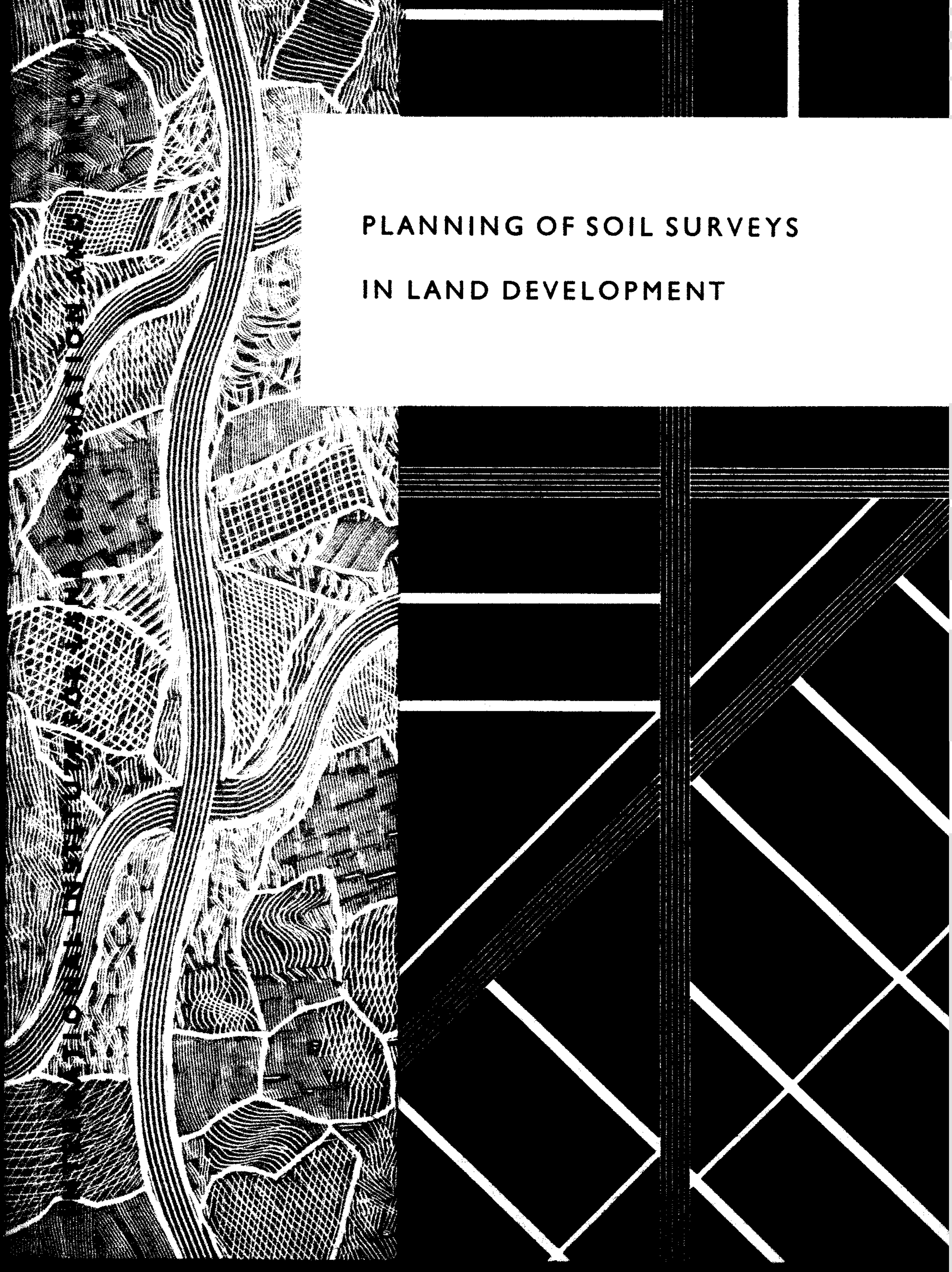
PLANNING OF SOIL SURVEYS IN LAND DEVELOPMENT



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PLANNING OF SOIL SURVEYS IN LAND DEVELOPMENT

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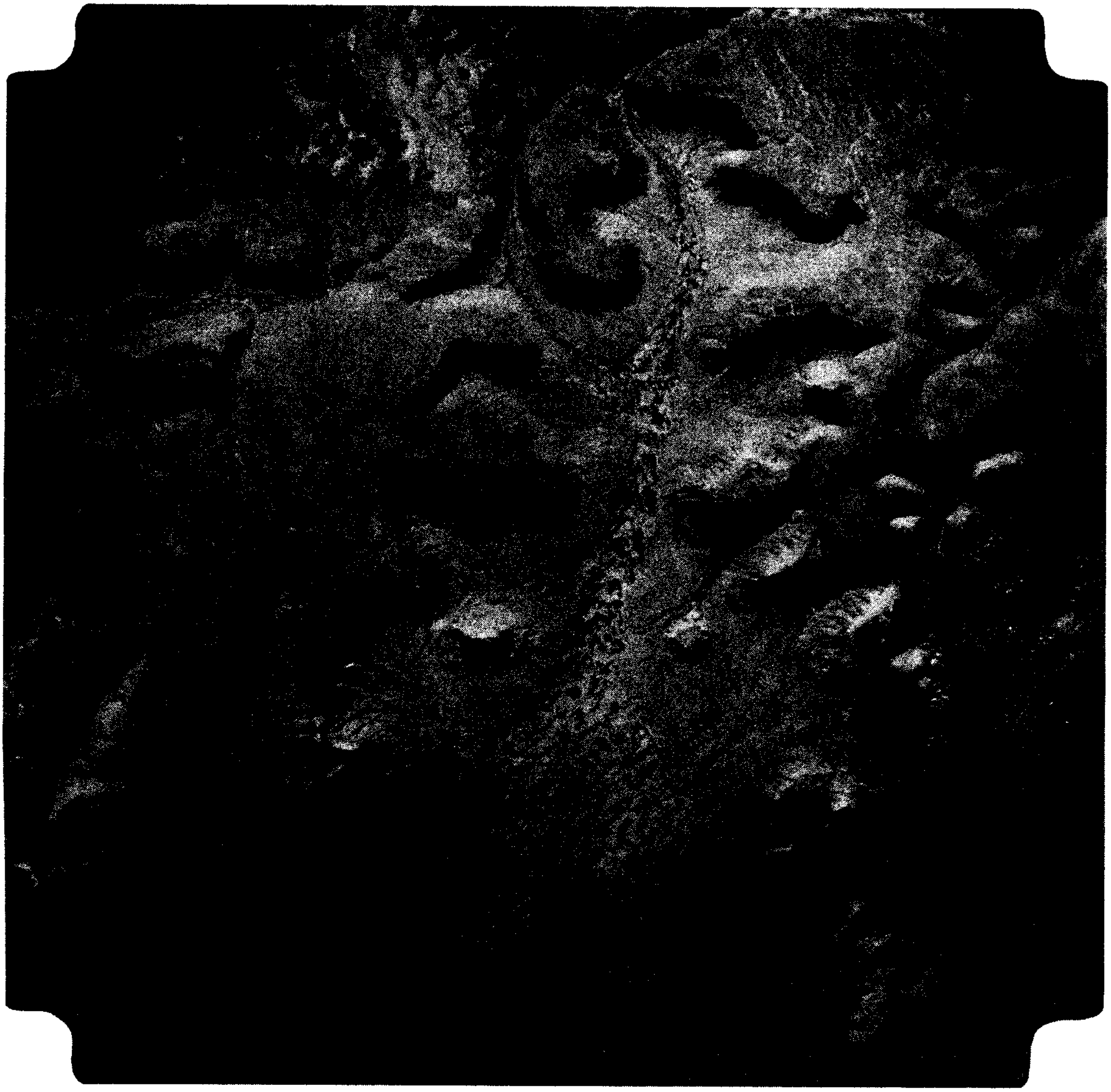
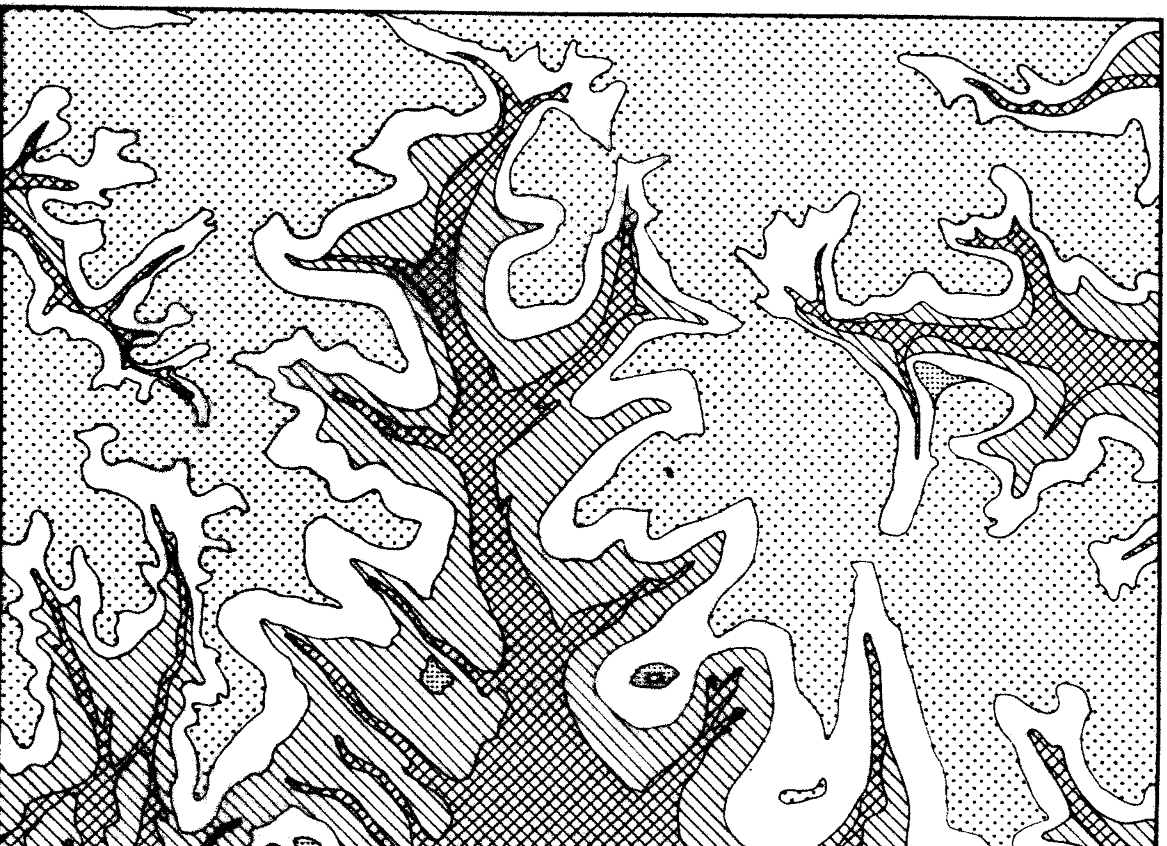


Photograph taken with Wild RC 5a film cam. 9 × 9 in. Wide-angle Aviogon lens f = 6 in. Height 3000 m (10,000 ft.). Negative scale 1:20.000. Photo: Air Survey Co., London



1. SOIL SURVEYS FOR DEVELOPING REGIONS AND FOR DEVELOPMENT PROJECTS

1.1. INTRODUCTION

Soil surveys to be used in development planning and in the execution of development projects must be carried out with practical methods and with an open eye for the practical needs of the project. Even more than in standard soil survey in this case does the accent lie on having a sufficiently accurate description of the soils and a sufficiently practical soil map that can be used for the development project. These maps should give all the essential information on the soils within the project, as far as it is useful for the practical aspects of the use of the soils as a whole. This means that they should contain all essential information and not only that which is necessary for the first stages of the project.

This is often forgotten by those people who are concerned with the first stages of a project and who forget that after all the soil map, together with related investigations, must also form the basis for the land use after the execution of the works in a project. A typical example of this is the "landclassification survey" as carried out according to the specifications of the U.S. Bureau of Reclamation. The specifications of this survey are only sufficient for obtaining a statistical inventory of the surface area covered by the main classes of land for irrigation purposes. This survey is therefore very helpful in determining the capacity needed for various structures. It is however absolutely insufficient for all the following stages of a project.

A sufficient basic knowledge of the soils must be gathered. On the other hand, some people think more about the theoretical background of the soils and their genesis than about those factors which may be of extreme importance for the execution of the project. This danger must also be avoided, giving yet another reason for a very careful consideration of the specifications for soil survey.

After the soil survey has been carried out, also sufficient attention must be paid to the application of the survey data. The subject of soil survey interpretation, which can be said to belong to the field of "land classification" is as essential as the soil survey itself. Also for this special methods and specifications are needed.

1.2. Pedology and soil survey

As the word is generally understood, pedology is the pure science that is concerned with the study of the soils in their natural environment.

This means first and foremost the genesis of the soils and their classification. It is a very fascinating science, which although young compared with various sciences such as geology and biology, has booked some very interesting results. In slightly over seventy years, this science, starting with the concepts of Dokuchaev, has developed into a world wide science with a large store-house of various techniques used by many thousands of people. It is especially fascinating therefore, to see that all these people, working in so many different parts of the world, can agree on very many of their basic concepts after the relatively slight amount of research, in comparison with the very complicated subject, that has been possible in this short span of time. Pedology as a science is less generally advertised than e.g. nuclear physics. Still, if one looks at the very complicated system of the soil, which is influenced by such different outside factors as climate, time, parent material, vegetation, and the various activities of mankind, it is astonishing to see what has been accomplished. Pedology, being a fundamental part of soil science is indispensable for all the practical aspects described in the following parts. It also has its own practical importance when soils from distant regions or even continents have to be compared.

Soil survey is often considered as part of this mainly fundamental research. It certainly has a very important meaning for that part of soil science. On the other hand, the need for soil surveys from the practical point of view, especially for development projects and for town- and country planning, is ever growing. We actually feel, that this is also one of the reasons that fundamental science receives more time, attention and money. In this respect also soil science is very comparable to nuclear physics. From other parts of natural science we could also cite many examples of the pure science coming into its own, only because the applied side of the science gained commercial, economic or social importance. The chemical D.D.T. was first synthesized somewhere in the last decades of the 19th. century. Its importance for world agriculture dates, however, only from about 15 years ago.

