THE USE OF AIR-PHOTOS FOR SOIL CLASSIFICATION AND MAPPING IN THE FIELD

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USE of air-photos as bases in soil survey work has steadily increased since they were first used in 1929 by Bushnell and his co-workers. They have now almost entirely displaced all other types of bases for soil survey work. Indeed, unless a soil map for a particular area is urgently needed, mapping is not undertaken until air-photos are available. The clarity with which air-photos show detail of cultural and land features has, in fact, led some to be over-enthusiastic about them, and to suggest that a soil survey can be interpreted largely from them without field work. Useful as they are as bases for field work in soil mapping, little about soils can be learned from air-photos without careful study on the ground. The photos permit rapid and accurate plotting of soil boundaries, but sound classification and mapping of soils can be achieved only by detailed field study of the soils themselves, supplemented by laboratory study of samples. Examinations of soil profiles are essential. Air-photos show soil patterns, not soil profiles. To the competent soil scientist who has studied the soils of each pattern on the ground, air-photos do suggest the kind of profiles present.

THE SOIL TYPE

We shall first review briefly what soils are and how they are classified, for this information is essential to an understanding of the use of air-photos in surveying. Soils may be defined as “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.”

Soil consists of several more or less distinct layers, or horizons; and the cross-section of these horizons from the surface of the ground to the parent material is known as the soil profile. Soils vary greatly both in degree and kind of profile expression, depending upon the intensity of the different soil-forming factors,

1 Material for this paper has been drawn from many sources, including published papers, reports, books, and the experience of many soil surveyors. Specific literature citations are therefore not made in the text, but a few selected references listed at the end of the text deal with the subject matter of the paper.

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on the length of time that they have been active, and on the nature of the materials from which the soils have developed.

In order to systematize our knowledge about soils and make predictions about their behavior, it is necessary to have a classification based on their characteristics and their relationship to their environment. The basic unit in the natural system of soil classification is the natural soil type. The natural soil type is narrowly defined as: "A group of soils having soil horizons similar in differentiating characteristics and arrangement in the soil, including texture of the surface soils, and developed from a particular kind of parent material."

Soil types are three-dimensional geographic bodies. They have an irregular upper surface—that of the earth itself, an indistinct lower boundary, and evident but not sharp perimeters. They are defined in terms of observable properties of the soil profiles making up the type, including kind and sequence of horizons and characteristics of the individual horizons, depth, and relief. All soil characteristics, both internal and external, are considered jointly in defining the soil type, and each type has a unique combination of properties. From the observable characteristics, a whole series of qualities may be interpreted, including fertility, productivity, erosion hazard, drainage, and the like. A moderate range in characteristics is allowed within a soil type, but the type must be sufficiently homogeneous to permit accurate predictions of soil behavior for the individual types.

As needed, soil types are divided into phases according to differences in depth, slope, stoniness, and the like, which are not significant to the behavior of the soil in the natural landscape, but which are significant to its use under cultivation or in a changed environment. Soil types and phases of soil types are the principal units shown on modern detailed soil maps.

The name of a soil type has two parts: a series name plus the class name of the texture of the surface soil. Thus, Miami loam is a soil type. Those soils having common profiles, except for the texture of the surface soil, are grouped together in a soil series. Thus, Miami loam, Miami silt loam, and Miami silty clay loam belong in the Miami series. Series are grouped into families, and these into great soil groups.

The natural system of soil classification is basic and comprehends combinations of all relevant soil characteristics. For many applied purposes, however, only one or a few of these characteristics are significant, and technical groupings of the classes of the natural system are made to meet some particular objective. For example, the soil types and phases of an area may be grouped according to suitability for agricultural uses, according to management requirements under a particular use, or according to suitability for use as subgrade or surfacing material for roads or airfields. A given technical grouping is very useful for the objective for which it is made, but it cannot be safely used for any other purpose.

Since the results of research and experience are synthesized by soil types, a map showing their distribution permits us to apply our knowledge to specific areas. An excellent practice for one soil type may be ruinous for another.

Soil Maps

Soil scientists in the United States now produce in the field: (1) Detailed soil maps, (2) reconnaissance soil maps, and (3) detailed-reconnaissance soil maps. In addition, schematic maps with no field work and exploratory maps with varying amounts of field work are prepared. Air-photos are used in the production of all of these kinds of soil maps.

