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Soil Survey Manual

By
SOIL SURVEY STAFF
Bureau of Plant Industry, Soils, and
Agricultural Engineering

This is a Revision and Enlargement of U. S. Department of Agriculture Miscellaneous Publication 274, the Soil Survey Manual, Issued September 1937, and Supersedes it.

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CONTENTS

INTRODUCTION

The *Soil Survey Manual* is intended for use by soil scientists engaged in soil classification and mapping. Attention is directed primarily to problems and methods of making and interpreting detailed basic soil surveys in the United States and territories.

The earlier edition,[1] published in the autumn of 1937, reflected the developments growing out of the ideas, work, and publications of hundreds of scientists since the beginning of the United States Soil Survey in 1899. Substantial progress has been made since 1937 in the soil survey itself and in related fields of soil research. Further, soil surveys are now used by more people, in more ways, and, above all, with more precision than formerly.

The increased use of soil maps and interpretations has led to increased testing of the results, both scientifically and practically. Inadequacies appeared that required correction. Continually, new knowledge about soils needs to be incorporated into the classification and into the interpretations. New research methods and new cartographic methods need to be evaluated, adapted, and used as they are appropriate to improve soil surveys and to reduce their costs.

Nearly the whole of the earlier edition of the *Manual* has had to be revised. Although some appear to be drastic, few of the revisions are out-and-out changes; most of them are modifications and elaborations to achieve the specificity and completeness required to make the final results more nearly quantitative and more useful. For example, essentially all soil mapping is now done on aerial photographs, and the discussion of the older cartographic methods has been condensed in appendices.

Some new terms have been added and a great many redefined, especially to permit increased accuracy. This process of redefining will need to go on as long as soil research continues. The discovery of new relationships and the formulation of new concepts require an expansion of language.

Many of the technical terms used in soil science are common words, taken out of the body of language and given precise and sometimes unusual meanings. A large part of them originated as folk terms among rural people. Such words as "loam," "texture," "structure," "heavy," "light," "profile," "horizon," and even "soil" may have a deceptive familiarity to the layman using the language of soil science. Similar technical words have arisen in the same way in the other languages, often with slightly different shades of meaning, not revealed in the ordinary lexicon. The meaning of coined words, like "Lithosol" and "illuviation," or of those taken bodily from other languages, like "gley" or "Chernozem," once

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[1] SOIL SURVEY MANUAL. U.S. Dept. Agr. Misc. Pub. 274, 136 pp., illus. 1937.

learned, are not so likely to be confused with other meanings as are redefined common words.

Even though newly coined words are more easily defined than the older ones are redefined, their use on soil maps and in soil survey reports intended for the general reader is limited. For some new concepts a writer has no alternative to technical terms. These he needs to define for the general reader. Commonly, however, the older more general words must be used in soil survey reports, insofar as possible, in order to capitalize on the readers' present understanding. But in the scientific work itself specific terms should be used in the sense of accurate definitions. Thus there is no escape from a certain amount of "double language."

Need of accurate definition.—Special effort has been made in this revised text of the *Manual* to define terms and to use them as specifically as possible. Since the early edition, much progress has been made toward uniformity of terminology among soil scientists. Better definitions are still needed within our own language, and especially better transliterations among the various languages. Some nearly arbitrary selection among alternatives has been necessary in the *Manual.*

A separate glossary is not included because much duplication would result and because many definitions are clearer when set within an explanatory context. Where definitions might lead to long and highly technical statements, explanations are given instead. Page numbers of the Index in bold type refer to definitions and explanations of the terms.

The relationships of the soil survey to other researches have deepened and broadened as its uses and interpretations have expanded. It has seemed that this *Manual* should be broad enough in scope to lead into the most important of these relationships, but it cannot develop them in detail. Even the field of soil classification, above the lower categories, lies mostly outside of its scope. A few references to fuller discussions are given in the text, and a suggested reference shelf is included near the end.

Since the earlier edition was prepared (during 1935–36) all phases of the work have been under study by the Soil Survey staff. Following intensive study and revision, mimeographed copies of new statements about many individual subjects treated in the *Manual* were circulated both for guidance in making soil surveys and for criticisms and suggestions. Since all the basic soil survey work in the United States is carried on cooperatively with the State land-grant colleges and universities, several scientists in those institutions have helped a great deal in criticizing statements on special subjects and the draft of this edition of the *Manual.* Besides, informal cooperation is carried on with the research organizations of several foreign countries. Scientists from these countries have given us the benefit of their valuable experiences and judgments. Several read all or parts of the draft manuscript and made valuable suggestions for its improvement.

Other modifications can be expected, especially in classification and nomenclature, as our knowledge and experience advance.

Some prospective changes are under study and are mentioned here and there in the text.

The authors have had great help from the criticisms and comments given by readers of the *Manual* published in 1937. It is hoped that readers of this revised edition will note errors and omissions and call them to the attention of the Soil Survey staff so that any subsequent edition may be improved.

Arrangement of topics.—It is assumed that most readers of the *Manual* will have had training equivalent to that of a graduate holding the Bachelor of Science degree from a curriculum in soil science like that officially recommended by the Soil Science Society of America.[2] It is expected that many readers will need to carry on collateral reading in soil classification, general soil science, geology, interpretation of aerial photography, geography, economics, and general agriculture.

The authors have further assumed that soil survey party chiefs and those wishing to prepare for such responsibilities will want to study all parts of the *Manual.* Therefore, the topics are arranged roughly in the order that problems arise in starting, carrying out, and completing a soil survey, although, of course, a party chief must have a view of all aspects to begin with, since the several phases of the work are closely interrelated. It is assumed that others who are not concerned in the whole job may find the *Manual* a helpful reference for particular items that can be located from the table of Contents or the Index.

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[2] Soil Sci. Soc. Amer. Proc. 6: 507. 1941.

SOIL AND LANDSCAPE

First let us briefly review the working concepts of soil and of the principles of scientific method upon which this *Manual* is based. These have been formulated only after many years of trial and error.

When the Soil Survey began in the United States, more than 50 years ago, there was no organized body of knowledge that we have come to know as soil science. This is not to say that nothing was known about soils. Indeed farmers had learned a great deal through experience over the centuries, and much of their knowledge had been brought together in several compilations, some as early as Roman times. With the rise of agricultural chemistry during the nineteenth century, more was learned about soils that was useful. Yet it was not until some time near the end of the century that the knowledge about soils gained from farming, from agricultural chemistry, from biology, and from geology was coordinated. Nor could it be coordinated without some unifying concept of the soil itself.

The early concepts.—With few exceptions, like Hilgard's ideas,[1] the notions of soils held by soil workers at the time the Soil Survey began were based upon assumptions stemming mainly from the ideas of the great German chemist, Liebig, as modified and perfected by agricultural chemists and plant physiologists working on samples of soil in laboratories and greenhouses and on small plots of soils in the field. The soils were rarely examined below the layer turned in regular tillage. The assumption of soil character, or working theory, which was more or less unconsciously conceived, may be briefly summarized as the balance-sheet theory of plant nutrition or the-soil-is-like-a-bank idea. Soils were considered to be more or less static storage bins for plant nutrients that could be used by plants but had to be replenished as used. Of course, the amounts of nutrients removed from soil by harvested crops and those returned in manure, lime, and fertilizers are important to an understanding of soil productivity;

[1] The soil scientists of today cannot help being amazed at the general neglect of E. W. Hilgard's important and pioneer work, first in Mississippi (GEOLOGY AND AGRICULTURE OF THE STATE OF MISSISSIPPI. 391 pp., Jackson, Miss. 1860.); then in the Cotton Belt as a whole (A REPORT ON COTTON PRODUCTION IN THE UNITED STATES; ALSO EMBRACING AGRICULTURAL AND PHYSIO-GEOGRAPHICAL DESCRIPTIONS OF THE SEVERAL COTTON STATES AND CALIFORNIA *in* volumes 5 and 6 of the 10th Census of the United States. Washington. 1884); and finally in California (SOILS; THEIR FORMATION, PROPERTIES, COMPOSITION, AND RELATIONS TO CLIMATE AND PLANT GROWTH IN THE HUMID AND ARID REGIONS. 593 pp., illus. New York and London. 1906.).

but a great deal more is needed for our understanding of soils and their management requirements. In fact, this simple balance-sheet theory, by itself, has but little prediction value.[2]

The early geologists generally accepted this notion of soil fertility. They filled the conceptual storage bin with ground rock of various sorts—granite, sandstone, calcareous till, and the like. They went further, however, and showed how the weathering processes modified this material and how the geological processes of landscape formation used it in the construction of land forms, such as glacial moraines, alluvial plains, loessial blankets, and marine terraces. Shaler's monograph on the origin and nature of soils[3] went about as far as it was possible to go with this geological concept of soils; although many details were added in Merrill's treatise.[4]

Professor Milton Whitney and his coworkers in the new soil research unit of the United States Department of Agriculture, established near the end of the nineteenth century, were impressed by the great variations among natural soils—persistent variations in no way due to the effects of agricultural use. Special emphasis was given to soil texture and to the ability of the soil to furnish plants with moisture as well as nutrients. Professor F. H. King of the University of Wisconsin was also emphasizing the physical characteristics of soils.[5]

The Soil Survey began in response to the recognized need for helping farmers locate themselves on soils responsive to management and, once located, for helping them to decide what crops and what management practices were best for the particular kinds of soil on their farms.

In early surveys, soils were conceived to be the weathering products of recognized geological formations, defined by land form and lithological composition. Many of the earlier field workers were trained in geology, because only geologists were skilled in field methods and in the scientific method of correlation appropriate to the field study of soils.

Shortly after field work began, it became obvious that many important soil characteristics were not definitely related to either broad land form or rock type. It was noted that naturally poorly drained soils have different characteristics than naturally well drained soils, and that sloping soils are unlike level ones. On broadly similar glacial till from Maine to Montana, and down to the Ohio River, markedly contrasting soils are developed in

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[2] See KELLOGG, CHARLES E. CONFLICTING DOCTRINES ABOUT SOILS. Sci. Monthly 66: 475–487. 1948.

[3] SHALER, N. S. THE ORIGIN AND NATURE OF SOILS. U. S. Geol. Survey Ann. Rpt. 12: 213–345, illus. 1891.

[4] MERRILL, G. P. A TREATISE OF ROCKS, ROCK-WEATHERING AND SOILS. New ed., 411 pp., illus. New York and London. 1906.

[5] See for example, KING, F. H. A TEXTBOOK OF THE PHYSICS OF AGRICULTURE. Ed. 3, 604 pp., illus. Madison, Wis. 1910.

the various climatic and biotic zones. Yet for several years the geological view dominated in the field, and the balance-sheet theory of plant nutrition in the laboratory. Although they were taught in many classrooms until the late 1920's, neither theory actually worked well in the field as a basis for reliable predictions to farmers. As a consequence, all sorts of special little concepts were formed that broke down in contradiction when applied to a great continental area like the United States.

Broader and more useful concepts of soil were developing among some American soil scientists, especially Hilgard. The necessary data for formulating these broader concepts came in rapidly from the field work of the Soil Survey during the first decade of its operations. After Hilgard, the longest reach toward a more satisfactory concept was made by Coffey.[6]

Soil profiles and the concept of individual soils.—Meanwhile, beginning in 1870, a new concept of soil was developing in the Russian school of soil science.[7] The results of this work became generally available to Americans through the publication of Glinka's great textbook in German and especially through its translation into English by C. F. Marbut.[8] Boiled down to its essentials, soils in the Russian concept were conceived to be independent natural bodies, each with a unique morphology and resulting from a unique combination of climate, living matter, parent rock materials, relief, and time. The morphology of each soil, as expressed in its profile, reflected the combined effects of the particular set of genetic factors responsible for its development.

This was a revolutionary concept, as important to soil science as anatomy to medicine. The soil scientist did not need to depend wholly upon inferences from the geological nature of the rocks, or from climate, or from other environmental factors, considered singly or collectively; rather, he could go directly to the soil itself and see the integrated expression of all these in its morphology. This concept made it not only possible but necessary to consider all soil characteristics collectively, in terms of a complete, integrated natural body, rather than individually. In short it made a soil science possible.

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[6] COFFEY, G. N. A STUDY OF THE SOILS OF THE UNITED STATES. U. S. Dept. Agr. Bur. Soils Bul. 85, 114 pp., illus. 1912.

[7] See the following references:

GEDROIZ, K. K. SOIL-ABSORBING COMPLEX AND THE ABSORBED SOIL CATIONS AS A BASIS OF GENETIC SOIL CLASSIFICATION. (Trans. by S. A. Waksman) Nossov Agr. Expt. Sta. Paper 38, 29 pp. Lenigrad. [In papers on soil reaction 1912-25.]

KELLOGG, CHARLES E. RUSSIAN CONTRIBUTIONS TO SOIL SCIENCE. Land Policy Rev. 9: 9-14. 1946.

NEUSTRUEV, S. S. GENESIS OF SOIL. Russ. Pedol. Invest. 3, Acad. Sci., 98 pp. Leningrad. 1927.

[8] GLINKA, K. D. THE GREAT SOIL GROUPS OF THE WORLD AND THEIR DEVELOPMENT. (Trans. from the German by C. F. Marbut.) 235 pp. Ann Arbor, Mich. 1917.

With the early enthusiasm for the new concept and for the rising new discipline it made possible—soil science[9]—some went so far as to suggest that the other sciences were unnecessary to soil study. Perhaps some extreme statements in this tone were made to declare a certain sense of autonomy and freedom from the older concepts of geology and agricultural chemistry rather than from thoughtful conviction. Certainly the reverse of independence from other sciences was true, for besides laying the foundation for a new science with its own principles, the new concept made the other sciences even more useful. In soil morphology, the soil scientist found a firm basis on which to classify the results of observation, of experiments, and of practical experience, and to develop principles of prediction value.

Under the intellectual leadership of C. F. Marbut[10] the new concept was further broadened and adapted. As first explained, this concept emphasized individual soil profiles—soils at points on the earth's surface—even to the subordination of external soil features and surface geology. This weakness become more clearly evident in the United States, perhaps, because of the great emphasis upon detailed soil maps for their practical prediction value. Progress was rapid because of the large body of important field data already accumulated. By 1925 a large amount of morphological and chemical work was being done on soil profiles throughout the country. The data available around 1930 were summarized and interpreted in accordance with this concept, as

[9] Terminology is still confused. A large amount of applied soil science, and even some fundamental soil science, is still included under agronomy in several colleges and universities in the United States. Partly to differentiate it from applied agricultural science, another large field of application is termed "soils engineering." Terms like "soils geology" and "forest soils" are also used for parts of the field of soil science. "Soil technology" has been used in the narrow sense of soil manipulation—drainage, irrigation, erosion control, tillage, and the like—and also in the broader sense of all applied soil science. Similarly, "soil conservation" is commonly used not only in the narrow sense of erosion control but also in various broader senses up to "soil management for sustained production."

In Europe generally, the word "scientist" has a somewhat more exalted connotation than in the United States. Thus individuals hesitate to call themselves "soil scientists." They prefer a single word like "pedologist." Unfortunately, in the United States, pedology has come to mean only those phases of the more general field of soil science that relate directly to soil morphology, genesis, and classification. In this sense pedology is even too narrow for the work of the Soil Survey. Further, the term "soil science" has at least some self-evident connotation to the layman. The authors see no better alternative in the United States than "soil science" for the general field—for the science that treats of soils, including their nature, properties, formation, functioning, behavior, and response to use and management. In many countries this also defines "pedology" as the term is now used in them.

[10] See the following:

MARBUT, C. F. THE CONTRIBUTION OF SOIL SURVEYS TO SOIL SCIENCE. Soc. Prom. Agr. Sci. Proc. (1920) 41: 116–142, illus. 1921.

——— A SCHEME FOR SOIL CLASSIFICATION. 1st Internatl. Cong. Soil Sci. Comm. 5, Proc. and Papers 4: 1–31, illus. 1928.

SOIL SCIENCE SOCIETY OF AMERICA. LIFE AND WORK OF C. F. MARBUT. 271 pp., illus. Columbia, Mo. 1942.

viewed by Marbut, in his great work on the soils of the United States.[11]

Marbut always emphasized strongly that soil classification should be based on soil morphology, since theories of soil genesis were both ephemeral and dynamic. He was led to emphasize this point so much—perhaps even to overemphasize it—because of the previous errors made by acceptance of the balance-sheet theory and the geological concept under which soils had been assumed to have certain characteristics without the scientists taking the trouble to examine the soils to see whether they were like they had been assumed to be. Marbut was trying to make the point abundantly clear that examinations of the actual soils were essential for developing a system of soil classification and for making soil maps of prediction value. (This still needs emphasis today. Even yet schemes of soil classification and mapping are occasionally put forward that are designed to avoid the work of profile examination!)

Extreme interpretations of Marbut's emphasis upon morphology as the basis for classification led to the suggestion that the soil classifier could neglect genetic principles and relationships. Such extremes should be avoided. A soil is not really understood until its genesis and the reasons why it varies from other soils are known. Not until the morphology and genesis of a soil are known can research to discover new and improved management systems be planned most effectively. Without such organized knowledge, purely empirical mass plot work alone must be resorted to with the hope that something will work. This is the situation now with many tropical soils. The Ground-Water Laterite soils are an example. Until their genesis is worked out, finding practical systems of soil management by empirical plot trials alone seems nearly hopeless. Fundamental soil research should be emphasized more as a basis for classification, applied research, and the invention of new techniques.

One may conceive, perhaps, of the development of an accurate system of soil classification on the basis of morphology alone; but in practice it is doubtful that completely satisfactory results can be had. Besides accurate morphology, genesis is needed to guide the work and to test the results. Neither one nor the other can be neglected. Yet in the meantime, classification of soils of obscure genesis shall need to be handled as well as possible, largely on the basis of morphology alone.

Soils as dynamic three-dimensional landscapes.—The concept of soil was gradually further broadened and extended around 1930 and the years immediately following.[12] This revision in concept was not so dramatic as the earlier one; it was more a matter of consolidation and balance. Previously the major emphasis had been on the soil profile. Soil profiles come very near to occupying

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[11] MARBUT, C. F. SOILS OF THE UNITED STATES. *In* U. S. Dept. Agr. Atlas of American Agriculture, pt. 3, Advance Sheets No. 8, 98 pp., illus. 1935.

[12] See KELLOGG, CHARLES E. MODERN SOIL SCIENCE. Amer. Scientist 36: 517–536, illus. 1948.

single points on the earth's surface; whereas soils have shape and area, breadth and width, as well as depth. Morphological studies began to be extended from single pits to long trenches or to a series of pits over a soil area. The morphology of a soil is expressed by a range of profiles from a modal profile, not by a single profile or even by a typical one. Further, early emphasis upon genetic soil profiles had been so great as to suggest that in the absence of such genetic profiles, as in a young Alluvial soil, there was no "true" soil! A sharp distinction had been drawn between rock weathering and soil formation. Although distinction between these sets of processes is necessary, it is equally necessary to recognize that rock weathering and soil formation are sets of processes going on at one time in the same landscape. Soils are dynamic not only as soil profiles but also as landscapes.

Clarification and broadening of the concept of soil also grew out of the continuing emphasis upon detailed soil mapping and especially with the emphasis upon predictions of estimated yields for adapted crops under physically defined sets of management practices for each kind of soil shown on the maps. Many of the older descriptions of soils had not been sufficiently quantitative, and the classificational units had been too heterogeneous for making the yield predictions and management predictions needed for individual farm planning. The use of air photos, begun during the late 1920's, had greatly increased the accuracy of plotting soil boundaries. To meet the needs for farm planning, greater precision of interpretation was also required. This development of schemes for summarizing predicted yields and soil behavior under defined sets of management practices not only made the soil survey far more useful but also forced a reconsideration of the very concept of the soil itself.

Soil defined.—First of all, soil is the natural medium for the growth of land plants, whether or not it has "developed" soil horizons. Soil in this sense covers land as a continuum, except on rocky slopes, in regions of continuous cold, in very salty playas, and elsewhere that the cover of soil disappears. Soil has many forms. Its characteristics in any one place result from the combined influence of climate and living matter, acting upon the parent rock material, as conditioned by relief, over periods of time, including the effects of the cultural environment and man's use of the soil.

In studying the characteristics of soil and in predicting its potentialities for use, we cannot work with the whole continuum at once. Individual kinds of soil must be recognized. To make use of experience and of the results of research, classification becomes a necessity. It is through classification, as a tool, that we organize our knowledge and remember it, see relationships among soils and between them and their environment, and formulate principles of prediction value.

In the sense of an individual in the continuum, a soil is a dynamic three-dimensional piece of landscape that supports plants. It has a unique combination of both internal and external characteristics that have definable ranges of expression. Each individual kind of soil has a modal set of characteristics within the limits set by *our* logic. Its upper surface is the surface of the land; its lower surface is defined by the lower limits of soil-forming processes; and its sides are boundaries with other kinds of soil, where changes occur in one or more differentiating characteristics, related, in turn, to one or more of the genetic factors. Through research, the behavior of soils under defined conditions can be predicted.

Many thousands of unique kinds of soil exist in the world—as many as there are significant combinations of the genetic factors. The characteristics of each can be learned through observation and research in the field and in the laboratory. The history of a soil and its potentialities are contained in these characteristics, considered collectively. *The influence on soil behavior of any one characteristic, or of a variation in any one, depends upon the others in the combination.* (Probably more faulty predictions about soils result from failures to recognize this principle than from any other error.) A general system of soil classification comprehends all observable relevant characteristics.

Soils, then, are landscapes as well as profiles. The soil mapper has always recognized this in drawing soil boundaries. Commonly they come at the foot of an escarpment, at the margin of the swamp forest, or at some other obvious boundary among natural landscapes. The hardest soil boundaries of all to plot are those that can be located only through repeated examination of soil profiles because the controlling genetic variable is obscure. In detailed soil mapping, examinations of soil profiles are always essential to test the location of boundaries and to identify the bounded landscapes.

In the concept of soil as landscape, slope is an important soil characteristic. Soils, like other natural bodies, have shape. Formerly one wrote "soils on sloping land;" now we say simply, and more correctly, "sloping soils." Temperature is an important soil characteristic, even though it cannot be preserved in samples. The same may be said of stoniness and microrelief. A soil is a natural thing out-of-doors. Like a river or a glacier or a volcano, it cannot be brought into the laboratory. Thus, no matter how much and how valuable are the data we obtain on soil samples in the laboratory, the final synthesis into predictions can be made accurately only on the basis of all the characteristics of a soil as a landscape out-of-doors.

Since one cannot distinguish accurately under all conditions between "soil" and "not-soil," a precise general definition is impossible. The same is true of other well-understood basic words like "house," "plant," or "stone." Many thousands of individual kinds of soil have been defined. In most of these, but not all, one can decide clearly between the soil and the not-soil beneath it. Ordinarily we think of soil as including the upper part of the earth's crust that has properties different from the rock material because of the influence of the soil-forming factors. Yet the definitions of many individual soils must go further and include layers beneath that influence their behavior. Then, some soil-landscapes that support plants gradually thin to moss-covered rock and finally to bare rock with no clear separation between soil and not-soil that applies generally. Plants may be grown under glass in pots filled with samples of soil, with peat, with sand, or even with water. Under proper conditions all these media are productive of plants but some are not-soil. Plants even grow on trees; but trees are regarded as not-soil. Yet perhaps the most important quality of soil is its productivity for plants.

The following general definition of soil may serve those who need one: *Soil is the collection of natural bodies occupying portions of the earth's surface that support plants and that have properties due to the integrated effect of climate and living matter, acting upon parent material, as conditioned by relief, over periods of time.*

Scientific methods.—To understand the significance of any particular soil characteristic, or of any one genetic factor, sets of soil characteristics must be defined and compared. These sets are the units in soil classification.[13] To find the place of an unknown soil in the system of classification, or to understand the relationship of one soil to others in the system, the sets of characteristics are compared. This method of scientific correlation is the principal tool in soil classification.

Because of its universe and methods, soil science does not fit neatly with the physical sciences, the biological sciences, or the earth sciences. It is all three, but is not any one exclusively. Principles and methods from all three are used, in addition to those that are peculiar to soil science itself.

A large and growing body of fundamental scientific knowledge is the concern of soil science and of no other discipline. These facts emphasize the importance of seeing the science as a whole. No matter how much a soil scientist specializes, he must maintain a broad view of the whole field. In some sciences, like chemistry and plant physiology, for example, dependence is placed chiefly on one general scientific method—the experimental method. Unconsciously, some have assumed that the experimental method is the only method in science. Certainly it is a very useful one in soil science. With this method, the specific effects of variations in individual soil characteristics, and groups of soil characteristics, can be observed under defined conditions. The scientist then sets up experiments on plots representing an individual soil in which he can control the other variables, or at least account for their effects, besides the one under study. A large part of what has been learned about the behavior of specific kinds of soil has resulted from controlled field experiments, natural experiments, and the analyses of the records of operating units—farms, gardens, and forests.

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[13] See section on Units of Soil Classification and Mapping.

Yet a great many matters must come under scientific study that cannot be subjected to experiment. For example, we can get at the relative influences of different climatic regimes on the genesis of unlike soils from granite, say, through the use of both the experimental method and the method of correlation. The experimental method deals with soils at small places, almost points. Through the method of correlation the sets of data from different places are compared and principles developed from them that fit the facts.

Useful results can only come out of those experimental plots that are fair samples of a defined kind of soil. To interpret the results, either for an understanding of soils or for predictions about their behavior, they must be synthesized in terms of defined soil units. This is the function of soil classification. Its stuff comes from observation and the experimental method; its working tool is the method of logical scientific correlation.

Soil classification depends upon the results from all branches of fundamental and applied soil science. On the other hand, the results from the other branches of soil science can only be synthesized for accurate application through soil classification, whether soil maps are made or not. Soil classification has been so intimately associated with soil mapping, for which it is an immediate necessity, that some individuals in other branches of soil science have not always seen that, in the long run, soil classification is just as important to their work, especially to the orderly application of their results.

In applying soil science to forestry, farming, grazing, and engineering, some means must be had for recognizing the individual units of the classification system in the field. Few people among those needing to use the principles and predictions of soil science can identify these units. Thus it is essential to have soil maps. Assuming an adequate system of soil classification, with the units consistently named and with reliable predictions, an accurate soil map makes possible the orderly application of our knowledge to specific areas—fields, farms, forests, gardens, roadways, and the like.

Soil mapping itself is an applied science or art. The quality and usefulness of the result, however, depend upon a vast background of both fundamental and applied science. They depend upon what is known generally and upon what is known specifically by the particular group of scientists doing the work. Every soil survey area presents a new challenge. It is by no means simply a matter of mapping a few dozen standard soil types and phases. Soils are not so easily standardized. The relationships between each soil and its neighbors, and between each soil and the factors of its environment, must be sought out and clarified. All likely potentialities for use must be explored and definite judgments arrived at, insofar as possible, in quantitative terms.

This places a high premium on the resourcefulness of the field scientist in making full use of all existing data and principles and in capturing the essentials in the soil-use experience laid out

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before him. Nor can the field scientist depend exclusively upon local sources of information. Important potentialities are suggested from experiences on similar soils elsewhere, even in other countries. Then the final results must be presented in terms of adapted crops, management practices, and land use systems, with awareness of the factors that influence such systems. In short, a modern soil survey is a difficult research undertaking requiring intense thoroughness and broad scope.

The rewards of work well done can be very satisfying, both intellectually and emotionally.[14] Certainly the complexities involved in understanding a soil and predicting its behavior are enough to tantalize the imagination of any man. Then with accurate soil maps, land users everywhere can make full use of science and technology to bring forth the great potentialities in the soil, under efficient management systems, for the sustained abundance the world so desperately needs.

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[14] For the personal story of a soil surveyor's life in the field, see Macy H. Lapham's CRISSCROSS TRAILS: NARRATIVE OF A SOIL SURVEYOR. 246 pp., illus. Berkeley (Calif.) 1949.

CHARACTER OF SOIL MAPS AND REPORTS

A *soil map* is a map designed to show the distribution of soil types or other soil mapping units in relation to other prominent physical and cultural features of the earth's surface. The units may be shown separately or as soil associations named and defined in terms of taxonomic units. This definition is intended to exclude maps showing single soil characteristics like texture, slope, depth, color, or arbitrary combinations or two or more of these; maps showing soil qualities like fertility or erodibility; or maps showing individual soil genetic factors or combinations of them.

Maps of one or more soil features may be made directly from field observations or by selection and generalization from a soil map. On a soil map, however, combinations of all observable features relevant to the nature and behavior of the soil are comprehended as named taxonomic units—natural bodies with distinct sets of soil characteristics.

Selected interpretations of soil conditions may be shown on maps. From a soil map one may derive a series of simple interpretive maps of the same area showing, for example, the relative adaptability to alfalfa, corn, or other plants, erosion hazards under defined classes of management, drainage requirements for optimum production, irrigation potentialities, and many others. In the making of such generalizations, some soil boundaries are omitted; for example, those boundaries between soils equal in erosion hazard on the map of erosion hazard. But these particular boundaries may be important on another interpretive map, say one showing productivity classes. Thus different boundaries are omitted on different interpretive maps made from the same soil map.

Most such interpretations are ephemeral. They need to change with changes in the agricultural arts and in the cultural environment. If a basic soil map is made accurately, such interpretive maps can be revised easily from time to time as needed. But if only "judgment" maps are made on the spot, without a soil map, with any significant change in the agricultural arts or the cultural environment all the field work needs to be done over again. In planning soil surveys, this point can scarcely be overemphasized. Occasionally "short-cut" rural land surveys are made for some narrow objective, perhaps at a slightly lower cost than for a basic soil survey, only to become obsolete in a short time. Such maps cannot be repaired because vital data were ignored, facts were mixed with interpretations, boundaries between mapping units were drawn inaccurately, or because of some combination of these. Some rural areas have been mapped more than once by such short-cut surveys at a total cost approximating or even exceeding that of a basic soil survey and still there is no usable map for making predictions or recommendations to farmers about adapted crops, estimated yields, and soil management practices.

A soil map by itself, without a text guide to its interpretation, cannot be useful to anyone except those soil scientists intimately acquainted with the units as named in the map legend. To all others an accompanying text, as well as the map legend, is essential. The soil survey includes both map and text. In the text, commonly called the *soil survey report*, are described the natural and cultural features of the area surveyed; the characteristics, use capabilities, management requirements, predicted average crop yields, and predicted long-time effects of management systems for each of the soil types, phases, and other mapping units; and the principal factors responsible for soil formation.

The character and form of soil surveys vary with the soil conditions, the agricultural potentialities, and the problems to be dealt with. Also, they have changed over the years with advancements in soil science and in cartographic techniques. Even more important has been the increased demand for precision in order to make effective use of the great developments in agricultural technology.

UNITS SHOWN ON THE MAPS

Identification of units.—The first step in making a soil survey is the establishment of the units of classification to be shown on the maps. Their nomenclature within the general system of classification *follows* their accurate definition, based upon observations made in the field as supplemented by data from the laboratory. The basic unit is the natural soil type—the lowest[1] unit in the natural (or genetic) system of soil classification. By "natural system" is meant the system in which all relevant features of soils are considered as unique interrelated sets of characteristics, including those important to the practical purposes that soil maps serve, but without exclusive emphasis upon any one of them.

Each soil type is unique. It is defined as a unique combination of surface features, like slope and stoniness, and of internal characteristics—the texture, structure, color, chemical composition, thickness, and other properties of the horizons that make up the soil profile to whatever depth is significant. These units are characterized by field and laboratory observations of the chemical, physical, biological, and mineralogical features of the horizons, the geological nature of the parent rock material, and the geomorphological characteristics of the landscape.

Any one soil type includes the soils that are alike in characteristics that are significant to the nature and functioning of the soil in the natural landscape. Differences in features that are not significant in the natural landscape, but which are significant to

[1] The soil phase as a subdivision of a soil type may be regarded, from some points of view at least, as a lower unit. But since phases are separated within soil types, series, families, and great soil groups on the basis of differences significant (as differentiating soil characteristics) only under culture and not in the natural landscape, they are not usually regarded strictly as essential parts of the natural system. (See also p. 289 *et seq.*)

the use of the soil in farming, forestry, or grazing are recognized in subdivisions within the soil type (or soil series). Commonly, differences in slope, stoniness, or degree of erosion within the soil type that are not significant in the natural landscape but which are significant to its use are shown as *soil phases*. Whereas soil types are defined within a narrow range of a whole set of characteristics, including all those of genetic or applied significance, phase distinctions within soil types are based wholly on applied considerations. Thus soil types everywhere should be defined in the same way; but phases are more narrowly defined where the agriculture is intensive and less narrowly defined where it is extensive. The guides to phase distinctions are wholly pragmatic.

In defining the classificational units, including phase distinctions, emphasis is given to the relatively permanent features that influence response to management and not to ephemeral or transitory features, like the differences in plant nutrients caused by recent fertilization, liming, or similar soil management practices. It must be recognized that the immediate productivity of areas of the same soil type, or phase, may vary because of recent management history. This is especially true of soil types that respond greatly to fertilizers. Nevertheless, there should not be significant differences in productivity for climatically adapted crops among areas of the same kind of soil, if properly mapped, *when given the same management*. In very old agricultural areas, however, practices have changed the soils fundamentally, and their classification.

Observable features and inferred qualities.—In carrying out the soil survey and in reporting the results, the observable features need to be clearly distinguished from those soil qualities that are learned only by inference.

In the completed soil survey, the features of each kind of soil are listed. Among those observed directly are slope (degree, shape, and pattern), stoniness, depth, and the color, structure, texture, and other significant features of each horizon of the soil profile. Other observations include soil temperatures, kinds of plants and their rooting habits, features caused by erosion, and so on. Many characteristics are determined partly through the use of scientific instruments. Among these are the contents of clay, organic matter, plant nutrients, exchangeable cations, and the various clay minerals in the soil horizons. The pH of each soil horizon is also determined. As needed, the degree of aggregation, permeability, kind and amount of soluble salts, and the effects of additions of water are determined. It may be emphasized again that the soil units may be grouped and interpretive maps made according to one of these observable characteristics, but such maps are not basic soil maps.

Through interpretation from observed features, the qualities of kinds of soil may be learned by inference. Soil fertility, for example, may be estimated from observable characteristics, from the results of experimental plots, and from the experiences of farmers having records on fields consisting largely of one kind of soil. Soil fertility, however, is not directly observable. It is the quality that enables the soil to provide the proper compounds, in the proper amounts and in the proper balance, for the growth of specified plants, when other factors, such as light, temperature, moisture, and the physical condition of the soil, are favorable. Thus soils may be grouped into fertility classes only by inference. The same is true of tilth—the physical condition of the soil in respect to its fitness for the growth of a specified plant. Combining both of these qualities, fertility and tilth, one arrives at the concept of productivity, defined as the capability of the soil for producing a specified plant or sequence of plants under a specified set of management practices.

Groupings of soils by inferred qualities are essential to the interpretation of a soil survey. Besides fertility, tilth, and productivity, several other qualities may be inferred from the basic soil survey if the research is carried on competently. These qualities include erodibility, irrigability, response to drainage, workability or physical condition in respect to tillage, and crop adaptability. Groupings of soils according to use capability, either in the general sense or in the special sense employed by the Soil Conservation Service in its program of assistance to farmers, are easily made from the detailed soil map and report, or can be read directly from the soil map.

Identification of boundaries.—Having established the units of classification and identified these units on the ground, boundaries are drawn among them on accurate base maps or aerial photographs. The scales to be used depend upon the uses to be made of the map and the relative intricacy of the soil pattern.

After the soil units have been defined and their relationships to the environment worked out, most soil boundaries can be located on the land surface by recognizing where changes in one or more of the genetic factors occur. That is, excavations or borings are needed chiefly to identify the profile of a soil landscape. The actual boundary can usually be drawn most accurately by careful observations of the landscape. Nonetheless, there are important exceptions where the relationships between the differentiating soil features and genetic factors are obscure. For example, the depth and thickness of an iron crust or of a horizon of carbonate accumulation, or the depth to a water table, may be variable although there is no corresponding variation in surface features. In such instances, examinations of the soil are necessary for locating boundaries as well as for identification.

Soil boundaries must be drawn accurately. Despite the large proportion of attention given to soil classification in contrast to methods of soil mapping, a large part of the poor soil maps in the world are poor mainly because of inaccurate boundaries—boundaries guessed at rather than determined. In soil survey work great emphasis must be given to honesty in research. It is more difficult to check the results of a soil mapper than to check those of a laboratory worker, and the damage from incorrect soil boundaries may be very serious to the map user.

KINDS OF SOIL MAPS

Depending upon the detail with which boundaries between the mapping units are plotted in the field, three general kinds of original soil maps are recognized: (1) Detailed, (2) reconnaissance, and (3) detailed-reconnaissance. Of these the detailed soil survey is the most useful and most important. The third, detailed-reconnaissance, is not really a separate kind but is a soil map having parts of each of the first two kinds.

Besides original soil maps made from field surveys, there are relatively small scale soil maps showing associations of the taxonomic units. *Generalized* soil maps are developed through orderly abstraction from original field surveys, either detailed or reconnaissance. *Schematic* soil maps are compiled from spot field observations of the soils and their genetic factors, and from maps of geology, climate, land form, vegetation, and relief. Generalized soil maps of representative areas guide the compilation of schematic maps and are usually included in some parts of them.

Detailed soil maps.—On a modern detailed soil map, the soil types and phases are mapped in the detail required to show all boundaries between mapping units, including areas of one unit within another, that are significant to potential use (generally to plan field management systems). The classificational units are defined narrowly enough to be homogeneous genetically and to permit making such significant differential predictions as available knowledge permits; and the boundaries between mapping units are plotted on base maps or aerial photographs from observations made throughout their course, along with such natural features as streams and lakes and such significant cultural features as ditches, roads, railways, and houses.

Specific guides on the many items are presented elsewhere in this *Manual.* The base map needs to be complete and accurate because land lines (section lines, township boundaries, and the like), roads, houses, streams, and other obvious features are needed as local reference points by map users. Great detail in soil mapping, without a detailed base, is largely wasted, since the user is usually unable to locate himself properly and read the map accurately. Accuracy of a soil map is therefore not determined primarily by general geodetic accuracy but by what might be called local accuracy—the relation of the soil boundaries to the other features that the map user can identify. For example, even though a soil boundary may be plotted within the general limits of accuracy, should it be on the wrong side of a house or road, the usefulness of the map and the user's confidence in it are greatly reduced.

The detail of boundaries required depends partly upon the prospective use of the map. If small bodies of one kind of soil occur within areas of another kind of soil and thereby significantly affect management, the small bodies of soil should be separated or indicated on the map by defined symbols, even if they are an acre or less in extent. Judgment in mapping such areas is also influenced by the relative contrast between the two kinds of soil.

Even with large map scales some taxonomic units are often so intricately interlaced with one or more others that the association of them needs to be recognized as the mapping unit. In mapping areas of complex patterns where all the soils contained in paddocks or fields are treated alike, it may be more useful to show well-defined soil complexes than to map individual taxonomic units in minute and intricate detail.

The scale of mapping depends upon the purpose to be served, the intensity of soil use, the pattern of soils, and the scale of other cartographic materials available. Commonly a scale of 4 inches equal 1 mile (1:15,840) is now used for field mapping and one of about 2 inches equal 1 mile (1:31,680) for publication. Few detailed soil surveys that meet modern standards can be made in field scales less than 1:20,000 except in comparatively uniform terrain. For planning irrigation developments and in areas of very intensive farming the field mapping scales may need to be larger, say 1:7,920 or even 1:5,000. For engineering work, like planning for highway or airport construction, the detail needed may require a field mapping scale of around 1:2,500 or even 1:1,000,

In former years many soil maps were made in the field at a scale of 1 inch equals 1 mile (1:63,360 or 1:62,500) and published at the same scale. Later, the field mapping scale was doubled to 1:31,680. After the use of aerial photographs became general, the field scale was increased again to around 1:20,000 or 1:15,840. Publication scale continued for some time at 1:63,360 or 1:62,500. Some of the detailed maps plotted in the field on aerial photographs and reduced to these scales in publication are extremely difficult to read. So the publication scale was later increased to 1:48,000 and then again to 1:31,680 or 1:24,000. These larger scales have become necessary for easy legibility, although broad geographic relations among the soils are less clearly seen with the reduced total area of land on a single map sheet. The advantage of having the detailed soil survey of a county on one single map, however, has had to be sacrificed for clear reading of detail in reference to individual fields and farms.

No general rule can be laid down for guiding the number of soil examinations required per unit area nor for the intervals between traverses, except that these can rarely be more than one-fourth mile wide and usually need to be narrower.

Reconnaissance soil maps.—On a reconnaissance soil map the boundaries between the mapping units are plotted from observations made at intervals and not necessarily throughout their whole course as on the detailed soil maps. Reconnaissance maps vary widely, from "semidetailed" soil maps that approach the specifications of a detailed soil survey to maps of soil associations made from traverses at intervals of several miles. Reconnaissance maps are usually planned for exploratory purposes—to discover and outline areas of soil suitable for more intensive development (see page 435 *et seq.*). They are particularly useful in new and relatively undeveloped regions for identifying areas of promise for settlement or more intensive use.

In some reconnaissance surveys, the classification units are less precisely defined than in detailed soil surveys. Usually the mapping scale is smaller and fewer mapping units can correspond to the taxonomic units. In older reconnaissance work, it was customary to show named soil types on the map for areas that were really undefined mixtures of that soil type with others. This was done especially where research was insufficient to develop a complete classification. It is now possible to make far better and more useful maps by using defined soil associations.

In modern reconnaissance mapping, the taxonomic units are sought out, defined, and named as in a detailed soil survey. These are then mapped in groups as geographic associations. Such an association may contain several sharply contrasting soil types and phases. Each association is defined in terms of the named taxonomic units, their relative proportion, and their pattern. The associations are named in terms of the more prominent taxonomic units.

During the progress of the work, representative sample areas of each soil association are mapped in the detail required to meet the specifications of a detailed soil survey. These areas are carefully located, and small maps showing the detail are reproduced separately in the accompanying text. The usual supplemental laboratory data and other data are assembled by taxonomic units. Predictions about adapted crops, estimated yields, management requirements, and so on are also made for these units as they are in the detailed soil survey.

Agricultural scientists and advisers can examine the sample areas and learn how to identify the individual taxonomic units within the particular soil associations that concern them.

This scheme of reconnaissance soil mapping has a wide application in new and relatively undeveloped areas. It makes possible better appraisals of regional potentialities than the older reconnaissance soil maps with poorly defined mapped units. It permits the rapid surveying of large areas where development cannot await the completion of a detailed soil survey. At the same time it gives advisory agriculturists an opportunity to make those specific recommendations that can only be made on the basis of local, narrowly defined soil types and phases.

Good reconnaissance maps can be made only if there is enough detailed mapping of representative sample areas to establish the modal definitions of the taxonomic units and their permissible ranges of variability. Specifications for individual maps will vary widely. In mountainous regions or other areas not likely to be used intensively, traverses are made at less frequent intervals than on land suitable for farming.

Many of the soil maps made in the earlier years of research in the United States, which were looked upon as detailed soil maps in terms of the techniques of that time, are regarded as reconnaissance soil maps under modern specifications. The increased detail did not come in any single year and there were wide variations in the skill and vision of individual supervisors and soil survey party chiefs.

Detailed-reconnaissance soil maps.—On a detailed-reconnaissance map some portions satisfy the specifications for detailed soil maps, whereas other portions are reconnaissance soil maps. Such maps are made of counties or other geographic units containing areas of soil used or potentially useful for agriculture and other large areas that are unsuited. The part covered by reconnaissance may be rough mountainous land, raw acid peat soils, stony desert soils, dry sandy plains or hills, or other landscapes unsuited to farming.

The boundaries between the detailed and reconnaissance types of survey on the one map may be made in one of two ways: (1) The boundaries may follow section lines or other land lines and be shown in a smaller sketch map on the margin of the soil map; (2) the legend on the map may be divided into two parts. The mapping units listed under the reconnaissance legend, and boundaries among them, are defined and mapped according to the specifications for the reconnaissance map; whereas those units listed under the detailed legend and boundaries among them and between them and the units listed under the reconnaissance legend, are mapped according to the specifications of the detailed soil map.

Where the area covered by reconnaissance is considerably larger than the area covered in detail, it may be convenient to publish the reconnaissance portion separately from the detailed mapping. The detailed maps can then be published on extra sheets at a larger scale.

Generalized soil maps.—In order to see the broad geographic relations among soils, small-scale maps are necessary to bring out the contrasts among regions. The best of these are generalized from detailed soil surveys. Such maps vary in scale and detail from soil association maps of counties at a scale of 1 inch equals 1 mile (1:63,360) to single maps of large regions showing associations dominated by one or more great soil groups.

The descriptive legends of soil association maps indicate the relative proportions and patterns of the several classificational units that compose them. If the map is included as a part of a detailed soil survey, the text that explains the individual taxonomic units on the detailed soil map can serve for both. If the soil association map is published separately, descriptions and predictions for all taxonomic units within the associations should be attached, perhaps in tabular form.

The publication of detailed soil maps at scales as large as 1:31,680 and 1:24,000 has increased the need for generalized soil association maps so that broad areas can be viewed as a whole. Since the county is a convenient unit for many kinds of agricultural work in the United States, a soil map is needed to exhibit the whole county in such a way that the various parts of it stand out according to the principal soil features and patterns that are basic to types of farming and community problems.

Since the uses of generalized soil maps are so varied, it is more difficult to write specifications for them than for detailed soil maps. For the lowest level of generalization, the one most useful in agricultural advisory programs, we may proceed on the following basis: Farms are usually made up of several soil types. It is the combination of soil types that gives the soil association its distinctive character and sets the potentialities and limitations within the farm unit. Experience on individual fields is synthesized, classified, and extended on the basis of soil types and phases as defined in the detailed soil survey. Experience with whole farm units, made up of combinations of soil types, is synthesized, classified, and extended on the basis of soil associations. Consequently, the legend and detail of a useful soil association map are planned to show the use suitabilities of these broad geographic groups of soils. Of course, boundaries between soil associations cross some farms, just as the soil type boundaries cross some fields. If large areas of a single soil type do dominate many whole farms, the soil type may be shown separately. But rarely is this possible. In recognizing very small strips of highly productive Alluvial soils, for example, it must be recalled that the Alluvial soil usually is only part of the farm and is used in association with the adjacent uplands. In such instances, it may be misleading to separate small strips of Alluvial soils as a distinct association and the upland soils as one or more others. In other words, excessive detail in the soil association map can lower its usefulness.

The development of a proper legend for such a generalized soil association map requires judgment based upon a study of both soils and farming systems in whole farm units. The form of the legend for a soil association map is influenced by cultural environment, or expected cultural environment in a new area, more than is that for a detailed soil map. It must be so influenced if the soil association map is to be most useful for indicating whole-farm and community problems and potentialities. Well-made soil association maps interpreted in the light of data from experimental plots, fields, and farms, are exceedingly valuable for classifying farms according to their basic potentialities and for guiding agricultural advisers in the geographic emphasis they should give within a county or district to various educational and demonstration programs. Soil association maps serve as an excellent basis, in fact the only satisfactory one, for suggesting the approximate locations of experimental farms, pilot-research farms, and demonstration farms[2], and for suggesting where the experience from these farms is most applicable. For the exact location and plans of such farms a detailed survey is required. Soil association maps indicate the areas where the agricultural adviser should emphasize liming, erosion control, drainage, forest planting, use of phosphatic fertilizers, expansion of pastures, and like practices or combinations of them.

Still smaller scale soil association maps of States or regions are useful in assisting the advisers in community development.[3] On these, the smallest land area to claim attention is larger than a farm, generally about the minimum size for a homogeneous agricultural community.

Schematic soil maps.—In form and appearance these resemble generalized maps of soil associations. Scales are usually small, say 1:1,000,000 or smaller, although useful ones are made at larger scales. For many areas, especially in new and undeveloped regions, it is useful to have an approximate or estimated soil map even in advance of an organized field soil survey, either reconnaissance or detailed. Such maps may be made by estimating the soil pattern. If carefully done by highly competent scientists, this is a great deal more than guessing.

First, all available data, both at spots and in map form, on the soils and the climate, vegetation, geology, and land form, are gathered and studied. In wild areas, these data may consist mainly of notes taken by scientific travelers and rough maps made from aerial photographs without proper ground control. A soil is the unique result of five interrelated factors: (1) Climate and (2) living matter, as conditioned by (3) relief, acting on (4) parent rock materials for periods of (5) time. Therefore, if reasonably good estimates can be had of all but one of these factors, the missing one may be interpreted by geographic correlation. This is the principle. If good topographic maps are available, often surprisingly good soil maps can be forecast by experienced soil scientists thoroughly familiar with the combinations of environmental factors that produce different kinds of soil.

Since the amount and reliability of available data vary greatly from place to place, schematic soil maps always need to be accompanied by a sketch map showing relative reliability.

[2] An *experimental farm* is one on which experiments are conducted on single enterprises without regard to the farm unit as a whole, say plot studies of fertilizers, crop varieties, and rotations, or pasture experiments with grazing animals. On a *pilot-research farm* the aim is to find the optimum combination (or combinations) of practices suited to the farm as a unit. Both the experimental and pilot-research farms are managed for research results, and decisions are made by the scientists in charge. On the *demonstration farms*, proved practices are applied mainly by concentrating advisory services to help the *operator* make the best decisions possible toward optimum farm and home development. *Predevelopment* farms, part way between pilot-research and demonstration farms, are sometimes established a few years in advance of settlement as guides to the new settlers.

[3] For an example of this use see MONTGOMERY COUNTY [Alabama] FARM PROGRAM. Agricultural Extension Office, Montgomery, Ala., 61 pp. (c. 1947.)

The interpretation and use of schematic soil maps for agricultural and engineering purposes follow the same course as for generalized maps. The soil associations need to be defined according to the taxonomic units that compose them, their proportions, and their patterns. Then the characteristics and predictions may be given for the individual taxonomic units insofar as they can be estimated; and soil potentialities and problems for community development may be given for whole soil associations. Commonly it is not possible to go further down the scale in the taxonomic classification than great soil groups, with subdivisions according to parent rock, slope, depth, and stoniness.

The compilation of a schematic soil map is often the first logical step in planning more detailed study and survey of a large undeveloped area. After compilation of the schematic soil-association map, representative sample areas may be mapped in detail. Keys and tables of predictions for the local soil types and phases *within* each soil association can be worked out. After the sample areas have been mapped in detail, the approximate schematic map first drafted can be revised. The schematic map can then be published, along with the detailed sample maps and their explanations, as a useful guide for appraising the potentialities of the various parts of the region. The published survey should include specific guides that will enable agricultural advisers to recognize local soil types and phases, for these will aid them in making specific recommendations to soil users.

Exploratory soil maps.—These maps resemble schematic soil maps except that the mapping units are identified mainly by original observations of soils within the area, even though the boundaries are largely compiled from other sources.[4]

REQUIREMENTS FOR THE SOIL SURVEY REPORT

The report, or text accompanying the soil map, is an essential part of the soil survey. Since its form and content depend upon the purposes to be served, these must be thoroughly understood in advance. The report is not an extra chore to be done after the map is made; it needs to be developed along with the mapping in the field. For a basic general-purpose soil survey, a complete statement of all essential soil characteristics and their variabilities needs to be included, regardless of the immediate practical needs to be served. The soil scientists in the field need to know as much as possible about the probable uses; but they must also not be prejudiced by these to the point of omitting significant soil characteristics because they seem relatively unimportant at the moment. Time and time again, soil surveys have been found to be very useful indeed for purposes never dreamed of by the soil survey party doing the original field work. If the essential facts were recorded, the maps could be interpreted readily for the new purpose; otherwise, the field work had to be done over again.

[4] As one example see KELLOGG, CHARLES E., and NYGARD, IVER J. EXPLORATORY STUDY OF THE PRINCIPAL SOIL GROUPS OF ALASKA. U. S. Dept. Agr. Agr. Monog. No. 7, 138 pp., illus (map). 1951: Washington, D. C.

The uses of the soil survey are expanding so much that more than one report is sometimes necessary. For the lay reader, explanation of interpretations as they relate to his immediate problems may be all that is required. This may be included in the basic report or published separately. Such statements may need to be revised from time to time with changes in the agricultural arts and in economic conditions, and issued as supplements. Then too, special reports on engineering features or other interpretations may be necessary. Ordinarily, the publication of such special reports in the United States is a responsibility of the cooperating local research institute, like the State agricultural experiment station, rather than the Federal Soil Survey.

Normally, as the work progresses, the soil survey report grows out of the descriptive soil legend. The soil descriptions are already complete when the mapping is finished. The available geological, climatic, and agricultural data are obtained in advance of the field mapping, for they are useful in developing the descriptive legend and guiding the taking of field notes.

PURPOSE OF SOIL MAPS AND REPORTS

The Soil Survey includes those researches necessary (1) to determine the important characteristics of soils, (2) to classify soils into defined types and other classificational units, (3) to establish and to plot on maps the boundaries among kinds of soil, and (4) to correlate and to predict the adaptability of soils to various crops, grasses, and trees, their behavior and productivity under different management systems, and the yields of adapted crops under defined sets of management practices.

The fundamental purpose of a soil survey, like that of any other research, is to make predictions. Although the results of soil research are being applied increasingly to engineering problems, such as the design and maintenance of highways, airports, and pipelines, applications are chiefly in the agricultural field including forestry and grazing. It is purposeful research.

The many thousands of different kinds of soil have unlike management requirements for economic, sustained production. For centuries farm families learned as best they could through trial and error what methods worked best on their various fields. This knowledge passed on from father to son, but it could not be transferred readily to other areas, nor could the experience on other farms be applied safely.

With the development of modern science, agriculture is being made continually more efficient. Progress has been phenomenal during the 50 years since soil surveying began in the United States. Even the rate at which agricultural efficiency is being increased is itself accelerating as this *Manual* is being written. Experiments with soils, plants, and animals are being continued in many parts of the world. New farming systems are being tested in both research and practice. Fundamentally, soil classification serves as the basis for classifying, synthesizing, and reporting these results of research and experience. The more agricultural science progresses, the more important this work becomes. The investments in machinery and materials per acre of cultivated land are increasing. The planning of farm systems for optimum sustained production needs to be done far in advance of the operations for the best results made possible by modern science, with revisions from season to season. The importance of precise recommendations—differential recommendations from field to field and from farm to farm—increases. Soil maps serve as the basis for such differential recommendations.

Crop plants and soil management practices are so sensitive to the differences in soil that a soil survey adequate for this basic need is certain to serve a great many other purposes as well. In fact, no other maps of large areas of land are made in such detail and involve so many significant factors as do soil maps.

SYNTHESIS OF AGRICULTURAL DATA FOR APPLICATION TO SPECIFIC AREAS

The soil survey is an integral part of an effective agricultural research and advisory program. It is clearly impossible to carry out exhaustive and expensive researches on every field and farm. Representative samples of land must be chosen. The soil type or phase, accurately defined and named in a standard system of classification, is the only reliable basis yet found for selecting such samples. Every experimental plot is a sample of a landscape. It should be an accurate and representative sample of a kind of soil worth sampling. Thus the soil survey has an important rôle in the planning of research, especially in the selection and location of experimental fields and farms.

New discoveries from experimental work and on farms need to be extended to other areas of similar soils. For optimum use, new methods must be tested widely in farming systems. As the new discoveries are tested, the results can be classified by kinds of soil. When we know that a certain soil area is Miami silt loam, let us say, a great body of research and farm experience is available to allow us to predict its management requirements, the crops that may be grown and their yields, and the long-time effect of various management systems on its productivity.

Without the results of a large amount of correlative research and of careful farm analyses to help them, the scientists in soil survey will be unable to give good predictions. Contrariwise, it is through the soil survey that the results of a host of other researches can be precisely applied.

Through study and comparison of soil types and phases which are defined as sets of soil characteristics, of the sets of genetic factors that go with them, and of the synthesized results of farm analyses and correlative research, general principles of soil behavior are developed for various levels of soil groupings. In going to the higher categorical levels of classification, from soil type to series, to families, to great soil groups, and finally to suborders, the number and precision of the generalizations are reduced.

For detailed predictions and recommendations, the soil type, or a phase of a soil type, is the safest base because of the narrow range of characteristics. If all possible interpretations are to be given, it is the only possible base. But for some one interpretation, as response to liming or the erosion hazard, several soil types and phases can be grouped together.

It should be emphasized that soil scientists, acting strictly as soil scientists, give predictions rather than recommendations. The prediction statements and tables in a soil survey report are designed to predict the results from using the soil types or phases in various defined ways. But the alternative to be recommended for a specific operating farm depends upon the economic environment of the farm and the skill, facilities, and desires of the operator. Then too, for most soils several combinations of practices are possible.

Given an accurate soil map of a farm, alternative cropping and soil management systems for that farm may be developed from the predictions given. With competent soil survey work, with predictions about the other production factors—livestock feeding, performance of machinery, disease protection, and the like—and with adequate consideration of the economic factors, optimum farming systems can be developed.[1] Clear statements of the alternatives are necessary so that agricultural advisers and farm operators can make proper selections from among them.

Since the decisions about farming practices are made within millions and millions of individual managerial units, classification must be detailed enough to include all the significant soil characteristics—all basic land features that significantly affect soil use and management. The maps must be detailed enough to indicate areas of soils significant to a farm management system. They must show these areas accurately in relation to local reference points shown on the map that the user may recognize on the ground.

FARM PLANNING

Increasingly, the results of the soil survey and of the correlative research are applied by the farmer, often with some advice, through the development of a farm plan. Such a plan to be useful does not need to be elaborate. In addition to the use of each field, it shows field boundaries, alternative boundaries, and more or less permanent structures, such as buildings, fences, drainage and irrigation canals, terraces, waterways, and the like. The soil boundaries may be obtained from the soil map. A few of these may coincide with certain field boundaries. In fact, a major contribution of soil mapping to farm planning is the help it gives in relocating field boundaries in order to make fields more nearly uniform. A field containing one kind of soil can be handled more effectively than one containing two or more contrasting soils. The use of the several fields should be indicated tentatively as far in advance as practicable, with alternative cropping systems, so that shifts can be made with unusual weather or with significant changes in economic conditions.

A good farm plan is carried beyond the field layout and cropping system to a farm budget. Such a budget is very important as a test against the physical layout. Farm plans that have called for drastic changes have often failed unless first tested against an estimated budget. To make a budget, at least rough inventories are required of carry-over feeds, machinery, and livestock.[2] For most farms, several alternative plans, with budgets, may be calculated, any one of which will maintain and improve the soils.

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[1] For a discussion of the development of optimum farming systems, see Black, John D., *et al.* FARM MANAGEMENT. 1,073 pp., illus. New York. 1947.

[2] See Johnson, Neil W., and Barnes, C. P. PLANNING FARM RETURNS. U. S. Dept. Agr. Yearbook 1943–47. (Science in Farming): 905–910, Washington, 1947; and also Black, J. D., *et al.* in the General Bibliography.

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The one chosen depends upon the skill, resources, and likes of the farm family.

It is unnecessary here to go into a detailed explanation of farm planning except to point out its requirements so that those making detailed soil surveys can make sure their work will be satisfactory for the purpose. In planning, the farmer and his adviser should consider the enterprise combinations that are adapted to the farm as a whole, their economic feasibility, and the skills, resources, and desires of the farm family. No matter how listed, all phases of soil use and farming practices are interrelated. With that in mind, the following is a check list of the principal elements in the farm plan for sustained production that depend wholly or partly upon a proper interpretation of the soil conditions that are taken into account in soil classification and mapping and in the soil survey report.

1. *Major land uses.*—The plan needs to be balanced among the major land uses—crops requiring tillage, forestry, and pasture—according to the pattern of soil types on the farm and the requirements for balance among the several enterprises. Where livestock is produced, the farm needs a proper balance between pasture and feed crops. The several farm operations have to be balanced in relation to the labor supply. Provision needs to be made for the home orchard and garden where practicable.

2. *Cropping system.*—A well-planned cropping system is needed that fits the kinds of soil on the farm. Usually crops should be grown in rotations or mixed cultures. Good seed of those varieties having the greatest disease resistance, drought tolerance, yield, and quality should be used. Most soils produce best with crop rotations that include meadows having deeply rooted legumes or grass-legume mixtures.

3. *Tillage methods.*—The methods employed in tillage should be aimed to prepare seedbeds properly and on time, to make the soil receptive to water, to incorporate organic material, lime, and fertilizer deeply where necessary, and to control weeds. Where soil blowing is a hazard, the surface must be left cloddy and trashy. Many good machines are available from which selections can be made. On some soil types, the moldboard plow, or turning plow, is best; on others, it should not be used.

4. *Protection.*—Both crops and livestock should be given the necessary protection against winds, insects, and other hazards. It is often important to know whether or not the soil can be used for growing shelter belts.

5. *Water control, use, and disposal on the land.*—Every farm needs an orderly system of water use and disposal. Many farms have naturally well-drained soils and dependable rainfall. A large number do not. Excess runoff of rain water must be reduced to the minimum with protective close-growing plants, strip cropping, terracing, or in other ways, so that the water will soak into the soil for plant growth and not be lost or cause erosion. On

erodible soils where rains are intense, unless the management plan provides for runoff and erosion control, all other practices may come to nothing. Although the amount of erosion that has already taken place is significant, the important thing is to assess the hazard of erosion, whether or not much has taken place. Some soils need drainage. Low lands need protection from floodwaters. Many soils will respond to irrigation. Some of these practices require community effort, but a lot can be done by the farm family itself.

6. *Use and conservation of organic matter.*—Large and unnecessary losses of animal manure and crop residues often take place through fire, leaching, and neglect. Yet many soils respond enormously to the addition of organic matter. Part of the need for soil organic matter can be met in a cropping system itself by using a grass-legume mixture, deeply rooted legumes, green-manure crops, and cover crops.

7. *Reaction control.*—On acid soils liming is a first essential to create soil conditions favorable for the availability of the other plant nutrients and for the deeply rooted legumes. In the regions of low rainfall, provisions are required for eliminating excess salt or alkali and for preventing their accumulation under irrigation.

8. *Fertilization.*—A system of fertilization may need to be developed in the farm plan to make possible the best combination of high-yielding crops. We must always recall that fertilization may offer an excellent opportunity to expand the choice of crops that may be grown. One cannot recommend the precise amounts of fertilizer to use from the soil map alone; other aspects of the farming system already mentioned and previous use must be considered. For both lime and fertilizer recommendations, it is helpful to have the results of appropriate chemical tests in areas where reliable ones have been developed. The reader should be able to interpret from the soil map and report, however, the general fertilizer requirements and the production that may be expected from systems involving their use; but the need for phosphorus, say, on any one field will depend also on the amounts that have been used in former years and on other phases of the farm plan.

These aspects of farm planning are so clearly interrelated that decisions about one influence the others. The crop rotations, for example, depend on liming and fertilizing and the erosion hazard; the nitrogen fertilizer required depends partly on the legumes grown and the manure applied; and so on.

Farm classification can be a great aid to advisory work and to farm planning, especially where the soils, and the optimum sets of practices to go with them, are contrasting. With a detailed soil map and the pattern of farm boundaries, farms may be grouped according to amounts and kinds of soil resources into classes of farms having similar potentialities and problems. The need for this kind of farm classification is greatest in areas where the local variations among soils are greatest. In Iowa, for example, the need is less striking than in a State like Tennessee, where the local soil variations are many and great.

RURAL LAND CLASSIFICATION

The results of the soil survey are often applied through an intermediate grouping of the soil types and phases, often called "land classification." The soil units shown on the map may be grouped into classes on any one of several bases, such as (1) degree of some characteristic like texture, stoniness, slope, or acidity; (2) adaptability to some crop or group of crops; (3) productivity under certain sets of management practices; (4) erosion hazard and general management requirements for erosion control; (5) potential irrigability; and (6) response to lime, phosphate, potash, or other fertilizers. It is clearer to call groupings like these "soil groups" than to label them "land classes," in order to avoid the broad connotation of the word "land."

The data of the soil survey are often used to classify, for various purposes, specific geographically defined bodies of land, like sections, "forties," or farms, as shown in a cadastral survey. A clear distinction is needed between the classification of specific land tracts—sections, lots, or other cadastral subdivisions—perhaps more aptly referred to as land classification, and the classification of land into kinds, types, or classes irrespective of cadastral or property boundaries. In the former, distance from market, size of tract, and other relevant factors of the institutional environment can be evaluated with some accuracy; whereas distance from market or size of area are not relevant in grouping the soils, let us say, according to productivity for adapted crops, except as the general social and economic environment fix the perimeter within which the groupings need to be made. No one recommends, for example, that research be undertaken now to find the productivity of soils in Maryland for paddy rice, nor of those producing sugarcane in Hawaii for buckwheat or rye.

Multiformity of land classes.—In a sense the soil survey may be called a kind of land classification. Although it does not include all the characteristics of place, it certainly recognizes a larger proportion of the ones relevant to local land use, and more accurately, than any other survey systematically carried over large areas. But as the term "land classification" has been most commonly used, it usually refers to something far less complete and detailed than a modern soil survey.

