major applications of their work, and to inform geologists of some of the recent developments within their own field.

In the original planning of this issue, it was intended to include papers representing all branches of both basic and applied geology. Owing, however, to the limitations of time, many of the scientists from whom manuscripts were requested were unable to contribute. As a result, the scope of the issue is somewhat less broad than might be desired. It is hoped that in some future issue a supplementary series of papers, together with additional discussion, may serve to round out the topic, and provide an up-to-date, over-all picture of the rôle which aerial photos play in earth science.

THE USE OF AERIAL PHOTOGRAPHS IN SOIL MAPPING

Mark Baldwin, Howard M. Smith, and Howard W. Whitlock[1]

WITH aerial photographs in hand the soil mapper is equipped with seven-league boots! The vertical view of the picture covers far more area than earth-bound vision. It lays before one, for miles around, the farm fields, the wooded patches, roads, and streams arrayed in panoramic display. Relationships which before, at best, could only be conceived after long struggles through briars, swamps and tangled vines, are made clear at a glance.

In 1917 when the call was issued for volunteers to train as pilots and observers in the United States Army Air Force (then part of the Signal Corps) four or five men of the Soil Survey responded. They all were graduated from the "ground school" and entered the more interesting and exciting phase of training at flying fields. After the first flight or two, they began to notice the pattern on the earth below them. The highways, streams, farmsteads, and fields were perfectly obvious to any of the cadets, but the soil men looking down began to see through these features the soil pattern—the arrangement of the soil areas and boundaries—and the relationships of this pattern to the more readily visible features of the landscape. They saw these features as they had never been able to see them before. First of all was the greatly increased range of vision, whereby a visible boundary could be followed out for miles. Then there was the advantage of moving rapidly over to new locations while keeping the old ones in view. And many more features of the earth itself are visible from the vertical or bird's-eye view than from the horizontal or worm's-eye view, from the ground or fence post.

So flying, while it removed the soil surveyor from actual contact with the soil, offered exciting possibilities in the field of soil mapping. At least one of these fugitives from the Soil Survey began to sketch the landscape and the soil boundaries, while on his third or fourth flight in the early summer of 1918. It didn't go too smoothly because his efforts were diverted by the flying instructor who insisted that the cadet devote his attention to learning to fly rather than making pictures of the landscape. Also the advantage of seeing many square miles of territory at once had the disadvantage of offering the soil surveyor more features than he could handle before he was moved on at a terrific speed of 50 or 60 miles an hour. There were also difficulties with scale.

[1] Agriculture Division, Food and Agriculture Organization of the United Nations; Soil Scientist, Division of Soil Survey, Bureau of Plant Industry, Soils and Agricultural Engineering, United States Department of Agriculture; and Cartographic Engineer, Division of Soil Survey, Bureau of Plant Industry, Soils and Agricultural Engineering, United States Department of Agriculture, respectively.

Then the flying soil surveyor was given the opportunity of seeing aerial photographs of the terrain over which he had been flying, and was given permission to take some of these photographs into the field for mapping trials. These pictures had been taken with plate cameras, rather insecurely mounted in the plane, if mounted at all; and most of them while intended as vertical pictures were actually obliques taken at various angles determined by the vagaries of the flight and the position of the photographer. With all their defects their usefulness was obvious, and it was evident that the photograph itself rather than a map compiled from the photograph was what the soil mapper wanted in the field; and that the job of compilation of the soil map should follow the field work.

When the war ended and the volunteer army was demobilized, the soil surveyors "returned to earth," but they did not forget their experiences in observing and mapping soils from the air, nor did they forget the progress made by the army in aerial photography. In May, 1926, two of the men who had been in the Army Air Forces, T. M. Bushnell, then in charge of Soil Survey at Purdue University, and Mark Baldwin of the Division of Soil Survey in the U. S. Department of Agriculture, drove to the Flying Field at Rantoul, Illinois, to enlist the interest of officers of the Army Air Force there. They secured such co-operation as it was possible for the Air Service to give, but it was due almost entirely to the interest and persistence of Mr. Bushnell that the use of aerial photographs in soil mapping got a thorough try-out in Jennings County, Indiana. The entire county was photographed in November, 1929, for the specific purpose of soil surveying.