Modern detailed basic soil maps show all boundaries between narrowly de-
fined soil units, including areas of one soil within another. All soils and all areas of soil that are significant to potential use are shown. All soil boundaries are observed by the soil scientist throughout their course, and are plotted in their correct positions relative to natural and cultural features. On these maps the soil boundaries are so accurately located and the mapping units they enclose are so precisely defined that the behavior of any individual unit shown on the map can be predicted and use and management for it can be recommended.

_Reconnaissance soil maps_ show boundaries observed on the ground at intervals, not throughout their entire course, and are therefore less accurately plotted than detailed basic soil maps. The maps are on a smaller scale than the detailed maps, and the soil units are less precisely defined. Reconnaissance soil maps are used mainly for general planning on a community or county-wide basis. In mountainous or arid regions suited only to extensive use, reconnaissance maps, supplemented by detailed maps of sample areas, furnish all of the soils data needed.

_Detailed-reconnaissance soil maps_ are, as the name implies, a combination of the two types already described. Parts of an area with intensive use or potential use are mapped in detail, and areas suited only to extensive use are mapped in reconnaissance.

_Schematic soil maps_ are derived from data on soils, climate, vegetation, geology, and land form, and from topographic maps and airphotos. The soil scientist estimates the soil boundaries and defines the map units from interpretations made from these data. Exploratory soil maps have mapping units defined, in part at least, by field observations, but boundaries are located as on the schematic maps. These maps are used mainly for advance planning in undeveloped regions.

**Use of Air-Photos in Field Mapping**

Single-lens vertical air-photos have now almost completely displaced all other types of bases in detailed soil mapping in the United States. Their outstanding advantage is the wealth of ground detail, which permits the field scientist to keep himself accurately located at all times and to plot soil boundaries precisely. In addition, some soil boundaries show plainly on the photos, and others not at first obvious can be interpreted by the field scientist after he becomes familiar with the area in which he is working. Air-photos are relatively low in cost and are easily obtained. They free the field scientist of the responsibility of preparing a base map, and permit him to concentrate his time and effort on the soils.

Air-photos have several serious shortcomings as base material. Scale is not uniform among photos and in different parts of the same photo; and elevations are not shown on photos as on topographic maps. A very large number of pictures are required to cover an area the size of a soil survey project; this requires the construction and orientation of many match lines between the individual air-photos. The joining of soil boundaries along these lines is both tedious and time consuming, especially in areas with complex soil patterns. For most areas, however, these disadvantages are more than offset by the advantages.

Air-photos at the scale of four inches equals one mile are used on most detailed soil surveys. Smaller scales are used in areas with simple soil patterns and extensive soil use, or a combination of the two; larger scales are used where the soil pattern is complex or use is intensive. Air-photos giving stereoscopic coverage of an area are normally needed. They permit the field scientist to accomplish his work more rapidly than he could with only alternate air-photos and also
improve the accuracy of the finished map. Of course, in areas of very low relief, little or no additional information can be obtained by use of the stereoscope; so only alternate air-photos are needed.

Aerial mosaics and photo-maps are now used successfully, especially in regions of low relief where stereoscopic coverage is of little or no advantage. Some detail is lost in reproduction of these types of bases from the original air-photos, but the larger area covered by each field base sheet is a distinct advantage, as it reduces greatly the number of match lines. Some scientists use the mosaics or photo-maps as a field base and have single-lens photos for stereoscopic study in the office. The data obtained from the stereoscopic pairs are transferred to the field base. Thus the advantage of the larger field base map is retained and stereoscopic coverage is also obtained.

The new field scientist, untrained in the interpretation of aerial photographs, soon learns to correlate items on the air-photos with features on the ground by studying both soils and photos in the field. After he has gained such experience he is able to study the photos in the office, and make many interpretations that will increase the speed and improve the accuracy of field work. Using the stereoscope, he sketches details of drainage, marks ridge tops, and tentatively-delineates some of the major slope boundaries. Swampy areas, high cliffs, and woodland trails are sketched, and traverses are planned so that major obstacles will be avoided and best coverage of the area will be obtained. Where good topographic maps are available, they are studied with the air-photos and are helpful in interpreting them. Features not readily recognized on the air-photos are identified with the aid of the topographic map and are then plotted on the air-photo. Geologic maps are used in a similar way. Geologic boundaries significant in soil mapping that do not show on the air-photos are transferred to the photograph from the map. Some important soil boundaries that are correlated with differences in land form or drainage are tentatively sketched. All such interpretations must be verified by field examination.

