THE ORIGIN, DISTRIBUTION, AND AIRPHOTO IDENTIFICATION OF UNITED STATES SOILS

With Special Reference to Airport and Highway Engineering

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Technical Development Report No 52

May 1946

U S DEPARTMENT OF COMMERCE

CIVIL AERONAUTICS ADMINISTRATION

WASHINGTON, D C

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FOREWORD

The objective of the work reported in this publication has been to develop information and techniques which will assist the engineer in the mapping and evaluation of soils[1] with respect to their use in airport and highway engineering. The methods which have been developed are not expected to replace, but rather to supplement existing techniques They are intended to provide an additional useful tool for studying the soil, geology, and other terrain characteristics of sites for specific engineering uses such as airports and roads, and for the location of gravel pits and rock quarries

As the work has been confined purposely to those fundamentals necessary for an engineering evaluation of soils, the report does not provide minute details An attempt has been made to introduce guides for studying soils from a knowledge of geology, pedology, and airphotos, and not to develop a stereotyped procedure by which the engineering properties of soils can be unmistakably extracted in a routine fashion.

The report consists of two separate but closely related groups of subject matter, followed by a chapter describing the application of the techniques The first part, consisting of chapters II to VII, provides a means of studying soil through the application of the principles of soil origin and development It supplies the engineer with an abridged version of geology and pedology necessary for the application of those principles Chapters VIII to XII, which comprise the second part, describe a new technique for identifying soils from airphotos that is based partly upon geology and soil development Hence, the first supplies information concerning factors influencing soil formation in the various parts of the country and outlines the differences among soils formed in diverse ways, while the second provides a means for determining the characteristics of the soils

In both parts of the report soils are grouped in accordance with their mode of formation The first is illustrated on a map (plate 1) and the second in the several sections of the Airphoto Analysis Chart and in the numerous airphoto plates in appendix B, which is a separately bound album This grouping consists of four major divisions, each subdivided according to textures of the soil or the rock from which residual soil was derived The four major groups are denoted as residual soils, which are those formed by the disintegration of rocks in place, glacial soils, loessial or aeolian soils, and lastly, alluvium and associated water-laid deposits, which are divided into soils of the Coastal Plain, soils of the filled valleys and Great Plains outwash mantle, and recent alluvium On the map the differentiation among these primary groups is made with colors, textural variations within the group are indicated by symbols In addition, there are regions here referred to as "non-soil areas," which usually consist of mountains, canyons, badlands, or scablands, where soil characteristics are usually of minor importance in the design and construction of engineering works These are set apart by a separate color on the map

There are minor differences in soil grouping between the two parts of the report This is due largely to the practical difficulty in separating certain groups on a map of small scale, while on airphotos refinement in detail is entirely feasible.

Although variations are such that the different colors or symbols indicate only the approximate extent of the soils represented, and imply that these soils

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[1]The term "soil" as used throughout this report denotes all of the unconsolidated portions of the earth's crust, including all sizes from the finest particles to the coarsest gravels

Boundary between High Plains materials and older formations exposed by erosion.

merely predominate in the areas shown, it is intended that the map establish, as closely as possible, real boundaries that have a practical meaning for engineering use Obviously, such an objective cannot always be achieved for in some cases, such as those where glacial and loessial soils are contiguous with one actually overlying the other, the transition from one material to the other is gradual, and there may be no sharp boundary line between the two. On the other hand, some of the borders between the different soil groups are well defined, as illustrated in the frontispiece

There are occasional variances with previous geological or soil maps of different nature These differences do not connote errors, but are intended so that the material of significance to engineers be given primary consideration. For example, in some filled valleys where shallow deposits of alluvial or aeolian soils locally overlie indurated rock strata, the classification for this purpose may be that of the non-soil group because underlying lava flows are of greater importance to construction than are the water-laid and wind-deposited soils, although classification favoring the latter may more accurately describe the surface soil Conversely, a symbol representing the overlying material is often appropriate even though the underlying rock may be of considerable engineering significance aside from its influence upon soil formation At places in the loess belt bordering the Mississippi River, for example, limestone is often encountered in grading operations, yet the bedrock is actually subordinate to the loess and thus it is not represented on the map However, if regard need be given to the rock as a factor in the engineering soil problems, this factor may be evaluated by study of the literature and through the use of aerial photographs of the area in question

It is recommended that in reading and analyzing certain portions of the text, particularly those pertaining to the map and to pedologic and geologic considerations, the reader have available for convenient reference a geologic map of the United States (52) and maps illustrating land forms (54) and other soil interpretations (43) (44) Naturally, any reference to a certain portion of the country can be even more readily comprehended through reference to maps and literature dealing with that locality alone (81) (683)

The study has produced supporting material which is too voluminous for incorporation in this report Nevertheless, some numerical data are included in appendix A Likewise geologists and pedologists will not find a complete treatment of these subjects as the information given is intended to supply the engineer with sufficient data to enable him to start his work, after which a more complete study of the references in the bibliography will be necessary

As in all surveys, parts of the data here presented are more detailed, and possibly of higher accuracy, than others. In general, the information on glacial and other soils in the central and eastern part of the United States, except possibly the Atlantic Coastal Plain, is given in greater detail than that for the western United States At the time of this writing additional field surveys of the western United States were being conducted as a refinement of the data for those areas as here presented

The research was initiated as a part of studies of the effects of weathering upon stabilized soil which were conducted by the Engineering Experiment Station, Purdue University, working under contract with the Civil Aeronautics Administration through its Technical Development Division, John Easton succeeded by D M Stuart, Chief, under the immediate supervision of its Airport Development Section, F H Grieme, Chief, who devoted much attention to the early advancement of the project, succeeded by D S Jenkins, one of the authors. The soil stabilization studies were conceived largely by Major W M Aldous, Army Air Forces, formerly of the Civil Aeronautics Administration As the specified phases relating to soil stabilization progressed, the value of the soil classification work in other fields of aviation and engineering became apparent and the scope was expanded to include the study of the engineering characteristics of the soils of the United States This extension was carried out under the original contract but on a cooperative basis in that some finances were supplied by Purdue University and part of the research was conducted by the Civil Aeronautics Administration. The contracted research was performed by Purdue University, E. C. Elliott, President, and Dean A. A. Potter, Director of the Engineering Experiment Station. Use was made of some of the facilities of the Indiana Joint Highway Research Project, R. B. Wiley, Director and Head, School of Civil Engineering and Engineering Mechanics.

The authors are indebted to several individuals and organizations for valuable suggestions, constructive criticism, and help in preparing the manuscript. Specific among these are the comments and criticisms by R. W. Hockensmith, C. B. Brown, and G. W. Musgrave of the U. S. Soil Conservation Service, O. L. Meinzer and C. L. McGuiness of the U. S. Geological Survey, and R. C. Moore, State Geologist of Kansas, regarding technical information related to the soil map and text. Likewise, the authors are grateful to J. G. Steele of the U. S. Soil Conservation Service, C. B. Hunt and others of the Division of Military Geology, and Nelson Sayre of the Ground Water Division, both Divisions of the U. S. Geological Survey, and W. E. Smith, American Geophysical Union, for technical review of the manuscript. Most of the airphotos were obtained from the Agricultural Adjustment Agency through R. H. Moyer, Chairman of the Committee on Aerial Photography, whose assistance in this phase of the work was invaluable.

The work at Purdue University was supervised by Professor K. B. Woods, who also prepared chapters III, IV, and VII on Residual Soils, Loessial Soils, and Non-soil Areas, parts of chapters II and VI on Geology and Pedology and Waterlaid Soils, and portions of the soil map. Professor D. J. Belcher conceived and was largely responsible for the development of the airphoto interpretation, prepared the chapters VIII to XII on Airphoto Analysis of Soils, and assisted in the preparation of the soil map. Professor L. E. Gregg prepared chapter V on Glacial Soils, parts of chapters II and VI on Geology and Pedology and Waterlaid Soils, portions of the soil map, and supervised the laboratory tests of the soils. David S. Jenkins supervised the work for the Civil Aeronautics Administration, conceived the expansion to a nationwide basis, prepared chapter XIII on Application of the Data to Airport Development, assisted in preparation of the soil map and, assisted by David M. Cooksey, Jr. and others of the Civil Aeronautics Administration, edited and prepared the manuscript for publication. The illustrative sketches for the Airphoto Analysis Chart were prepared under the supervision of John Sebastian, and the soil map (plate 1) was prepared for printing by A. M. Weber, both of the Civil Aeronautics Administration. The ground photography resulting in illustrations dispersed throughout the manuscript was conducted by R. E. Frost of the Joint Highway Research Project staff. Numerous other members of the highway research organizations aided in drafting the original copy of the map, conducting soil tests, and assembling information in the form of aerial photographs, bibliographic references, and summaries of the test data.

CHAPTER I

INTRODUCTION

Soils are products of nature upon which they are almost wholly dependent for their formation, distribution, and physical and chemical characteristics Therefore, in their natural states, soils are subject to analyses and interpretations based on natural processes Thus, if knowledge is available of the original material from which a soil was formed and of the conditions to which it was exposed, general information concerning the resulting soil is immediately derivable.

In addition, available detailed data for one soil may be applied in general to a second soil that originated and developed under the same conditions as the first This is the fundamental hypothesis upon which the methods described in this report are based It holds true for all geological formations, whether they be of bedrock or of transported material moved by wind, water, or ice

Although the process of soil formation follows this basic principle, the soil mantle is more complex than these statements might indicate The countless combinations of local conditions that have existed during thousands of years have complicated this mantle and probably there are no two locations where the soils are identical throughout their depths to bedrock To illustrate a possible set of variables hypothetically, a bedrock in a certain location weathered and produced several feet of soil which later was covered by a series of glaciers and the consequent glacial debris During one or several of the interglacial periods this location was an outwash area and later, perhaps, a lake bed too, so that deposits of granular material and lacustrine silts interbedded with unassorted till covered the residual soil Each was weathered to some extent before being covered by the next Finally, the last glacial invasion left a covering of till which has been exposed to weathering since the glacial period

Evidence of changing conditions such as these has been used for many years by geologists in analyzing the structure and physical history of the earth, while those interested mainly in the pedological[2] concepts of soil science have established a classification only partially based on these variations and the principle that similar soils originate from similar materials under similar conditions. The material of primary interest to the pedologist is that which is relatively near the surface It includes the soil which has been appreciably weathered and in which plants grow, as well as the original or "parent" material from which the soil was developed Any deposit beneath the parent material and essentially different from it is generally not considered unless it has some influence on the development of the soil above or upon plant development Thus, in the illustration previously cited, the material of pedological significance is

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[2]Briefly defined, pedology is the science that treats of soils in their natural state To the pedologist, soil is not a construction material, but is a profile differentiated into natural horizons Hence it has been desirable to distinguish between "pedological characteristics" and "engineering characteristics" of soil In the same vein "engineering soil tests" describe physical tests used in the design of engineering installations but by no means embrace all physical tests.

the final covering of till left by the last glacial invasion, that of engineering significance includes all layers which affect stability and strength of foundations, excavation, drainage and ground-water characteristics, down to and possibly including the bedrock Since the beginning of this century, an increasing amount of time and effort has been spent in developing the pedological analysis and classification of soils, as is evidenced by the vast amount of published literature concerning the subject The bases for identification and classification have changed during the course of development from those concerned primarily with differences in parent material, which are essentially geological, to those which include the influence of other environmental factors such as climate, vegetation, and topography, in addition to parent materials More recently, " there has been a continued development toward a system based strictly on soil characteristics - less on environmental and external features and more on the internal soil morphology " (43, p 981)

With this development of pedology an increasing degree of differentiation between the groups, particularly the "series," has resulted as additional refinements in soil characteristics have been recognized, consequently, the number is constantly increasing, there being at present several thousand series recognized in this country alone This, of course, conforms with the fact that soils are infinitely variable in nature so that it is possible to divide a classification in infinite detail The detail required in such a system of classification depends upon the degree of refinement necessary for its practical application

In this country the greatest application of pedological concepts has been in the field of agriculture Outstanding among the important results of this application are the soil surveys and reports of government agencies such as the U S Department of Agriculture (43) (44) and the agriculture colleges of various states, both in surveys made separately (352) (755) and in cooperative endeavors (205) (362) By these means, descriptions and pedological classifications of soils within the areas surveyed have been recorded, and maps have been prepared to show the locations of these soils in accordance with information available at the time of the survey All of the country has been included with the degree of accuracy varying in different localities, but in general the smaller the area considered and the more recent the survey, the greater the detail obtained Among the many reports some discrepancies and contradictions exist mainly as a result of changes made in the classification and the greater detail obtained in more recent surveys as compared with those of earlier dates

Within the past few years, investigations and uses such as those made in Michigan (454), Missouri (483), and Indiana (5), have proven the feasibility of applying pedological principles to engineering soil problems, especially those arising in highway design and construction When established engineering soil tests were used for investigating the possibility of correlation, it was shown that within reasonable limits pedological data could be converted to engineering test data, and vice versa Thus, new uses for much of the pedological information built up in the past were apparent, also, the results indicated that some future engineering soil analyses could be based on soil forming processes so that the data, instead of being limited in application to one situation only, could be applicable to all other locations where similar conditions existed

This pedological approach to the determination of the characteristics of soils naturally has some limitations in its application to engineering. In general, the limitations are those of depth and of detail, the first of which excludes from consideration materials below those included in the scope of pedology while the second is concerned with the heterogeneous character of soils and the degree of variation which can exist pedologically without practical significance to engineering problems The fact that this method of soil analysis is not applicable to materials beneath those of pedological significance does not imply that soils at these greater depths were not derived through processes essentially the same as those by which soils are formed today, nor does it imply that the depths considered in pedology are limited to a few feet immediately beneath the surface In fact, the "profile" of weathered soil and parent material is often many feet in thickness, an example of one of the deeper unconsolidated formations being the deposits of windblown soil or loess along the lower Mississippi valley where depths of one hundred or more feet have been reported (32, p 389) (43, p 1067)

As soil forming processes have operated only to certain depths which vary in different areas and with different materials, the design and construction of deep foundations, tunnels, and similar works is influenced little by the soils considered in pedology On the other hand, practically all of the highway, railroad, and airport soil problems are within this limit Between these two extremes are some types of soil engineering, such as those dealing with earth dams and levees, where the principles may apply

Because of the comparatively small amount of work which has been done toward adapting pedological concepts to engineering, the limitations concerning the detail practicable for such usage have not been definitely established It appears, however, that for this purpose the geological derivation of the parent material is of major importance as a basis for classification and as a factor affecting the physical characteristics of both the parent and the weathered soil Also, age (time elapsed since deposition), topography, and climate are important factors in this respect Hence, in its present state of development, the engineering interpretation of factors determining soil characteristics is concerned with environmental (geomorphic) features more than with internal soil morphology There are exceptions to this perspective For example, the natural structure of some soils determines to a great extent their permeability, strength, compressibility, and similar properties affecting engineering performance On the other hand, factors such as color, number, relative arrangement, and thickness of horizons, depth of weathered soil, and even chemical composition, all of which are of importance in pedological classification, have been minimized The detail is thereby simplified and a revision of nomenclature is made possible Undoubtedly, future knowledge and needs may alter the importance of some factors and increase or decrease the amount of detail necessary for practical use

This work in adapting pedological principles to engineering soil analyses can be considered only pioneering in nature, and the specific data which have been obtained are relevant only within somewhat limited areas The principles, however, have world-wide application With the recent and rapid expansion of transportation facilities throughout the world, the need for using these principles in studying airport soil conditions has become urgent and according to indications, this need will be even greater in the future At present, the knowledge of soils, from the standpoint of either pedology or engineering, is slight or non-existent in many parts of the world, but partially to balance this deficiency there are geological data available for almost all parts of the world Added to these, and frequently of much greater importance in analyzing soils with desirable detail, are the data obtainable from aerial photographs (92) (5) Not only can the relief and soil pattern be observed in this manner, but evidence of differences in characteristics of soils derived from different materials and under different conditions have been shown to be readily perceptible in the photographs (93)

As a result of the many new soil problems arising through increased airport development and the need of a rapid method for study of soil areas, this research project was undertaken When the study was inaugurated it was planned that through various available means fifty of the known major soils of the continental United States be classified and catalogued in accordance with their properties pertaining to their use as airport runways As the work progressed it was found that more soils could be conveniently included and that the fundamentals for converting a pedological system of classification for soils in this country could be established on an engineering basis In addition, the technique of airphoto identification of soils was further developed as an advantageous aid in obtaining engineering detail

Throughout this report occasional reference is made to pedological soil names This is done entirely for illustration purposes and as an aid to those familiar with those names

The results of this research are based upon a relatively small amount of engineering soil test data and a comparably large amount of information obtained from geological and pedological literature, aerial photographic evaluation, and extensive field inspections in many areas The report, then, is concerned not so much with details but rather the methods for obtaining details when and where the necessity exists Because of the limited amount of time spent, the relatively small amount of detail considered, and the large amount of area involved, this work is of the exploratory nature intended to show the feasibility of obtaining in this manner the soil data required in airport development In any work of this scope, including as it does the entire United States, only the broad fundamentals of a technique can be presented For application to an individual local problem it will be necessary, as repeatedly suggested, for the engineer to obtain all local data available, and to temper his conclusions with considerations of climate, topography, vegetation, and all other influences

CHAPTER II

NOTES ON GEOLOGY AND PEDOLOGY

Geology is the science that investigates the structure of the earth, the successive physical changes it has undergone, and the causes which have produced such changes Geologists divide the rocks of the earth into three general groups igneous, sedimentary, and metamorphic The igneous rocks are those that were formed through the solidification of molten material In age they range from the oldest granites to recent lava Sedimentary rocks were formed when igneous and other rocks were decomposed through natural processes and the resulting debris was transported by natural agents to new locations, deposited in layers and consolidated Some were again uplifted, eroded, transported, and redeposited Metamorphic rocks were formed from either the igneous or sedimentary rocks when heat and pressure altered their structure and physical characteristics Within the three general groups there are many subdivisions, for detail descriptions of which the reader is referred to other sources (28) (33)

The process of rock transformation may be illustrated by the disintegration of granite (igneous rock) to provide fine-grained matter which was transported, deposited, and compressed into layers of semi-consolidated clay-shales (sedimentary rock), which in turn through gigantic applications of heat and pressure were changed to slates (metamorphic rock) The granite is sometimes metamorphosed direct, to form gneisses and schists

These destructive (erosion) and constructive (deposition) actions, in combination with pronounced but gradual uplifts and lateral movements have caused most of the country to be both below and above the seas at least once throughout the ages Hence, the absence of material of a certain geologic period in a particular locality does not always mean that sedimentation had not occurred in that area during that time Conversely, the fact that rocks of a given age outcrop locally does not necessarily imply that younger strata were never formed above the rock now exposed

The final form and texture of sedimentary rocks and of all transported soils (map, plate 1, and Airphoto Chart) are dependent upon the character of the suspended material and the conditions of transportation under which they were moved and deposited Although not a sedimentary carrier, ice is included as a transporting agent along with wind and water These three agents of transportation operate under natural laws that limit the particle size and quantity of the load, and the distance which its various fractions can be moved

Wind is a selective agent from the start and accepts generally those particles lying within the range of fine sand to very fine silt, but may include some material of the clay sizes Once having accepted this restricted type of material for transport, the wind quickly sorts the load into two distinct classes and moves them unidirectionally The material classed as sand is literally rolled along the ground, often for relatively short distances, never rising higher than a few feet from the surface Material thus moved horizontally and as a body, or dune, by the wind, is subject to direct influence by extraneous surface conditions occurring along its path The silt and very fine sand, and whatever clay particles are present, are lifted high above the surrounding ground features and carried along a straight path The fine sand and silt is dropped vertically as individual particles over the adjacent landscape, disregarding entirely the presence of surface features The distance that silt is carried may be infinite although the depth of deposit at distances much greater than 100 miles from the source in the United States becomes insignificant as a consideration in engineering work The clay may be carried long distances as dust before deposition

Ice, because of its great ability to incorporate fragments in its mass, can carry a volume of material that is limited, not by the volume of ice, but by the amount of loose material available All sizes are moved for long distances across hills and valleys and are deposited over vast areas In continental ice the path is somewhat directional

Water as an agent of transportation has established the most diversified collection and distribution system Like ice, water gathers all textural classes from boulders to clay Unlike ice, but like wind, it immediately commences the process of sorting into sizes, dropping some, but always carrying further, and for varying distances, those sizes that are of smaller diameter Water flowing from tributaries gathers material from many and diverse sources It mixes and conveys the particles, grains, and fragments along its path, which, unlike the path of wind and ice, is always downhill The volume of material moved is a function of the size and velocity of the stream and its tributaries, and of the quantity and erodibility of the available material in its watershed

The restrictions that limit the particle size and amount, as well as distance and direction of movement, also have an influence on the method of deposition Ice, over-riding all but the largest obstacles, often blankets the original land features with the heterogeneous assortment of materials that constitute its load An association of the character of the transported load and the few forms peculiar to ice-deposited material gives purpose and significance to the identification of these land forms

The dual role played by wind in separating and transporting sand and silt permits an almost precise evaluation of textures occurring in these two categories. First, sands forming in one of the characteristic shapes assumed by dunes create an individual dune which is a land form that is practically unmistakable After having moved some distance from the source the proportion of silt-sized material remaining in the dune is relatively low Although the major sorting accomplished by the wind occurs during the erosion phase, the loess (silt) is further separated during the transportation-deposition phase, as shown by grain size analyses of loess on an areal basis (343) However, performance observations and physical tests made in connection with this work indicate that this additional segregation of sizes is not greatly significant to design More significant are the environmental conditions such as topographic position and character of underlying material

It is of equal importance to appreciate the significance that lies in the mechanics of loessial deposition These silts falling vertically, grain by grain, have only minor regard for the existing land forms on which they settle They blanket hillsides and hilltops, plains or valleys, theirs is generally a one-stop trip, for once the loess is deposited it is seldom reclaimed by the wind That particular characteristic preserves the land form of the original deposit and minimizes the confusion that otherwise would result from the influence of other than the transporting wind

The depositional characteristics of water as a transporting agent are fairly well known While it compares favorably with ice in the variety of sizes of materials which it will carry, it also introduces a sorting action associated with aeolian deposits, but not with glacial action Unlike wind, water is subject to a definite channelization and cyclic volume change with corresponding changes in velocity These changes introduce variations in depositional conditions creating (vertically) at any one point a series of beds or lenses of varying textural properties, the texture and depth of each of these depending upon the velocity and duration of conditions at the time of deposition.

Ice-deposited materials are generally of such recent origin that they have not contributed materially to the formation of hard rock To a much greater extent there exists rock formed by the induration of windblown, sandy materials These two together constitute but a minute fraction of the total when considered with the rocks originating from water-deposited sediments It is probable that the comparative absence of indurated loess among the sedimentary rocks can be accounted for by the fact that loess is deposited in significant depths only in association with rolling relief, and usually adjacent to, but considerably above the local base plane of erosion The relatively steep slopes prevailing in loessial areas, and the susceptibility of silt to erosion are conditions favorable to removal before hardening processes can alter the loess into a rock form

Attention is then first focused on those rocks that derive their textural and structural characteristics from the action of moving water Nearest the source, velocity of the flowing water is great enough to carry the more granular portions of the debris greater distances. Where the velocity decreases, more coarse-grained particles are lost, and gradually the material being deposited decreases in size until only the finest of particles remain in suspension Conditions at one reach of a stream are never constant, however, as a flood of one magnitude may carry only silt to a given location, but another, of greater force, may move even the gravels to that vicinity It is commonplace, therefore, to find both vertical and horizontal differences in texture and thickness of related strata Introduce also the differences in cementing materials that bind the individual grains together and there is created a class of stratified material that, when weathered, produces various and distinctive land forms that are unique to sedimentary rock areas

For those rocks which were formed beneath the waters of the seas, the finer materials were precipitated slowly and, upon being combined with the calcareous remains of marine organisms, provided the ingredients necessary for the formation of limestones and calcareous shales Upon the retreat of the seas and the uplifting of the land these rocks were exposed, sometimes in horizontal position, though often tilted perhaps to the extent of becoming vertical or nearly vertical in their present form As some of these exposed rocks are more resistant than others, differential erosion occurs leaving the strongest strata as protruding land forms above the valleys occupied by the weaker materials

Differential erosion of course is not limited to those areas where the strata have been tilted Oftentimes the cap rock in a system of horizontal rock layers may be worn away locally, thus exposing less resistant stone at lower levels, which, in turn, breaks down at such a rapid rate that the adjacent sections where the cap rock is intact remain at elevations sometimes far above those of the surrounding land In that way rolling and rough topography is formed through the creation of natural drainage channels, and, within a distance of a few miles, very marked changes in the rocks of engineering significance may occur.

Most of the mountains formed by changes in the earth's crust are brought about by the great diastrophic movements which uplift, warp, and sometimes fault the strata into long, narrow ridges It is through such changes, obviously dependent on enormous pressures, that many of the metamorphic rocks are produced The structure of these materials is quite variable although ordinarily jointing and fracturing are common features associated with metamorphic rocks Other changes may occur merely through the exposure of the rocks to heat generated by molten material in sections adjacent to these rocks Oftentimes this magma reaches the surface by flowing through fissures and cracks in strata which have already been formed, and upon reaching the surface may be dispersed in sheets of lava (fig 1) which sometimes fill the lowlands and depressed areas to great depths Upon cooling, these form the basalt and the lava rocks, such as those found on the Columbia Plateau

In contrast, the molten material has often been solidified without having reached the surface, later to be exposed by erosion of the overlying and surrounding formations Because of the slow rate of cooling and solidification of these primary rocks, their structure is different from that of the igneous materials cooling on the surface, the former being more coarse in texture Still different in mode of formation, the igneous rocks may be produced by a lava flowing from the craters of volcanos, the explosion of the volcano having previously removed any overlying rock, thus making possible a path by which the lava reaches the surface In this way, cinder cones form about the craters, with the flows radiating from the centers These cones are easily recognized by their form and symmetry (fig 2).

Fig. 1. Broken lava beds in western New Mexico. The cooling of the surface formed a crust that subsequently collapsed after the still fluid lava had drained to lower areas.

Fig. 2. The unique outline of cinder cones is well illustrated by this (Tertiary) volcanic land form in central Arizona.

Aside from all of the indurated materials as factors in soil formation, there are the unconsolidated deposits which cover approximately half of the country, and which, according to the definition used in this work, constitute soil both in their unweathered and weathered states. These are materials of fairly recent geologic origin produced through processes of glacial erosion and distribution, alluvial action, or wind transportation. They include some of the deepest of soil formations overlying the solid bedrocks, depths of a few hundred to several thousand feet not being uncommon. In contrast, the soil materials derived through the weathering of rock strata are seldom more than a few feet in depth, it being generally believed, for example, that weathering of perhaps a hundred feet of limestone is required to produce a foot of residual soil.

Although the composition of surface materials and attendant land forms are of primary importance in determining soil characteristics, geological data in this form are not generally available, except through some additional amount of interpretation. Most of the information produced has been collected, arranged, and published on the basis of a time or age classification system (40)[3]. Consequently, to convert this information to a form usable for determination of soil characteristics, it is necessary that the engineer be familiar with the nomenclature and sequence pertaining to geologic elements. Although the geologic time intervals are not generally of significance in engineering problems, nor of particular interest to the engineer, most geologic literature, such as that cited in the bibliography of this report, requires that the reader thereof be familiar with the geologic time scale. Therefore, Table I and accompanying discussions are included here as a ready reference. In the tabulation, symbolic of the time-strata relationship in which the oldest of strata normally lie at the base of a system of bedrocks in nature, the chronological progression of geologic intervals is read from the bottom upward.

The periods included in the Archeozoic and Proterozoic, usually collectively referred to as Pre-Cambrian, represent more than half of the history of the earth, according to the present conception of time intervals. Rocks of these periods,

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[3]Those interested in references to the pros and cons of stratigraphic versus lithographic mapping of geologic formation should consult pages 2-5 of this reference.

although generally well represented in North America, are not differentiated with much exactness because of the scarcity of fossils available for correlation. It has been definitely established that both igneous and sedimentary rocks were formed during Pre-Cambrian time, but, with only a few exceptions, these were metamorphosed to form numerous variants of the metamorphic group.

While Pre-Cambrian eras are well represented in North America, the actual exposures of rocks of this age are only sparsely distributed in the United States, these being almost entirely in the form of cores of mountains either existing at present, or long ago reduced to moderate heights. In the West (fig. 3) many mountains in Colorado, Idaho, Wyoming, and adjacent states, consist of these ancient materials, and many which are similar in age but different in method of exposure are found in some of the canyons, such as that of the Colorado River in Arizona. Farther to the east, in the vicinity of the Great Lakes, Pre-Cambrian rocks, which form minor projections from the great "Canadian Shield" to the north, are largely buried by glacial drift, so that occasional outcrops, particularly the "ranges" of Minnesota and upper Michigan, are the only surficial vestiges of these very ancient periods of time. Similarly, a considerable portion of New England consists of these materials partly overlain by a thin glacial mantle, which, in comparison to the bedrocks, is only incidental in determining the prominent land features.

The most spacious of all Pre-Cambrian exposures in this country are those in the Piedmont and Blue Ridge provinces (20) extending from southern New York to Alabama. Here, to a considerable extent, these igneous and metamorphic rocks produced the soils existing throughout the region. Aside from the Blue Ridge Mountains which, of course, are still eminent in topographic position, the rocks in this section constitute the remains of a group of mountains that were worn down, and in the process supplied enormous quantities of debris now along the Atlantic and Gulf coasts and inland.

The history of all the periods in the Palezoic era is, as was the case with the Pre-Cambrian rocks, of greater importance in the eastern half of the United States than in the West. This is true, not so much because of the lack of Palezoic formations in the West, but rather because younger materials extensively overlie the Palezoic rocks, sometimes to great depths. These were the periods in which the great sedimentary formations were built up throughout the inner portion of the country in conjunction with the inland seas that covered as much as sixty percent of the country at one time.

Fig. 3. The relief of this chain of subdued mountains is typical of many Pre-Cambrian outcrops in the western United States. Archean granites, schists, gneisses, and quartzites form these mountain cores.

Fig. 4. Cambrian (St. Croixan) sandstone exposed in the driftless region of southern Wisconsin.

In contrast to the rocks of Pre-Cambrian age, those of the Cambrian period were largely sedimentary (fig 4) However, most of these sandstones, shales, and limestones have been changed by subsequent folding, faulting, and internal reactions to heat and pressure, so that they have been metamorphosed and are in no way comparable to the sedimentary rocks Much of the Cambrian strata have been buried by younger formations, so that those of consequence to soil formation are now limited to the Ridge and Valley belt (20) in the East, the non-glaciated region in Wisconsin, and other isolated sections in Missouri, Texas, and states west of the Rocky Mountains

Following the Cambrian period of geologic age a great portion of the United States was submerged so that in large inland seas sedimentary materials were deposited These later hardened to limestones and shales. During this time there was very little igneous activity, and thus primary rocks among these Ordovician strata are unusual and relatively unimportant At the close of this period of deposition, pronounced uplifts in the East and in the Mississippi Valley region resulted in the formation of arches or domes, which have protruded above all succeeding seas Outstanding among these are the Cincinnati Arch, which is responsible for the present Blue Grass Region of Kentucky and the Nashville Basin of Tennessee, and the Ozark Dome in northern Arkansas and Missouri Further prominent outcrops of Ordovician rocks are those in the valleys of the Appalachian region exemplified by the famous Shenandoah Valley and its limestones and distinctive residual soils

With the exception of some metamorphic materials such as the slates in the Taconic region of eastern New York, the Ordovician rocks east of the Mississippi River consist predominantly of alternating beds of limestones and shales, while in those of the Ozark Dome the sandstone replaces the shale In the level, less dissected regions, limestone, being more resistant than the shale, is the cap rock, hence, the residual soils are derived predominantly from limestones. In contrast, where the terrain is more dissected, shales, limestone fragments, and colluvial materials are more frequently encountered in engineering construction than are the associated residual limestone soils Finally, formations which may be of Ordovician age in the West have not been completely differentiated from those of the Silurian period which followed These are of minor importance in that they are now mainly in the form of mountains and rugged topography not conductive to the formation of deep soils

Outcrops of formations of the Silurian age, as is the case with the older strata, are confined largely to the eastern United States Even in the East the great majority of Silurian strata of limestone, sandstone, shale, and other sedimentary rocks, are covered with glacial drift so that these rocks are important only as sources of aggregate and as influences determining the topographic features in many localities Most of the actual outcrops from which the soils were derived are spread throughout the Appalachian Valley regions and in more narrow bands surrounding the Ordovician outcrops that have just been discussed Limited surface exposures of Silurian materials are locally important in Arkansas and Oklahoma, and likewise in California, Nevada, and Utah Some of the Siluraın strata of the East have been folded and faulted and because of intervening erosional processes these materials sometimes occur as arches or ridges outstanding as resistant topographic expressions Such a ridge is Tuscarora Mountain in southern Pennsylvania and Maryland (635).

In respect to the regions of outstanding deposition in Devonian times the period is scarcely different from that of the Silurian in that most of the outcrops are confined to the eastern portion of the United States where in turn the greater amount of these rocks have been covered through glacial deposition In fact, the Devonian strata largely parallel those of the Silurian age not only in occurrence but in lithologic characteristics, the rocks being primarily limestones, carbonaceous and other shales, and some sandstones Scattered outcrops of Devonian materials may be found in northern California, southern Oregon, and eastern Nevada

TABLE I

GEOLOGIC TIME DIVISIONS
(Modified from Schuchert and Dunbar (41))

ERA	PERIOD		EPOCH
Cenozoic	Quaternary		Recent Pleistocene (Glacial)
	Tertiary		Pliocene Miocene Oligocene Eocene
Mesozoic	Cretaceous		Upper (Cretaceous Proper) Lower (Comanchean)
	Jurassic		Morrison
	Triassic		
Paleozoic	Permian		
	Pennsylvanian	Carboniferous	(Pottsville, Allegheny, Conemaugh, Monongahela)
	Mississippian		
	Devonian		
	Silurian		Cayugan (Upper) Niagaran (Middle) Medinan (Lower)
	Ordovician		Cincinnatian (Upper) Mohawkian (Middle) Canadian (Lower)
	Cambrian		St Croixan (Potsdam) (Upper) Acadian (Middle) Waucoban (Georgian) (Lower)
Proterozoic (Algonkian)	Pre- Cam- brian	Keweenawan Upper Huronian Middle Huronian Lower Huronian	
Archeozoic (Archean)		Laurentian or Timiskamian	
		Keewatin	

Following chronologically are the formations of the Carboniferous system, so named mainly because of the extensive coal deposits formed during these times Here again the character of the rocks is that of the sedimentary materials with sandstone and shale being predominant in the so-called Pennsylvanian formations, and limestone and shale prevailing in the Mississippian group These are the most widespread of all outcrops thus far considered in the geologic time table, and in extent they are not limited to the eastern and central states as has been the case previously Important and outstanding surface features in Pennsylvania, south and westward through the Mississippi Valley, and in the Great Plains region are controlled by these rocks Farther to the west in almost every state, outcrops chiefly of limestone predominate among the sedimentary formations

Texturally, the rocks of the Mississippian period are limestones, sandstones, and shales, sometimes in the form of massive strata, but elsewhere laminated and thinly bedded Beginning in eastern Pennsylvania where these material are predominantly sandstones and shales, the formations of this age extend about the northern boundary of the Ridges and Valleys, and grade into sandstones, limestones, and shales, in local outcrops along the western edge of this province, throughout its length, to Alabama Outcrops dominated by sandstones and shales reappear in central and southern Ohio and northeastern Kentucky, as well as in other isolated areas. From southern Indiana, southward into the Pennyroyal District (54) of Kentucky and the Highland Rim of Tennessee and Alabama, the limestone members become of greater importance, often as rocks high in silica content. Similarly, cherty limestone prevails in the Mississippian rocks of the Springfield Plateau section of Missouri, Oklahoma (fig. 5), and Arkansas.

Fig. 5. Outcrop of limey chert in the Arbuckle Mountains of southern Oklahoma.

The Pennsylvanian rocks are the primary coal-bearing members of the Carboniferous materials. East of the Mississippi River these are subdivided into Monongahela, Conemaugh, Allegheny, and Pottsville. The formations consist of massive to thin-bedded sandstones, shales, many beds of coal and associated underclays, conglomerates, limestones, and other sedimentary materials. Sandstones, being outstanding and more resistant to weathering than most of the other materials, frequently occur as cap rock on plateaus or on hills in dissected regions. In the latter instance, colluvial materials are more important for engineering purposes than are the residual soils derived from the cap rock sandstones in the adjacent areas. Likewise, the clay-shale strata are very troublesome in some dissected regions.

Materials of the Permian period, which closed the Paleozoic era, are in the eastern portion of the country limited to an elliptically-shaped area extending lengthwise from approximately the location of Pittsburgh in Pennsylvania southwestward almost to the most southerly point of Ohio. In the central and western states outcrops of Permian rocks prevail in a band from southern Kansas through Oklahoma to central Texas, where physiographically they form the eastern stretches of the Great Plains region. Similar rocks of greater depth are exposed in western Texas and New Mexico and in the plateau sections of northern Arizona and southern Utah, and additional rocks of this age are confined to more limited sections of Montana, Wyoming, and Colorado. Permian beds in the Guadalupe Basin of western Texas and New Mexico are primarily of marine origin and were deposited during periods of a slowly receding sea. As a result, these strata change abruptly from limestones - representing coral beaches - to shales, gypsum, salt, marls, and even sandstones. Those beds of northern Oklahoma and Kansas are primarily continental deposits where sandstones and shales predominate. Many of the strata of this age are commonly referred to as "red beds" because of the peculiar color of the rocks, probably accounted for by the generally widespread arid conditions which existed during the time that those materials were formed. It should be noted, however, that neither the color nor the name applied to the formations of this age is exclusively confined to those materials, there being red beds in numerous other areas and other age groups in different sections of the country.

In proceeding upward through the Mesozoic era, the center of interest shifts from the eastern and central portions of the country to the West, for it is there that the formations of Triassic, Jurassic, and Cretaceous periods are most abundantly exposed. The Triassic rock of the East were formed principally as a belt of lowlands extending from New York City through Pennsylvania and Maryland into Virginia, with outliers elsewhere in Virginia and the Carolinas, and a northern extension represented by the Connecticut Valley (fig. 6). The rocks consist of soft sandstones, shales, and conglomerates, and are largely red in color. Igneous rock in the form of sills, dikes, and similar structural features, such as the Palisades overlooking the Hudson River, are outstanding land forms frequently serving as sources of aggregate in these lowlands.

Only slightly removed from the Triassic lowlands are the Cretaceous materials forming the inner borders of the Coastal Plain from New Jersey south to Washington, D. C., and resuming their course in North Carolina to extend in an incurvate band terminating approximately at the juncture of the Ohio and Mississippi Rivers. These materials are of diversified texture, ranging from poorly consolidated rocks through marls and clays, to sands and gravels. West of the Mississippi, beginning in southern Arkansas, the Cretaceous outcrops become more extensive in their distribution, particularly through the central and eastern parts of Texas.

Fig. 6. Outcrops of minor intrusion in the Connecticut Valley, the Triassic sedimentary rocks on the right having been tilted by the intrusion of igneous materials exposed on the left.

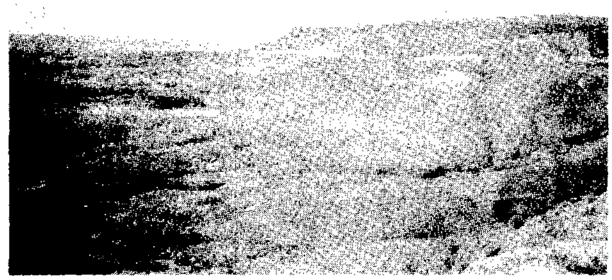

Fig. 7. Highly dissected Triassic "red beds" in the Painted Desert of Arizona. Differences in texture and resistance of the rock strata are manifested by variations in ground slopes and erosional features.

The Triassic deposits of the interior western states are primarily red in color and, like those of the Permian, the deposits consist mostly of sandstones and shales with some limestones, salt, and gypsum. Volcanic ash is frequently found in the red beds of Arizona and Utah. The Painted Desert of Arizona (fig. 7) and the Great Red Valley of the Black Hills contain these rocks. Throughout the Colorado Plateaus the Triassic materials consist primarily of soft sandy shales, grading into limestone beds in Nevada. The Triassic marine formations of Nevada and California outcrop in rough mountainous areas, and in the former state the thickness of these beds is reported to exceed 25,000 feet.

Jurassic rocks are surface materials only in more or less isolated sections of most of the states west of the Great Plains. They consist primarily of sandstones and shales, are frequently red in color, and frequently contain gypsum. Volcanic activity is indicated in many of the Jurassic beds. Rocks of both Jurassic and Triassic ages are extensively distributed in California and adjacent states, these having been originally deposited as marine, lacustrine, and fluviatile sediments later indurated and finally metamorphosed

West of the Mississippi River, the Cretaceous rocks are important surface materials in many sections of the Great Plains, the Colorado Plateaus, and the Gulf Coastal Plain, and to a minor extent in California and Oregon During the Middle Cretaceous times, a trough-like land form known geologically as the Rocky Mountain geosyncline stretched from the present Gulf of Mexico to the Arctic Ocean This lowland was the basin of a shallow interior sea, its width extending approximately from Minnesota to Idaho, and from central Oklahoma to Nevada (41, p. 348). Preceding and following this inundation, in early and late Cretaceous times, much of the inner portion of this country was an area of deposition for fluvial materials As a result, non-marine beds blend with the marine beds in many cases along the western border of the Great Plains The four important groups of rock strata in the Great Plains and in associated areas of adjacent mountains, are commonly referred to as Dakota and Laramie of fresh water origin, and the Colorado and Montana of marine origin. Along the Pacific Coast the upper Cretaceous formations consist of marine deposits

The lower Cretaceous rock exposures cover a large area in Texas beginning with the Edwards Plateau and extending northeastward into Oklahoma and western Arkansas The Edwards Plateau consists of massive limestone, while the rocks to the north and east vary in texture from limestones and shales through sandstones even to clays Paralleling these formations and extending from the Rio Grande to southern Oklahoma and Arkansas are upper Cretaceous materials of the Coastal Plain. In physical and topographical characteristics these resemble contemporaneous strata in Alabama and Mississippi, being largely composed of marl, chalk, weakly cemented calcareous rocks, and clays, sands, and gravels.

Along the western border of the Great Plains in northeastern New Mexico and southeastern Colorado and in eastern Kansas, the basal rock member is the famous Dakota sandstone This member outcrops along the eastern border in Kansas from the big bend of the Arkansas River northward into southeastern Nebraska Outcrops are extensive in the Great Plains region of Colorado and northeastern New Mexico, in a semi-circular area around the Black Hills, and along the borders of other mountain uplifts along the western border of the Great Plains The upturned strata along the mountains collect water which flows eastwardly beneath much of the surface of the Great Plains region where it becomes the source of artesian water of reliable, but limited, volume. This member is several hundred feet in thickness and consists primarily of sandstone, although there is an abundance of shale

The members of the Colorado group, which includes the Benton shale and Niobrara chalk in central Kansas, are found extensively in northeastern New Mexico, southern Colorado and in many sections of Montana and Wyoming, as well as in the Colorado Plateaus The chief rock type of the Colorado group is shale, although sandy shales, limestones and massive gravel-forming sandstones are encountered

The Montana group is considered under two categories In and around the Black Hills and primarily in South Dakota, the surface exposures consist of Pierre shale The cap rock on the outer borders of the shale consist of the Fox Hills sandstone In Montana and Wyoming, the Montana group consists primarily of marine shale, blended into fresh-water sandstones (Eagle, Claggett, Judith River, and Bearpaw formations) Many of the cap rocks of the Colorado Plateau are of Cretaceous age (Mesa verde) Scattered outcrops are found also in other Rocky Mountain states, while these materials in California are associated with volcanic activity

Following the close of the Mesozoic era, the so-called Tertiary (41, p 383) and Quaternary groups in combination form the Cenozoic era. These groups are subdivided into the Eocene, Oligocene, Miocene, and Pliocene - all in the Tertiary period which preceded the great epoch of continental glaciation - and the Quaternary, which includes the Pleistocene and Recent. The materials of the Tertiary period of deposition prevail throughout three principal regions of the country: the Coastal Plain, the Great Plains and Wyoming Basin, and the sections within and west of the Rocky Mountains.

In the Coastal Plain these deposits are mainly of marine origin and for the most part are unconsolidated - a condition which is somewhat duplicated in portions of the Great Plains where outwash materials are often referred to as the high plains mantle (Ogallala-Arikaree). Originally this unconsolidated high plains mantle was of considerably greater extent, but erosion has removed parts of the mantle, sometimes thousands of feet in depth, thus exposing earlier Tertiary (and older) materials which, since their deposition, have been semi-consolidated into weak rocks mainly of the character of sandstones and shales.

The oldest of these rocks are those of the Fort Union group and the associated Cannon Ball marine member of the Lance (fig. 9). Above these are the Wasatch, Bridger, Uinta, and White River Groups. In general, these rocks consist of friable, colored sandstones, "somber" clay shales, and many deposits of coal. Where coal is on or near the surface, as in southeastern Montana, large areas have been burned and the resulting material is referred to as scoria. Widespread deposits of Tertiary rocks of both marine and continental origin are found in beds many thousands of feet in thickness, along the coast in Washington, Oregon, and California. These materials vary from unconsolidated sands, silts, gravels, tuffs, volcanic ash, lacustrine clays, and diatomite, to consolidated conglomerates, sandstones, shales, and tuffs.

Fig. 8. Dissected granite of the Idaho batholith formed near the close of the Mesozoic Era.

Fig. 9. Braided stream channel cut in the Eocene (Lance - Wasatch) rocks of the northern Great Plains region.

Among the formations of Tertiary age are igneous rocks which outcrop extensively in all the Rocky Mountain states and those to the west, an example of which is the Columbia and slightly younger lava flows in Oregon, southern Idaho (fig. 8), and the Yellowstone Park District. While some of these primary materials are represented in present mountain systems, the more typical land forms are plateaus, of which the Columbia Plateau alone is more than 200,000 square miles in area. Other Tertiary volcanics outcrop southward throughout the Basin and Range province and in many mountainous outliers. Associated with lava flows, fresh-water lakes have been, and in some instances still are, in existence in Idaho, Oregon, Washington, Nevada, Utah, and California. The lakes have resulted in the deposition of lacustrine and fluviatile materials consisting of volcanic ash, diatomite, clays, and some weakly consolidated sandstones and shales.

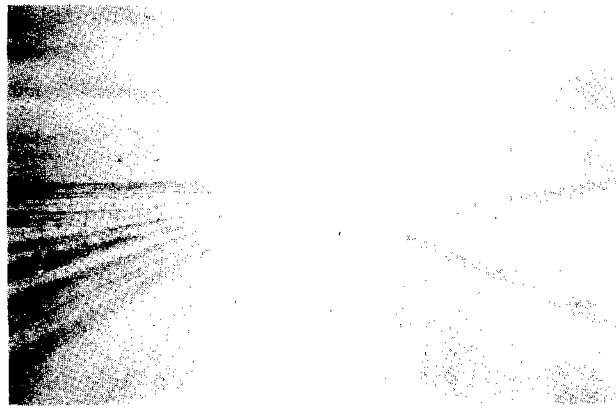

Fig. 10. Physical features such as these in northeastern Wyoming are representative of conditions associated with the Tertiary formations of the northern Great Plains and the Wyoming Basin.

Following the close of the Tertiary period there was, throughout all of the northern sections of the country, widespread continental glaciation, which resulted in the formation of a mantle of debris commonly denoted in its entirety as glacial drift. In some localities this mantle is as much as several hundred feet in thickness, and in composition varies throughout the entire range of clays, silts, sands, gravels, and boulders - all being derived from different types of bedrocks. Several stages of glaciation are known to have occurred, and during interglacial periods fine materials washed from the drift were laterally transported by winds to form sheets of loess. The windblown materials derived from this source, combined with those fine-textured soils removed by the wind from the semi-arid to arid regions, provided extensive deposits of this one-sized soil throughout the central and northwestern portions of the country, especially in conjunction with major stream valleys (fig. 11). Mountain glaciers existing locally in sympathy with the continental ice sheets formed moraines and terraces at the base of some of the western mountains.

Fig. 11. Deep deposit of loess in eastern Nebraska.

Not all of the Quaternary deposits are of the glacial or windblown origin, however, there being along the Atlantic and Gulf Coasts bands of unconsolidated (principally marine) materials, most of which are contemporaneous with the glacial deposits in the north. Other Quaternary materials prevail in all of the valley sections of the Basin and Range region in Utah, Nevada, California, and Arizona, and to a lesser degree in a number of other western states. In these situations, outwash derived through the wasting of mountains was deposited by flowing water in the form of fans, valley trains, and terraces (fig. 12), and occasionally lacustrine plains, bolsons, or playas.

Fig. 12. System of outwash terraces near the Shoshone River in Wyoming.

Currently, materials of Recent age are constantly being deposited on the flood plains of streams and rivers, and in some instances deltas are being formed, as is the case with the Mississippi River where, in time and under favorable circumstances, the materials will become shales.

The orderly process of soil development and the sensitive response of parent materials to environment markedly enlarges the significance of such a map as the one appended to this report. To one acquainted with geology in the applied sense, the designation of a particular soil area as one in which "soils have been derived from the weathering of limestone," is equivalent to a multi-page description of land features; the soil scientist encompasses these details and in turn further organizes them into details largely based on ground slope and often on subtle variations in the soil responding to differences in the parent rock. Therefore, he envisages not only the situation of a limestone parent material and the type of topography so intimately associated with this rock but also he is free to draw from mental storage the facts regarding soil color, acidity, texture, structure, drainage, and many other details. Therein lies the intrinsic value of the soil series name, for that name (based on a type location) although highly esoteric, implies in rather precise terms the origin and character of the parent material, the number and depth of horizons in the profile, the color, texture, drainage, acidity, and surface slope. In addition it connotes many things related to these properties found in the particular profile, whether it be suitability to the cultivation of peanuts, a given bearing ratio, or perhaps a notable susceptibility to frost heaving in cold climates. Thus the words Miami, Susquehanna, Frederick, Tulare, Hyrum or Sioux are full of meaning to those acquainted with this unfortunately named science of soil formation. Often the connotations associated with these names are interesting. The Hyrum and the Sioux series imply somewhat undesirable soils agriculturally. To an engineer they should, figuratively speaking, shout a welcome, since both are gravel deposits commonly found associated with large flat areas of fine textured soils where gravels are needed for construction.

It suffices, for this report, to say that the processes of weathering, in combination with other chemical and mechanical actions, creates a soil profile, or series of layers, that in many areas bears little resemblance to the parent, or underlying, material. Parent material is usually considered as the relatively unweathered material from which the soil originated, generally located at the base of the profile. It may be rock, glacial drift, loess, or some type of water laid material. The layers of the soil profile are referred to as horizons.

Generally, the "A" horizon is the surface material or the topsoil. It has undergone severe chemical weathering since it receives the unsaturated, slightly acid solution that is rain water. Not only chemical weathering has taken place to remove the soluble portion, but an actual mechanical migration of colloids and clay size particles has also occurred.

The "B" horizon (figs. 13 and 14) or the zone of accumulation, possesses not only the products of weathering originating within the zone, but it has also received by mechanical migration the clay particles from the "A" horizon. This accumulation of clay in the profile may result in a claypan development.

Fig. 13. A shallow cut section in glacial drift showing the exposed A and B horizons. The contrast in texture and porosity between these two horizons is implied by the distinct break in the upper boundary of erosion that coincides with the exposed portion of the B horizon.

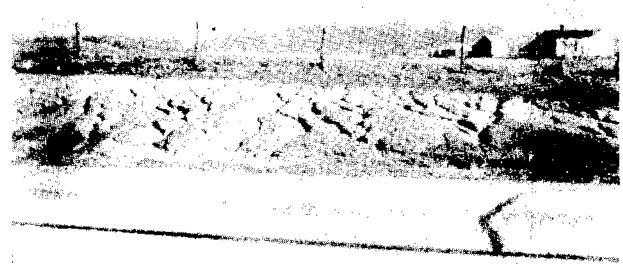

Fig. 14. Erosion of the plastic silty-clay B horizon in a relatively deep residual soil accentuates the differences existing within a weathered profile. The intensification of red in the lower profile is reproduced as a medium gray.

Because of variations in rainfall and age, the development of many soils will vary from this general process. Humid areas provide excellent conditions for strong profile development. The easily-weathered glacial materials in the humid regions probably provide the classic example. Under such conditions the materials that are sensitive to weathering respond to comparatively slight changes in slope so that there is a definite recurrence of a particular profile on similar slopes within a given parent material area.

Several factors other than rainfall tend to modify profile development. When there is an absence of clay-forming minerals in the parent material the horizons having contrasting textures do not occur. In these areas profile development has little influence on design, construction, and drainage. If within these humid areas, there is encountered a "young" soil such as is found on flood plains or on steep slopes, here too, profile development will be found weak or non-existent. An impervious material deposited in backwater, or in lacustrine areas likewise will not manifest a strong profile In such instances the texture and impermeability have reduced the amount of water flowing through the profile and in effect have made it a young soil in terms of weathering In these the parent material is only slightly altered Vegetation also may influence the development of the profile by seriously affecting the water-intake of the surface, or the infiltration capacity of the soil.

In considering climatic zones where the rainfall is low and evaporation losses from the soil high, there is a correspondingly low degree of chemical and mechanical weathering, this results in a comparatively weak profile development. As the influence of evaporation increases, evidences of precipitated calcium carbonate appear in the profile In the areas most favorable to this action cemented beds of caliche form in the profile

The use of information on profiles - commonly referred to as pedological methods - for construction and design purposes requires some consideration of the depth of excavation to take place Prevailing ground slopes are often in excess of permissible grades, therefore, cuts are required. If depth of cut does not exceed the depth of the weathered profile, the material forming the "B" horizon will act as subgrade Where a cut exposes parent material, a set of contrasting soils will form the subgrade in the cut For example, in glacial drift the plastic silty-clay "B" horizon will be exposed at the entrance to and exit from the cut while in the center semi-granular parent material will form the subgrade In many airport sites the angle between the established grade and natural ground slopes is very small - often less than one degree Under these circumstances several hundred feet of subgrade may fall within the "B" horizon even though the profile may be only three or four feet in depth The change in texture and moisture condition between the various horizons of the profile has considerable influence on the supporting power In subgrade stabilization, the design of the mix should take these predictable changes into account since the proper admixture proportions will vary widely.

