SOILS BULLETIN

6

aerial photo interpretation in soil survey

FOOD AND AGRICULTURE ORGANIZATION
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The author wishes to thank the Director of the Instituto Geográfico "Augustin Codazzi," Colombia, for permitting him to build up a collection of aerial photographs of Colombia, many of which illustrate this text. Access to the international collection of aerial photographs at the I.T.C. Delft, made it possible to greatly extend the geographical coverage of the illustrations and thanks are also due to governments and organizations who have permitted these photographs to be reproduced. Credit for individual photographs is given in the text.

The name of many who through their publications and discussions have greatly influenced this monograph appear in the list of references but the influence of many other authors pervades the text throughout.

Special credit is due to Mr. J. Vermeer, Senior Soil Scientist at the I.T.C. who with his remarks materially contributed to the formulation of the ideas in this book.

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CHAPTER I

AERIAL PHOTO INTERPRETATION IN GENERAL

Introduction

Aerial photographs have been used for several decades in the study of the earth's surface. As a means of illustrating and explaining landscape phenomena, the bird's eye view which air photographs provide is without rival at comparable cost. Figure 1 clearly demonstrates their illustrative value.

However, the use of air photos merely as illustrations helping to tell a story should not be confused with air photo interpretation, which is a much more recent and more subtle application of air photography. The air photo interpreter views his photographs not as pictures but as reflections of a huge variety of natural phenomena, from the complex relationships of which he must deduce the information he requires.

It is a mistake to imagine that the air photo interpreter has at his command information which cannot be obtained on the ground. If differences are recorded on the air photos it must be that field conditions responsible for these differences exist on the ground.These differences could be identified and mapped on the ground although, in many cases, the work would be exceedingly slow and tedious and might entail the use of elaborate equipment. Once differences have been noted and their distribution mapped on air photos, on the other hand, it is usually a simple matter to establish the exact nature of these differences by ground observation. The question is not, therefore, whether air photos can provide a solution where field work would fail, but rather one of comparing the difference in time and effort required to achieve the same results by the two methods. Sound interpretation of air photos can make much arduous fieldwork superfluous.

Various scientific disciplines employ air photo interpretation. They extract, from the vast range of information in each set of air photos, such data as is relevant to their particular field of study. In order to do so, they must learn how to handle the photographs and they must also know how different objects on the surface of the earth are represented in a photographic image. The study of the image of those photographed objects and the deduction of their significance is usually called "aerial photographic interpretation."

At first sight Figure 2 seems to be a disordered arrangement of colour tones, lines and patterns. The terrain represented is an area of about 1,600 hectares in the Cauca Valley, Colombia.

The geomorphologist, in studying this photo, will identify features like abandoned riverbeds (1), swampy slackwater areas (2), the foot of alluvial fans (3 and 4), while the geologist may look first at the edge of the Andes Mountains shown at the lower border of the photograph. The engineer is interested in the condition of the terrain in order to plan roads, irrigation canals, etc., and the botanist will find very intersting patterns in the swamps of the slackwater areas. The hydrologist is interested in the spatial arrangement of the waterbodies and their position in relation to the main river.

The archeologist will find interesting patterns near point 5, old cultivation patterns of the native tribes which formerly inhabited this area, while at point 6 he will notice some light dots which indicate former dwelling sites. The agronomist will observe that most of the crops are grown on the natural levees accompanying the abandoned riverbeds.

The soil scientist, knowing that the pattern of the soils is closely related to relief, drainage conditions, vegetation and other features, will study these features and so build up his inventory of the soils.

From this example two conclusions may be drawn. Firstly that an aerial photograph can be considered to represent a whole collection of maps, and secondly, that a scientist, in order to evaluate properly what features of the photograph are of interest for his particular study, also needs to know what all the other features mean. He must be able to judge their significance and to discard those which are not relevant to his study.

The possibility, provided by an aerial photograph, of examining a terrain without actually being on it, was quickly grasped of course by military people. The methods they developed were based almost exclusively on direct identification of the photographic images. Adequate ground control was lacking in most cases. When these methods were applied to civilian sciences, like geology and soil science, it soon became clear that the methods were inadequate. The overenthusiastic approach of early photo-interpreters in such sciences led to serious errors and disappointments, and this was one of the reasons why many scientists in these disciplines became reluctant to use aerial photo interpretation. However, it was obvious that aerial photo interpretation approached systematically and with adequate ground control did have great value. The scientists, who have contributed most to the development of aerial photo interpretation have been those who have exploited its possibilities most cautiously. This was a wise approach, because it led to an objective and unbiased view of both the advantages and the limitations of photo interpretation. Gradually, a more balanced approach to photo interpretation has developed and, nowadays, almost all scientists are convinced of its very great utility.

Aerial Photography and Photogrammetry

In order to make maximul use of aerial photographs some knowledge of a few auxiliary subjects is required. These subjects include: aerial photography, elementary photogrammetry, and simple photogrammetric instruments.

Aerial Photographs

Aerial photographs are taken with a camera mounted in an airplane. During a flight, exposures are made at regular intervals in such a way that there is 60% overlap between photographs. Each part of the terrain thus appears on 2 consecutive photos. This is necessary in order to obtain a three-dimensional picture by means of a stereoscope. Adjacent runs usually have a sidelap of about 25%.

Various filters can be used and various types of films are available. The most common type of film is the panchromatic one. Infrared (Fig. 3), full colour and so-called "false" colour photography have advantages for special purposes, and it often depends on the type of survey to be made, which film type is chosen. As a future possibility radar "photography" and infrared scanning must be seriously considered to obtain additional information. Although at present these developments are still at an experimental stage, the results look very promising for special purposes.

The photographs can be printed in various ways. For exact photogrammetric purposes photos are printed on glass plates, but for normal photo interpretation paper copies suffice. Usually the copies are made at the size of the original negatives, and are called, therefore, "contact copies" or "contact prints." They may be on doubleweight, singleweight or lightweight paper and can be printed glossy, semimatt or matt, depending on the use to be made of them. For field work matt, doubleweight copies are preferred while for office work singleweight glossy paper is recommended. This often means that for a particular survey two sets of photographs are needed; a slight expense in comparison with other expenditure of the survey, such as transport.

From the single copies a composite assembly can be made, called a "photo mosaic" or simply a "mosaic". Mosaics can be prepared in sheets, like topographic maps. Through photogrammetric procedures (rectification and restitution, enlargement or reduction) the mosaic can be adjusted to an existing system of coordinates. Depending upon the degree of adjustment, a mosaic is called "uncontrolled", "semicontrolled" or "controlled."

Cameras

Cameras with a short focal distance produce the so-called wide angle or super wide angle photographs. The cost of such photographs is lower than that of normal angle photography, because the plane can fly at a lower altitude and special arrangements for high altitude flying are not required. Apart from this, wide angle photographs offer a more exaggerated stereoscopic image of the terrain and for that reason are preferred in photo interpretation, except for very mountainous terrain.

Standard aerial photography often has to serve multiple purposes, and some photographs may have to be used by various disciplines in an integrated survey. To meet a wide range of needs none but the best photography taken with the best types of camera will do.

There are, however, some occasions when aerial photography can just as well be taken with a normal hand camera out of a single-engine small plane. Such is the case, for example, when a temporary situation has to be recorded, like the seasonal flooding of an alluvial plain.

Photoscale

There is no common scale for all fields of photo interpretation. Forestry engineers prefer large scales, since they have to study individual trees. Geologists prefer a small scale, because a small-scale photograph presents a view of a very large area. Soil surveyors usually prefer intermediate scales.

The range of scale is normally between 1:5,000 to 1:100,000. Which scale is best for a certain survey depends on various circumstances. If a scale of 1:20,000 is selected, it means that four times as many photographs will be needed than would be necessary with a scale of 1:40,000. For this reason, a small scale may be preferable.

On a small-scale photograph, however, some details which would be of interest to the photo interpreter may not be visible. Compared with 20 years ago it is now possible to show much more detail on small-scale photographs and this improvement in technology has led to a tendency to use smaller scales for photo interpretation. In surveys of natural resources the photoscale still is usually larger than the scale of the final published map.

In some cases it may be desirable and possible to supplement the detail information supplied by the available air photographs. Consider for example, a situation in which knowledge of a certain type of erosion is required in addition to general soil survey information, but the pattern of this type of erosion is too small to be seen on the photo scale employed for the general survey. In this case it may be possible to obtain the required additional information by making low-level reconnaissance flights in a small aeroplane, during which the type and extent of the erosion is annotated on mosaics (see Figs. 4 and 5). Photographs taken with a small hand camera on such flights may provide an alternative, or additional, solution to the problem. The combination of these two types of surveys, one with standard aerial photography and the other with reconnaissance flights may prove to be cheaper than taking and interpreting photographs at a larger scale on which all erosion patterns would be registered.

Enlargement of small-scale photographs has less value for air photo interpretation than is commonly realized. For one thing, the size of the photographs becomes too cumbersome to handle conveniently, and for another, details which do not appear on the original negative cannot appear on the enlargement either. For annotation in the field enlargements can be very useful.

Elementary photogrammetry

An aerial photograph is a central projection of the terrain and as such shows distortions due to relief. Usually photogrammetric techniques have to be applied in order to fit the aerial photographs into a map. The displacement due to relief on an aerial photograph is along a line through its "principal point," the centre of the photograph. This property is used in "radial triangulation" which graphically or mechanically rectifies the position of a numer of control points. The assembly of control points is then used as a base map, on which the lines of the photo interpretation are transferred.

Instruments

A stereoscope is an optical device used to obtain a stereoscopic image of a pair of photographs. The most simple form is the pocket stereoscope shown in Figure 7. The magnification of a pocket stereoscope is from 2½ to 3 times, and it provides an excellent stereo image of the terrain. The disadvantage is that the photos must be placed so close together that they partly cover one another and the whole of one photograph cannot be scanned in one operation. Also, the pocket sterescope does not provide sufficient space for drawing on the photograph.

To overcome these difficulties the prism-mirror stereoscope (see Fig. 6) has been designed. Through a prism and mirror system the distance between the photos is considerably enlarged and more space is allowed for drawing. The stereoscope can be used with or without binoculars to give high or low magnification. The binoculars may have different magnifications from 3 to 8 times. The binoculars are used for detailed study of a small portion of the terrain and also for measurements of height, using a parallax bar. For routine photo interpretation the stereoscope is used without binoculars.

It is advantageous to use the two types of stereoscopes in combination. The pocket stereoscope provides a clearer image than any type of prism-mirror stereoscope, and therefore serves better for the study of a terrain which still presents problems of interpretation. When normal photo interpretation has become a matter of routine, then the prism-mirror stereoscope without binoculars can be used for more efficient and more rapid photo interpretation.

Recently zoom stereoscopes on which magnification can be set for any value within a certain range, have appeared on the market.

A special type of stereoscope is the scanning stereoscope of Fig. 8. When two such stereoscopes are placed opposite each other it is possible for two persons to view simultaneously the same pair of photographs. By means of adjustable mirrors the whole image of the photographs can be scanned without moving the photos or the stereoscopes. Such an arrangement has special value for instruction or for consultation between interpreters.

Some firms have constructed stereoscopes with special devices for drawing directly onto a map. This may be a mechanical device, like a pantograph, which transfers a tracing movement on the photo directly onto a map; or it may be a double prism system, by means of which the interpreter views simultaneously the stereo image of the photo and the base map. In either case, the surveyor draws on the base map by following lines which he sees on the aerial photo. Some technical training is needed to operate these instruments.

An example is the Stereosketch (Hilger and Watts, London). This is a prism-mirror stereoscope with enlarged base. Through a specially constructed prism the observer sees the photographs and also the topomap which is placed on a horizontal planetable below and between the photo supports. While viewing the photos stereoscopically, the interpreter can annotate directly on the map. The planetable can be moved up or down, to adjust for scale differences between map and photos.

It is still more usual to draw interpretation lines directly on the aerial photos whilst they are under the stereoscope and later to transfer these lines onto the base map. This may be done with a sketchmaster (see Fig. 9), in which the image of the aerial photograph is projected through a viewing prism onto the map with devices to adjust the scale of the photo image to that of the map. It is also possible to transfer interpretation lines by direct vision onto an accurate topographic map or onto a photo mosaic. In this respect mention must be made of photographic enlargement or reduction through which the photo interpretation can be adjusted to any map scale.

Practical information on the subjects of aerial photography and photogrammetry for interpretation purposes can be found in the Manual of Photographic Interpretation, Am. Soc. of Photogrammetry, Washington, 1960.

For more exacting techniques the reader is referred to the Manual of Photogrammetry issued by the same society.

General principles of air photo interpretation

A good technical konowledge of photographs and instruments is a common base for all photo interpretation. It also includes the realization that the photograph shows the terrain in different shades of gray ranging between black and white, and that these different shades are caused by differences in reflection of the objects on the surface of the earth.

The first questions to be answered relate to the cause of high or low reflection from different parts of the terrain (see the paragraphs on colour as an element in photo interpretation in Chapter 3).

The second component of the photo image is the impression of relief, as seen in three dimensions through the stereoscope. Relief is exaggerated in the stereoscopic image. This is an advantage, although it takes some training to translate the exaggerated impression in terms of reality.

The stereo image of the landscape provides a much better view of the major terrain features than can be obtained by normal vision from any point on the earth's surface. In the first place this is due, of course, to the apparent point of observation high above the earth and unobstructed in all directions. Few points on earth can offer a similar site for observation. Secondly, whereas in actual observation in the field three-dimensional perception is lost at distances larger than approximately 1,000 meters, the three-dimensional stereo image, exaggerated several times compared with normal vision, permits the photo interpreter to observe very slight relief differences, apparently from a large distance. The pattern of such differences often can be observed much more easily than would be possible on the ground.

Several authors (Buringh, 1960, Lueder, 1959, Vink, 1963) recognize various phases of photo interpretation. Commonly the first step of photo interpretation is called <u>recognition and identification</u>, or "photo reading."

The recognition and identification phase refers to the study of clearly visible objects and features with the aim of making an unquestioned identification. The ability to do so depends to a large extent on the interpreter's degree of familiarity with the features of the earth. The more experience one has, the more one is able to recognize and identify objects. Experience can also be built up with the use of "photo keys." A photo key is essentially an aerial photograph or part of it with an object indicated and described. Photo keys can be made of different subjects. A good collection of photo keys on land use is found in "Land use and its pattern in the United States." Agricultural Handbook Number 153, U.S. Dept. of Agriculture.

In that book some 168 aerial photographs are assembled showing different types of land use occurring in various parts of the U.S.A.

Keys meant to explain a specific phenomenon are very often selected on their "illustration" value, that is an area was chosen where a certain feature was prominently visible. Attention is then drawn to the prominent feature, often with the exclusion of other phenomena. This is satisfactory when keys are used simply for instruction but their systematic use in survey work requires a more balanced approach in the selection of examples. In relation to soil survey the value of keys is restricted since, on an airphoto, the soil profile is not visible and any deductions on the nature of soil profiles based on external patterns and phenomena would be extremely unreliable. This point deserves emphasis, for only in exceptional circumstances and in relation to very limited areas, will photo keys assist in the identification of kinds of soil.

On the subject of keys in photo geology Revertera (1960) has some very interesting remarks.

"If so much in normal geological research work is achieved by comparison, analogies and correlation, this is even more the case in photo-geological procedures. Most information obtained from air photos is, strictly speaking, inferred, indirect evidence by which the nature of the object is deducted with a more or less high degree of accuracy. The term "canned geology" as photo-geology has often been called, is justified to some extent, but then a concoction of fresh food can sometimes be greatly improved by adding a canned ingredient."

And further on:

"Keys consist of stereograms - selected parts of a stereo pair, cut out and orientated for stereoscopic vision through a pocket stereoscope. The cuttings should be glued to sheets that won't warp. Annotation can either be done directly on the prints, but preferably on transparent overlays which are fastened to the sheets along one edge only and can be lifted up for better vision. Annotation on the prints themselves should be discouraged as this tends to exaggerate the differences between the outlined units. The stereograms should be accompanied by an appropriate description of geological data and if necessary of characteristic types of vegetation, etc. Lithological conditions should be pointed out above all, as such information is most badly needed. The description should be concise and confined to essentials, such as: type of rock, mineral composition, degree of shattering, jointing and decomposition, type of soil produced, mode of occurence, presence of contact zones, influence on vegetation, etc. Good stereograms are more useful than long-winded descriptions and should be original photographic prints of the best quality. Printed reproductions (clichés) are not advisable as much of the important detail is often lost in these."

"A collection of keys covering a larger region should be kept in loose-leaf files accompanied by an index mosaic on a reduced scale showing the sites of individual key areas and their distribution. This will assist in estimating the degree of reliability by extrapolation."

From this it follows that a key is not simply a picture of the terrain with a short story about what is directly visible, but also a source of relevant, concise information about the specific conditions which are encountered in the field and which are related to the photographic image. In the same way it is possible to construct keys which can be used in soil mapping, always with the restriction that the photo key serves more to point out a soil <u>pattern</u> than a soil <u>profile</u>. Only when working in similar areas, where speed is essential and where the scale is small, extrapolation can be carried out by means of keys.

In the recognition and identification of objects on the aerial photograph various grades of difficulty exist. For most people it is easy to identify a river or a town or another well-known object familiar to them in daily life. But for the identification of a geological fault or of a natural levée more specialized knowledge is necessary.

Often the photo interpreter is faced with a phenomenon unknown to him and not to be found in the existing photo keys. The phenomenon may have features peculiar to a certain terrain or to a certain human activity. Sometimes the photo interpreter is still able to detect in such a specific phenomenon a more universal process and then he can separate the general process characteristics from the characteristics due to the specific conditions. A certain amount of deduction intrudes into this kind of reasoning.

The next phase of photo interpretation is concerned with analysis. Photo analysis starts with a choice of features to be analyzed. The geologist may measure slopes and dips of geological strata. For him the vegetation is often a nuisance, and he will try to disregard it as much as possible in his analysis. The soil conservationist may analyze the pattern of soil erosion in terms of type and degree. The analysis should be concerned as much as possible, with directly visible and measurable elements and patterns. It should be done systematically over the whole area.

However, a certain amount of deduction often plays a role in the analysis. For example, let us suppose that soil erosion is being analyzed in a certain area. Two adjoining grass fields in the same relative position may have the same type and degree of erosion but, if one is recently grazed and the other one is covered with a high stand of grass, the erosion will show up much better in the first field. Through deduction based on knowledge of the pattern of erosion, the erosion is estimated in the second field using the pattern in the first field as a reference.

From the foregoing it will be clear that the analysis must be executed by a professional in the field of study. The choice of elements is usually of such a highly specialized nature that an amateur would make serious mistakes and oversights. At the same time the professional must be in the position to constantly refresh his terrain knowledge by checking his analysis in the field. This basic necessity is taken for granted in all that follows.

For some studies the analysis of aerial photographs is the direct goal, but for many it is an intermediate step toward arriving at a classification of the terrain. Differences in the analytical elements point to differences in terrain conditions, that is to say different units which have to be brought into a classification. According to Buringh (1960): ".... the units are defined and classified in terms of analogue, i.e., as different or varying physical or cultural characteristics of the earth surface...."

In soil surveys, for instance, the aim of photo analysis is to arrive at a classification of land surfaces which, through subsequent field work and laboratory analysis, can be transferred into soil mapping units.

The various phases of photo interpretation can now be listed as follows:

1. Recognition and identification.

2. Analysis.

3. Classification.

As already said, the ability to do a good job in any phase is built up by experience. This experience is called by Vink (1963) the "reference level of interpretation." Visual observations on the aerial photographs are referred to the knowledge in the human mind or compared with existing photo keys.

Deduction is not listed as a separate phase because it plays a role in all phases.

CHAPTER II

PRINCIPLES OF INTERPRETATION FOR SOIL SURVEYS

Stephens (1953) has described the opening stages of a soil survey as follows:

"A soil survey begins with a general inspection of the project areas. In this way the soil surveyor gains an appreciation of the broad soil patterns in relation to the geographic location, the landforms and the characteristic landscapes of the project area. It is only after he has a mental picture of the general run of the country that the soil surveyor sets out to plan the pattern of his traverses and his inspection sites. He works on the principle that soil has shape and area, breadth and width, as well as depth, and that it is necessary first to look over an area before deciding where to look under it."

This admirable statement remains valid although, since 1953 when it was written, air photo interpretation has played an increasingly important role even in the early stages of soil survey.

The purpose of a soil survey is to make an inventory of the soils occurring in a certain area. A very important part of the survey is the soil map.

Now what is the soil map? It is a pictorial representation of the terrain with the soils indicated by symbols and identified in the legend. The transitions from one soil to another (or from one association of soils to another association) are indicated by a line - the soil boundary.

It is evident from this definition that the construction of the soil boundaries is a very important element in the compilation of the soil map.

In a conventional survey the problem of determining where to draw soil boundaries is solved by augering and digging of profile pits in combination with a study of the landscape. Very rarely is there time to determine each single length of a soil boundary by augering at both sides to prove that the soils are truly different. In normal practice the soil surveyor relies upon his knowledge of the correlations between soil profile differences and soil landscape changes, and the best soil surveyor (in the sense of the best compiler of the soil map) is the one who knows most about this correlation and knows how to represent it on the flat piece of paper (map or aerial photograph) which is going to be the soil map.

Jointly with his mapping work the soil surveyor has to locate suitable sites for detailed study and for the sampling of profiles. Choice of site for a profile pit should ensure firstly that the profile is characteristic of a particular mapping unit and secondly that the mapping unit concerned represents as large a part of the survey area as possible, in order to increase the efficiency of the survey.

This profile study is no less necessary in surveys which make maximum use of aerial photographs. A soil profile with its vertical succession of horizons (see Fig. 10) never can be the subject of air photo interpretation for it is simply not visible on the air photo.

So the reader, apprehensive of being introduced to a soil survey method which does not involve digging in the field, may feel reassured. In all the following paragraphs and chapters there may not be much emphasis on that aspect of soil survey, but it is everywhere implied as the foundation of sound soil surveying.

The first use of an aerial photograph in soil surveys was as a base map. Single contact copies, enlargements or mosaics were used in the field for orientation and for plotting the sites of profile inspections, soil boundaries and symbols. In this respect alone the aerial photograph has great advantages over a topographic map on which only

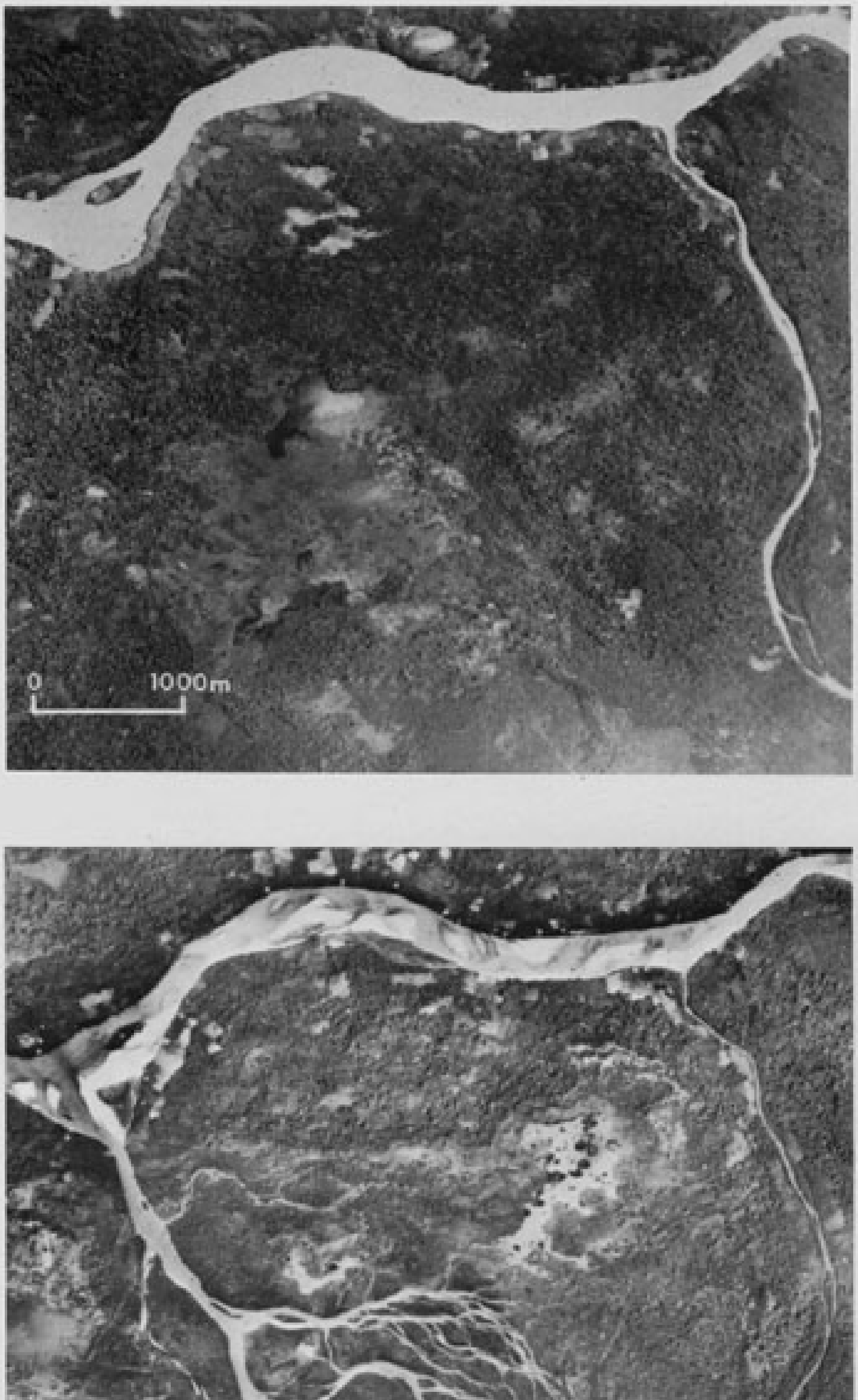


Fig. 1. a) Photograph taken 14 June 1946
b) Photograph taken 8 January 1960
This set of photos of the same terrain (river Arauca, border between Colombia and Venezuela) demonstrates how dynamic is nature.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

Fig. 2. STEREOTRIPLET OF THE LANDSCAPE BETWEEN LA UNION AND TORO.

1 *1 : Old streambeds.*
2 : Marshy basins or slackwater areas.
3 : Foot of the alluvial fan of the Toro River: the scars of the old courses form a "bird's foot", similar to a delta formation.
4 : Foot of the alluvial fan of La Unión.
5 : Traces of prehistoric cultivation.
6 : Prehistoric building sites.