In rough or heavily wooded country, the field worker has great difficulty in observing soil boundaries throughout their course. In such areas, the soils are identified, and their boundaries that coincide with land-form boundaries, drainage lines, or vegetation pattern are projected from the line of traverse as far as they can be seen and beyond that left hanging. Then in the office the stereoscope is used to connect the boundaries not completed in the field. Thus the scientist is able to "observe these soil boundaries throughout their course" without having actually seen them on the ground. This technique facilitates both speed and accuracy of mapping in areas of difficult terrain.

Boundaries between soils are associated with significant changes in one or more of the soil-forming factors: Climate, vegetation, parent material, relief, or age. These boundaries are not always sharp; soil types may merge into one another through transitional belts several yards or more wide. In the field, soil boundaries are located and delineated as the mapper crosses them on the line of traverse. Many soil boundaries are correlated with topography, and the field scientist commonly orients his traverse at approximately right angles to the drainage, or to the "grain" of the country, in order to cross the greatest possible number of soil boundaries. Traverse lines are spaced at distances of 500 to 1,000 feet; even so, many side trips are necessary.

The principal value of air-photos in soil mapping is that they permit the field scientist to keep accurately located on the ground at all times. Thus, the air-photos aid him in plotting the soil boundaries in their correct position relative to local land features. In addition to major land features, such as broad
land forms, streams, roads, and houses, which are shown on most types of base maps, a wealth of local detail is available on most air-photos, especially in thickly settled regions. Fences, isolated trees, hedgerows, bushes, ditches, dead furrows, rock outcrops, and even individual large stones appear in such detail that the mapper has an almost unlimited number of control points for use in plotting soil boundaries. The experienced field scientist utilizes this feature of the air-photo to the maximum and is able to attain a high level of mapping accuracy.

In large forested areas or other undeveloped regions, much of this local detail, which is largely a reflection of the activities of man, is lacking. In such areas, if the mapper is to keep correctly located, the air-photo must be mounted on a plane-table like any other base. In fact, the use of the plane-table may improve accuracy even in areas with good photographic detail.

The chief value of air-photos is the wealth of local detail that assists the mapper in keeping located and in plotting soil boundaries precisely, but other features are apparent on the photographs or can be interpreted from them. Such features as land form, drainage pattern, land use, and vegetation pattern on the air-photos give the mapper clues that aid him in placing soil boundaries and identifying the soils.

Land form and the pattern of stream dissection are the most prominent major features that can be interpreted from air-photos. Experienced field men quite readily recognize such features as bottom lands, terraces, alluvial fans, upland plains, hills, and mountains on the air-photos of most regions. Generally soil and slope boundaries coincide with the land-form boundaries and can be accurately located on the air-photos, but many additional boundaries not related to land form occur. Broad differences in texture of parent materials are only sometimes related to both land form and the drainage pattern. Local variations in texture of materials on a given land form are great enough in many places to result in different soil types. Hence, soil type or texture cannot be interpreted from land form alone. On similar land forms, differences in lithology of the parent material also result in widely different soil types within an area as small as a county. For example, in some counties in New York State, terraces that cannot be differentiated on the air-photos have quite different soils. Gravely outwash terraces composed mainly of sandstone and acid shale materials have soils of relatively uniform sandy texture throughout the profile, whereas similar terraces composed of limestone materials have soils with a finer textured surface layer and a moderately clayey subsoil. These two kinds of soil have quite different properties both for agricultural and engineering uses. Similar differences in soils related to lithology and physical characteristics of the parent material are observed on till plains and moraines. It is apparent, then, that land-form interpretations, though useful in locating soil boundaries, are not dependable criteria for defining soil types within the areas delineated.

Local differences in tone on the air-photos provide many clues for location of soil boundaries in the field and may aid in identification of the soils. On broad stream flood plains, tone differences reflect both soil texture and drainage. The areas with light tone indicate recently deposited, relatively coarse-textured material, and the successively darker tones indicate increasingly finer texture and poorer drainage. The tones are a guide in locating the soil boundaries, but additional features, including lime content and presence or absence of pans, are considered in defining the soil type and must be evaluated by field examination of the soils.

Alluvial fans, which are commonly of coarser texture than the adjoining
flood plains, may appear as lighter tones. In some places, however, they contain more moisture than the adjacent areas and appear darker. The outer rim of the fan may be marked by a darker tone because it is wet by seepage.

