# ENGINEERING PROPERTIES OF KANSAS SOILS

by 1264

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# INTRODUCTION

Soils, like water, are one of man's most vital natural resources. Soil covers most of the land surface, except for the steep and rugged mountain peaks and the lands of perpetual ice and snow. Soil is defined by engineers as the natural occurring rock debris, including the enclosed water and organic matter, which is found on or near the surface of the earth and can be moved by conventional earth moving machinery. The agriculturalist defines soil as the material on the surface of the earth capable of supporting vegetation. The geologist defines soil as all unconsolidated uncemented material produced by the weathering of the earth's mantle. In their natural state, soils are formed by the decomposition and disintegration of the earth's rocky crust, some remaining in place as residual soils while others are transported and deposited by the natural agencies - gravity, wind, water, and ice in their present position. Variations in the soil mantle occur due to the countless combinations of local conditions that have existed during millions of years and to the varying soil constituents and it is thus likely that there are no two locations where the soils are identical throughout their depths to bedrock. Because of the variations in composition and heterogeneous deposition, natural soils show extreme ranges of strength and compressibility. Still all soils have many characteristics in common. Every soil consists of mineral, organic matter, water, and air. The proportions vary, but these major components are usually present.

It is common to be told that soils vary to a degree that defies prediction. The purpose of this report is to show that the soils of Kansas fall naturally into eleven so-called physiographic provinces, Fenneman (1) and within each province the soils fall into three natural categories; upland, slope, and valley soils. Further it will be shown that the upland soils within a province will be similar over the entire province as will the slope and valley soils though the upland, slope, and valley soils will vary greatly from each other. The basic variation within each area usually lies in the thickness of the soil stratum rather than in the physical characteristics of the soil. Thus the classification, strength, and compressibility of an upland soil within a province will be found to be surprisingly constant.

Most soils have a profile, that is, a succession of layers above the weathered rock. These layers are the result of vegetation growth and are of prime importance to the agriculturist. They were first described by Dakuchaev (2) in 1873 and their importance to engineering construction has only recently been recognized. The soil profile consists usually of three or more layers (known as horizons) lying upon each other successively like the pages of a book. Most soil profiles include these three master horizons, identified by the letters from uppermost to lowermost as the A, B, and C horizons. The combined A and B horizons are called the solum, sometimes called "the true soil." The C horizon is the parent material from which the solum was derived and thus lies beneath the A and B horizons.

Soils have been classified in many ways, since the description of various soil types will vary according to the intended use of the soil. For the soil engineer, soil is either a foundation upon which he will rest his structure or a type of borrow material which he can use for fills and embankments. Casagrande (3) devised the most commonly used engineering classification scheme which was modified by the U. S. Army Corps of Engineers (4). Most Highway Departments use the A. A. S. H. O. scheme (5) while engineers constructing airfields use the F. A. A. classification (6). The engineer is also interested in the size of particles, Krumbein (7), Casagrande (8), ASTM (9), the effects of moisture on the soil as measured by the Atterberg limits test (10), the shearing strength, Coulomb (11), Rankine (12), Bishop and Henkel (13), the compressibility, Terzaghi (14) and in some cases the mineralogy. Engineers must also consider the competing economic uses that might be made of the soils by agriculturists and others.

## Statement of the Problem

In Kansas, soils and rock formations have been described locally but no effort has been made to review the overall engineering picture of the soils. This study has been carried out to aid engineers in predicting in advance the type of soil to be expected in various parts of the state and the engineering problems that may be encountered so that the soil investigations for structures can be both adequate and economical.

Until recent times, soil engineers have relied almost exclusively upon detailed borings for the appraisal of soil conditions in connection with engineering projects. Each project was pursued without any idea of the soils that would be found and thus the soil investigations all started from "scratch." It was not possible to tentatively choose a reasonable foundation type until the first hole was drilled. Thus much time was lost either during the drilling or by the numerous return trips to the site to secure adequate information. Too often a spread footing is used on sites where drilling was extended to 100 feet while on other projects, piles were designed that penetrated deeper than the drill holes. This procedure is certainly uneconomical and time consuming, since it requires extra sampling and testing and/or unnecessary risk.

Another method for preparing soil investigations is proposed in this report, based on the principle that soils can be classified in place by means of the soil profile characteristics, easily obtained from the Department of Agriculture and the Geological Surveys. Long range planning and preliminary estimates can be made with the proper use of such information, thus saving time and money. All general soil information must be checked by some detailed borings and final recommendations made on the findings from the detailed soil report.

The following general guide for soil investigations is suggested:

1. Obtain information concerning the structure including size, shape, tolerance to deflections and expected permanence.

2. Check the expected soil conditions from the Department of Agriculture, county soil reports and bedrock condition with the State Geological Survey.

3. Design a tentative foundation based on the expected soil conditions and type of structure.

4. Lay out and conduct a soil investigation that will measure soil variability and exact thickness of the various soil layers. Plan for sampling to yield information on shear strength and compressibility to a depth, dependent upon the expected size and spacing of the footing, where stress is dissipated to a negligible amount.

5. Reevaluate the foundation concept if necessary.

6. Complete soil investigation and finalize foundation design.

Scope of the Study

The scope of this report is a thorough search of all the existing literature from the State Highway Commission of Kansas, the State Geological Survey of Kansas and the U. S. Department of Agriculture for data, much of which is unpublished, that will allow a generalization of the soil conditions in the various portions of Kansas.

## GEOGRAPHY OF KANSAS

Kansas is at the heart of the Nation. Its central position among the states is evident in Fig. 1. Kansas has the distinction of having within its borders two significant landmarks. One of these is the geographical center of the adjoining 48 states, located approximately one mile north and one mile west of the town of Lebanon in Smith County, Kansas; the other is the Meades Ranch triangulation station or the geodetic datum known as the North American datum of 1927 in Osborne County, Kansas. This is the point of origin of all Federal mapping in the United States as well as in Canada and Mexico.

Kansas lies between 36° 59' 55.2" and 40° North latitude, and 94° 37' 03.4" and 102° 03' 02.3" West longitude. It is almost in the shape of a parallelogram with the exception of the northeast where the Missouri River cuts across the corner of the state. The greatest dimension, 411 miles, is east and west and the average width north and south is about 208 miles.

Kansas experiences much more extremes of temperature than would be expected for its midwest location. The three climatic factors responsible for the extremes in temperature are the following.

1. Altitude. Kansas lies between 686 feet in the east and 4,135 feet in the west, above sea level. Since temperature changes at the rate of about 3.3°F for each 1,000 feet in elevation, this makes a difference in the weather and climate in Kansas from east to west.

2. Land and Water Bodies. Kansas has a continental location, far from large oceanic bodies. Land cools and heats four to five times faster than water and this heating in summer and cooling in winter has much to do with the extremes of temperatures.

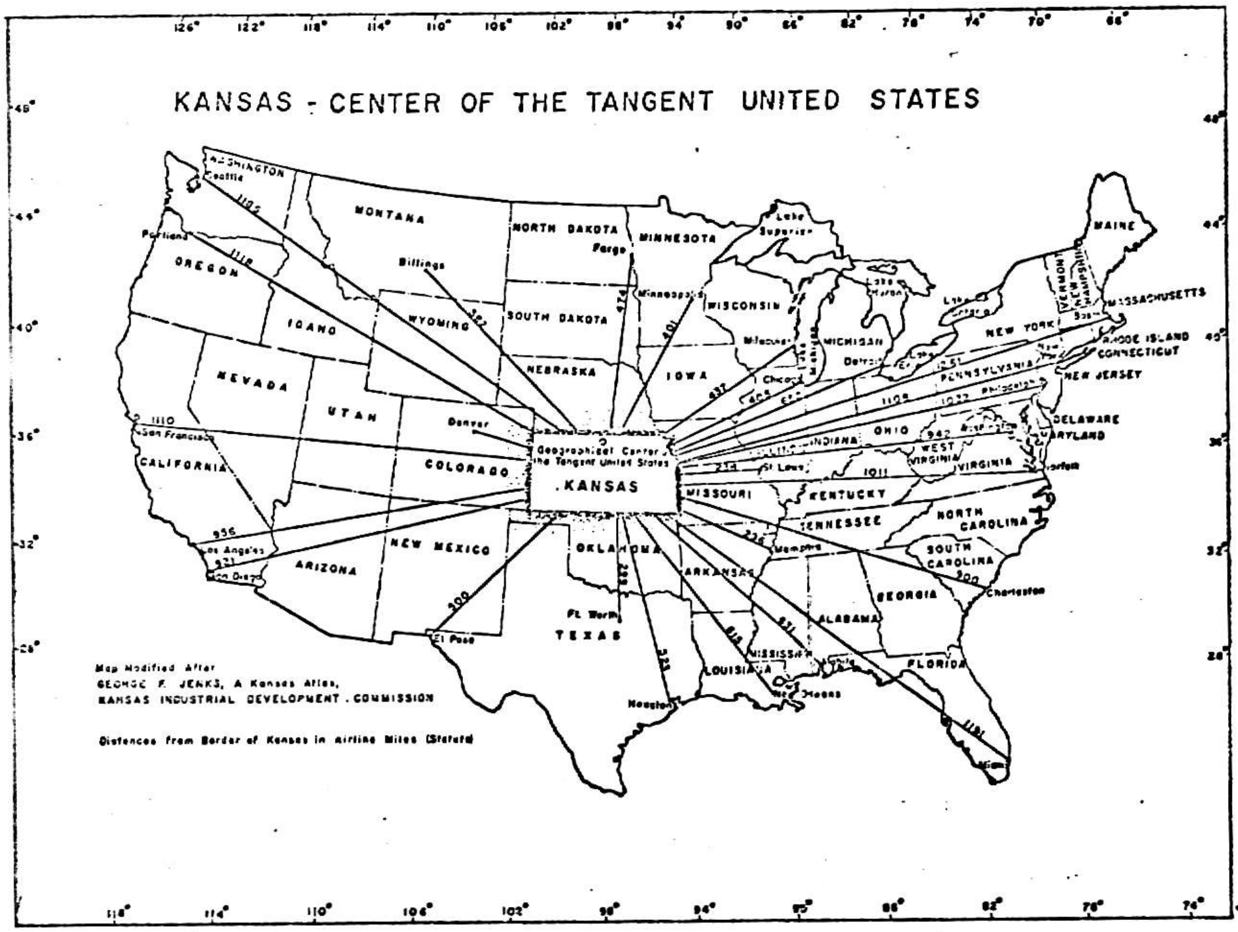



Fig. 1. The State of Kansas, from Self (15)

3. Cyclonic Storms. Kansas lies in the belt of cyclonic storms, an area that receives cold and warm air masses at irregular intervals, but especially during the winter months. These air masses cause such weather phenomena as high winds, tornadoes, hail, frost, blizzards, heat, floods and droughts.

As a result of these storms and the variation in altitude, Kansas has three rather distinct climatic zones (Fig. 2). Average winter and summer temperatures in these three zones are shown in Table 1.

The nearest ocean body to Kansas is the Gulf of Mexico and since there are no mountain barriers to onshore winds that blow over Kansas from this source area, the Gulf is by far the greatest source of precipitation in this area. Western Kansas is considerably farther from the Gulf of Mexico than is eastern Kansas and since there is a general trend for air to move from west to east, the onshore southerly winds tend to shift towards the east as they move towards Kansas. Thus western Kansas receives considerably less precipitation than eastern Kansas.

Normal annual precipitation ranges from slightly more than 40 inches in southeastern Kansas to near 30 inches in the northeastern counties and decreases rather uniformly to the west to a low of some 16 inches per year. The average for the state as a whole is about 27 inches (Fig. 3).

There is no prolonged dry season, but because of the fact that warm air can hold more moisture than cold air, most of the precipitation comes during the warm season. This rainfall is due to air being lifted and cooled by convection causing the well-known local thunderstorms of Kansas.

The month of least precipitation is January, when only 3 percent of the year's fall of moisture occurs. There is a steady increase in normal

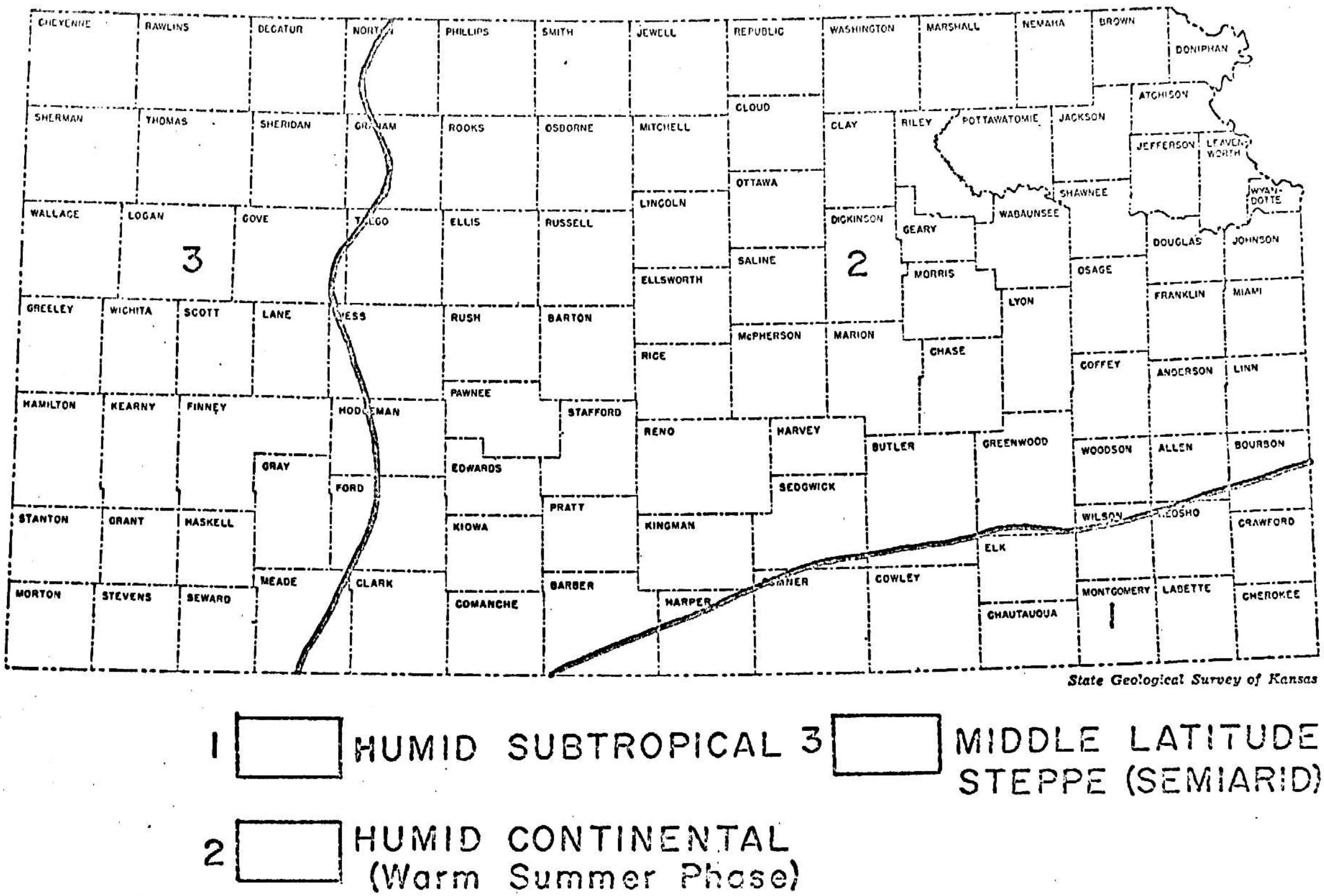



Fig. 2. Climates of Kansas

Table 1.

Average Temperatures from Mohler (16).