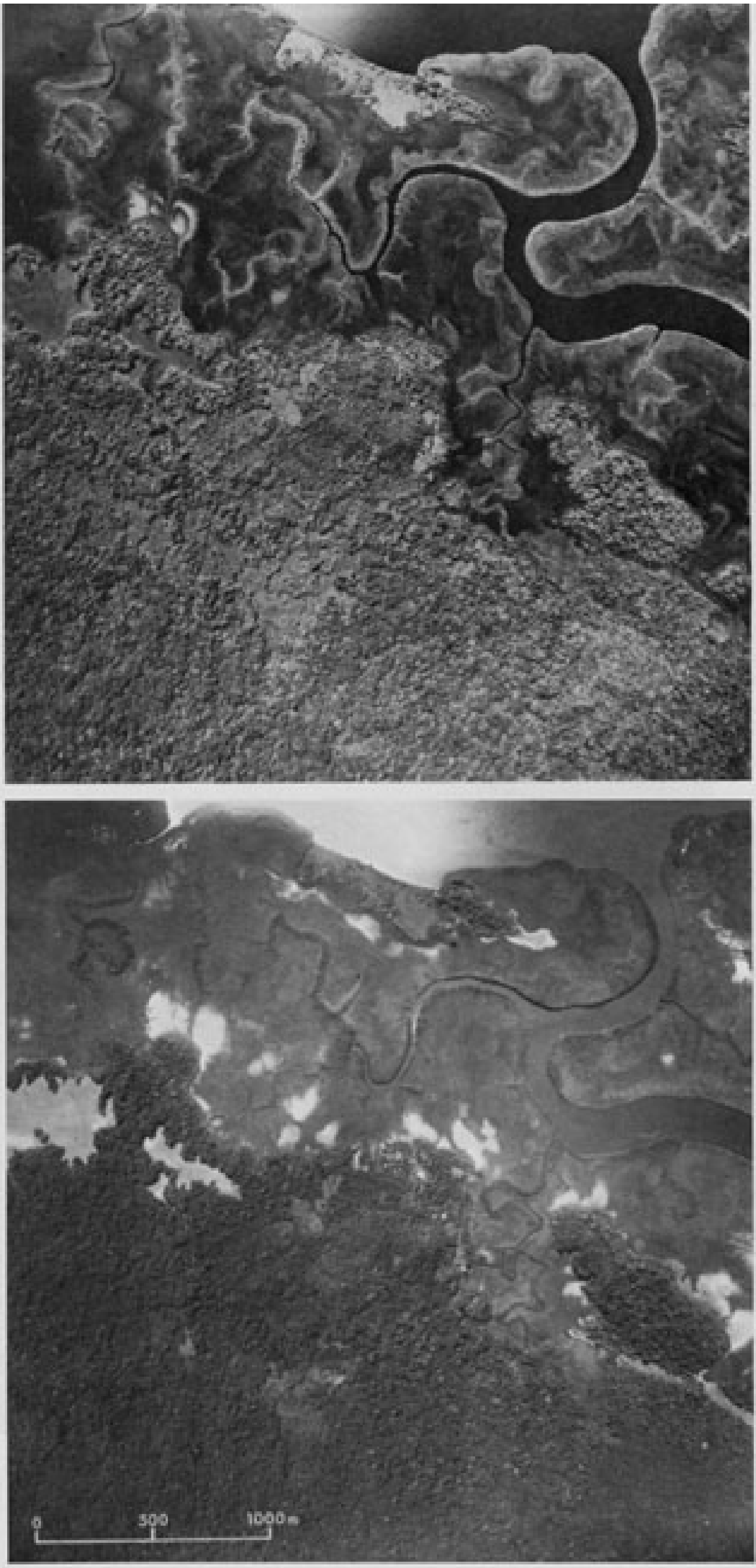


Fig. 3. *Infrared (above) and panchromatic photos of a coastal area in West-Africa. Hydrological conditions are more accentuated in the infrared photo. (Photo 1957, Courtesy Institut Géographique National, Paris)*

Fig. 4. Additional surveying by small planes is often very useful when only small-scale photography is available. (Photo by author)

Fig. 5. This erosion type is not visible on airphotos at a scale 1 : 40.000. Survey is done from helicopter, annotating degree and extent of erosion on photo-mosaics. Size of erosion-gullies approx. 1m wide and deep. (Photo by author)

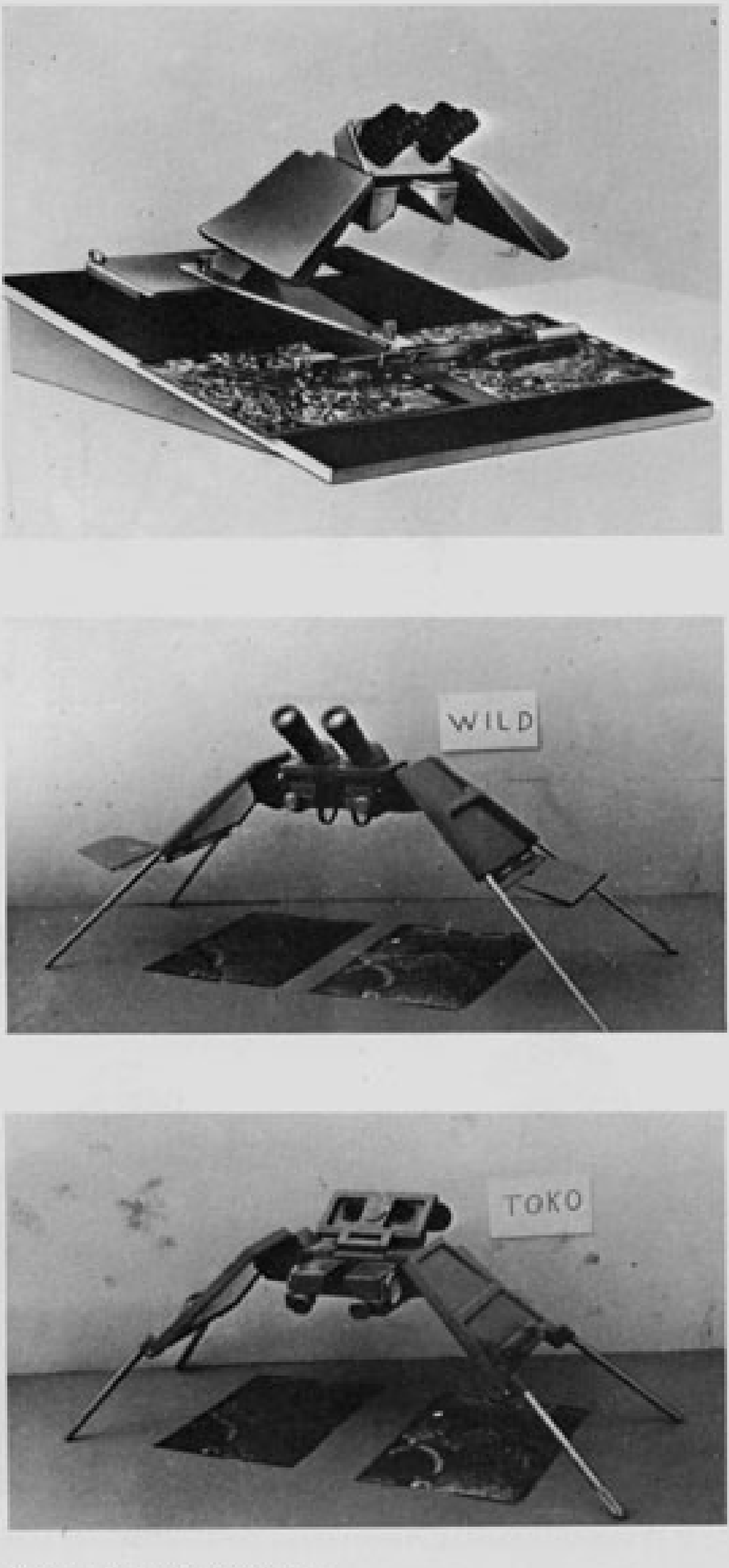


Fig. 6. Prism-mirror stereoscopes.
- *a) Stereoscope with attached parallax bar for height-measurement; Carl Zeiss, Germany.*
- *b) Stereoscope with binoculars in position for enlarged viewing; Wild Co., Switzerland.*
- *c) Stereoscope with bonoculars in unused position, Toko Co., Japan.*

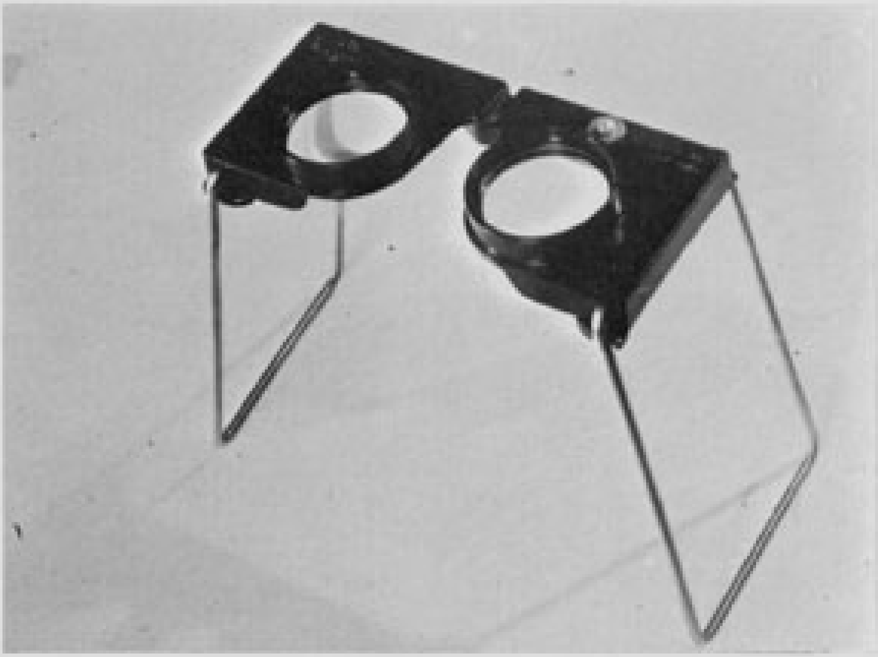


Fig. 7. Pocket stereoscope with adjustable eye-base; Casella Ltd., London.

Fig. 8. Double-scanning stereoscopes for simultaneous viewing; N.V. "De Oude Delft", The Netherlands.

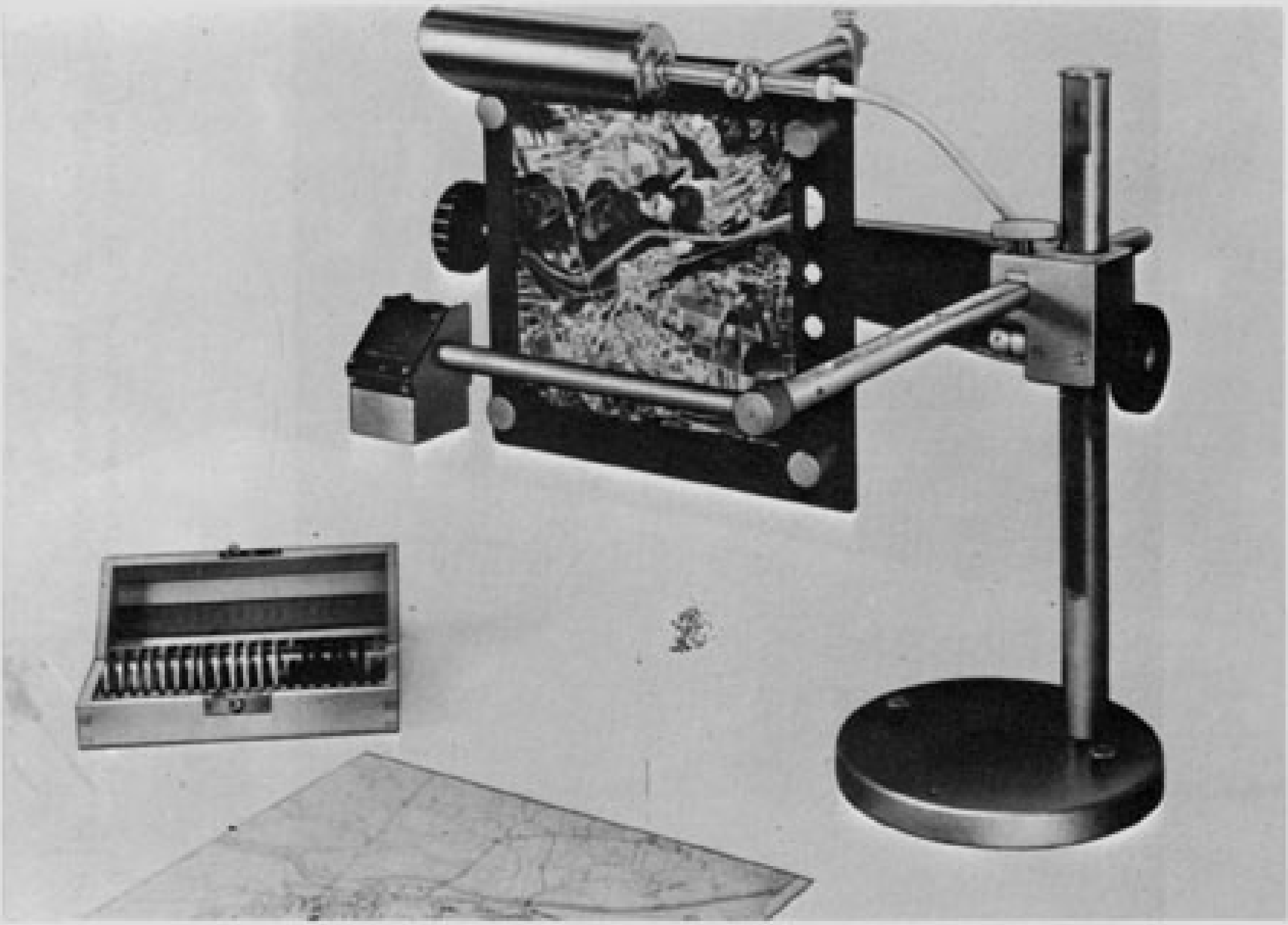


Fig. 9. Aerosketchmaster for transfer of data from photo to map. Adjustable to scale ratios 1 : 5 through 5 : 1; Carl Zeiss, Germany.

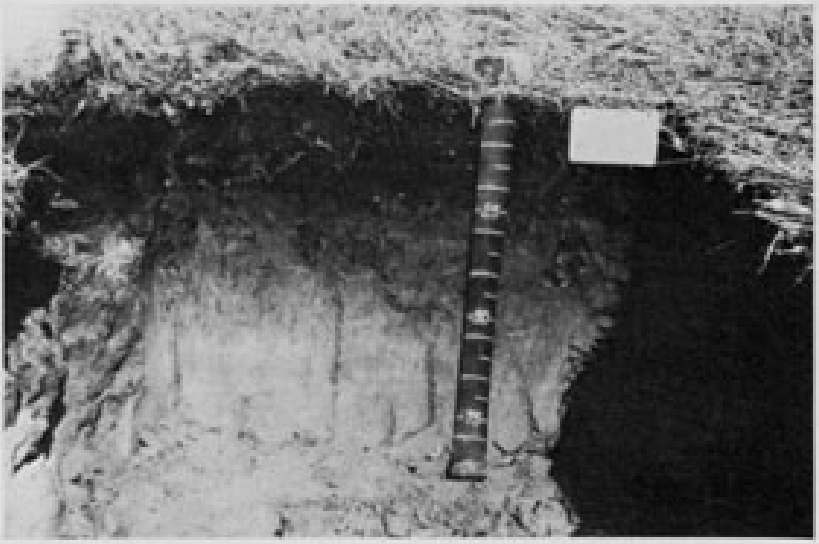


Fig. 10. Tropical hydromorphic soil. The profile-characteristics of a soil can never be studies from the air. (Photo by author)

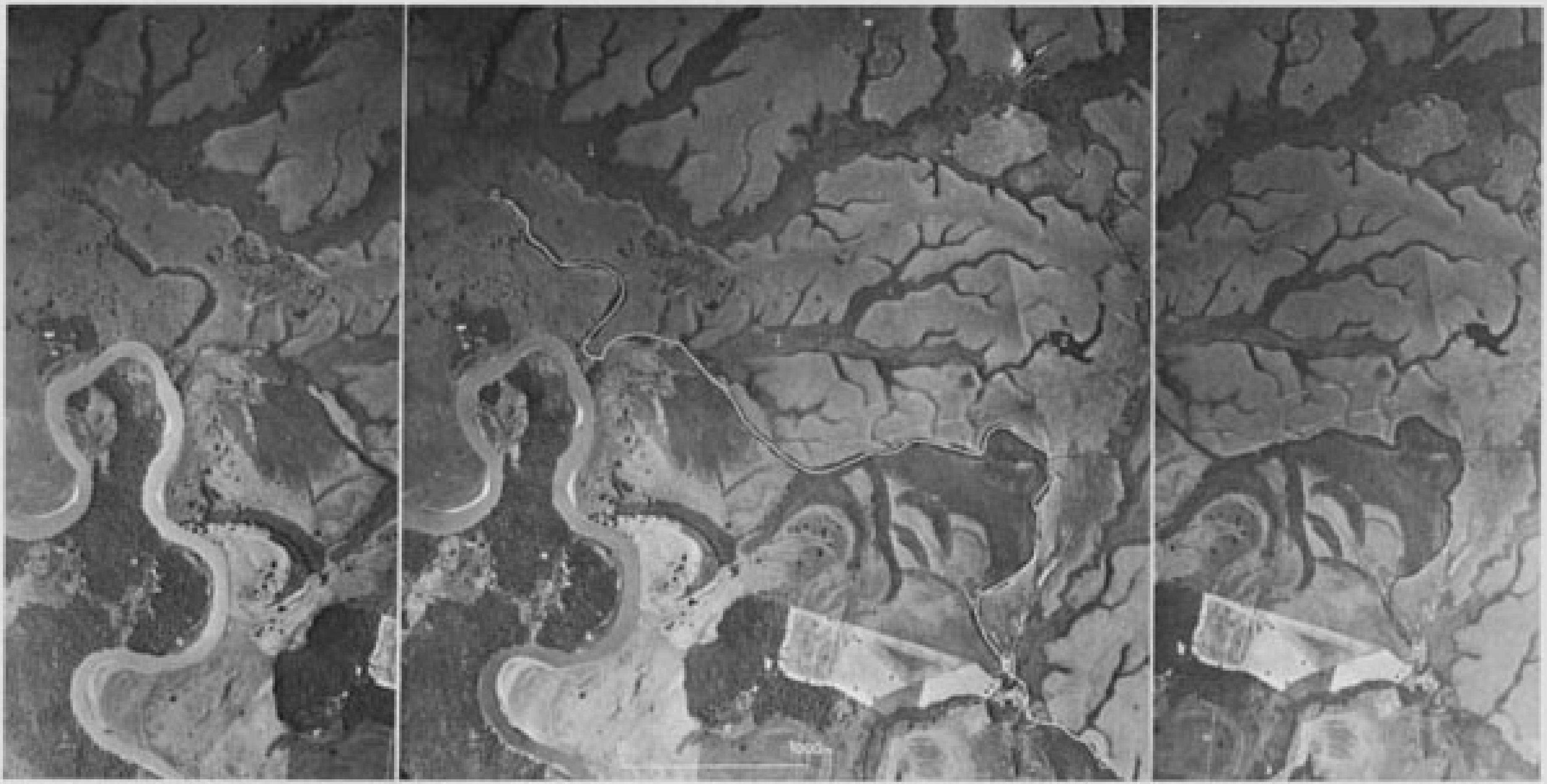


Fig. 11. Stereotriplet of the floodplain of the Cauca River adjoining terrace.
a – a boundary between floodplain and terrace
1. marshy, drowned valleys
2. farmpond.
The terrace is composed of lacustrine clays; the form of the valleys suggests a regression of the riverlevel followed by a transgression. (Photo 30 January 1957, Courtesy Cauca Valley Corporation, Cali, Colombia)

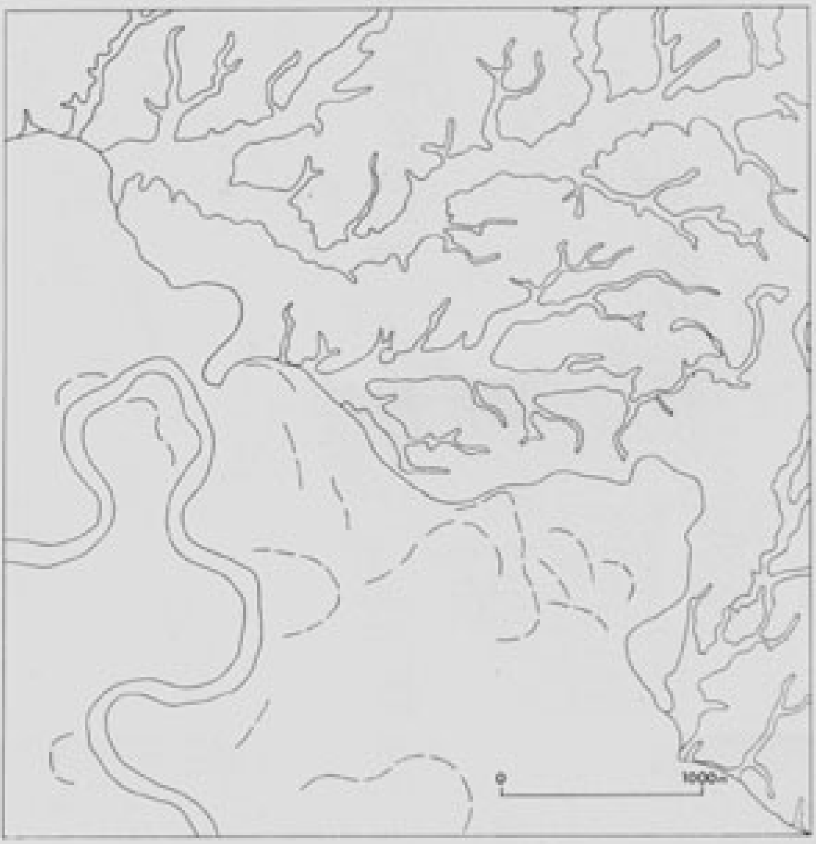


Fig. 12. Pattern of soil associations in the terrace area of Fig. 11 Scale 1 : 40.000. Meanderscars in the floodplain are indicated with dash lines.

Fig. 13. Long profile cut in clayey marl, north of Montijo, Spain, showing marked change in soil characteristics. (Photo by author)

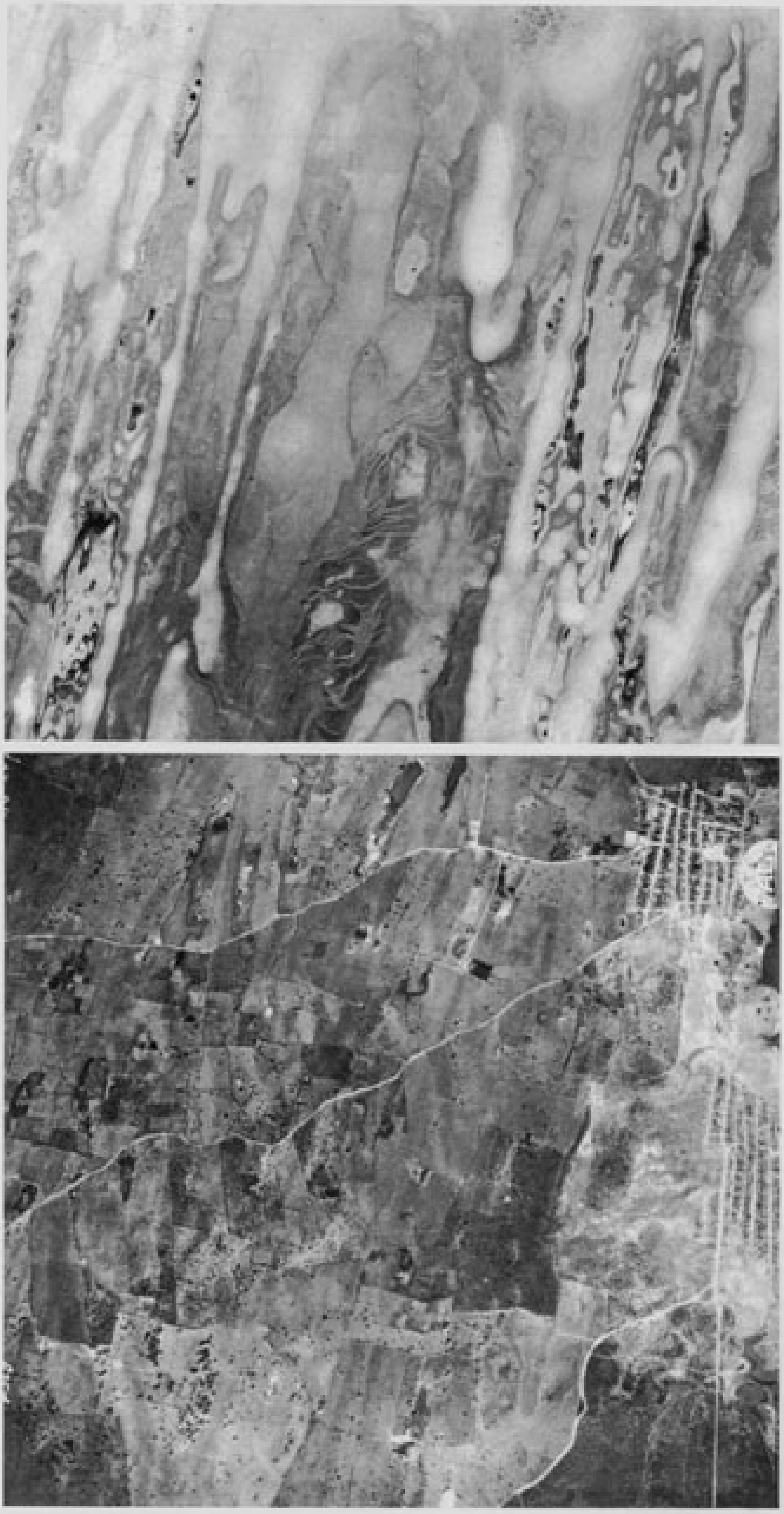


Fig. 14. a) Pattern of longitudinal river dunes south of the river Ariporo, Llanos Orientales, Colombia. Scale 1 : 40.000.
b) Pattern of longitudinal coastal dunes south of Barranquilla, Colombia Scale 1 : 40.000.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

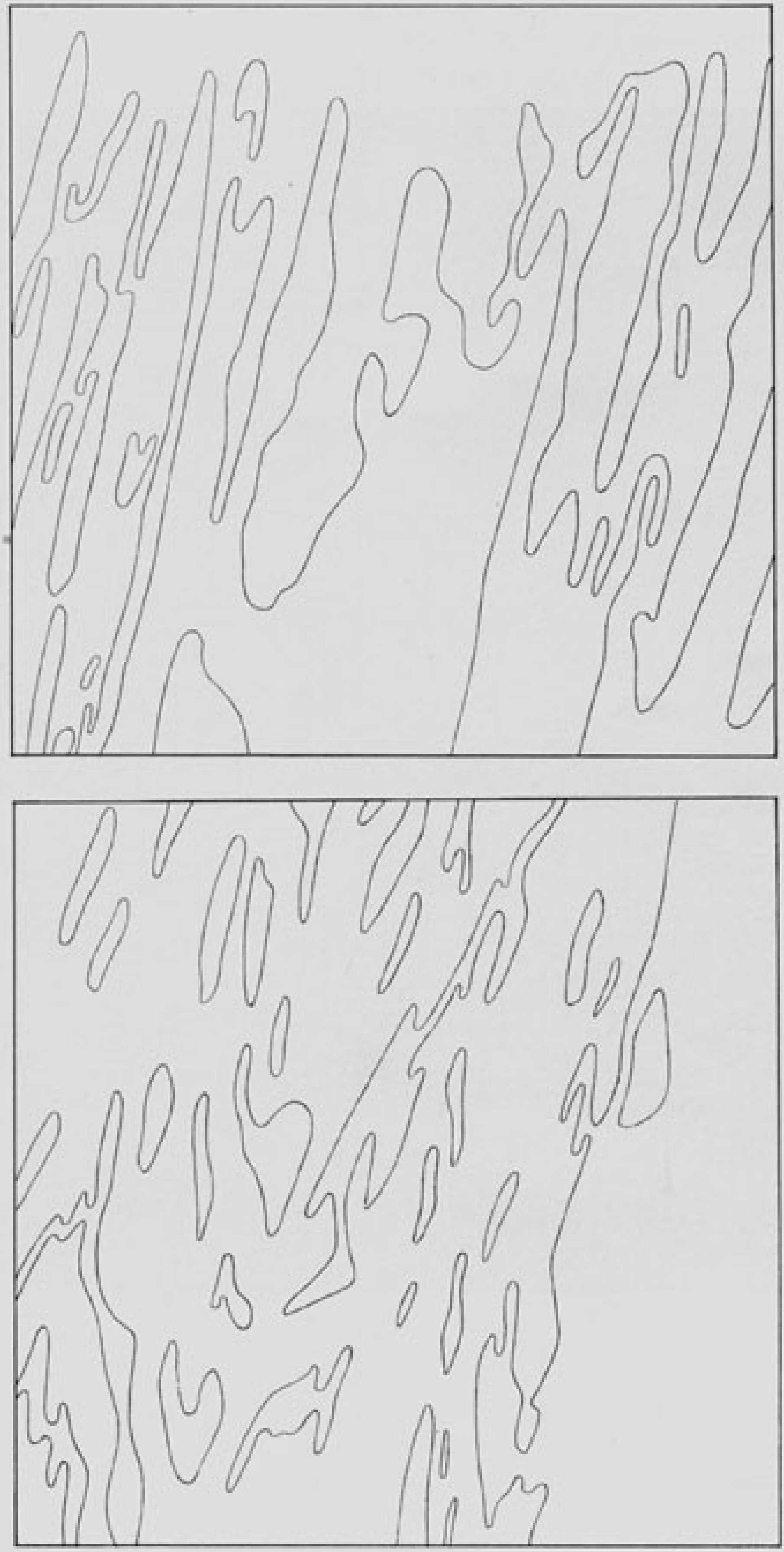


Fig. 15. Analysis of the pattern element 'landform' of the airphotos shown in Fig. 14. The similarity in pattern is an indication of a certain similarity in soils. See text.