The term "land classification" can easily become very confusing. The attributes of any area are exceedingly numerous, and their relevance varies enormously in different parts of the world; yet any one or any combination of the attributes *may* be chosen as criteria for a "land classification." The matter is even worse than that. Many "land classifications" are more or less personal interpretations of undefined combinations of attributes, economic appraisals, or use experiences, often in relationship to a shifting undefined standard. Lands have been classified using tax delinquency, condition of farm buildings, growing vegetation, intensity of use, patterns of use, and so on as criteria of use capability or other land qualities, in both meticulous detail and broad sweeps. Many of these classifications have been useful but some have been misleading indeed, partly because ephemeral standards were used in the work and especially because factors relevant and vital to the purpose of the classification were not taken into account.

The misuse of land classifications often comes about by shifting a fixed method from one soil or cultural region to another. For example, in some areas a general relationship has been found between soil quality for farming and tax delinquency, partly because of the common overassessment of unresponsive soils. In such an area, land classification based primarily on tax delinquency and whether or not land is cleared may give a workable basis for rural zoning. A similar classification fails badly, however, in an area where there is plenty of labor for clearing land, or where unresponsive soil is not overassessed. In some soil regions an exceedingly close relationship exists between native vegetation and soil groups based on the productivity of the kinds of soil for cultivated crops. Yet possibly only 100 miles away, with a slight difference in climate, the "good indicator" species push well over onto soils unsuited to farming. Since plants grow as a result of a combination of growing conditions, they cannot be taken as a certain evidence of either climate or soil. Examples of similar errors could be multiplied many times.

Land classifications based mainly on present land use are perhaps the most likely to mislead. Yet they can be very useful, too. Many institutional, economic, and historical factors, besides soil productivity, have combined to determine present use. Intensive use does not necessarily indicate highly responsive soils, adapted crops, nor optimum farming systems. Large areas of responsive soils in the world remain largely unused because of lack of transport or industry, or from the accidents of colonization; but land-use maps, especially where intensity of use can be interpreted from the maps, can be useful as a supplement to the soil map. By comparing the two maps, one may ascertain what users have found to be possible and what areas are used with less than the possible intensity. Such comparisons give a beginning point for searching out the obstacles to optimum soil use, many of which may turn out to be economic or institutional.

Another source of confusion in land classification to many has been the search for a simple, all-purpose classification of land according to its characteristics and capabilities. This the authors now regard as an impossibility, despite hopes expressed in the first edition of this *Manual* and elsewhere. If the classification is simple, relevant factors must be omitted. The number of significantly different soil series runs into the thousands for the continental United States alone. There are even more in the tropics. Then, when we add to these the necessary phase distinctions for variations within soil types, the number of kinds of soil becomes much larger. Besides soil, as defined in this *Manual*, there are climatic variations that are significant to growing plants within the environment even of some soil types. All sorts of variations in vegetation may be expected. Thus the classification cannot be simple except for an easily defined, narrow, single purpose. As already explained, it is generally far cheaper to make a basic soil survey from which a great many simple groupings, or "land classifications," may be derived by interpretation, than to concentrate on one narrow immediate objective at a time in separate surveys.

Nor can there be an all-purpose classification or grouping. A grouping made primarily to indicate erosion hazard and for planning erosion control will not serve adequately as a grouping for tax assessment, for example. It will fail one purpose or the other. Even with an accurate, highly detailed soil survey in hand, an up-to-date timber cruise may be needed for some kinds of land classification, or perhaps a detailed map of field patterns and land use. For still other purposes, additional research to establish costs for drainage, irrigation, or land clearing is required. To go ahead and get all these data, along with the detailed soil survey, on the chance that they may be needed some day, would increase the cost beyond reason.

Groupings by use capabilities can be made from a good soil survey with adequate correlative research; but such groupings are bound to be transitory and will need to be changed with changes in the agricultural arts, especially in new or undeveloped areas.

Some confusion between soil maps and land classification has resulted from assumptions of 25 years and more ago that soils were defined in terms of soil profile alone. (Regrettably, some in the Soil Survey staff once made this error, too.) Actually, as already explained, landscapes are classified and mapped in soil surveys, not simply soil profiles. Some who accepted the early definition of a soil type as a profile, and who realized that any mapped area had actually a range of profiles, attempted to get around the difficulty by conceiving "land types" or "natural land types" as mapping units defined in terms of soil profile, slope, stoniness, depth (including truncation by erosion), and the like. Such a definition of "land type" is not necessarily different than the present concept of "soil type." But some went further too, and included, under the same name, other mapping units now recognized as soil phases or soil complexes. This led to great confusion, especially in the absence of nomenclature and definitions to differentiate kinds or groupings of "land types." As nearly as one can make out, these "natural land types" can be placed in soil classification as (1) soil types, as now defined in terms of all soil characteristics, including slope, stoniness, and depth, as well as soil profile; (2) phases of soil types; and (3) associations (or complexes) of soil series, soil types, or phases. By using defined units in soil classification, one may go ahead, with orderly abstraction, to the higher taxonomic groups and to soil associations for generalized maps.

Clearly it is best to use soil classification and nomenclature throughout.[3] Then the results of research and experience can be utilized at all levels of generalization. It is difficult to see the need for the "natural land type." Assuming that "land types" could be somehow standardized and research results related to them, they still remain an inadequate basis for genetic classification. For this, we must fall back on soil classification. Future progress in taxonomic land classification seems to lie primarily along the line of improving our soil classification and of including better definitions of the categories, the individual units within the categories, and the geographic associations of taxonomic units. There appears to be no other reliable basis for a scientific classification. Conceivably, one might develop a nongenetic system, based wholly upon morphology, but the prospects are dim.

Classification of social units of land.—The very term "land" itself connotes use. The broad use classes include: (1) Cropping, (2) grazing, (3) forestry, (4) recreation, (5) mining, (6) urban, (7) public services (highways, railroads, airports, electric power lines, cemeteries, and so on), (8) wildlife preservation, and (9) protection (land managed to protect water supplies or other lands). Some of these are often combined, as for example, forestry, protection, recreation, and wildlife preservation. Besides, some land is essentially not capable of producing materials or services of value and may be called *wasteland*. One might add still another class as *idle land*—land capable of producing but not now being used.

The soil survey is concerned primarily with the first three use classes—cropping, grazing, and forestry—but also has a great deal to contribute to management plans for the others. Some kinds of soil can be used only in certain of these general use classes. That is, some are not useful for cropping but may be used for forestry or grazing. Other kinds of soil can be used in any of the ways listed, except perhaps for mining. Thus, often the same kind of soil has a different set of capabilities within these several broad use classes. Generally, of course, people tend to use the soils for the most intensive use for which they are economically capable. But there are many exceptions. Usually soils unsuitable for farming are used for forestry, recreational parks, and the like; but in a densely populated community on highly productive soils, some of those productive for crops may need to be used for wood lots, parks, and public services.

In the classification of specific tracts of land—farms, ranches, forests, pastures, or gardens—according to potential productivity, say for tax assessment, or of prospective tracts according to irrigability, assumptions of the use class must be made. The determination of the use class of a particular tract is partly a matter of the potential productivity of the kind of soil, and partly a matter of its geographic position and size in relationship to other kinds of soil, to existing or proposed roads, canals, wells, and markets, and to other land tracts.

[3] Except for miscellaneous land types as defined later.

For example, one cannot assign a soil area to use for crops unless the area is large enough for an economic unit. Thus, in regions of soil dominantly suited only to grazing or forestry, small areas of soils well suited to crops must be assigned to the other dominant use, except as they may be located strategically at a ranch or forest headquarters. Soils suitable for grazing cannot be so used, at least with full intensity, in the absence of a water supply. On the other hand, a small area of soil suited only to grazing or forestry, but surrounded by a large area of soil well suited for crops, may be little more than wasteland if no economical management plan can be developed for it.

Although distance from market does not directly affect the classification of taxonomic soil groups or land classes, it may greatly affect the classification of social land units or tracts. As a simple example, we might imagine a large area of Chestnut soils, well suited to the usual range of crops, extending out from a railway station. For the first 5 or 6 miles potatoes may be grown in the rotation. At greater distances from the market, wheat may dominate, first primarily for direct sale and, at greater distances, with increasing amounts used for stock feed. Finally, a place is reached where essentially all the crops, both forage and grain, are marketed through livestock. From an analysis of production and marketing costs a schedule may be prepared showing the percentage reduction in the basic rating of the units because of this distance factor. Then too, the distance must be corrected according to transport facilities: Poor roads must count more than good roads. The relationship between the effective distance and the rating factor is a second order differential equation, not a linear one, since the differences in costs of marketing per acre of cropland between, say, 5 and 6 miles are much greater than those between, say, 35 and 36 miles because of the difference in use.[4] Somewhat similar schedules are needed for land units with intermittent water supply.

The contrast between simple taxonomic land classification and the classification of specific land tracts may be illustrated in a system designed for classifying land according to irrigability. As a first step, a detailed soil classification and map is made for the area. For purposes of planning the layout of the project, the soils are grouped according to their arability under irrigation, without regard to location within the area. Such a soil grouping, or "land classification," and map predict what would be the result of irrigation for every part of the area. Then questions need to be raised about the accessibility of specific tracts of arable soils to roads and canals and about the combination of various soil areas into economic farm units. Some areas of soils cannot be irrigated economically, of course, because of their unresponsiveness or likelihood of deterioration, regardless of location; some other soil areas are highly suitable except where isolated in small

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[4] Such an equation and its development is explained in A METHOD OF RURAL LAND CLASSIFICATION by Charles E. Kellogg and J. K. Ableiter. U. S. Dept. Agr. Tech. Bul. 469, 30 pp., illus. 1935.

tracts that cannot be reached economically or fitted into a farm unit; and areas of other kinds of soil are called irrigable if water can be supplied conveniently, but nonirrigable if water charges are high.

Thus, two quite different maps of the same area, both accurate, might be called "land classification according to irrigability." The first one represents the distribution of taxonomic groups and might better be called, perhaps, "a grouping of soils according to arability under irrigation." The second map, made on the basis of the first one with consideration of the additional factors of location, is a classification of geographically defined areas and should be called, perhaps, "a classification of land according to irrigability." This second map follows an accurate development of the first one from a detailed soil survey. Besides serving this immediate purpose of developing the land classification according to irrigability, the detailed soil survey is used for developing individual cropping and soil-management systems optimum for the specific kinds of soil that were grouped into the more general classes.

The classification of specific geographically located areas of land ordinarily must take account of those characteristics of place that influence decisions among the land-use classes and the decisions about relative intensity of use within the classes. In classifying land for tax assessment, for example, the soil units—types and phases—are first rated according to their productivity under alternative systems of management, within each use class, on a taxonomic basis. Secondly, the use classes of the geographic land tracts—sections, forties, or farms—are determined. Many tracts have mixtures of the use classes, say both cropping and grazing. Thirdly, ratings of the taxonomic groups within the use classes for each geographic land tract are adjusted according to distance from market, water supply, and so on, as these influence potential production.

This brief discussion has dealt only with a few principles and examples, but it is hoped that readers may test old schemes of "land classification" and new ones certain to be proposed. Further discussion would scarcely be appropriate in this *Manual.* No general guides for "land classification" exist, partly because of the wide variety of activities included by at least someone under this term.

LAND APPRAISAL

Rural land appraisals for determining the value of land as mortgage collateral or for tax assessment might be regarded as special kinds of land classification. Social land units, mainly farms, are evaluated in terms of potential production within the institutional and legal environment.

Tax assessment.—Some of the essentials of a method of land classification for tax assessment have been outlined as an example under the heading Multiformity of Land Classes (p. 28). For accurate work, a basic detailed soil survey is required, partly because of the need for indicating the relevant factors in relation to farm boundaries, and partly because adjustments will need to be made from time to time as conditions change.

If the basic soil factors are recorded, as in a basic soil survey, reinterpretations and regroupings in the light of changed conditions can be made easily and in an orderly fashion. But if they are not and only judgments of soil productivity, or of soil groups based on such judgments, are recorded, each revision will require a complete resurvey. For example, let us think of a modern detailed soil survey that indicates 150 or so separate kinds of soil for some area, like a county. These units may be grouped into 5 or 10 productivity classes, or into any other number of classes, according to the accuracy required and the availability of precise data for evaluating differences in responses to management. If, however, *only* these classes are mapped, the survey is soon out of date. If the soil types and phases are accurately mapped, the groupings can be readjusted and revisions made in the appraisal of specific tracts without additional mapping.

Besides the basic soil resource, the appraisal may need to take account of farm improvements—buildings, fences, and the like—according to the State laws governing appraisal. In some States improvements are not taxed; in most they are. If these improvements are appraised in terms of replacement value, absurd results may be had, say where previous owners have constructed buildings far larger and more elaborate than the farm unit requires. Often the laws require that land must be appraised according to its productivity in the most intensive possible use, say for crops, even though it is actually used for extensive grazing or forestry. In the various States special statutes may permit present use to carry some weight. Laws vary widely in the degree to which potential use of farm land for urban or suburban residences must be weighted in assessment. Presumably the ideal in assessment is to make appraisals, according to potential productivity, that differentiate fairly among all the properties. Everyone realizes that excessively high taxes are unfair. A great deal of land that has reverted to the State because of nonpayment of taxes would have remained in private hands had the assessments been reasonably based upon the productivity in such uses as forestry and grazing, instead of on a presumed productivity for farming. But very low taxes are also unfair. Speculators may be allowed to hold undeveloped or only partially developed land needed for settlement at little or no cost—land which they hope to sell or use later at great profit.

Before a proper job of soil groupings and alternative ratings for the various use groups can be developed, and especially before attempts are made to appraise social units, a study needs to be made of both common laws and statute laws that influence assessment. Then appropriate schedules can be developed and adjusted ratings of the taxonomic groups made, in terms of the combinations of present characteristics that need to be dealt with, for each property within the area. Nearly every area presents special problems.

Appraisal for loans.—An accurate detailed soil map with ratings of the individual soil types and phases according to crop potentialities, estimated yields, and long-time effects of the alternative management systems furnishes the best basis for estimating the productivity of a farm and its basic long-time value. It is, of course, helpful to have also records of the individual farm business.

The appraisal of a farm cannot be based, however, upon the soil alone. The distance from market and other characteristics of place must be considered as they affect the kinds of uses for the farm and the productivity of the farm unit. Buildings, fences, and other improvements need to be evaluated in relation to the potential use of the farm unit, as well as water supply, noxious weeds, and the like.

Besides the basic value of the land and its improvements in relation to potential use, the loan appraiser can scarcely escape taking account of the prospective manager of the farm and his skill in relationship to its potentialities.

SETTLEMENT OF NEW LANDS

For centuries land settlement was on a trial-and-error basis. Those fortunate enough to find responsive soil in an area large enough for effective community development, and able to adapt their practices to kinds of soil new to them, were successful. Many thousands of settlers were not so fortunate; their work and efforts came to little or nothing, and their most productive years were wasted.

Through the use of soil surveys these wastes can be largely avoided, at least those due to improper soil and lack of advanced knowledge of what soil management practices to follow. Some exceptions must be allowed for little known kinds of soils never before used by civilized man equipped with the tools and services of modern industry. But the number of these is really small outside the tropics.

It must be emphasized, however, that the soil survey of a new or undeveloped area needs to be correlated with soil conditions in known areas. The necessary predictions of crop adaptability, yields, and management requirements will need to be based, in new areas, upon research results and farm experience gained from similar soils elsewhere, although perhaps not identical ones.

In planning a community, the soil map is useful in locating roads, schools, and other public services in order to keep costs at a minimum and provide orderly settlement as compactly as possible. Helter-skelter settlement with individual settlers far from one another, even though on responsive soils, raises serious social problems and results in high costs for medical facilities, transport, and schools.

In a new area, usually the best procedure is to make a reconnaissance or schematic soil association map (as defined earlier) from existing data and scattered observations in order to identify the most promising places for settlement. This map serves for broad planning of highways and other public services. Then detailed soil surveys should follow in the various parts of the area according to priority of development, considering soil character and other relevant factors. Beyond these considerations, the use of the soil survey for settlement is not unlike its use in settled areas.

GUIDANCE OF PROSPECTIVE FARM BUYERS

The modern soil map and report furnish the prospective farm purchaser with more relevant information upon which to make a decision than does any other single publication. This point is important, and those writing soil survey reports need to bear it in mind. A part of the use of the soil survey for this purpose parallels its use for land appraisal for loans, already briefly outlined. In addition, it gives a picture of the surrounding land and the potentialities of community development. The soil map and report help a prospective buyer select the area in which he wants to buy before he gets down to considering a particular farm. The report explains the farming systems followed by other farmers, the crops grown, the market facilities, and so on. In short, the soil survey report and map should give the prospective buyer a clear picture of the principal potentialities and problems.

After reading from the soil map the kinds of soil on a farm he may be considering, the prospective buyer can consult the tables of yield predictions and management requirements and develop a tentative farm plan with budget estimates of expenses and income. For accuracy, these need to be adjusted to other soil differences due to past management. Where practicable, he should compare these estimates with other budgets from similar farms as another check.

No matter how accurate the soil map or complete the supporting data, purchasers should be advised to visit a farm before making a final decision. Factors that are important to an individual family defy accurate description in writing and figures.

LAND-USE PLANNING

Most land users have some sort of plan to guide their operations. Some farmers have only a simple plan of the crop pattern for the following year; others have carefully prepared plans in writing, with a map, for several years in advance—plans that are revised with the seasons. As science and technology are used more and more for optimum sustained production, individual farm planning becomes increasingly important. This kind of planning is usually called "farm planning," since it deals mainly with decisions made within farm boundaries.

The term "rural land use planning" on the other hand, is commonly used for policies and programs that influence the use of lands in a whole community or area containing many individual farms or other units of operation. Examples include the planning of irrigation or drainage districts, rural transport systems, electric power distribution lines, flood-control structures, large dams, public land acquisition, rural zoning, and the like.

Many county plans or goals have been made by farm leaders and agricultural advisers jointly. These vary widely in detail and scope.[5] For the best development of these plans or programs, a detailed soil survey and carefully generalized soil association map are most helpful. Because the soil survey for individual farm planning needs to be detailed, it is difficult to obtain a view of the soil resources in the whole community and in the contrasting parts of counties except with a soil-association map generalized from it.

For many planning purposes, it is helpful to the users to have the boundaries of soil associations as an overlay on the detailed soil map and also separately on a smaller scale map showing the roads, say on a scale of about 1 or ½ inch equals 1 mile. As has already been pointed out, the experience gained from pilot-research farms, demonstration farms, and from the analysis of other farms can be synthesized by soil associations in order to guide advisory programs and other public programs designed to eliminate handicaps for economic sustained production.

The planning of irrigation.—An especially detailed soil map is required in planning irrigation. This map is often a difficult one to make because soil characteristics need to be considered in relation to a very different environment than the natural one. Deep layers that contain soluble salts or that are impervious to water, which may have little or no influence on the soil under desert or semiarid conditions, may be very important to its behavior under irrigation. Soils that are well drained naturally may become swamped with extra water. The soil survey must predict such conditions and whether or not they may be overcome and, if so, by what methods.

Here, too, generalized maps, based upon the detailed ones, are needed for planning the transport and water facilities in the area as a whole and for arriving at a final map of irrigability as explained previously in the discussion of land classification.

The planning of drainage.—In principle, planning of drainage is similar to the planning of irrigation. Here also, soil characteristics of little influence in the natural state become very important when the soil is drained. Many expensive drainage projects have failed because the soils were unproductive after drainage. In some instances, the soils were very sandy, and after a brief period

[5] A large number of these have been developed. This is not the place to review this work in detail. A recent example, among a great many, is the one already cited—MONTGOMERY COUNTY [Alabama] FARM PROGRAM (c. 1947). A pioneer rural plan was published by Lee Roy A. Schoenmann as LAND INVENTORY FOR RURAL PLANNING IN ALGER COUNTY, MICHIGAN (Mich. Acad. Sci., Arts, and Letters 16: 329–361, illus. 1932) based upon the SOIL SURVEY OF ALGER COUNTY (U. S. Dept. Agr., 1934). Other examples include: LAND USE CLASSIFICATION IN MIDLAND COUNTY, MICHIGAN, LAND-USE PLANNING REPORT (Bur. Agr. Econ., U. S. Dept. Agr. and Mich. State Col. 1940); and AGRICULTURAL PLANNING, VALLEY COUNTY, MONTANA. (Bur. Agr. Econ., U. S. Dept. Agr., and Mont. State Col. 1941. [Processed.]).

of cultivation the organic matter disappeared and the soils became too loose and too dry in summer for crop growth. Others had organic soils so acid that enormous quantities of lime were required for raising the pH to that level necessary for crop plants. Such additions of lime, besides being costly, often worsen the problem of other nutrient deficiencies through unbalance.

Drainage of peat lands raises problems requiring the special attention of soil survey parties. After drainage, organic soils often shrink and settle unevenly. For this reason tile drainage frequently fails. The tiles may get out of position. In detailed soil surveys where drainage of such lands is proposed, through soundings and study of the deep materials, it is possible to predict such settling and recommend measures by which difficulties may be avoided. Often it is necessary to arrange for keeping the water table nearly constant through combined drainage and subirrigation, even using the same canals.

Public land acquisition.—Land purchase, as for blocking out National or State forests or grazing districts or for the development of public parks, needs to be planned in relation to the use capabilities of the whole area affected by the purchase units. The detailed soil survey is an essential basis for appraising individual parcels, and, if supplemented with a generalized map of soil associations, for planning the project boundaries. Such purchases can have pronounced influences on community development and, with proper planning, can reduce scattered settlement and otherwise assist the objectives of rural zoning.

The planning of large dams for water storage.—The effects of alternative locations and heights of the structures upon land use needs to be taken into account. By carefully plotting alternative pool lines on the detailed soil map, accurate comparisons can be made. Thus it may be found that one alternative may cover with water much more soil productive for crops than another. Then, after the pool line has been established, plans can be developed with a detailed soil map for the economic use of all partially flooded farm units, through reorganization, in order to keep the "taking line" (the line below which land is purchased) as near the pool line as possible and thus hold the area of unused land or public land around the pool to a minimum. In the margins of some pools, areas of highly productive soil are flooded only occasionally. Such areas may be used for crops to good advantage a large part of the time if attached to an economic farm unit. With a detailed soil survey, such planning can be done in an orderly way.

Planning measures for flood reduction.—Often planning for flood reduction involves the study of the soil conditions of a whole watershed in order to estimate infiltration rates, runoff, and the effects of land management and structures on runoff and erosion. Costs and benefits of alternative plans should be calculated. A detailed soil survey, supplemented by a generalized soil-association map, furnishes a very large part of the basic data for such planning. A full set of predictions and yield estimates under alternative systems of management for each mapping unit is essential for accurate results.

Rural zoning.—Ordinances are often developed by county governments to promote orderly use of the land.[6] Roads, schools, and other social services for scattered farms in areas generally unsuited to farming are very costly for other taxpayers. Such isolated settlers often increase the fire hazard in forests. By blocking out areas suited mainly to forestry, grazing, or recreational use, in which settlement for farming is not permitted, roads and schools may be provided for the community more efficiently. Accurate soil maps, along with interpretations made according to use capability, furnish a sound basis for developing such ordinances.

These few brief examples are only intended to give the reader an idea of the kinds of use to which soil surveys are often put in rural land-use planning. All such uses cannot be specifically anticipated in advance; but when a soil survey is undertaken in any area, supervisors should be fully aware of any such possible uses. Even though a rural zoning ordinance does not yet exist, for example, if it is clearly needed to solve serious problems of local government management, the soil survey work should be done in anticipation of its use for that purpose.

ASSESSING POTENTIALITIES FOR SPECIAL CROPS

The economical production, use, and marketing of many special crops depends upon having more than the minimum volume of production needed to support canneries, freezing units, or other special processing and marketing facilities. When a new enterprise of this sort is undertaken in a community, a large area, often split among many different farms, must be developed at once, along with the factory and marketing facilities. Special interpretations of the soil mapping units may be made for the crop, and interpretive maps prepared from the soil map showing classes of soils according to their use capabilities for the particular crop. Such maps serve as a sound basis for assessing the potentialities for the enterprise in a community and for indicating the particular farmers that may cooperate.

FOREST MANAGEMENT

Foresters are becoming increasingly aware of the importance of an understanding of soils and their relation to growth, stand composition, and other factors affecting optimum forest management. Even the incidence of certain forest diseases, like little-leaf of shortleaf pine for example, is related to groups of soils. The soil survey makes possible the synthesis of results from research and from experience and the orderly application of the available

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[6] See the following: ELY, R. T., and WEHRWEIN, G. S. LAND ECONOMICS. 512 pp., illus. New York. 1940; and WEHRWEIN, G. S. THE ADMINISTRATION OF RURAL ZONING. Jour. Land and Pub. Util. Econ. 19: 264-291. 1943.

knowledge, in forest management in much the same way as in farm management.

ENGINEERING USES

Soil surveys are being used increasingly in engineering work, especially in highway and airport planning and construction and for predicting trafficability of heavy vehicles. The basic facts about soils needed to predict their behavior in fields include most of those needed to predict their behavior as subgrades or foundation materials. The several soil properties have different relevancies for the two interpretations—agricultural and engineering—but the same basic classification serves both.

Detailed soil maps are helpful first of all in planning locations for structures and for predicting the problems of construction and maintenance to be dealt with. Especially in the absence of detailed geological surveys, they are useful in locating such materials as sand, gravel, clay, and suitable "topsoil" for dressing banks and other areas to be planted.

For detailed highway and airport planning, a highly detailed original survey is usually needed on a scale of about 1:1,200, using the same basic soil classification as that described in this *Manual,* with such refinements as may be required, especially for indicating the physical properties of deep strata. After engineering tests on soil horizons have been made and classified by soil type, each type can be characterized and its behavior subsequently predicted without extensive testing. Classification by tests alone, unrelated to genetic soil types, gives little that can be used as a basis for prediction at a new or proposed site without additional time-consuming and costly testing.

Since the interpretation of soil classification and soil maps for engineering purposes is a highly specialized field in itself, the reader is referred to a special manual on the subject,[7] and to a summary of soil surveys in the United States as they pertain to engineering uses.[8]

OTHER USES

Soil surveys, besides their many widely recognized uses, also serve a host of others to which some attention must be given. For many areas they are the most complete base map and are so used in the absence of up-to-date topographic or planimetric maps. This fact, and the fact that detailed soil maps, detailed topographic maps, and detailed geological maps are often used to supplement one another, emphasizes the need for geodetic accuracy, standard scales in publication, standard symbols, and correct naming of features.

Soil maps have been used to locate and design pipelines. They are helpful in locating radio stations. With interpretation, they

[7] MICHIGAN STATE HIGHWAY DEPARTMENT. FIELD MANUAL OF SOIL ENGINEERING. Rev. ed., 304 pp., illus. Lansing. 1946.

[8] OLMSTEAD, F. R., HICKS, L. D., and BODMAN, G. B. ENGINEERING USE OF AGRICULTURAL SOIL MAPS. Highway Res. Bd. Bul. No. 22, 128 pp., illus. 1949.

can be used as maps of surface geology. They are useful in studying land form and geomorphological processes. With study of sample areas, they can be used to construct maps of the original vegetation and to predict successions of plant cover.

The hazards of nutritional deficiencies among plants and even among animals may be anticipated from soil maps where the relationships of deficiencies to soil types have been identified through correlative research at sample sites. In recent years, important relationships have been worked out between many soil types (and soil groups) and deficiences of such trace elements as copper, boron, manganese, molybdenum, iron, cobalt, and zinc, as well as of phosphorus, potassium, calcium, nitrogen, magnesium and sulfur. By no means all important soil types have been characterized, especially for the trace elements, and much more research is needed. As already explained, recommendations for an individual field depend partly on previous and current management as well as on soil type; yet the area where these deficiencies are likely, and the general practices to be followed, can be interpreted from a proper soil map.[9]

With generalized and schematic soil association maps, broadly defined agricultural potentialities and problems that relate to the soil or soil use can be seen regionally, nationally, or even on a world-wide basis of comparison.

INTERNATIONAL COORDINATION

Since all places in the world having the same combination of soil genetic factors have the same kind of soil, knowledge gained through research and experience in one place is relevant to all like places. Contrariwise, good practices for sustained production on one kind of soil may be wasteful or even ruinous on a different kind.

The need for close correlation between those engaged in soil surveying and other researches is obvious if proper definitions and predictions are to be developed for soil types and if full and accurate use is to be made of other research results. This is true internationally as well as nationally. To make optimum use of agricultural science in any country, it is essential to have a consistent world-wide scheme of soil definition and nomenclature. That is, the results of competently managed research on a well-defined Latosol, Podzol, or Chernozem are useful in all countries having soils like the ones investigated, regardless of where the work is done.

Much work has been done in this field of soil geography. More is needed. The unrealized opportunities for improving the planning of agricultural research and for increasing its effectiveness to all are very great. Fortunately, as this *Manual* is being prepared, greatly increased emphasis is being given to soil classification and mapping in many countries and to the exchange of soil scientists and of information about soils.

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[9] See Ignatieff, as cited in the General Bibliography.

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PREPARATION FOR FIELD WORK

Before going to the field for survey work, plans are made and the essential materials and equipment assembled.

WORK PLAN

Most soil survey work in the United States is conducted as an integral part of the soil research programs of the United States Department of Agriculture and the State agricultural experiment stations. Besides, other State and Federal research, service, and educational agencies cooperate in projects of special interest to them by furnishing personnel or materials.

Many technical details and the services of several kinds of specialists are involved in a soil survey. Besides the soil scientists in field and laboratory, at least some assistance, often a great deal, must be had from geologists, plant scientists, and others. Skilled photogrammetrists, cartographers, draftsmen, and editors are essential to the work. Several agencies are usually involved as participants or as interested users of the results.

A clear understanding of the work to be done and the role of each participant needs to be had at the start. The general specifications, plan, and assignment of professional workers are set forth in a *Soil Survey Work Plan,* drawn up by the supervisory scientist, with the help of those responsible for cartography and laboratory services, and agreeable to the sponsoring agencies. Above all, a qualified scientist needs to be selected for *party chief.* Upon him, more than upon any other individual, depends the thoroughness of the research and the quality of the final soil map and report.

The essential items of the *Soil Survey Work Plan* are:

1. Name, location, size, and boundaries of survey area. (Include sketch map for areas other than whole counties.)
2. A paragraph describing the principal physical features of the area.
3. The names of initiating and cooperating agencies.
4. Reasons for the survey, together with any special uses to be made of it.
5. Type of survey (detailed, detailed-reconnaissance, reconnaissance of soil associations) and features to be mapped, including any special features not included in the standards for a basic soil survey.
6. Field and publication scales for the maps.[1]
7. An annotated list of previous surveys of soil, relief, geology, or vegetation.[1]
8. Equipment and transport needed and agencies responsible for supplying.
9. Names of proposed workers (and agency of each) for soil survey party, including party chief.
10. Kind, scale, quality, source, and availability of base map materials and the primary control in the area.[1]
11. Scale and other features of map to be published and method of construction from field sheets.[1]
12. Plans for preparation and publication of report.

13. Date for initiating field work, location of first field headquarters, and estimated date for completion of field work.
14. Plans for supplementary laboratory work and scientists responsible for it.[2]
15. Estimated costs by contributing agencies:
    (a) Field mapping by man-days, including salaries, travel, and equipment.
    (b) Supplemental research and summaries for soil ratings and soil survey report.
    (c) Supplemental laboratory work.
    (d) Map preparation and editing.[1]
    (e) Publication.[1]

[1] Developed jointly with Cartographic Section.
[2] Developed jointly with laboratories of cooperating agencies.

ASSEMBLY OF CARTOGRAPHIC DATA

The use of good cartographic base material is essential for a successful soil survey. On it depends the accuracy of plotting the soil boundaries and symbols, the rate of progress, the methods and costs of map construction, and the quality of the published map. Since all these items directly affect the cost and accuracy of soil maps, supervisory scientists need to give the assembly of cartographic materials first priority once an area is selected for survey.

Even the order in which areas are taken up for soil survey should be guided by a study and analysis of available cartographic data. That is, no area should be selected for survey in advance of aerial photography or equally good base material unless the most compelling reasons exist for doing so; and areas having good topographic base maps made with the aid of aerial photographs should be given preference.

Preliminary study and analysis.—Before its selection for use in the field, cartographic material needs to be studied in relation to all operations in both the field and the cartographic office, considering accuracy, economy, any special needs of a cooperating agency, and efficiency of use by the field party and by the cartographers. All available cartographic material is considered. Some may be helpful even though it is not used directly as the principal base.

If new aerial photography is under contract, usually a soil survey should be postponed until the photographs are released. The availability of new topographic maps, still in manuscript form and not yet generally available, should influence the selection of a specific area. Although uncontrolled aerial mosaics may appear useful at first glance, in the final analysis they may be more expensive than individual aerial photographs because of poor quality, lack of stereoscopic coverage, and inaccuracies. Topographic maps made with high standards of accuracy may have to be discarded because of insufficient detail and small scale. The efficient use of aerial photographs may be limited in some areas by insufficient control for constructing an accurate base map.

Without such an analysis, an area may be selected for which so little good material is yet available that costs for field work or map preparation, or both, may be very high; or a poor combination of materials may be selected from among those available. Such failures in initial planning lead to inaccurate soil boundaries, excessive costs, and substandard published maps. Plans for the survey are worked out jointly by soil scientists and cartographers, so that all costs—for field work, map compilation, and publication—are taken into account. A minor change in field operations, for example, may have a large influence on later costs.

Locating material.—So many agencies obtain aerial photography, prepare aerial mosaics and planimetric and topographic maps, and establish control that the field scientists cannot be expected to know all that is available or about to become available. Although some agencies release map information periodically, these reports do not cover many activities in planning and operational stages. Since most Federal mapping agencies and many commercial firms maintain offices in the Washington area, the Cartographic Section of the Division of Soil Survey maintains liaison with nearly all map-making groups. It is a regular function of the cartographic office to maintain records of all available materials and of work in progress and to seek materials from all agencies for any new survey area. In this way, it is possible to obtain complete information on the status of aerial photography, mapping, and control activities for any area in the United States.

Selection of scale.—Many factors need to be weighed together to determine the best scale to use for a soil survey.

The purpose of the map needs first consideration. Since most detailed soil maps are designed to carry the data needed in planning efficient farming systems, the map must have large enough scale to indicate areas of significance in farming, either by boundaries or by defined symbols. This does not mean that the scale needs to be large enough so that field boundaries, terraces, ditches, and farm buildings can be plotted directly on the soil map. Most farm plans should be drawn on enlarged aerial photographs or other large sheets so that details important only to the specific farm may be written on them. Soil maps on such large scales would be too unwieldly to file and use. The scale of the soil map needs only to be great enough to permit accurate plotting and recording of the significant data.

If the survey is reconnaissance—with a generalized or schematic map of soil association and only samples of each association in detail—the scale can be much smaller.

Generally, the scale of mapping increases with the intricacy and complexity of the soil pattern and especially with intensity of soil use or potential use. The patterns of soil types and phases are very complex in areas of Ground-Water Podzols and Half Bogs or of Lithosols and Alpine Meadow soils, for example, but the low potentialities for use argue against the practicality of highly detailed mapping except in sample areas to define the mapping complexes or associations. Where small areas of soil must be enclosed with boundaries, the scale needs to be large enough to show them without exaggeration and to permit placing clear symbols in them. If field sheets have a large proportion of the symbols outside of the areas they represent and keyed into them with an arrow, the scale is too small, excessive detail is being mapped, the symbols are too long, or there is some combination of these evidences of poor planning.

The scale should be no larger than necessary to show the details required for the objective of the survey. A large increase in scale increases the number of separate sheets to deal with, the amount of joining of sheets, and costs for compilation and reproduction.

The scale of manuscript maps made in the field or generalized from highly detailed field sheets needs to be reasonably close to the publication scale. Except in special surveys, where the field sheets indicate data not to be published, and photographed copies of them serve the special purpose, the field scale should rarely be more than twice the publication scale. Otherwise the published map is likely to be too complex for easy reading or data on the field sheets must be omitted. The selection of only part of the data from the field sheets increases compilation costs and the chances for error. Some poor soil maps have been made at great cost by publishing at 1 inch to the mile (1:63,360) work done in the field at 4 inches to the mile (1:15,840). If a field scale of around 1:7,920 is clearly needed and the map is to be published at 1:31,680, a manuscript map (besides the field sheets) ordinarily is required at some scale above 1:15,840.

In the United States most detailed basic soil maps are now made with field scales between 1:15,000 and 1:20,000 and published at 1:24,000 and 1:31,680. Yet, very detailed surveys, say in irrigated areas or other intensive areas of complex soils, may be made at field scales as large as 1:5,000. For detailed highway and airport planning, soil maps are often required at scales as low as 1:1,000, but those rarely need to be reproduced in large editions. Scales for soil association maps made in reconnaissance surveys may run from 1:20,000 to 1:500,000, depending on the purpose.

Except for detailed-reconnaissance surveys, uniform scale should be used throughout an area. Mappers using base material of varying scale are likely to map the soils in varying detail also. A lack of uniformity in the kinds and sizes of soil areas shown greatly reduces the usefulness of the soil map, since it presents a distorted picture of the soil pattern. Such distortion can be seen on a few published soil maps for which field sheets of unlike scales had been assembled to a uniform scale.

Much cartographic base material is flexible enough to permit reproduction at a number of scales for field use. Many aerial negatives have a scale of 3.168 inches equal 1 mile (1:20,000). Prints of excellent quality and detail can be had at scales from 2 inches equal 1 mile (1:31,680) to 8 inches equal 1 mile (1:7,920). Of course, aerial film may be at various scales; yet reduction and enlargements are usually satisfactory within one-half to three times the original scale. Aerial mosaics or planimetric and topographic maps can be considerably enlarged or reduced to appropriate scales for field mapping.

The cartographic laboratory of the Division of Soil Survey is equipped to prepare enlargements and reductions of aerial photographs, aerial mosaics, planimetric maps, and topographic maps as may be required in cooperative soil surveys.

Since it is usually possible to obtain the base material at a proper and uniform scale, it is important to decide on a definite scale for the soil survey in the planning stage, and to make the original requests for material at that scale. This is far more economical than attempting changes in scale after the base material is received. Such changes may require recopying and cause avoidable delays.

Factors determining type of material selected.—Frequently two or more kinds of cartographic material suitable as bases for soil mapping may be available. An area may be wholly or partly covered by two or more types of aerial photographs, aerial mosaics, planimetric maps, or topographic maps. The choice of materials depends upon their relative advantages for the whole job, including map compilation and reproduction as well as field use. The base material selected must be adequate for the whole job, not for just one activity alone.

Uncontrolled aerial mosaics, for example, may appear advantageous for field use, yet they may be wholly unsatisfactory for constructing the final map because of inaccuracies. Obsolete or substandard maps present similar problems. Such maps often require so many revisions that their value is offset by time-consuming corrections in both field and office. Work plans calling for the use of such materials, made without analyses of the whole process, have led to high costs in relation to the accuracy of the published map.

Available materials of possible use may include aerial photographs, of single or multiple lens, aerial mosaics of varying accuracy, photo maps, planimetric maps, or topographic maps. If no suitable base maps or aerial photographs are available, and the survey must be made, the field scientist may need to make a map with the plane table or, in wild heavily wooded country, with the compass. (See pp. 455 to 463.) Where two or more types of base material must be used, careful evaluation should be made to obtain uniformity in accuracy, planimetric detail, and scale. Other uses of the survey besides publication influence the selection. If, for example, a detailed classification of land tracts is to be made, as in irrigation planning or in assessment, a different base may be better and cheaper than that employed for the usual basic soil survey. Time is sometimes an important element in selection. Material readily available may be used even though better material will be available at some later date. If differences in quality are great, the survey schedule should be altered if possible.

Generally, the best base materials for detailed soil surveys, in order of preference, are single-lens aerial photographs, controlled aerial mosaics, transformed multiple-lens aerial photographs, standard-accuracy topographic quadrangles, standard-accuracy planimetric maps, and original plane-table maps. It is best of all to have both good aerial photographs and accurate topographic maps.

Relatively large-scale reconnaissance surveys are best made on controlled aerial mosaics or standard-accuracy topographic or planimetric maps. Small-scale reconnaissance surveys are made on many types of general maps having good accuracy and planimetric detail or on aerial photo indexes.

Since a complete soil survey is expensive, proper selection of the base material can have a great influence on efficiency. Frequently mistakes in planning are caused by overemphasizing the cost of the base material. Where aerial photography is available, costs for pictures rarely exceed 1 to 2 percent of the cost of the entire field work. Even original aerial photography would seldom exceed 5 to 10 percent of the total. Yet the base material frequently means the difference between an excellent soil map and a poor one. Costs of base material need to be weighed against its use in all operations—field mapping, map preparation, and publication. The use of low-cost materials may give apparent savings for the field sheets, but result in doubling the costs of map preparation and reproduction. Since conditions vary widely from place to place, no hard-and-fast rule can be given for selecting base material. Each area must be studied as an individual problem.

Procedure for obtaining base material.—After the work plan has been developed and the base material decided upon, it is furnished through Cartographic Section or, by arrangement with them, directly from other sources. Plans should be made as far in advance as possible, since many agencies have small staffs available for supplying photographic prints and other materials and some delays are inevitable.

KINDS OF BASE MATERIALS

The characteristics, advantages, and disadvantages of the principal kinds of base material used in soil mapping are outlined in the following paragraphs.

Aerial photographs.—Nearly all detailed soil mapping is now done on aerial photographs. Improvements in them and in their use and interpretation are being made continually.

Types.—Oblique and vertical pictures may be regarded as two basic types of aerial photography. Multiple-lens photography is a combination of the two. Single-lens vertical photographs are best for soil mapping, although oblique and multiple-lens photographs can be used. Thus emphasis in this *Manual* is given to single-lens vertical photographs flown to the specifications of the United States Department of Agriculture.

Stereoscopic and alternate coverage.—Specifications of the United States Department of Agriculture for aerial photography require the overlap in line of flight to be about 60 percent; whereas the overlap between adjacent flight lines averages around 30 percent. This overlap, with which all ground images appear on two or more photographs, permits stereoscopic vision of any ground object within the area. Such photography is said to have *stereoscopic coverage;* and adjoining photographs are called *stereoscopic pairs.*

If every other photograph in a continuous stereoscopic series is removed, the remaining series is called *alternate coverage,* and adjoining photographs, *alternate pairs.* Alternate pairs of photographs overlap only about 20 percent—too little to permit stereoscopic study of the entire area. Such alternate coverage is inadequate for constructing base maps by photogrammetric methods based upon stereoscopic coverage.

Contacts and enlargement.—Aerial photography is exposed on film or glass negatives at a predetermined scale and fixed negative size. The scale of the photograph depends on the height of the aircraft and the focal length of the camera. The size of the negative varies with the aerial camera.

The scale of aerial photography depends on the purpose of the photographs. Most of the aerial photography for the United States Department of Agriculture is flown with an 8.25-inch focal length aerial camera at altitudes of about 15,000 feet. The resulting scale is approximately 3.168 inches equal 1 mile, or 1:20,000. Such negatives give satisfactory reductions and enlargements within a scale range of about 1:7,500 to 1:32,000. Most needs for soil mapping can be met within this range of scale.

Aerial photographs made directly from the original negatives are called *contact prints.* These have the same scale as the negatives. In contact printing no rectification of errors or scale changes can be made, although poorly exposed negatives can be improved. Contact prints are the most economical to make. When properly processed they are best in quality.

Aerial photographs may be readily enlarged or reduced; this is one of their great advantages as a base for soil mapping. The process requires projection of light through the negative and precise adjustments for scale. It is therefore slower and more expensive than contact printing. Some detail is lost in the preparation of enlargements, but with skillful operators using modern processing equipment and the original negatives the loss is negligible.

Enlarging has certain advantages. With adequate ground control, all prints in an area can be brought to a nearly uniform scale. Prints having excess tilt, causing displacement of objects and scale changes, can be rectified to minimize the errors. Pictures for areas having photography at two or more contact scales can be brought to a common scale. Such operations require more time than simple enlarging; and for scale-ratioing or rectification, adequate ground control is essential. Nonetheless, later savings may more than offset the cost of bringing pictures to a common scale.

Satisfactory enlargements from average film should not be expected at scales requiring more than a 2½-diameter enlargement from the contact negative. The photograph becomes grainy and much detail is lost.

Photographs flown for the United States Department of Agriculture are usually made with aerial cameras having a negative size of either 7 by 9 inches or 9 by 9 inches. Enlargements, of course, increase the size of the photograph as well as the scale. The following shows how the size of sheets, in inches, varies with enlargement:

Contact prints (Scale 1:20,000 3.168 in. = 1 mile) Inches	*Enlargements (Scale 1:15,840 4.00 in. = 1 mile) Inches*	*Enlargements (Scale 1:7,920 8.00 in. = 1 mile) Inches*
7 by 9	11 by 14	22 by 27
9 by 9	14 by 14	27 by 28

Photo indexes.—Photographic indexes are available for most of the photography available in the United States Department of Agriculture, and in other government agencies as well. These are prepared by fastening the individual photographs of an area together. The images are matched and the photographs overlapped so that all marginal data are visible. The assembly is then photographed at a smaller scale, often in several sheets for convenient handling. Most indexes available in the United States Department of Agriculture are on sheets about 20 inches by 24 inches and have a scale of around 1 inch to the mile (1:63,360). Four to five index sheets cover an average county.

Photo indexes are useful for determining the number and location of individual photographs within an area. Since the low cost of the indexes is easily made up in the time saved, they should always be obtained when available. They are also useful for schematic mapping.

Advantages and disadvantages.—The greatest single advantage of aerial photography in soil surveying is the wealth of ground detail shown. Physical and cultural features that it would be impractical to show on base maps are represented in infinite detail on the aerial photograph. Field boundaries, isolated trees, small clumps of bushes, rock outcrops, buildings, and plant cover all assist the soil scientist in orientation and in plotting his data. Photographs increase both the speed and accuracy of his work. Streams, lakes, and swamps that are difficult to plot accurately by ground methods become control on the photographs.

Because large areas can be photographed rapidly, field scientists may be supplied with highly detailed base material in a short time. Compared to other methods of obtaining original bases with comparable detail, aerial photography is by far the most rapid and economical method. Isolated areas, difficult to map by ground methods, are no handicap to the photographic aircraft, provided suitable landing fields are within operating distances. Aerial pictures are especially helpful to the soil scientist faced with the problem of making accurate soil surveys in wild areas proposed for agricultural development.

Stereoscopic vision, or the ability to see depth, is another advantage of aerial photographs in soil mapping. With photographs having overlap adequate to permit stereoscopic study, the soil scientist has before him a relief model of the area, complete with all of its intricate cultural and physical detail. Such a model affords an opportunity for study of the area in advance of field work. His traverses can be laid out most effectively. The study of plant cover, relief, drainage patterns, and other details helps greatly in planning the field work. Streams, swamps, and other features may be tentatively drawn in advance.

Adequate base maps having the necessary detail to carry the soil survey data can be constructed economically and within a reasonable time from aerial photographs, provided that the photography is of good quality, that the ground control is adequate, that modern photogrammetric facilities are available, and that qualified photogrammetrists supervise the work.

Despite these advantages, aerial photography has some disadvantages and limitations in soil surveying. Photographs are inferior to good topographic or planimetric maps in the following ways: (1) Elevations are not shown; (2) the photographs lack a precisely uniform scale throughout the area because of variations in ground elevations and altitudes of the photographic aircraft; (3) the soil scientist is forced to handle more sheets than when using large maps, resulting in more matching, joining, and filing; (4) differences of scale between adjoining photographs create some minor difficulties in matching and transferring soil boundaries from one photograph to another; (5) distances and directions cannot be so accurately measured because of distortions due to tilt, displacement, and other inherent errors; and (6) although far more detail is shown than on standard maps, it is not always so legible and more skill is required to interpret it. Many details on aerial photographs, such as field boundaries, fence rows, wooded areas, and crops are ephemeral and change more rapidly than the selected features shown on a standard map. For this reason old photographs may be more difficult to use than good maps made from them about the same date as they were taken. Yet these limitations are small in relation to the advantages.

Procedure for obtaining.—Approximately 90 percent of the United States has been photographed during the past 15 years. The major portion of this photography is suitable for soil mapping. Much of it is old and difficult to use because of changes in vegetation and cultural detail. Areas are being continually reflown, however, as changes justify.

Once the survey area is selected the order for photographs should be placed as soon as possible. Such requests should give the exact boundaries of the proposed survey, the scale of photography needed, whether stereoscopic or alternate coverage is to be used, and the date the survey is to commence. Any special requirements, such as weight of paper or finish, should be added also. Aerial film held by other Federal agencies is normally available on loan to the Cartographic Section for the preparation of reproductions. Because of limited facilities, however, it is necessary to have some photographic prints prepared by the agency having the original film. As prints from much of the aerial film are in great demand, it often takes a long time to get prints or enlargements.

In estimating the time required to obtain original aerial photography, time must be allowed for preparing specifications, awarding contracts, photographing the area, and inspection and acceptance of the work. Perhaps the most uncertain factor is weather. The frequency of suitable days for photographic flying varies in different parts of this country and in different seasons. In places aerial photography taken at some seasons is better than that taken in others. For example, the best photography in the southeastern part of the United States is had during the winter months, when the vegetation least obscures the ground.

Costs.—The cost of original aerial photography varies greatly, depending on the local weather conditions, availability of airfields, and so on. That flown to specifications of the United States Department of Agriculture has varied considerably in different contracts from year to year. During the 10-year period 1939-49, yearly average costs varied from $1.93 per square mile in 1939 to $4.06 in 1945. Costs in 1949 average $2.71 per square mile, or less than one-half cent per acre.

Reproductions from original film are furnished from other agencies at rates based on costs of labor and materials. Within the United States Department of Agriculture unit costs in 1950 for reproduction were as follows:

Quantity:	*Contact prints (1:20,000) Each*	*Enlargement (1:15,840) Each*
1 to 5	$0.80	$1.55
6 to 100	.50	1.00
Over 100	.45	.90
County coverage	.40	.80

Where original aerial photography is available the cost of contact prints in stereoscopic coverage for a county is about 26 cents per square mile. For stereoscopic coverage with 1:15,840 enlargements the cost per square mile is 52 cents. These costs are a minor fraction of the total for a basic soil survey.

Aerial mosaics.—Aerial mosiacs are made by assembling and matching individual aerial photographs to form a continuous photographic image of an area. A few photographs may be used to cover a small area, or hundreds of them may be assembled for a large one. Several methods of assembly may be used, and the results vary widely in accuracy and usefulness.

Types.—The two general types of aerial mosaics are the uncontrolled and the controlled. The uncontrolled mosaic is made simply by matching like images on adjoining photographs without the use of ground control. No corrections are made for scale, tilt, or displacement. Since the photographs are matched by picture images only, without geographic control of their position, an uncontrolled mosaic is not suitable for accurate mapping and is difficult to use in map construction. In making a controlled mosaic, the photographs are adjusted to ground control; distances and directions are measurable; and the individual photographs are brought to correct scale and corrected for tilt and displacement. Each photograph is matched and adjusted so that image points on the photograph fall in their true geographic positions on the map grid. Since a controlled mosaic closely approaches the accuracy of a good planimetric map, the soil scientist can use it as a base in soil surveying.

Between the inaccurate, uncontrolled mosaic, on the one hand, and the accurate, controlled one, on the other, are a wide variety of semicontrolled mosaics for which different forms of ground control are used. Thus mosaics vary greatly and must be carefully checked for adequacy before use in detailed soil mapping.

Advantages and disadvantages.—An aerial mosaic has the advantage of covering a large area in one photograph. Thus fewer sheets need be matched. Mosaics can be made to cover a specific area, like a township, a small watershed, or a drainage basin. Where controlled mosaics are available, their accuracy over that of the individual photographs is also an advantage to the soil scientist in plotting soil boundaries and in transferring them to adjoining sheets.

In reproducing sheets for field use from a mosaic, a small margin of overlap can be retained, or the sheets can be reproduced to match without overlap. This is an advantage, since the soil scientist frequently has difficulty in matching adjoining aerial photographs that have wide margins of overlap.

A major disadvantage of aerial mosaics in soil surveying, as compared to overlapping photographs, is that mosaics themselves cannot be used for stereoscopic study of the area. The great value of such advance study of an area has already been emphasized.

As with planimetric and topographic maps, the accuracy of mosaics cannot always be assessed by their appearance. They must be field checked. Extreme difficulty may be had in the field with a mosaic that appears in the office to be of top quality. Even though an uncontrolled or semicontrolled mosaic may be usable in the field, it may be impossible to construct an accurate map for publication except at great additional expense. Thus the whole job should be considered when planning the use of an aerial mosaic.

Preparation.—The Cartographic Section of the Division of Soil Survey is equipped to prepare a limited number of controlled aerial mosaics suitable for soil mapping in areas with adequate ground control already established. The normal procedure is as follows: Obtain all ground control in the area, plot it, lay out the projection, and construct a radial plot; obtain the original aerial film; restitute all prints to fit the controlled grid, using care in the processing to insure a uniform tone and quality; trim the photographs, apply the adhesive, and adjust and assemble the prints on the mosaic board; prepare the necessary sheet borders, titles, and footnotes; make copy negatives of the complete mosaic; and reproduce the number of copies required.

Procedure for obtaining.—Where it is best to use controlled mosaics for a soil survey, the request for such work should be made well in advance. Facilities are not available for preparing mosaics for all soil surveys, nor should mosaics be recommended unless they will expedite field work, use of field sheets by co-operating agencies, and map publication.

Costs.—The cost of aerial mosaics for a soil survey is naturally higher than for the individual pictures used; yet in some areas the use of a good controlled mosaic may reduce the total cost of the survey. Part of the costs may be charged to the normal cost of the map preparation. Obtaining control data, preparing the control plot, and making the necessary sheet layouts are a normal part of the map preparation in many areas. The aerial prints have to be supplied to the field party anyway; therefore only the operations of assembling, adjusting, and reproducing the mosaic are added costs.

The cost of mosaics is generally less than that of preparing a planimetric map for the soil survey and higher than that for individual aerial photographs.

Photomaps.—The photomap is a form of aerial mosaic. Unlike the conventional mosaic, physical and cultural features are shown as they are on a planimetric map, and the sheets are laid out uniformly on a definite projection, as is done with standard topographic or planimetric maps. Photomaps are usually reproduced in large quantities by offset lithography or some similar process. Frequently, the planimetry is shown in color. Color emphasizes and gives greater legibility to planimetric detail, for it contrasts with the black-and-white photographic background.

Types.—No fixed standards have been established for photomaps. Although good accuracy may be generally assumed, because of the expense of constructing and reproducing a photomap, the soil scientist should test the accuracy of a photomap before using it in the field.

Photomaps are usually published in sheets in minutes of latitude and longitude depending on the scale; but in sectionized parts of the United States, the sheets may be laid out to cover one or more townships.

Photomaps vary widely, depending on scale and purpose. Some are published with only grid lines and appropriate titles and footnotes; others show the usual planimetric features—roads, drainage, buildings, railroads, power lines, and the like—sharply defined with appropriate standard symbols, and with place names for the prominent features. On printed copies of some photomaps the planimetric detail is indicated by overprints in color—drainage in blue, cultural features in black, and special features in other appropriate colors. Such photomaps are sometimes called *planisaics*. A few photomaps include topography or terrain form lines, with the contours or form lines printed in brown, as on standard topographic quadrangles. These are called *toposaics*. Photomaps with contours to show exact topography can usually be assumed to be well constructed and accurate. Where approximate form lines of the terrain are shown instead, the photomap is probably made to less precise standards.

Three general types of photomaps can be roughly defined as follows: (1) Those reproduced in small editions by photography rather than lithography, in which the photographic background appears like it would in the aerial photograph, with lines and symbols in black or white lines on this background; (2) those printed in large editions by offset lithography in black and white, with planimetric line work overrun in black on a photographic halftone background made with a fine dot screen; and (3) those reproduced by offset lithography in two or more colors, with the photographic background shown by halftone screens in black or grey and the planimetry, contours, or other special features overrun in appropriate contrasting colors.

Advantages and disadvantages.—Since the photomap is an advanced stage of the aerial mosaic, it has many of the same characteristics, advantages, and disadvantages. The delineation of cultural and drainage features is a major advantage over the conventional controlled mosaic, since it eliminates or reduces the possibility of errors in interpretation of planimetric detail and the resulting errors in soil boundaries that may occur when mosaics are used. The soil surveyor normally spends less time classifying and delineating such detail with a recent photomap than with an aerial mosaic.

Normally, the photomap can be relied upon to be more precise than the conventional mosaic. Photomaps sufficiently precise to meet the standards for published soil maps can be used readily in the map assembly.

The disadvantages of the photomap are similar to those of the controlled mosaic. Photomaps cannot be used for stereoscopic study of an area. This is a handicap, but not so great a one as that encountered with the conventional mosaic, on which physical and cultural details are not delineated.

Because of methods used in producing them in large numbers, photomaps frequently lack the photographic detail found on photographic copies of a mosaic. Unless exceptionally fine screens are used in the offset lithography, the photographic detail reproduced is not of high quality.

Procedure for obtaining.—Photomaps prepared by other organizations, like other base materials, are obtained through the Cartographic Section. Full information on the accuracy of photomaps needs to be had before their use is recommended. It is not practical to prepare photomaps for use in soil surveying alone.

Accurate identification of drainage and cultural features require field editing.

From time to time, however, photomaps may be produced for publishing a soil map. A controlled mosaic can be constructed in advance of field mapping and used by the soil scientist as a base for mapping. The surveyor classifies the cultural and drainage features on the mosaic while making the soil survey. By using the original mosaic as a base, and preparing color separations for drainage, culture, and soils, the Cartographic Section can prepare the soil map as a photomap.

Cost.—A photomap costs more than a conventional controlled mosaic, because costs for field editing, drafting the cultural and drainage features, and making lithographic reproductions must be added. The cost of a soil map as a photomap should be comparable to that for the conventional soil map, provided color tints for soils were omitted from the photomap.

Topographic maps of standard accuracy.—A topographic map presents both horizontal and vertical positions of the physical features of a land area on a flat plane at definite scales. Published maps usually show such cultural features as roads, railroads, and buildings in black; drainage features in blue; and contour lines in brown. Some also show additional features, such as vegetation, in overprints of green or other colors.

Most topographic maps published by the United States Geological Survey and other Federal maps meeting these requirements carry marginal notes indicating compliance with the National standards of map accuracy. The standards for horizontal accuracy of maps published at scales larger than 1:20,000 prescribe that not more than 10 percent of the tested points shall be in error by more than one-thirtieth of an inch. On maps published at scales smaller than 1:20,000, the error shall not be more than one-fiftieth of an inch. These limits of accuracy apply only to positions of well-defined points, like roads, monuments, large structures, and railroads, which are readily visible and which can be plotted at the scale of the map within one-hundredth of an inch. Standards for vertical accuracy require that not more than 10 percent of the tested elevations be in error by more than one-half of the contour interval.

Types.—Because of the prescribed standards of accuracy, topographic maps vary little, even though published by different agencies. Some differences may be noted in format, scales, boundaries of latitude and longitude, and classification and presentation of planimetric detail—differences due primarily to needs for meeting specific requirements.

Standard topographic maps are published in quadrangles bounded by parallels of latitude and meridians of longitude. Generally, topographic quadrangles are 30 minutes, 15 minutes, 7½ minutes, or 3¾ minutes of latitude and longitude. Scales vary with topography and contour interval. The most usual publication scales are 1:24,000, 1:31,680, 1:48,000, 1:62,500, and 1:63,360.

Maps of smaller scale are useful to the soil scientist only for reconnaissance mapping. Few topographic maps are published at scales larger than 1:24,000.

Advantages and disadvantages.—The reliable accuracy of standard topographic maps gives them definite advantages in measuring distances and directions. The topographic pattern is very helpful to an understanding of soils and in the study of drainage, irrigation, and erosion cycles. The planimetric detail on the maps relieves the soil surveyor of a part of this task when mapping soils.

As a base for detailed soil mapping, the topographic quadrangle lacks the ground detail—field boundaries, isolated trees and bushes, fences, and similar features—that are shown on a good aerial photograph or mosaic. The small scale of many topographic quadrangles and the lack of coverage for large areas are further disadvantages. Drainage patterns on the standard topographic quadrangle are not shown in the detail needed for soil maps. Some old topographic maps are not accurate and need a great many revisions. The topographic maps of recent years, made from aerial photographs, are much more accurate.

In planning the use of topographic quadrangles in the preparation of soil maps for publication it must be recalled that a great deal more is involved than simply transferring soil boundaries to the quadrangles. Their use may or may not reduce costs, depending on the project.

Where recent, large-scale topographic quadrangles cover all, or a large part, of a soil survey area they are very useful in publishing the soil map. The use of such accurate quadrangles eliminates the necessity of constructing a base, which is especially helpful in areas with much culture. Then too, in densely wooded areas an accurate topographic map shows more points for location than an air photo. Such quadrangles serve only as a manuscript base, however, even after they are assembled into sheets of the size needed for the soil map. It is still necessary to transfer the soil data to this manuscript and prepare glass negatives or nonphotographic metal-mounted blue-line manuscript maps[1] for the color separations that show culture, soils, and drainage. These color separations are then drafted or engraved, new lettering layouts are prepared, and the printed lettering is applied to the color separations. Plates for the soil separation tints are then made and the various tints blocked out. Composite proofs are prepared and edited. The complete color separations are then copied, lithographic plates made, and the lithographic copies printed.

With old topographic quadrangles, made to less precise standards and requiring much revision, it may cost more to prepare the soil map than to make a new base from aerial photographs. The difficulties of transferring soil boundaries and symbols from the aerial photographs and adjusting them to fit old

[1] See Notes on Map Compilation and Reproduction, Appendix III.

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quadrangles, and of revising the planimetry, more than offset the saving made by using them.

Only recent large-scale topographic quadrangles covering most of the survey area are recommended for use as a base. It is best of all if both aerial photographs and recent topographic maps made from aerial photographs are available.

Procedure for obtaining.—Standard topographic maps are published mainly by the Topographic Branch of the United States Geological Survey, the United States Coast and Geodetic Survey, and the Army Map Service of the Corps of Engineers.

The Cartographic Section of the Division of Soil Survey receives new lists and new topographic quadrangles as they are published and can supply available topographic maps needed for soil surveys. In addition, the Cartographic Section can supply information about areas in progress, expected dates of completion, and details concerning the topographic mapping program. Frequently preliminary proofs or copies of manuscript material may be obtained in advance of publication, where the need is urgent. When aerial photographs are supplied for a soil survey the Cartographic Section normally forwards all available standard topographic quadrangles as well, since such maps are helpful as reference for place names and for soil study, even though not used as the mapping base.

Costs.—The topographic quadrangle of standard accuracy is expensive to construct and publish. It serves many useful purposes, besides serving as a planimetric base for soil maps.

Planimetric maps of standard accuracy.—A planimetric map presents the horizontal position of the physical features of an area on a flat plane at definite scales. Unlike the topographic maps, no vertical distances are indicated. Otherwise, they are usually published in a form like topographic maps. Although no generally accepted precise standards for planimetric maps have been established, many mapping agencies have established standards that approach or equal those for topographic maps. Only such accurate planimetric maps are used for soil mapping.

Types.—Although standards for planimetric maps vary more than those for topographic maps, they are usually published in quadrangles similar to topographic maps and at approximately the same scales. Some differences result from variations in the map needs of the agencies preparing them. As a base for soil mapping, these differences are minor, compared to accuracy.

Advantages and disadvantages.—Planimetric maps have some of the same advantages of topographic maps as a base for soil surveying. A major exception is the omission of topography so valuable for soil study and interpretation. Then too, accuracy is less certain. Where accuracy is equal to that of good topographic maps, planimetric maps are helpful, even though the soil mapping is done on aerial photographs.

Procedure for obtaining.—As with standard topographic maps, the Cartographic Section receives copies of published planimetric quadrangles and can obtain them when needed. Where available, they are normally supplied with the aerial photographs for reference.

Cost.—Although cheaper than topographic maps, accurate planimetric maps cost more than the conventional controlled mosaics for comparable areas.

Other types of maps.—Many other types of maps are published by public and private agencies. These range from the small-scale road maps distributed by oil companies to the large-scale detailed maps used in city planning. Most of these are designed, constructed, and reproduced to meet a special purpose. Certain details on such maps are usually emphasized to meet special requirements by exaggerating certain items and subordinating others. The small-scale road map is a typical example. On such a map the highways, highway numbers, towns, cities, points of interest, and mileage distances are prominently shown, while drainage, railroads, pipelines, power lines, and public land lines are omitted or subordinated.

Aeronautical charts are special-purpose maps designed and constructed specifically for air navigation. The scale is small so that large areas may be shown on a single sheet. Ground features prominent from the air are emphasized in bold and simple symbols. Other features of equal importance on the ground but less noticeable from the air are subdued or omitted entirely. Elevations are shown in gradient tints, permitting the navigator to determine quickly the necessary flight altitude over a given area. Navigation data are shown in bright overprints.

The plats prepared from public land surveys are another form of special-purpose map, designed to present the data of the survey. The scale is large, and plats usually include a survey unit, such as a township. Courses and distances, subdivisions of sections, acreage figures, and other data from the survey are shown. Cultural and drainage features are reduced to a minimum and are accurate only on the survey lines.