A. Humid Subtropical Climate

| Month | Average temperature |
| --- | --- |
| January (winter) | above freezing |
| July (summer) | 80° F |

B. Humid Continental

| Month | Average temperature |
| --- | --- |
| January (winter) | below freezing |
| July (summer) | 75° F - 80° F |

C. Middle Latitude Steppe

| Month | Average temperature | |
| --- | --- | --- |
| | Southern part | Northern part |
| January (winter) | above freezing | below freezing |
| July (summer) | 75° F - 80° F | 75° F - 80° F |

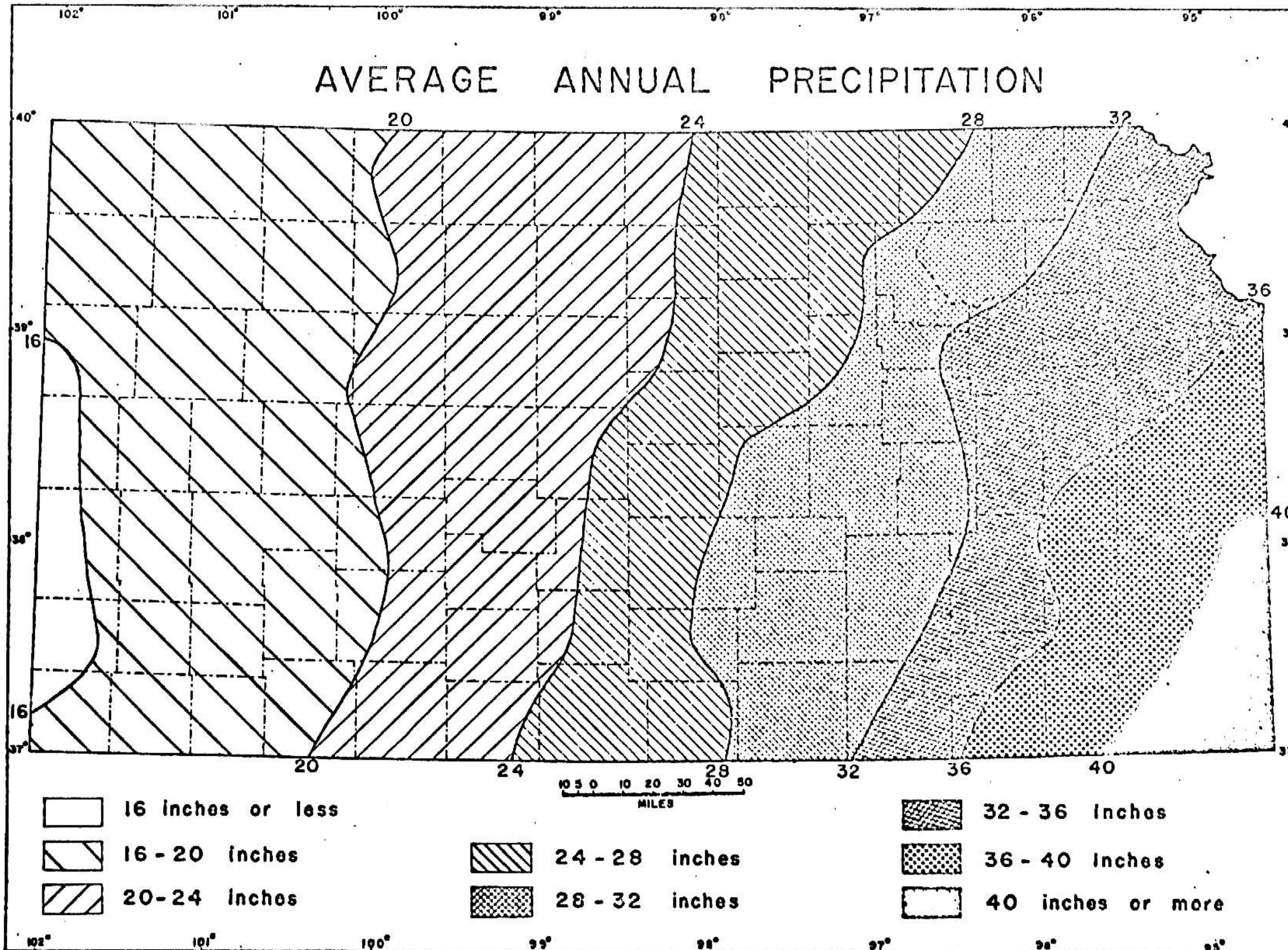



Fig. 3. Average Annual Precipitation, from Flora (17)

precipitation until June, which on the average receives more rain than any other month. After that, rainfall decreases until near the end of July, except in the extreme western counties. After September, there is a steady decline in precipitation until the end of the year.

# GEOLOGY OF KANSAS

Geology is the science that treats the study of the earth, its material and structure, and the agencies and processes that affect the earth as a whole. Geological knowledge is especially useful in soil engineering in predicting structure, stratigraphy, and variations, both horizontal and vertical, in the soil and rock strata. A wealth of information is available from the State Geological Surveys such as:

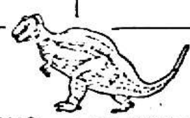
1. The thickness and character of the rock strata in detail to the underlying Precambrian crystalline rock.
2. The depth and character of reliable water supplies.
3. The discontinuities such as faults, folds, and jointing in the bedrock including strike, dip, and extent.
4. The presence of economic minerals and the extent of commercial extraction in active areas.
5. The fluctuations of water level in streams and the change in the stream channel that are expected.

The bedrock in Kansas ranges in age from Precambrian to Quarternary (Table 2). Little is known about the lower Paleozoic rocks, because of the depth of burial beneath the state (Fig. 4).

At the close of the Precambrian period, the irregular surface of Kansas was composed of igneous and metamorphic rocks. Since then shallow seas have covered much or all of Kansas intermittently for millions of years during the Paleozoic and Mesozoic eras. Streams from surrounding highlands and the wave action against the shores deposited successive layers and mixtures of clay, silt, sand, and lime in these seas. These sediments were lithified into sedimentary rock units as the result of cementing action and compaction following deposition.

Table 2.

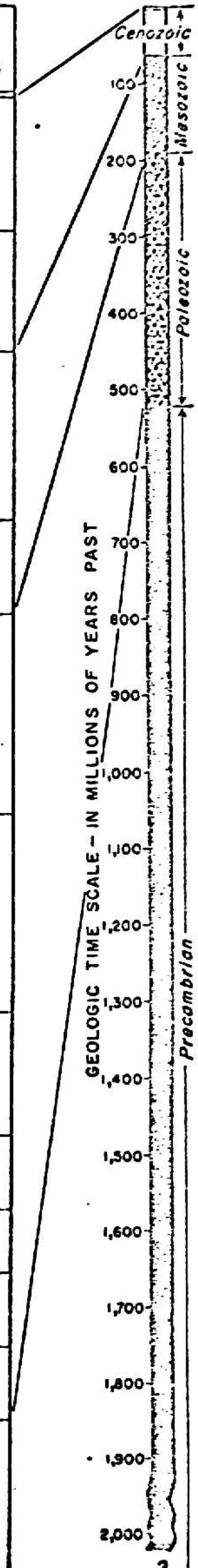
GEOLOGIC TIMETABLE AND KANSAS ROCK CHART

| ERAS | PERIODS | ESTIMATED LENGTH IN YEARS* | TYPE OF ROCK IN KANSAS | PRINCIPAL MINERAL RESOURCES |
|---|---|---|---|---|
| CENOZOIC | QUATERNARY (PLEISTOCENE)  | 1,000,000 | Glacial drift; river silt, sand, and gravel; dune sand; wind-blown silt (loess); volcanic ash. | Water, agricultural soils, sand and gravel, volcanic ash. |
| CENOZOIC | TERTIARY | 59,000,000 | River silt, sand, and gravel; fresh-water limestone; volcanic ash; bentonite; diatomaceous marl; opaline sandstone. | Water, sand and gravel, volcanic ash, diatomaceous marl. |
| MESOZOIC |  CRETACEOUS | 70,000,000 | Chalk, chalky shale, dark shale, vari-colored clay, sandstone, conglomerate. Outcropping igneous rock. | Ceramic materials; building stone, concrete aggregate, and other construction rock; water. |
| MESOZOIC | JURASSIC | 25,000,000 | Sandstones and shales, chiefly subsurface. | |
| MESOZOIC | TRIASSIC | 30,000,000 | | |
| PALEOZOIC | PERMIAN  | 25,000,000 | Limestone; shale; evaporites (salt, gypsum, anhydrite); red sandstone and siltstone; chert; some dolomite. | Natural gas; salt; gypsum; building stone, concrete aggregate, and other construction materials; water. |
| PALEOZOIC |  PENNSYLVANIAN | 25,000,000 | Alternating marine and non-marine shale, limestone, and sandstone; coal; chert. | Oil, coal, limestone and shale for cement manufacture, ceramic materials, construction rock, agricultural lime, gas, water. |
| PALEOZOIC | MISSISSIPPIAN  | 30,000,000 | Mostly limestone, predominantly cherty. | Oil, zinc, lead, gas, chat and other construction materials. |
| PALEOZOIC | DEVONIAN | 55,000,000 | Subsurface only. Limestone, black shale. | Oil |
| PALEOZOIC | SILURIAN | 40,000,000 | Subsurface only. Limestone. | Oil |
| PALEOZOIC | ORDOVICIAN  | 80,000,000 | Subsurface only. Limestone, dolomite, sandstone, shale. | Oil, gas, water. |
| PALEOZOIC | CAMBRIAN | 80,000,000 | Subsurface only. Dolomite, sandstone. | Oil |
| PRE-CAMBRIAN | (Including PROTEROZOIC and ARCHEOZOIC ERAS) | 1,600,000,000 + | Subsurface only. Granite, other igneous rocks, and metamorphic rocks. | Oil and gas. |

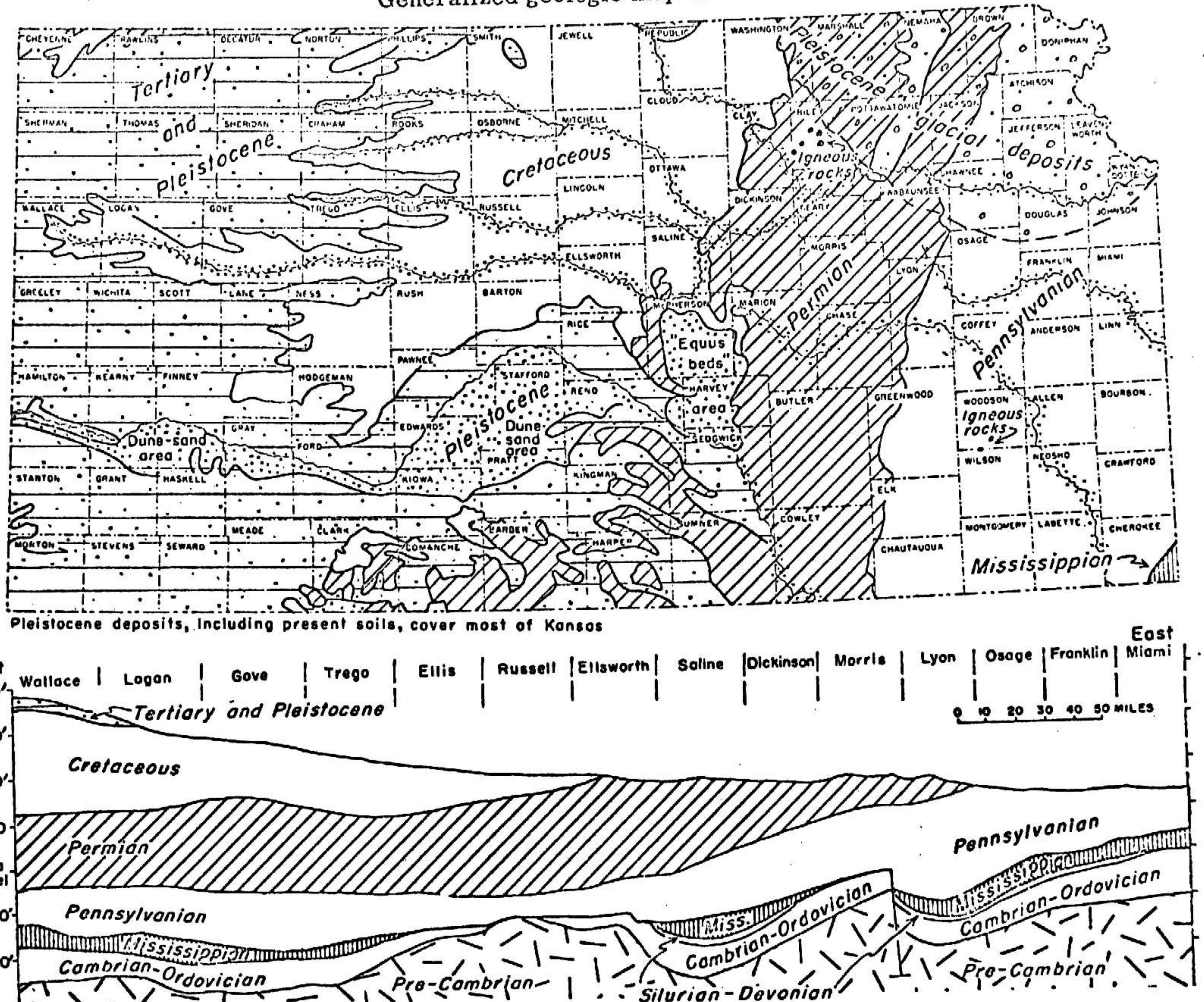
(Not scaled for geologic time or thickness of deposits)

*Committee on Measurement of Geologic Time, National Research Council

State Geological Survey of Kansas



Generalized geologic map of Kansas




Generalized cross section of Kansas rocks

—State Geological Survey of Kansas

Fig. 4. Generalized Geologic Map of Kansas

After the retreat of the Cretaceous seas, Kansas underwent a long period of erosion. Late in Tertiary time, extensive deposits of gravel, sand and silt were spread all over the state by streams coming from the Rocky Mountains to the west, forming a huge deltaic like layer of coarse debris which is thickest near the mountains and thins to negligible thickness at the break of the plains.

During Pleistocene time, two huge continental ice sheets, the Nebraskan and the Kansan, invaded northeastern Kansas leaving behind the overcut and refilled river valleys and the till plains. Since Pleistocene time, the surface of Kansas has had essentially its present configuration subject day by day to erosion by wind and water.

Essentially all the surface rocks of Kansas ranging in age from Mississippian to the present are of sedimentary origin. These consist mainly of shale, sandstone and limestone. The maximum thickness of sedimentary rocks in the deepest part of the Hugoton Embayment is only about 9,500 feet. The section of sedimentary beds in other parts of Kansas is relatively thin as compared with this and the geosynclinal troughs and deeper basinal areas such as the Denver basin.

Igneous rock masses occur in Kansas in only two counties, Riley and Woodson. The Riley County igneous rocks, probably of Cretaceous age, are greenish, fine-grained basic volcanic rocks. In Woodson County, boulders of granite and granite porphyry are found scattered over an area of about 120 acres. The origin and age of these granite bounders is still in doubt, Schoewe (18).

The rock strata in Kansas constitutes a very shallow synclinal structure as shown in the Generalized cross-section of Kansas rocks (Fig. 4).

In the eastern one-half, the rocks dip mainly towards the west, while in the western, the main inclination is in an easterly direction. Seldom does the dip of surface rocks exceed 35 feet to the mile, Moore, Frye and Jewett (19).

Two definite structures are noted in the east-west cross-section (Fig. 5), at wells No. 24 and 13, which cause the Precambrian to occur at a shallower depth. These structures fade out to the south and are not evident in Fig. 6. Faulting and folding are quite common in the bedrock on a local scale and these have been carefully delineated by the Kansas Geological Survey in most areas.

