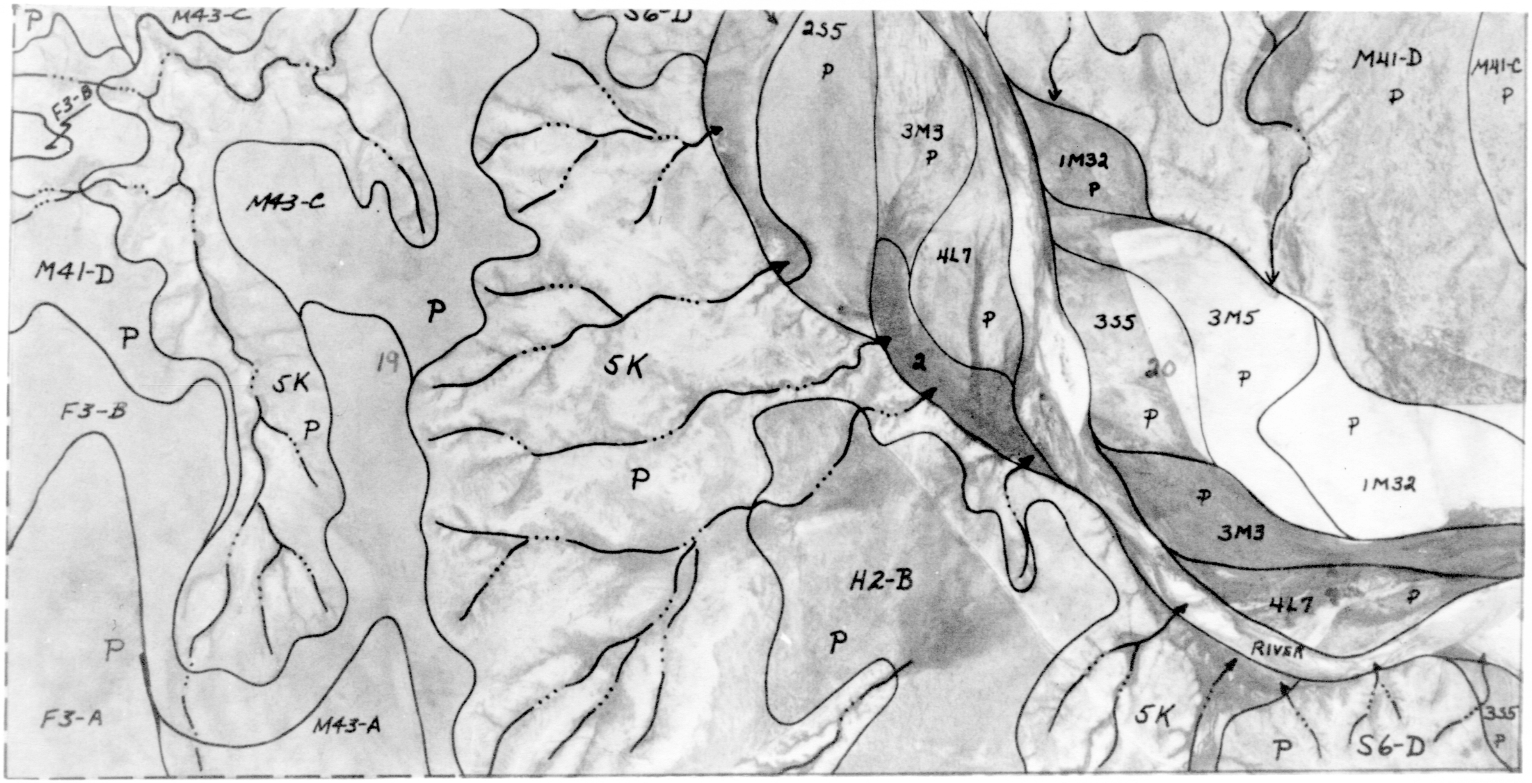
Sections 19 and 20, T 12 S, R 36 W.

Lismas clay, 5K, is shown on Pierre shale outcroppings cut by many small drainageways. Associated with this unit is Promise clay, H2-B, occurring on smoother, Concave slopes.

To the left are found Ulysses and Colby soils with Oelrichs silty clay loam, F3-A, on nearly level mixtures of Pierre clays and loess.

The stream transversing section 20 is the North Fork of the Smoky Hill River. To the south are steep slopes on Pierre formation, while to the north are mapped several complex units of alluvial soils.

PLATE VII



M43-C
S6-D
2S5
M41-D
M41-C
F3-B
3M3
1M32
M43-C
M41-D
4L7
3S5
3M5
19
5K
20
2
F3-B
5K
1M32
3M3
H2-B
4L7
RIVER
F3-A
M43-A
5K
S6-D
3S5
P

Table 11. Evaluation of factors pertaining to roads and airfields based upon Unified classification and determined characteristics.

Soil	Unified Classification	Value as Foundation when not Subject to Frost Action	Value as a Base Directly Under Bituminous Pavement	Potential Frost Action	Compressibility and Expansion	Drainage Characteristics	Compaction Equipment Needed	Dry Unit Weight (lb/ft^3)	Field C.B.R. (lb/ft^3)	Subgrade Modulus (lb/ft^3)	Suitability as a Source of Topsoil	Suitability as a Source of Sand or Gravel
Bridgeport	ML-CL	Fair to poor	NS	Medium to very high	slight to medium	Fair to poor	rubber tired, sheepsfoot	101*	5-15	100-200	Poor	NS
Colby	ML-CL	Fair to poor	NS	Medium to very high	slight to medium	Fair to poor	rubber tired, sheepsfoot	112*	5-15	100-200	Poor	NS
Dwyer	SP-SM	Fair to good	Poor to NS	None to slight	very slight	Excellent to fair	crawler tractor, rubber tired, sheepsfoot	111*	10-40	200-300	Poor	Good
Keith	ML-CL	Fair to poor	NS	Medium to very high	slight to medium	Fair to poor	rubber tired, sheepsfoot	103*	5-15	100-200	Good	Good
Likes	SP	Fair to good	Poor to NS	None to very slight	almost none	Excellent	crawler tractor, rubber tired	115	10-25	200-300	Poor	NS
Lofton	CL	Fair to poor	Fair to poor	Medium to high	medium	Nearly impervious	rubber tired, sheepsfoot	95*	5-15	100-200	Poor	NS
Manter	SC-SM	Fair to good	NS	Slight to high	slight to medium	Fair to very poor	rubber tired, sheepsfoot	115	10-20	200-300	Poor	Good
Promise	CL	Fair to poor	Fair to poor	Medium to high	medium	nearly impervious	rubber tired, sheepsfoot	104*	5-15	100-200	Poor	NS
Richfield	ML-CL	Fair to poor	NS	medium to very high	slight to medium	Fair to poor	rubber tired, sheepsfoot	105	5-15	100-200	Good	NS
Ulysses	ML-CL	Fair to poor	NS	medium to very high	slight to medium	Fair to poor	rubber tired, sheepsfoot	102*	5-15	100-200	Fair	NS

* Maximum dry density determined in laboratory (see Table 7).
NS - Not Suitable

Table 12. Evaluation of factors pertaining to embankments and foundations based upon Unified classification and determined characteristics.

Soil	Unified Class.	AASHO Class.	Value for Embankments	Permeability 1/ (cm/sec)	Compaction Character.	Value for Foundations	Requirements For Seepage Control
Bridgeport	ML-CL	A-6	Poor to fair stability	$K=10^{-4}-10^{-7}$	Good to fair	good to poor	toe trench to none
Colby	ML-CL	A-6	Poor to fair stability	$K=10^{-4}-10^{-7}$	Good to fair	good to poor	toe trench to none
Dwyer	SP-SM	A-3	Fairly stable	$K=10^{-3}$	Good	good to poor	upstream blanket & toe drain or wells
Keith	ML-CL	A-6	Poor to fair stability	$K=10^{-4}-10^{-7}$	Good to fair	good to poor	toe trench to none
Likes	SP	A-2-4	Fairly stable	$K=10^{-3}$	Good	good to poor	upstream blanket & toe drain or wells
Lofton	CL	A-7-6	Stable	$K=10^{-6}-10^{-8}$	Fair to good	good to poor	none
Manter	SC-SM	A-4	Fairly stable	$K=10^{-4}-10^{-7}$	Good to fair	good to poor	upstream blanket & toe drain or wells
Promise	CL	A-7-6	Stable	$K=10^{-6}-10^{-8}$	Fair to good	good to poor	none
Richfield	ML-CL	A-6	Poor to fair stability	$K=10^{-4}-10^{-7}$	Good to fair	good to poor	toe trench to none
Ulysses	ML-CL	A-4	Poor to fair stability	$K=10^{-4}-10^{-7}$	Good to fair	good to poor	toe trench to none

1/ K = coefficient of permeability in cm/sec; for use in Darcy's equation: $V = Ki$, where V = discharge velocity in cm/sec, and i = the dimensionless hydraulic gradient.

Table 13. Evaluation of factors pertaining to agricultural engineering and conservation based upon Unified classification and determined characteristics.