Special-purpose maps of the kinds described in preceding paragraphs have little or no value as bases for detailed soil surveys. Such maps are very useful, however, for reference.

For broad reconnaissance soil surveys special maps may be useful as bases. Aeronautical charts, for example, are useful for rapid small-scale surveys of large areas. They have sufficient detail for orientation, accuracy is good at the small scale, and the generalized relief facilitates soil mapping.

The Cartographic Section can supply field parties with many special maps, including aeronautical charts, geologic maps, forest maps, coast and harbor charts, conservation survey maps, Census Bureau maps, Post Office maps, and highway maps.

EQUIPMENT

Requirements for equipment vary so widely from area to area that only those of general use are discussed here. Other sections of the *Manual* mention items for special needs. Plane tables, and accessories for them, and compasses are dealt with in the Appendices.

SPECIAL EQUIPMENT FOR AERIAL PHOTOGRAPHS

The materials used to delineate culture, soil boundaries, and symbols on aerial photographs and mosaics should be selected for ease of use, including correction, neatness, clarity, and permanence. These materials are now sufficiently standard that they may be readily obtained from commercial suppliers.

Pencils.—Despite a wide range in personal preference for types and hardness of pencils, the basic requirements are the same. The pencil marks need to be sharp, clear, and legible, but made without scratching or cutting the photographic emulsion. Pencils should be soft enough to leave a legible line yet not soft enough to smear with ordinary handling of the pictures. Too soft a pencil leaves a coarse heavy line that smears a dirty residue over the surface of the photograph and conceals other data. A very hard pencil scratches or indents the photographic emulsion, makes inking difficult, and requires such hard erasures for making corrections that the photographic emulsion may be broken.

Variations in the surface of the aerial photograph and in atmospheric conditions partly govern the choice of pencils. On hard and glossy photographs it is necessary to use a soft pencil for the line work to adhere. On the softer matte finishes, a harder pencil is better. A softer pencil is used during damp weather or in humid climates than is used during dry weather or in the desert.

Depending on conditions just mentioned, standard drafting pencils of good quality ranging from H to 4H are used in dry regions, and HB to 3B for moist regions or during periods of damp weather.

Inks.—Inks should be bright-colored, of opaque density, free-flowing, waterproof, rapid-drying, and of the kinds that photograph well.

Where the inking is done directly on the aerial photograph, a standard waterproof drafting ink should be used. If the inking is done on an acetate or plastic overlay, rather than directly on the aerial photography, special inks are used that adhere well to these media and that are easy to handle. These are called acetone inks and they etch the plastic slightly. Such special inks are too difficult to remove for use directly on photographs; in their removal the photographic emulsion is frequently damaged and brown stains are left. Standard waterproof drafting inks may be used on acetate or plastic overlays if sealer coatings are applied over the ink work immediately to prevent rubbing off or chipping. Such plastic sealer coatings can be applied with a soft cloth, brush, or spray. They dry rapidly, are transparent, and can be marked on with pencil or ink. Only a light coat of sealer should be applied. In preparing some kinds of contact prints from the original sheets, the sealer sticks to the rollers if too much has been used.

Only those colored inks are used that permit good photographic copies of the field sheets. Many colors do not photograph well unless copied through filters. Such filters may bring out any one color by subduing another. The use of filters also increases the time required for copying. Generally, black, red, and brown photograph well. The photographic qualities of blue, green, and yellow are normally poor but may be increased by mixing small amounts of the more photographic colors with them.

Mixed colors, as for example, black mixed with blue, should contrast on the field sheets and yet permit satisfactory copying. If a line is to appear in blue on a field sheet yet contain enough black to permit good photo copies, only a little black ink should be mixed in the blue.

Transparent overlays.—A number of transparent materials suitable for overlays on aerial photographs or mosaics are on the market. These fall into two general classes: (1) Plastics and (2) acetates. Both can be obtained in a variety of thicknesses and finishes.

Overlay materials should have dimensional stability. If one without dimensional stability is selected, difficulties are had in maintaining registry between the overlay and the photograph and in matching one overlay with another.

The most useful materials for overlays range from 0.005 to 0.080 inch in thickness. Enough thickness is needed to give stiffness and to avoid curling, yet not so much that sheets are bulky and difficult to handle.

The best overlays are transparent, with a grained surface. These have maximum transparency and their surface is suitable for both pencil and ink work. India ink can be used on ungrained acetate or plastic if soiling with perspiration or other oily substances is avoided. A sealer needs to be applied immediately afterward.

A transparent dimensionally stable material, with matte finish on one side and about 0.008 inch thick, is entirely satisfactory.

Types of photo paper.—In ordering aerial photographs and mosaics it is sometimes helpful for the soil scientist to specify the type and finish of paper on which the photographs are to be printed. Of the many kinds, some are satisfactory and others unsatisfactory for soil mapping.

Most photographic papers are available in three thicknesses or weights, as light, single, and double. Lightweight papers are too thin and flexible for most soil mapping. They tend to curl and lack dimensional stability. Where copies of field photographs thin enough to use over a light table in transferring data from one sheet to another are wanted, the lightweight papers are satisfactory. An extra thin paper is made that is especially good for this purpose.

Single-weight paper is somewhat thicker than the lightweight papers and is commonly used for printing aerial photographs to be used only in offices. Even this weight is too light for satisfactory field use where photographs are handled a great deal and exposed to variable weather conditions.

Double-weight paper is approximately twice the thickness of single-weight. It is stiff and does not curl, has a reasonable degree of dimensional stability, and is best for photographs that are to be used in the field for soil mapping.

Photographic finishes are classed broadly as glossy, semimatte, and matte. The surface of a glossy photograph is too slick and polished to accept pencil or ink well, and cannot be used conveniently. Semimatte and matte finishes take pencil and ink well, and these finishes are used on photographs on which survey data are to be plotted.

Waterproof papers are advantageous on some soil surveys. They can be processed somewhat faster than the conventional photographic paper and, if properly processed, their dimensional stability is somewhat better. For soil surveys in warm humid regions the waterproof paper has the advantage of absorbing less moisture.

Pens.—Pens should have points ranging from medium-fine to fine. Pens with stiff firm points are much preferred to those having soft flexible nibs. Unless used by an expert, pens with highly flexible nibs spread, and lines are either too heavy or too light. Such points soon lose their spring if abused and need to be discarded. The stiffer, coarser pen lasts longer and permits more uniform and consistent line work.

Erasers.—For cleaning soft pencil lines from aerial photographs art gum is usually satisfactory. Hard pencil lines can be removed with a soft pliable eraser. Ink lines not removable with a soft pliable eraser can be taken off by first dampening with alcohol or water and then erasing. Care must be taken not to let the photographic emulsion become wet enough to break or tear with erasing. Coarse or abrasive erasers should not be used on photographs. The emulsion becomes so scratched and broken that reinking is difficult or impossible.

The sketchmaster.—The sketchmaster is a small instrument used to reflect the image of the aerial photograph to a manuscript map. The photograph is mounted parallel to the manuscript map on a tripod-supported frame. The operator looks down through a half-silvered mirror at the front of the instrument and sees the image of the photograph superimposed on the manuscript map (fig. 1). He can adjust the length of the three legs to correct for tilt and difference in scale. The sketchmaster can be used for sketching at scales ranging from one-half to twice that of the photograph.

Simplicity, compactness, and portability make the sketchmaster an excellent instrument for use in field offices to transfer planimetric and soil data from the field sheets to a manuscript map. It

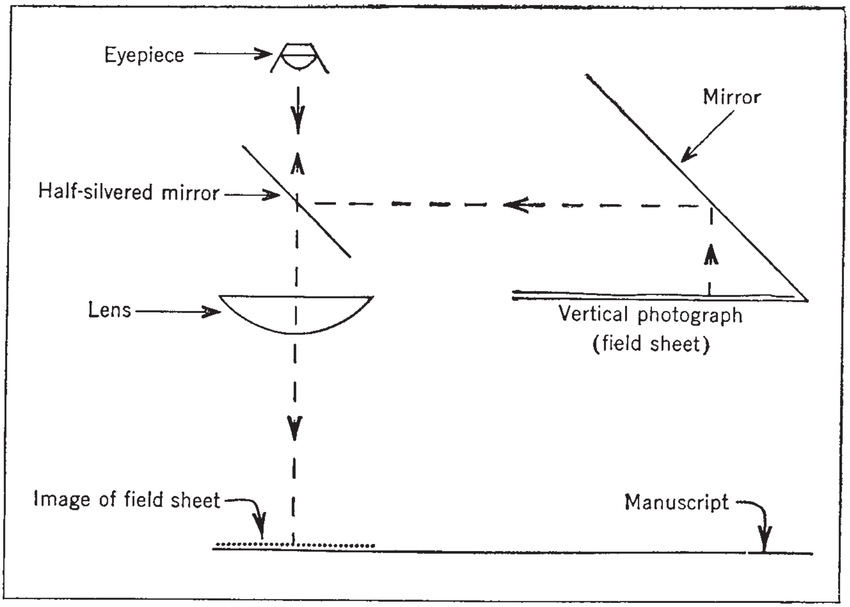

FIGURE 1.—Diagram showing the principles employed in a common type of sketchmaster used for transferring map data from a photograph to a manuscript map.

may be used for overlays and other field sheets as well as for aerial photographs.

Sketchmasters may be vertical or oblique. The vertical sketchmaster is used with vertical aerial photographs and the oblique is used with oblique aerial photographs. Since the vertical aerial photograph is used mainly in soil mapping, only the vertical sketchmaster concerns us here. The same general techniques are used with overlays of vertical aerial photographs or plane-table sheets.

In working with the sketchmaster, a framework of control is first indicated on the manuscript map, and into this framework planimetric detail is transferred from the photograph. This framework assists the operator to orient his instrument and thus to transfer the map data to their correct position on the manuscript. The framework may consist of photogrammetric stations, or culture and drainage, along with established section lines or other land lines.

If the manuscript map is a standard topographic or planimetric map, only soil boundaries and symbols, and revisions in culture and drainage need to be transferred.

An operator uses a sketchmaster about as follows:

(1) After inspecting the aerial photograph to make certain that the detail is clearly delineated, it is inserted in the frame so that it is perfectly flat and all detail is shown.

(2) The instrument is placed on the manuscript map. Looking through the eyepiece, the operator orients the instrument so that the image reflected from the instrument is near the correct position on the manuscript.
(3) Among the lenses furnished with the instrument one is selected that removes practically all the parallax at the scale to be used. With a low rig, for example, a large numbered lens is used. If a point on the manuscript moves in a direction opposite to that of the eye of the operator, a smaller numbered lens should be selected.
(4) The instrument is adjusted for scale by lowering or raising the frame on all three legs. The final leg adjustment is made with the screw feet. Correction for any tilt in the photograph may be made by adjusting the length of one or two legs.
(5) The detail on the manuscript should coincide with the detail reflected to it from the aerial photograph.
(6) The detail on the aerial photograph is now ready to be transferred to its correct position on the map manuscript. The eye is shifted slightly to bring individual controls into exact register as the detail in their vicinity is being traced. When tracing a stream, for example, the operator holds to the control on or near it. If there is no control on a feature, a skilled operator can properly orient nearby points in order to locate boundaries correctly. Transferring can be extended out to the edges of the vertical photographs.

Good light is required. The mirrors should not be touched with the hands since the salt in perspiration decomposes the chemical coating of the mirror and spoils it.

SOIL-SAMPLING TOOLS

The soil scientist's most important tool is the humble spade, supplemented by the pick and the soil auger. For exposing soil profiles for morphological examinations, as in the initial work of preparing a mapping legend, for sampling, or for photographing, the spade is used almost entirely. For the more frequent routine examinations of soils in mapping, the spade is generally but not always superior to the auger. For example, where the chief differentiating characteristic between two soil types or phases is the depth to a deep underlying stratum of clay or is the color of the substratum, a soil auger may be better than the spade, both faster and more convenient. Perhaps the worst feature of the auger is its destruction of soil structure, so important in classification and identification. In dry, stony soils, the auger is difficult to use; nor can the spade alone be used rapidly; and the pick becomes the most useful tool. Whenever practical, the spade should be given preference over the soil auger, especially in excavating the upper part of the soil—the solum. Where the soil auger is used frequently in identifying soils, some exposed profiles of the soil types should also be examined in order to check the results.

Spades and picks.—For use in collecting samples, especially after the preliminary excavation has been made, the flat square-pointed spade (fig. 2, *A*) is most convenient. The best generally useful spade, however, for ordinary use in mapping, is a modified post hole spade (fig. 2, *B* and *C*). The sharp corners of the post hole spade are removed for best results. The common tiling spade tapers somewhat too much at the end, although it is a useful tool for some soils and generally superior to the post hole spade for

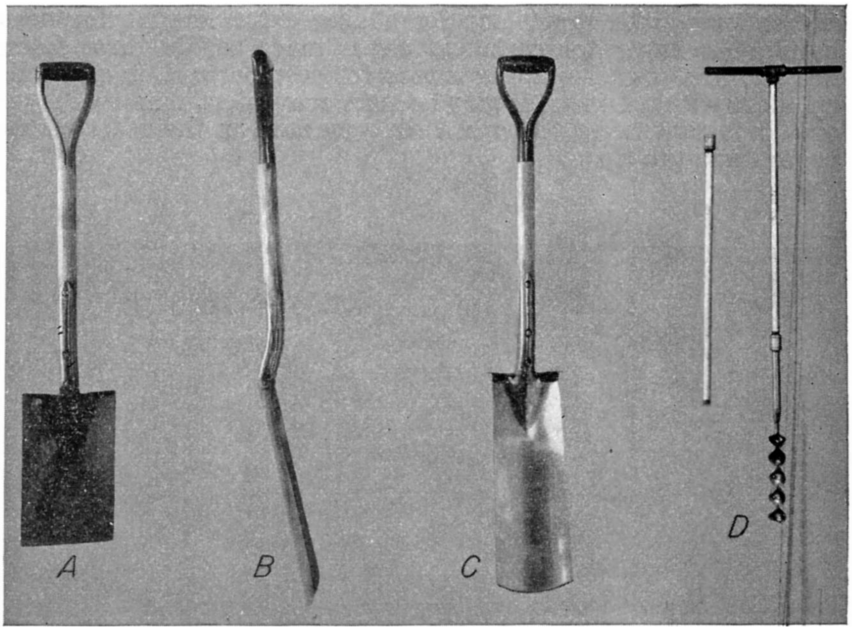

FIGURE 2.—Soil-sampling tools: *A*, Square-pointed spade, especially useful in collecting samples; *B*, side view, and *C*, front view of post hole spade, the most generally useful sampling tool; and *D*, soil auger with extension.

gravelly soils. Where deep holes are required, as in examining irrigated Alluvial soils, the long-handled irrigator's shovel is useful. It may be necessary to supplement this shovel with a heavy crowbar to penetrate dry cemented and compact layers.

The pick should always be at hand, especially for making holes in hard, dry, stony, or gravelly soils. In some soils a small trench pick will serve satisfactorily, but commonly a heavier pick with a long handle is better. One prong should be sharply pointed and the other made as a chisel. A heavy chisel-pointed bar is useful for penetrating strongly cemented or indurated hardpans.

A geologist's hammer, or small hand pick, one end of which can be used as a hammer, is also useful in examining rocks and the soil in cuts along roadsides. For moist soils and those containing many woody roots, a chisel-pointed hammer is better; whereas for dry soils a sharp-pointed hammer is better.

Augers.—The screw, or worm, type of soil auger (fig. 2, *C*) consists essentially of a 1¼- or 1½-inch wood auger, from which the cutting side flanges and tip have been removed, welded to a steel rod or iron pipe with a crosspiece at the top for a handle. The worm part should be about 7 inches long, with the distances between flanges about the same as the diameter, 1¼ to 1½ inches. If the distance between flanges is narrower, it is difficult to remove the soil with the thumb. For ordinary use augers are 40 to 60 inches long, with provisions for adding extra lengths for deep boring. An auger for continual use is made solidly throughout, and another extension auger is used for deep borings. In clay soils an auger with a 1-inch bit may be more convenient than the larger one. It is convenient to have a scale marked on the shaft of the auger from the tip.

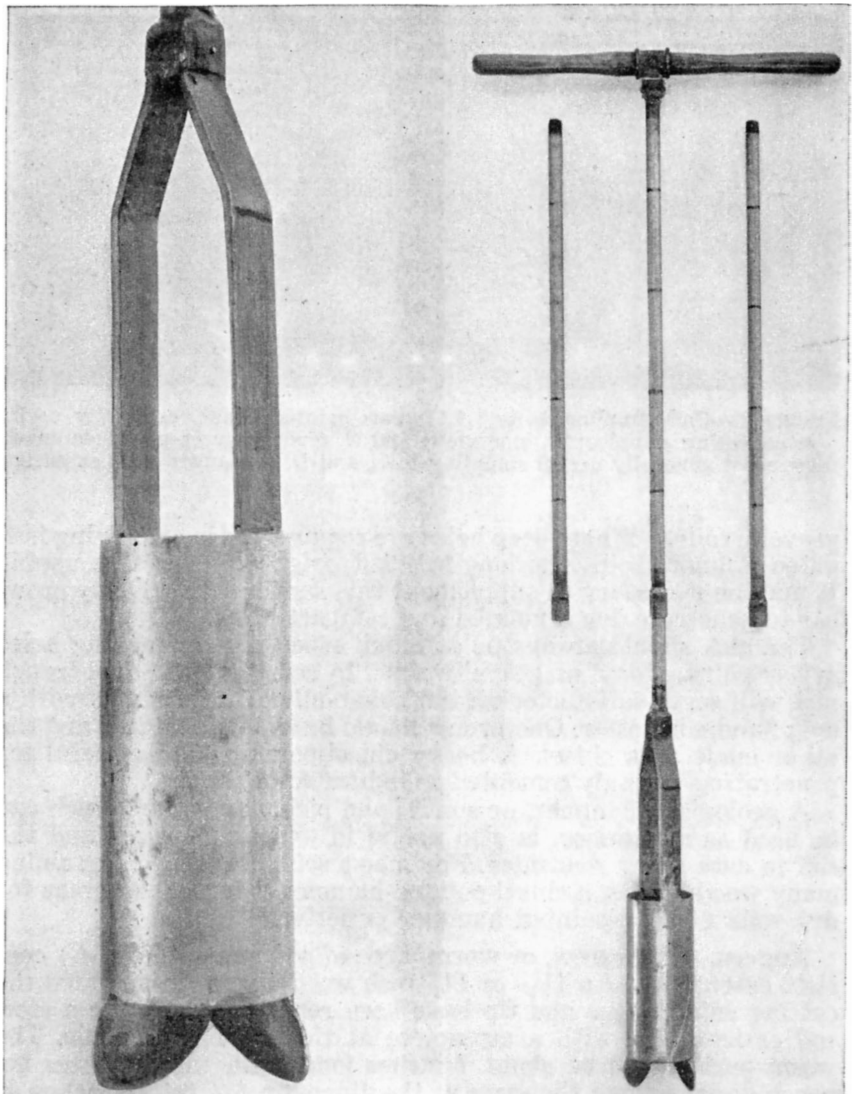

FIGURE 3.—Core type of soil auger: Left, a close view of the bit; right, a view of the whole auger, with extensions, marked at 6-inch intervals.

Generally, the core, or post hole, type of soil auger shown in figure 3 is better than the older screw type. The core type is especially favored in dry regions, and the screw type in wet ones. The core type gives a larger and less modified sample. It works well in loose dry sand and in compact soils. The cylinder is about 2 to 4 inches in diameter, commonly 3½ inches. The cutting blades are so constructed that the soil is loosened and forced into the cylinder of the auger as it is rotated and pushed into the soil. Each filling of the cylinder corresponds to a penetration of 3 to 5 inches. Although both ends of the cylinder are open, the soil becomes packed enough to stay in it while the auger is removed. If the cylinder is only partly filled, or if the soil is very dry and sandy, it may need to be tamped with a stick thrust through the upper end of the cylinder before it will stay in the auger when pulled out of the hole. Small cylinders are best for very sandy soils. A few taps of the cylinder on the ground or on a board usually loosens the soil for removal.

The core-type auger disturbs the soil, but less so than the screw-type auger. A better view of soil structure, porosity, consistence, and color can be had with the core auger, but even so, excavations are necessary for proper morphological studies. The core-type auger is not well suited to use in wet clay soils. Generally, with soils that are naturally moist for much of the year, the screw-type auger is faster.

Although soil augers are simple in design and somewhat crude in appearance, considerable skill is required to use them effectively in making dependable observations of the soil profile.

Peat sampler.—Examinations of deep deposits of peat are made with a special sampler. Although several devices are used, the one most common in the United States is the Davis peat sampler or some modification of it, as shown in figure 4. The instrument consists of 10 or more sections of steel rods, each 2 or 4 feet long, and a cylinder of brass or duraluminum, approximately 14 inches long with an inside diameter of three-fourths inch. The cylinder is provided with a plunger, cone-shaped at the lower end, and with a spring catch near the upper end. The sampler is pressed into the peat until the desired depth is reached for taking a sample; then the spring catch allows withdrawal of the plunger from its enclosing cylinder. With the plunger withdrawn and locked in that position, the cylinder may be filled with a solid core of the organic material by a further downward movement. The cylinder protects the sample completely from any contamination and does not destroy its structure when the instrument is removed.

Beginning at the surface, samples of peat are taken consecutively at intervals of 6 inches or 1 foot. The lengths of steel rods used allow an easy estimation of the depth of each sample. For very deep deposits, extra 2- or 4-foot rods are used. Each rod is threaded at one end to screw into a small coupling on the reverse end of another rod. For light work, the rods may be screwed and unscrewed with pliers; for heavy work in deep deposits, small pipe wrenches are used.

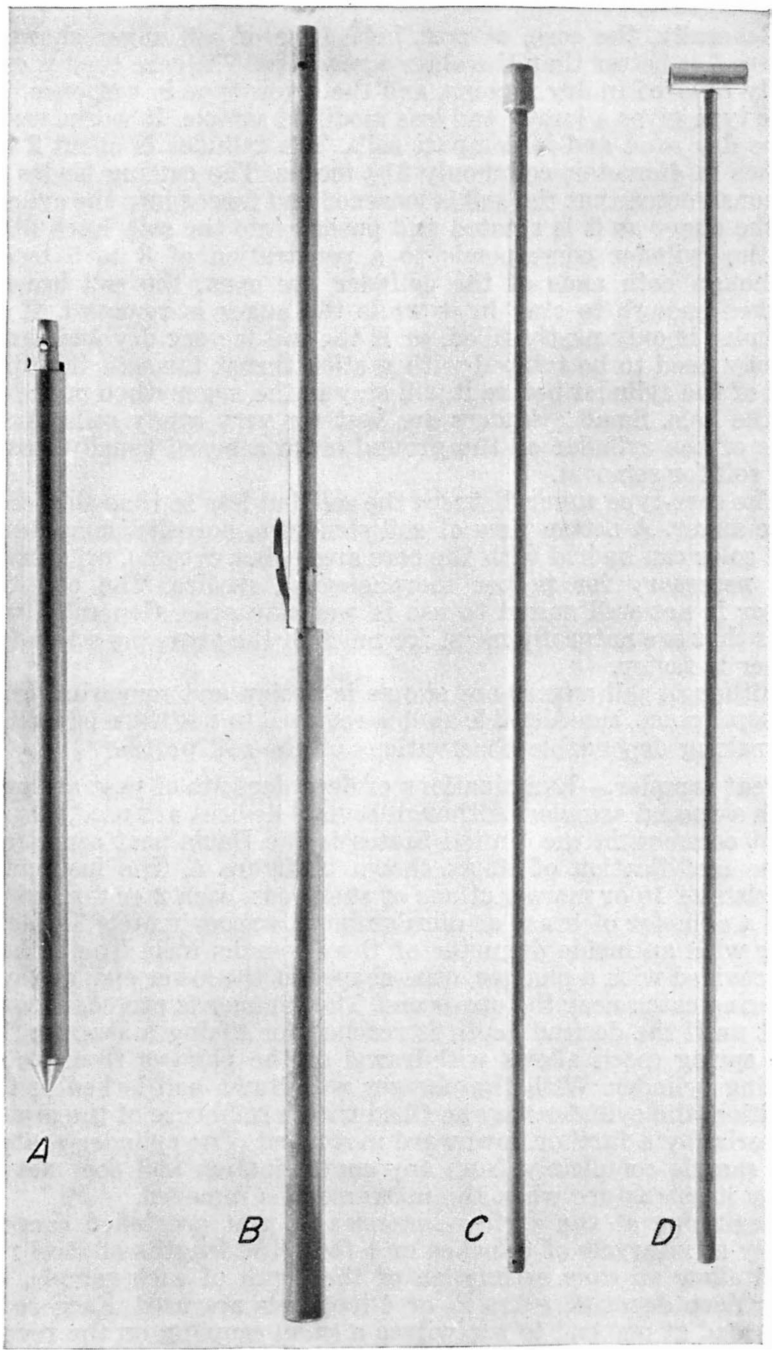

FIGURE 4.—Peat sampler: *A*, The head closed, ready for pushing into the peat; *B*, the head extended, as just prior to taking a sample; *C*, one 2-foot extension rod; and *D*, the top extension rod.

Other sampling tools.—Power augers, mounted on the rear of a truck or on a trailer, some custom made and others obtainable from manufacturers, are used in some soil surveys, either for special studies or for cutting through cemented or very compact dry soils. Some of these are of the core type, either similar to the hand core auger already described or so constructed as to obtain an undisturbed core of a complete soil profile.[2] Others are of the screw type. Further experience is needed with power augers. A custom-built one in use is shown in figure 5.

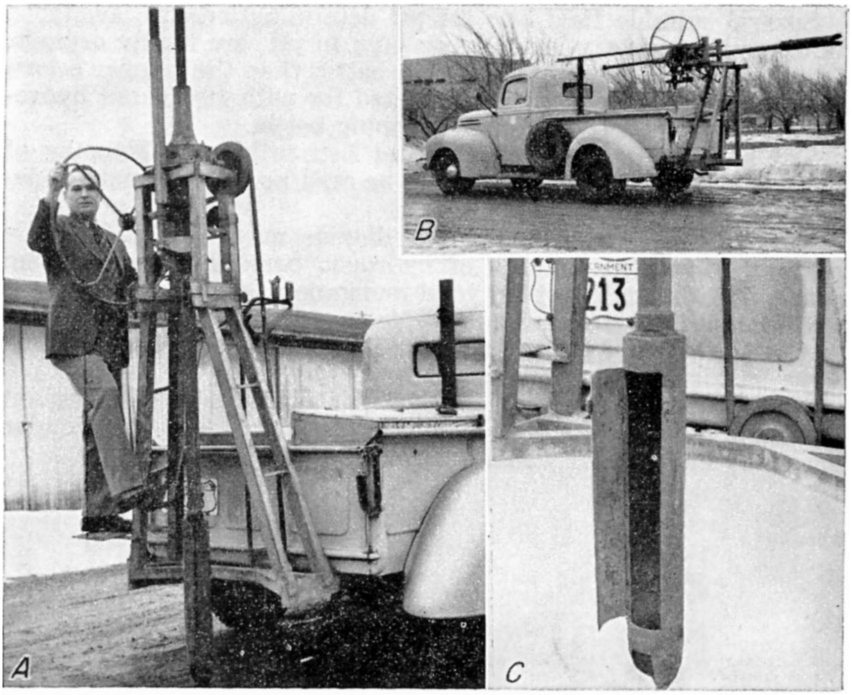

FIGURE 5.—Custom-built power soil auger: *A,* Mounted on a pick-up truck in position to operate; *B,* in position for transport; and *C,* close view of bit.

Another tool used little in routine soil mapping but of use in collecting soil samples is the King soil tube, or a modification of it, which consists of a long, narrow tube that can be driven into the soil. It is used primarily in collecting soil samples for moisture and bulk-density (or volume-weight) determinations. A short, wide tube is used for collecting samples from soil horizons for bulk-density determination. An angled cold chisel is convenient for cutting out blocks of compact or cemented soil. An ordinary

[2] For a description of a power auger see KELLEY, O. J., HARDMAN, J. A., JENNINGS, D. S. A SOIL-SAMPLING MACHINE FOR OBTAINING TWO-, THREE-, AND FOUR-INCH DIAMETER CORES OF UNDISTURBED SOIL TO A DEPTH OF SIX FEET. Soil Sci. Soc. Amer. Proc. 12: 85–87., illus. 1947.

trowel is used for sampling thin horizons and for filling sample sacks. A special trowel for this purpose consists essentially of an ordinary curved garden trowel with about one-half of the blade cut away (longitudinally) and sharpened. A straight-bladed steel fern trowel is also a good tool. A handy tool for examining soil profiles is a small steel pick of the type used by French workmen in laying slate roofs. The head of this tool has a broad-bladed chisel on one prong and a small hammer on the other. Finally, every soil morphologist needs a strong knife.

FIELD TESTING APPARATUS

Several suitable field kits for pH determinations are available. Where soils are very low or very high in pH, are highly organic, or are salty, an electrical field kit is better than the simpler colorimetric ones. Carbonates may be tested for with 10-percent hydrochloric acid solution in a small dropping bottle.

The sections on Soil Reaction and Estimation and Mapping of Salts and Alkali in the Soil should be read and appropriate apparatus obtained as required.

Besides these tests, manganese dioxide may be tested for by using a 10-percent solution of hydrogen peroxide in a dropping bottle. This is not a test for total manganese, and effervescence is not necessarily correlated with toxic concentrations. The peroxide test is useful in the field as a partial indicator of boundaries among some lateritic and latosolic soils.

No kits for chemical "quick tests" for available or soluble plant nutrients in soils are recommended. In some areas, particular ones may be useful if well standardized by field plot tests.

PLOTTING AND ASSEMBLY OF FIELD DATA

The plotting and assembly of field data are discussed early in the *Manual* because of their importance to preparation for field work, but some points may not be clear until later chapters dealing more specifically with soil classification and mapping units are studied.

AERIAL PHOTOGRAPHS IN SOIL SURVEYS

Characteristics of aerial photographs

The kinds of aerial photographs have already been described. First of all, an aerial photograph is not a map but a perspective view of a portion of the earth's surface. Like all perspectives, it does not present a true scale, and precise measurements of distances and directions cannot be made on it. In addition to the distortions of a perspective, there are those created by tilt, differences in elevation, and inherent errors of photography. Yet in contrast to maps made by ground methods, aerial photographs show more ground detail, permit a three-dimension view of the features, and afford an economical method for obtaining base material rapidly for large or inaccessible areas. From them, accurate planimetric and topographic maps can be made. For most soil mapping, there is no better medium than the aerial photograph.

Oblique photographs are taken with cameras (often hand held) pointed down at an angle such that the longitudinal axis of the camera forms an angle of less than 90° with the ground. They are classified as (1) *high oblique*, which show the horizon, and (2) *low oblique*, which do not show the horizon. The high oblique shows a large area of the terrain in panorama, whereas the low oblique shows only a small area of the ground. Although obliques serve many purposes and are useful in reconnaissance surveys as an aid to the identification of boundaries, they are not readily converted to maps and are not so satisfactory for soil mapping as vertical pictures.

Vertical photographs are taken with fixed-level cameras pointed straight down from the aircraft so that the longitudinal axis of the camera is perpendicular to the horizontal plane of the ground. Three broadly defined types are (1) the continuous-strip photograph, (2) the multiple-lens, and (3) the single-lens.

The strip photograph is a continuous-strip exposure. Strip photographs may be taken from low altitudes at high speeds by synchronizing film motion with the ground speed of the aircraft. In this way good pictures can be taken with poor light. Strip photographs so taken have little use in soil mapping because of their large scale and small coverage.

Multiple-lens photographs combine vertical and oblique camera angles. The cameras usually have three, five, or nine lenses. One lens takes a vertical view, and the others obliques. With a transforming printer, the obliques are transformed to the plane of the vertical picture to produce a composite vertical photograph composed of the center vertical picture and the transformed obliques. The multiple-lens camera is widely used where rapid and economical coverage of large areas at small scale is needed. Although the pictures are occasionally used in soil mapping, they are not recommended if single-lens pictures are available. The usually small scale, necessity for transforming prints, and difficulties of map construction make them less satisfactory than single-lens pictures. Multiple-lens photographs are also obtained through the use of multiple cameras, arranged and mounted to make vertical and oblique exposures. The tri-metrogon photograph is an example.

Single-lens photographs, which are taken in a series of independent overlapping exposures, are recommended for soil mapping. They have convenient size for field use and map construction, permit stereoscopic study, give excellent detail of ground features and also have satisfactory ranges of scale.

In discussing the use of aerial photographs in this *Manual*, single-lens vertical aerial photographs, made to the specifications of the Department of Agriculture, are assumed unless otherwise stated. Where it is necessary to use other types of photographs or single-lens photographs of lower standards, the Cartographic Section of the Division of Soil Survey will advise the soil scientists about methods to use and their specific weaknesses. Excessive tilt, insufficient overlap, and other deficiencies may make it impossible to use the pictures stereoscopically or to construct accurate maps from them.

Flight lines and overlap.—Most aerial photography in this country is flown north and south. Flight lines are as near straight and parallel as possible; they should not deviate from the true direction by more than 5 degrees. Flight lines are usually continuous across the area, with the first and last photograph on each flight line falling entirely outside the area boundary.

In line of flight, consecutive photographs should overlap an average of 60 percent, with no overlap less than 55 percent nor more than 65 percent. Overlap in line of flight is referred to as *endlap*. The overlap between adjacent flight lines, or *sidelap*, should average 30 percent, with none less than 15 percent nor more than 45 percent. (See figure 6.)

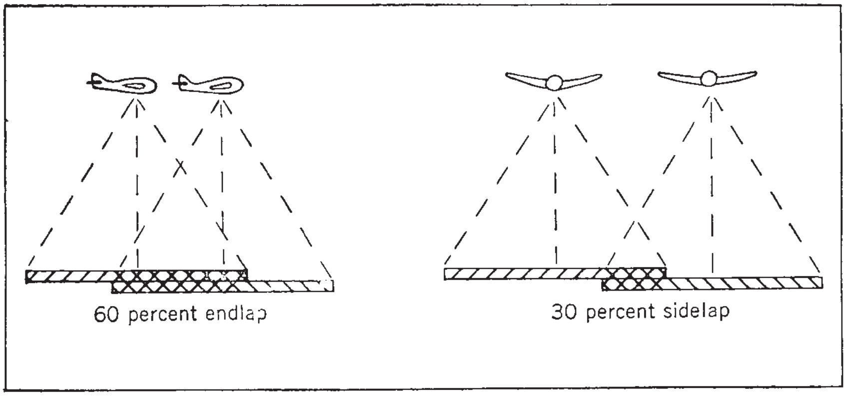

FIGURE 6.—Diagrams showing overlap in single-lens photographs.

Adequate overlap is essential for stereoscopic study in the field and for the photogrammetric processes used in map construction. Where alternate photographs—every other photograph in line of flight—are used, the overlap of standard pictures averages only 20 percent.

Full stereoscopic coverage should be obtained for soil mapping, even though the soil boundaries are plotted only on alternate photographs.

Scale.—The scale of aerial photographs is not always accurate nor uniform like that of a good map. The scale varies between photographs because of varying altitudes of the aircraft, differences in ground elevations, or tilt of the camera. The sketch in figure 7 shows that a photograph taken at camera station *A* will not be the same scale as a photograph taken at station *B* because the aircraft is at different altitudes at the times of exposures. Thus, the 20-acre field *C* will not measure the same as the 20-acre field *D* because of the elevation differences within the photograph.

The scale given for photographs is the approximate average scale computed from the mean altitude of the entire area flown, from that of a

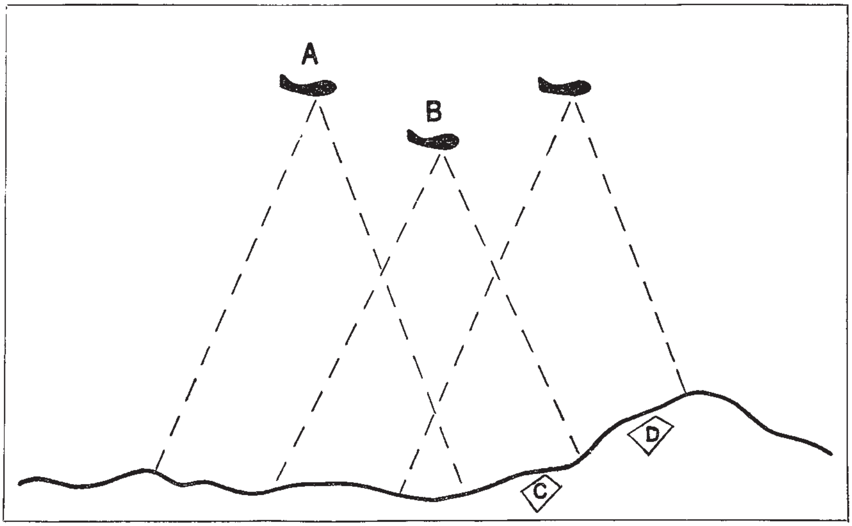

FIGURE 7.—Sketch showing differences in scale at various heights. A photograph taken at station *A* will have a different scale from one taken at station *B*. Patterns of the two 20-acre fields at *D* and *C* have different dimensions on the photographs.

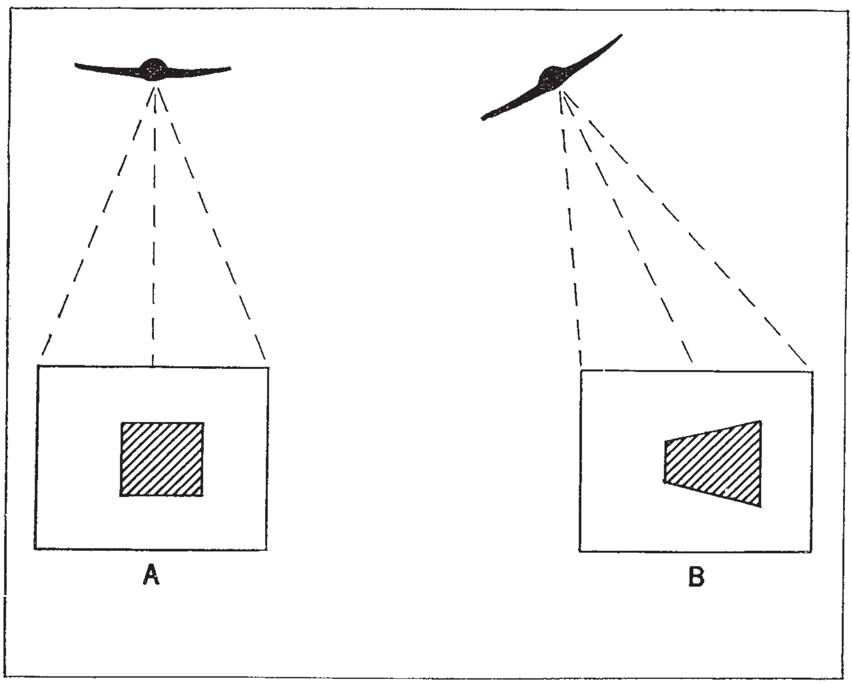

FIGURE 8.—Sketches showing distortion of a square in an aerial photograph because of tilt: *A*, normal; *B*, with tilt.

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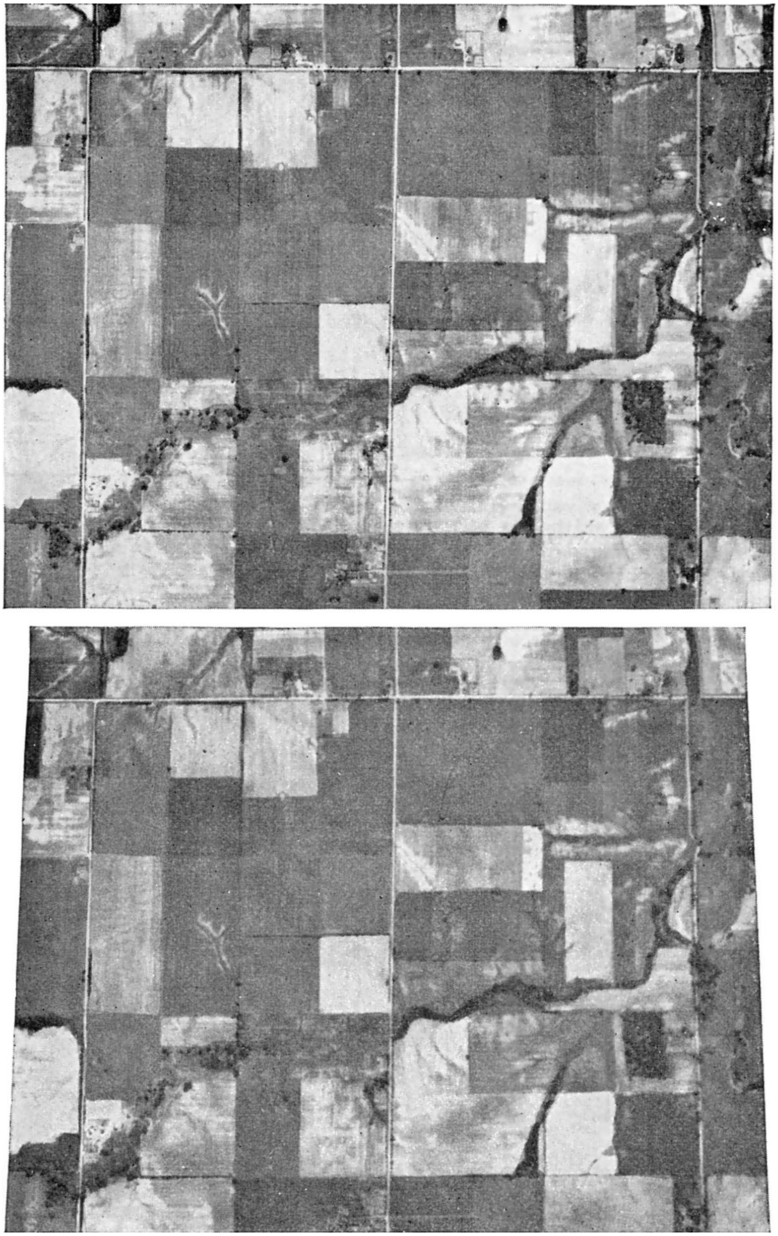

FIGURE 9.—Air photographs for the same area: Upper, normal; lower, with tilt.

fraction of the area, or from a specified datum plane. Photographs flown for the United States Department of Agriculture do not deviate more than 5 percent from the average scale. Most of this aerial photography has a scale of 1:20,000 (3.168 inches to 1 mile) from which satisfactory enlargements or reductions can be made.

Tilt.—When the plane of the camera is not level the resulting photograph is tilted. The greater the tilt, the more the objects in the photograph are distorted in shape and size. Figure 8 illustrates such distortions in the shape and scale of a square field. Figure 9 shows aerial photos for the same area, normal and with tilt. Excessive tilt may sometimes be detected by comparing images in overlapping photographs. In standard photography used by the United States Department of Agriculture tilt does not exceed 5°, nor average more than 2° in a 10-mile flight line, nor average more than 1° for an entire area.

Crab and drift.—To maintain a true flight line in the presence of side or quartering winds, it is frequently necessary that the photographic aircraft fly at an angle to the flight line. The camera is rotated to compensate for the angle of flight. Failure to do so results in *crabbed* photographs as illustrated in figure 10,*A*. *Drift*, a special form of crab, results when exposures oriented to the flight line continue to be made even though the aircraft has drifted from the flight line. Edges of successive photos are parallel but side-stepped, as sketched in figure 10,*B*. Standard specifications do not permit crab to exceed 10° from the true flight line in any two or more pictures.

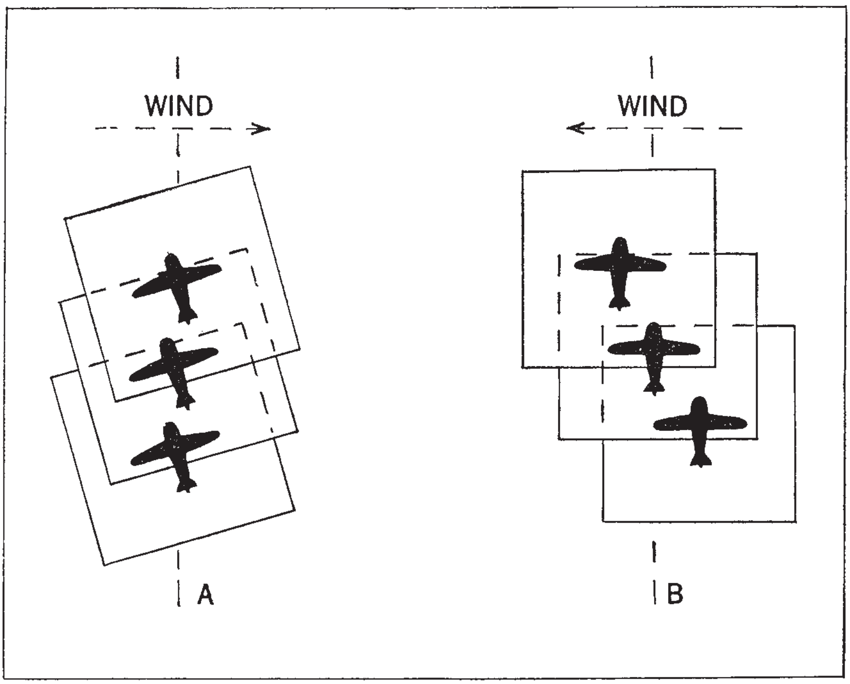

FIGURE 10.—Sketches showing irregularities in aerial photographs: *A*, from crabbing; *B*, from drift.

Displacement.—If a vertical photograph is in a plane parallel with a section of flat ground, the relationships between images in the photograph and objects on the ground are similar. If the ground objects are not all in the same horizontal plane, however, the photographs do not present objects in correct relationship to one another. This difference is called *displacement*, illustrated in figure 11. It can be seen that displacement is inward, toward the center of the photograph, for objects below the datum plane; and outward, from the center, for those above the datum plane. An object appearing at the center of an untilted photograph is not displaced, regardless of relief. Displacement and tilt are so interrelated that the layman finds it is impossible to differentiate between them. The vertical datum plane is considered only when heights of objects or differences in elevation are to be measured, as in the construction of a topographic map.

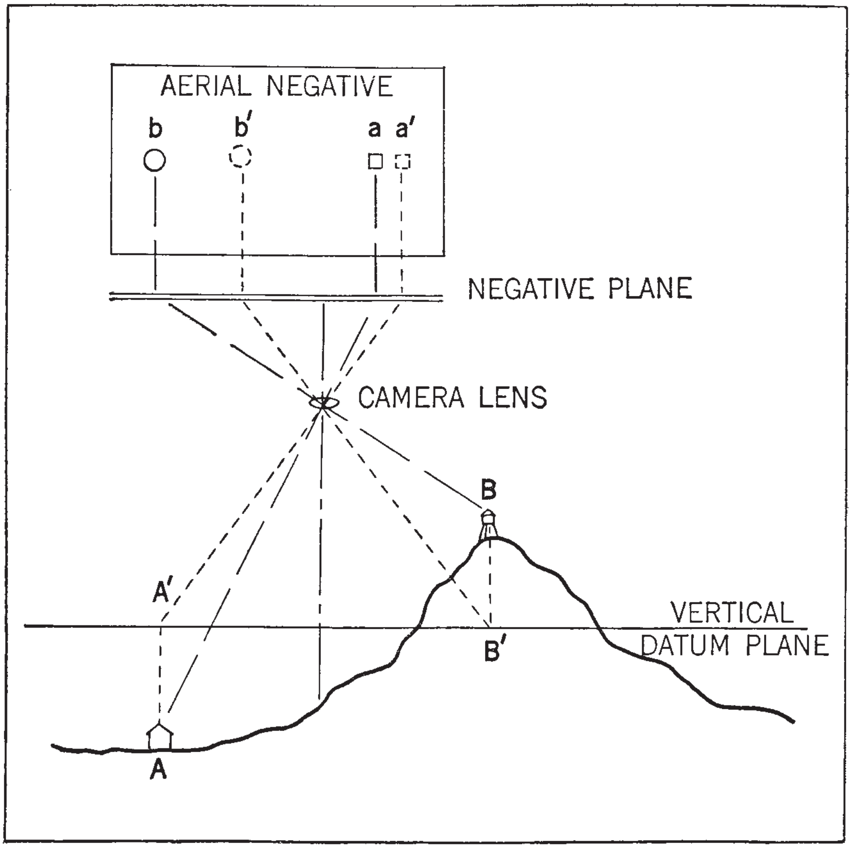

FIGURE 11.—Sketch illustrating displacement in aerial photographs. Note building *A* in the valley and watertower *B* on the hill. A vertical line through the building intersects the datum plane at *A'*. Since the building is below the datum plane, it will appear at point *a* on the aerial negative rather than at its true ground position *a'*. Similarly, the watertower, above the datum plane, will appear at *b* rather than at its true position *b'*.

Inherent errors.—Inherent errors arise from the physical limitations of materials and instruments used in taking and preparing aerial photographs and are more or less common to all photographic processing. They result from improper grinding or other imperfections in lenses, curvature of the lens field, inefficient shutters, and expansion and contraction of photographic film and papers. These errors are reduced to the minimum in modern aerial photography where only precision mapping cameras, excellent laboratory equipment, and special aero film and paper are used.

Code numbers.—Aerial photographs are marked when taken and processed to permit indexing and rapid selection. Although organizations indicate different information in various ways on their aerial photographs, the following are usually shown: (1) Date of flight, (2) time of day, (3) owner of film, (4) scale of negative, (5) project or area, (6) film roll number, and (7) exposure number. Some also show altitude, focal length of camera, type of camera, and the like.

Each aerial photograph made for the United States Department of Agriculture bears a code letter designating the project or area and individual numbers to designate the roll of film and exposure. These are in the northeast corner for north-south flights and in the northwest corner for east-west flights. The code number for the area is limited to three letters; the roll of film is indicated by number, beginning with one and continuing unbroken; and numbers indicate the exposures, beginning with one for each roll of film and continuing unbroken. For example, in the designation ABC–46–122, ABC indicates the county or area, 46 the roll of film in that county or area, and 122 the exposure in that roll. In the adjacent corner are numbers for the month, day, and year the exposure was made. On the first and last exposure in each roll of film appears the abbreviation for the organization owning the film, the approximate scale of the negatives, and the time of day the exposures were made. The organization abbreviation and approximate scale precede the usual area symbol, as BPI–1:20,000–ABC–46–122. In the adjacent corner, immediately following the date, the time of day is placed, as 6–15–48—11:30.

Photo indexes.—Aerial photographic indexes are prepared for large areas. Without an index the user of photographs is seriously handicapped in selecting the photograph for a specific area or in locating adjacent photographs in adjoining flights. Photo indexes are prepared by laying the overlapping photographs so that the index numbers of each print are visible. Standard specifications usually require the index to be in sheets 20 by 24 inches at an approximate scale of 1:63,360. The soil survey party should have the photo index of the area to expedite the location of individual photographs.

Stereoscopic vision

Although individual aerial photographs are flat in appearance, overlapping pairs can be viewed under a stereoscope and the topography of the ground becomes apparent: hills and valleys appear, buildings and trees stand up, and the slight depressions of drainage can be seen. Thus viewed, the aerial photograph looks like a detailed relief model. The soil scientist can study the ground before going into the field. Drainage and trails that are obscure on the flat photographs can be outlined in advance. Travel routes can be selected. Stereoscopic study of the pictures, both before and after the mapping, helps him to see the relations between kinds of soil and land forms.

Theory of stereovision.—In normal vision, the observer sees objects in three dimensions, namely length, width, and depth. The ability to see depth depends on sight with two eyes, each at an equal distance from the object but viewing it from a different position, or angle. Each eye registers a slightly different image. These images are fused or combined by the optic nerves and brain to give depth perception or a third dimensional view of the object. The distance between the eyes is so short that the angle and difference becomes so small at great distances that it is difficult to register depth perception.

When viewing two overlapping aerial photographs under the stereoscope, one sees the same ground area from widely separated positions. The right eye is viewing the area in one photograph, the left eye the same area in another photograph. The effect is the same as if a person were viewing the area with one eye located at one camera position and the other eye at the next camera position. The brain so fuses the images that one sees the relief in the photograph, or the third dimension.

The average person with normal vision should have little difficulty with stereoscopic study of aerial photographs. Occasionally a person with apparently normal vision is unable to use the stereoscope. This may be expected of older persons whose eye muscles are not flexible. Some feel eyestrain when first using the stereoscope.

Stereoscopic vision requires some practice. At first it may be difficult to adjust the photographs and fuse the images; yet after practice this can be done rapidly with little or no eyestrain.

Types of stereoscopes.—Stereoscopes are constructed on two basic principles. Those most commonly used in the study of aerial photographs are (1) the mirror type, which utilizes the principle of reflection, and (2) the lens type, which makes use of the principle of refraction. A third type, less commonly used, is the prism stereoscope. In this type prisms serve as reflectors, much as mirrors do in the mirror stereoscope. Designs of all types vary widely.

The mirror stereoscope has four mirrors fastened in a frame and arranged to transmit the photographic image to the eye by reflection (fig. 12). Since these stereoscopes are usually large and bulky, they are not easily portable and are used mainly for office work where plenty of table space is available. Some mirror stereoscopes are designed to fold up and fit in a small case that can be carried in a large pocket. Even these are too bulky to carry in the field while mapping.

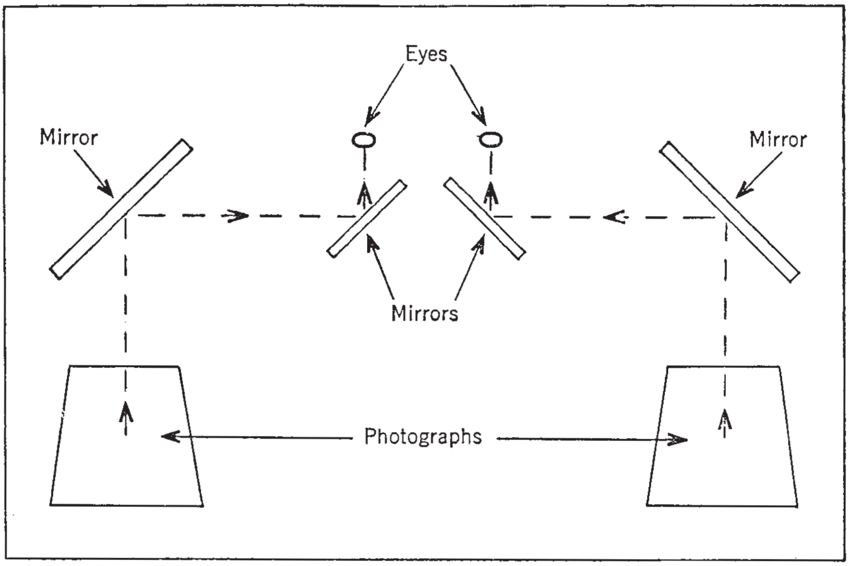

FIGURE 12.—Sketch showing the essentials of the design of a mirror stereoscope.

The mirror stereoscope gives an image nearly free of distortion. It has a wide field of vision—wide enough for one to view an entire photograph. The wide separation of the mirrors allows the photographs to be viewed without overlapping, which makes adjustment and fusion of the picture simple. Many instruments have a horizontal adjustment of the outer mirrors which allows them to be placed at various distances from the eyepiece. With this adjustment, larger scale photographs can be viewed than with the conventional lens-type stereoscope. Owing to the great optical distance between the eye and the photograph, the fused image appears to be reduced.

This is a disadvantage in studying fine detail, especially on small scale photographs. The disadvantage may be overcome by fitting the stereoscope with magnifying lens, but this increases the size and cost of the instrument.

The mirror stereoscope is especially good for the office study of aerial photographs. It is simple for the beginner to use and requires little practice.

Lens stereoscopes have two magnifying lenses mounted in a frame and supported on a stand so that the photographs are viewed directly through the lenses, or eyepieces. The lenses are ground so that the lines of sight are bent outward (fig. 13). These instruments are usually small, compact, and light. Many are designed for field use and fold into a small unit that can be carried easily by the soil mapper in the field. Most use, however, is in the field headquarters.

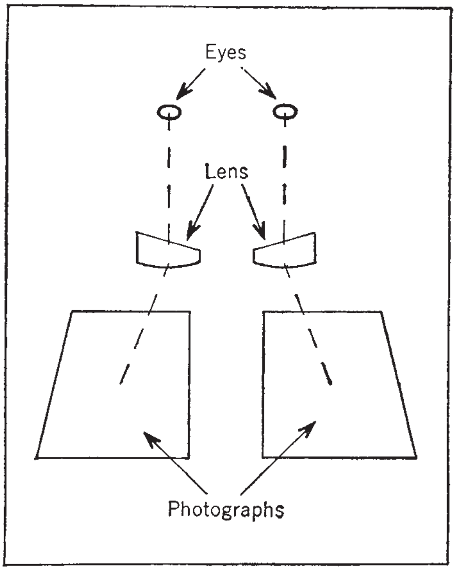

FIGURE 13.—Sketch showing the essentials of the design of a lens stereoscope. The thin edges of the lenses are inside.

The lens stereoscope gives a distorted image. It has a small field of vision, and only part of the photograph can be viewed at one time. The close spacing of the lenses, combined with direct vision, makes it necessary to place the photographs very close together or even to overlap them. Thus adjustment of the photographs and fusion of the images are somewhat difficult. For the same reason, large-scale photographs cannot be viewed satisfactorily except at the margins. Despite these disadvantages, the lens stereoscope is a useful tool for the soil scientist.

The lens stereoscope magnifies, which is a definite advantage, especially when studying minute detail or very small-scale aerial photographs. It emphasizes the relief, which is helpful in viewing nearly flat terrain.

The lens stereoscope is helpful for the field study of aerial photographs where the scale is small enough to permit its ready use. Appropriate models are light, compact, and relatively cheap.

Care of stereoscopes.—Stereoscopes are generally of rugged construction and will withstand a reasonable amount of hard use; but they are optical instruments and should be treated accordingly. "First-surface" mirrors are used in stereoscopes. In these the silver is applied to the front of the glass and not to the back. The silver coating is highly susceptible to scratching and corrosion and should not be touched. All first-surface mirrors should be protected with a soft cloth or chamois covering when not in use.

A first-surface mirror may be cleaned with soft clean cotton and alcohol. The cotton needs to be free from any grit that might scratch the silvered surface. The silvered surface is wiped gently with just enough pressure to remove the dirt. Fingerprints should be cleaned off immediately, since their residues corrode the mirror.

The lens type of stereoscope should be cleaned and cared for like a pair of glasses. Stereoscopic lenses are usually ground with one side thinner than the other in order to reflect the light rays outward. Such lens must be placed in the frame with the thick edge outward and the thin edge inward.

Use of the stereoscope.—To use the stereoscope in studying aerial photographs one must first acquire the knack of adjusting the photographs and accustoming the eyes to stereoscopic vision. This ability may be acquired in different ways.

One of the simplest methods is to place a small cross on two separate sheets of paper. With each sheet of paper under the lens, or mirror, of the stereoscope, one may look directly through the eyepieces of the stereoscope and focus the eyes on the crosses. Unless the crosses by chance are fused, one sees two crosses. After the eyes are focussed, one sheet is held firmly and the other moved slowly. The crosses move either nearer or farther from each other. The sheets are slowly shifted until the two crosses coincide and appear as one. During the operation, the eyes are not shifted nor the focus changed.

Once the crosses coincide, the sheet is moved until the image separates into two crosses again; then again the sheets are shifted until the crosses appear as one image. This practice is continued until "fusing" can be done rapidly. When the crosses are fused, the approximate location of the sheets with reference to the lens or mirrors is noted. The sheets are removed and then replaced to try focussing the eyes and fusing the crosses rapidly. When the operation can be performed quickly and accurately, one is ready to attempt stereoscopic vision with two aerial photographs.

To start, one may select two stereo-pairs of terrain with moderate relief and a distinct pattern of ground features. The photographs should be of equal tone and scale. The center of the photograph—its optical center—is located at the intersection of lines drawn between collimation marks, usually appearing as small ticks at the center of each margin, and marked with a cross. The picture centers are transferred to the overlap area in each adjoining picture, and the two crosses on each picture connected with a line. The photographs are placed under the stereoscope with the overlapping detail approximately in coincidence and the lines on the photographs parallel to the eye base. The shadows should fall toward the observer and both photographs need to be well and uniformly illuminated.

The photographs are shifted horizontally and adjusted until the crosses and connecting lines are fused. Then the relief can be seen. One of the photographs should be shifted until fusion is lost, and later recovered. With practice, images may be fused rapidly. As skill develops, the observer fuses the images by observing the physical features and less by watching the crosses and connecting lines.

After skill in these exercises has been obtained, it is time to try two photographs without the centers marked and connected. Two such pictures are placed under the stereoscope with the index finger of each hand just under the same selected physical feature in the overlap area on each photograph. The eyes are focussed and the pictures shifted until the fingers approximately coincide. The fingers are moved away and the images slightly separated. Then they are adjusted until they again coincide. This practice needs to be continued with other stereo-pairs. Once the knack of placing the photographs and adjusting them until they fuse has been acquired, the operator is ready to use the stereoscope in the study of aerial photographs.

Lenses need to be focussed properly. Many stereoscopes have an adjustment for varying the spacing of the eyepieces, so that they can be separated to the correct interpupillary distance of the observer's eyes.

Generally, on aerial photographs man-made features appear in geometric patterns—with straight lines, sharp angles, and circles.

Natural features, generally, have irregular and curved lines, as in twisting streams, curving shore lines, and the like.

For interpretation of size one needs to know the approximate scale of the photograph. A round image may represent a silo on a large-scale print, and one of the same size, a large gas storage tank on a small-scale print. Size is sensed by comparison among the ground objects.

The tone, or shade, in which various features appear on an aerial photograph is due mainly to the amount of reflected light. The amount of reflected light depends upon the texture of the surface of the object and the angle at which the light is reflected. An object that reflects a large amount of light appears in a light tone on the photograph. If little light is reflected, the object appears dark.

Because of differences in the angle of reflected light, the tone of an object may be different on two consecutive photographs, especially if the surface is smooth and a good reflector of light. Thus, in one photograph, with the light rays reflected from the water to the camera, a water area appears light; in an adjoining photograph, with the angle of reflection away from the camera, the same body of water appears dark. Most natural features, however, reflect light in all directions and appear in intermediate tones, for some of the reflected light finds its way to the camera lens.

For stereoscopic study, the light should be good and each photograph should be equally illuminated, but without glare. Where possible, the observer should face the source of the light. Of course, these lighting conditions cannot always be arranged in the field.

The photographs are placed under the stereoscope in such a way that the one taken to the left of the overlap area is viewed by the left eye, and the one to the right of the overlap by the right eye. If the position of the photographs is reversed, and the left eye views the right photo and the right the left, the image of relief appears in reverse. In such an arrangement, points of low elevation appear high, and points of high elevation low. This is commonly called a pseudoscopic image.

Photographic characteristics.—Certain characteristics of aerial photographs are the basis of stereoscopic interpretation. The most important ones are the shape and size of features, the tone in which the features appear on the photographs, and the shadows cast by the features.

The shape of features is important in the interpretation of ground detail from aerial photographs. The observer needs to study the shape of ground objects as they appear on the vertical photographs in comparison with how the same features look on the ground. Frequently the tone of objects appears darker or lighter in photographs than their contrasting ground colors would suggest.

Shadows on aerial photographs often reveal the size, shape, and identity of objects. The shadows suggest the heights of objects, which are not revealed by the horizontal dimensions alone. A one-story building, for example, may look like a five-story one in the picture except for the shadow. But shadows can be deceptive. If the ground under the object slopes abruptly, the shadow may be distorted. The height of the sun at the time of exposure also affects the length of the shadow. Yet many objects with little width, like fences, flagpoles, and chimneys, are difficult to identify except by their shadows.

Interpretation.—Most field scientists become proficient in photo interpretation by using the photographs in the field where opportunities are continually offered to compare ground features with their photographic images.

Study of the photographs of the area to be covered a day or so in advance can be helpful. The accuracy of interpretations is checked by observations of the ground detail. Images that are unidentifiable in the office can be identified in the field. With such practice, the soil scientist can rapidly train himself in aerial interpretation. It must always be recalled, however, that accurate photo interpretation depends on familiarity with ground conditions. Ability to interpret pictures accurately in one area is not necessarily followed by similar accuracy in another area with different conditions.

The time of day and season of the year in which photographs are taken influence interpretation. In order to have good light, most photography is taken under ideal weather conditions and during the middle part of the day. The length of shadows naturally depends upon the height of the sun. Shadows on photographs taken in summer are shorter than those on photographs taken in winter. Similarly, shadows appear much longer on photographs taken a few hours before or after noon than on those taken at noon.

Features appear differently on aerial photographs in the different seasons. Cultivated fields vary from season to season. In wet seasons, streams appear large and many small ponds may be visible. In the dry season, the same area may have no ponds and the streams may be dry beds. During summer, deciduous forests present a mass of treetops that obscure the ground detail. In winter, pictures of the same area show a confusion of tree trunks, emphasized by shadows, and trails, small drains, and other ground detail are clear. Snow on the ground obscures much of the detail. The experienced photo interpreter takes all of these factors into consideration when studying the photographs.