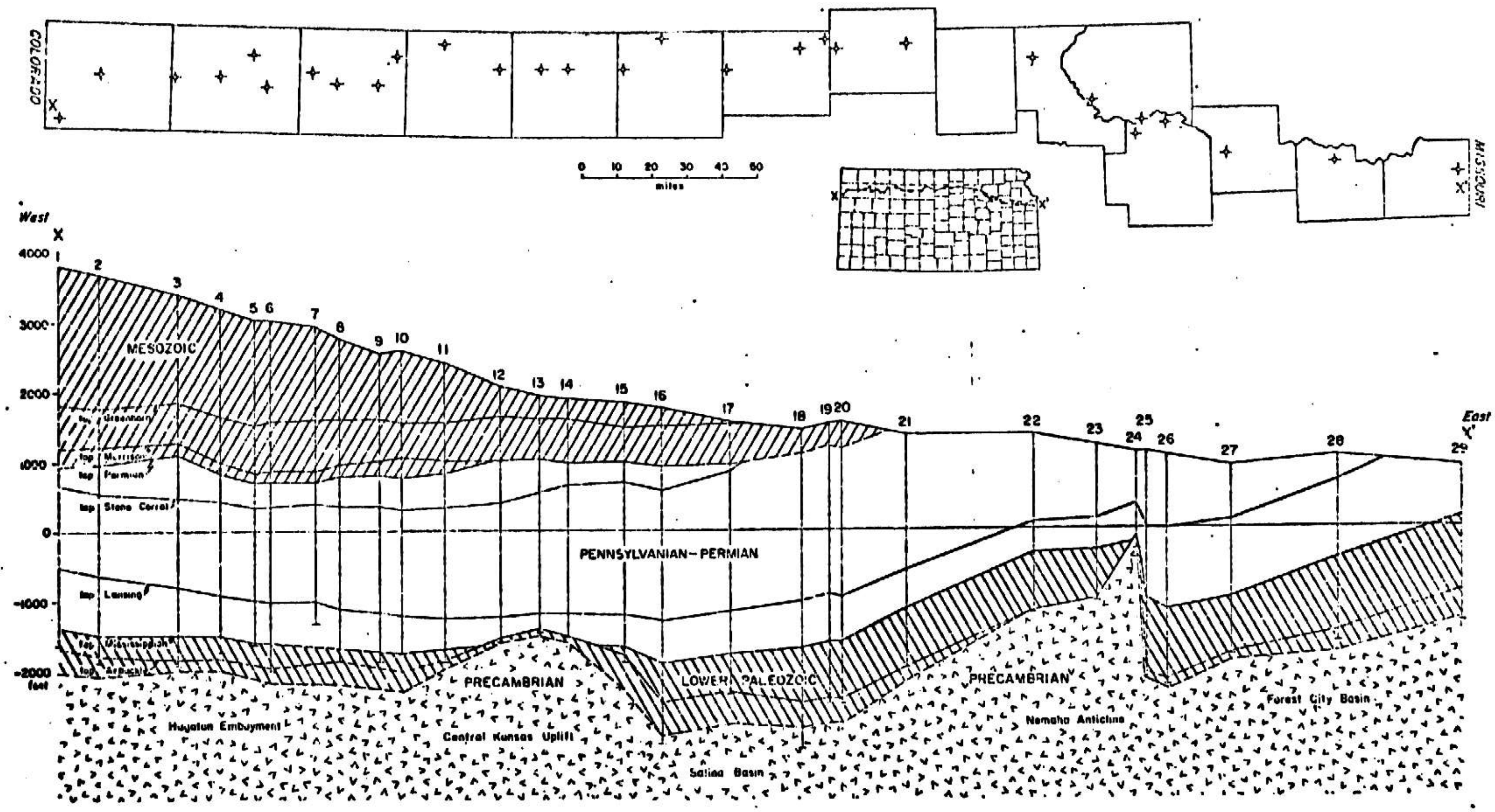



Fig. 5. West-east Cross Section from Sherman County to Johnson County showing stratigraphic relation of major units in Kansas.

from Merriam and Hambleton (20)

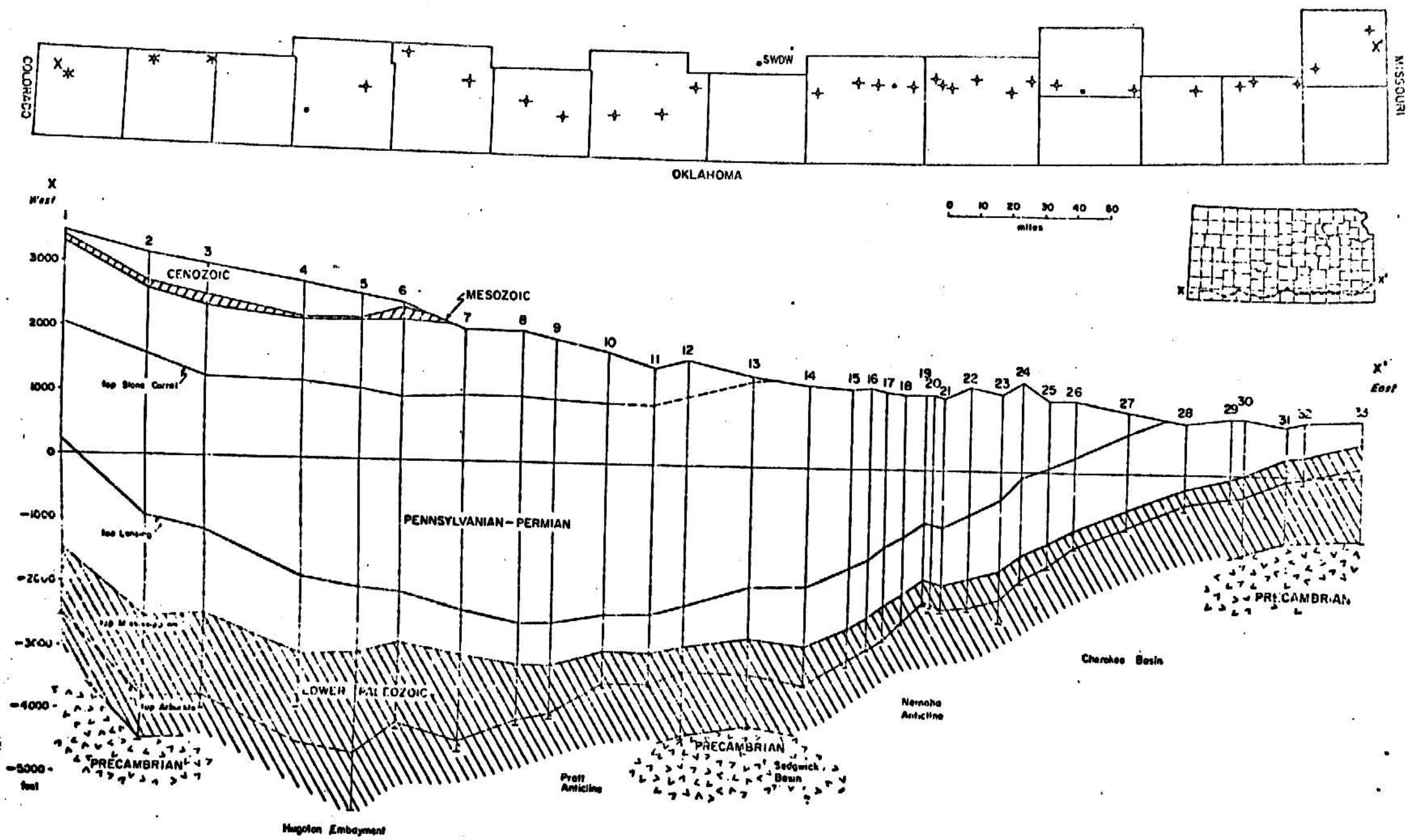



Fig. 6. West-east Cross Section from Morton County to Crawford County showing stratigraphic relation of major units in Kansas.

from Merriam (21)

## PHYSIOGRAPHIC PROVINCES OF KANSAS

The term physiography, according to Lobeck (22), is used in the same sense as geomorphology, except that it includes treatment of the atmosphere and oceans. The physiography of the United States was first completed by Fenneman (1 and 23). The study of physiography attempts to separate an area into subdivisions which have a similar geological history, a common geological structure, similar soil and rock materials, and lying within the same climatic regime. Thus the soil profile, the soil materials and the rock below the soil within the province will be similar or will vary in a logical and predictable manner.

Within a physiographic province in Kansas, the soils fall into three natural categories:

1. The Upland Soils.
2. The Soils occurring on slopes to streams and rivers.
3. The Valley Soils.

Thus within a province, the soils on all uplands will be the same with only a difference of thickness in a predictable manner and similarly those of the slopes and the valleys.

The state of Kansas is best described as a plain sloping from some 4,000 feet in Wallace County to a low of 700 feet in Montgomery County. The local relief is usually less than 100 feet but reaches a maximum of about 400 feet in areas bordering major stream courses. The physiographic provinces of Kansas are shown in Fig. 7. It will be noted that the bulk of the state lies in the Great Plains province which has been divided into the High Plains to the west and a number of minor provinces to the east, which in general represent the break from High Plains to Central Lowland. The eastern portion

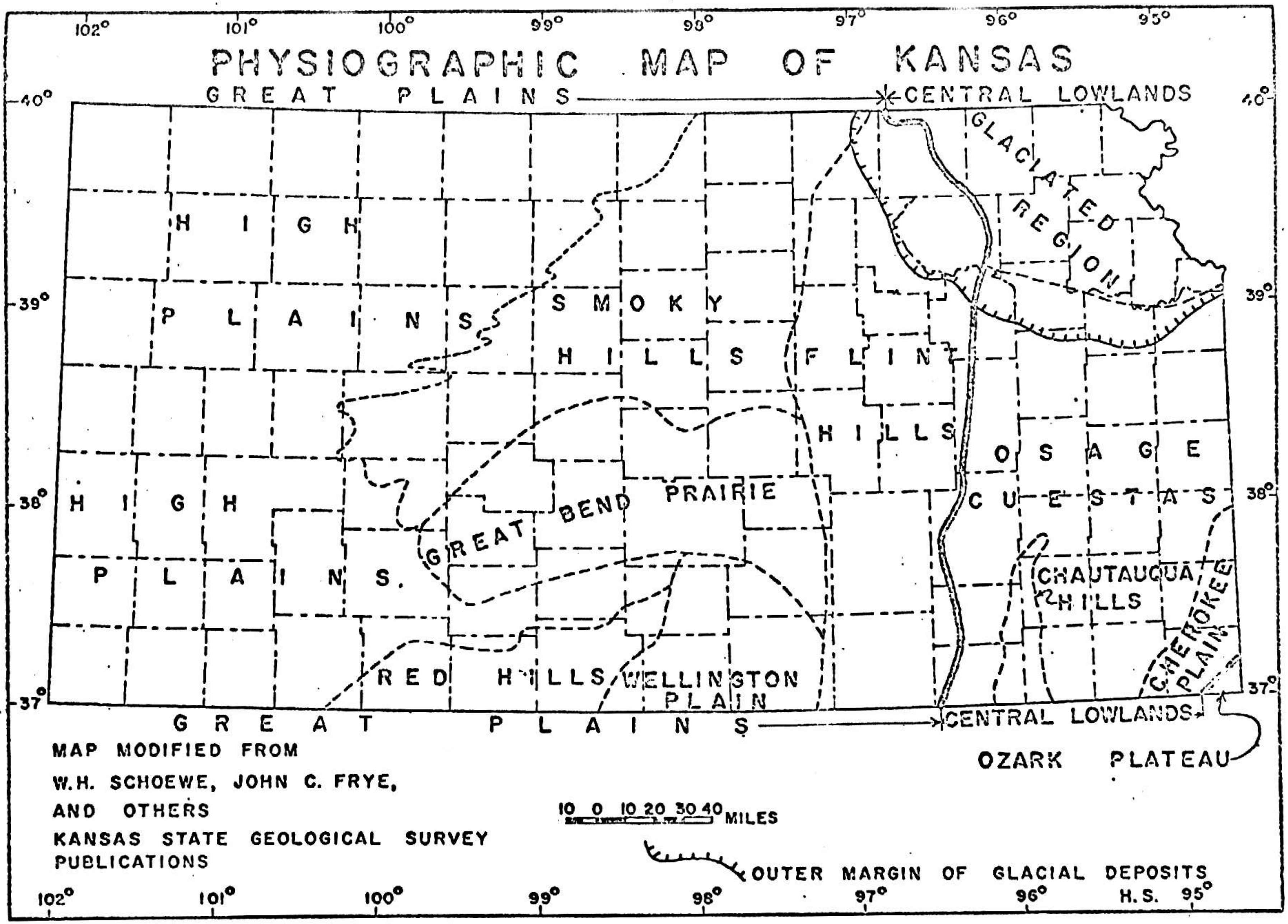



Fig. 7. Physiographic Map of Kansas

of the state lies within the Central Lowland province and is divided into a northern glaciated area and a southern cuesta plains province.

Kansas has been divided into the following eleven physiographic regions, Frye and Leonard (24).

1. Dissected Till Plains

The Dissected Plains lie in the northeast portion of Kansas. It is an area of well-rounded rolling hills underlain by glacial till of Kansan and Nebraskan age, mantled by loess. The area is dissected by a well established dendritic stream pattern. Bedrock, mostly shale and limestone of Pennsylvanian age is exposed in the deeper valleys. The stream valleys are overcut by some 50 feet and are filled with alluvium. The soil horizons are quite thick on the loess.

2. Osage Cuesta Plain

The Osage Cuesta Plain consists of a series of northeast-southwest, irregularly trending east-facing escarpments between which are flat to gently rolling plains. The cuestas are developed on the less resistant rock of Pennsylvanian and lowermost Permian age. Stream valleys leading from the Dissected Till Plains are overcut more than those originating in the cuesta area. The soils are residual and relatively thin except in these overcut valleys which may have as much as 100 feet of alluvial soils.

3. Cherokee Plain

A relatively flat area to the east of Osage Cuesta developed on the cherty limestones and weak shales of Mississippian and lowermost Pennsylvanian age. The stream valleys are wide, shallow and flat-bottomed. The soils are residual and quite thin.

4. Ozark Plateau Province

A very small portion of Springfield Plateau of Missouri extends into the extreme southeast corner of Kansas in Cherokee County. The surface is essentially flat with sufficient slope to effect good drainage. The area, less than 50 square miles, constitutes the border of a westward dipping structural plain, which lies over some 50 feet of limestone of Mississippian age.

5. Chautaqua Hills

Chautaqua Hills are the rounded hills without a Cuesta appearance, developed on the thick sandstones of the Douglas group. As a result of erosion in the sandstone belt, the surface has been dissected into a series of low hills. The relief is nowhere more than 250 feet.

6. Flint Hills Upland

A series of north-south trending Cuesta ridges extending entirely across east-central Kansas. It is the most rugged hilly surface feature in Kansas and has a structurally controlled drainage. The bedrock is the cherty limestone of early Permian age. The soil is residual and has a very thin A horizon over a 3 to 6 feet B horizon of clay containing chert fragments.

7. Smoky Hills Plain

It is a dissected High Plains area formed by erosion of the High Plains. This area is divided into an eastern section underlain by the Dakota sandstone and a western section underlain by the Carlile shale, lying over the prominent Greenhorn limestone cuesta. Age of bedrock is Cretaceous. The soil horizons are quite thin and have developed from both the deposition of granular materials and windblown materials.

8. Great Bend Region

This area developed as a result of deposition during the Pleistocene age. Sand dunes derived from Pleistocene alluvium dominate the topography. Drainage is well established and the streams indicate that maximum erosion occurred during early Pleistocene with subsequent deposition filling the overcut valleys. Age of much of the rock is recent Quarternary. The soil horizons are thin or absent.

9. Wellington Area

An area of rolling topography mostly under-cultivated and with reddish colored soils. Shales and limestones of the Permian age outcrop the area. The soil horizons are very thin or absent.

10. Red Hills Area

A scenic hilly area of the most rugged and striking topography. It is similar to the Smoky Hill section except for the difference in bedrock type. Rock layers are shale, sandstone and gypsum, mostly Permain in age with some Quarternary. Sinkholes and red beds of rock and soil are present. The soil horizons are quite thin or absent.

11. High Plains Region

It is a flat to rolling treeless plain bounded on both the east and the west by an escarpment. Along the eastern margin, the escarpment in the north is formed by the Fort Hays limestone and in the south by the Ogallala formation. The western escarpment is west of the Colorado line. Most of the rock is Tertiary in age, but considerable Cretaceous chalky limestone is present with some Quarternary age deposits along the Arkansas River. The soil horizons are thin or absent and have developed on Pliocene and Pleistocene alluvium and windblown silts and sands.

## SOILS OF KANSAS

Both transported and residual soils are well represented in Kansas. The areas of each are distinct and well delineated with southeastern and Central Kansas, the site of residual soils while the remaining portion of Kansas is underlain by transported soil materials.

The residual soils have developed on progressively younger bedrock from east to west. The bedrock of extreme southeastern Kansas is Mississippian while to the west a wide band of Pennsylvanian and then Permian occur with a north-south trend, as shown in Fig. 4. Soils in these areas have developed on limestone, shale and sandstone, with shale the predominant parent material. In this area varying soils occur in bands as the bedrock trends. Thus the soil may change abruptly to east or west of a given area, but is apt to be constant for long distances north or south, parallel to the axis of the outcrop.

Relief in this area is high and numerous steep slopes afford an excellent opportunity to examine the bedrock and soils. Relief in excess of 200 feet is not uncommon from the upland to the valley floors. Most major streams flow in a west to east direction originating in the Colorado highlands. Stream valleys are sharp sided and generally timbered with hardwood forests. All major valleys are overcut by 50 to 100 feet and are underlain by alluvium.

The mineralogy of the soil is obviously dependent upon the parent material, but clays of the Illite and Montmorillonite type mixed with silt and sand sized particles of quartz and feldspar predominate. In most cases, mineralogy is not important except in those soils having a liquid limit above 40. These should be checked for undesirable volume change characteristics.

The transported soils fall into all of the categories; gravity, wind, ice and water transported materials, with the wind transported materials on the surface predominant over all others.

The transported soils fall into the following categories:

1. The alluvium derived during the uplift of the Rocky Mountains, which is found in the western part of the state and is usually overlain by wind deposited soil materials. This stratum has been named the Ogallala formation by the geologists and consists of coarsely elastic fragments of quartz, feldspar and rock fragments. The stratum contains irregular discontinuous beds of sands and gravels cemented by calcareous materials and similar shaped and sized beds of clay and silt. The stratum is coarsest and thickest in the west becoming finer and thinner in the east, until it ends at the break of the Plains.