CHAPTER III

RESIDUAL SOILS

The term residual soils is meant to apply to those materials which have been developed in place from bedrock, and consist primarily of insoluble residue of the rock material In this work, an endeavor has been made to distinguish between soils developed from consolidated rock and those consisting of unconsolidated materials which have been transported by wind, ice, and water in rather recent geological times

Residual soils are widely distributed throughout the United States. As shown on the map, plate 1, the largest continuous area is in the east-central part of the country, between the glacial boundary and the Coastal Plain Almost equal in size and somewhat similar in outline is that group of residual soils west of the Mississippi which extends from the Missouri River and the northern boundary of Kansas southwestward to the Rio Grande Other areas of this category exist along practically all of the western edge of the Great Plains, in the Wyoming Basin and Colorado Plateaus, and elsewhere in large and small extent, throughout the Rocky Mountain states and those bordering the Pacific Coast

The descriptions which follow refer to the thirteen residual soil groups outlined by names, symbols, and boundaries on plate 1

Limestones, Including Dolomitic and Cherty Limestones

Soils developed from limestone are to be found in the United States in the East, the Midwest, the Southwest, and to a limited extent, in the West. Within the Appalachian Mountain region there is a series of ridges and valleys consisting of bedrock of Ordovician, Cambrian, Mississippian, and other ages The soils of the Shenandoah Valley of Virginia, the inner Blue-grass Region of Kentucky and the Nashville Basin of Tennessee, are included in this group. Similarly, limestones consisting entirely of the Mississippian age, form the parent materials for soils of a continuous belt reaching from southern Indiana into western Kentucky and east and southward through Tennessee into northern Alabama

West of the Mississippi River a smaller area of Cambrian and younger limestone soils occurs in the Arbuckle Mountains in southern Oklahoma In eastern Kansas there is a north-south band of soils derived from cherty limestone of Permian age and known as the Flint Hills Finally, these soils occur extensively as surface material of the Ozark Plateau, the Edwards and Stockton Plateaus of southwestern Texas, and the Kaibab Plateau in Arizona (fig. 15) Additional limestones are widely distributed throughout the United States but in most instances these are intermixed with shales and sandstones, the resulting outcrops being too small to be shown on plate 1

For the most part the topography of limestone regions is undulating to mildly rolling, except where crustal movements have turned the strata appreciably Ridges and valleys are common but in the larger areas limestones form the cap rock of plateaus of great extent Since most of the constituents of limestone are soluble, these materials are famous for subterranean streams such as Lost River in Indiana, for caves such as Carlsbad Caverns in New Mexico and Mammoth Cave in Kentucky, and for sinkholes (fig. 16)

Soils developed from limestones consist largely of the insoluble residue which is left on the surface as the soluble material is carried away by leaching processes and erosion Iron, being an insoluble component of the rock, is one of the materials that remain, and accounts for the predominantly red color of soils derived from limestones (18, p 108)

Fig. 15. Failure of flexible pavement located on soils derived from the limestones of the Kaibab Plateau in Arizona.

Fig. 16. Sinkhole in Mississippian limestones of southern Indiana.

Although many limestones contain chert in the nodule or bedded form, few contain sufficient quantities of chert to influence strongly the soil profile. In several instances limestones passed through a stage of development conducive to the formation of generous quantities of chert. Where these rocks have been exposed sufficiently to develop soils, the high chert content has influenced the character of the profile to the extent that special consideration must be given them. The cherty soils of the East are mapped as Clarksville, Baxter, Elliber, and Frankstown (37). Although not separated from other soils of limestone origin on the map (plate 1), these form somewhat banded and parallel areas starting at the Virginia-Tennessee border and extending southwestward across Tennessee and northwestern Georgia into east-central Alabama, terminating near the Coastal Plain border. An inner band partially encircles the Blue-grass Region of Kentucky and connects with a similar area that partially encircles the Nashville Basin and continues southward to terminate at the Alabama-Tennessee border.

Other cherty soils dominate in the Ozark region of Missouri and northern Arkansas and again in the Kansas Flint Hills. These are variously mapped as Baxter, Clarksville, Summit, and Crawford.

Dolomitic limestones are more weather resistant than those forms of limestone that are nearly pure calcium carbonate. The magnesium carbonates in dolomite being less soluble than calcium carbonate retard soil development and lend a silty influence to the soil texture. Limestones of this nature are widespread in distribution but localized in occurrence. Climate too is an important factor, particularly precipitation; other things being equal, it is to be expected that the soil mantle would be deeper in the more humid climates. Thus, owing to the dry climate, the youthfulness of the formation and the composition of the parent rock, the soils of the Edwards Plateau are shallow, poorly developed, and dark colored, while those of the Shenandoah Valley are deep, well-developed, and red in color.

These several variables have been recognized by the pedologist in the preparation of general soil maps (43) (44) as is indicated by the variety of soil names used. For instance, soils of the northern Appalachian Valley are mapped as Hagerstown-Frederick, while those of the southern portion and adjacent areas of northern Alabama are known as Decatur-Dewey-Clarksville. In the inner Blue-grass region of Kentucky the soils are mapped as Maury-Hagerstown;

in Indiana and Kentucky as Hagerstown-Frederick; in central Tennessee as Dickson-Bater and Maury-Hagerstown; in the Ozark Plateau as Baxter-Lebanon and Clarksville-Lebanon; and finally those of the Edwards and Kaibab Plateaus as Valera-Ector.

Physical tests show that soils derived from limestone are relatively plastic. They frequently have a liquid limit of 50 or 60 and above, with correspondingly high plasticity index numbers. The texture and plasticity notwithstanding, these soils are remarkably well drained, largely because the bedrock permits percolation of water through cracks, crevices, and sinkholes and because the soils develop a rather fragmentary structure. However, there are areas of imperfectly and poorly drained soil in the cherty limestones of the Highland Rim of Tennessee and Kentucky, and when the natural structure of the well-drained soils of this group is destroyed in earthwork for engineering structures, they too become plastic and react much the same as other clay-like materials under pavements (fig. 17). Pumping of rigid pavements in the highway systems of the various states has been observed to be extensive in limestone-soil regions. Likewise infiltration capacities of the undisturbed soils may not prevail at all when the soil is moved. During construction these materials are not easily manipulated because of their plastic characteristics; in addition, solid bedrock generally exists at from three to ten feet below the surface. Sinkholes can become a major engineering problem, but occasionally vertical drainage may be accomplished by perforating the limestone.

Fig. 17. Pumping of rigid pavements, under suitable conditions of climate and traffic, is a highway problem in limestone-soil regions.

Sandstones and Sandstones and Shales

Soils developed from rocks in which sandstone is the predominating material, occur in the Appalachian Plateau and sections of the Interior Low Plateaus in southern Indiana and western Kentucky, in and near the Ouachita Mountains in Oklahoma (fig. 18) and Arkansas, in large areas of central Texas and north central Kansas, and in several denuded sections of the Great Plains in eastern Colorado and in northeastern New Mexico. The Colorado Plateau in Arizona, Utah, and Colorado, contains extensive outcrops of sandstones with some shales.

Sandstones are sedimentary rocks consisting predominantly of fragments of quartz grains which are consolidated and cemented. Variations of sandstones depend largely on the cementing material and they are named accordingly, i.e., calcareous sandstone, ferruginous sandstone, and siliceous sandstone. The presence of other minerals is indicated by the use of terms such as micaceous. These sedimentary deposits will vary in structure depending upon such conditions as water currents at the time of deposition, which result in the development of marine sandstones, those that are stratified or bedded or cross-bedded and those that are laminated. Most sandstones contain varying quantities of silt and clay, since these materials would be carried in suspension in the water currents during periods of sedimentation.

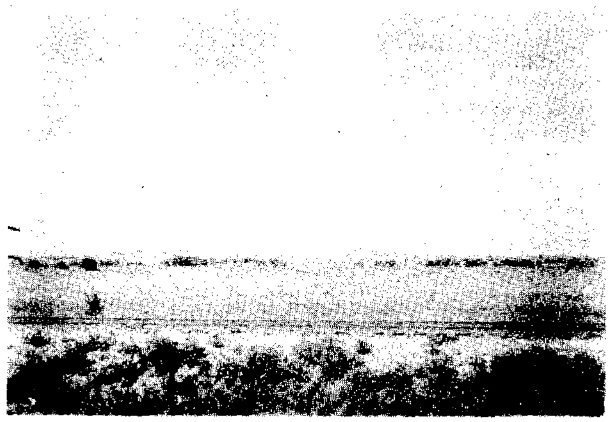

Fig. 18. Undulating topography with low Monadnocks in the distance associated with the residual soils originating from Pennsylvanian sandstones in eastern Oklahoma.

These and other physical and chemical variations are important in studying and evaluating the soils derived from such rocks. For instance, a sandstone in a humid climate with a calcareous binder is likely to have a deeper soil mantle than a similarly located sandstone with an iron binder; likewise, in a humid climate a sandstone with a siliceous binder will produce a very thin soil, since the entire mass is resistant to weathering. In the weathering of sandstones the quartz grains are highly resistant, since these grains are themselves a result of weathering activity; in semi-arid or arid regions the wind often collects these grains to form sand dunes. Sandstones when exposed, erode by water and wind action into steep slopes resulting in cliff-like topography that facilitates the runoff of surface waters which in turn carry with them most of the soil materials as they are being formed. The net result of these factors is a rather thin soil mantle. Despite these considerations there are some large expanses of level to undulating sandstones on which soils are formed to a depth of as much as ten feet or more. This is illustrated in parts of western Kentucky and southern Indiana. The soil mantle overlying Cambrian sandstones (fig. 19) in the driftless region of Wisconsin is relatively deep and coarse textured. When sandstones overlie weaker materials such as shales, mesas or similar land forms frequently occur.

The residual soils indicated on plate 1 adjacent to the mountains in eastern Colorado, as well as in many other similar positions, are no doubt colluvial materials occurring as a band several miles wide. It is important that in any specific area adjacent to mountains careful consideration be given to the existence of both colluvial and alluvial materials. In this, and in many other instances throughout the country, detailed information may be obtained from aerial photographs. Eventually, as more accurate boundaries are made available, many of these areas now indicated as residual will, no doubt, be revised.

Because of the favorable sub-surface drainage provided by sandstone and because the soils are primarily of shallow depth, the engineering problems associated with the latter are, for the most part, not serious. However, the massive sandstone capping pools of the Cumberland Plateau in Kentucky, Tennessee, and Alabama inhibit downward movement of water, and extensive areas of imperfectly and poorly drained soils are found on the leveler areas. The same is true in western Kentucky coal fields and Missouri and Arkansas. Extensive grading operations for airports will almost invariably require large quantities of rock excavation. The plasticity of the residual soil developed from sandstone will vary through quite a range, depending upon the climate, topography, and the chemical constituents of the rock. In the fine-grained sandstones and particularly where sandstones are interbedded with clay shales, soils of moderately high plasticity are to be expected. Sandy-silty clays are the prevailing textures although the textural range includes sands and silts.

Fig. 19. The soil mantle overlying Cambrian sandstones in the driftless region of Wisconsin is relatively deep and coarse-textured. Cuts in hilly sections, such as that in the background, would invariably require rock excavations.

Shales and Sandstones

Associated with the sandstones and sandstones and shales in the eastern United States are shales and sandstones which have been set aside in a separate grouping. These rock formations are limited in extent but the engineering problems concerned with the bedrock materials are of such magnitude as to justify separate consideration. These materials occur in southwestern Pennsylvania, southeastern Ohio and western West Virginia, and consist of alternating beds of sandstones, shales, coals, underclays, and minor strata of limestones. They are of upper Pennsylvanian and Permian age (Dunkard series). Pedologically these soils are indicated on general soil maps primarily as Upshur (which also has a colluvial phase), Muskingum, and Miegs.

Although strong, resistant sandstone members occur in this region (grindstones are made from the Marietta sandstone at Marietta, Ohio), the area is much dissected and the stream valleys are narrow, all of which make extensive grading operations necessary in the construction of airports. For the most part the various strata are thin-bedded, and a cut of 20 or 30 feet may expose a variety of shales, clays, and other materials. The resulting materials used in embankments, plus being a mixture of shales, clays, and various stones, are very difficult to compact properly and the resulting subgrade support for pavements is variable. Cuts in these strata frequently result in large landslides.

Shales

Clay shales occur extensively as interbedded materials with sandstones and shales throughout all the sedimentary rock regions of the United States. In those cases where the individual strata are thin and are interbedded with limestones or sandstones, the more resistant rock is more often than not the cap rock and as a result the surface soils may be derived from a material entirely different from the predominating material in the geologic column.

Notwithstanding the prevailing conditions just mentioned, rather large sections of several states contain soils developed entirely or at least predominantly from clay shales. The Cherokee shale of lower Pennsylvanian age (fig. 20) occurs as a wide, low-lying trough across eastern Kansas and western Missouri, while the Pierre shale of upper Cretaceous age occurs widespread from the Missouri River westward in South Dakota to and around the Black Hills, covering parts of southeastern Montana, northeastern Wyoming, and northwestern Nebraska. Other clay shales producing very plastic soils occur in central Montana, Colorado, New Mexico, and Utah.

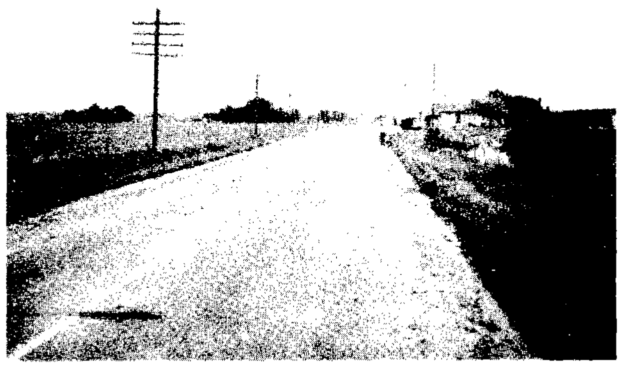

Fig. 20. Topography characteristic of soils derived from Cherokee shale (Pennsylvanian) in the west-central United States is level to gently undulating.

In South Dakota in the shale area around the Black Hills and in north-central Montana, the surface soils developed from these shales are indicated as Pierre and Boyd soils. In Colorado and New Mexico as well as in parts of Utah, these soils are included in a variety of series based primarily on climatic influences. Even though an attempt was made to isolate and map only the larger outcrop of clay shales, some of the materials indicated as shales in the Colorado Plateaus, for instance, as well as in the Piedmont section of Colorado may, on occasion, contain surface outcrops of other than clay-shale rock.

The principal constituent of clay shale is clay, which in itself is a product of thorough weathering. These shales are thin bedded sedimentary materials, deposited in quiet waters. As the materials disintegrate to form soil, the finely stratified layers tend to produce flat, plate-like pieces which retard vertical penetration of percolation and render drainage installations ineffective for removing underground waters in subgrades under pavements.

Topographically, these materials occupy depressed troughs, or, as in the case of the Pierre shale in the Great Plains (fig. 21), they are maturely dissected to form wide expanses of undulating to gently rolling terrain. The larger exposures of clay shale in the Great Plains are subjected to low amounts of precipitation. This factor and the imperviousness of the shale which causes high runoff and erosion, combine to produce soil material of shallow depth. In fact, the overlying developed profile grades almost imperceptibly into the underlying shale. Both the soils and the shale are plastic and have test constants indicating a poor material for pavement subgrades (fig. 22). The resulting soil is referred to in both the geological (502) and pedological literature as "gumbo." These materials invariably have high moisture contents under pavements, even when found in arid or semi-arid regions.

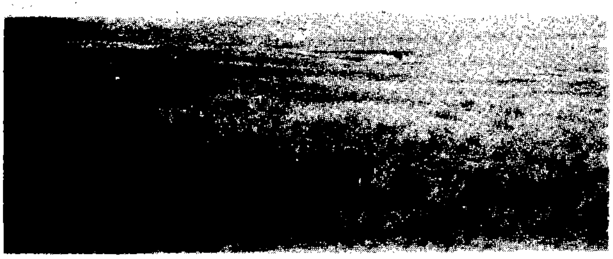

Fig. 21. Land features associated with the soils weathered from Pierre shale (Cretaceous) in South Dakota.

Fig. 22. This residual soil which originated from clay shales in the arid regions of the southern Great Plains is shallow in depth and plastic in physical characteristics.

Sandstones, Limestones, and Shales

In some more or less isolated sections of the country there are rocks of several different ages in which alternating beds of limestones, sandstones, and shales occur in varying proportions. East of the Mississippi, residual soils derived from rocks of this nature are important locally in the Appalachian valleys of central Pennsylvania, eastern Tennessee, northwestern Georgia, and eastern Alabama, while in the Interior Low Plateaus (20) - specifically in central and western Kentucky and southern Indiana - corresponding soils are more widespread. Similar materials are indicated on plate 1 in the Colorado Plateaus in southwestern Colorado and Utah, central Montana, in the Black Hills of South Dakota and Wyoming, and in eastern Kansas and northern Oklahoma (fig. 23). The physical characteristics of the soils derived from these alternating strata vary in part with the character of the underlying rock from which they were derived.

Limestones and Shales

Somewhat closely associated with soils formed by the decomposition of limestones is a group of similar materials developed from rocks in which shales are of equal or greater importance than the limestones. In the East, soils of this category are dispersed throughout the Ridges and Valleys from Pennsylvania (typical parent material - Martinsburg shale) to Alabama as well as in two separate sections nearer the Mississippi. The first of these is the outer Blue Grass region of Kentucky where Ordovician rocks of this nature (Maysville and Eden) extend into southern Indiana and Ohio (fig. 24). The second forms a portion of what is known as the Highland Rim overlooking the Nashville Basin in Tennessee. The materials of this group which are Mississippian in age reach into southern Kentucky and southward into northern Alabama.

West of the Mississippi the soils originating from limestones and shales are of local significance in three separate parts of southern Missouri and to a greater extent in central and eastern Kansas and northern Oklahoma. Similarly, these soils prevail in a considerable portion of the southern Great Plains in central Texas, and along the western edge of this province in northeastern New Mexico and southeastern Colorado. The parent rocks in these sections west of the Mississippi range in age from Ordovician to Cretaceous.

Fig. 23. The physical characteristics of soils in the regions where alternate strata of soils derived from sandstones, limestones, and shales prevail, vary with the character of the rock immediately beneath the surface. This illustration of a pumping pavement in northeastern Oklahoma indicates that the sub-grade soils are relatively plastic.

Fig. 24. Slabby rock fragments, shallow soils, and semi-rough topography are characteristic of the regions underlain by Ordovician limestones and shales. Here the rock-soil mixtures are important in grading and fill construction.

In the outer Blue-grass Region of Kentucky these soils are mapped as Fairmount-Lowell, while the soils derived from rocks of Mississippian age in southern Kentucky and central Tennessee are indicated in part as Dickson-Baxter. Some of the soils in Missouri (Ordovician) are generally referred to as Hagerstown-Frederick, as are most of those in the Ridges and Valleys of the Appalachians. In Texas, soils derived from these rocks are usually indicated as San Saba and Crawford in part. In remaining areas the correlation between parent rock and surface soils is not generally indicated on available maps.

Although all of the materials of this group are primarily derived from limestones and shales, a general uniformity of soil texture is not necessarily indicated, since there is a wide range in physical and chemical characteristics of the rock from which the soils were derived The range in age alone is great, materials of Ordovician, Mississippian, and Cretaceous having been included Furthermore, the chalky limestones and calcareous shales of Cretaceous age have been subjected to not more than sub-humid climatic conditions, also the chemical and physical character of the Cretaceous rocks should produce soils considerably different from those derived from limestones and shales of Ordovician age

The Ordovician materials consist of varying depths of alternating strata of hard limestone and soft argillaceous shale, the amount of shale has been variously estimated as ranging from 20 percent to 80 percent of the total Dissected topography is common and differential weathering occurs as a result of the resistant limestone disintegrating less rapidly than the underlying soft shale. Near the base of the hills are colluvial and talus materials consisting of plastic clays intermixed with various-sized fragments of hard limestone Construction operations are difficult since cut slopes, unless they extend into the unweathered bedrock, will frequently produce landslides Because of the rock-soil mixture, adequate compaction is difficult to obtain Under these conditions subgrade support will vary greatly from place to place In extensive earth work operations the solid, slabby-limestone fragments should be separated from the clay-shale material if embankments and subgrades are to be well compacted

Limestones and Sandstones

Located in southern Missouri and northern Arkansas in part of what is commonly known as the Ozark Plateau there are extensive formations of limestones and sandstones of Ordovician age This somewhat unusual combination of bedrock textures prevails in a region which, in general, is highly dissected as a result of the wasting of friable sandstones and the cutting action of streams Not all of the terrain is rough, however, there being a considerable portion of the area in the form of uplands which have not been appreciably affected by the pronounced dissection (20, pp 647-652) and are thus topographically favorable for airport construction

General soil maps (43) (44) imply that the influence of limestone is greater than that of the sandstone in this region, for the soils are indicated mainly as those of the Clarksville-Lebanon group, although some Muskingum is included Similarly, on the general soil map of the state of Missouri (483), Hanceville soils are dispersed throughout the Salem Plateau region indicative of the materials derived from sandstones, yet the Clarksville, Lebanon, and Baxter are predominant

Red Bed Shales and Sandstones

Red bed shales and sandstones form the surface materials of the western half of Oklahoma, a small section of south-central Kansas, a large area of central Texas and eastern New Mexico, and in some isolated areas in and around the Colorado Plateaus in Utah and Arizona These shales and sandstones are highly colored with red predominating and, although they are of different ages (Permian, Triassic, Jurassic), they are referred to repeatedly in the literature as red beds Large deposits of gypsum, salt, and limestones frequently occur as surface outcrops The principal soils belong to the Miles, Vernon, Zaneis, and Renfrow series (43) (44). Numerous local deposits of gypsum are found on the surface, some of which are of sufficient extent to develop gypsum sand dunes In the Pecos Valley and associated areas of New Mexico and in Arizona and Utah the low rainfall is a major contributing cause for the lack of true residual soil development The sandstones form the cap rock, being more resistant than the shales, and the disintegration caused by infrequent rains and wind has resulted in the deposition of sands or silty soils as surface materials throughout most of these regions

The residual soils developed from red bed materials on the eastern edge and beyond the Great Plains in Texas, Oklahoma, and southern Kansas are predominantly red sandy soils when developed on sandstones and red sandy clays when developed on sandstones and shales For the most part the soils are friable, erode readily and where sand is the predominating material, local sand dunes are formed, sinkholes may occur in places where gypsum is the surface material Where the soils are derived from deep beds of shale they are more plastic and resemble the soils developed from other shale materials Within this area and primarily adjacent to the east-flowing streams, sandy soils or even sand dunes predominate These materials are blown from the adjacent flood plains, the sand probably having been derived from the Great Plains Tertiary mantle to the west in combination with the sandy materials of the red beds themselves Where such streams flow through or near gypsum deposits, salt flats, such as that in Alfalfa County, Oklahoma (605), occur in the flood plains and on terraces of the major streams Since the climate is sub-humid and since evaporation losses are high, calcium carbonate is frequently found in the lower part of the soil profile

Sandstones and Shales with Lava, Tuffs and Diatomaceous and Micaceous Shales

Sandstones and shales with associated rocks of volcanic, metamorphic, and organic derivation are found intermittently along the entire west coast as well as along the west wall of the Great Valley through California into Oregon in the Willamette Valley These rocks are chiefly of marine origin of Tertiary age, but rocks of Cretaceous age occur particularly in southwestern Oregon and adjacent to the Great Valley of California.

Massive sandstones predominate, but many shales are included These materials are interbedded with some lava flows, tuffs, and diatomaceous and micaceous shales, and because of this complexity in textural types, they have been separated from the sandstones and sandstones and shales that are extensive in the eastern and southeastern states These materials are much younger than the sandstones of the East and for the most part they have been warped and folded as a result of the mountain making processes in the West The resulting topography is not necessarily to be correlated with the rock texture (19) Many areas of these rocks outcrops are so rough as to make the residual soils of small importance to engineering. Soils derived from these rock are included largely in the Melbourne and Altamont series (44), in which sandstone is recognized as the predominating material

Shales, Clays, Sandstones, Limestones, and Scoria

Throughout large portions of the northern Great Plains and in outlying sections in Montana and Wyoming, and in sections of the Colorado Plateaus in Utah, New Mexico, Arizona, and Colorado, there is a group of residual soils which are derived from shales, clays, sandstones, and scoria These rocks are predominantly Tertiary in age and include White River group, (Brule formation and Chadron clay), Uinta group, Bridger group, Green River formation, Wasatch group, Fort Union group (Tongue River and Lebo shale), and Lance formation (Hell Creek and Tullock) Areally, the Fort Union and Wasatch groups are by far the most extensive, the former consists of alternate beds of sandstone and shale with occasional seams of coal (502), grading into dark gray gumbo shales with impure sandstones, while the Wasatch rocks are chiefly non-calcareous clays, shales, sandstones, and coal beds Pierce and Andrews (769, p 136) state, "the clays and loosely constructed shales and sandstones of the Wasatch slump readily, and the formation is mostly obscured by landslide materials, debris, and colluvium " The materials of the White River group are likewise poorly consolidated and consist in part of "a porous crumbling clay, pale flesh color when dry but light brown when damp" (190), while Bridger rocks are described as "sombre colored sandstones, siltstones, clays, mudstones, shales, and limestones" (768) The red scoria beds, which are the result of the burning of thick seams of coal,

(502) are important surface materials in much of this region of the Great Plains and in some areas these clinker beds are parent materials from which two to five feet of soil have been developed.

The prevailing topography of this large section of the Great Plains is undulating to rolling although some areas are very rough - particularly near the mountains. Under the erosion conditions prevailing in this soil region it is obvious that much of the soil is not a true residual type but often consists of reworked materials which have been moved by wind, water, and gravity (fig. 25). As a result of textures and the generally weak structure of these rocks, combined with a lack of dense vegetation and infrequent but intense precipitation of short duration, badlands are developed on a grandiose scale. These topographic monstrosities (fig. 26) are common where the shale outcrops adjacent to the valley walls of drainage channels as, for instance, along sections of the Yellowstone, Missouri, White, and Little Missouri Rivers and many of their tributaries.

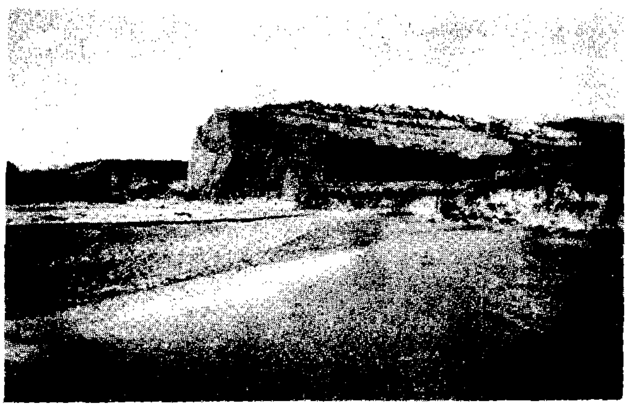

Fig. 25. Stream channel in central New Mexico bordered by Tertiary valley fill with massive sandstone outcrops in the distance.

Fig. 26. Relief typical of the big bad lands in South Dakota.

Important to the engineering of airports and highways are the large terraces that frequently parallel the larger streams. Those of the Yellowstone River in Montana (19, p. 64) are particularly noteworthy and are reported to be of such size as to make their identification difficult while driving parallel with the stream. Of local importance are beds of bentonite and volcanic ash.

Sandstones, Sandy and Clayey Shales, and Clays

Soils derived from alternate thick beds of sandstones and shales with some clays are indicated in Colorado and Wyoming north of the Park Range, between the Medicine Bow range and the Laramie range, between the Laramie range and Big Horn Mountains, and on the outer slopes almost surrounding the Big Horn Basin. Similar materials are shown extensively in a number of places in central Montana and in the southern Colorado Plateaus. Geologically these materials are included in the Montana group and the Mesa Verde formation of upper Cretaceous age.

The Montana group is further divided into Bearpaw shale, Judith River formation, and Claggett and Eagle formations. Both the Bearpaw and Claggett are dark gray clay shales which develop into "gumbo" soils similar to the Pierre in South Dakota. Interbedded with these shales are the Judith River and the Eagle formations; the first consists predominantly of sandstone and shale with some coal while the latter is essentially a massive sandstone. The Mesa Verde formation replaces the

Montana group south of the Big Horn Mountains. These rocks, like those of the Montana group, include deep alternate beds of sandstone and shale.

Because of their proximity to several mountain ranges, it is probable that these soils, particularly in Wyoming and Colorado, contain much colluvial and reworked materials.

Metamorphic and Intrusive Rocks

Metamorphic and intrusive rocks are associated with the mountainous areas of the country. The intrusive rocks are old and form the cores of mountain ranges. The metamorphic rocks, usually associated with the intrusions are widespread but occur as long narrow bands. They have been warped and faulted greatly and when they occur in mountain ranges the soils formed are often shallow and unimportant for engineering purposes. However, there are many sections of the country where exposures of these materials are sufficiently level to make them important as soil forming rocks and as areas which can be used in connection with airport construction. The largest single expanse of these materials is in the Piedmont section paralleling the Coastal Plain from southern Pennsylvania across Maryland, Virginia, North Carolina, South Carolina, Georgia, and into Alabama. Similar materials are indicated in small areas in central and western Texas, a small section in north-central Idaho, a long narrow north-south band to the east and paralleling the Great Valley of California, and in isolated sections of New Mexico, Colorado, Oklahoma, and Missouri. In California some sedimentary rocks are included with these materials.

Pedologically, the Appalachian Piedmont soils derived from granite, gneiss, and gneissoid schists are mapped as Cecil, Appling or Durham in the southern sections and as Chester, Porters and Ashe in the northern Piedmont and Blue Ridge mountains (37). These acid crystalline rocks generally develop sandy topsoils underlain by pronounced sandy clay to clay "B" horizons. Soft, partially disintegrated rock is found at various depths but more commonly at depths of three to five feet.

Micaceous schists weathering to friable sandy soils are mapped as Louisa; (fig. 27) mica schists, chlorite schists, phyllites and occasional areas of gneiss are mapped as Manor. These are shallow soils varying between one and three feet in depth, occurring chiefly in the southern Piedmont. Slates producing shallow, silty soils occur in South Carolina, in an associated area of North Carolina, and locally in eastern Georgia and Virginia; on agricultural soil survey maps these are associated with the series names Alamance and Georgeville. The Cardiff are shallow silty soils developed on the slate ridges bordering the Triassic belt in Pennsylvania, Maryland and Virginia.

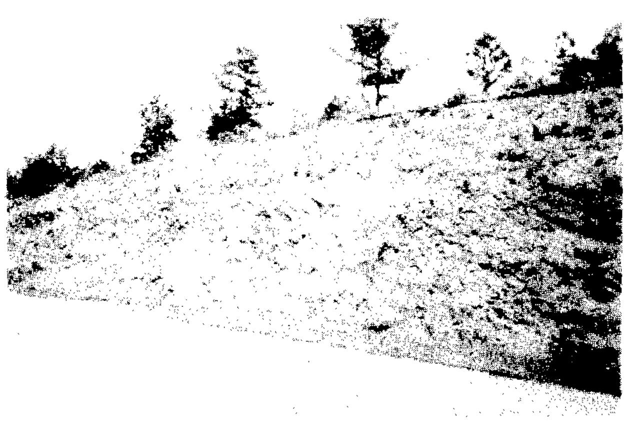

Fig. 27. Exposed in this highway cut are metamorphic formations of mica schists overlain by soils having granular texture (Louisa).

Schists, although generally basic, have undergone so much alteration that they are characterized by a wide variety of minerals. This disparity between minerals creates unusual properties associated with soils high in mica, talc, sericite, or chlorite. Soil textures may vary from sand (mica) to clay.

Soils derived from these groups of rocks occur in somewhat dissected and moderately rolling or even rough topography. As a result, engineering structures placed in these regions may extend below the depth of soil mantle into the underlying rock. Where the soil materials are used for embankments on subgrade materials they are likely to exhibit plastic and even expansive properties - particularly where large quantities of mica are found. Rigid pavements constructed on those soils are subject to pumping under certain conditions of climate and traffic.

Extrusive Rocks - Basalt and Lava

In contrast to the metamorphic and intrusive rocks represented in part by granites, which are molten rock cooled beneath the surface, basalts and lavas are molten rocks extruded through volcanoes or fissures and cooled on the surface. These materials are found locally in the eastern Piedmont and in some states of the Great Plains and the West. The volcanic type of eruption frequently results in very rough topography, and for this reason the rock may have a very thin soil cover. As a consequence, many of these sections in the western states are mapped (plate 1) as non-soil areas. However, there are many small (fig. 28) and a few large areas of lavas and basalts (fig. 29) in the United States which warrant attention as a soil forming material of importance to engineers.

Fig. 28. The relatively shallow soils which originate through the weathering of lava beds, in central New Mexico, are of little consequence in highway and airport engineering problems.

Fig. 29. Soils derived from basalt are often superficial even in the broad level areas that are common in the western portion of the United States.

The dark colored, basic crystalline rocks of the Piedmont include diorites, diabase, and basalt. These low quartz rocks have correspondingly high percentages of feldspars and hornblende that, on weathering, produce clays. The Davidson soil series mapped extensively in the eastern Piedmont is derived from quartz-free diorites, diabase, hornblende schists, gabbro and basalt. These deep, red clay soils (up to 20 or 30 feet in depth) are referred to as Iredell (claypan), Montalto and Orange (37).

The largest single exposed area of basaltic material is found in Washington, Oregon, and southern Idaho, represented physiographically as the Columbia Plateau. In Miocene (Tertiary) time these areas were topographic lowlands. Lava flowing intermittently from fissures and volcanoes covered most of the land surface of this vast region. Various estimates indicate the basalt to be 4,000 feet or more in total thickness (19). Since these flows occurred during different intervals of time and since each flow did not necessarily cover the entire area, fresh-water lakes and drainage systems became established during the hundreds of years frequently intervening between flows. Lacustrine clays, together with sands and gravels in the form of terraces and outwash plains, as well as volcanic ash and even diatomaceous materials, remain in many present day exposures as evidence of these peculiar activities. It is probable that many lakes and stream channels remain buried beneath the subsequent lava flows. Many such deposits covering large areas in southeastern Idaho and along the Snake River between Idaho and Oregon as well as along the Columbia River in Washington and Oregon appear as present day surface materials. These are mapped and will be discussed under "Soils of the Filled Valleys and Great Plains Outwash Mantle." In more recent time loess materials have been deposited on certain sections of the Columbia Plateau.

Much of the Columbia Plateau is an arid to semi-arid region in which soils are not of great importance for agricultural purposes unless irrigated. However, these soils developed from the underlying basalt and lava are mapped as Aiken, and in part Deschutes and McCammon. The Aiken soils are deep red in color, plastic, and are highly colloidal. The McCammon and Deschutes soils are shallow for the most part but when developed under humid conditions they are frequently found to be relatively deep and very plastic.

CHAPTER IV

LOESSIAL SOILS

Texturally aeolian or wind-transported, soils consist of numerous deposits of fine sands, large areas of silt with more or less uniformity of grain size, and an occasional, but small area of volcanic ash Since the sands are deposited primarily by water and are reworked by wind, they are appropriately discussed in the chapters on "Glacial Materials," and "Water-Laid Soils " In contrast, wind-deposited silts (loess) are widely distributed and cover extensive areas, generally they are not intermixed with soils of different origin or texture, and are remarkable for their uniformity in engineering characteristics Thus, in this work wind-blown silts are considered as one of the primary soil divisions

Although wind-deposited silts have long been recognized as such, it has been only in the past 30 years that these materials have been associated directly with the melting of the great continental glaciers In reporting on the Greenland glacier, Hobbs (145) describes this aeolian action as taking place immediately after summer thawing periods when winds of high velocity blow from the ice sheet over recently deposited outwash debris This wind-collected dust is carried many miles beyond the edge of the ice where it settles slowly on the earth's surface as a superficial deposit of wind-blown silt. Under similar conditions in the United States, silts have been deposited in the flood plains of the larger rivers and in glacial lakes During dry periods winds blowing across the recently deposited alluvium carry these silts to adjacent uplands The southern loess found on the uplands along the eastern side of the Mississippi River is a good example of this method of deposition In semi-arid regions loess is frequently the result of desert winds Thus there are recognized two types of loess, glacial and desert.

That wind-blown silts in the United States are primarily glacial is indicated by the proximity of such materials to the glacial boundaries in the Midwest and West Loess frequently covers some of the older glacial drift The surface soils of large sections of Kansas, Nebraska, Iowa, Missouri, and Illinois are loessial materials, frequently of great depths Although no loess is shown in Montana on the map accompanying this report, Weed (507) mentions loess and loess-like materials associated with the glacial boundary near the Flat Wood Mountains Similar materials are found in southeastern Washington and north-central Oregon as well as along the Snake River and elsewhere in southern Idaho The Mississippi River valley silts, previously mentioned, extend in a belt some fifty or sixty miles in width on the eastern uplands, and from New Orleans to the Ohio River at the junction with the Mississippi These same materials may be found extensively along the Mississippi River almost to Minneapolis, including adjacent areas in Wisconsin, and in South Dakota along the Missouri and Big Sioux Rivers to some distance north of Sioux Falls Similar materials are important surface soils on the uplands along the eastern bank of the Wabash River and on the north bank of the Ohio River in southern Indiana In addition, some of the surface materials of the Great Plains and other similar regions in the West are mixed with some wind-blown silt, which originated either from glacial outwash or the semi-arid Great Plains outwash materials to the west According to Lobeck (32) loess deposits in other countries include the European deposits just south of the glacial boundary in northeastern France, Belgium, Germany, Poland, Czechoslovakia, Rumania, and a large part of the Ukraine of southern Russia; the loess in the pampa of northern Argentina - east and south of a former glacier, and central eastern New Zealand, again adjacent to mountain glaciation The extensive silts of China are, at least in part, wind-blown from the flood plains of the larger streams such as those of the Yellow River.

Because of their favorable chemical and physical characteristics these soils are important agriculturally where precipitation is adequate or where irrigation is possible For this reason agronomists, as well as geologists and climatologists, have developed information which can be used to advantage by the engineer

Because of their texture, method of deposition, and relatively shallow depth, loessial deposits generally have little influence on physiography and it is seen from plate 1 that the loess of this country occurs in parts of several physiographic provinces (19). The behavior of loess in connection with engineering structures can best be treated by discussing loessial soil areas as five geographic units. These are: (1) the Columbia Plateau loess of Washington and Oregon, (2) Columbia Plateau of southern Idaho, (3) the High Plains section of the Great Plains in eastern Colorado and western Nebraska and Kansas, (4) the Central Lowlands in eastern Nebraska and Kansas (fig. 30), Iowa, Missouri, Minnesota, Wisconsin, Illinois, and Indiana, and (5) the Mississippi Ruin deposits of the Gulf Coastal Plain.

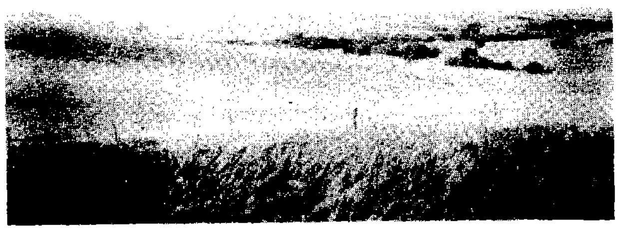

Fig. 30. The topography and vegetation as shown by this view in Nebraska is typical of those attendant to the loess deposits in the eastern portions of the Great Plains.

The loess-covered part of the Columbia Plateau in Washington, Oregon, and a small section of west-central Idaho lies at an average elevation of about 2,000 feet. The mean annual rainfall is 20 inches or less and the native vegetation is chiefly bunch grass. The silt is some 75 feet or more in depth (32) although transition zones between the deep silts and other materials will contain isolated mounds, or islands of silt surrounded by bare rock exposures (plate 3). In other transition zones the thin silt cover blends with the underlying soil to such an extent that it is hardly distinguishable as loess. Agriculturally this treeless plateau is famous for large-scale wheat farming. The winters are long and cold while the summers are hot and dry. This lack of rainfall preceding the winter freeze, combined with the fact that loess soils are, in general, free draining, probably is important in minimizing frost heaving in subgrade soils under pavements in this loessial area. Pedologically the principal soils are mapped under the names of Nez Pierce, Palouse, Walla Walla, Ritzville, and Portneuf (320) (744). Table II, which was prepared from information contained in "Soils and Men" (43), emphasizes the pedological importance of rainfall and elevation. Geologically this material is known as the Palouse formation or Palouse Soil. This somewhat ambiguous designation is ascribed to the fact that a difference of opinion still exists among geologists regarding origin of the material, since some believe that the material is partly residual from the underlying basalt and reworked by wind. Also, it is noteworthy that layers of volcanic ash having considerable depth have been found. Bryant (166) summarizes these ideas by stating, in part, "... the belt of the 'Palouse Soil' is windblown dust or loess, though other material is included in the mass ...". One of the unusual features of this region is the channelized scablands (163) (164). These are strips of bare basalt and where erosion has been severe, deep canyons have been formed, called coulees. These scablands are the result of erosion by glacial streams during the melting of great continental ice sheets, although the breaking of the ice dam, which caused glacial "Lake Missoula," might have released sufficient water to have eroded at least a portion of the Columbia Plateau Of the 2,000 square miles of scablands, Grand Coulee is perhaps the better known by engineers, both because of extent and because of the recently constructed Grand Coulee Dam During the Wisconsin stage of glaciation, the present course of the Columbia River was temporarily dammed by ice, thus diverting the flow through what is now known as Grand Coulee It was during this period that the wide expanses of sands and gravels were deposited in central Washington These materials are indicated on the map (plate 1) as Valley Fill materials while the major areas of scablands and coulees are shown with appropriate symbols and color

TABLE II

TABULATION OF SOILS OF THE "PALOUSE" REGION OF WASHINGTON, OREGON, AND IDAHO, WITH AVERAGE VALUES OF RAINFALL AND ELEVATION

Pedological Soil Name	Approx Annual Rainfall (Inches)	Approx Elevation Above Mean Sea Level (Feet)
Nez Pierce	20-30	2,000 - 4,000
Palouse	18-22	1,500 - 3,500
Walla Walla	14-18	1,000 - 2,000
Ritzville	10-15	500 - 1,500
Portneuf	5-12	200 +

The widespread loess along the Snake River in southern Idaho lies at an elevation of some 4,000 to 6,000 feet, the rainfall is ten inches or less, and the vegetation is primarily desert shrub and sagebrush Because of the underlying Columbia River basalt, this area is largely a plateau Pedologically, the surface materials are mapped as Portneuf and associated soils Russell (323) describes the fine yellow soil as being of aeolian origin derived from the alluvium of streams and mountain outwashes, and presents a vivid picture of the dust storms of the region Lack of adequate boundary data permits only general treatment of this area and some inconsistencies should be noted Although most of the Snake River Plateau is shown on the accompanying map as windblown silt, it must be kept in mind that the loess is very thin or is entirely missing in some sections, leaving the lava flows exposed as scablands Also, some residual soils derived from lava must be expected in some sections At some of the extremities of the Snake River Plateau, mountain slopes are encountered, the outwash from these consisting primarily of sands and gravels As is frequently the case in mountainous areas, these outwashes may extend several miles from the mountains proper

The Great Plains loess of eastern Colorado, Kansas, and Nebraska occur in a section of what is generally known as the High Plains, which is a large level treeless area sloping gently eastward In western Kansas, eastern Colorado, and western Nebraska the loess overlies Rocky Mountain outwash materials In central Kansas the underlying bedrock is chalky limestones and shales while in eastern Nebraska and Kansas the silt has been deposited on both old and young drift As a result of erosion, particularly along valley slopes, these underlying materials frequently become exposed in many small isolated areas which are of considerable importance in the engineering of airport and highway pavements The loess readily absorbs as well as retains moisture This fact accounts for the large-scale wheat-corn farming in this district and is of engineering importance in relation to drainage In "Soils and Men" (43) these soils are mapped in western Kansas and Nebraska as Keith (sample 1384C - appendix A) and Holdridge-Hall in central Kansas and Nebraska, while in "Soils of the United States" (44), Rosebud - a non-loessial soil - replaces the Keith (See results of tests on sample 1384C from this area in appendix A, which indicates a windblown silt). According to the "Lexicon of Geologic Names of United States" (50), some question remains concerning the age of the silt deposits of Nebraska although they are usually referred to as Peorian loess This is a yellowing silt which in eastern Nebraska overlies the Loveland loess described as "Bed of reddish joint clay, which frequently shows stratification and often contains sand and pebbles in lower part " The Sandborn formation of Kansas includes the loess as well as underlying Great Plains outwash and other rock materials on the valley slopes Elias (384, p. 163) in his excellent description of Wallace County, Kansas, proposed the name "Sanborn formation" to replace the old terms "Tertiary marl" or "Plains marl " Again Elias (383) mentions the possibility of the red Loveland loess occurring in northwestern Kansas beneath the Sanborn Smith (400, p 124) mentions buried volcanic ash occurring immediately under the Sanborn and even reports tests on the material There is substantial evidence that loess deposits occur in areas outside those indicated on the map, (plate 1) Specific indications can be observed on the aerial photography index sheets for Sioux and Dawes Counties, Nebraska Wing (430) reports that loess in Kansas is found over a large part of Cloud and Republic counties and ranges in depth from a few inches to 30 or 40 feet In connection with Riley and Geary Counties, Kansas, Jewett (388, p 95) states that "The thickness of the loess is probably nowhere more than 50 feet and generally is much less." Smith (400, p. 121) shows loess deposits in southwestern Kansas on a sketch map and reports numerous tests on loessial and other materials from this district Although there are specific areas as shown on the map as loess, the loessial belt of the Great Plains has not been expanded greatly over the more commonly used boundaries because of lack of substantial boundary data However, information from the above references and others indicates the need for some enlargement of the presently used boundaries

The wind-blown silts of the Middlewest corn belt - Iowa, Illinois, Missouri, Indiana, and small sections of South Dakota, Minnesota and Wisconsin - occur, in the physiographic sense, in sections of the Central Lowland. Some of these and associated drift materials are frequently considered prairie soils With few exceptions, these silts are underlain by old drift materials The precipitation varies from 30 inches to perhaps 40 inches. The soils are mapped as Moody, Marshall, and Tama in eastern Nebraska and Kansas and Western Iowa, and as Clinton-Boone-Lindley along the Mississippi River from southern Illinois into Wisconsin and Minnesota, along the southern section of the Missouri River, and adjacent to the Illinois River. Knox soil is mapped along the Missouri River associated with the Marshall soils, while Pike-Princeton and associated soils are indicated in Indiana, although in one instance this material is indicated as Memphis The surface silts of this area are indicated as Peorian loess but Smith (343) refers to materials under the Peorian loess in Illinois as late Sangamon loess Gumbotil is frequently associated with the Sangamon soil. Fenneman (20), Leverett (151) (154), and many other writers consider most of the older till in Missouri, Iowa, Illinois, and Indiana as having been covered with loess, one striking evidence being the more or less uniformly silty texture of the surface horizon The loess boundary shown on the map accompanying this report excludes these shallow silts on drift from the loess proper since, from an engineering viewpoint, problems of pavement design and construction are entirely different from those encountered in the deep loess areas In fact, the presence of one or even two feet of silt on an impervious claypan in a humid climate, creates a problem in pavement and drainage design of considerable magnitude, particularly where cuts through different horizons are necessary As a result of the method of deposition in which the coarser and deeper silts occur near the source and the shallow finer textured ones a considerable distance away, loess boundaries are only approximate at best and should be considered as probable transition zones rather than real boundaries

The Mississippi River loess, extending along the east bank of the flood plains from New Orleans to the mouth of the Ohio River, are found primarily deposited on Coastal Plain materials. Here again the silts are deepest (100 feet or more) adjacent to the river, gradually thinning out over a distance of some fifty miles east of the Mississippi. Crowley's Ridge in Arkansas and Missouri, lying west of the river, is covered with loess and is a noteworthy exception. These silts are known as Memphis both pedologically and geologically, although the thin deposits occurring on level to undulating topography are mapped pedologically as Grenada. The rainfall is approximately 50 inches and the vegetation is luxuriant. It is important to note the similarity in engineering characteristics of these with similar silts of the Palouse region in Washington, despite the obvious differences in climate and vegetation in the two areas.

Fig. 31. This view from a high point on the plateau in eastern Washington illustrates the rolling topography typical of the Palouse loess deposits in the Northwest.

The topography of the various loessial soil regions generally presents a distinctive undulating to rolling type (fig. 31) with the deeper deposits, associated with the larger streams in loess areas, usually hilly to undulating while the transition zones will assume, in general, the topography of the underlying rocks which vary from extremely flat to extremely hilly or even mountainous. In his excellent description of the typical Palouse topography Fenneman (19, p. 253) states "The district has a rolling surface of broad, rounded, wave-like swells, rising generally 20 to 80 feet above valleys, which contain neither streams nor channels." In more humid regions the erosion may be more severe and the resulting topography is more sharp. The drainage pattern has a trellised appearance, with many small finger-like streams that empty at abrupt angles into the larger ones. The loessial deposits in the Middle West on old glacial deposits are undulating to flat and they may even contain some depressions, particularly in transition zones of large sections of Illinois, Iowa, and Missouri where the wind-blown silt is shallow. The Mississippi River valley loess is distinctly hilly along the eastern edge of the valley where the soil is deep but the thinner deposit on the underlying Coastal Plain materials is undulating to flat. Here again, some depressed situations are to be found. The loess of Kansas is found in flat to undulating areas in the south-central portion of the state while in the northeastern part the area is rough. The vegetative-covered, wind-blown silt hills give the landscape a characteristic hummocky but soft, pleasing appearance. Where severe erosion is present, nearly vertical slopes prevail. In fact, highway engineers have long been familiar with this peculiarity and have constructed cuts through these silt hills with vertical cut slopes (fig. 32).

The several wind-blown silts have many strikingly similar engineering characteristics. When tested they show a remarkable uniformity in physical properties. They are generally uniform in texture, consisting of 50 to 90 percent of particles of silt size and being referred to frequently as "rockflour silt." They can often be readily identified by visual inspection. The liquid limit is approximately 30 and the plasticity index number is approximately 6. Tests on a number of samples obtained at random, but widely distributed, are included in "Results of Classification Tests on Loessial Soil," appendix A. For the most part these samples were obtained at appreciable depths below the surface and in most instances represent the parent or unweathered soil. The similarity in texture of the deeper deposits is striking.

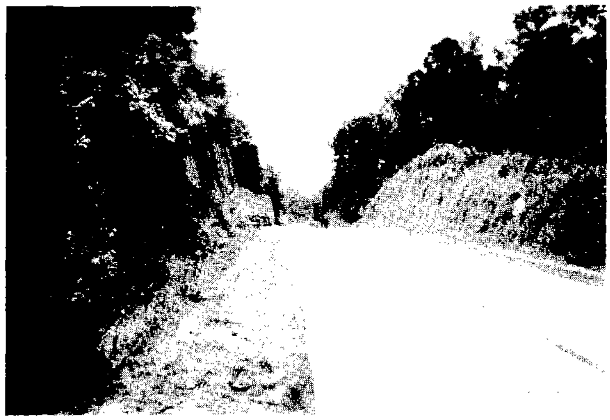

Fig. 32. Vertical slopes in a cut through loess in southern Mississippi. Deep deposits of soils of this nature form the eastern border of the Mississippi River lowlands from the Ohio River almost to the Gulf.

Exceptions to this similarity occur where a break in the continuity of the depositional process has occurred and in transition zones where the wind-blown silt is of shallow depth and consequently is influenced by the underlying materials. A possible example of the former situation is illustrated by sample 1253C, which was taken 90 miles south of Spokane, Washington, at a depth of twenty feet, from the top of a hill in a road cut. Examples of the shallow loess on drift are illustrated by samples 1159C, 1160C, 1162C, and 1164C. In these transition zones, widely varying characteristics are to be expected, since these wind-blown materials are probably finer in texture than those found closer to the source and also because the soil formation processes have been such as to have developed a distinct soil profile, primarily because of rather level topography. In addition, these thin superficial deposits may be altered by the underlying material. For instance, when thin deposits of silts are found on deep beds of gravel, as is true in the extreme western portion of Kentucky, these materials are exceedingly well drained. On the other hand, when found on some glacial till or on plastic residual soils, they frequently reflect the plastic clay-like characteristic of the underlying soils. Also the source of the material may be of importance. According to Lobeck (32, p. 393) the loess deposits of Nebraska and Kansas are more siliceous, coarser, and more laminated with sand than those of eastern Iowa because the material was transported by strong winds of the high plains and was not derived from flood plains.

Wind-blown silts in their natural states are well drained because true loess deposits are characteristically penetrated by vertical tubes, calcite-filled hollows left by the decay of grasses and roots (32, p. 389). This peculiarity in structure permits vertical percolation of water rather than horizontal movement and is an important reason for the prevalence of vertical slopes in loess regions. This is a significant feature in regard to earthwork since precautionary measures need be employed for other than vertical cut slopes. Grass or other dense vegetative cover is a necessity for embankment slopes in loess areas. Retaining walls have been used to advantage where neither vertical slopes nor vegetative cover were used. The excellent drainage properties where these soils occupy well-drained positions, together with their exceptional uniformity in texture generally facilitate earth work including removal and replacing under favorable moisture conditions However, if loess is dry it is difficult if not impossible to compact, and at the same time it tends to blow away If it is excessively wet, it may exhibit quicksand properties in either cut or fill sections Because of the porous structure, a large "shrinkage factor" is required in estimating earth work.

For providing subgrade support for pavements, loessial soils are probably the best of the non-granular types Because of the uniformity of texture throughout their depth, these soils afford very uniform support regardless of depth of cut or height of fill This is a very desirable feature in pavement design The favorable water-flow characteristics are important economically, in drainage design for engineering structures, and are contributing factors in minimizing frost action in cold, humid climates Pavement pumping is also minimized for the same reason, although some pumping is known to exist in some instances where heavy traffic and poorly drained positions are encountered Cuts of sufficient depth to reach the underlying materials should always be treated with caution since those materials will have greatly different characteristics affecting subgrade support, drainage, frost action, and pavement pumping Stream alluvium in wind-blown silt deposits, although having definite silt characteristics as evidenced by test results, should be handled differently from the upland areas since the typical loess structure will be destroyed and since water-table conditions may be entirely different from those on the upland.

CHAPTER V

GLACIAL MATERIALS

Glacial materials are of second order derivation in that the drift originated from one or more types of bedrock and was transported to its existing location by ice and associated forces Through this process the contributive bedrock materials were naturally intermixed in many different combinations so that homogeneity with respect to chemical, physical, and mineralogical composition seldom exists in glacial deposits Yet, despite the heterogeneous character of the drift, there is a consistency among the various forms of glacial deposits which requires a separate engineering classification of soils under the heading The origin, chronological existence, and extent of continental glaciation has been treated so thoroughly in geologic literature (41) (157), that only a cursory discussion of this background sufficient to introduce a grouping of glacial soils is presented here.

Although there have been several glacial invasions of the United States, those of concern here occurred in Pleistocene geological time In forming these deposits, sheets of ice thousands of feet in thickness carried tons of debris sometimes hundreds of miles and deposited it in depths ranging up to several hundred feet Thus much of the drift is composed of material which is foreign to the bedrocks in the locality and to the soils derived from them, and bears little relation to climate, topography, and other local influences

There are sections in the glaciated region where rock outcrops or where the drift overlying bedrock is shallow enough to make the rock have considerable influence on soil conditions Where these situations occur well within this region, the soils - for the purpose of this general interpretation - are usually considered as a part of the glacial deposits, on the other hand, similar situations along the outer drift boundaries justify the classing of these soils with those originating from other sources Hence, any discrepancies between the drift boundaries on plate 1 and the boundaries shown on geological maps are accountable in this interpretation

The region of glacial soils stretches almost entirely across the northern part of the country, the exception being mainly in the vicinity of the Rocky Mountains and the area to the west where these soils occur in separated groups East of the Rockies, glacial soils are continuous to the Atlantic coast with the Missouri and Ohio Rivers and the upper boundaries of Pennsylvania and New Jersey forming the approximate southern limit of coverage Major exceptions from drift soils within these boundaries are the driftless "island" in Wisconsin, the loess-covered areas in the upper Mississippi and lower Missouri, Ohio, and Wabash River valleys, and portions of southern Indiana and southeastern Ohio where residual soils prevail Exceptions outside of these boundaries are the glacial soils in northeastern Kansas and southern Nebraska, and in northern Pennsylvania and New Jersey

The primary basis for a congruous differentiation of glacial soils is one of form or method of deposition In general characteristics, the deposits resulting from a given action are all similar regardless of the derivation or age of the material or of physiographic influence such as topography and climate. Thus, till, in the form of moraines (155, pp. 35-47), till plains[3] drumlins, and other physical features, consists of drift as it was left by the melting ice, unaltered except for the weathered soil near the surface, in contrast, the soils of the kames, eskers, terraces, and outwash areas, are more nearly homogenous and invariably granular in texture because of the mode of their formation - the sorting action of flowing water which was glacial melt Still different in nature are the lacustrine and associated

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[3]The nomenclature used here is designed to emphasize topographical features and related soil textures; therefore, it may not be entirely consentient with that used predominantly in geological literature

deposits where the quiet waters of now-extinct glacial lakes made possible the accumulation of silts and clays in the lake beds, while wind and wave action built up beaches of granular materials in forms somewhat the same as those bordering the present lakes of comparable size. Finally, with the exception of recent alluvium which is discussed elsewhere, there are beds of muck and peat scattered throughout the glacial region usually in association with lakes, ponds, and marshes.