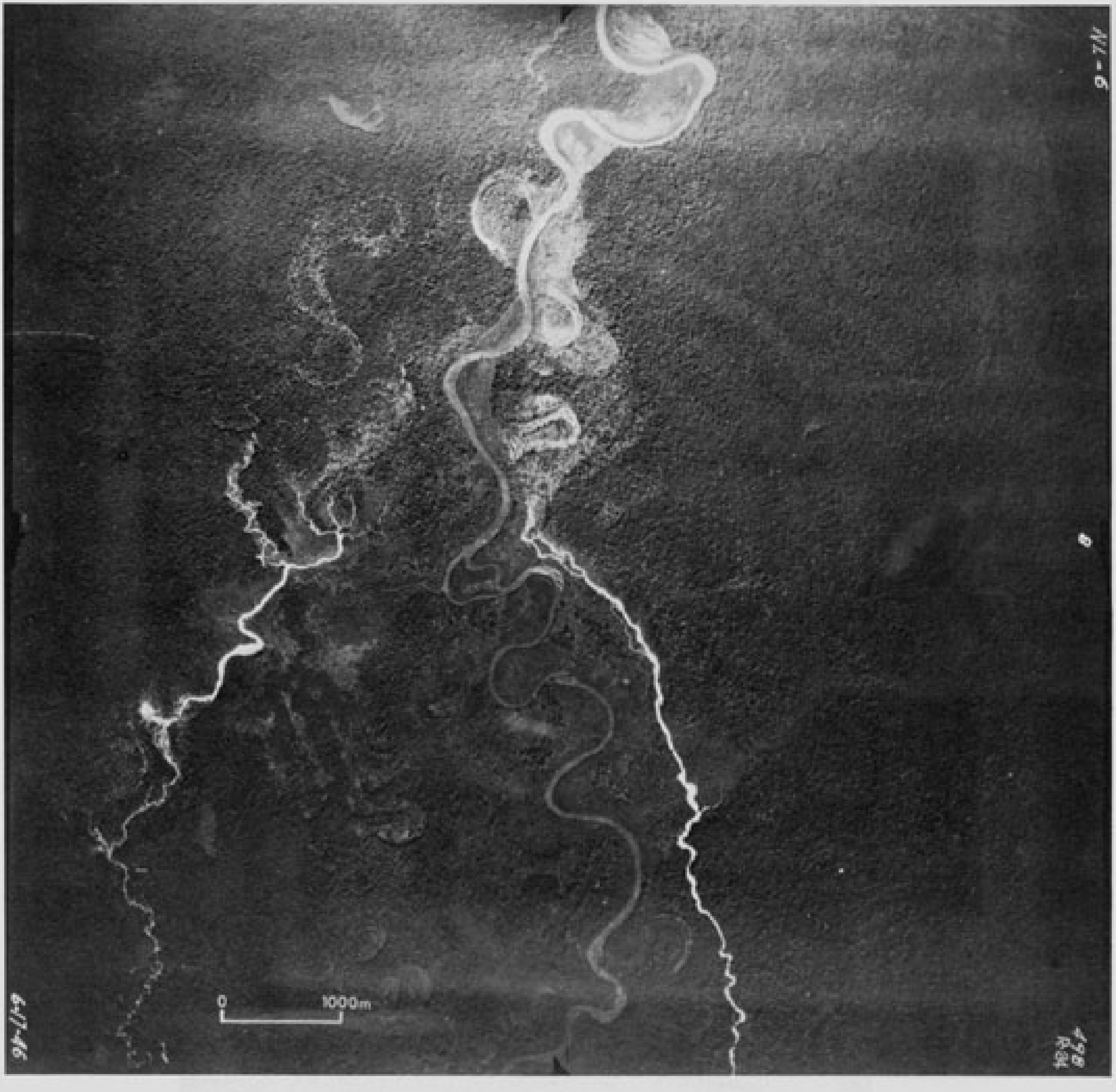


Fig. 16. River clogging up its own bed. For explanation see text.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

Fig. 17. a) Pattern of beach ridges near the river Sinú, Colombia. Scale 1:50.000. b) Pattern of pointbars along the river Magdalena, Colombia. Scale 1:60.000. The similarity of the two patterns in itself is suggestive of similar soils, but the patterns must be studied in their surroundings. See text. (Courtesy Instituto Geográfico, "Augustín Codazzi", Colombia)

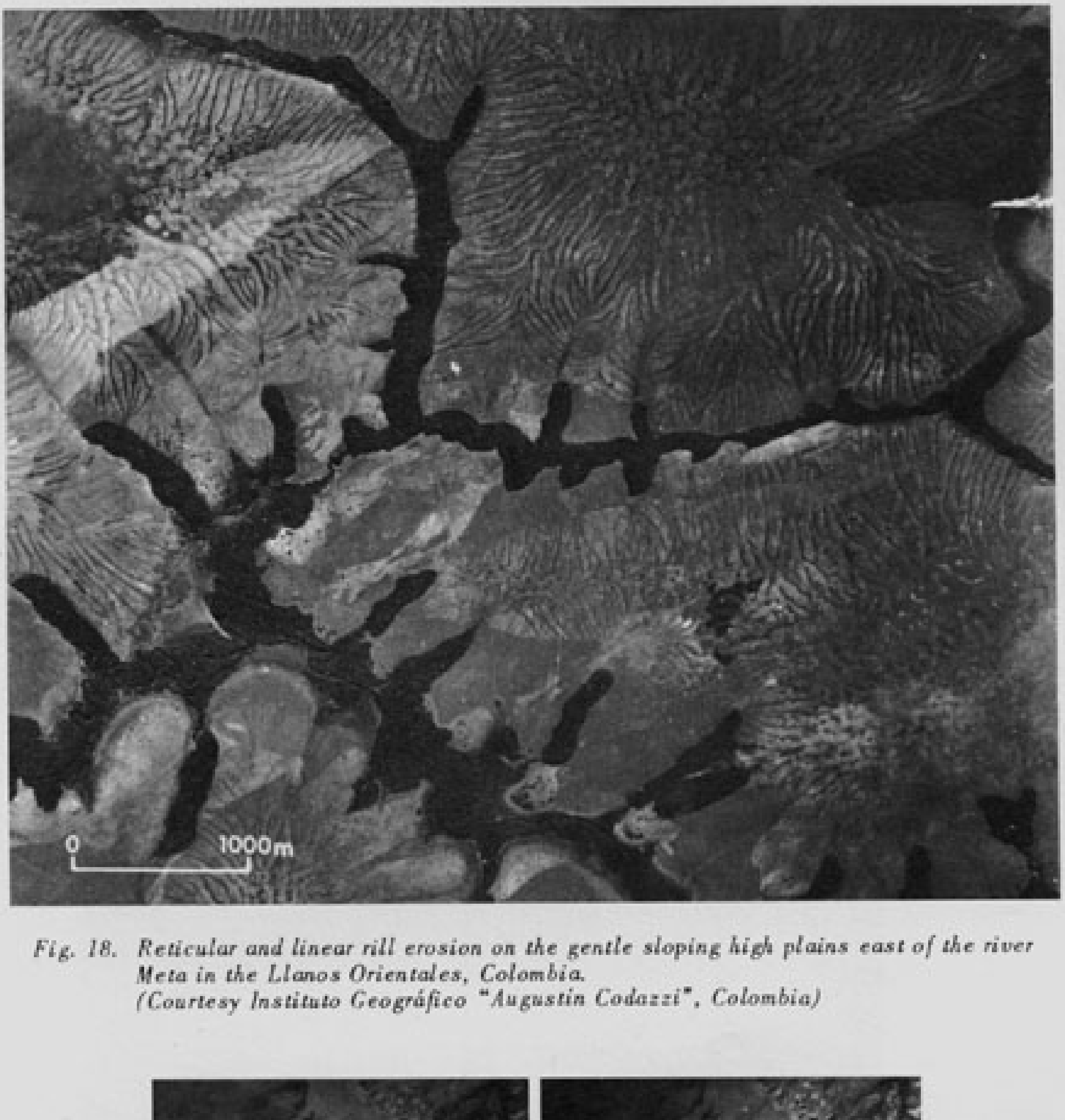
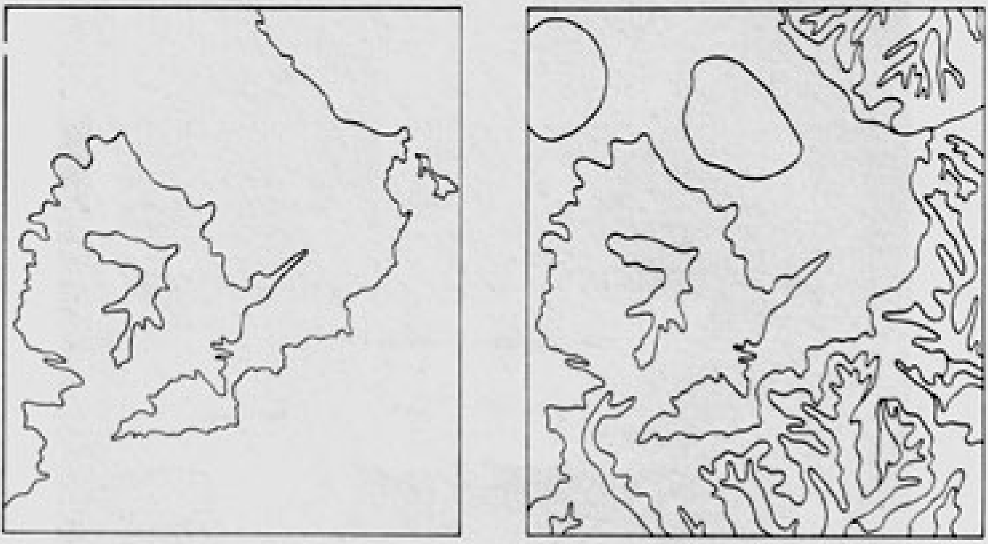


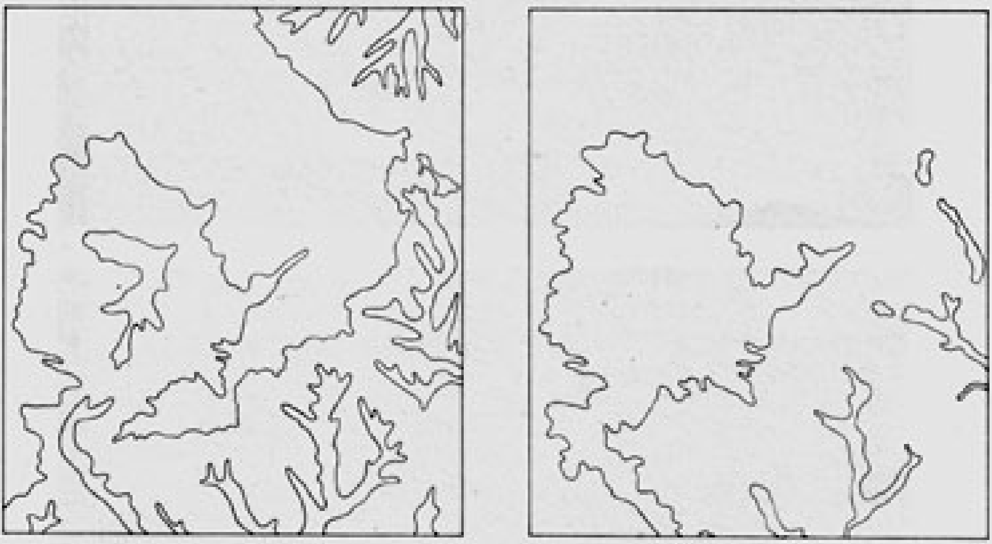
Fig. 18. Reticular and linear rill erosion on the gentle sloping high plains east of the river Meta in the Llanos Orientales, Colombia.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

Fig. 19. Stereogram of a partly dissected high plain in the Llanos Orientales, Colombia. Approx. scale 1:85.000.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)



a. Land type

b. Relief



c. Gully and drainage pattern

d. Vegetation

e. a+b+c+d (d in dash-line)

f. Soil map

Fig. 20. Photo-analysis of different elements in Fig. 19. Most elements with a "high" weight give the same boundaries. This provides "converging evidence".

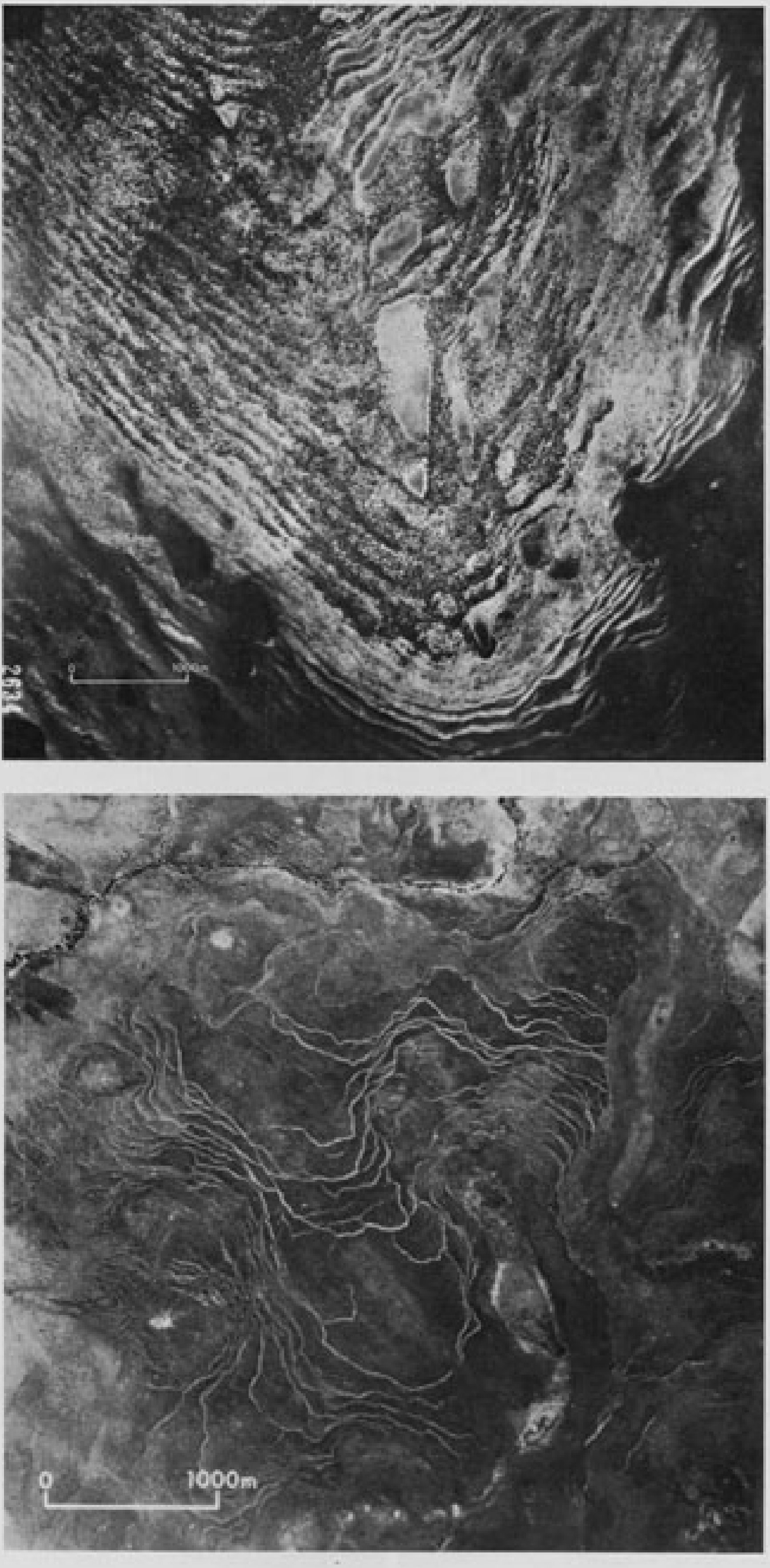


Fig. 21. *a) Solifluction ridges Kalabo district, Barotseland, Zambia.*
(Courtesy Government of Zambia)
b) Solifluction ridges Llanos Orientales, Colombia, near Venezuelan border.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

a selection of the features of the surface are recorded. Each road, house, tree, field boundary, or river is shown on the aerial photograph and the soil surveyor always knows exactly where he is located, except in tall and dense vegetation. Any of the observation points can be plotted on the aerial photograph with great accuracy in relation to all the features mentioned above.

In addition to its use as a simple field map the aerial photograph can be studied stereoscopically. This brings a new element into the use of the air photo. Such a study of the terrain allows the soil surveyor to select even more judiciously his sites for observations and his profile pits. He can plan his traverses according to the lay of the land and, in most environments, he can abandon the conventional regular grid method of surveying, replacing it by "selective sampling." During the field work, features observed in the stereo image are used as a guide in plotting the soil boundaries and the sites for profile pits are selected in order to get a representative sample of a large soil mapping unit, rather than as a means of locating the soil boundaries.

As a consequence of this method, compared with conventional field work, the density of soil profile observations is less while the value of the identification of the soils remains the same and the accuracy of the plotting of soil boundaries is greater. Let us make this clear with an example. The photograph of Figure 11 and the map drawn from it in Figure 12, show a simple pattern of soil distribution, which, however, can be drawn in very much detail. Apart from the alluvial floodplain the two main landscape elements pictured are a terrace and a number of drowned valleys within this terrace. Field studies reveal that the soil pattern outside the alluvial floodplain is also quite simple; each landscape element consists of a soil association with only a few soil series in it. Not too many field observations are needed to establish this. Let us assume 10 profile observations. In a conventional grid soil survey it would be necessary to have a large number of observations. Some standards have been adopted for the required density of observations although these vary from country to country. Let us assume a standard of one observation per square cm of the map. According to conventional standards any map not having this density of observation ought to be reduced in scale until such is the case. It would obviously be unsatisfactory to reduce the scale of the map shown in Figure 12 to meet these standards, for in the process valuable information about the patterns of the soils would be lost.

The above example has been specially chosen to show that even a soil surveyor with little or no experience in photo interpretation can make use of aerial photographs in incidental cases. The relation between certain terrain features and soil boundaries in this case is so obvious that no one could possibly miss it.

This random use of the aerial photograph, however, cannot be applied to any type of terrain, especially if the interpreter lacks experience. Looking again at the photograph of Figure 11 we see that in the alluvial plain a much more confused pattern is visible. There are very few relief differences, many colour differences, many differences in lines and patterns, and it is difficult to say at first sight which of the lines and patterns represent actual soil boundaries. To make a proper soil map of such an alluvial area, the inexperienced soil surveyor would have to fall back on the conventional grid survey.

At this point a number of soil surveyors, especially those from developed countries, may rightly object that a conventional grid survey may not be necessary, even in a complex alluvial area. Accumulated experience of the relationships between soil profiles and external features of the landscape may make it possible to obtain very reliable results from a "free survey" in which the positioning of samples and of boundaries is decided by the lay of the land as it is observed on the ground. In many countries, however, the absence of soil surveyors having the required experience would make a laborious grid survey unavoidable and the end product is not always satisfactory in terms either of map quality or of efficient use of man power.

In order to overcome this loss of efficiency a more systematic approach to aerial photo-interpretation is needed.

Before proceeding to the description of methods developed in the last 20 years it is necessary to point out a few limitations of the use of aerial photographs. There is first of all the fact that one of the principal objects of study, the soil profile, is not registered in any way on aerial photographs. Many attempts have been made to arrive at statements about the soil profiles by studying their secondary features on the aerial photographs, but none has been successful. It is indeed impossible to make any quantitative description of a soil profile based purely on the study of aerial photographs.

Sometimes it is possible by intelligent reasoning to arrive at certain qualitative statements, or to deduce from the aerial photograph a particular characteristic of the soil profile. Figure 16 illustrates such a case. It shows the river Ele descending from the eastern branch of the Andes Mountains into the Llanos Orientales (eastern plains) of Colombia. The river winds its way through a virgin forest and the water of the river apparently is lost downstream. At the sides of the river and at some distance from it, new streams originate which with irregular flow develop new river beds in the forest. The deductive story of this phenomenon is that the river is charged with very sandy sediments clogging up its own bed and elevating it above the surrounding country. Due to the very permeable character of the river bed and its banks, the water filters through the sand and returns to the surface in the slackwater areas away from the natural levees of the river. Such a phenomenon is only possible if the materials are very permeable and, since we can see that this is an alluvial area, the deduction is valid that the soils along the river are of a very sandy texture. But such statements are of limited value and are mainly of a qualitative nature. They must never be taken as a substitute for a proper profile description on the spot.

Another limitation is that differences in soil types, phases, and often of series are not always systematically visible on the surface of the earth and therefore are not reflected on the aerial photograph. This is especially true for areas where different physiographic processes have acted upon the terrain, as for instance where a thin aeolian cover lies on an alluvial sub-stratum. The pattern of the buried material which constitutes an important part of the soils is not reflected in any way on the surface, because the aeolian cover determines the surface features of the terrain.

From these remarks it follows that for detailed soil surveys the interpretation of aerial photographs has only a limited value. With this limitation in mind it is possible to arrive at a proper evaluation of photo interpretation. Starting from the dictum "soils are landscapes as well as profiles", we see which aspects of soil character can be studied advantageously on aerial photographs. These are the spatial and landscape aspects of soils, such as relief, slope, position of one soil with respect to another, or relative drainage conditions of adjoining soils. Often these features are obscured by vegetation or other objects covering the surface of the earth and the study of the spatial aspects of a soil may have to be done through the knowledge of existing relationships between the soils and the vegetative, physical and cultural features of the area. This study can be called "physiography of soils", and is based on geomorphology supplemented by aspects of physiography, like vegetation, water regime, human activities etc. which influence soil development.

Physiographic considerations have not always received the attention they deserve in taxonomic soil classification but they are certainly of vital importance in soil mapping. Within a landscape two soils may differ very greatly in their profile characteristics and yet, because they are closely related genetically, may have important properties in common. The relationships between such soils can only be appreciated as a result of physiographic studies in which air photo interpretation can play a major part.

The area north of Montijo, Spain, shown in Figure 13, provides a good example. Here a soil association has developed over a clayey marl parent rock. Continuous ploughing during centuries has been responsible, together with normal soil creep and colluviation, for a very advanced smoothing of the original relief simply by filling in pre-existing valleys and depressions. Material from the knobs is continually moving down and the depressions receive this material. Shallow soils (Rendolls) now exist on the sites of old knobs and deeper soils (Grumusterts) in the depressions. The difference between the convex and concave landscape elements is often much smaller than in Figure 13. On an airphoto the eroded parts of the terrain would show up as lighter coloured areas, and their delineation would not be difficult. Seemingly this pattern does not make much sense when compared with the present relief, but if one realizes that the light coloured areas combined make up a pattern of original relief then it becomes clear how logical is the pattern and how inter-related are the soils. The soil in the depressions, developed in colluvial material, could not exist without the more elevated landscape elements and soils developing here. The smoother relief protects the shallow soils from complete erosion. Where relief is smoothest the soils of the knobs are somewhat deeper, overlying also a thicker layer of weathered parent material.

In surveying such soils it would not suffice to say that there are two different soils, one deep, the other one shallow, both having marl as parent material. It is necessary to correlate the two soils in terms of dynamic landscape forming processes, which at the same time are responsible for some important characteristics of the soils. This would give a better insight into the soil profile differences; into the differences in taxonomic classification (quite large in this example); and would also provide a better understanding of certain problems of management, in this case soil conservation.

It would be claiming too much to state that only photo interpretation could give us this type of information. Dedicated field work and observations can very well provide the solution for many baffling problems of landscape formation and of soil patterns. It is equally true, however, that not enough field research capacity is available in terms of money and personnel and that the introduction of aerial photographs has been one of the major promotors of this kind of landscape study, giving soil surveyors a better understanding of soil dynamics and soil distribution. It is already possible in many cases to make certain qualitative pronouncements about soil differences on the basis of this type of study.

With the foregoing limitations and possibilities in mind it is possible to state the uses of aerial photographs in soil surveys: 1. to study more intensively the physiographic aspects of soils; 2. to extract information about the differences between soil mapping units, mainly of a qualitative character, but as far as the spatial aspects are concerned, also of a quantitative character; leading to 3. the delineation of the soil boundaries with greater precision and speed.

CHAPTER 3

METHODS OF INTERPRETATION FOR SOIL SURVEYS

There are 3 principal methods of photo interpretation for soil surveys.

1. Pattern analysis (Frost et al., 1960)

Pattern analysis is based on identification of major landscape units and the division of these into smalller units, characterized by the so-called "local pattern elements." It starts from the assumption that each pattern element is correlated with certain soil conditions. Pattern elements are: landform, drainage, erosional features, vegetation, photographic tone and cultural features.

2. Element analysis

This method is developed by Buringh (1960) and has the advantage that it can be used by soil surveyors without much experience in photo interpretation. Systematic analysis is made of those elements which it is known may have some relation to soil conditions. The resulting classification of units is then used as a basis for field work.

3. Physiographic analysis

Physiographic analysis, already mentioned by Buringh, is quickly developing (Butler, 1959, Goosen, 1961, Vink, 1963). The method is based on a thorough knowledge of physiographic processes (assumed to be basic for any soil surveyor) and their reflection on aerial photographs. The terrain is classified into physiographic units, each of which contains a unique associaton of soils. To apply the method, the surveyor needs more experience and a "high reference level." but the much greater productivity obtained in mapping is a great advantage.

The three principal methods of photo interpretation will be discussed one by one.

Pattern Analysis

The pattern elements, which according to Frost (1960) are indicative of surface and sub-surface conditions are: landform, drainage, erosional features, vegetation, photographic tone and cultural features. The starting point is the identification of large regional patterns which serve to divide the area into major landscape units. Frost describes the principle as follows: "Having grasped the original context of the soils to be studied, the interpreter divides the major landscape units into smaller units and examines local pattern elements under the stereoscope. Each pattern element suggests certain soil conditions. Each element should be studied independently. If all the findings agree, then soils can be identified and described with reasonable accuracy."

"This method requires thorough knowledge of geomorphology or adequate representations of the landforms in a guide or key."

This reasoning is applied, for instance, in the following example. A volcano often has a radial drainage pattern. If on an aerial photo one recognizes a radial drainage pattern there is a strong possibility that the aerea photographed is a volcano. If, moreover, the stereoscopic study reveals a conical hill with one or more depressions at or near the top then the possibility is a certainty.

So two or more different pattern elements may point to the same smaller land units. This is similar to what Lueder (1959) describes as "converging evidence."

The method has been excellently described by Frost (loc. cit.). He gives numerous examples of the identification and classification of landscape units through converging evidence of pattern elements.

In the following paragraphs some examples will be given in which not all the pattern elements converge. This is done with the purpose of pointing out the reliability of the method so far as some special soil conditions are concerned, but also to show certain restrictions which the photo interpreter has to make when applying the method.

Figure 14 shows two photographs, which at first sight appear to show different terrains. However, the analysis of the pattern element landform reveals that in both cases the area shown consists of elongated smoothly-rounded ridges alternating with depressions or swales which often do not have an external drainage outlet. This pattern element is represented in Figure 15, and it becomes immediately obvious that both patterns are quite similar. It is known that the area shown in Figure 14 (a) is a terrain of longitudinal riverdunes, built up from sand blown out of a river valley in the dry seasons. The wind came constantly from one direction (indicated by the direction of the dunes). By comparison it can be inferred that the second photograph (Fig. 14 (b)) represents a similar terrain and in fact this is the case.

From this example it is clear that when sufficient keys are available, identification of an unknown landform becomes easy. Not too much must be inferred though.

The longitudinal riverdunes shown in Figure 14 (a) can be correlated to the rivers in the neighbourhood, but such is not the case with the dunes of Figure 14 (b). In this last case the dunes are coastal dunes at a distance of some 30 km from the coast.

So, although comparison reveals a similarity, it would be dangerous to conclude an absolute identity of the two cases. Some conditions of the soils will be similar, or even identical, but others may differ considerably. In the present example, the parent material, vegetation, climate and the time of soil development are all different and this combination of contrasting factors will surely result in different soil profiles.