Soil	Unified Classification	Dikes and Levees	Farm Pond Reservoirs	Pond Embankments	Agricultural Drainage	Irrigation	and Diversion	Waterways
Bridgeport	ML-CL	Good	Fair	Good	Good	Excellent	Fair	Fair
Colby	ML-CL	Good	Good	Good	Poor	Very poor	Poor	Poor
Dwyer	SP-SM	NS	NS	Poor	Good, naturally	Good	Poor	Good
Keith	ML-CL	Good	Good	Good	Fair	Good	Good	Good
Likes	SP	NS	NS	NS	Good, naturally	Good	Poor	Good
Lofton	CL	Very good	Very good	Very good	Poor	NS	NS	Good to fair
Manter	SC-SM	NS	NS	Poor	Good, naturally	Good	Poor	Good
Promise	CL	Very good	Very good	Very good	Poor	NS	NS	Good
Richfield	ML-CL	Good	Good	Good	Fair	Good	Good	Good
Ulysses	ML-CL	Good	Good	Good	Fair	Fair to good	Good	Good

Table 14. Evaluation of factors of disturbed soils pertaining to use at residential sites based upon Unified classification and determined characteristics.

Soil	Unified Classification	Workability as a Construction Material	Compaction Characteristics	Shearing Strength When Compacted and Saturated	Compressibility Compacted and Saturated	Permeability When Compacted	Lack of Corrosion Potential
Bridgeport	ML-CL	E to G	G	F	G	Semi-pervious	E
Colby	ML-CL	E to G	G	G	G	Semi-pervious	E
Dwyer	SP-SM	E	E to G	G to F	E	Pervious to semi-pervious	E
Keith	ML-CL	E to G	G	F	G	Semi-pervious	E
Likes	SP	E	E	G	E	Pervious	E
Lofton	CL	E	G	F	G	Impervious	E
Manter	SC-SM	E	E to G	F	E	Semi-pervious to impervious	E
Promise	CL	E	G	F	G	Impervious	E
Richfield	ML-CL	E to G	G	F	G	Semi-pervious	E
Ulysses	ML-CL	E to G	G	F	G	Semi-pervious	E

E = Excellent F = Fair VP = Very poor
G = Good P = Poor NS = Not suitable

Table 14. (continued)

Soil	Value as a Road Base When Not Subject to Frost Action	Value as a Road Sub-base When Not Subject To Frost Action	Value as a Road Sub-base When Subject to Frost Action	Value as an Untreated Roadway Wearing Surface	Value as a Roadway with Surface Stabilization with Additives
Bridgeport	F	NS	F to P	F to NS	E to G
Colby	F	NS	F to P	F to NS	E to G
Dwyer	E to G	G to F	G	E	G
Keith	F	NS	F to P	F to NS	E to G
Likes	G	E to G	G	G	E
Lofton	F	NS	F	F	G
Manter	G	G to F	E to G	E	G
Promise	F	NS	F	F	G
Richfield	F	NS	F to P	F to NS	E to G
Ulysses	F	NS	F to P	F to NS	E to G

E = Excellent　F = Fair　VP = Very poor
G = Good　P = Poor　NS = Not suitable

Table 14. (continued)

Soil	Value as a Foundation Material for Low Buildings on Compacted Fill	Value as a Low Berm (6 ft.) For Sewage Lagoons	Value as a Compacted Lining For Water Reservoirs and Sewage Lagoons	Value as a Domestic Sewage Disposal Bed	Value as a Domestic Sewage Disposal Bed (undisturbed)
Bridgeport	G to F	G	G-E	NS	E
Colby	G to F	G	G-E	NS	E
Dwyer	G	G to NS	NS to G	E	E
Keith	G to F	G	G-E	NS	E
Likes	G	NS	NS	E	E
Lofton	G	G	E	NS	E
Manter	G	G to E	E to G	E to NS	E
Promise	G	G	E	NS	E
Richfield	G to F	G	G-E	NS	E
Ulysses	G to F	G	G-E	NS	E

E = Excellent F = Fair VP = Very poor
G = Good P = Poor NS = Not suitable

Profile Descriptions

Bridgeport Series

The Bridgeport series in Logan County consists of light colored, deep, medium textured, well drained, calcareous, weakly developed, alluvial soils in the Chestnut soil zone. They occur as low terraces and alluvial fans in the Smoky Hill River valley; and as alluvial valley sediments in the larger tributaries to the Smoky Hill River. They differ from the Las series in being deeper, well drained and occupying higher positions in the Smoky Hill River Valley. They differ from the Roxbury soils, which occur in similar positions, by being lighter colored; more calcareous in the surface layers, and having less evidence of profile development. The Bridgeport series is one of the most important alluvial soils in Logan County both in extent and productivity.

<u>Soil Profile</u>: Bridgeport loam, 1M32), cultivated.

A_1p 0-7" Grayish brown (10YR 5/2) loam, dark grayish brown (10YR 3.5/2) when moist; weak fine granular structure; slightly hard dry, friable when moist; calcareous; abrupt boundary.

A_1 7-18" Grayish brown (10YR 5/2) heavy loam, dark grayish brown (10YR 3.5/2) when moist; weak fine granular structure; slightly hard dry, friable when moist; calcareous; gradual boundary.

C_1 18-40" Light grayish brown (10YR 6/2.5) loam, grayish brown (10YR 4.5/2) when moist; massive, without structure, but porous; slightly hard dry, friable when moist; calcareous; gradual boundary.

C_2 40-60" Light grayish brown (10YR 6/2.5) loam, grayish brown (10YR 4.5/2) when moist; massive, without structure, porous; dry soft, friable when moist; calcareous with few fine crystals of $CaSO_4$ and soft concretions of $CaCO_3$; clear boundary.

Cu 60-70" Very dark grayish brown (10YR 3/2) and grayish brown (10YR 5/2) when moist, stratified layers of sandy loam and clay loam textures without structure; abrupt boundary.

D 70" Fine sand of the valley. Fill.

<u>Range in Characteristics</u>: The A_1 horizon will range in texture from a heavy loam to light clay loam with loam predominant. It will range from 10 to 20 inches in thickness, generally calcareous

to the surface but may be noncalcareous to 10 inches in depth. The profile is generally uniform in texture but may have some slight stratification of sandy loam textures. The profile is unmottled to depths of 40 inches or deeper.

Inclusions: Included within these soils are small areas of Las soils (3M3). This inclusion will not exceed 5% of the mapping unit.

Topography: These soils occur on nearly level single slope that predominantly less than 1% in gradient but may include areas up to 2% and short, low terrace encarpments.

Drainage: Surface runoff is medium. Internal soil drainage is medium, soil permeability is moderate. The water table normally lies between a depth of 6 to 20 feet.

Vegetation: Mid and short grasses, including blue grama, buffalo-grass, western wheatgrass and sideoats grama.

Use: Use principally for the production of alfalfa and row crops with smaller tracts remaining in native grass.

Distribution: Throughout the county in Smoky Hill River valley and along Turkey, Ladder, Twin Butte, and Chalk Creeks.

Type Location: 100 feet north of established trail through cultivated field on quarter line between the SW¼ and the SE¼ section 22-T138-R35W. approximately ½ mile southwest of the town of Russel Springs.

E. L. Bell/12-18-59

Colby Series

The Colby series in Logan County are light colored, well drained, non-Chermozemic Regosols developed from Peorian loess and other physically similar sediments in the Chestnut soil zone. These soils occur on strongly sloping convex surfaces. They have grayish-brown calcareous silt loam A horizons with friable, calcareous, silt loam substratums. They differ from the Ulysses series in being more weakly developed and having lighter colored, more calcareous surface layers and from the Berra series by having loessial parent material. These soils occur extensively in the south half of Logan County.

Soil Profile: Colby silt loam, 5 to 12% slopes, (M41-D), grassland.

A_1 0-5" Grayish brown (10YR 5/2) silt loam, dark grayish brown (10YR 4/2) slightly hard dry, friable when moist, abundant fine roots, calcareous at lower limits, clear boundary.

AC 5-24" Pale brown (10YR 6/3) silt loam, grayish brown (10YR 5/215) when moist; weak coarse prismatic structure, slightly hard dry, friable when moist, abundant fine roots, few soft lime concretions, strongly calcareous; diffuse boundary.

C 24" Very pale brown (10YR 7/3) silt loam, pale brown (10YR 6/2.5) when moist; massive, soft dry, strongly calcareous, extending to a depth of several feet in Peorian loess.

Range in characteristics: The A horizon will range from 4" to 6" in thickness, from loam to clay loam in texture with silt loam dominant, with a maximum darkness of 10YR 4.5/2 dry, in virgin sod. The substratum is predominently silt loam with compound weak coarse prismatic and weak fine and medium granular structure, with a color range from grayish brown (10YR 6/2) to very pale brown (10YR 7/3), dry colors. The maximum limits for these soils is an A horizon 4" to 6" in thickness, with at least a portion of the A horizon calcareous, and a maximum darkness of 10YR 4.5 value, when dry, under virgin sod.

Inclusions: Included within this mapping unit will be areas of "Narrow loamy floodplains" (1M42). Some Ulysses soils (M43-D) may occur on portions of the lower gradiant slopes and in accumulation areas. These soils will not exceed 10% of the mapping unit.

Topography: These soils occur on single, smooth, convex slopes and U shaped drainageways ranging from 5 to 12% in gradient.