On the map (plate 1), distinction among the various forms of drift has been made only where isolated areas of the soils were large enough to be set apart from the others with clarity. Even the organic deposits, shown with ostensible minuteness, are not set forth entirely, and the aggregate area of such deposits which have been omitted may be equal to the total of those shown. Similarly, the extensive granular deposits of sand and gravel are only partially mapped, it being impractical to show all formations such as kames, eskers (fig. 33), and terraces, some of which would be hardly more than the width of a pencil line on a map of this scale. For detailed analyses of specific areas reference can be made to aerial photographs of those areas and to literature.

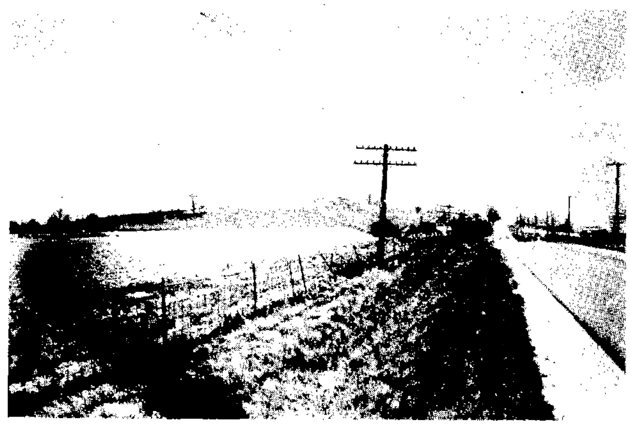

Fig. 33. The topographic expression of eskers is illustrated by this view of that type of granular deposit in the till plains of central Ohio.

Old Drift

From the standpoint of age all the several drifts have been separated into two classes, the young or Post-Illinoian, and the old, consisting of Illinoian and older materials. Although the disparity in laboratory test results is not great, age is a logical differential for soil classification because of the contrasting texture and pattern which have been verified by numerous observations and samplings. Throughout most of the area where old drift prevails there is a consistant trend toward silty soils in the upper horizons, these silts being similar to soils of the loess as it is mapped here. Among other things, the fact that loess is closely associated with the old drift and in some cases is known to cover it lends credence to an interpretation which places these soils in the category of windblown materials. Yet the influence of till on the characteristics of the soil and related land features is evidenced by the contrasting patterns in plates accompanying the airphoto analyses of old drift and loess. Therefore, without regard to the origin of the surface mantle, these soils are appropriately classed as old drift.

Most of the old drift was subsequently covered by materials deposited in later glaciations or by thick deposits of loess. Thus, only in southern Ohio, Indiana, Illinois, Iowa, Nebraska, and in the northern sections of Kansas and Missouri, is the old drift exposed to an extent warranting its consideration as a separate entity among glacial soils; other situations where similar drift of undetermined age prevails (155) have been disregarded because these materials are of only local importance to the soil pattern and soil characteristics.

The original level surface of the old drift, both east of the Mississippi and to the west, has been altered considerably by erosion and dissection. In Ohio, Indiana, and Illinois, these soils are of Illinoian age, while the remainder are largely composed of Kansas drift, both consisting almost entirely of till, principally as till plains and rather unimportant moraines. Large deposits of granular and lacustrine soils which are characteristic of the young drift to the north are of little consequence compared with the complementary till soils. Most of the topographic features are dependent upon erosion (fig. 34), which in much of the Kansas drift region has removed a large portion of the original deposits, and thus has formed dissected and rolling topography. In contrast to the Kansas drift region where the differences in elevation may be great but the slopes gentle, the topography in the Illinoian drift section is to a great extent still level, especially in some of the areas which are far from the outer boundary. Locally, however, some dissection has occurred. Near the outer borders of this drift where dissection has progressed to an advanced stage, some of the land forms are similar to those in the Kansan drift, and some of the soils are as closely related to the adjacent bedrocks as they are to the till.

Fig. 34. Despite the nearly level surface in the upland of the old drift, erosion is potentially of concern because of the silty soils in the upper horizons.

Somewhat similar in extent to the widespread mantle of silt, there is within the old drift a characteristic formation of plastic soils in the subsurface horizon, this formation being sometimes referred to as "gumbotil" and sometimes known as "claypan development." The effect of this plastic soil on drainage features is unmistakeable, for throughout most of the old drift region internal drainage is retarded so that the silty soils in the upper horizons, especially in the level areas, are naturally water-logged. However, artificial drainage is often effective in alleviating engineering soil problems caused by this poor natural drainage. The depth and thickness of the claypan must be considered in locating and spacing drains. Furthermore, these plastic subsurface soils are of concern from the standpoint of compaction and stability of subgrades.

The till beneath these upper horizons is composed principally of fine soil, there being occasional fragments of rock included both in the Illinoian and in the Kansan drift. Field observations and laboratory tests indicate that the Kansan till is by nature slightly more plastic than that of the Illinoian drift, the latter having been found to be more nearly similar to the younger till to the north (5) and differing from it mainly in the depth of overlying soil.

Young Drift

The sparseness of large granular and lacustrine deposits among glacial soils is conspicuously limited to the old drift, for in the young drift these assorted materials are abundant and cover an area more than equal to that of the old drift. Even then, these soils of assorted drift are much less extensive than the young till in area, though possibly not in importance to engineering design and construction. The till itself is not all of one kind throughout this region, that of the East being different from the till in the central states which, in turn, is only similar to the unassorted drift in the West. For the most part, these differences are manifested in topographic features and in composition and depth of the drift to bedrock.

East of Ohio the topography is determined largely by underlying rocks and only occasionally are local features primarily dependent on the drift. The glacial mantle is not deep in the sense that it is deep in the central states; rather the drift deposits average possibly 10 to 15 feet in depth on the uplands but may reach 50 or more feet in depth in the valleys and lowlands. Usually boulders and stones, prodigious in quantity and occasionally in size, are strewn throughout the till, and most of these components are similar to the underlying rock formations in the vicinity, a fact which indicates that the till was transported only relatively short distances by the glaciers. Smaller rock fragments, likewise similar to the bedrock, are profusely contained in the till, and these fragments combined with the larger rocks account for the fact that some of the till is reasonably permeable.

Fig. 35. Example of the topography typical of the till-covered portions in the seaboard section of New England. The level outwash and lacustrine areas are in marked contrast to these undulating ground features.

With only a few outstanding exceptions the topography of this till is rolling to rough (fig. 35) and even rugged as determined by underlying formations of igneous and metamorphic rocks mainly in New England and by sandstones and shales in New York and Pennsylvania. The principal exceptions alluded to are those of the Mohawk Valley and the Lake Ontario section in New York, the seaboard of New England (452, pp. 64-76), and some New England lowlands such as the Connecticut Valley (289). Although in these unusual instances the till features, such as moraines and drumlins, are of more than ordinary importance, still the lacustrine deposits and associated granular outwash materials are of greatest concern in these sections.

In some of the locations where, according to the map in plate 1, the soils are of lacustrine origin, actually the deposits consist of marine sediments. This applies particularly to parts of the Atlantic Coast (427) (430) and to the Champlain-Hudson lowland (526) (722), although part of the soils in these situations are definitely of the lake-deposited variety. Extensive though these lacustrine deposits are, they are much more limited than those of greater expanse in the central states, and by that token they are in their entirety slightly dissimilar. The differences lie mainly in the fact that shore and delta deposits of granular soils are sometimes scattered throughout the entire bed of the lake indicating different stages of deposition around and beneath the waters of the lake during its existence. Similar conditions in the larger lacustrine areas of the central states are confined mainly to bands around the periphery of the lake basin, while in the East they may prevail throughout and result in soils of interspersed and interbedded sands, gravels, and clays. Later discussions concerning the soils of the Coastal Plain will show similarity between some of these lacustrine materials and those formed in conjunction with marine waters and on a vastly greater scale.

Despite the apparent lack of distinct separation between soils of different textures in these lacustrine situations, the clays which are the most singular product of this method of fomration are in Boston (445) essentially the same as they are in Chicago, Detroit, or Fargo, the principal distinguishing feature being the color and the location. Hence, the Boston "blue clay", so well known in engineering literature, corresponds in mode of formation with the Albany clay (528), the Hartford clay (289), and the clays of "Lake Chicago" (151) and "Lake Agassiz" (153). More important than the interbedding and intermixing of soils of different textures in these lake-bed areas is the fact that the soils may at once be favorable as well as unfavorable for airport location, depending upon the relation of these two classes of materials to each other at the site in question. More thorough analysis and interpretation through treatments of separate phenomena, such as the terraces (fig. 36) associated with the present Connecticut River (289) (444) or the evidence of extensive glacial waters in central New York (517), may be supplemented by the data obtained from aerial photographs of such situations.

Fig. 36. The famed terraces in the Connecticut Valley occur at numerous elevations and illustrate the conditions (289) prevalent at the time of the melting of the ice on this structural trough.

Coincidentally, the majority of population in the eastern portion of the young drift region is concentrated in the lowlands where, in addition to the soils just discussed, granular outwash materials formed through glacial drainage are distributed from Maine to New Jersey and even inland. Throughout these areas even the alluvium is often granular in texture, and the effect of materials of this nature on airport development problems can hardly be discounted.

Westward in the central states there are, in the vicinity of Lake Superior, some young drift soils which, in physical composition and engineering characteristics, are similar to the till soils of New England. Glacial materials of this category can be attributed mainly to the "young red drift" (152) of Wisconsin glaciation, some of which was later covered by a mantle of gray drift dissimilar in character and different in origin. The general similarity between the soils here and those in New England lies in the fact that lithologically the components of the drift are primarily igneous and metamorphic rocks. This till is coarse-textured and contains a large amount of rock fragments (fig. 37), stones, and boulders, in a manner such that the soils are largely porous and well-drained internally, albeit there are numerous swamps and ponded areas. However, in contrast to the land forms of New England the topography here is not nearly so rugged even in "ranges" such as the Mesabi and Gogebic. Rock outcrops are not particularly numerous or important except in the vicinity of the Canadian boundary, and the average total depth of the drift is greater here than in the east. While drift of this stage of glaciation stretches as far south as the tip of Lake Michigan (138) (152), it is only in the Superior Upland (2), where the underlying bedrocks are igneous and metamorphic, that soils of this till have these properties.

Fig. 37. View of an airport site in the Superior upland during grading operations. The texture of the drift is well illustrated by the material shown on the surface.

Aside from this exception most of the drift of the central states is composed predominantly of materials originating from sedimentary rocks and is correspondingly underlain by rocks of that nature. Most of the topographic features are those established by the drift and not by the rock formations. The drift being young, large-scale erosion and dissection is rare, and in many instances a local natural drainage pattern has hardly been created. The entire section is one in which the ice originating from different centers was guided by prominent protrusions of resistant rock and correlative lowlands such that lobes of ice were formed which sometimes competed in the invasion of several different localities. As a result of this manner of invasion, prominent systems of terminal and recessional moraines are everywhere present in these states. In much of this section, especially that which is proximate to the present Great Lakes, there are complex arrangements of granular drift, outwash of gravel and sand, mucks and peats, and lacustrine silts and clays combined in a juxtaposition unparalleled in this country.

This drift of omnifarious character prevails throughout most of Minnesota, Wisconsin, and Michigan, (fig. 38) and extends southward into Illinois and Indiana to about the forty-first parallel; morainic topography is accentuated sometimes to the point of being steep and rough, while intervening and marginal areas consist largely of outwash plains of sand and gravel. Even the till tends to be granular in character, probably as a result of deposition, retransportation, and redeposition of the drift during various stages of glaciation. Myriad lakes and deposits of organic materials are typical (fig. 39). Although the soils here are mapped entirely as those of the young drift, there are two sections, one athwart the boundary between Illinois and Wisconsin and the other north of the driftless region in the latter state, where extraneous materials usually attributed to Illinoian glaciation (155) (751) exist. Inasmuch as these locations are somewhat removed from the main area of old drift and many of the landforms and soil characteristics approximate those of the conterminous young drift, age has been disregarded in designating these materials on the map.

Fig. 38. The peculiar topography and vegetative cover illustrated in this view are typical in many areas throughout the Great Lakes section of young drift. Sandy soils, high groundwater tables, and bogs and swamps are representative of these sparsely settled localities.

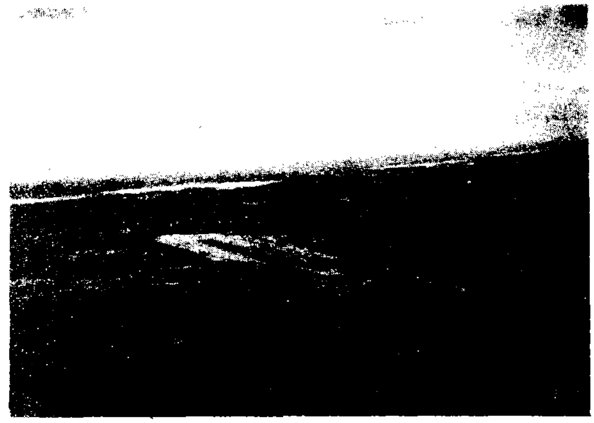

Fig. 39. An airport located on level sandy outwash adjacent to extensive deposits of organic materials and attendant lakes.

In striking contrast, that drift in Ohio, Indiana, and Illinois which is south of the forty-first parallel is predominantly in the form of broad and suprisingly level till plains broken at intervals by moraines which in many instances are not prominent and topographically are not far different from the surrounding land. The numerous lakes and organic deposits and the large areas of outwash sands and gravels, characteristically associated with young drift, are practically non-existent in the plains section, although granular materials in the form of kames and eskers on the uplands, and terraces in the river valleys, are everywhere readily available (151) (154).

Within the concept of soil formation used in this manual, major differences among soil profiles in the till plains are dependent more on topography than on any other feature, the soils being weathered to a greater depth in the flat or depressed positions and accumulations of organic matter in the top horizon being confined largely to the soils in the depressions (fig. 40). Climate and vegetation play an important part, of course, but their effect is largely regional rather than local. These depressed and relatively low-lying areas often represent incipient drainageways which have not been developed to the extent of becoming stream channels. Both the subsoil and the parent material of most of the till are predominantly rather fine-textured, the parent material containing some pebbles and rocks except in the well-known boulder belts where this relationship obviously does not apply (fig. 41). For the most part the soils are rather poorly drained internally, and yet almost without exception they are pervious to the extent that artificial drainage installations, where economical, could be helpful in removing water from the soils and improving poor natural drainage conditions. Occasionally, sites suitable for airport development are available on the broader terraces, and as such they constitute the acme of advantageous conditions from the standpoint of topography and soil combined.

Fig. 40. This location in the till plains of Indiana illustrates the level to undulating topography and the correlation between soil formation, soilcolor and topographic features whereby organic material tends to accumulate in the top horizon of soils in depressed (black) positions.

Fig. 41. Illustration of ground conditions prevailing in the boulder belts of the young drift in the central states.

Till plains similar to those just mentioned but more limited in expanse are more definitely associated with moraines and variable outwash features occur in northern Iowa and to some extent in southern Minnesota. Here the till is largely of the Wisconsin age, although some Iowan drift is definitely recognizable in both the northeastern and to a less extent northwestern portions of Iowa (153) (372), both belts extending into southern Minnesota. These plains are level or only gently undulating with the exception of occasional hillocks, some of which are kamey and contain gravel and which stand above the surrounding land. The soils of these level lands are comparable in engineering characteristics to those of the plains farther east, they, in general, tending to be poorly drained and sometimes ponded in the depressed locations. For the most part the morainal belts are outstanding as topographic features and are easily distinguished from the surrounding till. In that respect, the drift here is somewhat similar to the more granular drift of the lake region. Actually more than a small amount of soils in this area consist of outwash of sand and gravel comparable in texture but not in extent to those of the outwash areas in Michigan, Wisconsin, and the northern part of Minnesota.

An outstanding feature near the western edge of this section is that major land form known as the Coteau de Prairie, which in geographic location approximates the intersection of the boundaries of South Dakota, Minnesota, and Iowa. Beneath the deep deposits of drift, some of which are 400 to 500 feet in thickness, there is a rock core so massive and so resistant that it split the Wisconsin glacier into lobes which extended far to the south on both sides of the Coteau. Earlier glacial deposits and subsequent loessial materials account for the soils of this section (663), the latter predominating as indicated on the map (plate 1). Major moraines (fig. 42) marking the outer borders of the Wisconsin and Iowan drifts loop about this land form and extend to the north, thus providing prominent surface topography in contrast to the low surrounding plains which are from 50 to as much as 400 feet lower than the moraines and as much as 800 feet below the crest of the Coteau.

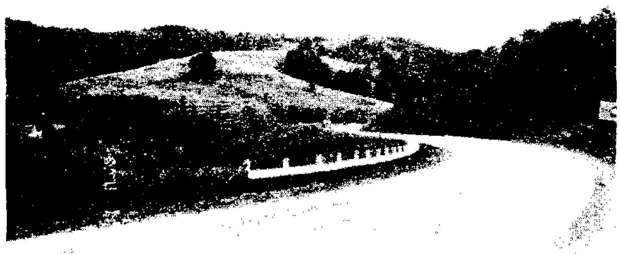

Fig. 42. Morainic topography in northern Iowa and southern Minnesota.

The glacial soils to the north and west of these till plains, more specifically in the southern half of Minnesota and the eastern parts of the Dakotas, form a transition zone between the drift of the humid areas in the central states and the drift of the more arid regions in the Great Plains. In some respects the textures of these soils are similarly transitional because the influence of granular drift is of some importance, but not nearly as specific as it is in the drift bordering the Lakes. The topography is largely morainic, drift of this form being almost equal in area to the more level intermorainic till which at most is gently rolling.

Fig. 43. Gravel pit opened in a glacial terrace.

Of slightly less extent are the widespread areas of outwash sands and gravels (fig 43), some of which are within themselves as much as ten miles in width and perhaps one hundred miles in length Upon the whole these outwash features are limited to sinuous bands along the stream channels, yet in a few instances on some larger outwash areas are practically disassociated from the present streams Illustrative of these and other drift features, and demonstrative of the value of geologic investigations to soil analysis as well, is the interpretive work by Leverett (462) dealing with the glacial geology of Minnesota and adjacent states The map of Minnesota accompanying that report contains about all the information necessary for a comprehensive analysis of glacial soils within an entire state, and, as such, it is with greater detail representative of the intentions of the authors in preparing the map (plate 1) of the entire country

Westward in Montana and in those sections near the Missouri River in the Dakotas the soils of the young drift, while inherently similar to the young drift in the till plains, are affected considerably by the lack of precipitation This climatic effect is manifested mainly in the depth of weathering and accumulation of calcium carbonate near the surface. Most of the drift is of Wisconsin age as indicated by the symbol used on the map, however, in the southern portions, and particularly those sections south of the Missouri River, much of the drift is at least as old as the Illinoian Near those southern boundaries, where the glacial cover is thin, the underlying rocks are the dominant influences in soil formation and the age of the drift is not of primary consequence in engineering problems.

Except where erosion has been particularly severe, such as in badlands and coulees, the topography consists almost entirely of very broad and gently sloping plains broken at intervals by abrupt protrusions somewhat in the manner of cuestas. More outstanding, and probably the most exaggerated of all morainic belts in the entire glacial region, is the Missouri Coteau which lies to the north and east of the Missouri River and stretches from central South Dakota northward into Canada This belt stands out as a gigantic system of knobs and basins in which many small lakes and ponds have been formed and in which the drift is characteristically stony. Not all of the conspicuous features of this escarpment are due to the glacial mantle, however, as the maximum depth of the drift which overlies the bedrocks is only about 150 feet

Although the data concerning glaciation in Montana are not as abundant as in many areas, some investigators (139a) have indicated that abundant deposits of gravel are available throughout this section In the southern parts terraces of considerable size are often associated with major stream valleys, while to the north large beds of Tertiary gravels (Flaxville) underlie glacial materials at only a shallow depth These gravels are analogous to those which outcrop among the Tertiary shales, clays, sandstones, and scoria near the angular intersection of the Missouri and Yellowstone Rivers

Probably the most unique of glacial soils throughout all of the young drift of the central United States are those in the beds of the old glacial lakes which in their antiquity were associated with the present Great Lake system These soils consist of silts and clays which are very uniform in grain size and texture and were undoubtedly deposited in the deeper portions of the lakes during their existence Not all of the lacustrine materials, however, are of this nature. Usually near the edges but sometimes far within the basins, are numerous deposits of sands and gravels which were deposited near the shore of the lake at different stages Undoubtedly these sands and gravels were developed not only by the action of waves and wind, but some were also deltas where inflowing water deposited the debris Associated with these lakes were sand dunes similar to those adjacent to all but the smallest of present-day lakes As the topography within the basins is nearly level (fig 40), the streams meander except where greatly entrenched All of these lacustrine features in combination provide an interesting and unusual soil pattern which is readily discernible through aerial photographs (see chapter XI) Outstanding among these lacustrine situations (156) are the beds of Lake Agassiz (463) (464), Lake Souris (568), and Lake Dakota (668) (669), in addition to those adjacent to the present Great Lakes.

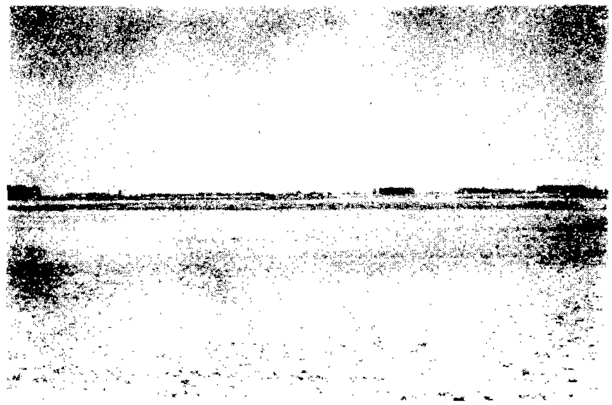

Fig. 44. The level topography and even the soil textures of the lacustrine plains in the central states can be detected in this ground view, although they are much more evident in the aerial photographs of the same or similar locations.

The drift soils in the Rocky Mountain region and near the Pacific coast are confined principally to the valleys, and their characteristics show distinctly the effect of the surrounding rough topography and conditions attendant to the melting of the glaciers. In many locations, especially in the long and narrow valleys of the mountains, the soils in effect are hardly different from those of the valley fill which are discussed later in this report. Upon the melting of the glaciers large amounts of water were channelized in these valleys resulting inevitably in assortment of the debris; consequently, the soils are inherently granular. The similarity in physical composition of these soils and valley fill materials lies in the fact that both were formed by this process of transportation by water.

Some of this western drift in the vicinity of Puget Sound is of the mixed and unassorted variety. This is particularly true of the soils bordering the southern reaches of the Sound. Here rolling and sometimes rocky deposits of till are mainly moraines which on the south apparently form a barrier preventing extension of marine waters into southern Washington. Beyond the moraines and bordering the Chehalis River, gravels and sands deposited as outwash are predominant. Similarly, within the borders of the morainic belts a maze of plains consisting of gravel and sands extend northward (fig. 45). Some prominent rock outcrops stand far above the general level of the glacial deposits, and in some places there are abrupt breaks in the topography especially near streams and the Sound itself. Bogs are not uncommon.

Fig. 45. Soils throughout this valley in eastern Washington are of granular glacial drift.

CHAPTER VI

WATERLAID MATERIALS

Among the soils that originated through the action of transporting media are those deposited principally by flowing water These include the soils of the Coastal Plain, those of the filled valleys and Great Plains outwash mantle, and the recent alluvium. The first two groups are composed of materials which are predominantly of geologic "age," i.e , not formed during the last few hundred years, while the recent alluvium consists of soils deposited by the rivers during the time that they were essentially of their present character

Soils of the Coastal Plain

As shown on the map (plate 1) the Coastal Plain as a soil province does not coincide everywhere with the physiographic Coastal Plain The Coastal Plain region borders the Atlantic Ocean and the Gulf of Mexico and as a physiographic province is continuous from Long Island to the Rio Grande, varying in width from a few to several hundred miles As a soil province, it is modified at the north edge by glacial drift in New Jersey and on Long Island, and is made discontinuous in the Mississippi Valley section by alluvium and by a loess belt adjacent to the alluvium on the east Otherwise, the soil province is coincident with the physiographic province [4]

The materials of this soil group are of both marine and continental origin all having been deposited during recent (Cretaceous or later) geological times Since the time of deposition of the oldest formations represented, the land, or at least part of it, has been both submergent and emergent sometimes alternately Practically all of the strata relevant to soils near the surface are unconsolidated or slightly indurated at best, although there are many and occasionally extensive formations of limestone, sandstone, and rocks of less definite character which have considerable influence on the topography if not on the soils Thus, the origin of a portion of these soils may be contentious - residual versus sedimentary - but not of particular significance in this general classification, for any interpretation discounting the influence of bedrocks as parent materials, if in error at all, is expiable by the fact that such influence is not great enough to alter the unique contexture of soils which prevail in this region of the country

Contrary to the implication of its name, the Coastal Plain is not literally an unbroken surface sloping gently from its inland border to and beneath the sea Yet, aside from differential erosion and attendant land forms, it has essentially the nature of a plane beds of each age being characteristically thin at their inner margins and gradually becoming of greater thickness as they extend seaward Elevations near the boundary on the interior are as great as 700 feet east of the Mississippi and more than 1,000 feet in Texas, and either occurs at locations not more than 250 miles from the Gulf Altogether, these several features have, in many sections somewhat removed from the Coast, been accentuated by dissected land forming rolling and even rough local topography where several of the major streams have become entrenched and minor escarpments formed These inner sections are often referred to as the inner or upper Coastal Plain to differentiate them from the low, level, and less mature land forms of terraces adjoining the Ocean and Gulf.

Of the two major divisions of physical features which have been mentioned, that of the outer terraces is the less extensive, although it is not confined to positions immediately contiguous to the coast In fact, at some places on the Atlantic seaboard the terraces extend inward almost the entire width of the Coastal Plain, similarly, more than half of the total surface area in Florida is covered in this way Generally the topography of the terraces is level, pronounced differences in elevation occurring mainly near the stream channels and occasionally on the

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[4] An additional situation, the Grand Prairie in Texas, could be considered as an exception where the Coastal Plain is modified by extraneous soil conditions See Fenneman (20), page 101, footnote

shore where dunes have been formed. Almost without exception the streams in this low belt enter from the highlands and meander for some distance finally terminating in drowned valleys and estuaries. Some of the major river channels in the east are drowned as far inland as the border of the Coastal Plain - the "fall line"; hence water levels rise and fall with the tides at Philadelphia, Baltimore, Washington, and Richmond. Farther to the south and westward where the band of terraces falls far short of reaching this inner boundary this condition does not prevail, although many prominent cities are located at the fall line on some of the more important streams.

Fig. 46. View showing the topography and vegetation typical of the terraces in positions somewhat removed from the coast and marshlands bordering the streams. In this particular instance, the soil is sandy and well-drained internally.

The terraces throughout most of the region have a maximum elevation approximating 200 feet above sea level increasing to as much as 300 feet in southern Texas and many are of granular texture (fig. 46). Swamps and marshlands which often lie in the lowlands between terraces are everywhere common, especially along the immediate coast and inland as borders to the sluggish streams. Outstanding among these are the Everglades of Florida and the Okefenokee and Dismal Swamps, all three being removed some distance from the coast. Several stages of terracing have been recognized and in some instances correlated in widely separated areas. Outstanding examples of correlations are those made in Maryland (436) and Florida (299).

Inland from the terraces the upper portion of the Coastal Plain consists of deposits of Tertiary and Cretaceous ages arranged such that they occur in belts of varying width, but being oriented such that their boundaries resemble the boundary of the coast deviating only at the Mississippi Valley. Differences in the resistance of various strata are manifested in a more minute system of belts made up of the higher lands on more resistant outcrops separated by intervening lowlands where the strata were easily eroded. The degree of difference between these higher and lower sections varies from the Cuestas of New Jersey (512) to the minor escarpments of Texas (695). The deposits of different ages and the accompanying belted pattern can be appreciated at a glance on geological maps of this region (52). The vegetation of the Coastal Plain responds strikingly with these belts as represented by the famous "Timber Belts," (fig. 47) "Cross Timbers," and "Flat Woods" areas.

Unlike most of the other parts of the country this region is not one in which the soils are unequivocally related to distinct and separate geological and physical features as are those where the residual soil is derived from underlying bedrock, or where the soil of an esker is dependent upon a distinct process of glacial deposition. Doubtlessly similar natural processes of formation account for these soils as they now exist, but the inter-relation of marine and continental deposits is often concealed in the present land features, and the pattern of causation is thus obliterated. Nevertheless, this is not particularly detrimental to an engineering classification of soils because, regardless of the process of formation the sands, for example, of the fall-line hills in Georgia (308) or the Carolinas (651) can from the standpoint of texture be reasonably grouped with the sands of the beaches as well as those covering the "Limesink District" of the upland in northern Florida (301).

Fig. 47. Timber belts such as these in southern Alabama occur on the sandy soils throughout the Gulf states.

By far the most widespread soil in the entire Coastal Plain is that material here denoted as interbedded and intermixed sands, gravels, clays, and silts. Although this designation is seemingly inexact, it is strictly descriptive of the soils as they exist as a group in the field, being random in physical characteristics and distribution. Numerous investigations such as those by Darton (181) (436), Salisbury and Knapp (515), Deussen (685), and others, corroborate this by well drillings and other sub-surface explorations. The heterogeneous arrangement of this material is well illustrated through a number of figures and plates, e.g. (515 - figure 39; plate Vb) in those publications. Not only are soils having different characteristics stratified sometimes in relatively thin layers, but in addition the strata dip, form pockets, and outcrop on the surface in a way such that materials having highly divergent engineering properties may intermittently occur on the surface within limited horizontal differences. Hence, changes from one material to another may be encountered many times on the surface of an area the size of a modern airport. Such variations, while being outside the scope of a map having a scale such as that of plate 1, are readily discernible locally through inspection of aerial photographs.

Most uniform in composition and secondary only in area covered are the abundant sands which are important almost everywhere throughout this coastal region. In major deposits these soils occur in situations ranging from the low terraces of New Jersey and Florida through the previously mentioned fall-line hills to the tufaceous sands near the Red River Valley in Oklahoma (183). These materials are not limited just to those areas where they are shown on the map, for, in fact, numerous locations in the Black Belts and on the clays and organic deposits elsewhere have deposits of these soils in amounts which are of considerable consequence to engineering construction in those sections. Some of the Coastal Plain sands are attributed to the disintegration of weak sandstones in place (651) (183), although by far the majority are considered to be directly sedimentary through marine or alluvial deposition. Supplementing both methods of formation the winds have redeposited the sands in dunes not only near the beaches but sometimes in uplands such as those of northern Florida. These sands (fig. 46) are highly erosive (fig. 48).

Fig. 48. In the sandy soils of the inner Coastal Plain erosion forces are effective in dissecting the surface both locally and regionally. Note the vertical banks in this major gully.

Probably the most unique soil of this region is the sand-clay which consists of the component materials not interbedded or intermixed but integrated in proportions such that the soils are granular in nature yet plastic and cohesive to the extent that tests for limits of consistency are possible (see Table VI - soils No. 882C, 884C, and 916C in appendix A). From the standpoint of drainage and vulnerability to the adverse effect of moisture these soils warrant considerable attention to their clay-like characteristics, although compaction tests show that they are materially influenced by the fraction of granular particles. Through occasional and intentional samplings soils of similar characteristics have been found in widely separated sections of the country; however, these occasional samples notwithstanding, there are data to substantiate the assumption that this class of material is confined largely to the southern states where the soils are those of the Coastal Plain or have been derived from the metamorphic rocks typical of the Piedmont region.

The most singular soil of the Coastal Plain is the clay which, as such, occurs in more than just those situations shown on the map. Those that are not shown, however, are so small that they can be delineated only in areas which are limited in extent, and for that reason they are for this purpose included in the soils of the interbedded and intermixed variety. The clay just north of Washington, D. C., for example, is but one of the small areas of various clays associated with eastern Cretaceous formations.

The largest and most important sections where these materials predominate are those of the "Black Belts" (fig. 49) (fig. 50) in Alabama, Mississippi, and Texas. These soils lying at an angle to the present Mississippi River in Alabama and Mississippi on the east, and in Texas on the west, define former shores of the Gulf of Mexico. Soils of these famous belts are, as the name implies, black on the surface when not perfectly dry. They are of "waxy" consistency. Soils No. 868C-870C in Table VI of appendix A are representative of a profile of soils of this character. For the most part these materials are underlain by formations of marl and chalk such as the Selma of Alabama (202) and the Eagle Ford, Austin, and Taylor of Texas (695) (81). They have exceptionally high shrinkage factors and draw away from any concrete structure when dry leaving large soil cracks which often cause failures due to the entry of water behind and under the structures. Like all clays they are highly impermeable when moist [illegible]se of the large cracks which develop when these soils are dry, much movement of underground water may occur temporarily before swelling can seal them. Cracks as large as one foot in width at the surface and fifteen feet in depth have been observed in these soils.

Different geologically but not in engineering characteristics are a considerable amount of younger materials near the coast of Texas and Louisiana where the clay soils are geologically of the Beaumont and associated formations. Here the topographic expression is that of the coastal terraces which have been sometimes construed to be surfaces of old deltas formed by outwash from the higher lands to the north and west. By that interpretation they are similar to the delta deposits of the present Mississippi, but of necessity were formed on a much larger scale. These plastic soils near the coast are sometimes overlain by a thin veneer of sandy materials, yet the ground-water table is high and the sands are usually so shallow that the clays cause the predominating engineering soil problems.

Fig. 49. Throughout the "Black Belts," except in those sections bordering entrenched streams, the ground surface is usually level as illustrated by this view in eastern Texas.

Fig. 50. The performance of pavements underlain by clay soils illustrates the importance of proper attention to subgrade stability in dealing with these plastic soils.

East of the Mississippi, particularly in southern and central Florida, the clays overlie Tertiary limestones; occasionally, and particularly in the uplands, sink-hole topography prevails so that it appears that these clays may be directly associated with underlying calcareous formations. On the other hand, some of the formations beneath the upland have not been indurated and thus consist of greenish clays or only slightly solidified materials. Some rock formations outcrop in Florida to the extent that there is little, if any, soil cover, this condition being outstanding in the vicinity of Miami (299).

The gravels and sands of the Coastal Plain, actually much more extensive than depicted in plate 1, are possibly more important as subsurface deposits than as surface materials. Aside from the sands and gravels diffused throughout the congeries of interbedded and intermixed soils, a few areas of these granular materials are outlined on the map by the designated symbol. Although some of the gravels are, in part, among the oldest of materials represented in this region, by far the greater part are of more recent origin with the majority being assigned to the Pliocene epoch.

Along the Atlantic seaboard and parts of the Gulf Coast these materials are subjacent to the younger terrace deposits from which they have received protection against erosion. Farther inland they sometimes outcrop or exist at only shallow depths beneath the surface; in such a position they have become important natural resources in many of the states bordering the Gulf (421) (469) (202) Coeval deposits of sand and gravel which once existed still farther inland have been largely removed by erosion, only remnants, such as those surmounting high interstream divides in Texas, remaining These are the famed but often indefinite "Lafayette" gravels of geological literature, representing a formation widespread throughout the entire Coastal Plain and, according to some sources of information, beyond its borders

Soils of Filled Valleys and Great Plains Outwash Mantle

The soils of filled valleys and the Great Plains outwash mantle are indicated in this report as one of three soil divisions among the waterlaid materials. This grouping is, of course, not entirely in harmony with either geological or pedological methods, but is distinctly an engineering approach based on a reasonable similarity in texture of the soils, the generally prevailing topography, and a similarity in the method of deposition Both the climate variations, which are of great importance to the pedologist, and the age differences of the deposits which are of primary interest to the geologist, are large. However, for engineering purposes these variations are not sufficiently great to preclude the soil grouping under one division. For purposes of discussion these materials are separated into two subdivisions These are the outwash mantle on the Great Plains and soils of the filled valleys The mantle is referred to in parts of this and other texts as "Tertiary" mantle although evidences of Quaternary deposits have also been found. Parts of this area are also referred to as the High Plains. The soils of the filled valleys have been further subdivided into "unconsolidated", "consolidated in places", and "semi-consolidated."

Great Plains Outwash Mantle

The major portion of Great Plains outwash materials are in a part of the High Plains section, including The panhandle of Texas and Oklahoma; adjacent areas in New Mexico, Colorado, and Kansas; and rather small areas in Nebraska, Wyoming, and South Dakota The Great Plains, in the physiographic sense, is much larger, occupying not only this Rocky Mountain outwash soil area but all of the vast area in central-western United States (54) and including soil materials of aeolian, residual, and glacial origin.

The topography of this expanse of interior land is generally flat; however the entire region slopes gently eastward from the base of the Rocky Mountains at an average fall of about 10 feet per mile This otherwise monotonously flat area is dissected here and there by the several streams of the region Many of the larger east-flowing rivers have their sources in the Rocky Mountains The largest rivers in the area are the Arkansas, the Canadian, and the Cimmaron Because of the need for water, population of the West is concentrated along these streams, and the important surface transportation routes often follow these river valleys. Because the dissection is more prominent along the river valley walls, the casual observer traversing the Great Plains may receive the impression that the area is more rugged than it actually is. There are other breaks in the topography such as badlands and some canyon-like areas along the Canadian and other east-flowing rivers in Texas and Oklahoma and there are many large and small arroyos cut by torrential summer run-off.

The boundaries of the Great Plains are frequently established on the basis of climate, the rainfall, for instance, varying in amount from 10 to 15 inches on the western boundary to 20 inches on the east In the Texas-New Mexico area, the summers are long and hot with correspondingly short, moderate winters, a significant factor in connection with the high evaporation losses of ground water.

The relatively small amount of rainfall has a decided effect on vegetation (fig. 51). The region is, in general treeless and is covered with short grass in contrast with the "long grass" of the adjacent prairies to the east. The area is used primarily for grazing, although most of the river valleys are intensively cultivated where irrigation is feasible (plate 53), particularly along the western border of the plains.

Fig. 51. Because of the semi-arid climate which prevails throughout the Great Plains, the region is largely devoid of trees and is characterized by short grasses and desert vegetation.

The geology of the High Plains is as interesting as it is intricate (52). Beneath the Tertiary mantle the bedrocks consist of shales, sandstones, limestones, and conglomerates, laid in almost horizontal strata (190). The dip of the strata is, in general, gently eastward and where these strata become surface materials along the eastern boundary, as they do in eastern Kansas, central Oklahoma and Texas, low east-facing escarpments are found. On a portion of the western boundary, these strata bend sharply upward and in places are almost vertical; in southeastern New Mexico they emerge from under the mantle at the Mescalero escarpment and are the bedrocks of the Pecos plains (557). Following the establishment of the Great Plains as a land surface, the Rocky Mountains underwent a prolonged and severe period of erosion. Much material from the mountains was carried by the now extinct streams flowing across the Great Plains in an eastwardly direction. The position of these streams was ever-changing with the accumulation of additional debris. Their pattern is seen in plate 52. As a result, a considerable portion is covered with a deep mantle of water-deposited sand, gravel, and silt. Much of this material is a conglomerate with calcium carbonate binder and is frequently referred to as "mortar beds," although in many places loess overlies the outwash, now considered as the Sanborn formation (384). Other names frequently found in the literature include "Tertiary marl" and "Plains marl" (50).

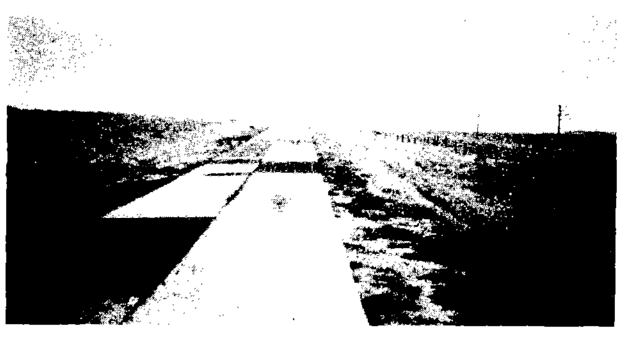

Fig. 52. The performance of this rigid pavement located on the soils of the High Plains mantle is poor, despite the semi-arid climate and the sandy and silty texture of the soils.

Near the Rocky Mountains can be found alluvial fans of great extent, which consist of eroded materials from the mountains The mountain outwash found in the High Plains section in New Mexico, Texas, Oklahoma, Kansas, Colorado, Nebraska, southeastern Wyoming, and southern South Dakota are identified geologically as Arikaree and Ogalala (190). The border between the two as indicated in plate 1, is in northeastern Colorado and southwestern Nebraska The northernmost area, which is the older of the two, consists essentially of loosly cemented sand containing calcareous concretions The younger formation also consists primarily of sands with some gravels and silts, calcium carbonate being the cementing material. To the south, in Texas and New Mexico, caliche is found near the surface and even outcrops on occasion

Pedologically the soils in the southern area of the Great Plains mantle are mapped as Amarillo (683), covering roughly the eastern half, and Springer the western half Sands are indicated as such. Both these materials extend northward almost to the Arkansas River in Kansas and Colorado In the western section some small portions of this mantle are indicated as Otero. North of the Arkansas River the soils of the High Plains, excluding the sands and loess, are indicated as Rosebud although some discrepancy exists where the loessial Keith is also indicated as Rosebud (44) In some cases (43), the Baca-Prowers soils are indicated in the northern panhandle of Texas, Oklahoma, Colorado, New Mexico, and Kansas These are described as granular friable soils with crumbly clay subsoils underlaid by chalky layers of carbonate of lime To the south and east of and adjacent to the Baca-Prowers are the Zita-Pullman soils, while the Regan-Springer are reported to be sandy, silty soils with calcium carbonate occurring from one to three feet below the surface The Amarillo are sandy silty materials with calcium carbonate occurring at depths of three to five feet or more. Field and laboratory checks on the Springer indicate there are many areas that are especially granular In contrast the Amarillo soils were less variable in texture

In the extreme southern portion of the Great Plains, primarily on the Edwards and Stockton Plateaus (690), this superficial mantle either has been eroded or was never deposited in these areas Likewise, along the eastern border of the Great Plains, from the Edwards Plateau to the Missouri River, erosion has denuded most of the area of the silt, sand, and gravel deposits, although extensive patch-like areas of the material are still to be found Most of the stream valleys in this area have been filled to considerable depth with the material eroded from the Great Plains and from areas further west. Considerable denudation is also found along the Platte and Arkansas Rivers in northeastern and southeastern Colorado and adjacent areas to the north and south of these streams This area (fig 53) is frequently referred to as the Colorado Piedmont (19). Likewise, most of these deposits have been removed from the Great Plains area of western North and South Dakota, Montana, and most of Wyoming, and as a result, the surface soils are indicated on plate 1 as residual, derived from shales, clay, sandstones, and scoria (190). Outlying remnants of these extensive river-deposited materials are indicated on the map in east-central New Mexico, southeastern Montana just north of the Black Hills, and in a number of locations in Wyoming, Utah, and Colorado associated with the Uinta Mountains Geologically, most of these are referred to either as the Browns Park formation or the Bishop conglomerate Other similar materials are indicated in Wyoming at the southern extremity of the Wind River Mountains and in a large area between and slightly north of the Park Range and Medicine Bow Mountains in southern Wyoming and northern Colorado Owing to the similarity of texture the materials of the Santa Fe formation (50), found in isolated areas in the Rio Grande valley of southern New Mexico and much more extensively through Albuquerque, Santa Fe, and northward, are included on plate 1 with the mountain outwash of the Great Plains

Sands occur in many rather small isolated areas in sufficient number to constitute a relatively high percentage of the total surface materials of the Great Plains mantle. The Nebraska Sand Hill region constitutes the largest single area of sand, this material being found between the Platte and Niobrara rivers and from the Wyoming-Nebraska line as far east as Elgin, Nebraska According to Lobeck (32), these sands are derived from the Great Plains Arikaree, the silt having been removed by wind action. Other deposits of sand are found on the leeward side of rivers, the sand having been blown from the adjacent flood plains.

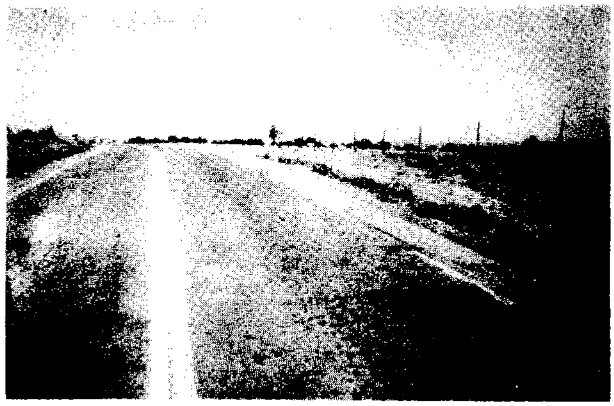

Fig. 53. The soils forming the subgrade for this pavement were derived from black shale in the denuded sections of the Colorado Piedmont.

Detailed data covering the engineering characteristics of the mountain outwash materials of the Great Plains are not abundant. However, there is reason to believe that the textures of the surface soils are reasonably consistent within the area indicated, and in the absence of detailed data, general information becomes important. Taking the group as a whole the surface soils are rather deep averaging possibly six to twelve or fifteen feet. They are predominantly silty in texture with sands and gravels to be expected at frequent intervals. These soils are especially porous and absorb a large portion of the total rainfall. This feature minimizes erosion except where the superficial mantle is shallow or where streams flow across or through the material. Because of the texture and the state of consolidation, artificial drainage for the purpose of lowering initially high water levels is not often necessary. However, owing to the accumulation of moisture under pavements, as well as the need for sizeable surface drains to convey torrential run-off from summer thunder showers, drainage is often a major factor in airport design. Because of the prevailing level topography, earth work is not a problem except in rare situations. It follows that uniformity of subgrade support may be expected generally. The entire region is susceptible to wind erosion and because of the semi-arid climate, vegetative coverage is sometimes difficult to establish. Pavement pumping is not a serious problem. The high alkali content may be a problem, particularly in Texas and New Mexico.

Filled Valleys

Throughout all of the states west of the Great Plains erosional processes have been and are at work wearing down the mountains and filling the adjacent valleys. In some instances this valley fill has been carried hundreds of miles from its source in the mountains and deposited along the wide valleys of present streams, such as the Arkansas River through eastern Colorado and Kansas. There the distinction between filled valley soil and recent alluvium is often obsecure. The process by which these mountains are becoming both reduced and buried under the debris from their own slopes is an interesting one. Probably more than ten percent of the total potentially usable land area in the United States is comprised of materials derived in this manner, some of them being old and at least partially consolidated. Because the topography of filled valleys is generally level, the soils prevailing in these intermontane areas are significant to the location of airports and highways, in locations where flooding from present streams does not occur.

<u>Valley Fill - Unconsolidated.</u> Unconsolidated valley-fill materials are found widespread in Nevada and Utah as well as in southern California, southern Arizona and southwestern New Mexico. These same materials are indicated (plate 1) in the Great Valley of California, and in sections of the Willamette Valley in Oregon, as well as in the interior of Oregon, in long, narrow valleys of Idaho and western Montana, some areas in southern Wyoming, South Dakota (fig. 54) and southern Colorado, and finally in the Great Bend, south of the Arkansas River in central Kansas. In the Basin and Range province many of the streams flowing from the mountains onto and across the valleys have no outlet to the sea (192). Geologically, this condition has existed during long intervals and inland lakes such as Great Salt Lake have been developed. Old lakes Bonneville (191) and Lahonton (195) together with literally dozens of small lakes occurred throughout the Basin and Range province, particularly in Nevada, southern California, Arizona, and New Mexico. Both Bonneville and Lahonton at one time had outlets several hundred feet above the present level of the water in Great Salt Lake. During this time interval in geologic history, inflowing streams deposited coarse materials near the perimeter of the then existent lake level, remnants of which remain now as beaches and terraces (fig. 55). The finer sediments were carried into the lake proper and were slowly deposited as silts, clays and colloidal materials. As these lakes receded, more and more of the lake beds became exposed until at the present time lacustrine sediments exist as surface materials in two very extensive deposits and in numerous small ones. Topographically these areas provide good locations for airports; however, the poor character of the soil often outweighs the topographic advantage. On the other hand, where airports must be located on these flat lacustrine soils, the beaches and terraces, are sometimes conveniently located for obtaining suitable granular materials to imporve the otherwise poor subgrade soils.

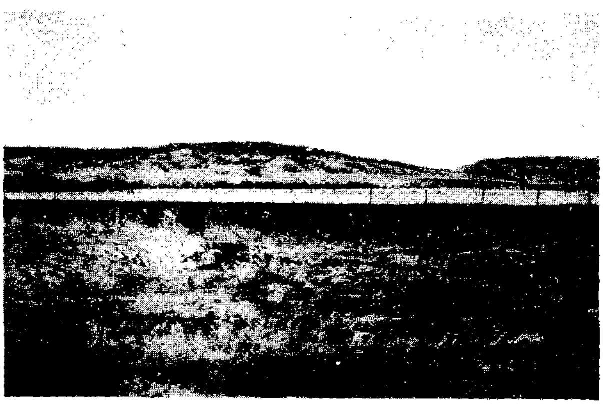

Fig. 54. Gravels such as those shown in this location in South Dakota are abundant in local outwash areas and stream valleys throughout the Great Plains.

Fig. 55. Terraces such as those faintly discernible on the mountainous side and shown by arrows are remnants of valley fill in the basins of Tertiary lakes formed when the lakes were at their highest stages. This situation in Utah is one associated with extinct Lake Bonneville and the present Great Salt Lake.

Throughout this vast region, rapidly flowing streams from the adjacent mountains carry immense quantities of broken rock fragments, boulders, sands, silts, and clays. As these rivers emerge from the mountains onto the flatter valley slopes they lose their coarse sediments and carry the finer ones out into the valley proper. This process has been going on through the ages and alluvial fans, consisting primarily of granular materials, are to be found throughout the region, often extending many miles from the mountain proper. As these fans build up, the stream beds become higher and higher, and the granular texture of the resulting deposits is conducive to high water losses through the bed of the stream. This is, of course, an important matter in considering the ground-water resources of this otherwise arid or semi-arid region. Evaporation and the use of these waters for irrigation almost consume most of the water of these streams so that only the flood waters generally reach the sea. The result of all these processes is the deposition, within this vast network of valleys, of hundreds or even thousands of feet of sands, silts, clays, and gravels.

The valley-fill soils indicated as unconsolidated on plate 1 include materials of these various deposits. Texturally, they vary through a wide range, from colloidal lacustrine materials to boulders and a variety in texture may be encountered frequently in relatively short distances.

Land forms in the valleys of these desert regions are of sufficient importance to be described briefly. Adjacent to the outflowing streams, alluvial fans are distinct and easily recognized, while at their extremity this detritus blends and is hardly distinguishable as fan material. In these inter-mountain valleys, fans occasionally slope gradually from the base of the mountain until they intersect an alluvial fan derived from the mountains on the other side of the basin.

It is to be remembered that in these desert regions the rare rains are often violent and large quantities of water concentrate in the washes in a relatively short period of time (230). The interval between such storms may be weeks, months, or even years. The waters draining into the washes eventually reach a basin without an outlet, thus producing a temporary lake. In some cases where rainfall is sufficient, perennial lakes may be formed, such as Pyramid, Winnemucca, and Great Salt Lake (54). Others which occasionally become dry include Honey, North Carson, and Sevier. Most of these numerous undrained basins gradually lose their waters by percolation and evaporation, forming what is known as "playas"; these are exceptionally flat and, as a result, a small amount of water will cover a large area to a shallow depth. Since the inflowing waters carry much material in suspension, aggradation occurs. However, these playas may be dry for long periods and since they are practically barren of vegetation, degradation by wind action may occur (fig. 56). As a result, the finer material may be blown entirely away, while the sands may be collected to form dunes (189); the remaining coarse material forms "desert pavement." Dunes of considerable extent are found north of Winnemucca, south of the Carson desert, within the Salton Basin and in numerous other localities. Typical of the streams which emerge from the mountains and later become lost in the desert are the Quinn, Humboldt, Carson, Walker, Bear, Weber, and Sevier rivers.

Fig. 56. The valleys in the western states are often swept by high winds so that wind erosion and the formation of sand dunes are commonly associated with valley fill materials.

The Mohave Desert (265) in southern California and the Gila Desert (222, 224, 229) in southwestern Arizona (sometimes considered as an extension of the Mexican Sonoran Desert) have typical basin and range topography, the chief difference being the greater area of valley-fill materials and the smaller number of mountain ranges or individual peaks, in addition, some of these basins or bolsons have drainage outlets to the sea The Mohave Desert consists of a series of undrained basins, the centers of which become what are known as soda lakes, borax lakes, and alkali marshes (248) The Mohave River is the principal stream of this basin but its waters never reach the sea In contrast, the Gila Desert south and east of the Mohave has an outlet to the sea by way of the Gila River Other important streams include the Salt, Colorado, Verde, and Williams rivers The Salton Sea (247), which is below sea level, together with other sections of the Imperial Valley, probably at one time received the flow of the Colorado River.

Valley-fill materials predominate in sections of southern New Mexico and western Texas within numerous basins Important among these is the Tularosa (562) which is a desert plain more than a hundred miles long. Within this basin there is a large alkali marsh where winds have continually swept the surface clean of fine material resulting in the formation of extensive areas of dunes. Some of these sands are derived from gypsum, probably from the Permian rocks in the vicinity. Sinkholes occur in some sections, being of both gypsum and limestone origin (The northern part of the Tularosa Basin contains rocks of the Santa Fe formation - a more consolidated material than that being discussed.) Similar to the Tularosa Basin are the Hueco (undrained), the Jornada del Muerto (559) and the Estancia Valley (561), topographically, all three are large long troughs. The Plains of St. Augustine in west-central New Mexico is essentially another bolson and one of the more northerly sections of valley-fill materials in this region

The Big Bend lowland lying largely south of the Arkansas River in central Kansas, has been included with the grouping of unconsolidated valley fill soils and is the easternmost extension of these materials shown on plate 1. The surface soils of this locality are probably of alluvial origin (52).

Located in southern Colorado and extending southward into northern New Mexico is the San Luis Valley (287) which contains extensive deposits of valley-fill soils. Essentially, this is a structural basin, probably having been dammed with basalt that was later breached by the Rio Grande River now draining the basin. This is a high flat inter-mountain area, which for practical purposes, may be considered as a filled valley, since alluvial fans, outwash materials, and lacustrine sediments are found in deep and extensive beds. Strata of gravel absorb most of the inflowing waters from the adjacent mountain sides and it is reported that the Rio Grande loses much of its waters while crossing the valley because of the porous nature of the underlying materials (19, p 131) The valley is swept by high winds and sand dunes are found extensively on the eastern side.