The base map, except for certain ground control by U. S. Coast and Geodetic Survey and by railroad and highway profiles, was prepared by Mr. Bushnell and the field party of soil surveyors. There was further control by means of plane-table traverse around and across the county. A grid of section lines on a scale of 1:31,680 was developed from the control and the aerial photographs. Into this grid the detailed map data, chiefly the soil boundaries and symbols were reduced and copies from the field survey made on the original photographs. Bushnell described the work briefly in a paper presented to the Indiana Academy of Science in 1929 and published in their proceedings.[2] Bushnell had presented to the 1927 meeting of the same society a paper also published in the proceedings, a description of methods worked out as a small-scale trial of the use of aerial photographs in soil mapping in Indiana.[3]

One of the chief objections to the use of this method was the cost of the pictures—$5.00 a square mile in Jennings County. This seemed prohibitive to many administrative officers. But this difficulty was largely removed in the 1930's when the Agricultural Adjustment Administration and the Soil Conservation Service of the United States Department of Agriculture got into the field with liberal appropriations and together photographed a great proportion of the arable lands of the United States.

In the meantime the techniques of the photography itself, of preparation of control and base map data were being improved rapidly, and have made use of aerial photography in soil surveying more efficient and accurate. Many men in different organizations and professions have contributed to the perfection of these techniques, but it was the field men of the Soil Survey who recognized the value of aerial photographs in their own field nearly thirty years ago and took

[2] Bushnell, T. M., Aerial Photographs of Jennings County, Proc., Indiana Academy of Science, vol. 39, 1929, pp. 229–230.

[3] Bushnell, T. M., Aerial Photographs for Indiana, Proc., Indiana Academy of Science, vol. 37, 1927, pp. 63–72, illus.

some of the first steps towards the use of pictures in mapping specific features of the terrain.

With simple photo-interpretation methods, the experienced soil mapper can interpret directly for his soil map much of the photographic detail, *when on location with the picture in the field.* This applies more to soil boundaries than to soil classification, however. Each soil type is the result of a unique combination of 5 factors: climate, vegetation, relief, parent rock, and time. Their combined effect is reflected in the soil profile. Boundaries between soils occur where there are changes in one or more of these genetic factors. Positive identification and classification of the soil requires an examination of the soil profile in the field.

After a soil scientist has become fully familiar with the soils of an area and their relationships to the visible features of the landscape by field study, many soil boundaries may be plainly visible to him, on the pictures. In some areas, the colors of the surface of soil types are sharply contrasting as on the till plains of Indiana and Ohio, for example. Here the boundaries are seen most clearly on photographs made in early spring or late fall when fields have the least cover. Often so much detail can be seen on the pictures that the mapper must continually guard against the tendency to show more of it than is meaningful from a practical point of view, considering the scale on which the map will be published and the use of the map.

Frequently the type of vegetation, when it can be identified on the photograph, gives a clue to the kind of soil beneath; but here again, the clue must be verified by examination in the field. It cannot be stressed too strongly that aerial photographs are in no way soil maps. A skilled scientist, familiar with the area *on the ground*, can get a lot of useful information by interpretation. In an unfamiliar area one may easily be badly misled.

Features such as roads, railways, canals, and other similar details only need be identified and classified by legend symbols on the picture. One can leave the delineation and inking of these to the cartographer! And other culture such as shorelines, streams, rock outcrops, escarpments, buildings, and urban areas are quickly identified and outlined. Go only where necessary to examine the soil, for one is no longer tied to a traverse! Easily recognized features of the landscape as roads, fences, buildings, trees, field shapes serve for locations—at least in "civilized" country. The cartographer will not need traverse for control either. All he will want located on the pictures are a few selected U. S. Geological Survey or U. S. Coast and Geodetic Survey control stations. He will indicate, too, which ones he wants located; and send descriptions of just where to look for them.

It cannot all be painless, however. There are coniferous forests on terrain of slight relief, featureless grassed plains, very large open fields, and pictures lacking sharpness of detail. These present problems of photo-interpretation. Place two pictures covering the area in question under the stereoscope. Immediately objects take on new form. Trees "run up on stems," and buildings attain height. Features of the landscape all assume their natural three-dimensional shapes. They are distinct in outline, and not confused with the shadows they cast on the ground.

Two types of stereoscope should be available—one which will allow the pictures to be shifted freely without moving the instrument, for use in the field-office and a pocket-size for use in the field. These, in all probability, will not be suitable for use with large-scale pictures. All work placed on the picture by this means should be tentative, subject to check and correction in the field.

For places where the stereoscope fails—and there are such—there still remains the old planetable. Orient the picture on it and run a little traverse or take a few cross-sights. But remember—"a little traverse," here and there—no long unbroken ones as in the "good old days." There'll be an argument with the unequal scale of the picture.[4] Tie into local landmarks whenever possible; and when cross-sighting for location, don't pick targets in the next county—choose the nearest ones. Remember that unequal scale! Boundaries should coincide with the local scale of the picture. The cartographer will adjust scale discrepancies of pictures and soil boundaries together.

Usually aerial photographs used for soil mapping are made to meet U. S. Department of Agriculture specifications with regard to overlap, tilt and other requirements. All are vertical pictures.