Soil survey is the most typical link between theoretical or fundamental pedology and the applied aspects of soil science. The modern soil surveyor should therefore feel himself in an intermediary position. On the one hand he has to study the fundamentals of a science, but on the other hand he has to execute his surveys in such a way that they become of practical value for the people in the area concerned. For this purpose he should be prepared to look for the most effective survey methods.

1.3. Practical aspects of soil survey

The handling of very large areas has many specific aspects. The planning of whole countries and of areas of the size of 100.000 square km. or more is extremely useful. This gives a chance of selecting the best areas for land development. Of course this selection is made

not only on the basis of soil survey, but also taking into consideration various political, social, technical and even religious factors.
All this makes it necessary to pay very careful attention to the best map-scale for these general inventories. It should give sufficient information for selecting the areas with the best soils for land development, but on the other hand it is not necessary in this stage to give a lot of detailed information that may never be used. The aerial photograph, together with a necessary minimum of field work provides the solution. The use of photos of scales 1:40.000 to 1:70.000 flown with wide-angle or super wide-angle cameras and of the very best quality may have special possibilities for a first general classification of the areas for further practical research.
The soil survey in development plans is the basis for many other maps. It even can be said that in practical planning the soil map generally is a research paper on the background. It is a very essential research paper, because all the fundamental data are assembled on it. For practical use soil survey interpretation maps are derived from the soil map. These may be of a purely technical nature, when they are called *soil quality maps* or of a somewhat more complex nature, in which case they are called *soil suitability maps* (see par. 4). The idea of making these maps is that the very complex information which is given on the soil maps and related maps is divided into those aspects having particular significance in the various phases of a development plan. This makes for easier reading of the essential data, i.e. on soil salinity, soil drainage, soil permeability etc. and on the suitability of the soil for various crops and the possibility of various improvements (BURINGH, 1960). Sometimes these maps are excerpts of the soil map, in which case they should not give data or boundaries that cannot be found on the soil map. In general they do not have specific survey problems, but certainly some specifications as to the way of publishing. In particular the use of too many details on the base map is not allowable on a land classification map. A land classification or soil survey interpretation map is by definition used by many people who are not familiar with the methods used in the survey. For publication of the map, therefore, special care should be taken to avoid details that are not permissable due to the mapping scale of the soil survey.
It is also possible to make land classification maps which are based on a combination of maps such as the soil map, the hydrological map, the topographic map (contourlines), the engineering soil map (deeper observations) and the geological map. In that case the combination should be taken into account by producing all these maps on the same topographic base so as to make an accurate combination of these various data possible.
Also in general not all the data of each map are taken into the combination. Thus the land classification map is a "combined excerpt" of the various fundamental data.
This is a very important aspect which should gain in importance with the increasing demand for "overall" natural resources surveys.
Various other specific information on the assumptions under which the soil survey interpretation has been made must also be printed on the map itself. Even although the report always should be read before any use is made of the soil map, the land classification

map, or the soil survey interpretation map, we find that it is absolutely necessary to avoid any misunderstandings by giving the main assumptions in a general way as a printed text easily readable on the map.
The subject matter handled is too important for practical use for any misunderstandings to be allowed.
For the use of soil surveys in land development projects and also in various other practical uses, it is very necessary that the soil surveyor pays close attention to those aspects of his soil investigations which will be used in the practical execution of the project. This means that, especially in this case, the legend of the soil map is determined not only by theoretical pedology, but still more by the need for bringing in the essential data. The scale of the survey is of course of extreme importance in considering all this. The efficiency of the survey for the project demands that it be carried out in as short time as possible, which means either that not too large a map scale should be used, or not too small a "basic mapping unit" (see par. 3.4.) should be adopted. On the other hand all essential information must be given on the map. Only careful consideration of these two factors in mutual discussions between the people in charge of the execution of the project and the soil surveyors can give the best possible solution. If this is not done the deception may lead to very disagreeable consequences during the execution of the project.
Sometimes it is unavoidable that the soil survey does not give all the necessary information. This is typically the case if a standard soil survey has been made of a large area, which can only take the various problems into account in a general way. The execution of a specific project in part of that area may then need specific information which in principle is available on the soil map, but the detail of which is insufficient for the case on hand. This also may be important if the soil map is already a few years old. The execution of the project must have the most recent data, for instance, concerning the amount of soil erosion. In this case the soil map probably gives some erosion indications, for instance as phases. Then, however, the project may need a special soil erosion survey, to provide the latest information and to give more details of this specific aspect. Soil erosion surveys using the existing soil maps in combination with recent air photos are the best solution in that case.
Apart from soil survey interpretation maps, other land classification maps must also be made for the execution of a project. The project is based not only on the soils, but also, for instance, on specific detailed information on the topography, the hydrology and various other aspects that come only partly from the soil survey. For instance an example is the availability and quality of irrigation water in case of irrigated farming, or the availability and quality of drinking water for projects that include the organisation of cattle ranges. In this case, as indicated before, the land classification map is not only based on the soils, but for instance on the hydrologic map and the topographic map as well. This integral approach will become more important as soon as the planning of projects gets more careful attention. The inclusion of various specialists in the team executing the survey for a development project is therefore of the utmost importance.

1.4. THE SOIL MAP IN A DEVELOPMENT PROJECT

There is sometimes a tendency to hand to the client or to publish only the land classification or soil survey interpretation maps. We think this wrong, because after all the soil map provides the main basic information that can and should be used in later phases of the development. Therefore the organisation ordering the survey should be prepared to pay a certain amount for having the soil map finished even if, for the first phases of the project, land classification maps are of more direct use. These land classification maps are only a first interpretation of the soil map according to the direct needs. They are, however, never to be re-interpreted for various other purposes or for changing circumstances. The soil map is the one map which can always be re-interpreted, both for the gradual development of the project, and for changes in coming years. The whole outlook of the project is certain to be gradually changing due to the changes which take place in any kind of farming which has passed from the stage of original traditional methods.

Sometimes during a project some aspects of the soils themselves are changed by amelioration methods developed by engineers. In this case the soil map must be revised, but if the survey is of good quality this always takes less time than the execution of a new soil survey, because in general only a small part of the total area and only some aspects of the soils have been changed. This revision has to be done in the field, because even if good records of the technical changes in the project have been kept by the engineers the changes themselves will never be quite according to what was planned. The engineer's record can however give the areas in which the changes have taken place, and thus indicate the areas which must be revised.

The soil map in a land development project should not be seen simply as a document of regional importance using a regional legend. It is also important to have the main information on the soil classification of the various soils occurring in the mapping units according to a world system, such as that published by the U.S. Department of Agriculture (1960). The use of this system of world wide soil classification which is now being developed as a scale of reference for the main soil characteristics, will make it possible to "transfer the results of research and experience among all countries according to kinds of soil" (KELLOGG, 1955). On the other hand the survey for a project is always important as a sample area for a national soil survey. In this way the scientific and practical sides of soil survey always touch each other. These various aspects are described in the publication by KELLOGG (1955), almost all of which could be cited in this text.

We shall limit ourselves, however, to concluding this paragraph with one quotation: "We must not permit the suggestion that in the soil surveys, we have an uneasy choice between two alternative kinds of surveys, one for the scientist and one for the practical man. A soil survey that is not basically sound on the scientific side has little chance of serving the practical users".

2. AIR PHOTO INTERPRETATION IN SOIL SURVEYS

2.1. AIR PHOTO INTERPRETATION AS A TOOL

Air photo interpretation is an essential tool in modern soil surveys. It should be applied, however, in a systematic way, following the methods which have been developed for this. The method developed by BURINGH (1960) at the I.T.C. is what we call full systematic air photo interpretation. This method always requires a systematic field check as well (see par. 2.2.).

In the following paragraphs we shall try to give a rough impression of the amount of field observation which in general we think is necessary for the various publication scales of soil maps. In its full implications however, this only is valid for the soil scientist who does not take sufficiently to heart the maxim that "each soil unit is a particular kind of landscape. It is defined by its landform and profile and ranges in each" (Soil Survey Manual, page 131). This can also be expressed in the following: "its landform 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" (Soil Survey Manual, page 155). Various other quotations can be given to the effect that the efficient soil survey takes the landscape into its survey as well as the profile. The efficiency of a soil survey is mainly determined by the way in which the soil surveyor can combine these two aspects of the soil. If this is done, the rigid grid survey is almost wholly out of the picture and instead there comes the more flexible way of surveying as it is handled by most modern soil surveys in various parts of the world.

On the one hand this makes for a better and more efficient system of soil survey. On the other hand it certainly makes it necessary to have better trained field personnel. This is also the reason why the various data from tables 2–5 (par. 3.4) are given with a large margin.

According to BURINGH (personal communication) it should be remembered that the field observations of a soil survey consist of three different kinds:

1. observations for soil description and classification,
2. observations for soil boundaries, and
3. special observations according to the practical purpose of the survey.

In any area the most efficient survey method is determined by the physiographic features, their correlation with the soils, the expert knowledge of the soil surveyors working in the area, and by the practical purpose of the survey. According to these the three different kinds of field observations will be combined in a different way, both as regarding the total number of observations and the percentages of each kind. This holds still more for the use of air photos, which in theory is of the same order. The air photo gives a systematic approach to what any competent soil surveyor would do in the field anyway. In many cases it does have the result, that the soil association is easier to map than the soil series. In this way the air photo certainly has a direct influence on soil science regarding the general kind of soil map which will be provided.

In soil surveys the air photo is a tool which may perhaps be best compared with the microscope in biology, where it is a tool which has had a certain influence on the relative importance which is attributed to various biological phenomena. This is now perhaps being gradually replaced by the more modern instruments and methods such as biochemistry. In the same way the air photo is a tool, but the most efficient use of this tool will make it possible to map the soil associations quite easily, and perhaps in some cases will have the influence of a slightly more practical effect on the execution of soil surveys over large areas for practical purposes. This is certainly not meant to detract the systematic and theoretic pedological field research, but the latter should be done in well chosen sample areas.

In this way the sample area gives various possibilities without a large area having to be mapped in an impractical way. First of all the sample area is used as a control for the interpretation of the air photo and for establishing correlations between the phenomena observed from the air photo and in the field. Secondly it is then used to describe and investigate the variations within the soil mapping units as used for the total survey area in correlation with air photo interpretation. Thirdly the sample area provides the best localities for research of a more theoretical pedological nature which is certainly necessary for more investigation into the soils of a region.

Generally the sample areas are picked specially for their typical characteristics, thus giving the possibility of studying pedological phenomena in the most interesting spots. They are also the best areas for specific investigations of a more practical nature.

The specifications for a soil survey using air photo interpretation must consider the various aspects of the survey.

First of all a list of specifications for the air photos must be prepared (see appendix). Secondly the way of executing the air photo interpretation must be indicated. In the third place the way of choosing the sample areas and of describing the soils in these areas must be indicated. In the fourth place the general field check which follows after the investigations in the sample areas have advanced sufficiently should be described, together with the kind of chemical and physical soil analyses which must be made. All this can, however, only be done after a careful discussion with all persons and organizations concerned, of 1. the purpose of the soil survey, 2. the scale of map which is really needed for this purpose, 3. the time within it should be ready and the number of personnel available. In many cases it is this last point which raises the most difficulties. The only practical way of approach to the specifications of a soil survey is therefore to realize what can be done. The putting-out of specifications without sufficient thought to these points is in most cases senseless and does not give satisfaction either to the organization ordering the survey or to the people who have to be trusted with the execution.

The ordering of a soil survey even if it is done by tender is not to be compared with a tender for a construction of a road or a bridge. Soil survey is a piece of research. This gives a fundamental difference with projects of construction, where the necessary research has been done before the project is undertaken.
The organization which handles a soil survey by tender is in fact hiring a temporary extension to its soil survey department. Of course the financial consequences should be kept within the reasonable limits of a budget in the same way as any research must be budgeted for and controlled. But the commercial tender as such should be handled very carefully, because it may make for poorer quality work than the client has a right to expect, simply because the client himself does not realize that research always brings up new problems which can sometimes be put on the shelf if they are of a more or less theoretical nature, but which sometimes give the indication of very important practical aspects of the use of the survey in the region concerned.

2.2. Soil survey and the aerial photograph

The field methods used in soil survey often have a very personal aspect, which is caused partly by the variations in the set-up of the soil classification system and legends of the various countries, and partly by the influence of the physiography of the area to be mapped.
The efficiency of a soil survey is largely dependent on the personal experience and capabilities of the soil surveyor. We all know, that there are enormous differences between the time needed by different persons for a survey of a certain area. The cost of the soil survey is also very largely influenced by this personal aspect. Part of this difference is caused by the more or less effective use that the soil surveyor makes of various indications in the field such as the geomorphology, vegetation, land use and other phenomena. This holds especially for semi-detailed soil surveys, for instance on a scale of 1:50.000. An equivalent of this is the scale of 1 inch to 1 mile which is very often used in Britain and America. But nevertheless this approach is also very important for the production of detailed soil maps. For soil maps on very small scales, such as 1:100.000 or less, the use of the soil

association in a physiographic sense is undisputed. There, in any case, every capable soil surveyor would use the physiographic boundaries as his main units, indicating them as associations of, for instance, series families or soil groups.

The *use of air photos* for soil surveys is in fact comparable to the use which any soil surveyor makes of the correlative indications in the field, but in this respect the air photo has some very definite advantages. First of all it is possible to analyse systematically the whole area to be surveyed, using the air photo. Secondly if vertical air photos are used, the point of view of the whole area is the same. The soil surveyor trudging up a hill (which in any case is often a very rare phenomenon) to get a view over an area, is often hampered by the vegetation which he finds blocking his view, even when he has climbed the hill. So the third advantage, a very simple one, is that the whole countryside may be viewed. There is a fourth advantage, which consists of the possibility of planning in advance the field work to be done in the area, taking into account the indications of the physiography that have been studied on the air photo. All these various aspects are important in determining the enhanced production of soil surveys by the use of air photo interpretation.
The necessity of going into the field to really map the soils always remains as the soil as such is not to be seen on the aerial photograph. All lines drawn in air photo interpretation for soil surveys are based on the above mentioned correlations, but the soil surveyor who has some experience of this kind of work succeeds in drawing almost all the lines needed for his survey. Of course a large part of this efficiency is also determined by his pre-interpretation knowledge of the area. Roughly it may be said, however, that about 80% of all the observations made in the field during a normal soil survey are needed for locating the boundaries, the other 20% being used to describe the soils. In an average case, using air photo interpretation, it is possible to reduce the amount of field work for locating the boundaries to about 10%. This means that the total observations are reduced to about 30% of the field observations normally made during a traditional soil survey. Also, because of more careful planning of the field traverses, the lines to go between the observations will, on the average, be shorter. So therefore it may be said that at least in very many cases the efficiency of the soil survey using air photo interpretation is about 3 times as high as that of the traditional soil survey.
Of course, depending on the kind of basic soil survey unit used, there are various differences. In general the physiographic unit is the one most adapted to soil surveys based on air photo interpretation. So the association of the series, and some phases of the association, is often a better basic unit for this kind of survey than some of the preconceived soil series. In this case much depends on the way in which the basic soil series have been defined originally. In general this also means that for large scales, for instance soil surveys to be published in the scale of 1:10.000 (6 inch at 1 mile), the amount of field work in the same area will be relatively much greater than in the case of a soil survey to be published on the 1 inch to 1 mile scale. It is impossible to give exact data on this, but we do have some graphs that give an idea of this relationship (VEENENBOS, 1957) (Figure 1).