A few of the characteristics of some major features as they appear in aerial photographs may be helpful in acquiring skill in photo interpretation. With experience, the soil scientist can broaden his information.

Streams.—Streams are usually identified by their irregular widths and winding courses, frequently emphasized by the growth of brush and trees along the banks. In heavily wooded areas, small streams are difficult to detect. Water in stream beds is suggested by dark or light lines, depending on the angle of the reflected light. Dry stream beds are easily recognized in the open and usually appear in light tones.

Bodies of water.—Ponds and lakes appear lighter or darker than the adjoining shore, depending on the reflected light. Furthermore, they are flat. The shore lines are sharply defined and appear as irregular outlines. One end of a large lake in a photograph may appear light and the other end dark.

Marshes.—Swamps and marshes have a blurred appearance. Many display very winding channels, or small bodies of open water. Very wet areas or those partially covered with water usually appear darker than the surrounding ground.

Forests and brush.—Wooded areas appear as dark masses with irregular outlines. The intensity of tone for deciduous cover varies with the season. In summer the tone is very dark; in winter it is lighter. Coniferous forests appear dark in tone, regardless of the season. Brush areas have a dark tone in summer and a lighter one in winter, but shadows are lacking. Stereoscopic inspection suggests the height.

Cultivated areas.—Cultivated fields are readily identified by their contrasting tones and their boundaries. Many field edges are well defined by fences, hedges, trails, or roads. Terraces, contour strips, and other patterns show clearly.

Some crops can be identified by planting patterns and tone or shade. Fields with heavy standing crops or grass appear dark. Fields from which crops have been harvested recently appear lighter. During harvest of crops such as hay, wheat, and corn, fields acquire a distinctive pattern. Shocks appear as dark-colored, regularly spaced dots against a lighter background. Because of the rough surface and damp soil, freshly plowed fields are usually very dark. The pattern of plowing is frequently visible on the photograph. Orchards, vineyards, and similar plantings are readily identified by their distinctive spacing.

Roads, trails, and paths.—Roads usually appear as light lines. Cement concrete roads have well-defined edges and appear light except for streaks of oil drop in the center of each lane. Bituminous concrete or other black-surfaced roads may seem dark. Most improved roads are identified by long straight stretches, gentle curves, and regular width. Unimproved roads are more irregular, have sharper curves, and vary in width.

Trails meander and often follow the contour. Paths are even more indistinct and irregular. If used a great deal, paths and trails appear as light streaks.

The appearance of roads, trails, and paths changes with the season because of shadows cast by trees and partial covering by overhanging vegetation.

Railroads.—Railroads appear much like roads on the photographs but are usually darker and narrower. They have long straight stretches and smoother curves than roads. The roadbed material affects the tone appearance of the railroad. Large cuts and fills, water tanks, spur lines, and stations are distinct along the right-of-way.

Buildings.—Buildings are readily identified on aerial photographs. Their size is suggested by their relation to the scale of the photograph; and comparative heights can be estimated from the shadows. Isolated buildings often have roads or trails leading to them. Individual buildings in groups may be indistinct because of the collective shadows.

Land form.—With practice, land form may be suggested from the photographs. In fact, land forms may be clearer in aerial photographs than on any map or from the ground. As a start, the soil scientist may consult some of the standard texts on this subject.[1]

USING THE AERIAL PHOTOGRAPH

Techniques of using aerial photographs in soil mapping differ from those of using maps because measurements of courses and distances are less precise. Even though the vertical aerial photograph looks like a map, it is not an accurate plan of the ground surface.

Stereoscopic interpretation and delineation.—To begin with, the soil survey party should study the photographs of the survey area. Each mapper needs to be familiar with the film-roll and picture numbers, the sequence of flight lines, and direction of flights. Study of the photo index will also serve to give a view of the whole area and of the conditions to be met during the survey. Such study can be helped by laying out photographs for parts of the area on a table top as a sort of rough unassembled mosaic.

Once the survey is under way, it is helpful to study the photographs with the stereoscope before going into the field. Preliminary interpretations of features can be made and the scientist can familiarize himself with the ground conditions.

It is frequently helpful to delineate in advance certain ground features. Drainage can be accurately plotted on the photograph. The plotting of drainage features in heavily wooded areas is especially helpful to field orientation. Trails and obscure paths can be marked for reference. Possible places where streams may be crossed and routes through rough terrain can be tentatively selected. Buildings that might otherwise be overlooked can be marked for checking in the field. Such features as gullies, areas of eroded soil, pasture or idle land, and forests can be tentatively outlined and the time of scientists in the field thereby conserved. Delineations should be made in pencil, to be inked after confirmation in the field. Rivers, lakes, and other prominent water fea-

[1] See, for example, SMITH, H. T. U. AERIAL PHOTOGRAPHS AND THEIR APPLICATIONS. 372 pp., illus. New York. 1943.

tures can usually be inked in advance. Clearly defined stream courses can be inked as dashed lines, and after field inspection the dashes can be closed, or dots inserted, to indicate either perennial or intermittent streams.

Match lines and matching.—A *match line* is an arbitrary line drawn in the overlap area of a photograph to serve as a boundary for the mapping on the photograph and is to be matched by a similar boundary drawn through identical points on the adjoining photograph.

When stereoscopic pairs of photographs are used in mapping soils, the match lines should be placed to limit the plotting of data to the central parts of the pictures where distortion is least. If alternate photographs are used, match lines must be placed near the outer limits of the photographs in the narrow margin of overlap. Necessarily, a match line so placed includes the least accurate outer edge of the photograph. Thus using alternate pictures may increase the difficulty of plotting soil boundaries accurately, of matching soil boundaries from one sheet to another, and of transferring soil data to the base map, and decrease the accuracy of area measurements.

Match lines can be placed on photographs either with or without the stereoscope. In the stereoscopic method, a line is placed approximately midway in the overlap area of a photograph. This photograph and its adjoining mate are placed under the stereoscope, the images fused, and the match line transferred to the adjoining picture. This process is continued through the line of flight and between adjoining flights.

In placing a match line without the stereoscope, two distinguishable features are selected along the outer edge of the area to be mapped on the photograph and connected by a straight line. The same features are identified on the adjoining photograph and connected. The process is continued throughout the area.

If it is helpful in soil mapping, the match lines may follow some prominent ground feature, like a road, railroad, or river, even though it is irregular or curving. In sectionized areas, match lines may coincide with the land lines.

The colors of match lines should contrast with those of other lines. Green ink is frequently used for match lines.

Although the placing of match lines requires time, they are a necessity for good mapping. They avoid mapping of duplicate areas on adjoining photographs, facilitate the transfer of soil boundaries from one photo to another, and simplify the cartographic transfer of soil data from the aerial photograph to the base map.

Soil boundaries and other mapping should be broken sharply and precisely at the match line when inked. Soil symbols should be kept within the match line if possible.

The matching of the mapping on one photograph with that on another can be done in several ways. The mapped photograph and an adjoining unmapped photograph can be placed under the stereoscope and the images fused. The mapping along the match line of the completed photograph can then be transferred stereoscopically to the adjoining unmapped photograph, although this is not good practice. It is better to join sheets *after* mapping as a check on the uniformity of the work being done by individual members of a soil survey party.

If adjoining photographs are at the same scale, a strip of transparent paper or plastic can be placed along the match line of a mapped photograph. The marginal mapping is marked on the transparent strip. This strip is then placed along the match line of another mapped photo for checking or of an unmapped photo for transfer of the soil boundaries to the match line.

Another method, which is particularly useful when adjoining photographs vary in scale, is to transfer boundaries by reference to photographic images. Along the match line one observes the relationship of the soil boundaries to such features as isolated trees, clumps of bushes, field corners, and the like. The same features are located along the match line of the adjoining photograph and the boundaries checked or transferred to their same position of relationship to that feature. Difficulty is had if distinguishable ground objects are few.

One could scarcely overemphasize the need for care in matching the mapping on one photograph with that on others, both for joining of lines and for checking of the classification. Roads and streams need to be continuous from one photo to another. Special care is needed at the corners where four photographs come together. Without a systematic method, it is easy to make errors that will make later interpretations of the mapping difficult or doubtful.

A record should be maintained of the matching of adjoining photographs. This is especially useful where a number of soil scientists are working in the survey area. A transparent overlay over the photo index makes a good means of keeping such a record. As the photographs are matched, the overlay can be marked. Some place the letters N, S, E, and W on each sheet and cross them out as the sheet is joined on the north, south, east, and west.

Inking on the photograph.—After completing the survey on a photograph in pencil, with boundaries matched to previously completed and adjoining photographs, the field sheet should be inked. For clarity and checking, it is helpful to ink the three major classes of features in contrasting colors that have good photographic qualities. For example, roads, railroads, buildings, and other cultural features may be in red, drainage features in blue-black, soil boundaries and symbols in black, and section lines and numbers in red or green to avoid confusion with roads.

Each group of features can be inked in a separate operation. Culture can be inked first in red, for example, and the classification of roads and other features checked. Drainage can then be inked in a blue-black and inspected to see that individual drains are properly joined, matched, and classified. Soil boundaries can be later inked in black. When inking the soil boundaries, it is best to close each individual area as one proceeds, or to ink the soil boundaries up to some specific line, like a road or field boundary. As a soil area is closed, the symbol should be placed as near the center as practicable. If the soil area is long or irregular, additional symbols should be added for easy reading of the mapping, but no more. Soil symbols should be placed to be read from the same direction throughout the survey and should be approximately parallel. Where soil areas are so small that the symbol must be placed outside the area, it must carry a pointer to the area to which it applies. Place names are usually the last to be inked. These can be in black or in the same color as the feature to which they apply. By leaving them to the last, they can be placed where they will not obscure soil symbols and other detail. Place names need to be arranged in ways that leave no question about which features they designate. Names of railroads, rivers, and other features that continue across a number of photos need not be repeated on each one—only enough for clarity. Care should be used in the placing of stream names so that no confusion arises as to which branch of a stream a name applies.

The inking of the major features on a soil map separately, and in contrasting colors, permits the checking of each group of features individually. This usually results in fewer mistakes. The colors also facilitate the interpretation of the original field sheet by other users. If all plotted data are inked in one color, the field sheets appear congested and it is harder to check and to interpret them.

Inking on overlays.—Inking on overlays is done in the same way as inking on photographs. Opaque inks should be used, as overlays are frequently reproduced by direct printing methods. If standard waterproof drawing inks are used on plastic overlays, they should be coated lightly with a plastic spray to seal in the ink and prevent chipping.

Orientation of the aerial photograph.—One of the advantages of the aerial photograph is the rapidity with which it may be oriented in relation to the local detail and the unusual ease with which the soil scientist can locate his position on the photograph. Normally in field use, the photograph is oriented by locating features on the ground having images readily identifiable on the photograph.

In relatively flat areas with scanty detail, orientation is more difficult. In some places it is helpful to mount the photograph on a plane table set up over an identifiable point. The photograph may be oriented toward a second identifiable point with the plane table oriented by its compass. Then short traverses may be run in the area. Since variations of scale within the photograph make some difficulty, it is necessary to tie the traverse to all identifiable landmarks along the route. Long unbroken lines of traverse are rarely necessary. Nearby rather than distant features should be used for orientation because of scale variations within the photograph.

Heavily wooded areas present problems in both orientation and location. These can sometimes be overcome by running short traverses into the wooded area from the identifiable features on the outskirts of the area. Stereoscopic delineation of drainage features on the aerial photograph before going into the field often helps a great deal, and stereoscopic study of the relief while in the field contributes to orientation and location in wooded areas, especially in hilly districts.

Sometimes it is necessary to carry the orientation forward from one photograph to another. This is done by overlapping the photographs. The photo centers are first marked by drawing intersecting lines from the tick marks on the sides of the photographs and transferring the center of the rear photograph to the forward photograph and that of the forward photo to the rear one. The photographs may then be laid over each other so that the centers are superimposed in the overlap area. With a compass, a magnetic north line may be placed on a photograph that has been properly oriented by identifiable features. Then the north line is transferred to adjacent overlapping photographs either by association of identifiable features or stereoscopically, and the second photograph is oriented by using the compass.

The aerial photograph may be oriented with respect to true or magnetic north when it is used with a detailed map of the area. Two matching and identifiable points should be selected on both the photograph and the map, preferably along a line near the center of the photograph. The compass bearing of the line through the points on the map can be measured with a protractor and the photograph oriented accordingly. When the orientation is made with a compass, the points selected should be easily identifiable on the ground. Unless the land is too heavily wooded, a plane table with compass is better than a hand compass.

Shadows on the aerial photographs serve to give rough compass orientation provided one knows the time of the year and day at which the photograph was taken.

Plotting soil boundaries.—Plotting of soil boundaries is largely a matter of keeping oneself properly located with relation to the detail of the photograph and drawing the soil boundaries in relation to the identifiable images on both the photograph and the ground. Keeping himself accurately located on the picture is the first requirement of the soil mapper. Soil boundaries are plotted in relationship to easily identified landmarks, such as field boundaries, streams, buildings, edges of forests, isolated trees, roads, and similar features. With abundant detail, compass orientation and measurement of distances are not necessary and the soil scientist is not tied to a traverse. He is free to move about and examine the soil types as necessary. As measurements are not necessary, the difference in scale within the photograph or between photographs are of little or no significance.

New features that need to be mapped and that have been established since the photos were taken should be located by survey *resecting*: intersecting lines, as nearly as possible at right angles to each other, from identifiable positions, locate a new position. Measured distances from identifiable features will give the location of such features. Usually the intersection of two measured distances will be accurate enough for this purpose.[2]

When one has become thoroughly familiar with the soils of the area and their relationships to the features of the landscape, many soil boundaries may be visible on the photographs. These boundaries can be plotted on the photographs and verified as the survey progresses.

On photographs of heavily wooded areas or others with few identifiable features, it may be necessary to measure directions and distances in order to plot the soil boundaries accurately. This is best accomplished by using the photograph on the plane table. If the photograph is oriented by the compass and its scale is known, measurements of directions and distances are largely a matter of correcting for distortion. Every attempt should be made to tie to identifiable images as often as possible and to use the local scale for that portion of the photograph when measuring distances.

Corrections.—Corrections on aerial photographs need to be made carefully. If the photographic emulsion is broken or scratched, ink will run and smear so that symbols and lines will not be legible. Corrections of ink lines should be made with a soft eraser or with cotton and alcohol. If a photograph is so damaged that it cannot be reinked legibly, it is best to superimpose a thin sheet of transparent plastic over the area and reink the data on this. The plastic overlay should be securely fastened to the photograph.

HORIZONTAL CONTROL FOR AERIAL PHOTOGRAPHS

To transfer the soil boundaries and symbols from an aerial photograph to a compilation base, a planimetric map of good quality is required. In areas having no adequate map, it is necessary to construct a base from the aerial photographs.

The scale of the map, its accuracy, and orientation and placement on the earth's surface depend on horizontal ground control. This control is the framework of a map and comparable to the foundation and steel frame of a large building. After completion, the frame is hidden from view.

A horizontal ground-control station is a precise point on the earth's surface, the position of which has been accurately determined by field survey methods in relation to certain parallels of latitude and meridians of longitude. Many such stations are scattered throughout the United States. These have been and are being established by the United States Coast and Geodetic Survey, the United States Geological Survey, the Corps of Engineers of the United States Army, the Lake Survey, the Mississippi River Commission, and, to a limited extent, by private mapping and engineering firms. The positions and descriptions of these stations are readily available from the records of the establishing agency.

[2] See also Appendix I. Map Preparation with the Plane Table.

Distribution and extent.—Soil survey parties are not equipped to establish ground control and depend upon and use the control already established by other agencies. Using these control stations as a base, the Cartographic Section of the Division of Soil Survey establishes photogrammetric control points between widely spaced ground points by a process commonly known as radial triangulation. These photogrammetric control points (also called supplemental control) are then used on the map base for the proper orientation and placing of each aerial photograph in order that all culture, drainage, and soil boundaries may be shown in their true positions on the soil map.

The density of established horizontal ground controls in the United States varies from 2 to 3 miles between stations in highly developed areas to 75 miles in some of the Western States. It is general practice for the Cartographic Section to utilize all established horizontal ground-control stations immediately adjacent to an area that is being mapped, because they add to the accuracy and simplify the preparation of the soil map.

With the radial triangulation method, the distribution of ground-control stations ideal for accuracy is one in approximately every 16 square miles of area, plus points in the near vicinity of all map corners, and points in every 3 to 5 photographs along the boundaries of the area. Unfortunately, these conditions seldom exist. Either too few points have been established or they are not distributed proportionately. Thus, in most survey areas it is necessary to use each control station. Where sufficient ground control is lacking within the area, it is necessary to use control stations up to 5 miles beyond its border. Aerial photographs are needed for the station and for the intervening area. Established ground control is so sparse in some mapping areas that it is necessary to use surveys of railroads, highways, and utility companies and the General Land Office. These, of course, provide a lower degree of accuracy than proper control stations.

Description of control stations.—Horizontal ground-control stations fall into three general classes: (1) Monuments, (2) landmarks, and (3) road and fence intersections.

The first is most important. Monuments are permanently established by geodetic triangulation and traverse with a high degree of accuracy. The exact point located is marked by a concrete block, galvanized pipe, or cut stone with a bronze station marker imbedded in the top. Some of the older stations are marked by triangles or crosses cut into stone monuments or on natural rock outcrops. Many of these have bronze markers cemented in drill holes in the rock. Most of these stations are described at length so that they may be readily recovered. The descriptions include distances and directions from two or three towns, a route description to the station site from some town, ownership of the property on which the station is located, distances from nearby objects to the station, and angles and distances to reference, witness, and azimuth marks.

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Landmarks used as ground-control stations include church spires, smokestacks, water towers, air beacons, lighthouses, flagstaffs, and sharp mountain peaks. Their positions are obtained through triangulation and they usually have a high order of accuracy. Short descriptions are available, including date of their location.

Third, and of a lower order of accuracy, are such ground points as the intersections of the center lines of roads, intersections of the projections of fence lines with the center lines of roads, railroad intersections, road and railroad crossings, and intersections of roads or railroads with section lines. These stations are obtained along the route of a transit traverse, and their position and a short description are available from the establishing agency. They are of relatively lower accuracy than others because they are not marked in any way on the ground and the recovery of the precise point established by the traverse is problematical.

Methods of locating and identifying stations.—With the initiation of a soil survey in an area, the Cartographic Section of the Division of Soil Survey obtains positions and descriptions of all established ground-control stations that exist in and adjacent to the area. The stations are then plotted on some type of existing map, and aerial photographs are obtained that will completely cover not only the area of the soil map, but also adjacent ground-control stations that need to be used for control purposes. Attempts are made in the Cartographic Section to identify each control station on a photograph. This is a very exacting task because the basic construction of the compilation depends on *all* points being identified precisely. A large percentage of points are identified in the office with certainty. Those in doubt or which cannot be identified are then referred to the soil scientist for recovery and identification in the field.

The exactness and care required of the soil scientist in the recovery and identification of ground control on aerial photographs cannot be overemphasized. The misidentification of a control station on an aerial photograph, if not detected in the radial assembly of the photographs or in the compilation, will cause distortion in the scale of the base and displacement of all planimetry and soil boundaries in the area governed by the station. Even when the misidentification is found, the station cannot be used, which weakens the accuracy of the radial triangulation or of the secondary control points. The field party should use every care possible when requested to recover and identify ground-control stations on photographs.

In requesting the information, the cartographers furnish the party chief with the photograph covering the general area of the station and with the approximate location of the station indicated on the face of the photograph by a red triangle made with a grease crayon. A copy of the description of the station is attached to the photograph.

The landmark or intersection class of station is not usually described at length because it is easily recovered. Perhaps the major factor in recovery and identification is for the soil scientist to be positive of the identical point described in the original control survey. Some intersection stations such as water tanks, church steeples, and airway beacons are moved, and consequently their new location on the ground would not be represented by the old survey position. The date of the survey in the description of each such station enables the soil scientist to find out from local residents whether or not the station has been moved since the control survey established its position. After the soil scientist is positive of the recovery of the station, he identifies it on the photograph furnished him for that purpose. A small penciled circle, preferably in red crayon, about one-fourth inch in diameter, should be drawn around the station on the face of the photograph. On the reverse side, a slightly larger concentric circle should be placed directly opposite the first one and the name of the station written nearby in medium-hard black pencil. Ink should not be used on the face of the photographs used for control identification. It is not necessary for the soil scientist to locate the point on the photograph by pricking it; the exact location will be determined later in the office with the aid of a stereoscope and pricked with a fine needle. If the field man judges that the cartographer will have difficulty in pricking the point stereoscopically, he should include a sketch on the back of the photograph showing the ground detail immediately around the station.

Monumented stations present more of a problem in field identification than either of the two previous types, because many cannot be accurately identified on the photograph even with the aid of a stereoscope. The monumented stations fall into three classes: First are those stations that may be accurately pricked with a fine needle when viewed through a stereoscope or magnifying glass. The surveyor should circle the pricked point on the back of the photograph with a medium-hard pencil, write the name of the station, and, if necessary for clarity, make a small sketch of the ground and objects immediately adjacent to the station. He may give a short note on the accuracy of the identification.

Second are those stations that cannot be identified directly because they are located either in open areas nearly free of detail or in sparsely wooded areas. With these, the field scientist should obtain measurements from identifiable objects, such as roads, fences, buildings, and small trees in the vicinity of the station. These *tie points* should be as nearly at right angles to each other from the station as possible, for this will provide the most accurate position of the station when it is plotted on the photograph. Three tie points are sufficient and they may be as much as four or five hundred feet from the station. The surveyor should be cautious in his selection of tie points, for fences and buildings may be moved or rebuilt, roads may be changed, and small trees may have grown since the photographs were taken. Usually the soil scientist can tell whether or not a tie point existed at the time the photographs were taken by referring to the date in the upper left-hand corner. The tie points should then be pricked with a needle, and a small red crayon circle placed around each. On the back of the photograph, opposite the area of the tie points, a sketch should be made, in black pencil, showing the general positions of the tie points, the station, other pertinent detail, and the measured distances from the station to each tie point. The name of the station should be written and a north arrow for direction included. Although the sketch does not need to be drawn to scale, it should be carefully done, because from it the Cartographic Section will identify the true position of the station.

Third are monumented stations established in heavily wooded areas where no tie points are available and the station cannot be identified directly. With these, the soil scientist is limited to recovering the station on the ground from the description furnished him and by making a careful study of the area on the photographs with a stereoscope. When he is satisfied that his identification is the best he can do, he should prick the location, circle it on the front and back of the photograph, and otherwise handle like the first group.

The designating characters stamped into the bronze station markers should agree with the description of the station. The United States Coast and Geodetic Survey generally places two or three reference markers in the near vicinity of the station. These markers are stamped with an arrow pointing toward the station, and the station itself is stamped with a triangle. Along some traverses, monumented stations are set in pairs, usually over 500 feet apart, and the soil scientist should take care that he does not identify the wrong station.

In the examination of photographs in the field for control purposes, a stereoscope should be used whenever possible. If one is not available, then a magnifying glass should be used for pricking all points.

USE OF AERIAL MOSAICS AND PHOTOMAPS

Aerial mosaics and photomaps are generally used in soil surveying much like individual aerial photographs, except they cannot be used for purposes requiring stereoscopic vision. If the mosaic or photomap is uncontrolled, its use will parallel that of the photographs. If it is well controlled, it can be used much like a well-constructed planimetric map. Since mosaics and photomaps cannot be studied stereoscopically, more care is needed to locate accurately drains and other features in densely shadowed areas, and thereby avoid errors in plotting soil boundaries. Isolated buildings and trails may be overlooked or inaccurately identified.

A set of stereoscopic photographs may be used, however, along with a mosaic. These can be retained in the field office, studied before going into the field, and the necessary interpretations and delineations made. These interpretations can be transferred to the mosaic before taking it into the field. In transferring any changes in cultural features to the mosaic, one must be sure to note them in a bright contrasting color and be certain that they are placed on the set of sheets that carries the plotting of soil data.

Matching on controlled mosaics and photomaps is much simpler than on individual photographs. Mosaics and photomaps are usually constructed to be reproduced in quadrangles or similar sheet forms. These sheets are usually bounded by latitude and longitude lines and will fit together with no overlap. Their outer grid line serves as a matching boundary, and the detail can be matched by abutting the adjoining sheets. If the mosaic or photomap has an overlap area, it is usually very narrow, and grid lines that can be used for matching will usually appear on the inward side of the overlap area.

Since mosaics and photomap sheets normally cover a larger area than individual aerial photographs, fewer sheets are required to cover the survey area. This greatly reduces the number of match lines between sheets and the time required to transfer and to match boundaries.

Inking on mosaics and photomaps is done like it is on photographs. Overlays over a photomap or mosaic are handled like overlays over the individual aerial photographs. Since mosaic and photomap sheets are large, overlay material must possess good dimensional stability.

The use of poor, uncontrolled mosaics can frequently lead to serious difficulties in field mapping and later construction of the map—difficulties that may result in a poor map and increased cost.

USE OF TOPOGRAPHIC AND PLANIMETRIC MAPS

When using topographic and planimetric maps obtained from reliable sources and constructed by precise methods, one can assume that the cultural and physical details have been properly plotted and classified, that place names are correct, that projections and grids are accurately laid out, and that the map conforms generally to high accuracy standards.

Although more accurate than aerial photography, topographic and planimetric maps lack the minute ground detail appearing on photographs that is so helpful in soil mapping. Also such maps are commonly on too small a scale for field mapping. As topographic and planimetric maps are bounded by grid lines and are so precisely constructed that adjoining sheets match, there is little or no difficulty in joining them.

Inking on the topographic or planimetric map is done with a good grade of waterproof drawing ink. As cultural and drainage features are already printed on the map, inking involves only the soil boundaries, symbols, and changes in features. Such changes are plotted by plane-table methods and inked on the maps in a bright contrasting color such as red or carmine. Old features that have been abandoned or no longer exist are crossed out in red ink. It is helpful if these corrections and changes are made on the set of maps on which the soil data are plotted.

If the mapping is very detailed, a separate set of maps may need to be used for changes. All changes should be noted on one set of maps, either on those bearing the soil data or a separate set, but not part on each.

Where topographic or planimetric maps of high accuracy standards and sufficiently large scale exist, they are valuable as a base for soil mapping. Even though the soil mapping is done on aerial photographs, for reasons already explained, topographic maps are extremely valuable in the field work. In some instances, the field work is done on the photograph and transferred to the topographic or planimetric map with a sketchmaster.

THE FIELD LEGEND OF SYMBOLS[3]

The field legend accompanying the field sheets must include a list of all symbols other than the standard ones shown on plates 1 to 5. Occasionally, it will be necessary to add a conventional sign for some feature that is not included with the standard symbols. Any added symbols should be submitted in legend form, together with detailed definitions. Recommendations about publication of such symbols should be made, together with a statement of need and importance. Enough standard symbols are provided for in plates accompanying this *Manual* to take care of nearly all situations.

The legend includes both the symbols used to designate the individual mapping units and those used for any special soil, land, or water conditions, such as rock outcrop, gravel pit, or intermittent stream. The field name for each mapping unit is listed, along with the appropriate symbol. Where fractional symbols are used, it must be recalled that each combination is a separate, individual symbol to be named in the legend.

Standard symbols for phases of stoniness, rock outcrop, eroded soil, soil blowing, and the like need to be repeated in each legend, with definitions giving the acres that one symbol represents.

The party chief needs to check his field legends with the field sheets continually during the survey, and especially at the end of it, to be certain that the legend is complete and consistent. Failures to do so lead to unreasonable costs in map construction and to errors in correlation and in the final publication.

DETAIL OF FIELD MAPPING IN RELATION TO PUBLICATION SCALE

To show the detail significant to farm planning and to the application of agricultural science to farms, it is necessary to map soils at relatively large scales. Nearly all detailed soil surveys are now mapped on aerial photographs at scales of 1:20,000 (3.168 inches to 1 mile) and 1:15,840 (4 inches to 1 mile). Some highly detailed surveys are made at even larger scales, say as large as 1:7,920 (8 inches to 1 mile).

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[3] The making of soil legends is discussed in the section on The Soil Mapping Legend.

Reconnaissance soil surveys are mapped at relatively smaller scales, although field mapping is frequently at 1 inch or even 2 inches to the mile (1:63,360 to 1:31,680) in order to use topographic maps or aerial photographs. (See section on Reconnaissance Soil Mapping.)

Since several copies of the field sheets may be reproduced photographically, it is usually impractical to publish all of the detail mapped in a very detailed soil survey. The scale of mapping may need to be 1:7,920 (8 inches to the mile) to meet a complex agricultural problem. If the soil map of an average-sized county in the United States—about 980 square miles—were published at 8 inches to 1 mile, it would require a map about 21 feet by 21 feet or about 180 quadrangle sheets, each 17 by 22 inches. Such a map would be costly, bulky, and difficult to use.

It is sometimes necessary to consolidate or even delete some of the soil separations for practical publication of the map, especially if the original survey includes transitory features or minor subdivisions of soil phases. The problems of excessive detail in classification and symbolization are discussed in several parts of the *Manual*. Faulty soil classification, with uncontrolled legends, is the biggest single cause.[4]

Where transitory features, such as present land use, need to be mapped or subdivisions of phases are to be mapped but not shown on the published map, secondary sheets may be used to advantage. The mapping of excessive or unnecessary detail on the master map should always be avoided. If the published map is to be much smaller in scale than the field sheets, its cost may be greatly increased unconsciously by the mappers. Without realizing how costs may mount, some field men are inclined to say: "Well, it doesn't matter if we use separate symbols for two or more similar soils, we can always tell the cartographers to combine them." It is the responsibility of the soil scientist to map only the detail relevant to the purposes for which the survey is made. Detail beyond this clutters and complicates the field sheet, slows down the field work, and increases the cost of map preparation and publication.

Any lack of clarity caused by excessive detail increases costs and reduces accuracy. Careful judgment must be used in showing detail. Symbols need to be within the delineated areas and large enough for legibility; cultural and drainage features, civil boundaries, place names, and like information that makes the field sheet usable must be legible and of appropriate size. Symbols for mapping units need to be as short as possible so that they may be placed inside the areas and still be legible. Arbitrarily "standardized" legends with long fractional symbols are poor. Such symbols take up too much space on the map. Illegible field sheets are useless.

In figures 14 and 15 the same map is shown at several scales: (Figure 14 shows a map at 4 inches to 1 mile (1:15,840). The

[4] See sections on The Soil Mapping Legend, Units of Soil Classification and Mapping, and Plotting Soil Boundaries in the Field.

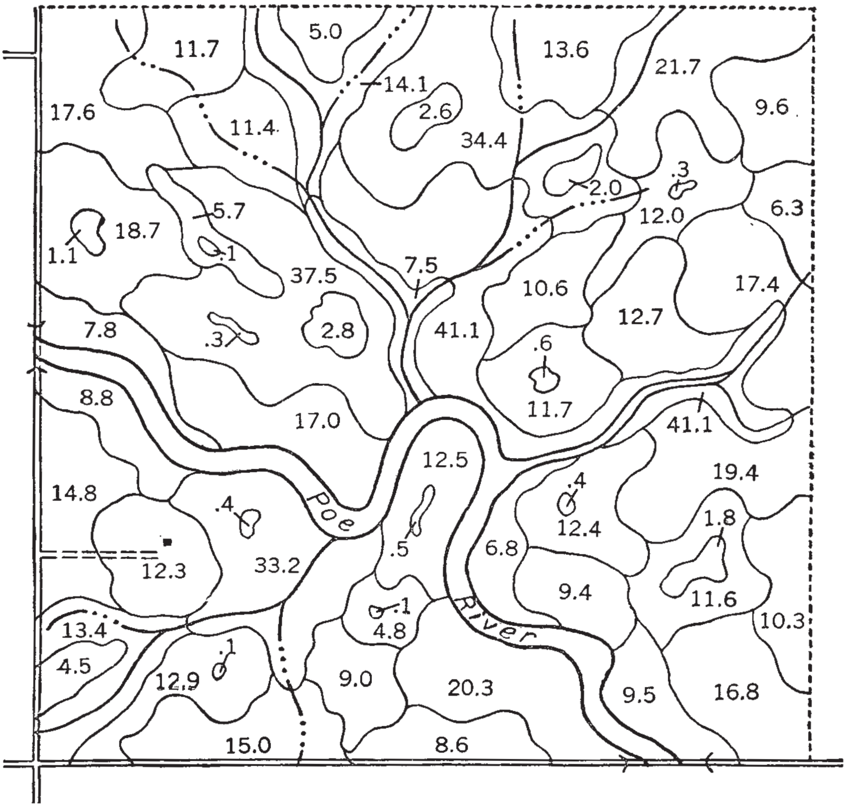

FIGURE 14.—Map at scale of 4 inches equal 1 mile. The number within an individual area gives the acreage of the area. (Compare with fig. 15.)

same map is shown in figure 15 at *A,* 3 inches to 1 mile (1:21,120); *B,* 2 inches to 1 mile (1:31,680); and *C,* 1 inch to 1 mile (1:63,360). The extent to which the detail mapped at 8 inches to 1 mile can be legibly published at smaller scales is apparent.

Combining small areas for publication.—When the detail on the field sheet is too intricate to show at the publication scale, small areas must be consolidated. When consolidations are made, the areas must be properly marked with symbols to show the disposition of the areas for which classification is being changed.

One method used to consolidate the detail to meet the requirements of the publication scale is to transfer all detail, except soil symbols, to the manuscript map and then, with reference to the field sheets, combine or omit the areas too small for publication. This method has the major disadvantage of taking a great deal of time in transferring delineations that will later be eliminated from the map. A better method is to combine the areas on the field sheets before map construction is undertaken. This combin-

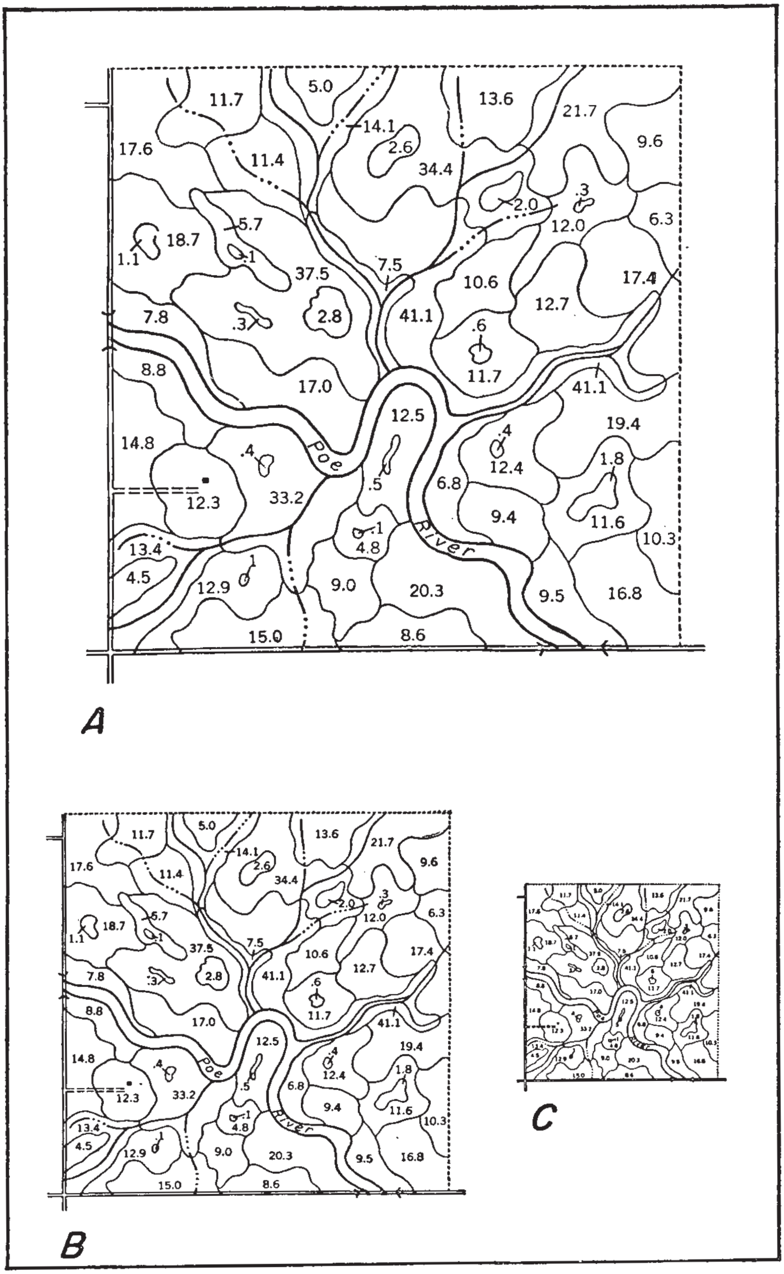

FIGURE 15.—Copies of the same soil map at different scales: *A*, 3 inches equal 1 mile; *B*, 2 inches equal 1 mile; and *C*, 1 inch equals 1 mile. The number within an individual area gives the acreage of the area. (Compare with fig. 14.)

ing requires ability to visualize the mapped detail at its publication scale and to follow definite rules about which areas must be combined or omitted. A helpful guide is a sheet of transparent acetate on which are outlined areas of minimum size for the scale of publication. This can be placed over the field sheet and shifted here and there to determine whether or not areas are too small for publication.

Table 1 gives a general idea of the smallest sized areas, at various field mapping scales, that may be shown at different publication scales. In this, only isolated or scattered areas are considered. If a large part of the total area were mapped in this maximum detail, it would be impossible to show it at the scales indicated.

TABLE 1.—*Minimum size of areas that can be shown on published maps of various scales from field sheets at different scales*

FIELD SURVEY SCALE OF 8 INCHES TO 1 MILE (1:7,920)

Ground area		Size on field sheet (inches)	Possible publication scale (inches to 1 mile)
Acres	Feet		
0.45	100 x 200	0.15 x 0.30	4
0.86	150 x 250	0.22 x 0.38	3
1.35	200 x 300	0.30 x 0.45	2

FIELD SURVEY SCALE OF 4 INCHES TO 1 MILE (1:15,840)

Acres	Feet	Size on field sheet (inches)	Possible publication scale (inches to 1 mile)
0.45	100 x 200	0.075 x 0.15	3
1.35	200 x 300	0.15 x 0.23	2
3.44	300 x 500	0.23 x 0.38	1

FIELD SURVEY SCALE OF 3.168 INCHES TO 1 MILE (1:20,000)

Acres	Feet	Size on field sheet (inches)	Possible publication scale (inches to 1 mile)
0.86	150 x 250	0.09 x 0.15	2.5
1.33	200 x 300	0.12 x 0.18	2
3.44	300 x 500	0.18 x 0.30	1

If it is not feasible to combine small areas directly on the original field sheets, this can be done on reproductions of the sheets or on a transparent acetate overlay. Only the necessary symbols and soil boundaries are copied. If no need exists to keep the field sheets as they were originally mapped, the combinations may be made directly on them. Where made directly on the aerial photographs or copies of them, combinations should be indicated in a bright color that contrasts with the background of the photograph.

Especially where the soil scientist has difficulty in visualizing the field sheet at publication scale, it may be reproduced to the approximate scale for publication, and he can then make the consolidations on the small-scale reproductions. This method is costly.

All such schemes are expensive makeshifts. If the survey is properly planned in relation to both field and publication scale, they should be unnecessary. Office consolidations are never completely satisfactory. If complexes must be shown, their boundaries should be drawn in the field.

If unpublishable detail is to be mapped—and it is often necessary to do so—plans for handling it should be made at the start of the survey. Such detail may be shown (1) on the master map with special colors, provided this does not obscure or confuse the boundaries, planimetry, and symbols to be used on the published map; (2) secondary sheets may be used for the material not to be published; or (3) two manuscript maps may be drawn as the field work progresses, one showing all details and one showing only the material to be published. Commonly this last is the most economical alternative. Small areas of strikingly contrasting conditions may be shown by conventional signs.

Where much selection is required from the field sheets, arrangements should be made to have this work done by a skilled soil scientist familiar with the area, preferably the party chief, and the estimated cost should be included in the *Soil Survey Work Plan.* (See p. 43.)

INSPECTION OF FIELD WORK

Each field party is visited several times during the progress of the survey by the soil correlator in charge. He inspects the field work and consults with the party chief. Besides examination and revision of soil classification in the descriptive legend, the field maps themselves are checked in the field for legibility and accuracy of soil identification and placement of soil boundaries.

Special attention is given to legibility of soil symbols and place names, closure of soil boundaries, accuracy of classification and symbolization of cultural and drainage features, systematic placing of match lines, accurate matching of sheets, neatness of line work, and other items that influence the accuracy of the field work and the ease with which it can be used in map construction.

Party chiefs should continually check and advise the members of the party in order to insure neat and accurate inking of the field data. New employees especially need help until they are acquainted with the standards required in soil surveys. They should not be left to their own devices.

FINISHED FIELD SHEETS

The finished field sheet is the final product upon which the work and reputation of the scientist depends. It should be accurate, neat, and legible. It serves many other users and must be easily and accurately interpreted.

CONVENTIONAL SIGNS

The various mapping agencies of the Federal Government have developed and agreed upon standard symbols for most ground features. These standards are generally accepted for soil maps and should be used when practical.

Some special maps require symbols not normally found in the standard series. Such special symbols may be necessary because of the scale of the map or the data to be emphasized, but none should be used that may be confused with the standard ones.

In soil mapping, few such additional conventional signs are necessary.

For published soil maps the standard conventional signs are used almost exclusively. Such symbols are placed on the map according to rigid specifications as to weight of lines, sizes and spacing of dots and dashes, and the size and style of lettering. In field mapping, the standard symbols should be used, although exactness of line work is not so important.

Although some conventional signs used in the field mapping of soils do not conform to the general standards, it is still necessary that they be standardized. In the broad program of soil mapping throughout the country, standardization of as many techniques and methods as possible increases efficiency.

The cultural and natural features, other than kinds of soil, plotted in soil surveys throughout the United States are sufficiently similar to make the standardization of conventional signs practical. With a set of standard symbols, soil scientists do not need to learn new ones for each survey. By using the same symbols over and over, mappers develop skill in making them neatly and rapidly. The use of a standard set of conventional signs for natural and cultural features greatly facilitates the work of the cartographer. Obviously, the symbols for the thousands of different kinds of soil cannot be standardized.

To insure standardization at a range sufficiently wide to cover most features besides soils, a series of standard symbols for use by soil scientists are shown in plates 1 to 5. These standards include some alternatives. One set corresponds to those used on the finished soil map and closely approximates the symbols adopted generally by Federal mapping agencies. The other group represents a simplified form of the same symbols. This simplified set of symbols is solely for the convenience of the soil scientist in inking field sheets. It eliminates such symbols as double-line roads and substitutes a single line in color, and simplifies the spacing and dots for other signs. This simplified set of signs may not be appropriate in cooperative surveys if another organization plans to use the field sheets as base maps.

Signs and symbols are shown in the plates and are discussed under major classes as follows:

Works and structures

Roads.—On field sheets, roads are indicated according to the following distinctions:

1. First-class or good public motor roads are shown by solid lines. These include those public roads that may be used for automobiles at medium speeds and for hauling the greater part of the year and include all Federal, State, county, or other public roads in condition for such travel, all main or through roads in passable condition in sparsely settled sections, and all city streets and park drives open to the public.

2. Second-class or poor public motor roads and all private roads, regardless of condition, are indicated by dashed lines. Secondary roads include those public roads which, through disuse or neglect, are either impassable for automobile travel and for hauling or cannot be traveled without risk to an automobile, except at low speeds. Public roads that are passable for wagons but are not good for motor use are classed as poor motor roads.

Public roads are shown by solid or dashed lines, according to their condition; whereas private roads are shown by the dashed symbol, irrespective of condition. Public roads are those built or maintained by a public highway agency. Private roads include neighborhood roads in rural districts (except those of sufficient length and importance to be regarded as through routes, as defined above), lanes and stub roads to farms, country houses, or institutions, cemetery drives, and race tracks, and roads built or maintained by private or neighborhood funds.

Wagon roads winding through timber and other unimproved roads used principally in farm operations ordinarily are not shown on the published map. In sparsely settled country, however, such unimproved roads are shown if they offer to the public the only access to important places or to a large area of country. Occasionally, in unsettled areas, pack trails impassable to wagons or motorcars may offer the only opening to a region and should appear on the final map. It is convenient to indicate all traverses on the field sheets, but roads or trails that are not to appear on the published map should not be inked.

The class of road should be shown on the field sheets with the appropriate symbol rather than by figures. It is not convenient to indicate with figures precisely where one class of road ends and another begins, and the surveyor is apt to omit figures in a few places. In highly detailed surveys, especially where the soil map is used as a basis for detailed land classification, the class of primary roads must be subdivided according to the type of surfacing. All-weather roads may be shown with one line heavier than the other, and other primary roads by the conventional symbol. By appropriate modification, different symbols may be used for graveled roads and for paved roads where this distinction is necessary.

Buildings in general.—The map shows such permanent buildings as dwellings, public buildings, shops, factories, and other industrial establishments. Uninhabited dwellings, whether farmhouses or miners' and lumbermen's cabins, are shown only where they are important landmarks in sections of sparse culture. The conventional black square is used for all buildings except those exceeding the size of the symbol when their dimensions are plotted to scale. Houses should not be shown right next to roads unless the distance that separates them from the edge of the right of way is so small that it cannot be plotted to scale. Symbols for dwelling houses should be inked square and of uniform size on the field sheets. They are best made by outlining in ink an open square with sharp corners, and afterward filling in with ink. If houses are shown too small, it becomes difficult to make the symbols square, and, unless these are inked square and sharp, their identification as symbols for houses becomes uncertain. If it is important to distinguish houses from summer or winter cottages, the latter may be shown by leaving the square open. These symbols are used on published soil maps only where recreational land use is especially important and their use is specified in the work plan for the survey, otherwise the ordinary house symbol is used.

House blocks.—In towns of 2,500 population and under, individual houses, churches, schools, stores, factories, warehouses, and similar buildings are shown, except in business districts where buildings are constructed wall to wall and are shown as single block symbols.

In cities with population over 2,500, only prominent landmark buildings, like schools, churches, universities, colleges, and city halls are shown. Schools and churches are shown by the conventional symbol, and other buildings should be named. No other individual buildings are indicated within the city limits.

Churches and schoolhouses.—A church is distinguished by a cross, and a schoolhouse by a pennant attached to the house symbol at right angles to the roadway. A building used as both a school and a church bears the school symbol.

Railroads.—Railroads, whether operated by steam, electricity, gasoline, or other motive power, including all railroad lines listed in the Office Guide of the Railways, are shown by the broad-spaced symbol representing a railroad of any kind.

Electric trolley lines in urban areas or beyond city limits are shown by the standard railroad symbol and are designated by operating name and type, such as "Philadelphia Rapid Transit (electric)."

Double tracks, railroad yards, spur tracks, and switches are shown so far as the scale allows. Adjacent parallel tracks of two railroads are shown by staggered tie symbols and both lines are named. Adjacent tracks of one line are shown by extending the tie symbols across both tracks.

Railroads or electric trolley lines within a roadway are shown by fine cross lines having the same spacing as those on the corresponding line outside of the road. In such instances it is necessary to use the double-line road symbol on the field sheet instead of the usual single line.

In railroad yards with parallel spur tracks, only as many tracks should be inked as can be engraved legibly at publication scale, as too many tracks make difficult inking, illegible field sheets, and impracticable engraving. Where switches and sidings occur alongside single tracks, both the main track and the side tracks are inked in finer lines than the main track elsewhere; these fine lines are inked first and the extension of the main track inked afterward in a heavier line, in order to make clear copy.

Crossings at grade are shown by continuous railroad and road symbols; at grade separations, crossings are indicated by a break in the symbol for the lower crossing. A railroad crossing over a road is shown by a broken road symbol, and a road crossing over a railroad by a broken railroad symbol. (The words "overhead" or "underpass" should not be used.)

Railroad-station buildings.—A railroad-station building is shown like other buildings, except that its symbol is carried conventionally across the track to indicate the location of a train stop if this is not clear from the culture. The conventional station symbol is not drawn across the track where there is no station building; and its use is generally confined to small villages.

Bridges.—Symbols are used to show bridges across streams more than 300 feet wide, other bridges if named, and bridges in sparsely settled sections wherever the existence of a bridge is vital to the use of the road. Bridge ends are not shown for viaducts over railroads, railroad yards, roads, or streams. Names of large viaducts are given, however.

Drawbridges on roads and railroads are shown by separate symbols. Ordinary bridges and trestles on railroads are omitted. Wherever its presence would reduce the legibility of the map, the bridge symbol also is omitted.

The footbridge symbol is rarely used—only where the bridge is isolated and an important way into a large area.

Ferries.—Ferries are shown by symbol wherever the stream is wide enough to allow; where it is too narrow, the word "Ferry" is written. Names of ferries are placed on the map.

Fords.—The symbol for a road ford is similar to that used to represent a private road. The names of important fords appear on the map.

Trails.—The mapping of trails depends on their relative importance. In mountain and desert regions and in heavily wooded areas, especially where sparsely settled and where traveling is done largely along trails, important trails should be mapped and named. In the more densely populated districts where railroads and roads are plentiful, only trails such as those leading up mountains or through unimproved areas otherwise not readily accessible are shown. A mere "way through" not regularly traveled does not constitute a trail.

Steamboat routes.—Steamboat routes on lakes and rivers, over which regular public service is maintained by ferries or passenger boats, are indicated by fine dashed lines and the words "Steamboat route."

Canals and ditches.—Canals, whether for navigation, irrigation, or drainage, are shown by a double-line symbol if their actual width can be indicated at the scale employed, otherwise by a single blue line. Abandoned trunk canals constituting prominent topographic features are indicated by the long-dash symbol.

In the mapping of irrigation ditches, both mains and important laterals are shown. The mains are so designated. Canals and ditches are inked in blue.

Canal locks.—The lock symbol should point up current. The symbol for canal locks is inked only insofar as it can be engraved legibly at the publication scale, and the upper and lower gates are inked separately only where both gates can be shown legibly.

Aqueducts, water and oil pipes.—Only the principal aqueducts and pipelines are shown.

Power-transmission lines.—The alignment of high-voltage (100,000 volts or more) trunk power-transmission lines should be obtained in the course of the field survey and shown on the field sheets. Sections of power-transmission lines within corporate limits and lateral distribution systems should be omitted. Trunk lines are usually built on private right-of-ways and, in most parts of the country, are placed on steel towers. Power lines should be inked in red. They are not shown in sections of heavy culture.

Tunnels.—Tunnels of all kinds, whether for railroads or canals, are shown by tunnel symbols. The route of the tunnel is indicated by broken lines. Railroad or road tunnels are inked in black, aqueduct tunnels in blue.

Dams.—Permanent dams in streams, lakes, or reservoirs are indicated by a heavy line. Where a road follows the top of the dam, the road is shown in its correct place, and the road line on the upstream side is thickened to represent the dam. The dam should be inked to its mapped length and labelled "dam." The important ones are named.

Reservoirs.—The shore line used to represent a reservoir should correspond to the normal full state of the reservoir that is controlled by the dam. Artificial reservoirs surrounded by dams on all sides are not enclosed by the dam symbol, but are outlined in blue, like lakes and ponds. Small reservoirs are further emphasized by a blue water lining.

Levees.—Levees are shown on United States Geological Survey topographic quadrangles by hachures or contours printed in brown, and when these sheets are used as a base map, this symbol is used. The symbol to be used on other sheets is shown on plate 2 and should be inked in black.

Wharves, and so on.—Wharves, docks, jetties, breakwaters, and similar structures should be indicated by firm sharp lines and shown in such detail as the scale of mapping allows. These structures are inked in black, in outline only, as plotted to scale in the field. A narrow wharf or pier, however, is represented conventionally by a double line about the width of a narrow road. Jetties and breakwaters are inked in single heavy black lines.

Lighthouses, and so on.—All lighthouses and lightships are located on the map and shown by their respective symbols.

Lifesaving stations.—Lifesaving stations in general are shown by the house symbol, followed by the letters LSS; but lifesaving stations of the Coast Guard are shown by the same symbol followed by the letters CG.

Cemeteries.—Cemeteries are shown with their actual outlines; the name is inserted if the cemetery is a well-known landmark and if there is space; otherwise a cross is placed within the outline, or the letters CEM alongside it. Private cemeteries that are too small to plot to scale may be shown conventionally by a small square enclosing a cross, but they are omitted unless they constitute landmarks in a thinly settled country.

Airports and landing fields.—Boundaries of airports and landing fields are indicated, including those of municipal, commercial, and private airports; Federal intermediate landing fields; marked auxiliary landing fields; army airfields; and naval air stations. The symbol used for the boundary is that shown for a cemetery or small park on plate 5. The name is added, or the word "airfield."

Mines and quarries.—Mines and quarries are indicated by the pick-and-hammer symbol, together with the word "coal," "limestone," "granite," or other as appropriate. In sparsely settled sections with little culture, isolated mines, quarries, and even prospects (sawbuck cross) that constitute landmarks and are widely known are shown, together with their names.

Gravel pits are shown by the pick-and-shovel symbol. Large ones are outlined and indicated by either the symbol or by the words "gravel pit."

Oil and gas wells.—Producing oil and gas wells are indicated by a special symbol. Where such wells are so numerous as to be practically indistinguishable, only the approximate outline of the field (by dashed lines) is shown.

Furnaces and smelters.—No additional conventional sign other than that for a house is used to represent furnaces, and in many areas it is not practicable to name them. In sparsely settled sections, however, the furnaces may be the most important landmarks, and they may have well-recognized names which cling to the localities even after the practical disappearance of the furnaces themselves. In such areas, it is helpful to give the names, even though nothing remains but a ruined stack. The same rule applies to smelters, except that those shown on the map should be restricted to smelters in active or prospective operation.

Coke ovens.—Only coke ovens connected with mines in operation are shown on the maps.

Drainage

Tidal shore lines.—On soil maps the line of mean high tide ordinarily is taken as the shore line. The shore line bordering mangrove swamps, however, may be lower than mean high tide. In determining the margin of mean high water, the highest (semimonthly) tides are excluded and an average taken of the usual high tides as generally marked by the limits of vegetation. The charts of the United States Coast and Geodetic Surveys are frequently useful in checking the position of shore lines.

Shore lines of all waters should be inked in a firm continuous blue line and not broken for wharves, piers, and similar structures that may be built over the water. Such structures are inked in black. Sea and retaining walls that are simply artificially constructed parts of the shore lines are inked in blue.

Marshes in general.—Where large areas of fresh-water and salt-water marshes are recognized as soil types or soil phases no special symbol is used. Large areas designated as a land type may carry the special symbol or not, depending upon whether it will improve the readability of the map. Small areas are shown by their respective symbols, defined as to the acres represented by each one. Only small detached areas of marsh similar to adjacent larger bodies of marsh carry these symbols. Other wet spots are shown by the wet-spot symbol, *q.v.* Most marshes on low coasts are traversed by a network of tidal channels. Unlike the rills in mud flats, these channels are fairly permanent in location, and those that exist at mean high tide are mapped individually insofar as the scale allows.

Submerged marsh.—Marshlands that are partly submerged for many months each year are differentiated from ordinary marshes. Small areas are represented by inking grass tufts in blue (no horizontal lines between symbols) on the water surface.

River shore lines.—The mapping of broad braided rivers offers a perplexing problem, because these rivers are subject to periodic fluctuations and changes in width. As a general rule the width shown corresponds to the normal stage, defined as that water level remaining nearly stationary for the greater part of the year. This excludes stages of relatively short duration resulting from floods, whether periodical or out of season, and low-water stages. Generally, the normal stage exists for about 9 to 11 months for most streams in the relatively humid sections. If any stage of water other than the normal has been mapped by other government agencies, instructions should be sought as to the availability and best use of such cartographic material.

In areas where the flow of rivers, though active for brief periods, dwindles or ceases altogether for many months, the normal or prevailing stage is very low. Thus, rivers like the Platte and much of the Missouri are normally braided and are represented as such on the map. Where the streams have wide bottoms of unstabilized sediments, the land is shown as sand or riverwash and the principal channels are indicated as intermittent or perennial streams, double line or single line as may be required. Other bodies of land within the normal flood plain, having trees or other stabilizing vegetation, or cropland, are shown as soil types or phases. Rock outcrops are shown appropriately as such. Except in brief periods, many rivers in desert areas are no more than broad sandy washes, and they are shown by strips of sanding.

Natural lakes.—The shore line of a natural lake or pond is that corresponding to the normal stage of water. It is not necessarily the exact shore line found at the time of the survey, for the survey may have been made during a period of flood or extreme drought. An effort should be made to ascertain the shore line of the normal stage, as usually marked by a line of permanent land vegetation. The shore line used to represent a large lake subject to a gradual rise or fall over long periods is that line found at the date of survey. This date should be indicated on the water surface in ink.

Artificial lakes.—The shore line of an artificial lake is the line that represents the margin of the water surface at the full normal stage of the lake, as controlled by the dam.

Island shore lines.—The shore line of an island is that corresponding to the stage of water used for determining the adjoining mainland shore line. Islands exposed only at a stage of water below that accepted for the mainland shore line should not be mapped.

Drainage classification.—Field sheets need to indicate clearly and accurately all perennial and intermittent streams. On detailed soil surveys the pattern should be complete, partly because this pattern helps greatly in reading the soil map, especially where detailed topographic maps are unavailable. With soil types and phases well defined in terms of classes of soil slope and with the detailed drainage pattern, the length, shape, and direction of slopes are suggested to the experienced map reader.

In practice, it is well to indicate the drainage by dashed pencil lines on the photographs in advance by stereoscopic study. The lines must be confirmed and classified in the field.

Perennial streams are ordinarily inked as solid lines, but dashed lines are sometimes used instead. Since much advanced use is made of photographic copies of soil survey field sheets, the mapper should attempt to make it possible to distinguish streams from soil boundaries by form as well as color. Where a great deal of such advanced use is anticipated, perennial streams should be inked in long dashed lines with a few arrows, not enough to clutter the map, but enough to indicate the direction of the stream and help to distinguish it from adjacent soil boundaries.

Intermittent streams are classified on detailed soil surveys. Those crossable with agricultural machinery are shown with one dot between dashes, and those uncrossable are shown with two dots between dashes. Unclassified intermittent streams, as on reconnaissance soil surveys, are shown with three dots between dashes.

Perennial streams.—A perennial stream is one that flows throughout most of the year except in years of extreme drought. It is represented on the field sheet by a solid blue line or a blue line with long dashes, as just explained. It is important that the perennial character of streams thus shown be reasonably well established, especially in semiarid and arid regions where the water in these streams is vitally important to the use of the soil. In dry regions, streams having perennial water holes in their beds, even though water is not flowing everywhere on the surface during dry periods, are shown as perennial streams on the soil map. In some instances, local inquiry is necessary to supplement field observations.

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Wide streams are shown by two lines drawn to scale. The double line should be used only when the actual width of the stream can be represented to scale without exaggeration. Narrower streams are shown by solid blue or dashed lines, increasing in width with the size of the stream. Stream lines taper toward the source, but should remain deep and strong to the very head.

Intermittent streams.—An intermittent stream is one that is dry for a large part of each year, ordinarily for more than 3 months. In arid and semiarid regions, intermittent streams are not reliable sources of water for stock, in contrast to perennial streams. The general standard symbol for unclassified intermittent streams is a dashed line with three dots between each pair of dashes. This symbol is ordinarily used for all intermittent streams in reconnaissance soil surveys. In detailed soil surveys, however, it is important to distinguish clearly between streams that are crossable with the usual agricultural machinery in the area and those that are not crossable. Thus, it is necessary in soil mapping to make a slight departure from the standard symbol.

Those intermittent streams that can be crossed with agricultural machinery are shown with the conventional dashes and one dot between them. Those intermittent streams that cannot be crossed with the ordinary farm machinery are shown by dashes with two dots between each pair of dashes. *Thus a detailed soil map should have no three-dot, or unclassified, intermittent streams.*

All clearly observable and mappable intermittent drainage should be shown and classified on detailed soil maps, even though a little of it may have to be omitted on published maps. (This should not be interpreted to mean that all insignificant rills and shallow gullies are shown individually.) The complete drainage system has an important relationship to the pattern of soil types and phases and assists greatly in reading and interpreting the soil map. Aggraded flats and valley floors without well-defined stream channels or scars are properly shown as miscellaneous land types or as strips of sand.

Disappearing streams.—Some streams, especially in areas underlain by limestone, disappear abruptly into caverns and may continue their courses for long distances through subterranean channels. The points of disappearance and reappearance should be located accurately, but only the surface drainage is shown.

Springs.—Only large and important springs are shown on the soil map in well-watered areas. In arid and semiarid regions, springs should be located with great care because of their vital importance to soil use. These springs usually have names that should appear on the soil map. Intermittent springs or those having salty or otherwise undrinkable water should be so designated on the map or in supplemental notes. Walled-in springs are shown like wells, by blue circles; but a spring that is a source of a stream is shown by a blue circle from which the outlet stream is plotted. The symbol for a spring needs to be made very clearly to be read distinctly.

Wells and water tanks.—As with springs, the importance of wells and water tanks depends upon their relative importance to soil use in the area. In arid and semiarid regions, both wells and tanks are shown. Artesian wells are so designated. They may or may not be flowing at the surface. In regions of few wells, all should be shown; but in thickly settled areas with many nonflowing artesian wells their presence may be explained in the report without showing them individually on the map.

Intermittent and dry lakes.—Shallow lakes and ponds that are dry for many months of each year are characteristic of arid and semiarid regions. Some of these are shown on the field sheets as specific kinds of soil. Other dry salt lakes and old playas, although not intermittent in the usual sense, are so closely akin to intermittent lakes in appearance and formation that they are shown by the same symbol. Those of large size and importance should also be described in supplemental notes.

Relief

Important mountain ranges, plateaus, bluffs, basins, valleys, and gulches are indicated on the map, generally, by the position of their names as well as by the soil conditions. Bluffs, cuts, depressions, fills, mine dumps, and narrow steep ridges are shown either by the standard symbols or by means of other conventions described in the text.

Depressions.—Natural depressions or sinks, like those common in limestone areas, are indicated on the field sheets by hachures, or by the standard symbols.

Mine dumps.—The symbol is used when mine dumps are not extensive enough to justify the inclusion of a miscellaneous land type in the mapping legend.

Boundaries, marks, and monuments

Boundaries, marks, and monuments to be shown on soil maps are indicated by the standard symbols or by other conventions described in the text.

Civil boundaries.—All civil boundaries, whether National, State, county, district, civil township, reservation (including National or State parks, forests, monuments, and bird and game preserves, and Indian, military, or lighthouse reservations), land grants, corporations (city, town, or borough), parks, and cemeteries, are shown on the map by their respective symbols.

Since these boundaries cannot be identified from aerial photographs in the office, the field scientist needs to plot them. Boundary monuments and other definite evidences of civil boundaries should be plotted, since they help in map compilation.

Necessary descriptions, survey notes, and plats of important boundary lines should be consulted. Data on National or State reservation boundaries can be obtained from headquarters prior to the beginning of the field work. Data on minor civil subdivisions can be obtained locally while the survey is in progress. Many boundaries are obscured or obliterated by natural causes or artificial works; some were indifferently marked when established; and others have lost some or all of their marks. Information from local settlers may prove of value and save time and effort in the search for obliterated lines. The word of a resident cannot be taken as authoritative, but merely as supplementing information from official sources.

Even though established land lines, as section lines, may have been placed incorrectly on the original survey, they are accepted as the *de facto* lines to be shown on the maps according to their actual position on the ground. Although some of the old Government Land Office plats may show sections to be regular, they may be irregular and must be shown on the finished map as nearly as possible according to the actual location of section corners on the ground.

Some civil boundaries are defined by statute to follow natural boundaries, such as streams or divides between drainage basins. Boundaries following large rivers should be given special attention, for they may be variously defined, as at the middle of the stream, its main current, or one of the banks. United States Geological Survey Bulletin 689 may be consulted for State boundaries. Although the field mapper is to identify the boundary line on the ground and then plot it on the map, ground conditions are sometimes found to be uncertain or lines indefinite or unmarked; for example, they may lie in streams that have shifting channels or banks difficult to determine. Again the line may not have been accepted by those living on both sides of it or by the proper county or State authorities; its location may be in dispute or even under litigation in court. The location of the State boundary line, therefore, should be subject to special attention.

The following general principles may be helpful: (1) A line marked on the ground and once accepted by competent authority is the real boundary, regardless of a statute (apparently) to the contrary. (2) Where the description of a particular bank or point in a stream is indefinite in wording or difficult of application, past practices or rulings must be sought. (3) Early Supreme Court decisions have ruled that a boundary moves with a gradually shifting channel or bank, but does not follow sudden shifts or cut-offs, and these rulings have generally been followed in recent decisions. (4) If a statute defines a boundary line as coincident with some channel or other part of a river, the location of the river itself at the time the statute became effective should govern, unless there has been a gradual change in the position of the river, as just indicated. If it is necessary to know the generally accepted location of a river at some past time, say at the time a law was enacted that made the river a State boundary, refer to General Land Office plats that were made at about the time in question. Supreme Court rulings must govern if they have been made, but few decisions that affect the details needed on soil maps have been handed down by the Court.