Drainage and Permeability: Moderate to rapid surface drainage. Steep slopes and low rainfall usually will not permit moisture penetration below 3 feet. Permeability is moderate and internal drainage is medium to rapid.

Vegetation: Short grasses - predominantly buffalograss and blue grama.

Erosion: Colby, a light-colored Regosol in loess has such weak horizonation that no soil character of degree has been found that will serve for reliable differentiation of the more eroded areas from those little, if any, modified by accelerated erosion. The more eroded areas are somewhat less dark in the weak A_1 than in virgin areas, but they are not measurably less dark than the Ap in other cultivated areas that are without clear indications of soil modification by accelerated erosion. The management needs, potential crop production, suitability for use, and capability classification are alike for the more eroded areas and the less eroded.

Use: Majority of these soils are utilized as native range, however, fringe areas, usually skirting drainageways, are being cropped.

Distribution: These soils will prevail on D slopes in the western and central portions of the county.

Type Location: 300 feet south of the center of section 25-T14S-R34W, in large pasture on smooth slope to the south, gradient of 8%.

E. L. Bell/12-17-59

Dwyer Series

The Dwyer series in Logan County includes dark colored, coarse textured, calcareous Regosols formed in aeolian and wind reworked calcareous sand deposits of probable Tertiary origin in the Chestnut soil zone. They are coarser textured than Otero soil with which they may be associated and differ from Tivoli soils in having free carbonate in or near the surface. The Dwyer soils are most extensive of the moderately coarse and coarse textured soil in the county.

Soil Profiles: Dwyer loamy fine sand, (L6-X), grassland.

A_1 0-5" Brown (10YR 5/3) loamy fine sand, dark grayish brown (10YR 4/2.5) when moist; slightly coherent clods breaking easily to single grain sands and granular silts; dry soft; loose when moist; plentiful fine roots; weakly calcareous; clear boundary.

AC 5-12" Light yellowish brown (10YR 6/4) fine sands, yellowish brown (10YR 5.5/4) when moist; structureless single grain sands; dry loose, loose when moist; plentiful fine roots; calcareous; diffuse boundary.

C 12-60" Very pale brown (10YR 7/3) fine sands, pale brown (10YR 6.5/3) when moist; structureless single grain sands; dry loose, loose when moist; plentiful fine roots to 15 inches decreasing to few and fine at 20 inches; calcareous; sands extending down deeper than 60 inches.

Range in Characteristics: Principal variations within these soils will be the depth of darkening in the A and AC horizons and the texture of the immediate surface. The depth of A and AC horizon will range from 8 to 16 inches with an average of 12 inches. The immediate surface of these soils may have 3 inches of sandy loam texture near the margin of the delineations where the soils grade to heavier textured soils.

Inclusions: Included within these soils will be small areas of Otero sandy loam. This inclusion will not exceed 15% of the mapping unit.

Topography: These soils occur on low hummocky slopes that range from 3 to 8% gradient on the sides of hummocks.

Drainage: Surface runoff is slow, internal soil drainage and soil permeability is very rapid.

Vegetation: Under heavy grazing the vegetation is made up of sparse stands short and mid grasses with a high percentage of crown cover of sagebrush.

Use: Used exclusively as rangeland.

Distribution: These soils occur on high terrace escarpments above the flood plain and in upland positions immediately adjacent to the Smoky Hill River throughout the county.

Type Location: .2 mile south of south end of river bridge across the Smoky Hill River and 100 feet west in SE4 section 1-T14S-R34W in native pasture.

E. L. Bell/7-25-59

Keith Series

The Keith series in Logan County comprises deep, dark, medium textured, well developed zonal Chestnut soils formed on calcareous silty loess-mantled tablelands of the High Plains. They are more advanced in profile development than the Ulysses soils having distinct B horizons and generally noncalcareous to depths of 15 inches or more. They differ from the Richfield soils in having slightly thicker solums with B horizons of lower clay content and weaker structure. Keith soils are an extensive and important cultivated upland soil in the county.

Soil Profile: Keith silt loam, 0 to 1 slopes, (M4-A), cultivated.

A_{1p} 0-6" Dark grayish-brown (10YR 4/1/5) silt loam, very dark grayish-brown (10YR 2.5/2) when moist; weak very fine and fine granular structure with lower two inches compacted to weak coarse platy breaking to weak fine and medium granular structure; dry slightly hard, friable when moist; noncalcareous; abrupt boundary.

A_1 6-11" Very dark grayish-brown (10YR 3/1.5) heavy silt loam, very dark brown (10YR 2/2) when moist; moderate medium granular structure; dry slightly hard, friable when moist; noncalcareous; clear boundary.

A_3 11-17" Very dark grayish-brown (10YR 3/2) light silty clay loam, very dark brown (10YR 2/2) when moist; moderate medium granular structure; dry hard, friable when moist; noncalcareous; clear boundary.

B_{21} 17-21" Dark grayish-brown (10YR 4/2) light silty clay loam, very dark grayish-brown (10YR 3/2) when moist; moderate medium sub-angular blocky structure; dry hard, firm when moist; clay films thin and patchy; noncalcareous; clear boundary.

BC_{ca} 21-41" Grayish-brown (10YR 5.5/2) light silty clay loam, dark grayish-brown (10YR 4/2) when moist; moderate medium subangular blocky structure; dry hard, firm when moist; clay films thin and patchy; calcareous with lower portion having few fine soft concretions of $CaCO_3$; gradual boundary.

Cca 41-57" Light grayish-brown (10YR 6/2.5) heavy silt loam, brown (10YR 5/3) when moist; weak coarse prismatic breaking to weak medium and coarse subangular blocky structure; dry slightly hard, friable when moist; few fine soft threads of segregated $CaCO_3$; calcareous; diffuse boundary.

C 57-70" Very pale brown (10YR 7/2.5) silt loam, brown (10YR 5/3) when moist; massive, soft, calcareous loess.

Range in Characteristics: The A horizon is dominant silt loam averaging 8 inches in thickness with a range of 6 to 16 inches. The structure of the B horizon varies from weak to moderate, and fine to medium subangular blocky with weak medium subangular blocky predominating. The range in depth to lime enrichment is 15 to 30 inches with an average of 18 to 22 inches. The Keith series will be held to soils with a dark grayish brown dry color to more than 15 inches depth. Depth to darkening has preference over depth to lime enrichment in marginal areas. A_3 horizons are generally thinner than the profile included in this description and often absent in the sequence of horizons.

Buried horizons of an older soil occur within the solum of the present soil, ranging in depths of 15-30". Their occurrence is unpredictable from visible surface features and apparently unrelated to the present relief of the land. No attempt has been made to separate them as another mapping unit. A profile of Keith silt loam, 0-1% (M4-A), with a buried soil horizon; located near the southwest corner of SW¼ section 9, T11S, R33W is described below:

A_p 0-8" Dark grayish-brown (10YR 4/2); very dark grayish-brown 3/2 moist) silt loam; weak fine granular; dry slightly hard, moist friable; neutral. Clear boundary.

B_2 8-19" Grayish-brown (10YR 4.5/2); very dark grayish-brown

3/2 moist) light silty clay loam; compound weak fine subangular blocky and weak fine granular; dry slightly hard; moist friable; neutral; abrupt boundary.

B_{2-b} 19-40" Dark grayish-brown (10YR 4/2; very dark gray 3/1.5 moist) silty clay loam; moderate medium subangular blocky; dry hard, moist friable; pale brown (10YR 6/2.5 dry) limy coating on surfaces of peds but not impregnating peds; strong calcareous; diffuse boundary.

C 40" Light gray (10YR 7/2; pale brown 6/3 moist) silt loam; massive; dry soft, moist friable; calcareous loessial material.

Inclusions: Included in these soils will be small areas of M4-B which occur as slightly raised knolls and short slopes. This inclusion will not exceed areas of Lofton silty clay loam of less than 5 acres, shown by spot symbols, will be included and not exceed 3% of the mapping unit.

Topography: This mapping unit is confined to slopes that are dominantly 1% and less in gradient, occurring mainly as broad flats and divides between drainageways within a young and coarse textured plains.

Erosion: Accelerated erosion has removed as much as 50% of the original A horizon. In no instances will less than 4 inches of A horizon be found. Wind erosion has been most active on slightly raised knolls while water erosion has caused sheet erosion on the lower ends of slopes exceeding one quarter mile in length. No erosional phase has been recognized.

Drainage: Surface runoff is medium. Internal soil drainage is medium and soil permeability is moderately slow.

Vegetation: Short grasses, blue grama and buffalograss predominate with scatterings of western wheatgrass.

Use: Used principally as dryland farming of cash crops with winter wheat and grain sorghums as chief crops grown.

Distribution: These soils occur on the nearly level slopes on the tablelands in northern and extreme southwestern portions of the county.

Type location: 557 feet south and 278 feet east of the NW corner of section 36-T11S-R35W, approximately 4 miles east of the town of Winona, in cultivated field.

Remarks: Type location listed above is site of characterization sample Nos. 2-57-Kan-55-2-(1-8); LSL #5894-5901, July 8, 1957.

Keith silt loam, 1 to 3% slopes (M4-B).