Where soil differences are very intimately correlated with phenomena which can be seen on the aerial photograph, the accuracy of the boundaries drawn may be much higher even than the accuracy achieved in an intensive field survey. So in some cases we have as an advantage of the air photo not only the greater efficiency, but also an improvement in the accuracy of the boundaries. The following figure, derived from a publication by BURINGH (1960), gives an indication of the various relationships for a survey on scale 1:50.000, taken from a practical example somewhere in Iraq (Figure 2).
The method for a systematic interpretation of air photos can be only summarily described in this paper. A fuller publication on this subject is given in BURINGH's publication cited above. We shall indicate here only some aspects.
First of all we have the so-called *elements of interpretation*. In all we now recognize up to about 20 different elements. These may be divided into 4 large groups. The first division contains the elements concerned with geomorphology. Secondly we have the group of elements concerned with vegetation and land use. Thirdly we have some general aspects of colour tone and texture of the aerial photograph. There is a fourth group consisting of the very specific human aspects, such as the sites of dwellings, dykes, way of running of irrigation canals and many more such criteria. Some indications of this are given in fig. 3, which is also derived from the above cited publication by BURINGH.
Briefly, this diagram of elements may be explained as follows. Of the various individual elements used in interpretation, six different kinds were chosen. First of all the area is analysed according to differences in land type, that is in large physiographic or geomor-

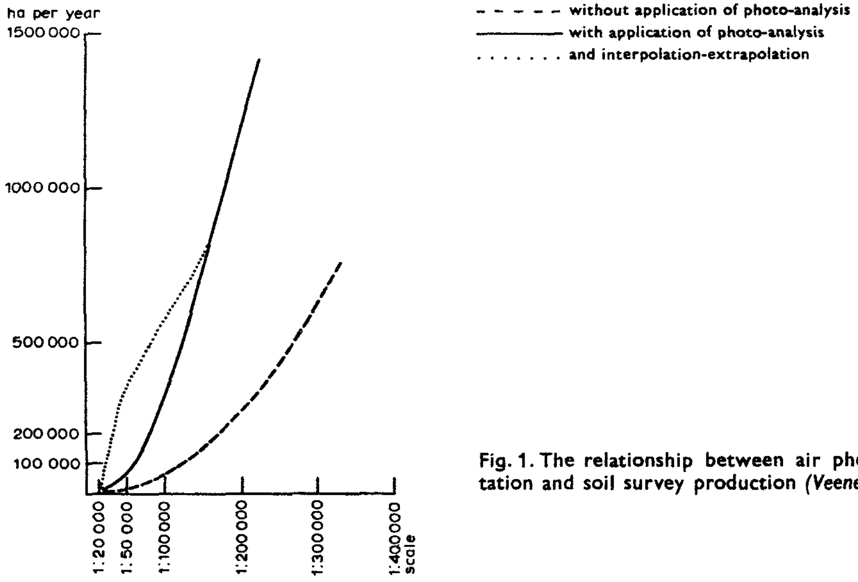


Fig. 1. The relationship between air photo interpretation and soil survey production *(Veenenbos 1957)*

phological units. Secondly a separate analysis is made according to the differences in slope seen with the stereoscope in all parts of this air photo lay-out. Thirdly a similar analysis is made according to drainage conditions and the same is repeated for gully and drainage pattern, parent material, vegetation and land use. On the assumption that the value of each of these elements, in this case at least, is equal to the correlation with soil boundaries, the 7th diagram gives the value of the photo interpretation. In this figure

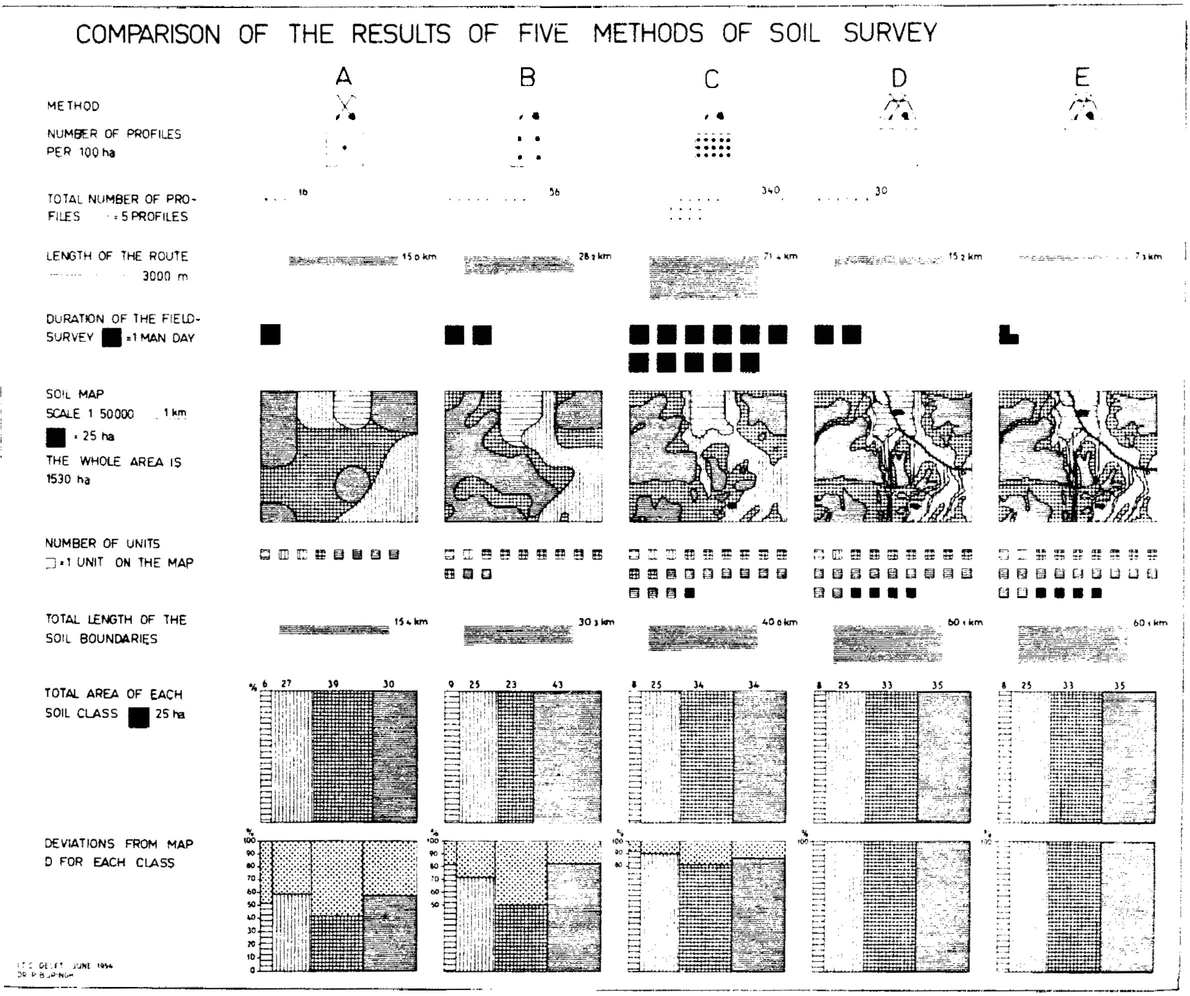
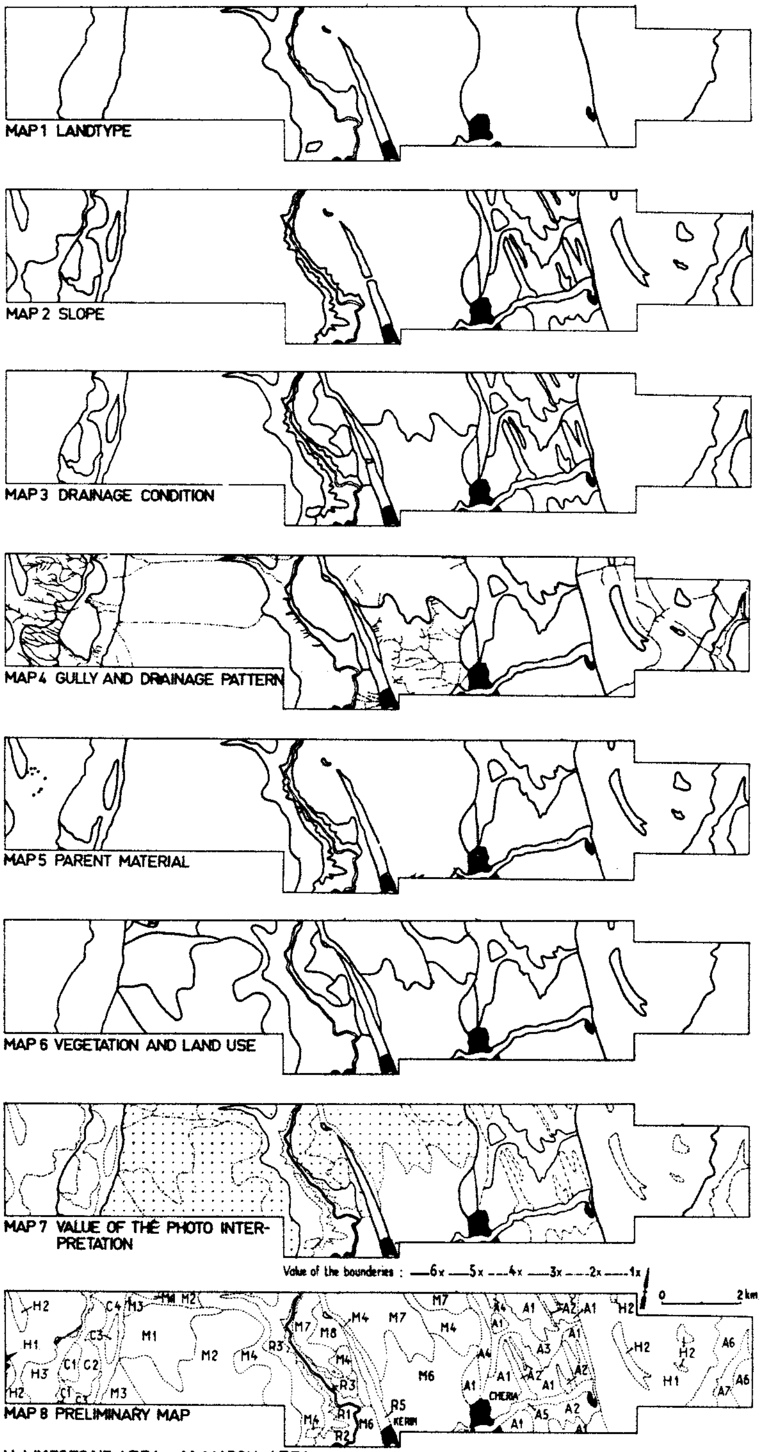


Fig. 2. Five different methods of soil survey *(Buringh, 1960)*

INSTRUCTION MAPS FOR AN AIR PHOTO INTERPRETATION

EXAMPLE OF A PART OF ELGHAB, SYRIA

A PRELIMINARY STUDY FOR A SEMIDETAILED SOIL SURVEY



H LIMESTONE AREA M MARSH AREA

H1 H2 H3 M1 M2 M3 M4 M5 M6 M7 M8

C COLLUVIAL AREA R RIVERLEVEE AREA A ALLUVIAL TERRACE-AREA

C1 C2 C3 C4 R1 R2 R3 R4 R5 A1 A2 A3 A4 A5 A6 A7 VILLAGE RIVER ORONTES

INTERNATIONAL TRAINING CENTRE FOR AERIAL SURVEY, DELFT, THE NETHERLANDS, Dr. Ir. P. BURINGH 1953/58

each boundary line has been given a value according to the number of various analyses of individual elements in which it appears.
In this way the line occurring six times is the most certain to correlate with the soils. In the same way one can indicate a relative difference between all the various other lines. The boundary only occurring once, and then only on the map of vegetation and land use, is a very uncertain one and will need special attention during the field check. Based on these considerations, map 8 in this figure gives the preliminary map which is the result of the air photo interpretation. This map, which in general is called an air photo interpretation map for soil survey purposes, is the basis for field work, and enables decisions to be taken about points that need special attention. The systematic traverses and sample areas are also largely determined by studying this interpretation map. After the field check when the boundaries have been controlled and the soils have been described, the soil map is delivered. The interpretation map is not a soil map, but it is a very useful tool for making a soil map, as indicated above. The nomenclature of the classification on the interpretation map however, should never be in terms of soils, unless one has special pre-interpretation knowledge about the soils derived from previous field observations. This depends, among other things, on which survey-procedure is followed (see BURINGH, 1960).

The interpretation according to individual elements, as described above, is not the only method of air photo interpretation for soil surveys. In fact, we prefer to use the method of what we call physiographic analysis as far as possible. The way of looking at the photographs in itself is the same, so the same phenomena are used. The difference lies in the fact that these phenomena are not seen as separate individuals, but that we try to find as soon as possible the physiographic systems that have been and are predominant in the formation of the area. These physiographic systems are sometimes of a structural and stratigraphical geologic nature. In other cases there are more sedimentary or erosional processes. The following may give an idea of what we consider to be physiographic elements useful for our work.

- The system of a meandering river with its levees, point bars, playas, ox-bows, basins, etc.

- The formation caused by a braiding river system, a very typical phenomenon in periglacial areas and periods, but which also exists, for instance, in some parts of the arid zone and of the humid tropics.

- An eolian system, such as is formed in deserts, but also in the dry tundra areas.

- Various glacial systems and fluvio-glacial phenomena.