Among the northern Rocky Mountains in Idaho and western Montana there are twenty or more long, narrow filled valleys, several of which contain sediments deposited during Tertiary time In many of these valleys glacial deposits in the form of valley trains, outwashes and terraces are deposited over the Tertiary sediments. These valleys contain the major streams of this mountainous area and they, in turn, are constantly depositing materials on their flood plains In the past, these same streams have in some instances cut terraces through the Tertiary sediments, three having been found in a number of valleys (19, p 219) In addition, during the advance of the great ice sheet, several of the valleys were dammed and extensive lacustrine deposits were formed This system of narrow, deeply filled valleys is indicated on plate 1 as unconsolidated valley-fill material

East of the coast ranges there is a chain of intermittent valleys extending from south of Puget Sound to southern California. For the most part, this system of valleys is filled with water-deposited sediments, of which the surface soils, at least, are unconsolidated. The Puget trough has been only partially glaciated Its surface materials consist of deposits of sands and gravels, and in some places, glacial drift. Part of the Cowlitz Valley and a large section of the Columbia River Valley and the Willamette Valley in Oregon are composed of unconsolidated valley fill including important gravel terraces. The populous Willamette Valley is drained by the Willamette River, a somewhat sluggish stream. The outer slopes of the valley contain alluvial fans and terrace remnants. The valley proper contains a portion of the Columbia River basalt and much of the valley fill contains volcanic ash, cinders, and lava fragments, as well as some residual soils derived from these materials.

Fig. 57. Unconsolidated materials deposited in a long narrow valley and now exposed by a deep highway cut.

The Great Valley of California, often referred to as the "Central Valley", is some 400 miles long and 50 miles wide and occupies a large portion of central California. A large part of the inner valley is extremely flat, with slopes increasing to steep gradients only near the mountains. Sediment-laden streams originate in the adjacent mountains, cross the steep valley slopes, and add alluvium to the accumulation of materials within the valley. The valley is sub divided into the Sacramento, San Joaquin (260), and Tulare Basins. The surface materials are largely silts, clays, sands, and gravels, coarser materials predominating along the outer valley slopes. The depth of filling amounts to hundreds of feet and it may be that some of the deeper strata are of Tertiary age.

The Central Valley is highly important agriculturally and, as a result, excellent soil reports are available. The valley-fill materials are included in a variety of soil series (44), such as the Fresno, Gila (both alluvial materials), Imperial, Placienta, Sacramento, San Joaquin, and Stockton. The residual materials along the outer valley slopes are denoted as Altamont, Aiken, Sierra, and others. In the Willamette Valley the soils are indicated (627) generally as Willamette for the valley fill, Amity for the recent alluvium, and Aiken and Melbourne for the residual. The glacial materials in the Puget Sound area are mapped pedologically as Everett. The unconsolidated materials bordering the Pacific Ocean are also indicated as Willamette, Dublin, or as sand.

Coastal Plain materials in this region are found to a limited extent along the extreme western coast; large river delta areas, such as that on which Los Angeles is located, are sometimes considered as Coastal Plain. These materials on the west coast are indicated in plate 1 as sands or as unconsolidated valley-fill materials, as their relationship to Coastal Plain soils and to valley-fill is about equal.

Valley Fill - Consolidated in Places. In certain sections of the Columbia Plateau in Oregon and Washington and in a few isolated localities in the Basin and Range province of Nevada and Utah, as well as in some adjacent areas of California there are valley-fill materials which are consolidated in places. The largest single area is found along both sides of the Snake River in southwestern Idaho and eastern Oregon. Small deposits are found in the Klamath Falls region of southern Oregon and northern California as well as along the Yakima River valley in central and southern Washington. The largest deposit in the Basin and Range province occurs north and west of the Colorado River in the extreme southeastern portion of Nevada and in small adjacent sections of southwestern Utah and northwestern Arizona.

Fig. 58. Although the filled valley in the foreground is of limited extent, the materials deposited through the erosion of the adjacent mountains are of great depth.

Geologically, these sediments are described under numerous formations and series (50), including Rosamond series, Esmeralda, Mascall, Payette, Latah, Ellensburg, Guye, and other formations. During intermittent lava flows there were irregularities left in the surface and in them, drainage channels or fresh-water lakes were formed. These lakes were of considerable extent and were probably much larger than the present-day exposed sediments indicate. Because of the interrupted flows, lava deposits are frequently found interbedded with lacustrine and alluvium as well as with volcanic ash and other materials. Beds of diatomite of appreciable thickness are found interbedded with such materials; on occasion, as at Klamath Falls and other sections in Oregon, Washington, and California, they occur on the surface. Since the time that these materials were deposited, many of the underlying rocks have become warped and folded resulting in somewhat rough topography. Streams crossing these areas have developed terraces of considerable extent. Fenneman (19, p. 246) states, "the Snake and its larger tributaries, Boise, Payette, and Owyhee have terraced valleys several hundred and and locally 500 to 1000 ft. deep and varying in width from one to ten miles." Many of the lacustrine deposits in central Oregon are folded and eroded to the extent that they are indicated on plate 1 as non-soil areas. In contrast, in the Klamath Falls region there is, at the present time, a fresh-water lake.

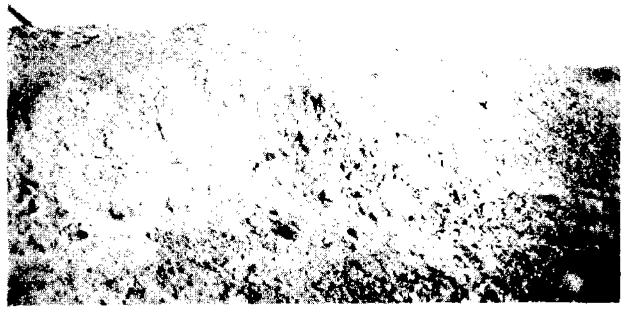

Fig. 59. Granular valley fill not far removed from the source and deposited in the form of an alluvial fan.

Exposed surface materials of these lake and river deposited sediments consist of clays, sands, gravels, (fig. 59), and weakly cemented sandstones and shales in places. Interbedded with these materials there are diatomaceous sediments (626), volcanic ash, and even lava flows. From this description, it can be seen that the texture of the surface materials necessarily vary through a wide range. Topographically, the area is largely level but on river terraces and in uplift regions dissection has resulted in rough topography. For the most part, these sediments are well drained with the exception of local exposures of lacustrine clays. The large stream terraces and adjacent uplands are and will continue to be used for the location of airports. These valley-fill sediments occurring as terraces and upland materials along the Yakima River in Washington are similar in texture to those materials along the Snake River in Idaho and Oregon. However, wide expanses of alluvium are to be found in the Yakima Valley, which is one of the important fruit raising districts of the world. This alluvium, derived primarily from the adjacent lacustrine and river-laid sediments, contains a high percentage of volcanic ash. In contrast, the hundreds of square miles of sands and gravels, principally on the eastern side of the Columbia River in central Washington and east of the Yakima district, are probably outwash materials of glacial origin, overlain in places by a thin mantle of wind-blown silt. Pumice deposits, occurring as one large desert plain, are found in parts of the Deschutes and Klamath river basins in west-central Oregon (620) (624).

Valley Fill - Semi-Consolidated. Associated with the lacustrine and stream-laid materials in Washington, Oregon, California, and adjacent sections of Nevada and Utah are a variety of semi-consolidated sediments, which, compared with material here classified as "Valley Fill - Consolidated in Places", contain fewer clays and more gravels and conglomerates, as well as weakly consolidated sandstones and shales. These materials are found principally along the Deschutes River in Oregon, in a fairly large region of the Basin and Range province in northern Nevada and Utah, along both walls of the Great Valley in California, and along the coast.

The Oregon materials are known primarily as the Rattlesnake formation, while those of California have been subdivided into several groups. The Santa Clara formation in western California has been described as "coarse gravel, sand, and sandy clays" (50), while the Rattlesnake formation of Oregon consists mainly of gravels derived from lava. These sediments are largely fresh-water deposits and, like many of the valley-fill materials, vary considerably in texture from place to place.

Recent Alluvium

In the early history of the country the major stream valleys were dotted with small settlements, since river transportation was one of the most desirable means then available. As the population increased and these settlements became large towns and cities, water from the river became increasingly important. Arteries of communication to serve these centers of population have been and are continuing to be developed along the rivers in the immediate valley or along the adjacent uplands. This has been true in connection with many of the major highways and railroads, and may be expected to follow to some extent in connection with airport development. Therefore, recent alluvial deposits and associated terraces, older in age and higher in topographic position, have become important as potential locations for many airports. In preparing the soil map of the United States (plate 1) on a relatively small scale, it is difficult, if not impossible, to indicate boundaries showing all minor and many major recent alluvial and terrace deposits.

Fig. 60. Broad alluvial plains in the Missouri River Valley at the base of a limestone escarpment.

Major areas of recent alluvium in the United States are confined to a few of the large rivers that, in their lower reaches, have reached a mature stage and have formed wide valleys and flood plains that are periodically refreshed by overflow. The best example of this is, of course, the lower Mississippi Valley, but this type of deposit is also widespread in parts of the tributary valleys of the Ohio, Missouri, (fig. 60) and the Red, as well as the Columbia rivers. The origin of these materials is found in the watersheds that draw from inumerable varieties of soil material. In no one case is an area that is large enough to be considered major alluvium drawn entirely from any one parent material. The development of residual soils from the great variety of rocks present in this country as well as erosion of transported deposits of glacial drift, wind-blown sands, and silts, contribute to the mineralogical composition of the soils.

Almost without exception the relief that is typical of alluvium may be described as flat or gently undulating. Scars that are cut by the currents of the flood waters create long depressions or channels and build up corresponding low ridges that offer the only break in relief in these areas. Where the flood plains are exceptionally wide, the flood waters that cover them periodically seldom create current scars except near the channel bank. In these areas, typified by the delta country in Mississippi and Arkansas, the land is monotonously flat.

In a few instances the river has cut down sufficiently to have established a high erosion potential. This condition has resulted in dissection of the now elevated alluvial deposits. Relief in these areas is characterized by flat topped ridges that mark the surface of the old flood plain. Whether the intervening valleys in dissected terraces are wide and sloping or narrow and rough depends to a large extent on the texture of the alluvium

In considering the soil problems that are associated with these alluvial deposits, it is necessary, first, to refer to the two chief variables that control the texture of the soil at any one point The first variable is the character of the upland soils of the water shed from which the stream draws its sediments Obviously, in a stream drawing its sediments from an area that is composed chiefly of fine textured soils, the alluvium will consist almost entirely of silt and clay sizes, provided the stream gradient is not too great for deposition to occur On the other hand, if the stream drains an area that is predominantly granular, there will be an absence of fine-textured material in the lowlands and terraces constructed by the river These contrasting conditions are well illustrated by two rivers, the Walnut and the Arkansas, that are located within a few miles of each other in southcentral Kansas The former, draining a limestone area, has a large percentage of silty clay alluvium while much of the sediment of the Arkansas is derived from the Great Plains outwash mantle producing sandy alluvium in a comparable location Therefore, the soils of a watershed have an important influence on the engineering problems that are associated with the flood plains that may be many miles removed from the headwaters

The second and perhaps the principal consideration in alluvial deposits is that of the character of the stream in the immediate vicinity Throughout the thalweg of a long stream such as the Mississippi River, the texture of the suspended material, and thus of the alluvium will vary from the headwaters, where the gradient is relatively steep, to the delta where the velocity of the stream is reduced Incomplete test data show that there is a gradual and rather uniform decrease in the particle size of the sediments that are deposited in comparable positions from the Wisconsin area of the Mississippi Valley down to the lower reaches in Louisiana The percentage of gravel drops off rapidly from the head of the stream as does the velocity of the current, but moving downstream, the textural trend is from the fine gravels through coarse and fine sands into silts in the Illinois and Iowa areas Below the mouth of the Ohio River, the textures are predominantly silts and silty clays while silty clays and clays are found almost entirely in the southern states Likewise, the texture of the glacial terraces along the Wabash River varies from coarse in northeastern Indiana to fine gravel at its junction with the Ohio River

There are two other distinct but rather uniform texture patterns associated with recent alluvium, for at any one point in the stream there is a general symmetry that centers about the main channel This symmetry extends from the natural levee, which is built up of the coarsest material in the rapidly moving stream, to the valley walls and the other more remote reaches where the finest particles are deposited by the more quiescent waters To illustrate this, a cross section of the Mississippi Valley in Wisconsin may show fine gravel and coarse sand deposited as a natural levee with chiefly fine sands and silts in the lower areas more removed from the main channel Likewise, a section across the valley in the Illinois-Iowa area would reveal medium sands in the natural levee, a predominance of silty soils in the broad flat areas adjacent to the valley wall, and small local deposits of silty clays and clays in isolated areas In the lower valley the natural levee consists of sand textures while the area immediately behind the levees is chiefly silty clays and clays

The gradient influences this trend Although the natural levee nearly always contains the coarsest material, soil textures in the slack-water areas are more erratic because of local influences, (fig 61) As in the upper Ohio, it will be found that the younger the valley the more narrow will be the terraces and the greater will be the local variations In more mature sections of the valley (Owensboro, Kentucky) the texture is more uniform and the variations less pronounced

In considering the profile in depth at any one point in an area of alluvium, it is apparent that the stream at this point once possessed the characteristics of a youthful stream that had a higher velocity. As the stream approaches maturity, the velocity of the channel currents drops and the texture of the sediments becomes correspondingly fine. Therefore, in examining this profile, it is reasonable to expect that the surface textures will be the finest (in general) since they represent the deposits of the slowest currents of the stream, and as samples are taken in this profile at greater depth the texture can be expected to become increasingly coarse. This is well illustrated on the Missouri near Ft. Peck where clay and silty clay overlie fine sand at 160 inches, and on the Platte in Nebraska where fine sand and silt are underlain by sand and gravel at 42 inches (198). This general rule applies to all points in the stream but its significance varies, because in the section of the stream that is youthful, layers of any one particular texture will be rather thin whereas in the more mature section of the stream, the layers will be much better developed, deeper and more significant. It must be remembered also that this characteristic of deposition is influenced by local currents and that it represents a trend rather than a detailed and uniform progression of texture downward.

The contributions of local tributaries to the texture of alluvium are quite important since they may change the character of the alluvial soil drastically. In many local situations tributaries flowing into the main stream deposit coarse textured materials immediately below the mouth. In parts of Kentucky, Tennessee, Mississippi, and Louisiana, where the streams drain areas of wind-blown silt, there will be found local surface deposits of silt, as at the mouth of the Big Black River of Mississippi, that present a strong contrast with silty clay and clay textures of the large areas of the flood plains. Hence, it is necessary to examine the local conditions before applying any general laws of deposition.

Fig. 61. Youthful stream valley in Idaho, actually shown on Plate 1 as a non-soil area. Here the amount of alluvium is limited by the narrowness of the valley and the velocity of the stream.

The conditions that develop these deposits generally cause them to be refreshed at frequent intervals by flood waters. This progressive building up of the deposits largely inhibits any tendency for the soil to develop a weathered profile such as is found in the upland soils. In addition, the relief in these areas is of such nature that most of the engineering construction in highway and airport work does not involve cuts of any appreciable depth.

Where the flood plains and streams are sufficiently large to have been indicated on the map the texture will be predominantly that of fine sand, silts, and clays. Since the valleys containing coarse materials are so narrow these will not appear on the map at the scale used. Between these extremes the texture of alluvium in general may vary from coarse gravels to the finest clays. The textural variation within a single construction project might be influenced entirely by the position of the project in the valley, depending upon the extent of the project and width of the valley. Aerial photographs provide details on the texture of the surface deposits and indicate much more with respect to possible subsurface conditions. Whether granular material is available as a subsurface deposit depends largely upon the history of the river and the character of the formations upstream.

Fig. 62. Gravel in a terrace in South Dakota consisting of materials deposited by the melt waters during glacial times.

Streams draining glaciated regions are almost invariably endowed with elevated and sometimes spacious terraces composed of sands and gravels deposited during glacial times by the melt water then carving the valley (fig. 62). Widespread examples of these terraces are found along the Missouri River (20, p. 564), upper Mississippi and Minnesota Rivers (462, pp. 87-88), the Wabash and Miami Rivers (150), the Mohawk River (517), and the Connecticut River (289) (450). Several of the larger rivers in these regions follow, in part pre-glacial channels and even though the present volume of water is very small in comparison to that which must have flowed during and immediately following glaciation, these streams are degrading and cleaning out their old valleys (47).

Streams drawing from bedrock areas may or may not have gravel associated with them depending upon the character of the rock and the gradient of the stream. Gravels are seldom associated with streams in limestone areas unless the limestone contains high percentages of chert fragments, and then these gravels are not suitable for use except as road metal and for filling. However, in the long plains streams of the west and southwest, which cut across numerous grandular formations in their upper reaches, extensive alluvial gravel deposits are often found in the heart of completely non-granular soil areas and limestone regions. At the border of sandstone ridges or other areas of resistant rock the streams may often change their gradient abruptly and deposit granular materials at these points. In the alluvial soils of the Coastal Plain areas where the gradients are low and the general textures fine, ranging from sand to clay, the most granular materials are found either at the junction of present streams or on elevated terraces that are actually remnants of old streams, now long abandoned. A discussion of streams in arid and semi-arid regions is given in that section of this chapter entitled "Soils of the Filled Valleys and Great Plains Outwash Mantle."

The engineering soil problems associated with these deposits are as variable as the textures and ground-water conditions. However, seldom is it necessary to place subgrades in cuts of any appreciable depth. Fills are commonly constructed in these areas to insure a protection against flood waters and the choice of local material for fill construction is not always satisfactory. An examination of aerial photographs aids in the selection of the most satisfactory sites from the standpoint of drainage and texture and also the location of borrow materials, just as topographic, geologic, and soil maps serve as aids for this purpose.

Fig. 63. An alluvial fan and terraces at the foot of a mountain range in the Great Basin of Utah.

CHAPTER VII

NON-SOIL AREAS

It has been desirable to map numerous sections of the United States as non-soil areas for it is of equal importance to know that there is little or no soil mantle as to know the type of soil in other areas This is especially true in this field since the absence of soil has a direct association with construction methods, equipment, and costs This grouping for classifications is not confined in its application to mountainous or other rough terrain, but includes scablands where the surface may be level to gently sloping, yet the soil cover may be very shallow, sometimes intermittent in occurrence, and often amorphous in derivation, or even non-existent Likewise, those locations where stream erosion has produced canyons in harder materials (fig 65), and badlands in soft shales, are considered as non-soil areas in this engineering classification of soils. The materials thus exposed, although not soils in the sense of developed profiles, are nevertheless physical equivalents in problems of design and construction Actually, within many of the large sections designated on plate 1 as non-soil areas there are valleys, mountain parks, and other land forms of sufficient extent and with soils of depths great enough to be of consequence to airport development, but because of their limited extent and the scale of plate 1, these areas cannot be shown on that map.

Throughout the eastern part of the country non-soil areas are largely incidental, there being few outstanding mountain ranges which are comparable to those of the West, canyon topography is similarly localized, scablands are very sparsely distributed, and badlands do not exist

With only two outstanding exceptions, mountains are in the form of long and relatively narrow chains From south to north these are primarily the mountains of the Unaka and Blue Ridge groups, stretching from northern Georgia to southern Pennsylvania; the Taconic Mountains in southern New York and the western New England States, the Green Mountains in Vermont, and the White and associated mountains of New Hampshire and Maine The outstanding exceptions in this arrangement are the Adirondacks and Catskills, both in the state of New York Most of these protruding land forms owe their existence to outcrops of very old and resistant igneous and metamorphic rocks, such as the lower Cambrian quartzites of the Blue Ridge and the Pre-Cambrian granites, schists, and gneisses of the Adirondacks The greatest divergence from this form is the case of the Catskills, which are composed of sedimentary rocks of Devonian age that have not been affected by localized uplifts, but rather seem "to be due to the superior resistance of the rocks of which they are composed" (525, p 11), these rocks being similar in age to those that all but surround this group of mountains

Mountains other than those just mentioned prevail within and along the west edge of the Ridge and Valley province (19) Although some of these are formed by folded rocks ancient in origin, age is not of primary consequence in that a variety of geological periods are represented in the anticlinal and monoclinal ridges, such as the Cumberland Mountains in Kentucky and Tennessee, Kittatinny Mountain in New Jersey, and numerous minor ridges scattered throughout the Province.

A large portion of the canyon topography is associated with the Allegheny Plateau (both glaciated and non-glaciated) in situations where the major streams have cut deep channels and attendant large-scale erosion has exposed the rocks in escarpments and steep valley walls. Actually, many locations of this type have not been mapped as non-soil areas on plate 1 because the exposures are in narrow bands immediately adjacent to the rivers Typical situations in this category are those of the Genessee River in New York, the Kanawha and the Upper Ohio Rivers in and bordering West Virginia, and the Cumberland River in southeastern Kentucky Large sections in eastern West Virginia and northern Alabama and southern Tennessee represent similar conditions, these being highly dissected plateau regions where the total area of rock outcrops and rough topography is probably equal to or in excess of that of locations conducive to significant soil development Conditions of this type are necessarily somewhat localized (fig. 64) so that each instance is a case for individual analysis that can be made by study of the literature dealing with restricted areas and by inspection of aerial photographs.

Fig. 64. The conditions manifested by this highway cut and the distant topography in West Virginia represent localized situations which in fact are non-soil areas although not mapped as such in plate 1.

Usually placed in the category of scablands are the partially exposed bedrocks near Miami, Florida (299), the numerous bare outcrops in the Nashville Basin in Tennessee, and exposures in the northern parts of Michigan and Minnesota. Some of the situations in the two latter states are actually rough enough to exceed the conditions normally associated with scablands, examples of those being the Huron Mountains, the Copper Range in the Keweenaw Peninsula, and the Mesabi and Shore Ranges in Minnesota. However, much of the area near the boundary between Canada and Minnesota is nearly level but practically barren, the Pre-Cambrian rocks there having been exposed by the scouring action of the glaciers. Excellent illustrations of this are the aerial photographs of St. Louis County, Minnesota.

West of the Mississippi River and east of the Great Plains, the outstanding non-soil areas are those of eastern Oklahoma and western Arkansas in association with the Ouachita and Boston Mountains. Although not implied on the map, numerous other rock outcrops occur in the Ozark Plateau in and about the St. Francois Mountains, and near the Osage, Gasconade, and White Rivers and their tributaries. Similarly, in the Arbuckle Mountains of southern Oklahoma (244) and a comparable area in central Texas, rock outcrops are abundant to the extent that the soil mantle, where it exists at all, is shallow and often has little effect on engineering considerations, although there again, there are within those expanses many soil areas of a mile or two in extent which are suitable for airports. On plate 1 portions of these areas are indicated as residual soils derived from metamorphic and intrusive rocks.

In all of the states west of the Great Plains there are mountain ranges, mountainous outliers, and many individual peaks surrounded by filled valleys, most of which are included in plate 1 as non-soil areas. Even within the Great Plains there are a number of outliers such as the Black Hills of South Dakota and Wyoming. This is a region where uplift of considerable magnitude occurred in recent geologic time; as a result there are exposed schists and quartzites, including Pre-Cambrian granites. Numerous young intrusive rocks are also to be found. As this region was elevated, the originally horizontal sedimentary rocks became tilted and those in the center of the uplift were eventually eroded away. The tilted strata surrounding the center of uplift produced rough uneven topography, and these rocks are still going through erosional processes. This general description of the Black Hills is at least in part typical of other similar but smaller uplifts, particularly in Montana. Chief among these are the Sweet Grass Hills and the Bearpaw, Little Rocky, Highwood, and Judith Mountains. The core material in most of these uplifts consists of Tertiary intrusive and extrusive rocks

Many of the land masses of western Montana, Idaho, and large portions of Wyoming, Colorado and some sections of New Mexico are mapped as non-soil areas Typical of these are the Big Horn Mountains of Wyoming and southern Montana, the Snowy Range north of Yellowstone National Park, the Wind River Range in central-western Wyoming, the Laramie Range in southeastern Wyoming and the Front Range, Medicine Bow Mountains, and Park Range extending northward from Colorado into southern Wyoming Although mapped as non-soil areas, these contain numerous "parks" that have well-developed soils occurring on rolling topography The Uinta Mountains of northeastern Utah and northwestern Colorado which comprise the largest east-west range in the United States, consist of a tremenduously large uplift, the core rock being primarily of Pre-Cambrian metamorphic materials Although the exceptionally large mountain region of Idaho and western Montana does not contain peaks which compare in elevation with other high mountains in the west, such as in Colorado, this vast area is one of the roughest regions in the country. Its only relatively level portions are the Tertiary lake deposits and other filled-valley materials The rock materials in the mountains are almost entirely igneous and metamorphic rocks and contain very little soil covering

Separating the lowlands of the Puget Trough, Willamette Valley and Great Valley from the Columbia Plateau and Basin and Range province are the Sierra Nevada and Cascade Mountains The rocks of the Sierra Nevada Range are predominantly granite while those of the mountains to the north extending into Washington are, for the most part, covered with lavas and tuffs Scattered throughout these mountain systems are granitic and volcanic peaks, which rise above the general mountain level Mt Rainier is an example of the latter The basaltic scablands (163) of the Columbia Plateau in Washington are the most extensive in the country.

Bordering the Pacific Ocean there is a system of parallel ranges of mountains and associated valleys generally referred to as the chain of Coast Ranges The rough topography in some instances is caused by variable resistance of the rocks, while in other situations folding and faulting accounts for the peaks and ridges The rocks are largely young (Carboniferous to Tertiary) limestones, sandstones, and shales, frequently metamorphosed, although many intrusives and some Cambrian and older igneous materials are locally important

In the Basin and Range Province of Nevada, Utah, southern California, and southern Arizona and New Mexico the mountain ranges or, in some instances, peaks, are largely covered with a variety of volcanic materials, although metamorphic and sedimentary rocks of Jurassic and Carboniferous ages may be found Older materials are represented in some of the mountain chains in the southern sections

Some non-soil areas are indicated in sections of the Colorado Plateaus - the rough topography being a result of dissection as well as numerous volcanic formations Steep escarpments are typified in the transition between the Colorado Plateaus and the lower-lying Uinta Basin just south of the Uinta Mountains in northeastern Utah and northwestern Colorado Similarly, the escarpment which divides the Great Plains from the Coastal Plain in southern Texas is a very rough area

In contrast to the mountainous topography, there are literally hundreds of canyons in the West formed by streams that have cut through both soft and hard rock (fig 65) Although the Grand Canyon of the Colorado is the largest and most famous of these, others such as those cut by the Yellowstone or by the Arkansas River in leaving the South Park in Colorado, are non-soil areas of considerable magnitude

In many isolated areas of North and South Dakota, Montana, Wyoming, eastern Colorado, and eastern Nebraska a peculiar type of erosion occurs which is well described by the term "badlands." The "Big Badlands" southwest of the Black Hills along the White River in South Dakota are probably the best known. The valley wall of the Little Missouri River as it flows northward from the South Dakota boundary through North Dakota to the Missouri River consists almost entirely of badlands and the same may be said of much of the Yellowstone River valley in southeastern Montana. Other areas of badland topography are also associated with the Missouri River in central Montana, and most of the streams in Montana and northern South Dakota below the glacial boundary are bordered at least in places by large or small areas of badlands. In the southern Great Plains the Canadian River has formed badlands by cutting through the mantle and now flows in a deep valley which is 10 to 20 miles in width.

Fig. 65. A non-soil area in the canyon of the Little Colorado River, Arizona.

Although not indicated on plate 1 as such, similar topographic features may be found in the Pine Ridge escarpment of northern Nebraska and southern South Dakota and in the outer rim of Goshen Hole in eastern Wyoming and western Nebraska.

Badland topography is the result of excessive erosion of poorly consolidated materials in a semi-arid climate. Since the precipitation usually occurs as torrential rain for a brief period of time, this one factor alone is conducive to the erosion of weakly cemented shales, sandstones, and clays. In addition, the aridity of the climate is not conducive to the growth of sufficient vegetation to arrest or prevent erosion. The Fort Union, Lance, Brule, Green River, and similar rock formations in the Great Plains region consist of alternating strata of materials with varying degrees of erosional resistance, a factor which combined with climatic conditions, accounts for the many peculiar types of erosional features of that section of the country. Of practical importance in regions where badlands prevail is the fact that this type of erosion progresses into the uplands as a sapping process. This results in excessively wide valleys, deeply eroded along the sides, but frequently broad and level near the river. Agriculture is practiced in such regions, as is the case in the valley of the Little Missouri in North Dakota, and airports might be located in the heart of badland areas.

CHAPTER VIII

THE PRINCIPALS OF AIRPHOTO INTERPRETATION

The complete analysis of an airphoto, made for the purpose of determining soil conditions, is accomplished by analyzing, singly, the elements of the soil pattern, weighing their importance, and combining these factors to evaluate the soils of the area in question. To assist in this analysis, the three sections of the airphoto analysis chart (pocket) has been compiled. This chart presents separately the four most important of the several principal elements which, when combined, constitute a soil pattern.

The shape of and relationship between adjacent surface features that are seen in an airphoto are referred to in this report as land forms. The land is the form and substance resulting from a process of geologic and pedologic development, subsequently modified by the destructive processes of weathering and occasionally by crustal movement. For example, the form of a volcano (fig. 66), is developed by the emission of materials from a vent. This process results in a symmetrical cone with long sweeping slopes surrounding a central crater. Thus the form is related to the process of development. Having recognized the form as volcanic, the great variety of rocks formed by other processes has been eliminated from consideration. The substance and, therefore, the durability of the cone may vary widely because of the possible variables in composition. Climatic forces which are the chief agents of destruction vary with location. The destruction of the cone by weathering is a continuing process, the severity of which is dependent upon the local conditions. Land form weathering is chiefly a function of the uniformity and resistance of the rock material.

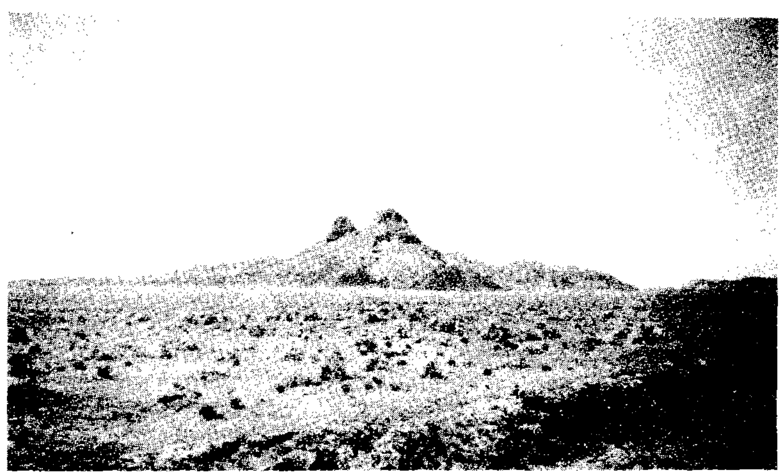

Fig. 66. Weathered volcanic cones in the southwest suggesting the original form of the central cone and sweeping sideslopes - now dissected.

To introduce the subject of land forms a volcano was used as an example, not because it is a predominant form but because the usual conception of a volcano is not only reasonably accurate but widespread. Less striking and therefore less familiar are the land forms presented by moraines, terraces, till plains, coastal plains, and the host of others later to be considered. The till plain land form that includes wide areas of gently undulating relief and the terrace land form that is characterized by level surface features occurring between two areas having different elevation (one higher and one lower than the terrace) are more important as widespread engineering considerations than the volcano

From this point on the examination becomes more detailed and becomes increasingly so as refinement is desired. The trend is also away from geologic factors of soil formation, erosion, land use, and vegetation The process of interpretation carried to this degree can be assimilated quickly and requires neither a comprehensive background nor wide field experience Beyond this the results become more and more dependent upon experience

This partial example serves to illustrate the preliminary steps in the analysis as well as to establish the inference that each land form has characteristics that identify its origin and, in general, the type of material making up the mass The land form elements shown in chart 1 aid in making this association These facts are of significance since both the relief and the type of material introduce engineering and related problems that are associated with the land form

The elements that make up the soil pattern are visible surface features that are directly or indirectly influenced by the physical and chemical properties or moisture conditions of the soil profile and the underlying rock or other parent material These elements form patterns of their own, among them are the land form (already illustrated), surface drainage, and erosion, soil color, which are shown on the airphoto analysis chart, and slope, vegetation, land-use, biological evidence, micro-relief, and farm and highway practices which could not be shown on the chart advantageously To list these details and to organize and assist in their interpretation is the chief function of this section of the report

As stated in the foreword, and as repeated throughout this text, this method of identifying and classifying soils is no more a mechanical process than any other system of soil identification Likewise, the aerial photographs used as illustrations for this report present typical soil patterns and, within limitations of photographic reproduction, show the significant variations responding to climatic, textural, or tectonic influences Thus while the illustrations present average situations and patterns, they do not include the gamut of conditions produced by nature On occasion it has been desirable to include photographs of exceptional conditions such as plates 29, 34, and 41, which emphasize features otherwise difficult to illustrate

Land Form

The local structure of the earth is perhaps the most general element of the soil pattern In single or paired pictures covering an area of several square miles it is often, although not always, possible to identify positively the parent material that controls the form of the land With additional pictures showing a greater portion of local area, accurate identification of the land form is almost a certainty Clearly, the greater the area available for inspection the more evident becomes the land form pattern It can be said with a high degree of accuracy that land forms of different origin will not produce similar patterns.

By determining the land form the observer largely establishes the type of parent material with which he is to deal Reference to geologic maps will often assist the beginner in this determination Geology, like pedology, often requires some translation for engineering use Where bedrock forms the parent material, geologic maps and literature should supplement experience in visualizing the general structure. Where transported surface deposits cover the bedrock, geologic maps may often prove misleading For this reason the attached map (plate 1) showing deposits of the country will prove valuable The aerial photographs provide most of the necessary details, since it is on them that we have the record of the relative weather resistance, depth of soil mantle, water conditions, and other properties and features that are directly related to construction and location problems As a rule (having the usual exceptions), in areas where bedrock influences the soil indications of the type of bedrock will be apparent. Likewise, glacial-drift areas also have distinctive patterns as do aeolian deposits of sand or silt, coastal plains or other water laid materials

Sedimentary rocks such as limestone, sandstone, or shale are originally formed under water in nearly level beds When these are elevated above sea level and remain in a horizontal position forming plateaus, erosion reduces them by dissection that produces a particular type of stream pattern leaving flat-topped islands of rock In arid countries these are mesas or buttes, in humid climates they are monadnocks, having the same island-like shape but somewhat modified side slopes caused by the protecting influence of vegetation The shape of these is maintained by a cap of resistant rock which protects the underlying materials from erosion Since sedimentary rocks are stratified, and the strata vary in physical properties, a difference is reflected in the weathering resistance of each stratum Thus, in examining such formations (plate 10) the existence of clay-shales is indicated by the presence of "soft" slopes occurring below the cap rock

Where these stratified formations are folded, as in the Appalachian Mountain system they control the stream pattern to such an extent that a rectangular pattern is developed Branches of streams follow parallel courses in the alternate beds of soft rock or shale Instead of the ordinary bends expected in a stream the turns are often right-angled (fig 67 and plate 15)

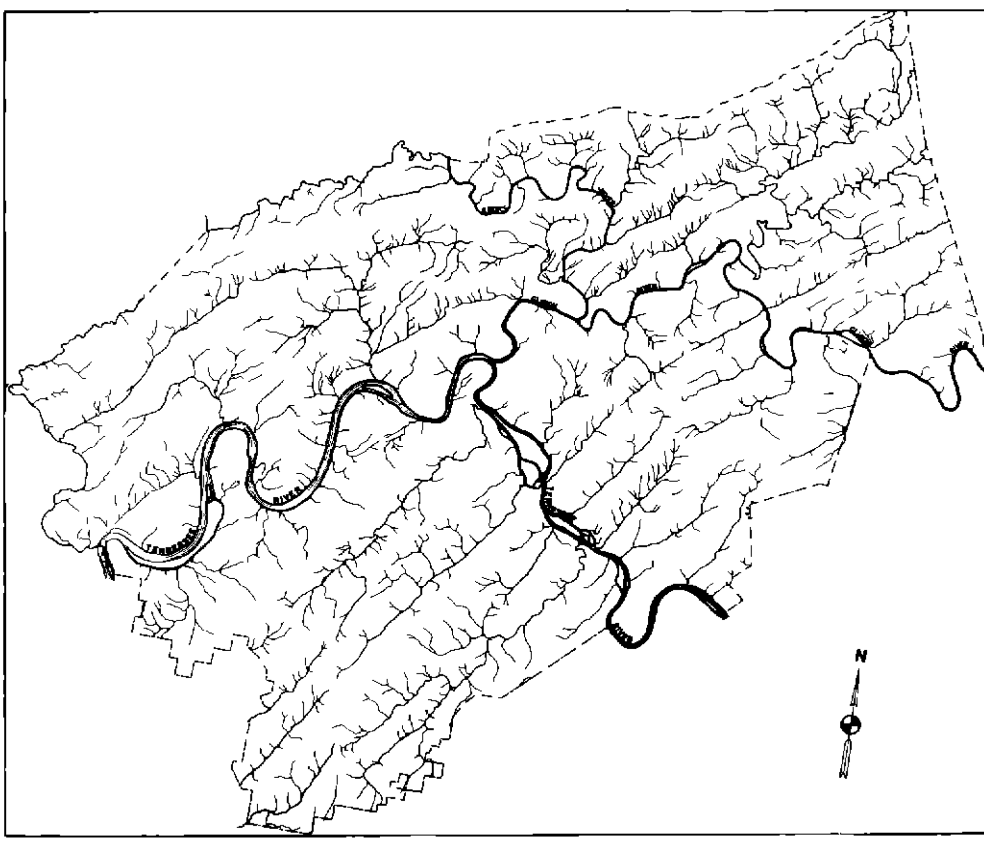

Fig. 67. This drainage pattern occurring in Roane County, Tennessee is typical of areas of tilted sedimentary rocks (Traced from a soil map Soil Survey by M E Swan and others, No 15, Series 1936, May 1942)

The intensity of development of the general land form is often in proportion to the age or the progress that weathering has made. As in the case of limestone, scattered sinkholes indicate early stages of weathering (plate 14). As weathering progresses the roofs of subterranean caverns collapse and leave ridges of limestone. Granites by reason of their mode of occurrence as mountain cores and similar forms readily lend themselves to identification (chart 1).

The distinguishing land form features by which glacial drift, loess, sand, and other parent material areas can be identified are related either to their texture or to some physical features peculiar to their method of deposition. Texture, composition, and origin largely determine the resistance of a material to erosion and weathering; under similar conditions of weathering the same type of parent material will respond in a similar fashion to produce a characteristic land form. It is reasonable to assume that, regardless of geographic location the same type of material will produce similar soils under similar climatic conditions.

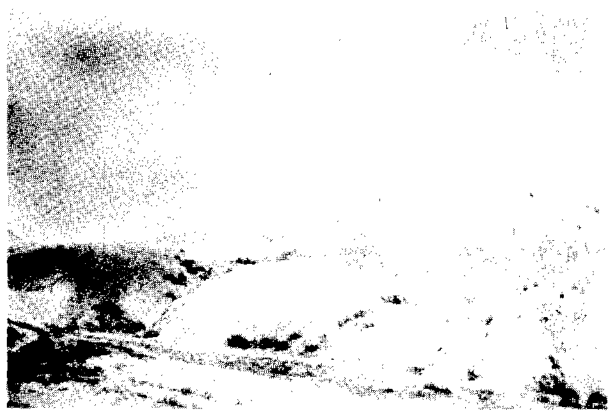

Fig. 68. The weathering of clays produces slopes, the character of which are related to the cohesive properties of the soil, and which are denoted as "soft" slopes in this text.

Slope

Prevailing ground slopes may also be considered an element of the soil pattern. These slopes now being considered are a product of weathering and are classed as micro-relief rather than the higher order macro-relief that is usually produced by structural influences. In examining photographs the observer receives a general impression of the local slopes in an area. These are generally a function of texture with rock, granular, and semi-granular materials assuming the steepest slopes. Where slopes appear to be "soft", the soil can be expected to have a relatively high clay content (fig. 68). The observer will find areas near small streams the most productive in which to examine this feature. At bends where the current may be attacking the bank of the stream, fresh exposures unmodified by the accumulation of debris at the foot are available for inspection. However, slopes over which runoff passes are the more reliable indicators. The difference between the prevailing slopes in areas of silty clay, and those in areas of less plastic materials can be readily detected.

Surface Drainage

If all or nearly all of the water from rain, melting snow, or ice infiltrates into the soil, no surface drainage pattern can be developed. Where a significant portion of this water runs off the surface, a drainage pattern is formed, and the amount that runs off determines the intensity of the pattern. In this sense surface drainage does not mean only rivers and streams but the immediate and local pattern caused by runoff on an acre, a section, or a square mile of ground surface. Briefly stated it is a direct function of soil permeability and ground slope, within rather wide limits of slope surface drainage is a function of the permeability of the profile Porous sands absorb the rainfall and surface drainage does not develop (plate 42) But most plastic clays and silty clays resist the penetration of moisture which encourages surface runoff and the development of a drainage pattern.

A drainage system may vary in complexity Complete absence or a simple extension of surface drainage from a stream into the upland probably indicates a pervious material. A highly integrated system with branches reaching to all parts of the area indicates poor internal drainage (plate 38) which for engineering use generally means a plastic subgrade, difficult construction, and added need for a base course, and provisions for drainage Obviously on the same parent material the velocity of surface runoff will be greatest on the steepest slopes This relation to slope in itself creates differences in the respective soil profiles those on the steepest slopes are shallow and weakly developed, while those on the flat slopes are deep and less pervious In most cases, where there is no reworking of the surface materials by overflow or wind-erosion the surface drainage element is highly reliable

"Functional texture" is introduced in this drainage discussion because of the apparent inconsistency of some fine-grained soils that would normally be expected to produce surface drainage Aerial photographs register the effective drainage of the profile which in a few instances disregards texture The limestone soils, although silty clay in texture, have a well-drained profile, thus, the limestone soils have a granular functional texture They are usually red in color and lack evidence of surface drainage, indicating a porous profile This condition of good drainage is not commonly related to the fine-textured soils that are high in active clay content. The process of weathering and profile development produces an open granular structure in which the clay particles are segregated into lumps with ample space between for percolating water The porous limestone parent material absorbs the water and prevents water-logging of the profile, a condition which would otherwise result in a consequent swelling and closing of the soil structure When compacted during construction, this structure is destroyed and the immediate subgrade or fill reacts essentially as any other plastic soil material

Erosion

Erosion is closely related to surface drainage There are two general types of soil erosion, one in the form of gullies and the other as sheet erosion Although certain chemical properties of soil influence the degree of erosion, it is controlled largely by texture and other physical properties

Gully erosion being the most significant to engineering works and most discernible on the airphotos, merits the principal consideration As gullies generally cut through the profile, they often provide detail on depth and textural differences within the profile. They occur on sloping ground and are frequently located between the shallow upland drainage-ways and the flood plains of established streams The cross-section shape of a gully is largely controlled by the cohesive properties of the soil particles Silts, sands, and sand-clays develop vertical sides or U-shaped gullies This relationship does not carry over in the same degree to arid climates (see fig. 69) Examples of these U-shapes are found in Coastal Plains areas and in the Piedmont provinces Figure 48 shows a ground view of a gully of this type. They are characterized by a sharp drop-off from the ground surface to the bottom of the gully at the headward end. They are often stubby, as shown in fig 70, extending only a short distance into the upland A gully having a very broad rounded shape (fig 72) indicates a deep, uniform profile in a semi-plastic to a plastic soil V-shaped gullies as shown in fig 73 are indicative of granular material Where the V-gully becomes very broad and shallow (fig. 74) a silty or fine sandy material on a claypan is indicated. This same shape may occasionally be associated with a shallow soil on bedrock but the presence or absence of rock outcrops in the vicinity will confirm or deny this alternate choice. The two types associated with clay textures, such as those in figs. 72 and 74, will progress for long distances into the upland (fig. 71). Gullies in silt soils have the additional feature of vertical fins or columns preserved by sod or brush. "Catsteps", another form of erosion common in some areas, characterize loess on steep slopes. These contour-like shelves resulting from the slipping of the loess are clearly visible under magnification. Occasionally a similar form of erosion is found on steep slopes in residual soil areas. Plates 6, 7, and 8 show these gullies.

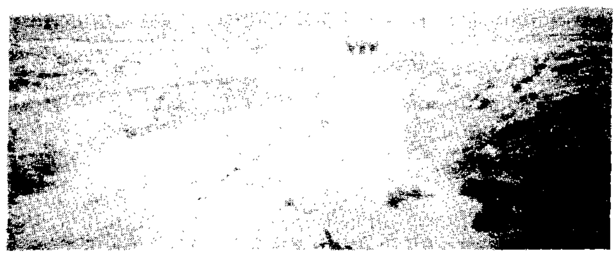

Fig. 69. A typical gully type found in arid regions where low flows undermine dry soil banks to create steep slopes.

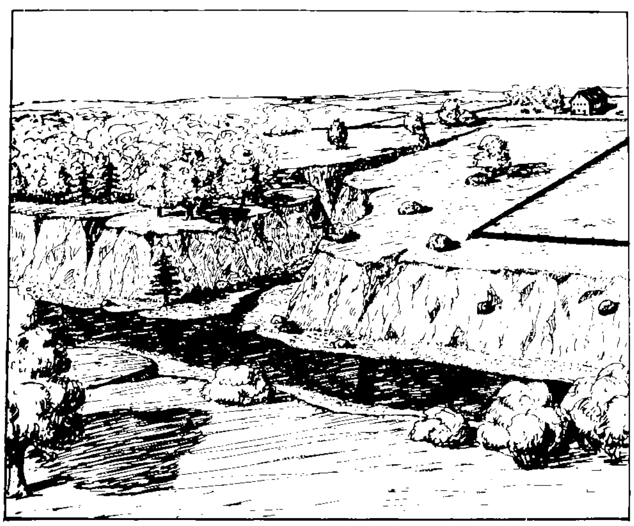

Fig. 70. This line drawing shows the related features of a gully in semi-granular materials. The relatively short length and steep gradient together with the cross section characteristics shown are typical of these gullies.

Fig. 71. The long, low, uniform gradient and the smooth slopes of this gully are evidence of a deep profile of plastic finegrained soil.

Thus, the gully is a partial key in recognizing the plastic unstable silty clays, the silts, or the sands; in distinguishing between well-drained and poorly-drained soils, and in anticipating excavation of earth or rock. Unfortunately the airphotos cannot always be used satisfactorily to view gully shapes since they often are so small as to necessitate large magnification of stereoscopic pairs which is very difficult. Reference to chart 1 will emphasize the fact that in several instances similar gullies will occur in soils not necessarily derived from the same type of parent material. Yet, the general shape with regard to texture is very consistent.

Fig. 72. This stereopair illustrates the type of gully found in deep uniform deposits of plastic silty-clay soils. This gully in a lakebed area can be compared to that shown in Plate 43 to evaluate the extent of the drainage way. Low, uniform gradients; long, well-rounded side slopes; and extensive surface distribution are the common features characterizing these gullies.

Fig. 73. Stereo-inspection of this V-shaped gully illustrates the slopes assumed by soils containing considerable proportions of silt and sand with some gravel. Small water-worn boulders in the channel proper classify this as glacial material. Close inspection of the side slopes will show that a slight change in slope is coincident with the outcropping of several small boulders that have been partially exposed by erosion.

Soil Color

The color of the surface soil material is often a result of conditions that have controlled the soil-profile development. In black and white photography soil color tones are registered as varying gray values; these are evident on photographs giving indirect information on the texture and drainage of the profile.

Fig. 74. A broad gully with eroded flanks and a rill channel is indicative of a sharp change in texture or cementation in adjacent horizons.

In the matter of color tones it is pertinent to consider the variations in shades as they must occur under varying moisture conditions. Fortunately the specifications covering good aerial photography rule out photographs taken when there is an excessive amount of surface water. This limitation provides ample time for the well-drained soils to assert themselves following a heavy rainfall and before photography is undertaken. Soil moisture conditions may be far from a state of equilibrium when acceptable photography is obtained. Under such conditions the shades of gray may vary considerably from those existing in the same area at another time but the color contrast between the well-drained and poorly-drained soils within the area will remain and is often heightened by relatively high soil-moisture contents. At the other extreme, involving subnormal rainfall and low moisture in the top soil, it is evident that the drying out process will tend to lighten the over-all color tones to a certain extent. It is equally evident that the organic and mineral compounds that provide the basic color value in the soil will not be significantly effected by seasonal droughts.

Because of minor variations in the gray value caused by moisture fluctuations in a soil and the variable factors introduced by conditions inherent in photography no consideration has been given to quantitative measurement of these tones.

Soil color (surface) is a function of the soil texture, reaction (acidity or alkalinity), and vegetative cover which is, in turn, controlled over large areas by the climate and in local situations by the immediate ground-water conditions, often irrespective of climate. Initially the most confusing part of photo-interpretation is that pattern created by cultivation. These patterns are regular in shape and are obviously a product of human effort. The soil color pattern is irregular and shows through most cultivated crops. Where the cover crop is dense, it can be traced by close examination or by interpolation from adjacent fields.

The color elements or patterns vary from one area to another assuming different shades and varying in actual color (plate 39). Plate 36 is an example of a highly developed color pattern (in young glacial drift) reliably reflecting slight changes in elevation and ground-water conditions. The black areas are deep, wet, plastic silty clays while the slightly higher light areas have a better water condition, a shallow profile and a higher silt content. Red, white, and black are the common colors found in surface soils. In humid temperate areas, the black color is generally related to soils existing in low, poorly-drained situations.

Occasionally this applies to sands, therefore, it can be seen that reliance on color alone is as erroneous as dependence on any other single element The so-called black soils are a product of climatic influences that are favorable to grass cover When these are viewed from the air (plate 50) they are found not to be uniformly black but to contain a variety of shading with distinctly black soils in depressions

Red in soils often indicates a well-drained profile having a low water table In ordinary photography red filters are used to remove haze These give red areas a dark gray value on the prints Many soils in the South have a red color and almost all limestone soils except under special rainfall conditions are red

Red is also a dominant color in many clay-shale deposits and the outcropping of "red beds" that weather to rounded slopes (fig. 7) is often associated with landslides and fill failures In these cases the color is not indicative of good drainage

White or light gray colors in soils of the humid regions are usually an indication of extremes in moisture variation They are subject to seasonal saturation and drought, saturation during long rainy periods because of retarded internal drainage and dryness because of a favorable position An exception to this is found where the white parent marl and chalks of the Coastal Plain outcrop or are otherwise exposed by local erosion Obviously sands are an exception to this and can be distinguished from a light-colored silty clay or other elements of surface drainage and dune shapes if present

Vegetative Cover

Vegetatives cover is perhaps the most difficult of the elements in the soil pattern to interpret The significance of vegetation varies widely with climate and other factors, usually requiring local expereince for detailed interpretation However, to those with local experience, as is often possessed by those who apply these techniques to their local problems, both natural and cultural vegetative cover is a reliable indicator of soil characteristics

As an indication of ground-water conditions the over-all vegetative pattern often provides an excellent boundary between very wet and relatively dry areas Swamp vegetation presents an entirely different appearance when contrasted with forested areas occupying well-drained hills This contrast between wet and dry ground vegetation is valid in all climates where rainfall is sufficient to create this condition Within a swamp area where the water table is sufficiently high to obliterate other elements of the soil pattern, vegetation alone remains Muck and peat bogs have separate and distinguishing patterns of their own that indicate a variation in conditions within the area In forested areas, forest fires complicate the pattern although the fires are often confined to the dry land Lumbering operations also tend to influence the pattern In general, wet and dry positions are distinguishable by the vegetation that they support (fig 75) giving the observer a general impression of cover type Although the presence of poplar indicates moist ground, jack pine implies sand and gravel beds, tamarack, muskeg, and willow, wet and swampy ground It is also true that many species such as white pine and aspen are tolerant of drainage and soil conditions and will grow on sandy as well as clay soils and in wet or dry positions

Low rainfall areas provide many instances of the interrelationship between soil, ground water, and vegetation Salt grass indicates a ground-water table probably not more than eight feet below the surface Mesquite, birch, willows, cottonwood, and palms also indicate wet ground In contrast, the sagebrush, shadscale, cactus, Joshua tree, and yucca do not depend upon ground water (35) While these plants are too small to observe individually in ordinary airphotos, rather pure stands commonly occupy belts that have features characteristic to the particular plant Since some types of vegetation are tolerant of a wide range in soil conditions, it is necessary, on occasion, to avoid placing too much emphasis on this one factor without supporting evidence from other elements. Recent photographs made with long focal length lenses have vastly improved the detail available for this type of interpretation.

Fig. 75. Various vegetative forms occurring in relatively pure stands under various soil-moisture conditions.

Fig. 76. "Dead furrows"; spaced at regular intervals and running parallel. These shallow ditches serve as open drains in areas of very flat relief typical of lakebeds. In this instance and in others where the soil is high in silt content, the color responds to the effect of drainage as is shown by the soil adjacent to the dead furrow which has dried to some extent. Clay soils do not become white in this fashion.

Land Use

Land use and other human influences are included as an element of the soil pattern. The pattern of contour plowing, terracing, and strip-cropping are forms of erosion control signifying a friable soil on a less pervious subsoil. Check dams, levees, crops, crop boundaries, plow lines, and many others carry some special significance depending upon the locality. "Dead Furrows" (fig. 76), the inevitable sign of plastic, poorly-drained soils, are the farmer's attempt to obtain surface drainage of an impervious profile. Orchards thrive in well-drained locations and, therefore, when observed on level ground good subdrainage is implied, and the soil will generally be of the sandy to sandy clay loam texture.

These then are the major elements of the soil patterns, the land form, surface drainage, slope, erosion, color, vegetative cover, and land use. Created directly or indirectly by physical properties of the soil, they form a basis of interpreting the engineering characteristics of the soil and of foreseeing problems that directly affect the cost of construction and maintenance of pavements.

Some Limitations of Interpretation

One of the important axioms of interpretation is the recognition by the interpreter of the inherent potentialities and limitations of these techniques and their relation to engineering work. The accuracy of the results of photo-interpretation vary with two major factors; the chief and relatively fixed factor is the type of formation.

Recently waterlaid materials as a general class are subject to variations in texture without corresponding and related surface indications. With the lack of necessary indications as well as the wide range of textures common in these deposits, subsurface predictions concerning them may be subject to considerable error if the interpreter does not realize the limitations that exist In considering recent alluvium it is also advisable for the reader as well as the interpreter to know the end point of a particular study. The relatively level relief typical of recent alluvium favors runway and roadway construction in that little excavation is required to obtain acceptable grades. In such a situation the condition and texture of the surface deposits are important - in fact much of the usual soil sampling stops at three or five feet in such areas. To understand this is to realize that the most accurate part of the interpretation of alluvium is the important part and that the variations in depth below the principal surface deposit are not always important.

Other and older waterlaid deposits in the form of terraces are not necessarily limited in this way and in many instances it is accurate to say that sampling at a certain specific location will show from "two to four feet of reddish clayey sand over 50, 60, or 80 feet of gravel and sand - depending on the height of the terrace." Obviously in such a situation there will be seams of sand without gravel or lenses of silt included but because of their depth, they will rarely influence construction and more rarely would they be located by field parties.