The profile horizons are thinner than M4-A with an average depth of 15 to 18 inches to free lime. The structural development of the B horizon is generally weaker. They occur on gently sloping slopes with average gradient of 2% and in association with M4-A.

E. L. Bell
7/14/59

Soil type: Keith silt loam, minimum profile
Location: .13 mile east and 100 feet south of the northwest corner of section 26-T.12S.-R34W.
Date of sampling: June 28, 1961
Collectors: O. W. Bidwell, Elbert Bell, Richard Davis

A_{1p} 0-3" Dark grayish-brown (10YR 4/2; 2.5/2 moist) silt loam; plow layer with very weak fine granular structure; dry slightly hard, friable when moist; noncalcareous; abrupt boundary.

A_1 3-8" Dark grayish-brown (10YR 3.5/2; 2.5/2 moist) weak fine granular structure, upper one inch compacted from tillage; dry slightly hard, friable when moist; noncalcareous; clear boundary.

A_3 or B_1 8-11" Dark grayish-brown (10YR 3.5/2; 2.5/2 moist) light silty clay loam or heavy silt loam; moderate fine and medium granular structure; dry slightly hard, friable when moist; noncalcareous; clear boundary.

B_2 11-15" Dark grayish-brown (10YR 4/2; 3/2 moist); light silty clay; weak medium subangular blocky structure breaking to moderate medium granular; dry hard, moderately firm when moist; weaky and patchy clay films on surfaces of subangular blocky structural peds; noncalcareous; clear boundary.

B_3 15-34" Light brownish-gray (10YR 6/2; 5/2 moist) heavy silt loam; weak coarse subangular blocky structure; dry slightly hard, friable when moist; calcareous with few fine threads of segregated $CaCO_3$; gradual boundary.

C 34-40" Light gray (10YR 6.5/2.5; 6/3 moist) silt loam; massive; dry soft, friable when moist; calcareous loess.

Profile described by Elbert Bell

Soil Type:	Keith silt loam, Modal profile
Location:	Logan County, Kansas. 557' S and 278' E of NW corner Sec. 36, T11S, R35W, 4 miles E of Winona.
Date of Sampling:	August 19, 1959
Collectors:	Elbert Bell, Clarence Call
Physiographic Positions:	Upland, elevation approximately 3300'.
Climate:	Average annual precipitation, about 19". Annual temperature about 53°.
Topography:	Nearly level summit of High Plains mantled with loess. Plane surface with gradient less than ½%.
Drainage:	Well drained.
Vegetation:	1959 wheat stubble, unworked.
Use:	Cultivated land.
Sample Numbers:	S-59-Kan-55-4-(1-4) for KSHC and BPR

0-5" A_{1p1} S-59-Kan-55-4-1	Dark-grayish-brown (10YR 4/2 dry; 2.5/2 moist) silt loam; weak very fine and fine granular; slightly hard; friable; noncalcareous; abrupt boundary.
5-7" A_{1p2} S-59-Kan-55-4-1	Dark-grayish-brown (10YR 4/2 dry; 2.5/2 moist) silt loam; weak coarse platy breaking to fine and medium granular; slightly hard; friable; noncalcareous; abrupt smooth boundary.
7-11" A_1 S-59-Kan-55-4-1	Very dark-grayish-brown (10YR 3/1.5 dry; 2/2 moist) heavy silt loam; moderate medium granular; slightly hard; friable; noncalcareous; grades to
11-16" A_3	Very dark-grayish brown (10YR 3/1.5 dry; 2.5/2 moist) light silty clay loam; moderate medium granular; hard; friable; noncalcareous; grades to
16-22" B_{21}	Dark-grayish-brown (10YR 4/2 dry; 3/2 moist) light silty clay loam heavier than above horizon; moderate medium subangular blocky; clay films weak and patchy; hard; firm; noncalcareous; grades to
22-32" B_{22} S-59-Kan-55-4-3	Grayish-brown (10YR 5.5/2 dry; 4/2 moist) light silty clay loam about same as above; moderate medium subangular blocky; clay films weak and patchy; hard; firm; calcareous; grades to
32-42" B_{2ca}	Grayish-brown (10YR 5.5/2 dry) light silty clay loam; moderate medium subangular blocky; clay films weak and patchy; hard; moderately firm; calcareous with about 2% of small soft concretions of $CaCO_3$; grades to
42-53" C_{ca}	Light-brownish-gray (10YR 6/2.5 dry; 5/3 moist) heavy silt loam; weak medium and coarse subangular

blocky; slightly hard; friable; calcareous with few small soft concretions and fine threads of $CaCO_3$; grades to

53-70" C S-59-Kan- 55-4-4*	Very pale brown (10YR 7/2.5 dry; 5/3 moist) silt loam; massive; soft; very friable; calcareous.

Except where moist, the colors refer to dry soil

Profile described by Elbert Bell

Soil Type:	Keith silt loam, maximum profile
Location:	.1 mile east and 25 feet north of the center of section 12, T.11S., R.34".; 1½ miles northwest of Monument, Kansas.
Date of sampling:	June 28, 1961
Collectors:	O. W. Bidwell, Elbert Bell, Richard Davis

A_1	0-9"	Very dark-grayish-brown (10YR 3/2; 2/2 moist) silt loam; moderate medium and fine granular structure; dry slightly hard, friable when moist; noncalcareous; clear boundary.
A_3 or B_1	9-17"	Very dark-grayish-brown (10YR 3/2; 2/2 moist) light silty clay loam; moderate medium granular structure; dry hard, friable when moist; noncalcareous; clear boundary.
B_2	17-27"	Dark grayish-brown (10YR 4/2; 3/2 moist) light silty clay loam; moderate medium subangular blocky structure; clay films weak and patchy; dry hard, firm when moist; noncalcareous; clear boundary.
B_3b_1	27-42"	Grayish-brown (10YR 5.5/2; 4/2 moist) light silty clay loam; weak medium subangular blocky structure; dry hard, friable when moist; calcareous; gradual boundary.
C_{ca}	42-56"	Light brownish-gray (10YR 6/2.5; 5/3 moist) silt loam; weak coarse prismatic breaking to weak coarse subangular blocky structure; dry slightly hard, friable when moist; calcareous with few fine threads of $CaCO_3$; diffuse boundary.
C	56-62"	Very pale-brown (10YR 7/2.5; 6/3 moist) silt loam; massive; dry soft, friable when moist; calcareous loess.

Profile described by Elbert Bell

Likes Series

The Likes series in Logan County comprises relatively light colored, moderately deep, coarse textured, calcareous, immature, alluvial soils that are somewhat excessively drained. They are formed in sandy alluvial fans at the termination of upland drainageways that empty onto low terrace positions along the Smoky Hill River Valley. They differ from the Bridgeport series, which occurs in similar positions, by being coarser textured throughout. They differ from the Las Animas series by being coarser textured, generally deeper to sands, and occurring in higher positions in the valley. The Likes soils have a very limited occurrence in Logan County.

Soil Profile: Likes loamy sand, (2S5), grassland.

A_1 0-12" Grayish brown (10YR 5/2) loamy sand, dark grayish brown (10YR 4/2) when moist, weak fine granular structure with few single sand grains; dry soft, loose when moist; numerous roots; calcareous; gradual boundary.

AC 12-50" Light brownish gray (10YR 6.5/2.5) loamy sand, brown (10YR 5/3) when moist; massive with only weak suggestion of granular structure in the upper portion; generally incoherent; few rootlets to 36 inches, calcareous; gradual boundary.

C 50" Loose calcareous sands.

Range in characteristics: The surface horizon ranges from 7 to 14 inches in thickness, is dominant loamy sand with occasional light sandy loam. The depth of the profile ranges from 36 to 50 inches and may be stratified with lenses of sands as sandy loam textures. These soils have been confined to profiles that dominantly loamy sand to depths of 36 inches or more.

Topography: Nearly level fans and aprons with gradients not exceeding 2%.

Drainage and Permeability: These soils are somewhat excessively drained due to the porous nature of the profile. Surface runoff is slow. The internal soil drainage is rapid and the soil permeability is rapid. The watertable normally stands at depths greater than 10 feet.

Vegetation: Mid and short grasses with considerable ground coverage of sage brush, cactus and yucca.

Use: Rangeland. Small areas have been broken for cultivation but abandoned due to the unstable condition of the soil.

Distribution: These soils have limited and scattered occurrence along the south side of the Smoky Hill River.

Type Location: 300 feet south of the south end of bridge across Smoky Hill River and .35 mile east in the NW¼ section 26-T13S-R35W, in native pasture.

E. L. Bell
12/30/59

Lofton Series

The Lofton series in Logan County consists of dark colored, noncalcareous chestnut soil with compacted clay subsoils that occur as upland basins or depressional areas within the Chestnut soils zone. They differ from the Keith soils, with which they are associated, in having much finer textured solums and deeper to fine carbonates. The B horizons of the Lofton soils are more clayey and more compacted which renders them less permeable than the Lubbock soils.

Soil Profiles: Lofton silty clay loam, (INT.), cultivated.

Ap 0-5" Dark gray (10YR 4/2) heavy silty clay loam, very dark gray (10YR 2.5/1) when moist; moderate fine granular structure; hard dry, firm when moist; slight acid in reaction; abrupt boundary.