- Volcanic systems, such as the volcanic cone itself, with its slopes and lava- or mud flows.

◀ Fig. 3. Diagram of elements of air photo interpretation *(Buringh, 1960)*

We can go on citing examples such as these for a long time (see also DURY 1960). It demonstrates however, that the importance of sedimentology is also stressed by working with the aerial photograph.

Sedimentation and its opposite: erosion, are much more important in soil formation than is sometimes mentioned in literature. We attribute very special importance to the study of sedimentology in soil surveys. The pattern of soil is just as much a question of the erosional and sedimentary processes as of the processes that form part of the pedogenesis. We

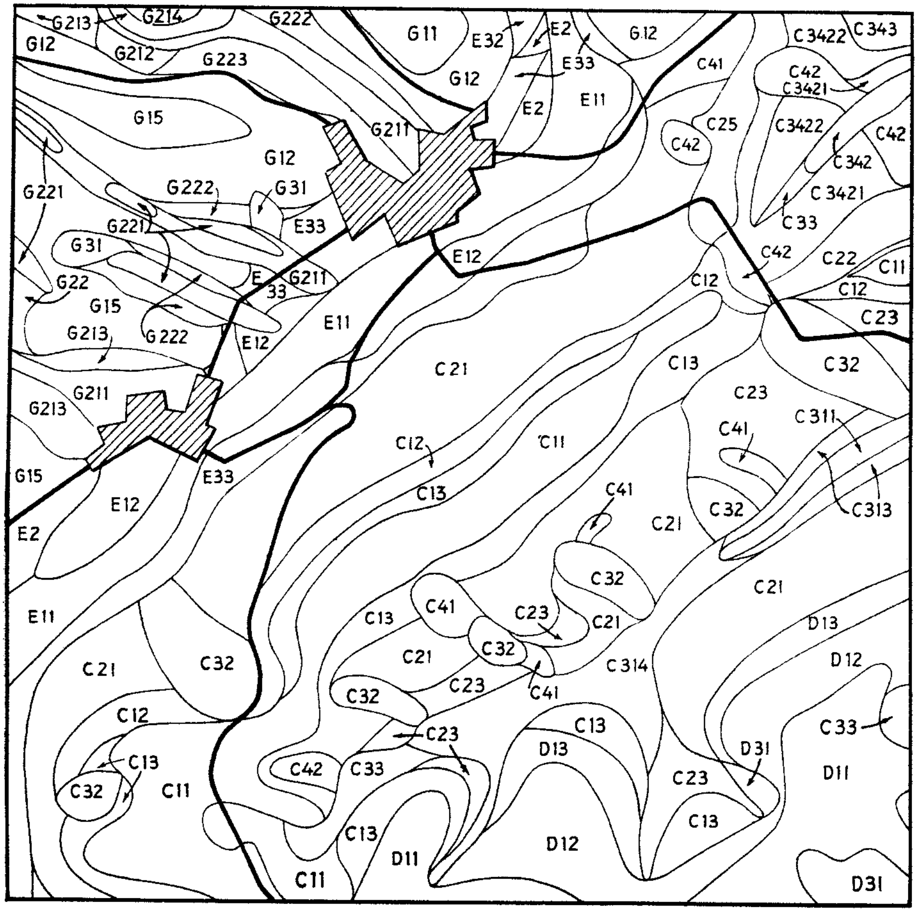


Fig. 4a. Comparison of a photo interpretation map (a) and of the soil map of the same area (b) established during the field check (scale 1:25.000). I.T.C. experimental area, Luxemburg

feel therefore that the influence of the air photo interpretation in this direction may be all for the good of soil survey both for its quality and for its efficiency. This does not mean, of course, that we want to detract from the importance of pedogenesis and of soil classification. We think, however, that as soil survey and in general the study of soils in the field advances, a more proper balance will be reached between geogenesis and pedogenesis.

There are various procedures for combining the field survey with the use of aerial photo-

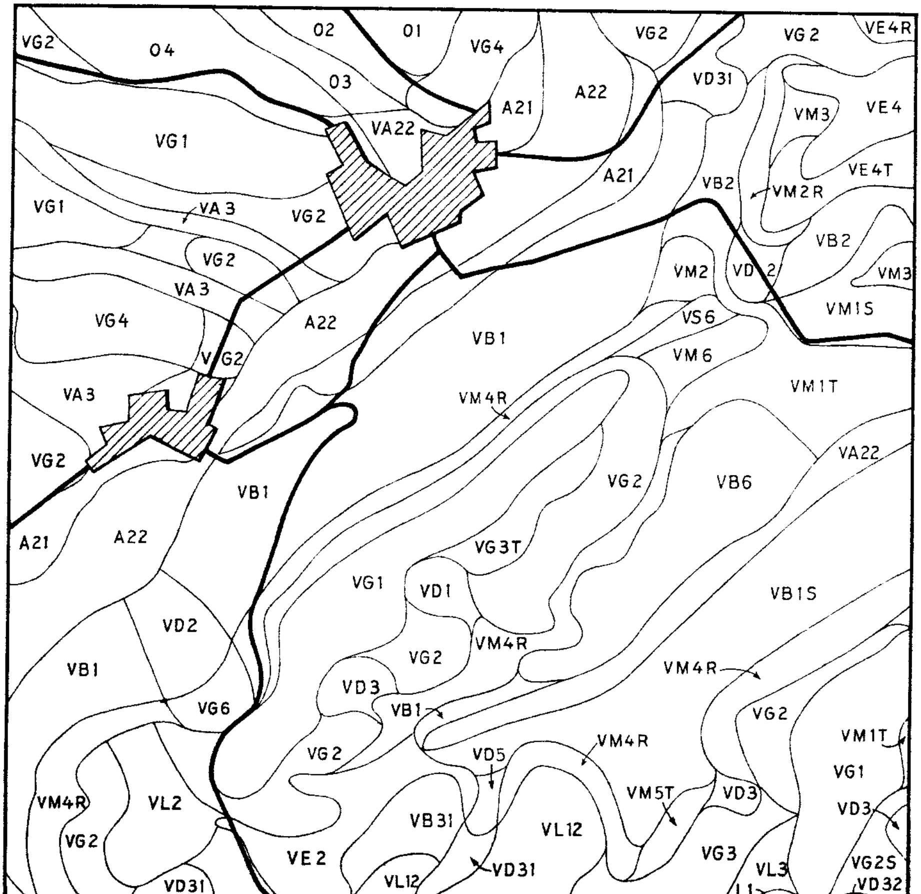


Fig. 4b.

graphs in soil surveys. They have been described extremely well by BURINGH (1960) and the scope of this paper does not permit us to give a detailed description of them. We recognize in general three groups, in the first of which the air photo is mainly used as a base map. Sometimes a small amount of analysis of the air photo is applied, but then it is only done during the mapping of the soils in the field. For the man who is acquainted with the results and possibilities of air photo interpretation this first group is slightly out of date, although certainly in most cases the use of the air photo is an advantage even if it is used only as a base map. The second group consists of those procedures that are most useful for mapping of soils in countries where the various parts of the area are in general easily accessible and where accuracy is more important than time. In this group of methods the field survey indicates the boundaries, and the air photo analysis is only used for simplifying the finding of these boundaries and for locating them as exactly as possible wherever a good correlation with the interpretation elements is found. The third group is more specially adapted to unknown or little known areas which are not so easily accessible or which lie far away from the centre from which the survey is carried out. In this case a full air photo interpretation of the photos of the area is made before going into the field. The field work does not exclude the checking of boundaries, but in so far as sufficient correlations are found, the boundaries taken in the first interpretation are maintained. The main field work then consists, at least if the interpretation has proved to be of good quality, of describing the soils found in the physiographic soil associations that form the main units of the map. In figure 4 (see pp. 20 and 21) an example is given of the air photo interpretation map of an area and of the soil map of the same area which was the result of the fieldcheck made on the basis of this interpretation. The legends of both maps are given in table 1[1]).

It will be seen that there is in this area almost never a full correlation between photo interpretation and soil map. Therefore, the photo interpretation can never be taken as a final result. Still the advantage of the photo interpretation in this experimental area was such that a gain of at least 50% of manpower, time and money over the conventional field methods could be recorded. This is especially significant as the map made in this case is published on scale 1:25.000 and therefore it is more detailed than is usually the case in large development projects.

2.3. THE LEGEND OF THE SOIL MAP

As has been described in the Soil Survey Manual (SOIL SURVEY STAFF, 1951) the setting up of a soil survey legend requires special skill. Careful decisions on all aspects of the soils considered and on their relative importance in the survey area are necessary. For a soil survey which is carried out with the use of air photo interpretation this is still more urgent because the relative importance of the interpretation lines and of their classification for the soil survey must also be considered. A line which seemed of primary importance

[1]) See pp. 23–25.

TABLE 1. Legend of the maps shown in figure 4 and their correlation

a. Photo Interpretation map		b. Soil map		
Legend Nr.	Description (40 numbers from a legend with 220 numbers)	Legend Nr.	Description (38 numbers from a legend with 121 numbers)	Correlates with Interpr. nr.
C	AREA CHARACTERISED BY STRONG DIFFERENCES IN RELIEF	**O**	AREA OF THE ARDENNES	G
		O1	Acid brown soils in very gravelly sandy loam, on shales	G11
C1	Remnants of plateau	O2	id. in gravelly sandy loam on shales	G12
C11	Flat and undulating tops			
C12	Steep slopes	O3	Colluvial soils of sandy loam to sandy clayloam	G222
C13	Moderate slopes			
C2	Sloping area between remnants and valley sides	O4	Complex of soils in sandy mark and in shales in gullies and small valleys	G213, G214, G223
C21	Moderate slopes			
C22	Ridge of undulating slope surrounding remnant	V	VALLEY AREA	C+D+G
C23	Steep to moderate slopes			
C24	Steep directed slopes	*VL*	*Association of the shallow loess covers*	
C25	Gentle sloping area down to G 1			
C3	Gullies	VL12	Greybrown Podsolic soils and BFS[1]) in loess on clay	D12
C31	Main gullies to river plain			
C311	Bottom	VL2	BFS in loess on gravel	C11
C312	Steep slopes	VL3	Complex of BFS in shallow loess covers, in marks and in conglomerates	
C313	Moderate slopes			
C314	V-shaped bottoms			
C315	V-shaped gullies with recent erosion	*VM*	*Association of BFS in Marks*	
C32	Steep short gullies on slopes, V-shaped	VM1	BFS of varying depth in sandy loam to sandy clay-loam	C12 + C23 + C32
C33	Heads of big gullies			
C34	Deeply incised short gully patterns	VM2	BFS of less than 30 cm. depth with marlfragment	
C341	Bottom	VM2R	idem, steep phase	C3421
C342	Sides	VM3	BFS deeper than 30 cm with marlfragments	C11 + C3422
C3421	Steep to moderate sides			
C3422	Moderate to gentle sides	VM4R	Complex of lithosols and shallow BFS, steep	C12 + C23 + C32 + D13
C343	V-shaped bottoms			
C4	Concave depressions			
C41	With visible surface drainage	VM5	Complex of VM2 and VLM3	
C42	Without visible surface drainage	VM5T	idem, moderate to steep slopes	C33
		VM6	Complex of BFS and Rend-zina's	C11

(turn page)

[1]) BFS = Brown Forest Soils

a. Photo Interpretation map		b. Soil map		
Legend Nr.	Description (40 numbers from a legend with 220 numbers)	Legend Nr.	Description (38 numbers from a legend with 121 numbers)	Correlates with Interpr. nr.
D	MIDDLE PLATEAU W. OF ALZETTE	*VB*	*BFS in solifluction material*	
		VB 1		
D 1	Undulately plateau			
D 11	Undulating top	VB 1 S	BFS of varying depth in sandy loam on weathered marls	C21
D 12	Gentle sloping area	VB 2	idem, moderate slopes	
E	RIVER-VALLEYS	VB 31	BFS of varying depths in sandy loam on weathered marls and Buntersandstone	C25
E 11	Actual floodplain, mainly pastures			
E 12	Actual floodplain, mainly cultivated	VB 32	BFS deeper than 50 cm in slightly gravelly mandy loam to sandy clayloam	C 13
E 2	Young terraces			
E 32	Older terraces, lower level	VB 6	Complex of BFS of varying depths in slightly mandy loam to sandy clayloam	C 11
E 33	Older terraces, sloping		Complex of BFS in sandy loam to sandy clay loam on various substrata	C21 + C23
G	UNDULATING COUNTRY IN N.PART OF AREA	*VG*	*Gravelly BFS*	
G 1	Upperpart of the Spurs	VG 1	Very gravelly soils in slightly sandy loam to sandy clay loam	C 11 + D 11, G 15 + G12
G 11	Flat and gently rolling tops			
G 12	Moderate slopes	VG 2	Gravelly soils in sandy loam to sandy clay loam	D 12, C 12, C 13 + G 213 C25 + C3422, G 15 + G 12
G 15	Spurs of a lower level			
G 2	Gullies	VG 3	Complex of transitional soils, VG 2 dominating	
G 211	Main Gullies, bottom			
G 212	Main Gullies, slopes	VG 3 T	id. moderate to steep slopes	C 12
G 213	Main Gullies, moderate slopes	VG 4	Gravelly soils of varying depth on yellowish brown gravelly clay loam	G 12, G 15
G 214	V-shaped bottoms			
G 22	Smaller gullies	VG 6	Soils in gravelly solifluction covers	C32
G 221	Bottoms			
G 222	Slopes			
		VS	*Association of the sandy soils*	
		VS 6	Weak acid brown soils etc in loamy sand	C 11
		VD	*Association of BFS and related soils in depressions*	

a. Photo Interpretation map		b. Soil map		
Nr. Legend	Description (40 numbers from a legend with 220 numbers)	Legend Nr.	Description (38 numbers from a legend with 121 numbers)	Correlates with Interpr. nr.
		VD 2	BFS in slightly gravelly sandy loam	C 32 + C 3421
		VD 3	BFS and Acid Brown Soil in gravelly loamy sand to sandy loam	C 314 + C 32 + C 33
		VD 31	BFS in sandy loam to sandy clay loam	C 41 + C 42
		VD 5	BFS with marl fragments in sandy loam to sandy clay loam	C 314
		VE	*Complex of recent and sub-recent erosion gullies*	
		VE 2	Acid Brown Soils in loamy sand to sandy loam	C 33 + C 41, C 42
		VE 4	Complexes of soils in slightly loamy sand to clay loam	C 23 + C 341
		VA	*Colluvial soils*	
		VA 22	in sandy loam to sandy clay loam with marlfragments	C 311 + C 313 + C 314 + G 211,
		VA 3	in gravelly sandy loam	G 211 + G 213
		A	*Alluvial soils*	
		A 2	Alluvial deposits of the river work in the valley	
		A 21	Transitional zône with colluvial influence	E 12 + E 2 + E 33
		A 22	Well- and poorly drained soils	E 11 + E 12 + E 2

during the interpretation may have to be left out of the soil map, or at least may come down to a low level of classification in the legend of the soil survey. Other lines, which looked rather dubious during the interpretation may be found to indicate some extremely important differences in soils.