Another example is shown in Figure 17. Two photos are shown of which the first represents a coastal area in which a number of parallel or nearly parallel smoothly curving lines can be seen. They appear as a complex. There is a river nearby. Stereoscopic study reveals that the lines are formed by alternate ridges and depressions elongated in the direction of the lines and that the height difference is in the order of 2 meters. The second photo shows a very similar pattern. The ridges are also located in an area not far from the coast with their general direction parallel to a nearby river. The question is "If the phenomenon on one of the photographs is explained, can the other one be safely interpreted, using the first as a key"? Before giving an answer to this question, we will first look at some differences in the two patterns. The pattern of the first photograph is smoothly curving and more or less parallel to the coast line, while the direction is perpendicular to the main direction of the river. In contrast, the pattern of the second photo is parallel to the river and, in fact, follows some of the curves of the river. The pattern of the first photograph is that of old beach ridges, while the pattern of the second photograph represents a complex of point bars deposited by the river. In terms of geomorphology this difference in origin is, of course, important. Nevertheless, some of the soil conditions on the ridges may be quite similar. The parent material in both cases has been transported by rivers in the direction of the sea. In the first case the material actually reached the seas, was reworked by marine action and deposited on the coast, while in the second case the material did not reach the sea and was deposited on the river banks.

So a comparison of the two patterns is very useful in that attention is drawn toward the great similarity in soil pattern even when the agent of sedimentation is different. On the other hand complete identity cannot be assumed because in the first case sedimentation occurred in salty water and it is quite likely that salts are still present in the subsoil.

Still another example is illustrated in Figure 21. Photograph (a) represents an area in the Kalabo district, Barotseland, Zambia, and photograph (b) represents an area in the Llanos Orientales, Colombia, near the border of Venezuela. Both areas represent level terrain with a savanna vegetation. The common feature of both photographs is the occurrence of lines or bands of a lighter colour. When this pattern is analyzed the main characteristics can be described as follows:

Generally parallel curving lines, sometimes connecting at small angles, approximately parallel to contours. Each band is a very low ridge. Such a pattern is typical for solifluction processes (see Goosen, 1965). It occurs very often in aeolian deposits in low tropical savanna areas, and in soils which are quite heavily leached. The common feature is that the cohesion of the soils is low, but the texture may be quite different, ranging from silty clay to loamy very fine sand.

This example shows that pattern analysis of seemingly different areas can result in a correct correlation of the phenomena. It must be emphasized, however, that the deductions should not be allowed to lead too far and should not encompass quantitative description of the soil profile. In the case shown it is only possible to state that at some time in their history these soils suffered solifluction because of low cohesion in combination with water saturation. Other deductions about texture, profile development and mineralogy would be speculations which are not justified.

The lack of proper keys for comparing all different patterns in the world is sometimes the cause of confusion. When a certain phenomenon is studied for the first time, the investigator is often inclined to consider that the feature is unique to the area he is studying or at least that the phenomenon will only occur under conditions very similar to those he is studying.

An example may be found in Figure 18, which shows a superficial, reticular rill erosion on the level broad summits, gradually transforming into a linear pattern on the slopes toward the forested drainage ways. This pattern is somewhat alike to certain patterns of gilgai gullies, so a student familiar with gilgai soils might be inclined to recognize them in Figure 19. Yet no gilgai phenomena are present there. The soils consist mainly of kaolinite and quartz, and lack the mineral montmorillonite, responsible for the gilgai phenomenon.

Similarly, Figure 18 might be confused with periglacial areas, where periodic freezing and thawing produces polygonal and striped soil patterns. Yet, Figure 18 is from a tropical area in Colombia and no glacial activities have ever acted upon this particular landscape.

Even when two particular patterns are caused by an identical physiographic process, it is not possible to assume identity of soil profiles. Figure 51 shows a type of rill erosion quite similar to Figure 18, yet the soils are not alike. The phenomenon will be discussed briefly in Chapter 3, when considering physiographic analysis.

This may demonstrate the care one has to take in using a simple pattern analysis as an absolute means of identification. The principal conclusion to be drawn is that a pattern must always be studied in relation to its surroundings. On this aspect more will be said when discussing physiographic analysis.

In general the method of pattern analysis has made valuable contributions to the study of landforms and its relation to soils. Its use is reliable in areas of known geomorphological history and where conditions not visible on the photograph, like climate and time, are more or less equal. At the same time it follows that use in unknown areas can be rather dangerous and that wrong conclusions are easily reached. Assuming that a certain pattern or even a combination of pattern elements is indicative of certain soil conditions is dangerous. The question must always be asked: is the combination of pattern elements uniquely typical for the soil conditions, or is it "poly-interpretable"?

Element Analysis

Aerial photo analysis according to individual elements, as developed by Buringh (1960) is based upon the fact that most of the features of the earth's surface are in some way connected with soil conditions. For some elements the connection is direct, as in the case of relief; for others, such as land use, the connection is more loose. All the elements considered are supposed to be related to the soil forming factors: climate, organisms, parent material, relief, time and human activity. Elements of human activity are included not only because human activity adjusts itself to the conditions of the soils, but also because human activity can change the condition of the soils, especially when it is intense or has acted over a long period of time.

The study of the elements in the stereo image of aerial photographs starts with the elimination of those elements which have no relation at all to soils. An example might be the land use pattern found in large parts of the mid-western United States of America. This pattern was set out in the last century according to a very regular grid of mile and quartermile sections, and the boundaries, roads, fences, etc., often do not have any relation to the local soil conditions, but traverse them straight. In other cases, however, roads may be very indicative of soil conditions. In an alluvial area, for instance, like the delta of the Rhine in the Netherlands, roads which have been in use for centuries usually follow higher ground. They curve along with the natural levees of the river sediment area and so may provide a very useful indication of the soil conditions, especially in those cases where other elements, like relief, are but faintly visible on the air photo.

From this example it may be clear that in each individual case a judgement has to be made to eliminate those elements which have no relation to the soil conditions in order to concentrate interest in related elements.

A division of the elements in two groups can be made:

1. Elements which are systematically and closely correlated with soil bodies.

2. Elements which only point to a change in soils, but do not coincide with soil bodies.

An example of the first group is the relief of an undulating area of aeolian sand. The alternation from convex to concave relief usually coincides with a change in the drainage conditions, at least, of the soils. An example of the second group of elements might be vegetation, which may be so altered by human activities that present differences are not directly indicative in themselves of a soil change.

However, any classification of the elements in different groups is somewhat artificial. A certain element may in a certain case belong to one group, but in another case may shift to another group. This often depends on local conditions. Therefore, in the selection of elements to be analyzed in a specific area, deduction plays a role, and a reliable selection can only be made by those trained people who have a high reference level.

Within the elements, an order may be established according to relative weight. An element is said to have "high weight," when its relation to soils is very direct, and is said to have a "low weight," when its relation to soils is more of a secondary, inferred nature. Largely based upon this consideration the soils department of the International Training Centre for Aerial Survey and Earth Sciences (I.T.C.) uses the following categories (Vink, 1963):

"1. Elements with a positive direct relation to one or more aspects of the soils themselves (clearly waterlogged soils, patterned ground).

"2. Elements related to the general morphology of the terrain (landtype, relief form, slope, drainage pattern, watershed pattern, rivers and creeks and other patterns).

"3. Elements related to special aspects of the terrain (stratigraphy, gully form, gully pattern, colour of the earth's surface).

"4. Elements related to the vegetation cover (natural vegetation, specific trees, land use).

"5. Elements related to specific human aspects (ditches and canals, dikes, parcelling, roads, patterns and sites of buildings and villages, archeological objects).

"6. Inferred elements or elements based on "converging evidence" (water and drainage conditions, some cases of stratigraphy, parent material, microrelief)."

In this order the weight is decreasing from top to bottom of the list.

The breakdown of the photo image into a large number of elements has a high teaching value, since it is possible to introduce inexperienced students gradually into photo interpretation.

The general principle of the method of element analysis is shown in Figures 19 and 20. Figure 19 shows a savannah area which, in Figure 20, has been analyzed according to the following elements:

(a) landtype,

(b) relief,

(c) gully- and drainage pattern,

(d) vegetation.

In Figure 20 (e) the different analyses have been combined in one drawing.

The soil map, as established by photo interpretation and field work, is given in Figure 20 (f). All symbols are omitted. It will be seen that in this case the vegetation proved to be of little importance in locating the exact position of the soil boundaries.

Sets of keys may also be established. This comment refers especially to the classification of certain elements, such as drainage patterns which can be classified according to their form into several groups, like dendritic, radial, parallel, reticular, etc.

When applied systematically, the element analysis provides a series of maps on which all the different analyses are drawn. These maps together make up the photo interpetation map for the purpose of soil survey and will show a very large number of lines some of which may prove to be soil boundaries, whilst others may have to be erased during subsequent fieldwork. In practice, however, such a method is very time-consuming. More usually the photo interpreter makes up a list of elements on the basis of which he arrives at a classification of terrain units, each characterized by a certain combination of elements. Using this classification the aerial photographs are analyzed to produce directly a photo-interpretation map for soil survey purposes.

According to Buringh (1960) each element is characterized by variations in:

(a) grade or density,

(b) type or shape,

(c) size,

(d) regularity,

(e) site of geographical position.

In the following paragraphs various individual elements will be discussed, with examples of their significance. A choice has been made, omitting numerous elements with a less universal application.

The elements discussed are listed in Table 1, in which the main aspects of their importance in photo interpretation for soil surveys is indicated.

TABLE 1

Importance of photo interpretation elements for soil surveys.

	Visibility in stereo image	Relation to soil condition	Coincidence with soil boundaries
Landtype	High	High	High
Relief	High	High	High
Slopeform	High	High	High
Drainage conditions	Medium	High	Medium
Constructional drainage system	High	High	High
Destructional drainage system	High	High	Medium
Natural vegetation	High	High	Medium
Parent material	Low	High	High
Colour	High	Low	Low
Land use	High	Medium	Low

This table gives general rules. Local conditions may change the qualifications.

Landtype

This is usually the first element to be analyzed. The special value of this analysis is that it breaks up the area into rather homogeneous units. The units are called variously landscapes, landtypes, landform type, etc. (for recent discussion see Verstappen (1966)).

What is meant can be shown best by a few examples.

The photo of Figure 11 shows clearly two main landscapes, first the terrace area, including drowned valleys, second the alluvial plain. There is no problem in drawing the boundary.

For larger areas of complex character more specific knowledge may be required, but the analysis in itself is not difficult. Figure 22 shows the landscape map of 13 million hectares in the Llanos Orientales, Colombia. This map was prepared in a few weeks' time, at the beginning of the soil survey. Of course, some corrections were made later on, but they were minor.

The classification of landtypes is receiving a lot of attention lately, especially among students of physical geography. This is encouraging. It is in the interest of soil surveyors to follow, and to participate in, this discussion closely for there would be great advantage in establishing a widely accepted system of landtype classification.

Relief

Relief plays a very important role in determining the nature and magnitude of various soil forming processes, such as erosion or drainage. The use of agricultural machinery depends for a large part upon relief conditions. Thus, in the practical application of soil survey the study of relief must play a decisive part.

Relief is so complex that it is extremely difficult to classify it properly. The Soil Survey Manual of the U.S. Department of Agriculture proposes a few criteria; normal, abnormal, excessive and depressional relief are defined, but in such a way that what is normal in certain cases may be excessive under another climate and with a different kind of soil. It is difficult, therefore, to find a reliable guide for comparison, when relief is studied under the stereoscope. Usually the percentage of slope is taken as a yardstick, but since the boundaries between classes of slope are necessarily of an arbitrary nature, two slopes may be separated which would be better united in one class.

The magnitude of relief can also be used to indicate various classes. In this connection it is customary to talk of:

mega-relief (continents, oceans),

macro-relief (mountain range, plains),

meso-relief (hills, mesas, escarpments, natural levees and basins in alluvial plains),

micro-relief (undulations of meander crooks or beach ridges; gilgai relief), and

nano-relief (sandripples, wormheaps, mole hills).

A simple pattern of relief, composed of convex and concave relief elements and forming together a certain landform, indicative of a specific landtype, has been shown already in Figure 14 (a). In order to arrive at a classification of terrain units in this example it is not necessary to go to a very detailed analysis of all the different aspects of relief.

But in other areas, such as the one illustrated in Figure 25, relief is very complex indeed and it is not possible to identify a consistent pattern by merely looking at the photograph. In such a case, an analysis of relief into its various components becomes necessary. A detailed analysis of the area shown in Figure 25 would lead to the recognition of various types of relief according to grade of slope, slopeforms, the size of certain slopes, the regularity of patterns and the site. The major relief forms of this particular landscape are connected with glaciation, and with processes of water erosion subsequent to the glaciation. In another part of the same area a depressional relief can be recognized; a relief originally formed also by glaciation, but subsequently modified by processes of accumulation like colluviation and peat formation. Still other parts of the terrain show slopes which, although quite steep, have in principle a concave form. This is related to a strip of colluvial material at the foot of the proper mountain slopes.

In such a way the detailed analysis of the element "relief" leads to the discovery of a number of different types, some superimposed upon each other and due to different processes.

The most cautious approach is to register during the analysis only the changes in relief. A change in relief usually is accompanied by a change in soil conditions. Later field work will then establish what the relative and absolute importance is of the different relief forms.

Slopeform

Slopeform is usually considered as a part of the general relief, but can also be taken as a separate element. Attempts have been made to correlate slopeform with specific soil conditions. See Frost (1960) for example, who connects cross sections and gradients of gullies with soil characteristics.

In itself, slopeform is a very important "external" property of soil bodies deserving of separate systematic analysis and classification as a part of air photo interpretation. It has long been a major object of research in geomorphology and lately more attention has been paid to the relationships between slopeform and soils, or at least to those conditions of soil and of soil parent material which affect slopeform.

Cohesion is a particularly important factor in this respect for it determines both the angle and form of slope which develops under the influence of erosion. Cohesion depends on grain size, grain form and many other characteristics. A high cohesion will result in steep slopes, and a low cohesion in more gentle slopes. Differences in cohesion within a vertical section through soil, parent material and parent rock are responsible for curving slopeforms. A concave slope is formed when cohesion is decreasing, while a convex slope will result when cohesion increases from top to bottom. An illustration of the latter is given in Figure 24 which shows a cross section of a partly dissected terrain with deep, leached soils. The cohesion is low in the eluviated, upper part of the soil; increases in the illuviated horizons; and reaches a high, constant level in the parent material. In the corresponding slope sequence level ground gives way to a convex slope which gradually changes into a straight slope.

Drainage conditions

Some specific drainage conditions can be identified without doubt. The analysis then gives some quantitative information about soil conditions at the time the photo was taken. This is especially the case in flooded and swampy areas.

Water on the surface of the ground acts as a mirror and, when the position of the sun is such that part of the reflected light enters the camera directly the corresponding part of the aerial photo shows up very bright. That bright part is usually called a "hot spot." The part which is bright on one photo appears darker on the adjacent photo, abd it is this contrast in reflection which is indicative of the "hot spot." A "hot spot" may occur also in vegetation when horizontal leaves reflect the light in one direction.

Other characteristics of a very wet area are a flat surface in a depressional position, and an irregular pattern of vegetation in those parts which are continuously swampy.

Generally speaking aerial photographs are taken in a dry (cloudless) period. This means that at some time of the year the area is probably wetter than is shown on the photograph. The area at the time of photography may not be at its driest if the photography is done at the beginning of the dry season but, as a rule, it is safe to assume that conditions shown are not at their wettest. Except where wet areas are bordered by an abrupt change in relief, the limit between inundated and non-inundated soil is normally rather transitory.

In this respect the use of infrared photography may be discussed. Infrared photography is often used to delineate sharply a boundary between water and land. Such a boundary is much clearer on infrared photos than on panchromatic photos. This clarity permits a swampy area to be delineated very accurately but, in a sense, this is misleading, for only the conditions at the time of photography are registered. For a complete survey of such areas additional coverage is needed either by vertical aerial photography at different seasons or by reconnaissance flights in the wet season. Usually this latter alternative is easier, because it is normally very difficult to take satisfactory vertical aerial photography during a wet (cloudy) season.

Constructional drainage system

A close correlation often exists between the drainage system and soil conditions. In constructional landscapes the drainage often indicates in what way the parent material of the soils has been deposited.

Figure 23 shows a river which seasonally floods its alluvial plain. On the natural levee are numerous small lines perpendicular to the direction of the river which indicate the way in which the water of the river overflows the natural levees.

Another example of a constructional drainage system is shown in Figure 27. This is a coastal area in which numerous creeks invade the flat lowlands. The periodical overflows of these creeks causes sedimentation of silt along the banks. Farther away from the creeks this influence of sedimentation decreases and peat formation occurs. The areas of peat formation are also characterized by a different vegetation. These areas are delineated on the map of Figure 28 by a dashed line.

In intensively cultivated areas the drainage system may be quite obscured by the processes of cultivation. However, a careful analysis of the drainage pattern is still possible in many cases. Figure 29 shows an aerial photograph of a polder in a region of old marine sediments in the Netherlands. A careful analysis by stereoscopic observation results in Figure 30, which provides a very important clue to soil conditions.

Destructional drainage system

This is often also called "Gully pattern."

An extreme example of an intensive gully pattern is shown in Figure 31. Differences in intensity and of pattern correspond clearly to differences in landform. That the parent material is also different, cannot be seen directly but can be deduced with a high degree of probability.

Sometimes the cross section of a gully provides an indication of a specific soil condition. When the side of a gully descends first gently, and then changes abruptly to a steep face, it is most likely that a hardened soil horizon is present. Whether this is a claypan, a plinthite layer or caliche, must be answered by field investigation.

Often gully forms are related both to climate and parent material. A disturbing influence however is the fact that soil formation may be the result of a former climate, and then the gully form may also be related to those past, and possibly unknown, climatic conditions.

Direct correlation between gully form and rock type cannot always be assumed since under different circumstances a single parent material may give rise to different forms of gullies. Gullies in well drained loess, for example, are characteristically steepsided but imperfectly to poorly drained loess of identical mineralogical and textural composition is likely to erode into gullies which, in cross section, have much smoother slopes.

The preceding statements may give the impression that the study of gullies is of limited value in photo interpretation. This is not, in fact, the case. The statements are made deliberately, however, because connections between gully form and specific soil conditions are often too readily assumed. Keys suggest a readymade solution, but variety in nature is much larger. Therefore it is better, at least for the soil surveyor, to register only the differences, and to leave the deductions until more knowledge has been gathered in the field.

Natural vegetation

The vegetation is commonly thought to show a very close correlation with the soils. This is only partly true. Vegetation patterns which are seen on the photographs are often influenced by processes only remotely related to the soil. Figure 32 shows an area with quite a contrast in vegetation. The left side of the photograph has a savannah vegetation with only some gallery forest along the larger gullies. To the right of the small river the area is covered by a dense forest, in which however the pattern of gullies shows up as differences in forest vegetation.

In this case the high contrast in vegetation is caused by burning. The river has served as a fire break. Locally forest clearing has already started and it can be expected that, in time, the forest to the right of the river will also partly disappear.

This example shows that a high contrast in vegetation is not necessarily connected with a large difference in soil. The soils at both sides of the river are practically identical.

So the first step in analyzing vegetation is to evaluate which other processes may have affected the natural vegetation. Once these have been taken into account, then the natural vegetation can be regarded as quite a good indicator of soil conditions. Consider Figure 33, which shows a dense, luxurious tropical forest in a very wet area of the western Andes in Colombia. Rainfall is well over 5,000 mm. The terrain is rugged and the vegetation covers very steep slopes. Stereoscopic observation reveals that even on the steep slopes the forest has a high percentage of palm trees. This is an indication that the soil is at least continuously moist and often very wet. From this fact one could deduce, in the absence of climatic data, that soil formation is influenced by an abundant water supply.

The foregoing example shows a case where a specific vegetation, although indicative of a certain soil condition, does not yet serve to indicate different soil bodies. But local variations in vegetation are often correlated with differences in soil bodies.

Such a case is shown in Figure 34. Basically two types of vegetation are shown. One is a dense forest composed of trees with rather small crowns. Such a forest has also been called a "rachitic" forest. The other forest type shows crowns which are much larger and a general appearance of this type is a much coarser texture. Field work has revealed that the "rachitic" forest type corresponds to a terrace some 3 to 5 meters higher than the surrounding alluvial area. This difference in relief, however, is not visible directly on the aerial photographs, because the forest on the lower alluvial area is several meters higher than the forest on the terrace. Therefore the actual relief is obscured and the apparent relief may be even inverted. The delineation of the "rachitic" forest type, however, reveals quite correctly the boundary of the terrace.

A less clear case is presented in Figure 37. Here the vegetation grows in an elongated pattern parallel to the rivers. Field investigation revealed a semi-circular line of springs in the area, visible in the upper part of the photo, due to a geological fault along that line. The fault is obscured by local erosion, colluviation and sheetwash but the forest has developed (or has maintained itself against fires) where the spring water trickles down on or near the surface.

Parent Material

The geological substratum is least obscured in areas where the soil mantle is thinnest; namely in areas having a climate in which long dry periods are followed by heavy rain showers and in which, as a result, erosion is the dominant physiographic process. This is the case in many subtropical countries.

Processes of erosion often reveal the structural characteristics of the underlying solid geology and even when the structure is not obvious in the photographs, it can sometimes be inferred by a study of related features such as the relief and drainage patterns. Analysis of geological structure through study of relief and drainage can sometimes suffice to identify the probable nature of the soil parent material. Figure 26 illustrates a case in point, perhaps the simplest possible example, that of limestone identified by the characteristic pattern of sinkholes and of other forms of deep depression having no external drainage outlet.

A more difficult example is presented in Figure 35 but the analysis of the drainage pattern of this area (Fig. 36)suggests some conclusions. The drainage pattern is dendritic and this usually occurs in areas where there is no structural control of drainage. This is the case in areas of horizontal rock strata or, in general, in areas where resistance to erosion by gullies or by rivers is uniform in all horizontal directions. The parent material of the hills in Figure 35 is described in the title of that figure. The mantle of colluvial scree surrounding the foot of the hills should also be noted.

Many fine examples of parent material identification can be found in Frost (1960), Lueder (1959), and in other texts on photo interpretation. In studying these examples the reader should be careful to avoid being misled by what may be termed "hindsight" interpretation - in other words, interpretation of features of the photo image that are said to be representative of a particular parent rock when, in fact, such identifications could not possibly be made without field knowledge of the area concerned. Despite this warning, there is no doubt that valuable information on soil parent material can be obtained by air photo interpretation, especially if the soil scientist collaborates with geologists in these studies.

Colour

Although colour (tone, pattern and texture) of a photo is not a property of the earth's surface, it nevertheless forms an important element in photo interpretation. It is the direct result of reflection from the surface and as such is related to field conditions. The term "colour" is used in this context to indicate all the different shades of grey in a panchromatic ("black and white") photograph. In the true colour photograph the relation between photo colour and field colour is of course much closer.

In respect to the interpetation of photo colour several misunderstandings have long persisted. A very common one is that sandy soils show up in a lighter tone than clay soils. This is often not the case. A ploughed field may have on its surface dry clods of clay each with a very shiny strongly reflecting surface. Such a field might show up as a very light colour on an aerial photograph. Nor is it ture that wet soils show up exclusively in dark tones on photographs. Wet and even swampy ground may be covered with a vegetation which has shiny, horizontal leaves, also reflecting light strongly and appearing in a light colour on the photograph. Buringh (1960), shows an interesting example of a terrain photographed in different seasons. Parts of the terrain which show up in white on one photograph are dark in the other one and vice versa.

It is often very difficult to determine the proper correlation between colour and cause, for in the analysis of colour it has to be realized from the outset that many different field conditions all contribute to the colour of the photo. Some of the influences are related to soils, others are irrelevant.

Many times the irrelevant influences dominate the colour "scene." That is why measuring colour tone on photos in terms of absolute figures of light intensity is usually pointless in the study of soils.

Much more valuable is the mental ability of the photo interpreter to discard random factors. This is a sort of multiple-factor-analysis, based on experience and sound reasoning.

In the analysis of colour tone exceptions to the fixed rules are numerous. Forest usually appears darker than grass but, if grassland is heavily dressed with fertilizer and not recently grazed, it may show up just as dark or darker.

Clear water shows darker than muddy water, but when the sun reflects directly into the camera, the reverse is the case. Eroded areas are often lighter in colour, unless, for example, the erosion has bared the red ferruginous subsoil of the tropics, when the colour will be darker.

The colour pattern and colour texture often provide a better means of correlation with specific conditions. The colour pattern of most types of erosion is quite typical. So is the colour texture of a mixed forest, or of open water.

On an air photo, such as Figure 39, the whole complex of colour is made up of different parts, super imposed upon each other. Quite frequently the analysis of colour consists mainly in the elimination of irrelevant parts. In Figure 40 the area shown in Figure 39 has been analyzed for separate colour influences, including cultivation, vegetation, burning, drainage and erosion. To see which of the factors are related to soil conditions, compare the analyses (a), (b), (c), (d) and (e) with the soil map (f), showing only the principal series of the soil associations.

Land use

Mankind is able to change the "natural" face of the earth and does so. Land use is for photo interpretation the most conspicuous aspect of that activity. In this respect land use has a "negative" influence on the interpretation of natural features and patterns. The natural drainage system of Figure 26 would be more clearly visible if the pattern of land use were not superimposed upon it. (This example may not be ideal because, if man had not acted, this particular area would be submerged beneath about 4 meters of seawater and no drainage system would be visible at all!)

The adjustment of land use to soil conditions provides a "positive" aspect in photo interpretation. Figure 38 shows an area in the south of the Netherlands, where 3 types of land use are found. The forest plantation occupies sandy and, for agriculture, excessively drained soils. The vividly contrasting fields belong to agriculture, and are established on medium textured, well- to moderately well-drained soils. Along the river (which is smaller than corresponds with the size of the valley, and is therefore a "misfit") mainly dark-coloured pastures are found on soils with imperfect to poor drainage. Here local agriculture corresponds with slightly higher areas. Correlation between land use and soil conditions is high, and the delineation of different soil bodies is possible by using land use as a guide. This is particularly important in this example, because relief is scarcely visible in the stereo image.

Differences in crops are often indicative of soil differences. An example is given in Figure 41. It represents part of a large sugar estate on soils formed in alluvial deposits. The layout of the fields is only for a small part adjusted to soil conditions but irregularities in the stand of cane within the fields are closely related to the soils. The colour contrasts between canefields, although large, have nothing to do with soil differences, for they reflect the cane cutting operations spaced to provide the factory with cane throughout the year.

Figures 38 and 41 show field patterns which contrast considerably. Figure 38 shows an area where agriculture was established many centuries ago. Adjustment to soil conditions is great. Figure 41, on the other hand, is typical for a recently introduced field pattern. Modern techniques in reclamation and exploitation result in a much lesser adjustment to soil conditions. This is an important consideration. Many beginners in photo interpretation for soil survey purposes are inclined to draw lines along field boundaries. But the problem is similar to the use of photo colour as an element: many striking features of land use must be discarded before drawing soil boundaries.

Use of the elements

Systematic photo interpretation according to elements starts from the principle that any element may be related to a certain soil mapping unit and therefore a change in the element may correlate with a soil boundary.

Each element in itself may have such a value, but of course the more often a line is determined by different elements, the higher the likelihood that such a line is really a soil boundary. This is called convergence of evidence. Still the use of the elements in principle is individual. Each element can be analyzed separately, it can be studied as such, classified and registered.

The individual analysis of the elements can be combined by superposition of the various analyses. This combination gives the photo interpretation map, which will normally have quite a large number of lines, not all of which are real soil boundaries. The subsequent field work is meant to determine which of the lines can remain on the map as soil boundaries, and which have to be eliminated. This is not the most efficient way, but inexperienced soil surveyors can use it to produce quite a good map. When experience has been accumulated, that is, when a high reference level has been attained, a more selective choice of elements can be made and field work will lead to fewer corrections in the soil boundaries. The selection is best done by assigning an order of importance to each element, based on Table 1, but adjusted to local conditions.