Civil boundaries should be verified before inking, as a precaution against errors in the interpretation of penciled field copy. Where civil boundaries of different classes coincide for a distance, the symbol of the major subdivision takes precedence, except in instances where greater clarity will be attained by another procedure. Where it is obvious that a civil boundary follows a stream or road for a short distance, the boundary symbol may be omitted to avoid confusion. In some places, however, clearness may be increased by placing the boundary symbol (in red) immediately alongside the stream or road.

County subdivision.—Only such county subdivisions are shown on soil maps as appear reasonably permanent in character and location. Those subject to frequent changes at county elections are excluded.

In general, counties are divided into small units. These bear different designations in different States, or even different designations within different counties of the same State. In the States organized from the public domain and surveyed under the public-land system, one or more of the so-called congressional townships has usually been taken as the unit of organization. In New England, and in other parts of the country affected by New England migration, are found town units, in which are vested many of the powers that in the South and in the newly settled West pertain to the county. Some counties in Maine, New Hampshire, and Vermont, in addition to the towns and cities—the only regular subdivisions—have partly organized or unorganized territory laid off by these States as plantations, gores, grants, purchases, locations, and islands.

The following summary, taken from census reports, gives the names of the primary divisions of the county, or its equivalent, in the several States and Territories:

Alabama	Election precincts.
Alaska	Recorders districts.
Arizona	Election precincts.
Arkansas	Townships.
California	Judicial townships.
Colorado	Election precincts.
Connecticut	Representative districts.
Florida	Election precincts.
Georgia	Militia districts.
Hawaii	Election districts.
Idaho	Election precincts.
Illinois	Townships and election precincts.
Indiana	Townships.
Iowa	Townships.
Kansas	Townships.
Kentucky	Magisterial districts.
Louisiana	Police jury wards.
Maine	Towns and cities.
Maryland	Election districts.
Massachusetts	Towns and cities.
Michigan	Townships.
Minnesota	Civil townships, townships, and ranges.
Mississippi	Beats.
Missouri	Townships.

Montana	School districts, townships, and election precincts.
Nebraska	Townships and election precincts.
Nevada	Townships and election precincts.
New Hampshire	Towns and cities.
New Jersey	Townships.
New Mexico	Election precincts.
New York	Towns and cities.
North Carolina	Townships.
North Dakota	Civil townships, election precincts, school townships, and school districts.
Ohio	Townships.
Oklahoma	Townships.
Oregon	Election precincts.
Pennsylvania	Townships, cities, and boroughs.
Puerto Rico	Barrios.
Rhode Island	Towns and cities.
South Carolina	Townships.
South Dakota	Civil townships, election precincts, school townships, and school districts.
Tennessee	Civil districts.
Texas	Commissioners' precincts and justices' precincts.
Utah	Election precincts.
Vermont	Towns and cities.
Virginia	Magisterial districts.
Washington	Election precincts.
West Virginia	Magisterial districts.
Wisconsin	Towns.
Wyoming	Election districts and election precincts.

Public-land lines.—In the so-called public-land States, all lands that have at any time been subdivided or "sectionized" by the General Land Office must be shown on finished soil maps by indicating such township and section lines as have been run and have been approved by the Land Office and are not under suspension. Theoretically, all corners are marked on the ground, but in practice many are difficult or even impossible to find.[5]

In well-settled parts of the country, where land lines often become property lines and sections are generally marked by roads and fences, the construction of a public-land survey net is comparatively simple. But in unsettled country or in settled areas where the roads or fences seldom conform to section lines, it is necessary to find on the ground and to locate on the map enough section corners to enable the cartographer to construct a land net built up from the Land Office plats and notes and tied to the located section corners. In some instances the old Land Office surveys are inaccurate, and the plats in no way conform to the actual section corners on the ground; therefore as many corners should be located as possible.

For map compilation it is not essential to ink the section lines on aerial photographs if they can be accurately drawn in the office from the pattern of roads and fences and from located section corners plotted on the pictures. Many users of the photographic copies of the field sheets, however, desire the lines drawn for their convenience, and the section numbers placed at the centers of the sections in figures distinctly larger than those used as soil symbols. Township and range numbers are placed on the outer edges of the sheet.

In order to avoid confusion with other cultural features, public-land survey lines are inked on the field sheets with a fine line in black or, preferably, in red or green, except where roads or canals are coincident with them. Township and range lines are made heavier. Only those township and section lines and parts thereof that have been surveyed and approved by the General Land Office, are not under suspension, and are indicated on the land plats by solid lines, should be inked on the maps. The fractional distances for section lines less than a mile are usually found

[5] For a description of the public-land survey system, see Beaman, W. M. TOPOGRAPHIC MAPPING. U. S. Geol. Survey Bul. 788: 161–378, illus. 1928.

on the land plats, and where accurate plats are available, such distances afford a means for plotting fractional land lines. Land lines broken at water surfaces on account of shore meanders should be broken as shown on the plats. Meander lines are not plotted or inked, and section lines are not drawn across meandered streams or lakes or across meander land.[6]

Search for public-land corners.—The time warranted in search for obscure corners is determined by the probable regularity or irregularity of the net and the proximity of corners already found. The less local information there is at hand, the greater the necessity for pioneer hunting for the needed land ties. In districts with few evidences of section lines, diligent search needs to be made on the ground for enough corners to prepare an accurate grid, because many users of soil maps locate themselves in relation to the public-land lines.

In a region where there are few roads on section lines, assistance in finding corners may be had by using an oversheet of tracing paper or cloth, upon which has been laid out to field scale either a single typical township or an entire land net covering the area to be mapped, built up in advance from the Land Office plats and notes. Such a tracing, placed in position over a field sheet as soon as the first land corner has been plotted, indicates graphically the *theoretical* location of other corners; and as more corners are found, the further placements of the tracing become more serviceable as a guide.

The field mapper should be familiar with the system of rectangular land surveys and the intricacies peculiar to it. Acquaintance with the standard monuments used for the several classes of land corners, their marks, and their bearing trees, as well as knowledge of the manner in which blazes on trees become overgrown with bark, will prove most useful both in searching for corners and in determining their authenticity where this is in doubt. Public-land corners that have been found in the course of field work are inked in red with the symbol for found-land corners. The map compiler is better served by having the location of the corners plotted than by the drawing of the lines themselves.

Township and range numbers.—Township and range numbers are placed along the margin of the map opposite the middle of each township, with the township numbers along the right and left and the range numbers along the upper and lower margins.

Triangulation stations and transit-traverse stations.—The triangulation stations and transit-traverse stations which have been tied to a traverse are indicated accurately on the field sheets in red ink with the open triangle and dot symbol. They are shown on aerial photographs as already explained in the discussion of horizontal control for aerial photographs.

Level bench marks.—Level bench marks are not to be shown on the field sheets, as their positions have not been determined geodetically. Field mappers need to distinguish triangulation stations, transit-traverse stations, and level bench marks one from another. Figures 16 and 17 show the standard markings of tablets used by the United States Coast and Geodetic Survey and the United States Geological Survey, respectively.

SPECIAL SYMBOLS

Several special symbols for soil maps are shown in plates 6 and 7. Most of these are for areas of soil phases or miscellaneous land types that are too small to enclose with boundaries and are yet large enough to influence soil use and management significantly. Definitions for these land types and phases are given in appropriate sections of the *Manual.*

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[6] Meander land is unsurveyed land, usually between a former lake and shore or stream border at the time of cadastral survey and the present shore or border, commonly at a lower elevation.

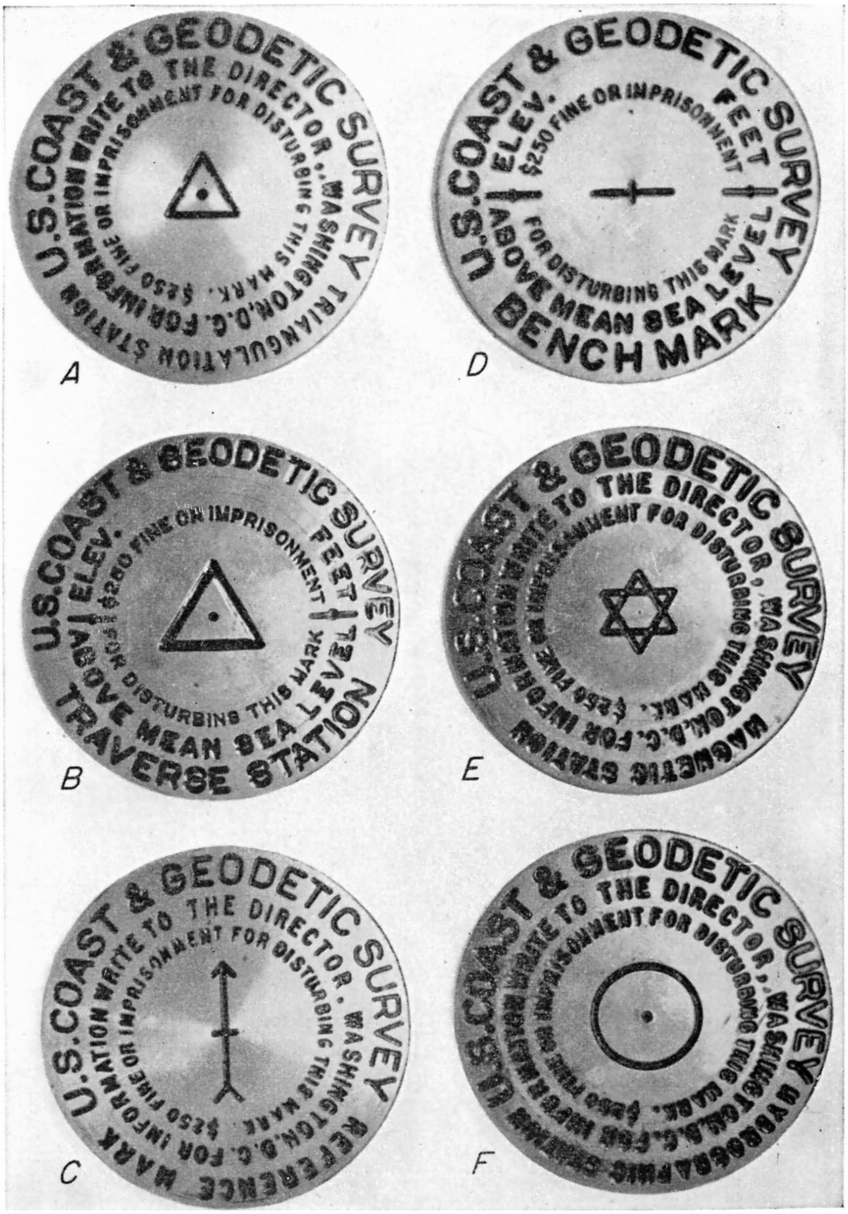


FIGURE 16.—Standard station marks of the United States Coast and Geodetic Survey: *A*, Triangulation station mark; *B*, traverse station mark; *C*, reference mark; *D*, bench mark; *E*, magnetic station mark; and *F*, hydrographic station mark. (Courtesy of Coast and Geodetic Survey.)

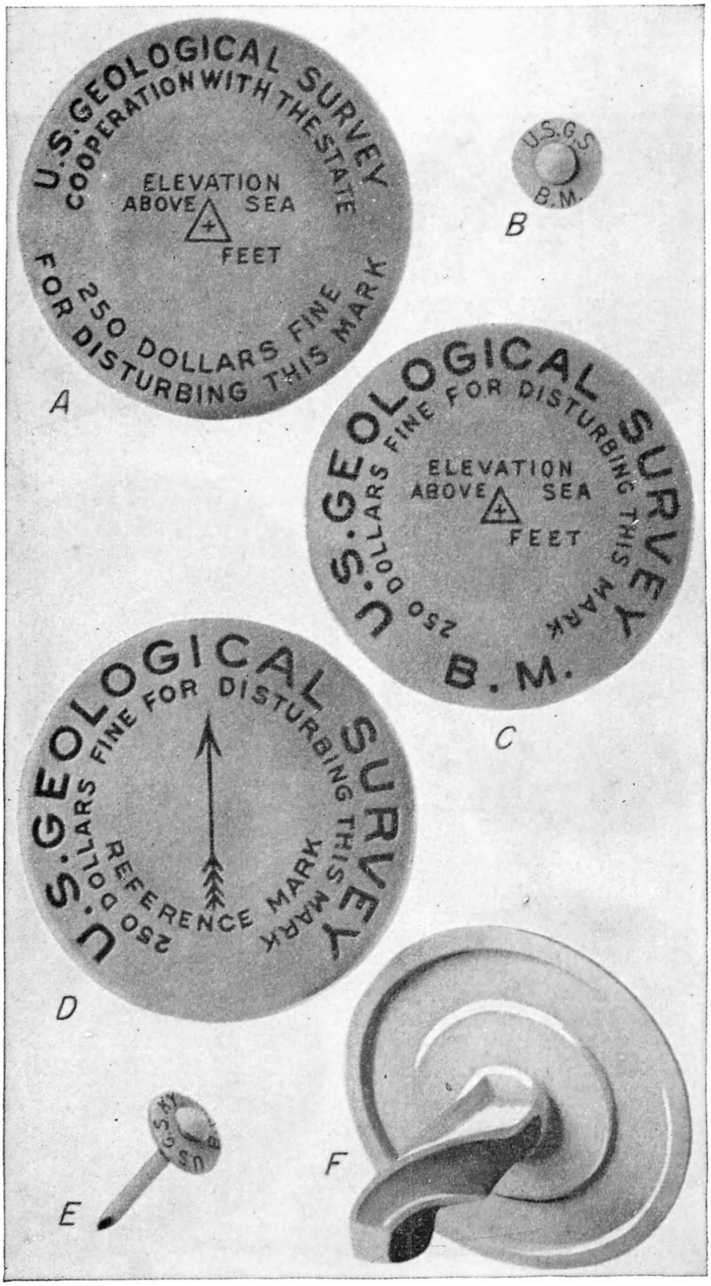


FIGURE 17.—USGS station marks: *A*, Triangulation or transit-traverse (marked "TTR" and numbered). *C*, Level bench mark, which may be later used as transit-traverse station, marked "TTR" and numbered. *D*, Reference tablet for triangulation, with arrow to station. *B* and *E*, Copper temporary level bench marks. *F*, Reverse side of *A*, *C*, or *D*. (Courtesy of USGS.)

Symbols for small areas need to be defined in terms of the acres represented by one symbol. Each area definition varies from map to map, depending on scale, intensity of land use, and purpose of the soil map. Names of symbols and the features they identify are as follows:

Name of symbol:	*Feature*
Rock outcrop	Small area of exposed bedrock.
Stoniness	For a small area of a stony phase: (a) stony, and (b) very stony.
Gravel	Small area of a gravelly type.
Chert fragments	Small area of a cherty type.
Clay spot	An exposure of clay.
Clay butte	A small clay butte—remnant of an old surface—like the miniature clay buttes in the Badlands.
Gumbo or scabby spot	Small area of Solonetz or of truncated solodized-Solonetz.
Sand spot	Small area of very sandy material.
Lava flow	Small or large area of nearly barren lava. (Reconnaissance legend only.)
Made land	Small area of fill, and the like.
Blow out	Small area of soil deeply truncated by wind.
Moderate wind erosion	(See section on The Soil Phase.)
Severe wind erosion	Do.
Wind hummocks	Small area with hummocks of wind-drifted soil.
Overblown soil	(See section on The Soil Phase.)
Moderate sheet erosion	Do.
Severe sheet erosion	Do.
Moderate gully erosion	Do.
Severe gully erosion	Do.
Moderate sheet and gully erosion	Do.
Gully	For use where individual gullies are shown to scale. (See section on Accelerated Soil Erosion.)
Uneroded spot	For small area of an uneroded soil in a larger area of eroded soil.
Kitchen midden	Old refuse dump of prehistoric people where too small to enclose with a boundary.
Wet spot	An area of soil too small to enclose within a boundary that is imperfectly to very poorly drained and is at least one drainage class lower than the area within which it is placed.
Areas of salt- and alkali-affected soil:	
Saline spot	An area of saline soil too small to enclose within a boundary.
Strongly affected	(See section on Estimation and Mapping of Salts and Alkali in the Soil.)
Moderately affected	Do.
Slightly affected	Do.
Free of toxic effect	Do.
Location of sample and reference number	Dot and reference number.

PLACE NAMES

Accurately determining the place names of cultural and physical features is very important to the soil survey because they help the user to locate himself. Names should be selected to identify all prominent features adequately. In areas where such features are sparse, it is important to name the less prominent features so that sufficient place names are given for orientation. In an isolated rural area, for example, a country store or some similar feature that would normally be unimportant, should be named. But names that contribute nothing to the use of the map and to the reader's location should be omitted.

Place names to be shown.—Names of the following features should be shown on field sheets:

- Cities, towns, villages, and other settlements.
- Rural post offices and railroad stations.
- Country schoolhouses.
- Country churches.
- Experiment stations and substations.
- Isolated ranches and resorts that are important landmarks in sparsely settled districts.
- Important public institutions, like universities, colleges, and State hospitals.
- Railroads (steam or electric). Besides the name of the railroad, it is helpful to give the name of the branch, line, or division, for complete identification.
- United States highways (use number).
- Bridges, ferries, and fords.
- Through trails.
- Principal steamboat routes on large lakes and rivers.
- Large canals, ditches, and aqueducts.
- Tunnels, dams, lakes, reservoirs, and large public works.
- Lighthouses, lightships, and lifesaving stations.
- Large parks and cemeteries, if the scale will allow.
- Airports and landing fields.
- Isolated mines, quarries, prospects, and oil wells.
- Isolated furnaces and smelters.
- Civil divisions.
- Reservations.
- Hydrographic features.
- Prominent features of relief.
- Springs, wells, and tanks, especially in arid sections where these features are of vital importance.

Determining correct names.—The soil scientist uses the best maps available in an area for guidance on place names. The place names on maps published at the National map standards have been carefully checked and edited and can be assumed to be correct. Less precise maps are also useful in determining the place names for some features. Such names should be checked or confirmed while in the area.

Where no maps are available for reference, or where the larger scale of the soil map requires the naming of features that do not appear on previously published maps, the soil scientist must use care in determining the names of the features and their correct spellings. Information may be obtained from local residents. It is best to consult more than one such source of information. If such discussions result in differences in place names, courthouse records may be checked. Local engineers and land surveyors are frequently a good source of reliable information. Questionable names are noted and submitted for decision to the Board of Geographic Names.

Lists of place names.—A complete list of the place names used throughout the survey is unnecessary. An annotated list of doubtful names is needed. The important point is that names appear on the field sheets in proper relation to the features they designate. Proper interpretation of stream names can be confusing unless the names are properly placed.

LETTERING

Neatness and legibility of lettering is perhaps more important on soil maps than on most other kinds of maps, because large numbers of many kinds of soil areas and many physical and cultural features are shown and because so much use is made of photographic copies of the field sheets. So many soil symbols and place names are used that the detail becomes confusing unless the lettering is neat, legible, and well placed. Each soil scientist must learn the art of freehand lettering.

The soil scientist should use a natural, simple style of lettering that can be done rapidly, and use it consistently (pl. 8). "Fancy" or "artistic" styles should be avoided. Among the many styles, the single stroke, either slant or vertical, best meets the requirements of soil scientists. It most nearly approaches the strokes ordinarily used in writing, adapts itself to small space, can be condensed or expanded without affecting the legibility, is easy to do, and can be made rapidly.

Figure 18 shows the single-stroke slanted letter in capitals, lower case, and numerals and suggestions for the order of strokes. In the illustration, the directions of the strokes are indicated by arrows and the sequence by numbers. Both slant and vertical letters are formed in the same manner. It is well to form the habit of following the directions and sequences of strokes as suggested in the illustration.

Skill comes with practice. The pen should be held as in writing and the strokes made with an even, steady motion. Slant or vertical lines are made with a downward stroke, and horizontal lines with a stroke from left to right. The slant of the letters should be uniform. A fine-point stiff pen is best; crowquills are too flexible. As waterproof ink dries rapidly, the pen point should be frequently wiped with a cloth or chamois.

Letters should be well formed and properly spaced. Properly made letters are of different widths. *W*, for example, occupies more space than *I* or *J*. In lettering symbols and names, this should be taken into account and the letters spaced to give neatness and proper position. With practice, one acquires the knack of spacing letters and judging the amount of space a specific word or symbol will occupy.

Aligning letter symbols and words approximately horizontal and parallel adds greatly to the legibility of the finished field

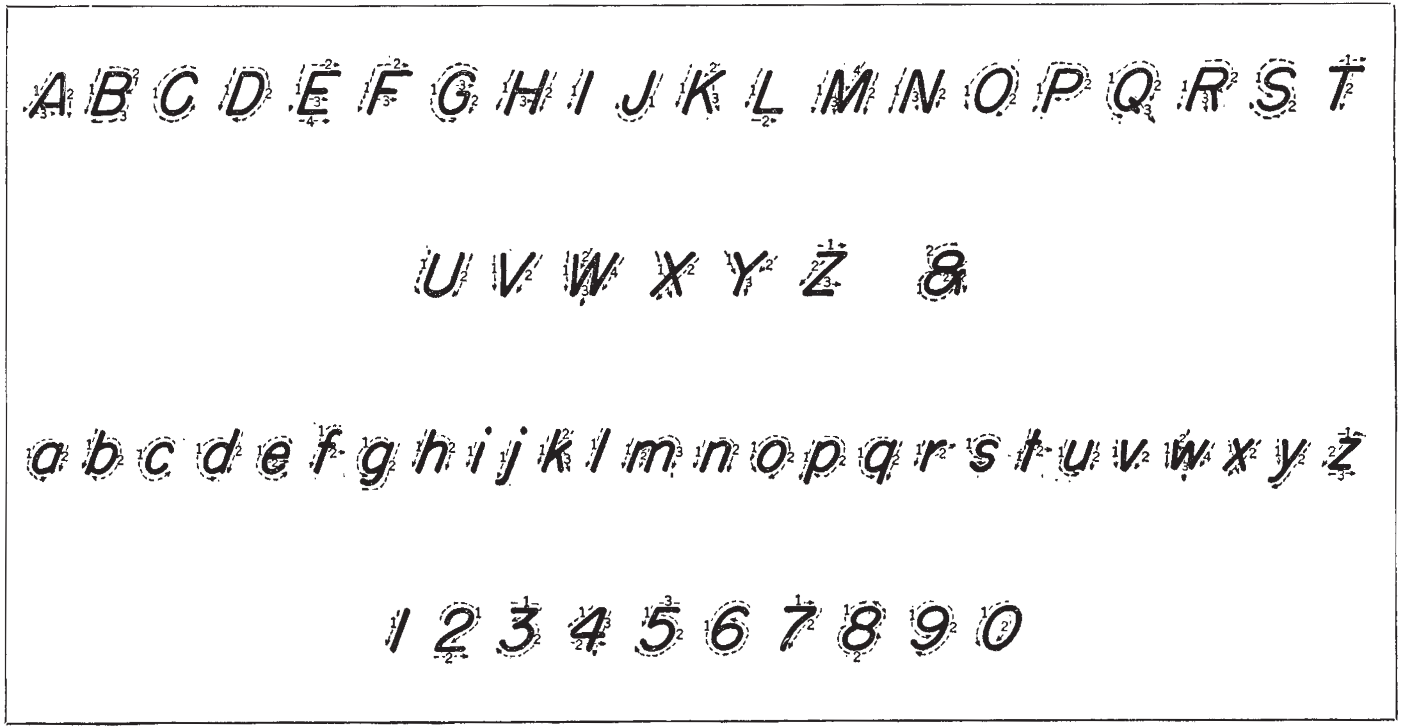


FIGURE 18.—Suggested order and direction of strokes in freehand lettering on field sheets.

sheet. Other things being equal, names of natural features are oriented with the features, and names of cultural features are horizontal.

Soil symbols should be placed as near the center of the delineated area as possible. Where soil areas are large and irregular, more than one soil symbol, placed to permit easy identification of the area, is helpful. When an area is so narrow that the symbol cannot be placed in a horizontal position, it should be placed in the area at an angle or vertically. Symbols are placed outside of their specific areas, with an arrow indicating the area, only when absolutely necessary.

It is standard mapping practice to use slant or vertical capitals, or capitals and lower case letters, to designate specific classes of physical or cultural features. In soil mapping, it is helpful to conform to these standards within the limitations of single-stroke letters. Standards for soil survey field sheets are as follows:

Features	*Lettering*
Civil divisions and cities over 2,500 population	Vertical, capitals.
Towns and villages under 2,500 population	Vertical, capitals and lower case letters.
Large water features, double-line rivers, large lakes and reservoirs	Slant, capitals.
Small water features, small streams, branches, creeks, lakes, ponds	Slant, capitals and lower case letters.
Large physical features, mountain ridges, valleys	Vertical, capitals.
Small physical features, hills, knobs, gaps	Vertical, capitals and lower case letters.
Cultural features, railways, power lines, bridges, airports, universities, cemeteries	Slant, capitals.
Soil symbols	Slant or vertical, capitals or lower case letters and numerals, as standardized for the survey.

CHECKING FIELD SHEETS

In order to meet modern requirements, most soil mapping demands that a great amount of detail be shown on the aerial photograph. Intricate patterns of boundaries among soil types and phases need to be accurate. Besides, the drainage and cultural features must be indicated clearly.

The soil scientist must recall that regardless of his knowledge of soils or his ability to classify and locate soil areas on the ground, the success of his work depends on its legibility. The results of his researches must be readily understood by others. Some omissions and errors are inevitable, of course, but a successful party chief keeps them to a very low minimum.

It is essential that all data be carefully reviewed and checked and properly matched from one field sheet to another. In order to do this accurately, it is well for the soil scientist to know where and in what form such oversights most frequently occur. With such knowledge, he can concentrate his inspection and checking on the most common causes.

Common errors.—From inspection of a great many field sheets, the following are found to be the most common mistakes, in order of their frequency:

1. Incorrect matching between aerial photographs.
2. Failures to close soil boundaries.
3. Areas without soil symbols, or with questionable ones not named in the legend.
4. Incorrect interpretation of cultural and drainage features.
5. Incorrect place names.

Differences in matching between aerial photographs occur perhaps most frequently at corners where more than two photographs abut. The most common failures are illustrated in figure 19. Aerial photographs overlap, have differences of scale in adjoining

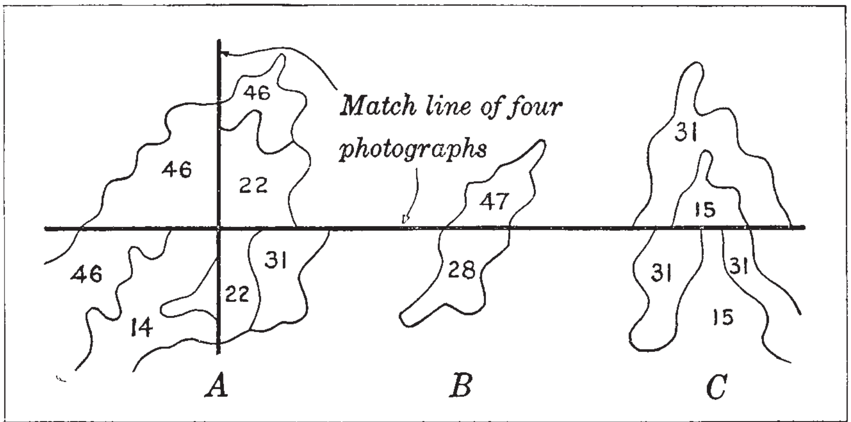


FIGURE 19.—Examples of failures to match aerial photographs: *A*, Corners fail to match; *B*, boundaries match, but not symbols; *C*, symbols match, but not boundaries.

pictures, and vary in light and dark tones; therefore, unless a systematic method is used, mistakes may frequently occur when inking the penciled field sheets. A few suggestions on avoiding such mistakes may be helpful.

1. Match lines should be placed on all photographs before mapping.
2. Match lines should be straight for long distances if possible, or follow sharply defined features, such as prominent roads or rivers. A stereoscope is useful in placing match lines on aerial photographs.
3. The matching boundaries should be transferred by relation to physical features that can be identified on the photograph rather than by scale. Some feature may be selected closely approximating the boundary line on the completed sheet and located on the adjoining sheet to continue the boundary. This can be done rapidly and accurately with the stereoscope.
4. Insofar as practicable, in order to avoid the distortion along the margins, only the center of the aerial photograph should be used for mapping.
5. Some cartographic difficulties in joining sheets may be avoided by transferring soil boundaries and symbols from the mapped sheets

to the adjoining new ones, but often this is bad practice. By studying the differences in mapping of individual members of the party at such margins, the party chief has a good check on the consistency of the mapping. In fact, many good party chiefs avoid giving individuals blocks of photographs for this very reason. By having match lines near roads, differences can be most conveniently adjusted. This scheme perhaps leads to some more work in joining but the ultimate objective of developing an accurate and consistent soil map is more nearly attained.

Omission of adequate boundaries to close all classified areas is a common error. Some typical examples of failures to close soil boundaries, thus leaving uncertainty of classification, are shown in figure 20.

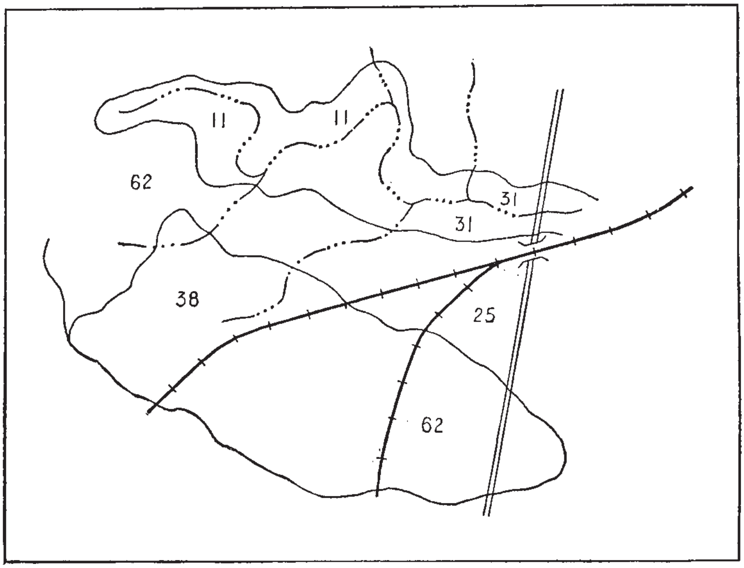


FIGURE 20.—The omission of soil boundaries causes serious errors.

To avoid such errors in closing boundaries, it is best to ink, individually, the drainage and culture first. Then the delineated soil areas are inked; each area is completely closed and its soil symbol placed before proceeding to the next one.

Areas without symbols, or with questionable or incorrect ones, occur in various forms. An area may be closed without a soil symbol; symbols may appear on the field sheet that do not appear in the accompanying legend or are unnamed; and illegible symbols may result from careless lettering or poorly made corrections. Listing each new symbol as soon as it is used, eliminates the appearance of symbols on field sheets that do not appear in the legend. When any new symbol appears to be required and is used temporarily, it should immediately be taken up with the chief of party for approval. If disapproved, the temporary symbol should be replaced before inking. This applies to *combinations* of letters and numbers used to indicate individual soil areas, not simply to the individual letters and figures in such combinations.

Practice and care in lettering, judgment in placing symbols, and careful erasures and reinking of corrections will reduce illegibility to the minimum. A carelessly made 91 may be read as 11, 71, or 77. Corrections should not be made by marking over the old symbol.

Incorrect interpretation of drainage or cultural features can seriously reduce the accuracy of soil maps. In figure 21, the

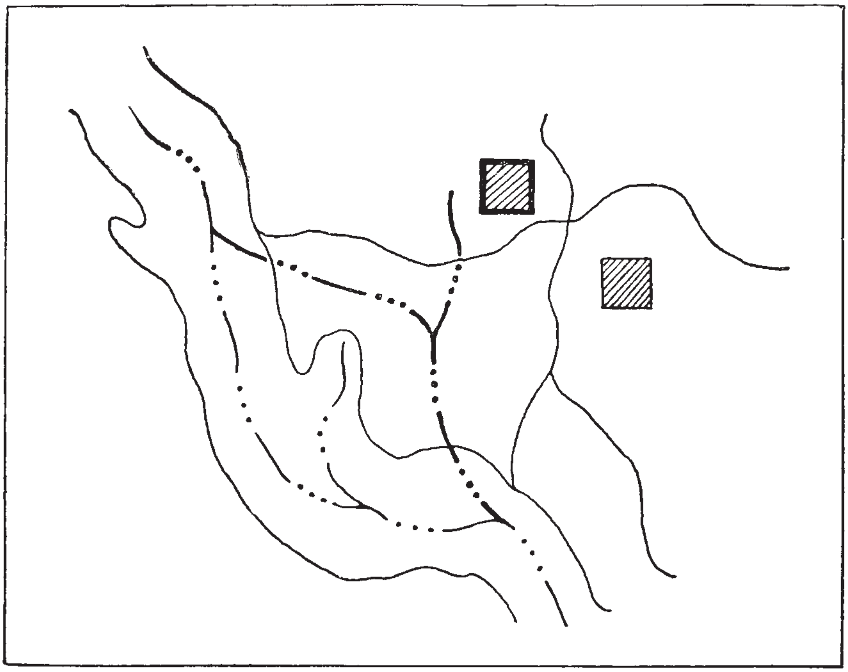
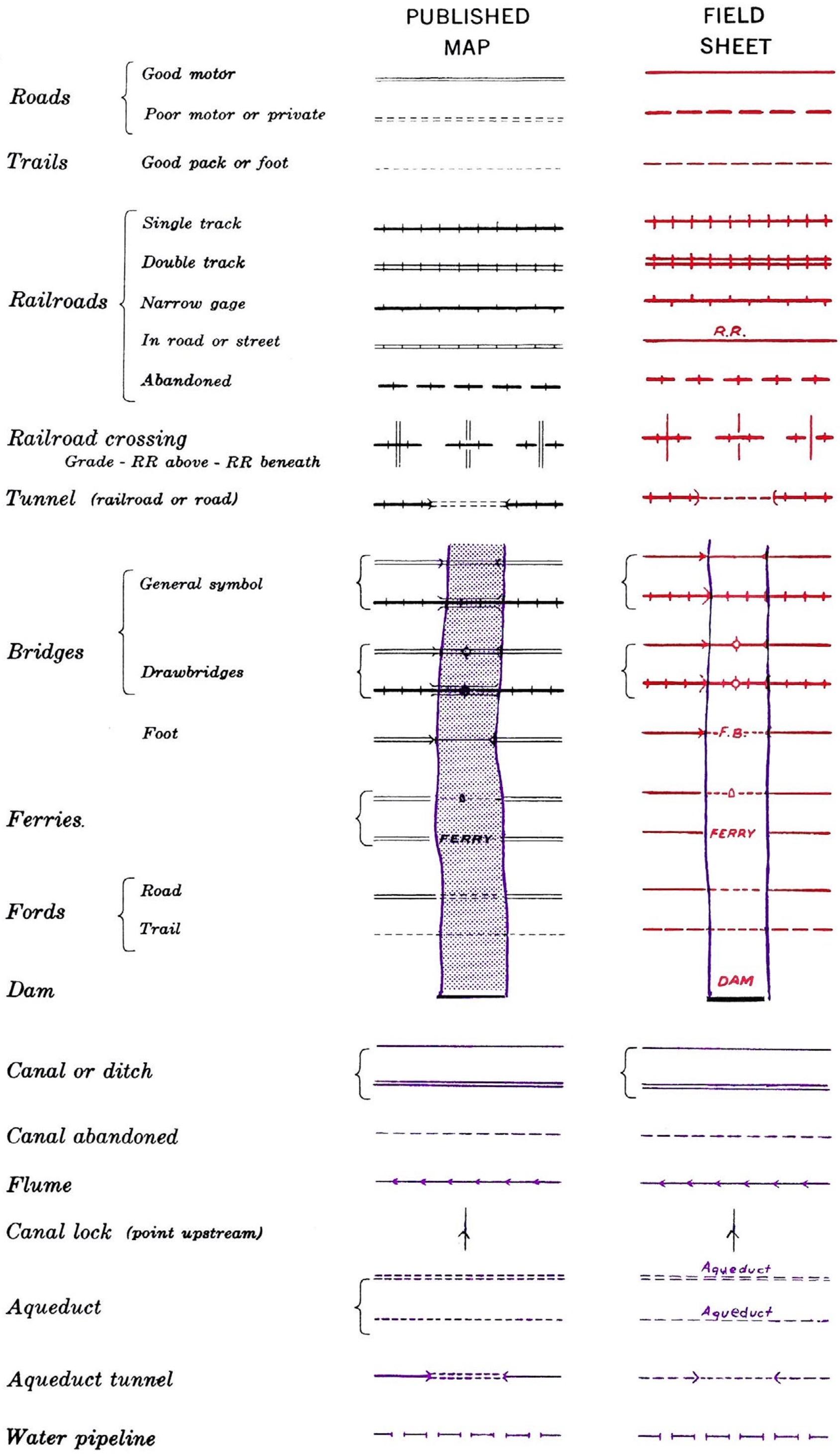


FIGURE 21.—Due to heavy woods, the positions of a fire tower and stream, light shade, were misinterpreted in contrast to their true positions, heavy shade. Consequently other drainage and soil boundaries are seriously in error.

locations of a stream and fire tower were misinterpreted due to heavy timber and the dark tone of the aerial photograph. Heavy lines indicate the true position of these features, light lines their mapped position. Because the soil boundaries were located in relationship to these two outstanding features, the result is incorrect soil classification of the area; and the necessary adjustment will affect the soil boundaries of adjoining areas. Had a careful study of the aerial photograph been made with a stereoscope, this error would not have occurred. Such instances can be greatly reduced by careful observation in the field, a study and understanding of photographic interpretation by the sur-

WORKS AND STRUCTURES



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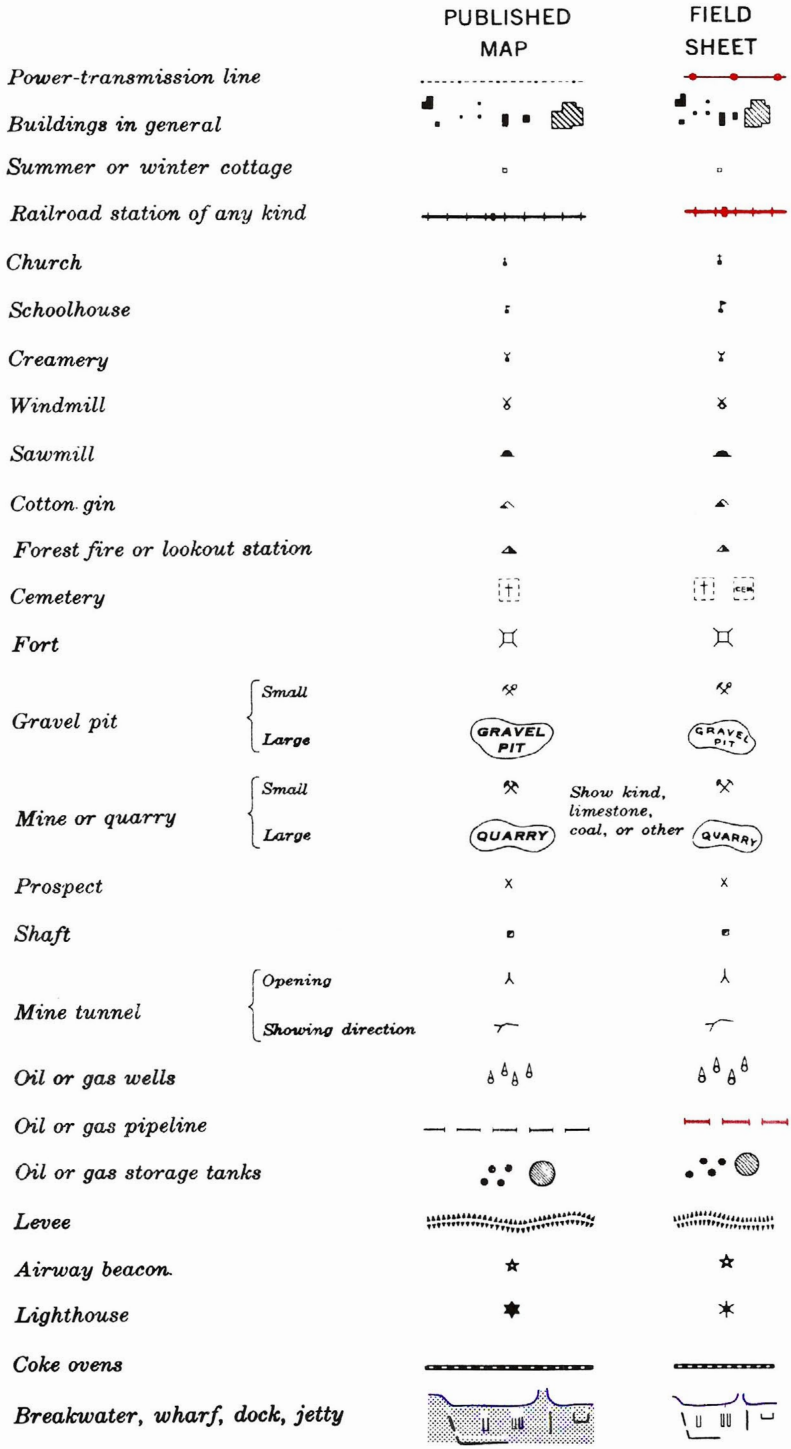
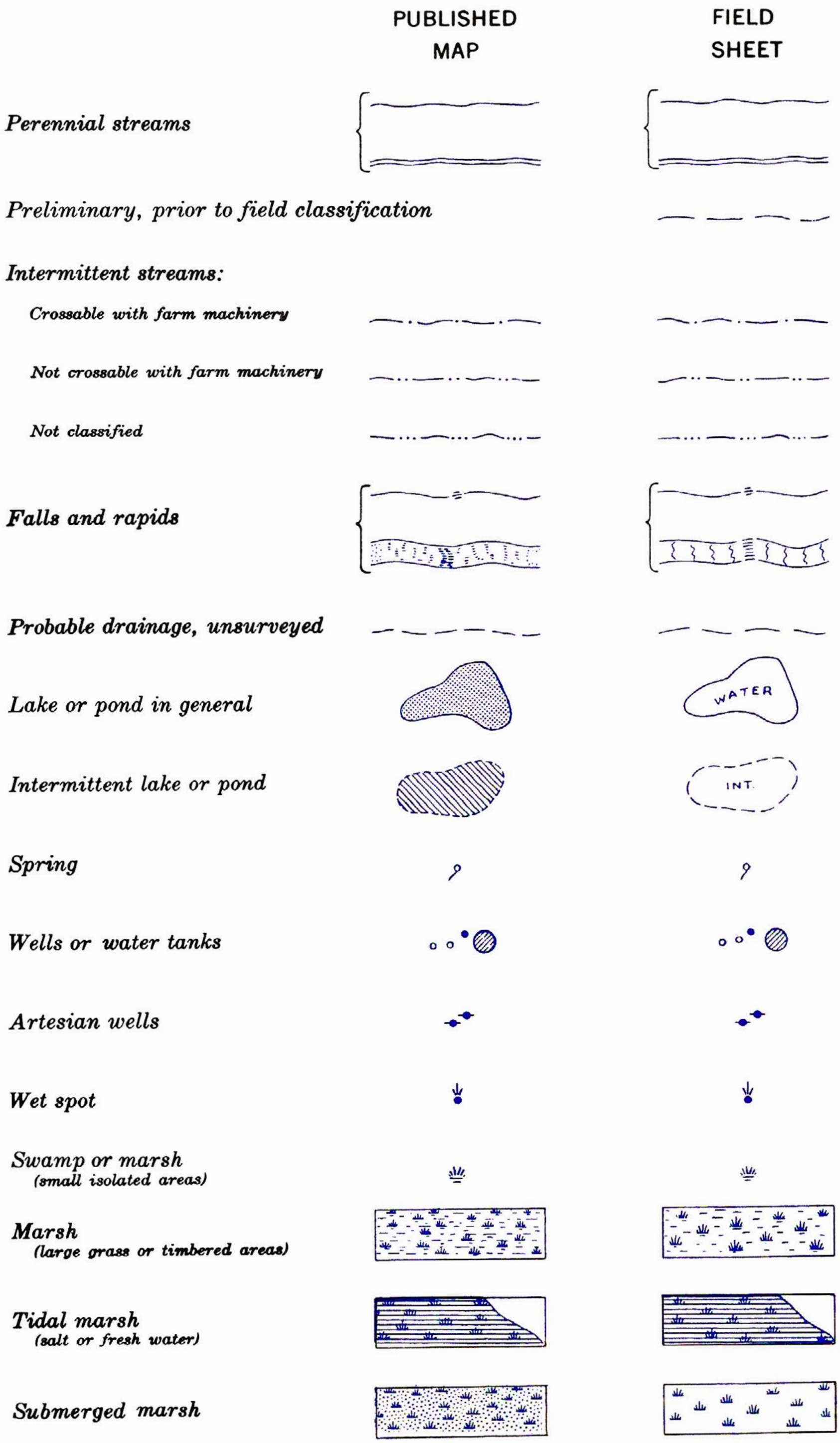
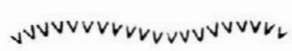
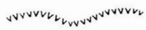
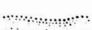
WORKS AND STRUCTURES - CONTINUED



DRAINAGE


PUBLISHED MAP
FIELD SHEET
Perennial streams
Preliminary, prior to field classification
Intermittent streams:
Crossable with farm machinery
Not crossable with farm machinery
Not classified
Falls and rapids
Probable drainage, unsurveyed
Lake or pond in general
WATER
Intermittent lake or pond
INT.
Spring
Wells or water tanks
Artesian wells
Wet spot
Swamp or marsh (small isolated areas)
Marsh (large grass or timbered areas)
Tidal marsh (salt or fresh water)
Submerged marsh

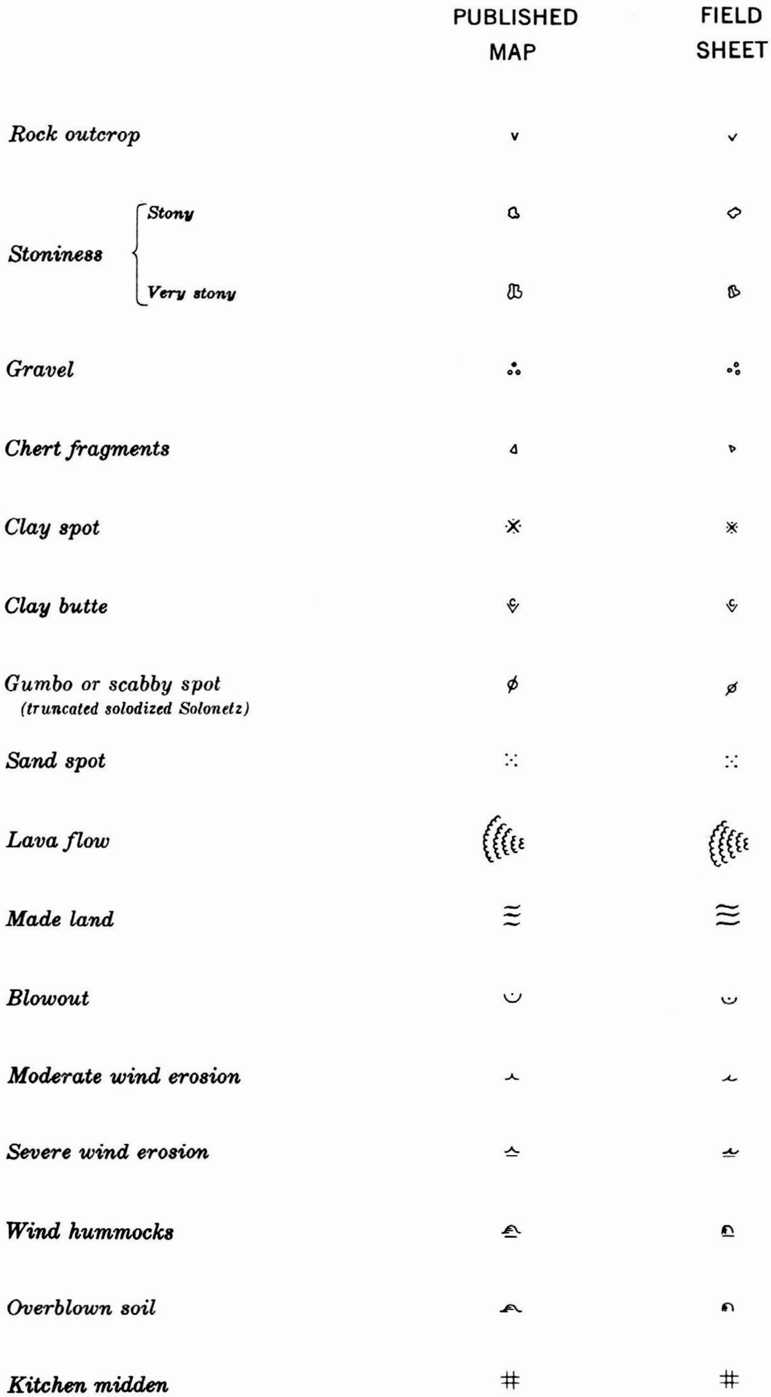
RELIEF

	PUBLISHED MAP	FIELD SHEET
Escarpment, other than bedrock		
Bedrock escarpment		
Prominent hills or mountain peaks		
Sink holes and depressions:		
Easy to cultivate across		
Difficult or impossible to cultivate across		
Containing water most of the time		
Sand wash (riverwash)		
Mine dump		
Sand dunes (dune land)		

BOUNDARIES, MARKS, AND MONUMENTS

	PUBLISHED MAP	FIELD SHEET
National, State, or Province line		*(Red or green)*
County line		*(Red or green)*
Civil township, district, precinct, or barrio		*(Red or green)*
Reservation line		*(Red or green)*
Land-grant line		*(Red or green)*
City, village, or borough		*(Red or green)*
Cemetery; small park, etc.		*(Red or green)*
Township line		*(Red or green)*
Section line		*(Red or green)*
Township and section corners, recovered		
Boundary monument		
Triangulation point or primary-traverse station		
Permanent bench mark (and elevation)	BM × 1232	B.M. 1232 ×
Supplementary bench mark (and elevation)	× 1232	× 1232
Any located station or object (with explanatory note)	⊙	⊙
Location of major soil samples (not published)		Ⓢ

SPECIAL SYMBOLS



SPECIAL SYMBOLS - CONTINUED

	PUBLISHED MAP	FIELD SHEET
Areas of soluble salts or alkali:		
Strongly affected	A	A
Moderately affected	M	M
Slightly affected	S	S
Free of toxic effect	F	F
Location of sample and reference number	• 26	• 26
Saline spot	+	+
Uneroded spot	U	U
Moderate sheet erosion	S	S
Severe sheet erosion	SS	SS
Moderate gully erosion	G	G
Severe gully erosion	GG	GG
Moderate sheet and gully erosion	SG	SG
Gully:		
Not crossable with farm machinery		
Crossable with farm machinery		

STYLES OF LETTERING FOR FIELD SHEETS

ABCDEFGHIJKLMNOPQRSTUVWXYZ&

abcdefghijklmnopqrstuvwxyz

1 2 3 4 5 6 7 8 9 0

Freehand vertical lettering to be used for cities, towns, churches, schools, ranches, state or county names, reservations, section numbers, land grants, and civil divisions. Also for hills, mountains, plateaus, valleys, peninsulas, islands, and other natural land features.

ABCDEFGHIJKLMNOPQRSTUVWXYZ&

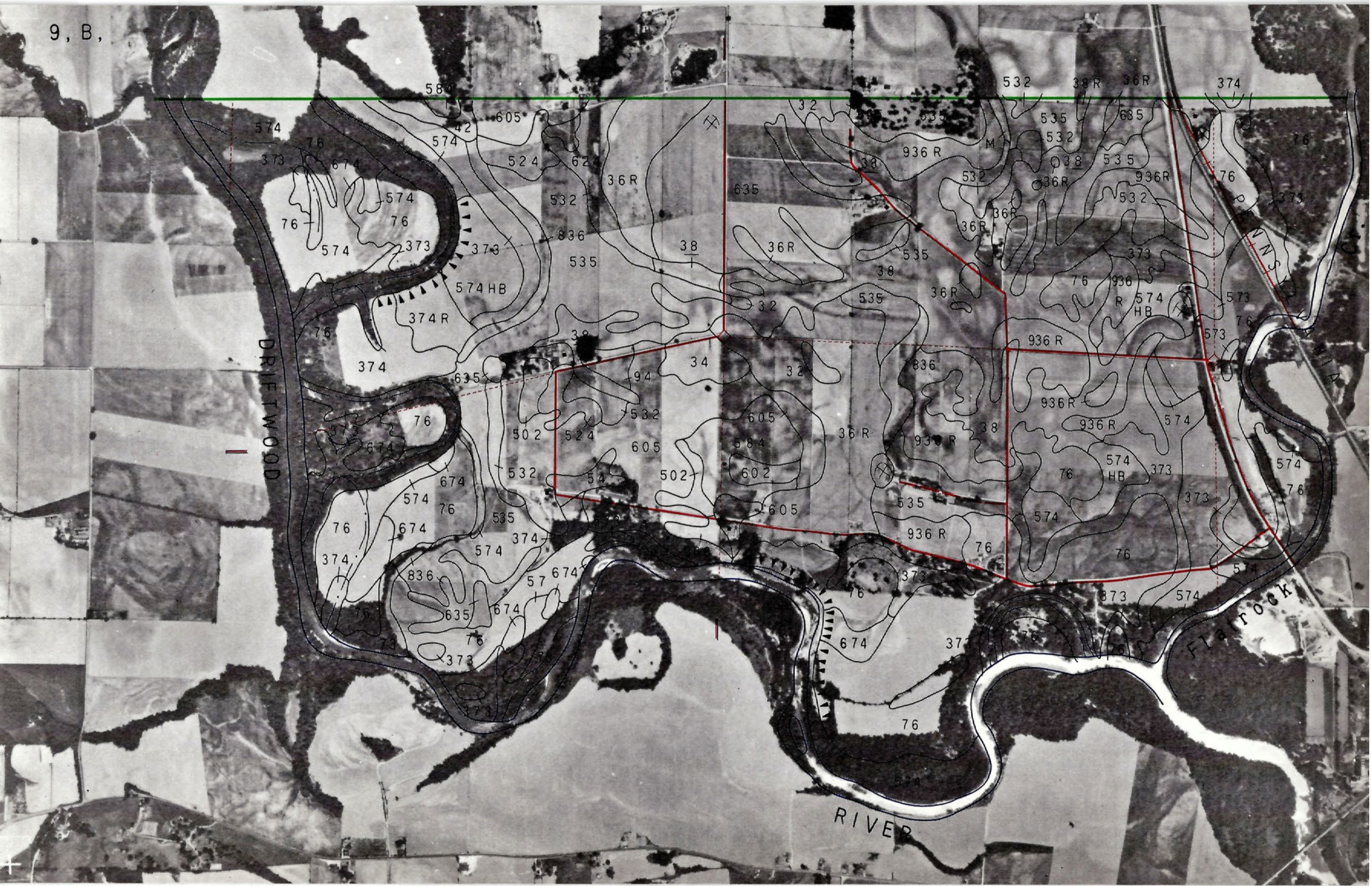
abcdefghijklmnopqrstuvwxyz

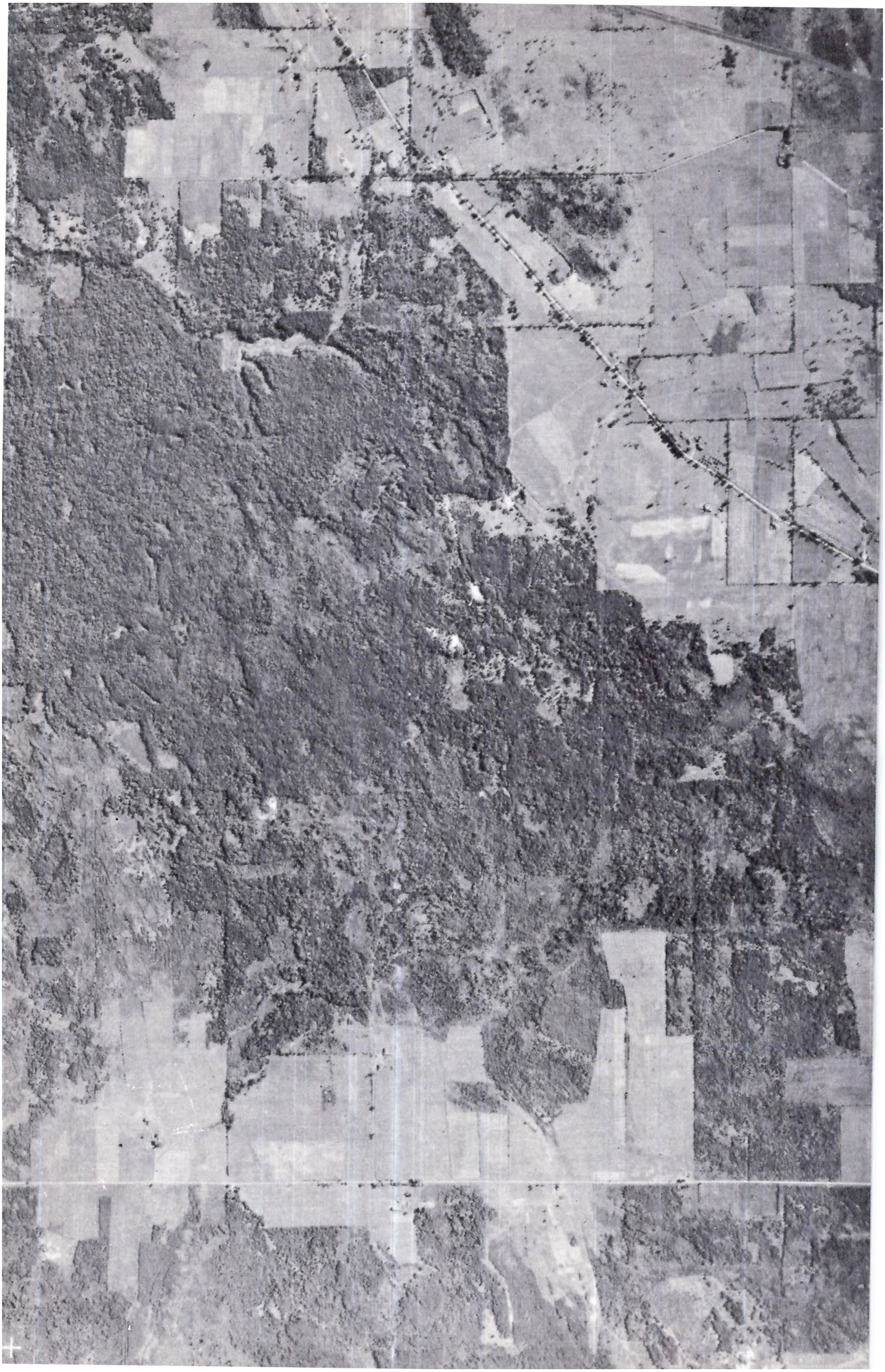
1 2 3 4 5 6 7 8 9 0

Freehand slant lettering to be used for public works such as railroads, canals, U. S. highways, tunnels, bridges, dams, institutions, mines, camps, ditches, pipelines, wells, and for all hydrographic features such as oceans, bays, gulfs, lakes, ponds, rivers, streams, springs, falls, marshes, and glaciers.

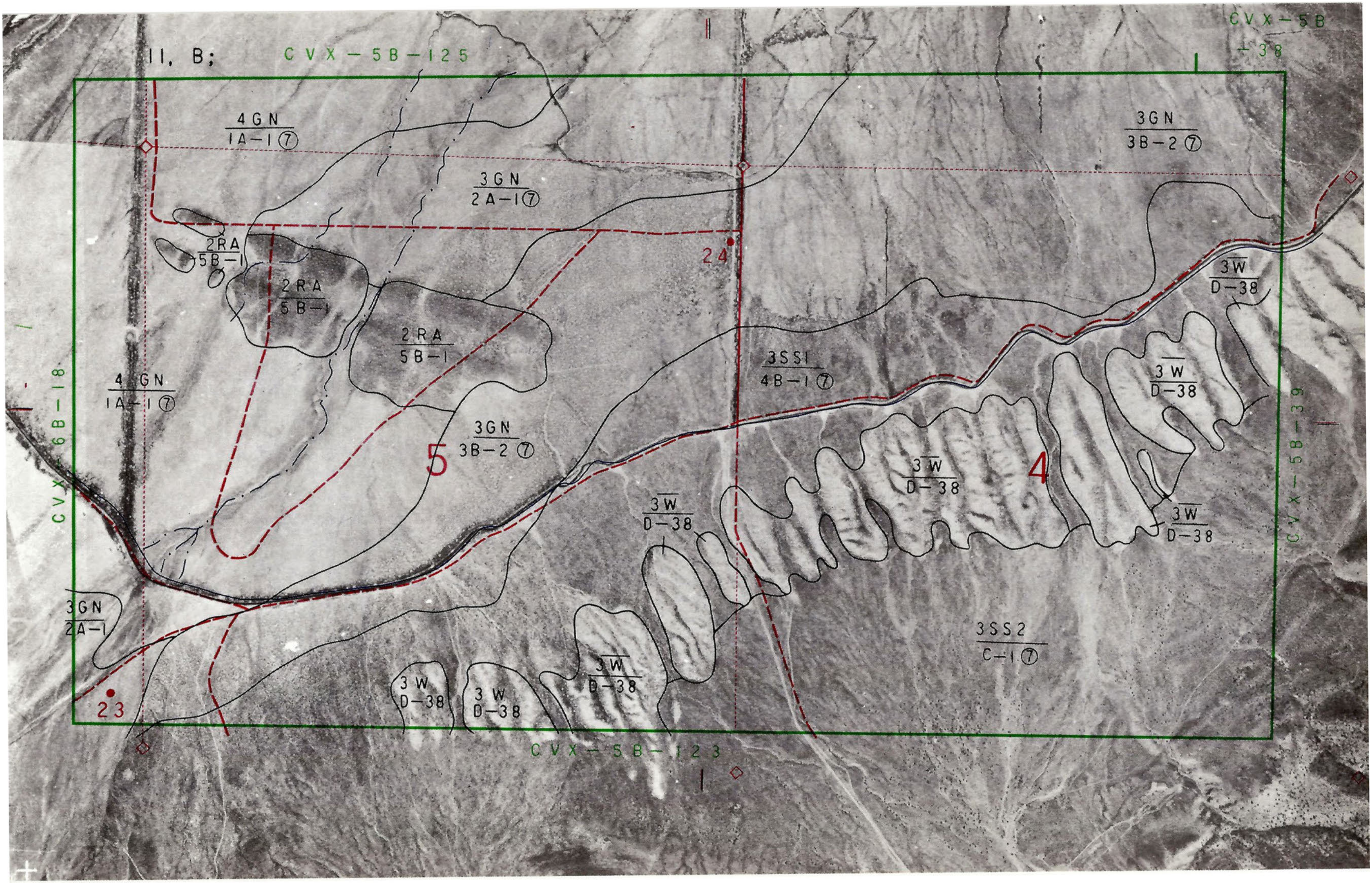
SAMPLE FIELD SHEETS ON AERIAL PHOTOGRAPHS

The three following two-part plates illustrate the use of aerial photographs as a base for original soil maps, or field sheets. Numbers 9, *A*; 10, *A*; and 11, *A* are aerial photographs of widely contrasting landscapes; 9, *B*; 10, *B*; and 11, *B* are the same photographs with the original soil maps on them as drawn in the field. These plates illustrate the application of several principles discussed in different parts of the ***Manual***, including inking of various symbols in red and black and match lines in green. It will be seen that some soil boundaries coincide with marks of pattern boundaries on the photographs and that others do not. Notice, also, the variation in number of reference points that the mapper walking over the terrain has for location. All soil units shown on the original soil maps were, of course, identified by observations on the ground, including soil profile examinations.


9, B,
DRIFTWOOD
RIVER
Flatrock



10, B;


II. B;
CVX-5B-125
CVX-5B-38
4GN / 1A-1 ⑦
3GN / 2A-1 ⑦
3GN / 3B-2 ⑦
2RA / 5B-1
2RA / 5B-1
2RA / 5B-1
24
3SS1 / 4B-1 ⑦
3W / D-38
4GN / 1A-1 ⑦
CVX-6B-18
5
3GN / 3B-2 ⑦
3W / D-38
4
3W / D-38
3W / D-38
CVX-5B-39
3GN / 2A-1
3SS2 / C-1 ⑦
3W / D-38
3W / D-38
3W / D-38
23
CVX-5B-123

LEGEND FOR PLATE 9, *A* AND *B*

A sample photograph and field sheet in a characteristic general farming area of the eastern Middle West—Bartholomew County, Ind. The scale is about 1: 20,000. The zonal soils belong in the Gray-Brown Podzolic group. Besides types and phases of these, there are types in the Humic-Gley and Alluvial soil groups. Only parts of the pattern of light-and-dark in the fields correspond to boundaries between Gray-Brown Podzolic and Humic-Gley soils. The soils have developed from Pleistocene valley-train materials, partly overlain by more recent alluvium and some wind-blown fines. The relief is nearly level to gently undulating. On the whole, drainage is good. Some of the boundaries separate soil-slope phases. The soils are used for general mixed farming in units of medium size. Corn and soybeans are prominent on the Alluvial soils. Here many local reference points—houses, isolated trees, field lines, road corners, and wood-lot boundaries—help the mapper to keep himself located. Yet it will be noted that the boundaries of the low-lying Alluvial soils (all those numbers ending with 73, 74, or 76) do not coincide with those of the woodland along the streams. A low sand dune in the northwestern part of the map does not show clearly in the photograph (area 605 on the map).