All this is complicated by the time factor. The air photo interpretation is expressly carried out to expedite the field work in the soil survey. This means a very large cut in the time for pondering about a possible field legend.

It also means that by definition the decision on this legend must be taken on a small part of the field observations of the soils which are available in a traditional field survey. Even the experienced soil surveyor must realize that this means an extra mental effort (cf. Soil Survey Manual, pages 124–127). A preliminary field legend of the soil survey should therefore be made at a predetermined moment, so as to avoid the mistake of making it too late. If a legend is made too late during the field work, in many cases a large amount of unnecessary fieldwork will be done. The aim, a soil survey which is both accurate and efficient, will then tend to get lost in a confused mass of poorly directed observations.

The first field legend will certainly need some corrections and additions at a later stage, but these can only be made efficiently if the first draft legend is available as soon as can be reasonably expected. On the other hand, the field legend should be made in such a way that eventually it can be used as a basis for a definite legend. A certain time during which revisions in the field legend are made should be followed by a period when the acquired knowledge can be applied to the systematic survey.

It is impossible to give quantitative indications on the time needed for the various steps of a soil survey. This differs according to the survey procedures followed, to the publishing scale of the soil map, and to the physiography of the area and its correlation with the

Place	*Phase*	*Result*
OFFICE	1. air photo interpretation	— photo interpretation map with (physiographic) "classification"
FIELD	2. first field reconnaissance	— first draft legend of the soil map
	3. mapping of sample areas or catenas	— second draft legend of the soil map + first partial draft of the soil map
	4. first field survey	— checked field legend made final + second partial draft of soil map
	5. second field survey	— remainder of the survey carried out with final field legend + first general draft of soil map + additional notes on dubious points
	6. third field survey (revision survey)	— spot visits on dubious points (where possible) lead to final draft soil map + revised field legend

Place	*Phase*	*Result*
OFFICE	7. map editing + draft report	— final polishing of map + careful editing of the final survey legend + the survey report which is as essential as the soil map itself
	8. soil survey interpretation + final report	— all notes and observations on quality and suitability of the soils are combined to give the final report + soil survey interpretation maps

soil units to be mapped. The following steps should be taken as indicative of the gradual grouping of air photo interpretation, field observations, and deductive knowledge to form a soil map and report of good quality and of practical value:
This diagram also demonstrates, that the legend should be made during the field work. Any attempt to make a legend after the fieldwork has been "completed" gives rise to unexpected problems and to soil maps of poor quality.

2.4. VARIOUS ASPECTS OF THE USE OF AERIAL PHOTOGRAPHS IN A SOIL SURVEY

There are various aspects in the use of aerial photographs in a soil survey. Some of these are inherent in the aerial photo interpretation itself, but various others could also be applied, at least in theory with other soil survey methods.
They may be summed up as follows:

1. *Base-map*

The aerial photograph if flown relatively recently is by far the most reliable base map for orientation in the field. As a reporting map it gives the soil surveyor the possibility of constructing his own base map if no suitable topographic maps are available.

2. *Systematic preparation of the field work*

In theory the systematic preparation of the field work can be done without the aerial photograph if various other maps and data on the physiography, the vegetation and the geology of the area are available. In the latter case, the preparation tends to be less comprehensive because the physiographic picture of the survey area is never obtained as completely as by air photo interpretation.

3. *Quantitative data on the physiography*

The air photo interpretation, as commonly used in soil survey until now, does not provide for quantitative data such as river-gradients, gradients of old terraces, height of formations etc. Their relative height may, however, be estimated by making use of the parallax bar. This technique must be developed more carefully in the near future. Good topographic maps give rather exact height data which are very useful for the soil surveyor. A better understanding and closer co-operation between photogrammetrist and soil surveyor, especially in the survey of development regions, will certainly provide the best and quickest solution of this problem.

4. *Final editing of the map and report*

The stereoscopic image provides the opportunity of recombining all observations when writing the report and when considering various aspects of soil survey interpretation (landclassification: soil quality, soil suitability, etc.).

2.5. Air photo interpretation, is it quantitative?

The remark is often heard, that photo interpretation is not quantitative, whereas photogrammetry, of course, is a very quantitative science. Even some people working on interpretation have pronounced opinions that this is an art and art is almost never quantitative. Now one may just as well ask whether microscopy is quantitative. In some cases, like sedimentary petrology, microscopy is extremely quantitative. On the other hand, in the biological sciences there are very many examples of the use of the microscope in a non-quantitative way.

The interpretation of aerial photographs is not an independent science but a method of extreme importance for various sciences. The sciences themselves, however, are called, for instance: geology, hydrology, glaciology, archeology, or soil science. For each of these sciences various aspects can be studied with the help of aerial photographs but many other aspects are not at all related to what can be seen or deduced from the photographic image. The interpretation of the aerial photograph is starting to influence the sciences just named. But interpretation still remains a group of methods, and not a science as such. The question of whether interpretation is quantitative or not is therefore only of very limited importance. To take soil science as an example, interpretation of air photographs is not very quantitative, but soil science itself has an enormous amount of quantitative methods and data. Historically, however, these quantitative data have mostly come from chemistry. The man making soil maps is first of all a soil scientist who expresses his observations on a map. The soil surveyor strictu sensu is a very recent phenomenon.

Therefore, not only the interpretation of aerial photographs but also the whole system of soil survey lacks a fixed quantitative basis. This is very often reflected in the difficulty of making good specifications for tenders asking for soil surveys. In the same way as the microscope has influenced biological sciences, the aerial photograph and, more gene-

rally the contact between surveyors and photogrammetrists on the one hand, and soil scientists on the other, should provide a possibility of quantifying this part of our science (see also STEUR, 1961).
It is sometimes suggested, that there is no fundamental difference between photogrammetry and the "interpretation" sciences. The main fundamental difference is, however, that in photogrammetry the objects to be mapped are not themselves subjects of research, whereas in the "interpretation" sciences the research of the objects themselves comes first and foremost.
Photogrammetry as it has developed in the last decade is mainly mathematics, whereas many of the sciences which use photographic interpretation are typical "natural sciences". As such, they are inherently more descriptive and less mathematical. Nature must be described first of all and the mathematical treatment of natural phenomena can only be partly succesful.
The problem of quantifying soil surveys and their specifications has various aspects. In the first place comes the accuracy of the base map, which in fact is a problem of general photogrammetry. It has however, some specific relations to the problem of soil survey itself. The second problem is in fact a problem of classification of the soils in soil survey. This is a specific problem of soil science, and it will remain the central problem in soil survey as long as this science continues to develop. In the following paragraphs we shall try to contribute to this development.

3. SURVEY PROBLEMS

3.1. VARIOUS KINDS OF SOIL SURVEYS AND THEIR PREPARATION

Apart from the "rigid grid" soil survey and the soil survey with full systematic air photo interpretation other methods of soil survey are used by various people and their organisations. In particular the following methods must be mentioned:

1. *The "rigid grid" survey*, i.e. the survey with field observations at fixed intervals in both directions.
This survey can be executed by setting up a legend before, during or after the field work is done. If the legend is made during the survey, which is certainly preferable, the intelligent use of this system almost invariably leads to the less rigid system mentioned sub 2.

2. *The "grid" survey as a basic means, with in addition some observations on the physiographic correlation of the soils, and with some additional observations on the soils.*
This system is a conventional one used in many standard and project soil surveys. If used by capable soil surveyors it is excellent, if laborious. The advantages of the physiographic survey are not used to give a more efficient survey, but to provide for more exact soil boundaries. The grid observations on the soils unquestionably provide a very systematic description of the soils.

3. *The "grid" survey with some physiographic observations, followed by air photo interpretation.*
This method has proved to give good results. It is very laborious, and many of the advantages of the photo interpretation are lost because it is only carried out after the field work has been done.

4. *The physiographic soil survey without air photo interpretation but with optimum use of the data of topographic maps (contour lines), old topographic maps (tradititional land use), land use maps, geological maps, etc.* This method, if systematically handled by a compe-

tent soil surveyor, can give almost as high an efficiency and accuracy as the soil survey with air photo interpretation.

It is, however, only applicable in highly developed countries where all these maps are available and of good quality. Even then it never gives the wealth of detail and the accuracy of good air photo interpretation. It has the advantage that large sheets can be handled at the same time and that no special training in air photo interpretation is required. For the soil surveyor who can profit from this method, the training in air photo interpretation has also proved to be very easy. Of course no stereoscopes have to be bought for this method.

5. *The soil survey with air photo interpretation according to any of the procedures described in the preceding paragraphs.*

As sufficient attention has been paid to this, we shall only stress that this method is the only one which gives good efficient results in almost all cases where air photos of good quality are available. Even if they are not available they can generally be procured for a price which is only a small fraction of the total cost of the soil survey.

The cost of the photography compared with the increase in efficiency of any project and compared with the total cost of the project is negligible. The only trouble may come from a climate which sometimes allows only a few days per year for photographic flights.

Each of these survey methods has its own specific problems. A full treatment of all these is not our purpose. In the following we shall only treat those problems which are of a more general interest.

3.2. Photoscale, mapping scale and publishing scale

On various pages of the Soil Survey Manual (Soil Survey Staff, 1951) some quantitative remarks on the scale of surveys are given. This scale is not only a question of the photogrammetric or topographic base map, but it is especially relevant to the amount of observation to be done during the field mapping of the soils. In soil survey, therefore, the scale always has a very fundamental significance. Unless certain suggestions made in par. 3.4 are taken into account this fact still remains. In soil survey the enlarging of a published soil map is generally not allowed. This is partly due to the number of observations made, but it is also related to the classification problem mentioned in the following. It is quite possible that two surveys of the same region are made on the same base map, for instance 1:25.000, but the one is published on scale 1:50.000 and the other on scale 1:200.000 (see also Steur, 1961).

In both cases the map 1:25.000 is used in the field because it is a very convenient scale for orientation. The location of profile pits and augerings is therefore done on this map in both cases. In the case of the map to be published on the scale 1:50.000, the number of field observations will be much greater than in the case of the 1:200.000 map. The relevant detail of observation will be quite different, not only as far as the number of observations is concerned, but also as to the classification of the soil investigations (Soil Survey Manual, pages 94–99).

On the other hand, we often see that the scale of base maps is different, but that of the published soil map is the same. We have examples for instance of field mapping on scale 1:25.000 and 1:50.000 respectively, that both lead to a soil map published on scale 1:200.000.

There is no theoretical reason for this, but a very practical one, that is the necessity of having sufficient space on the field map sheet on which to write all the observations of the soils and the landscape.

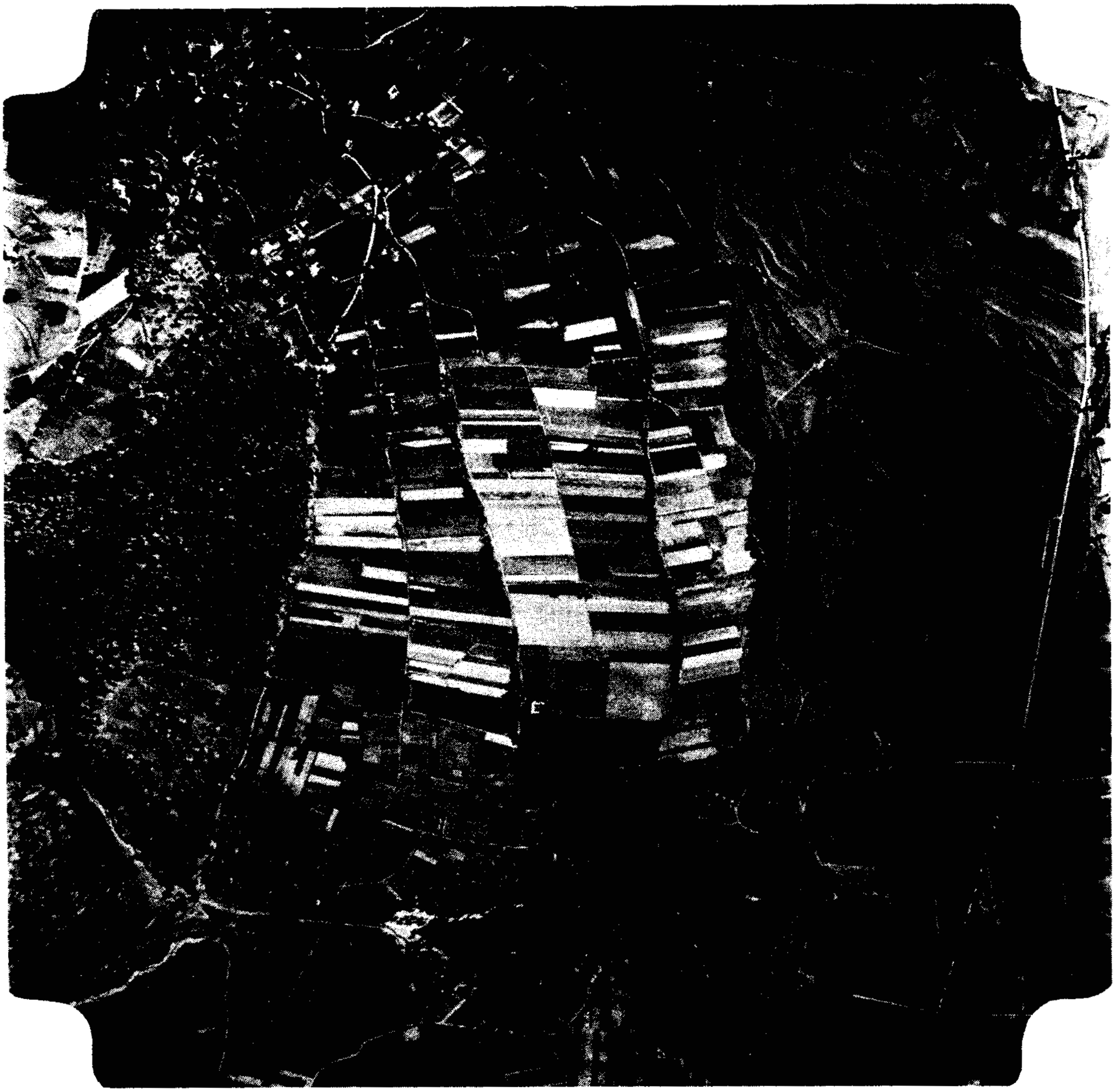
In so far as the air photo is only used as a base map, the same rules as for any topographic map are valid. In many cases the photo scale is used in the field, so normal contact prints are sufficient. In some cases, especially in sample areas, the photo is enlarged for monocular use as base map, when enlargements of 3 or 4 × the original photoscale are sometimes extremely useful.