Physiographic Analysis

Physiographic analysis of air photos is based upon a thorough knowledge of the relation between physiography and soils, and upon the recognition of dynamic processes rather than of static elements. The elements are just as important as in "element analysis." but they are used in a different way. Many of them are not used primarily in the drawing of boundaries, but are used rather as basic material in constructing an

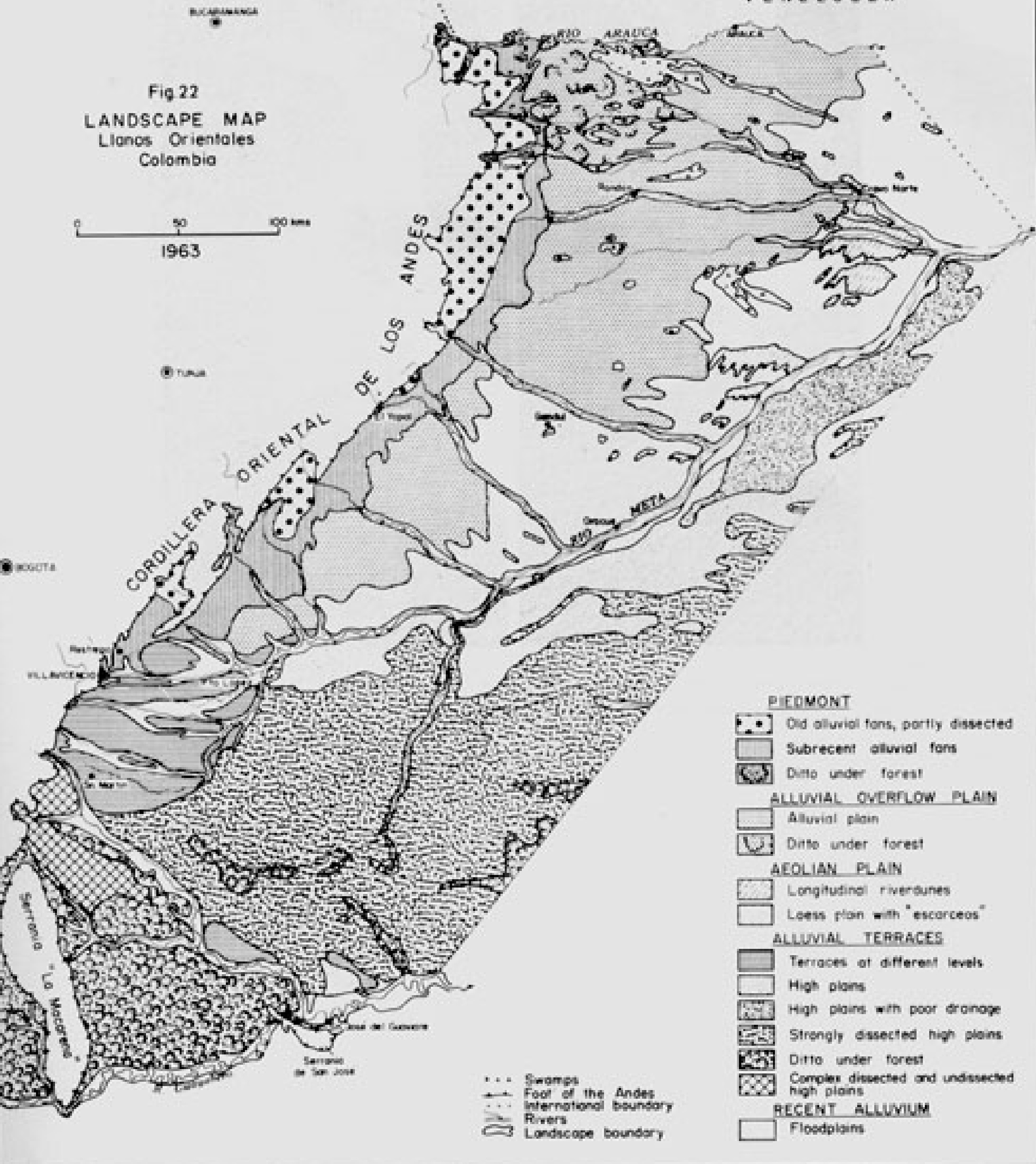


Fig. 22. Landscape map, dividing an area in different landtypes.

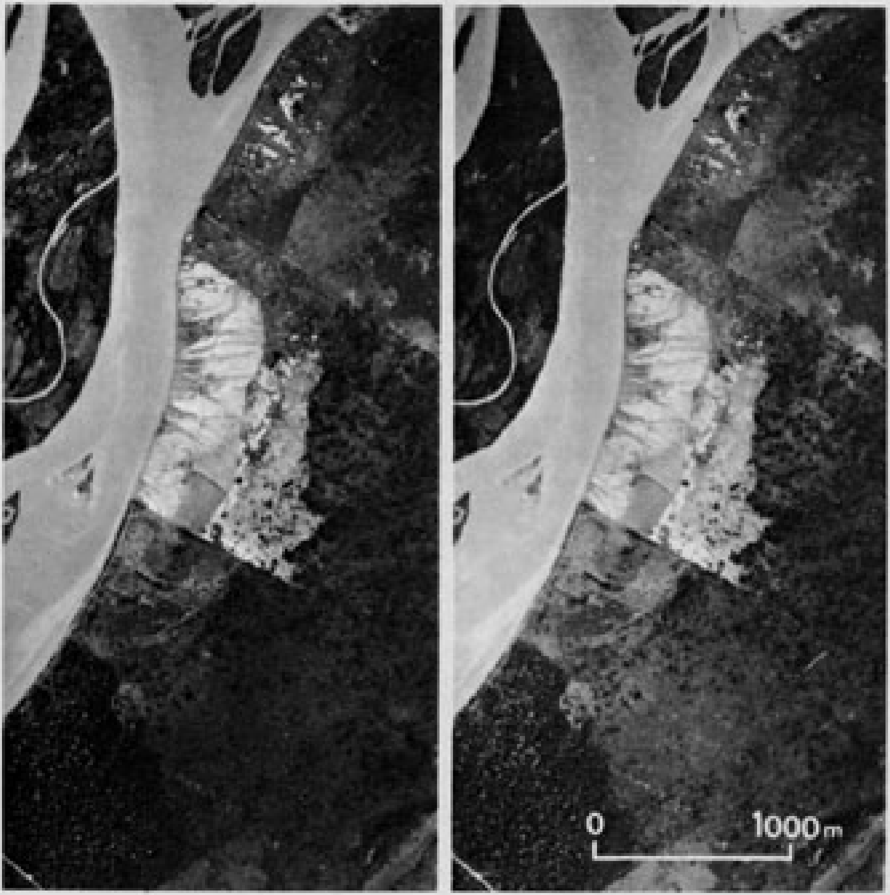


Fig. 23. Stereogram of the Magdalena river with "overflow-streaks" on the natural levee. (Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

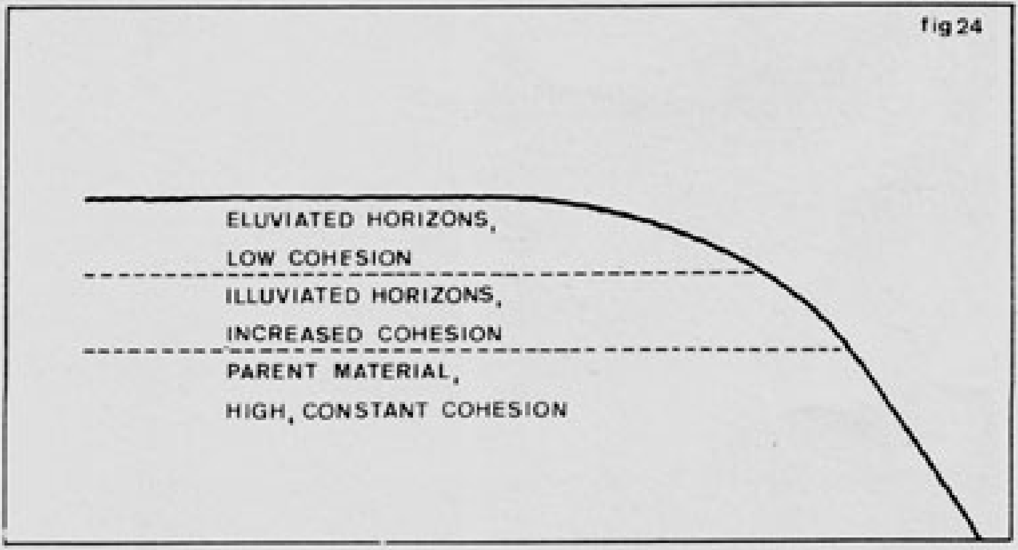


Fig. 24. Slopefom as related to soil cohesion. Example refers to a highly leached, well-drained latosol.

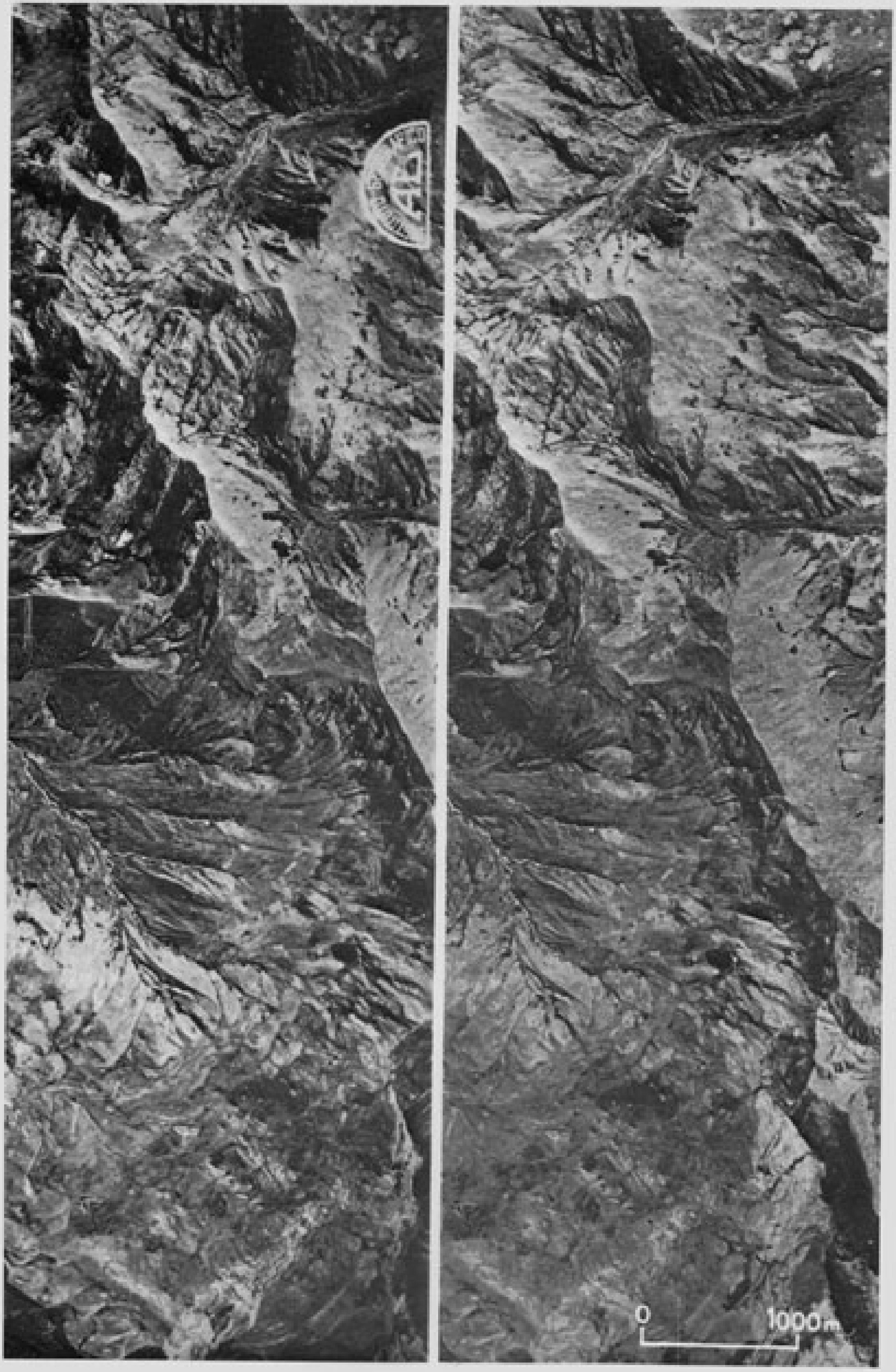


Fig. 25. Stereogram showing an area with complex relief in the Eastern Andes. (Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

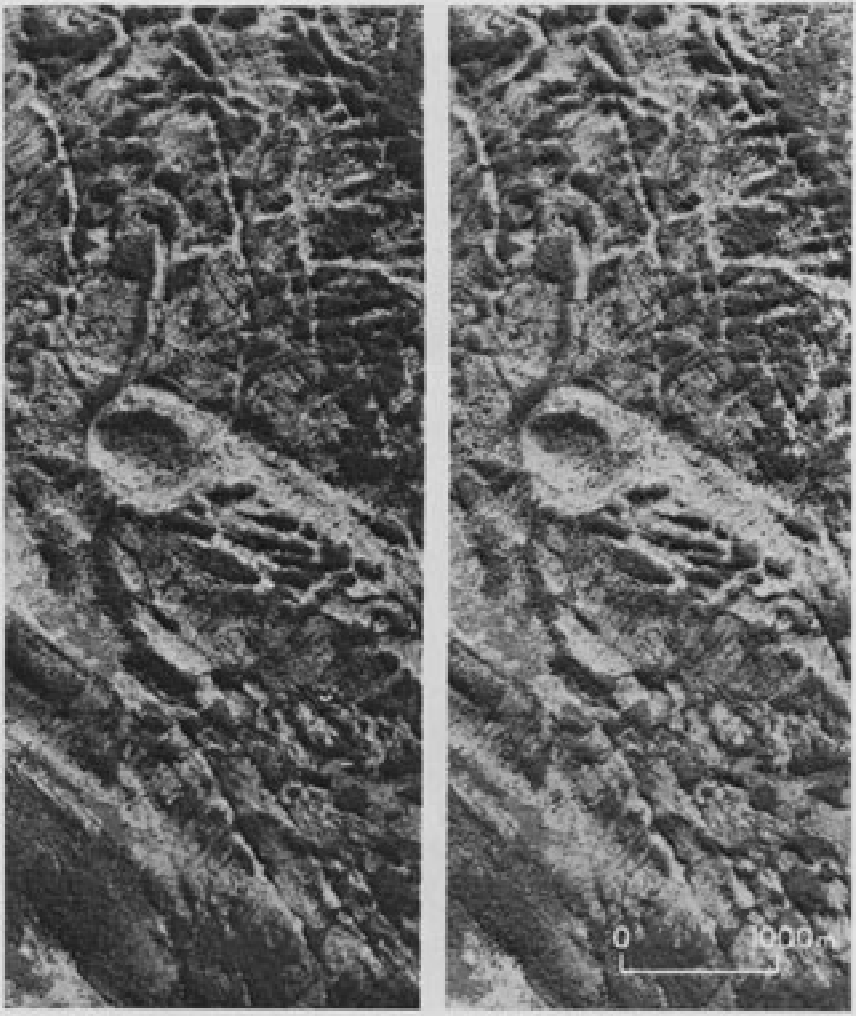


Fig. 26. Stereogram of a limestone area in the Central Andes, Colombia. The identification and recognition of the sinkholes leads directly to accurate deduction on the character of the parent material.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

Fig. 27. Airphoto of a coastal area of the Pacific Ocean. (Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

Fig. 28. Drainage pattern of Fig. 27.

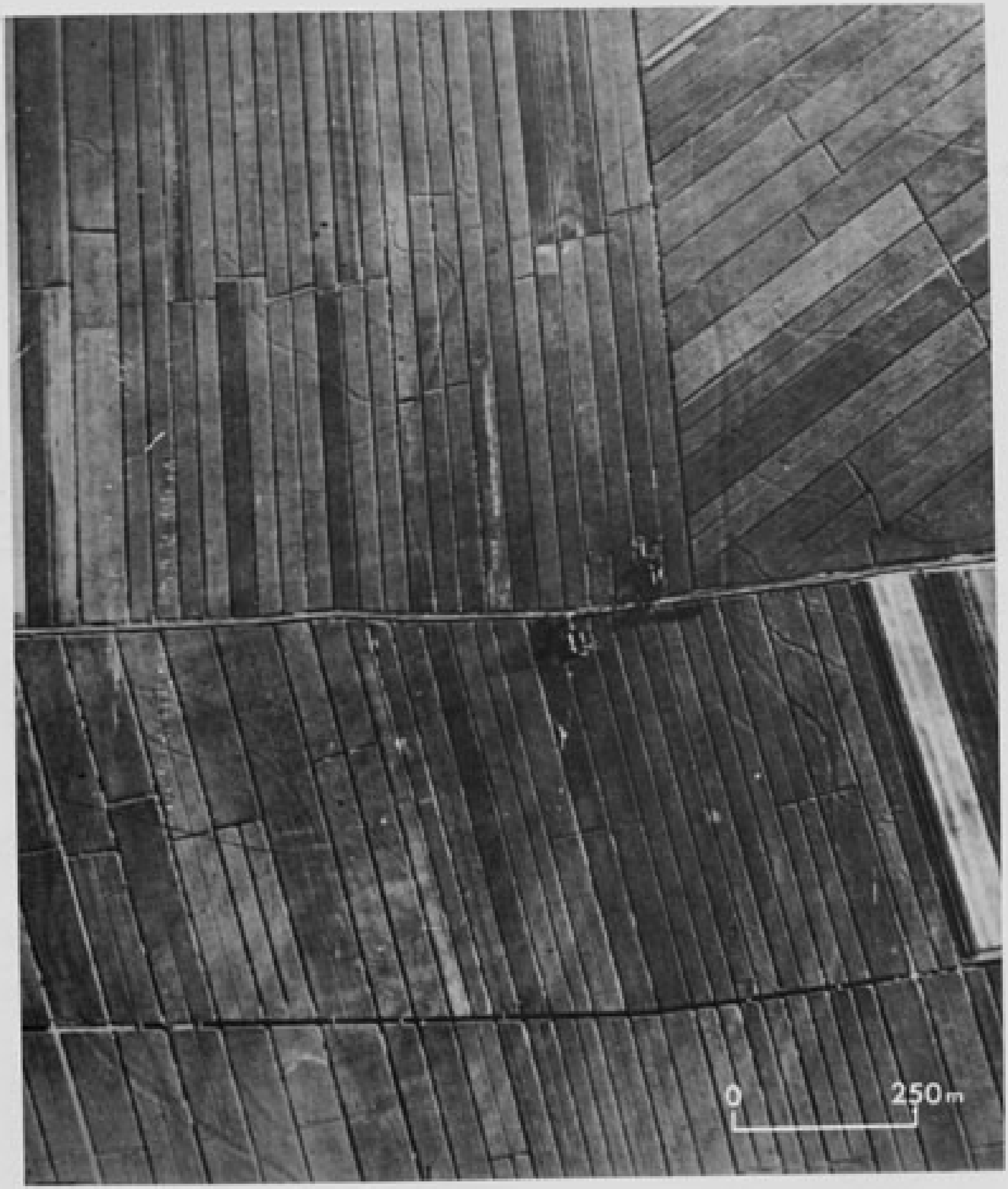


Fig. 29. Airphoto of a polder in a region of old marine sediments. A number of silted-up creeks can be observed. The soil pattern is closely related to the creek pattern. This last can be analyzed accurately under the stereoscope.
(Photograph by Allied Air Forces. Scale 1 : 10.800. Courtesy Luchtfoto-archief Stichting voor Bodemkartering, Wageningen)

Fig. 30. The result of the systematic analysis of the drainage pattern of Fig. 29. (Courtesy Prof. Buringh, Agric. University, Wageningen, The Netherlands)

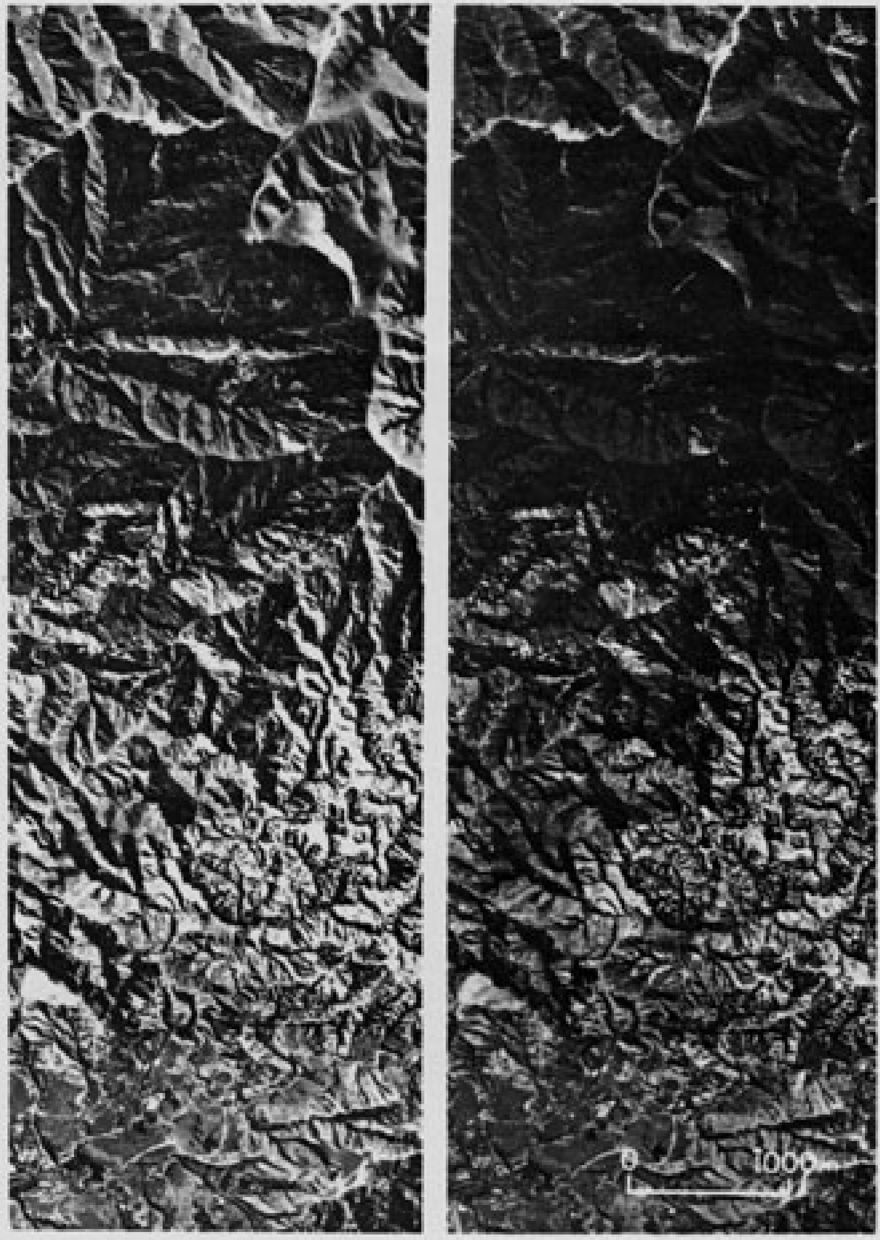


Fig. 31. Stereogram of an area in the Central Andes, Colombia. The two different gully patterns visible on the photo coincide with different relief and rocktypes. Although an experienced photo-geologist might identify rocktypes with the help of keys, the soil surveyor, since in any case he must study the soil-profiles on the ground, should leave identification to the fieldwork.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

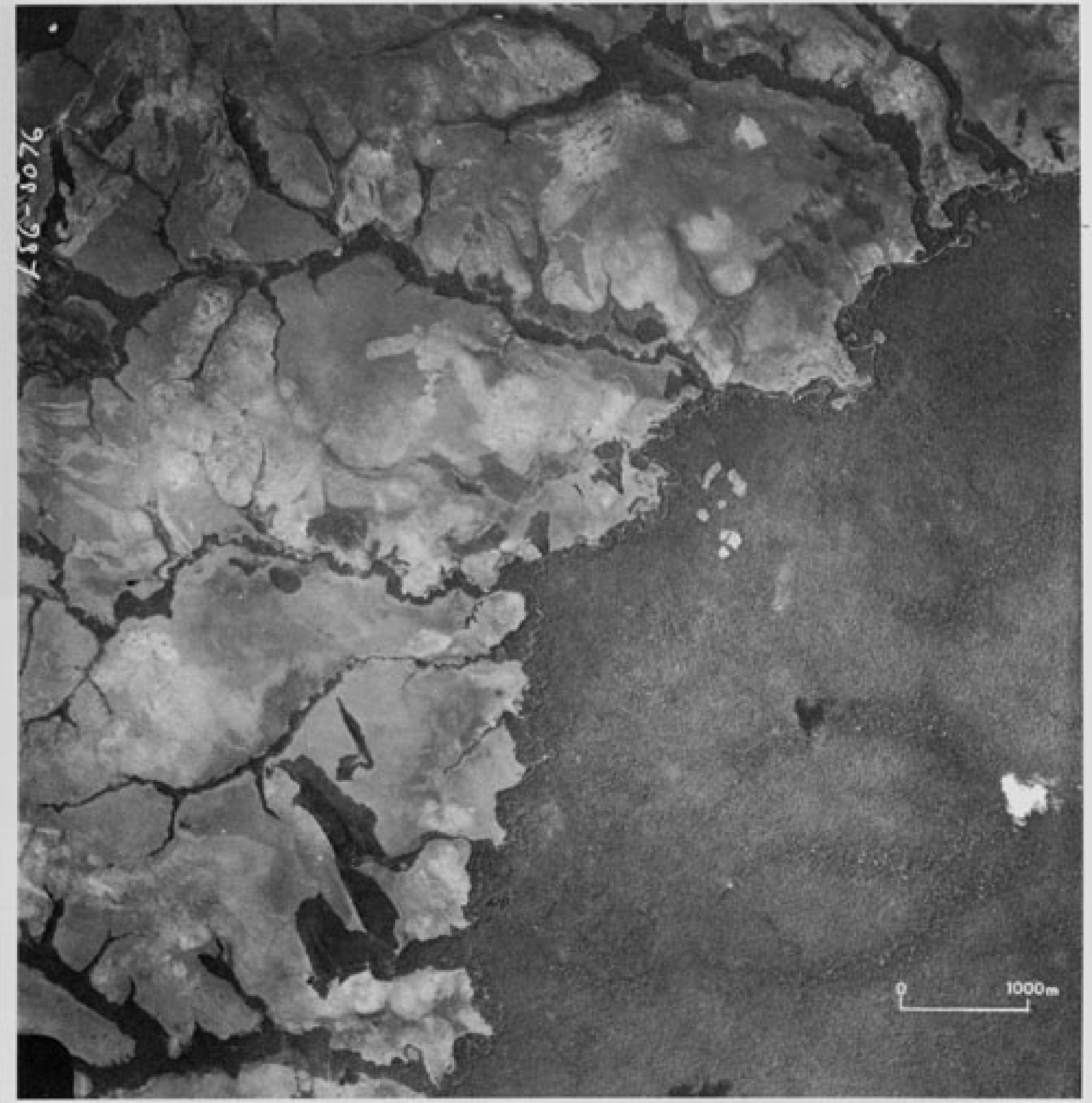


Fig. 32. Airphoto of the transition savannah-forest in the neighbourhood of the Orinoco-Amazon divide, Colombia. The location of the change in vegetation is not directly correlated to a soil boundary.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

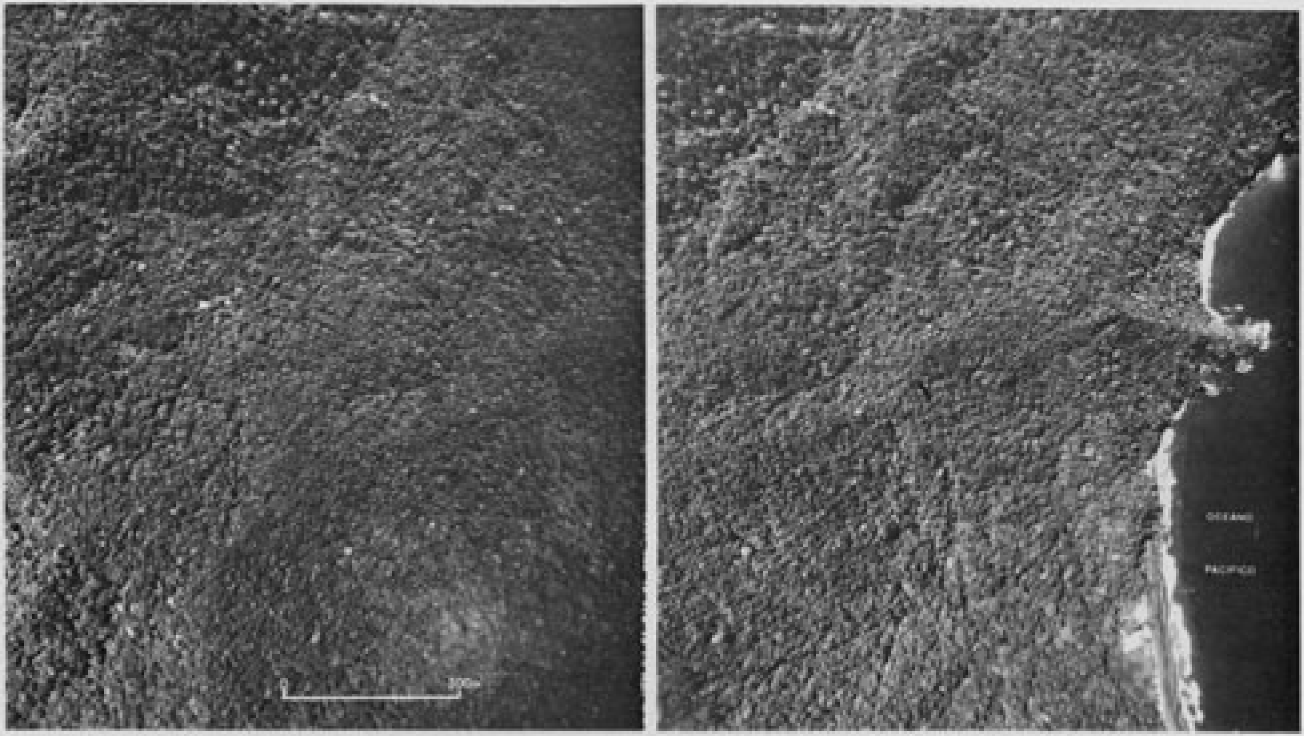


Fig. 33. Stereogram of an area in the Western Andes, Colombia, near the Pacific Coast, where rainfall exceeds 5000 mm.. Note the palmtrees growing also on steep slopes. (Courtesy Instituto Geográfico "Augustin Codazzi", Colombia)