B_1 5-8" Dark gray (10YR 4.5/1) light silty clay, very dark gray (10YR 2.5/1) when moist; strong fine granular; very hard dry; very firm when moist; clay films and surface of peds distinct; mottled with reddish brown (5YR 4/3) common medium prominent mottling; noncalcareous; clear boundary.

B_{21} 8-20" Gray (10YR 5/1) clay, very dark gray (10YR 3/1) when moist; strong medium subangular blocky structure; extremely hard dry, extremely firm when moist; clay films distinct; mottled with reddish brown (5YR 4/3 common medium prominent mottling; noncalcareous; clear boundary).

B_{22} 20-30" Gray (10 5/1) clay, very dark gray (10YR 3/1) when moist, moderate medium subangular blocky structure; extremely hard dry, extremely firm when moist; clay films distinct; mottled with yellowish brown (10YR 5/4) few fine faint mottlings; noncalcareous; gradual boundary.

B_3 30-43" Gray (10YR 5.5/1) heavy silty clay loam, very dark grayish brown (10YR 3.5/2) when moist; weak medium and coarse subangular blocky structure; very hard dry, firm when moist; clay films thin and continuous; noncalcareous; gradual boundary.

BC 43-55" Light brownish-gray (10YR 6/2) light silty clay loam, dark grayish-brown (10YR 4/2) when moist; weak coarse subangular blocky structure approaching massive, dry slight hard, friable when moist; clay films weak and patchy; noncalcareous diffuse boundary.

C 55-67" Light gray (10YR 7/2 silt loam, brown (10YR 5/3) when moist; massive calcareous loess.

Range in Characteristics: The A horizon is dominantly noncalcareous to slightly acid silty clay loam with occasional light silty clay texture occurring. Depth to free carbonates will vary from 40 to 72 inches according to the size of the soil area. They vary in size from 100 feet in diameter to 16 surface acres with an average of 6 to 8 acres. The smaller areas, less than 5 acres, are shown by a spot symbol.

Topography: These soils occur as roundish slightly depressed areas which lie a few inches to a few feet below the surrounding soils on the nearby level High Plains uplands flats.

Drainage and Permeability: The surface runoff is ponded, internal drainage and soil permeability is very slow. Rainfall often collects and stands on these soils for several weeks at one time. Tillage is frequently impossible at seeding time and planted crops often drown out before maturing. Seeded crops grow to maturity and are harvested only during the extreme drier years.

Vegetation: Mainly annual weeds.

Use: Use conforms to the land use of adjacent soils with the majority of the soils in cultivation.

Distribution: Confined to the nearly level divides and flats within the High Plains tablelands in the northern and extreme southwestern portions of the Logan.

Type Location: (1) Taken from the center of a depression located in the N½ of the SW¼ section 11-T12S-R34W, in cultivated field. Area delineated is approximately 10 acres in size. (2) 580 feet north and 475 feet east of the south quarter corner of section 1-T12S-R34W, in cultivated field. Area indicated by symbol is approximately 1.5 acres in size.

E. L. Bell
6/27/59

Manter Series

The Manter series in Logan county includes deep, moderately dark colored, moderately coarse textured, weakly developed zonal soils of the Chestnut Soil Group. They are formed in reworked calcareous sandy deposits of Tertiary and Quaternary materials that occur as elongated ridges in upland positions. The Manter soils differ from Dwyer soil in being finer textured, coherent, and having more evidence of solum development. The Manter are more uniform texturally, leached of lime to greater depths, and have more profile development with incipient B horizons when compared to the Otero soils which occur on slightly steeper slopes of apparently younger materials. The Manter soils are minor in extent, occupying approximately 1500 acres in the county.

Soil Profile: Manter fine sandy loam, 1 to 3% slopes (S5-B), cultivated.

A_1	0-6"	Dark grayish-brown (10YR 4/2; very dark grayish-brown 3/2 moist) sandy loam; weak fine granular; dry soft, moist friable; non-calcareous; gradual boundary.
B_{21}	6-14"	Dark grayish-brown (10YR 3.5/2; very dark brown 2.5/2 moist) heavy sandy loam; very weak fine granular to massive; dry soft, moist friable; very weak and patchy clay films; noncalcareous; gradual boundary.
B_{22}	14-26"	Dark grayish-brown (10YR 4/2; very dark grayish-brown 3.5/2 moist) heavy sandy loam; massive; dry soft, moist very friable; very weak and patchy clay-skins; non-calcareous; diffuse boundary.
C	26"	Brown (10YR 5/3; dark brown 3.5/3 moist) sandy loam; massive; calcareous.

Range in Characteristics: The textures within the solum range from heavy sandy loam to heavy loamy sand with incipient B horizons to A-AC-C profiles. The depth to calcareousness varies from 18 to 30 inches with an average of 20 inches.

Inclusions: Included within these soils will be small areas of Otero sandy loam and Ulysses silt loam that are too small to delineate. This inclusion does not exceed 5% of the mapping unit

Topography: These soils occur chiefly on long narrow convex ridges running in a south and southeastern direction on the south side of the Smoky Hill River and the North Branch Smoky Hill River. These soils occur on slopes with an average gradient of 2½ to 3%.

Drainage and Permeability: Surface runoff is slow. Soil permeability and internal drainage is rapid.

Vegetation: Mid and tall grasses with some sagebrush and yucca plants.

Use: Use both as rangeland and cropland.

Distribution: These soils have discontinuous occurrence along the south sides of the Smoky Hill River and its north branch throughout the county.

Type Location: .1 mile north and 100 feet west of east quarter corner of section 7-T14S-R36W in cultivated field.

E. L. Bell
11/23/59

Promise Series

The Promise series in Logan County comprises deep, dark colored, fine textured Regosols formed in clayey alluvial-colluvial slopes below outcroppings of Pierre shale in the Chestnut soil zone within the High Plains Region. The soils are uniformly clay throughout and may contain moderate amounts of salts below the surface. They differ from the Orman soils in having less compacted clayey horizons, lesser amounts of free salts and occurring on more sloping topography. The Promise soils are relatively inextensive in the county.

Soil Profile: Promise clay, 1 to 3% slopes, (H2-B), cropland.

Ap	0-3"	Brown (10YR 4.5/2) silty clay, very dark grayish-brown (10YR 3/2.5) when moist; structureless plow sole; very hard when dry, very firm when moist; slight calcareous; abrupt boundary.
A_1	3-8"	Brown (10YR 4.5/2) clay, very dark grayish-brown (10YR 3/2.5) when moist; moderate medium granular structure; very hard dry, very firm when moist; thin continuous clay films; slightly calcareous; clear boundary.
AC	8-20"	Light yellowish-brown (1Y 5.5/3) clay, olive brown (1Y 4.5/4) when moist; weak fine and medium granular structure; very hard dry, very firm moist; thin patchy clay films to 16 inches; calcareous; clear boundary.
C	20-60"	Pale yellows (2.5Y 6.5/3) clay, light olive brown (2.5Y 5/4) when moist; massive in structure; extremely hard dry, extremely firm when moist; calcareous; mottled with N 8/0, common medium prominent

whitish mottling of gypsum salts as threads and nests.

Range in Characteristics: The A_1 horizon will range from 4 to 8 inches in thickness and may have a slight olive brown color when cultivated. The AC horizon varies from 7 to 15 inches in thickness, and may have some common fine prominent mottlings of gypsum salts. The C horizon will occur at depths varying from 16 to 24 inches and extend down to depths or 4 to 8 feet or more. The C horizon rests on unweathered Pierre shale on most colluvial slopes or grade to loessial-like silts and clays where the soils grades into the adjacent loessial uplands. These soils can have considerable variation in the amount and occurrence of mottling of gypsiferous salts within the profile. Salts do not accumulate in harmful amounts except in small isolated areas that are indicated by the presence of inland salt grass on the native rangeland.

Inclusions: Included in these soils will be small areas of Richfield silty clay loam that occur on the fringe areas and isolated residual knolls of Lismas clay within the delineations. These inclusions will not exceed 10% of the soils.

Topography: These soils occur on single smooth and slight concave slope up 3% with an average gradient of 2%.

Drainage and Permeability: Surface runoff is rapid. Internal soil drainage and permeability is very slow.

Vegetation: The principal grasses are western wheat and blue grama with lesser amounts of buffalograss. Occasional areas of inland salt grass are found where salts have accumulated near the surface. Switch grass may occur in areas that receive additional amounts of water as run in.

Use: Used principally as rangeland. When cultivated yields are low and crop failures frequent due to poor plant-soil-moisture relationships.

Distribution: The Promise soils occur as a pure mapping unit in the vicinity of McAllister and Colluvial slope leading down to the North Branch Smoky Hill River

Type Location: .2 mile east and .2 mile north of southwest corner of section 18, T12S, R36W, in cultivated field.

E. L. Bell
7/9/59

Richfield Series

The Richfield series in Logan County consists of dark colored, moderately fine textured, well developed zonal Chestnut soils developed in silty loess that mantles the broad flat tablelands in the High Plains Region of Central Western Kansas. They are more advanced in development than Ulysses soils having heavier textured and more structural developed B horizons. They differ from Keith soils in having generally thinner A horizons that rest abruptly on B horizons of heavier and stronger structure, with generally thinner solums. The Richfield soils in Logan County are transitional in morphological characteristics, representing the minimal concept of the series, as the grade to the more friable Keith and Ulysses soils of the northern Chestnut Soil Zone. They are of limited extent in the county, occurring in the extreme southern portion of the county in the extension of the Harrison Flats of Wallace County. Their occurrence in southwestern Logan County represents the most northern extent of Richfield soils in northwest Kansas.