The photo-scale has a very special significance, however, in the case of air photo interpretation for soil surveys. Experience has taught us that in general a scale of about 1:20.000 is the most useful.

Apart from the scale, and especially in more or less flat or undulating countries, the photographs should be taken with a wide-angle lens. For reconnaissance or exploratory surveys, a scale of 1:40.000 or 1:50.000 is sometimes used. It is not impossible that if the quality of the photographs is extremely good, then sometimes air photos of scale 1:70.000, especially if they have been taken with a super wide-angle lens, may be useful for exploratory surveys and general reconnaissance of the natural soil resources of large areas. In that case the first exploratory survey may determine the priorities of development areas in various parts of a country. A second series of air photos on scale 1:20.000 and taken with a wide-angle lens, may then be confined to the areas of special priority for development projects. On the photoscale all these data have a very empirical character. We have the impression that although in general these figures are valid, much also depends on the photographs and the time and season of flight are of extreme importance. Some research on the photo scale and the mapping scale may be necessary to give a full quantitative evaluation of this problem.

The *publishing scale* of a soil survey should be determined first of all, as only after the determination of this scale can reasonable specifications be put forward. Alternatively, the basic planning unit might be indicated (see par. 3.4). The number of observations per unit area is, however, not fully quantitatively studied. Sometimes we find specifications that allow for a distance between two points of observation on the publishing scale to be 1 inch or more. In a field soil survey in which no air photo interpretation is used, this is certainly too much. On the other hand, one sometimes reads of specifications in which nine observations per square centimeter of the published map are thought to be necessary (see par. 3.4, table 2). This is an extreme number, which sometimes may be useful or even necessary, but in general is somewhat exaggerated. The Soil Survey Manual (page 322)

Maienfeld, Switzerland



Photograph taken with Wild RC 5a Automatic film cam. 18 × 18 cm. Wide-angle lens "Aviogon" f = 115 mm (4½"). Height 1400 m (4,600 ft.). Scale 1:12,000. Photo: Eidg. Vermessungsdirektion

gives the following specification: "On detailed soil maps to be published at about 2 inches to the mile (1:31,680), boundaries should be accurate within at least 100 feet". This is an accuracy of 1 mm on the publishing scale of the boundaries. It does not mean, that the whole country must be mapped with a grid of this same density. Even without the use of air photos, the correlation with the physiography and the general knowledge of the soil surveyor make it possible to have a much less dense grid.
In general STEUR (1961) indicates 4 observations per cm^2 of the published map as being sufficient.
In fact the systematic mapping with a specific grid of equal distance is only necessary in very special cases. Normally it is the most wasteful and time-consuming way of making soil surveys. This holds still more if air photo interpretation is used. See also BURINGH (1960). The number of observations per unit area of the map, however, need not always be the same in all parts of one soil map. The "detailed-reconnaissance" maps give a detailed survey of the more important parts of an area and only a reconnaissance of the less relevant parts (see Soil Survey Manual).

3.3. TOPOGRAPHIC MAPS AND AIR PHOTOS AS BASE MAPS FOR SOIL SURVEYS

As far as possible the base maps for soil survey should be made by well trained photogrammetrists. The training of students in air photo interpretation only gives them a basic training in the making of base maps so that they can help themselves in so far as this may be necessary in special circumstances. They should know at least how to make a slotted template map from the air photographs and to take in some controls if they are available. In that way a map can generally be delivered which is of sufficient accuracy for the base map of a soil survey in a development project. Of course here a lot also depends on the quality of the photograph and on its scale. Apart from the making of a semi-controlled basemap, the air photograph has its advantages as a base map for the field work, the so-called field map or working map. The main advantage here is that even in those countries where detailed topographic survey sheets are available the air photograph, at least if it has been taken not too long ago, gives a better picture of the fields of the farms. As the fields are a very important means of orientation in the field during a soil survey, this is often of extreme importance. This also holds for other features such as: irrigation canals, small roads, vegetation boundaries, etc.
It can be said that the orientation of the soil survey in the field has special aspects for which no general rules can be given. In a soil survey of an area with permanent agriculture, at least the main features of the land use can be of help. In the other extreme, an area with typical shifting cultivation, only very recent air photographs are useful for orientation. This is of very great importance, and may even justify the flying of a new photocoverage of an area specially for this purpose. In that case of course, the photographs should be taken in such a way that they are of the best possible quality for interpretation purposes. A tentative list of specifications for this purpose is given in the appen-

dix. As far as possible the soil surveyor must avoid making his own measurements for orientation, apart from very rough general measurements such as can be made by pacing out distances or walking with a chain.

The soil surveyor is not a surveyor in the sense that he does all the geodetic work himself. In some cases it may be an advantage to teach a soil surveyor how to help himself, but in general this should be done by experts trained for topographic surveys. In the case of the choice between a man with good survey training and little or no knowledge of soils on the one hand and on the other hand a man who is a good soil scientist but has little or no survey knowledge, the latter is always to be preferred. Knowledge of soil science and especially of the field branches of soil science is the main requirement for any soil surveyor.

The survey qualities of a soil map rest therefore first of all on the qualities of the maps provided for the soil surveyor for 1. orienting himself in the field and making his notes, 2. for producing his data as a reporting map. In many cases in the past soil surveyors had not much choice which map or kind of map to use. At the present stage of our knowledge there is no excuse for not using the best possible base maps both in the field and for the final publication. The question remaining is, what is the best map in a certain case. This is not a question of photogrammetry but of soil science. The base map is a tool for noting the differences in soils observed during the soil survey. There should therefore be a relation between the kind of base map used and the soil survey method (see also STEUR, 1961). The scale of the base map as it exists before the soil survey is no criterion. The only criterion is the required accuracy of the soil survey. We shall see in the next paragraph, that various considerations play a part in determining the best scale of soil survey, and, related to this, the number of field observations per surface area. If e.g. for some reason or other there exists a base map in the topographical survey of twelve inches to one mile (ca. 1:5000) this is no reason for publishing the soil map on this same extremely large scale. It may well be better to have the soil survey published on three inches to one mile (ca. 1:30.000). The base map then, should be reduced to that scale, at least in so far as the publication is concerned. The existing twelve inch to 1 mile (1:5000) map may however be of extreme importance for orientation in the field.

Reduction of an existing base map brings new problems. In general it is not sufficient just to reduce the base map and then bring the soil boundary lines on to it. The reduced base map gives a lot of very detailed topographical information that may be irrelevant and even excessive as far as the soil survey information is concerned. As will be pointed out in the next paragraph, the surface area represented on a certain scale of soil map has a minimum, in general five millimeters, square on the publication scale. If more detail is given on the topographical base than is allowed according to the accuracy of the soil survey this information is excessive and should be taken out of the base map. The topographic base of a soil survey should not give the maximum information on the topography but should give the proper amount of information to make it possible for the user of the soil survey to see just what he must be able to see and nothing more. If this rule is not observed the

user of the soil map is always liable to get a wrong impression of the accuracy of the survey (see also PANNEKOEK, 1961).
This also means that in many cases a soil survey must use 1:20.000 photographs flown with a wide-angle camera for its interpretation, whereas the base map may well be compiled from air photographs of a smaller scale, e.g. 1:70.000. This must not be seen as excessive demands on the part of the soil surveyor using air photos for interpretation purposes.
It is simply a question of the use of air photos for quite different sciences.

3.4. THE QUANTITATIVE PROBLEM IN SOIL SURVEYS

The formulation of specifications for soil surveys is giving difficulties to almost everybody concerned. In this respect we consider not only governments wanting to set up soil surveys of their countries but also the consulting firms who are doing surveys of soils for specific projects. This on the one hand makes it difficult for the governments to see to it that their ideas are taken over by the people charged with their execution, while on the other hand the consultant is very often at a loss as to how to proceed with his project and stay within reasonable limits of time and money. The few handbooks existing in this field, such as the United States Soil Survey Manual, or publications of the nature of the book by CLARKE (1957), give only rather vague indications. The best way of solving this problem is and will be to give the whole project into the charge of an extremely well qualified soil survey expert. The personal qualifications of the personnel executing the soil survey are and will always be the main factor in the quality of the soil survey.
These qualifications consider equally their theoretical knowledge of soil science and their practical experience in the execution of a survey. But even then it is good to realize the quantitative problems involved. This may also help our colleagues in this subject to try and bring the discussion from the always rather vague field of personal experience into a more scientific discussion. The following does not pretend to give any solution of the problem. We think, however, that somebody has to write something on this subject so as to concentrate opinion more on this very important practical aspect of soil survey.

There are some fundamental differences between the survey problems in soil survey and the survey problem e.g. in topographical surveys. The first is, that basically the topographical survey is concerned with lines, not with surface areas. The surface areas, even if they are of extreme importance as in cadastral surveys, are derived from the lines forming the boundaries. Even if fundamentally a surface area problem is considered it is usually reduced to the survey of exact lines, such as slopes, which are indicated by the exact measurement of contour lines.
In this way even the complex situation of the geomorphology of a mountain area is reduced to the measurement of some lines that can, at least on a map, be indicated very accurately. In soil survey this is not possible. Here we have the special need of indicating and

describing the characteristics of area units. The soil profile in soil classification may sometimes be seen as only a two-dimensional unit, but for all practical purposes it is a three-dimensional landscape. This holds both in soil science for agriculture, and in engineering terminology. In this text we are using the soil in the concept as given in the "Soil classification, 7th approximation", published by the United States Soil Survey (1960). This definition reads in short: "Soil is the collection of natural bodies on the earth's surface, containing living matter and supporting or capable of supporting plants." This is not meant as a slightening of the engineer's concept, but is only given because it is the one most generally used.

Apart from the fact that we are surveying surfaces, another complication is the fact that these surface areas often are very heterogeneous, and in most cases they do not have very exact boundaries. For finding a sufficiently homogeneous soil individual the latest concepts go down to the pedon as the smallest volume that can be called a soil (Soil classification, 1960). This pedon is a concept to present the soil individual and has three dimensions. The lateral dimensions are large enough to permit study of the nature of any horizons present, and its area ranges from one to 10 m^2, depending on the variability in the horizons. For practical reasons it might perhaps be better to take the pedon of a slightly larger size, e.g. up to 25 m^2. This does not make any difference in the practical handling, as far as soil classification is concerned, but it is much easier to handle a unit of this size as the basic practical unit for the agricultural aspects of a soil survey. As may be seen from this remark, even the limits of a pedon have a rather subjective aspect.

Because of the size of the pedon, this basic unit could only be shown on very large scale maps. If we take a figure of 2 mm for the minimum distance of soil boundaries on a printed soil map, this means that the smallest pedon could only be shown on a map of at least 1 to 500. The largest pedon as it is now formulated in the soil classification could still be shown on a map of 1:5.000. This only holds if the distance between individual observations is nowhere less than 1 mm on the publishing scale of the soil map. On the average we can therefore say that any soil map of a scale smaller than 1:2500 may contain, and always in fact does contain at least some impurity in any of the soil mapping units. The Soil Survey Manual (page 277) bears us out in this respect, because it gives the specifications that a mapping unit may have the same name as the correlated taxonomic unit of soil classification if the impurity of any soil unit on the map is not more than about 15 %.

The gradual character of most soil boundaries makes all this still more difficult. The subjective aspects of deciding on a soil boundary in the case of gradual transitions is a very serious one. It can be solved in different ways according to the personal vision of the soil surveyor limited only by general correlation rules. The correlation of various parts of a survey, and also of various surveys, is therefore a very typical problem in soil surveys. The way this has been solved in most surveys is also indicative of the typical aspects of personal experience and qualifications. This personal aspect is still more important if we consider mapping scales smaller than 1:2500.

From the preceding remarks it may be understood that the smaller the mapping scale (or the larger the "*basic mapping unit*", see following text), the more the personal element of compilation has its influence on the final aspect of the soil map. For a soil survey on scale 1:10.000 (about 6 inch to 1 mile) this is not very serious. In national standard surveys especially, the problem is solved by formulating soil series as basic mapping units. These soil series may be defined on a national scale, and through personal correlation and exchange of soil descriptions and chemical analyses may be handled in a rather definite and quantitative way. The series may be further subdivided into various phases according to certain definitions related to such aspects as slope, drainage, stoniness etc. that can be given in more or less quantitative classes.

A good description of the soil series is given on page 280 of the Soil Survey Manual. This reads: "The soil series is a group of soils having soil horionzs similar in differentiating characteristics and arrangement in the soil profile, except for the texture of the surface soil, and developed from a particular type of parent material." In some cases the soil family may also be used in the same respect. The soil family could be defined as: "The group of soils, belonging to the same subgroup of the taxonomic classification and developed from a particular type of parent material." However, this gives even larger problems of national correlation. The family may be seen as the next highest unit in soil classification and it is therefore used on maps of smaller scales, such as 1:25.000 or 1:50.000. This invariably brings with it the enlarged amount of impurity in any mapping unit. Instead of the maximum percentage of 15% impurity, a criterion of 30% impurity is sometimes then used.

But even in detailed soil surveys, the soil complex is often necessary to describe certain mapping units (STEUR 1961). According to the Soil Survey Manual, the soil complex is an association, the taxonomic members of which cannot be separated individually in a detailed soil survey (page 304). In general the soil complex is now used in detailed or semidetailed soil surveys for those units where the taxonomic units are carefully known but which cannot be given as separate units on the map. The specifications demand, according to the feeling of many soil surveyors, that the complex should be indicated by the percentages of the various taxonomic units included within the mapping unit. It is very useful to describe the soil complex in this way because it certainly has a slightly different aspect from the soil association as we shall describe it in the following.

The soil association is the most important concept for all soil surveys on scale 1:25.000 and smaller. As the Soil Survey Manual puts it, it is a group of defined and named taxonomic soil units, regularly geographically associated in a defined proportional pattern. If some people are still somewhat afraid of using the soil association, this is partly due to the fact that they do not understand the geographical pattern and the physiography which forms the background of these soil patterns.