In contrast to the limitations indicated as typical of alluvial materials as one extreme, consider windblown materials in the form of loess and sand Both of these are identifiable in aerial photographs, both form in deposits of measurable depth - as much as 100 feet - and each falls into a separate and distinct textural class having well-defined limits of grain size Such information on texture and other properties at considerable depths is important here because the hill slopes that characterize these deposits create a need for considerable cutting and filling to obtain satisfactory vertical alignment The texture is fixed within narrow limits by the type of formation so that a prediction of texture, uniformity, and depth (approximate compacted dry weights of both and Atterberg limits of silts) then depends upon the second factor, the familiarity of the interpreter with these deposits.

The examples cited above probably represent the two extremes These and the multitude of situations falling in between are individual problems that face the photo-interpreter. Few are those that appreciate the infinite detail (pertinent and otherwise) recorded on aerial photographs for it is only by actual ground study and sampling of type-areas and a concurrent and thorough examination of photographs of the same areas that their true value can be known.

The great multitude of conditions encountered, types and purposes of surveys, detail required or needed, and the variable ability and experience of those making the survey make it clear that field inspection and sampling are desirable and often necessary. However, the lack of experience may be overcome, particularly in local areas, and in numerous types of formations only occasional field checking may be necessary even though many square miles may be under survey.

CHAPTER IX

AIRPHOTO ANALYSIS OF RESIDUAL SOILS

The chapters of this report concerned with the analysis of airphotos have been subdivided on the basis of the origin of the soil, they will be found to correspond generally to the early chapters dealing with the background of information and literature on the conditions relating to these soils and to the principal divisions used in making the map Under the heading of Residual Soils the subdivisions, based on the mode of formations of the rocks, are soils derived from sedimentary, metamorphic, and igneous rocks

Sedimentary Rocks

The section dealing with soils derived from sedimentary rocks has been subdivided on the basis of distinguishing land forms The space here devoted to these soils is not entirely compatible with the areal extent in this country of some of the forms.

Sandstones, Shales and Limestones (Tilted)

These rocks generally produce areas of rugged relief Because of this the influence of soil on construction and design is less than in less rugged terrain, and problems concerned with the character of the bedrock become prominent

Land Form Sedimentary rocks, when found in alternate order and tilted position, develop one of the strongest of land-form patterns The contrasting texture and weather resistance of these common rocks is reflected in the drainage pattern and in the marked difference in slope characteristics of adjacent rocks.

The detail of the pattern may vary widely depending upon the angle at which these originally flat-lying strata of rock now repose The more this dip angle departs from the horizontal, the greater will be the local variations in relief Similarly the detail may vary with the relative thickness of adjacent beds and with the recurrence of similar rock types Climate has little significant influence on the pattern except upon the texture - or intensity - of the drainage pattern Even in humid climates the vegetative cover serves to emphasize the land-form pattern by establishing a color contrast between forested hillsides and cultivated fields on more gently sloping terrain

Regardless of these variations in detail the general land-form pattern is characterized by the persistence of the various strata along the line of outcrop Thus the first impression gained from an aerial view (plate 9) of this type of land form is of parallelism Hills, valleys, and streams have a definite directional trend that controls the drainage, land-use pattern, and even the centers of population and transportation systems

Drainage In the majority of these areas the secondary drainage system of the smaller streams follows the weak bedding planes formed by strata or soft rock, usually cutting across more resistant strata at joints and fractures thus creating a trellis (rectangular) drainage pattern The major stream channel shows less control by the rock structure. Fig 67, a drainage map of Roane County, Tennessee illustrates this pattern as does plate No 9 and the chart

Erosion Climate has a great influence on the amount of active erosion present Arid climates are characterized by infrequent periods of intense rainfall The lack of such vegetative protection, as is afforded by more humid climates, together with the intensity of rainfall and prevailing steep slopes permit the surface water to carve the relief without control.

Although vegetation inhibits erosion to a large degree, some erosion can be observed on the airphoto wherever there is appreciable runoff The form of erosion will be controlled primarily by the specific type of rock and soil under observation, and the vegetation. Reference to the general discussion of erosion will provide descriptions of the types of gullies occurring in these sedimentary rocks.

Gully shapes conform to those in other materials as illustrated in figures 70 and 71. Thus a gully in a typical sandstone soil area is shown in figure 77.

Color. The soil colors associated with these residual materials are relatively constant over wide areas. In the humid regions the limestones produce red soils that register as dark gray on most photographs. Although there are red sandstones in the west, most other sandstones produce soils that are much lighter, including various shades of yellow and brown which register as very light tones in pictures. Shales, especially the "clay" type, have a very uniform grey to dark grey color.

Fig. 77. The simple gully having a V-shape and few tributaries is representative of erosion in sandstone soil-areas.

Vegetation and Land Use. In the discussion of land form and drainage it was emphasized that climate largely controlled the vegetative cover. In humid regions the prevailing slope as much as the soil influences the cover. The sandstones and limestones are commonly the "cliff-makers." Where the slopes are steep and the soils shallow, timber cover is common. Unprotected limestones, where sufficient area is exposed, weather to gentle slopes and produce rich soils that are usually cultivated. The sandy shales have the pattern of sandstone while the clay shales are dissected and are dissected and are cultivated in small fields.

The key to vegetation in arid climates lies in the ground water and in the field of geo-chemistry. For this report it suffices to say that the chemical and mineralogical properties of rocks vary as do their physical properties and where the weather resistance of two unlike rocks may be similar they may well vary in respect to patterns influenced by the dominant chemicals present.

These tilted rocks are studies in contrast. Side by side are sandstones, shales and limestones; and side by side are orchards, forests, cultivated fields, and quarries. Each of these is related to the quality of the soil, depth of profile or nature of the rock.

Typical Profile. The majority of the sandstone soils occur on slopes that are considered steep and for this reason and consequent erosion the profile of this residual soil is shallow. These soils range from two to five feet in depth; they have a fine sandy to silty topsoil, and a sandyclay "B" horizon. The percentage of rock fragments increases rapidly as bedrock is approached Under arid conditions physical weathering predominates and very little clay is produced, thus resulting in an extremely shallow soil and little profile development

Problems Rock excavation is common in such areas The movement of seepage water in the zone where the soil rests on the rock causes failures of fills and unstable subgrades Solution channels developed in the limestone may convey water long distances to outcrop in runways and highways if intercepted by excavation operations. Where these flows are seasonal, apparently safe structures built during dry seasons may become unstable when rain fills the limestone stratum An example of this is shown in plate 63

Sandstones, Shales, and Limestones (Horizontal)

Land form The occurrence of horizontal or nearly horizontal strata of sedimentary rocks is common The land-form pattern produced by these layers of alternating rock is as striking as the dissimilar pattern of the tilted beds Dissection of a plateau of these rocks advances largely without influence from the alternate beds of rock, hence, instead of a pattern comprised of ridges of resistant rock and valleys cut in soft rock, an uncontrolled or meander type of dissection occurs (chart)

The land form resulting from this type of dissection is one composed of hills and ridges having gently rounded tops of approximately the same elevation, and relatively steep sides with broken slopes Plate 10 illustrates this land form well because in that dry area vegetation does not obscure details Plate 11 illustrates how land use and vegetative cover serve to emphasize the general land-form pattern in humid areas (See also plate 12)

Drainage Here the random pattern of the drainage is best found in the system of small and intermediate streams In the streams draining much larger watersheds, the broad influence of other types of rock is often felt It is not uncommon to find a major stream marking the boundary of an area of similar rock Its principal tributaries are often influenced by rock underlying the area but not sufficiently exposed to influence engineering construction (except dam and bridge foundations) Therefore, it is the smallest tributary stream that more truly indicates the nature of the materials encountered in construction

Erosion In the sense of recent erosion there is a wide variety of conditions that may furnish either little or ample opportunity to study gullies The more significant (in this instance), geologic erosion, has shaped the hill slopes so that they represent a compromise or balance between the climatic attack of weathering and erosion, and the weather resistance of the various rock strata. Consequently, on hillsides of this type ledges of resistant rock will form "outcrops" or bands that approximate the same elevation These are the steep slopes on the hillsides of this land form and they may be of sandstone or limestone The "soft" slopes above or below the resistant rock are clay shales A study of the recent erosion on these will permit greater refinement and a rather accurate prediction of the texture band.

Color Here the color pattern is consistent with the description given in the preceding land form In many instances the shales will vary in color within a few feet This color variation, naturally, registers on the film and enables the observer to trace its pattern of outcrop even though interrupted by slides or talus.

Vegetation and Land Use Reference to the tilted land form containing the same rocks will give general coverage of this element of the pattern An examination of plate 2 will indicate the interrelation between vegetation, rock type, and slope

Typical Profile Where these areas are dissected, as they generally are, the existing soil mantle is made up largely of colluvial material. The truly insitu residual soils are shallow and relatively insignificant.

Problems. The rapid change within short distances from hard massive rock to soft shale and the attendant seepage along rock surfaces are the sources of the common problems associated with pavement performance.

Fig. 78. Sinkholes occurring in limestone regions vary widely in their size and appearance. These two views illustrate the size of those appearing as pinpoints on airphotos (5 or 6 feet in diameter) to the average sinkhole having a diameter of 30 to 50 yards.

Limestone

Land form The distinguishing features of limestones are several in number but the most outstanding and, therefore, the most important is the presence of sinkholes, fig 78 The frequency of occurrence of sinkholes is largely determined by the solubility of the limestone Where the limestone is flat-lying the sinkholes approximate a circle in the aerial view but tilting of the rocks introduces an elliptical shape with the major axis parallel to the bedding planes.

This form of internal drainage, the quality of the soil that favors cultivation, and the gentle slopes characteristic of limestone areas combine to give this distinctive land form Because of the susceptibility of limestone to chemical weathering this rock is usually covered with some of its own residuum, slopes have a smoothly flowing appearance and outcropings of the bare stone, except on valley walls, are rare

In addition to the sinkholes, the valleys cut by large streams flowing through horizontal limestone areas are characterized by U-shapes, exposures of the bare rock and a notable absence of talus slopes The absence of surface runoff from limestone accounts for many unusual valley sections found in these regions Undermining and collapse caused by streams which are underground rather than on the surface, probably account for most of the valley sections Such streams as exist clear the valley floor of debris but fail to modify the valley section. The tributaries to the main stream are short, they have compound gradients, form definite angles where the valley walls meet and are noticeably few in number Variations from the normal include dolomitic and cherty limestones Plates 15 and 16 indicate these patterns

Drainage The principal drainage of a limestone area is subterranean. Rainfall that is not immediately absorbed by the porous soil structure is soon carried to a sinkhole either as direct surface runoff or in a small stream The entire surface drainage system and all of its characteristics including valley shapes both in cross section and profile, resemble those of a porous, well-drained material which, in fact, it is

Here, for the purpose of explaining an apparent inconsistency, the term "functional texture" previously discussed is applied to the limestone soils Texturally they are plastic silty clays and normally would be considered impervious. Field inspection will show that the soil has aggregated into a mass of nut-sized particles with ample space between the individual pieces for the rapid percolation of water While many soils develop a similar type of open structure, few have a well-drained parent material Lacking that, the profile soon becomes water logged and the fragments swell and further retard drainage

Erosion The pattern of erosion in a limestone area is almost a redundant consideration since it serves chiefly to emphasize the points already discussed For instance, sheet erosion around a sinkhole merely heightens the color contrast and makes that feature more prominent in the photos Because the soil derived from limestones is remarkably consistent, details of the profile obtained from a study of gullies is generally unnecessary Probably the best airphoto information derivable from gullies in these areas pertains to depth of the soil to bedrock.

Color. Various shades of red predominate in these regions The general condition of good drainage is conducive to the development of these colors that are associated with well drained soils Within local areas differences in bedrock impurities may produce deep, blood-red or reddish yellow colors It is of particular significance that the yellow influence is always associated with a high silt content in the entire profile. These soil colors, registered on the film through a haze filter, appear as dark gray tones to very light gray tones on the airphoto prints The reddish-yellow soil areas are recorded in the lightest grays and the deep reds in the darkest tones

Vegetation and Land Use. Within the United States those limestone areas lying in climatic zones conducive to soil development and to plant life are generally rich and fertile and, therefore, are highly cultivated. The Kaibab Plateau in Arizona is probably the major exception. There, lack of both rainfall and irrigation water, and inaccessibility have discouraged agriculture. As a result of this, and more recently the establishment of national forests, the magnificent stands of native timber have been preserved. In small areas however, orchards and general crop development are numerous.

Typical Profile. Depending upon the local slope and erosion conditions, the depth of profile may vary from a thin azonal soil to a well developed profile as much as 10 or 12 feet deep. The deep soils occur on undulating terrain, and where significant profiles are developed the topsoils to a depth of 8 to 10 inches are of a friable silty texture. The subsoil or B horizon is of silty clay (see appendix A, Residual Soils) and possesses the characteristic well-drained structure. The presence of chert in the profile in varying amounts in commonplace. The weathered surface of the bedrock is very uneven and is not characterized by the transition zone of rotten rock found in other parent rock types.

Problems. In such areas the principal item of concern may be grading that involves rock excavation and the associated special problem of effectively capping sinkholes. The number of sinks as well as their condition can of course be determined quickly by photographic inspection.

Fig. 79. Steeply dipping, thin bedded dolomitic limestone in the Arbuckle Mountains region (see area B, plate 15). Note the narrow banding in the airphoto pattern and the insignificant soil cover in the ground view.

Shale

Land form. Probably the largest single area of shale in the United States is the rather uniform clay shale in South Dakota (plate 1). There are numerous smaller areas of clay shale throughout the south central and western states, and in the Appalachian valleys of the east. This type of shale is distinctive, whereas the land form of sandy shales closely resembles that of sandstone, the principal difference being that the former are less rugged because of the relative weakness of the sandy shale as compared with the sandstone.

The clay shales are poorly consolidated beds of clay that weather easily to form a plastic soil mantle. Because the mass of the deposit is a clay, it is not unexpected that the terrain will consist of low rounded hills. The susceptibility of shale to weathering and erosion creates a land form that is characterized by much dissection and slopes that have a soft, flowing appearance. Plate 17 is an aerial view of the Pierre shale that illustrates this land form

Drainage. Nowhere is surface drainage more thoroughly developed than in a truly argillaceous shale. Reference to plate 17 will show the completeness of the surface drainage pattern and the resulting erosion The thickness of these beds and the fine texture of the particles renders the mass so completely impervious that much of the rainfall is discharged as surface runoff Where the shales are uniformly and horizontally bedded the drainage pattern is of the dendritic type, where variations in texture or cementing of strata occur, especially in tilted structures, some control of the drainage pattern may be observed when the channels intersect the more resistant strata

Erosion Erosion in an exposure of clay shale is usually active, a condition that supplies ample evidence for verifying the soil texture The gullies formed by active erosion in these soils are shallow and broad with gently rounded side slopes Erosion of the parent shale is of similar form except that the portion of the gully in unweathered shale approaches a V-shape The gradient is usually uniform and the distance from the headward end to the foot considerable Landslides and related forms of erosion are especially common where intense rainfall occurs

Color Soils developed from shales are usually of the same color as the parent rock although weathering has modified the original color by leaching process The high proportion of surface runoff in these areas and the impermeable character of the shale combine to reduce the influence of slope on profile development, therefore, varying colors corresponding to "soil-positions" are not often observed, and where they do exist, the lighter shades are sometimes found in the valleys, due to the effect of vegetation there in contrast to the very dark grey bare hillsides (see plate 17)

Vegetation and Land Use The large exposures of this type of rock are in predominantly dry climates that have sparse vegetative cover The largest area of nearly similar material (shales and sandstones - see plates 1 and 19) that occurs in a humid climate is found in eastern Ohio, Pennsylvania, and West Virginia Here the vegetation does not seem to be particularly significant.

Inasmuch as soils developed from shales are not productive, as a rule, the land is often devoted to grazing Erosion on hillsides and water-logged profiles on level areas make these soils unsatisfactory for cultivation (see also plates 10, 11, and 12 for shale exposures of lesser extent)

Metamorphic Rock and Intrusive Rocks

Gneiss, Schists, and Slates

Land form. The term metamorphic permits the inclusion of all altered rocks that have undergone pressure and temperature of sufficient intensity to change their physical properties over that of the original rock Obviously the degree of metamorphism will vary, in many instances where the rock has been only slightly altered it will occur as a border line case Here the land form probably resembles that ascribed to the original unaltered rock type Where metamorphism has been pronounced, the various distinct classes of rock develop their own particular pattern Because of the naturally rough terrain characteristic of these areas, less study has been given to these rock patterns than to those types producing more level terrain

Limestone that has undergone metamorphic change is marble and while there are a few areas of this material in the United States, the rock are not exposed over a sufficiently wide extent to have developed a specific pattern A limited number of observations made on this material have not shown the signs of weathering by solution that is observed in connection with the weathering of limestone The same applies to the development of patterns on metamorphosed sandstones However, the slates formed by the alteration of shale duplicate the shale pattern in all the elements except one, the change that the clay shales undergo to form slate so improve their weather resistance that all of the general slopes in a slate area will be steep. Therefore, the land form pattern of slates is one of a highly dissected area characterized by shallow soils and steep slopes. Plate 20 shows such a material in one of the southeastern states.

In a Piedmont upland where large areas of mica schist and other related metamorphic rocks occur, there is developed on a large scale a directional trend in the rock that is probably caused by planes of weakness due to concentrations similar to those found in specimens of any of these rocks. Where granites have intruded into layers of sedimentary rocks, the transitional or contact zone between the two is often altered. Plate 20 shows the distinct transition between sandstone and the batholith.

Surface Drainage. The surface drainage pattern developed on these materials is likewise variable, depending on the properties of the individual rocks and somewhat upon climate. The highly dissected pattern of drainage on slates are indicative of the imperviousness of the material as well as the shallowness of the soil profile. In contrast, the mica schists and similar rocks weather more easily, produce deep soil mantles, absorb a large percentage of the precipitation and therefore have less active drainage systems. The drainage in these rock areas is reasonably influenced by local variations in texture and structural flaws within the rock. Where the bedrock is metamorphosed granite, the surface drainage is rather poorly developed; in the areas examined the pattern has not differed materially from that typical of granite.

Erosion. Erosion is often a serious problem to the landholders in regions containing these rocks. Metamorphism often produces a crystal-line structure and a considerable percentage of the minerals are extremely weather-resistant. The resistance and size of these crystals produce a sandy quality in the soil. The hilly terrain characteristic of these areas provides an opportunity for a large quantities of runoff, which in combination with the sandy texture, creates a considerable amount of erosion. Large active gullies are found in the Piedmont (fig. 80).

Fig. 80. This young gully is in the friable sandy soils produced by the weathering of mica schist. The shape of this gully is like that found in other soils having similar profiles and textures.

Color. Brownish-red is the prevailing color of these soils. Variations in position, i.e., steep slopes or poorly drained depressions, create color differences. On the steep slopes the soils appear light colored, indicating a combination of good surface drainage and probably some erosion, while the depressions appear dark, indicating a deeper red to chocolate brown. Soils developed from slate are generally dark gray, and those developed from quartzite are light.

Numerous situations arise in which the local rock contains a relatively high proportion of clay forming minerals Here the increased clay content of the soil is primarily reflected in color changes (plate 21)

Vegetation and Land Use Inasmuch as these rocks occur under all conditions of climate, an infinite variety of soils and vegetation result, therefore, it is difficult to offer a general rule that will apply to the entire country in the interpretation based on vegetative cover and land use Locally however, vegetation and land use will often be consistently correlated with soil texture, depth and color, and the observer of airphotos can generally develop his own guides for his vicinity.

Typical Profile The typical profile developed on slates is extremely shallow, contains many rock fragments, and is generally silty in texture The various types of schists are generally susceptible to weathering and produce a soil mantle of considerable depth The properties of the soils will vary widely for instance, in the case of chlorite and talcose schist, the weathered material appears to retain the character of the individual grains although the bond between the grains is destroyed This results in a "soil" that is best compared to talcum powder, the individual particles have no cohesion and under the conditions observed, have been highly unstable Rocks high in mica produce a "sandy" profile of considerable depth, the notable exception being the micaceous slates of northeastern Georgia. In general the soil profiles developed from altered granite are similar to the related granite soils

Problems Engineering construction in most of these areas, especially in terms of runway and roadway construction, involve cuts that extend into bedrock that is frequently disintegrated to considerable depths The class of excavation varies with the character of the individual rocks Constructing fills or attempting to bind these soils with admixtures in the presence of sericite, talc, and mica introduces a very difficult mixture with which to work

Granites and Related Rocks

Land form Granites are usually formed below the surface of the earth, then intruded into overlying rocks In many cases the granite is then exposed by erosion and removal of the surface materials This general process accounts for many of the western mountains. Where the granite core has weathered to form a trough between two crests of sedimentary rock, small mountain "parks" may be found

Plate 22 shows a complete land form of granite occurring in such an environment Although unusually small, this is a pattern that will illustrate the situation where a granite core is surrounded by the upturned strata of sedimentary rock that originally covered the area These normally occur on a much larger scale

Surface Drainage The amount of surface drainage that develops depends largely upon the areal extent of the exposure In some parts of Virginia (plate 23) large exposures of granite have developed a completely integrated drainage system that shows the lack of structural control on the development of streams The absence of stratification, planes of weakness, and other characteristics that commonly influence stream channels in residual soil areas permits this random dendritic drainage pattern to develop

Erosion There is a wide variation in the amount of erosion in granitic materials because the broadness of the term granite permits the inclusion of a variety of rocks High-quartz-content granites have a preponderance of weather resistant materials and as a result, sandy soils are produced that are susceptible to erosion on ordinary slopes On the other hand, most of the granites in the east and southeast have a sufficiently large proportion of clay-forming minerals to produce a hard, sandy clay, "B" horizon which minimizes erosion If, as it does in many instances, the "B" hroizon becomes sufficiently impervious, sheet erosion will be prevalent This condition also leads to the creation of a water-fall type of gully wherein the surface runoff is maintained as a result of the profile development. Where erosion cuts through to the transition zone between the "B" horizon and the unweathered rock, gullies form rapidly and headward growth progresses at a remarkable rate because of the undercutting by water that falls over the ledge provided by the sandy-clay horizon.

Color. There is a relatively small variation in color tones observed in these areas. Most granitic soils are reddish brown in color and where these tones lighten appreciably, it is a direct indication of the increasing sand content in the soil (see plate 23). In an area of appreciable extent it is possible to map those soils having a higher sand content by tracing the border of the light colored soil.

Vegetation and Land Use. In the east where the climate is humid, these soils have been cultivated for long periods of time. However, it is characteristic that only the gently rounded hill tops are used in farming, while the steeper slopes on either side of small valleys or gullies are devoted to timber. In the west, where there are large climatic variations within distances due to changes in altitude, a great range both in vegetation and land use may be observed. The mountain parks are almost always sufficiently moist to have produced a forest cover; here the conditions are usually suitable for grazing and a moderate amount of cultivation. Where the climate is dry, these soils are usually exceptionally poor in water holding capacity and, therefore, vegetation that does occur will be found in the bottoms of gullies and other positions where water is retained naturally.

Typical Profile. Depending upon the relative quartz content of the granitic rocks, the profile both in depth and texture will vary considerably. The influence of slopes on erosion also produces marked variation in the types of the weathered profile. In general it can be said that the low-quartz rocks produce a relatively deep (5 to 10 feet) profile in which the top soil is texturally a silty sand and the "B" horizon a compact, dense, red sandy clay. Below this, and beginning at approximately 40 inches, the transition zone begins; here rotten rock is encountered in increasing amounts as bedrock is approached and in many instances this is a gradual change. The sandy granitic soils are weathered from high-quartz granites that are naturally more weather resistant. A large proportion of the weathering is accomplished by physical means. Therefore, the depth and intensity of development of the profile in these are much less than in the low-quartz soils.

Problems. In almost all instances of construction for either airports or highways, it will be necessary to make cuts that will require hard rock excavations. Fractures produce seams that, when encountered, may carry sufficient water to create local subgrade difficulties. In a similar way during the wet seasons of the year, seepage in the zone of transition between the weathered profile and the bedrock may cause minor slips in cut slopes as well as a soft subsurface condition.

Extrusive Rocks

Basalt and Lava

Land form. These extrusive rocks are classified as those materials of volcanic nature that have issued from cones or fissures in the surface and flowed over the surrounding area to cool and harden. Lavas and basalts are the chief forms of this material. While lava is of small consideration in this country because of its limited distribution, there are extensive areas of basaltic lava, especially in the northwestern states. Both materials weather rapidly to form deep, plastic soils. However, much of the basalt, especially in Washington state, has been covered, as shown in plate 25, by superficial deposits of loess and sand.

Because of the fact that these materials have issued from the earth in a viscous form and have sought depressions, they form either plateau-like features or occupy valleys cut in other rocks or older volcanic flows.

Surface Drainage Because of the variety of forms that these materials may take it is difficult to ascribe any one drainage pattern to them Many of the lavas are so porous that they absorb a large portion of the precipitation Much of the basalt that has been studied in connection with this report has been marked by channels cut during glacial times (plate 3), so that if a drainage pattern characteristic of basalt exists, it can not be described in the present report

Erosion Since basalt forms a soil high in silt and clay it can be expected that recent erosion will provide some information on the texture of the soil and the depth of the profile In a limited number of cases it has been possible to identify the basalt directly since the more or less unique columnar structure on weathered faces and the accompanying talus slope can be seen in photographs.

Color The residual soils formed on basalt are chiefly reddish brown in color Although in places in the Rio Grande Valley in northern New Mexico, these soils are of light grayish tan color (Further field data are needed to establish significance to be attached to variations in color of the soils derived from basalts and lavas)

Vegetation, Land Use, Typical Profile, and Problems. (Pending further investigations which are not complete at the writing of this text, comments on these elements are withheld).

CHAPTER X

AIRPHOTO ANALYSIS OF AEOLIAN SOILS

It is because of their general relationship that the wind blown materials, loess and sand dunes, have been considered under the heading of Aeolian Soils. This obviously does not include the identification of sands of alluvial or glacial origin that may be closely associated with the dunes As a mapping detail it would be impossible and unnecessary to have distinguished dunes from other sand deposits, for that reason the sands are mapped as such and are credited to the various subdivisions of the principal soil groups

Loess and Sand Dunes

Loess

Land form The texture and occurrence of loess determines, to a great extent, the basic land form that it assumes The underlying theme of this land form pattern is the repetition of similar hills forming a series of parallel ridges.

Loessial silts are derived principally from the flood plains of large streams, therefore, the pattern is found to be most striking adjacent to the rivers At the valley wall tre terrain is characterized by extreme roughness, the hills having relatively sharp crests and steep sides At greater distances from the source the hills retain their parallelism but the crests become more rounded and the differences in elevation less pronounced

It cannot be expected that the land form pattern and the corresponding drainage pattern will be found arranged in perfect order Changes in wind direction during the centuries of deposition may have modified the pattern, but in the large majority of cases there is ample evidence of parallelism retained in the land form to positively identify the material as loess In fact, vertical photographs record this pattern in post-Kansan loess in Minnehaha Co , South Dakota and of unidentified loess in Sioux and Dawes Cos , Nebraska

The nearest resemblance to this land form is found in folded or upturned beds of sedimentary rock, however, anything more than cursory inspection will distinguish these from the loess pattern Magnitude, scale, unequal side slopes, and erosion pattern all serve to set these apart from the loess

In areas where the loess mantle is thin or where rough relief has been covered (plate 30), the land form is not truly that of loess Instances such as these occur as transition zones at the fringe of a loess belt Here it is necessary to rely on other distinguishing elements of weathered silt to identify the material as loess

Drainage Since the slopes and direction are fixed by the land form, the drainage develops in response to the established slopes producing a trellis form Where complicated by erratic winds during deposition the drainage has assumed a random pattern much as the hills themselves For several reasons - including local topography, varying winds, and more than one source-area - the typical pattern of the loess land form may be indistinct In such instances the proximity of the source-area, the long sweeping slopes, and the erosion pattern indicate that loess forms the parent material.

Erosion. Where the land form and drainage patterns of loess are interrelated and establish the type of deposit, erosion in silt takes a form related to the texture but not necessarily confined to wind blown forms; therefore, if the land form pattern is not distinguishable the analysis need not break down Among the physical and chemical properties that contribute to the erosive qualities of silt-size material, the lack of cohesion between particles plays a major part

Therefore, when it is exposed to running water, erosion takes place and gullies are formed Lacking cohesion the individual particles easily separate resulting in the formation of nearly vertical faces on the sides of gullies. Since this is a property of slightly or non-cohesive soils it is not confined to the silts. This property is so highly developed (especially in loess) that any manner of cover, however small, will protect the material immediately beneath it thus forming a ridge or pinnacle of a shape or extent that is governed by the cover rather than the soil material The net effect of this characteristic is to produce gullies and other erosive forms that have not only vertical sides but fin-like extensions projecting from the erosion face. "Catsteps" formed by the slumping of silt on the steepest slopes is a not-too-common form of erosion in loess.

Color In an aerial photograph the predominantly yellow-brown of silt will register as light gray to white Where the land is cultivated many fields will appear gray Grass and grain, commonly found on silts, display a hair-like quality on the airphotos that the observer soon associates with loess In relatively dry areas such as that in eastern Washington, the surface soil has a definitely black color Here the grain crops or stubble, in contrast, give a light color.

Vegetation and Land Use Loess is known as a fertile soil and is often cultivated intensely Rainfall is the chief variable controlling the cover In the lower reaches of the Mississippi Valley rainfall is sufficiently high to maintain a dense forest cover while in the dry areas of the west short grasses may thrive The famous Palouse region is almost entirely devoted to wheat raising.

Typical Profile In humid areas the profile of a loessial soil varies with the slope of the ground In positions where, for any reason, moisture or ground water accumulates, the silt will weather to a silty clay material. Thus, the profile of a loessial soil will be found to consist of silt as a shallow topsoil, a silty clay material forming the "B" horizon, and the parent material the unweathered silt The depth of development of the weathered profile will vary with the slope, being the deepest in the depressions It is worthy of note that the "B" horizon has a well-developed structure Where the loess mantles an unrelated material such as bedrock, it is often found that ground-water movement has been retarded causing an accelerated weathering of the profile Claypan development of the profile is associated with this condition In extreme cases of saturation due to position, the material had weathered to a very plastic silty clay In local areas a darker gray may be found within a light-colored, cultivated field, these are slight depressions or drainage-ways that have developed a more pronounced soil profile

Problems After having identified a soil area as loessial in origin and checked the observation by studying the lesser elements, soil boundaries representing similar profiles can be drawn along any location specified on the photograph. Fortunately for soils engineers conditions standardize the methods of dealing with these soils The relief that is associated with this type of deposit is usually so rough that cuts and fills are required especially when cutting across the main trend of the hills. With this as a controlling factor the importance of the weathered "B" horizon of a profile becomes negligible over large areas In instances where the claypan occurs the relief is often gently rolling and the weathered profile assumes much more importance especially in terrain suitable for airports

Long experience has shown that cut slopes in loess must either be nearly vertical, stair-stepped and sodded, or sloped and sodded immediately Erosion will seek out the flaws in or variations from these practices

When a photo study of the hillsides reveals no significant breaks in slopes, buried rock is not to be anticipated in cuts After having established this condition, the construction will then deal with one of the most amazingly uniform materials in the world, for samples of many of these deposits indicate no significant variation of the parent material to depths of thirty, sixty, and even eighty feet

Since silts represent the "unhappy medium" in textures promoting frost action, such action is associated with positions favorable to a shallow groundwater condition.

Fills constructed of this material may appear highly unstable during construction and yet perform satisfactorily. Silt is very critical of water content and when an excess is used during compaction it may become impossible to use ordinary paving equipment. Form alighment also suffers.

Sand Dunes

Land form. The sand dune in its basic form is one of the most easily recognized land forms. The characteristic shapes, so intimately bound up with the other elements of the soil pattern, seldom leave the observer in doubt as to its origin and composition.

Sand swept up from alluvial, lacustrine or residual plains, forms into dunes that may assume one of several typical shapes depending upon their local environment. Melton (36) deals splendidly with these in the Great Plains; but in the humid areas some technical conflict is encountered. Barchane dunes are common in sandy outwash plains of the glaciated regions where the crescent shape (barchane) is readily distinguished from the other glacial land form patterns. Here the "horns" of adjacent dunes may be found pointing in opposite directions and thus violating the rule of horns downwind. Where the horns are pointed into the wind the dune is usually framing the leeward side of a local swamp area. If the dune, probably resulting from a blowout during a period of drought, should break away and move across country, it would soon adjust itself into the category of the ordinary barchane. Regardless of shape, the steep side of these dunes is downwind. (fig. 81).

Fig. 81. A highway cut exposes the typical cross-section of a barchane dune having a steep lee side and a long sloping windward face. Vegetation on dunes regardless of location is drought resistant in comparison to adjacent lower and more moist soil-positions.

Some dunes, plate 33, have a double crest that forms a trough at the top that is parallel to the longitudinal axis of the dune. This trough is often neatly subdivided into cells by transverse ridges connecting the double crest.

Drainage. Drainage being internal, there is no visible pattern. The very lack of a pattern is evidence of the porous nature of the mass.

Erosion Without surface drainage there can be no water erosion except that by waves where dunes border bodies of water In extremely unusual cases of erosion in sand dunes a very obvious alluvial fan forms at the base of the slope. Wind erosion is common on old dunes stabilized by vegetation Fire, overgrazing, or other conditions may kill the protective cover of vegetation and permit a local blowout to form.

Color The impression of light gray to white tones is universally associated with sand dunes as well as with nearly all forms of sand deposits Where there is sufficient rainfall to support tree growth on sand dunes it is, even then, possible to observe this characteristic color It is appropriate to restate the warning that with certain soils such as sand dunes color is one of the least reliable of the elements on which judgment can be based, i e , all dunes may appear light in color but not all light areas are dunes - nor are they all sands - nor are they all well drained

Vegetation and Land Use A sand dune is, possibly, the best drained soil-area within a given region The uniformity of texture and moisture condition produces a uniformity of vegetative cover so that within reasonably wide climatic variations dunes will be covered with a typical plant or group of plants that are readily distinguished from those growing under other soil (or moisture) conditions Red oaks thrive on dune sand in the north central states, certain species of pine in the south coastal areas, and short grass in the majority of western states where dunes are found.

Dunes receive rather limited treatment from the agricultural standpoint, they are chiefly devoted to wood lots and grazing Occasionally the well-ordered pattern of a melon patch will be seen

Typical Profile. Without any known exception the profile development in dunes is so slight as to be insignificant in engineering considerations The very nature of the dune form makes deep grading of cuts a common occurrence.

Problems As a subgrade material, sand is often considered the best Protection of cut slopes against wind erosion is a necessity in most instances

CHAPTER XI

AIRPHOTO ANALYSIS OF GLACIAL MATERIALS

Because of the variety of land forms resulting from glaciation the glacial materials have been divided into Moraines, Till Plains, Kames and Eskers, Outwash Plains, Lacustrine, Muck and Peat, and Terraces Terraces or Valley Trains associated with glacial drainage lines have been included because of their importance as a source of aggregate and as extensive well-drained sites for airports and highways On the other hand, drumlins, although distinctive glacial features, have been omitted because of their relative unimportance Figure 82 shows the organization of the section of the chart dealing with glacial and aeolian materials

Moraines

Land form The pattern of hills that form a moraine can best be described as "jumbled" The heterogeneous nature of the materials comprising a moraine and the uncontrolled form of the individual hills combine to give a rather distinctive land form pattern Inasmuch as the general texture of the soil in the moraine may vary widely, the shapes of individual hills within a morainic area may not be similar Likewise, some moraines may be made up almost entirely of fine-textured materials or, as in the base of many terminal moraines drawing from granular areas, they may be almost entirely of gravel

In general, the type of material within a moraine will vary not only in the cross-section but longitudinally Where the glacier has gathered debris from local beds of clay shale, the moraine will be fine-textured and the slopes of the hills gentle, conforming to the weathering characteristics of clays An outstanding example of the other extreme is found in the terminal moraine forming the southwest boundary of Lake Souris in North Dakota Here the hills are actually an aggregation of kames made up of very granular materials See plate 34

Perhaps the only other land form to be confused with that of the moraine is formed by sedimentary rocks The outstanding difference in appearance between these and the moraines is the banded and rather regular patterns of outcrops of sedimentary rocks

In detail, the hills can be found to run not only more or less continuously along the line of outcrop but in almost every instance they have dissimilar slopes on opposite sides of the individual hills This feature is controlled by the weather resistance of the rock and the dip of the strata

Surface Drainage The surface drainage developed on a moraine is obviously controlled by the original relief Corresponding to the heterogeneous nature of the moraine, the drainage pattern is best described as random Local influence of texture will bring out or minimize the surface drainage pattern, in the fine-textured soils the drainage will be highly integrated In the moraine referred to in North Dakota, there are few, if any, continuous channels since most of the water is absorbed by the granular materials Many undrained depressions are characteristic of all types of moraines

In many instances, the drainage pattern is the only apparent indication of the presence of minor moraines, especially those of the recessional type Here, the watershed or divide marks the crest of the moraine Stereoscopic vision without some means of establishing contour may fail to identify the general rise of the slope of the land towards the crest of the moraine, since its width may be in such proportion that there is no apparent slope except that revealed by the drainage pattern

Erosion Erosion in morainic areas is often pronounced In granular-textured soils the erosion is generally at a minimum, but in the average condition where the material may be termed as "semi-granular" for the purposes of this work, the prevailing slopes in terminal moraines create a great deal of erosion, often exposing the parent material Plate 35 illustrates this erosion pattern A great variety of gully shapes will be found and these, as indicated in the discussion in chapter VIII, will vary with the texture of the material being eroded.

Color The wide variation in the soil colors in a morainic pattern is one of the distinguishing features that separates a moraine from other slightly similar land form patterns The non-uniform texture together with the wide variation in slopes creates a multitude of variations in the soil profile These variations in the profile react to form contrasts in the color of the top soil, thus, the soil pattern of the moraine will range from extremely light of sloping positions where erosion is active, through the intermediate tones corresponding to the shallow profiles, to undrained depressions that have a deep profile, a high water table, and an accumulated deposit of organic material that renders the surface color black. This is in contrast to other types of materials such as shale hills that might otherwise be confused with moraines The shale producing such hills is invariably more uniform in texture and more impervious - a condition that minimizes differences in soil colors Where colors vary in shale areas it is usually along lines of outcrop and is in response to some local influence of structure or texture Thus, a color manifestation merely serves to emphasize the origin rather than to confuse it with the moraine

Vegetation and Land Use Most of the glacial drift is to be found in the more or less humid sections of the United States Being confined to the northern border states, the drift is influenced by climate that is favorable to agricultural uses and in many instances to fruit raising Therefore, the moraines are intensively cultivated except on the steepest slopes where erosion has removed the weathered soil It is not a coincidence that fruit orchards are a feature of many morainic areas They require for healthy growth a well-drained position and the prevailing slopes of a moraine are apparently favorable to this condition

The general land-use pattern is directly associated with the cultivation mentioned in the previous paragraphs Since the occurrence of glacial materials coincides with a favorable climate, most of the land is cultivated The well known fertility of most glacial materials is also a contributing feature towards the rather large percentage of cultivated areas

Typical Profile Because of the wide variation of the slopes found on moraines, the range of depth, texture, and development of profiles is great On the steepest slope, where erosion has either prevented the profile development or has destroyed it, the parent material is exposed These areas are clearly defined on aerial photographs In the depressions or in areas having very gentle slopes the profiles are generally deep and well developed The "B" horizons are generally sandy clays and present a considerable contrast in texture when compared with the parent In the less typical instances where the moraine consists of fine-textured materials, erosion and the relative impermeability of the parent material inhibits profile development so that they are shallow, weak, and relatively unimportant in construction

Problems The problems associated with construction and design in moraines are numerous Where cuts are made to maintain a reasonable grade, a great variation in texture may be expected within short distances Thus, one cut may be made in semi-granular soil and an adjacent cut may intersect stratified layers of clay, gravel, sand, or silt One of the chief difficulties encountered is coping with water-bearing seams Many of the individual hills in a moraine may have one or more of these seams dipping at odd angles These are especially important to locate and to intercept by drainage installations Needless to say, not all of these can be anticipated precisely by the use of aerial photographs and it is particularly important that field borings be made. The function of the aerial photographs in a situation such as this is to show where such a condition may occur and to indicate those areas where field exploration is necessary.

Till Plains

Land form The pattern of the till plains is that of a very gently undulating plain This material was deposited by the ice in its progress across the land and therefore, in many places where the ice movement was continuous and uniform, the till plains are very broad and extensive. Apparently the motion of the ice and method of depositing this material created a remarkably uniform surface condition Moraines interrupt this pattern and mark the positions where the ice either stagnated temporarily or reached its maximum extension Subsequent erosion, since the disappearance of the ice, has not changed the relief of the till plains to any marked degree

Surface Drainage The surface drainage of till plains can be described as dendritic The gentle slope of the land and the absence of any marked topographic obstructions has permitted this dendritic drainage pattern to develop The intensity of the pattern is somewhat dependent upon the general texture of the drift Inasmuch as the prevailing slopes are very low, a comparison of drainage patterns in various till plain areas indicates the relative texture The till of Ohio and other eastern states is composed of materials that were drawn largely from areas of sandstone, shales, igneous, and metamorphic rocks, while the till plains of western Ohio, Indiana, Illinois, Missouri, and Iowa are composed largely of debris from limestones and clay-shales Consequently, the till of the east, having much more granular material in it, is better drained than the mid-western till plains

Erosion Serious gully erosion in undisturbed till plains is not common because of the very gentle gradients However, there is extensive sheet erosion and rill erosion, largely because of the high quantities of run-off resulting from the relative imperviousness of the soil Conspicuous on the airphotos are both rills, which appear as fine hairlike lines, and the sheet erosion seen where the light-colored topsoils of the slightly higher ground is being eroded and deposited in the dark more organic areas that mark the depressions Therefore, it is conservative to say that erosion in till plains is of limited significance when studying the soil undisturbed textures, but that erosion protection on all graded areas is essential

Color The color pattern of the mid-western till plains is one of the most intensely developed of all areas Where the parent contain considerable quantities of calcareous materials, the very striking black and white pattern shown in Fig. 40 and in plate 36 is developed This contrasting pattern is found throughout the till plains although its intensity is somewhat modified in areas where the general profile is fairly well drained The till having the weakest color pattern is found in eastern Ohio and sections of New York, while it is most intensely developed in western Ohio and Indiana Exceptions to this are found in the areas shown on the map (plate 1) as old drift In Ohio, Indiana, and Illinois, these are characterized by uniform white colors with very little black associated, even in depressions Areas of old drift west of Illinois are characterized by gray tones due to the prairie development (plate 37)

Vegetation and Land Use The till plains are so broad in extent that they cover the transition between the natural forest and the prairie areas west of the Mississippi River In the more humid regions of the eastern states, wood lots are a common occurrence, whereas in the West native grasses are the only natural vegetation commonly encountered

This area is known chiefly as the corn belt Because of its natural fertility, the land is occupied by cultivated fields through which the color pattern is obvious at all times of the year In old drift deposits the profile has been leached to such great depths that they are not as productive as the young drift This condition and the parallel one of clay-pan development are reflected in the rather limited land use Locally known as "crawfish" soil, much of the land is given over to wood lots that are generally located in particularly wet positions

Typical Profile In the young drift the depth of the weathered profile varies from approximately two to four feet so that any subgrade in the till plains will, in all probability, be located in or on the weathered profile In referring to the plates 36 and 38 showing these patterns, it will be found that the light-colored areas represent slightly elevated positions having somewhat more favorable drainage than the dark ones In these light portions the profile is much more silty than in the dark depressions and is weakly developed in comparison Dark areas are typically silty clays to a depth of several feet and are coincidental with high ground water Thus, they represent developments of plastic silty-clay that are in a wet condition during most of the year In the old drift, the profiles are often weathered to depths of from eight to ten feet, in these instances weathering has created a concentration of clay that is well termed a "claypan" This deep profile is made up chiefly of silty top soil that may extend to a depth of two feet, underlain by silty clays that are mottled, occasionally cemented, and usually contain black concretions

Problems The problems associated with these profiles are largely those of recognizing and insuring against the texture and drainage conditions The silty clays occurring in the "B" horizons of each of these profiles are not considered good subgrade materials The surface silts when water logged are particularly unstable Provisions for correcting this condition, such as insulating pavements or increasing pavement thicknesses, are common forms of compensating for a naturally weak subgrade.

Kames and Eskers

Land form Kames and eskers are found only in glaciated areas and are not easily confused with other glacial forms Both kames and eskers represent remnants of glacial stream beds deposited upon other glacial forms and having no necessary textural relationship to the underlying material, whether it is a till plain, moraine, or alluvium An esker (shown in plate 40) is a ridge composed of sand and gravel that may vary in length from several hundred yards to two or three miles In height they commonly vary from 20 to 60 feet These ridges are often serpentine in shape and very much resemble a stream channel in plan, a natural characteristic since they are in effect the bed-load of streams once flowing in the glacier

The steep sides, narrow width, proportionately great length and serpentine outline are the distinguishing features of this land form A kame is merely a single hill of gravel that, if extended in any particular direction, would form an esker Kames may occur as isolated hills or in groups of hills, usually symmetrical

Surface Drainage Because of the limited watershed and the porosity of the material that form kames and eskers, these formations do not develop a surface drainage pattern It is not uncommon for an esker, however, to influence the drainage pattern of a surrounding formation, such as that of a till plain In such instances water courses of the adjacent areas are usually deflected or are otherwise controlled by the presence of the esker, and swamps at the base are commonplace.

Erosion Erosion on kames and eskers is not common, although occasionally an observer will notice that on the steepest slopes small gullies have developed. Quite often these are started by some outside influence such as the breaking of the sod cover by cattle.

Color Kames and eskers are seldom cultivated so that an unmodified soil color is seldom seen They are generally covered with a natural growth of grass or trees, but in spite of this, light tones that often indicate a well-drained soil show through the cover and lend emphasis to the fact that this is a well-drained material

Vegetation and Land Use The natural vegetative cover on these is, of course, influenced by climate, but in each case the type of vegetation can be classified as a drought-resistant form Hence, in humid areas, trees favoring dry soil conditions will be found on these formations, in the drier sections short grasses cover the kames and eskers, while adjacent soils having more favorable moisture conditions produce a more luxuriant cover

Inasmuch as these materials are granular they have produced very little weathered soil. This condition, together with the droughtiness of the material, restricts the use of these areas to grazing and natural stands of timber

Typical Profile. The typical profile developed on these deposits is weak and insignificant, weak because of the porosity of the material and the steepness of the slopes and insignificant because these are usually sources of granular borrow Where they are encountered in construction, they provide excellent subgrade and the profile has very little influence

Problems Interbedding of silts, sands, and gravels is characteristic in these forms. In using the deposit as a source of borrow, it is usually desirable to work against an open face, thereby mixing segregated materials As a subgrade situation, the occasional seams of silt that often occur may carry water and produce local areas of frost heave or otherwise unstable material.

Drumlins

Because of the limitation of space and the limited distribution of drumlins they are not presented on the Airphoto Analysis Chart

Land form Drumlins are easily identified by their form and shape, since they are one of the few glacial features that have been shaped along the lines of ice movement The directional trend of drumlins is especially noticeable when more than one occurs in an area In such instances they appear as a series of parallel ridges smoothly tapered on both sides and at each end. In longitudinal cross section they resemble a rather broad cigar with one end having a longer taper than the other (plates 2 and 41)

Surface Drainage. These land forms occur on approximately the same scale as eskers and consequently have a relatively small drainage area, therefore, little surface drainage pattern can be expected, although the texture of the soil, being less granular, causes more surface runoff and occasionally the materials that are found in drumlins are sufficiently impervious to create a very active form of surface drainage.

Erosion Because of the relatively steep slopes forming the sides of drumlins it is not uncommon to find short gullies eroding the steep sides of these ridges These gullies are narrow, shallow, and short

Color The soils developed by the weathering of drumlins are light in color because of the reasonably good drainage conditions that prevail A contributing factor in the light color is the tendency toward podzolization - that is found in the cool humid climate of the northern states where drumlins commonly occur.

Vegetation and Land Use. The fact that the materials that make up this land form are in a well-drained position (due to the prevailing slopes) together with the general occurrence of these forms in cool humid regions restricts the natural vegetative cover to the forest trees that thrive under moderately dry soil conditions.

Drumlins, where not too steep, are often devoted to extensive orchards and in most other instances they are either permitted to retain their native cover or are used for pasture

Typical Profile The typical profile occurring on a drumlin is very shallow and weakly developed because of the slope favoring surface runoff and good internal drainage The influence of podzolization creates a light-colored, silty topsoil, the conversion of the parent material, by weathering, to form a "B" horizon produces a sandy, gravelly clay that seldom exceeds two feet in depth.

Because of the relief of these features, cuts into drumlins pass almost immediately into parent material, thus minimizing the influence of the profile.

Problems. Problems associated with excavation and cuts in drumlins are practically identical with those in morainic areas

Outwash Plains

Land form Outwash plains are created by glacial meltwater breaking through moraines or other land features, transporting the materials that have been eroded, and depositing them on wide areas of relatively low land where the waters are free to spread without being strictly confined. This process of formation is directly associated with other types of water-formed features and since, in many instances, rather high current velocities are involved, a wide range in texture may be expected

In the ideal situation an outwash plain would resemble an alluvial fan both in outline and cross-section In such a case the texture would vary from coarse near the source to fine sediments at the outer fringe of the fan This general banding can be observed in several instances Unfortunately, the general land features prevailing at the time of formation do not permit this pattern to develop uninfluenced by existing channels and hills In addition to the influence caused by local land features, the fact that the period of deposition may continue over a considerable time not only changes the horizontal variations in texture but also the vertical Depending on the relative movement of the ice with respect to the source of the outwash, one may find either coarse materials at the base of the formation overlain by fine-textured sediments or these textures in reverse order

Aerial photographs of outwash areas, as in plate 42, show distinct remnants of channels that have carried the swiftest currents during the time of formation and have now been abandoned, partially filled. These channels, where the currents were probably moving at maximum velocity, also create local differences in texture much as are observed in rivers where natural levees are formed by flood water

In summarizing the land form pattern of an outwash plain, then, the features that can be ascribed to this type of formation are a rather level to gently undulating relief, marked by numerous abandoned channels, none of which have actually eroded sufficiently to form valleys or terraces Often they appear to be a series of more or less connected lakes or muck-filled depressions. In examining these areas in aerial photographs the ground-water conditions and soil texture are obviously the objective These textures are identifiable by the surface patterns characteristic of gravel, sands, silts, and lake-laid deposits of silts and silty clays In most instances lacustrine deposits are absent because the flowing water seeks, and generally finds, an existing river through which these fine-textured sediments may escape.

Surface Drainage Any one surface-drainage pattern cannot be attributed to outwash areas simply because the formation contains such a variety of textures and conditions In most instances, and especially in the more granular sections, surface drainage is not developed beyond that existing at the time of deposition. In areas of flat-lying silts and clays, it is to be expected that erosion and drainage channels may have been formed These are invariably areas of high ground water, since they occupy the lowest portion of the outwash and therefore receive most of the underground water supplied by rainfall absorbed in the granular areas. The amount of surface drainage that has developed within an area such as this is a function of the permeability of the entire profile.

Erosion Erosion in an active sense is not often found in these areas chiefly because of the gentle slopes and low gradient of existing streams In addition, the general texture of these soils does not promote surface runoff The few areas of lakelaid deposits adjacent to outwash do exhibit signs of erosion

Notwithstanding the very low gradient of the land, the imperviousness of the profile in these lacustrine areas causes surface runoff which is accompanied by erosion

Soil Color As in the parallel case of surface drainage no one color can be designated as characteristic of outwash plains In fact, extremely wide variations are common Where muck deposits are associated with sand and gravel, as they often are, the color variation is most pronounced The black or very dark gray of muck serves to emphasize the light colors of the adjacent sand and gravels The variations in color and their relations to the soil are best illustrated by reference to the aerial photographs shown in plates 42 and 44

Vegetation and Land Use The vegetative cover characteristic of outwash plains often responds to the texture and water conditions that prevail In the higher and drier areas, often on sand dunes, the xerophytic plants prevail The transition continues from that condition to the swamps containing muck and peat that are sometimes covered with tamarak

Land use likewise varies considerably Orchards and other crops are common in these areas where the well-drained soils are found and muck farms, truck gardens, "moss factories" and related land uses are found in poorly drained areas

Typical Profile Typical profiles found in the gravelly areas are represented by "B" horizon development generally extending from 18 to 36 inches in depth representing weathered portions of the gravels that produce sandy clays This combination of clay and weather resistant minerals gives, in some instances, a surprisingly plastic mixture of sand and clay Below this the sand and gravel may extend for considerable depths Uniformity in this type of deposit is not expected and seams of silt or sand provide considerable variation.

In sands the weathering seldom produces a profile that can be considered significant from the standpoint of construction problems Seldom is there a texture change indicated in these materials.

Within the silts and silty clays, profile development has usually been arrested by a condition in which the high ground-water table minimizes the effect of mechanical and chemical processes that create a weathered profile

Problems The problems of outwash plains are those chiefly related to subgrade The seeming difficulty caused by stratified materials is minimized by the fact that the prevailing land slope seldom requires heavy cuts for runway alignment.

Lacustrine

Land form The land form pattern associated with a lacustrine deposit is one of the most level of all geomorphic features. The large areas indicated on plate 1 represent wide expanses of almost unbroken relief Glacial Lake Agassiz, occupying adjoining areas in Minnesota and North Dakota and extending for many miles northward into Canada, is perhaps the largest Occasionally, because of some relative change in the elevation of the deposits, they become dissected in a manner directly related to their form and texture Such an instance may be found along the southern shore of Lake Superior in the vicinity of Superior, Wisconsin Here the red lacustrine clays (Superior clay) have been highly dissected, but the flat-topped hills, having common elevations, retain the semblance of the land form The well-rounded, uniform slopes are indicative of the clay-like texture (76 8 percent passing No 200 sieve, liquid limit 57)

Where sufficient coverage is available, the shore line or morainic barriers may be seen Often these lakes have been formed by terminal moraines, but other structural features may have impounded glacial water to form a temporary lake

Surface Drainage. Inasmuch as the texture of these deposits is fine and their position with respect to the surrounding land, low, they will receive a large amount of surface water The general tendency of these deposits is to have impervious profiles, resulting in a high degree of development of the surface drainage pattern Because of the low gradients that prevail the primary drainage system will extend for long distances and will be characterized by meanders.

Erosion The only erosion to be observed in lacustrine areas will be found adjacent to the drainage channels Here the side slopes of the drainageway will be soft and well rounded, indicating the texture and uniformity of the deposit Figure 71 shows a typical ground view of this feature Where the top soil is silty the process of erosion will form a wide fringe that borders the gully proper

Color The colors that are developed on lacustrine soils are usually drab In many cases they will be found to be a dark gray, broken only by slightly lighter areas that represent very small knolls or surficial deposits of silt or sand In examining the photographs of large sections of the Lake Agassiz basin, there is found a distinct correlation between the silty soil (Beardon) and the lighter-colored pattern of the photographs The silty clays (Fargo) have developed a dark gray color.

Vegetation and Land Use The natural vegetation occurring on lakebeds under humid conditions must inevitably be of a swampy nature, while in the dry climate that would include the desert area of Lakes Lahonton and Bonneville, there is an extreme variation in vegetative cover.

Here again the wide variation in climate tends to a multitude of uses for this type of land In humid areas the excess moisture in the soil almost precludes its use for cultivation unless some form of drainage is installed Therefore, a ditch system and the use of "dead furrows" will be associated with cultivated fields in lakebeds Figure 75 indicates the appearance of a dead furrow in such a field while reference to plate 43 will show their appearance on an aerial photograph

Typical Profile Because of the general imperviousness and the high groundwater conditions that prevail in most of these deposits, profile development has been retarded to such an extent that it has no appreciable influence on engineering structures Below the loose top soil it is commonplace to find deep beds of laminated silts and clays Associated with the lacustrine deposits there are old shore lines of beach ridges composed of granular materials assorted by wave action and heaped up in ridges paralleling the original shore line These serve as excellent sources of borrow in an area where such material is badly needed

Problems Inasmuch as there is little variation in relief the chief concern when constructing pavements in these areas is to provide as much drainage as is practical as well as to assure sufficient supporting power in the subgrade.