2. The wind transported silts and fine sands which cover much of the state were derived from two sources: the semi-arid rain shadow east of the Rockies and the wide river valleys of Glacial and Post-Glacial times. These are in general so intermixed and similar as to be considered as one material. In general, the blow sand is confined to extreme western Kansas and to the Great Bend area. This "blow sand" is predominantly derived from the arid region and is a poorly graded fine sand, consisting of quartz and feldspar.

The loess is thickest and coarsest near the Colorado line becoming thinner and finer-grained to the east. To the north or east of each major stream, the loess thickens and is coarser, thus causing an unusual complication in this remarkably uniform material. The loess has a maximum thickness of some 100 feet in western Kansas and is rarely more than 25 feet in central and eastern Kansas. The mineralogy is similar to that of the blow sand with quartz and feldspar predominating, except in the badly weathered loess deposits in which the clay minerals are a significant fraction.

3. The glacial till is confined to northeastern Kansas and is generally bounded on the west by the Blue River and the south by the Kansas River. The deposit is thickest and least sorted to the northeast becoming thinner and more of a glacial-fluvial material toward the boundary. The surface has high relief and the area is usually described as a Dissected Till Plain. The till was deposited by the Kansan and Nebraskan glaciers which are the first of the four glacial epochs. The coarser fragments are of distinct granitic and quartzitic type, indicating a source in western Minnesota and various resistant sedimentary limestones and sandstones. The finer fragments are individual grains of quartz and feldspar with a large portion of clay mineral.

4. The alluvium of the river valleys can be visualized by considering the great deluges of water down the present river valleys, which occurred as the glacier retreated from the area. This great volume of water overcut the river valleys to a very wide and deep cut in the existing valleys. As the glacier melted, the gradient of the streams was greatly reduced and rock debris was encountered in the bottom of the glacier. The streams were thus refilled to their present configuration. In most major valleys this alluvium consists of some 50 to 100 feet of material that is coarsest at the bottom and finest at the top. The material at the base is usually a bouldery sand and gravel while the top layer is a silt or silty clay. The topography of the valley is quite flat with a gentle slope from the valley wall to the river.

5. The recent alluvium consists of fine-grained materials washed from the highlands to the valley slopes and river valleys. This is usually a

silt or silty clay and appears as a deltaic deposit along the river valley walls and as a continuous cover some 10 to 15 feet in depth over the river valleys. Since it is chiefly derived from loess, it is most commonly a silt sized poorly consolidated material and slopes at an ever decreasing slope towards the river from the valley walls.

## Classification of Soils

The characteristics of soils may easily be studied by the use of agricultural and engineering classification. Agricultural classification enables us to assemble knowledge about the general properties of the soils with sufficient accuracy for economic layout of an engineering soil survey, while engineering classification of various soil layers permits an evaluation of the reaction of the soil to stresses induced by various types of loading.

### Agricultural Classification

The original Russian classification system has undergone numerous changes. Agricultural soil scientists in the United States have, during the past fifty years, taken an active part in improving this system. There are two systems of agricultural classification of soils now in use in the United States. One of these is the 1938 system, Baldwin, Kellogg and Thorp (25), later modified by Thorp and Smith (26). The current comprehensive system was developed in 1960 by the U. S. Department of Agriculture (27) and was placed in general use by the Soil Conservation Service in 1965. This system is still under study as the placement of soil series in families may change as more precise information becomes available.

The American classification in general use is based on the Dakuchaev's scheme, which divides the soils into three orders: Zonal, Intrazonal, and

Azonal. These orders are broken down into the suborders and great soil groups as shown in Table 3.

The great soil groups are related to temperature and precipitation as shown in Table 4. The great soil groups are further divided into family, series, class, and phase, much like the Biological Taxonomic Classification.

If we look at a cross section along a line across the upper midwest, we would find the A, B and C horizons as shown in Fig. 8.

Thus we can predict with a surprisingly great accuracy the various layers (horizons) to be expected in any area. In general rainfall west of Lincoln, Nebraska is less than 30 inches per year and the soil groups are desert and chestnut soils. The A horizon thins as rainfall decreases and the B horizon is alkali minerals mixed with clay changing to pure alkali in the more arid regions. East of Lincoln the land is covered with grass vegetation eastward across the prairie soil group and the A horizon is quite thick and is underlain by a well developed clay B horizon. At a point where the vegetation changes to forest the soils change to podzols and the A horizon is much thinner. The B horizon consists of an upper, almost pure silica silt and a lower clay.

The information from the pedological classification scheme is extremely valuable in planning soil investigations since these are available for all sections of the United States through the Department of Agriculture. Most counties have a local agricultural office called the Soil Conservation Service and all state colleges have an agronomy department having the following basic information:

1. Soil maps outlining the aerial extent of the various soil series with complete descriptions of the various horizons in regard to size distribu-

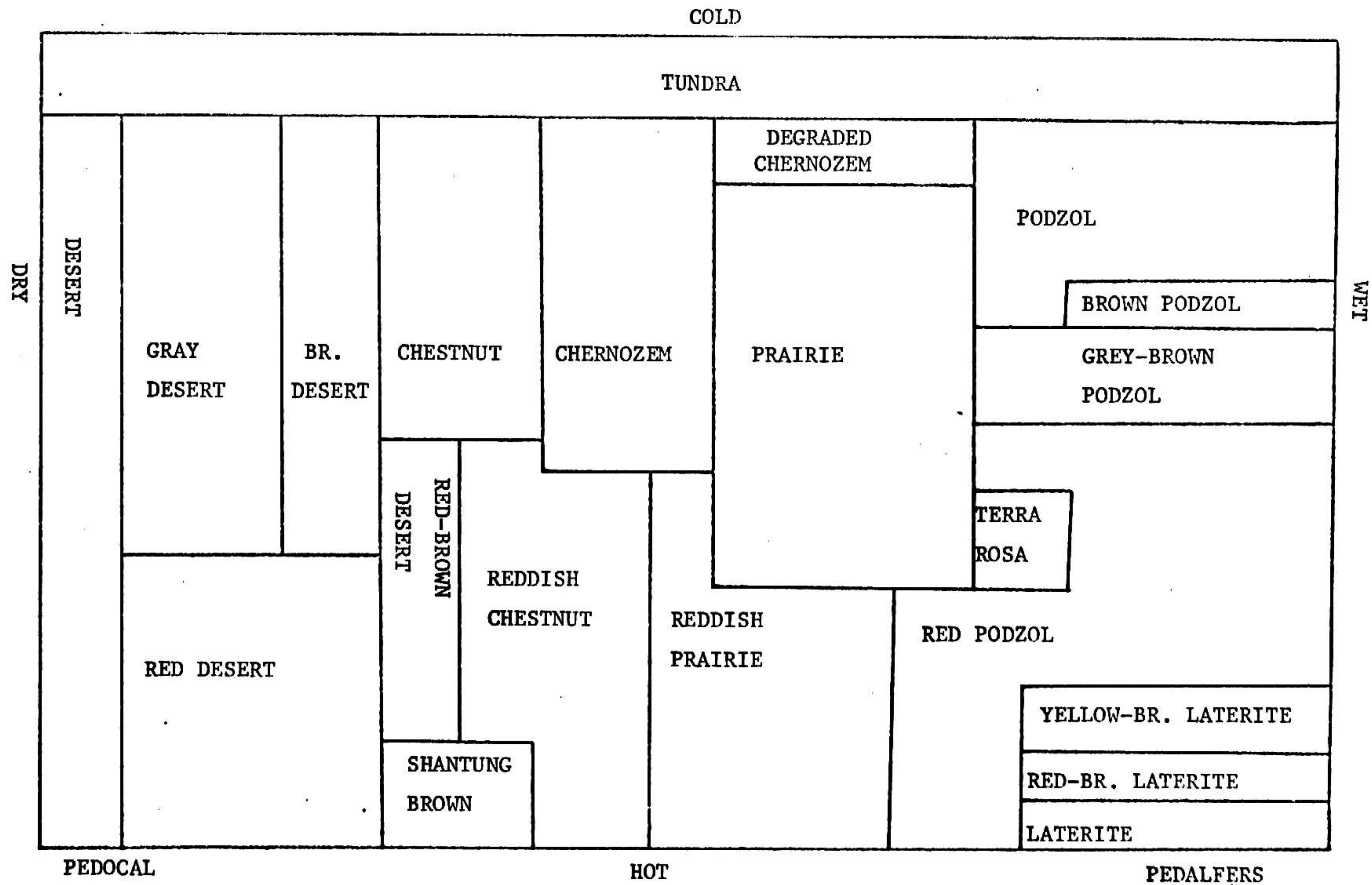
Table 3.

American Classification of Zonal, Intrazonal and Azonal Soils.

| | | | |
|---|---|---|---|
| Zonal | | Soils of the cold zone | 1. Tundra soils |
| | Pedocals | Light coloured soils of arid regions | 2. Desert soils |
| | | | 3. Red desert soils |
| | | | 4. Sierozem |
| | | | 5. Brown soils |
| | | | 6. Reddish-brown soils |
| | | Dark coloured soils of arid, sub-humid and humid grasslands | 7. Chestnut soils |
| | | | 8. Reddish-chestnut soils |
| | | | 9. Chernozem soils |
| | | | 10. Prairie soils |
| | | | 11. Reddish prairie soils |
| | Pedalfers | Soils of the forest-grassland transition | 12. Degraded chernozem soils |
| | | | 13. Non-calcic brown soils |
| | | Light coloured podsolized soils of the timbered regions | 14. Posdol soils |
| | | | 15. Brown podsolic soils |
| | | | 16. Grey-brown podsolic soils |
| | | | 17. Yellow podsolic soils |
| | | Lateritic soils of forested warm temperate and tropical regions | 18. Red podsolic soils |
| | | | 19. Yellowish-brown lateritic soils |
| | | | 20. Reddish-brown lateritic soils |
| | | | 21. Laterite soils |
| Intrazonal soils | | (Halomorphic saline and alkaline) soils of imperfectly drained arid regions and littoral deposits | 1. Solonchak or saline soils |
| | | | 2. Solonetz soils |
| | | | 3. Soloth (soliti) soils |
| | | Hydromorphic soils of marshes, swamps, seep areas, and flats | 4. Wiesenboden (meadow) soils |
| | | | 5. Alpine meadow soils |
| | | | 6. Bog soils |
| | | | 7. Half bog soils |
| | | | 8. Planosols |
| | | | 9. Ground-water podsol soils |
| | | | 10. Ground-water laterite soils |
| | | Calomorphic soils | 11. Brown forest soils (Braunerde) |
| | | | 12. Rendzina soils |
| Azonal soils | | Class I - Lack of development due to external factors such as low temperature or aridity. | |
| | | Class II - Lack of development due to the nature of the parent material, e.g., quartz or gypsum sand. | |
| | | Class III - Development potential but unaccomplished, e.g., recent alluvium. | |

Table 4.

Relationship of Great Soil Groups.



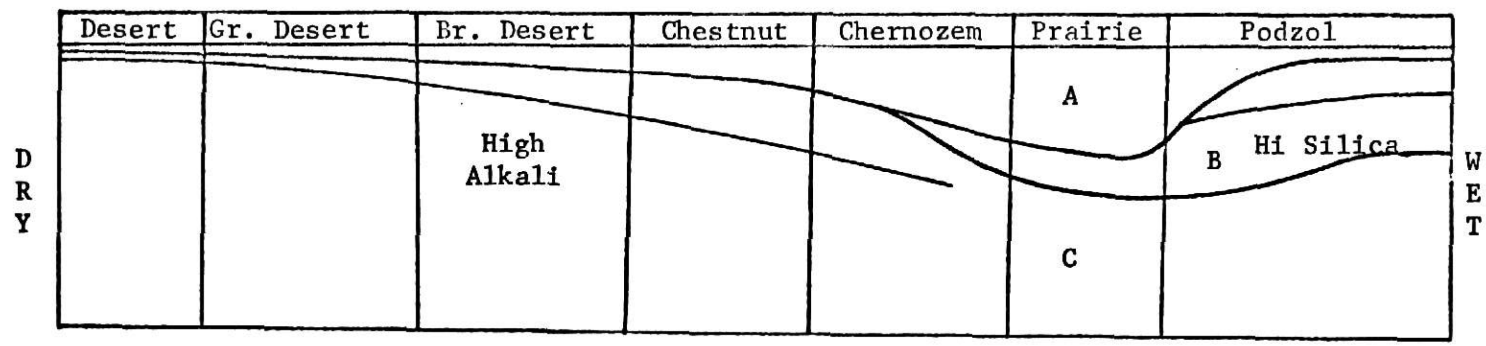



Fig. 8. Cross Section across the Upper Midwest

tion of the particles, permeability, and in some cases engineering data such as atterberg limits and classification.

2. Depth to and character of the bedrock in the area including a geological section in many cases of the several layers of bedrock.

3. The depth to and fluctuation of the ground water table including the annual rainfall and in many cases the distribution of the rainfall throughout the year.

4. The temperature variation during the year including the low and high record temperature. In most cases the depth of frost penetration is noted.

5. The type of vegetative cover to be expected in the various areas, e.g., forests on the valley walls and grass on the highlands, etc.

This information is presented in the county soil survey reports in the form summarized in Fig. 9 from the Iowa State Soil Survey.

Figure 10 shows principal soil associations of Kansas.

On the basis of texture of the surface soil, each soil series is subdivided into soil type. Agricultural soils are classified texturally by horizons according to percentages of sand, silt and clay (Fig. 11). Agricultural soil bulletins containing complete descriptions of soil types and maps of their location have been published by U. S. Department of Agriculture in cooperation with Kansas Agricultural Experiment Station for many counties in Kansas.

Engineering Classification

Engineering classification of soils is based on the following physical properties of the soil sampled.

Fig. 9 Relationship of Slope, Vegetation and Parent Material to Soils of the Fayette and Fayette-Dubuque General Soil Association Areas