It is also sometimes neglected because people are somewhat ashamed of the variability of the soil units they indicate on their map. As is discussed on our preceding pages, there is no need at all for this shame, as it is simply a truth of soil science that cannot be avoided. This is all the more reason for indicating the possibilities and limitations of this kind of work to people ordering soil surveys. The soil association can be modified by using the phase (stoniness, slope, drainage, etc.) as a further definition of the soils on the map. In this way the map often gives not all the theoretical pedological information that one would like to have, but it is certainly possible to make soil maps, on rather small scales such as 1:50.000, 1:100.000 or even smaller, that are of extreme importance in land use planning and for other practical purposes.

Tables 2 to 5[1]) give some data of the specifications needed for the various soil surveys on the different scales. STEUR (1961, b) gives the following data: 16 observations per hectare for 1:5.000, 4 observations per ha for 1:10.000, 2/3 observ./ha for 1:25.000, 1/6 observ./ ha for 1:50.000 publishing scale of the soil map. The soil surveys of O.R.S.T.O.M. (France) use 1 to 2 observations per cm^2 for their soil maps in various parts of the world.

SCHELLING (1961) indicates a varying number of observations beginning at 6 or 7 per ha and ending at 3 or 4 per ha for a soil map which was published on scale 1:10.000. In table 2, a description of the various maps and their purposes is given, and the approximate average number of observations is indicated. We have tried to give average data both for the case without air photo interpretation, and for the case where full well-qualified systematic air photo interpretation on air photos of suitable scale and quality is used. Some figures are also given of the most appropriate scales both of the sample area soil maps and of the air photos.

Apart from the scale of the aerial photograph, various other aspects of the quality of the aerial photograph come into the picture. It is not our purpose to give a full description of these in this publication. Factors such as the focal length of the lens, the time and season of flying and various others are essential for good photo-interpretation for soil purposes. In air photo interpretation for soil surveys vertical air photos are always preferred. The interpretation of obliques gives special difficulties, that can only be partly overcome (see also appendix).

Table 3 gives general data on the size of the area of 1 cm^2 on various mapping scales and on the number of field observations to be made. These field observations have been calculated according to two principles. If 9 field observations per cm^2 of the publishing scale of the map are made, the principles indicated in the Soil Survey Manual for detailed soil surveys are most closely followed. The alternative of 5 or 4 observations per cm^2, however, bears a closer relation to practical experience. Of course, this is never a question of a regular grid over the whole survey area.

In general the experienced soil surveyor uses his knowledge of the physiography as much as possible in determining where to make his field observations.

In the case of a more or less rigid survey, the "detailed survey" indication could be used for scales of 1:50.000 and larger if a grid of at least 9 observations per cm^2 of the publishing scale was used. The word "semi-detailed" could then be used for those surveys where

[1]) See pp. 40–43.

the scale is not smaller than 1:250.000 and where at least 4–9 observations per cm^2 are used. In other cases the words "schematic", "generalized" or "exploratory" should be used. It is not our purpose to indicate that we think this to be the best solution of the survey problem, but we do think that it may be useful to provide this terminology for discussion, because it also shows that the terminology of soil surveys is partly a question of the publishing scale and partly a question of the number of field observations made for this scale. For surveys where less rigid grids are applied, a different solution seems to be advisable. In this case the terminology of table 5 would be more appropriate. As the use of physiographic indications is a normal routine for all good soil surveyors, this table is probably more worth considering.

The detail of the map could then be indicated in the following way. According to BURINGH a "basic mapping unit" (see table 4) should be printed on the map as a figure consisting of an oblong and a square (see fig. 5).

This basic mapping unit would be enlarged or reduced together with the map in the same way as is done with a scale indicator on any topographic map. The soil map could in that case be enlarged because the figure of the basic mapping unit would be enlarged to the same extent. The degree of accuracy and of detail in the case of soil surveys would always remain true.

The size of this basic mapping unit in any conventional soil survey (without systematic air photo interpretation) would be determined by the smallest area in which at least one observation is made. As the size of the basic mapping unit is normally taken at 0,25 cm^2 this would mean a "normal" density of 4 observations per cm^2. If the amount is less, the basic mapping unit should be proportionally enlarged. In those cases where a more detailed survey has been done, the basic mapping unit indicated on the map should be proportionally reduced. With the help of systematic interpretation of aerial photographs, the soil surveyor himself, if possible after consulting a soil correlator, should indicate what is to his best possible knowledge, the size of the basic mapping unit. In this case, the size

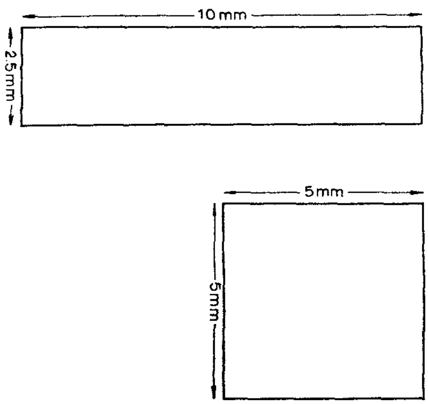


Fig. 5. The basic mapping unit (approx. 5.4 × enlarged)

TABLE 2. Some data on mapping scale and field observations (explanation, see at bottom of table)

Kind of units to be distinguished on maps[1]) (see SSM p. 277 and 303)[2])	Publishing scale of map	Main purpose of map (SSM p. 15/19)[2])	General category of map (SSM p. 15/19)[2])	Approximate average number of observations per km²/100 ha		Approx. scale of sample areas	Approx. scale of aerial photographs
				without api[3])	with api[3])		
t ≈ m	1: 2.500	– farm surveys – very detailed projects	very detailed	500–4000	500–4000	–	1: 10.000
t ≈ m	1: 10.000	– research surveys, sample areas – surveys for detailed projects – surveys for large farms	detailed	100–500	100–500	–	1: 10.000
t ≈ m C_t (a)	1: 25.000	– research surveys, sample areas – surveys for detailed projects	detailed to semi-detailed	± 100	10–50	–	1: 20.000
(t ≈ m) C_t a_1 (a_2)	1: 50.000	– surveys for projects – regional surveys	semi-detailed	12–25	1–3	1: 20.000	1: 20.000
a_1 a (a_3)	1:100.000	– reconnaissance surveys for large projects – regional surveys	detailed-reconnaissance	2–45	± 1	1: 20.000	1: 20.000
(a_1) a_2 a_3	1:200.000	– national surveys – reconnaissance surveys for very large projects	reconnaissance to generalized	± 1	0,5–1	1: 20.000 1: 50.000	1: 20.000 1: 50.000
a_2	1:400.000	– national reconnaissance surveys (general inventory of areas)	generalized to schematic	–	–	1: 50.000 1:100.000	1: 20.000 1: 70.000
a_2 a_3	1:600.000	– national reconnaissance surveys (general inventory of areas)	generalized to exploratory or schematic	–	–	1: 50.000 1:100.000	1: 40.000 1: 70.000

a_3	1:1000.000	– schematic maps of national areas – Comparison of areas on international level	schematic or exploratory	–	–	1: 50.000 1:200.000	1:500.000 1: 70.000
a_3	less than 1:1000.000	– schematic maps of continents; – comparison of areas on international level	schematic or exploratory	–	–	1:200.000 1:400.000	1: 70.000

[1]) Apart from phases that can be shown on all kinds of maps (Soil Survey Manual, p.289).
[2]) SSM: Soil Survey Manual.
[3]) api: Systematic air photo interpretation following the I.T.C. method.

Explanation of table 2

t = taxonomic unit (= unit of the soil classification, based on general genetic and morphological principles)

m = mapping unit

a = association.

- a_1 = a of series
- a_2 = a of family
- a_3 = a of groups (undiff. group)

$t \approx m$ if at least (70% of the surface area of m = t)
(85%: SSM, p. 277).

In this case if it is considered necessary, m may be called the same as t, although in general this is not thought advisable.

Density of boundaries C_t = well defined complexes of $(t \approx m)$ – units on published map: 2,5 mm for oblongs, 5 mm for square and round forms (circular).

Taxonomic classification: 7th approximation (U.S. Soil Conservation Service, 1960)

Order – VII, Suborder – VI, Group – V, Subgroup – IV: on morphological and genetical principles (international, stable)

Family – III, Series – II, Pedon – I: on morphological and applied (agricultural) principles (national, flexible)

detailed projects:	< 100 km²	large projects	: 500–5000 km²
projects	: 100–500 km²	very large projects:	> 5000 km²

TABLE 3. Some data on field-observations in soil surveys, *not using air-photo interpretation* (see Soil Survey Manual, p. 94)

Scale of the map	Size of 1 cm² area on the map	Approximate amount of field observations per km² (= 100 ha.) observations per cm² area of the map: 9	5	4	2
1:2.500	625 m² = 0,000625 km²	14400	9000	8000	4000
1:10.000	1 ha = 0,01 km²	900	500	400	200
1:20.000	4 ha = 0,04 km²	225	125	100	50
1:25.000	6,25 ha = 0,0625 km²	144	80	64	32
1:50.000	25 ha = 0,25 km²	36	20	16	8
1:100.000	1 km²	9	5	4	2
1:200.000	4 km²	2	1	0,8	0,5
1:250.000	6,25 km²	1,5	0,9	0,7	0,35
1:400.000	16 km²	0,5	0,35	0,3	0,15
1:500.000	25 km²	0,35	0,2	0,15	0,1
1:600.000	36 km²	0,25	0,15	0,1	0,05
1:1 million	100 km²	0,1	0,05	0,05	0,03
1:2.5 million	625 km²	0,01	0,005	0,005	0,003
1:3 million	900 km²	0,01	0,005	0,005	0,003
Basic mapping unit in cm²		0,11	0,20	0,25	0,50

TABLE 4. Some general data on soil surveys of different publishing scales

Publishing scale of the survey	Approximate gain in time and cost through use of air photo interpretation	Minimum area on the map in hectare ("Basic mapping unit")	Basic minimum unit area for planning in hectare (approx.) ("Basic planning unit")[1]: factor	surface area
1:2.500.000	70 %	16.000	12	200.000 ha
1:1.000.000	75 %	2.500	8	20.000 ha
1: 250.000	80 %	160	6	960 ha
1: 50.000	70 %	6	4	24 ha
1: 20.000	20 %	1,00	2	2 ha
1: 10.000	10 %	0,25	2	0,5 ha

[1]) With "basic minimum unit area" (basic planning unit) is meant the smallest area that still may be used as a separate unit for planning. Without the use of a more detailed survey the separation of smaller units is not allowed by scientifically sound practice. The data given in this column are estimates based on personal experience in combination with general surveying practice in soil surveys. They are only valid if the soil map has been made to the best possible specifications (see table 2 and 3).
The "factor" for the basic planning unit is very tentative. It might be necessary to increase this factor still more for the smaller scales.

TABLE 5. Names and scales of soil surveys in physiographic surveys

Scale	Mapped (basic mapping unit 0,25 cm^2)		Enlarged	
1:10.000	Soil series map	Soil series map	Soil family map	Soil association map
1:25.000	Soil series map	Soil association map	Soil family map	Soil association map
1:50.000	Soil family map	Soil association map	Soil association map	
1:50.000	Soil association map		Soil association map	

depends on 1. the detail and accuracy of the photo interpretation, 2. the reliability of the interpretation as observed in the field, 3. the number of field observations.

This is a rather subjective way of indicating the basic mapping unit. On the other hand, it has the advantage that the soil surveyor himself is taking the full responsibility of the work which he has done. Besides this, the average "impurity" of the individual mapping units might be indicated (see above).

Table 4 gives a repetition of some of the data in the preceding tables. It also introduces two new elements. First of all the percentage gain in time and cost through use of air photo interpretation over the traditional field survey and secondly the basic minimum unit area for planning. The first is a rough figure from experience, partly corrected from older data. There is probably a certain optimum for the use of air photo interpretation, which of course does not indicate that the air photo interpretation should only be used at or near this optimal point. There is no direct relation between the number of observations per unit surface area and this approximate gain because the gain is determined not only by the number of observations but also by the efficiency with which the whole field work is carried out and by the way of choosing the observation points. It should be stressed, however, that all these data are very general and have only orientative meaning.

The basic minimum unit area for planning is something which is introduced for the first time in this publication. The idea is that the minimum area on the map is not to be allowed as a minimum planning area. After all, only the most accurate survey gives exactly this minimum area on all parts of the map. This means that the minimum area for planning is always larger than the minimum area of the soil map. We propose to take a rough factor of 4 times the minimum area on the map to calculate the minimum area for planning in the case of semi-detailed soil surveys.

It seems likely that, especially for the smaller scales, this factor must also be taken proportionally larger than 4. In principle the purpose of introducing this factor is that one always has difficulties with non-soil surveyors who are studying the soil map to understand its meaning. It should be made possible for such people to have a somewhat better insight into the possibilities from this point of view also. But for the soil surveyors themselves we think it essential that they should try to realize more the limi-

tations and possibilities of the various mapping scales which they are now handling. In a tentative way we have introduced larger factors for those soil surveys which have a basic mapping unit of more than 50 hectare surface area and a smaller factor (= 2) for those surveys of which the basic mapping unit is equal to 1 hectare or less (see table 4). This is even more important when the table is read from the point of view of the client ordering a survey.
As soon as certain limits of scale (or basic mapping unit) are changed, the possibilities for using the map change rather abruptly.

3.5. Gradual transitions of soil boundaries

A special difficulty in soil survey is the gradual character of most soil boundaries. In fact this is also partly related to the scale of publishing of the soil map, because a boundary that may look quite definite on a small scale, may have to be mapped as a gradual transition on a larger scale. This is often not sufficiently described, although in practical soil survey it is always realized. In fig. 6 some examples of gradual boundaries are given, from the simple fact of clay over sand wedging out the one over the other through a loam over bedrock, ending in a gradual transitional pattern in the horizontal direction. These are just a few examples of the kind which every soil surveyor meets every day. In fact even for the experienced soil surveyor these gradual transitions always remain a problem.