Muck and Peat

Land form Muck and peat are here listed under glacial developments since many of the large deposits are associated with glaciated areas These materials are usually formed in depressions already existing and filled with water The gradual filling in of these channels, ponds, and lakes by vegetation growing in and along the edge creates the muck and peat swamps of today These will be observed in various stages of development, but in each instance the original outline of the lake will be very clearly marked Usually small bodies of water remain near the center to indicate either the presence of an underground spring or the fact that the development has not proceeded sufficiently to complete its work

Surface Drainage Since these deposits represent the lowest elevation in the area they seldom have any surface drainage pattern Occasionally water may flow in restricted channels, but this is not necessarily surface drainage from the muck Where these areas are drained by open ditches, such structures have been installed in an effort to lower the water table and to make the deposit suitable for agricultural purposes

Erosion None

Color The very high organic content of these deposits invariably shows a black or very dark gray in contrast to the much lighter soil colors in nearby areas

Vegetation and Land Use The vegetative progression that helps to identify these areas is a very interesting one In many cases it is possible to see the distinct change from the nearby upland vegetation through swamp forest vegetation, marsh vegetation, and aquatic vegetation to the edge of the open water (if any) Plate 44 shows this pattern and an associated "bomb shell" pattern that is not readily explained Dachnowski-Stokes gives an excellent cross-section of this trend in "Soils and Men" (43)

Depending upon the local conditions and efforts that have been made to reclaim these deposits, there may be an intense development of truck farms on these bogs In the northern states, particularly northern Wisconsin, Michigan, and Minnesota, most of these areas have not been developed Occasional "moss farms" may be observed.

Typical Profile These deposits vary from a few feet up to one hundred or more feet in depth Almost invariably they are underlain by porous water-bearing materials that contribute to the conditions that are favorable to the formation of the bogs The material in the form of peat is a fibrous mass in which leaves, bark, and fragments of limbs and twigs can be identified In the muck these have reached an advanced stage of decay In either instance these materials are wet, partially consolidated, and contain a very large proportion of organic material.

Problems Deposits of these materials always present a problem in providing a stable foundation for any structure imposed upon them The high ground water, and subsequent shrinkage if drained, presents only one phase of the problem When these areas are drained, it is not uncommon for them to become ignited and burn for long periods of time, resulting in a formation of underground cavities that eventually collapse and contribute to the settlement The mere operation of draining such a deposit has resulted in a uniform lowering of ground level by as much as four feet The high degree of instability of these materials makes it necessary either to bridge or excavate in most cases

Terraces

Land form In glaciated areas and those adjacent to the glacial border, the principal streams were formed by glacial melt In some instances they coincide with lines of pre-glacial drainage but in every instance the volume of water issuing from the melting glacier was so much in excess of the normal precipitation occurring before or after glaciation that the river valleys are not in proportion to the streams now occupying them

The large volume of water that carved these valleys also carried much glacial debris as sediments that were deposited in the stream bed and flood plains of the rivers At the present time the relatively small streams now occupying these valleys have lowered their channels leaving extensive deposits of glacial materials as high terraces or valley trains At the point of discharge from the glacier the meltwater dropped most of the very coarse material and as the stream continued down the valley gradually losing its velocity it also deposited, by selective deposition, the gravels, coarse sands, fine sands, and silts at increasing distances from the source.

In summary, it is characteristic of streams in glacial areas to occupy disproportionately large valleys and to have one or more high terraces occurring at frequent intervals along the stream This is not only characteristic of large rivers but continues down through the smaller classes of streams, even to those bordering on the intermittent type

Surface Drainage Since these terraces are composed of sands and gravels with some silt - and at their most distant extremities, of sand - they are well drained, except in minor slack-water areas Being well drained internally they have preserved their original form As a rule, the only surface drainage pattern that will be found on these terraces will be that created by major channels originating in the upland and crossing the terrace to gain entry to the principal stream Otherwise, all the water discharged on the surface of the terraces by surface run-off from the adjacent uplands is absorbed and carried to the principal stream as ground water

It is not quite accurate to say that there is no evidence of surface drainage on these terraces because the dark mottled areas that develop on the surface actually mark the infiltration basins through which the water percolates downward In the form of a comparison, these might be described as very weakly developed sinkholes, such as occur on a larger scale in soluble limestones Several instances of well-developed sinkholes occurring in gravel are found in the Great Plains

Erosion The weathering of these level granular materials produces a sandy clay profile or "over-burden" that is several feet in depth In localities where this is well developed, erosion of the surface soil sometimes occurs, especially near the face of the terraces where steep slopes are found In such instances, short V-shaped gullies carrying runoff mar the sides of the terrace, indicating the presence of a relatively impervious but thin topsoil as well as a granular substratum

Color The colors of the soils on these terraces vary from white to light gray in appearance on aerial photographs The white is indicative of a large proportion of sand in the surface horizon while a uniform gray pattern is the common tone observed in photographs of reddish-brown soils associated with weathered gravels The small dark spots, usually circular in shape, are the extremely shallow depressions marking the areas where water percolated down through the soil

Vegetation and Land Use The natural vegetative cover occurring on these land forms is almost completely destroyed since the soils occurring on these terraces are excellent for farming In the west where the rainfall is scanty the soil moisture in these well-drained terraces is sufficiently low to prevent the growth of trees In such areas the trees are usually confined to the low levels of recent alluvium that have a more favorable ground water condition In the extreme northern areas within the States, some of the terrace remnants, too small or remote to be cultivated, are covered with a growth of pine

Because these soils are porous and rich, they are suitable for the cultivation of orchards and they are among the first soils that can be worked in the spring These two properties make them desirable for farming and it will be found that most of these terraces are entirely cultivated

Typical Profile Where these terraces are composed of combinations of sands and gravels the sands are largely siliceous in nature and the gravels, calcareous or igneous In the process of weathering, both the calcareous and igneous materials form clays and silts Thus, the weathered profile commonly consists of a sandy topsoil several inches in depth underlain by a "B" horizon development of sandy to gravelly clay that may extend as much as four feet into the deposit Below this, for considerable depths, sands and gravels will be found On sandy terraces the sands are weather resistant and consequently fail to develop a significant profile

Problems The combination of level terrain and the well-drained nature of the profile makes these areas ideal locations for airports.

CHAPTER XII

AIRPHOTO ANALYSIS OF WATERLAID MATERIALS

The outline of the Airphoto Analysis Chart indicates that the materials of the Great Plains Outwash Mantle, Coastal Plains, Filled Valleys, and Recent Alluvium are to be discussed in this section These in turn are subdivided into divisions that deal with important features, characteristics, or soil textures of the principal area For example, the Coastal Plains are divided on the basis of relief characteristics into "Lower" and "Upper", and further divided into the prominent clay belts on the basis of texture It will also be noted that under Streams, "Mature" and "Old" are shown "Young" streams are not included, chiefly because they have not developed alluvial plains of sufficient extent to be widely considered

Soils of the Coastal Plain

Land form Soils of the Coastal Plain are predominantly water-deposited materials eroded from adjacent uplands during periods of continental submergence When this province along the eastern and southern seaboard was elevated above sea level, the land form that prevailed at that time was a level to gently sloping surface Since these deposits were not all placed and elevated at the same time there is considerable variation within the Coastal Plain On that basis the Coastal Plain has been subdivided into two classes, with a third subdivision - the Clay Belts - provided to accommodate the "problem soils"

The divisions based on relief are termed the upper and lower Coastal Plain, the upper areas are dissected and have little resemblance to the common conception of Coastal Plains based on the general impressions associated with the level terrain of the lower plains area Because of the age and height above the base plain of erosion, dissection has created, in the upper plains, a region of valleys and ridges not obviously associated with water-laid deposits (plates 48 and 49)

On the lower Coastal Plain, that is of relatively recent age, there is little dissection and the rivers flowing from the higher ground are characterized by their low gradients and wide valleys At the coast these streams are building deltas and associated with their mouths there are large areas of swamp and marshland On the shore line, barrier beaches and lagoons are typical. On the East Coast wide streams of very short length and without appreciable valley walls are characteristic (plate 46) These occupy drowned valleys indicating that the land is once more being submerged

The land form of the clay areas is not topographically distinct from either one of the other two subdivisions This group includes the Black Belt soils and also those clays pedologically identified as Susquehanna, Orangeburg, Lufkin, and related soil series (44) Within this group the land form is generally characterized by intricate dissection, although the slopes that have weathered to gentle grades (seldom reaching seven percent and not exceeding 10 percent) characteristic of clays, are found in this subdivision and not associated with the sand-clays and sands forming the balance of the Coastal Plain materials

Surface Drainage. In the upper Coastal Plain it has been indicated that much dissection has progressed through geologic time Therefore, the surface drainage conforming to this dissection extends into the upland areas forming a pattern that is fine in texture, indicating a high degree of development This dissection has left only a relatively small percentage of the original surface, therefore, the cultivated fields generally occupy only a small portion of the land since they are confined to relatively level uplands or to the alluvium In the lower Coastal Plain the surface drainage is less complete and channel features are replaced or modified by a large proportion of swamp land The principal drainage systems here are the rivers that drain the higher and more remote sections; associated with these are extensive networks of artificial drainage systems. This situation is particularly true in the more fertile East where the hand-excavated ditches date from slavery days.

The drainage pattern most commonly found on the clay areas is best described as dendritic. The gentle seaward slope and the impervious profile make ideal conditions for the development of a pattern of this type.

Erosion. Erosion is one of the major agricultural problems of the South. In the upper Coastal Plain erosion is most active because of the high drainage potential. The active "U-shaped" gullies are readily observed since the sand-clay texture and profile development combine to permit a waterfall action at the head of a gully with consequent undercutting.

In the lower Coastal Plain, due principally to the low drainage potential rather than any general differences in the soil, erosion is insignificant. In the clay belts where the top soils are silty clays and the subsoils are relatively impervious the conditions are ideal for sheet erosion. Even on the remarkably gentle slopes (Fig. 82) a large amount of surface runoff occurs, carrying with it much of the soil mantle. In many places this erosion has progressed sufficiently to expose the underlying strata that are chiefly white chalk-like shales, marls, and limestones.

Color. The general color of the Coastal Plain soils is commonly described as red or reddish-brown. However, in any one area covered by a single photograph there is a considerable variation in soil color, due partially to changes in texture but also attributable to the ground water conditions and erosion. Even in the so-called Black Belt where soil colors are often considered to be uniform when viewed from the ground (fig. 82), the variations include all shades of gray and in many instances both white and truly black tones occur (plate 50). In the Alabama sections of the Black Belt it was found that the texture of the materials varied in harmony with the changes in color, the blackest areas having the highest clay content. With increasing amounts of silt the gray value becomes lighter. In areas where the underlying chalk is exposed by erosion a white value is indicated. In the lower Coastal Plain where slight differences in relief create similar differences in ground water conditions, the wet areas are easily identified by the darker color of the soil. In this way many small channels, probably constituting meanders of streams making the original deposition, can be detected. In all sections of the Coastal Plain the lightest tones are associated with areas of sand so that, even in areas generally considered as sand-clay, a study of the photographs will show local areas having a higher sand content and a consequent improvement in drainage conditions.

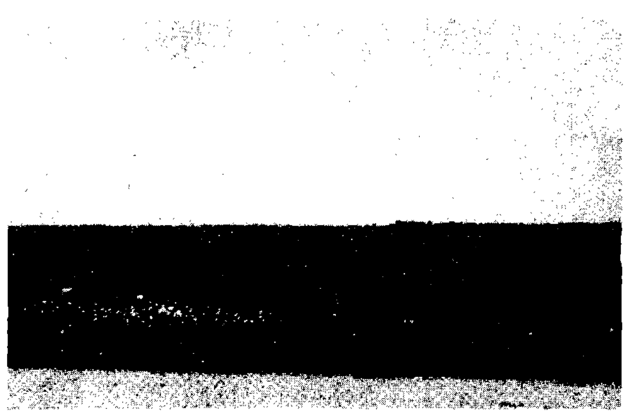

Fig. 82. This ground view is a typical scene in the Black Belt area, showing the very gentle slopes prevailing in these sections. The apparent uniformity of black color, as viewed from the ground, is disclosed in the airphotos (plate 50) as being quite non-uniform in shade with corresponding variations in plasticity, drainability, and stability.

Vegetation and Land Use In most of the Coastal Plain, especially in the southeastern states, the famous pine forests occupy a large percentage of the land that is no longer suitable for other purposes Here and there on isolated hills small farms may be observed These usually occupy less sandy positions Within these cultivated fields the influence of a higher percentage of fines will be noted by the variations in color The sand-clay texture typical of some sections of the Coastal Plain seems to be particularly critical of water retention, unbelievably fine distinctions in texture and plasticity can be made by aerial observations of these colors in cultivated fields Both the upper and lower Coastal Plain in the Florida-Georgia-Alabama sections are devoted to southern pine native cover, where associated with cultivation these timbered areas are either dissected or sandy In the northern extension of the Coastal Plain on the East Coast practically all of the suitable land is cultivated - the balance is swamp, covered by cypress and related water-loving vegetation (plates 46 and 47) The subdivision of the Coastal Plain dealing with the clays is somewhat more complicated in that the Black Belt soils are largely planted in cotton Where erosion has seriously affected the Black Belt soils, grazing is now becoming an important land use The lighter-colored clays seem to be less desirable agriculturally and much of this type of land has reverted to second-growth forest cover

Typical Profiles The more or less alluvial origin of these Coastal Plain materials makes for stratification Likewise the relative youth and mineralogical composition of these materials do not seem to have been favorable to profile development so that, even among the pedologists, there is not ready agreement on either profile descriptions or boundaries for many of these areas

In conformity with the engineer's usage of these soil-areas for airports it is seldom necessary to make cuts that go below the depth of soil that influences the pattern recorded on aerial photographs Hence, sand-clays are referred to with the thought that the materials encountered in airport construction will be sand-clays At greater depths there may be wide variations in texture, these will not materially influence construction problems or subsequent performance of pavements Likewise, this same type of analysis can be made in most of the other soils found in the Coastal Plain However, in the widespread and complex designation of interbedded and intermixed materials drastic changes in texture will be found within extremely short distances Deposits of gravel may be found either in recent alluvial deposits where currents naturally decrease in velocity or on high interstream ridges that mark terraces formed by ancient rivers These terraces have been preserved as ridges standing above the surrounding land simply because they are more weather resistant due to their high permeability In considering the Black Belt, where the clays rest on marls or related material, it is more feasible to speak in terms of typical profiles Here the silty nature of the top soil is indicated by evidence of sheet erosion and the preventative land-use practices of terracing and contour plowing This type of erosion indicates an impermeable soil when present on such low slopes Supplementing this, the gullies that are formed in the weathered slopes of the hills have, in common, the very gentle slopes indicative of silty clays and clays The wide but shallow gullies infer a contrast between the easily eroded topsoil and the erosion-resistant silty-clay subsoil material Therefore, using these elements of the soil pattern and observing possible evidence of rock in the area, it is possible to construct a profile for any given location With the aforementioned analysis, the remaining variable is that of the depth of the soil over the rock. This can be estimated by the presence of exposed rocks, slopes, erosion, and soil color

Problems. In the lower Coastal Plain the range in texture from dune sands to clays, together with a flat relief and high ground water condition, establishes the type of problems involved in airport and highway construction Where the texture is fine and the ground water table high, it is usually desirable to elevate the grade line by constructing fills In many instances it has been observed that the construction of fills using the same silty clay or clay soils does very little to improve the situation and it is necessary to import granular base material, often at great cost. If the characteristics of the soil rather than the methods of construction are at fault then reconnaissance with photographs provides an easy means of locating the nearest areas of granular material that can be used in improving subgrade conditions Discharging accumulated surface water from runways may require extensive erosion-control structures

In the Black Belt, the ground water conditions are unusually good for a soil area possessing this texture Nevertheless, the performance of flexible pavements in these areas has indicated that the normal saturation by rainfall is sufficient to give the subgrade a low bearing value during some seasons of the year However, on the lighter-colored clays, the performance of pavements has been noted to be as poor as on any soil in the country This may be partially attributed to the fact that these clays are "chemically active"

Soils of the Filled Valleys and Great Plains Outwash Mantle[5]

Great Plains Outwash Mantle

Land form The soils of the Great Plains outwash mantle are ancient alluvial deposits derived from the Rocky Mountains to the west Originally this vast area must have been a plain gently sloping eastward from the mountains with all signs of other land features buried beneath this relatively deep deposit The remaining outwash mantle typified in the High Plains is a remnant

However, it is necessary to subdivide the area into approximately three classifications This is desirable since erosion, eating into these materials from the east, has removed considerable quantities of this mantle and in many places has exposed the once-buried land features (plate 54) In many areas this process has proceeded to an advanced degree so that little, if any, of the mantle now remains Therefore, these denuded sections should be placed in a separate category concerned with consolidated materials The principal subdivision, though, deals with the High Plains areas which are essentially level where the soils are composed of water-laid materials that are unconsolidated The intermediate classification is one of transition between the preserved Tertiary mantle and the areas where it has been almost entirely removed

The natural laws of deposition would indicate that within the High Plains those water-laid materials occurring at the greatest distance from the source have, in general, the finest textures and those occurring near the mountains contain a large percentage of fragments. Plate 51 typifies the pattern that is characteristic of some of those portions of the level or undulating High Plains at considerable distance from the mountains where contour cultivation is practiced Two other variations often occur in this division of the plains Near the base of the mountains it is much more common to find the remnants of streams and abandoned channels that carried or are carrying the sediments that have built up this mantle At increasing distances these channels become less pronounced Plate 52 is a vertical photograph illustrating this characteristic The pattern - that is so often associated with the finer textured materials and seems to replace the channelized pattern - is that of many more or less circular depressions noted in plate 51

In the intermediate subdivisions of the High Plains the characteristic pattern is generally associated with some of the major streams crossing the plains from west to east In these areas, closely associated with the stream channels, some of the mantle has been removed by erosion Here, within a distance of a few hundred feet up to a few miles may be found the preserved Tertiary mantle on the

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[5]At the time of writing none but the preliminary field work has been done on airphoto analysis of soils of the filled valleys and the Great Plains outwash mantle Field work under way is expected to provide the details necessary for such analysis, and for that reason the information presented here has been limited largely to the general considerations of terrain, and does not include airphoto details - - Ed.

uplands and progressive denudation of the underlying materials as the stream valley is approached (plate 53) Within short distances a wide variety of materials may occur as is witnessed in aerial photographs of these areas (plate 53) The relatively porous mantle of the upland shows no indication of bedrock underlying it and they may be considered as having the same pattern as that found in one of the first two classifications However, in the area between the uplands and the alluvial soils adjacent to the rivers, erosion has exposed the materials and weathered to the extent that the natural slopes that they have assumed are in harmony with their physical properties These are often highly dissected and present an extreme contrast to the alluvium and to the level upland.

Sections where the material has been entirely removed can hardly be classified with the Tertiary mantle (plate 54) Although these will contain a wide variety of land forms corresponding to the type of rock that has been exposed, it is necessary to discuss them since they are so intimately associated with the plains materials

Seldom are these materials found tilted at steep angles, so that when erosion of these strata occurs, they bear a strong resemblance to the land forms described in the section on sedimentary rocks in horizontal positions Here, as in other areas, the clay shales assume soft, gently rounded slopes and the more resistant limestones and sandstones form abrupt breaks in the pattern Occasionally dykes and related forms of igneous rocks may be seen

Surface Drainage. In the areas of gently undulating relief there is very little surface drainage of the primary type since the light rainfall characteristic of those areas is generally absorbed by the soil mantle. In the plate (51) showing the Ogallala formation, the primary drainage system is unusual in that it concentrates water in the depressions, seepage into the soil and evaporation account for the total rainfall Where the Tertiary mantle has been removed and steep slopes are common, the high percentage of run-off due to these steep slopes creates very active surface drainage and erosion In these instances the surface drainage pattern is not so important since the weathered slopes of the different materials are easily observed and have a significance directly related to their physical properties

Erosion In these areas two types of erosion are encountered, occasionally they are found in direct association Wind erosion, forming sand dunes and silt hills, is very active in many districts and these two land forms have been covered in the discussion of aeolian soils Water erosion, where it occurs, is particularly indicative of the texture and profile, since it not only provides gullies for a study of their shape, but also gives an opportunity to study the texture of the materials of alluvial fans at the bottom of the slopes. Fig 69 shows that the characteristics of gullies in humid climates do not apply uniformly to gullies in the arid regions Here it is necessary to place more emphasis on the shape of the gully with respect to its position in the watershed, slope of the channel, and whether the material is of recent origin or partially consolidated and cemented by caliche

Color Occasionally color is one of the weakest elements in the soil pattern In some instances it follows a very close relationship with the texture and/or moisture in many areas where there are variations in the soil It will be noticed in plate 51 that the bottoms of the depressions are extremely dark when compared with the slightly lighter color of the higher areas In these situations it will be found that the soil in the bottom of the depressions has a much higher clay content than the adjacent light gray soils However, in vast areas where the materials are well-drained internally, as well as where wind action has provided recent covering, the color pattern will be confined to only slight variations in shading, representing variations that are insignificant in the light of present information Where the Tertiary mantle has been removed it is not uncommon to observe red colors that are associated with some of these consolidated materials. The light colored fringe that is associated with erosion in many of these areas is an indication of the caliche forming in the subsoil The relative abruptness of the slopes associated with this erosion is an indication of its depth and degree of cementation

Vegetation and Land Use In examining these materials in the more dry climates, the soil moisture conditions are uniform and there seems to be little significance in the relationship between plant growth and soil texture The majority of plants in these areas are of the grass and low shrub variety There is a distinct relationship between local areas of seepage water and exceptionally lush growth of some species of moisture loving trees, this is not necessarily related to soil texture In these areas land use is almost entirely confined to grazing and therefore is of little significance Grain crops are also common but they do not add appreciably to the interpretation except that they indicate some small degree of soil moisture preference over the drier areas

Typical Profile The typical profile can hardly be developed for this area The wide variations that occur in texture both vertically and laterally make it impossible to establish any one profile as typical

Problems The infinite variety of textures and water conditions in the plains makes it unwise to attempt a generalization on engineering problems However, by examination of the photographs the small localized areas of ground water can be identified when present and considered from the standpoint of their relationship to the texture of the soil and the contemplated engineering structures One of the most interesting problems that is yet relatively new is that created when a large impervious surface such as a runway is constructed in these dry climates There is evidence that after some period of time the protection afforded by the impervious surface cuts off evaporation and permits moisture to collect in the subgrade either by capillary action or by vapor transfer

Land form The land form of, and that associated with, filled valleys consists of high upland areas, usually mountainous in character, on either one or both sides of a wide valley In the sense that these land forms are referred to in this report, they occur only in the arid southwestern and western sections of the country The significance of the arid climate is great because of its influence on vegetation and the characteristic rainfall that occurs in arid regions The lack of complete vegetative cover combined with the intense rainfall makes erosion extremely active Therefore, the mountains that are largely devoid of vegetation and are highly dissected by erosion that is contributing the materials to the filling of the central valley

This land form, illustrated in plate 55, includes two distinct divisions The first occurring in the mountainous zone is that characterized by erosion and the second including the lower valley region is being built up by the deposition of the materials eroded from the higher slopes. The latter is the important zone to those concerned with the construction of airports

Surface Drainage The drainage pattern developed in these areas follows somewhat the same division described above In the area where the materials are being cut down and removed, the drainage pattern will vary depending upon the type of rocks that form the mountain In the zone of deposition the drainage pattern undergoes a constant change from the upper margin of the depositional area to the central section of the basin. At the upper margin, the general land slope is still sufficient to maintain a rather simple drainage pattern The waters descending from the uplands are seldom increased in the lowlands by local rainfall Therefore, in the upper margin of the depositional zone the channels are formed in coarse alluvial materials These channels are characterized by steep sides and in many instances they are fairly well established

As the gradients of the streams decrease toward the central area, channels have more of a tendency to meander, since it is here that deposition of intermediate (and predominant) textures occur Also it is in this area that much of the water is absorbed in the soil to form a relatively shallow ground-water table As the central zone is approached the average size of the materials deposited becomes increasingly fine. Often surface water reaches these areas only during brief seasons of the year At these times lakes form and the fine textured sediments settle out and the water disappears by evaporation When no lake is present there may be seepage lines in local parts of the valley where ground water is forced to the surface by impervious strata of lacustrine origin

Erosion Erosion by water in the valley proper is very slight since it is an area of deposition Erosion by wind is the chief type observed in these areas Normally the wind will gather loose sands and form groups of dunes that will move across the level areas sometimes creating sharp contrasts in texture within very short distances Fortunately these can be identified easily in aerial photographs

Color The limited amount of work, in connection with this report in these areas, prevents any detailed description or evaluation of soil colors In the central valley in California, however, the response of color to textural changes has been found to be definite as it is in many other climates In the area investigated, the lacustrine clays assume a dark color and the fine sandy areas adjacent to intermittent streams are correspondingly light

Vegetation and Land Use A great deal of investigational work has been done by others in correlating vegetative types with soil and moisture conditions Additional work planned in this area contemplates the investigation of the vegetative pattern in aerial photographs. Work done by others has shown that vegetative types indicate the relative depth to ground water and the presence or absence of alkalies in the soil In photo-interpretation it has been found that where these two conditions are definite, then the vegetative pattern formed by the plants that correspond to these conditions can be identified At the present stage of development this is an element of the pattern that, when combined with color and knowledge of the formation of alluvial deposits, must be used as a basis for second order inference of soil conditions

Typical Profile and Problems. The wide variety of textures both in areal and vertical distribution makes discussion of a typical profile impractical. Here the influence of surface flow is important and the protection of engineering structures against erosion and deposition is paramount Since it is often necessary to avoid the low central areas because of periodic flooding, airports may, on occasion, be placed on the gentle slopes above the lacustrine area In these situations changes in the channels of contributing streams and seepage along impervious strata will constitute the major difficulties Again the evidence shows that construction of a large impervious surface will permit moisture to collect immediately under the surface with the possible softening of the subgrade if no provision has been made to insulate the pavement from the plastic material

Recent Alluvium

Land form Streams are generally classified with respect to age designations of young, mature, or old This classification is readily adaptable to a general description of the type of streams that are observed in aerial photographs

The young streams are those that are eroding their valleys and increasing the local differences in elevation They have constructed only minor alluvial terraces but have not yet reached the stage where they flow entirely within the confines of their own alluvium Mature streams are those which have advanced in age to a point where the stream has constructed flood plains and terraces and has started to widen the valley section by dissection and development of local watersheds adjacent to the main valley rather than direct cutting by the main channel itself Old streams are those that have developed wide flood plains and associated terraces These streams are characterized by meanders, oxbows and abandoned channels In considering the land form of a stream in its entirety, it is often the case that the headwaters of the stream will be flowing in a young valley and in passing down the river to its mouth, the valley goes through the more advanced stages of maturity and old age In a related manner it is also conceivable that two streams having the same life span will have valley sections that will be classified in different ages The nature of the area through which a channel flows controls this type of classification A stream may be many times the actual age of an old stream and yet be considered young if it happens to flow through areas of resistant rock Another stream may be considered old in terms of valley section even though its life span may be short, provided it is flowing through soft, erodable materials.

Surface Drainage. Surface drainage developed on terraces and flood plains is significant where it is observed Most flood plains are refreshed from time to time by overflow, a condition that generally removes any surface drainage pattern that exists or actually prevents any surface drainage development because of the short interval between periods of flooding Therefore, the absence of a surface drainage pattern on flood plains is not necessarily an indication of the presence of porous material On elevated terraces that are above overflow - and these are largely confined to at least mature and old streams - the time interval is usually sufficient to have permitted drainage patterns to develop in proportion to the permeability of the particular area In places where rivers were once glacial channels the terraces will probably be constructed of gravels and sands and in those instances they are sufficiently porous to have developed a very weak drainage pattern. It is particularly important that there is a differentiation made between the true drainage pattern and current scars that are made by flood waters; these are seldom connected and merely represent a local channel with very little actual drainage area. Current scars are nearly always associated with areas adjacent to the normal stream channel

Erosion Erosion on flood plains that are periodically refreshed is seldom observed. The very flat slopes that characterize these deposits are not conducive to rapid runoff and, therefore, there is little opportunity for erosion to occur. Within a valley area the principal signs of erosion will be observed on the valley wall and on the steep sides of higher terraces This is especially true where surface drainage is developed on the terrace and the water is discharged across the face of the terrace onto the recent alluvial deposits. In instances where the terraces are high and the faces abrupt, considerable erosion may have taken place to form notched gullies

The texture of the terrace material will be indicated by this erosion feature This, together with the surface drainage, contributes the greatest amount of information on these terrace deposits Where very slight surface drainage patterns have developed and are associated with short, V-shaped gullies on the terrace faces, the observer can be sure that the terrace is composed of a weathered soil profile near the surface that is underlain by stratified granular materials In situations where the gullies extend for considerable distances from the face of the terrace and are characterized by soft rounded slopes, then the texture of the deposit will be found to be silty clay

Color The soil colors associated with alluvial deposits are indicative of the surface texture but do not necessarily reflect the character of the underlying material As in other types of formations, light colors are associated with the better drained sandy and silty materials while dark gray areas indicate fine textures and generally poor drainage Across any one section of a valley, it is nearly always possible to observe the very light color of the natural levee that is built up by deposits of the coarsest material that the stream is carrying Against the valley wall and at some distance removed from the stream channel drab colors of the fine-textured materials deposited in the slack-water areas are often seen

Terraces that are of such age to have developed a weathered profile have in some instances distinctive color patterns. Gravels that have weathered to form a sandy-clay horizon are distinguished by rich reddish-brown colors that photographs a medium gray The mottled effect that is associated with gravel terraces is caused by the very small local areas through which water percolates most readily These areas contain a more advanced profile development and for that reason have a darker surface color, thus giving the effect of mottling not associated with the majority of other deposits

Vegetation and Land Use Since these areas are chiefly devoted to agricultural use, vegetation has little significance except locally where it marks wet swampy areas Usually, the land-use pattern is significant since by either the absence or presence of drainage installations it is possible to evaluate the porosity of the profile One of the most common features associated with poorly drained terraces is the dead furrow developed by the farmers' method of plowing, leaving these shallow furrows to function as open drainage channels Figure 75 and plate 43 give the ground and air appearances of this type of drainage.

Typical Profile It is impossible to establish a typical profile for this wide variety of materials It can be taken for granted that the profile at any point will contain evidences of stratification that are caused by changes in the relative position of the channels as well as progressive development in the erosion of the watershed It is almost a foregone conclusion that in old stream valleys and in areas that have been glaciated, the material in the profile will contain increasingly large amounts of granular material with increasing depth Reference to the discussion under the heading of Recent Alluvium (chapter VI) will provide a better understanding of the variations caused by age, the characteristics of the watershed, and local influences.

Problems The engineering problems associated with alluvium are generally related to the texture of the material and the water conditions created by both ground water and flooding Because of the generally level terrain, cuts are rather infrequent except in passing from flood plains up into terraces and thence into valley walls The location of an airport is seldom made in an area subject to flooding unless levee protection is provided. Where borrow material is required for runway fills or the construction of levees, the reconnaissance of the local areas will provide the location of a wide variety of textures

CHAPTER XIII

APPLICATION OF THE DATA TO AIRPORT DEVELOPMENT

The information presented in this report dealing with soils and techniques for determining soil characteristics from aerial photographs and other aids has practical applicability to several fields of engineering For use in airport and highway engineering a new technique is introduced, which, after it has been further developed and exploited, is expected to provide new tools with which not only detailed reconnaissance for location can be made rapidly, but by which tentative cost estimates and even pavement designs may be projected The location of construction sand and gravel by means of the airphoto technique is of obvious value in all types of construction in which these materials are utilized Excavation estimates can often be made with accuracy from airphoto identification of the soil and rock characteristics, and frequently the properties of foundation materials, including those at dam locations, as well as seepage zones and areas of artesian flow, can be determined with reliability by use of the information and procedures discussed in the preceding chapters

The potential value of these data and techniques in connection with airport design and construction becomes immediately apparent to the reader However, its use is by no means confined to the construction and design phases of airport development. It is probable that even greater total economies may be accomplished if information on soils can be utilized in the earliest stages of development when the airports are being planned and the sites are being selected In the past the character of the soil at an airport site has been, at most, a minor consideration in selecting the location, and in the great majority of cases this factor has not been considered at all in site selection Soil borings, for example, are not obtained until the individual site has been selected and the runways have been actually laid out. As shown later in this chapter, the character of the soil on which an airport is to be built may affect the cost of the airport by large amounts.

The development of a municipal airport, other than one established for military purposes or emergency landings, should be based upon three scientific studies First, an urban airport plan for the municipality and its environs should be prepared This should be based upon a thorough economic study of the air-transportation requirements of the entire community and, if properly made, will include the location, number, size, and class of all airports needed in the foreseeable future The second essential is a site-selection analysis for each of the airports included in the urban plan This must be based upon a balancing of all costs including, of course, such major cost factors as those of pavements, drainage, grading, and turfing which are closely related to soil conditions The third requirement, procedure for which is better established than for the first two, is an engineering design and master plan for each of the individual airports after the sites have been scientifically selected by means of the first and second studies

During the war, the urban planning of a group of airports to serve all of the aviation needs of a community, and the development of scientific methods for site selection with respect to all economic considerations were relegated to roles of minor importance In the preparation of a national plan of airports it is recognized that these problems are yet to be solved, and furthermore that a large part of this work must be done by local and private engineers The National Airport Plan (House Document 807, 78th Congress, Second Session, 1944) emphasizes that the airports listed therein have not been located, and of course engineering plans have not been prepared for them This was clearly set forth in the letter transmitting the airport plan to Congress, in which the Acting Secretary of Commerce stated

> "Airport requirements for most metropolitan areas are subject to change as the planning bodies for such districts complete comprehensive municipal surveys. Also, many military airports undoubtedly will be made available for civilian use eventually Both

considerations will make necessary revisions of the plan to conform with the policy finally established. Attention is called to the fact that no attempt has been made in the report to select sites. This was necessitated by the existing limitations of time, personnel, and funds, and as well by our conviction that this phase should be worked out in close collaboration with State and local agencies "

It is obvious therefore that much work remains to be done by private, local, and State engineering organizations in preparing urban airport plans and selecting sites on an engineering basis, as well as in the more generally understood tasks of design and construction This is not only true in connection with airports included in this National Airport Plan, but also with respect to those which will appear in its annual revisions and those several thousand airports which it is expected will ultimately be developed without assistance from the Federal Government In this rapid expansion of the nation's airport facilities it is to be expected that some important factors such as soil characteristics might be either overlooked or lightly considered Although soil is not the only factor influencing the economy of the airport, it is one of the most important considerations, and in many instances may be controlling. In the future these private, local and State agencies which will perform most of the technical direction for airport development will find it possible to effect major economies by considering this soil factor in all planning, site selection, and design It is expected that the techniques presented in this report will prove to be of tangible value to practicing engineers and to their communities in this program, especially when applied to local situations after some of the generalities necessarily presented here have been modified by local trial and verification.

Owing to the great cost of airport pavements, excavation, and storm drainage facilities, and the almost complete dependence of these costs upon soil properties, the soil assumes relative importance which may be greater than any other single factor or group of factors influencing the Urban Airport Plan, the selection of the sites and the economy of each airport. Illustrative of the high relative cost of these three items of expense are the values given in Table III for forty representative airports of classes 2, 3, and 4, selected at random from a group of several hundred throughout the United States

TABLE III

CONSTRUCTION COST, EXCLUSIVE OF LAND AND TERMINAL BUILDINGS, OF FORTY REPRESENTATIVE AIRPORTS IN THE UNITED STATES

	Excavation		Drainage		Paving		Total
	Dollars	Percent	Dollars	Percent	Dollars	Percent	Dollars
Mean	191,900	26	83,800	11	409,800	53	778,000
Minimum	28,112		7,655		90,744		205,413
Maximum	677,889		245,890		1,122,242		1,696,497

The urban airport plan and the National Airport Plan should be correlated, and one made a part of the other In addition, the distribution of airports within the urban plan must necessarily conform to established requirements for airport spacing and obstructions * It might seem, therefore, that there would be very little

*Airport Design Information, Civil Aeronautics Administration, 1944.

freedom of choice with reference to soil characteristics if the urban plan contained more than two or three airports. However, with the need in medium and large cities for segregation of air traffic into four or five categories, each of which will except upon emergency, be required to use a certain type of airport, the load-supporting characteristics, drainability and stability of the soils at the several sites may determine the best use to which each site can be put For example, a pavement designed to support heavy ships could be constructed on a granular location (one consisting of sand or gravel) at a cost of several hundred thousand dollars less than one located on a clay site, as shown in a subsequent example in this chapter. Conversely, turf, which is being widely advocated for surfacing of airport runways that are to be used by light planes, may be established and maintained on a clay loam soil at nominal cost although it might be very expensive or perhaps impossible to establish the turf on the granular and well-drained site because of the deficiency in moisture necessary to sustain plant life and the continuous loss of plant nutrients by leaching through the sand and gravel Here then the location of the two airports might be adjusted within the urban plan to the financial advantage of each on the basis of the soil characteristics, if other factors permitted. Although more use of this information can be made in connection with the selection of the individual site, it should not be overlooked that vast areas can be investigated accurately and in detail for the overall urban plan by means of the airphoto techniques and other information presented in this report. This degree of coverage would seldom be possible if it were necessary to make a thorough field investigation including soil sampling at each of the possible sites.

Probably the most valuable use to which the airphoto techniques can be put in connection with airport engineering is in the selection of an individual site for an airport of pre-determined size and class. This selection procedure is not unlike the solution of other engineering problems, in which the number and refinement of unknowns that can be determined are in proportion to the number and refinement of the knowns. If the investigator has extensive knowledge of the type of terrain and soil existing at similar locations, including laboratory analysis of similar soil samples, and if he can positively identify areas having these known characteristics from the airphotos, it follows that he can determine the soil characteristics in detail Conversely, if this ground information is not available much less detail can be obtained from the techniques here described This is directly in line with the hypothesis on which this work is based, as stated in the foreword of this volume

The first step is to determine the major soil areas that will be encountered This is done by referring to the accompanying soil map (plate 1) Second, all available information on this similar soil areas is obtained. Sources of this information will be found in that portion of the text of this publication dealing with the particular soil areas involved (chapters II to VII) and in the references contained in the bibliography Third, with this background of knowledge and by frequent reference to the Airphoto Soil Analysis Chart, the county photographic indexes or other photographic mosaic of the entire vicinity in question are studied for the indications of soil conditions Continuous reference to the text and illustrations of this report will be necessary at this time, as many of the airphoto techniques and indications can be applied to the county photographic index sheets Fourth, for those areas for which additional detail is desired and for which stereoscopic coverage is needed the individual airphoto contact prints are required. These can be obtained by reference to the photo index sheets From the contact prints the details of the terrain, and thus of the soil, will become evident, and if desired, a soil map of the area similar to Fig 83 can be prepared.

As an example of economies which can be effected in some cases by means of these methods, the following application is presented As stated in the foreword and as repeated in the introduction and elsewhere, it is again stressed that the use of topographic, geological, and soil maps, and resort to all available sources of data are recommended in addition to the use of these techniques. In fact, the method is often more useful where other data such agricultural soil maps or results of soil borings are also consulted than in isolated areas of the world where ground information is entirely lacking As also previously stated, there are a great many factors other than soil which influence airport costs and site selection

Selection of an Airport Site for a Midwestern City

Problem. A new class 4 airport, consisting of 5,500 foot runways having supporting capacity for 74,000 pounds wheel-loads is to be developed initially. The airport is to be within eight miles of the center of the city. If the center of the new airport is closer than six miles from that of the existing class 2 private-flying airport, a new location must be provided for this smaller field. Wind coverage of 90 percent is to be provided in accordance with airport size planning standards[6], from which it is determined that runways in three directions (N-S; NW-SE, and NE-SW) are satisfactory. Estimates of pavement costs are to be based on CAA soil classification[7] shown in Table IV

TABLE IV

SOIL AND MATERIAL CLASSIFICATION

C A A Soil Classification	Material Passing 10 Sieve			Material Passing 40 Sieve			Capillary* Rise of Minus 10 Material	Calif * Bearing Ratio (Soaked)	Subgrade & Subbase Classification			
	Sand %	Silt %	Clay %	Liquid Limit	Plasticity Index	Volume Change at FME			No Frost Good Drainage	Severe Frost Good Drainage	No Frost Poor Drainage	Severe Frost Poor Drainage
E - 1	85	0-10	0-5	25	0-6	0-6	0-12	20	F_a R_{1a}	F_a R_{2a}	F_a R_{1a}	F_a R_{2a}
E - 2	75	0-15	0-10	25	0-6	0-6	0-36	20	F_a R_{1a}	F_a R_{2a}	F_1 R_{1a}	F_2 R_{2a}
E - 3	55	10-40	0-20	35	0-10	0-10	36	18	F_a R_{1a}	F_1 R_{2a}	F_2 R_{1a}	F_3 R_{2a}
E - 4	55	10-30	5-25	45	5-15	5-15	36	13-40	F_1 R_{1a}	F_2 R_{2b}	F_3 R_{1a}	F_4 R_{2b}
E - 5	65	20-75	0-20	45	0-10	0-15	36	9-20	F_2 R_{1a}	F_3 R_{2b}	F_4 R_{2a}	F_6 R_{2b}
E - 6	55	5-70	10-40	50	10-30	10-30	36	6-12	F_3 R_{1b}	F_4 R_{2b}	F_6 R_{2b}	F_7 R_{2c}
E - 7	55	5-70	15-50	60	15-40	20-40	36	4-8	F_4 R_{1b}	F_6 R_{2b}	F_7 R_{2c}	F_8 R_{2c}
E - 8	55	5-50	30	70	20-50	30-50	36	3-5	F_5 R_{2b}	F_7 R_{2c}	F_8 R_{2c}	F_9 R_{2d}
E - 9	55	5-50	30	80	30-60	40-60	36	2-4	F_6 R_{2b}	F_8 R_{2c}	F_9 R_{2d}	F_{10} R_{2d}
E - 10	55	30-80	30	60	0-25		36	1-3	F_8 R_{2c}	F_9 R_{2d}	F_{10} R_{2d}	F_{10} R_{2d}

*As capillary rise and California bearing ratio have not been determined for the soils described in this report these values shown in the table may vary with those of the soils discussed

[6] Design Manual for Airport Pavements, Civil Aeronautics Administration, U. S. Department of Commerce, March 1, 1944.

[7] Airport Design, Civil Aeronautics Administration, U. S Department of Commerce, April 1, 1944.

Solution of the Problem. The soil map (plate 1) shows that the area is located within the Wisconsin glacial drift of western Ohio. Referring to chapters V and XI of the text it is determined that the following soil formations may be encountered in the Wisconsin drift (1) upland morainic areas of rolling to hilly relief in which the soils vary widely within short distances and are generally plastic in the low areas and more granular in the higher land; (2) upland glacial till plains which are flat to rolling and consist of plastic clays and silty clays; (3) elevated glacial terraces, some of which may be entirely granular, and others that consist of drift-covered or alluvium-covered rock terraces; (4) glacial and post-glacial channels and outwash areas filled with glacial debris, terraces, and recent alluvium; (5) limestone areas covered thinly with glacial drift; and (6) miscellaneous areas, such as rock outcroppings, eskers, kames, and rock terraces.

The county index sheet shown in plate 58 is selected for this illustration because all of the six glacial formations make their appearance in this one ideal example On plate 58 the following features are readily apparent the smooth and rather narrow area extending from the north center of the sheet southward through the westward edges of the city and southwest is a filled stream valley occupying the lowest topography and consisting of recent alluvium To the northwest of the stream the area having a mottled pattern consists principally of a moraine of hilly glacial drift such as is shown on plate 35. To the east of the stream channel and north of the city the index sheet discloses many sinkholes which show that limestone is present at shallow depths beneath the thin glacial drift (plate 13). Throughout the eastern and southwestern portion of the photograph numerous smooth appearing areas are observed These are in irregular sweeping sinuous-appearing bands, often bordered by rugged appearing areas such as that the west of the existing airport shown in plate 59 These areas are low, soil-covered, granular terraces, while the more rugged adjacent areas consist of drift-covered rock terraces Just to the northeast of the city there will be observed an area about 1½ miles in extent, which has a general rectangular shape and appears to be an elevated granular terrace In the south and southeast portions of the sheet we find the distinctive mottled appearance that is characteristic of the glacial till plains such as those described in chapters V and XI and illustrated in plate 36 and the Airphoto Analysis Chart. At the extreme southwestern edge of the sheet, just south of the railroad and small village, is a second elevated granular terrace similar to that northeast of the city.

Based on the foregoing indications the following tentative conclusions are drawn prior to the study of the individual aerial photographic contact prints The alluvial valley (shown on figure 83 as area "AL") will be subject to flooding as evidenced by the overflow channels and surface erosion seen in the vicinity of the numerals "BCA-2-100 " Nevertheless, the parts of this area which lie in the close proximity of the city should be given detailed study because of the economic advantages which they offer over more remote sites The morainic area to the northwest will require heavy grading and excessive excavation, but in keeping with the principle of locating the airport on the most economical site, rather than simply on level topography, the parts of this area lying close to the city may, if desired, be further studied by means of contact prints Both of the elevated granular terraces should be studied in detail as they offer the best sites for pavement and drainage economy The terrace just northeast of the city is advantageous because of its proximity, but might require moving of the existing airport, while the converse is true with respect to the terrace at the southwest edge of the area Sites in the vicinity of the present airport and other low granular terraces to the east and southeast in close proximity of the city should also be studied from the contact prints Because of the level topography and the close proximity to the center of population the glacial drift plains to the south of the city should not be rejected altogether, even though pavement and drainage here will be very expensive, and the cost of this land will probably be highest in the vicinity, owing to its agricultural value

Pursuing these preliminary conclusions further, the contact prints are obtained and studied, and from them the soil map of this area (fig. 83) is prepared. If, as previously suggested, knowledge of soil profiles on similar soils are avail-

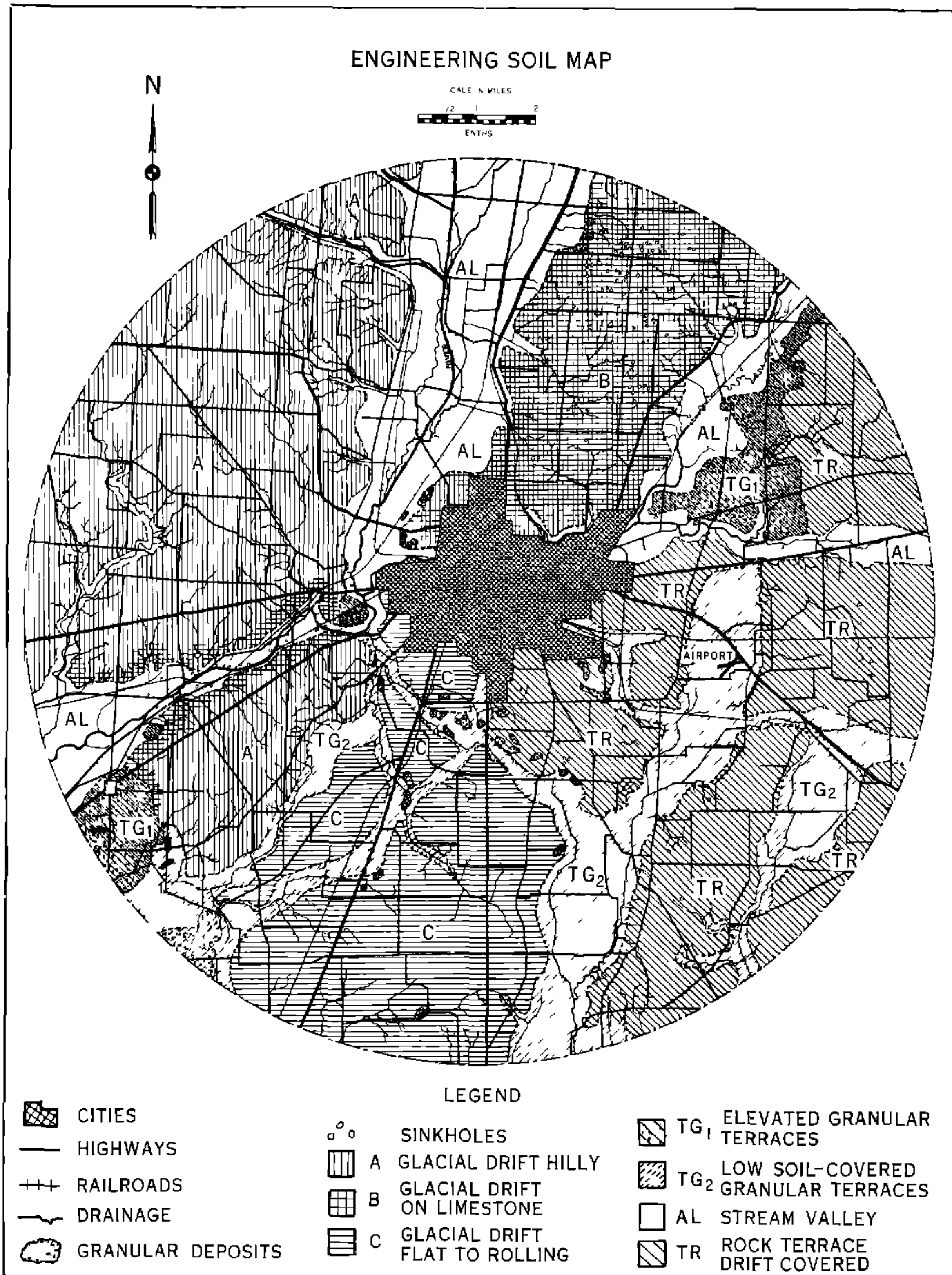
ENGINEERING SOIL MAP
N
A
AL
B
AL
AL
A
TR
TG1
AL
TR
TR
AIRPORT
C
AL
TG2
C
A
TR
TG2
C
TG1
TR
TG2
TR
C
LEGEND
CITIES
HIGHWAYS
RAILROADS
DRAINAGE
GRANULAR DEPOSITS
SINKHOLES
A GLACIAL DRIFT HILLY
B GLACIAL DRIFT ON LIMESTONE
C GLACIAL DRIFT FLAT TO ROLLING
TG1 ELEVATED GRANULAR TERRACES
TG2 LOW SOIL-COVERED GRANULAR TERRACES
AL STREAM VALLEY
TR ROCK TERRACE DRIFT COVERED

Figure 83

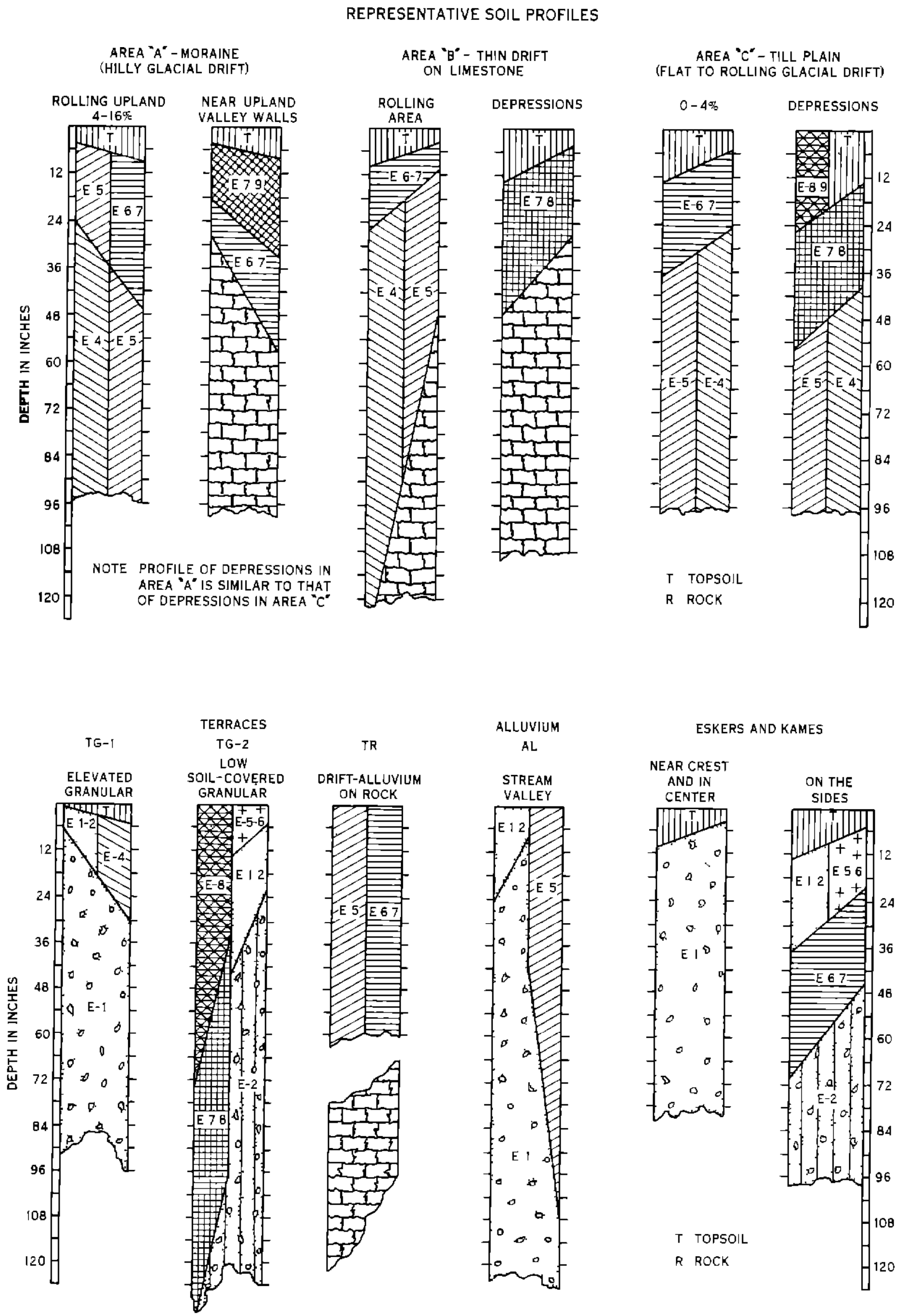
REPRESENTATIVE SOIL PROFILES
AREA "A" - MORAINE (HILLY GLACIAL DRIFT)
ROLLING UPLAND 4-16%
NEAR UPLAND VALLEY WALLS
AREA "B" - THIN DRIFT ON LIMESTONE
ROLLING AREA
DEPRESSIONS
AREA "C" - TILL PLAIN (FLAT TO ROLLING GLACIAL DRIFT)
0-4%
DEPRESSIONS
DEPTH IN INCHES
12
24
36
48
60
72
84
96
108
120
T
E 5
E 6 7
E 4
E 5
E 7 9
E 6 7
E 6-7
E 4
E 5
E 7 8
E-6 7
E-5
E-4
E-8 9
E 7 8
E 5
E 4
NOTE PROFILE OF DEPRESSIONS IN AREA "A" IS SIMILAR TO THAT OF DEPRESSIONS IN AREA "C"
T TOPSOIL
R ROCK
TERRACES
TG-1
ELEVATED GRANULAR
TG-2
LOW SOIL-COVERED GRANULAR
TR
DRIFT-ALLUVIUM ON ROCK
ALLUVIUM
AL
STREAM VALLEY
ESKERS AND KAMES
NEAR CREST AND IN CENTER
ON THE SIDES
E 1-2
E-4
E-1
E-8
E-5-6
E 1 2
E 7 8
E-2
E 5
E 6 7
E 1 2
E 5
E 1
E 1
E 1 2
E 5 6
E 6 7
E-2
T TOPSOIL
R ROCK

Figure 84

able - as they are in this case - typical soil profiles of the area in question can be prepared as shown in fig. 84 The detailed study of the airphotos and information in the text provide the following information.