In cultivated uplands of forested regions the soils with the poorest drainage—those in flats, depressions, and seep spots on slopes—appear as dark areas on air-photos because of the large amount of organic matter and moisture they contain. Boundaries for these areas can be readily plotted. In the dryer grassland regions, however, poorly drained soils are commonly lighter in tone because they are more strongly leached than the better drained ones. Nevertheless, in many regions, soils of intermediate drainage do not display a distinct tone and boundaries must be determined on the ground (see Plate 9, A\(^3\) and B). In places where broad areas of poorly drained soils are interspersed with small areas of better drained soils, the better drained areas appear as contrasting-toned spots, either lighter or darker, depending upon the region. The tones associated with differences in soil drainage are obscure or do not appear at all where hay and pasture crops cover most of the land, and on many air-photos made when all soils are moist (see Plate 10, A and B).

Tone is also a useful guide in locating slope boundaries, because light is reflected differently from slopes of different gradient and aspect. Shadows of the steeper slopes are also useful in locating boundaries. Even though some boundaries are readily apparent, the narrow range of slope allowed within a given soil type or phase requires field observations for correct slope classification.

Areas of eroded soil commonly appear as a lighter tone because they have lower organic-matter content and possibly because they have a lower moisture supply. Gullies appear as narrow white scars across the slopes. Some kinds of soil have a characteristic erosion pattern, and boundaries can be delineated on this feature.

Rock outcrops, except those of very dark color, appear as light spots; loose stones, if abundant, appear as "peppering" of small light-toned dots. Soil boundaries can be drawn on the basis of this characteristic pattern of light tones. Stone fences appear as narrow light or dark lines in a rectangular pattern and aid in judging the stoniness of an area. In some places, however, moss-covered lava flows are confused with meadows, and brush-covered tundra areas in cold regions are mistaken for grass.

Many other features are recognized and delineated by tones. Alkali soils in arid regions appear as light spots when dry or as dark spots with white rims when wet. Sinkholes appear as dark spots with light rims when widely spaced, but closely spaced ones may appear as a mottled light and dark pattern. Tiled drains show as narrow light lines across fields because the soil is drier over the drain. This pattern serves as evidence of restricted drainage, but again field examination of the area is necessary for proper evaluation of drainage condition and identification of soil types.

The pattern of land use is one of the most prominent features shown by air-photos, and to the extent that land use and soils are correlated, can be used as a guide in delineating and identifying soils. With experience the field scientist is able to recognize many of the different kinds of crops on the airphotos, and can make some estimate of the kind of soil present, but these estimates are commonly of a broad nature because many crops are grown on a fairly wide range of soils, even locally.

Woodlands commonly mark areas of soil that is poorly suited to agricultural

\[^{3}\] Plate numbers correspond to those in Soil Survey Manual from which these illustrations were adapted.
use, although in some regions no correlation exists between kinds of soil and woodland. In some places wooded areas indicate poorly drained soils, in others shallow or stony soils. In parts of the Midwest, the wooded valley slopes have light-colored soils that contrast with dark-colored soils on associated grass-covered ridge tops and uplands. With experience the field scientist learns to distinguish different kinds of forest on the air-photos and can use the forest as a guide to broad soil differences. In the northeastern United States the dark tones of pine and other conifers indicate soils on sandy and gravelly outwash materials; the lighter gray tones, soils on glacial till or residuum; and the fuzzy light-gray areas, with a scattering of conifers, areas of peat. The very dark shadings associated with red cedar commonly indicate limestone materials, but the soils range from shallow and stony to poorly drained and relatively deep.

All of the features described are used singly or in combination by the soil scientist, to assist in locating soil boundaries and in identifying the soil types in detailed soil mapping. In reconnaissance mapping the same features are observed and utilized. In many areas it is possible to locate many of the soil boundaries by the use of the stereoscope in the office. Field work then consists largely in checking the boundaries so drawn, adding others that are needed, and identifying the soils within the delineated areas. After the soil scientist has gained experience in an area he can delineate and classify areas with a very distinctive air-photo pattern without visiting them in the field, but it remains necessary to examine most areas in the field for proper identification. Air-photos, where available, are also used in preparation of exploratory and schematic soil maps. In fact they may furnish the best available data for location of soil boundaries, and interpretations and inferences drawn from the air-photos are important in defining the soil units shown on the map.