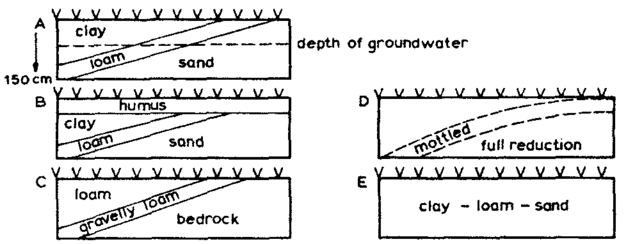


Fig. 6. Gradual transitions of soils

This problem is not to be solved by looking only at the one factor that gradually changes. The importance of any soil factor is determined not by that factor alone but by the whole complex of factors within which it occurs. In fig. 6 we have given two different situations for the clay-over-sand boundary, the one with a certain water level, the other with a covering layer of humic material. The tracing of the boundary in a case like this is also due to the influence which either groundwater level or humic material has on the whole reaction of the soil for practical purpose. The decision on where to put a line for a gradual boundary depends on the following factors:

1. publishing scale of the soil map,
2. field characteristics that should be easy to determine by field surveyors,
3. influence of other soil characteristics and of climate and site on the relative importance,

4. agricultural significance of the boundary, and
5. importance of the surface area of the various parts (soil units) on both sides of the boundary.

A full discussion on these aspects would lengthen our publication to an even more unmanagable length. We want to draw special attention to the fact that the field characteristics and the agricultural significance come in as specific determining factors. The former means that it is of course senseless to put a boundary from theoretical knowledge in such a way that no field surveyor can find it in the field with a certain accuracy. On the other hand the agricultural significance of the boundary also determines whether a certain boundary should be shifted. Together these have a very definite influence on the decision.

3.6. Agricultural significance of soil boundaries

Some people wonder, whether agricultural significance is not too unstable a factor in the decision of a soil boundary. In fact in most cases this is not true if the other four factors are also taken into account.

The soil map, then, almost always gives the maximum detail that would be possible on the published scale. Of course the accent on a certain soil boundary from the point of view of agriculture may change due to shifting of the land use or of improvement in agricultural techniques.

In theory the soil map certainly has to be reconsidered for that use, but in practice we almost always find that if the map has been executed by sufficiently experienced well-qualified soil surveyors, this aspect is less important than it would seem. Even although the soil classification and the terminology may change, the boundaries in most cases remain unchanged. The land classification maps, also called soil survey interpretation maps, derived from the soil map would certainly undergo a change. This is also the reason why the soil survey interpretation is less permanent than the soil surveys themselves. In general it can be said that the boundaries of a good soil map remain reasonably stable for the period of at least one generation of human life. The soil survey interpretation maps must be reconsidered over various shorter periods of time, from 5 years in highly developed agricultural areas and in areas that are due for rapid development in the near future or that are for specific development areas, to perhaps 10 or 20 years in those areas where a stable system of agriculture exists that is not very liable to change of circumstances from either technical or economic influences.

4. THE INTERPRETATION OF SOIL SURVEYS FOR PRACTICAL PURPOSES

The word "interpretation" in this part of our paper is used in a quite different sense. In the preceding part, we have been interpreting the air photo for the soil surveyor. We are now going to demonstrate to this soil surveyor, that his soil maps also need quite some interpretation for them to be useful for the people requiring his maps. This need for soil survey interpretation will grow more and more as soil survey and soil classification advance into more fundamental knowledge, while at the same time the need for soil surveys for practical purposes increases. The soil surveyor has developed in the last few decades from being the one man who knew something about soils in the field into a specialist in a very complicated part of the natural sciences. But only some of us have the freedom to keep to this fundamental part. In general it is our responsibility to bring the results of our research into the hands of the people who are interested in them, not only as a piece of scientific research, but also as a basis for their own work. As was said a few months ago in a commission meeting, the soil surveyor who only produces a beautiful soil map to hang on the wall, is doing something which is just as expensive as the buying of an old master. The painting of an old master or, if you prefer a modern master, which can also be very expensive, costs about the same as the soil survey of an average area. Then why not hang the painting on the wall and let the soil take care of itself? We are fully aware of the paradox in this saying. Still, the matter needs attention from this viewpoint also.

Soil survey interpretation is part of land classification. By land classification we mean the grouping of soils, studied from the point of view of the man who is using the soil. This subject of land classification contains many very different groupings of soils. We can indicate them roughly in the following groups:

Paricutin, Mexico

Photograph taken with Wild RC 5a automatic film cam. 18 × 18 cm (7″ × 7″), Aviotar lens f = 21 cm (8¼″). Height approx. 1700 m (5600 ft). Negative scale approx. 1:8000.
Photo: Messrs. Luis Struck, Servicio Aerotecnico, Mexico

1. Soil classification
2. Soil quality classification
3. Soil crop response classification
4. Soil use classification
5. Soil suitability classification
6. Advisory land classification
7. Administrative land classification.

Soil classification is the grouping of soils according to their inherent characteristics. It is the fundamental grouping of the soils themselves from the pure view of natural science and is the foundation for all the other groupings mentioned.

Soil quality classification looks at the grouping of soils from a technical standpoint, that is the technical qualities important for a certain use of the soils or for their improvement. This may be permeability, ploughability, erosion hazard, occurrence of an impermeable layer, indications about hardpan, about drainage, about solidity, and many other of the same kind. Such a classification is extremely useful for the man who needs only a few indications of the soil map in a very definite sense. It is in general necessary for him to have these indications. For instance a land consolidation engineer cannot be expected to know all about soil science, so the soil scientist must help him to the essentials needed for this technical job. He may sometimes have to discuss these questions with the soil scientist before the latter can make a sufficiently useful classification for him.

Soil crop response classification gives the response of a crop on a certain soil type for a certain management procedure. This may be for instance the application of various amounts of one or more artificial fertilizers. It may also be the response to drainage. The effect of growth of new varieties on various soils also falls in this category.

Soil use classification, or as it is more generally called, *land use classification*, is the registering of the present use of the soils. In this field we have the special World Land Use Survey of which Prof. L. DUDLEY STAMP is the eminent leader. This land use classification can also be carried out on the basis of the use of the soil type or soil series, in which case we call it soil use classification. This kind of classification is extremely useful because there often is an astonishing lack of knowledge about the actual way soils are used, not only in so-called developing countries, but also in the middle of our Western so-called civilized and very intensively used countries. We consider the soil use classification, however, as an auxiliary classification. We do not think it possible to give accurate predictions on the potential use of soils by studying only this kind of data. For this it is necessary to have more knowledge about the suitability of soils in general and especially, of course, about the particular soils themselves.

We therefore think that *soil suitability classification* is the central part of soil survey interpretation. We consider soil quality classification and soil crop response classification as being part of this kind of soil groupings (cf KELLOGG, 1961). Soil suitability classification indicates the suitability of a soil for a more or less specific use, or for an improvement of the soils. Therefore in the one case we speak of a suitability of use, whereas the other is called suitability of improvement. Fig. 7 indicates how suitability of use and suitability of improvement are connected. In this figure the possibility of a change of the profile, for instance by deep-ploughing is also to be considered. This change of the profile consists of a change in the soil itself, so that in this case a new classification of the fundamental characteristics of the soil must be made.

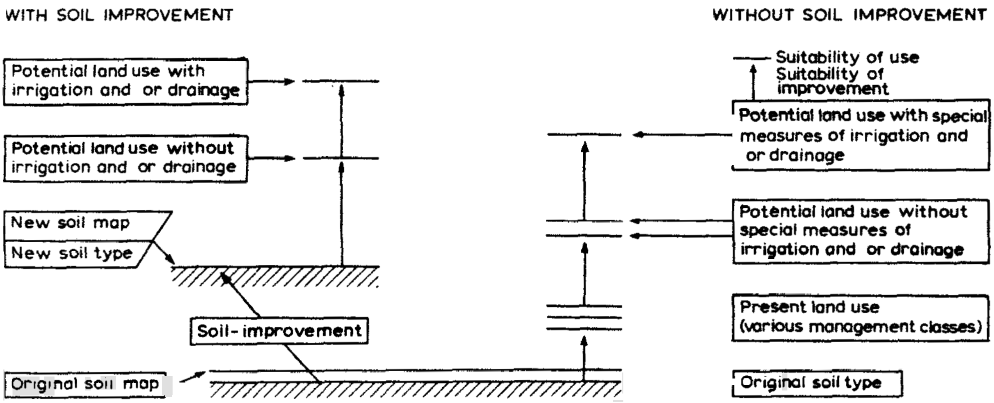


Fig. 7. Suitability of use and suitability of improvement

Soil suitability classification gives the alternative possibilities and potentialities of the soils without giving a conclusion as to the best way of using them. This is determined by the *advisory classification* and the *administrative classification* or sometimes by also using data of economic land use classification. These three are out with the scope of soil survey interpretation, although they are part of land classification. The soil surveyor sometimes has some function in advisory classification, but he should be very careful in this respect. The best use of the soil is not only a question of the soil itself, but of various social, political and economic considerations. Sometimes even religious considerations come to the fore, such as the possibility of keeping pigs in predominantly Islamic countries. The soil surveyor must concern himself with soil suitability classification, but he should be very careful not to set himself on the chair of the administrator.

Soil suitability classification is based on various assumptions and is never an absolute suitability. It is always considered under certain circumstances, but this is not always

sufficiently realized, even by those people who are working largely with this kind of classification. An example of this are the famous 8 classes of the U.S. Soil Conservation Service. Until 1957 these classes were used without any official indication as to the assumptions on which they were based, and it was only around that time that they were published (KLINGEBIEL, 1958). Sometimes soil suitability classifications are made by soil surveyors without their consulting anybody else. If the soil surveyor is himself a good agronomist, and if no possibility of consulting other people exists, he must sometimes do this as a first approximation. It is our experience that often this way of putting the question is the best way of entering into an effective discussion with other specialists concerned. But anyhow the soil surveyor must realize that it is also partly the farm economist, the agricultural engineer, the crop specialist and the soil fertility expert who are concerned with suitability and who have a say in this matter. Therefore the soil suitability research, and also the putting into practice of this kind of work, must be organized as soon as possible in teams of about 4 or 5 people, but I would never advise anybody to make a team larger than 5 people.
The soil surveyor must take the lead because he is the man who can handle his soil units as individuals and who also knows their variability. The other reason for which the soil surveyor must take a large part of this soil suitability work is the immense profit he himself gains from this, because he keeps in contact with the practical importance of a soil science and the needs of those people who are using the soil surveys. In this way his questions and his basic research are directed to the fundamental problems that have relation to reality. Some may think this a degradation of fundamental research but I feel that the main reason for the enormous amount of research in a science like physics is not first of all a question of the advancement of pure science.

The suitability of a soil for a crop is determined by the following 5 factors:

1. gross yield in pounds per acre,
2. cost of production of this yield in man hours, pounds of fertilizers, machinery, etc.,
3. the yield hazard, caused by the sensitivity of a crop on a certain soil to the less favourable influences of climate and man,
4. the quality of the product,
5. the soil pattern.

The scope of this paper does not permit us to give a full description of these factors. We refer to previous publications (VINK, 1956, 1958, 1960).
The quantitative working of the above factors is determined by the general economic circumstances, technical advance, and management level. The management level is very well described in the Soil Survey Manual (Soil Survey Staff, 1951) and by KELLOGG (1950). The definition of economic and technical level should in general be done in co-operation with specialists on these fields.

APPENDIX

AERIAL PHOTOGRAPHY FOR SOIL SURVEY PROJECTS

GENERAL TENTATIVE OUTLINE, SUBJECT TO VARIATIONS; BASED ON DRAFT SPECIFICATIONS MADE BY F. L. CORTEN AND A. P. A. VINK

Camera type

Wide-angle camera (i.e. f = 11 ... 12 cm for 18 × 18 cm image size; f = 15 cm (6″) for 24 × 24 cm (9″ × 9″) image size) if the terrain elevations per model are not more than 10 % ... 15 % of the flying height.

Normal-angle camera (i.e. f = 20 cm for 18 × 18 cm immage size; f = 9″ for 9″ × 9″ image size) if terrain elevations more than 15 % of the flying height do occur in one model.

Either wide-angle or normal angle where terrain elevations are of the order of 10% H... 15% H.

Flight plan

According to the boundaries of the main physiographic units but as far as possible east-west flight lines. East-west flight lines are certainly recommended if no definite preference according to physiography can be shown. Photo scale preferably 1:20.000 with respect to mean datum. (Photo scale alternatively between 1:25.000 and maximum 1:15.000). Time of flight: preferably in such a season that the significant soil conditions and the differences in vegetation types, show up as far as possible in the photographs with maximum tonal contrast.

In the case of reconnaissance soil surveys smaller scales, up to approximately 1:70.000 may be used. In this case the use of a super-wide-angle camera should be considered. East-west flight lines are recommended.

Survey navigation

Vertical photography. Average tilt values not more than 1°; maximum tilt = 3°. Longitudinal overlap average between 57 % and 60 %. Maximum 65 % and minimum 55 %. Side lap average 15 % maximum 25 % and minimum 10 %.

Crab shall be corrected for, up to a negligible degree, in any case not more than 10 mm on any point of the photograph.

Photography

Atmospheric conditions shall be such that no appreciable haze is present; the resulting negatives shall show some shadow detail, shall show detail contrast and shall be clear.

No more than 2 % of area cloud plus cloud shadow shall occur in any photograph. Development shall be carried to gamma = 1.2 approximately. Exposure shall be such that the minimum negative density is:

$$D_{min} = D_{fog} + 0.2\ D + 0.1\ D$$

Blurring and unsharpness due to image movement shall be completely absent.

Delivery

One set (or more if desired) of glossy contact prints plus one set (or more) of semi-matt contact prints shall be delivered. All photographs and flight lines shall be numbered. An index map shall be delivered, preferably a topographic map 1:25,000 (or 1:20,000) showing all photo- and flight-line numbers and principal points' positions. For small scale soil surveys, index-mosaics on scale 1:100,000 or 1:200,000 may be very useful. For sample areas a set of alternate enlargements (1:10,000 or 1:5,000) of excellent quality on semi-matt paper shall be delivered. The time of delivery of these enlargements should be within one month after the areas and photonumbers have been indicated by the senior soil surveyor in charge of the project. Semi-controlled mosaics in approximated photoscale (1:20,000 preferably) shall be compiled; preferably two (or more?) copies of each sheet on semi-matt paper shall be delivered. In some cases, uncontrolled mosaics are sufficient.
They may even be preferable if the time of delivery can be markedly put forward. The kind of control (or lack of control) should however always be indicated on the mosaics sheets.

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LIST OF ILLUSTRATIONS

Photographs provided by:
[1]) Wild, Heerbrugg, Limited, Heerbrugg, Switzerland; Topographical Survey of Switzerland, Wabern, Berne.