Area "A" - Morainic (Hilly) Glacial Drift The soils of this area are derived from glacial materials and represent the typical pattern of the Wisconsin morainic areas (plate 35) Here the soils are not sufficiently deep to be influenced by the underlying limestone In these morainic areas (fig 84) the parent material is classed as E-4 and E-5 (table 4) The more rolling areas have developed shallow profiles that vary from top soil to E-6 or E-7 in the "B" horizon, and to E-4 and E-5 in the parent or unweathered portion of the profile In the depressed areas of the upland moraine, the surface soils are seen to be darker and the subsurface soils are known to be more plastic and to have a deeper weathered profile than soils in the rolling-topographic class Their texture is similar to that of the flat to rolling till-plain (E-7) They are not as extensive in area as the till plains and usually contain many shallow drainage ways The plastic "B" horizon consists of E-6 and E-7 soil and is two to three feet in thickness Pavement design would be made on the basis of the poorest soil, E-6 or E-7 (with good drainage). Otherwise, since the soil texture is highly variable within short distances, it would be necessary to vary the design and pavement thickness continouously, which would seldom be economical, under usual practice.

Grading would be fairly expensive, although no rock would be encountered, and balanced cuts and fills with short haul, which would be possible because of the rolling terrain, would reduce the unit cost somewhat Compaction of embankments should be under the most rigid control because of the highly variable character of the fill material It would be necessary to provide surface drainage for all areas and the pipe sizes would be large because of the relatively low infiltration capacity of the soil, but because of the many available outlets the cost would be lessened somewhat

Along the valley walls of the river the drift is somewhat thinner with rock outcrops in many places These are shown on the map (fig. 83) as a mixture of area "A" and area "B" symbols.

Glacial Drift on Limestone. There are two areas of glacial drift on limestone in this vicinity These have been separated because of differences in their mode of deposition and their topographic position and the depth to bedrock The first, which has been designated area "B" on figure 83, consists of relatively thin glacial drift on limestone and contains numerous sinkholes The second, which is designated as area "TR", occurs as a drift-covered rock bench or terrace. In topographic position it lies between the granular terraces and the deep drift uplands

Area "B" - Thin Glacial Drift on Limestone This area is located north of the city and east of the river valley The area contains numerous conspicuous sinkholes which indicate the presence of limestone near the surface The relief is flat to rolling; hence, two representative profiles are shown in fig. 84 In the more rolling areas limestone may occur at depths from four to ten feet and the soil is influenced both by glacial drift and limestone In the depressed areas near the sinkholes the soils are shallow and more plastic, being influenced more by the rock Plate 13 is an airphoto clearly showing sinkholes which occur only in these areas of soluble limestone It can be seen that these sinkholes have numerous gullies draining into them, and that the area surrounding them is quite dark. Both of these facts indicate that the limestone has been covered by an unassociated material, as residual limestone soils are naturally porous due to their open structure which develops a free draining soil with an absence of surface gullies. The glacial-drift soils are relatively impervious and contain V-shaped gullies This area contains all of these elements, which shows that the area is glacial drift on rock The shape of the stream valley and the sharp right angle turns in the channel also indicate the presence of stratified rock.

The limestone areas to the north of the city present favorable sites except for the excessive cost of the rock excavation Although accurate estimates of this cost would require topographic analysis of the air photos not justified in this report, this cost would probably amount to several hundred thousand dollars for the Class 4 airport under consideration.

Areas "TR" Rock Terraces These terraces consist of glacial drift or stream deposits or both on a gently sloping rock bench or shelf In position they are lower than the uplands and higher than the stream terraces. There is a gradually rising ground slope from the stream to the upland. These terraces were probably formed by lateral planation of the stream at a time when the stream was much larger Rock terraces occur on limestone in this area, and in some sections a few sinkholes are present, which indicate a shallow cover as compared with the more rolling areas where the depth to rock is greater These terraces are not flat since they are covered by a mixture of drift and stream alluvium

The rock terraces contain elements often associated with upland drift areas, elements found in alluvial deposits, and elements found in limestone areas Some of these are the presence of sinkholes, the topographic position consisting of a shelf or bench-like formation; the presence of ripple marks; upland dissection in rolling areas, and the absence of gullying and dissection in the flat areas These, together with the gradual rise in elevation from the stream to the upland, tend to class the formation as drift and alluvium on rock

Airport construction on these areas will be similar to that on area "B", except perhaps that these areas are generally smaller and frequently can accommodate small airports only However, the area immediately east of the southernmost part of the city, and one three miles due south of the present airport, are sufficiently large for the airport under consideration, and because of proximity to the city the first of these offers good possibilities for total economy

Area "C" - Till Plains - Flat to Rolling Glacial Drift Although the soil characteristics of the glacial till plains are slightly variable throughout the Wisconsin drift (plate 36), becoming shallower and less plastic toward the west where rainfall is somewhat lower, in general the profile shown in fig. 84 prevails in these areas The color contrast between the white silty clay of the slightly elevated areas and the black plastic clay of the depressions is one of the most conspicuous distinguishing features seen on the airphotos

These soils are developed in upland topography of low relief varying from level depressions to perhaps six percent slopes The pattern is common of upland areas of deep Wisconsin drift The depressed areas, which are two to five feet below the higher land, are extensive, and contain the darkest, most plastic, and most deeply weathered soils of this group. The top soil is organic and usually extends to a depth of 12 to 18 inches This is underlain by a plastic layer of yellow to gray mottled clay of E-7 to E-8 class, extending to a depth of 36 to 48 inches. The parent material is of E-4 and E-5 class and consists of unweathered silt with clay, sand and calcareous gravel particles The soils in the higher parts of the rolling areas are light in color and better drained internally than the depressed soils They are of E-5 and E-6 class The weathered profile consists of a few inches of silty top soil on a two-to-three foot layer of E-6-7 soil consisting of clay with silt and sand underlain by the E-4-5 silt with clay, sand and calcareous gravel particles. Not infrequently, the sand contained in the lower horizon exists in layers, or lenses, a few inches thick. Where this occurs free water may become trapped in these layers and cause much damage in regions of severe frost.

Area "TG-2". The Low, Soil-Covered-Granular-Stream Terrace (plate 59) This terrace formation covers considerable area in this vicinity In position the terraces are higher than the alluvium or flood plains of the streams and lower than the elevated terraces designated as "TG-1" The terraces contain granular material that has been covered by stream alluvium and sediments washed from the uplands The depth to granular material varies from three to perhaps ten or twelve feet Since the soil cover in some places appears to be quite organic and of an impervious nature, it follows that it was deposited under slack-water conditions In the low and dark-colored depressed areas the cover is deep and consists of impervious organic clay of E-7 and E-8 class The lighter colored areas are slightly higher in elevation and have a three-to-four-foot layer of fine sand and silty clay on the granular material The natural drainage of the lighter and higher areas is better than that of the dark, ponded areas. Because of these variations, the profile representative of soils in this group is divided to illustrate both conditions (fig. 84).

Certain elements make it possible to identify the soil characteristics common to this formation. First, the area is waterlaid as it occupies a broad, flat position in a valley and contains numerous flow marks due to current action Since the area is in a glacial valley, the floor of which is granular, and because there is an absence of medium and large streams, the subsoil is indicated to be porous However, the soil covering has erased the granular pattern and contains instead a relatively impervious pattern which is evidenced by a network of fine surface drainage ways and dark depressed areas. Obviously, the water table in these terrace areas was originally high, but because of the texture of the subsoil, artificial drainage in the form of open ditches has been efficient in lowering this water level and permitting profitable use of the land. The spoil banks on most of the ditches appear as white lines, offering further evidence of the underlying granular material.

Where the soil covering is thin, and where flooding by nearby streams will not occur, the low granular terraces offer very good airport sites In pavement and drainage economy they are probably superior to all other formations in this vicinity except the elevated granular stream terraces "TG-1" Plate 59 shows the contrast between one of these areas on which the present airport is located and the nearby soil-covered rock terrace.

<u>Area "TG-1" Elevated Granular Stream Terrace (plate 60)</u> Terraces of this kind were formed by deposition of granular materials from large quantities of glacial-melt water These terraces are lower than the uplands and higher than the flood plains of the present stream. They consist of granular materials and are well drained internally One is two miles northeast of the city (plate 60). Another about six miles southwest of the city contains a large esker located in its western part (fig 83)

The elevated terrace areas contain a typical gravel pattern such as that shown in plate 60. First, the general color tone is light; second, they contain numerous small dark spots which are small clay deposits formed by the weathering of calcareous gravel; third, there is a definite directional pattern caused by wave action which indicates that the material was waterlaid, fourth, the soil is porous which is illustrated by the lack of dissection and gullying; fifth, all but the largest of the upland gullies discharge on to the terrace and do not cut across it, but develop outwash fans of granular material as the water is absorbed by the terrace, and sixth, stereoscopic examination shows that the terraces are flat, and higher than the flood-plain areas.

An excellent stereoscopic impression of the elevated granular terrace northeast of the city is obtained from plate 60 This location, and the one on an identical granular terrace soil six miles southwest of the city, offer the finest airport sites from the standpoint of pavement and drainage costs No imported subbase will be required for the pavement, and where grading operations expose suitable gravel in place, it will not be necessary to import base material Pavement gravel is available at the site for the cost of quarrying and washing Pavement design will be based on E-1 or E-2 classification, good drainage Subsurface drainage will be entirely unnecessary owing to the high porosity of the subsurface soil, and the minimum pipe sizing for storm drains will be required owing to the very high infiltration capacity of the surface soil which may be in the order of 1 to 1 5 inches per hour, or higher.

Because of the absence of rock and the fact that the topography is relatively level with small well-spaced knolls and depressions, which provide easy balancing of cuts and fills on short haul, grading costs will be nominal.

A comparison of the estimated costs of pavement and drainage for an airport at this site and for one located on one of the plastic clay sites in the vicinity is given in Table V

Area "AL" - Stream Valley This valley occupies the lowest topographic position in the area under consideration as it is the flood plain of the present stream It is a filled glacial stream valley, and is underlain by granular material at varying depths depending to some extent upon its width In areas where the valley becomes narrow the alluvium cover is only one to two feet in depth Where the valley is wide, water was pooled or moved with very slow velocities which enabled the finer suspended particles to settle. Because of this the alluvium cover is thicker than in the narrow reaches, and consists of silt and clay with fine sand and some organic matter

The valley contains several areas of natural levees consisting of sand that has been deposited during recent periods of high water These natural-sand levees are adjacent to the streams and are lighter in color and better drained than the soil on which they were deposited The areas where gravel is near the surface are shown by an increased shading of the gravel symbol on the map

The stream valley to the north is wide It becomes narrow just west of the city and widens again to the west of the area shown The stream contains several right-angle turns indicating that a resistant obstruction has forced it to change its course Under stereoscopic examination the valley walls are seen to be steep and in some places they rise vertically, indicating a resistant rock material. As this rock contains sinkholes, it is identified as limestone

The present stream valley contains elements that show the presence of a high ground-water table, organic soils, sand levees, and gravel in the subsoil. The overall color tone of the entire alluvial area is dark, which, together with the large dredged ditches indicates a high ground-water table The light color of the spoil banks indicates the presence of subsurface gravel River terraces are often found in locations where the stream velocity has changed due to a sudden change in the width of the channel

The ground water will be high during the winter and spring, often coming to the surface This fact will render the otherwise relatively fair material unstable during those seasons, and pavement design should be made on the basis of E-4 poor-drainage In addition it will be necessary to provide expensive diking and pumping facilities to prevent surface flooding during periods of high water.

Granular Material Granular materials can be obtained from any of the following locations, all of which are marked on fig 83: (1) upland eskers and kames, (2) elevated terraces, (3) the stream bed, and (4) the large, glacial-outwash area near the north county line Granular material in the form of crushed stone can be obtained by quarrying operations along the steep valley walls of the river.

At many places throughout the uplands, especially in the flat till-plains area, deposits of sand and gravel occur in the form of isolated, smooth, rounded hills rising abruptly above the surrounding terrain. These mounds or irregular shapes, which are kames, and eskers similar to those in plate 40. They consist of sorted boulders, gravel, sand, and fine sand, and were deposited during glaciation by melt water flowing from a crevice or opening beneath the ice This is indicated by their characteristic stratification, the material grading from coarse in the center to fine on the outside edges In addition to the eskers found on the uplands, a series of these formations is located on the large terrace in the southwest edge of the area

TABLE V

COMPARISON OF PAVING AND DRAINAGE COSTS FOR TWO AIRPORT SITES

To illustrate the difference in pavement and drainage costs at two widely differing available sites, those estimated costs for a site on the more plastic soil six miles south of the city are compared with those similarly estimated for the gravel terrace site two miles northeast of the city Final cost estimates would, of course be based upon field surveys

Plastic Site Six Miles South of City

Soil classification, E-6 to E-8	Design based on E-7, severe frost, poor drainage, for flexible pavement (F-8)	
Runways	13-inch subbase 220,000 sq yd @ 70¢	$ 154,000
Thickened turn arounds and taxiways	18-inch subbase 120,000 sq. yd @ 90¢ . .	108,000
Base	9-inch crushed aggregate base 330,000 sq yd. @ 80¢ .	264,000
Surface	2-inch surface 330,000 sq yd @ 70¢ .	231,000
	Total, paving	$ 757,000
	Total cost of drainage installation .	160,000
	Total, site 1	917,000

Granular Site on Gravel Terrace

Soil classification, E-1 to E-2	Design based on E-2, severe frost, good drainage for flexible pavement (F-0)	
No subbase		
	9-inch crushed aggregate base 220,000 sq yd @ 50¢	$ 110,000
	11-inch crushed aggregate base, ends and taxiways 120,000 sq yds @ 60¢	72,000
	2-inch surface 330,000 sq yd @ 60¢ .	198,000
	Total, paving	$ 380,000
	Total cost of drainage installation .	35,000
	Total, site 2 . . .	$ 415,000
Apparent savings, granular site over plastic site . .		$ 502,000

- - - - - - - - - - - - - - - - -

Airport Site in Red Bed Shales and Sandstones

As a second example of the application of these techniques, the following report covers the engineering characteristics of soils in the vicinity of a small

Oklahoma city For the general purpose of aiding in site selection the various soil areas are described with emphasis on those having terrain suitable for airport locations

Location Reference to the soil map (plate 1) shows that the area in question lies within the residual soil group developed from the red bed shales and sandstones. The area studied lies within an eight-mile radius of the city (plate 61) At present the area is served by one airport located one and one-half miles south southwest of the city (plate 62a) An area having a radius of eight miles surrounding the city is considered for a new airport site. This area is shown in the county aerial photographic index of part of the county shown in plate 61, and on the map of the area (fig 85) which was developed from the airphotos.

Summary

1. The area includes (a) residual soils developed by the weathering of sandstones and of shales, (b) high terraces, and (c) alluvial soils subject to overflow.

2 The residual soil areas have a relatively shallow soil development of approximately five feet The sandstones give rise to sand clay soils (E-4); the shales weather to produce plastic silty clays (E-6-8); the terraces are of clayey sand texture (E-2-3), and the alluvial soils are predominantly silty.

3. The existing airport is located on residual soil developed from sandstone.

Soil Origin The major upland soil of this area is represented by profile No. 1 (Area A on map). The sandstone weathers easily and produces a rather friable soil. In the transition to bedrock the texture becomes quite sandy Profile No. 2 (fig. 86) represents the areas marked A^1 and B with area A^1 representing the left section of the profile, which is a transition between the two extremes of the area These soils are probably derived from calcareous shales. The terraces (profile No. 3 fig 86) are extremely old deposits (see Airphoto Analysis Chart, Landforms, Old Streams) They are semi-granular in nature and are relics of the time when the nearby bedrock formed mountains that were subject to severe erosion. These terraces, once river flood plains, are now from thirty to fifty feet above the present alluvial soils. There is some indication that even higher and more extensive terraces exist near the present airport. However, they are somewhat dissected and can only be identified definitely by local examination.

The alluvium in the river flood plains appears to be remarkably uniform. The silt texture of this soil area can be attributed to the retardation of the erosion process and the type of valley Small areas of silty clay, developed in depressed areas of alluvium, are indicated on the soil map of this area (fig. 85) which was developed from the airphotos.

Aerial Photography The pattern of soils in this area naturally follows the same lines as the outcrop or occurrence of the various rock strata The difference in soil texture in the areas outlined on the map is due to the variations in rock type The sandstone soils have the marks of a highly erosive soil-sheet erosion on uniform slopes, terracing on hillsides, vertical gullies Plate 62a shows the site of the existing airport, which is two miles south of the city, one-half mile west of the central north-south highway, and south of the main east-west road. The erosion marks of a friable soil can be seen in the vicinity of, and east of, the central highway The two gullies (black) west of the airport represent the head of the erosion channel At their upper end they are more or less V-shaped and support vegetation As they progress southward they cut through the silty clay portion of the profile which is responsible for the V shape and proceed into the sandy substratum which was produced from the sandstones At this point the gulley takes the shape of a U which is typical of gullies in sandy soils and vegetation disappears. Plate 62b shows the pattern of one of the semi-granular high terraces located four miles northwest of the city For runways not to exceed four thousand feet in length this site would offer very good conditions for economy in pavement and drainage.

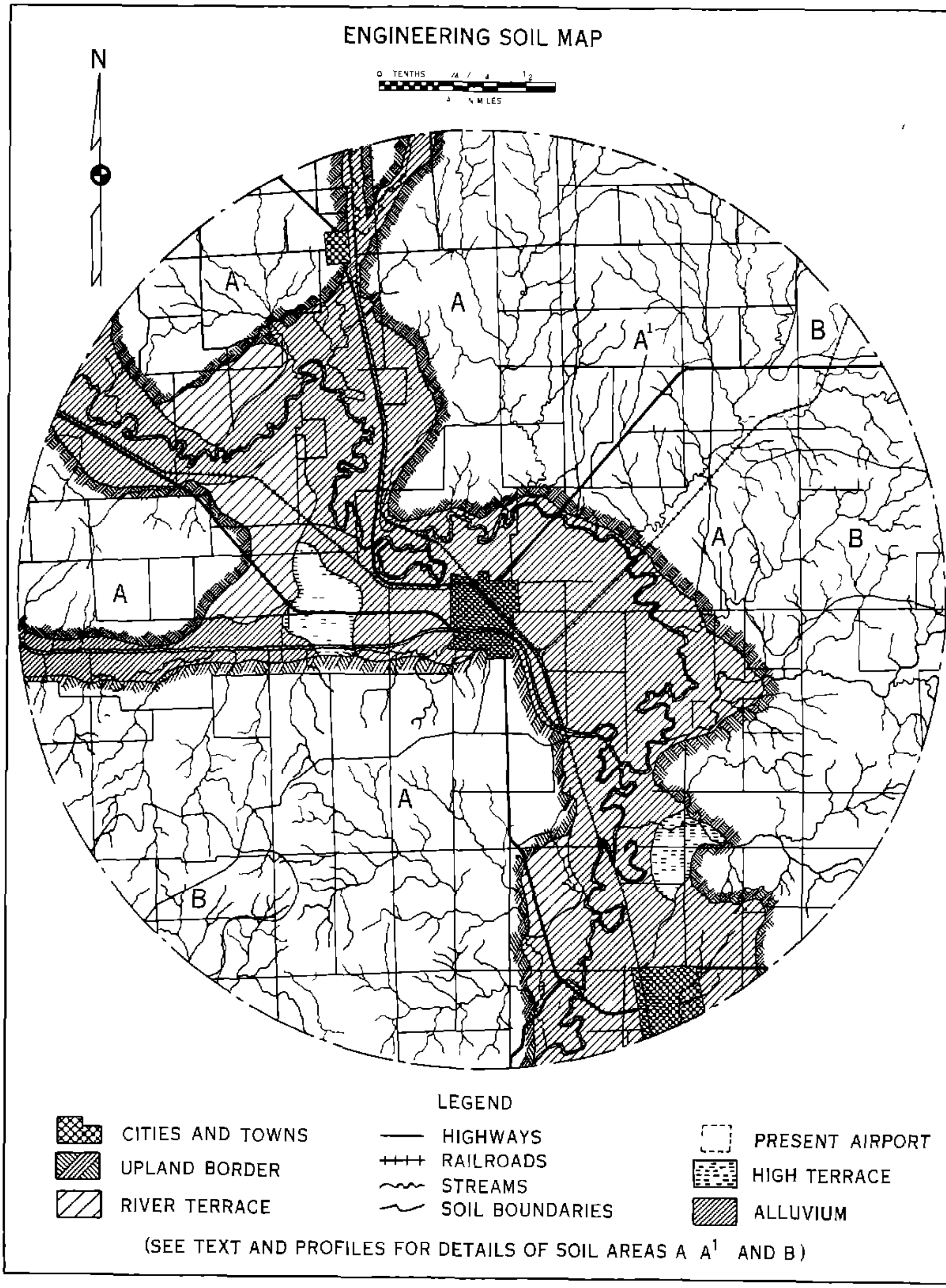
ENGINEERING SOIL MAP
N
A
A
A[1]
B
A
B
A
A
B
LEGEND
CITIES AND TOWNS
UPLAND BORDER
RIVER TERRACE
HIGHWAYS
RAILROADS
STREAMS
SOIL BOUNDARIES
PRESENT AIRPORT
HIGH TERRACE
ALLUVIUM
(SEE TEXT AND PROFILES FOR DETAILS OF SOIL AREAS A A[1] AND B)

Figure 85

REPRESENTATIVE SOIL PROFILES
FOR RESIDUUM DERIVED FROM SOME RED BED SHALES AND SANDSTONES

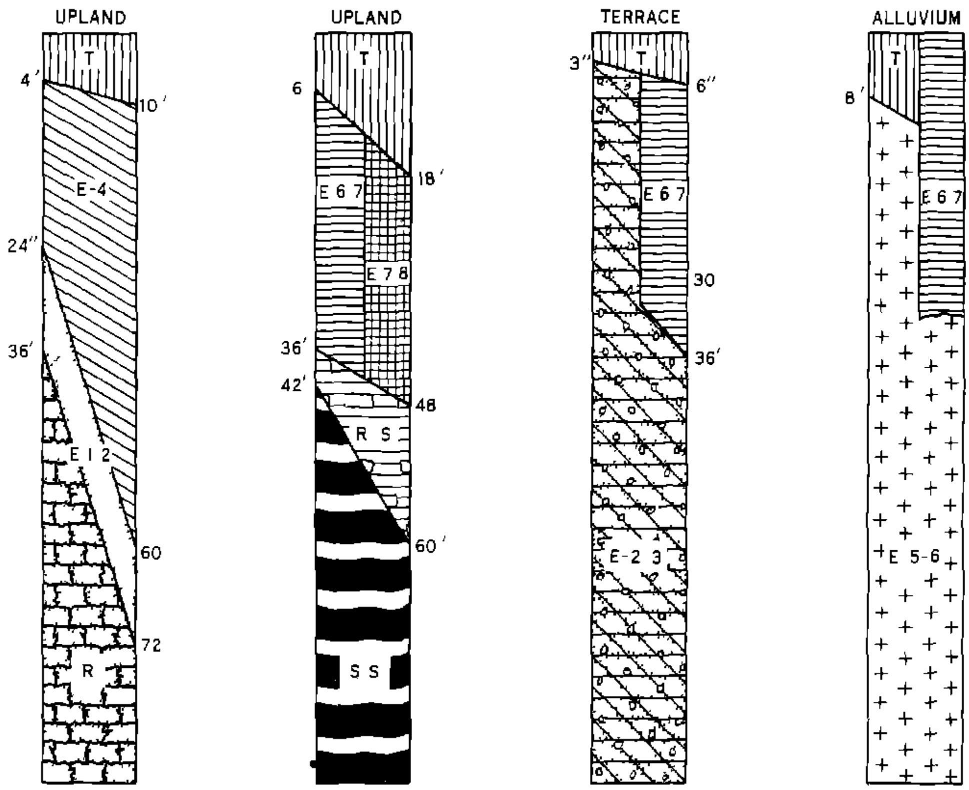

Figure 86

General The silty soils of the present flood plains in this area offer level terrain for an airport location However, the texture of these soils makes them difficult to handle during construction. Grading in this area would be a minor consideration because of the low relief Ground water conditions will be adverse during the spring and early summer, especially near the valley walls. In addition, the area is subject to flooding Silty soils such as these, when supplied with adequate ground water, are often difficult to compact, and since some fill construction would be required, compaction would be necessary.

Because of the prevailing slopes the residual soil areas in the upland are fairly well drained except where soils derived from clay shales are encountered Rock excavation may be expected in cuts having a depth greater than five or six feet Where rock underlies the soil at shallow depth, provision should be made to protect the subgrade from the seepage water that often flows on the rock at the base of the soil This will not generally be necessary on ridge tops The development of relatively porous soils from the sandstone and of impervious clays from the shales in these areas often produce closed aquifers with the clay trapping the infiltered water If this condition is not recognized and adequate artificial drainage provided, these pockets may fill with water and flood the subgrade for long periods, causing serious pavement failures

If one of the terrace areas can satisfy other requirements in site selection, it would probably furnish the best location from the standpoint of soil, drainage, and ease of construction These are relatively level areas of semi-granular soils having reasonably good internal drainage They are as stable as any major soil area in the vicinity Because of their elevation they are well above present floods, and their position with respect to the upland minimizes the danger of poor ground water conditions

There does not appear to be any granular deposits of appreciable size in this area

A Study of Ground Water Conditions

A third use of the techniques is in the determination of ground water conditions In some locations excess ground water may seriously affect the stability of subgrades and pavements The sources of this water may be a high water table, as often encountered in valley bottoms, artesian flow which may develop if the aquifer be tapped by very deep grading or other operations, and wet-weather spring flow which appears to exist in the following example, and which may be entirely overlooked if the detailed field survey is made during dry weather.

Often the geologic formations distinguishable on the airphotos, together with the information contained in chapters II to VIII and the literature cited in the bibliography, will disclose to the investigator the existence of potential danger from this source A situation of this nature was encountered in the development of an airport in the Appalachian region of sandstones, limestones, and shales. Although it was fully recognized that excess ground water might develop later, no other feasible nearby site was available in this case, and it was necessary to proceed with construction at this site as a war expediency. Water developed in the base course shortly after construction and for several months temporary drains flowed persistently for several days following rains until it became necessary to install complete subdrainage

The airphotos of this area shown in plate 63 were taken following the layout of the three runways, survey lines for which can be seen on the photographs Those pictures show that the highest surface elevations at the airport are at the northwest end of the field where a rock ridge trending northeast-southwest exists. From the top of this ridge the land surface slopes northward to a creek and southward and southeastward to the river Immediately south of the airport is a similar rock ridge, and a third rock ridge crosses the field diagonally The northeast-southwest runway is on this ridge The airport has a general east-southeasterly slope toward the river. Cuts have been made wherever the rock ridges mentioned above have been encountered during construction, and the remainder is on filled ground.

The underlying rocks are gray to black, fissile, calcareous shales, underlain by limestone A quarter to half a mile east of the airport rocks belonging to another formation crop out, indicating the position of a thrust fault that is present along the east side of this broad valley. This fault is well established in geologic literature pertaining to this particular area. About three-quarters to one mile west of the air field is a high anti clinal ridge The formations composing the east limb of this fold dip under the airport but at considerable depth.

The existence of sinkholes in the valley is not conspicuous and the ground surface appears to be held up by the cap of black shales overlying the more deeply buried limestone In a few places, however, sinkholes are distinguishable on the airphotos Along the crests of the rock ridges surface water appears to be entering the underlying formation, and these are therefore areas of ground-water recharge, and spring discharge occurs at some places along the bases of the rock ridges These are, apparently, wet weather springs that flow only when the water table is high.

There is a strong possibility that, in the construction of the field, sinkholes existing beneath the airport were obstructed by fill, thereby causing water that would normally drain away through them to back up and flow out at the surface beneath the runways Surface seepages at the bases of rock ridges, which cut diagonally across the airport, could have been obstructed in a similar manner and with similar results.

As the original field survey were made during relatively dry weather, such wet-weather seepages, or springs, were not in evidence, for the water table was too low at that time to permit ground-water discharge at the surface

Another possible type of ground-water discharge to be considered in this area is that along normal faults The structure of the rocks underlying the airport seems to be that of a closed syncline, the closure being brought about by the relatively impermeable formation along the thrust fault just east of the airport The mountain northwest of the airport (plate 63a) appears to be composed of rocks that have been folded into an anticlinal ridge The formations composing this ridge include among others, a water-bearing sandstone Fractures resulting from normal faulting of the rocks underlying the airport might penetrate the deep-lying sandstone formation, permitting water to rise along the faults and discharge beneath the airport. This type of discharge would be indicated by lines of springs cutting diagonally across the air field However, no such regularity of discharge areas can be observed on the airphotos of this area.

Although indications of excess ground water potentialities as clear as those in the foregoing example are not found in the majority of the areas encountered, the excessive cost that develops when it becomes necessary to install subsurface drains on peacetime commercial airports after the other construction work has been completed justifies exhaustive study of each potential danger spot, even though only one may be disclosed in many airports investigated In areas where the folding and outcropping of interbedded porous and non-porous strata are as clearly indicated as these shown on plate 63, disturbance of the natural permeability of the soil-rock mass by excavations and fills may be expected to result in concentrations of flow, especially where numerous nearby intake zones are exposed. .

Non-soil Areas of the West

In many of the western states such as Colorado, Idaho and others, the scattered bodies of soil lying within the extensive non-soil areas described in chapter VII are of utmost importance as airport sites They usually offer the only feasible landing areas within a broad region so rugged as to render many types of flying otherwise unsafe. Yet those engaged in private flying, frequently in low service-ceiling equipment, will often find themselves over these areas and in desperate need of an airport of some kind. Although such small soil areas as these could not be shown on the map (plate 1) their location and their soil, geologic, and drainage characteristics can be readily determined from the aerial photographs for any particular locality. The many intermediate landing areas that will be necessary in these rugged regions, both for safe local flying and for cross-country flights between the East and the Pacific Coast, can thus be located and their establishment facilitated by the use of airphotos Many of them can be made safe emergency landing areas for contact flying merely by removal of boulders and other obstructions, filling of gullies, and simple drainage, all of which can be quickly and accurately investigated on the airphoto, but which would otherwise require much difficult field investigation and study of meager large scale topographic maps generally available for these areas

APPENDIX A

TABLE VI

RESULTS OF CLASSIFICATION TESTS ON RESIDUAL SOILS

Lab. No	Location	Depth in	Represents in	L L	P I	Proctor Unit Wt	Proctor Opt M C	Proctor Pen Res	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
$841C_1$	Ala , Agr Exp Field, Lafayette	—	12-24	30 1	10 4	107 0	19 8	1000	2 74	43 5	25 5	31.0	Granitic and Metamorphic
$841C_2$	" " "	—	12-24	40.1	21 1	—	—	—	2 73	35 5	17 5	47.0	" " "
$841C_3$	" " "	40	—	56.0	25 7	—	—	—	—	—	—	—	" " "
$842C_2$	Ala , Alexandria Agr Exp Field	14	—	34 1	16.9	110 2	18.0	300	—	—	—	—	Limestone
$842C_4$	" " "	36	—	69.3	27.6	86.0	32 5	420	—	—	—	—	"
971C	Ariz , Navajo Indian Resv.	—	36-50	N P	N P	119 8	12.1	1080	2 62	86.0	10.0±	4 0±	Sandstone
$976C_1$	" " "	—	6-24 +	23 3	5 3	114 4	12 6	1000	2 63	53.5	30 0	16 5	Jurassic Shale
979C	" " "	—	4-8	N P	N P	117.3	13 2	960	2 70	67 0	23 5	9 5	Limestone
982C	" " "	—	9-24	N.P	N P	93 0	23 0	960	2 69	—	—	—	Basic Igneous
985C	" " "	—	9-24	N P	N P	112 2	14 1	800	2 61	71 0	21 0	8.0	Sandstone
986C	" " "	—	8-36	N P.	N P	119.8	12 1	1080	2 62	86 0	10 0±	4 0±	"
1308C	Ariz , US 89, 5 Mi. SE of Ariz -Utah Line	—	0-8	—	—	120 5	12 3	1450	—	—	—	—	Limestone
1309C	Ariz , US 89, 30 Mi SE of Ariz -Utah Line	24	0-30	58 1	39.3	—	—	—	—	—	—	—	"
1310C	" " "	—	Parent	—	—	—	—	—	—	—	—	—	"
1311C	Ariz., Jct US 89 & SR 67	36	20-40+	76.1	51.7	83.4	28.6	460	—	—	—	—	"
1312C	Ariz , SR 64, Balle Airport 31 Mi N of Williams	8	2-12	31.6	7 1	—	—	—	2.69	31 5	57 5	11.0	"
1313C	Ariz , SR 64, 15 Mi N of Williams	6	2-12	51 9	31 1	—	—	—	—	—	—	—	Basalt
1314C	" " "	24	12-36	62 2	41 3	—	—	—	—	—	—	—	"
1315C	" " "	—	—	—	—	—	—	—	—	—	—	—	"
1316C	Ariz , SR 64, 9 Mi. N of Williams	12	6-24	46.8	29.0	—	—	—	—	—	—	—	"
1317C	" " "	120	24-120	69.5	39.7	—	—	—	—	—	—	—	"
1346C	Ariz , US 66, 2-5 Mi W of Flagstaff	—	Cone	—	—	—	—	—	—	—	—	—	Volcanic Cinders
1347C	Ariz., US 66, Flagstaff	84	12-96	57 4	33.9	—	—	—	—	—	—	—	Limestone
1349C	Ariz , US 66, 10 Mi. E of Flagstaff	240	12-240	—	—	—	—	—	—	—	—	—	Volcanic Cinders

TABLE VI

RESULTS OF CLASSIFICATION TESTS ON RESIDUAL SOILS (Continued)

Lab. No.	Location	Depth in.	Represents in	L L	P I	Proctor Unit Wt.	Proctor Opt. M C	Proctor Pen Res	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1345C	Ariz , US 66, Area W of Flagstaff	18	6-36	84 0	47 1	—	—	—	—	—	—	—	Basalt
1343C	Colo , US 85, 3 Mi. N of Trinidad	30	8-144	42.4	23.6	—	—	—	—	—	—	—	Black Shale
1358C	Colo , US 50, 11 Mi E of LaJunta	96	—	—	—	—	—	—	—	—	—	—	Shale
853C	Ga , US 27, 8 Mi S of Rome	12	0-24	31 8	9 2	—	—	—	2 70	32.0	29 0	39.0	Limestone (Cherts)
854C	Ga , US 27, 3 Mi S of Bremmen	—	—	36 5	12 0	—	—	—	2.69	72 0	18 0	10.0	Mica Schist
855C	Ga , US 27, 8 Mi S of Rome	60	24-96	53.0	25 2	96 1	25 5	650	2.78	—	—	—	Limestone (Cherts)
856C	Ga , US 27, 14 Mi S of Rome	36	17-36	33 0	9 6	106 5	18 7	430	2 71	51 5	19 5	29.0	Shale and Sandstone
857C	Ga , US 27, 8 Mi. S of Cedarton	—	—	—	—	—	—	—	—	—	—	—	Micaceous Shale
858C	" " "	12	0-24	35 0	10 3	108.5	17 2	920	2 71	57 7	9 3	33 0	Mica and Talcose Schist
859C	Ga , US 27, 13 Mi. S of Cedarton	144	—	N P	N P	106 5	18 2	900	2 77	—	—	—	Mica Schist
860C	Ga , US 27, Carrollton City	36	24-48	33.6	13 1	111.2	16 0	490	2 70	69 0	11 0	20 0	(Cecil, Sand Phase)
861C	Ga , US 27, LaGrange	24	12-36	56 1	21 5	—	—	—	—	—	—	—	Granitic or Metamorphic
862C	" " "	120	36-144	61 7	17 5	91 5	28 8	400	2 55	35 5	29 0	35 5	" "
883C	Ga., US 27, 12 Mi SW of LaGrange	144	72-168	61 5	20 3	87 2	29 0	400	—	50 5	40.5	9 0	" "
1256C	Idaho, US 95, Idaho Co.	—	10-36	69 3	48 6	85.5	31 0	400	—	—	—	—	Basalt
1260C	" " "	—	36-48	64.2	29 8	—	—	—	—	—	—	—	
1261C	" " "	—	48 +	44 4	19.9	—	—	—	—	—	—	—	
1258C	Idaho, US 95, 49 Mi S of Lewiston	24	12-26	66 2	44.3	—	—	—	—	—	—	—	Basalt

TABLE VI

RESULTS OF CLASSIFICATION TESTS ON RESIDUAL SOILS (Continued)

Lab. No	Location	Depth in	Represents in	L L	P I	Proctor Unit Wt	Proctor Opt M C	Proctor Pen Res	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1259C	Idaho, US 95, Craigmont	18	7-22	32 7	15.6	—	—	—	—	—	—	—	Granite
1262C	Idaho, SR 15, 10 Mi. S of New Meadows	36	12-72	35.9	20.5	101.5	20.8	930	—	—	—	—	Basalt
1263C	Idaho, US 95, Idaho Co.	12	6-24	42.5	17 0	—	—	—	—	—	—	—	Calc Shale, SS & LS
1264C	" " "	120	24-144	68 4	32 2	—	—	—	—	—	—	—	Red Shale
1267C	Idaho, SR 15, 10 Mi S of New Meadows	300	96-360	71.4	32.4	87.3	30.0	430	—	—	—	—	Basalt
1105C	Iowa, US 20, Near W Edge of Dubuque	265±	—	36.3	19.1	—	—	—	—	—	—	—	Limestone
939C	Kan , 5 Mi E of Coffeyville	48	36-72	45 2	19 0	98.8	22.5	400	2.68	14 0	44 5	41 5	Limestone and Calc Shale
940C	" " "	24	0-36	39.4	15 3	—	—	—	2.61	20.0	50.5	29.5	" "
941C	Kan , US 166, 15 Mi. E of Coffeyville	42	36-42	58 1	27 1	—	—	—	2.70	23 0	31 0	46 0	Calc Shale and Sandstone
942C	Kan , US 166, 15 Mi E of Coffeyville	36	12-48 +	53.0	35.7	—	—	—	2 72	24 5	28 0	47 5	Shale and Sandstone
943C	Kan , US 66, 1 Mi N of Baxter Springs	48	12-72	61 9	27 5	—	—	—	2 79	19 5	42 5	38 0	Shale
944C	" " "	36	12-120+	51 2	34 1	100 2	21 9	200	2.66	24 0	34.5	41 5	"
1329C	Kan , US 50, Clare	30	4-40	69 8	40.2	—	—	—	—	—	—	—	Calc Shale, SS & LS
1373C	Kan , US 50, 14 Mi E of Newton	—	6-12	—	—	—	—	—	—	—	—	—	Shale
1374C	" " "	—	12-36	57 3	33 1	—	—	—	—	—	—	—	"
1375C	" " "	40	Parent	—	—	—	—	—	—	—	—	—	"
1377C	Kan , US 50, 5 Mi E of Peabody	—	10-20	47 3	27 0	—	—	—	—	—	—	—	Limestone
1378C	" " "	—	20-98 ±	47 0	30 8	99.3	31.0	410	—	—	—	—	"
1379C	Kan., US 50 S, 30 Mi E of Florence	—	—	62 7	43 1	—	—	—	—	—	—	—	Clay Over Cherty Gravel
1380C	Kan , US 50, 31 Mi E of Florence	—	0-36	56 8	28 4	—	—	—	—	—	—	—	Limestone

TABLE VI

RESULTS OF CLASSIFICATION TESTS ON RESIDUAL SOILS (Continued)

Lab. No.	Location	Depth in	Represents in.	L L	P I	Proctor Unit Wt.	Proctor Opt M C	Proctor Pen. Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1382C	Kan , US 50 S, Franklin Co.	30	0-36	54.8	31 1	----	----	----	----	----	----	----	Limestone and Shale
1383C	" " "	50	36-54+	52 2	33 7	99 8	23 0	280	----	----	----	----	" " "
850C	Ky , SR 71, 10 Mi S of Owensboro	72	48-96	31 5	6 9	102 5	19 7	900	2 70	16 5	68 5	15 0	Sandstone
851C	" " "	24	12-48	38 0	6 7	----	----	----	2 74	12 0	64 0	24 0	"
852C	Ky , SR 71, 10 Mi S of Morgantown	42	36-48	59 1	20 3	92 8	25 0	360	2 69	27.0	27 5	45 5	Limestone
877C	Ky , SR 71, 5 Mi S of Morgantown	42	36-48	45.3	23.1	----	----	----	----	----	----	----	"
878C	Ky , SR 71, 10 Mi S of Beaver Dam	96	72-144	39 5	18 0	----	----	----	2 68	10 0	35 0	55.0	
879C	" " "	48	12-72	17 4	4 4	----	----	----	2.64	54 0	31.5	14 5	Sandstone
945C	Mo , US 66, 22 Mi E of Joplin	----	----	33.8	11.4	----	----	----	2 66	16 0	50.0	34 0	Limestone
946C	Mo., Springfield Airport	48	36-60	38 6	18.8	----	----	----	2 71	30 0	36 0	34.0	"
947C	Mo., US 66, NE of Spring-field	264	240-360+	32 2	14 7	----	----	----	----	----	----	----	
948C	Mo , US 66, 30 Mi NE of Springfield	72	36-96	73 6	38 6	84 2	33 3	310	----	----	----	----	Cherty Limestone
949C	Mo , US 66, 34 Mi NE of Lebanon	96	72-144+	64 5	42 5	----	----	----	2 71	13 0	26.0	61 0	" "
1325C	Mo , US 40, Near St. Louis	96	0-360	----	----	89.2	25 2	520	----	----	----	----	Limestone
1323C	" " "	360	360-420	----	----	----	----	----	----	----	----	----	"
1326C	Mo , US 40, 22 Mi E of Kansas City	----	----	39 0	19.9	----	----	----	----	----	----	----	"
1230C	Mont , SR 1, Jefferson Co.	10	3-20	34 2	15.7	----	----	----	----	----	----	----	Schist
1231C	" " "	30	20-80	----	----	----	----	----	----	----	----	----	"
1236C	Mont , US 10, 47 Mi SE of Butte	36	12-180	29 3	10.4	----	----	----	----	----	----	----	Red Bed Shale

TABLE VI

RESULTS OF CLASSIFICATION TESTS ON RESIDUAL SOILS (Continued)

Lab. No.	Location	Depth in	Represents in	L L	P I	Proctor Unit Wt	Proctor Opt M C	Proctor Pen Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1237C	Mont , US 10, 30 Mi SE of Butte	72	24-84	----	----	----	----	----	----	----	----	----	Sandstone
1238C	Mont , US 105, 10 Mi E of Butte	----	----	----	----	----	----	----	----	----	----	----	Granite
1239C	Mont , US 10, 4 Mi S of Butte at Airport	24	0-36 +	----	----	----	----	----	----	----	----	----	"
1336C	Mont , US 10, 47 Mi SE of Butte	36	12-180	29 3	10 4	----	----	----	----	----	----	----	Red Bed Shale
1339C	N M , SR 64, N of Santa Fe	480	----	----	----	112 2	14 3	1050	----	----	----	----	Volcanic Ash
1000C	Ohio, SR 7, Chesapeake	----	----	38 2	17 4	106 0	16.2	1370	2 75	32.0	39 5	28 5	Calc Shales
1005C	Ohio, SR 7, 5 Mi N of Newport	36	----	46 4	25 3	101 7	20 3	1230	2 81	18 5	38.0	43.5	Calc Shales
1006C	Ohio, SR 125, 15 Mi W of Portsmouth	36	24-48	32 0	5 7	----	----	----	2 66	----	----	----	Shale and Sandstone
1007C	Ohio, SR 125, Adams Co	24	0-24	62 6	42 6	81.2	29 5	800	2.70	13 5	42.5	44.0	Limestone
1013C	Ohio, SR 17, School Rd. Near Cleveland	480	240-600	24.5	6 8	----	----	----	2.73	----	----	----	Red Shale
1019C	Ohio, SR 77, 2 Mi N of Marietta	240	120-360	26 6	9.2	----	----	----	2 73	23.0	62.0	15 0	
1020C	Ohio, SR 7, Belpre, Washington Co	12	0-24	24 6	7.6	----	----	----	2 65	38.0	42 0	20.0	Sandstone and Shale
1021C	" " "	48	24-60	47 4	26 0	----	----	----	2 74	37 5	41.5	21 0	" " "
1022C	" " "	96	60-120	N P	N P	----	----	----	2.70	75 0	11 0	14 0	" " "
1024C	Ohio, SR 7, Crown Point	----	----	44 4	22 2	----	----	----	2 77	22 0	33 5	44.5	Calc Shale, Landslide
1025C	Ohio, SR 125, 15 Mi W of Portsmouth	12	0-24	27 6	7 2	----	----	----	2 66	17 5	59.0	23 5	Shale and Sandstone
1026C	Ohio, SR 125, Adams Co.	48	36-48 +	65 0	35 5	----	----	----	2 83	8 5	32.0	59 5	Limestone
928C	Okla , US 77, 4 Mi N of Ardmore	12	6-20	60.0	40.9	----	----	----	2.64	----	----	----	Limestone and Calc Shale

TABLE VI

RESULTS OF CLASSIFICATION TESTS ON RESIDUAL SOILS (Continued)

Lab. No	Location	Depth in	Represents in	L L	P I	Proctor			Specific Gravity	Grain Size Analysis			Remarks
						Unit Wt.	Opt M C	Pen. Res.		Sand	Silt	Clay	
930C	Okla , US 77, S of Pauls Valley	36	6-60 +	38 9	18 3	101 9	20 0	290	2 66	26 0	46 5	27 5	Sandstone and Shale
933C	Okla, SR 19, 4 Mi W of Pauls Valley	48	0-60	26 5	10 0	113 8	15 0	520	2 68	57.5	16 0	26 5	Calc Shale
935C	Okla , 9 Mi NE of Pauls Valley	24	18-36 +	55 4	38 4	----	----	----	2 58	42 5	26.0	31 5	Limestone and Shale
936C	Okla , SR 19, 2 Mi E of Stratford	36	12-48	58 3	41 4	----	----	----	2 66	27 0	26 0	47 0	Shale and Sandstone
937C	Okla , US 75, 14 Mi N of Wetunka	24	0-24	25 0	8 9	----	----	----	2 66	43 0	36 5	20.5	Non-calc. Shale
938C	Okla , US 75, 22 Mi N of Wetunka	48	24-48	51.0	30 6	----	----	----	2.70	29 0	30.5	40 5	" "
998C	Pa , US 22, 10 Mi W of Pittsburgh	24	12-36	42.4	17 2	104.7	19.2	1380	2 72	20.0	44.5	35 5	Sandstone, Shale, and Limestone
1184C	S D , US 16, 5 Mi W of Pierre	---	0-24	74.3	37 9	83 5	33.0	370	2.70	30.0	40.0	30.0	Shale
1183C	" " "	36	24-120 +	----	----	----	----	----	----	----	----	----	"
1185C	S D , US 14, 1 Mi W of Haakon-Stanley Co. Line	30	18-40	53 6	30.1	----	----	----	----	----	----	----	"
1186C	" " "	72	48-144 +	----	----	----	----	----	----	----	----	----	"
1187C	S D , Badlands	96	72-120	76 4	51 5	----	----	----	2.65	18 0	42 0	40.0	Clay Shale
1188C	S D , Junct SR 40 and US 16	24	0-48 +	N P.	N P	----	----	----	2.73	28 0	61 0	11.0	Brule Shale
1189C	S D , Badlands Park	240	216-288	63 4	36 1	95 3	26 8	500	----	----	----	----	Clay Shale
1191C	S D., Rapid City, Army Air Base	36	16 +	37 1	19 8	----	----	----	----	----	----	----	
1192C	S D , US 14, 2 Mi W of Rapid City	20	10-40 +	39.6	16 9	----	----	----	2.73	----	----	----	Red Shale

TABLE VI

RESULTS OF CLASSIFICATION TESTS ON RESIDUAL SOILS (Continued)

Lab. No.	Location	Depth in.	Represents in.	L L	P I	Proctor Unit Wt.	Proctor Opt. M C.	Proctor Pen. Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1196C	S. D , US 14, 13 Mi NW of Rapid City	36	12-48	32.4	10.1	—	—	—	—	—	—	—	
1197C	" " "	60	48 +	34 2	15 8	—	—	—	—	—	—	—	
1198C	S. D., US 14, W of Spearfish	60	36-120	24 7	8.8	—	—	—	2.75	19 0	74 5	6.5	
863C	Tenn , US 41, 3 Mi NW of Tenn River	48	0-60	58.0	27.3	—	—	—	2.68	—	—	—	Limestone
875C	Tenn , 10 Mi S of Murfreesboro	48	12-72	35.3	14 2	105.0	19.8	410	2 66	30 0	33 5	36.5	"
876C	Tenn., US 41, 4 Mi N of Manchester	36	24-60	33 3	14 1	108 3	17.4	1030	2.61	—	—	—	Sandstone and Shale (Hartsells)
880C	Tenn., US 31 W, 21 Mi. N of Nashville	54	48-60	46 4	16 9	—	—	—	—	—	—	—	Limestone
881C	Tenn , US 41, 9 Mi. S of Manchester	144	72-144	45 2	20.5	98.7	22.0	800	2.56	—	—	—	"
927C	Tex , US 82, 1 Mi W of Gainesville	36	12-48 +	35 7	13 0	—	—	—	2 63	45 0	40.0	15 0	"
1289C	Utah, US 91, 11 Mi. S of Nephi	38	26-40 +	30 5	12.0	—	—	—	2.69	31 5	48.5	20 0	Red Shale
1292C	Utah, US 91, S of Sevier Reservoir	—	—	—	—	—	—	—	—	—	—	—	Sandstone
1293C	" " "	24	0-36	23.4	8.5	—	—	—	2 69	40 0	46.0	14 0	"
1294C	Utah, US 91, 35 Mi S of Holden	6	0-8	24.7	6.2	—	—	—	—	—	—	—	Volcanic
1295C	Utah, US 91, 45 Mi. S of Holden	36	18-60 +	—	—	113 0	15 1	360	—	—	—	—	"
1299C	Utah, SR 15, 2 Mi W of Zion National Park	—	—	30.3	14.5	—	—	—	—	—	—	—	Permian Shale
1300C	Utah, SR 15, Zion National Park	24	6-40	—	—	—	—	—	—	—	—	—	
1301C	Utah, SR 15, Near Coal Beds, Zion Nat'l Park	48	0-120	40.4	25.0	—	—	—	—	—	—	—	Shale

TABLE VI

RESULTS OF CLASSIFICATION TESTS ON RESIDUAL SOILS (Concluded)

Lab. No.	Location	Depth in.	Represents in	L L	P I	Proctor Unit Wt			Specific Gravity	Grain Size Analysis Sand			Remarks
						Unit Wt	Opt M.C.	Pen. Res		Sand	Silt	Clay	
1302C	Utah, SR 15, 12 Mi. E of Zion National Park	24	12–24+	—	—	—	—	—	—	—	—	—	Sandstone
1303C	" " "	6	0–12	19.4	5.8	—	—	—	—	—	—	—	"
1306C	Utah, US 91, Near Toquerville	—	—	—	—	—	—	—	—	—	—	—	"
1241C	Wash., US 195, 25 Mi. S of Spokane	20	7–30	29.9	8.1	114.6	15.2	1880	—	—	—	—	Basalt
1394C	W. Va., SR 9, 1.4 Mi. W of Kearneysville	72	—	42.9	21.1	104.6	20.0	420	—	—	—	—	Limestone
1395C	" " "	36	—	54.1	31.7	97.7	23.5	470	—	—	—	—	"
1085C	Wisc., US 14, SE of LaCrosse	144±	—	83.8	57.2	84.0	33.0	300	2.82	22.5	17.0	60.5	"
1199C	Wyo., US 14, Crook County	12	2–18	52.2	24.2	—	—	—	—	—	—	—	Shale
1202C	Wyo., US 14, 5 Mi. E of Morecroft	--	Beneath Pavement	38.4	20.8	—	—	—	—	—	—	—	
1203C	Wyo., US 14, 50 Mi. W of Morecroft	6	0–12	49.1	23.8	—	—	—	—	—	—	—	Sandstone and Shale
1204C	" " "	24	12–36	51.1	23.2	—	—	—	—	—	—	—	
1205C	" " "	48	36–60	47.3	30.0	—	—	—	—	—	—	—	
1206C	" " "	72	60–72+	34.8	10.3	109.5	16.5	920	—	—	—	—	
1217C	Wyo., US 14, Big Horn Mts.	18	0–40	38.2	10.6	—	—	—	—	—	—	—	Sandstone
1218C	Wyo., Big Horn Mts.	12	6–18	N.P.	N.P.	—	—	—	—	—	—	—	Granite
1223C	Wyo., US 20, N of Cody	—	12–36+	—	—	—	—	—	—	—	—	—	Red Shale

TABLE VII

RESULTS OF CLASSIFICATION TESTS ON LOESSIAL SOILS

Lab No	Location	Depth in.	Represents in.	L L	P I	Proctor Unit Wt.	Proctor Opt. M.C.	Proctor Pen Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1243C	Idaho, US 10, 2 Mi N of Cataldo	6	2-12	N P	N P	—	—	—	—	—	—	—	On Rock
1257C	Idaho, US 195, 1 Mi. SE of Idaho-Wash. Line	60	12-72 +	34 2	15.5	—	—	—	—	—	—	—	Palouse
1273C	Idaho, SR 25, 2 Mi W of Burley	30	12-30	N P	N P.	104 2	17 4	1100	—	—	—	—	Portneuf
1276C	Idaho, US 30 S, 2 Mi E of Delco	36	12-60	—	—	—	—	—	2 68	39.5	54 0	6 5	Portneuf
1277C	Idaho, US 30 S, Idahome Airport	12	0-36	N P	N P	—	—	—	—	—	—	—	Portneuf
1279C	Idaho, US 30 A, 13 Mi N of Utah-Idaho Line	8	0-20	36.1	7 5	—	—	—	—	—	—	—	Portneuf
958C	Ill , Vicinity of Springfield	120	48-144	—	—	107 0	16.8	980	—	—	—	—	
964C	Ill , N of Quincy	168	36-206 +	26 2	3 9	106 2	15 5	750	2.73	19 0	73.0+	8.0 +	
1103C	Iowa, US 20 Near W Edge of Dubuque	36	4-40	28 0	9.5	—	—	—	2 65	12 0	64 5	23 5	
1104C	" " "	120	40-240	25 2	7 8	108.3	16.0	390	2 59	6 5	76 0	17 5	
1157C	Iowa, SR 34, 4 Mi N of Burlington Airport	30	20-48	53 3	31 1	—	—	—	—	—	—	—	Depression on Drift
1158C	" " "	100	48-112 +	38 8	17.0	—	—	—	2.65	10.5	64 5	25 0	" "
1159C	Iowa, SR 34, 7 Mi W of Burlington Airport	20	18-36 +	57.9	35 2	—	—	—	2 70	22 5	50 0	27 5	Shallow Loess on Kansan Drift
1160C	" " "	46	40-60	42.1	25 9	—	—	—	—	—	—	—	"
1162C	Iowa, SR 34, Ottumwa	36	20-100	66 5	39.8	—	—	—	—	—	—	—	"
1164C	Iowa, Ottumwa Airport	36	20-40	71 4	42 1	—	—	—	—	—	—	—	"
1177C	Iowa, US 34, 55 Mi W of Creston	24	12-36 +	43 2	17 9	—	—	—	—	—	—	—	
1178C	" " "	144	36-144	31 8	11.7	—	—	—	—	—	—	—	