LEGEND FOR PLATE 10, *A* AND *B*

Sample photograph and field sheet in a mixed forested and farming area in Franklin County, N. Y. The scale is about 1: 20,000. The land is undulating to gently sloping. The zonal soils are Podzols, but the dominant soils in this area are imperfectly and poorly drained Gray Hydromorphic and Humic-Gley soils. The large wooded area includes poorly and very poorly drained soils from sandy material of marine origin and some small spots of well-drained soils. The open farm land is used mainly in long leys; only about 10 percent is plowed annually. The soils are developed on late Wisconsin drift of low relief. The photograph was taken in September at a time when the soils were moist and color contrasts among them were at a minimum. It will be noted that few reference points for location guide the mapper in the wooded area. Within it, the individual soil types and phases make such an intricate pattern that they are included in a defined complex as the mapping unit. Even the land-use boundaries cannot be drawn from the photograph alone in the cleared places. Although very useful to the soil mapper as a base, this photograph is an example of one from which little about the soil can be interpreted correctly in the office.

LEGEND FOR PLATE 11, *A* AND *B*

A sample photograph and field sheet in a semiarid, treeless region of Sierozem soils, Utah County, Utah. The scale is approximately 1: 16,000. A large irregular area of sloping eroded soil, developed from an old terrace remnant of Lake Bonneville, stands out distinctly as a light pattern in the lower right-hand corner of the photograph. A gently sloping, shallow, gravelly soil shows plainly as a dark pattern in the upper left-hand part. Elsewhere, patterns on the photograph fail to give reliable clues to the soil boundaries, and they must be "dug for."

veyor, and the effective use of the stereoscope. If the drainage pattern is penciled on the aerial photograph before commencing mapping by using the stereoscope, it will serve the surveyor continually as a means of orientation in heavily wooded or rough terrain.

Figure 22 shows how the location of place names is sometimes confused.

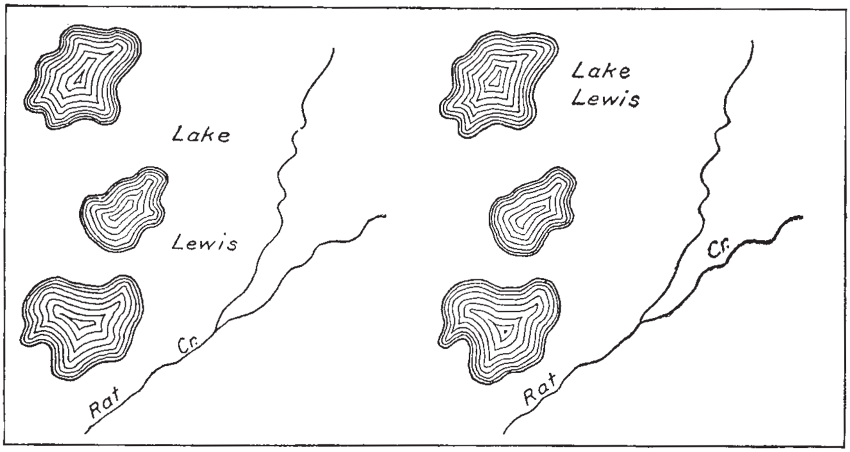


FIGURE 22.—Location of place names: Left, confusing; right, correct.

Transmittal letters.—Since the field and office work necessary to complete and to publish a soil survey continues over a considerable period and field sheets need to be shipped from one office to another, it is important that a complete record be made of all material transmitted. Even though it takes some time to check and to list large numbers of aerial photographs and other field sheets, it must be done. Shipments need to include a transmittal letter that itemizes the material. Such lists may be attached to the transmittal letter, with copies in each package.

The code, roll, and individual picture numbers should be given for aerial photographs; topographic quadrangles should be listed by name; and plane-table sheets should be assigned a number. Other maps or mosaics should be listed by name or assigned a number for identification. Supplementary material, such as photographic indexes and legends, should also be itemized.

Upon receipt of such material in any office, it should be immediately checked against the transmittal lists and receipt acknowledged. Any discrepancies need to be traced at once so that missing materials can be located.

Special instructions.—All the base-map material transmitted should be accompanied by an index map showing the location of the individual sheets and their relation one to another. Photographic indexes are ideal for aerial photographs. If photo-

935034°—51——9

graphic indexes are unavailable, a suitable one can be made by plotting the approximate center of the flight lines on a suitable base map and placing the photo numbers along the flight line in relation to the center of the pictures.

For topographic quadrangles or other base maps, an adequate index can be laid out on a small-scale map of the area. Such indexes should be marked with the name of the quadrangle or some identifying number or letter.

Overlay material, whether used with aerial photographs or other base material, is marked in the same manner as the base material. When overlays are transmitted with the base material, a specific statement that such overlays are included is needed. If corrections and additions are made on a separate set of maps, these maps are named or numbered like the sheets bearing the soil data and plainly marked and referred to as "correction sheets."

To help in locating specific sheets and in checking the material, separate items should be in order. Aerial photographs are kept in sequence by code symbol, roll number, and print number. Other base material is arranged by either name or number.

Marginal data.—Each field sheet should bear the name of the area or county, the State, the date of the survey, and the name of the soil scientist, or names, if more than one is responsible for the mapping on that particular sheet. Names of others who inked or checked the plotted data should be indicated. The scale of the field sheets should be shown. Commonly the full notes can be put only on the back of the sheet. Where they can be put on the front, they should be, so they will then appear on photographic copies of the field sheets. At least the date and the initials of the mapper should be placed on the front where they will not obscure the photograph numbers.

For use in the marginal lettering of the published map, the full name of the cooperating State agency, the name of its head or director, and the name of the soil scientist in charge of the State soil survey should be furnished. The names of both Federal and State soil scientists participating significantly in the survey are needed.

[For more detail on base map preparation see: SWANSON, L. W. TOPOGRAPHIC MANUAL PART II. U. S. Coast and Geod. Sur. Spec. Pub. 249, 570 pp., illus. 1949.]

EXAMINATION AND DESCRIPTION OF SOILS IN THE FIELD

Two essential elements of a soil survey require intensive field research: (1) Complete descriptions of the mapping units and (2) the location and plotting of soil boundaries. We shall review generally the problem of developing a complete mapping legend before discussing in detail the many individual items that enter into descriptions of soil units—the descriptions that serve as a fundamental basis for soil identification, classification, and interpretation.

Following the decision to make a soil survey of an area, a work plan should be prepared that sets forth the scale of mapping, the general methods to be used, the names of the scientists in the party and its organization, administrative arrangements for transportation, materials, and laboratory service, and the like, together with full descriptions of the uses to be made of the field results, insofar as they can be anticipated, and of all available maps, soil data, and aerial photographs. Where two or more research organizations are cooperating in the soil survey, their relationships need to be defined. (See pp. 43 to 48.)

A descriptive legend, as complete as possible, including *all* soil separations and *all* symbols that are to appear on the soil map, except for the standard symbols given in plates 1 to 5, should be prepared and made available to each member of the field party before any plotting of soil boundaries is undertaken. The first duty of the party chief in a new area is the preparation of such a legend, with at least skeleton descriptions of the mapping units. As the work progresses, especially in a new and undeveloped region, this legend needs to be revised from time to time.

On entering the area to be surveyed, the party chief should scout it thoroughly to get a general picture of the soils, geology, vegetation, and agriculture. Wherever possible this should be done in company with the regional supervisory scientist and the representatives of interested State and local agencies. Frequently, however, it is necessary for the party chief to undertake this work on his own responsibility. He should, of course, obtain the help of any competent and interested soil scientists available.

It is helpful for the party chief to reach the area in advance of his assistants so that he may familiarize himself with the soils, collect the preliminary data, prepare a preliminary field legend, and plan the work program. Toward this end, he must first have clearly in mind the objectives of the soil survey. His problem will be to determine how the soil mapping units and other features may be defined and shown on the map, clearly and definitely, without oversimplification on the one hand and without excessive detail on the other. First, the party chief must determine the mapping units and symbols to be shown. Next, these units must be examined carefully at several places and clearly described. It is desirable that all soil units be examined and described in advance of any mapping. Where this is impractical, all the principal soil units may be defined, together with the subordinate ones in part of the area, leaving the others to be determined later as work progresses.

Where a new soil survey area lies adjacent to areas already mapped, representative examples of soil types already established and described should be examined in them. Full use should be made of any soil maps and reports available within the same general region or for like soil regions in other parts of the country. Usually, the party chief will find it extremely helpful to establish a small working library of soil reports and books or bulletins describing the geology, vegetation, and agriculture of the area.

CLASSIFICATION IN FIELD LEGEND

The setting up of a legend for a detailed soil survey requires first of all the identification and definition of the individual taxonomic units—soil series, soil types, and soil phases. These are sets of soil characteristics that are determined from the examination of sample areas. No soil type or phase can be *identified* on just two or three features alone, although one may be *separated* from a similar soil type or phase on the basis of one of two differences only.[1] Many fail to appreciate this distinction. In our minds we comprehend soils by comparison. Until we compare the soils of widely different climatic and biologic zones, we often fail to appreciate how very many characteristics most of the soils in a local area may have in common.

In a detailed soil survey enough taxonomic units—sets of soil characteristics—must be established and defined to permit the clear recognition and identification of every significant area of each soil in the project. The characteristics in each set are not precisely fixed; some range from the norm, or central standard, of the unit is allowed. In establishing these permissible ranges, no characteristic can be allowed so great a range that the fundamental nature of the unit, as a soil landscape, differs significantly from place to place in morphology, genesis, or behavior under use. Nor should the range in any characteristic be fixed narrower than its significance to the unit as a whole. In the present state of soil science, at least, it is impossible to lay down general quantitative rules about individual characteristics, because the influence of any one characteristic, or of a change in any one, depends upon the others in the set. That is, with one profile combination of clay minerals, exchangeable bases, texture, and structure and with a given land form, slope ranges within the set should be held narrowly, say between ½ and 2 percent of slope. With

[1] A soil phase may be separated from the typical soil type or another phase of the same soil type on the basis of a difference in a single feature, such as slope; but a phase in one soil type is separated from a phase in another soil type on the basis of a set of characteristics.

other combinations of characteristics, the slope range may be 3 to 7 percent, 3 to 10 percent, 30 to 50 percent, or any one of a great variety. Small differences in clay content are critical in some sets of characteristics and not in others. The same may be said for any characteristics of soil horizons or array of soil horizons within the profile. Arbitrary combinations of "single-factors" are bound to lead to absurd results.

In defining soil units we must rely on experience and judgment in selecting allowable ranges for any set of soil characteristics. The practical purpose of the soil map must be served, and morphologically unlike soils must be separated.

The individual soil units need to be sufficiently homogeneous to permit making those differential predictions about their behavior and use that the principles and data of soil science permit us to make. We should go further toward narrower ranges in characteristics *only where sound scientific evidence shows that such differential predictions can be expected after further research.* Whatever classification is established in the field, the party chief should continually test it against the results of other research and against the experience of land users. Unnecessary separations reduce the value of his map.

As methods of measuring soil characteristics are refined, and with experience in the field, the soil scientist can establish and recognize continually narrower ranges in soil characteristics. We must guard against establishing narrower ranges just because our methods permit it. It is nearly as bad an error to split up soil types or phases into units not significantly different from one another as it is to include two significantly different units, inadvertently, within one. Furthermore, it is important that the boundaries between the units come at the place of greatest significance in terms of the sets of soil characteristics as a whole. As a simple illustration, we may think of stoniness: Let us say that areas of one soil type are similar in all differentiating characteristics except stoniness and that the range in stoniness extends from a low degree, where the soil can be cultivated, to a high degree, where it cannot be cultivated. In defining phases, or subdivisions, of this soil type, the main point of separation should be that critical place above which the land cannot be cultivated and below which it can be cultivated. On another soil type, this same separation may be neither significant nor necessary because other soil characteristics make it unsuitable for cultivation, regardless of stoniness. It would be as great an error to define stoniness narrowly in the second example as it would to omit the subdivision in the first.

Unreasonably detailed soil classifications, where they occur, commonly result because the soil correlator, the party chief, or both, have failed to face the job of classification. Many experience a real temptation to avoid the mental effort required. A common way of evading the problem of classification is that of setting up arbitrary classes of selected soil characteristics, such as texture, structure, color, and the like, along with arbitrary depths, classes of slope, accelerated erosion, and stoniness, and then letting combinations of these fall where they may. The soil scientist can shrug his shoulders and say: "We have recognized the facts." But the job of the scientist is not only one of gathering facts. He should gather the *relevant* facts and present them in ways whereby they may be readily interpreted. That is the purpose of classification. The details of soil analysis and morphology go into the notebook, not on the map. Between the detailed descriptions and the map lies the problem of soil classification.

Under a scheme devised to avoid classification, if class intervals are selected that will show significant differences in soil characteristics where the allowable range in these characteristics is narrowest, the intervals selected will certainly be much narrower than significant for places where the allowable range of characteristics is wider. The final result is an enormous number of arbitrarily defined separate units (really undefined as soils and even sometimes identified only by local numerical symbols without names that tie them into a standard system of soil classification!), the large majority of which are not really significantly different from one or more other units. In the application of such a scheme, despite the large number of separations—perhaps 2,000 where a proper system of classification would require only 150—some of them will still be too heterogeneous for making practical predictions, either because the arbitrary class intervals for some soil characteristics were not narrow enough in a few instances, or because of exclusion from consideration of characteristics relevant in only a part of the soil units. Such a scheme leads inevitably to poor soil mapping. For one thing, soil boundaries can be plotted accurately only if they come at a *significant* place in the landscape. Besides that, if soil mappers have a large number of boundaries to draw, they are less likely to get any of them accurately placed than they are if they have a smaller number of really significant boundaries.

As explained in detail in subsequent chapters, each separate observed characteristic of a soil horizon—as color, structure, texture, and pH—should be described in notes with standard terms for class intervals. Insofar as possible, standard terms should be used for inferred qualities, even though such qualities cannot be combined arbitrarily into meaningful soil types and other classificational units. The reader will note that some class intervals have slightly flexible ranges so they may be accommodated to specific sets of soil characteristics. Occasionally, class intervals for single characteristics need to be subdivided; often two or more need to be combined.

The normal soil.—First the classifier needs to study the relationships between the soil profiles in his area and the various combinations of environmental factors—slope, parent material, land form, vegetation, climate, and the like. He learns these relationships by comparison. As a general standard of comparison he should, if possible, define the *normal* soil (or soils). In the sense used here, a normal soil is one having a profile in equilibrium or nearly in equilibrium with its environment, developed under good but not excessive drainage from parent material of mixed mineralogical, physical, and chemical composition, and expressing the full effects of the forces of climate and living matter.[2] The typical representatives of the zonal great soil groups are normal soils. If the survey area lies within one principal climatic and physiographic region, one normal soil may serve as a standard for the whole area; otherwise each distinct region within the area will need to be considered separately.

The normal (or zonal) soil may not be the most productive nor the most extensive. Indeed, examples of zonal soils are not always found within the survey area. All the soils may be young, as in an active flood plain, or wet, as in swamps, or extremely limy, or very hilly, or because of some other combination of characteristics, development of a zonal soil has not occurred. In such a soil survey area all of the soils are members of intrazonal and azonal groups. Yet even in such areas, it is helpful to study similar climatic regions and to visualize what the zonal soil would be, if the appropriate landscape were present.

Frequently, several soil types in one area may all occupy normal positions but vary from one another in significant ways. That is, several soil types may satisfy all the requirements defining normal soils and belong to the same zonal great soil group, yet be developed from different mixtures of parent materials the natures of which are significantly reflected in the respective soils. In such a situation one may define the normal soil—the estimated normal soil—by orderly abstraction from the characteristics of those in the group.

A working concept of the normal soil, even in a survey area lacking one, can be a helpful standard for orderly study and arrangement of the other soils and for understanding their morphology and genesis.

Selection of sample areas.—The locating of sample areas should be directed toward one basic aim—to establish a standard for each unit against which other soil units can be compared. It must be emphasized that phases of soil types can be accurately defined and established only in relation to the defined standards for the soil types. The descriptions of some soils also take account of the effects of such processes as the silting of sandy soils being irrigated with muddy waters or flooded with water from glacier-fed streams, or the erosion of sloping hillsides, or the heavy fertilization of soils naturally low in nutrients, or the effects of long grass leys on podzolic soils. Still, the description should be objective and the conditions observed should be clearly apart from predictions of change that are expected to result from processes going forward.

Examinations of soil profiles may be made from road cuts during mapping, but detailed examinations for type descriptions

[2] Of course, it may be said that every soil is "normal" in the sense that it reflects its own history.

(and especially for important soil samples) should not be made in such places unless the road cuts are unusually fresh. Exposure of the soil in a road cut to freezing-and-thawing and to wetting-and-drying leads to great changes in soil structure. Layers of dust may accumulate on the soil along roadsides. In woodland areas the much greater light intensity along the roads favors the growth of grasses and other herbaceous plants that change the character of the upper soil horizons. At times dust from road-surfacing material is highly calcareous and changes the pH of upper layers of podzolic soils, after which other changes follow.

Having selected a representative place for a type description, an excavation is made extending through the solum and into the parent material. It is necessary that the excavation have at least one smooth vertical wall that is wide enough to show the entire profile clearly. It is important that this wall be as uniformly illuminated as possible and that the excavation be large enough to allow an examination of the soil in full depth. With Ground-Water Podzol, Tundra, solodized-Solonetz, self-swallowing soils, and other soils having well developed microrelief, it is helpful to have a trench dug in order that an accurate description can be made throughout both swale and mound.

Mapping units.—After establishment of the taxonomic units, the mapping units are defined. In a detailed soil survey most but not all of the taxonomic units—soil types and phases of soil types—are also mapping units. Even when plotting soil boundaries on aerial photographs of large scale, say 1:20,000 or 1:10,000, the pattern of some taxonomic units may be too intricate to be shown accurately and clearly. These intricate areas need to be combined into a soil association or soil complex[3] and shown as one mapping unit, defined in terms of the taxonomic units making it up (which are, in turn, defined as are any other taxonomic units), their proportions, and their pattern. Usually such areas bear a compound name derived from the names of the individual members of the complex. Solidized-Solonetz and associated soils must often be shown together in complexes. Ground-Water Podzols, Half Bogs, Bogs, and sandy Podzols are also often shown together in complexes on detailed maps.

A complex may consist of two phases of a single soil type that are taxonomically distinct but not mappable as separate units; it may consist of two or more soil types in the same series, or of two or more types in different families, great soil groups, or orders.

No definite rules can be laid down for deciding exactly what level of intricacy in soil pattern should be selected for the change from the mapping of each unit separately to the mapping of defined complexes. The uses of the map and the character and pat-

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[3] The term "complex" is used in detailed soil mapping for those soil associations or parts of soil associations that are shown together because of necessity for clear cartographic presentation. The individual members of all soil associations are shown separately in detailed soil mapping where it is cartographically feasible to do so. (See section on Units of Soil Classification and Mapping.)

tern of the soils need to be taken into account. If the contrast in response to management among the soils is very great, every effort short of confusing cartography should be made to separate them. In some instances this means separating soil areas of only one-half acre or even less on very detailed maps where soil use is intensive. If the soils are similar in many characteristics, or if they are all unresponsive to management anyway, defined complexes should be used where appreciable savings in time can be made without reducing the prediction value of the map. If the soils in an intricate complex must be treated alike in fields, mapping of the individual components may not contribute anything to the prediction value of the map, and the highly intricate pattern may confuse the ordinary user.

The use of complexes does not relieve the scientist of the necessity of accurately describing the profiles of all their components. Data from the laboratory can be used only to characterize individual taxonomic units in the complex. This is also true of carefully planned experimental plots. Data on use experience by fields, however, can be used only to characterize the complex as a whole. Yield estimates and management requirements are needed for the defined complex as a whole.

Exceedingly intricate soil maps are less serviceable to most users than those where complexes are used as mapping units rather than the individual taxonomic units. On the other hand, where complexes are used without careful definitions of the individual taxonomic units and of their proportions and patterns, the maps cannot meet the requirements of a detailed soil survey. Complexes should be used sparingly on detailed soil maps for potentially arable soils.

Most reconnaissance soil surveys are far more useful if the individual taxonomic units are defined exactly as in a detailed soil survey and then combined into defined soil associations or soil complexes for mapping than if more broadly defined taxonomic units, with undefined inclusions, are used as mapping units.

Yet even on detailed soil maps of large scale, mapping units named in terms of a single taxonomic unit are bound to include small portions of other taxonomic units and of intergrades with other taxonomic units—say up to 15 percent.

DESCRIPTION OF SOIL UNITS

The value of soil descriptions depends upon the representativeness of the site selected, their objectivity, their completeness, and their clarity. Since making soil surveys is a very large activity, necessarily involving a great many scientists, the need of standard terminology can scarcely be overemphasized. Soil descriptions by different individuals within the same soil survey party, in different parts of the country, and even in different countries, need to be compared and correlated so that relationships may be established. The field descriptions are used by the regional supervisory scientists, the laboratory scientists, and others. Furthermore, a field party chief may need to turn over his notes and maps to a successor before the project is completed.

Great efforts toward standardization of terminology have been made in recent years. Improvements have been truly remarkable, partly because of the large amount of earlier work already done and partly because of the recognized need. These changes are among the most important ones reflected in this *Manual* over the earlier edition. Standardization can, however, be carried too far. Soils are anything but simple. Our terminology must be broad enough and flexible enough to permit accurate descriptions of all relevant features in all significant detail. We must find a reasonable position between extreme orthodoxy, on the one hand, and the sloppy or irresponsible use of terms on the other. Blind following of standard terminology may lead the soil scientist to overlook important features or to ignore fine but significant distinctions in special sets of soil characteristics.

Despite the improvements made, there is much farther to go in improving terminology. Responsible soil scientists are not in complete agreement on some of the terms used in this *Manual*. Some nearly arbitrary selection has been necessary. With further study and more refined measurements, some definitions will doubtless be changed. Furthermore, individual scientists may wish to use supplementary terms and classes. This should be done by all means where judgment indicates a real need. Usually, however, it is possible to define soils within the framework of terminology suggested in this *Manual*, so that the results can be understood by all.

Before taking up the details of each item in subsequent sections of the *Manual* it may be well to glance briefly at the principal items included in a proper soil description.

THE TAXONOMIC SOIL UNIT

Having established the normal soil as a standard set of characteristics for comparison, each unique local unit, resulting from a unique set of genetic factors, is defined. All the definitions should fit together, with no overlaps or gaps. These are the basic units of classification—soil types and phases of soil types.

Since the soil of the earth is a continuum, the units often merge into one another with gradual changes in characteristics through transitional belts several yards or more wide. Although divisions between units may have to be arbitrary, several characteristics usually change together. The outer limits of the definition of any one unit are bound to coincide with the outer limits of one or more other units. Thus, at the margins between two different soil units, the soils are more like one another than the soil near the margin of each is like the standard for that unit. Some field workers become disturbed over this obvious fact, especially where the transitional belts are broad. They may attempt to set up a new unit for the transition between the two. Often, however, this results in vagueness and overlapping, with two boundaries to define and recognize instead of one, each of which is as difficult as the first.

Each soil unit is a particular kind of landscape. It is defined by its land form and profile, and ranges in each. An individual soil profile occupies a very small place, essentially a point. Thus a soil area has an almost infinite number of profiles. Just as no two white pine trees are entirely identical, neither are any two soil profiles; but all trees called white pine have certain differentiating characteristics in common, as do all the soil profiles included in one named soil type. Each soil unit must be examined and described at several points in order to establish the modal profile and the allowable range in profiles. With experience and skill the soil scientist learns to associate soil profiles with the corresponding land form and can choose the proper places for the most useful examinations. The number of examinations required to establish a unit cannot be fixed. With a little preliminary examination in road cuts or with soil augers,[4] a skillful scientist may be able to prepare a good description from three major profiles, but usually more are required. As the work progresses, these descriptions need to be tested again and again in other areas of the unit. The final soil description is that of a three-dimensional soil-landscape.

In the field notes, observations must be clearly separated from conclusions and speculations. The condition of growing crops is an observable fact, but statements about soil productivity are inferred. The scientist may observe that the soil material is nearly uniform silt loam, rich in silt, low in clay and sand, and without coarse fragments. These are observable facts, whereas the interpretation that the soil is formed from loess is an inference from these and other observable facts. In making observations the soil scientist is guided by principles of genesis, by known relationships between soils and other features of the landscape, and by principles of soil management. These principles are helpful in making decisions about the significance of observable features.

This is not to suggest that speculation about the genesis and use capability of the soil are out of place. Quite the reverse. Such speculations are to be encouraged, but they should be clearly separated from observations. The descriptions of morphology, vegetation, land form, and geology should be as objective as possible. Any experienced soil scientist can testify to the great value of complete, objective original field notes. One can scarcely overemphasize their great usefulness. Many exceedingly important interpretations and relationships have been discovered after the descriptions were prepared—when they were being studied with other descriptions or with data from the laboratory—relationships that were not in the minds of the field men when the observations were being made and recorded. Above all, the features of the soil or landscape should not be left to memory alone.

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[4] The auger, of course, should not be used for major profile studies, nor should road cuts unless they are fresh.

Many soil scientists have difficulty in describing the obvious. Without the exercise of care, the soil scientist may return from a survey area or exploratory trip with complete notes and good photographs of the uncommon soils, crops, and farms but without clear objective descriptions of the common ones. Unless an adequate description of the norm is available, all notes taken lose accuracy and significance.

Whenever practical, basic and detailed studies should be made of virgin soils. Only in these can the upper layers be properly defined. Yet, some companion descriptions of cultivated soils are needed, because many soils change a great deal with cultivation in ways quite apart from deterioration due to erosion, loss of structure, or depletion of organic matter and nutrients. Podzols, for example, may have a thick organic mat, often destroyed in burning and clearing, that is a definite part of the natural profile and essential to an understanding of its genesis. The natural surface horizons of many soils have exceedingly low bulk-densities, which increase greatly after a few years of cultivation. To illustrate, good examples of Subarctic Brown Forest soils may have surface organic layers (A_{00} and A_0) 3 to 6 inches thick over a solum some 19 inches thick. After normal clearing and cultivation the whole solum may be 15 inches thick, due to normal losses of organic matter and increases in bulk density, without any soil removal by erosion or blowing. To make comparisons, one needs a clear concept of the standard cultivated soil as well as of the virgin soil.

Every reasonable attempt should be made to locate undisturbed virgin areas in order to describe and sample the very upper layers. Even though these are always mixed in cultivation, they are very important to an understanding of soil genesis. In them occur the most active biological processes that influence soil genesis in a natural landscape. Thus, the uppermost 1 or 2 inches of the solum may provide exceedingly important clues to genetic processes. Furthermore, forest fires or grazing may alter the surface of podzolic soils considerably. Fence rows are also to be avoided, since they often have an unusual flora and commonly have received accumulations of organic and mineral dust from adjacent fields. It is not at all uncommon for the A_1 horizons of podzolic soils to be thickened from 2 or 3 inches to 6 or 7 inches in old fence rows under grass.

The search for virgin examples of a soil unit should not, however, become an obsession that leads the scientist to something far different from the modal soil. In many survey areas it will not be possible to find good examples, especially of the productive soils, in virgin sites. It is far better to develop a cultivated standard from several good examples than to use an unrepresentative virgin one. Wherever possible the management history of these sites should be described. In many countries no good examples of the productive soils exist except in cultivated fields, orchards, or pastures. Even in our own country, virgin areas of Prairie and Chernozem soils are exceedingly scarce. Some of those that can be found may have something unusual about them that makes them suspect for use as standards. Where cultivated standards are used, every reasonable attempt needs to be taken to establish a norm for both management history and for the soil itself.

Perhaps this point deserves emphasis. Some soil scientists have what amounts to an obsession for basing soil classification on virgin soils, even to the neglect of cultivated soils, especially of those that have been markedly altered by long agricultural use. In long-cultivated landscapes, some man-made or anthropic soils are sufficiently different from the original virgin soil to require separate series designation for proper classification and interpretation, either to understand the genesis of the soils or to predict their crop adaptabilities and management requirements.[5] For such soils, the definitions must be sought in the cultivated fields. Sometimes virgin counterparts may be found for comparison and sometimes not.

By grouping all items needed in a soil description in the same way, soils can be compared easily, and several descriptions of the same soil type may be abstracted into one that is standard for the type. A suggested grouping is that given in the seven numbered paragraphs following.[6]

1. Land form, relief, and drainage.—First of all, a description is needed of the relief—the gradient, length, and shape of slopes, and their pattern. This can be usefully supplemented by brief descriptions of the kind of land form—dissected terrace, active flood plain, esker, drumlin, old plain of coalescing fans, and the like. Since these terms are primarily the responsibility of physical geologists and geomorphologists, their definitions and use should be followed. Where soil scientists need supplementary terms for finer distinctions, these should be consistent with the major definitions.

Relief and drainage need to be mentioned separately. Although runoff (or external soil drainage) is closely related to slope, internal drainage depends upon the permeability of the soil and of the material beneath it. Thus a permeable soil may be well-drained on a gentle slope, whereas a slowly permeable soil may be imperfectly or even poorly drained on the same slope. Relationships between slope and permeability cannot be defined broadly for all soils in terms of drainage. One must also take into account the character of the soil itself in assigning to it a drainage class. The climate influences drainage relationships. In a cool climate with nearly continuous rainfall, poorly drained soils may be found on steep slopes.

Where differences in elevation are significant these should be recorded, either from the topographic survey, if the map is available, or by approximate measurement with a barometer. Evidence of flooding or of recent showers of volcanic ash need to be

[5] For some excellent examples see EDELMAN, C. H. THE SOILS OF THE NETHERLANDS. 177 pp., illus. (Maps). Amsterdam. 1950.

[6] Only brief statements are given here of items discussed in full later.

noted. Where significant, the exposure of the site to wind or sun needs to be observed. Near the boundary between plant associations, a difference in wind or exposure may determine the association. Where moisture is limiting, north-facing slopes contrast sharply with south-facing slopes in both vegetation and soil. In northern Europe, east-west sand ridges often have Podzols on the north slopes and Brown Forest soils on the south slopes. In dry regions of the northern hemisphere south slopes may have Sierozem soils or even Lithosols, and the north slopes, Brown or Chestnut soils.

2. Parent material.—The first requirement is a clear description of the parent material itself—its texture, structure, color, consistence, and any other significant features, including depth and stratification. Its approximate mineralogical composition should be given insofar as it can be determined in the field. Often supplementary laboratory determinations are needed. Suggestions should be added regarding the rock source of the material, such as granite, basalt, sandstone, limestone, and so on, or mixtures of several kinds of rock. The manner in which parent materials originated should be suggested: weathering of rocks in place, wind-deposited material, glacial till, mud flow, local alluvium, general alluvium, and so on. Many terms that relate to mode of origin, such as glacial till, loess, and alluvium, are too general for soil descriptions although they are useful as supplements. Important suggestions about probable or possible differences between the substratum (as C horizon) and the original material from which the solum itself has been developed may be helpful.

3. The soil profile.—After the excavation has been made for the study of the soil profile, the major horizons should be located first. If these can be given letter designations, as A, B, C, and their subdivisions, well and good. Often this is not possible without some laboratory study. Generally, however, it is best to make an estimate of the letter designation and indicate uncertainties with a question mark. Where great uncertainty exists, the horizons may simply be numbered from the surface on down to the parent material.

With the horizon boundaries located, the depth and thickness of each are recorded, together with the character of the boundaries between them. The zero point for measurement is usually the top of the A_1 horizon. After measurement, each horizon is described with special attention to the following items:

Color: The color names and mathematical (Munsell) notations are taken from the standard color charts. Where the soil is streaked or mottled with contrasting colors, or where the outsides of aggregates are unlike the interiors, the principal colors are noted separately. Any relevant notes on moisture conditions may be added. Colors of moist soil are usually given in soil descriptions. In addition the authors recommend that the colors of air-dry samples be noted, especially for comparing soils in widely different locations.

Texture: Soil class is observed in the field by feeling the soil with the fingers. In former years the many disparities existing between soil class as determined in the field and by the old standard triangle were ignored. Recently these have been adjusted and the correspondence is now fairly close. In all cases of doubt, special samples should be forwarded to the laboratory for immediate attention so that the soil survey party may have a uniform basis for soil class determination.

Structure: Soil structure needs careful attention, partly because of its importance to soil productivity, soil permeability, and root growth, and partly because of its great significance in soil genesis. This latter fact emphasizes the importance of the upper layer of virgin soils, even though they may be destroyed in tillage.

Porosity.

Consistence.

Reaction and effervescence: Several useful kits are available for making these determinations.

Concretions and other special formations.

Organic matter and roots.

Chemical and mineralogical composition: Kinds and amounts of clay minerals, exchangeable bases, plant nutrients, and the like can be obtained only from laboratory examinations of samples representative of each genetic horizon. Where uncertainty exists about the uniformity of any particular horizon, it may be subdivided arbitrarily and samples taken from the several subdivisions.

4. **Stoniness.**—Where stones are present, notes on their number and size and their distribution in the profile are essential in evaluating the use capabilities of the soil, and in correctly establishing phases for stoniness within soil types.

5. **Erosion or truncation.**—Most sloping soils have at least some erosion. In areas of recent uplift, gullies and other evidences of erosion may be conspicuous natural features of the landscape. Mainly, however, severe erosion has followed changes in plant cover that have permitted greatly accelerated erosion over that normal for the type. Such features are noted and their relationship to use and the other factors of the environment suggested. It is exceedingly important to differentiate between natural erosion, however severe, and accelerated erosion. Notes on the accelerated erosion, where it exists, should be accompanied with the best possible estimate of the previous use history of the soil.

Notes on erosion, and especially on its effects, are needed for two somewhat different purposes: (1) To estimate the erosion hazard of the soil unit under different uses and management systems, and (2) to provide a basis for establishing proper classes of eroded soils and finally eroded soil phases within the soil type. Eroded soil phases need to be defined for each soil type in such a way that the definitions can be related to differential land-use predictions.

Besides truncation, the effects that erosion or soil blowing have in covering soils need to be noted.

6. Vegetation.—The principal plants are noted, both dominant and associate, and comments made about the cover generally. For example, it may be observed that a soil has a second-growth cover after cutting or fire, is revegetating after overgrazing, is now severely overgrazed, is in virgin hardwood forests, or the like.

7. Land use.—The principal crops and their condition, and the type of farming, are noted. Detailed studies of yield and soil management practices are made separately, not as a part of individual soil profile studies.

NOTEBOOKS

The soil scientist takes a great many notes in the field accurately and rapidly. So many notes are needed that methods should be systematic and simple. If the scientist sets up an overelaborate system, he may find it too much trouble. He must provide for soil descriptions at major sites of soil examination, for observations made between sites and during mapping, for photographs, for interviews with farmers and others, and for his usual travel records. In a survey area it is usually best to keep these classes of notes, and perhaps others, in separate books.

Individual preferences vary so much that no attempt has been made to standardize the size and format of notebooks. It is important that standard terms and symbols be used and that notebooks be legible so that other men may use them, as when one party chief or soil correlator is replaced by another.

Some prefer large notebooks with pages about 8 by 10 inches. These are easy to write in and have plenty of space for sketches as well as writing. Where working out of a car, these are best for detailed soil profile descriptions. So much equipment is needed anyway that their extra bulk is insignificant.

Some prefer smaller notebooks, 3 to 5 inches wide and 5 to 8 inches long, that may be carried in the pocket, especially for notes made while mapping. The more neatly a man writes, the smaller the notebook he can use satisfactorily.

Loose-leaf notebooks have the great advantage that individual descriptions may be filed together. Many prefer them, with standard forms similar to those illustrated on page 138. Although some use bound notebooks, for the greatest number of soil scientists, loose-leaf notebooks are probably best for soil descriptions. With notebooks having six or more rings, the loss of individual sheets is rare.[7]

Some sort of form is helpful in making soil descriptions, especially for beginners. With a definite outline, important items are less likely to be omitted. Just one omission may seriously reduce the value of a description, even spoil it altogether; and a great many items need to be noted. This is not to say that good notes cannot be taken without forms. Some prefer blank pages with finely ruled lines. It is easier to accommodate the description to the peculiarities of the soil. Important features may be described at length without trying to squeeze them into a form. Some who use plain notebooks paste or write a checklist of the items on the inside cover to aid their memories.

The important thing is that each soil scientist train himself to keep complete, accurate, standard notes. Perhaps his biggest job is to learn to note the commonplace—the common soils, vegetation, crops, farms, and farming practices. Most of us are inclined to accept these, unconsciously, as "norms." Since the mind comprehends by comparison, unless we train ourselves, we shall only note and photograph departures from the norms. Then, when we attempt to develop a descriptive legend or report, our notes will be inadequate. First we must describe the normal—our bench marks.

SUGGESTED OUTLINE FOR NOTEBOOK PAGE

A uniform system for describing soils can be helped with special notebooks that provide places for all the principal items that need to be noted. By using conventional abbreviations for the defined classes of the various features, as outlined in specific sections of this *Manual,* it is possible to get descriptions into a small space. Outline pages for such notebooks are shown in figure 23. It is most convenient to have these outlines printed on opposite sides of the same sheet for a loose-leaf notebook. The individual sheets may be removed and filed under the soil names. These sheets can be as small as 3¾ by 6¾ inches and punched along one of the long margins for use in a ring-binder pocket notebook; or they may be placed in a bound notebook. A similar outline can be used for a larger page, say about 7½ by 9½ inches, with an additional column in which to make a sketch of the profile and more space for remarks and discussion. A great advantage of using such a scheme lies partly in the use of standard

[7] When working intensively within an area, for soil descriptions, some prefer loose leaves or sheets of large size (8 by 10½ inches), held in a tatum holder or clip board. These can be filed by taxonomic units and conveniently summarized. Sheets held in a metal tatum holder are easy to write on and the metal gives good protection. Losses of notes may be held to the very minimum, since sheets can be removed and filed at the field headquarters each evening. For study in large areas, some prefer small bound notebooks, partly to avoid the danger of losing sheets and partly to reduce the equipment to be carried on planes and trains. Dangers of loss, through losing the whole notebook, are increased, however.

935034°—51——10

Soil type	Date	Stop No.	Soil type
Classification	Area		
Location		Elev.	
N. veg. (or crop)	Climate		
Parent material			
Physiography			
Relief	Slope	Erosion	
Drainage	Gr. water	Permeability	
Moisture	Salt or alkali		
Stoniness	Root distrib.		File No.
Remarks			

A

Horizon	Depth	Thickness	Boundary	Color Check. D(ry) or M(oist)	Texture	Structure	Consistence	Reaction	Spec. Feat.
				D M					
				D M					
				D M					
				D M					
				D M					
				D M					
				D M					
				D M					
				D M					
				D M					
				D M					

B

FIGURE 23.—Outline for standard notebook pages for soil descriptions: *A*, front side of sheet; *B*, reverse side of sheet.

notations, which makes it possible to abstract several descriptions of the same taxonomic unit into a general one for the unit as a whole.

For the outline shown in figure 23, *A* and *B,* the following abbreviations and notations are suggested. They are also useful as a check list when using a plain notebook.

Horizon: Use the standard horizon nomenclature. (See pp. 173 to 188.)

Depth: In inches or centimeters from the top of A_1, or surface mineral horizon, except for the surface of peat or muck in Bogs and Half Bogs. (See p. 185.)

Thickness: Average thickness and range, as 6(4–8).

Boundary[1]*:* Horizon boundaries are described as to distinctness: Abrupt—a; clear—c; gradual—g; diffuse—d; and according to topography: Smooth—s; wavy—w; irregular—i; broken—b. An abrupt, irregular boundary is ai.

Color: Soil colors are indicated by using the appropriate Munsell notation, such as 5YR 5/3. The spaces in the suggested notebook page under color are left open, except for checking whether dry or moist, in order to accommodate the small space to the need of the descriptions of individual horizons. If the soil mass is one solid color, only one notation is required. If the outsides of aggregates differ significantly from their interiors, both colors are needed. The description of mottled soil horizons needs to include the color of the matrix and the color, or colors, of the principal mottles plus a description of the pattern of mottling.

Mottling: A description of the mottling in soil horizons requires a notation of the colors and of the pattern. Colors can be given in terms of the Munsell notation or in their linguistic equivalents, since exact measurement is neither possible nor necessary. The pattern may be noted as follows:

Abundance:
- few . . . . f
- common c
- many . . . . m

Size:
- fine 1
- medium 2
- coarse 3

Contrast:
- faint . . . . f
- distinct . . . . . . d
- prominent . . . . p

Thus a medium-gray soil horizon mottled with yellow and reddish brown could be noted as: 10YR 5/1, c3d, 10YR 7/6 and 5YR 4/4 (or) 10YR 5/1, c3d, yellow and reddish brown.

Texture: The following notations are suggested:

gravel	g
very coarse sand	vcos
coarse sand	cos
sand	s
fine sand	fs
very fine sand	vfs
loamy coarse sand	lcos
loamy sand	ls
loamy fine sand	lfs
sandy loam	sl
fine sandy loam	fsl
very fine sandy loam	vfsl
gravelly sandy loam	gsl
loam	l
gravelly loam	gl
stony loam	stl
silt	si
silt loam	sil
clay loam	cl
silty clay loam	sicl
sandy clay loam	scl
stony clay loam	stcl
silty clay	sic
clay	c

Structure: The terms used follow the outline given on page 228.

Size or class:

very fine[2]	vf
fine	f
medium	m
coarse	c
very coarse	vc

Grade or distinctness:

structureless	0
weak[4]	1
moderate	2
strong	3

Form or type:

platy	pl
prismatic	pr
columnar	cpr
blocky[3]	bk
angular blocky	abk
subangular blocky	sbk
granular	gr
crumb	cr
single grain	sg
massive	m

Thus, the structure of the B horizon of a solodized-Solonetz may be c3cpr; that of the A_1 of a Gray-Brown Podzolic, m1cr; and that of the B_2 of a Reddish Chestnut, m2abk. Horizons having a mixed structure require two notations. The B_1 of a Red-Yellow Podzolic may be f1sbk or m2sbk.

Consistence: The notation of consistence varies with moisture content. (See pp. 231 to 234.)

Wet soil:

nonsticky	wso
slightly sticky	wss
sticky	ws
very sticky	wvs
nonplastic	wpo
slightly plastic	wps
plastic	wp
very plastic	wvp

Moist soil:

loose	ml
very friable	mvfr
friable	mfr
firm	mfi
very firm	mvfi
extremely firm	mefi

Dry soil:

loose	dl
soft	ds
slightly hard	dsh
hard	dh
very hard	dvh
extremely hard	deh

Cementation:

weakly cemented	cw
strongly cemented	cs
indurated	ci

Reaction: Use pH figures.

Indicate effervescence with HCl as:

slight	e
strong	es
violent	ev

Special features:

Concretions, for example, as:

lime	conca
iron	consir
siliceous	consi
Krotovinas	k

Other special features may be included under "*Remarks.*"

Soil type: Name, as Memphis silt loam, plus field mapping number, if any.

Classification: Especially great soil group, if known.

Native vegetation (or crop): Such as: oak-hickory; short grass; wheat; apple orchard.

Climate: Such as: humid temperate; warm semiarid.

Parent material: Such as: residuum from basalt; mixed silty alluvium; calcareous clay loam till.

Physiography: Such as: high terrace, till plain; alluvial fan; mountain foot slope. Add names of formations, where known.

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[1] In an outline, the lower boundary of a horizon is noted.
[2] Read "thin" and "thick" for platy instead of "fine" and "coarse."
[3] Unrecommended synonyms for subangular blocky are subangular nut and nuciform.
[4] "Very weak" and "very strong" may be noted as v1 and v3, respectively.

Relief: Give letter designation or name of soil slope class and indicate concave or convex, single or complex slopes. (See p. 161.)
Slope: Give approximate gradient of soil slope.
Erosion: Use appropriate class name and number. (See p. 261 *et seq.*)
Drainage: Use appropriate class name for soil drainage. (See p. 170 *et seq.*)
Ground water: Give depth to ground water or indicate "deep."
Permeability: Use appropriate class name. (See p. 168.)
Moisture: Indicate present soil moisture as (1) wet; (2) moist; (3) moderately dry; (4) dry.
Salt or alkali: Indicate concentration of either or both as slight, moderate, or strong.
Stoniness: Use appropriate class name and number. (See p. 217.)
Root distribution: Indicate depth of penetration as "deep" or to a certain depth or horizon; and abundance as "abundant," "plentiful," or "few."
Remarks: Include additional detail on listed items or include additional items, such as relative content of organic matter, evidence of worms, insects, or rodents, special mottling, and stone lines.

PHOTOGRAPHS[8]

Good photographs of profiles of the representative soil types, of characteristic landscapes, both natural and cultural, of evidences of soil processes, and of important practices, crops, and structures related to soil use and development are especially helpful. Such photographs are needed in published reports to supplement descriptions and recommendations and to give the reader a more direct "feeling" of the soils, landscapes, and agriculture. Many published soil surveys contain too few photographs of the soil and landscapes for the clearest presentation of the results of the research.

Besides their use in publications, photographs are a useful part of the record. Especially in a reconnaissance or exploratory soil survey where time is limited, photographs become an essential part of the field notes. Often one can take a picture more quickly than he can describe a landscape accurately.

Although both black-and-white photographs and color transparencies have their place, the greater need is for the former, especially since they can be reproduced easily and used as illustrations. The color transparencies, however, serve better in a record, especially for soil profiles[9].

The suggestions that follow are intended as general guides to soil survey party chiefs and others taking photographs for use primarily in soil survey reports and monographs presenting the results of the field work. During the progress of a soil survey, nearly ideal conditions of lighting may be selected; whereas on exploratory surveys many photographs need to be taken when the observer happens to be on the spot, regardless of weather, season, and time of day. Scientists vary individually in their flair for photography but with care and attention to a few simple

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[8] The use of photographs, drawings, and maps as illustrations in published reports and monographs is dealt with in the section on The Soil Survey Report.

[9] The Committee on the Exchange of Soil Pictures and Soil Profiles of the Soil Science Society of America issues detailed suggestions from time to time for making color transparencies.

principles, most can get useful black-and-white pictures under good conditions. Sometimes professional photographers may be available, but only a few have enough appreciation of soils to compose photographs that bring out the important relationships.

General requirements.—Some of the important requirements of black-and-white pictures for publication are as follows:

(1) Photographs must be clear and distinct if they are to be most useful. This means that the subject should be well lighted and in sharp focus. Every photograph loses some part of its sharpness in reproduction; consequently publication of a photograph may reduce rather than enhance the value of an otherwise good text unless the original is clear and has adequate contrast.

(2) Field notes for each photograph should include the date, the location, and a description with soil names. These notes can be transferred to a permanent record after the film is developed. Unless an orderly system of numbering, describing, and filing is used, time, film, and equipment are essentially wasted.

(3) Emphasis should be given the most important soils, crops, and farms, and especially the normal soil. As with the making of complete notes, most soil scientists need to train themselves to photograph the commonplace. Unconsciously, one tends to accept the norm and to describe and to photograph the outstanding departures from it, forgetting to record the norm itself. Unless he plans his photographs carefully, the beginner may finish his survey with photographs of all the unusual things but with none of the dominant soils and farms. Partly, too, this is because buttes, gullies, beaches, and the like, are easier to photograph than common undulating landscapes. The beginner is more tempted to photograph an outstanding set of farm buildings or a settler's makeshift cabin than the ordinary farm layout.

(4) A useful photograph brings out one or more important points about the characteristics of the soil, its important relationships to other soils, land form, vegetation, or geology, or its use and management. No matter how clear they are, simple "views", unrelated to the soil descriptions or soil maps, should be discarded. When a photograph is used to present an idea of a soil management practice or the yield of a specific crop, for example, it should be tied down to an actual soil mapping unit, described in the text, and to defined management practices. Many pictures can serve two or more purposes at once; for example, a photograph may show a sprinkler irrigation system, a type of terrace, or a special crop adapted to several soil types, and also its use on a particular soil type. Relief and land-use pattern may be shown in one photograph. Yet one should avoid getting too much in one photograph, lest all the points become obscure. This is especially true of a broad or distant landscape view. These rarely reproduce successfully unless they are simple and unusually clear. It is generally best to make just one point in a photograph and make it clearly.

(5) A great many pictures taken for soil survey reports are too small in scale—the photographer was much too far from the

center of interest. One should be as near the soil profile, the growing crop, the farmstead, or any other center of interest as good composition makes possible.

(6) Good composition is essential for a first-class photograph. Where convenient and other factors are considered, the center of interest should be a little off center, preferably a little to the left and a little below the actual center of the photograph. Unsightly telegraph poles, fence posts, commercial signs, and other things irrelevant to the story of the photograph should be avoided, especially in the foreground. Often the observer is concentrating so intensely on the soil or other feature while exposing the film that he fails to see things that ruin the picture. Good pictures, both published and unpublished, are useful for many years. Automobiles, women's apparel, men's hats, or other items that drastically change style and "date" the photograph should be avoided since they distract the reader from the main story.

(7) Many photographs need some sort of reference scale to give a correct idea of dimensions. For close-ups, a rule of natural wood or plain white with black figures is better than a pick, shovel, watch, or the like.

(8) A great many pictures are poorly illuminated and "flat." Black-and-white pictures taken with the sun directly back of the camera are rarely good. Many taken at high-noon in summer, "when the bushes have their shadows tucked beneath them," lack enough contrast. Usually the sun should be at an angle to the subject in order to get good contrast. Photographs to show microrelief, for example, need to be taken nearly crosswise to the sun in early morning or late afternoon. For color transparencies these contrasts of light and shadow are less important than is adequate light.

(9) Generally better pictures can be taken from a tripod than without one. The composition can be better planned, the lens can be more conveniently shaded, and the aperture can be reduced to permit greater depth of focus. Use of a tripod is especially important when the light is poor. A tripod will also permit more critical focussing, which is of special importance in making pictures of soil profiles.

(10) All parts of a picture important to its story should be in sharp focus. This seems obvious indeed but it deserves special emphasis. Most of the pictures needed in soil survey notes or publications are more effective if they have the maximum depth of focus obtainable. Most can, therefore, be made more satisfactorily with a small aperture and a long exposure in order to have the greatest possible part of the view in focus. Small openings are generally better for landscapes and for soil profiles but cannot be used with rapidly moving objects. Relatively few of the photographs needed in soil survey reports, however, must include moving objects.

Soil profiles.—Soil profiles are not easily photographed. It is especially difficult to get clear black-and-white pictures that bring out the significant contrasts in structure and color among the soil horizons. Yet only those that do bring out these contrasts are useful. Some general points to observe in taking pictures of soil profiles are the following:

(1) A representative site needs to be chosen. Usually it will be necessary to prepare a soil profile in a road cut because of the difficulty of making a pit large enough to have adequate lighting of all the horizons. The photographer must avoid the temptation of taking photographs where they may be made easily in cuts where the soils are not really representative.

(2) After a vertical cut has been made with a spade, the profile needs to be cleaned and dressed to bring out the structure and other features without interference of loose roots. Beginning at the top, fragments of the soil may be broken off with a large knife or fork to eliminate spade marks. Dust and small fragments may be blown away with a small tire pump. Brooms are also used but may leave streaks. It may be helpful to moisten the whole profile or parts of it with a hand sprayer for uniformity of moisture content and comparability of contrast. Moist soils are somewhat darker than dry ones and often the colors are more intense. If the whole profile is dry, it may be useful to moisten one-half, vertically, to show the contrast between the dry and moist soil.

(3) For scale, a 60-inch rule of unvarnished and unpainted wood, 1½-inches wide, and ½-inch thick, with large clear black figures at 1-foot intervals, is satisfactory. White rules with black figures have also been used successfully. Large ticks or half-lines can indicate the 6-inch intervals and small ticks the 2-inch intervals. Such a rule may be made in two or three sections held together by dowels or hinges. An ordinary folding bricklayer's 6-foot rule with clear figures can be used for very large scale pictures. The zero point of the ruler should always be exactly at the top of the A_1 horizon. The unused part of the ruler can be buried at the lower end of the profile.

Good scales not only help the reading of the individual picture but also make it possible to bring several pictures to a common scale by differential enlargement.

(4) For black-and-white pictures some prefer indirect lighting to avoid shadows. Others prefer to have the sun shining directly on the profile. Strong sunlight may give unnatural results because of shadows from the structural aggregates, pebbles, and root ends.

For color transparencies direct sunlight and bright sky are preferred by some, although good results may be had with indirect lighting if it is strong. Good lighting is so important that adequate color transparencies of soil profiles usually can be made only during the middle of the day from late spring to early autumn in most parts of the United States.

(5) Photographs of soil profiles are rarely good unless the camera is close to the profile, say within 4 to 8 feet, or at the very most, 12 feet. This means careful focussing for which a tripod is usually necessary in order to use the small opening required for

good depth of focus. Most people can get the best results by setting the shutter time and opening according to an exposure meter.

(6) With a good example of a soil profile properly dressed, it is safest to make three or four exposures at somewhat different combinations of opening and shutter time. When duplicate black-and-white photographs are taken, the camera should be moved slightly between exposures or the arrangement of the scale changed to make it easy to match the prints with the proper negatives later.

PARENT MATERIALS OF SOILS

Parent material refers to the unconsolidated mass from which the solum develops. It includes the C horizon and other materials above the C from which the solum developed. The unconsolidated material directly beneath the solum is called C, or parent material, only if the evidence suggests that at least a part of the solum is developed from material of the same kind. The term *"parent rock"* is used for rock from which the parent material was formed by weathering. In many soils there is little or no weathered material—no C horizon—between the solum and the parent rock; in other words, soil formation has kept pace with weathering. The upper part of the solum may be developed from one kind of material and the lower part from another. In many soils the solum is underlain with an unconsolidated nonconforming geological stratum that is not parent material; yet such geological strata are recognized and described insofar as they have an influence on the genesis or behavior of the soil. Such strata are designated as D layers.

We may conceive of weathering and soil formation as different sets of processes even though the sets have many individual processes in common and more often than not go on together.[1] Yet a nearly convincing case may be made for considering both together as soil formation, beginning with parent rock as the independent variable in the set of five genetic factors instead of parent material as here defined.

Generally, the parent materials of soils can be grouped into four classes: (1) Those formed in place through the disintegration and decomposition of hard country rocks, (2) those formed in place from soft or unconsolidated country rocks, (3) those that have been transported from the place of their origin and redeposited either before they became subject to important modification by soil-building forces or during such processes of modification, and (4) organic deposits.

The classification and nomenclature of rocks and of geological formations fall in the field of geology and will not be dealt with in this *Manual.* Geological materials need to be defined in accordance with the accepted standards and nomenclature of recognized authorities in the field. Each soil survey party chief should use as references the best textbooks,[2] handbooks, and monographs on

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[1] See discussion of soil profile and of solum in the section on Identification and Nomenclature of Soil Horizons.

[2] The following are examples:

CLARKE, F. W. THE DATA OF GEOCHEMISTRY. Ed. 5, U. S. Geol. Survey Bul. 770, 841 pp. 1924.

LONGWELL, C. R., KNOPF, A., FLINT, R. F. SCHUCHERT, C., and DUNBAR, C. O. OUTLINES OF GEOLOGY. Ed. 2, 381 + 291 pp., illus. New York. 1941.

FLINT, R. F. GLACIAL GEOLOGY AND THE PLEISTOCENE EPOCH. 589 pp., illus. New York. 1947.

geology that apply to the area within which he is working.[3] Besides lithological composition, the accepted authoritative names of the geological formations should be given where that can be done with reasonable accuracy. As soil research progresses, an increasing number of correlations are being found between particular geological formations and the mineral nutrient content of parent materials and soils. Certain terrace materials and deposits of volcanic ash that are different in age or source, for example, but otherwise indistinguishable, may vary widely in their contents of cobalt. Wide variations in the phosphorus content of two otherwise similar soils may reflect differences in the phosphorus content of two similar limestones that can be distinguished in the field only by specific fossils.

The principal broad subdivisions of the four classes of parent materials are suggested in the following paragraphs. The authors are mindful that in relation to soil formation the lithological composition often takes precedent over mode of formation of the rocks. That is, soils from basalt and limestone are likely to be more closely related than those from basalt and quartz diorite, for example.

MATERIALS PRODUCED BY THE WEATHERING OF HARD ROCKS IN PLACE

Materials produced by weathering of hard rocks in place are distinguished according to the nature of the original rocks and the character of the weathered material itself. We must always recall that quite different parent materials may be produced from similar or even identical rocks under different weathering regimes. As with the horizons of the solum, the texture, color, consistence, and other characteristics of the material are described. As much useful information about the mineralogical composition, hardness, and structure of the parent rock itself should be added as can be obtained.

Somewhere around three-quarters of the land area of the world is underlain by hard or soft sedimentary rocks, and perhaps one-quarter by igneous and metamorphic rocks.

Igneous rocks.—These rocks are formed by the solidification of molten materials that originated within the earth. Characteristic kinds that weather to important soil material are granite, syenite, basalt, andesite, diabase, and rhyolite.

Sedimentary rocks.—These include those rocks formed from the consolidation of sediments laid down in previous geological ages. The principal broad groups of hard sedimentary rocks are limestone, sandstone, siltstone, shale, and conglomerate. There are many varieties of these broad classes of sedimentary rocks, and many intermediate types between them, such as calcareous sandstone, arenaceous limestone, and so on. Many soils are developed

[3] Many maps of rock formations refer primarily to the hard rocks and not to the surface mantle of unconsolidated material, which may or may not be residual from the rocks shown on the maps.

from their weathering products and from those of interbedded sedimentary rocks.

Metamorphic rocks.—These have resulted from profound alteration of igneous and sedimentary rocks through heat and pressure applied to them. General classes important as sources of weathered parent material for soils are gneiss, schist, slate, marble, quartzite, and phyllite.

MATERIALS PRODUCED FROM SOFT ROCKS

Another group of materials, those produced from soft rocks, falls more or less intermediate between the group of mineral parent materials derived from hard rocks through residual weathering and the group derived from materials that have been transported.

Ash, cinders, and other volcanic ejecta may be regarded as unconsolidated igneous rocks; but they have been moved from their place of origin and usually they are immediately more or less reworked by wind and water.

Also included with the soft rocks are the unconsolidated equivalents of the sedimentary rocks already listed: marl, sand, silt, clay, and gravel. Usually such formations are described most appropriately within the categories that follow, but semi-indurated rocks are found that are intermediate in hardness and consolidation between those clearly recognized as hard rocks and those that are essentially unconsolidated. Chalk, for example, is one of these. It may be defined as an earthy limestone with a hardness less than 2.

Caliche is a very broad term for secondary calcareous material in layers near the surface. As the term is used, caliche may be soft and clearly recognized as the C_{ca} horizon of the soil; or it may exist in hard thick beds beneath the solum or exposed at the surface, especially in warm-temperate and warm regions of relatively low rainfall. The hardened form is also called *croûte calcaire*.

In this intermediate class are deposits of diatomaceous earth formed from the siliceous remains of primitive plants called diatoms.

TRANSPORTED MATERIALS

Taking the world as a whole, perhaps the most important group of parent materials is the very broad one made up of materials that have been moved from the place of their origin and redeposited during the weathering processes or during some phase of those processes, and which consist of or are weathered from unconsolidated formations. The principal groups of these materials are usually named according to the main force responsible for their transport and redeposition. In most places sufficient evidence can be had to make a clear determination; elsewhere the precise origin is doubtful.

In soil morphology and classification, it is exceedingly important that the characteristics of the material itself be observed and described. It is not enough simply to identify the parent material as alluvium, loess, or glacial till. Such names are used to supplement the descriptions of the material; and if doubt or uncertainty exists as to the correctness of the name, this fact is mentioned. For example, it is often impossible to be sure whether certain silty deposits are alluvium, loess, or the result of residual weathering in place. Certain mud flows are indistinguishable from glacial till. Some sandy glacial till is nearly identical to sandy outwash. Such hard-to-make distinctions are of little importance.

MATERIALS MOVED AND REDEPOSITED BY WATER

Alluvium.—The most important of the materials moved and redeposited by water is alluvium. It consists of sediments deposited by streams. It may occur in terraces well above present streams or in the normally flooded bottoms of existing streams. Remnants of very old stream terraces may be found in dissected country far from any present stream. Along many old established streams are a whole series of alluvial deposits in terraces—young ones in the immediate flood plain, up step by step, to the very old ones. Then too, recent alluvium often covers older terraces.

Generally, the alluvium may be divided into two main groups according to origin: (1) Local alluvium, like that at the base of slopes and along small streams flowing out of tiny drainage basins of nearly homogeneous rock and soil material, and (2) general alluvium of mixed origin, as that along major stream courses.

Colluvium.—The distinction between alluvium and colluvium is somewhat difficult and arbitrary. Some authorities hold that colluvium is strictly the material moved primarily under the influence of gravity, only imperfectly sorted, if sorted at all; and they include under alluvium all materials moved primarily by water. Generally, however, colluvium is used for the poorly sorted material near the base of strong slopes that has been moved by gravity, frost action, soil creep, and local wash. In the midwestern parts of the United States, for example, the established local usage by many soil scientists is to use the term "colluvium" for that part of the local alluvium at the base of slopes that has been moved into place through creep and local wash.

Lacustrine deposits.—These deposits consist of materials that have settled out of the quiet water of lakes. Those laid down in fresh-water lakes associated with glacial action are commonly included as a subgroup under glacial drift. Yet besides these there are other lake deposits, including those of Pleistocene times, unassociated with the continental glaciers. Some old lake basins in the western part of the United States are commonly called *playas* and may be more or less salty, depending on the climate and drainage.

Marine sediments.—These sediments have been reworked by the sea and later exposed either naturally or through the construction of dikes and drainage canals. They vary widely in lithological and mechanical composition. Some resemble lacustrine deposits.

Beach deposits.—These deposits, low ridges of sorted material, often gravelly, cobbly, or stony, mark the shore lines at old levels of the sea or lakes. Those formed on the beaches of glacial lakes are usually included with glacial drift, which is defined in another group.

MATERIALS REMOVED AND REDEPOSITED BY WIND

The wind-blown materials are generally divided into two classes, mainly in accordance with texture. Those that are mainly silty are called *loess*, and those that are primarily sand are called eolian *sands*, commonly but not always in *dunes*.[4]

It has been exceedingly difficult, both for geologists and soil scientists, to define loess precisely. Typically, deposits of loess are very silty but contain significant amounts of clay and fine sand. Usually, but not always, the material is calcareous. Most loess deposits are pale brown to brown, although gray and red colors are common. The thick deposits are generally massive, with some gross vertical cracking. The walls of road cuts in thick loess stand nearly vertical for years. Other silty deposits derived in other ways, however, have some or all of these characteristics. Then too, some wind-blown silt has been leached and strongly weathered so that it is acid and rich in clay. On the other hand, young deposits of wind-blown silty very fine sand, called loess, are exceedingly low in clay.

Characteristically, sand dunes, especially in humid regions, consist of sand, especially fine or medium sand, that is very rich in quartz and low in clay-forming minerals. Yet, nearly all transitions may be observed between the silty wind-blown materials called loess and the very sandy material in characteristic sand dunes. Especially in deserts and semideserts, the sand dunes may contain large amounts of calcium carbonate and of clay-forming minerals that would decompose to clay in a more humid environment. Examples may even be found of sand dunes, using sand in its purely textural sense, that consist almost wholly of calcium carbonate or of gypsum.

During periods of drought, and in deserts, local wind movements may pile up soil material of mixed texture or even materials very rich in clay. Piles of such material have even been called "soil dunes" or "clay dunes." It is better, however, to use an expression such as "wind-deposited materials" for local accumulations of materials of mixed textures moved by the wind than it is to identify them as loess or dunes.

MATERIALS MOVED AND REDEPOSITED BY GLACIAL PROCESSES

Several classes of materials moved and redeposited by glacial processes are as follows:

Glacial drift.—Glacial drift consists of all the material picked up, mixed, disintegrated, transported, and deposited through the action of glacial ice or of water resulting primarily from the

[4] Locally, loess is sometimes called "loam" regardless of actual texture. Relatively uniform wind-laid deposits of sand are sometimes called "cover sand."

melting of glaciers. In many places the glacial drift is covered with loess. Deep mantles of loess are usually easily recognized, but very thin mantles are so altered by soil-building forces as to be scarcely differentiated from modified drift.