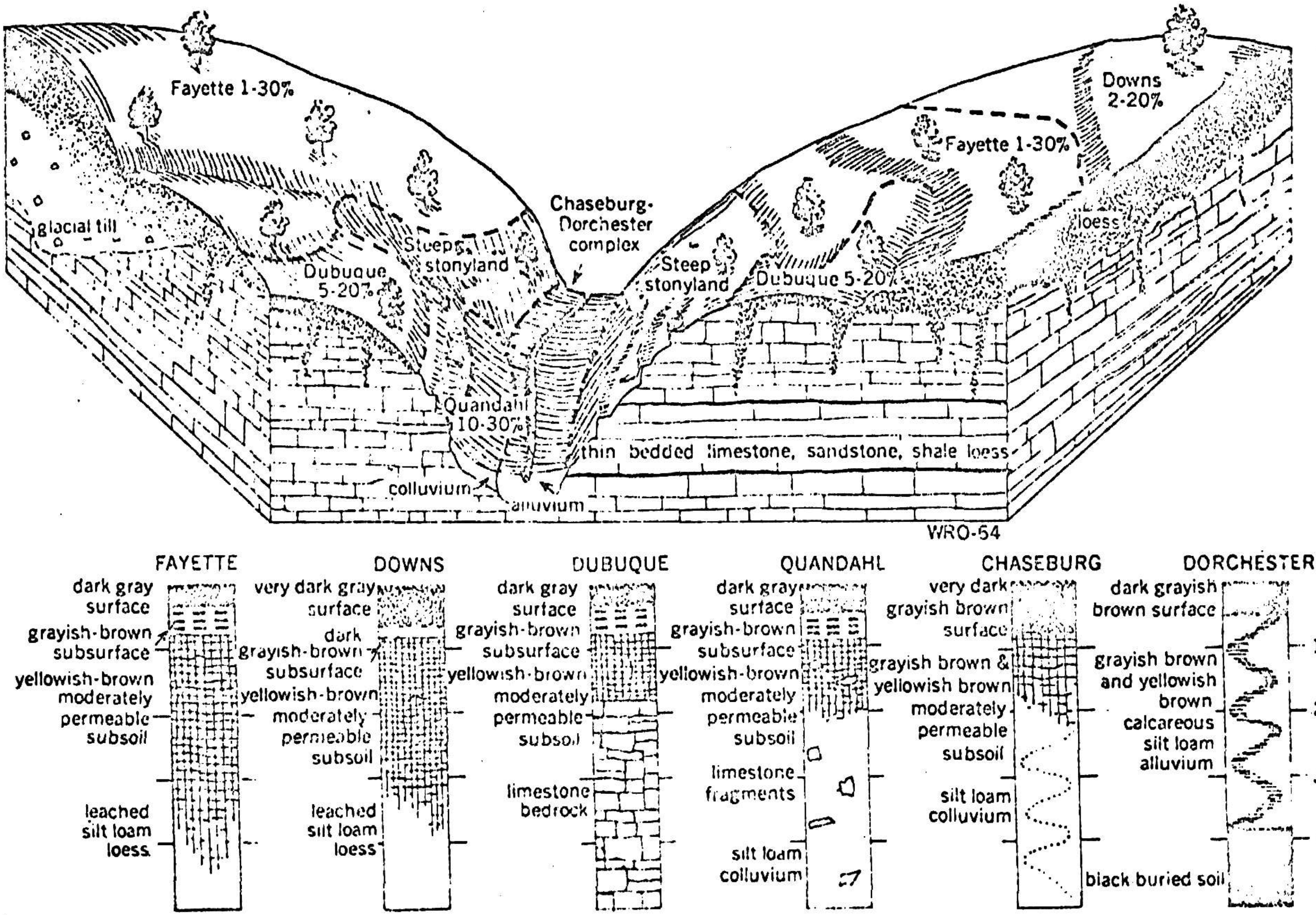
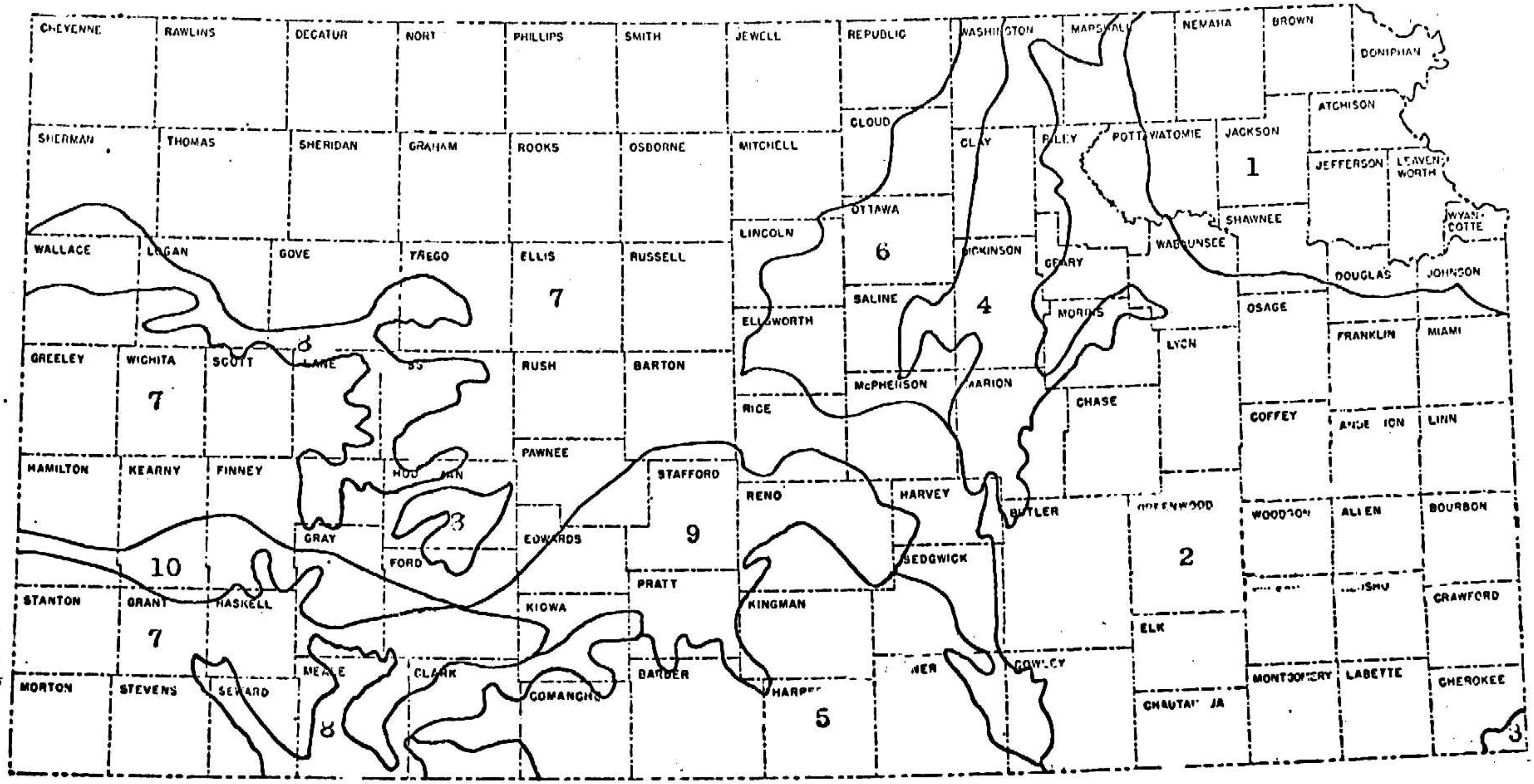
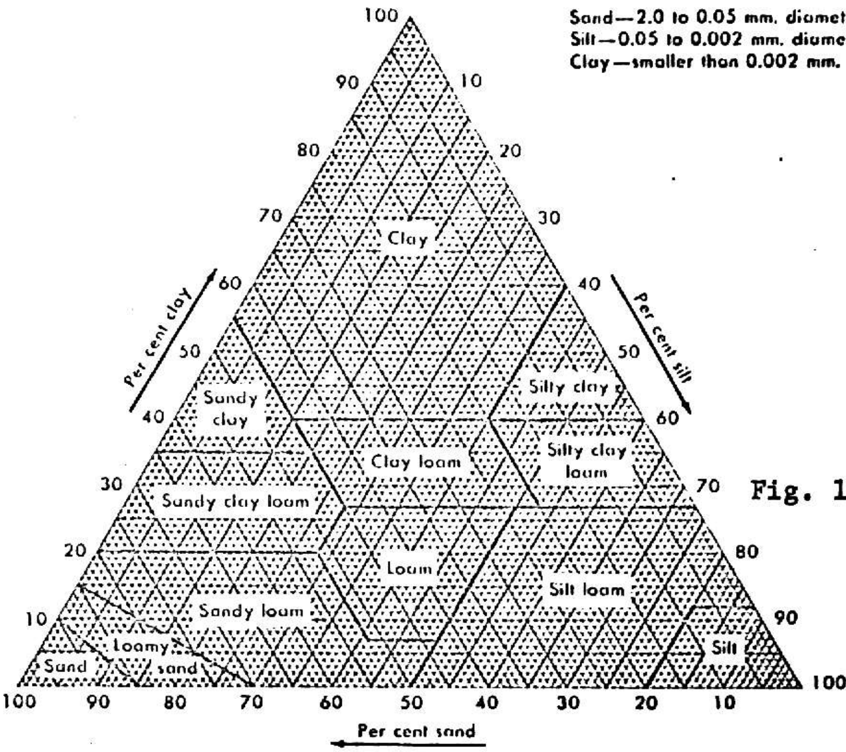


Fig. 10. Principal Soil Association Areas, from K.A.E.S. (28).




1. Monona, Marshall
   Sharpsburg, Shelby, Marshall.
   Grundy, Crete, Pawnee, Burchard, Shelby.
2. Sogn, Summit, Florence, Idana
   Summit, Woodson, Labette, Bates.
   Woodson, Parsons, Labette, Bates.
   Parsons, Dennis, Bates
   Cherokee, Taloka, Parsons, Dennis, Bates
   Darnell, Stephenville, Dennis, Boone
3. Bodine
4. Crete, Ladysmith, Kipp, Idana.
5. Idana, Renfrow, Kipson
   Grant, Albion, Vernon, Renfrow
   Vernon, Quinlan, Albion.
6. Lancaster, Hedville, Longford.
7. Hastings, Holdrege, Colby
   Keith, Colby
   Keith, Hoisington
   Richfield, Colby
   Dalhart, Richfield, Mansker
8. Canyon, Marshall
9. Pratt, Albion, Derby
10. Dune Sand, Tivoli.




Sand—2.0 to 0.05 mm. diameter
Silt—0.05 to 0.002 mm. diameter
Clay—smaller than 0.002 mm. diameter

**Fig. 11.** U.S. Department of Agriculture textural classification chart.

| Basic soil class | Subclass | Soil separates: Very coarse sand, 2.0-1.0 mm. | Coarse sand, 1.0-0.5 mm. | Medium sand, 0.5-0.25 mm. | Fine sand, 0.25-0.1 mm. | Very fine sand, 0.1-0.05 mm. |
|---|---|---|---|---|---|---|
| Sands | Coarse sand | 25% or more | | Less than 50% | Less than 50% | Less than 50% |
| | Sand | 25% or more | | | Less than 50% | Less than 50% |
| | Fine sand | Less than 25% | | —or— | 50% or more | Less than 50% |
| | Very fine sand | | | | | 50% or more |
| Loamy sands | Loamy coarse sand | 25% or more | | Less than 50% | Less than 50% | Less than 50% |
| | Loamy sand | 25% or more | | | Less than 50% | Less than 50% |
| | Loamy fine sand | Less than 25% | | —or— | 50% or more | Less than 50% |
| | Loamy very fine sand | | | | | 50% or more |
| Sandy loams | Coarse sandy loam | 25% or more | | Less than 50% | Less than 50% | Less than 50% |
| | Sandy loam | 30% or more; Less than 25% | | —and— | Less than 30% | Less than 30% |
| | Fine sandy loam | —or— Between 15 and 30% | | | 30% or more | Less than 30% |
| | Very fine sandy loam | Less than 15% | | —or— | More than 40%* | 30% or more |

1. Gradation. Gradation means the division of soil into fractions of gravel, sand, silt and clay. The gradation may easily be determined by sieve analysis and a grain size curve is usually plotted as percent finer (or passing) by weight against a log scale of grain size in millimeters.

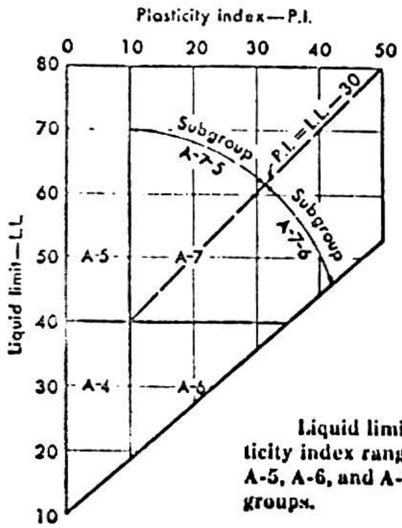
2. Plasticity. Plasticity refers to the ability of a material to be deformed rapidly without cracking or crumbling and then maintain that deformed shape after the deforming force has been released. The clay fraction in a soil produces plasticity, which varies with the type and amount of clay. Plasticity is evaluated by the range in moisture content, within which a soil exhibits plasticity, called the plasticity index (or P. I.).

Most highway organizations, including Kansas, use the AASHO system of classification (29). In this system (Fig. 12) soils may be placed into two general groups: granular materials and silt-clay materials, then further classified in seven basic groups, on the basis of gradation and plasticity. Three of the seven basic groups may be further divided into subgroups to designate variations within a group. This classification can be used directly for pavement thickness design since a great amount of actual experience in the area of highway construction was used to develop and modify the scheme.

General engineering soil classification areas (AASHO system) are shown in Fig. 13.

The FAA classification system shown in Fig. 14 is similar to the AASHO in that it is directly applicable to the design of airfield paving.

The Unified classification shown in Fig. 15 is generally more applicable to foundation engineering than the AASHO or FAA schemes. The use of this Unified classification allows for quicker and easier identification in the field and shows directly whether the soil will react as a granular or cohesive material.




Liquid limit and plasticity index ranges for A-4, A-5, A-6, and A-7 subgrade groups.

Group index charts.

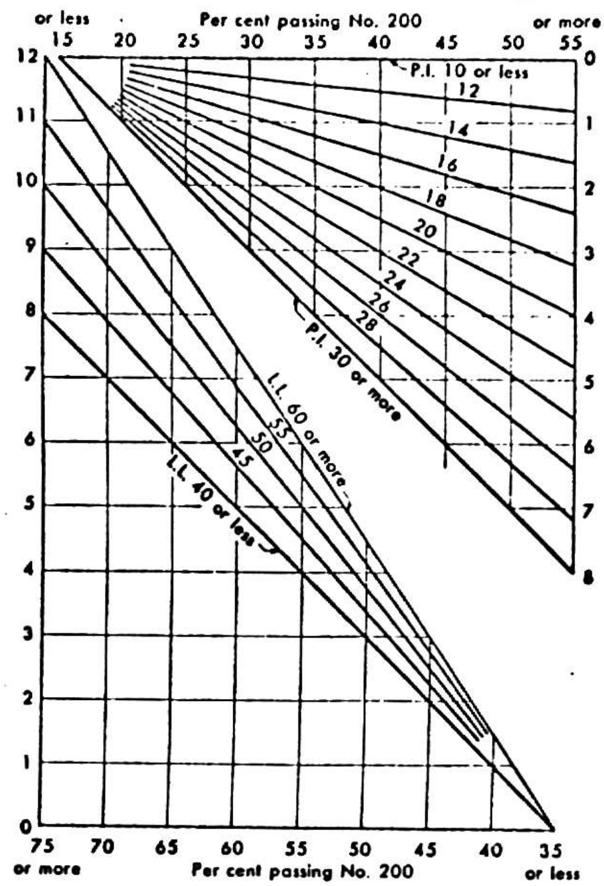



Chart B—Grain Size and L. L. Relations
Group Index Equals Sum of Readings on Both Vertical Scales

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

Classification procedure: With required test data available, proceed from left to right on chart; correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification.

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

Fig. 12. A.A.S.H.O. Classification System

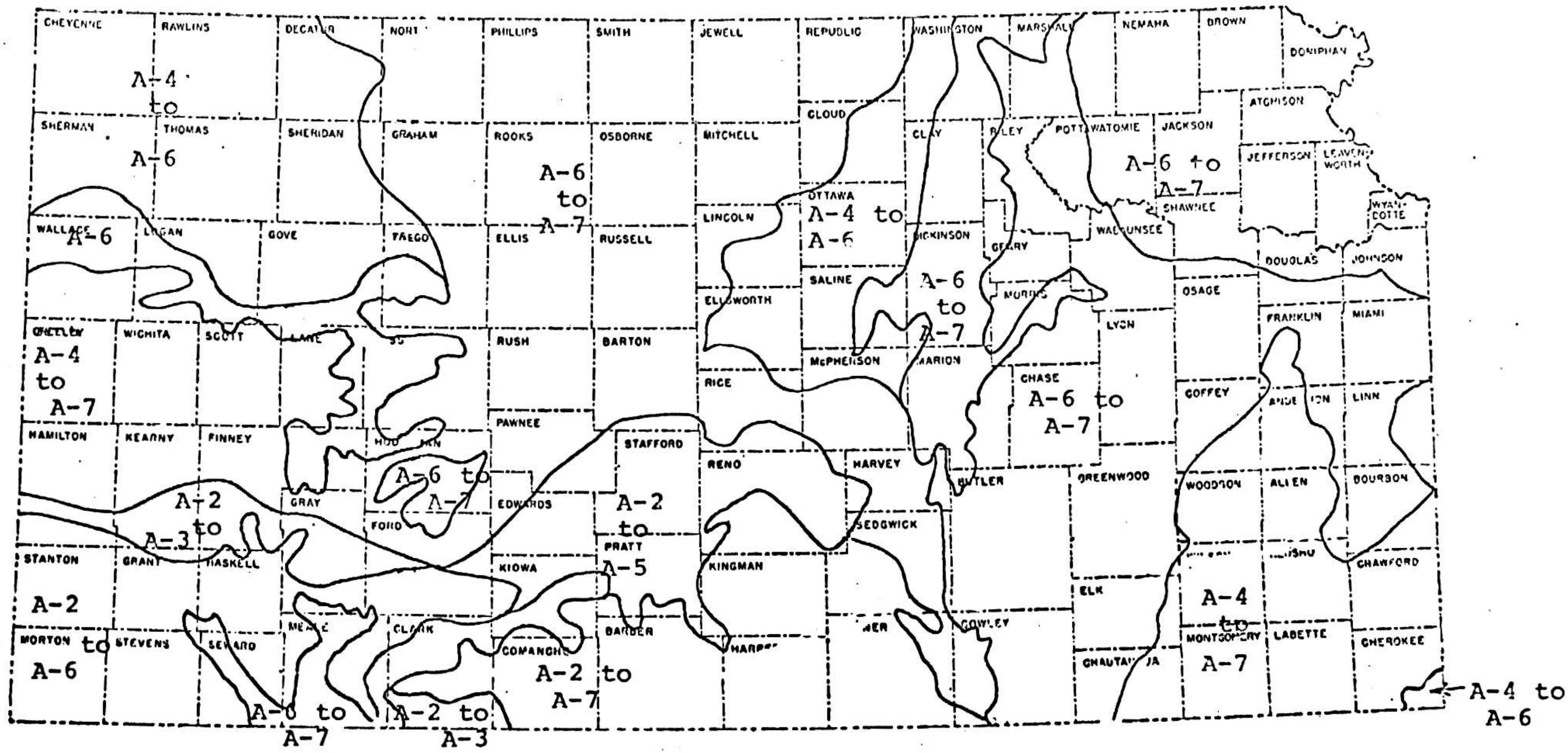



Fig. 13. General Soil Classification Areas

## Federal Aviation Agency Classification System

The FAA has prepared a soil classification system based on the gradation analysis and the plasticity characteristics of soils.