<u>Soil Profile:</u> Richfield silt loam, 0 to 1% slopes, (Mc-A), cultivated.

Ap 0-5" Dark grayish-brown (10YR 4/2) silt loam, very dark grayish-brown (10YR 3/2) when moist; compacted plow layer with lower 1½ inches weakly platy structure; dry slightly hard, friable when moist; noncalcareous, abrupt boundary.

B_{21} 5-11" Dark grayish-brown (10YR 4.5/2.5) silty clay loam, very dark grayish-brown (10YR 3.5/2.5) when moist; moderate medium subangular blocky structure; dry hard, firm when moist; clay films thin and continuous not clogging open pores; noncalcareous; clear boundary.

B_{22} 11-18" Grayish-brown (10YR 5/2) silty clay loam, very dark grayish-brown (10YR 3.5/2.5) when moist; compound weak medium prismatic breaking to moderately strong fine and medium subangular blocky structure; dry very hard, firm when moist; clay films thin and continuous with open pores; lower 2 inches becoming calcareous; gradual boundary.

B_{2ca} 18-27" Light brownish-gray (10YR 6/2) silty loam, dark grayish-brown (10YR 4.5/2) when moist; weak medium subangular blocky structure; dry slightly hard, friable when moist; mottled with N 8/0 few fine prominent streaks and films of soft segregated $CaCO_3$ and 10YR 3/2 few fine distinct very dark grayish-brown organic strains; calcareous; gradual boundary.

Cca 27-38" Light gray (10YR 6.5/2) silt loam, grayish-brown (10YR 5/2) when moist; weak medium subangular blocky structure; dry slightly hard, friable when moist; mottled with N 8/0 common fine prominent whitish streaks and films of soft segregated $CaCO_3$; calcareous; diffuse boundary.

C 38-48" Light gray (10YR 6.8/2) silt loam, grayish brown (10YR 5.5/2) when moist; massive, friable, calcareous loess of probable Peorian age.

Range in Characteristics: Variations are chiefly in thickness of sola and degree of profile development. The A horizon is consistently silt loam ranging from 4 to 7 inches in thickness. The clay content of the B_2 horizon ranges from 34 to 38% with moderately strong fine and medium subangular blocky structure ranging down to moderate medium subangular blocky structure. The depth to lime and lower limits of the B_{22} horizons ranges from 10 to 22 inches in depth. Criterion for distinguishing Richfield from Keith and Ulysses soils in the zone of gradation must be based primarily on the texture, thickness, and degree of structural development of the B_2 horizons. The Richfield soils will tend to have slightly browner colored horizons but this can not be employed as a differentiating characteristic.

Inclusions: Included within the Richfield soils will be small areas of Ulysses silt loam, 0-1% slopes, (M43-A) and Keith silt loam, 0-1% slopes, (M4-A). These inclusions will not exceed 15% of the delineated areas.

Topography: This mapping unit is confined to the nearly level, less than 1% slopes, broad flats on the summit of the High Plains tablelands.

Drainage: The surface runoff is medium. The internal soil drainage is medium and the soil permeability is moderately slow.

Vegetation: Short grasses, dominantly blue grama and buffalograss with small amount of western wheatgrass.

Use: Used principally as dryland farming of cash crops with winter wheat, barley, and grain sorghums as the chief crops grown.

Distribution: Richfield silt loam is confined to a relatively small acreage in extreme southwestern portion of Logan County.

Type Location: .15 mile south and 500 feet east of northwest corner of section 18-T15S-R37W, in cultivated adjoining Wallace County.

E. L. Bell
7/11/59

Ulysses Series

The Ulysses series in Logan County comprises dark colored, medium textured loessial upland soils in the Chestnut Soil Zone that are intermediate in profile development between the more developed Keith soils and the weaker developed Colby soils. They differ from the Colby soil by having incipient B horizons on the flatter slopes and being calcareous above 15 inches in depth with a surface darkening color of dark grayish brown (10YR 4/2), or darker, not exceeding 15 in depth. They differ from the Richfield soils that occur on the flat slopes by having less clayey B horizons of weaker structure and more friable consistence. The Ulysses series is the most extensive upland soil in Logan County.

Soil Profiles: Ulysses silt loam, 0 to 1% slopes, (M43-A), cultivated.

A_{1p}	0-5"	Dark grayish brown (10YR 4/2) silt loam, very dark grayish brown (10YR 3/2) when moist; weak, fine and very fine granular structure; slightly hard dry, friable when moist; noncalcareous; abrupt boundary.
A_1	5-7"	Dark grayish brown (10YR 4/2) silt loam, very dark grayish brown (10YR 2.5/2) when moist; moderate fine granular structure; slightly hard dry, friable when moist; weakly calcareous; clear boundary.
B_2	7-14"	Grayish brown (10YR 5/2) light silty clay loam, very dark grayish brown (10YR 3.5/2) when moist; weak medium subangular blocky and moderate fine granular structure; hard dry, moderately firm when moist; clay film are weak and patchy; calcareous; clear boundary.
Cca	14-48"	Light gray (10YR 7/2.5) silt loam brown (10YR 5/3) when moist; weak coarse prismatic and weak coarse subangular blocky structure; soft dry, very friable when moist; calcareous with few fine threads of soft segregated $CaCO_3$ to a depth 25 inches; diffuse boundary.
C	48-63"	Light gray (10YR 7/2.5) silt loam, brown (10YR 5/3) when moist; massive without evidence of structure; soft, friable, calcareous loess extending down several feet.

Range in Characteristics: The A_1 horizon ranges from 4 to 10 inches in thickness with an average of 6 inches; having a textural range of heavy loam to light silty clay loam, with silt loam predominant; with a color range in value of 10YR 3.5 to 4.5 dry. These soils are underlain with a B horizon 3 to 8 inches in thickness of weak subangular blocky structure, and a clay content not exceeding 32%. Weak B horizons are more prevalent than A-AC-C profiles in these soils. These soils have been held to a maximum depth of darkening of 15 inches of dark grayish brown (10YR 4/2) or darker. The minimum limits for these soils has been an A horizon 6 to 8" in thickness, with a dry color not lighter than grayish brown (10YR 5/2) calcareous under cultivation and usually non-calcareous to 6 inches under virgin sod.

Inclusions: Included within this mapping unit are small areas of Ulysses silt loam, 1 to 3% slopes, M43-B; and Keith silt loam, 0 to 1% slopes, M4-A. These inclusions do not exceed 5% of the mapping unit.

Topography: These soils occur as smooth single slopes and slightly convexed ridges.

Drainage and Permeability: Surface runoff is medium. The internal soil drainage is medium and soil permeability is moderate.

Vegetation: The native vegetation is short grasses, predominantly buffalograss and blue grama.

Use: Used mainly for dryland cash crop farming with winter wheat and grain sorghums the principal crops.

Distribution: Throughout most of the county except on the high plains flats in the northeastern portion of the county.

Type locations: 653 feet east and 233 feet south of the west quarter corner of section 36-T12S-R35W, 7 miles southeast of the town of Winona.

Remarks: Type location listed above is site of characterization sample Nos. S-57-Kan-55-3-(1-7); LSL #5902-5908, July 8, 1957.

Ulysses silt loam, 1 to 3% slopes, (M43-B)

Maximum and minimum limits for the series apply to this mapping unit. A-AC-C profiles are more common than B horizons, when B horizons are found they are light silty clay loam textured with weak sub-angular blocky structure. They occur on single smooth and slightly convex slopes averaging 2% in gradient.

Ulysses silt loam, 3 to 5% slopes, (M43-B)

These soils are A-AC-C profiles with depth of darkening r anging from 7 to 12 inches. They occur on slightly convex slopes averaging 4% in gradient.

Ulysses silt loam, 5 to 12% slopes, (M43-D)

The soils of this mapping are A-AC-C profiles with darkening ranging from 6 to 9 in depth. They occur on steeper slopes generally in U-shaped drainageways in the northeastern portion of the county.

Ulysses silt loam, eroded phase, 3 to 5% slopes, (M43-C-3).

The soils of this mapping unit occur as cultivated areas, adjacent Ulysses soils under virgin sod, that have areas within the delineation that has most or all of the darker A horizon removed by wind and water erosion. The eroded areas now have surface layers of a dry color of grayish brown (10YR 5/2) to pale brown (10YR 6/3) ranging from 1 to 4 inches in thickness and strongly calcareous. The eroded areas occupy from 20 to 40% of the delineation with an average of 30% of the surface area.

Ulysses silt loam, eroded phase, 5 to 12% slopes, (M43-D-3)

The soils of this mapping unit are similar to mapping unit M43-C-3 in profile characteristics and composition. They occur on steeper slopes adjacent Ulysses soils under virgin sod.