Till or glacial till.—This includes that part of the glacial drift deposited directly by the ice with little or no transportation by water. It is generally an unstratified, unconsolidated, heterogeneous mixture of clay, silt, sand, gravel, and sometimes boulders. Till may be found in ground moraines, terminal moraines, medial moraines, and lateral moraines. It is often important to differentiate between the tills of the several glacial epochs. Often they underlie one another and may be separated by other deposits or old weathered surfaces.[5] Many deposits of glacial till were later washed by lakes, but without important additions. The upper part of such wave-cut till is uncommonly rich in coarse fragments as a result of the wave action in glacial lakes. *Drumlins* are long cigar-shaped low hills of glacial till, with a smooth sky line and with their long axes lying parallel to the line of movement of the ice.

Till varies widely in texture, chemical composition, and the degree of weathering subsequent to its deposition. Most till is slightly, moderately, or highly calcareous; but an important part of it is noncalcareous because no calcite- or dolomite-bearing rocks were contributed to the material or because of subsequent leaching and chemical weathering. In detailed soil classification one needs to recognize about five groups of till according to texture: (1) Coarse textured, loose, porous till, consisting mainly of a mixture of sand, gravel, cobbles, and boulders; (2) sandy till with some gravel and perhaps a few stones and a little clay; (3) medium textured, gritty till having a relatively even mixture of sand, silt, and clay, with or without stones and boulders; (4) medium textured silty till that is relatively free of gritty particles; and (5) fine textured till having a predominance of silt and clay.

Glaciofluvial deposits.—These deposits are made up of materials produced by glaciers and carried, sorted, and deposited by water that originated mainly from the melting of glacial ice.

The most important of these is *glacial outwash.* This is a broad term including all of the material swept out, sorted, and deposited beyond the glacial ice front by streams of melt water. Commonly, this outwash exists in the form of plains, valley trains, or deltas in old glacial lakes. The valley trains of outwash may extend far beyond the farthest advance of the ice.

Especially near the moraines, poorly sorted outwash materials may exist in kames, eskers, and crevasse-fills.

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[5] In the Middle West, the term *gumbotil* is applied to tenacious clays, generally gray, plastic when wet, and hard when dry, which have been weathered from Nebraskan, Kansan, and Illinoian till during the interglacial periods.

Glacial beach deposits.—These consist of gravel and sand and mark the beach lines of former glacial lakes. Depending upon the character of the original drift, they may be sandy, gravelly, cobbly, or stony.

Glaciolacustrine materials.—These materials range from fine clays to sand. They are derived from glaciers and reworked and laid down in glacial lakes. Many of them are interbedded or laminated. The fine horizontal markings exposed in a section of glaciolacustrine clay, each related to one year's deposition and one season's glacial-ice melt, are called *varves*.

Fine examples of all the glacial materials and forms described in preceding paragraphs may be found. Yet in many places it is not easy to distinguish definitely among the kinds of drift on the basis of mode of origin and land form. In places, for example, pitted outwash plains can scarcely be distinguished from sandy till in terminal moraines. Often it is difficult to distinguish between wave-cut till and lacustrine materials. We must continually recall that these names connote only a little about the actual characteristics of the parent material. Certainly mode of origin of the parent material is not a sufficient basis, by itself, for separating soil classificational units.

MATERIALS MOVED AND REDEPOSITED BY GRAVITY

As strictly defined by some, *colluvium* is the unsorted or slightly sorted material at the base of slopes, accumulated largely as rock fragments that have fallen down the slope under the influence of gravity. In its extreme form this material is called *talus*. Rock fragments are angular in contrast to the rounded, water-worn cobbles and stones in alluvial terraces and glacial outwash. As mentioned before, colluvium is used generally for that part of the poorly sorted local alluvium that has accumulated at the base of slopes, in depressions, or along tiny streams, through gravity, soil creep, and local wash.

ORGANIC MATERIALS

In moist situations where organic matter forms more rapidly than it decomposes, peat deposits are formed. These peats become, in turn, parent material for soils. If the organic remains are sufficiently fresh and intact to permit identification of plant forms, the material is regarded as *peat*. If, on the other hand, the peat has undergone sufficient decomposition to make recognition of the plant parts impossible, the decomposed material is called *muck*. Generally speaking, muck has a higher mineral or ash content than peat, because in the process of decomposition the ash that was in the vegetation accumulates. Yet total mineral or ash content is not a dependable guide for distinguishing between peat and muck. Besides the accumulation of minerals through the decomposition of vegetation, large amounts of mineral matter may be introduced into peat formations by wash from surrounding uplands, by wind, and as volcanic ash. Nearly raw peat may contain 50 percent mineral matter as volcanic ash with only a small influence on the character of the peat.

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The color, texture, compactness, and other characteristics of peat materials in soils need to be described. The principal general classes of peat, mainly according to origin, are (1) woody, (2) fibrous, (3) moss, (4) sedimentary, and (5) colloidal.

CHARACTERISTICS AND ORIGIN OF THE PARENT MATERIAL

Both consolidated and unconsolidated materials beneath the solum that influence the genesis and behavior of the soil need to be described in standard terms. Besides the observations themselves, the scientist should record his judgment about the origin of the parent material from which the solum has developed; yet the observed facts need to be separated clearly from inferences and, where important, an indication of the relative probability of the relationships suggested.

The hardness, lithological composition, and permeability of the material directly beneath the solum are especially important. Evidence of stratification of the material—textural banding, stone lines, and the like—need to be noted. Many soils have obviously developed from stratified parent material; others seem to have developed from uniform material like that directly beneath the solum, although one can rarely be certain without chemical, physical, and mineralogical data on samples of the horizons. As weathering and soil formation go forward on interbedded geological formations, with natural erosion, sola developed from materials weathered from one kind of rock, limestone let us say, are underlain by those weathered from another, say shale or sandstone. Commonly, the upper layers of outwash deposits were laid down from more slowly moving water and are finer in texture than the lower layers. Wind-blown fines and volcanic ash are laid down in blankets of varying thickness over other rock formations. The examples of such complications are nearly endless. Then, too, these geological changes often go forward along with soil formation. Where loess or ash are quickly dropped on old soils, buried soils may be well-preserved. Elsewhere the accumulation of mineral material on the top of the soil is so slow that the solum thickens only gradually. In such places the material beneath the solum was once a part of it and has now been buried beyond the influence of the biological forces.

Where hard rocks or other strongly contrasting materials lie near enough to the surface to affect the behavior of the soil, their depths need to be measured accurately; for the depth of the solum, or of solum and parent material, over such nonconforming formations is an important criterion for series and phase distinctions.

LAND FORM, RELIEF, AND DRAINAGE

Its land form is an essential part of a soil, conceived as a three-dimensional landscape resulting from the synthetic effect of all the materials and processes in its environment. Kinds of soil profiles are associated with kinds of land form that influence their genesis. Although, like other features of the soil, land form by itself is not always a sufficient basis for differentiating between soil series, it is usually associated with other differentiating characteristics. Important differences in both parent material and soil profile are commonly covariant with differences in land form.

Most soil series and types have a relatively narrow range in land form. Yet there are exceptions. Soils of two areas may be developed from deep loess, let us say, laid down on a ground moraine in one area and over a terrace in the other. Soil profiles, slopes, and other characteristics may be similar in the two areas, yet the land over the old terrace may have better water supplies in the substratum. In such an instance, the soil series should be subdivided into phases, the typical (phase) on the ground moraine and a *terrace phase* for the soil on the old terrace.

The importance of land form is being recognized increasingly by soil scientists in soil classification and interpretation. Materials in terraces, volcanic ash deposits, and other formations of differing ages and origins that appear to be similar in the field may have significantly different chemical compositions. Where substantial differences exist in texture, clay minerals, or calcium content, the materials themselves and the soils developed from them are easily distinguished; yet, differences in cobalt and other trace elements of great importance to soil use and management sometimes are not associated with other characteristics of the material recognizable in the field. In many such instances, geological origin is associated with land form, which, in turn, serves as the basis of prediction to farmers and agricultural advisers.

Other important examples, among many, that show the need for careful studies of land form may be found in areas of old valley fills made up of gently sloping coalescing fans of unlike origin and stratigraphy. A large part of the irrigated soils of the world are in such valleys. A dependable classification of these valley soils is greatly facilitated by a clear understanding of the origin of the various surfaces, especially as these relate to predictions of drainage conditions and problems that develop when water is supplied.

Land forms should be named and described in the standard terms used and accepted by physiographers and geomorpholo-

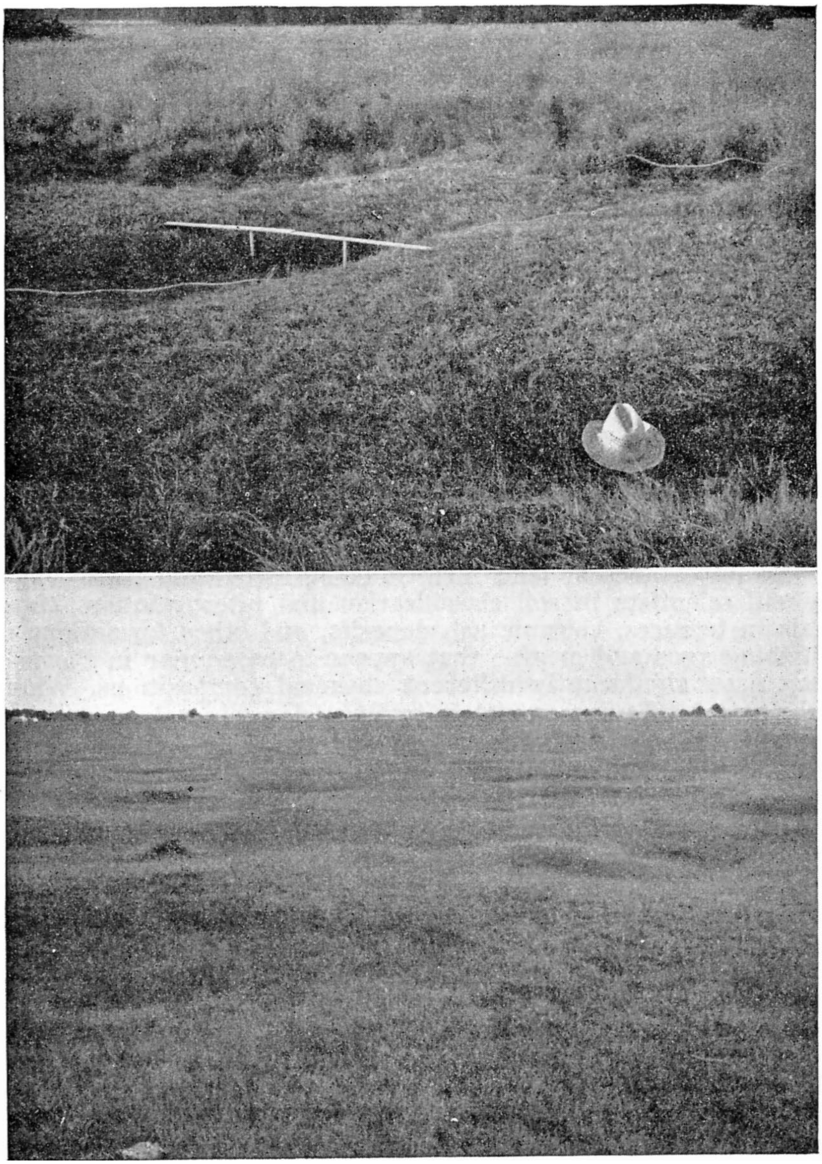

FIGURE 24.—Characteristic microrelief of the gilgai type: Upper, on Irving clay near Millican, Tex.; and lower, on Bell clay 15 miles southwest of College Station, Tex.

gists. Each soil survey party should use the most authoritative texts and monographs that apply to the survey area.[1]

RELIEF

Relief is sometimes used broadly to indicate simply the differences in elevation within an area or perhaps only the difference between the highest and lowest altitude of an area. More precisely, however, relief implies relative elevation and has been defined as the elevations or inequalities of a land surface considered collectively.

Microrelief refers to small-scale differences in relief. In areas of similar macrorelief, the surface may be nearly uniform or it may be interrupted by mounds, swales, or pits that are a few feet across and have significant differences in elevation of only 1 to 3 feet or even less (figs. 24 and 25).

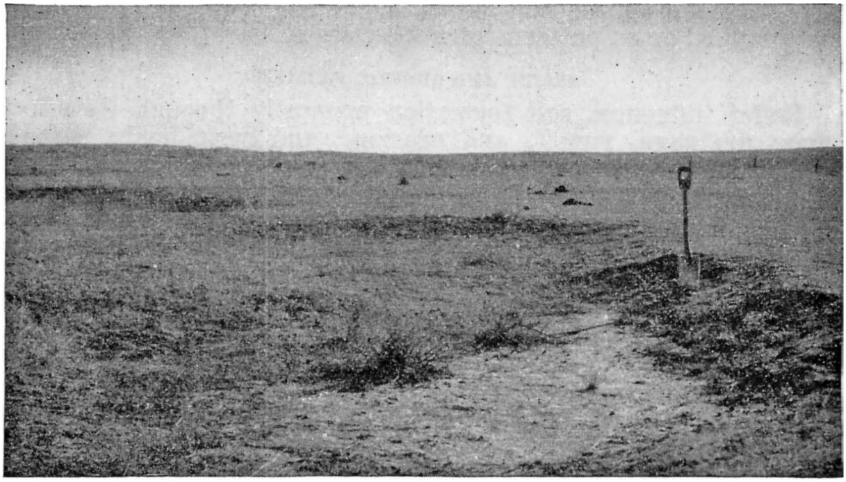

FIGURE 25.—Characteristic microrelief of truncated solodized-Solonetz. The low places are sometimes called scabby spots. Western North Dakota.

Examples include (1) the relief of Ground-Water Podzols with characteristic cradle knolls, (2) truncated solodized-Solonetz with low bare spots, (3) puff Solonchak with mounds, (4) the small mounds, *coppice mounds,* of soil material stabilized around

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[1] Some useful general texts are the following:

COTTON, C. A. CLIMATIC ACCIDENTS IN LANDSCAPE-MAKING. 354 pp., illus. Christchurch, New Zealand. 1942.

——— LANDSCAPE AS DEVELOPED BY THE PROCESSES OF NORMAL EROSION. Ed. 2, 509 pp. New York. 1948.

FENNEMAN, N. M. PHYSIOGRAPHY OF WESTERN UNITED STATES. 534 pp., illus. New York. 1931.

——— PHYSIOGRAPHY OF EASTERN UNITED STATES. 714 pp., illus. New York. 1938.

LOBECK, A. K. GEOMORPHOLOGY. 731 pp., illus. New York. 1939.

VON ENGELN, O. D. GEOMORPHOLOGY. 655 pp., illus. New York. 1942.

desert shrubs, and (5) the *gilgai*[2] microrelief of clays that have high coefficients of expansion and contraction with changes in moisture. Such microrelief consists of either a succession of enclosed micro-basins and micro-knolls in nearly level areas or of micro-valleys and micro-ridges that run with the slope.

Topography had a general connotation similar to relief, but has come to be used for the features disclosed on a contour map—even by some people for all the natural and cultural features considered collectively that are ordinarily shown on a topographic map. In soil descriptions the more specific terms—relief, physiography, land form, or soil slope—should be used rather than topography.

Soil slope refers to the incline of the surface of the soil area. It is an integral part of any soil as a natural body, not something apart from it. A simple, or single, slope is defined by its gradient, shape, and length. Depending upon the detail of mapping and the character of the soil areas, slopes may be defined as single or complex, or as patterns of slope classes.

RELIEF AND GENETIC PROFILES

Relief influences soil formation primarily through its effects upon drainage, runoff, and erosion,[3] and secondarily through variations in exposure to the sun and wind and in air drainage.

Theoretically, at least, the water falling on a perfectly level surface of permeable soil material is admitted until the material is saturated, or sealed, and then collects on the surface as a sheet. Uniformly flat and permeable soils are rare indeed. Rain water collects in depressions however slight, and penetrates some soils more rapidly than others. Because of runoff, strongly sloping soils receive less water than the average, and soils in depressions more.

The amount of water entering and passing through the soil depends upon the permeability of both solum and substrata, the relief, and the climate. In regions of nearly continuous rainfall, even strongly sloping soils may be very poorly drained. Nearly level soils on exceedingly pervious materials are excessively drained, even in humid climates, unless the water table is high. Thus, the specific relationships existing between relief or soil slope and soil genesis in one combination of climate and soil material cannot be applied to another significant combination.

In relation to soil genesis, four broad relief positions may be recognized. The definitions of these positions in terms of single or complex slopes vary among climatic regions and even on different geological materials within one region. Considering all

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[2] The name *gilgai* is adopted from Australia, where this phenomenon is extensive and developed in extreme degrees, with microrelief up to 2 feet. Other common names with similar or overlapping connotations are hog-wallowed, crab-holey, hush-a-bye, buffalo-wallowed, Bay of Biscay, self-swallowing, self-plowing, self-mulching, tiger-striped, leopard-spotted, puffed, corrugated, and pits-and-mounds.

[3] In this discussion the reference is to water erosion, not soil blowing.

possible combinations of climate and parent material in the world, soils in each of these four relief positions have a rather wide range of slope. Within each, and between them, intermediate positions need to be recognized in detailed classification. The four broad relief positions are described in the numbered paragraphs following.

1. **Normal relief.**—In this position are sloping uplands with medium runoff. Under the native vegetation, normal erosion removes materials as the solum deepens, thus bringing relatively new minerals into the soil from beneath.[4] This is the relief position of the normal soil, including modal representatives of the zonal great soil groups. The actual soil slope, in quantitative terms, varies with different combinations of climate and parent material.

2. **Subnormal relief.**—In this position are the nearly flat to sloping uplands with slow to very slow runoff. Erosion under the native vegetation is so slow that in humid regions the leached materials accumulate on the surface. The solum is relatively fixed and does not gradually move down as in many soils in the normal position. Given the necessary time, claypans and hardpans generally form from materials of mixed chemical and mechanical composition. Soils in this position often have fluctuating water tables, or perched water tables, near the surface part of the time. Planosols and Ground-Water Laterite soils are typically found in this position. Soils characteristic of this relief position may be found on fairly strong slopes in very humid regions and on seepy slopes.

3. **Excessive relief.**—This is the relief position for hills and hilly uplands that have rapid to very rapid runoff and more erosion than areas in the associated normal position. Soil development is stunted because of rapid erosion, reduced percolation of the water through the soil, and lack of water in the soil for the vigorous growth of the plants responsible for soil formation. Lithosols and the lithosolic associates of other soils are characteristic of this relief position. Other things being equal, the minimum slope is relatively low on very slowly permeable materials in dry regions and relatively great on permeable materials in humid regions.

4. **Flat or concave relief.**—In this relief position are nearly flat or depressed lowlands with either very slow runoff or none at all, excess water all or part of the time, and no natural erosion. Such lands retain all or nearly all of the water that falls as rain and often receive a considerable additional amount from adjacent uplands. The hydromorphic and halomorphic intrazonal soils are

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[4] The amount and character of natural erosion varies widely among the great soil groups. On Red Latosols, for example, it is relatively great, and on Chernozem relatively small or even insignificant. On some soils, like grassy Tundra, for example, natural erosion takes the form of a succession of slips rather than sheet wash. (See the first part of the section on Accelerated Soil Erosion.)

typically in this position. Soils characteristic of this position may be found on strong slopes in very humid regions of nearly continuous rainfall.

Within any soil zone one may find a group of strongly contrasting soil series that extend across all of the four relief positions described, yet are developed from similar parent material. Such a group of soil series is called a catena.[5]

Attempts have been made to develop uniformly defined stages or kinds of profiles, often indicated by numbers, according to evidences of natural drainage and land form or relief. Such schemes are appealing as guides to classification and for remembering characteristics, but they are not recommended. They are apt to be misused. Profile features result from such a wide variety of genetic factors that parallel analogs do not necessarily exist in different soil regions, or even on different parent materials within the same soil region. One catena can be adequately represented by four or five profiles, while another may need ten. If a uniform scheme has enough stages to accommodate the second catena, it may lead the field scientist to look for and to establish too many stages in the first catena, or to make the distinctions in the wrong places. Each catena needs to be defined by itself.

SOIL SLOPE CHARACTERISTICS

In defining soil classificational units, especially in detailed soil surveys, soil slope is given special attention. Within the permissible slope ranges of many soil types, phases need to be defined in terms of slope gradient that indicate differences significant to use and management. As with other important soil characteristics, the relative significance of differences in slope depends upon the other characteristics of the soil. Broad classes of soil slope, defined in terms of percentage alone without reference to other soil characteristics, have no consistent relationship to the capabilities of the soil for use. Thus, the definitions of slope classes must be adjusted among soil types, so that boundaries between soil areas are placed where the significant changes occur in soil slope for the particular kind of soil and so that insignificant boundaries are not added to the soil map.

Up to the present time, slope gradient—this one characteristic of soil slope—has perhaps been given undue emphasis over the other slope characteristics—shape, length, and pattern. The nomenclature for classes of soil slope does provide for recognizing units consisting (1) primarily of single slopes and (2) primarily of slope complexes. In actual practice, consideration is given to the relief of the terrain as a whole as well as to that of an individual soil area within it. That is, in a rolling terrain, the slope of a particular soil area is designated in the complex group

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[5] In East Africa, catena is used in a somewhat broader sense for groups of soils over a range in relief, but from similar or unlike parent materials. See MILNE, G., in collaboration with BECKLEY, V. A., JONES, G. H. GETHIN, MARTIN, W. S., GRIFFITH, G., and RAYMOND, L. W. A PROVISIONAL SOIL MAP OF EAST AFRICA (KENYA, UGANDA, TANGANYIKA, AND ZANZIBAR) WITH EXPLANATORY MEMOIR. 34 pp., illus. London. 1936.

even though it is single if considered only by itself. In contrast, soil slopes on fans and mountain foot slopes are regarded as single.

Ranges in soil slope are described for each mapping unit. The significant features of soil slope cannot be worked into the nomenclature except as they are included in the description of the classificational units, especially those of series and types. Even though phases within different soil types or series are given the same adjective in their name, as for example "slope" or "sloping," this does not and cannot mean that there are no other important differences in slope characteristics between the two units or even that the two are entirely similar in the gradient of slope. Often slope characteristics even more important than gradient, such as shape, length, direction, and pattern of slopes, are implied by the soil series name rather than by the adjective used in the phase name that refers to soil slope alone. Thus, the slope classes must be looked upon simply as convenient units of slope gradient, arbitrarily limited in terms of percentage, and somewhat analogous, for example, to the classes defined in terms of pH, which are used for expressing the acidity of soil horizons as "medium acid," "strongly acid," and the like.

In studying and describing the soil, important practical aspects of soil slope, besides its relation to soil genesis, need to be given consideration under the probable conditions of use and management: these are (1) the rate and amount of runoff, (2) the erodibility of the soil, and (3) use of agricultural machinery. None of these varies as a linear function of slope gradient alone, except where other characteristics of the slope and other soil characteristics are similar. It is well known that some soils, if cultivated, are not subject to erosion at 1 percent slope but may be at 2 percent; whereas others, such as some of the highly pervious Latosols of the humid tropics, are not subject to significant accelerated erosion even with soil slopes of 40 percent or more. The use of machinery and the rapidity and amount of runoff also depend upon many other soil characteristics besides slope gradient. Thus, in arriving at the definition for any soil unit, or of a phase, in terms of percentage of slope gradient, all important soil characteristics in relation to all significant aspects of soil use must be evaluated.

Classes by soil slope gradient.—Soil slope is normally measured by the hand level (fig. 26) and expressed in terms of percentage—the difference in elevation in feet for each 100 feet horizontal. Thus, a soil slope of 45° is one of 100 percent since the difference in elevation of two points 100 feet apart horizontally is 100 feet.

Slope classes have been established with alternative minimum and maximum limits in terms of gradient, so that all soil slopes within a given class, as named, will fall within broad limits and yet allow enough flexibility to make narrow definitions and subdivisions as needed for specific application to different soil types.

The slope classes provide for the recognition of either single or complex slopes as appropriate. The distinction is not mandatory. Generally, the terms for single slopes are used except in

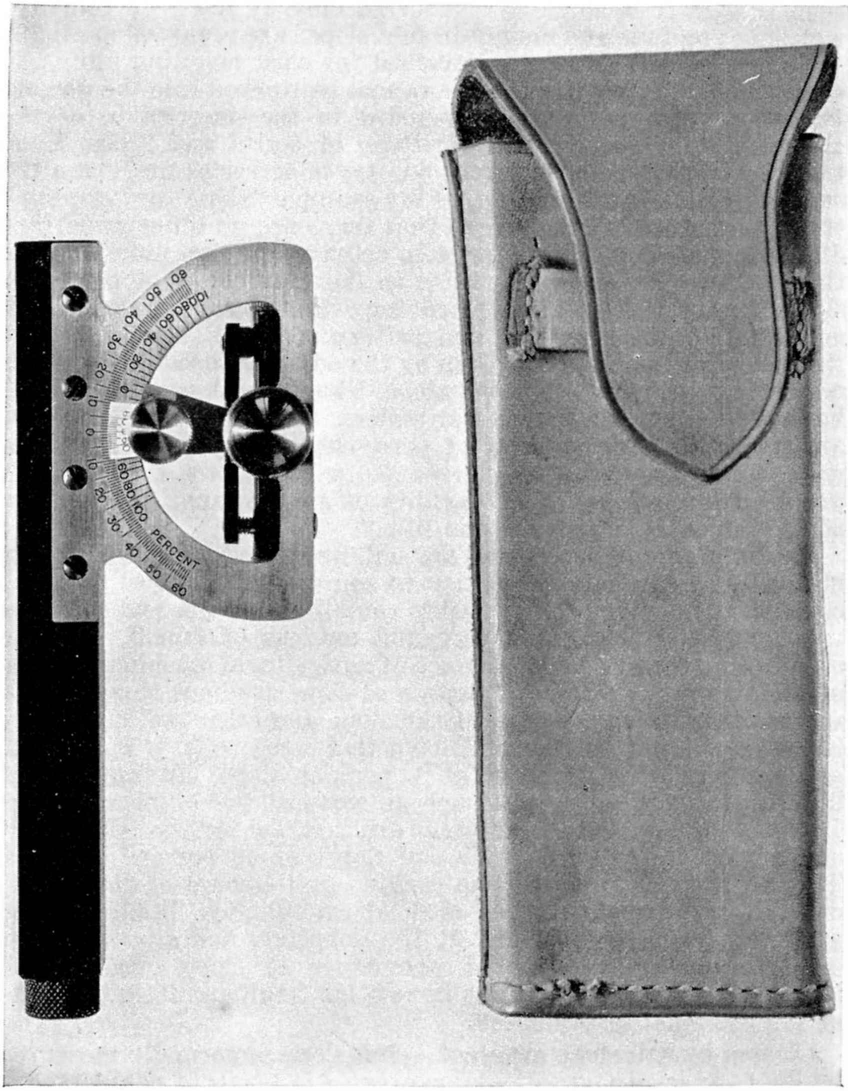

FIGURE 26.—Abney hand level with case.

areas where long established usage of terms for complex slopes make their use much more meaningful or where soil relief is very complex, as in areas of dunes and karst sinkholes. The soil slope classes are not always directly translatable into mapping units.

Slope classes are designated in the numbered paragraphs following.

1. *A class.*—In this class are level or nearly level soil areas on which runoff is slow or very slow. The soil slope alone offers no

difficulty in the use of agricultural machinery; nor is there likelihood of significant water erosion except possibly on very long slopes of highly erodible soils.

Limits	*Names*
Lower—0 percent. Upper—1 to 3 percent.	Single slopes—level; or level and nearly level.[1] Complex slopes—level; or level and nearly level.

[1] Where subdivisions are necessary in extremely detailed classification.

2. *B class.*—This class consists of gently undulating, undulating, or gently sloping soil areas on which runoff is slow or medium for most soils. All types of ordinary agricultural machinery may be used without difficulty, insofar as slope is concerned. Soils with B slopes vary widely in erodibility, depending upon the other soil characteristics. On some, erosion offers no serious problem; on many, relatively simple precautions are all that is needed; while for use under cultivation some very erodible soils need protection by terraces, or by other means, depending on the other features of the soil and the set of soil management practices.

Limits	*Names*
Lower—1 to 3 percent. Upper—5 to 8 percent.	Single slopes—gently sloping; or very gently sloping and gently sloping. Complex slopes—undulating; or gently undulating and undulating.

3. *C class.*—In this class are gently rolling, rolling, or moderately and strongly sloping soil areas on which runoff is medium to rapid for most soils. Insofar as slope is concerned, all types of farm machinery can be used successfully although some difficulty may be had in using the large and heavy types. Soils with C slope vary widely in erodibility under cultivation, depending upon the other soil characteristics and the management practices. On a few, erosion offers no serious problem, or else can be controlled by relatively simple practices; while others need careful management in which close-growing crops are used most of the time, with supplemental strip cropping or terracing where the soils are otherwise suitable.

Limits	*Names*
Lower— 5 to 8 percent. Upper—10 to 16 percent.	Single slopes—sloping; or sloping and strongly sloping. Complex slopes—rolling; or gently rolling and rolling.

4. *D class.*—This class is made up of very strongly sloping or hilly soil areas on which runoff is rapid or very rapid on most soils. Unless the slopes are very complex, most farm machinery can be used, but with difficulty, especially for the heavier types. Soils with D slopes are likely to erode under clean cultivation, except for the most pervious ones, like well-developed Latosols, for example. There are many exceptions, but the separation between those soils suited to ordinary rotations that include intertilled crops and those soils suited only to pasture or to rotations dominated by sod-forming crops commonly comes at the dividing point between C and D classes of soil slope.

Limits	*Names*
Lower—10 to 16 percent.	Single slope—moderately steep.
Upper—20 to 30 percent.	Complex slope—hilly.

5. *E class.*—In this class are steeply sloping or very hilly soil areas on which runoff is very rapid on most soils. Only the lightest types of agricultural machinery can be used. The arability of soils with E class slope varies widely. If the soils are highly fertile and permeable, they may support good grass, orchards, or even intertilled crops with a proper set of management practices. With many hilly soils, the distinction between areas useful for pasture and those suited only to forests coincides with the dividing point between the D and E classes of soil slope.

Limits	*Names*
Lower—20 to 30 percent.	Single slope—steep.
Upper—45 to 65 percent.	Complex slope—steep.

6. *F class.*—This class is used where the soils are unusually fertile and permeable and distinctions in soil slope above the E class therefore may be needed. Ordinarily, soils with such slopes are lithosolic and are included in the appropriate miscellaneous land type.

Limits	*Names*
Lower—45 to 65 percent.	Very steep.
Upper—None.	

The use of slope classes as a basis for phase distinction is discussed in a later section of this *Manual.* If properly defined, where variations in slope are significant, each slope class within a soil type can be given a specific set of yield estimates, productivity ratings, and management recommendations.

In the definition of detailed soil classificational and mapping units, the names for single slopes are more commonly appropriate than the names for complex slopes, although both need to be used, depending upon the features of soil slope besides gradient.[6] For soil associations, the names of the complex slopes are most commonly meaningful.

Other characteristics of soil slope.—In the description of soils in the field and in the definition of classificational units, the length and shape of slopes need to be described. Other things being equal, soils at the lower parts of long slopes are more likely to be gullied because of the concentration and velocity of the water. Concentration of water and other factors being equal, cutting is more likely on the convex slopes and filling on the concave slopes. For detailed description and definition of slopes and land form, the names and definitions employed by the geomorphologists are

[6] Except in highly detailed special soil surveys, however, it is not appropriate to have within one soil type two soil slope phases having the same slope class and differentiated on the basis of single versus complex slopes alone. For very highly detailed surveys in areas to be irrigated, the following distinctions according to shape of slope have been recognized: (1) Single slopes, (2) undulating, with short gentle slopes in all directions, (3) convex slopes, (4) concave slopes, and (5) concave-convex slopes on an incline, or inclined corrugations.

used. Regular patterns of slope are characteristic of most soil series, and especially of soil associations.

With accurate mapping and classification of intermittent drainage, a skilled reader of soil maps can visualize length and direction of soil slope from a detailed soil map.

ELEVATION

It is often necessary to observe the elevation where soils are studied, either from a topographic map or with a barometer, in order to correlate soil descriptions with each other and with the other observations of geology, land form, and climate.

EXPOSURE

In describing soils in the field, notes need to be taken of significant differences in exposure to wind and especially to sun that may have an important bearing on soil climate and vegetation at the particular spot. Near the critical limits of temperature, length of day, and moisture, quite different soils may be found on the north and south slopes of similar geological materials. Then too, near the critical boundaries between shrubs and trees or between grass and trees, strong winds favor the low vegetation. The skilled map reader can interpret exposure from a detailed soil map with well-defined units and a complete pattern of classified intermittent streams.

The climatic pattern of many mountainous regions is so variable within short distances that unless soil observations are carefully located in relation to elevation and exposure, they cannot be correlated with general climatic conditions.

SOIL DRAINAGE

Soil drainage, in a dynamic or active sense, refers to the rapidity and extent of the removal of water from the soil, in relation to additions, especially by surface runoff and by flow through the soil to underground spaces. Yet evaporation and transpiration contribute to water loss. Thus a nearly level Sierozem soil, having neither runoff nor percolation to the deep substratum, is well-drained because the water from all rains can distribute itself within the solum and move out by evaporation and transpiration without appreciable reduction in aeration of the soil material.

Soil drainage, as a condition of the soil, refers to the frequency and duration of periods when the soil is free of saturation or partial saturation. Such conditions can be accurately measured, although the field scientist shall need to estimate them by inference.

Accurate appraisals of the drainage conditions of soils are necessary in both soil descriptions and definitions. The problem is far more complicated than it may first appear to be. One may observe certain direct evidences of drainage or a lack of it, such as saturated soil at various times after rains or after additions of irrigation water, water-table levels, pools of surface water, and the like. Variations in soil drainage can be related by inference to differences in soil color and patterns of soil color. Mottling, the gray colors that accompany gleying, and the organic-rich material characteristic of many poorly drained soils are all good evidences, but not infallible ones. Other influences may cause similar evidences. Then too, soil slope and the texture, structure, and other characteristics of the horizons of the soil profile are useful as a basis for predicting permeability of the soil and drainage conditions. Here again, however, the scientist must consider climate, water-table levels, and other factors along with these evidences. Thus, the assessment of drainage is partly a matter of direct observation and partly a matter of inference from a large group of observations.

The concept of soil drainage is a broad one. Certain narrower aspects need to be defined first: (1) Runoff, (2) internal soil drainage, and (3) soil permeability. These last two are overlapping, but not identical qualities. That is, a slowly permeable soil may have medium internal drainage under the natural rainfall and slow internal drainage under irrigation. A soil of similar permeability may be regarded as having very slow internal drainage in a wet climate. The first quality, runoff, or external drainage, is closely related to soil slope; yet a rapidly permeable, nearly level soil may have slow runoff, as contrasted to rapid runoff on a slowly permeable soil of similar slope. A slowly permeable soil and rapidly permeable soil may both have very slow internal drainage because of a high water table. If this is lowered by tiling and ditching, the one may have slow internal drainage and the other rapid internal drainage after reclamation. It is important to be able to predict the *potential* internal drainage of poorly drained soils prior to reclamation.

Ordinarily, in soil descriptions, indication of the general soil drainage class, or that and permeability class, is sufficient. In detailed studies, however, and especially in predicting soil drainage under significantly changed conditions to be brought about through reclamation works for irrigation, drainage, and water control by dikes, separate indication of the classes of runoff and of internal drainage should be given also. An indication of the permeability of naturally poorly drained soils is essential to predictions of their suitability for use after artificial drainage.

RUNOFF

Runoff,[7] sometimes called surface runoff or external soil drainage, refers to the relative rate water is removed by flow over the surface of the soil. This includes water falling as rain as well as water flowing onto the soil from other soils. Where needed for clear descriptions, six classes are recognized on the basis of the relative flow of water from the soil surface as determined by the characteristics of the soil profile, soil slope, climate, and cover.

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[7] Sometimes the term "runoff" is applied to whole watersheds to refer to all the water entering stream flow, including that from springs. If any possibility of confusion exists, the term "surface runoff' should be used instead of "runoff" in soil descriptions and interpretations.

0. *Ponded.*—None of the water added to the soil as precipitation or by flow from surrounding higher land escapes as runoff. The total amount of water that must be removed from ponded areas by movement through the soil or by evaporation is usually greater than the total rainfall. Ponding normally occurs in depressed areas and may fluctuate seasonally.

1. *Very slow.*—Surface water flows away so very slowly that free water lies on the surface for long periods or enters immediately into the soil. Much of the water either passes through the soil or evaporates into the air. Soils with very slow surface runoff are commonly level to nearly level or very open and porous.

2. *Slow.*—Surface water flows away so slowly that free water covers the soil for significant periods or enters the soil rapidly and a large part of the water passes through the profile or evaporates into the air. Soils with a slow rate of surface runoff are either nearly level or very gently sloping, or absorb precipitation very rapidly. Normally there is little or no erosion hazard.

3. *Medium.*—Surface water flows away at such a rate that a moderate proportion of the water enters the soil profile and free water lies on the surface for only short periods. A large part of the precipitation is absorbed by the soil and used for plant growth, is lost by evaporation, or moves downward into underground channels. With medium runoff, the loss of water over the surface does not reduce seriously the supply available for plant growth. The erosion hazard may be slight to moderate if soils of this class are cultivated.

4. *Rapid.*—A large proportion of the precipitation moves rapidly over the surface of the soil and a small part moves through the soil profile. Surface water runs off nearly as fast as it is added. Soils with rapid runoff are usually moderately steep to steep and have low infiltration capacities. The erosion hazard is commonly moderate to high.

5. *Very rapid.*—A very large part of the water moves rapidly over the surface of the soil and a very small part goes through the profile. Surface water runs off as fast as it is added. Soils with very rapid rates of runoff are usually steep or very steep and have low infiltration capacities. The erosion hazard is commonly high or very high.

SOIL PERMEABILITY[8]

Soil permeability is that quality of the soil that enables it to transmit water or air. It can be measured quantitatively in terms of rate of flow of water through a unit cross section of saturated soil in unit time, under specified temperature and hydraulic conditions. Percolation under gravity with a ½-inch head and drainage through cores can be measured by a standard procedure involving presaturation of samples. Rates of percolation are expressed in inches per hour.

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[8] R. D. Hockensmith, Soil Conservation Service, made valuable suggestions concerning soil permeability.

In the absence of precise measurements, soils may be placed into relative permeability classes through studies of structure, texture, porosity, cracking, and other characteristics of the horizons in the soil profile in relation to local use experience. The observer must learn to evaluate the changes in cracking and in aggregate stability with moistening. If predictions are to be made of the responsiveness of soils to drainage or irrigation, it may be necessary to determine the permeability of each horizon and the relationship of the soil horizons to one another and to the soil profile as a whole. Commonly, however, the percolation rate of a soil is set by that of the least permeable horizon in the solum or in the immediate substratum.

The infiltration rate, or entrance of water into surface horizons, or even into the whole solum, may be rapid; yet permeability may be slow because of a slowly permeable layer directly beneath the solum that influences water movement within the solum itself. The rate of infiltration and the permeability of the plow layer may fluctuate widely from time to time because of differences in soil management practices, kinds of crops, and similar factors.

Sets of relative classes of soil permeability are as follows:

	Possible rates in inches per hour[1]
Slow:	
1. *Very slow*	less than 0.05
2. *Slow*	0.05 to 0.20
Moderate:	
3. *Moderately slow*	0.20 to 0.80
4. *Moderate*	0.80 to 2.50
5. *Moderately rapid*	2.50 to 5.00
Rapid:	
6. *Rapid*	5.00 to 10.00
7. *Very rapid*	over 10.00

[1] Very tentatively suggested rates through saturated undisturbed cores under a ½-inch head of water.

INTERNAL SOIL DRAINAGE

Internal soil drainage is that quality of a soil that permits the downward flow of excess water through it. Internal drainage is reflected in the frequency and duration of periods of saturation with water. It is determined by the texture, structure, and other characteristics of the soil profile and of underlying layers and by the height of the water table, either permanent or perched, in relation to the water added to the soil. Thus, a soil of medium internal drainage may be similar in permeability to one of slow internal drainage that has a more moist climate.

As needed, six relative classes of internal drainage are recognized and defined in the following paragraphs.

0. *None.*—No free water passes through the soil mass. In humid regions, the water table is at or near the surface most of the year. Even sandy or gravelly soils may have this natural drainage condition, but when they are drained—when the water table is lowered—they may become moderately or even rapidly drained internally.

1. *Very slow.*—The rate of internal drainage is much too slow for the optimum growth of the important crops in humid regions, and may even be too slow for the optimum growth of crops on soils of the semiarid regions. Soils may be saturated with water in the root zone for a month or two. Most soils of very slow internal drainage are blotched or mottled in nearly all parts of the profile, although some have dominantly gray surface soils and upper subsoils, and others have dark-colored surface soils that are high in organic matter. A high water table, or a very slowly permeable horizon, or both, may be responsible for very slow internal soil drainage.

2. *Slow.*—In slow internal drainage, the rate of movement of water through the soil is not so fast as in medium drainage but faster than in very slow drainage. Saturation with water occurs for periods of a week or two—long enough to affect adversely the roots of many crop plants. The rate of drainage is usually somewhat too slow for the optimum growth of the important crops[9] of the region. This is especially true in the humid temperate region, where most soils having slow internal drainage have black or gray A horizons. Mottling or blotching occurs in the lower A or upper B horizons as well as in the lower B and C horizons. Many soils with slow internal drainage have relatively high permanent water tables, or a fluctuating water table.

3. *Medium.*—Internal drainage is not so free as in rapid drainage but is freer than in slow drainage. Saturation with water is limited to a few days—less time than is required for it to injure the roots of crop plants. Internal drainage is about optimum for the growth of the important crops under humid conditions. Most soils of medium internal drainage are free of mottling and blotching throughout the A horizon and all or most of the B horizon.

4. *Rapid.*—The horizons somewhat restrict the movement of water through the soil as compared to very rapid drainage. Saturation with water is restricted to a few hours. Internal drainage is somewhat too rapid for the optimum growth of the important crops of the region.

5. *Very rapid.*—The rate of movement of water through the profile is very rapid, usually because of its high porosity, and the soil is never water-saturated. Internal drainage is too rapid for the optimum growth of most of the important crops adapted to the region. Most soils with very rapid internal drainage are free to a depth of several feet of those characteristic blotches or mottlings that suggest impeded drainage. The permanent water table is usually several feet beneath the surface.

SOIL-DRAINAGE CLASSES

On the basis of the observations and inferences used to obtain classes of runoff, soil permeability, and internal soil drainage,

[9] The reference to "important crops" is a general one, with exceptions for water-loving sorts like paddy rice.

935034°—51——12

general relative soil-drainage classes are described below. The soil-drainage class needs to be given in each soil description. Except in very young soils, the natural drainage conditions are usually reflected in soil morphology. Since their formation some soils have had their drainage markedly altered, either naturally or by irrigation or drainage structures. Seven classes of soil drainage are used in soil descriptions and definitions to describe the natural drainage under which the soil occurs.

In the numbered paragraphs following, each of the seven soil-drainage classes is defined first in broad general terms and then in terms of the morphological relationships existing among podzolic soils and among the dark-colored soils of the grasslands. Some relationships to the production of crops, especially of corn and small grains, are suggested. Examples of soil series that fall in each class are added in parentheses.

0. **Very poorly drained.**—Water is removed from the soil so slowly that the water table remains at or on the surface the greater part of the time. Soils of this drainage class usually occupy level or depressed sites and are frequently ponded. Very poorly drained soils in the podzolic soil regions commonly have dark-gray or black surface layers and are light gray, with or without mottlings, in the deeper parts of the profile. In the grassland regions, very poorly drained soils commonly have mucky surfaces with distinct evidences of gleying. These soils are wet enough to prevent the growth of important crops (except rice) without artificial drainage. (Portsmouth, Toledo, Brookston, Westland, Abington, Pamlico muck, and Everglades peat)

1. **Poorly drained.**—Water is removed so slowly that the soil remains wet for a large part of the time. The water table is commonly at or near the surface during a considerable part of the year. Poorly drained conditions are due to a high water table, to a slowly permeable layer within the profile, to seepage, or to some combination of these conditions. In the podzolic soil region, poorly drained soils may be light gray from the surface downward, with or without mottlings. Among the dark-colored soils of the grasslands, poorly drained soils commonly have slightly thickened dark-colored surface layers. The large quantities of water that remain in and on the poorly drained soils prohibit the growing of field crops under natural conditions in most years. Artificial drainage is generally necessary for crop production, provided other soil characteristics are favorable. (Henry, Waverly, Myatt, Melvin, Webster, Loy, Clermont, Bethel, Delmar, and Wehadkee)

2. **Imperfectly or somewhat poorly drained.**—Water is removed from the soil slowly enough to keep it wet for significant periods but not all of the time. Imperfectly drained soils commonly have a slowly permeable layer within the profile, a high water table, additions through seepage, or a combination of these conditions. Among the podzolic soils, somewhat poorly drained soils are uniformly grayish, brownish, or yellowish in the upper A horizon

and commonly have mottlings below 6 to 16 inches in the lower A and in the B and C horizons. Among the dark-colored soils of the grasslands, somewhat poorly drained soils have thick, dark A horizons, high in organic matter, and faint evidences of gleying immediately beneath the A horizon. The growth of crops is restricted to a marked degree, unless artificial drainage is provided. This is the lowest drainage class in which a zonal soil retains enough of its characteristics to be classed in that order. Many soils with this drainage class cannot be placed in the zonal order. (Taft, Calloway, Pheba, Fincastle, Lawrence, Crosby, Vigo, and Odell)

3. **Moderately well drained.**—Water is removed from the soil somewhat slowly, so that the profile is wet for a small but significant part of the time. Moderately well drained soils commonly have a slowly permeable layer within or immediately beneath the solum, a relatively high water table, additions of water through seepage, or some combination of these conditions. Among podzolic soils, moderately well drained soils have uniform colors in the A and upper B horizons, with mottling in the lower B and in the C horizons. Among the dark-colored soils of the grasslands, profiles have thick, dark A horizons and yellowish or grayish faintly mottled B horizons. (Grenada, Tilsit, Richland, Muscatine, Gibson, Bronson, Bedford, and Ellsworth)

4. **Well-drained.**[10]—Water is removed from the soil readily but not rapidly. Well-drained soils are commonly intermediate in texture, although soils of other textural classes may also be well drained. Among the podzolic soils, well-drained soils are free of mottlings (except for fossil gley), and horizons may be brownish, yellowish, grayish, or reddish. They may be mottled deep in the C horizon or below depths of several feet. Among the dark-colored soils of the grasslands, well-drained soils have thick, dark A horizons, reddish, brownish, or yellowish B horizons, and C horizons that may or may not be mottled. Well-drained soils commonly retain optimum amounts of moisture for plant growth after rains or additions of irrigation water. This is the characteristic drainage of modal representatives of the zonal great soil groups. (Baxter, Ruston, Vicksburg, Cecil, Memphis, Tama, Fayette, Barnes, Williams, Miami, Russell, Cincinnati, and Holdrege)

5. **Somewhat excessively drained.**—Water is removed from the soil rapidly. Some of the soils are lithosolic. Many of them have little horizon differentiation and are sandy and very porous. Among podzolic soils, somewhat excessively drained types are free of mottling throughout the profile and are brown, yellow, gray, or red. Among the dark-colored soils of the grasslands, many profiles have relatively thin A horizons, brownish, yellowish, grayish, or reddish thin B horizons, and no mottlings within the solum. Only a narrow range of crops can be grown on these soils,

[10] A well-drained soil has "good" drainage.

and the yields are usually low without irrigation. (Bruno, Dickinson, Flasher, and Oshtemo)

6. **Excessively drained.**—Water is removed from the soil very rapidly. Excessively drained soils are commonly Lithosols or lithosolic, and may be steep, very porous, or both. Shallow soils on slopes may be excessively drained. Among podzolic soils, excessively drained types are commonly brownish, yellowish, grayish, or reddish in color and free of mottlings throughout the profile. Among the dark-colored soils of the grasslands, profiles commonly have thin A horizons (except for sand types that may have thick ones). Enough precipitation is commonly lost from these soils to make them unsuitable for ordinary crop production. (Guin, Muskingum, Hamburg, Plainfield, Coloma, and Chelsea)

ALTERED DRAINAGE

Notes on altered drainage are needed to indicate changed drainage conditions where there has been no corresponding change in soil morphology. Such changes are commonly due to reclamation, as in artificial drainage or irrigation, but they may also be due to a natural deepening of the stream channels or to the filling of depressions. Altered drainage conditions need to be described, as they affect potentialities for crop production. Usually the same relative terms can be used for altered drainage as those used for natural drainage.

Descriptions and definitions of altered drainage conditions may serve as the basis for the establishment of drained or waterlogged phases of soil types or series.

INCIDENCE OF FLOODING

The descriptions and definitions of soils subject to flooding need to include statements describing the frequency and regularity of flooding in as much relevant detail as the available evidence permits. The following general classes are suggested:

1. Floods frequent and irregular, so that any use of the soil for crops is too uncertain to be practicable.

2. Floods frequent but occurring regularly during certain months of the year, so that the soil may be used for crops at other times.

3. Floods may be expected, either during certain months or during any period of unusual meteorological conditions, often enough to destroy crops or prevent use in a specified percentage of the years.

4. Floods rare, but probable during a very small percentage of the years.

IDENTIFICATION AND NOMENCLATURE OF SOIL HORIZONS

The description of a soil profile consists mainly of descriptions of its several horizons. A *soil horizon* may be defined as a layer of soil, approximately parallel to the soil surface, with characteristics produced by soil-forming processes. One soil horizon is commonly differentiated from an adjacent one at least partly on the basis of characteristics that can be seen in the field. Yet laboratory data are sometimes required for the identification and designation of horizons as well as for their more detailed characterization. The *soil profile,* as exposed in a cut or section, includes the collection of all the genetic horizons, the natural organic layers on the surface, and the parent material or other layers beneath the solum that influence the genesis and behavior of the soil.

Besides genetic soil horizons, many soils have layers inherited from stratified parent material. In making soil examinations, all distinguishable layers, or horizons, are separately described, regardless of genesis. These descriptions need to be completely objective and clearly able "to stand on their own," regardless of presumed genesis or nomenclature. Objective descriptions are the basic stuff of soil classification. Nothing can substitute for them. The more laboratory data there are available on collected samples, the more important the descriptions become; without them, the laboratory data cannot be safely interpreted, if indeed, they are relevant at all.

The profiles of numerous soils having properties quite unlike those of the original material have some characteristics due partly to inheritance from stratified parent material as well as to soil-forming processes, as in an alluvial terrace; or even partly to geological processes accompanying soil formation. That is, a soil with a well-developed profile may be gradually covered with volcanic ash, loess, wind-blown sand, or alluvium, for example, without seriously injuring the vegetation. The surface horizon becomes thickened and the lower part of the soil profile gradually passes beyond reach of active soil-forming processes.

Soil profiles vary in an almost endless number of ways. The important characteristics to be described have already been listed, and separate sections of this *Manual* explain the classes and terms for describing each one. Soil profiles vary widely in thickness, from mere films to those many feet thick. Generally in temperate regions, soil profiles need to be examined to depths of 3 to 5 feet. Normal soils are thinner toward the poles and thicker toward the Equator. Yet even in temperate regions, deeper layers, say to 6 feet or more, may be so important to soil drainage that they need to be examined, especially in the study and mapping of soils to predict their response to reclamation through irrigation or drainage.

Soil profiles vary widely in the degree to which genetic horizons are expressed. On nearly fresh geological formations, like new alluvial fans, sand drifts, or blankets of volcanic ash, no genetic horizons may be distinguished at all. As soil formation proceeds, they may be detected in their early stages only by laboratory study of the samples, and then later with gradually increasing clarity in the field.

In describing a soil profile, one usually locates the boundaries between horizons, measures their depth, and studies the profile as a whole before describing and naming the individual horizons.

NOMENCLATURE OF SOIL HORIZONS

It is not absolutely necessary to name the various soil horizons in order to make a good description of a soil profile. Yet the usefulness of profile descriptions is greatly increased by the proper use of genetic designations, like A, B, and C. Such interpretations show the genetic relationships among the horizons within a profile, whereas simple numbers like 1, 2, 3, 4, and 5, or undefined letters, like a, b, c, and so on, tell us nothing but depth sequence. The genetic designations make possible useful comparisons among soils. One cannot usefully compare arbitrarily defined "12- to 24-inch" layers of different soils, but B horizons can be usefully compared.

Since the advantage of letter designations is to show relationships among horizons, these designations must have genetic meaning. The application of any one of these letter designations to a soil horizon is an *interpretation* in addition to the description and not a substitute for it. The applicability of this interpretation is a matter of probability, not certainty. If the scientist can make no suggestions of genetic names—has no basis for them—the horizons should be simply numbered 1, 2, 3, and so on, from the topmost down to the lowest. If he is unable to suggest designations for some horizons and is exceedingly doubtful about others, he may (1) use numbers but put his best field estimate in parentheses after the number, such as 1(A_1), 2(A_2), 3, 4(B), 5, 6(C), and so on, or (2) use the designations followed by question marks (?) for the doubtful ones. Ordinarily the scientist can give designations to all horizons and indicate any serious uncertainty by question marks, as B_3 (?), for example, or uncertainty between two alternatives, as (B_2 or B_{2g}), for example.

Doubt about the designation of a horizon can often be removed, or at least reduced, if there are appropriate laboratory data to supplement the field observations. A final decision is often helped by the approximate field designation. While on the spot, looking at the profile as a whole, the scientist is making useful observations beyond those he can possibly write into a description. He should give his best estimate of the designation on the spot. Recognizing the uncertainty, further evidence may lead him to change the designation.

A general outline of the principal horizons and subhorizons is shown as a hypothetical soil profile in figure 27. No such profile

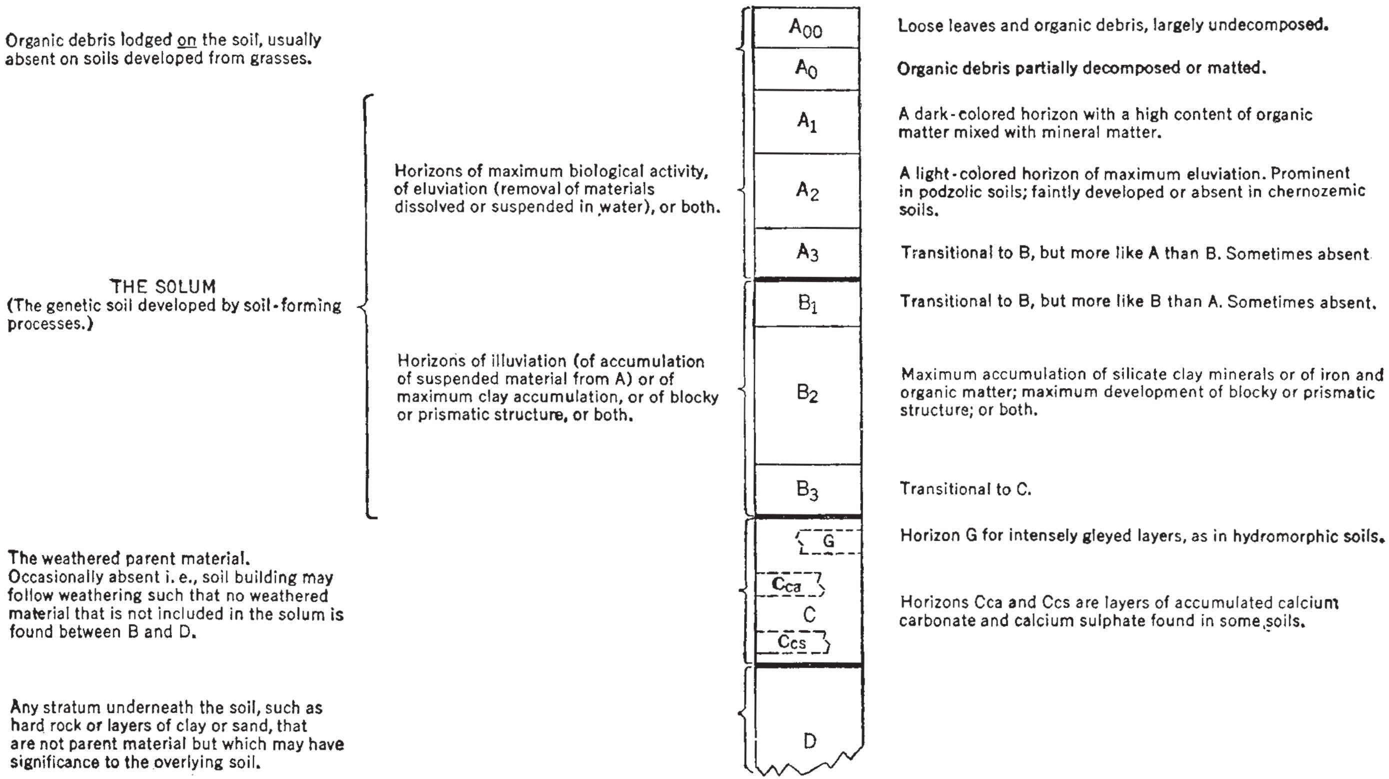

FIGURE 27.—A hypothetical soil profile having all the principal horizons. It will be noted that horizon B may or may not have an accumulation of clay. Horizons designated as C_{ca} usually appear between B_3 and C. The G may appear directly beneath the A.

could really exist in nature—the outline merely shows the relative positions of horizons. No one soil has all the various kinds of horizons in it. The simpler drawings in figure 28 present a few examples of how the horizons of actual profiles may be usefully designated. Capital letters are used for the main horizons, and lower-case letters and numbers in subscripts.

Originally the A–B–C nomenclature for soil horizons was applied in Russia to Chernozems. The A was used for the uniformly dark-colored surface soil, the C for the weathered material below the solum, and the B for the transitional horizon, as then regarded, between them. Later, these designations were used on Podzols and other podzolic soils in Russia and elsewhere in Europe; and the B became the layer of accumulation, especially of clay, iron oxide, and alumina. The early use of this nomenclature for soil horizons in the United States was adapted from its use in Europe on podzolic soils. Thus, at first, the notion became current that the B, to be a B, *had* to be a horizon of accumulation. During this early period, some even went so far as to designate the principal horizon of calcium carbonate accumulation in Chernozem and Chestnut soils as B!

Definitions have been expanded and revised since the earlier edition of this *Manual*, and further improvements may be hoped for. For example, the present definitions are not entirely adequate for many Tundra and Desert soils. Possibly additional symbols can be added usefully. Yet no set of symbols can substitute for adequate descriptions without becoming too unwieldy for accurate general use.

THE A_0 AND A_{00} HORIZONS

The A_0 and A_{00} horizons lie above the A_1 horizon of unplowed soils. They are not strictly parts of the A horizon or of the solum as herein defined, although, from some points of view, they might be so regarded.[1] The exclusion of these horizons from the solum in no way suggests that they are unimportant or that careful recognition is not essential to a useful description of many soils. Many important soil-forming processes owe their origin in part to materials produced in these layers. Although these horizons have typical thicknesses and characteristics for any one soil type under the normal undisturbed vegetation, their actual thicknesses vary widely because of fire and other common disturbances. These horizons are especially well developed in Podzols and are found on most unburned forested soils, although they are exceedingly thin on some. Thin but important A_0 or A_{00} horizons are occasionally found also on soils developed under grasses and desert shrubs.

A_{00} horizon.—This is a surface horizon consisting of relatively fresh leaves, twigs, and other plant remains, generally of the past year.

[1] Some letter other than A would be chosen by the authors for these layers if the use of A_0 and A_{00} were not so well established.

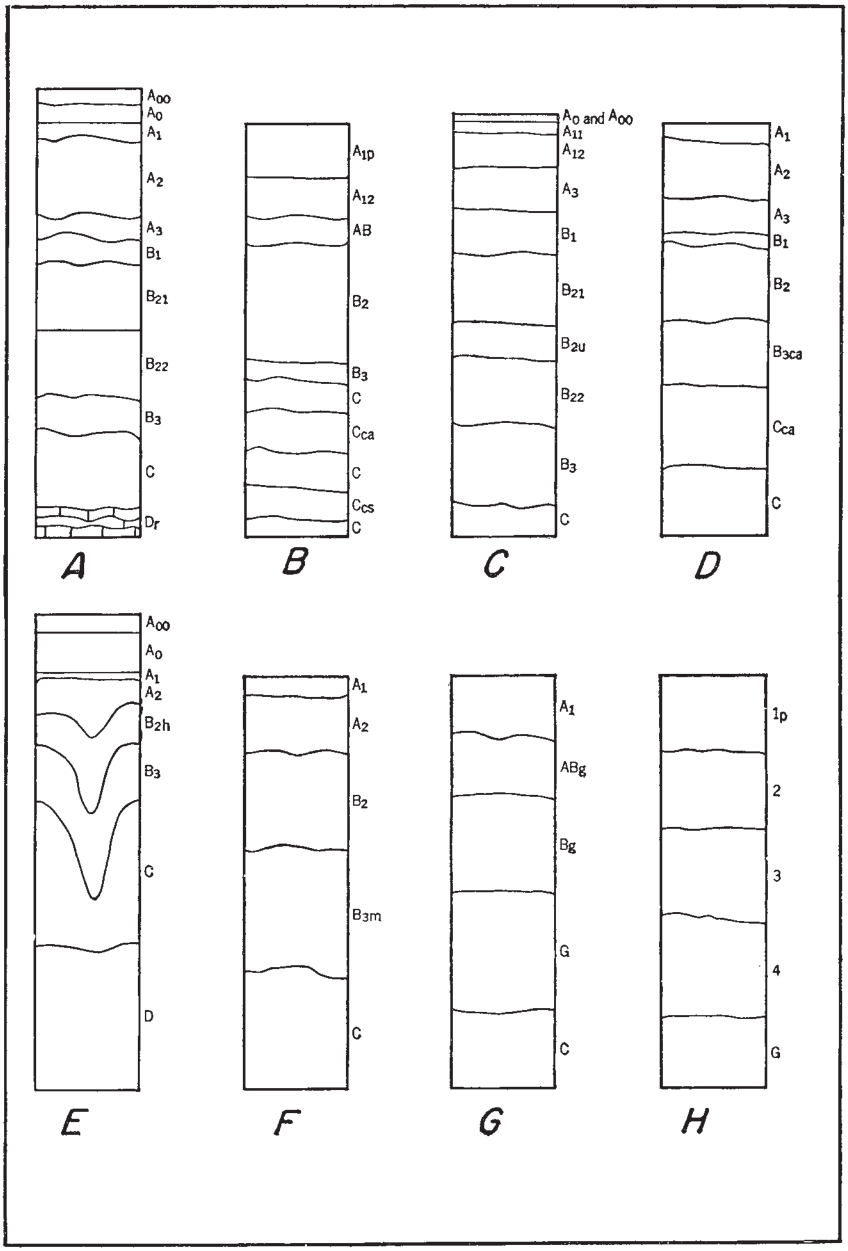

FIGURE 28.—Hypothetical profiles to illustrate a few horizon designations: *A*, Gray-Brown Podzolic; *B*, Chernozem (cultivated); *C*, Latosol; *D*, solodized-Solonetz; *E*, Podzol; *F*, Planosol; *G*, Humic Gley (Wiesenboden); *H*, Bog.

A_0 horizon.—This is a surface horizon, below the A_{00} if present, and above A_1; it consists of partly decomposed or matted plant remains.

The letters L, F, H, or others to indicate the character of the organic material may be used in the description of A_{00}, A_0, and A_1 horizons in addition to the designations suggested, but not in place of them.[2] Subdivisions of A_0 horizons are made as they are for any others.

The A_0 and A_{00} horizons are measured *upward* from the top of the A_1, if present, otherwise from the upper mineral soil horizon. It is important to observe this convention. The thickness of the A_0 and A_{00} horizons varies so greatly with fire that the surface of the A_1, or upper mineral soil, must be used as a general reference point rather than the upper surface of the A_{00}.

THE A HORIZON

The *A horizon* is a master horizon consisting of (1) one or more surface mineral horizons of maximum organic accumulation; or (2) surface or subsurface horizons that are lighter in color than the underlying horizon and which have lost clay minerals, iron, and aluminum with resultant concentration of the more resistant minerals; or (3) horizons belonging to both of these categories.

The A horizon, and especially the A_1, is the horizon of maximum biological activity and is subject to the most direct influences of climate, plants, animals, and other forces in the environment. In a sense, the A protects the rest of the soil; and in it many of the most important soil-building forces have their origin.

When the A horizon is used without subscript numbers, it refers collectively to all the subhorizons in it, excluding A_0 and A_{00}. The subhorizons are named and described in the following paragraphs.

A_1 horizon.—This is a surface mineral soil horizon having a relatively high content of organic matter mixed with mineral matter, usually dark in color. It may or may not be a horizon of eluviation. In nearly all soils it is the horizon of maximum biological activity and is subject to the greatest changes in temperature and moisture content. It is very thick in Chernozems and exceedingly thin in many Podzols. In some Podzols, Ground-Water Podzols, Ground-Water Laterites, and other soils, it is destroyed by repeated fires. Measurements of all horizons are referred to the top of the A_1, if present.