CONCLUSIONS

Soil scientists now utilize air-photos in all phases of soil mapping and are generally aware of the many clues to placement of soil boundaries and identification of the soils that can be interpreted from them. Air-photos serve to increase both speed and accuracy in soil mapping. In fact, without air-photos, modern detailed soil maps of many places could not be produced except at prohibitive cost. Although many soil boundaries are revealed by the air-photos, many others do not show at all and must be determined by field examination. In few places can the air-photo give all of the clues needed to identify the soil type, because it reveals mainly surface features, not internal or soil profile characteristics essential for identification of the soil. A scientist with experience in a given area can make some estimates of internal soil features from the photographs, but he cannot project his interpretative standards from one area to another because many of the clues that he uses have different significance in different areas. Hence, field study is always essential to proper classification of soils and correct placement of many of the boundaries on the soil map.

SELECTED REFERENCES

A sample photograph and field sheet in a characteristic general farming area of the eastern Middle West—Bartolomew County, Indiana. The scale is about 1:20,000. On the original soil map there are types and phases of well-drained grayish-brown forest soils, poorly drained dark-colored forest soils, and alluvial soils. Only parts of the pattern of light-and-dark in the fields correspond to boundaries between the well-drained grayish-brown forest soils and the poorly drained dark-colored forest soils. The soils have developed from Pleistocene valley-train materials, partly overlain by recent alluvium and some wind-blown fines. The relief is nearly level to gently undulating. 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).
EXPLANATION OF PLATES 10A AND 10B

Sample photograph and field sheet in a mixed forested and farming area in Franklin County, New York. The scale is about 1:20,000. The land is undulating to gently sloping. The dominant soils in this area are imperfectly and poorly drained gray to black forest soils. The large wooded area includes poorly and very poorly drained soils from sandy materials of marine origin and some small spots of well-drained light-gray sandy forested soils. The soils are developed on late Wisconsin drift of low relief. The photographs were taken in September 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.
SAMPLE FIELD SHEETS ON AERIAL PHOTOGRAPHS

The two-part plates (9 and 10) illustrate the use of aerial photographs as a base for original soil maps, or field sheets. Numbers 9A and 10A are aerial photographs of widely contrasting landscapes; 9B and 10B are the same photographs with the original soil maps on them as drawn in the field. Drainage which appears in blue and certain base information which appears in red and green are omitted. These illustrations were adapted from the new *Soil Survey Manual*, issued August 1951. 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 and accurate sketching of boundaries. All soil units shown on the original soil map were identified by observation on the ground, including soil profile examinations.

USE OF AERIAL PHOTOGRAPHS IN THE PUBLICATION OF SOIL MAPS

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AERIAL photography and photogrammetric techniques are essential to the Soil Survey program conducted cooperatively by the United States Department of Agriculture, the State experiment stations, and other interested Federal agencies. In this article we shall first mention how aerial photography reached its present importance in soil surveying and then discuss the methods of map production now followed.

Under authorization of Congress, the Department of Agriculture began mapping and classifying the soils of the United States and its Territories in 1899. In the early years, soils were not mapped in great detail. The scale used for field mapping seldom exceeded 1:31,680, so plane-table surveys and existing topographic quadrangles were satisfactory. They provided enough planimetric features for adequate orientation and for plotting the boundaries of soils. From the field map, a soil map was compiled and published at a scale of 1:63,360, usually a single sheet for a county.

The plane-table survey and the small-scale topographic quadrangle became inadequate, as the public demanded more detailed separation of the soils for use in agriculture, engineering, and allied pursuits. The detail demanded could not be published at the scales being used, nor could it be mapped in the field, without far more planimetric features for reference and orientation. The small-scale topographic quadrangles did not have the required planimetric detail. Plane-table surveys at large scale would cost too much. The problem was acute.

As a result of training during World War I, a few soil scientists became interested in aerial photographs. They were convinced that these photographs, with their wealth of planimetric detail, adaptability to various scales, and ease of reproduction, would solve many problems confronting the Division of Soil Survey. They began a persistent campaign for their use, and in 1929 were rewarded by the photographing of Jennings County, Indiana, for the specific purpose of soil surveying. Methods of map construction used for this county were crude in comparison with those now employed. Still, much was learned, including the fact that soil scientists could map soils on aerial photographs rapidly, accurately,