E. L. Bell
12-30-59

Soil Type:	Ulysses silt loam, Minimal profile
Location:	Logan County, Kansas. 1580' E and 72' N of SW corner of Sec. 36, T12S, R35W; 7½ miles southeast of Winona.
Date of Sampling:	August 18, 1959.
Collectors:	Elbert Bell, Clarence Call
Physiographic Position:	Upland. Elevation approximately 3200'.
Climate:	Average annual precipitation 18". Annual temperature about 53°.
Topography:	Gently sloping tableland below the summit of the High Plains mantled with loess. Gradient 2%.
Drainage:	Well drained.
Vegetation:	Clean summer fallow, probably for wheat.
Use:	Cropland.
Sample Numbers:	8-59-Kan-53-3-(1-3) for KSHC and BPR

A_1 0-8" S-59-Kan-55-3-1 — Dark-grayish-brown (10YR 4.5/2) silt loam, very dark-grayish-brown (10YR 3/2) when moist; weak fine granular structure; slightly hard dry, friable when moist; few worm casts; slightly calcareous; clear boundary.

AC 8-19" S-59-Kan-55-3-2 — Light-grayish-brown (10YR 5.5/2) silt loam, dark-grayish-brown (10YR 4/2) when moist; upper portion weak fine granular structure grading to massive in lower portion; slightly hard dry, friable when moist; few worm casts; strongly calcareous without evidence of segregated lime; gradual boundary.

C 19-60" S-59-Kan-55-3-3*	Light-gray (10YR 7/2) silt loam, light-grayish-brown (10YR 5.5/2) when moist; massive but porous; soft dry; friable when moist; few krotovinas and root cavities of darker material; strongly calcareous loessial material extending several feet in depth.

Except where specified moist, the colors refer to dry soil.

Profile described by Elbert Bell.

Soil Type:	Ulysses silt loam, modal profile.
Location:	Logan County, Kansas. 292' N and 151' W of E¼ corner Sec. 13, T13S, R35W. 4 miles W of Russell Springs.
Date of Sampling:	July 9, 1957
Collectors:	James Allen, Elbert Bell, Henry Otsuki
Physiographic Position:	Upland. Elevation approximately 3200'.
Climate:	Average annual precipitation, about 18". Annual temperature, about 53°.
Topography:	Nearly level table below the summit of the High Plains mantled with loess. Gradient less than 1%.
Drainage:	Well drained.
Vegetation:	Sorghums.
Use:	Cultivated land. Broken from virgin sod about 1947.
Sample Numbers:	S-57-Kan-55-4-(1-8); LSL #5909-5916.

A_{1p} 0-3" S-57-Kan-55-4-1 LSL #5909	Dark-grayish-brown (10YR 4.5/2 dry; 3/2 moist) silt loam; weak fine and very fine granular; slightly hard; friable; noncalcareous; abrupt smooth boundary to
A_1 3-5" S-57-Kan-55-4-2 LSL #5910	Dark-grayish-brown (10YR 4.5/2 dry; 3/2 moist) silt loam; weak to moderate medium subangular blocky and granular; slightly hard; friable; noncalcareous; grades to
B_{21} 5-9" S-57-Kan-55-4-3 LSL #5911	Dark-grayish-brown (10YR 4.5/2 dry; 3/2 moist) light silty clay loam; weak medium subangular blocky and moderate medium granular; clayskins weak and patchy; hard; moderately firm; noncalcareous; grades to
B_{22} 9-13" S-57-Kan-55-4-4 LSL #5912	Grayish-brown (10YR 5.5/2 dry; 4/2 moist) light silty clay loam; weak medium subangular blocky and moderate medium granular; clayskins weak and patchy; hard; moderately firm; calcareous; grades to

B_{ca} 13-25" S-57-Kan-55-4-6 LSL #5913	Light brownish-gray (10YR 6.5/2 dry; 5.2/5 moist) coarse prismatic and weak coarse subangular-blocky; soft; very friable; calcareous; with common fine threads of $CaCO_3$; grades to
BC_1 25-38" S-57-Kan-55-4-6 LSL #5914	Light-brownish-gray (10YR 6.5/2 dry; 5/3 moist) silt loam; weak coarse prismatic and weak coarse subangular-blocky; soft; very friable; calcareous;
BC_2 38-50" S-57-Kan-55-4-7 LSL #5915	Light brownish gray (10YR 6.5/2 dry; 5/3 moist) silt loam; weak coarse prismatic and weak coarse subangular-blocky; soft very friable; calcareous;
BC_3 50-63" S-57-Kan-55-4-8* LSL #5916	Light-brownish-gray (10YR 6.5/2 dry; 5/3 moist) silt loam; weak coarse prismatic and weak coarse subangular-blocky; soft; very friable; calcareous; grades slowly to
C 63-70" Not sampled	Very pale-brown (10YR 7/3 dry; 5/3.5 moist) silt loam; massive; soft; very friable; calcareous.

Except where specified moist, the colors refer to dry soil.

Profile described by Henry T. Otsuki.

Soil type:	Ulysses silt loam, maximum profile
Location:	300 feet north and 50 feet east of southwest corner of section 16-T.12S-R.34W.
Date of sampling:	June 28, 1961
Collectors:	O. W. Bidwell, Elbert Bell, Richard Davis

A_{1p} 0-3"	Dark grayish-brown (10YR 4/2; 3/2 moist) silt loam; very weak fine granular structure of the plow layer; dry slightly hard, friable when moist; noncalcareous; abrupt boundary.
A_1 or 3-9" AB	Very dark-grayish-brown (10YR 3/2; 2/2 moist) heavy silt loam; moderate fine and medium granular structure; dry slight hard, friable when moist; noncalcareous; clear boundary.
B_2 9-14"	Dark-grayish brown (10YR 4.5/2; 3.5/2 moist; light silty clay loam; weak medium subangular blocky structure; dry hard, moderately firm when moist; weak and patchy clay films; noncalcareous; clear boundary.
B_3 14-20"	Grayish-brown (10YR 5.5/2; 4.5/2 moist) heavy silt loam; weak coarse subangular blocky structure; dry hard, friable when moist; calcareous; gradual boundary.

C_{ca}	20-40"	Light brownish-gray (10YR 6.5/2; 5.5/2 moist) silt loam; weak coarse prismatic structure; dry soft, friable when moist; calcareous with few fine threads of $CaCO_3$; diffuse boundary.
C	40-50"	Light gray (10YR 7/2.5; 6/3 moist) silt loam, massive; dry soft, friable when moist; calcareous loess.

Profile described by Elbert Bell

ACKNOWLEDGMENTS

The author expresses sincere appreciation to the following persons and organizations who made the writing of this thesis possible:

To Dr. O. W. Bidwell, major professor, for invaluable assistance in collecting soil samples and in manuscript preparation.

To Mr. Elbert L. Bell, Area Soil Scientist (Kansas Area 7), Soil Conservation Service, for assistance in locating sampling sites, aid in collecting samples, for writing profile descriptions, and for providing figures, tables, and other data used in this thesis.

To Mr. E. Wayne Brenn, Logan County, Kansas, Work Unit Conservationist, Soil Conservation Service, who provided the aerial photograph field mapping sheets from which the plates were made.

To Mr. P. C. Allen of the Physical Research Division of the Bureau of Public Roads and to the State Soil Scientists, Soil Conservation Service, of Kansas, Wyoming, Nebraska, and Oklahoma who provided laboratory data of the soils studied and discussed in this thesis.

To the Kansas State Office, Soil Conservation Service, for granting educational leave to pursue graduate studies.

To all other individuals and organizations who provided assistance, suggestions, and inspiration for both laboratory and field work and in manuscript preparation.

LITERATURE CITED

1. Aandahl, A. R. Soil Survey interpretation: theory and purpose. Proc. Soil Sci. Soc. Am. 22:152-154. 1958.

2. American Society for Testing Materials. Procedures for testing soils. April 1958. 544p.

3. Bartelli, L. J. Use of soils information in planning and development in urban-fringe areas. Mimeo. paper presented to 16th Annual Meeting of Soil Conser. Soc. of Am. July 30, 1961 13p.

4. Bell, E. L. Soil Survey of Logan County, Kansas. Soil Cons. Service. (in press).

5. Bouyoucos, G. J. The hydrometer as a new method for the mechanical analysis of soils. Soil Sci. 23:343-349. 1927.

6. Bureau of Public Roads. Engineering Test Data. Beaver Co., Okla. Sample No. 59-OK-4-7 (Richfield); 59-OK-4-13, 59-OK-4-14 (Ulysses). Dec. 1959.

7. _____. Deuel Co., Neb. Sample Nos. BPR S34464-4-5, BPR S34466-7-8, S58-Neb-25-5, S58-Nev-25-6 (Keith). July 1960.

8. _____. Dundy Co., Neb. Sample Nos. S57-Neb-29-1, S57-Neb-29-2. (Bridgeport). June 1958.

9. _____. Ford Co., Kans. Sample Nos. S59-Kans-29-8, S59-Kans-29-12 (Ulysses); S59-Ks-29-7, S59-Ks-29-11 (Richfield. May 1960.

10. _____. Goshen Co., Wyo. Sample No. BPR-94289-90-91 (Keith). March 1956.

11. _____. Hitchcock Co., Neb. Sample Nos. S540Neb-44-2, S54-Neb-44-4 (Keith). May 1957.