The textural classification is based on a grain-size determination of the minus No. 10 material and the use of a biaxial soil chart, Fig. 6, that also includes definitions of sand, silt, and clay.

The mechanical analysis, liquid limit, and plasticity index data are referred to Table 5, and the appropriate soil group, ranging from E-1 to E-13 inclusive, is selected.

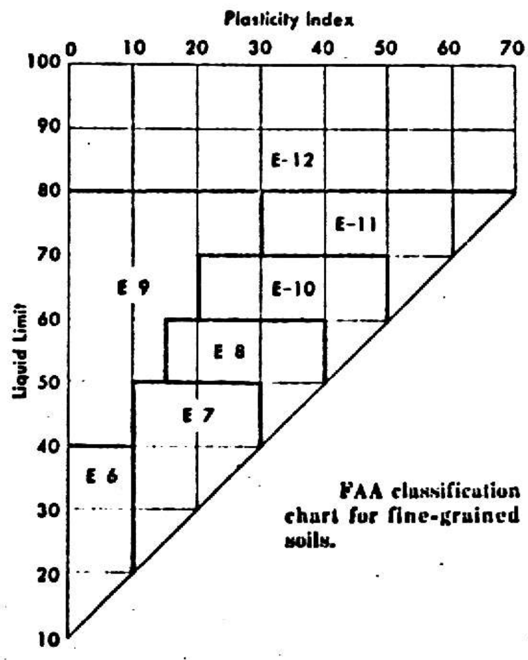
Two modifications of this procedure may be required. In one case, test results on fine-grained soils, groups E-6 through E-12, may place the soil in more than one group. When this occurs, the test results are referred to Fig. 7, where the appropriate soil group is determined.

The other modification is used when considerable material is retained on a No. 10 sieve since the classification is based on the material passing the No. 10 sieve. Upgrading the soil one to two classes is permitted when the percentage of the total sample retained on the No. 10 sieve exceeds 45 per cent for soils of the E-1 to E-5 groups and 55 per cent for the remaining groups, provided the coarse fraction consists of reasonably sound material. Further, it is necessary that the coarse fraction be fairly well graded from the maximum size down to the No. 10 sieve size. Stones or rock fragments scattered through a soil are not considered of sufficient benefit to warrant upgrading.

**FAA Classification of Soils for Airport Construction**

| Soil group | Mechanical analysis | | | | L.L. | P.I. |
|---|---|---|---|---|---|---|
| | Retained on No. 10 sieve* | Material finer than No. 10 sieve | | | | |
| | | Coarse sand passing No. 10, retained on No. 60 | Fine sand passing No. 60, retained on No. 270 | Combined silt and clay passing No. 270 | | |
| | per cent | per cent | per cent | per cent | | |
| E-1 | 0—45 | 40+ | 60— | 15— | 25— | 6— |
| E-2 | 0—45 | 15+ | 85— | 25— | 25— | 6— |
| E-3 | 0—45 | — | — | 25— | 25— | 6— |
| E-4 | 0—45 | — | — | 35— | 35— | 10— |
| E-5 | 0—45 | — | — | 45— | 40— | 15— |
| E-6 | 0—55 | — | — | 45+ | 40— | 10— |
| E-7 | 0—55 | — | — | 45+ | 50— | 10—30 |
| E-8 | 0—55 | — | — | 45+ | 60— | 15—40 |
| E-9 | 0—55 | — | — | 45+ | 40+ | 30— |
| E-10 | 0—55 | — | — | 45+ | 70— | 20—50 |
| E-11 | 0—55 | — | — | 45+ | 80— | 30+ |
| E-12 | 0—55 | — | — | 45+ | 80+ | — |
| E-13 | Muck and peat—field examination | | | | | |

*Classification is based on sieve analysis of the portion of the sample passing the No. 10 sieve. When a sample contains material coarser than the No. 10 sieve in amounts equal to or greater than the maximum limit shown in the table, a raise in classification may be allowed provided the coarse material is reasonably sound and fairly well graded.

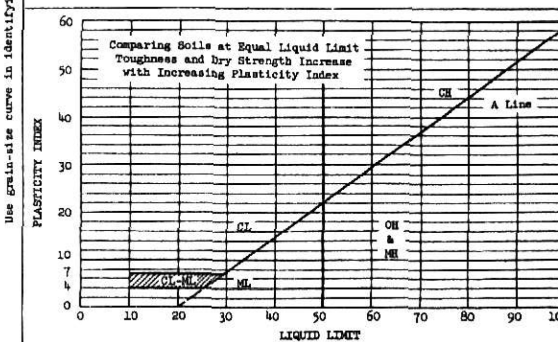



**FAA classification chart for fine-grained soils.**

Fig. 14. F.A.A. Classification System

## UNIFIED SOIL CLASSIFICATION
(Including Identification and Description)

| Major Divisions (1) | Major Divisions (2) | | Group Symbols (3) | Typical Names (4) | Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights) (5) | | | Information Required for Describing Soils (6) | Laboratory Classification Criteria (7) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Coarse-grained Soils. More than half of material is larger than No. 200 sieve size. (The No. 200 sieve size is about the smallest particle visible to the naked eye.) | Gravels. More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the 1/4-in. size may be used as equivalent to the No. 4 sieve size) | Clean Gravels (Little or no fines) | GW | Well-graded gravels, gravel-sand mixtures, little or no fines. | Wide range in grain sizes and substantial amounts of all intermediate particle sizes. | | | For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics. | Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows: Less than 5% = GW, GP, SW, SP, More than 12% = GM, GC, SM, SC. 5% to 12% = Borderline cases requiring use of dual symbols. | $C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 | |
| | | | GP | Poorly graded gravels or gravel-sand mixtures, little or no fines. | Predominantly one size or a range of sizes with some intermediate sizes missing. | | | | | Not meeting all gradation requirements for GW | |
| | | Gravels with Fines (Appreciable amount of fines) | GM | Silty gravels, gravel-sand-silt mixture. | Nonplastic fines or fines with low plasticity (for identification procedures see ML below). | | | Give typical name; indicate approximate percentages of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses. | | Atterberg limits below "A" line or PI less than 4 | Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols. |
| | | | GC | Clayey gravels, gravel-sand-clay mixtures. | Plastic fines (for identification procedures see CL below). | | | | | Atterberg limits above "A" line with PI greater than 7 | |
| | Sands. More than half of coarse fraction is smaller than No. 4 sieve size. | Clean Sands (Little or no fines) | SW | Well-graded sands, gravelly sands, little or no fines. | Wide range in grain size and substantial amounts of all intermediate particle sizes. | | | | | $C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 | |
| | | | SP | Poorly graded sands or gravelly sands, little or no fines. | Predominantly one size or a range of sizes with some intermediate sizes missing. | | | Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains, coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM). | | Not meeting all gradation requirements for SW | |
| | | Sands with Fines (Appreciable amount of fines) | SM | Silty sands, sand-silt mixtures. | Nonplastic fines or fines with low plasticity (for identification procedures see ML below). | | | | | Atterberg limits below "A" line or PI less than 4 | Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols. |
| | | | SC | Clayey sands, sand-clay mixtures. | Plastic fines (for identification procedures see CL below). | | | | | Atterberg limits above "A" line with PI greater than 7 | |
| Fine-grained Soils. More than half of material is smaller than No. 200 sieve size. | | | | | Identification Procedures on Fraction Smaller than No. 40 Sieve Size | | | | Use grain-size curve in identifying the fractions as given under field identification. | | |
| | | | | | Dry Strength (Crushing characteristics) | Dilatancy (Reaction to shaking) | Toughness (Consistency near PL) | | | | |
| | Silts and Clays. Liquid limit is less than 50 | | ML | Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity. | None to slight | Quick to slow | None | For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions. | | | |
| | | | CL | Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. | Medium to high | None to very slow | Medium | | | | |
| | | | OL | Organic silts and organic silty clays of low plasticity. | Slight to medium | Slow | Slight | Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses. | | | |
| | Silts and Clays. Liquid limit is greater than 50 | | MH | Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts. | Slight to medium | Slow to none | Slight to medium | | | | |
| | | | CH | Inorganic clays of high plasticity, fat clays. | High to very high | None | High | | | | |
| | | | OH | Organic clays of medium to high plasticity, organic silts. | Medium to high | None to very slow | Slight to medium | Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML). | | | |
| Highly Organic Soils | | | Pt | Peat and other highly organic soils. | Readily identified by color, odor, spongy feel and frequently by fibrous texture. | | | | | | |




PLASTICITY CHART

For laboratory classification of fine-grained soils

(1) Boundary classifications: Soils possessing characteristics of two groups are designated by combinations of group symbols. *For example GW-GC, well-graded gravel-sand mixture with clay binder.* (2) All sieve sizes on this chart are U. S. standard.

### FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS

These procedures are to be performed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

**Dilatancy (reaction to shaking)**

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

**Dry Strength (crushing characteristics)**

After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air-drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

**Toughness (consistency near plastic limit)**

After particles larger than the No. 40 sieve size are removed, a specimen of soil about one-half inch cube in size, is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its *plasticity*, and *crumbles when the plastic limit* is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

Fig. 15. Unified Soil Classification Chart.

Adopted by Corps of Engineers and Bureau of Reclamation, January 1952

021260A

Typical Soil Profiles

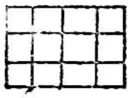
One soil profile for each of the soil association areas (Fig. 10), is shown for the upland soils in that area. In general, the soil profile of the slopes will be much thinner and A and B horizons will not be well developed or absent, because of erosion.

The soil characteristics in the profile will follow the following numbers and sequence:

1. Minimum depth to bedrock (in inches).
2. Soil slope (percent).
3. Subsoil permeability (inches per hour).
4. AASHO classification.
5. Value as subgrade.
6. Value as roadfill.
7. Value for highway location.
8. Value for embankments.

These characteristics were obtained from the Soil Survey Reports published by the U. S. Department of Agriculture in cooperation with Kansas Agricultural Experiment Station.

## PROFILE SYMBOLS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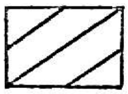
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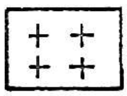
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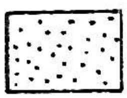
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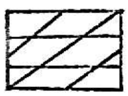
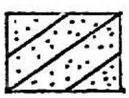

SILTY CLAY OR CLAYEY SILT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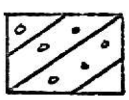
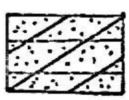
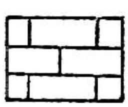
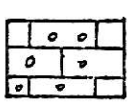
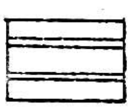

CHERTY SILT

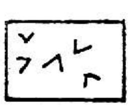

ALLUVIUM


COARSE SAND AND GRAVEL

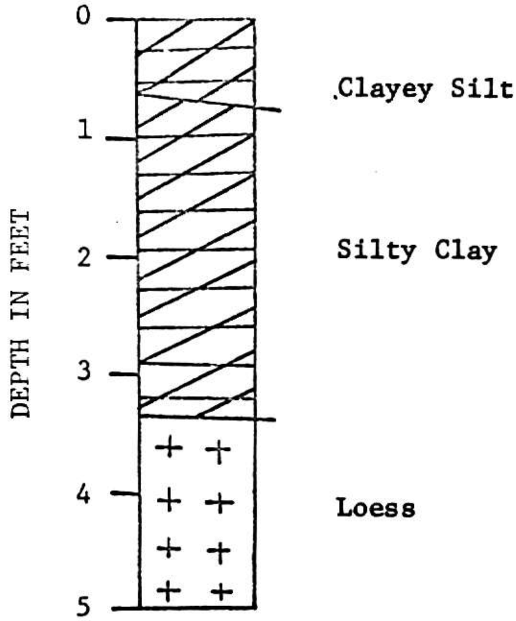

LIMESTONE


CHERTY LIMESTONE


SHALE


SANDSTONE

Clayey Silt over Loess and Glacial Till (1)*




General

This soil is the representative of the Monona, Marshall, Sharpsburg, Grundy and Crete series. Beneath the loess, lies the Kansas till which outcrops as the Shelby, Burchard or Pawnee series.

Soil Characteristics

1. 60 - 300.
2. 2 - 11
3. 0.05 - 2.50
4. A-6 - A - 7 - 6
5. Poor
6. Fair
7. Poor
8. Poor

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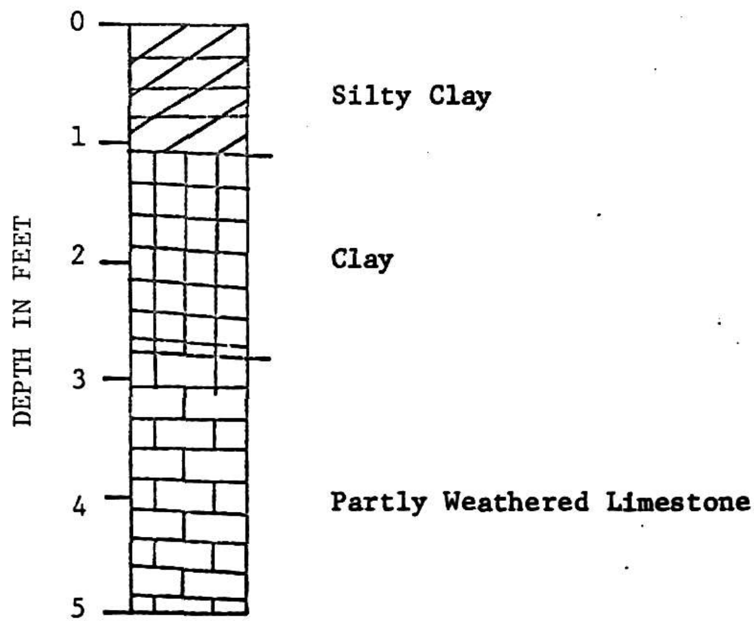
*Numbers in parenthesis after soil name refer to number of soil association in the soils map (Fig. 10).

Silty Clay over Limestone and Shale (2)



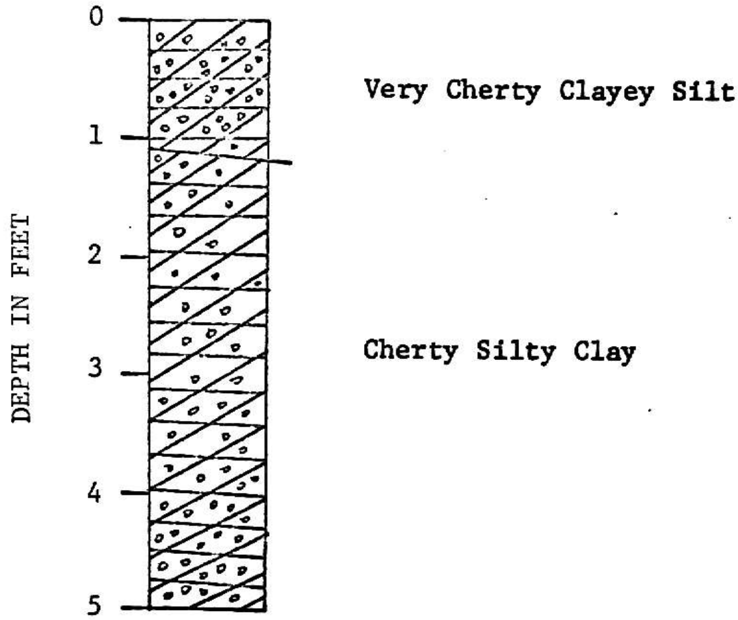

General

The topsoil layer of silty clay is replaced by silty sand in the Darnell, Stephenville and Boone series. At places, bedrock of limestone, shale or sandstone may be found at 10" to 40".

Soil Characteristics

1. 2 - 72
2. 2 - 15
3. 0.05 - 2.50
4. A - 4 - A - 7 - 6
5. Poor to Fair
6. Poor (Good in Bates series)
7. Poor
8. Favorable

Cherty Clayey Silt over Cherty Limestone (3)



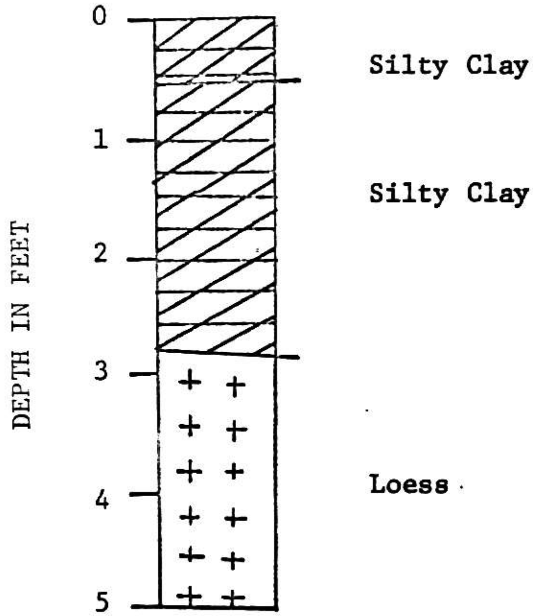

General

On the surface, chert up to 6" in diameter ranges from a few scattered pebbles to a complete cover. In places, there are beds of tripoli at a depth below 40 inches.