TABLE VII

RESULTS OF CLASSIFICATION TESTS ON LOESSIAL SOILS (Concluded)

Lab. No.	Location	Depth in.	Represents in.	L. L.	P. I.	Proctor Unit Wt	Proctor Opt. M. C.	Proctor Pen Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1354C	Kan , US 50, 3 Mi E of Deerfield	—	12-36+	40 7	18 4	100.0	21.3	450	—	—	—	—	
1360C	" " "	6	0-12	31.7	12 5	—	—	—	—	—	—	—	
1384C	Kan , US 50, 7 Mi E of Kendall	—	—	—	—	—	—	—	—	—	—	—	
903C	Miss , US 61, 5 Mi. S of Natchez	24	12-36	45.5	16 8	—	—	—	2.63	9.5	57.5	33.0	
901C	" " "	180	36-300	31.8	3 1	104 9	17.8	710	2.68	11.0	83.0	6.0	
950C	Mo , US 50 & US 63, Osage River Bridge	72	20+	42.8	19.6	98.5	22.5	980	2.70	28.0	43.5	28.5	Colluvial
1324C	Mo., US 40, Near St. Louis	144	72-144+	33.6	16.3	—	—	—	2.72	15.0	67.0	18.0	
1327C	Mo., US 40, 50 Mi. E of Kansas City	96	48-96	40.5	15.9	—	—	—	—	—	—	—	See Text
1328C	Mo , US 40, 22 Mi. E of Kansas City	14	10-36	48.9	27.1	—	—	—	—	—	—	—	See Text
1174C	Neb , US 20, 20 Mi. W of Sioux City, Iowa	120	24-240	—	—	—	—	—	2.69	13.0	75.0	12.0	
$838C_1$	Tenn , Shelby Co.	—	0-10	—	—	—	—	—	—	—	—	—	Topsoil
$838C_2$	" "	—	10-18	38.4	11.8	104 2	18 0	820	2.73	10.5	67.5	22.0	
$838C_3$	" "	—	28-60	29.0	4.9	104.5	18.2	580	2.69	11.5	72.5	16.0	
1251C	Wash., US 195, 35 Mi. S of Spokane	24	12-48	34.5	12.1	—	—	—	—	—	—	—	
1252C	" "	72	48-84	30.8	14 0	—	—	—	2.76	20.0	54.0	21.0	
1247C	Wash., US 195, 35 Mi. S of Spokane	240	84-240	30.7	7.5	99.5	21.4	460	—	—	—	—	
1250C	Wash , US 195, 30 Mi. S of Spokane	10	6-12+	N.P.	N.P	—	—	—	—	—	—	—	Alluvial Fan
1253C	Wash., US 195, 90 Mi. S of Spokane	240	72-240	41.5	22.3	98.8	20.0	880	—	—	—	—	See Text
1254C	Wash., US 195, 92 Mi. S of Spokane	300	60-360	38.9	13.4	—	—	—	2.81	21.0	60.0	19.0	Palouse
1255C	Wash., US 195, 100 Mi. S of Spokane	120	48-180	28 9	13.2	—	—	—	2.69	17.0	70.5	12.5	Palouse

TABLE VIII

RESULTS OF CLASSIFICATION TESTS ON GLACIAL SOILS

Lab. No.	Location	Depth in.	Represents in.	L L	P I	Proctor Unit Wt.	Proctor Opt M.C.	Proctor Pen. Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1244C	Idaho, 6 Mi W of Cataldo	120	24-240	----	----	----	----	----	----	----	----	----	Terrace
1246C	Idaho, Coeur D'Alene Airport	12	2-24 +	----	----	----	----	----	----	----	----	----	Terrace
1248C	Idaho, US 10, Coeur D'Alene Airport	15	6-20	----	----	----	----	----	----	----	----	----	Terrace
957C	Ill , 11 Mi N of Springfield (Co. Road)	24	12-36 +	53.6	30 2	----	----	----	2 69	10 0	49.5	40.5	
959C	Ill., 12 Mi N of Springfield (Co. Road)	180	48-240	18.5	4 0	126.8	10.5	530	2.70	50.0	33 0	17.0	
960C	Ill., SR 29, 10 Mi. NW of Springfield	240	120-240	----	----	105 2	20.2	200	----	----	----	----	
961C	Ill., US 36, W of Decatur	18	14	47 0	25 8	----	----	----	2.67	11.0	58 5	30.5	
962C	Ill , SR 48, NE of Decatur	72	48-96 +	----	----	121 1	12.7	390	----	----	----	----	
963C	Ill., SR 10, W of Champaign	30	16-36	52.6	29.4	----	----	----	2.74	13 0	49.0	38 0	
1075C	Ill , US 52, S of Kankakee	30	24 +	38.8	22.6	98.7	20 9	360	----	----	----	----	Lacustrine
1077C	Ill., US 52, SE of Joliet	15	0-30	47.9	24.6	----	----	----	----	----	----	----	
1076C	Ill., US 52, SE of Joliet	72	30 +	35 1	17 1	104.1	19 6	330	----	----	----	----	Young Drift
1078C	Ill., SR 64, E of Sycamore	96	----	20.3	8 5	121.1	11 7	470	2 76	46.0	34.0	20.0	
1156C	Ill., US 66, 14 Mi. SW of Chenoa	36	24-36	41.9	19.7	----	----	----	2.71	26.0	49 0	25.0	Young Drift
988C	Ind , 0.5 Mi. N of Baer Field, Ft. Wayne	12	12-24	33.2	13 2	----	----	----	2.74	30.5	37.5	32.0	
989C	" " "	60	60 +	28 4	11.5	112.4	16 2	1120	----	----	----	----	
990C	Ind , Junc SR 3 & Ent Rd. Ft. Wayne Munic Airport	48	12-60	41.4	21 0	----	----	----	2 74	36.0	30.0	34.0	
991C	Ind , Ent. Rd. to Ft Wayne Municipal Airport	12	12-24	27 7	9.1	----	----	----	----	----	----	----	

TABLE VIII

RESULTS OF CLASSIFICATION TESTS ON GLACIAL SOILS (Continued)

Lab. No.	Location	Depth in.	Represents in.	L. L.	P. I.	Proctor Unit Wt.	Proctor Opt. M. C.	Proctor Pen. Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1098C	Iowa, Mason City Airport	—	12-30	37.8	23.1	—	—	—	2.66	64.5	25.0	10.5	Outwash
1099C	Iowa, Waterloo, Canfield Airport	15	—	—	—	—	—	—	—	—	—	—	Terrace
1100C	Iowa, Waterloo, Livingston Field	48	—	—	—	—	—	—	—	—	—	—	Channel
1101C	″ ″ ″	24+	—	—	—	—	—	—	—	—	—	—	Channel
1102C	Iowa, US 20, W of Manchester	60+	—	29.8	10.7	—	—	—	2.70	63.5	18.0	18.5	
1161C	Iowa, US 34, 9 Mi. E of Fairfield	—	—	40.6	24.8	106.5	17.0	310	2.70	48.5	27.5	24.0	Old Drift
1163C	Iowa, US 34, Near Ottumwa	144	24-144	41.0	26.3	102.2	20.0	370	2.73	27.5	47.0	25.5	Old Drift
1165C	Iowa, US 34, 10 Mi. W of Osceola	30	24-36	43.6	25.7	—	—	—	2.71	40.0	39.0	21.0	Old Drift
1166C	″ ″	144	48-182+	36.6	23.0	114.0	14.8	280	—	—	—	—	Old Drift
965C	Mich., Montcalm County	24	—	38.4	24.1	105.0	19.2	200	2.67	32.0	26.0	42.0	
966C	″ ″ ″	60+	—	25.5	12.5	115.9	14.9	210	2.64	29.5	48.5	22.0	
967C	Mich., Gratiot County	60	17-65	20.1	7.8	114.6	15.7	230	2.69	39.5	31.0	29.5	
968C	Mich., Berrien County	—	24-132	30.1	15.1	113.6	15.4	400	2.74	25.0	36.0	39.0	
1046C	Mich., Iron County	—	15-24	—	—	104.8	14.6	900	2.78	19.0	18.0	13.0	
1047C	″ ″	—	50-60	—	—	130.2	8.0	*	—	—	—	—	
1048C	Mich., Ontonagon County	—	3-15	N.P.	N.P.	96.6	19.1	810	2.54	9.0	66.5	24.5	Lacustrine
1049C	″ ″	—	15-40	29.3	9.3	98.8	20.8	300	2.74	2.0	62.5	35.5	″
1050C	″ ″	—	45-60	28.9	7.7	99.9	18.8	780	2.71	—	—	—	″
1051C	Mich., Menominee County	—	6-21	—	—	114.5	12.2	500	2.66	63.0	30.0	7.0	Drumlin Material
1052C	″ ″	—	36-48	—	—	130.1	8.2	400	2.65	72.5	20.5	7.0	″ ″
1054C	Mich., Marquette County	—	12-24	—	—	106.3	16.0	600	2.61	—	—	—	
1053C	″ ″	—	30-50	—	—	120.3	10.0	1420	—	—	—	—	
1074C	Mich., Chippewa County	—	5-18	50.5	27.8	83.6	31.2	300	2.49	11.0	37.0	52.0	
1073C	″ ″	—	20-42	37.6	9.9	98.8	21.1	300	2.64	7.0	42.0	51.0	

* Penetration resistance greater than 2000 throughout extent of compaction curve.

TABLE VIII

RESULTS OF CLASSIFICATION TESTS ON GLACIAL SOILS (Continued)

Lab. No.	Location	Depth in.	Represents in	L L	P I.	Proctor Unit Wt.	Proctor Opt M C	Proctor Pen. Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1148C	Mich , Gladwin County	—	16-28	36.0	17.5	104.9	18 0	400	2.78	21.0	31.0	48.0	
1147C	" "	—	38-44	28.4	14.6	112.4	16 0	270	2.74	39.0	21.0	40.0	
1149C	Mich., Midland County	—	3-14	22.1	7.6	105 2	18 5	260	—	—	—	—	
1150C	" "	—	22-30	48.6	26.5	99.6	23 1	220	2.72	32.0	19.0	49.0	
1392C	Mich , Saginaw County	—	18-24	—	—	126.5	8 4	1080	—	—	—	—	Young Drift
1393C	" "	—	30-36	—	—	125.2	11.1	790	—	—	—	—	" "
1088C	Minn , Bemidji Airport	25	12-110 +	—	—	—	—	—	—	—	—	—	Outwash
1089C	Minn , US 2, Fosston	25	6-30	30.5	10.9	—	—	—	—	—	—	—	
1090C	Minn , "	50	30-84 +	22 6	10.2	118 2	13.0	240	2.68	47.0	35.5	17 5	
1092C	Minn , US 2, SE of Grand Forks	30	16 +	42 4	22.8	99 7	21 5	450	2.69	27.0	52 0	21.0	Lacustrine
1093C	Minn., Duluth Airport	10	4-10	N.P	N.P.	—	—	—	2 70	60.0	33.0	7.0	
1094C	" "	48	16-60	16 8	2.6	124 2	11.5	850	—	—	—	—	
1114C	Minn , US 71, N of Bemidji	—	0-10	—	—	—	—	—	—	—	—	—	
1097C	" " "	15	10-25	29.6	17 8	—	—	—	2.67	53.0	31.0	16.0	
1096C	" " "	30	25-35	N.P.	N.P.	—	—	—	2.64	43.5	47.0	9.5	Podzolized
1095C	" " "	48	48-144	20.2	6.5	117 1	12.1	430	2.52	49.5	36 0	14.0	
1110C	Minn , US 53, N of Duluth	8	4-15	N.P.	N.P.	—	—	—	2.63	58.0	37.0	7.0	Young Drift
1109C	" " "	36	15-40	—	—	—	—	—	2.73	58.0	37.0	5.0	" "
1111C	" " "	60	40-80 +	—	—	—	—	—	—	—	—	—	" "
1112C	Minn , US 53, N of Cotton	20	6-24	30.2	14.6	—	—	—	2.72	59.0	26.5	14.5	" "
1113C	Minn., Hibbing Airport	20	12 +	44.1	28.3	—	—	—	2.64	44.0	18.5	37.5	Lacustrine
1115C	Minn , NE of Red Lake (Lake Agassiz Area)	12	4 +	—	—	—	—	—	—	—	—	—	Young Drift
1091C	Minn., US 2, NW of Crookston	30	—	63.6	41.2	91.2	28.0	250	2.71	22 0	38.0	40.0	Lacustrine
1116C	Minn., US 2, E of Crookston	—	—	—	—	—	—	—	—	—	—	—	Beach Ridge

TABLE VIII

RESULTS OF CLASSIFICATION TESTS ON GLACIAL SOILS (Continued)

Lab. No.	Location	Depth in.	Represents in	L L	P I	Proctor Unit Wt	Proctor Opt. M C.	Proctor Pen. Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1117C	Minn , US 2, NW of Crookston	48	----	62.7	39.1	----	----	----	2.68	----	----	----	Lacustrine
1118C	" "	10	4-16	53 8	28 1	----	----	----	2.60	29.0	38.0	33.0	"
1121C	Minn , US 10, S Limit of Little Falls	30	----	----	----	----	----	----	----	----	----	----	Terrace
1122C	Minn , Monticello Airport	15	----	----	----	----	----	----	----	----	----	----	Terrace
1124C	Minn , US 14, W of Owatonna	24	----	39 8	23.7	----	----	----	2.61	52.0	31.0	17.0	
1123C	" "	72	----	30 6	14 2	----	----	----	2.68	67.0	25.0	8.0	
1125C	Minn., Waseca Airport	20	----	41.5	22.6	----	----	----	----	----	----	----	
1126C	Minn , SR 13, N of Albert Lea	24	18-40	56.7	34.3	----	----	----	2.68	38.0	31.5	30.5	
1127C	" "	44	40 +	33 1	13.7	----	----	----	2.66	65 5	23 0	11.5	
1131C	Minn , US 10, 5 Mi NW of Wadena	24	12-30	----	----	----	----	----	----	----	----	----	
1128C	" "	250	----	----	----	130.2	8.7	620	2 66	----	----	----	
1132C	Minn., US 10, S of Motley	30	18-40	37 9	22.2	----	----	----	----	----	----	----	See Text
1133C	" "	108	40 +	N.P	N P.	131.2	10.8	450	2 74	86.0	6.5	7 5	" "
1134C	Minn , SR 152, E of St Michael	72	----	28 7	13.3	109.8	16 2	320	2.71	61.5	27.5	11 0	
1135C	Minn , US 65, N of Dundas	20	----	45.3	26 4	----	----	----	----	----	----	----	
1136C	" "	144	36 +	24.8	12 4	113 4	14 5	300	----	----	----	----	
1137C	Minn , US 65, S of Albert Lea	---	16-72	53 7	28 7	----	----	----	2 59	24.0	43.5	32 5	
1138C	" "	80	72 +	30 7	14 0	104 7	18 2	470	----	----	----	----	
951C	Mo , US 54, 4 Mi N of Missouri River	8	0-8	37 9	21 2	----	----	----	----	21.5	42 5	36 0	Old Drift
952C	"	72	8-120	46 5	29.8	105 0	18 0	260	----	31.5	31 0	37.5	" "
953C	Mo , SR 15, 20 Mi N of Mexico	12	12-48	53 0	26.6	81 3	26 3	690	----	10 5	54.5	35.0	" "

TABLE VIII

RESULTS OF CLASSIFICATION TESTS ON GLACIAL SOILS (Continued)

Lab. No.	Location	Depth in.	Represents in.	L L	P I	Proctor Unit Wt.	Proctor Opt. M.C	Proctor Pen. Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
954C	Mo , US 36, 7 Mi. NE of Monroe City	48	36-60	57.0	31 8	——	——	——	——	8.0	39.0	53.0	" "
1319C	Mo , US 40, 5 Mi E of Columbia	12	0-18	27 4	7 4	——	——	——	——	——	——	——	
1320C	" "	28	18-36	28.8	12.1	——	——	——	2.64	24 0	57.0	19 0	
1321C	" "	50	36-60	41 5	22.2	105.0	18.8	520	——	——	——	——	Old Drift
1322C	" "	60	60-72 +	57 7	39.4	——	——	——	——	——	——	——	" "
1330C	Mo., US 40, 35 Mi. E of Columbia	12	10-18	32 8	12 8	——	——	——	——	——	——	——	" "
1331C	" "	30	26-34	59.0	33 0	——	——	——	——	——	——	——	" "
1332C	Mo., US 40, 35 Mi. E of Columbia	54	50-58	49.3	31 9	——	——	——	——	——	——	——	" "
1333C	Mo., US 40, 9 Mi E of Mineola	48	40-60	34.8	18 7	——	——	——	2.72	14.0	15.5	30.5	" "
1224C	Mont., W Yellowstone Airport	6	0-12	N P.	N P	——	——	——	2.57	77.5	16.0	6.5	Outwash
1226C	"	——	——	——	——	——	——	——	——	——	——	——	"
1119C	N. D., US 81, S of Grand Forks	24	——	——	——	——	——	——	2.73	39.0	48.5	12.5	Lacustrine
1129C	N. D., Grand Forks Airport	36	——	——	——	106.8	17 3	820	2.69	34.5	59.0	6.0	Lacustrine
1120C	N. D., Fargo Airport	8	0-10	60 0	27.5	——	——	——	——	——	——	——	"
1130C	" "	15	10-20 ±	66.8	40 4	88 7	27.1	80	2.64	22.0	39.5	38.5	"
992C	Ohio, US 6, 2 Mi. W of Bryant	96	48-144	30.4	16.7	106.0	18.4	800	2.72	14.0	31.0	55.0	
993C	Ohio, US 20, 1 Mi. W of Fayette	36	24-36	38.4	20.2	——	——	——	2.73	30.0	37.5	32.5	
994C	Ohio, Williams-Toledo Airport, Toledo	12	12 +	29 4	14.1	——	——	——	2.64	11.0	53.5	35.5	Lacustrine
995C	Ohio, SR 199, Near Toledo Municipal Airport	48	16-64 +	32.5	14.9	110.0	17 1	1140	2.67	36 0	30.0	34.0	"

TABLE VIII

RESULTS OF CLASSIFICATION TESTS ON GLACIAL SOILS (Continued)

Lab. No.	Location	Depth in.	Represents in.	L L.	P I	Proctor Unit Wt.	Proctor Opt M C	Proctor Pen Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
996C	Ohio, US 20, W of Freemont	12	12-24	42 2	16 6	----	----	----	2 69	22 0	44 0	34.0	
997C	Ohio, SR 13, Mansfield Municipal Airport	72	60-72 +	29.4	13.1	111 3	16 2	1170	----	----	----	----	
1008C	Ohio, Cherry Fork Airport	12	0-18	31.2	14 1	----	----	----	2 74	25.5	48 5	26.0	Old Drift
1009C	" " " "	24	24-40 +	50.5	31.5	97.9	24 0	1070	2.67	17 0	51.5	31.3	"
1010C	Ohio, SR 13, Mansfield Municipal Airport	24	12-36	33.6	18 1	----	----	----	2.75	23.0	39 5	37.5	Young Drift
1011C	Ohio, Cleveland Municipal Airport	20	----	N P	N P	----	----	----	----	----	----	----	Beach Ridge
1012C	Ohio, SR 13, E of Cleveland Municipal Airport	24	12-24 +	36 9	16 6	----	----	----	2 73	13.0	47 0	40.0	Lacustrine
1014C	Ohio, Akron Airport	24	10-60 +	24 9	7 2	----	----	----	2 57	----	----	----	Gravel Terrace
1027C	Ohio, Cherry Fork Airport	84	72-84	49 0	31 0	----	----	----	2.72	25.0	35.5	39.5	Old Drift
1028C	Ohio, US 62, Samantha	24	12-48	43.1	25 7	----	----	----	2.72	48.0	26.0	26.0	Old Drift
1029C	" " "	60	48-180	18.6	2 1	126.2	10.3	1800	2 76	51.5	31 5	17.0	"
1030C	Ohio, Lockbourne Airport, Columbus	60	12-60 +	41.4	24 7	----	----	----	2 70	30 0	32.5	37 5	Outwash
1031C	Ohio, N Part of Columbus	24	----	48 5	25 3	----	----	----	2 73	21 0	40.0	39.0	
1037C	Ohio, US 40, 2 Mi W of Springfield	60	----	16 8	1.7	----	----	----	2.72	50.0	34 0	16.0	
1033C	Ohio, SR 369, 1 Mi. N of US 40	20	10-30 +	36.8	17 5	----	----	----	2.70	50.5	28 0	21.5	
1034C	Ohio, 1st Rd N of Dayton Municipal Airport	18	12-25	45 5	23 9	----	----	----	2 68	34 5	42 0	23.5	
1001C	Ohio, Youngstown Airport (Vienna)	18	6-30 +	28 8	10.4	----	----	----	2 64	26 0	54 0	20.0	Young Drift
1002C	Ohio, US 21, S of Cleveland	36	24-60	32 7	12 7	----	----	----	2.76	24 0	41 0	35.0	"
1004C	Ohio, Kings Graves Rd , N of Youngstown	40	30-50 +	25 8	8 5	115.8	14 7	1050	2 75	28.0	39.0	33.0	"

TABLE VIII

RESULTS OF CLASSIFICATION TESTS ON GLACIAL SOILS (Concluded)

Lab. No.	Location	Depth in.	Represents	L.L.	P I.	Proctor Unit Wt.	Proctor Opt. M.C.	Proctor Pen. Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1015C	Pa , SR 19, S of Mercer	40	20-50	21.4	5 2	----	----	----	2.75	37.5	50.5	12 0	Moraine
1169C	S D., Sioux Falls Airport	15	12-36	67 6	44.3	----	----	----	----	----	----	----	Channel
1170C	S. D., Mitchell Airport	48	48-60 +	----	----	----	----	----	----	----	----	----	"
1171C	S D., 1 Mi N of Mitchell Airport	30	24-60	30 8	13 4	109.3	16 7	530	2.74	58.5	29.0	12.5	Young Drift
1172C	S. D , SR 37, Huron Airport	48	24-72	----	----	117 6	13.3	600	2.72	76.0	18.0	6.0	"
1173C	S D., W of Mitchell Airpt.	24	12-36 +	----	----	----	----	----	----	----	----	----	"
1175C	S. D., 1 Mi. W of Mitchell Airport	84	60-120	33.2	13.9	110.3	16.4	650	----	----	----	----	"
1176C	S. D , US 14, 32 Mi. E of Pierre	--	18-36	43.4	23.4	100.0	21.0	350	2.74	19.0	56.0	25.0	"
1182C	S. D , US 14, 25 Mi E of Pierre	96	60-120	40.2	24 4	104 8	19.5	410	----	----	----	----	"
1249C	Wash., US 95, S of Spokane	--	900 +	----	----	----	----	----	----	----	----	----	Terrace
1079C	Wisc., Janesville Airport	--	0-48	34 5	15 2	----	----	----	2.74	12 5	61.0	18.5	"
1080C	Wisc , Edge of Janesville Airport	30	18 +	39.5	16 8	----	----	----	----	----	----	----	"
1081C	Wisc., Madison Airport	24	12 +	40.1	18.6	----	----	----	----	----	----	----	Lacustrine
1083C	Wisc , Madison Airport	48 ±	16-60	33.8	13.3	103.7	18 8	600	2.82	11.5	69.5	19.0	"
1082C	Wisc., US 14, S of Madison	84	66-84 +	28 3	14 2	----	----	----	----	----	----	----	
1084C	Wisc , Lone Rock Airport	30	12 +	----	----	----	----	----	----	----	----	----	Terrace
1087C	Wisc., US 2, E of Superior	24	3 +	56.7	37.3	98.9	21.5	300	2.62	37.5	25 0	37.5	Lacustrine
1106C	Wisc., Eau Claire Airport	12	----	----	----	----	----	----	----	----	----	----	Terrace
1107C	Wisc., US 53, Chetik	20	10-30	33.6	15 2	----	----	----	2.73	58.0	29.0	13.0	
1108C	" " "	--	30 +	----	----	----	----	----	----	----	----	----	

TABLE IX

RESULTS OF CLASSIFICATION TESTS ON SOILS OF THE COASTAL PLAIN

Lab. No.	Location	Depth in.	Represents in.	L.L.	P I	Proctor Unit Wt.	Proctor Opt M C	Proctor Pen Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
$839C_1$	Ala., Aliceville Agr. Exp. Field	--	0-14	----	----	----	----	----	----	----	----	----	
$839C_2$	" " "	--	20-30	29.3	9 1	113.8	15.0	490	2.67	44.0	36.0	20.0	
$843C_2$	Ala., Black Belt Agr Sta , Marion Junction	40	----	55.3	27 4	90 8	26.2	390	----	----	----	----	
$843C_{2A}$	" " "	—	----	----	----	98.2	21 5	450	----	----	----	----	
$844C_1$	" " "	6	----	45.5	15.6	----	----	----	----	----	----	----	Topsoil
$844C_2$	" " "	50	----	41.8	17 4	99.8	22 0	330	----	----	----	----	
864C	Ala., US 31, 8 Mi. S of Montgomery	12	0-24	48.7	16 3	93.9	24 8	400	----	----	----	----	
865C	" " "	24	24-36	39 9	14 9	----	----	----	2.68	----	----	----	
866C	" " "	60	36-72+	45 7	19 0	95.0	27.0	110	2 72	----	----	----	
867C	Ala., US 31, 11 Mi. S of Montgomery	60	40-60+	63.7	36.4	----	----	----	2.67	----	----	----	
868C	Ala , US 31, 14 Mi S of Montgomery	12	0-24	51.6	17.7	----	----	----	2.66	----	----	----	
869C	" " "	36	24-72+	57 4	27.5	89.8	29 0	400	2.70	17.5	27.5	55.0	
870C	" " "	84	72-96+	73 4	43.9	----	----	----	2.67	----	----	----	
871C	Ala , US 31, 6 Mi. N of Lownes-Butler Co. Line	25	10-50+	46 8	26 2	99.6	21.9	330	2.66	27 0	27.5	45.5	
872C	Ala., US 31, 4 Mi S of Lownes-Butler Co Line	120	24-168+	86 1	36 8	----	----	----	----	----	----	----	
873C	Ala , US 29, 5 Mi S of Tuskeegee	12	0-24	61 0	19.4	----	----	----	2.65	52.5	16.5	31.0	
874C	" " "	72	24-84	59 0	20.4	83 8	30.5	1050	2.67	----	----	----	
882C	Ala., 7 Mi SW of Auburn	24	12-96	38.5	13.2	106 8	17.8	530	2.63	----	----	----	
884C	Ala., 3 Mi from Brewton	72	12-144	30.2	11.5	113.7	14.2	1400	2 66	65.0	11.0	24.0	
889C	Ala., Brewton Area	36	0-36	N P	N P.	----	----	----	2 64	----	----	----	
890C	" " "	48	12-48	31.2	8.6	----	----	----	2.64	----	----	----	
891C	Ala , Brewton Area Granular Borrow No. 1	72	144+	32.0	10.2	----	----	----	----	88.0	7 0	5.0	

TABLE IX

RESULTS OF CLASSIFICATION TESTS ON SOILS OF THE COASTAL PLAIN (Continued)

Lab. No.	Location	Depth in	Represents in.	L L.	P I	Proctor Unit Wt	Proctor Opt M C	Proctor Pen Res	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
892C	Ala., Brewton Area Granular Borrow No. 2	192	36-420	----	----	----	----	----	----	----	----	----	
894C	Ala , Terrace Area S of Brewton	36	24-48 +	N P	N P	----	----	----	----	----	----	----	
895C	Ala , Brewton Area	48	8-60 +	N P	N P	----	----	----	2 66	73.0	12 0+	15.0 +	
1036C	Ala., Wiregrass Agr Exp. Sta , Headland	--	22-42	----	----	112 8	10.5	400	----	----	----	----	
893C	Ala , Area No. 1, Brewton	15	3-26 +	N P	N P	----	----	----	2.63	----	----	----	Terrace
909C	Ark , 5 Mi W of El Dorado	12	0-18	30 7	11.1	----	----	----	2.62	50.0	27 5	22.5	
910C	" "	60	18-90	38.5	17.1	104.2	19.5	300	2.69	41.5	24.5	34.0	
911C	" "	108	96-120	45 1	24.4	----	----	----	2.74	46.0	31.5	22.5	
912C	" "	48	24-72	52.6	30.8	----	----	----	2 66	31.0	29.0	40.0	
913C	" "	78	72-84	62.0	26.5	----	----	----	2.67	15 0	41.0	44 0	
914C	Ark , Side Rd 5 Mi W of El Dorado	10	0-10	----	----	----	----	----	----	----	----	----	
915C	Ark , SR 15, Tent. Airport Site, SW of El Dorado	6	0-6	N P	N P.	----	----	----	2.64	81 0	11.5	8 5	
916C	" "	72	6-120	----	----	117 7	12 0	1150	----	----	----	----	
917C	" "	--	120 +	N P	N P	----	----	----	2 66	----	----	----	
896C	La , US 51, 9 Mi N of Hammond	6	0-12	19.1	0.5	----	----	----	2.61	42 0	47 0	11.0	Topsoil
897C	" "	--	12-24	24 2	8 0	----	----	----	2.66	31 0	51 0	18.0	
908C	La., US 80, 18 Mi. W of Monroe	48	24-96	62.4	39.7	----	----	----	2.56	5 5	44 5	50.0	
887C	La , US 51, 8 Mi W of New Orleans	--	----	54.3	38.0	----	----	----	2.66	15 0	45.0	50.0	Fill Area
905C	La., SR 15, 1 Mi. S of Winnsboro	12	0-18	N P.	N P	----	----	----	2 53	11.0	67 0	22 0	
906C	" "	40	18-60 +	47 0	23 8	97 0	22.8	380	2.62	12 5	61.5	26.0	
907C	La , SR 15, 10 Mi. N of Winnsboro	24	12-40 +	36.4	15 5	99.5	21 0	700	2.63	15 0	61.5	23.5	

TABLE IX

RESULTS OF CLASSIFICATION TESTS ON SOILS OF THE COASTAL PLAIN (Concluded)

Lab. No.	Location	Depth in.	Represents in.	L L	P I	Proctor Unit Wt			Specific Gravity	Grain Size Analysis Sand			Remarks
						Unit Wt	Opt. M C	Pen. Res.		Sand	Silt	Clay	
885C	Miss., US 90, 3 Mi W of Alabama State Line	--	——	59 5	26 8	----	——	----	----	----	----	----	Borrow Pit
886C	Miss., US 90, 18 Mi , SW of Alabama State Line	12	10-24	N P.	N P	109.7	14 1	440	----	----	----	----	Terrace
837C$_2$	Texas, Texas City	—	----	46 2	26 4	107.0	17 8	220	2.68	23.0	36.0	41.0	Subsoil
919C	Tex., US 82, E of Texarkana	20	4-48 +	57.9	20.0	82 9	31.5	1130	2.68	15.0	33 0	52.0	
920C	Tex , US 82, 14 Mi W of Paris	28	0-40	59 4	35 2	99.2	21.2	200	2.65	15.0	45 0	40.0	
921C	" "	168	40-192	58 4	42 6	----	----	----	2.65	13.0	39.0	48.0	
922C	" "	192	192 +	66 0	42 7	----	----	----	2 63	----	----	----	
924C	Tex , US 82, 10 Mi W of Bonham	60	30-60 +	52 4	31.3	----	----	----	----	----	----	----	
926C	Tex , US 82, 8 Mi W of Sherwin	48	12-84	50.2	35 1	----	----	----	2 67	21 0	30.0	49 0	
1070C	Tex , McLennan Co., 250 ft. from Dyke	--	0-6	25 0	7 5	107 6	15.3	450	2.66	57 5	27.5	15.0	Topsoil
1071C	Tex., McLennan Co., SW 14, C of Shed	--	0-6	33.5	23 3	106.2	15 9	320	2 64	16.0	58.0	26.0	
1072C	Tex , McLennan Co , SW 5, C of Shed	—	0-6	45 2	19 0	98 1	19.4	450	2.64	24.0	52.5	23.5	

TABLE X

RESULTS OF CLASSIFICATION TESTS ON SOILS OF THE FILLED VALLEYS AND GREAT PLAINS OUTWASH MANTLE

Lab No	Location	Depth in	Represents in	L L	P I	Proctor Unit Wt	Proctor Opt M C	Proctor Pen Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
972C	Ariz , SR 66, 12 Mi W of Joseph City	--	36-72	24 5	8 8	118 3	12 8	430	2 68	51 0	36 5	12 5	Alluvium from Shale
973C	Ariz , Navajo Indian Resv	--	6-24 +	48 5	30 1	97 3	21 0	310	2 65	20 0	50 0	30 0	Alluvium
974C	Ariz , Hopi Indian Resv	--	11-27	21 3	4 5	117 7	12 0	850	2 66	65 5	23 0	11 5	"
975C	" "	--	27 44	22 1	5 8	114 5	14 0	500	2.63	61 5	27 5	11 0	"
978C	Ariz , Navajo Indian Resv	--	9-24	38 2	18 0	101 6	19 5	340	2 65	26 5	43 0	30.5	"
980C	Ariz , SR 6, 12 Mi W of Joseph City	--	12-36	23 9	11 6	117 0	12 9	610	2 68	36 0	52 0	12 0	Alluvium from Shale
1307C	Ariz , US 89, Fredonia Airport	12	12-24 +	28 5	8 5	----	----	----	2 74	20 0	72 0	8 0	Valley Fill
1318C	Ariz , US 66, 32 Mi W of Flagstaff	--	6-24	71 5	50 3	93 9	25 3	300	----	----	----	----	Lacustrine
1334C	Ariz , Winslow	--	6-42	34 4	17 4	----	----	----	----	----	----	----	Alluvium
1348C	Ariz , Koch Field, Flagstaff Municipal Airport	24	12-36	26 9	13 0	----	----	----	----	----	----	----	Valley Fill
1350C	Ariz , US 66, 45 Mi E of Flagstaff	--	0-6	20 8	4 6	----	----	----	----	----	----	----	"
1335C	Ariz , Holbrook Airport	--	0-24	25 3	14 4	----	----	----	----	----	----	----	
969C	Ariz , Navajo Indian Resv.	--	46-80	----	----	107 5	13 0	200	2 64	----	----	----	
970C	" " "	--	8-24	----	----	112 5	13 0	780	2 66	52 0	38 0±	10.0±	
977C	" " "	--	24-60	----	----	112 7	12 8	610	2 68	----	----	----	
983C	" " "	--	16-46	----	----	117 7	11 8	1000	2 65	----	----	----	
1344C	Colo , US 85, 6 Mi S of Pueblo	48	12-72 +	34 4	15 8	109 3	17 6	436	----	----	----	----	Outwash from Granite Hills
1355C	Colo , US 50, 45 Mi E of Pueblo	18	6-36 +	28 7	8 8	----	----	----	----	----	----	----	River Terrace
1356C	Colo , Pueblo Municipal Airport	12	0-24	----	----	----	----	----	----	----	----	----	Alluvial Fan

TABLE X

RESULTS OF CLASSIFICATION TESTS ON SOILS OF THE FILLED VALLEYS AND GREAT PLAINS OUTWASH MANTLE (Continued)

Lab No	Location	Depth in	Represents in	L L.	P I.	Proctor			Specific Gravity	Grain Size Analysis			Remarks
						Unit Wt.	Opt. M.C	Pen Res.		Sand	Silt	Clay	
13590	Colo , Kelsey Field Lamar Airport	24	0-24 +	23.7	9 3	----	----	----	----	----	----	----	Alluvial Fan
12450	Idaho, US 10, W of Cataldo	—	----	38 5	13 9	----	----	----	2.72	----	----	----	Lacustrine
12650	Idaho, US 95, New Meadows	18	12-24	43.3	17.7	----	----	----	----	----	----	----	Valley Fill
12680	Idaho, Municipal Airport, N of Boise	12	1-20	N P	N P	----	----	----	----	----	----	----	Outwash from Granite
12690	Idaho, Mountain Home Air Base	48	0-60	----	----	----	----	----	----	----	----	----	Valley Fill
12710	Idaho, SR 15, McCall Airport	24	12-48 +	N P.	N P	----	----	----	2.72	----	----	----	"
12740	Idaho, SR 25, SE of Goodings	15	2-30	----	----	----	----	----	----	----	----	----	Alluvial Fan
12780	Idaho, US 30 S, 1 Mi. N of Idaho-Utah Line	48	12-60	----	----	----	----	----	2 65	67 0	28.0	5.0	(Lake Terrace) Hyrum
13630	Kan , US 50, Garden City Airport	40 +	40-48	----	----	----	----	----	----	----	----	----	Terrace
13640	Kan , US 83, 2 Mi N of Finney-Haskell Co Line	16	2-20	28 7	7 9	----	----	----	----	----	----	----	(Loess)
13650	Kan , 30 Mi. SE of Garden City	20	6-48	38 8	23.2	106.0	18 8	360	----	----	----	----	Amarillo
13660	" "	—	48-96 +	30.1	17 6	----	----	----	2.69	34.0	60 5	5 5	"
13670	Kan , Dodge City Airport	—	0-18	34 0	16 3	----	----	----	----	----	----	----	
13680	" " " "	20	18-36	48 4	26.0	----	----	----	----	----	----	----	
13690	Kan , US 50, Ford County	60	----	48.7	22.7	----	----	----	----	----	----	----	
13700	Kan , US 50 S, 30 Mi E of Kinsley	—	10-60	----	----	111.9	15.2	370	----	----	----	----	
13890	Kan , US 50 S, 30 Mi E of Kinsley	—	60-66 +	44.1	25.6	----	----	----	----	----	----	----	

TABLE X

RESULTS OF CLASSIFICATION TESTS ON SOILS OF THE FILLED VALLEYS AND GREAT PLAINS OUTWASH MANTLE (Continued)

Lab. No	Location	Depth in	Represents in	L L	P I	Proctor Unit Wt.	Proctor Opt. M C	Proctor Pen Res	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1232C	Mont , SR 1, Jefferson Co	10	4-18	—	—	—	—	—	2.75	52 0	36 5	11.5	Terrace
1233C	" " "	30 +	18-40	—	—	—	—	—	2 60	76 5	19 0	4.5	"
1234C	Mont , US 10, NW of Missoula	36	6-50 +	44 0	20.0	97 8	24 4	450	2 76	3 0	45 0	52.0	Lacustrine
1225C	Mont , US 191, 4 Mi N of West Yellowstone	18	12-24 +	N P.	N P	78.4	30.6	1400	2.37	53.0	31.0	16 0	Waterlaid Volcanic Ash
1228C	Mont , SR 1, 10 Mi N of West Yellowstone	24	12-48	35 3	15 6	—	—	—	2.66	32.0	44 5	23 5	Alluvial Fan
1229C	" " "	48	48-60	42 4	26 4	—	—	—	—	—	—	—	" "
1388C	N M , US 64, 6 Mi. E of Cimarron	6	0-10	50 0	30 7	—	—	—	—	—	—	—	
1342C	" " "	—	10-120	35 4	22.9	107 0	16 5	510	—	—	—	—	Mt Outwash
1341C	" " "	120	120-144 +	—	—	—	—	—	—	—	—	—	" "
1353C	N M , US 85, Airport 2 Mi N of Jct with US 64	15	2-20	29 7	15.4	—	—	—	—	—	—	—	" "
1337C	N M , US 89, 25 Mi N of Albuquerque	240	6-420	—	—	—	—	—	—	—	—	—	Valley Fill
1338C	N M , US 89, SW of Santa Fe	24	12-60	39 1	20.1	—	—	—	—	—	—	—	" "
1340C	N M , US 66, 25 Mi F of Gallup	72	24-120	63.0	39 3	—	—	—	—	—	—	—	From Shale
1352C	N M , US 66, 5 Mi E of Gallup	12	0-24 +	63 7	35 6	93 0	25 2	360	—	—	—	—	" "
1387C	N M , West Mesa Airport, Albuquerque	10	6-20	—	—	—	—	—	—	—	—	—	Valley Fill (from Granite)
1386C	N M , N of Albuquerque	3	1-5	30 8	14.7	—	—	—	—	—	—	—	Terrace

TABLE X

RESULTS OF CLASSIFICATION TESTS ON SOILS OF THE FILLED VALLEYS AND GREAT PLAINS OUTWASH MANTLE (Continued)

Lab. No	Location	Depth in	Represents in.	L L	P I	Proctor Unit Wt.	Proctor Opt M C	Proctor Pen Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
1193C	S D , US 14, Spearfish Airport	24	12-48	35 0	16 9	106.2	17 0	570	—	—	—	—	Terrace
1194C	S D , US 14, Spearfish Airport	48	36-60	32.8	13 0	—	—	—	2 70	—	—	—	"
1195C	" " "	84	84 +	28 5	4 1	—	—	—	—	—	—	—	"
1280C	Utah, US 30 S	28	10-40	37.2	20.7	—	—	—	—	—	—	—	(Lake Terrace) Hyrum
1281C	Utah, US 30, Near Bingham	24	12-36	—	—	—	—	—	2 69	67 0	23.5	9.5	(Lacustrine) Lahonton
1282C	" " "	54	36-108 +	36 2	21 6	107 3	19.0	450	—	—	—	—	" "
1283C	Utah, US 30 S, W of Blue Creek	—	24-60	71 0	40.0	—	—	—	—	—	—	—	Lacustrine
1284C	" " "	—	60-144	64 3	37 0	—	—	—	—	—	—	—	"
1285C	Utah, US 30 S, N of Blue Creek	24	18-36 +	N P.	N P.	—	—	—	2.63	42 0	52 0	6.0	Valley Fill
1286C	Utah, US 89, 23 Mi. S of Salt Lake City	125	125-300	—	—	—	—	—	—	—	—	—	Terrace
1287C	Utah, 2 Mi. N of Provo Near Lake Level	12	0-18	32 6	11 4	—	—	—	—	—	—	—	Lacustrine
1288C	" " "	20	18-36 +	28 7	8 8	—	—	—	—	—	—	—	"
1290C	Utah, US 91, 75 Mi S of Provo	36	12-48 +	34.6	14 9	107 3	17 1	500	—	—	—	—	"
1296C	Utah, US 91, Wash Co.	20	8-30	47 0	28 6	—	—	—	—	—	—	—	Valley Fill
1297C	Utah, US 91, 35 Mi. S of Cedar City	4	0-6	—	—	—	—	—	2 81	73 0	24 0	3.0	Valley Fill (Mohave) From Granite
1298C	" " "	24	6-36 +	—	—	126.5	10.5	830	—	—	—	—	" "
1304C	Utah, US 89, Near Utah-Ariz. Border	12	0-12	N P	N P	—	—	—	—	—	—	—	Valley Fill
1305C	" " "	18	12-36	—	—	115 8	13 4	105.0	—	—	—	—	" "

TABLE X

RESULTS OF CLASSIFICATION TESTS ON SOILS OF THE FILLED VALLEYS AND GREAT PLAINS OUTWASH MANTLE (Concluded)

Lab. No.	Location	Depth in	Represents in.	L.L.	P.I.	Proctor Unit Wt.	Opt M C	Pen. Res.	Specific Gravity	Grain Size Analysis Sand	Silt	Clay	Remarks
1200C	Wyo , US 14, Near Devil's Tower	20	10-30	34.0	12.8	——	——	——	2.62	——	——	——	
1201C	" " "	60	48-72	N P.	N.P	112.5	13.4	1850	——	——	——	——	
1207C	Wyo , 3 Mi W of Sheridan-Campbell Co. Line	9	0-15	45 7	25.7	——	——	——	2.65	26.0	51.0	23.0	Alluvial Fan
1208C	Wyo., US 14, 5 Mi. W of Cody	16	10-40	38.6	22.5	——	——	——	2 73	——	——	——	" "
1209C	Wyo , Sheridan Airport	36	24-48 +	39.8	27.1	——	——	——	——	——	——	——	" "
1210C	" " "	18	12-24	39 8	26.3	107 0	17 5	540	——	——	——	——	" "
1211C	" " "	7	——	38.1	22.3	——	——	——	——	——	——	——	Runway Subgrade
1212C	" " "	40	——	36 8	18.5	——	——	——	——	——	——	——	" "
1213C	" " "	——	——	——	——	——	——	——	——	——	——	——	" "
1214C	Wyo , Sheridan Air. Runway	——	2-8	29.9	18 1	119.6	11.8	850	——	——	——	——	Alluvial Fan
1215C	Wyo., Sheridan Airport	——	——	N P	N P	128.8	9.2	1032	——	——	——	——	" "
1221C	Wyo , US 20, Greybull Arpt.	36	0-36 +	——	——	——	——	——	——	——	——	——	Fan or Terrace
1222C	Wyo , Cody Airport	36	30-40	47 8	28 9	98 8	22.2	350	——	——	——	——	Alluvial Fan
1219C	Wyo , US 14, Big Horn Mts.	12	7-18	57 9	32.5	——	——	——	2.79	18.0	43.5	38.5	Alluvium
1220C	" " "	20	18-30	53.2	27.3	——	——	——	——	——	——	——	"
1227C	Wyo , US 20, E of Cody	18	12-30	26 4	9.4	——	——	——	——	——	——	——	Terrace

TABLE XI

RESULTS OF CLASSIFICATION TESTS ON RECENT ALLUVIUM

Lab. No.	Location	Depth in.	Represents in.	L L	P I	Proctor Unit Wt	Proctor Opt. M C	Proctor Pen. Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
840C1 840C2	Ark , Crittendon Co " "	— —	0–8 8 +	— 70.6	— 25.9	— 83.5	— 28 0	— 300	— —	— —	— —	— —	Miss. River " "
918C	Ark , US 82, Red River Valley	12	12–24	56 5	32 5	95 6	23.8	270	2 70	16 5	51 5	32.0	
1357C	Colo., Near LaJunta Air-port	12	0–60 +	—	—	—	—	—	—	—	—	—	
1242C	Idaho, US 10, Cataldo	60	2–96 +	N.P	N P	—	—	—	2.75	44 5	38 0	17 5	
1275C	Idaho, S of Rupert between US 30 S and US 30 N, Snake River	8	6–12 +	32 8	16 8	—	—	—	2 77	45 0	44 5	11 5	
1361C 1362C	Kan , US 50, Garden City Airport " " "	12 28	2–18 18–40	30 9 31 5	11 8 14.3	— —	— —	— —	— —	— —	— —	— —	Terrace "
1371C	Kan , US 50, Hutchinson Airport	24	—	64 0	47.3	—	—	—	—	—	—	—	
1381C	Kan., US 50, 35 Mi E of Florence	—	—	63.9	35.9	—	—	—	—	—	—	—	
1385C	Kan , US 50, N of Holcomb	—	10–14	27 4	12 4	—	—	—	—	—	—	—	Terrace
845C1 845C2	Ky , Owensboro Airport " " "	— 24	12–24 0–24	— 38 7	— 14 9	107 1 —	16 3 —	780 —	2.66 —	13.5 —	66.0 —	20.5 —	Ohio River " "
846C	Ky , Co. Rd., 1 Mi W of Owensboro Airport	96	0–120	—	—	—	—	—	2.67	26.5	70.0	3.5	
847C	Ky , Co Rd 5 Mi W of Owensboro	24	12–36	28 6	5 1	107 5	17 0	910	2.61	14 0	65 0	21 0	
848C	Ky , SR 75, 5 Mi S of Owensboro	24	12–36	37 0	18.4	—	—	—	2.68	8 0	54 0	38.0	

TABLE XI

RESULTS OF CLASSIFICATION TESTS ON RECENT ALLUVIUM (Continued)

Lab. No	Location	Depth in	Represents in.	L.L	P I	Proctor Unit Wt.	Proctor Opt M C.	Proctor Pen Res.	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
888C	La., US 51, 40 Mi NW of New Orleans	24	0-36	45.6	23 4	95 2	24 0	270	2.68	19.0	39.0	42.0	Terrace
898C	Miss., Near Miss. R , Natchez	—	—	39.5	16 4	—	—	—	2.64	12 5	53 5	34.0	
900C	Miss., Natchez	72	48-120	—	—	—	—	—	—	—	—	—	
904C	Miss , 1 Mi W of Natchez	36	24-40 +	57.1	30 6	86 5	28 0	380	—	—	—	—	
955C	Mo , US 24, W of Quincy, Ill.	12	12 +	40 7	19 9	102 3	19 5	290	2 67	11.5	53 0	35 5	
956C	" "	18	3-36 +	65 9	42 3	89 5	26 2	210	2.63	8.0	26.0	66.0	
1168C	Neb , US 275, Dodge Co.	240	120-480	—	—	—	—	—	—	—	—	—	
1179C	Neb , Adjacent to Omaha Airport	15	10-20	59.2	38 1	—	—	—	—	—	—	—	
1180C	" " "	30	20-38	42 4	19 6	—	—	—	2.67	12 5	65.5	22.0	
1181C	" " "	40	38-40 +	78.1	50 7	—	—	—	—	—	—	—	
999C	Ohio, SR 7, Grandview	8	4-12	41 6	13 1	—	—	—	2 67	24 0	46 0	30 0	
1003C	Ohio, New Matamoras	24	12-48	27 6	6 8	—	—	—	—	—	—	—	
929C	Okla , US 77, 5 Mi S of Davis	48	24-72	—	—	—	—	—	2.65	51 5	33 5	15.0	
931C	Okla , US 77, N of Pauls Valley	6	0-20 +	31.6	6 6	—	—	—	2.58	10.0	42.0	48.0	
932C	Okla , Pauls Valley Area	26	3-30	39 8	18 2	—	—	—	2 64	11.5	62 0	26.5	

TABLE XI

RESULTS OF CLASSIFICATION TESTS ON RECENT ALLUVIUM (Concluded)

Lab No	Location	Depth in.	Represents in.	L L	P I	Proctor Unit Wt.	Proctor Opt. M C	Proctor Pen. Res	Specific Gravity	Grain Size Analysis Sand	Grain Size Analysis Silt	Grain Size Analysis Clay	Remarks
934C	Okla , SR 19, 5 Mi NW of Pauls Valley	12	6-24	32 9	19.5	----	----	----	----	----	----	----	
925C	Tex , US 82, 10 Mi W of Bonham	24	0-72	64 9	36 8	----	----	----	2 56	22.0	38 5	39.5	
1016C	W Va , US 21, Airport N of Parkersburg	24	12-48	N P	N P.	----	----	----	2.69	72.0	16.0	12.0	
1018C	W Va., Parkersburg Airport	16	4-24	39.8	12 2	----	----	----	2.67	18 5	56 5	25 0	
1086C	Wisc , LaCrosse Airport	15	----	----	----	----	----	----	----	----	----	----	

TABLE XIII

SUMMARY OF DATA DERIVED FROM LABORATORY CLASSIFICATION TESTS

Total No of Samples	Limits			Proctor				Specific Gravity		Grain Size Analysis			
	No Tests Averaged	Average		No Tests Averaged	Average			No Tests Averaged	Ave	No. Tests Averaged	Average Percentage		
		L L	P I		Max Dry Wt	Opt M C	Penet *		Sp Gr.		Sand	Silt	Clay
13	5	36.2	11.5	1	107.6	15.3	450	3	2.61	3	36.5	38.8	24.7
9	8	29.3	10.3	5	111.0	15.3	896	3	2.66	2	67.1	10.9	22.0
39	0	—	—	10	121.2	13.1	621	12	4.72	5	65.5	24.1	10.7
16	0	—	—	1	128.8	9.2	1032	—	—	0	—	—	—
15	3	22.1	5.7	6	127.7	9.5	748**	6	2.65	6	74.3	18.2	7.6
20	4	31.8	12.5	6	118.6	12.3	804	14	2.68	13	65.6	26.7	7.6
55	34	28.2	7.6	16	90.6	18.1	767	38	2.68	31	22.3	62.4	15.2
37	26	23.8	8.8	26	40.0	13.6	756	25	2.68	24	51.0	31.3	17.7
22	21	30.1	13.7	9	111.0	16.6	608	12	2.70	12	42.5	32.9	24.6
60	59	36.4	10.5	14	102.5	19.9	575	36	2.69	28	19.9	52.9	26.8
81	80	38.5	20.7	34	104.1	19.0	487	39	2.70	40	28.2	40.1	28.7
66	65	50.7	28.4	20	99.0	22.4	475	34	2.68	34	25.9	37.4	36.6
48	48	65.5	38.5	17	87.5	28.8	386	19	2.69	17	15.1	36.2	47.4
12	12	64.2	38.3	4	87.3	28.3	331	5	2.64	4	20.8	43.9	35.4
7	7	58.4	19.5	4	86.3	29.9	745	5	2.64	4	38.4	29.7	31.9
500	372	—	—	173	—	—	—	251	—	223	—	—	—

Total		
	Samples Classified in Groups 1 to 12C	500
	Samples Classified in Groups 13 to 18C	18
	Samples Unclassified or Void	9
	Total	527
	Samples Classified on Basis of Test Results	440
	Samples Classified by Observation	78

Number of Samples Obtained by Staff	462
Number of Samples Obtained by Correspondence	65
Total Number of Laboratory Tests	1019
Number of Soil Series Represented	104
Number of States Represented	38
Number of Airport Sites Represented	30***

*Penetration at Optimum Moisture Content.

**Not included in this average - (Iron River - 1047C) - having a penetration resistance greater than 2000 throughout the extent of the compaction

***Represents only airport sites designated as such when samples were submitted.

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In evaluating and using this bibliography of some 700 references, the reader's attention is called to the methods used in organizing and compiling the list The first three parts, containing "General," "Maps," and "Aerial Photography," constitute perhaps the most important references used in this work In fact, the careful student of the subject will find that most of the maps listed as well as a large number of the references in the other two sections will be almost indispensable Particularly, the thoroughly documented writings by Fenneman (19) (20) are highly recommended as comprehensive treatments of the background essential to this work

The next six parts, including "Residual," "Glacial," "Loess," "Coastal Plain," "Great Plains and Filled Valleys," and "Major Alluvium," are listed in the order used on the map of "Principal Engineering Soil Groups " Those interested in certain restricted areas will find some of these references particularly useful

The remaining portion of the bibliography - and by far the largest portion - contains the remaining references used in the preparation of this report, listed alphabetically by states Most of these publications cover the geological or pedological aspect of a specific geographical unit or political subdivision in more or less detail Thus, those interested in great detail will find these state references very helpful

Even though this listing may appear to the casual reader to be extensive, it should be emphasized that it is by no means complete To illustrate, only a few of the many hundred Soil Survey Reports by counties, published by the United States Department of Agriculture, are included however, these reports, including maps, are generally available at the Superintendent of Documents, Washington, D C at a nominal cost Likewise, a large number of the publications of the United States Department of Interior are omitted Of the 226 published Folios of the Geologic Atlas of the United States, only a small fraction are listed in the bibliography There are some additional United State Geological Survey Bulletins, Water-Supply Papers, and Professional Papers not used in the preparation of this report but which contain information pertinent to the subject Complete listings of these publications will be found in the references listed or in the "Publications of the Geological Survey," U S Department of Interior, Washington, D C There are, of course, many additional sources of information to be found in publications of the various Geological, Pedological, and Geographical Societies

As to availability, most of the literature cited in this report (particularly bulletins) is now out of print, however, practically complete coverage of any subject is available at or through the larger libraries of the country For the prospective purchaser, dealers in used books are able to supply a surprisingly large number of publications now out of print

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