12. _____. Kimball Co., Neb. Sample Nos. S57-Neb-53-2, S57-Neb-53-11, S57-Neb-53-12, S57-Neb-53-26, S57-Neb-57-21 (Keith). Dec. 1957.

13. _____. Logan Co., Kans. Sample Nos. S59-Kan-55-1, S59-Kan-55-4 (Keith); S59-Kans-55-2, S59-Kans-55-3 (Ulysses). Jan. 1960.

14. _____. Morton Co., Kans. Sample Nos. S-60Kans-65-4, S-60 Kans-65-5 (Richfield): S-60Kans-65-3, S-60Kans-65-6 (Ulysses). Sept. 1961.

15. _____. Prowers Co., Colo. Sample Nos. S58-Colo-50-6, S58-Colo-50-7, S59-Colo-50-16, S59-Colo-50-18 (Richfield). Aug. 1960.

16. _____. Sharon Co., S. D. Sample Nos. 8385, 2747, 2386 (Keith). June 1961.

17. Bureau of Reclamation. Earth Manual, 1st. Ed. 1960.

18. Burmister, D. M. Identification and classification of soils--an appraisal and statement of principles. Symposium on The Identification and Classification of Soils. Spec. Tech. Pub. No. 113. Amer. Soc. for Test. Materials. June 1950. 91p.

19. Casagrande, A. Classification and identification of soils. Trans. of the Amer. Soc. of Civil Eng. 113:901. 1948.

20. Clayton, J. W., et al. Use of soil survey in designing septic sewage disposal systems. Va. Ag. Expt. Sta., V. P. I., Bull. No. 509. Aug. 1959.

21. Corps of Engineers. Unified soil classification system. Tech. Manual 3-357, with App. A and B. Waterways Expt. Sta., Miss. 1957 Revision. 50p.

22. Eikleberry, R. W. Physical land conditions affecting use, conservation, and management of land resources of Logan County, Kansas. Soil Cons. Serv. and Kans. Ag. Expt. Sta. Sept. 1954.

23. Federal Housing Administration. Engineering soil classification for residential developments. FHA Manual No. 373. Aug. 1959.

24. _____. Engineering soil classification for residential developments. FHA Manual No. 373, Revised. Nov. 1961.

25. Fenneman, N. M. Physiography of Western United States. McGraw-Hill. 1931.

26. Flora, S. D. The climate of Kansas. Climate of Kansas: Report of the Kansas State Board of Ag. LXVII:1-7. June 1948.

27. Fly, C. L. Natural agricultural resource areas of Kansas. Soil Conservation in Kansas. Report of the Kansas State Board of Ag. 1946.

28. Hill, D. E., and Shearin, A. E. Soils and Urban Development in Hartford County. Comm. Ag. Expt. Sta. Circ. 209. Feb. 1960.

29. Highway Research Board. Engineering Use of Agricultural Soil Maps. Bull. No. 22. 1949. 128p.

30. _____. Engineering Applications of Soil Surveying and Mapping. Bull. No. 83. 1953. 73p.

31. _____. Agricultural Soil Maps Status, July 1957. Bull. No. 22-R. 1957. 109p.

32. _____. Soil Series Cement Requirements. Bull. No. 148 by Leadabrand, J. A., et al. 1957. 17p.

33. _____. Air Photo and Soil Mapping Methods: Appraisal and Applications. Bull. No. 180. 1958. 38p.

34. _____. Soil Mapping: Methods and Applications. Bull. No. 299. 1961. 86p.

35. Jackson, M. L. Soil Chemical Analysis. Prentice-Hall, Inc. 1958. p. 240.

36. Johnson, C. R. Geology and Ground-Water Resources of Logan County, Kansas. State Geo. Surv. of Kans. Bull. 129. 1958. 175p.

37. Kellogg, C. E. Soil Classification: introduction. Soil Sci. 67:77-80. 1949.

38. Maytin, I. L., and Gilkeson, R. Soils of Clallam County. State of Wash. Eng. Soils Man., Wash. State Univ. 1961. 130p.

39. Michigan State Highway Department. Field Manual of Soil Engineering, 4th Ed. July 1960.

40. Miles, R. D., and Spencer, W. T. Cooperative Soil Mapping Projects in Indiana. Joint Highway Research Project, Purdue Univ. Bull. No. 1, 1961. Jan. 1961.

41. Morse, K. K., and Thornburn, R. H. Reliability of Soil Map Units. Mimeo. report, Univ. of Ill., undated. 12p.

42. Odell, R. T., Thornburn, T. H., and McKenzie, L. J. Relationships of Atterberg limits to some other properties of Illinois soils. Soil Sci. Soc. Am. Proc. 24:297-300. 1960.

43. Oklahoma State Department of Highways. Soils Manual. OSDH, Research Sec. 1959. 100p.

44. Portland Cement Association. Soil Primer. 1956. 86p.

45. Robb, A. D. Climates of the States: Kansas. U. S. Weather Bureau pub. No. 60-40. Nov. 1959.

46. Rose, A. C. Field methods used in subgrade studies. Public Roads Vol. 6. 1925.

47. Schollenberger, C. J. A rapid approximateomethod for determining soil organic matter. Soil Sci. 24:65-68. 1927.

48. Soil Conservation Service. Advisory Notice W-150, Engineering Section in Soil Survey Reports. 1958.

49. ______. Soil Memorandum, SCS-45. Engineering Interpretation from Standard Soil Survey. 1961.

50. Stokstad, O. Soil survey interpretations for engineering purposes. Soil Sci. Soc. Am. Proc. 22:164-168. 1958.

51. Stokstad, O., and Humbert, R. P. Engineering properties of soils. Soil Sci. 67:159-161. 1949.

52. Thornburn, T. H., and Larsen, W. R. A Statistical Study of Soil Sampling. Univ. of Ill. Civil Eng. Studies. 1959.

53. United States Department of Agriculture. Soils and Men. Yearbook of Agric. 1938.

54. Wright, P. H. Engineering Use of Agricultural Soil Surveys in Tennessee--A Pilot Study. M. S. thesis (C. E.) Univ. of Tenn. Dec. 1958.

ENGINEERING PROPERTIES AND CLASSIFICATION OF SELECTED SOILS OF LOGAN COUNTY, KANSAS

by

RICHARD DALE DAVIS

B.S., Colorado State University, 1957

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1962

A study was made to determine the engineering properties and classification of ten of the thirty-two soil series and mapping units recognized in the Logan County, Kansas, soil survey. These ten series were selected on a basis of widespread distribution both within Logan County and elsewhere, and in order to sample the whole range of parent materials and textural types found in the county. Three major horizons (usually A, B, and C) of each profile were sampled.

Due to the extremely wide occurrence and large extents of Ulysses silt loam and Keith silt loam both in Logan County and in other states of the Great Plains region, these soils were more extensively studied. Three horizons each of Ulysses and Keith soils were sampled at sites of modal, minimal, and maximal profile development to determine if significant differences existed in the engineering properties and classification.

The chemical tests performed, for characterization only, were approximation of organic matter content, determination of the pH of saturated soil paste and saturated paste extract, and determination of the conductivity of the saturated paste extract.

Physical tests performed were complete mechanical analyses by means of sieving and sedimentation (Bouyoucos hydrometer method), determination of Atterberg limits (liquid limit and plastic limit), and determination of optimum water content to achieve maximum dry density under standard compactive effort. The results of the former three tests were used to determine the classification by engineering properties according to the Unified system and the American Association of State Highway Officials (AASHO) method.

For the purposes of this study, significant differences in engineering properties and classification, both among horizons and among profiles, were determined by relative differences in the AASHO classification. This classification was judged to be the most sensitive, accurate index of changes in engineering properties presently available.

It was determined that loessial soils developed under similar conditions exhibited very little significant difference in engineering properties in any given horizon. Thus it was shown that, for Ulysses and Keith soils in Logan County, engineering properties were identical or very similar for a given series regardless of degree of development.

The engineering properties and classification of the other soil series clearly reflected the effect upon these properties and classification of texture, type of parent material, and degree and type of soil forming processes, particularly the development to textural B horizons.

The results of the examination of four of the soil series were compared with Bureau of Public Roads (BPR) data of the same soil series in other locations in Kansas, Oklahoma, Colorado, Nebraska, Wyoming, and South Dakota. One soil, the alluvial Bridgeport loam, was found to differ significantly in its engineering properties from profiles collected elsewhere due to the nature of its parent material. The other three series (Ulysses, Keith, and Richfield silt loams) were found to possess characteristics identical to, or not too different from those of other locations, with few notable exceptions. These exceptions were believed to be due to phase variations of the modal profile, in which case a difference in engineering behaviour might be predicted from study of the modal type profile description.

Again, the influence of textural type and other environmental conditions were illustrated.

It has been further demonstrated and concluded that the pedological approach and classification by series, with profile descriptions, is a reliable means of extrapolating information of engineering significance within a soil series from one location to another some distance away.

A method of interpreting and presenting soil survey data for engineering uses has been presented. This method incorporates information regarding geography, geology, climate, and soils presented in charts, tables, block diagrams, maps and aerial photographs.

The method was illustrated for Logan County, Kansas, and was undertaken to evaluate 39 properties and uses for engineering on a basis of both determined and estimated properties and classification.