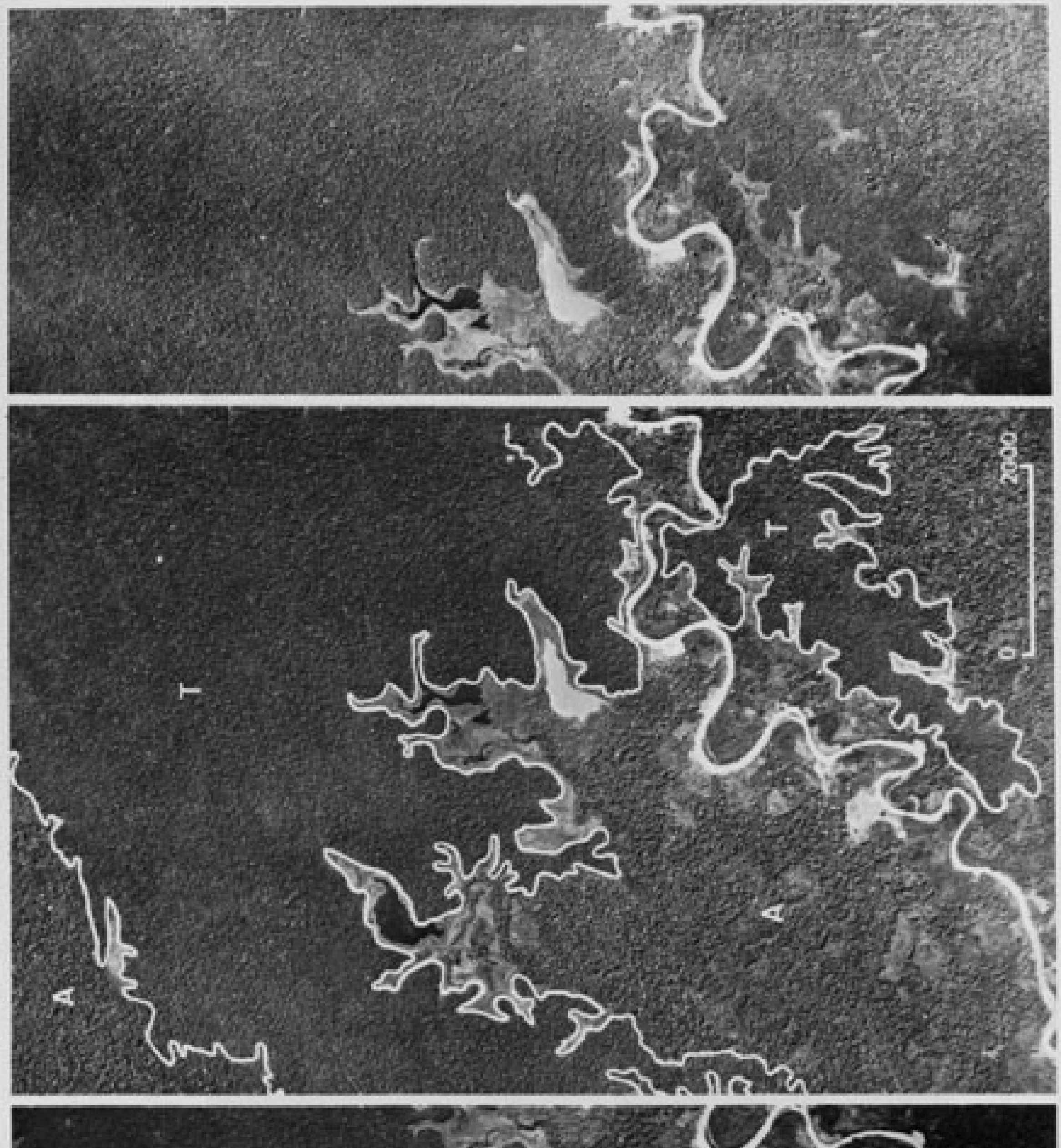


Fig. 34. *Stereotriplet of an area in the Middle Magdalena Valley, Colombia.*
Two different forest types correspond resp. with an alluvial plain (A) and a terrace (T).
(Courtesy Instituto Geográfico "Augustin Codazzi", Colombia)

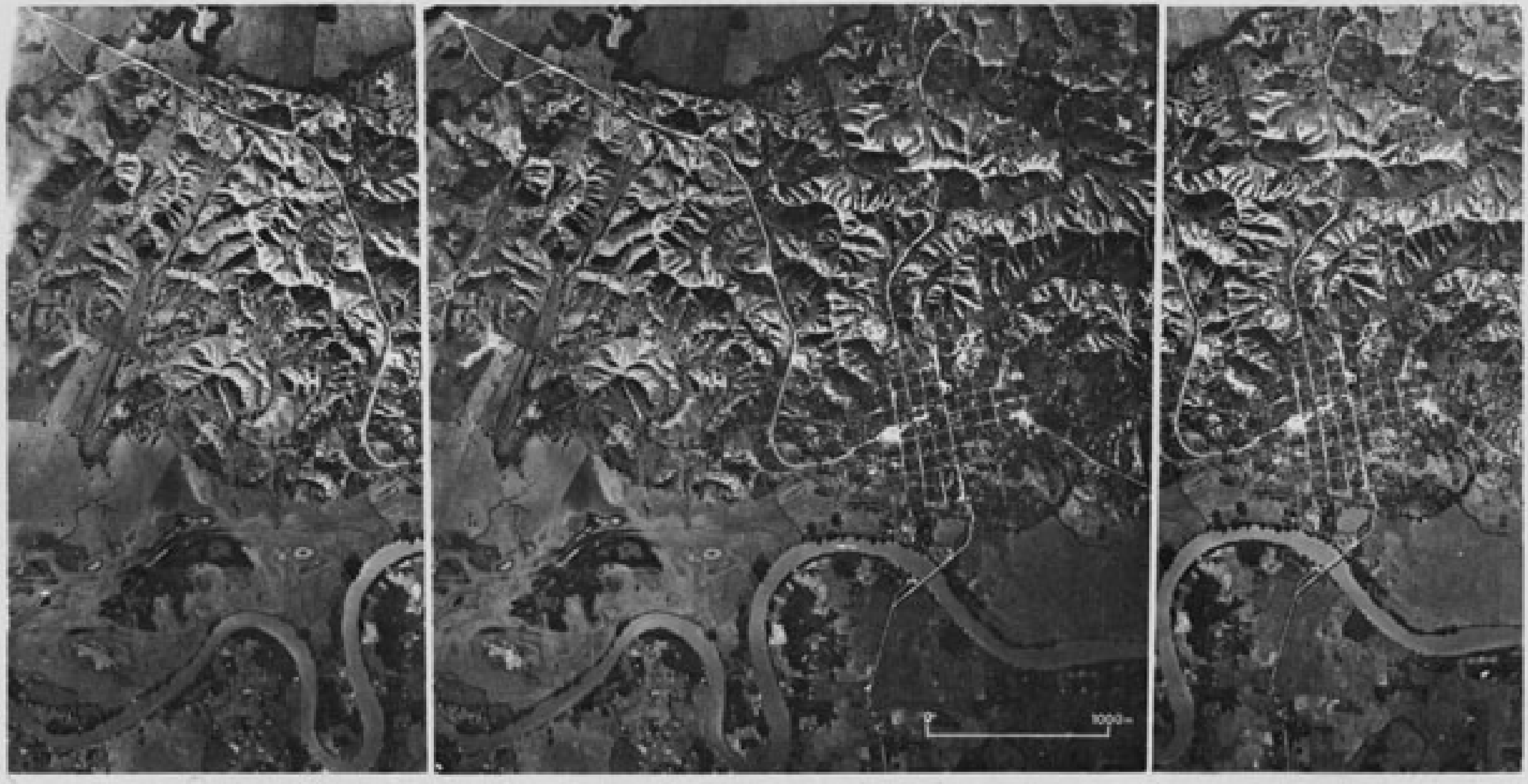


Fig. 35. Stereotriplet of a hilly area in the Cauca Valley, Colombia. The dendritic drainage pattern (see Fig.36) indicates that structural control is absent, but gives no further clue to the nature of the parent material. Field investigations showed that the material consists of lacustrine deposits, with local beds of diatomaceous earth, and interbedded with layers of volcanic ash.
(Courtesy Cauca Valley Corporation, Cali, Colombia)

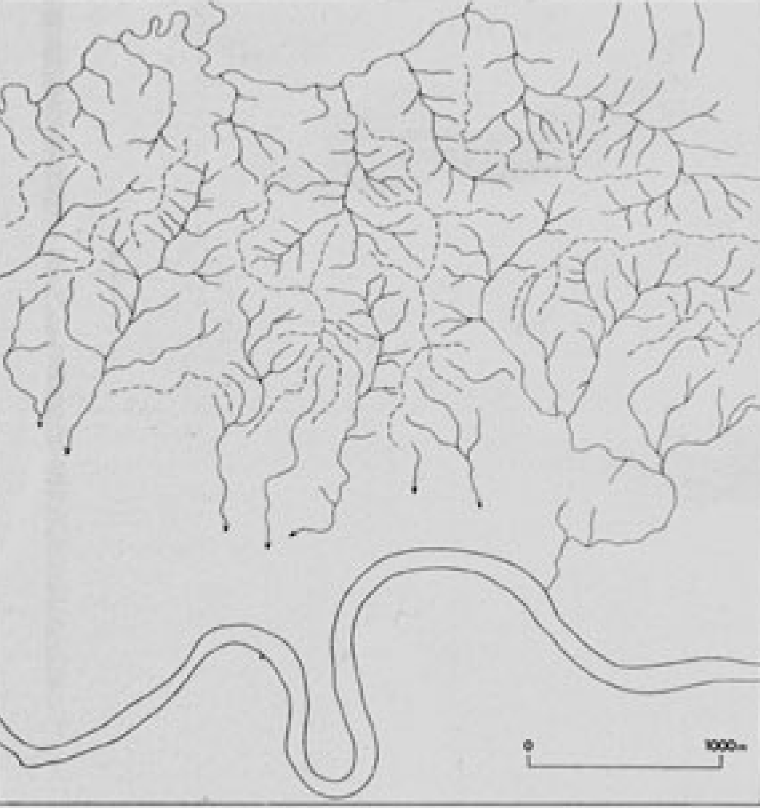


Fig. 36. Drainage pattern of Fig. 35.

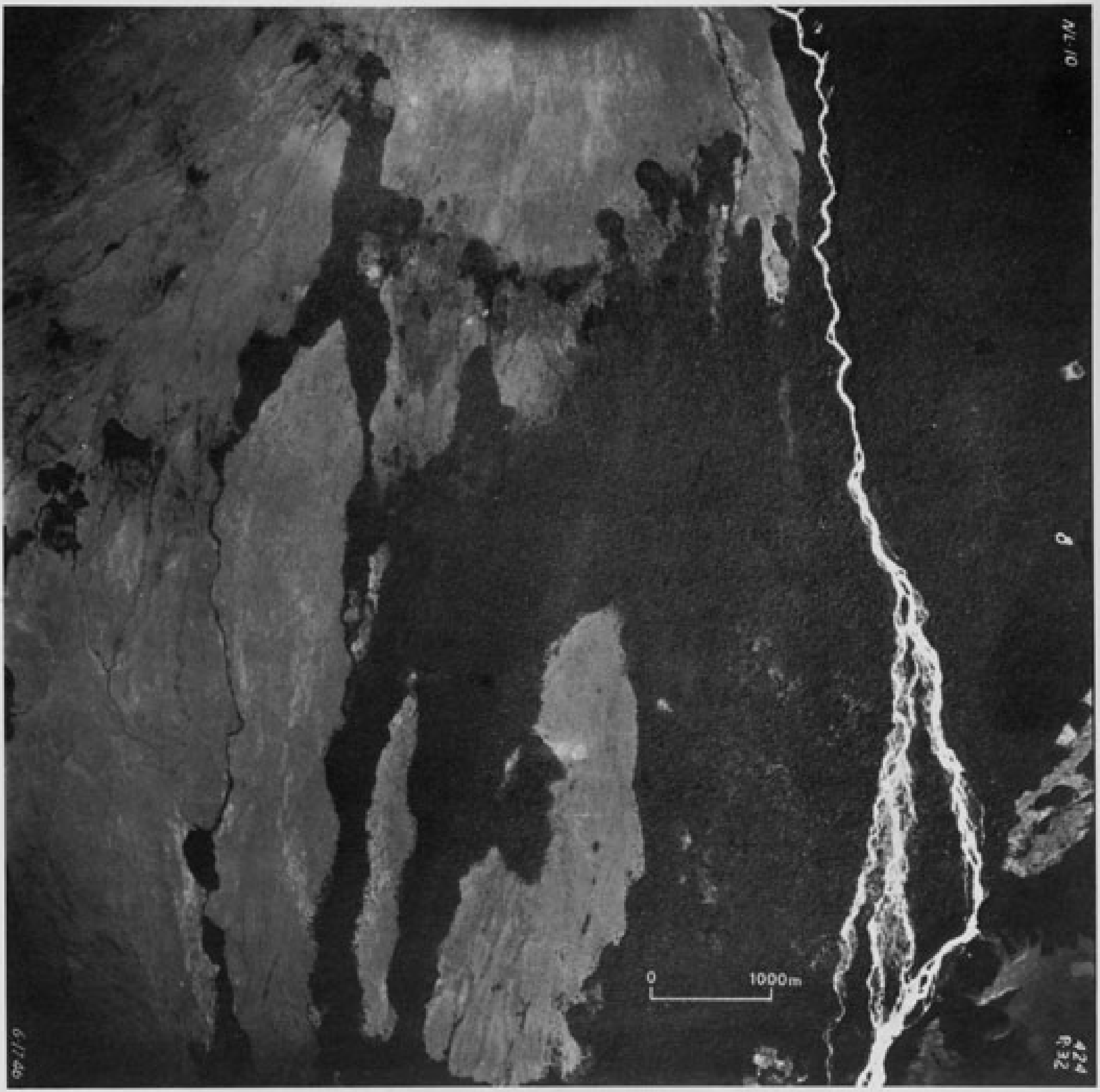


Fig. 37. Airphoto of a piedmont area east of the Andes mountains, Colombia.
For explanation see text.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

understanding of the physiographic relationships of the landscape. Since such relationships exist principally because of the interaction of physiographic processes, we can define the physiographic analysis as the analysis of processes, rather than of phenomena. We might say: the observed phenomena are translated in terms of the processes which originated and are originating them.

The idea can be explained as follows: Figure 42 shows an area in Colombia where the Magdalena river flows through a very flat terrain. The river spreads out in a somewhat deltaic pattern, but there is absolutely no influence of tidal movement, because the area is located far from the sea. The heavy load of the river causes rapid sedimentation along the riverbanks and also causes frequent branching of the river. At several points along the course of the branches, breaches can be observed through which the water spills into the marshy depressions. These "spillways" are accompanied by spillway deposits (also called "crevasse" deposits). The pattern is similar to a deltaic pattern. Some minor branches are not continuous, but end in the depressions. Land use is restricted to the most elevated river levees. The very active process of branching sedimentation can be called an alluvial overflow sedimentation. The area itself is then an alluvial overflow plain.

Once the process responsible for present physiography is recognized, knowledge of the universal laws of sedimentation is used to distinguish the photo interpretation units for soil survey purposes. This is not the place to enter upon a detailed discussion of specific processes but, in general, it may be said that the rate of sedimentation of material near the streams is highest, and that the textural composition of the sediments will become increasingly fine away from the streams. This knowledge, together with the observable elements of photo interpretation, discussed in the previous section, is quite sufficient to construct a reliable photo interpretation map.

Figure 43 shows an area in the Llanos Orientales in Colombia, which, at first sight, is somewhat different from the one photographed in Figure 42. The area now shown is part of a very extensive area of fluvial sedimentation, descending from the Andes Mountains in the direction of the Orinoco river. No active sedimentation is going on; on the contrary, the streams are incising somewhat below the plain and new gullies are forming (evidence by the whitish lines with angular form). Parts of the area are flooded in the wet season by rainwater.

When compared, Figures 42 and 43 show some similarities. In both cases there are meandering forms and from those meanders some spillways branch out. These spillways are again accompanied in both cases by small levees, and, in the case of Figure 42, the form sometimes becomes deltaic.

The general location of both photographs (of course not visible on the single photos) is similar, in that both areas are located where the principal rivers enter a very level area. Basically then we can talk of two alluvial overflow plains, and the recognized identical physiographic process is the system of sedimentation responsible for the appearance of the landscape. The recognition of the process helps very much in the interpretation of Figure 42. Of course, in this case an additional physiographic process must also be recognized, namely the process of renewed erosion.

Field investigation in both areas reveals that the soil profiles are completely unlike. No two profiles can be found which are similar, except in terms of the highest levels of soil classification. So the recognition of a similar physiographic process does not mean for a moment that the soils can necessarily be compared as individuals. The most important point is that the distribution of the soil, that is the location pattern of the soil bodies in the landscape is similar in both cases. The light textured soils are found near present or abandoned stream channels, while further away, heavier textured soils are found. In a corresponding pattern, the drainage condition of the soil changes from well drained to very poorly drained.

At this point it may well be asked what is the difference between a geomorphological analysis and a physiographic analysis for soil survey purposes. And indeed the geomorphological analysis of any terrain is the basic approach of the physiographic analysis for soil survey purposes. But the accent is placed differently. To explain what is meant Figures 44, 45 and 46 may serve.

Figure 44 shows an area with interesting geomorphological phenomena. Some features are observed, the most striking of which is the irregularly curved pattern of lighter bands on the photo, which through stereoscopic observation are revealed as very low ridges.

Another feature is formed by many small depressions which are often aligned. A third feature is formed by very smoothly rounded elevations, sticking a few meters above the general level of the terrain.

The geomorphological analysis of these phenomena is shown in Figure 45. This analysis, together with field investigation, reveals that the area is an aeolian plain with a few longitudinal dunes surrounded by a practically level area of loess in which, through a former solifluction process, the ridges have developed. The many small depressions are arranged in a "beaded" drainage pattern, which in itself is also evidence of former solifluction processes. Up till now the story is purely geomorphologic. The interpretation map (Fig. 45) provides a very good basis for explaining the geomorphology of the area, but is not in itself the proper starting point for a soil survey. Before that stage can be reached, other aspects must be taken into account, for instance the difference of vegetation on the solifluction ridges. The grass vegetation has developed better on the ridges because of very slight differences in local drainage conditions. Apart from this the intensity of the solifluction is closely related to the general drainage conditions of the terrain; where drainage is better, solifluction ridges are faint or absent.

Differences in tree growth must also be taken into account. In some cases, examination of tree growth may serve to delineate a specific mapping unit (as in the case of the largest dune). On the other hand, the density of small trees between the two main streams, compared with the absence of similar trees in most other parts of the area is probably explained by differences in burning (the central streams serving as a firebreak) rather than by differences of soil.

Taking such factors into account, the photo interpreter soil surveyor must make a photo interpretation map(Fig. 46) showing terrain units which, through subsequent field work, can be modified into soil mapping units.

The theme of the physiographic analysis is then to find and describe features of the stereo photo image which are characteristic of certain physiographic processes; can be used to identify these processes; and so, in turn, will provide the most important clues for delineating the soil pattern.

In most cases more than one process will be identified, often one superimposed upon the other. Then the particular features of an area must also serve to delineate different physiographic units, each one with a unique combination of soil series (a soil association), or even characterized by a single soil series. The identification of the mapping unit will largely be left to the field work, but many qualitative differences will be derived by photo interpretations.

For many processes examples could be given in the form of keys. But relying upon keys results often in pattern analysis, and however valuable that may be in many cases, it is too restrictive. The aim should be to develop a method valid for any situation. This is ambitious and photo interpretation techniques are not yet sufficiently developed to reach this goal, but the results obtained so far are very promising and encouraging.

Physiographic processes

Of the major physiographic processes acting upon the earth's surface the most important in relation to soil are erosion and sedimentation. It is important, of course, to recognize other processes, such as tectonic movements and volcanism, but on the whole, a pattern of soils in a given area is dominated by the first two processes mentioned. Many subdivisions can be made and many local factors may influence these processes. The most important step in a physiographic analysis is to recognize and identify the basic process acting in any specific case.

Sedimentation processes

Subdivisions of major processes ought to be made using concepts directly derived from geomorphology. Sedimentation, for instance, can be divided into:

alluvial sedimentation

lacustrine "

aeolian "

marine "

volcanic "

glacial "

For soil survey purposes the most suitable emphasis is often different from that of geomorphology. For instance, aeolian sediments are usually described in geomorphological textbooks in order of their prominence in relief. Special attention is given to dunes of all forms/while less obvious forms of aeolian sedimentation receive less attention or are sometimes completely overlooked (the same attitude is found in a number of books and publications on photo interpretation).

For the soil scientist the focus of attention is directed in quite a different way. Pedologically speaking, dunes are much less interesting than loess sheets, even if the former are a 100 meters high and the latter have only 50 centimeters thickness. This is so because pedology is an applied science and the level loess sheet is likely to have far greater agricultural potential than the dunes.

The most important alluvial sedimentation processes are as follows:

alluvial fan sedimentation

braiding river sedimentation

meandering river sedimentation

alluvial overflow plain sedimentation

delta sedimentation

As an example we will discuss the alluvial fan sedimentation.

Figure 47 shows an alluvial fan in a semi-arid, sub-tropical region. A few streams are seen leaving a badly eroded mountain area. At the edge of the mountains, the streams are building up a fan of classical form. The reduction in stream gradient causes this sedimentation and the coarsest sediments are deposited near the apex of the fan. Further down the fan, which may have an overall slope of 3 to 5%, finer sediments are deposited and it may be seen that land use is restricted to the lower middle and to the foot of the alluvial fan. This is because only there are soil moistur conditions sufficient for crop growth. Many old abandoned stream channels are visible, all radiating from the apex of the alluvial fan. The fan ends in a marshy plain. When this figure is compared with Figure 48 which also shows an alluvial fan, many differences will be noted. In the first place the form. The alluvial fan of Figure 48 is composed of a number of individual fans, all built up by streams coming from different directions. The fans coalesce where the mountain spurs end. Secondly, there is an interesting difference in land use. In Figure 47 land use was restricted to the lower part of the fan, whereas in Figure 48 it is restricted to the upper part of the fan; this time, the lower part is too wet for agricultural use in the absence of major drainage measures. In this case, the difference can be explained by the fact that the alluvial fan of Figure 48 is in a humid tropical area.

In both cases the basic principle of the physiographic analysis rests in the identification of features common to both fans. Both are situated at the foot of a mountain range. Sedimentation is caused by the drop in gradient, resulting in a slightly concave, gently sloping mantle of alluvial deposits, characterized by many abandoned stream channels (in the case of Figure 48 the latter are not so easily visible because of the intense land use). Basically both fans have many things in common, and this becomes obvious when local differences caused by climate and vegetation are disregarded. Of course, these local differences cannot be ignored in the final analysis since they are of fundamental importance in soil development but, as a first step, it is helpful to realize that the pattern of soils is correlated in both cases with a single, universal process of sedimentation. Profile development in the two areas differs enormously (as was the case with Figures 42 and 43) but relative changes in textural composition and drainage conditions are very similar. This means that a physiographic analysis of both alluvial fans will result in the identification of a very similar pattern of soils. Thus, although the identity of the soil profiles cannot be determined from the aerial photo, qualitative statements on the order of relative changes in texture and drainage can be made.

Erosion processes

Erosion processes are manyfold. The agent active in erosion may be water, wind, ice or even chemical solvents. Fine examples are given in various textbooks, like Lobeck (1939) or Dury (1959). The latter pays special attention to processes rather than to phenomena and is a very handy reference book for soil surveyors. In general, erosion can be defined as detachment and transport of particles. Many different types can be recognized including sheet erosion, rill erosion, gully erosion, wind erosion, glacial scouring, soil creep, landsliding, and others. The reader is referred to Bennett's "Soil Conservation" (1939), where an excellent description of types and processes of erosion is to be found, with special emphasis on the practical and theoretical aspects of importance to soil conservation.

Figure 49 shows an area in southwestern Colombia developed in old deposits of volcanic ash. Geological erosion has been responsible for the present physiography and the typically rounded (convex) slope forms are correlated with soil conditions as sketched in Figure 24. Intensive grazing at one side of the road has caused accelerated erosion almost to the point of "badland" formation. An analysis of the gully pattern (Fig. 50) reveals the different intensity of erosion on either side of the road very clearly. This example illustrates the need to consider human activity in physiographic analysis for, in contrast to the area shown in Figure 28, the change in gully pattern has no geological significance.

For soil conservation purposes it is very important to identify accelerated soil erosion, but for the purpose of identifying physiographic processes the limit between geological erosion and accelerated soil erosion becomes in many cases somewhat academic and is not sharply defined. That erosion can be very complex is seen in Figure 51 which shows an area of Milam county, Texas, U.S.A. On the gently sloping broad divides a pattern of rill erosion can be identified. On the level summits the pattern takes the form of reticular rill erosion but changes gradually into parallel rill erosion toward the drainage ways. The rills themselves appear black on the photo and this is because they have been filled again by superficial wash from the sides. So here we distinguish two types of erosion, one non-active which has resulted in the formation of rills, the second one local sheet wash, removing topsoil from the highest part and partly refilling the rills with this dark surface material. The two processes are superimposed and appear very similar, indeed almost identical, to the phenomena shown in Figure 18. Local conditions responsible for the processes may be quite different as indeed they are. The climate of Texas is different from that of eastern Colombia, and soilforming processes in general act differently. The similarity of the evidence suggest however, that the two processes have something in common, viz. erodibility of the two soils, leading to the same type of erosion, but superimposed upon different terrains.

These examples serve to illustrate the difference between physiographic analysis and pattern analysis. The pattern analysis is supposed to point to specific soil conditions. But we see from the examples that a phenomenon, apparently similar on the air photos, may be poly-interpretable. In such cases it is the task of the interpreter to select the correct interpretation. This he may not be able to do without knowledge of local conditions, but he must refine his interpretation of each phenomenon to its pure essentials. Then he may find that what he observes, can be better explained in terms of physiographic processes. The interpretation of a phenomenon may change as more facts become known. The best interpretation is probably the one that needs least change to fit new facts. The physiographic analysis must be as precise and specifically clear as possible, whilst allowing leeway for application under different curcumstances.

CHAPTER 4

EVALUATION OF DIFFERENT METHODS

Common Advantages

The application of aerial photographs is one of the major advances in soil survey during the last twenty years (Simonson, 1950). The air photo, first used as an accurate base map, soon developed into a tool which could be used systematically with very obvious advantage. Buringh (1960) summarized the advantages of aerial photo interpretation in five points:

"1. the results of the soil survey are more accurate;

2. the work can be done in a shorter time;

3. the cost is considerably decreased;

4. the work is carried out more economically and more efficiently;

5. new possibilities are created."

"1. Accuracy - Soil boundaries can be plotted more accurately than on maps, because of the many topographic details on photographs. In all soil surveys, which are not based on observations all over the area, but on observations made on traverses, The accuracy is even much higher. This is of special importance in inaccessible terrain. The consequence is an improvement in accuracy and quality of the soil maps."