Soil Characteristics

1. 24 - 36
2. 12 and more
3. 0.80 to 2.50
4. A - 4 - A - 6
5. Poor
6. Good
7. Fair
8. Poor

Silty Clay over Loess and Shale (4)



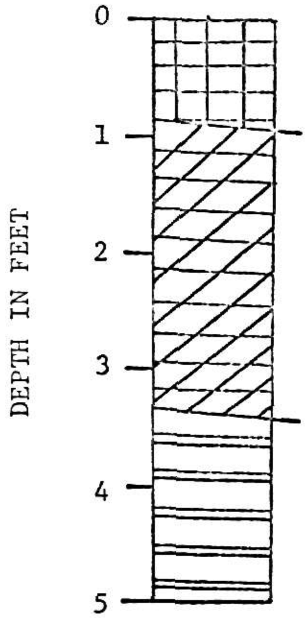

General

At some places in this soil association area, limestone and shale are encountered at 20".

Soil Characteristics

1. 20 - 140
2. 0 - 8
3. 0.05 - 0.50
4. A - 6 - A - 7 - 6
5. Poor
6. Fair
7. Good
8. Poor

Clay over Red Shale (5)



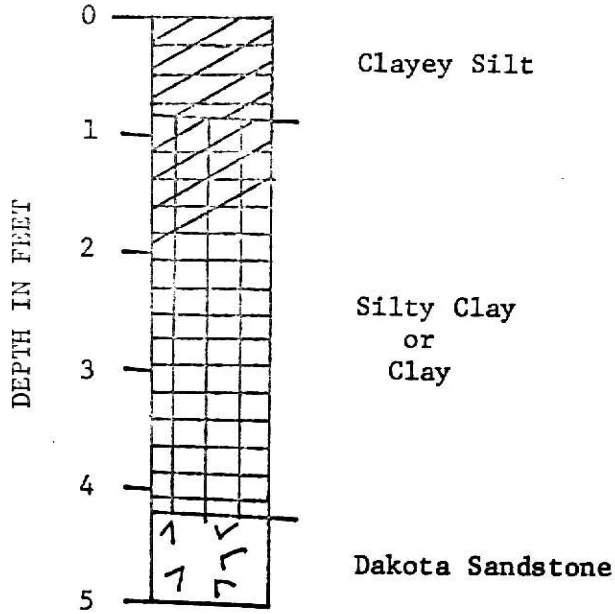

General

At places, the topsoil is silty clay or clayey silt. In the Idano series, the parent material is shale or loess, while in the Kipson series, layers of limestone may be encountered at 5 in. depth.

Soil Characteristics

1. 5 - 80
2. 2 - 12
3. 0.05 - 5.00
4. A - 2 - A - 7 - 6
5. Poor
6. Fair
7. Poor
8. Poor

Clay Silt over Sandstone (6)



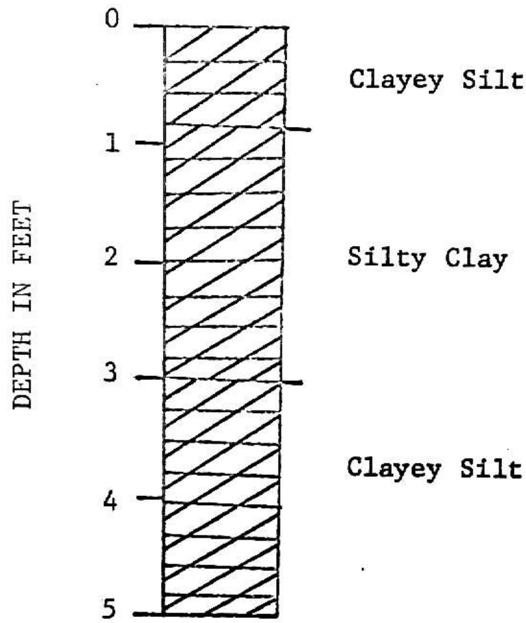

General

This soil is representative of Lancaster, Medville and Longford series. The Lancaster and Medville soils are redder and have less clay than Longford soils.

Soil Characteristics

1. 20 - 60
2. 8 20
3. 0.05 - 0.50
4. A - 4 - A - 7
5. Poor
6. Good
7. Good
8. Poor

Clayey Silt over Loess or Alluvium (7)



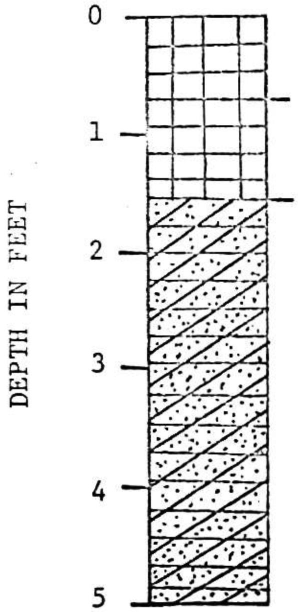

General

The topsoil in the Dalhart series is commonly silty sand. In the Colby series, the profile is not well-developed. The clayey silt is underlain by 10 to 15 feet of Loess or mixed outwash deposits.

Soil Characteristics

1. 48 - 300
2. 0 - 11
3. 0.05 - 2.50
4. A - 4 - A - 7 (A - 2 in Dalhart)
5. Poor to Fair
6. Fair
7. Good
8. Fair

Clay over Old Alluvium (8)




General

In the Canyon series, the topsoil layer is clayey silt instead of clay. At places, the bedrock is encountered at very shallow depths.

Soil Characteristics

1. 5 - 25 (Canyon series)

   60 - 140 (Mansker series)

2. 0 - 15

3. 0.80 - 10.1

4. A - 6

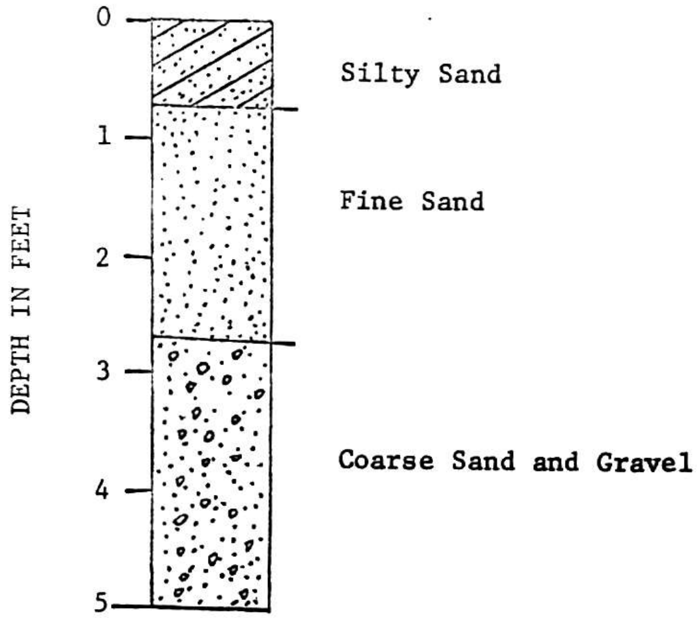
5. Poor

6. Good

7. Poor

8. Poor

Fine Sand over Aeolian and Outwash Sands (9)



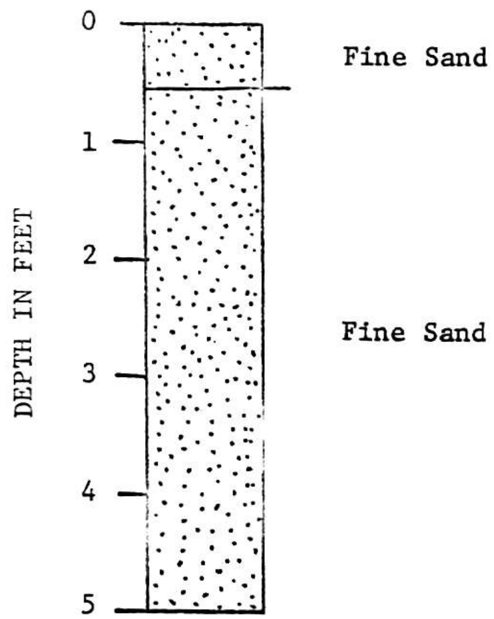

General

The A - horizon in this area varies from Silty Sand to Sandy Silt, but is dominantly Silty Sand. The B - horizon in this area varies from Fine Sand to Clayey Sand.

Soil Characteristics

1. 20 - 140
2. 1 - 10
3. 0.80 - 10.0
4. A - 2 - A - 3
5. Good
6. Good
7. Fair
8. Poor

Fine Sand over Aeolian Sands (10)




General

Mostly, the profile in this area is not well defined as the B - horizon is missing.

Soil Characteristics

1. 140
2. Dunes and Hummocks
3. 10 and more
4. A - 2 or A - 3
5. Good, if confined
6. Good
7. Fair
8. Poor

## ENGINEERING SOIL PROBLEMS

For purposes of discussing problems associated with different soil types, the soils of Kansas can be separated into the following categories: (See Figure 10.)

1. The Loess deposits of the uplands.

2. The Alluvial Silt washed from the uplands and deposited along the valley walls.

3. The Alluvial Fill in the overcut river valleys.

4. The Expansive Soils derived from volcanic ash or montmorillonite shales.

5. The Glacial Till Plains.

6. The Soil Solum.

### 1. The Loess

The loess cover varies from a maximum of more than 100 feet to an insignificant clay rich veneer. (24) The loess varies greatly in strength with both porosity and moisture content. In general, the loess deposits having a porosity greater than 0.40 will be very compressible, irregardless of moisture content. (32)

The loess can be drilled by conventional auger boring equipment, since the soil does not cave into the drill holes. In very dry deposits, it is sometimes necessary to add a small amount of water to the drill hole to facilitate the movement and retention of the soil in the auger. (34)

The material is extremely fragile and sampling is very difficult. The penetration record is of little value. Undisturbed block samples can be taken near the surface, but transportation of the samples is almost impossible. Shelby tube samples are difficult to obtain in loess soils because of damage during sampling, transportation, or ejection of the sample. (34)

In all cases it is suggested that in-situ testing procedures be utilized with compressibility tested by plate bearing test and strength by the bore hole shear device. (33)

Laboratory testing should be limited to samples that appear to be least disturbed. Laboratory tests of value consist of direct shear and consolidation for samples obtained at depths too great for in-situ testing. (33)

The moisture density relationships and the porosity (n) should be determined for all depths affected by applied loads. Tests for Atterberg limits and gradation can be used for classification only. These test results can be used for the design of pavements, but have little or no application to foundation engineering. (35)

In these loess deposits, an understanding of the effects of apparent cohesion is necessary for the appreciation of the effects of moisture. Apparent cohesion can simply be explained as a binding force of the surface tension of water at the contact points of the mineral grains at any moisture content, less than saturation. As the moisture content increases from about zero to complete saturation, the strength of soil varies as shown in Fig. 16. (30) Thus it can be seen from the curve in Fig. 16 that, at the most advantageous moisture content, the allowable bearing value of loess is about 3 kips per square foot, but with complete saturation, it is reduced to almost zero.

For a given site, it is often difficult do predict whether saturation will occur or not. The loess will not be saturated by lateral movement of ground water but is most likely to be saturated by a rise in the general

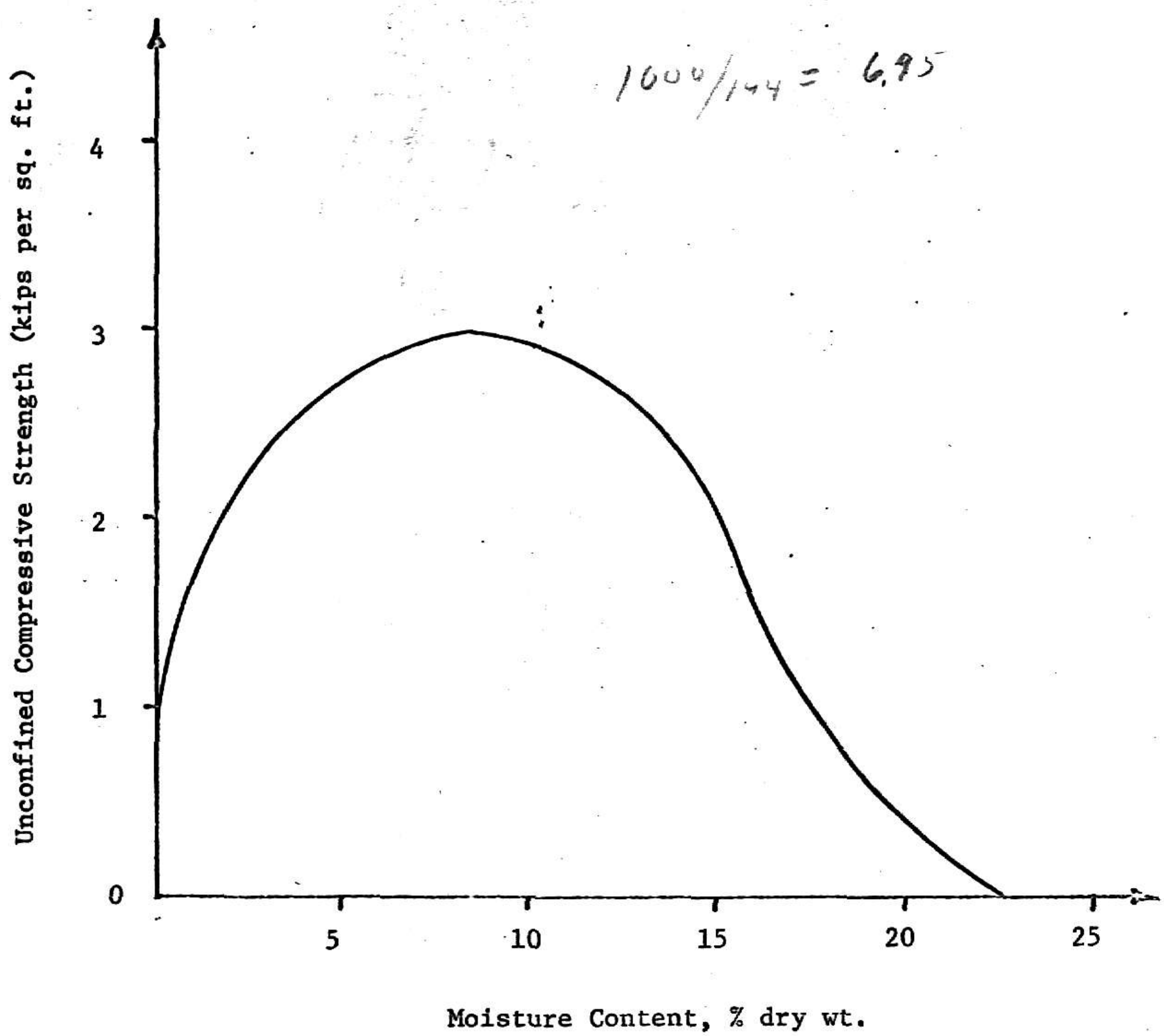



Fig. 16 Unconfined Compressive Strength - Moisture Content Relationship

(From Chang (30))

water table or by capillary action. Capillary action has been known to lift water in loess some 15 to 20 feet. (33) A good indicator of the zone of water table fluctuations is the mottled brown and grey color imparted to the loess by alternate wetting and drying. (36)

Under optimum moisture conditions, loess has an angle of internal friction of some 15° to 20° and a unit cohesion between 5 and 10 psi. When saturated the friction remains the same but cohesion is reduced to zero and thus the contact pressure should usually be limited to 1 kip per square foot. (37)

Frost action under pavements is very severe since the capillarity moves great quantities of water upward into the frost zone. This action can be prevented by putting an impermeable layer at or below the level of frost penetration or by using a heavily reinforced portland cement concrete paving. (38, 39) Work done by Chang (30) indicates that the strength and stability of loess can be improved considerably by small additions of portland cement.