A_2 horizon.—This surface or subsurface horizon, usually lighter in color than the underlying horizon, has lost clay minerals, iron, or aluminum, or all three, with the resultant concentration of the more resistant minerals. It is a horizon of eluviation—of leaching of materials out in solution and suspension.[3] Much of

[2] HEIBERG, S. O., and CHANDLER, R. F., JR. A REVISED NOMENCLATURE OF FOREST HUMUS LAYERS FOR THE NORTHERN UNITED STATES. Soil Science 52 (2): 87–99, illus. 1941; and LUNT, H. A. THE FOREST SOILS OF CONNECTICUT. Conn. Agr. Expt. Sta. Bul. 523, 99 pp., illus. 1948.

[3] A horizon within B or C resulting, for example, from leaching by water moving laterally through a gleyed layer, may fall within this concept of an A_2 horizon.

the dissolved and dispersed material, including clay, moves completely out of the whole soil, not simply into the B horizon. The A_2 is the principal gray or light-colored leached layer in Podzols (bleicherde), solodized-Solonetz, Planosols, and podzolic soils generally.

A_3 horizon.—This is a horizon transitional to the B but more like the A than B. (If a transitional horizon between A and B is not clearly divided, and especially where it is thin, it may be designated AB).

A_p horizon.—This is a plowed or otherwise mixed surface horizon including more than the original A_1 horizon. The subscript letter *p* indicates disturbance, usually by cultivation but occasionally by pasturing. Where the plow layer is entirely within the A_1 horizon, it is designated as A_{1p}.

THE B HORIZON

The *B horizon* is a master horizon of altered material characterized by (1) an accumulation of clay, iron, or aluminum, with accessory organic material[4]; or (2) more or less blocky or prismatic structure together with other characteristics, such as stronger colors, unlike those of the A or the underlying horizons of nearly unchanged material; or (3) characteristics of both these categories. Commonly, the lower limit of the B horizon corresponds with the lower limit of the solum. (See discussion of *solum.*)

Actually the accumulation of clay and the development of blocky or prismatic structure are covariant in many soils, but not in all of them. The relatively small accumulations of total clay in the B horizons of typical Chernozem and Chestnut soils, and in some Podzols, are not primarily responsible for their designation as B horizons.

Commonly the B is called an illuvial horizon, in the sense that colloidal material carried in suspension from overlying horizons has lodged in it. We must recall, however, that the clay in B horizons may also originate from differences of residual clay formation in place or by recombination of soluble materials brought into it in true solution. Texture differences between A and B horizons may also arise partly from differential destruction of clay, as in Red-Yellow Podzolic soils for example, as well as from illuviation and residual formation in place. When B horizon is used without subscript number or letter, it refers collectively to all the subhorizons in it. These subhorizons are named and defined as follows:

B_1 horizon.—This horizon is transitional to the A above, but more like the B than A.

B_2 horizon.—This is the subhorizon of (1) maximum accumulation of silicate clay minerals or of iron and organic material; or (2) maximum development of blocky or prismatic structure; or

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[4] Organic material is the chief added constituent in the B horizon of some Ground-Water Podzols and in "humus" Podzols.

may have characteristics of both. In B_2 horizons having both these features, but separated, the horizons need to be subdivided into B_{21} and B_{22}, as appropriate.

B_3 horizon.—The B_3 horizon is transitional to the C horizon, but more like the B than C.

THE C HORIZON

The *C horizon*[5] is a layer of unconsolidated material, relatively little affected by the influence of organisms and presumed to be similar in chemical, physical, and mineralogical composition to the material from which at least a portion of the overlying solum has developed. Any slight alteration of the upper part of the C, such as reduction of calcium carbonate content in glacial till, unaccompanied by other changes, is designated as C_1.

THE D LAYER

The *D layer* is any stratum underlying the C, or the B if no C is present, which is unlike C, or unlike the material from which the solum has been formed. The designation D_r is for consolidated parent rock like that from which the C has developed or like that from which the parent material of the solum has developed if no C is present.

OTHER HORIZONS

Besides the common horizons already defined, there are others that occur importantly but less regularly.

G horizon.—This is a layer of intense reduction, characterized by the presence of ferrous iron and neutral gray colors[6] that commonly change to brown upon exposure to the air. It is a characteristic horizon in soils developed wholly or partly by gleying. This process involves saturation of the soil with water for long periods in the presence of organic matter. One may speak appropriately of a "gley (glā) soil" but hardly so of a "gley horizon," since the genesis of the whole profile is involved. Besides the G, other horizons may be somewhat gleyed, indicated by the subscript *g*. Occasionally it may be necessary to differentiate in the description between fossil gley and active gley. Intergrades between B and G and between C and G may be indicated as BG and CG if more strongly gleyed than indicated by B_g and C_g.

The G horizon is usually included as a part of the solum, along with A and B, but those G horizons occurring within the C or beneath it are not.

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[5] Although commonly used and understood, the C is not strictly a soil horizon as herein defined, partly because it is little modified by biological processes in soil formation, and partly because it often has an undetermined lower limit.

[6] Some G horizons have olive colors—a few too nearly green for the standard color chart.

C_{ca} horizon.[7]—This is a layer of accumulated calcium carbonate below the solum and within the C. Such horizons are characteristic of most chernozemic and other soils of subhumid and semiarid regions. The C_{ca} horizon is not always clearly expressed in Chernozems and sometimes can be detected only by laboratory methods. It is found in some Prairie soils and in some podzolic soils, especially those developed from highly calcareous unconsolidated material. It is often referred to loosely as the "lime horizon" or the "lime zone." This layer may be thin or thick, and soft or very hard. Generally, the thickness and hardness increase from cool to warm climates. In cool and cool-temperate regions the hard layers are found mostly in gravel. In warm semiarid regions this layer becomes so thick that it can no longer be regarded strictly as a soil horizon. Although the explanation of its genesis is not wholly settled, broad geological processes have undoubtedly contributed, as well as those included under soil formation. The term *caliche* is applied to C_{ca} horizons, especially to the thick ones in the warm countries of the Western Hemisphere. For the hardened ones, *croûte calcaire* is an alternative term for *hardened caliche.*

Formerly C_c was used for what is now designated as C_{ca}. The subscript *ca* can also be used for accumulations of calcium carbonate in other horizons or layers.

C_{cs} horizon.—This is a layer of accumulated calcium sulfate within the C. Such horizons commonly occur beneath the C_{ca} horizons of chernozemic soils. The subscript *cs* may also be used for accumulations of calcium sulfate in other horizons or layers.

LETTER SUBSCRIPTS

Letter subscripts may be helpful in indicating processes that have been active within a horizon, or layer, but they are not necessary and cannot substitute for a proper description. Several suggested ones follow:

b: A subscript to add to the genetic designation of a buried soil horizon. Thus beneath one solum, or part of one, buried horizons are designated as A_{1b}, B_{2b}, and so on.

ca: An accumulation of calcium carbonate, as in D_{ca} or B_{3ca}.

cn: Accumulations of concretions rich in iron, iron and manganese, or iron and phosphate (like *perdigons,* for example, or the "shot" in some soils of the Pacific Northwest).

cs: An accumulation of calcium sulfate (gypsum), as in D_{cs}.

f: Frozen soil, as C_f under Tundra.[8]

g: A gleyed (glāde) horizon, as B_g or B_{3g}.

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[7] The use of *ca* as an abbreviation of calcium carbonate is preferred as a subscript to Ca, the chemical symbol, partly to have all letter subscripts uncapitalized.

[8] Permafrost is reserved for permanently frozen ground. A profile description can only indicate whether the soil is frozen at the time of the examination.

h*:[9] Outstanding accumulation of decomposed organic matter for the horizon, as in the B_2 of a "humus" Podzol, making it B_{2h}.

ir*: Outstanding accumulation of finely disseminated iron for the horizon, as in the B_2 of an "iron" Podzol, making it B_{2ir}.

m: A subscript (suggesting "massive") for indurated horizons composed mainly of silicate minerals, such as fragipans, within the solum or beneath it, which are indurated much more than horizons normally having the principal horizon designation given. Such an indurated horizon is given its appropriate designation, such as B, B_2, C, or G, and then the subscript is added to form B_m, B_{2m}, C_m, or G_m.[10]

p: Indicates plowing or other disturbance, especially of the A horizon.

r: A subscript applied to a D layer of hard rock like that from which the C has developed.

sa: An accumulation of soluble salts, other than calcium carbonate or calcium sulfate.

t*: Outstanding accumulation of clay for the horizon, as in the B_2 horizon of podzolic soil richer in clay than the B_2 horizon of the associated normal soil, making it B_{2t}. (From *Ton*—clay in German.)

u: Unconformable layer with inherited characteristics unlike those of the adjacent soil material, such as a stone line within a B horizon, making it B_{3u}.

The letter designations do not provide for all situations. For example, the A_1 of humus Podzols may be thickened from 4 inches to 20 inches through long treatment with earth-containing compost. All sorts of partially truncated profiles may have been buried. Where such generally unusual soils are important in a local survey area, special symbols may be added that do not conflict with the ones given above. A small subscript, *an* for example, may be used for man-made or anthropic layers beneath A_p, if present, and above the undisturbed layers. Thus an anthropic humus Podzol may have horizons A_{1anp}, A_{1an}, A_1, A_2, B_2, B_3, and C.

Further, the A–B–C nomenclature of soil horizons has been applied mainly to those consisting largely of mineral matter. The dominantly organic layers of hydromorphic soils, Bogs and Half Bogs, are not logically assigned one of these designations. The separate layers of these soils are simply numbered 1, 2, 3, and

---

[9] Subscripts marked with the asterisk (*) are ordinarily used only for B horizons.

[10] In some instances it may be difficult to assign an appropriate major designation, such as A, B, C, G, or D, to a prominently indurated horizon or layer. In such instances, if the induration is irreversible, the horizon can be given the designation M. The use of this designation should be carefully restricted. It is not used to indicate hard layers composed mainly of calcium carbonate, nor for that induration characteristic of the genetic horizon, as in B_2 (ortstein) of typical sandy Podzols and Ground-Water Podzols.

so on, down to the C or D, or to the limit of examination in a Bog soil and to the G or C in a Half Bog soil. A surface plowed layer, if still peat, muck, or peaty muck, may be designated 1_p; while the mixed organic and mineral surface of a cultivated Half Bog soil or cultivated burned Bog soil is designated A_p.

SUBDIVISIONS OF HORIZONS

The need often arises to subdivide the main horizons further, especially in detailed studies of soil morphology. In the collection of samples for research in soil genesis, thick horizons may include significant differences and may be subdivided arbitrarily for two or more samples. It is important that these subdivisions be clearly designated within the general system of horizon nomenclature. To do this, numbers 1, 2, 3, and so on are added to the complete horizon subscript. Thus three subdivisions of an A_0 horizon are indicated as A_{01}, A_{02}, and A_{03}. Two subdivisions of B_2 may be indicated as B_{21} and B_{22}. Such numbers in the subscript should follow any of the small letters used in the subscript. Thus subdivisions of A_{1p} become A_{1p1} and A_{1p2}. A buried B_2 horizon, subdivided into two parts, is labeled B_{2b1} and B_{2b2}.

THE SOLUM

The solum may be defined simply as the genetic soil developed by soil-building forces. In normal soils, the solum includes the A and B horizons, or the upper part of the soil profile above the parent material.

Although the concept of *solum* is commonly understood by soil scientists, this definition is deceptively simple. Especially in some of the intrazonal soils, the actual sola are not easily determined; and in some soils their lower limits can be set only arbitrarily, say at 6 feet or 2 meters, or at the lower limit of plant roots. Used with such soils, the term "solum" may need to be defined in relation to the particular soil.

These difficulties concerning the solum arise mainly from the fact that the processes of soil formation often merge with broad geological processes. Although it is important to distinguish between geological and soil-forming processes, it is equally important to recognize that they usually go on together and that soils are being influenced by both. It is of little use to argue semantically about certain phenomena in the profile that are the result of combinations of the two sets of processes or that can be ascribed sometimes to one and sometimes to the other. These difficulties are illustrated by some common examples in the paragraphs following.

Croûte calcaire.—Croûte calcaire, or hardened caliche, is often found in thick masses overlain by only a few inches of soil. The common C_{ca} horizons of Chernozems, let us say, are easily conceived as part of the soil profile, although they are not within the solum.[11] Their genesis and relationships to the solum raise no particular difficulties. It is another matter, however, to include some 10 to 25 feet of croûte calcaire under a Reddish-Brown soil as a part of its profile. Doubtless this croûte calcaire is related to the solum and should be described in any description of the soil profile; but certainly broad long-time geological processes have been at work, as well as soil-forming processes.

Laterite.—Laterite includes the sesquioxide-rich, highly weathered clayey material that is hardened irreversibly to concretions, hardpans, or crusts when dehydrated, and hardened relicts of such materials more or less mixed with quartz and other diluents. Laterite is found in many soils and is a distinguishing feature of Ground-Water Laterite soil. In the profile of a Ground-Water Laterite soil one may designate the horizons easily as A_1, A_2, A_3, and B_1, down into the B_2 or, perhaps, into the B_3. The same material may continue practically without change for another 25 feet or so with no definite place for dividing the solum from the material underneath it. It would be unreasonable to exclude the upper part of the laterite from the solum; and it seems unreasonable to include the lower part, far removed from the influence of organisms.

Gleyed soil material.—Gleyed soil material may begin a few inches below the surface of hydromorphic soils and, in some instances, continue on down for many feet essentially unchanged. Such conditions can arise through the gradual filling of a wet basin, with the A horizon gradually being added to at the surface and being gleyed beneath. Finally the A rests on a thick mass of gleyed material, which may be relatively uniform, especially in sandy types. Obviously the upper part belongs in the solum, while the lower part does not. This illustration does not extend to all gleyed soils. In many the G horizon is clearly a part of the solum and has a clear lower boundary with the C.

Permafrost.—Permanently frozen ground under soils of the arctic and subarctic regions is called permafrost. The upper boundary, or *permafrost table,* is said to be coincident with the lower limits of seasonal thaws. The upper boundary of frozen ground varies, of course, from month to month during the summer and from year to year, depending upon the season. The soil that freezes and thaws seasonally is above the permafrost table. The frozen ground may extend downward many feet, even several hundred feet. Here again, the morphologist may properly place some part of the frozen ground in the soil profile, or even in the solum, as a kind of "thermal" hardpan, especially if it contains organic matter and bears a definite relationship to the

[11] Admittedly this may appear to be somewhat arbitrary. In many Chernozems and Chestnut soils it may seem that the solum could be defined to include the C_{ca}; but in some developed from materials low in calcium the C_{ca} comes deep within the C, far below the solum.

upper horizons or solum. In many soils with permafrost, the permafrost table is deep beneath the solum, within the C or below it.

Some soils have no solum at all although they support plants. Examples include very young soils from recent accumulations of volcanic ash, alluvium, or loess. At least some time is required after vegetation has become established before recognizable genetic horizons are formed.

POPULAR TERMS FOR SOIL LAYERS

Several popular terms have long been used to refer to certain soil horizons or groups of horizons—terms that are exceedingly difficult to define precisely. They are very old and have been used by laymen in widely different senses.

Topsoil is a general term that is used in at least four senses: (1) For the surface plowed layer (A_p) and thus as a synonym for surface soil; (2) for the original or present A_1 horizon, and thus exceedingly variable in depth among different soils; (3) for the original or present A horizon; and (4) for presumed fertile soil or soil material, usually rich in organic matter, used to top-dress road banks, parks, gardens, and lawns.

The authors know of no way to settle on a specific definition that would make the term even reasonably clear in soil descriptions. It should be avoided except as a top-dress material.

Surface soil refers to the soil ordinarily moved in tillage, or its equivalent in uncultivated soil, about 5 to 8 inches in thickness. The depth varies among different soil regions. If the term is used without qualification, reference is made to the existing surface soil, regardless of origin. If reference is made to a former condition, the term needs to be modified to *original surface soil,* as in the statement, "50 percent of original surface soil has been lost by sheet erosion."

Subsurface soil refers to that part of the A horizon below the surface soil. In soils of weak profile development subsurface soil can be defined only in terms of arbitrary depths.

Subsoil refers to the B horizon of soils with distinct profiles. In soils with weak profile development, subsoil can be defined as the soil below the surface soil in which roots normally grow or in terms of arbitrary depths. It is a poor term inherited from the days when "soil" was conceived only as the plowed soil; hence that under it was "subsoil."

Substratum is any layer beneath the solum, either conforming (C) or unconforming (D).

MEASUREMENT OF HORIZONS

The designations and descriptions of several horizons of the soil profile follow their identification and location within the profile. The description of the profile as a whole can be aided

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greatly by a scaled diagram, sketch, or photograph on which the horizon boundaries are shown.[12]

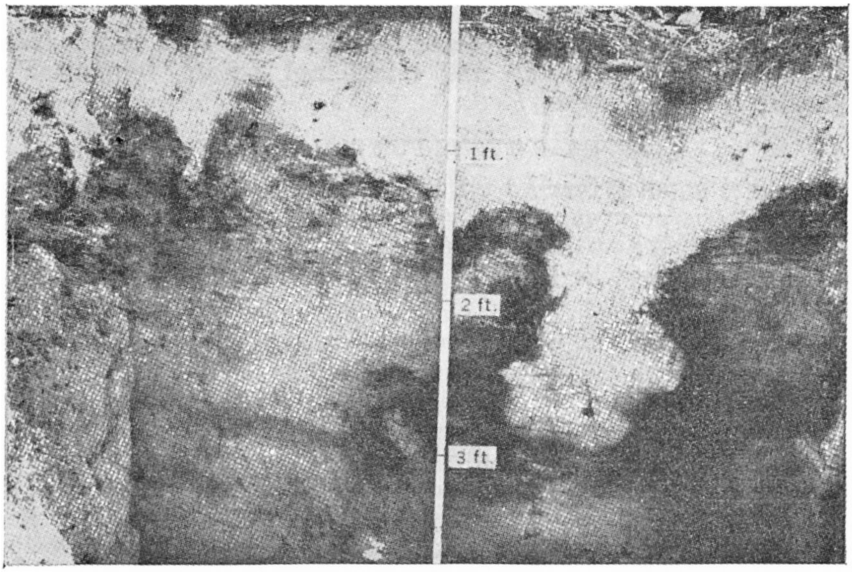

FIGURE 29.—Profile of a Podzol on sandy material illustrating an exceedingly irregular horizon boundary.

DEPTH AND THICKNESS

The profile description needs to include for each horizon (or layer) both (1) thickness in inches (or centimeters) and (2) depth of horizon boundaries below the top of A_1.[13] If both sets of figures vary widely, it will be necessary to give the two sets separately to avoid confusion. The upper boundary of a B_2 horizon, for example, may lie from 10 to 18 inches beneath the top of A_1, and the lower boundary from 20 to 32 inches below the top of the A_1; while the thickness may vary from 8 to 16 inches, not 2 to 22 inches as might be interpreted from the figures for depth below the top of the A_1. Even the figures for thickness and for depth do not describe very irregular horizons adequately. The main body of the A_2 of a Podzol, for example, may be 5½ to

[12] The reader will find many schemes for measuring horizons in various publications. The best ones are those coupled with conventional outlines of soil characteristics so that none is inadvertently omitted. C. C. Nikiforoff outlined an excellent scheme in his METHOD OF RECORDING SOIL DATA. Soil Sci. Soc. America Proc. 1: 307–317. 1936. The scheme he outlines needs only revision in classes and grades of horizon characteristics to bring it up to date with current practices. (See also p. 137.)

[13] This standard applies to all soils except Bogs and Half Bogs, in which the measurement begins at the top of the peat or muck, not counting fresh leaves or twigs (A_{00}). In other soils, if the A_1 is missing, the measurement is taken from the top of the A_p or other surface horizon, say the A_2 in severely burned podzolic soils or the B_2 of a truncated profile if it now lies at the surface.

8½ inches thick, with an upper boundary ¼ to ½ inch deep, and a lower boundary generally 5 to 8 inches deep but with irregular tongues extending down to 18 inches. The lower boundary of the underlying B_2 may vary similarly—as little as 10 inches deep to as much as 24 inches, but with a thickness of only 4 inches to not more than 12 inches.

In sandy Podzols with microrelief it is not unusual to find tongues of A_2 actually bending under the B_2 in such a way that a vertical cut into the soil will pass through A_1, A_2, B_2, back into a bulging tongue of A_2, then into B_2 again, and finally through the B_3 into the C (fig. 29). This example illustrates the need for a considerable trench for examining soil profiles and especially for taking samples, else serious errors may rise. Many soil horizons have similar tongues or other discontinuities, such as the common krotovinas of Chernozem and Chestnut soils, for example.

HORIZON BOUNDARIES

Horizon boundaries vary (1) in distinctness, and (2) in surface topography. Some boundaries are clear and sharp, as those between A_2 and B_2 horizons in most solodized-Solonetz and well-developed Podzols. Again they may be diffuse, with one horizon gradually merging into another, as between the A_1 and A_3 of Chernozem or the B_2 and B_3 of many Latosols. With these diffuse horizons, the location of the boundary requires time-consuming comparisons of small samples of soil from various parts of the profile until the midpoints are established. Small markers can be inserted until all horizons of the profile are worked out; then measurements can be taken; and finally the individual horizons can be described and sampled. Sampling can often begin with the lowest horizon to good advantage.

The distinction of the horizons to the observer depends partly upon the contrast between them—some adjacent ones are highly contrasting in several features—and partly upon the width of the boundary itself or the amount of the profile in the transition between one horizon and the next. The characteristic widths of boundaries between soil horizons may be described as (1) *abrupt*, if less than 1 inch wide; (2) *clear*, if about 1 to 2½ inches wide; (3) *gradual*, if 2½ to 5 inches wide; and (4) *diffuse*, if more than 5 inches wide.

The topography of different soil horizons varies, as well as their distinctness. Although observations of soil horizons are made in profiles or sections, and so photographed or sketched, we must continually recall that they are not "bands" (or literally "horizons" as that word is understood in everyday speech) but rather three-dimensional layers that may be smooth or exceedingly irregular. Horizon boundaries may thus be described as (1) *smooth*, if nearly a plane; (2) *wavy* or undulating, if pockets are wider than their depth; (3) *irregular*, if irregular pockets are deeper than their width; and (4) *broken*, if parts of the horizon are unconnected with other parts, as the B_2 in the limestone cracks of a truncated Terra Rossa.

HORIZONTAL VARIATIONS

The profiles of soils having well-developed microrelief cannot be satisfactorily described from pits. To describe such soils, or to understand how one soil profile merges into another at the soil boundary, a long trench is dug so that horizons may be measured, described, sketched, and sampled at appropriate horizontal intervals. Small stakes may be set on the margin of the trench at 6- or 12-inch intervals as reference points. Using one stake as a zero point, the relative elevations of the others can be measured with an ordinary surveyor's level or Y-level.

For the purpose of observing any horizontal cracking or patterns in the soil, it is often revealing to remove soil horizons, one by one from the top down, from an area of a square yard or more. One may, for example, discover gross hexagonal cracking of hardpans or claypans, unsuspected from the vertical cut alone, that suggest previous influences of freezing, moistening, or desiccation that have been interrupted by coverings now changed to a part of the solum.

SOIL COLOR

Color is the most obvious and easily determined of soil characteristics. Although it has little direct influence on the functioning of the soil, one may infer a great deal about a soil from its color, if it is considered with the other observable features. Thus the significance of soil color is almost entirely an indirect measure of other more important characteristics or qualities that are not so easily and accurately observed. Color is one of the most useful and important characteristics for soil identification, especially when combined with soil structure.

SIGNIFICANCE OF COLOR

The content of organic matter in soil, for example, is a characteristic that is commonly indicated only approximately by soil color. Generally in temperate climates dark-colored soils are relatively higher in organic matter than light-colored soils. In well-drained soils, the colors usually range from very pale brown, through the intermediate browns, to very dark brown or black, as organic matter increases. The most stable part of decomposed organic matter, humus, is darker than the raw or less well decomposed plant remains. Raw peat is brown, whereas the well-decomposed and more fertile organic soil produced from peat is black or nearly so.

As organic matter is neither all of the same color nor the only coloring matter in soils, soil color by itself is not an exact measure of this important constituent. Well-drained soils of the same relatively high content of organic matter are browner, less nearly black, under high annual temperatures than those of cool regions. Yet the dark clays of warm-temperate and tropical regions, which include some of the blackest soils in the world, seldom contain as much as 3 percent organic matter. Their color may range from medium gray to black with little or no change in the total content of organic matter. Self-mulching black clays with 2 or 3 percent of organic matter may lie side by side with reddish-brown latosolic soils having two or three times as much organic matter. Dark-colored soils low in organic matter may contain compounds of iron and humus, elemental carbon, compounds of manganese, and magnetite. Depth of color depends upon the nature and distribution of the organic matter as well as upon the total amount. In highly alkaline Solonetz soils, for example, the highly dispersed organic matter apparently coats each soil grain. Such soils are nearly black at relatively low contents of total organic matter.

The red color of soils is generally related to unhydrated iron oxide, although manganese dioxide and partially hydrated iron oxides may also contribute red colors. Since unhydrated iron oxide is relatively unstable under moist conditions, red color usually indicates good drainage and good aeration. Strongly red soils are expected on convex surfaces underlain by pervious rocks. Yet many red soils owe their color to inheritance from the parent material and not to soil-forming processes, since the redness in some rocks may persist for centuries even under moist conditions.[1]

In regions where the normal soils have red color, the well-developed red color is one indication that the soils are relatively old or at least that the soil material has been subjected to relatively intense weathering for a considerable time. Yet occasionally red colors develop very rapidly. Other things being equal, the red and yellow colors in soil generally increase both in prevalence and in intensity in going from cool regions toward the Equator. The intensity of weathering increases with temperature. Then too, many very old land surfaces may be found in warm regions, especially as contrasted with glaciated cool and temperate regions.

The yellow color in soils is also largely due to iron oxides.[2] Yellow colors in the deeper horizons usually indicate a somewhat more moist soil climate than do red colors. The general climatic differences may be in humidity and cloudiness rather than in rainfall. Where associated red and yellow soils are developed from the same kind of parent material, the yellow soils commonly occupy the less convex and more moist sites. Other things being equal, yellow colors are also more common than red colors in regions of high humidity and heavy cloud cover. Apparently, however, it takes a long time to change a yellow soil to a red one, since strongly sloping yellow soils may be found in regions of geologically recent uplift and rapid dissection.

Iron oxides occur in all colors ranging from yellow at the one extreme to red at the other. Thus many brown soils contain relatively large amounts of iron oxides in addition to organic matter.

Well-drained yellowish sands owe their colors to the fact that small amounts of organic matter and other coloring material such as iron oxide are mixed with large amounts of nearly white sand.

Gray and whitish colors of soils are caused by several substances, mainly quartz, kaolin and other clay minerals, carbonates of lime and magnesium, gypsum, various salts, and compounds of ferrous iron. The grayest colors (chromas of less than 1,

[1] Soils owing their color to inheritance from the parent material rather than from soil-forming processes are referred to as *lithochromic*.

[2] In the past red colors have been ascribed to unhydrated and yellow colors to hydrated iron oxides. It seems clear that red colors are due to unhydrated iron oxides, but a yellow color is more difficult to explain. Recent evidence suggests that some yellow soils lack hydrated iron oxides. This raises a question about the general occurrence of such oxides in well-drained soils. Although the question may not be answered one way or another at the present time, alternative explanations for yellow colors need to be examined. It is known that the particle size of some colloidal precipitates affects the color, and this may also be true of colloidal iron oxides in soils. Moreover, there is evidence that the ferric oxide in these Red-Yellow Podzolic soils of the southeastern part of the United States that have red B horizons is reduced more easily than is the ferric oxide in the associated soils with yellow B horizons. It has been suggested that the yellow color in some profiles may be due to a solid-solution mixture of iron and aluminum oxides.

values of 2.5 to 7.5) that occur in soils are those of permanently saturated G horizons. In these, the iron is in the ferrous form. Some soils are so rich in these compounds as to have nearly pure gray colors that appear bluish.[3]

Imperfectly and poorly drained soils are nearly always mottled with various shades of gray, brown, and yellow, especially within the zone of fluctuation of the water table. In the presence of organic matter, the proportion of gray generally increases with increasing wetness. Wet materials without organic matter rarely have the very light-gray color.

A light-gray color may indicate a very low content of organic matter and iron, as in the A_2 horizons of the Podzol, or in sands that consist almost wholly of quartz. Irregular layers of white clay, from which the iron has been removed, are commonly found in the lower parts of Ground-Water Laterite soils and Latosols. In arid and semiarid regions, certain soil horizons may be white or nearly white because of the very high content of calcium carbonate, gypsum, or other salts.

Nearly white colors sometimes occur as an inheritance from the parent material, as in Lithosols or Regosols on marls or other white rocks. The failure of soils to accumulate organic matter ordinarily indicates an environment unfavorable to plants and micro-organisms. White soils are almost invariably unproductive naturally, although a few are responsive to good management, such as some weakly developed Rendzinas.

COLOR PATTERNS

Nearly every soil profile consists of several horizons differing in color. For every soil examined and described in the field, the complete color profile should be presented. A single horizon may be uniform in color or it may be streaked, spotted, variegated, or mottled in many ways. Local accumulations of lime or organic matter may produce a spotted appearance. Streaks or tongues of color may result from the seeping downward of colloids, organic matter, or iron compounds from overlying horizons. Certain combinations of mottled colors, mainly the grays and browns, indicate impeded drainage. The word "mottled" means marked with spots of color. Some mottled colors occur unassociated with poor drainage, either past or present. A mottled or variegated pattern of colors occurs in many soil horizons and especially in parent materials that are not completely weathered.

Mottling in soils is described by noting: (1) The color of the matrix and the color, or colors, of the principal mottles, and (2) the pattern of the mottling. The color of the mottles may be

[3] The usual color of G horizons is of yellow hue, generally about 2.5Y, but of such weak chroma as to suggest the complementary hue in contrast to other stronger colors that predominate in the background against which the soils are viewed. The hue complementary to 10YR, the most usual in soil, is 10B, a blue. Before alteration from exposure to the air, the chroma of G horizons generally is less than 1; with exposure to air the color changes rapidly, sometimes within a few minutes. Few air-dry samples of G horizons have chromas of less than 1.

defined by using the Munsell notation, as with other soil masses; but usually it is sufficient and even better to use the standard linguistic equivalents, since precise measurement of the color of the mottles is rarely significant. In fact, descriptions of soil horizons containing several Munsell notations are difficult to read rapidly.

The pattern of mottles can be conveniently described by three sets of notations: contrast, abundance, and size.[4]

Contrast.—Contrast may be described as *faint, distinct,* or *prominent* as follows:

Faint: Indistinct mottles are evident and recognizable only with close examination. Soil colors in both the matrix and mottles have closely related hues and chromas.

Distinct: Although not striking, the mottles are readily seen. The hue, value, and chroma of the matrix are easily distinguished from those of the mottles. They may vary as much as one or two hues or several units in chroma or value. The pattern may be one of a continuous matrix with mottles or one of mixtures of two or more colors.

Prominent: The conspicuous mottles are obvious and mottling is one of the outstanding features of the horizon. Hue, chroma, and value may be several units apart. The pattern may be one of a continuous matrix with contrasting mottles or one of mixtures of two or more colors.

Abundance.—Abundance of mottles can be indicated in three general classes as: *few, common,* and *many,* based upon the relative amount of mottled surface in the unit area of the exposed soil horizon, as follows:[5]

Few: Mottles occupy less than about 2 percent of the exposed surface.

Common: Mottles occupy about 2 to 20 percent of the exposed surface.

Many: Mottles occupy more than 20 percent of the exposed surface. This last class can be further subdivided according to whether (a) the mottles set in a definite matrix or (b) there is no clear matrix color.

Size.—Size refers to the approximate diameters of individual mottles. Three relative size classes can be used as follows:

Fine: Mottles less than 5 mm. in diameter along the greatest dimension.

Medium: Mottles range between 5 and 15 mm. in diameter along the greatest dimension.

Coarse: Mottles are greater than 15 mm. in diameter along the greatest dimension.

In the detailed examination of some soil horizons, it may be necessary to add still further notes on the mottling to indicate whether or not the boundaries of the mottles are sharp (knife-edge), clear (less than 2 mm. wide), or diffuse (more than 2 mm. wide). Although many mottles are roughly circular in cross-section, others are elongated and merge into streaks or tongues. Although, normally, mottling carries no inferences of differences in texture as compared to the matrix, many soils show mottling in a freshly exposed horizon because of the slicing of incipient concretions.

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[4] This discussion is based on a recent paper: SIMONSON, R. W. DESCRIPTION OF MOTTLING IN SOILS. Soil Science. 7: 187–192. 1951.

[5] The suggested limits are tentative only. More research is needed to establish the most useful size classes and number of classes.

In soil descriptions the mottling can be most conveniently described by describing the mottles as to abundance, size, contrast, and color, such as, ". . . brown silt loam with few, fine, distinct reddish-brown and dark-gray mottles."

In verbal descriptions of soil mottling intended for the general reader, part of the detail needed in detailed soil morphology and correlation may be omitted. Thus, starting with the classes according to abundance, descriptions may be written as follows:

1. *Few:* ". . . brown silt loam, slightly mottled with red and yellow."
2. *Common:* ". . . brown silt loam, mottled with red and yellow."
3. *Many:*
   (a) If the matrix is clearly apparent: ". . . brown silt loam, highly mottled with red and yellow."
   (b) If no clear matrix exists: ". . . mottled red, yellow, and brown silt loam."

If contrast is not clearly shown by the color names, "faintly" or "prominently" may be added. Faint mottling can be implied as ". . . brown silt loam, mottled with shades."

If size is important "finely" or "coarsely" may be added, as ". . . coarsely mottled red and yellow clay", or ". . . brown silt loam finely and slightly mottled with reddish brown." Usually such distinctions are more confusing than helpful to the lay reader.

In the description of soil color, special notice should be taken of any relationships between the color pattern and structure or porosity. Structural aggregates in the soil must be broken to determine whether the color is uniform throughout. The black or dark-brown surface color of soil granules is often due to a thin coating, though the basic color of the soil material is brown or yellow. When such granules are crushed, the mass of soil is lighter in color than the original surfaces of the aggregates. Marked contrast between the color of the soil aggregates and the color of the soil when crushed is common. Coatings of red color often cover structural particles or sand grains; and a gray color may be due to a thin film of leached soil around darker aggregates.

EFFECTS OF MOISTURE

Soil color changes with the moisture content, very markedly in some soils and comparatively little in others. Between dry and moist, soil colors commonly are darker by ½ to 3 steps in value and may change from $-\frac{1}{2}$ to $+2$ steps in chroma. Seldom are they different in hue. Some of the largest differences in value between the dry and moist colors occur in gray and grayish-brown horizons having moderate to moderately low contents of organic matter.

Reproducible quantitative measurements of color are obtained at two moisture contents: (1) Air dry, and (2) field capacity. The latter may be obtained with sufficient accuracy for color measurements by moistening a sample and reading the color as soon as visible moisture films have disappeared. Both the dry and the moist colors are important. In most notes and soil descriptions, unless stated otherwise, colors are given for moist soils.

Comparisons of color among widely separated soils are facilitated by using the color designation of freshly broken surfaces of air-dry samples. Official descriptions for technical use, such as series descriptions, should include the moist colors, and preferably, both dry and moist colors if significantly unlike.

DETERMINATION OF SOIL COLOR

Soil colors are most conveniently measured by comparison with a color chart. The one generally used with soil is a modification of the Munsell color chart and includes only that portion needed for soil colors, about one-fifth of the entire range of color.[6] It consists of some 175 different colored papers, or chips, systematically arranged, according to their Munsel notations, on cards carried in a loose-leaf notebook. The arrangement is by *hue, value,* and *chroma*—the three simple variables that combine to give all colors. *Hue* is the dominant spectral (rainbow) color; it is related to the dominant wavelength of the light. *Value* refers to the relative lightness of color and is a function (approximately the square root) of the total amount of light. *Chroma* (sometimes called saturation) is the relative purity or strength of the spectral color and increases with decreasing grayness.

In the soil color chart, all colors on a given card are of a constant hue, designated by the symbol in the upper right-hand corner of the card. Vertically, the colors become successively lighter by visually equal steps; their value increases. Horizontally, they increase in chroma to the right and become grayer to the left. The value and chroma of each color in the chart is printed immediately beneath the color. The first number is the value, and the second is the chroma. As arranged in the chart the colors form three scales: (1) Radial, or from one card to the next, in hue; (2) vertical in value; and (3) horizontal in chroma.

The nomenclature for soil color consists of two complementary systems: (1) Color names, and (2) the Munsell notation of color. Neither of these alone is adequate for all purposes. The color names are employed in all descriptions for publication and for general use. The Munsell notation is used to supplement the color names wherever greater precision is needed, as a convenient abbreviation in field descriptions, for expression of the specific relations between colors, and for statistical treatment of color data. The Munsell notation is especially useful for international correlation, since no translation of color names is needed. The names for soil colors are common terms now so defined as to obtain uniformity and yet accord, as nearly as possible, with past usage by soil scientists. Bizarre names like "rusty brown," "tan," "mouse gray," "lemon yellow," and "chocolate brown" should never be used.

The soil color names and their limits are given in the name-diagrams, figures 30 to 36.

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[6] The appropriate color chips separately, or mounted by hues on special cards (4¼ by 7¼ inches) for a loose-leaf notebook, may be obtained from the Munsell Color Company, Inc., 10 East Franklin Street, Baltimore 2, Md.

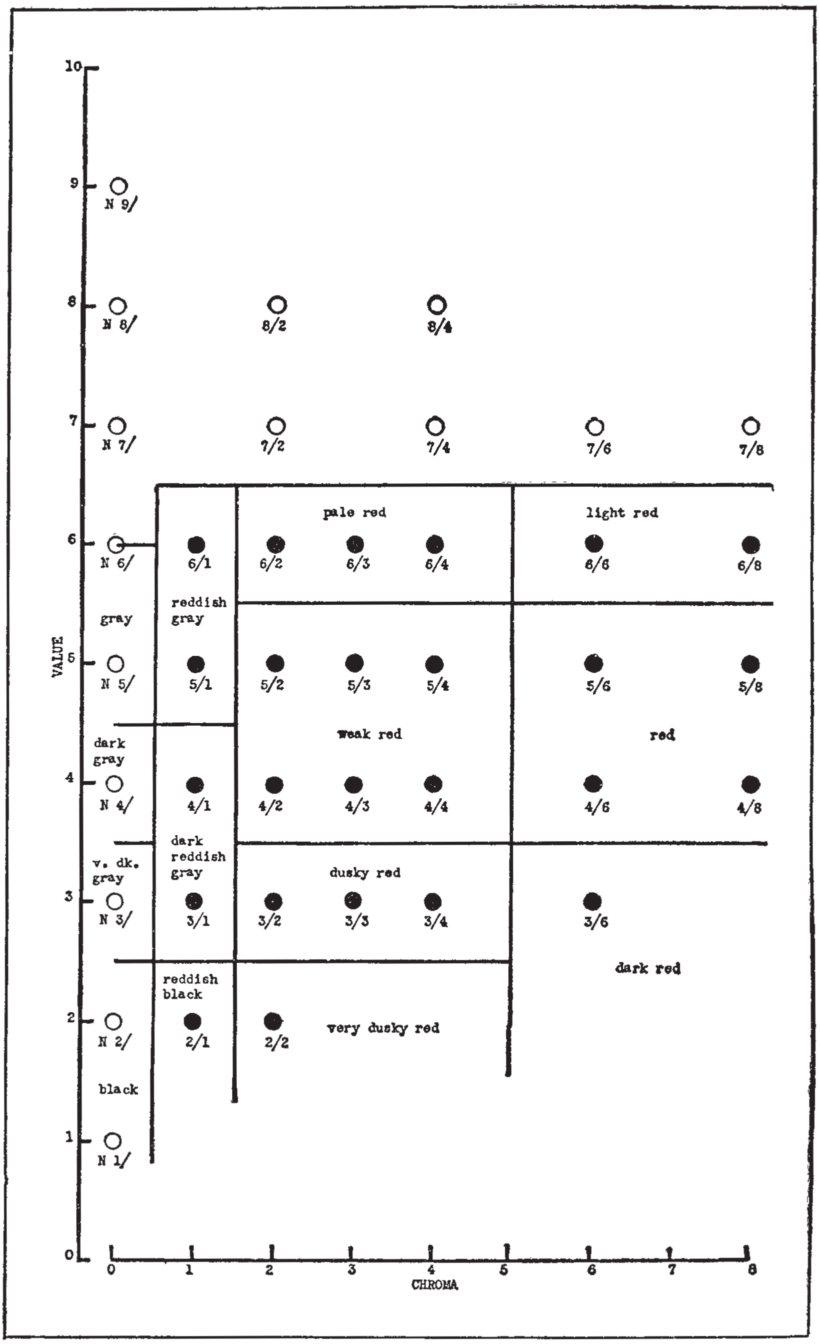

FIGURE 30.—Soil color names for several combinations of value and chroma and hue 10R.

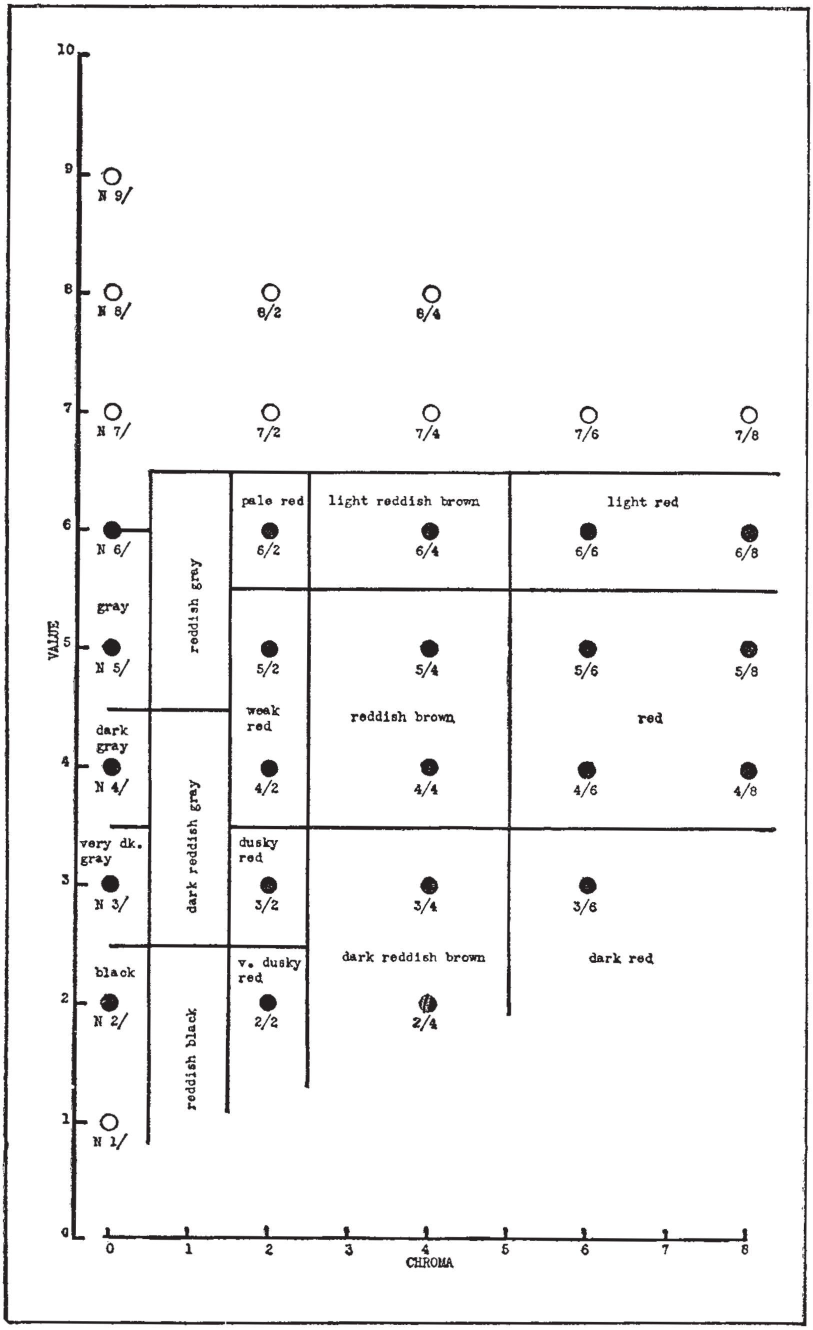

FIGURE 31.—Soil color names for several combinations of value and chroma and hue 2.5YR.

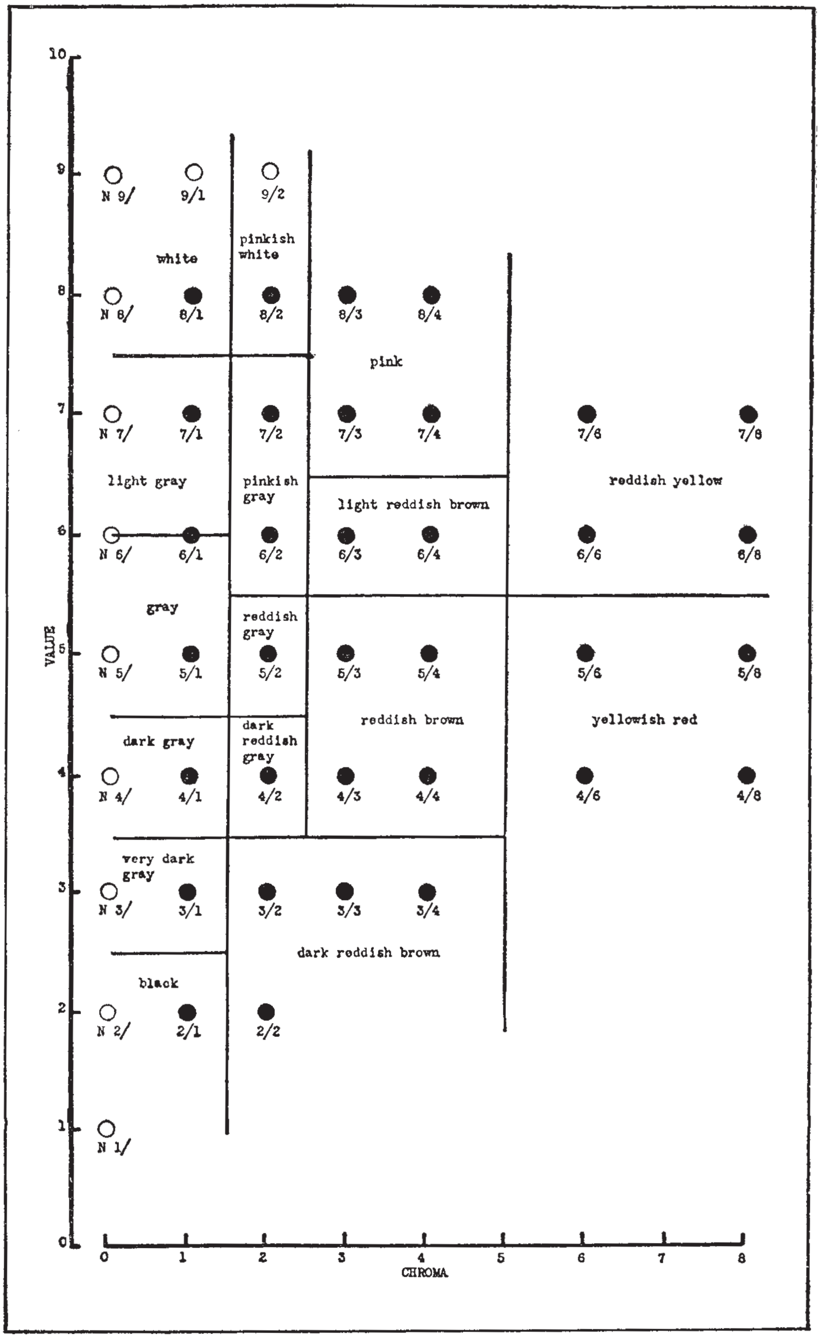

FIGURE 32.—Soil color names for several combinations of value and chroma and hue 5YR.

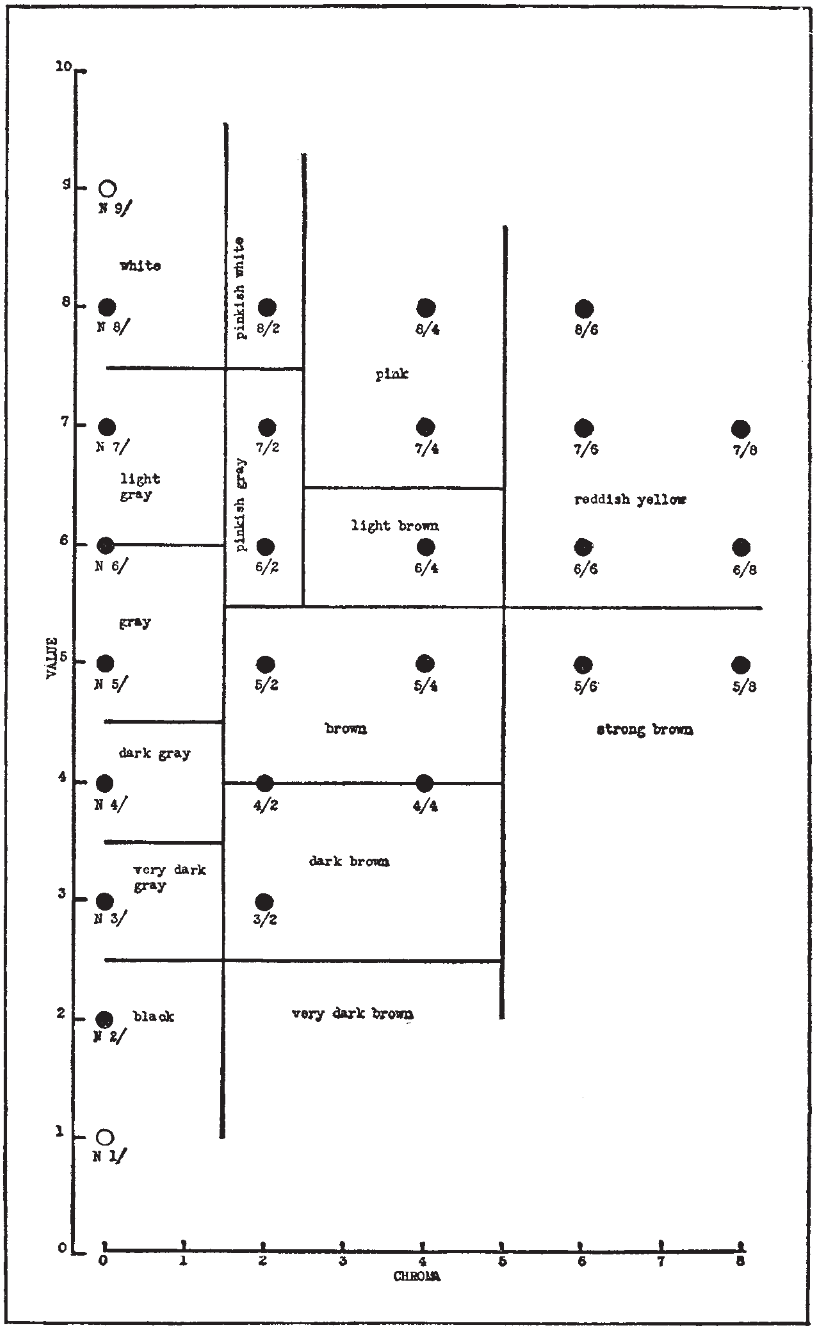

FIGURE 33.—Soil color names for several combinations of value and chroma and hue 7.5YR.

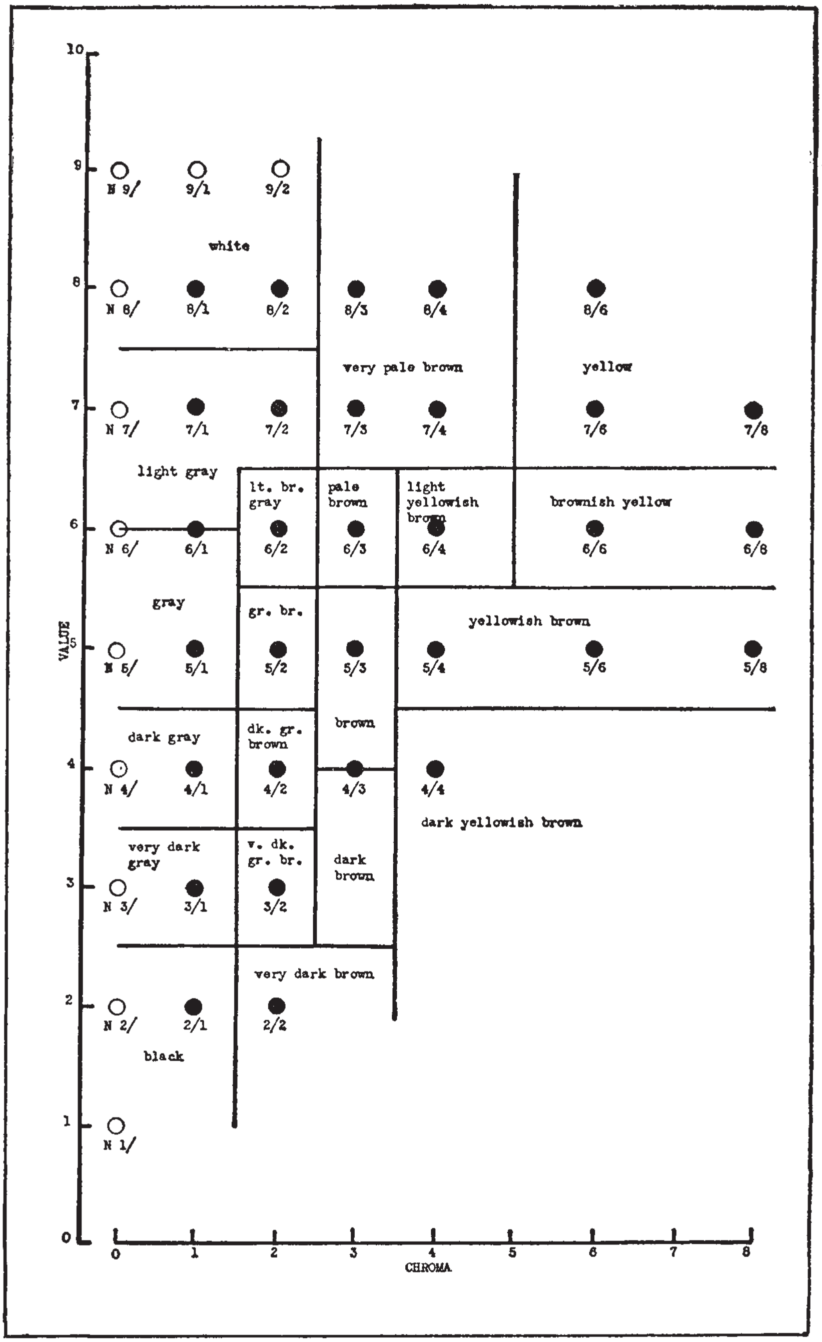

FIGURE 34.—Soil color names for several combinations of value and chroma and hue 10YR.

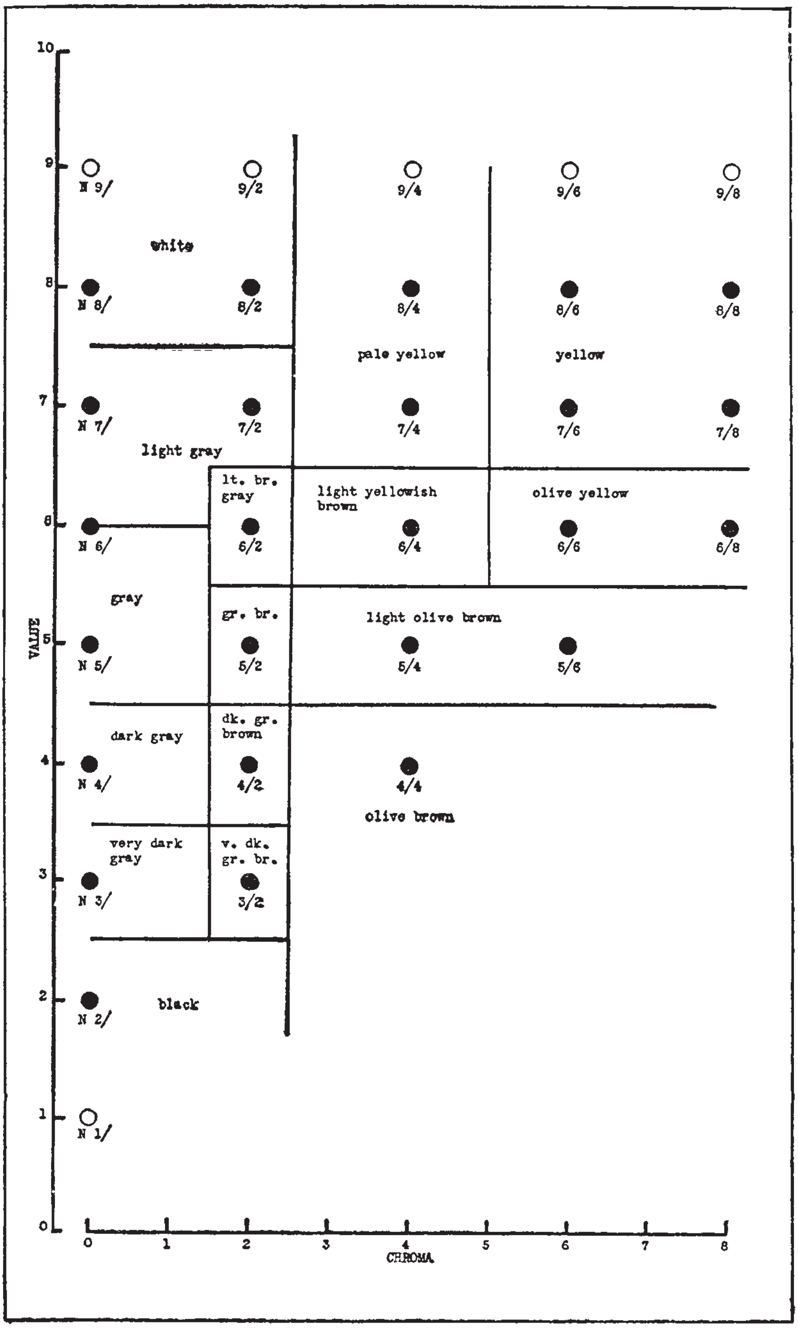

FIGURE 35.—Soil color names for several combinations of value and chroma and hue 2.5Y.

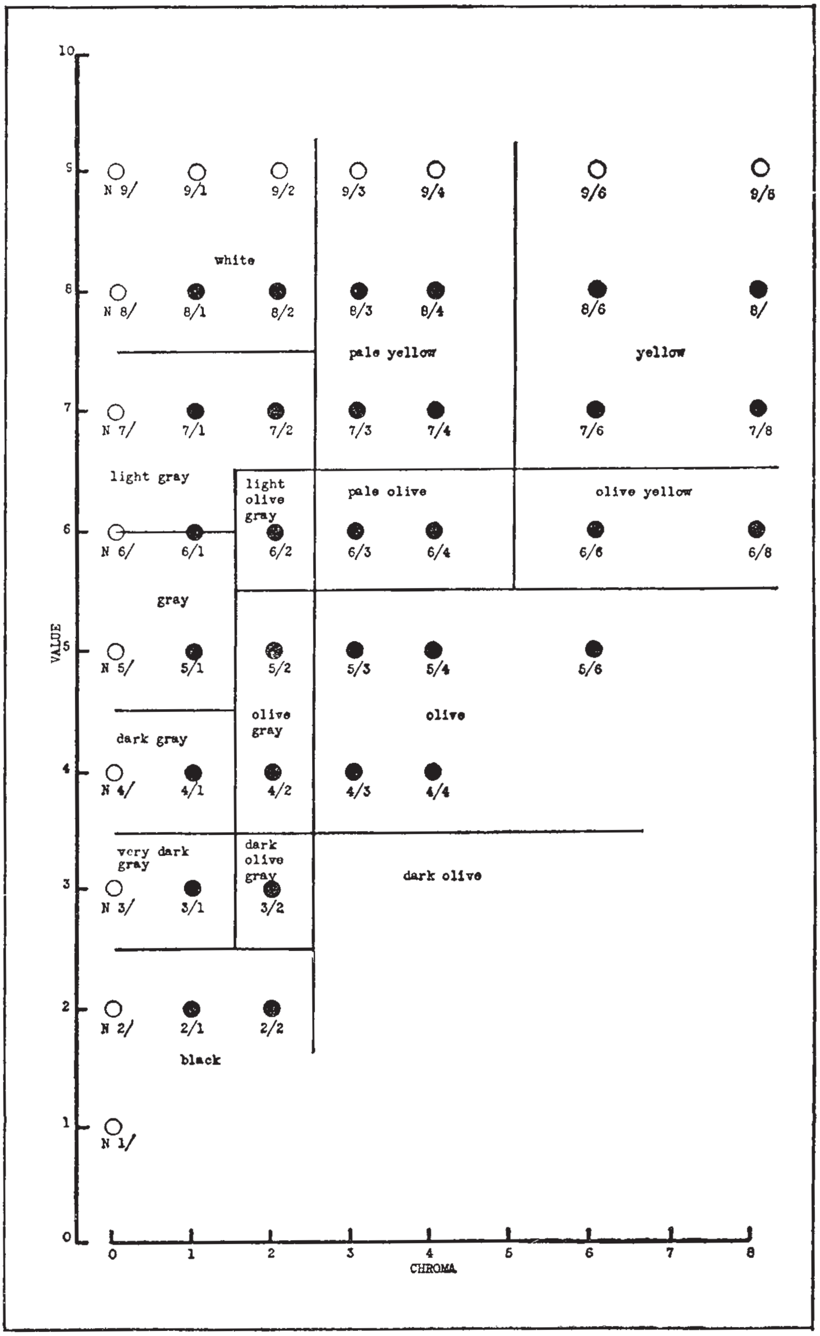

Figure 36.—Soil color names for several combinations of value and chroma and hue 5Y.

The Munsell notation for color consists of separate notations for hue, value, and chroma, which are combined in that order to form the color designation. The symbol for hue is the letter abbreviation of the color of the rainbow (R for red, YR for yellow-red, or orange, Y for yellow) preceded by numbers from 0 to 10. Within each letter range, the hue becomes more yellow and less red as the numbers increase. The middle of the letter range is at 5; the zero point coincides with the 10 point of the next redder hue. Thus 5YR is in the middle of the yellow-red hue, which extends from 10R (zero YR) to 10YR (zero Y).

The notation for value consists of numbers from 0, for absolute black, to 10, for absolute white. Thus a color of value 5/ is visually midway between absolute white and absolute black. One of value 6/ is slightly less dark, 60 percent of the way from black to white, and midway between values of 5/ and 7/.

The notation for chroma consists of numbers beginning at 0 for neutral grays and increasing at equal intervals to a maximum of about 20, which is never really approached in soil. For absolute achromatic colors (pure grays, white, and black), which have zero chroma and no hue, the letter N (neutral) takes the place of a hue designation.

In writing the Munsell notation, the order is hue, value, chroma, with a space between the hue letter and the succeeding value number, and a virgule between the two numbers for value and chroma. If expression beyond the whole numbers is desired, decimals are always used, never fractions. Thus the notation for a color of hue 5YR, value 5, chroma 6, is 5YR 5/6, a yellowish-red. The notation for a color midway between the 5YR 5/6 and 5YR 6/6 chips is 5YR 5.5/6; for one midway between 2.5YR 5/6 and 5YR 6/8, it is 3.75YR 5.5/7. The notation is decimal and capable of expressing any degree of refinement desired. Since color determinations cannot be made precisely in the field—generally no closer than half the interval between colors in the chart—expression of color should ordinarily be to the nearest color chip.

In using the color chart, accurate comparison is obtained by holding the soil sample above the color chips being compared. Rarely will the color of the sample be *perfectly* matched by any color in the chart. The probability of having a perfect matching of the sample color is less than one in one hundred. It should be evident, however, which colors the sample lies between, and which is the closest match. The principal difficulties encountered in using the soil color chart are (1) in selecting the appropriate hue card, (2) in determining colors that are intermediate between the hues in the chart, and (3) in distinguishing between value and chroma where chromas are strong. In addition, the chart does not include some extreme dark, strong (low value, high chroma) colors occasionally encountered in moist soils. With experience, these extreme colors lying outside the range of the chart can be estimated. Then too, the ability to sense color differences varies among people, even among those not regarded as color blind.

While important details should be given, long involved designations of color should generally be avoided, especially with variegated or mottled colors. In these, only the extreme or dominant colors need be stated. Similarly, in giving the color names and Munsell notations for both the dry and moist colors, an abbreviated form, such as "reddish brown (5YR 4/4; 3/4, moist)," simplifies the statement.

By attempting detail beyond the allowable accuracy of field observations and sample selection, one may easily make poorer soil descriptions than by expressing the dominant color simply. In all descriptions, terms other than the ones given on these charts should be used only in rare instances, and then only as supplemental expressions in parentheses where some different local usage is common.

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