"2. Short time - Time often is the limiting factor in soil surveys carried out in development projects. Work starts when the budget is approved, and all those who need the results being at the same time setting up plans. The results of the soil investigations are often delivered too late to be used to their utmost. This can now be avoided. The experience is that if the soil survey is finished in time, the results are fully applied. In semidetailed soil surveys only 1/4 to 1/10 of the normal time is needed, as a consequence the work capacity of the soil surveyors is increased by 400 to 1000%."

"3. Lower cost of the soil survey has created possibilities for investigating large, quite unproductive and thinly populated areas. Country-wide surveys of potential soil productivity can be made and promising areas can be selected."

"4. The efficiency of the soil survey is high. The terrain is studied in advance and afterwards. Field work is planned, sites for intensive field investigations are selected. One of the consequences is that the soil surveyors concentrate their work on promising areas. They also can easily check the work of assistants. Cooperation with other specialists becomes easier. If funds, transportation, time or manpower are limiting factors the application of a suitable procedure of soil survey in combination with aerial photo interpretation gives the opportunity to collect at least the most important information on soil conditions."

"5. New possibilities are created, for example:

(a) by using photographs or mosaics as reporting maps,

(b) by making semidetailed soil surveys,

(c) by soil mapping in difficult terrain,

(d) by delivering various types of soil maps at different stages of the work, because of the possibilities of the various survey procedures."

"As a consequence more intensive use is being made of soil maps and reports, more specialists become interested in them and even become 'soil survey minded.'"

Differences

Buringh's points are valid in the case of all the different methods of photo-interpretation and it will depend on the area and type of survey, together with the experience of the soil surveyors, which method is chosen. In the foregoing chapter some relative merits have already been discussed and a general conclusion may be summarized as follows:

The pattern analysis method can be used in areas where much knowledge has already been gathered about the relation between photo image and local soil conditions. This relation can be described by the investigators in the form of keys, valid for this specific area and can be used by soil surveyors who carry out the routine soil survey. It is a method which can be applied in semidetailed, in some cases even in detailed, soil surveys. The heavy dependence on keys is a cause of some restictions. In the first place the method can only be applied in areas where the principal soil pattern and its variations are already known.

In the second place the danger exists that the user of the keys relies too much upon a defined pattern, and may somewhat close his mind to the possibility of variations. The method may be described as a reference approach, in which the user refers to an already established soil pattern.

The element analysis method, which cuts down the photo image into its different components, can be applied universally, by surveyors who as yet still have to build up a high reference level. It is based upon the judicious registration of all features which might have a relation to soil conditions. Thus it results in a division of the terrain into many units, only a certain number of which will later prove to be soil mapping units. The subsequent field work will probably reveal that under the specific local conditions of the survey area, some elements do not have a systematic relation to the local soil conditions. The resulting disadvantage of the method is that field checking of boundaries remains a significant part of the survey. Since this task is alwasy necessary for detailed surveys the special advantage of element analysis is most apparent in detailed and semidetailed soil surveys. A further difficulty in the method is associated with the proper selection of elements, for the assignment of "weight" to different elements is not an easy task. The method in general can be called the pragmatic approach; pragmatic in the sense of teachable, instructive.

The physiographic analysis method is also universally applicable, but can only be executed by those soil surveyors who have built up a very high reference level of photo interpretation. This is the main disadvantage of the method. Possessing the desired reference level the soil surveyor/photo interpreter can rapidly map large areas proceeding from the general to the particular. The goal of the method is to identify boundaries, correlated to differences in physiographic processes, which will not need to be changed as the result of subsequent field work. Such an aim can usually be realized only in nondetailed soil surveys. This method may be called the genetic approach.

Application

Sharp differentiation between the various methods and their uses is somewhat artificial. In practice it may be that a mixture of the three approaches is used and this will depend on the way the soil survey is executed, and on the available knowledge and experience. In a very general reconnaissance soil survey it may well be necessary to use a broad physiographic analysis first, in order to determine the physiographic division of the landscapes. When this is obtained, sample areas may be studied in detail by the element analysis method. This will lead to the establishment of keys, which can be followed using the pattern analysis method in mapping the remaining parts of the area.

That the procedure outlined is not an academic one may be shown by an example from a large project of the UN Special Fund, which was executed by FAO in collaboration with the Colombian Government. The area mapped was 13 million hectares and complete coverage of aerial photographs was available. The scale of the photos was mainly 1:40,000. Mosaics were made from the photos at a scale 1:50,000. These mosaics were semicontrolled, that is to say they were adjusted to the general scheme of coordinates of the country.

Using the mosaics on which the general pattern of physiography is visible a landscape map was prepared. This map shows only major divisions, which are easily recognizable (Fig. 22).

The exact nature of some of the landscapes had then to be determined by a detailed analysis of the elements.

Based on the landscape map, sample areas were selected, in such a way that a represntative part of each landscape was included in at least one sample (compare Figure 22 with Figure 56). Twenty sample areas were studied in this survey covering a total area of 381,550 hectares. Although the average size of sample area was 19,000 hectares, they ranged in size from 8,000 to 45,000 hectares.

The sample areas were first analyzed according to elements. Subsequently, a photo interpretation map was prepared by detailed physiographic analysis. This served as a base map for the field work on a semidetailed basis. It was established in the field that the boundaries identified by photo analysis coincided very well with boundaries of soil associations actually located in the field. The boundaries were, in fact, practically identical.

Once the pattern of the soil associations was established, the complete photo interpretation of the whole area was undertaken, using the pattern of the sample areas as a guide and interpolating and extrapolating the knowledge obtained in the sample areas.

Evidently this procedure is a mixture of the various methods described earlier. The analysis of other areas using sample areas as a guide can be called a pattern analysis, and the interpolation and the extrapolation procedures are carried out according to the conditions set out by Buringh (1960):

> "a. The soil conditions in the area to be mapped must be similar to those of areas which have already been studied in detail or in semidetail; consequently the physiography and environment conditions are similar.
>
> "b. The photo interpretation should be carried out by an experienced soil specialist who has investigated areas to which the areas involved are similar.
>
> "c. The quality of the aerial paotographs should be excellent and it should be possible to identify the pattern of soil mapping units on them.
>
> "d. The reporting map is a reconnaissance soil map."

The classification of the terrain units was done completely on a physiographic basis. Gradual changes and other characteristics of the soil mapping units not visible in the photos were delineated with additional field checks.

Fig. 38. Land use pattern along the river Niers at the Dutch-German border
A - forest plantation
B - arable land
C - grassland.
(Courtesy Topographic Service, The Netherlands)

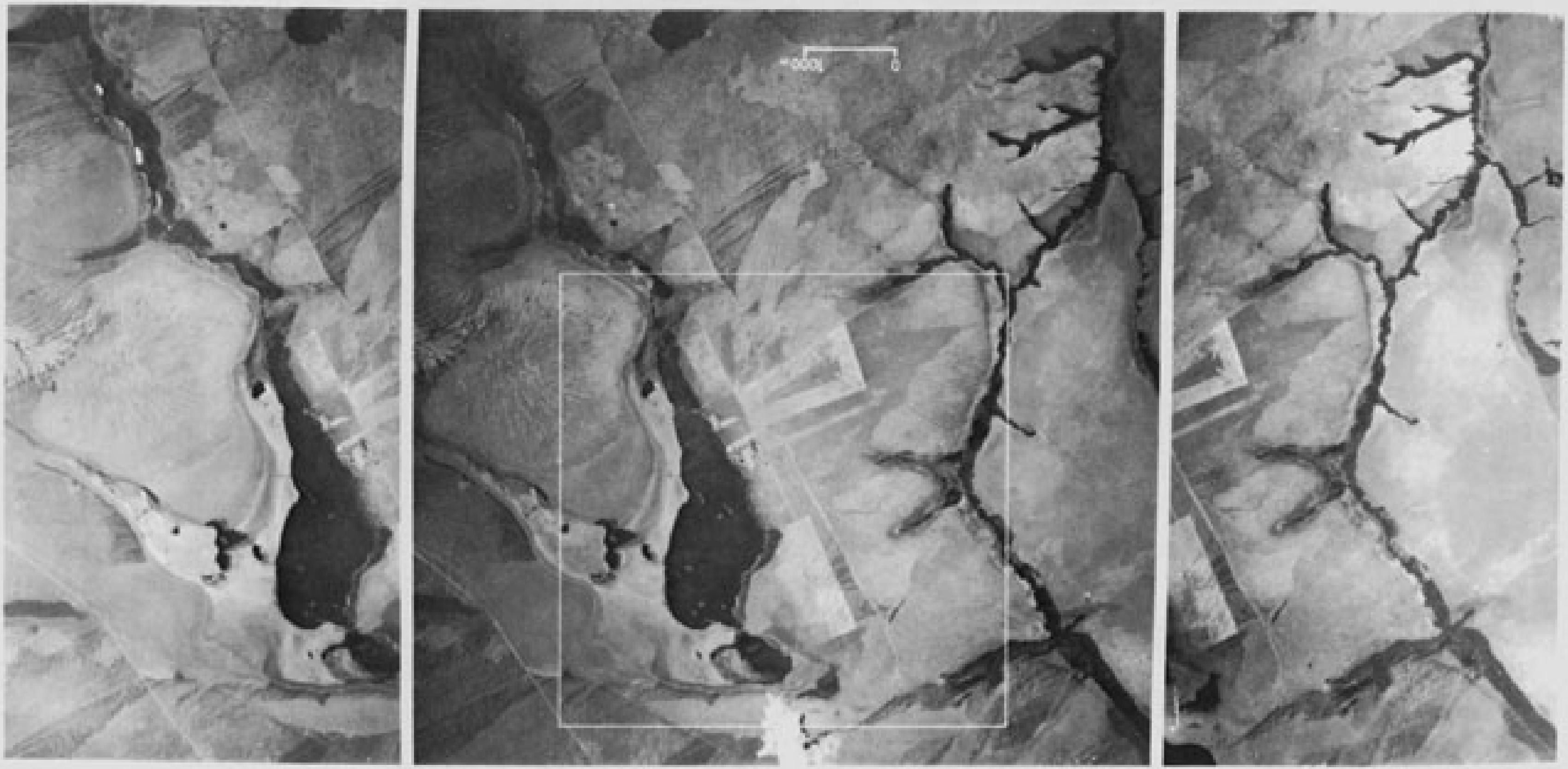
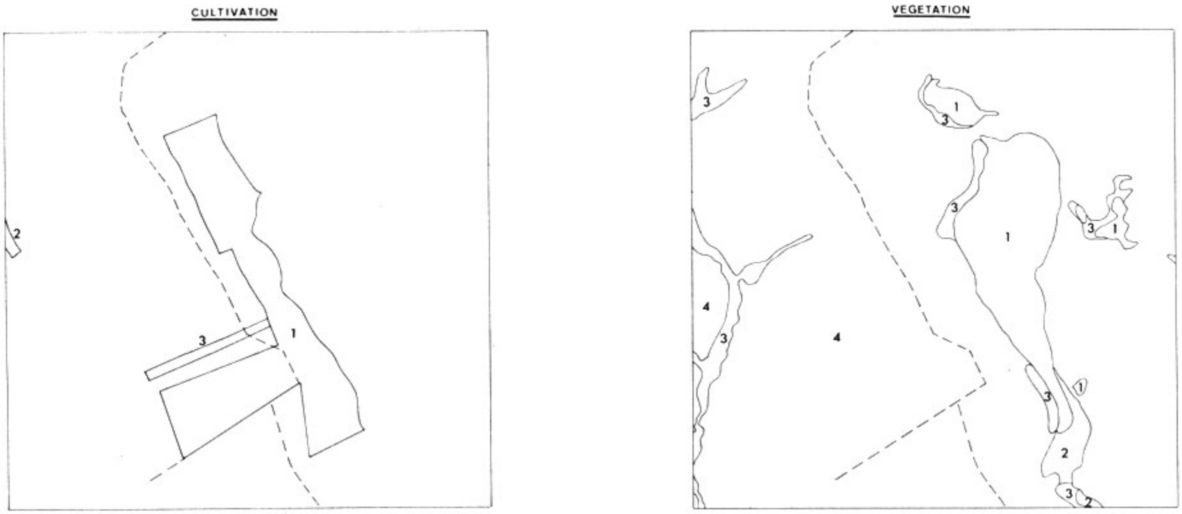


Fig. 39. Stereotriplet of an area in the Llanos Orientales, Colombia. Different field conditions cause different light reflection. The analysis of the resulting colour is given in Fig. 40.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

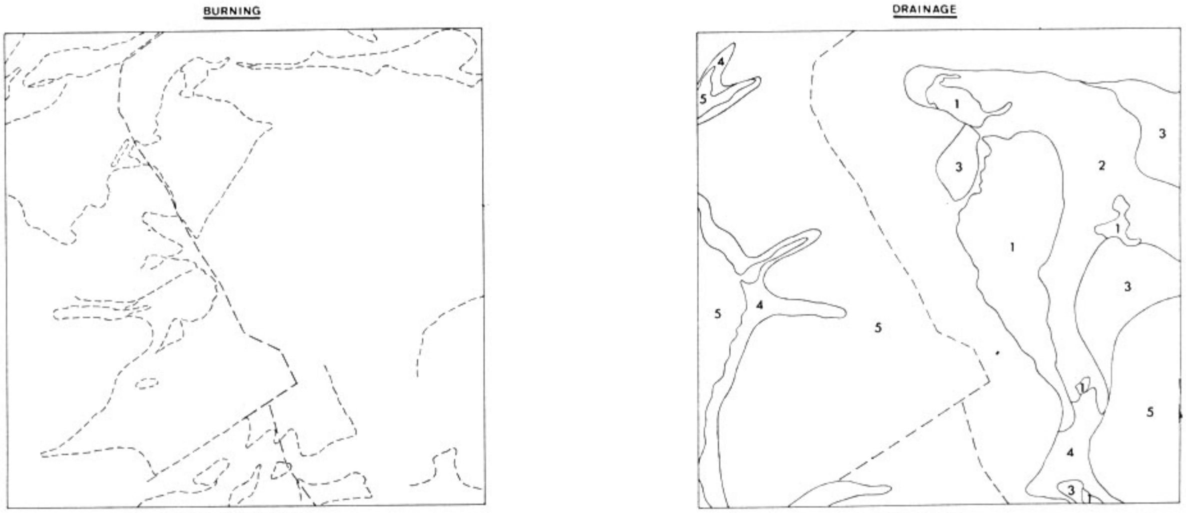


CULTIVATION

1 GRASSLAND TREATED WITH ROTAVATOR
2 SHIFTING CULTIVATION
3 MOWN LANDINGSTRIP

VEGETATION

1 NO VEGETATION
2 PALM-FOREST
3 MIXED-FOREST
4 GRASS

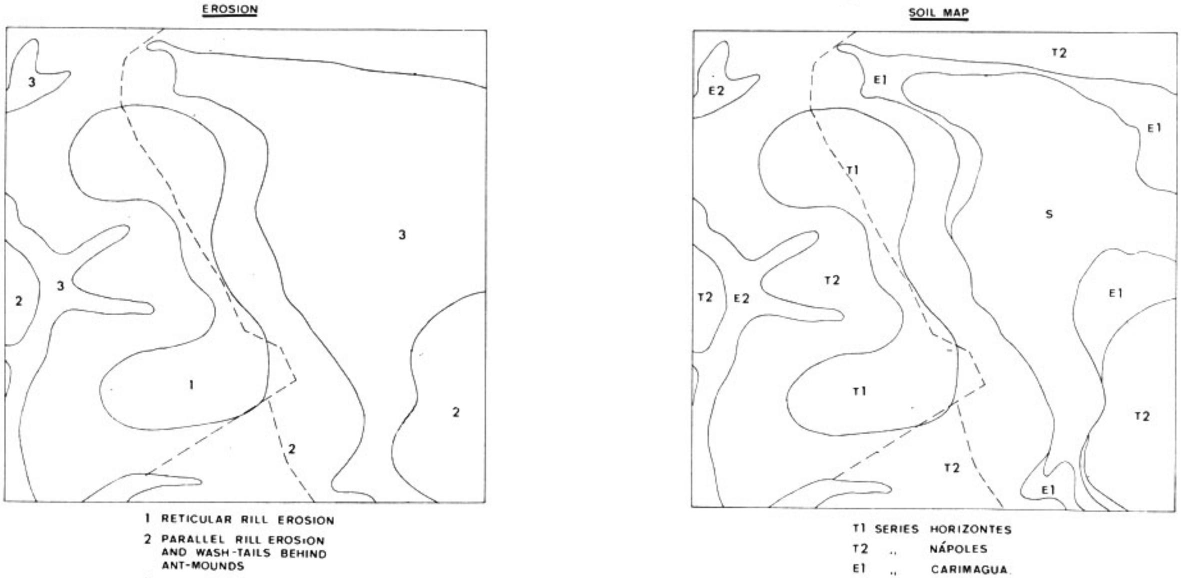


BURNING

DASH-LINES SEPARATE AREAS,
BURNED AT DIFFERENT TIMES

DRAINAGE

1 OPEN WATER
2 SWAMP
3 VERY POORLY DRAINED
4 POORLY TO IMPERFECTLY DRAINED
5 UNDIFFERENTIATED



EROSION

1 RETICULAR RILL EROSION
2 PARALLEL RILL EROSION AND WASH-TAILS BEHIND ANT-MOUNDS
3 NO EROSION

SOIL MAP

T1 SERIES HORIZONTES
T2 ,, NÁPOLES
E1 ,, CARIMAGUA
E2 ,, MANCHEGA
S ,, SWAMP

Fig. 40. The separate analysis of colour in fig. 39 as caused by different conditions.

Fig. 41. Stereotriplet of sugarcane fields in the Cauca Valley, Colombia. At "A" the cane is growing better, because the recently abandoned valley has better moisture conditions; at "B" the white bands are gravelly and sandy streamridges, on which the cane does not do so well.
(Courtesy Cauca Valley Corporation, Cali, Colombia)

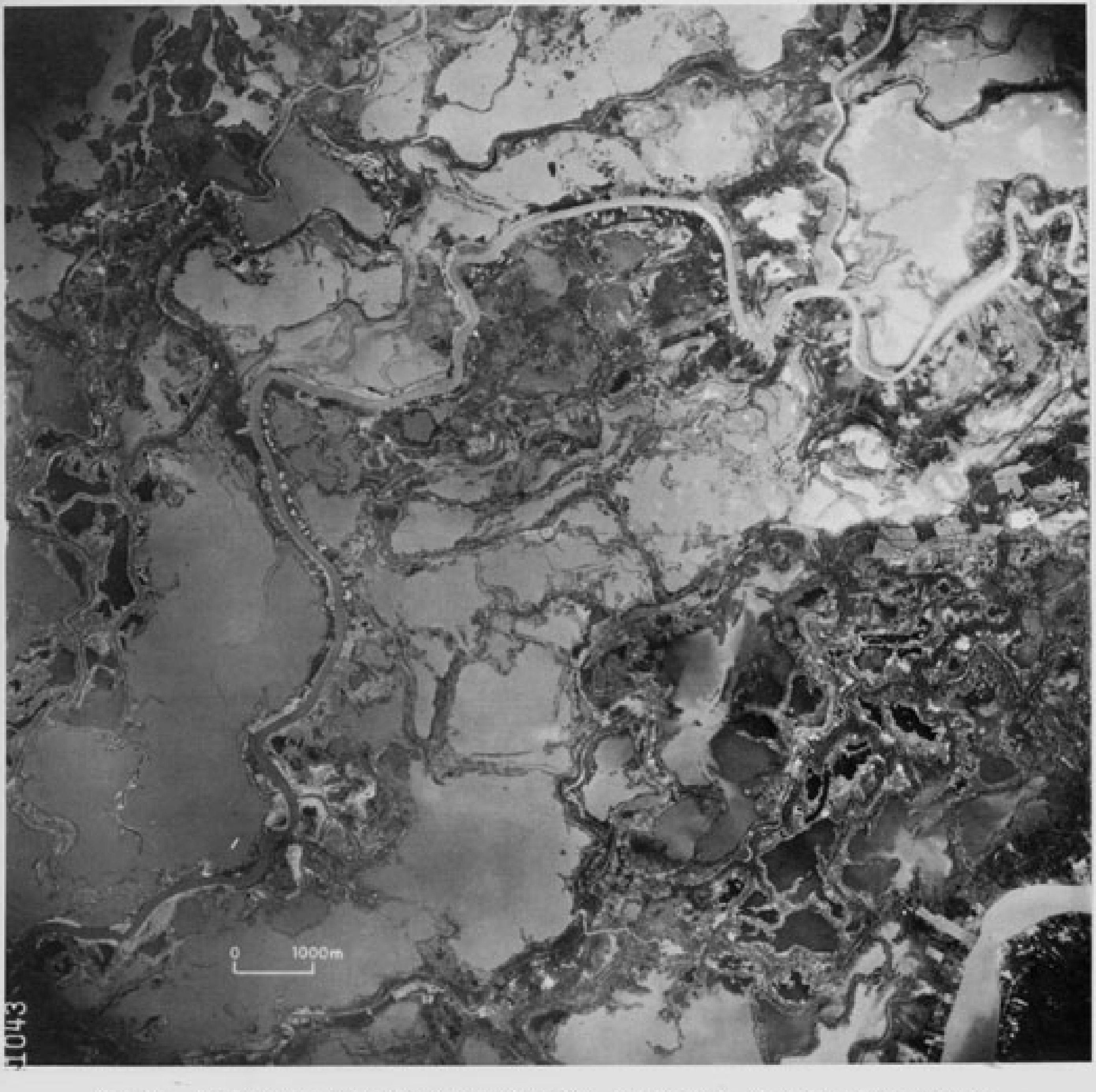


Fig. 42. Airphoto of a recent alluvial overflow plain, Bolivar Dept., Colombia. The numerous spillways with their deposits form a deltaic pattern, but the area is 50 m. above sea-level.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

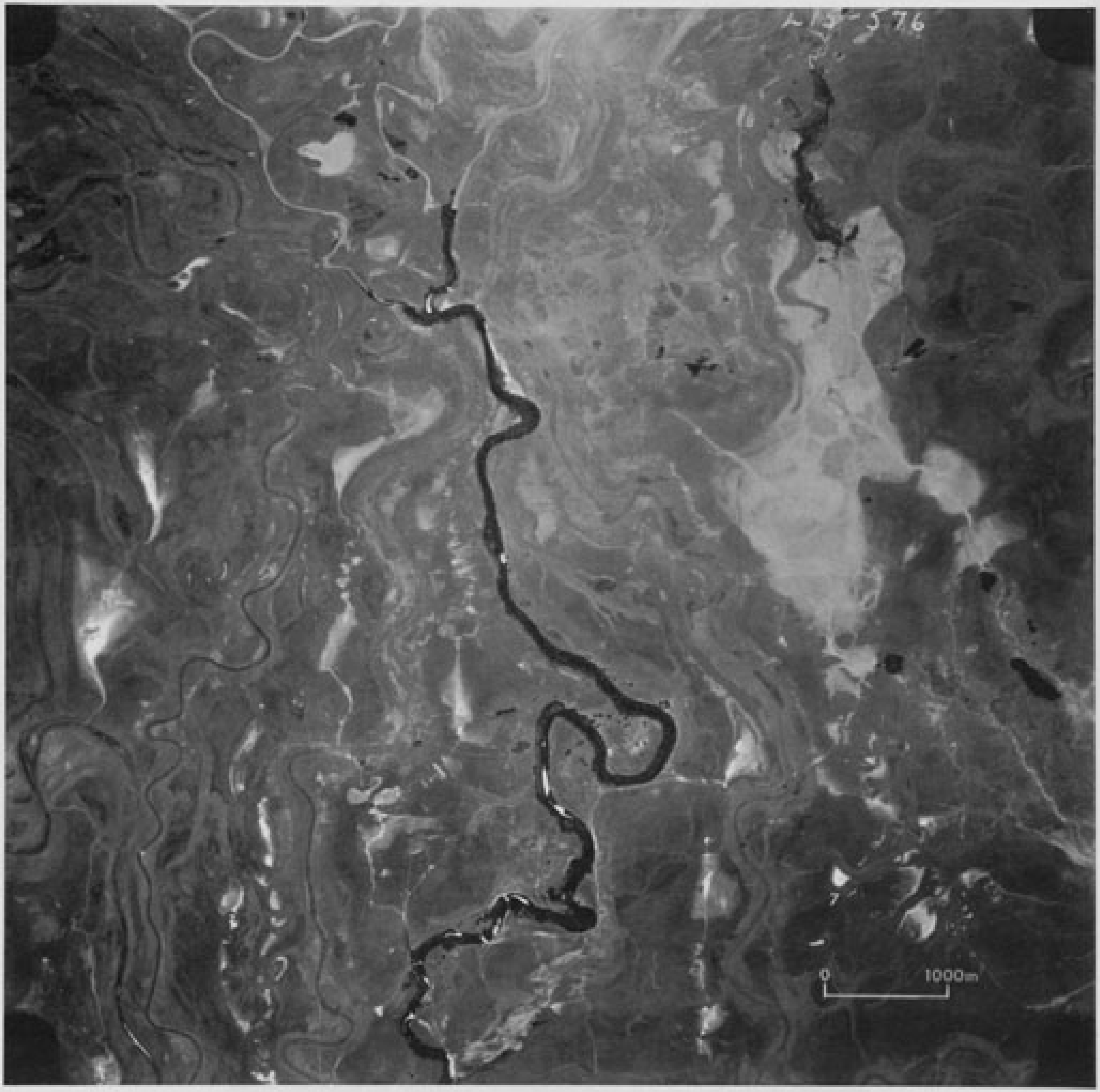


Fig. 43. Airphoto of an old alluvial overflow plain, Llanos Orientales, Colombia. The weaving pattern and the spillways are characteristic features. Conditions during sedimentation were probably not as wet as in Fig.42, because the spillways are less numerous. (Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

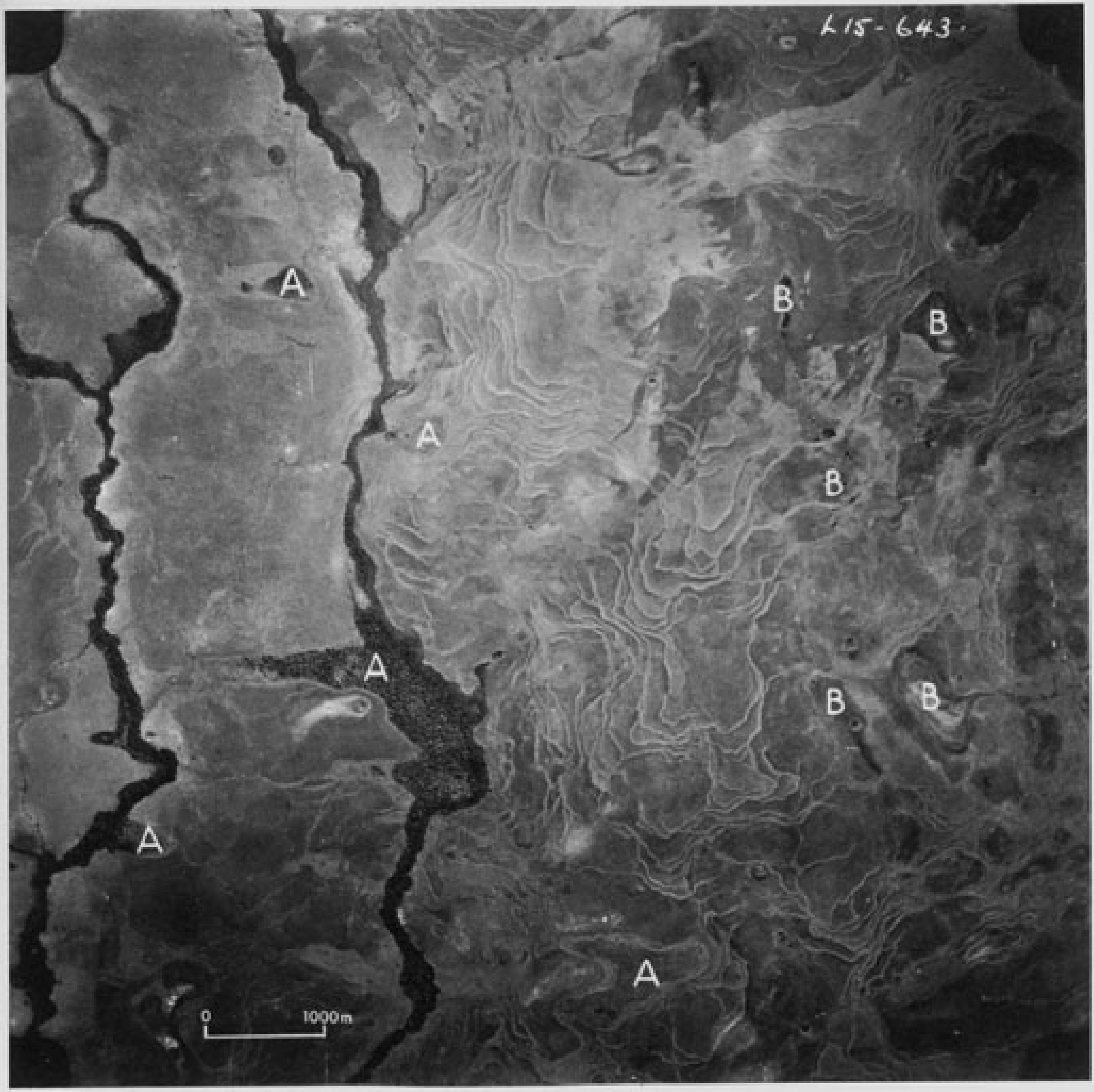


Fig. 44. Airphoto of an area in the aeolian plain of the Llanos Orientales, Colombia. The light-coloured bands are low solifluction ridges. Forested and non-forested dunes (A) are found sticking out some meters above the flat plain. Depressions (B) show a "beaded" alignment.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