2. The Alluvial Silt

The silt washed down from the uplands into the river valleys is found along most of the major streams in Kansas. The maximum thickness of these deposits is some 20 to 25 feet. Figure 17 shows a generalized cross section of this deposit and the associated highland and river valley deposit. These deposits are similar in nature to the upland loess except that their porosity is almost always more than 0.40. They must therefore be checked for compressibility, but these tests will indicate that the safe unit loading cannot exceed 1 kip per square foot. (33)

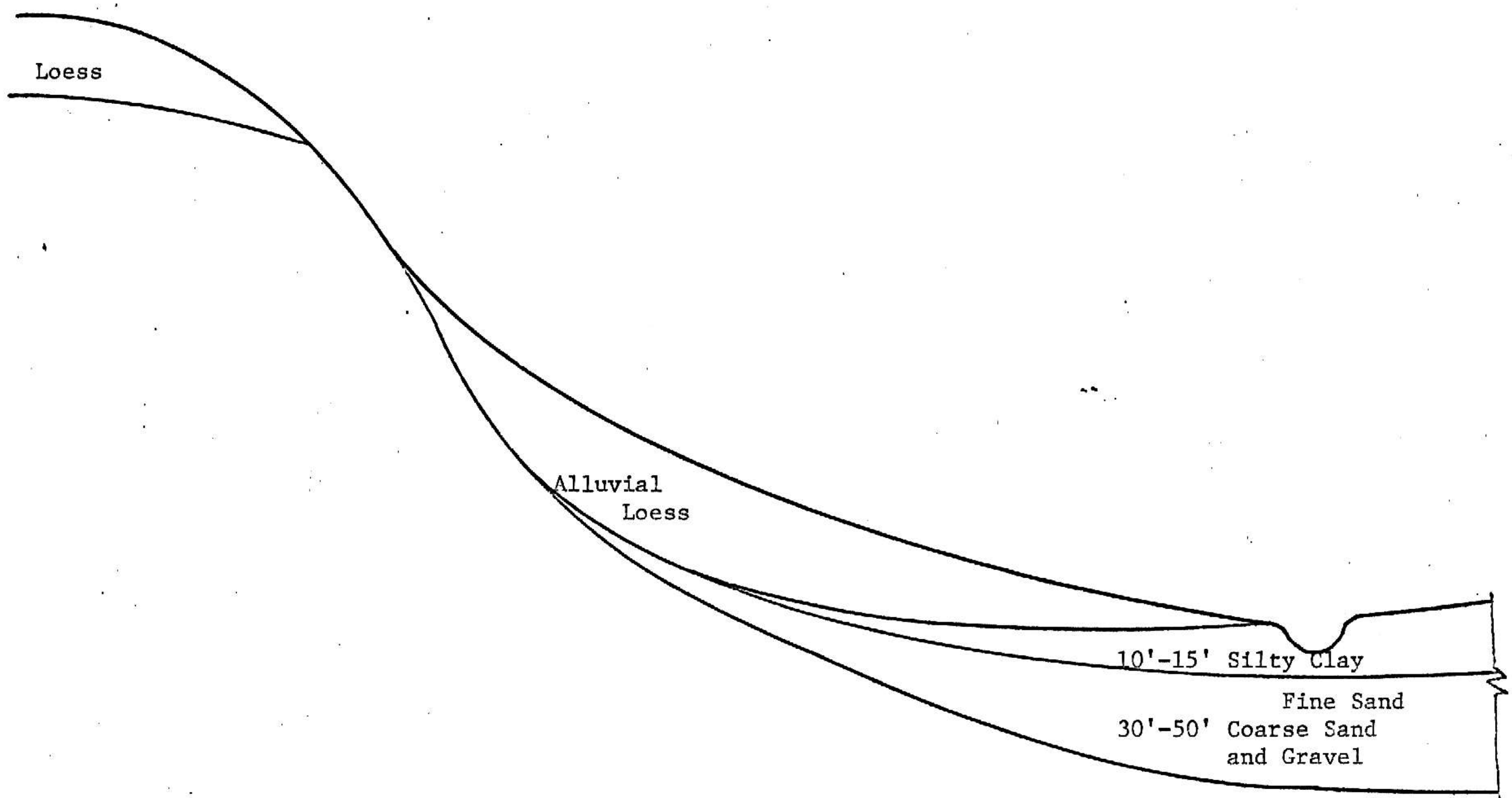



Fig. 17 Generalized River Valley Deposits

Drilling, sampling, and testing, of this material is similar to that of the loess except that saturation of the layer will cause caving of the drill hole and thus "mudding" or casing of the hole is often necessary. (33)

3. The Alluvial River Valley Fills

The river valleys flowing outward from, or around, the glaciated areas will be found to have been overcut and refilled as explained before. Included are all of the major rivers of Kansas except for the sections through the break of the plains where stream gradients are locally steepened. Typically, these river valleys have a surface of silt, silty caly or clay, 10 to 15 feet thick, which is usually soft and quite compressible. The underlying material varies from a fine sand at the top to a coarse sand, sand and gravel or bouldery sand and gravel at the bottom. This granular layer is usually 30 to 50 feet thick as shown in Fig. 17. The strength and compressibility of the upper cohesive layer varies so much, both horizontally and vertically within short distances, that it is best to design foundations in or on the underlying granular material by driven or pressure grouted cast-in-place piles. Pavements on the cohesive material do not perform well. (33)

The granular soils of the river valleys can seldom be drilled by auger type drilling equipment. Two methods may be used to penetrate this layer. (34)

1. The cased hole method consisting of driving a well casing to the level of each required sample, cleaning out the driven casing, and sampling below the bottom. This process can be repeated until the desired depth is reached.

2. The bentonite slurry or "mudded" hole method which consists of mixing bentonite with the drill water to form a viscous fluid which will not penetrate the porous material in the drill hole. Thus a hydrostatic head is

maintained in the drill hole, which supports the material and prevents caving. This hydrostatic head has an unknown effect on the penetration record but it in general increases the blow count (N) above the actual value.

Samples of granular soils can be taken only by split tube samplers or Denison barrels. Fortunately, the penetration record can be used to estimate the density and angle of internal friction with good reliability which in turn can be used for foundation design. Due to the impossibility of obtaining undisturbed samples, other testing is of little value. (40)

In designing foundations in or on granular materials found in river valley fills submergence is of importance since it reduces the unit weight ($\gamma$) of the soil. Regardless of the location of the existing water table at the time of the soil investigation, the water table should be considered to be at the top of the layer. This material has a good bearing capacity and performs well both under a spread footing and in contact with friction piles. The angle of internal friction is usually about 45°. The cohesion is zero and the porosity less than 0.40. When this material is saturated and unrestrained excavations or drill holes cave badly. (33)

4. The Expansive Soils

The expansive soils are restricted to the area of residual soils of eastern and south-central Kansas. The soil expansion in these areas is primarily due to the presence of a montmorillonite clay mineral and a climatic regime that consists of extended periods of drought after heavy concentrations of rainfall. The sites underlain by highly plastic clays should be investigated for the presence of these expansive soils. A simple method for testing the soil for this condition consists of running liquid limit tests on natural soil and then on soil mixed with 1 percent to 6 percent of lime (CaO), at intervals of 1 percent. A sharp decrease in the liquid limit will occur within this range if montmorillonite is present in the soil. (33) Correct design procedures are outlined in Parcher and Means. (31)

Drilling can usually be accomplished by auger boring equipment, although the soil may be very hard and thus require very heavy duty drilling equipment. The wall of the hole will not require support. (33)

Sampling for testing of the expansive qualities can simply be the auger cuttings, while Shelby tube samples should be taken for strength and compressibility. Split tube sampling and the penetration record are of negligible value. (33)

The Atterberg limits should not be used to estimate compressibility as proposed in numerous soil mechanics tests. (33)

5. The Glacial Till Plains

The glacial till plains lie in the loess mantled area and thus the surface soil is loess except on the steeper slopes. In almost all areas the loess is soft, compressible, and thin, so foundations should be extended through the loess to rest on the underlying glacial till. Due to the proxmity of the terminal extension of the glacier, the glacial till of Kansas is a very complex deposit of the typical glacial clay and the sorted granular alluvium deposited by the streams on and within the glacier. The area of each type of material is very irregular in size and shape, and it is impossible to predict the boundaries separating them. (41) A given structure may rest partially on sand and gravel, bouldery gravel, and glacial clay separated by boundaries impossible to predict without extensive drilling. It is very fortunate that the strength and compressibility of these materials are similar and fall within the range of 3 to 4 ksf which is adequate for most structures. (33)

Since the granular materials may be saturated, drilling methods similar to those used in the river valleys must be employed. The method of sampling depends upon the material. Split tube samples may be obtained from the granular materials and Shelby tube samples from the cohesive materials. (34)

Due to the random sized particles of the cohesive glacial till, sampling is very difficult. The testing procedures of the granular materials should be limited to the penetration record while the cohesive material should be tested for strength by triaxial shear with pore pressure and compressibility by the Consolidation test. (33)

6. <u>The Soil Solum</u>

The soil solum, or A and B horizons, varies in thickness and character directly with the amount of rainfall, slope, vegetation, parent material, and age of the surface. In Kansas, it is thickest in the southeast and thinnest in the west. The A horizon, or topsoil, does not contain enough organic matter to be detrimental. It is usually a dark brown silt or silty clay with a low plastic index and it is often less than one foot in thickness. This layer does not present a problem for foundations since most structures are founded below it, but it must be considered in the design of floor slabs and pavements. Samples can be secured in the disturbed state and testing procedures are limited to the tests necessary for soil classification. (36)

The B horizon has a maximum thickness of two to three feet and consists of a silty clay or clay. Due to its position it is not a problem in foundation engineering but must be considered in the design of pavements and floor slabs. Invariably classification tests will indicate that it is a less suitable material for pavements than the A horizon above so it is unwise to remove the topsoil in most cases. Samples can be obtained in the disturbed state and testing procedures should include those tests which are necessary for classification. (36) As with the expansive soils, a high liquid limit indicates that the expansive characteristics should be checked since this layer may be expansive in nature. (33)

# CONCLUSIONS

From the preceding, it is obvious that the work of agronomists and geologists has wide and useful application to the field of soil engineering. With the aid of these, the soil engineer can recognize that soils vary but that the variations are predictable in advance of the soil investigation and can thus be used as a guide for the soil investigation. With this preliminary information, the soil investigation can provide maximum information at minimum cost.

The engineering problems in each of the provinces are outlined and it is obvious that the different provinces have unique problems that require special drilling, sampling, and testing procedures. The use of this report as a guide can thus greatly decrease much unnecessary sampling and testing, and will produce data directly applicable to design and to the solution of engineering problems.

# BIBLIOGRAPHY


1. Fenneman, N. M., Physiography of Western United States, McGraw-Hill Book Co., New York, 1931.

2. Dakuchaev, V. V., Natureforsch Ergesellsch, Arbiet St., Petersburg, 1879.

3. Casagrande, A., "Classification and Identification of Soils," Transactions, ASCE, Vol. 113, 1948.

4. Corps of Engineers, "The Unified Soil Classification System," U. S. Army Engineer Waterways Experiment Station, Technical Memorandum No. 3-357, Vol. 1, March 1953. Revised April 1960.

5. AASHO, "Specifications for Highway Materials," Designation M 145-49, 1949.

6. FAA, "Airport Paving," 1956. Modified in 1968.

7. Krumbein, W. C., "A History of the Principles and Methods of Mechanical Analysis," Journal of Sedimentary Petrology, London, 1931.

8. Casagrande, A., The Hydrometer Method for Mechanical Analysis of Soils and Other Granular Materials, Cambridge, Mass., 1931.

9. ASTM, "Standard Test Method," D 422-61T, 1961.

10. Atterberg, A., "Uber die Physicalische Bodenuntersuchung Und Uber die Plastizatat der Tone," Internationale Mitteilungen fur Boden Kunde, Vol. 1, 1911.

11. Coulomb, C. A., "Experiments on the Application of the Rules of Maxima and Minima to Some Problems of Stability Related to Architectural Works," Memoirs, Royal Academy of Sciences, Paris, Vol. 7, 1776.

12. Rankine, W. J. M., "On the Stability of Loose Earth," Phil. Transactions Royal Soc., Vol. 147, 1857.

13. Bishop, A. W. and D. J. Henkel, The Measurement of Soil Properties in the Triaxial Test, E. Arnold Publishing Co., London, 1957.

14. Terzaghi, Karl, Erdbaumechanik, F. Deuticke Publisher, Vienna, 1925.

15. Self, Huber, Geography of Kansas Syllabus and Atlas, W. M. C. Brown Co., Iowa, 1963.

16. Mohler, J. C., "Climate of Kansas," Kansas State Board of Agriculture, 1948.

17. Flora, S. D., "Climate of Kansas," Kansas State Board of Agriculture, 1948.

18. Schowe, W. H., "The Geography of Kansas, Part 2, Physical Geography," Transactions, Kansas Academy of Science, Vol. 52, No. 3, 1949.

19. Moore, R. C., Frye, J. C. and J. M. Jewett, "Tabular Description of Outcropping Rocks in Kansas," Kansas Geol. Survey, Bull. 52, pt. 4, 1944.

20. Merriam, D. F. and W. W. Hambleton, "Relation of Magnetic and Aeromagnetic Profiles to Geology in Kansas, in Symposium on Geophysics in Kansas," Kansas Geol. Survey, Bull. 137, 1959.

21. Merriam, D. F., "The Geologic History of Kansas," Kansas Geol. Survey, Bull. 162, 1963.

22. Lobeck, A. L., Geomorphology; An Introduction to the Study of Landscapes, McGraw-Hill Book Co., 1939.

23. Fenneman, N. M., Physiography of Eastern United States, McGraw-Hill Book Co., New York, 1938.

24. Frye, J. C. and A. B. Leonard, "Pleistocene Geology of Kansas," Kansas Geol. Survey, Bull. 99, 1952.

25. Baldwin, Mark, Kellogg, Charles E. and James Thorp, "Soil Classification," U.S. Dept. Agr. Ybk., 1938.

26. Thorp, James and Guy D. Smith, "Higher Categories of Soil Classification; Order, Suborder and Great Soil Group," Soil Sci., 67, 1949.

27. Soil Survey Staff, "Soil Classification, A Compresive System," U. S. Dept. of Agriculture, 1960.

28. Kansas Agricultural Experiment Station, "Major Soils of Kansas," Circular 336, Manhattan, July, 1956.

29. AASHO, "Standard Specifications for Highway Materials and Methods of Sampling and Testing," Ed. 8, Vol. 2, 1961.

30. Chang, Chung-I, "Stabilization of Loess by Cement for Foundation Purposes," M.S. Thesis, Kansas State University, 1969.

31. Parcher, J. V. and R. E. Means, Soil Mechanics and Foundations, Charles E. Merrill Publishing Co., Columbus, Ohio, 1967.

32. Drannikov, A. M., "Construction on Loess Soil of Small Thickness," Proceedings of 3rd Asian Regional Conference on Soil Mechanics and Foundation Engineering, Haifa, Israel, 1967.

33. Personal communication with major advisor, Wayne W. Williams.

34. Hvorslev, M. Juul, "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes," Report on a Research Project of the A.S.C.E., 1949.

35. Terzaghi, G. L. and R. B. Peck, Soil Mechanics in Engineering Practice John Wiley and Sons, 2nd Edition, 1967.

36. USDA in Cooperation with KAES, "Soil Survey Reports for Kansas Counties."

37. Peck, R. B., Foundation Engineering, John Wiley and Sons, 1952.

38. Oosterbaan, M. D. and G. A. Leonards, "Use of an Insulating Layer to Attenuate Frost Action in Highway Pavements," Record 101, Highway Research Board, 1965.

39. Penner, E., Oosterbaan, M. D. and R. W. Rodman, "Performance of City Pavement Structures Containing Foamed Plastic Insulation," Record 128, Highway Research Board, 1966.

40. Bowles, J. E., Foundation Analysis and Design, McGraw-Hill Book Co., 1968.

41. Frye, J. C. and K. L. Walters, "Subsurface Reconnaissance of Glacial Deposits in Kansas," Kansas Geol. Survey, Bull. 86, pt. 6, 1950.

# ENGINEERING PROPERTIES OF KANSAS SOILS

by

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## ABSTRACT

In this report, the information obtainable from pedologists and geologists is shown to be applicable to and valuable for soil engineering. Sufficient background material from each of these areas is given to illustrate the development of the methods, principles, and information that can be used in soil engineering.

A logical sequence to guide a soil investigation is given that will maximize information while minimizing the cost of gathering data for the structural design of foundations.

The state of Kansas is shown to consist of eleven contrasting provinces, within which the soils may be grouped into upland, slope, and valley soils. Within a given province, the upland soils will be found to be similar throughout the province as will the slope and valley soils, but the upland, slope, and valley soils will vary greatly from each other. Typical soil profiles and the engineering performance of the various upland soils are given.

The engineering problems of each of the commonly occurring materials are shown including general strength and compressibility estimations. Recommendations for drilling, sampling, and testing are given as a guide for the selection of the proper equipment and methods to gather sufficient information for the design studies while eliminating data which has no application.