Contact prints are used most commonly. The usual scale for these is 1:20,000 but occasionally others are used. Ratioed prints—pictures having smaller or larger scale than the original contact negative—are used for special purposes. Scales of 1:7,920; 1:15,840; 1:31,680; and 1:63,360 are examples. As sharpness of photographic detail is extremely important in soil mapping, it is especially desirable that prints be made directly from the original negative.

Older methods of map compilation from contact and ratioed prints required that the mapping be on every picture using only a limited area around the principal point of each. Present methods, where consecutive prints with adequate overlap are available for compiling, permit field mapping on every other print.

The chief disadvantage of contact and ratioed prints for use in the field is the large number required to cover the average soil survey area. This results in a very large number of match-lines or common boundaries between the mapping on adjoining pictures, even where only every other one is used. They are unwieldy to handle also when it becomes necessary to lay them out consecutively for a study of the soil relationships over the total area covered, or to use them in the field for inspection of broad areas.

Aerial mosaics with varying degrees of control are frequently used. Only those with adequate horizontal control are suitable. Lithographic reproductions should not be employed as they usually lack sufficient sharpness of detail. Prints can be prepared at any convenient scale and sheet size. Common scales are 1:31,680 and 1:63,360.

As compared to contact and ratioed prints mosaics have the advantage of uniform scale on which mapping can be carried to the edge of the sheet. Each sheet covers a larger area than either of the others and fewer sheets are required for a given area. This materially reduces the amount of match line between pictures and the time required to transfer and check them. The smaller number of pictures can be laid out in sequence more easily for study, and are less unwieldy when used for inspection of broad areas in the field.

A photo index and full stereoscopic picture coverage should be provided for each soil survey area. The index is indispensable for rapid handling of the pictures and can be used as a progress map in the field. The need for stereoscopic coverage has been made clear previously.

The kind of paper on which the pictures are printed is of importance to the field man. Double-weight paper of semi-mat finish is most satisfactory as it takes ink efficiently, does not reflect light and thus is kind to the eyes of the mapper.

In most cases the soil mapping is placed directly on the photograph. Pencil is used in the field and the work is inked in the field-office. A few mappers apply the ink directly in the field, but in general this is not recommended. Special inks have been developed as ordinary drawing inks are subject to flaking off. Red,

[4] Assuming either contact or ratioed prints are used.

black, brown, green, and blue inks are in general use; blue less than the others because it does not photograph well. These special inks are not entirely satisfactory because they do not flow well, and thus are difficult to use. A portable light table is desirable for field-office inking.

Mapping is sometimes done on transparent overlays. This permits the use of the pictures again for other purposes, including planimetric map compilation. At present, compilation of most base maps for soil surveys follows the field mapping. As pictures without soil boundaries are required for this, the use of overlays for soil mapping obviates the necessity for a double set of pictures. Where compilation of the base map precedes the field mapping, one set of pictures is sufficient and overlays are of no significance. Overlay mapping can be reproduced cheaply, and such reproductions may be used for farm planning before the published maps are available, but reproductions made from mapping placed directly on the photographs are far better for this purpose as the photographic detail is retained as a background for the soil information.

The disadvantages of the overlay are numerous. They tend to obscure the detail of the photograph, making difficult its use in mapping. It usually has a different coefficient of expansion from that of the picture so that work placed on it under differing temperatures does not coincide equally with the detail of the picture. Inking of work on overlays is more difficult and time consuming than inking directly on the pictures.

Mapping on the individual sheets of a survey should be carried to clear-cut outer boundaries to form match-lines between the sheets. On pictures or picture overlays these match-lines should pass through identical points on the adjoining prints. Straight roads, fence lines, railways, canals and so on should be used where possible. Well defined streams may be used in places; and lines of convenience that do not coincide with any physical feature of the landscape are necessary in many places. Long straight match-lines are preferable to short ones. Crooked or indefinite mapping boundaries between pictures are undesirable. By careful adherence to these principles in the field, much time is saved in compilation of the manuscript map.

Upon completion of the field mapping the photographs are sent to the cartographer. Using the latest photogrammetric methods he prepares a planimetric map manuscript from which, by means of metal-mounted blue-line plates and lithographic processes the final multi-colored map is produced.

It requires more time to complete the mapping of a soil survey area on aerial photographs than by any of the old methods. Thus this is not the determining factor in favor of aerial photographs for soil mapping. Rather it is the greater accuracy and amount of soil information obtained that recommends them. It can be said that without aerial photography, the soil scientist would be confronted with a difficult problem—that of finding another means of mapping accurately the soil detail now required for the planning of efficient management for our soils, farms, and farming enterprises.