Fig. 45. Geomorphological analysis of the photo of Fig.44. Major dunes are indicated with a dotpattern, depressions with a closed line. The intensity of solifluction ridges is related to drainage conditions. See text.
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

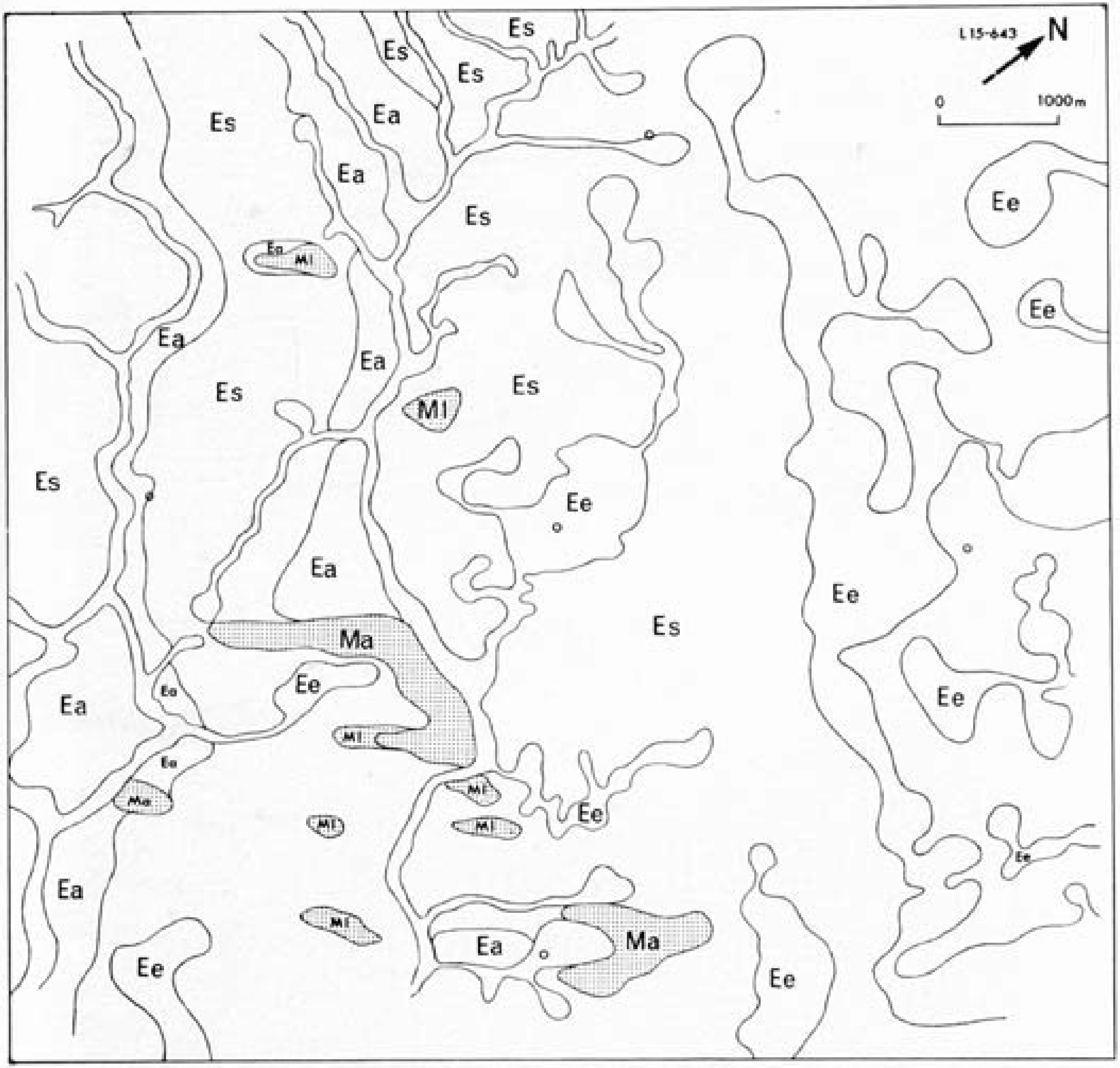


Fig. 46. Physiographic analysis of the photo of Fig.44. The terrain is now divided in units, most likely to be soil associations. Fieldwork is needed to identify the soils.

Ma - High dunes
Ml - Low dunes
Ea - Aeolian plain without solifluction ridged (drainage better than poor)
Es - Aeolian plain with solifluction ridges (drainage poor)
Ee - "Esteros" (broad, shallow drainage ways, marshy conditions).

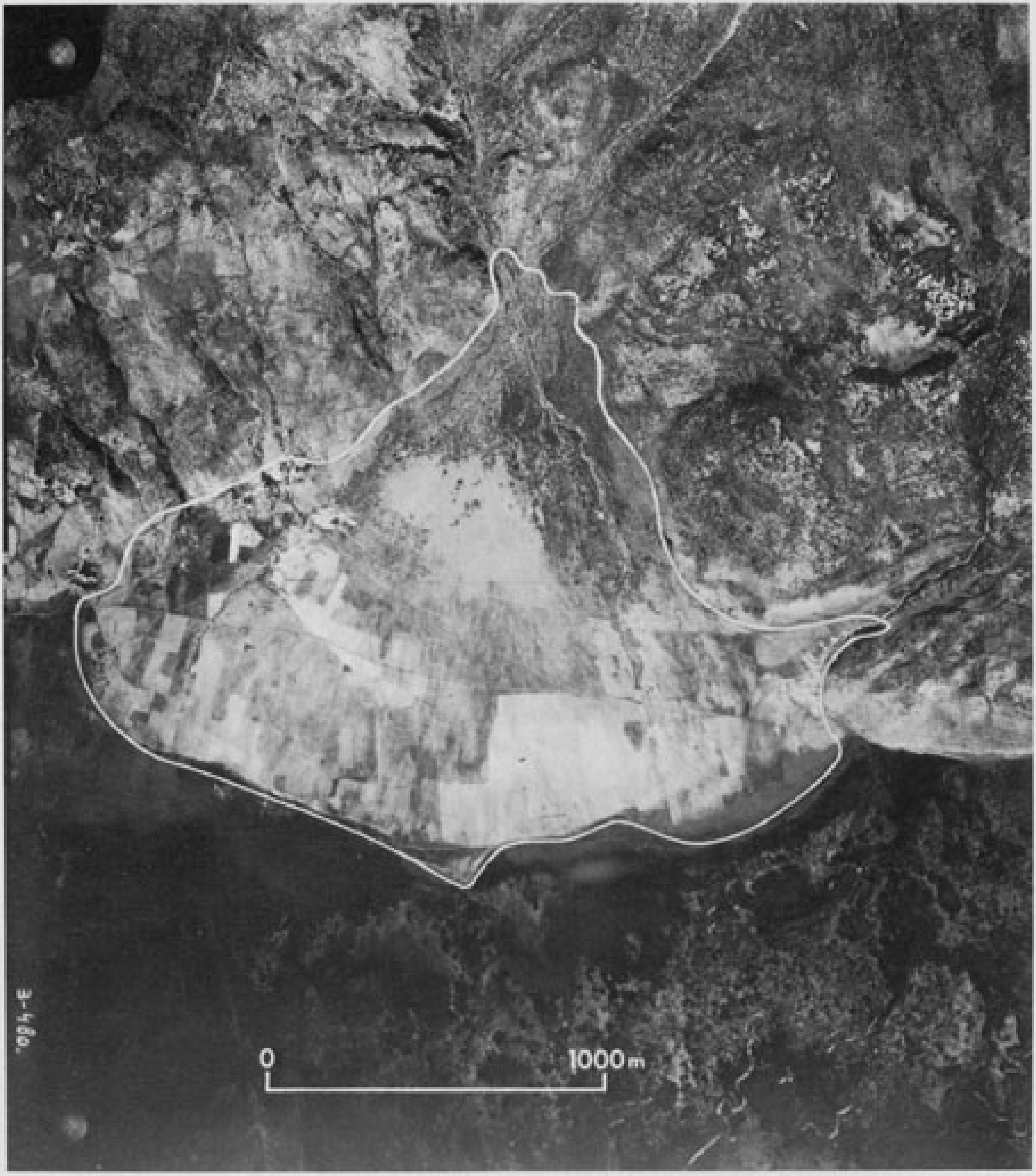


Fig. 47. Airphoto of an alluvial fan in the "El Ghab" Valley, Syria. (Courtesy Government of Syria)

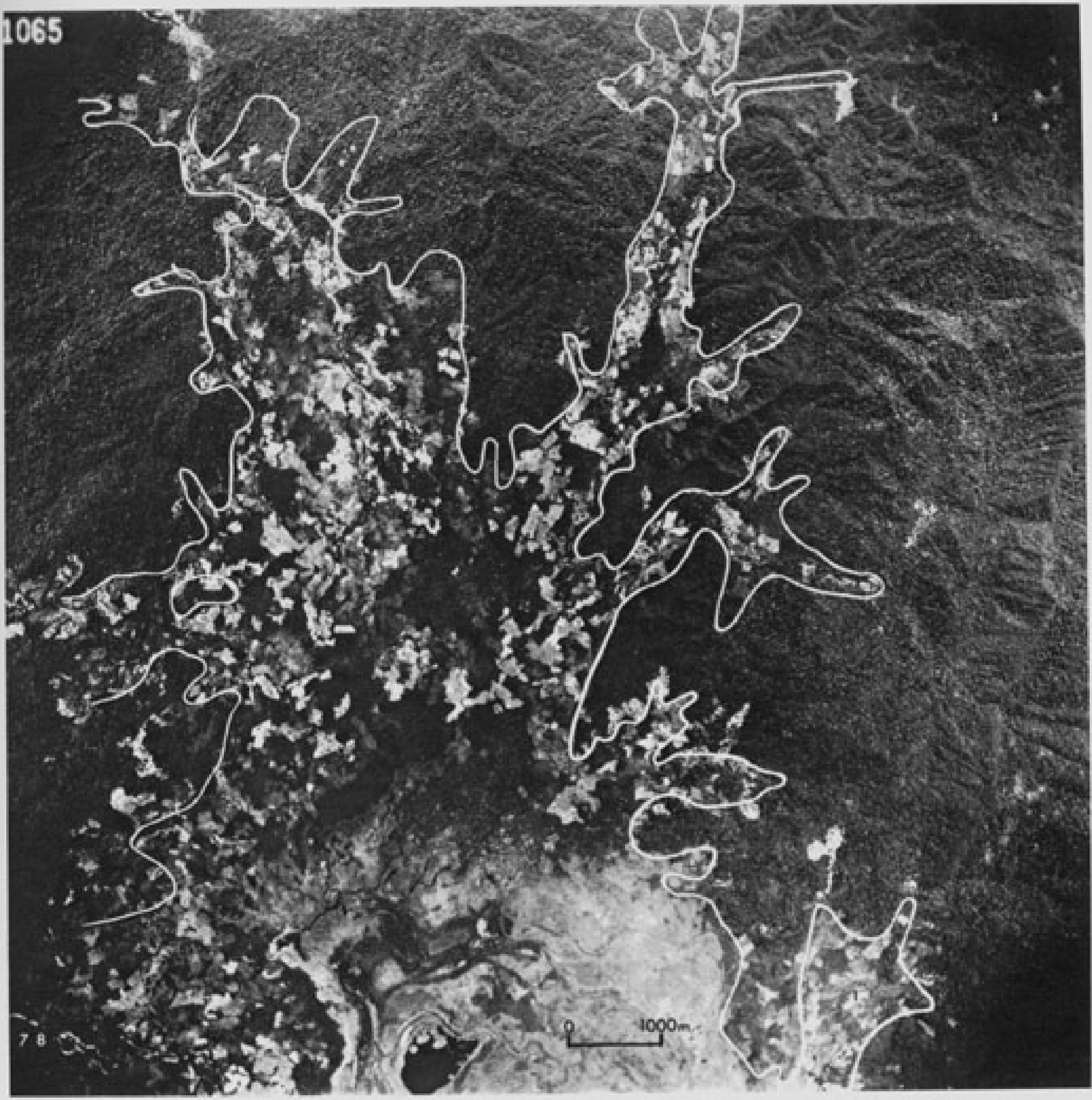


Fig. 48. Airphoto of an alluvial fan in the Magdalena Valley, Colombia. (Courtesy Instituto Geográfico "Augustin Codazzi", Colombia)

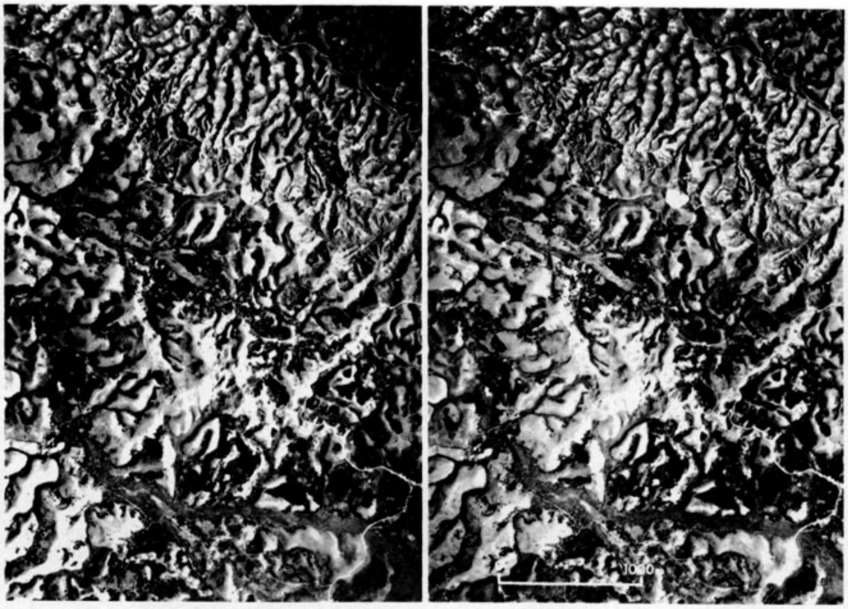


Fig. 49. *Stereogram of a severely dissected plateau in S.W. Colombia. Parent material is volcanic ash. Overgrazing is resulting in sheet and gully erosion.*
(Courtesy Instituto Geográfico "Augustín Codazzi", Colombia)

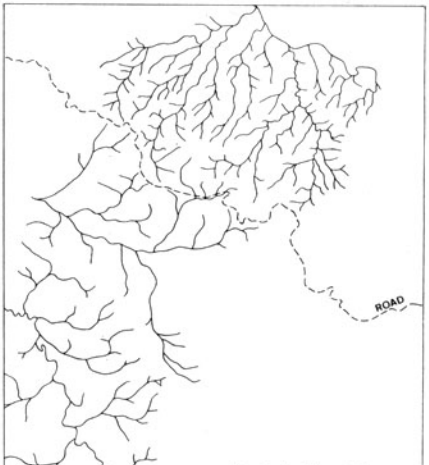


Fig. 50. *Analysis of gully pattern of Fig. 49. The different intensity of the dendritic pattern is due to accelerated erosion, and has no relation to differences in parent material.*

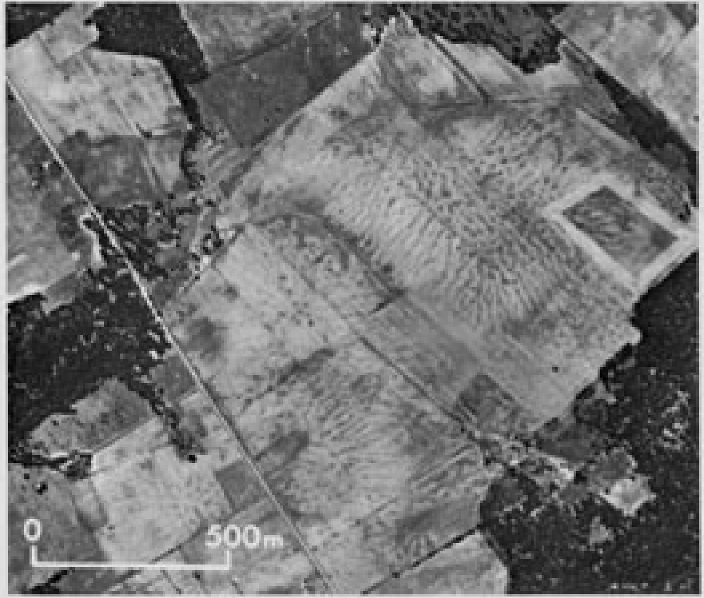


Fig. 51. *Airphoto of an area in Milam Co., Texas, U.S.A. The old rill erosion (see text) shows up clearly, because present local sheetwash accentuates the pattern. (Courtesy United States Department of Agriculture)*

Fig. 52. Stereotriplet of an area around the Tomo river, near the Orinoco river. This smoothly dissected plain is formed around granitic outcrops of the Guayana Shield. Strong aeolian action has reworked the original alluvial sediments.
(Courtesy Instituo Geográfico "Augustín Codazzi", Colombia)

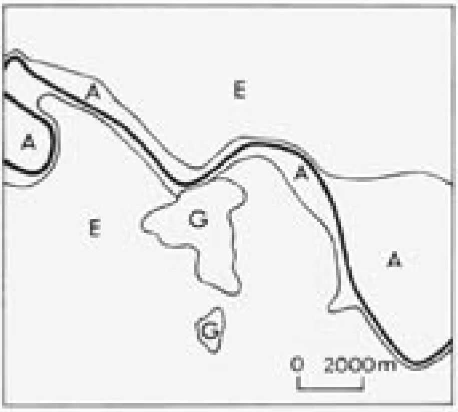


Fig. 53. Schematic soil map of Fig.52. For legend see Table 3.

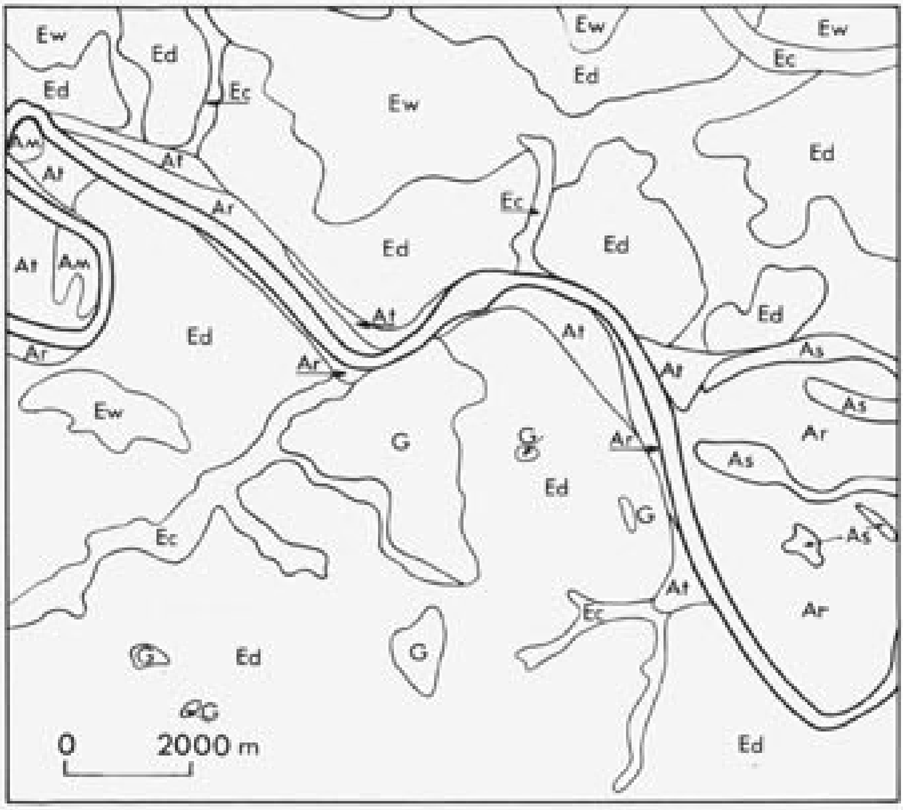


Fig. 54. General reconnaissance soil map of Fig.52. For legend see Table 3.

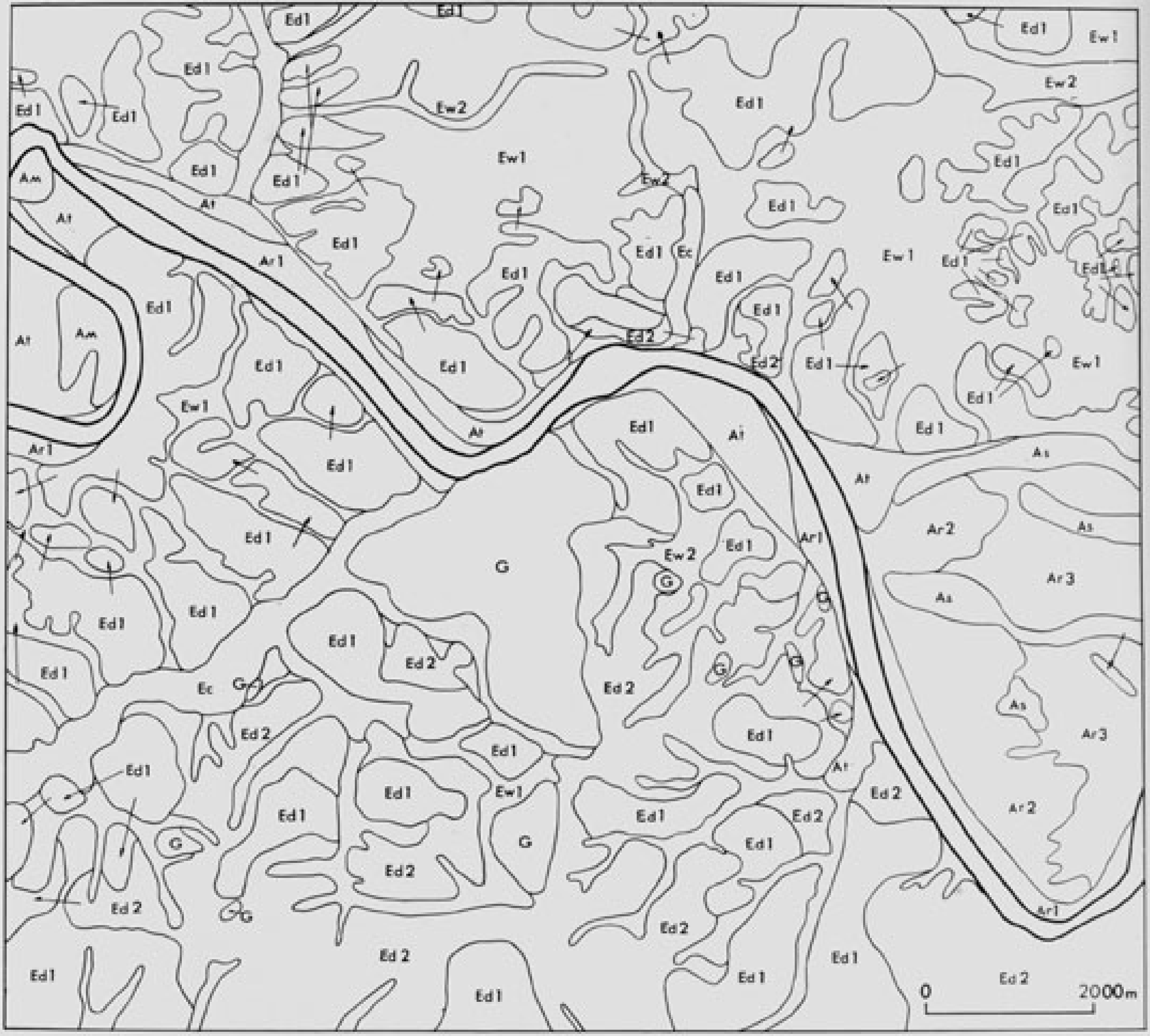


Fig. 55. Semi-detailed soil map of Fig. 52. For legend see Table 3.

In this special case the area of all sample areas combined, surveyed in a semi-detailed way, was 3% of the total area. Not a very high percentage but justified in view of the speed of survey required, the planned scale of the final soil map and the existence of a uniform soil pattern over large distances. The scale of the final map is 1 : 250 000.

In different circumstances the choice of method, or combination of methods, may change. This will depend on the type of survey, the experience and reference level of the soil surveyors. No dogmatic approach can be prescribed at the present stage of development of photo interpretation technique. Innovations are bound to come and are indeed necessary. As long as scientific standards are maintained, and increased efficiency is achieved, soil surveys will benefit.

In all the different methods careful use of photo keys can be made, bearing in mind the emphasis of previous chapters, that a single phenomenon may reflect in different situations in quite different ways. Similarly, a given pattern may be poly-interpretable representing different things on different photographs. For these reasons, it is desirable to have a number of keys for each specific phenomenon or process; a collection showing how local conditions, such as climate, etc., may influence both the photo-image and the processes in various ways. To assist in the creation of such photo-key collections it is hoped that there will be a steady increase in the international exchange of air photographs.

CHAPTER 5

CHARACTER OF THE SOIL MAPPING UNITS AND LEGEND ESTABLISHED BY PHOTO INTERPRETATION

Establishment of Soil Mapping Units

In the course of a conventional soil survey lacking any special application of air photo interpretation, soils are studied, identified and delineated in the field. Individual soils may be taken as the soil mapping units (with some impurity allowed), or they may be conveniently combined into soil associations, mapping units composed of more than one taxonomically defined soil.

In this procedure the identification comes first, and the delineation afterwards. The establishment of the soil boundaries (the delineation) is supported by an adequate amount of "digging."

This is not the place to enter into a detailed discussion of the character of the mapping units thus defined, nor of the taxonomic classifications which can be used to identify individual soils, but it is of particular interest to discuss in what way the nature of the soil mapping units is influenced when air photo interpretation is used in soil survey.

In the first place, air photo interpretation affects the procedure for establishing the identity and extent of the different soil bodies. Based on air photo study certain lines are found, supposedly soil boundaries. The validity of this supposition is subsequently checked in the field. This means that the traditional sequence of identification and delineation, mentioned earlier, is reversed. With the use of air photo interpretation delineation comes first, identification afterwards.

How is it possible to delineate something which has not been identified? Indeed, the expression "first delineation, then identification" is oversimplified. For the sake of discussion, the identification of soil bodies can be conveniently split into two parts - the external and the internal aspects of identification. The external aspects include relief, slopeform, relative drainage conditions, etc., while the internal aspects are the characteristics of the soil profile.

In air photo interpretation most of the external aspects can be studied, classified, and used for the delineation of soil bodies. The identification of the internal aspects is left to the field work.

These points are summarized in the following table:

	Phase 1	Phase 2	Phase 3
Conventional soil survey	Identification of external aspects	Identification of internal aspects	Delineation
Soil survey with air photo interpretation	Identification of external aspects	Delineation	Identification of internal aspects

Correlation Between Air Photo Interpretation and Soil Differences

Before we can use air photo interpretation with confidence we must satisfy ourselves that soil bodies can be identified sufficiently accurately on the basis of their external aspects as to justify the use of these aspects for delineating the distribution of the soil bodies. Are soil differences sufficiently reflected in the external aspects alone as to justify their delineation on this basis? Do changes in physiography coincide with changes in soil bodies?

In general, an affirmative answer can be given to the last and most basic of these questions. Under normal conditions changes in soil and in physiography occur together. Whether or not the most striking accumulation of changes in physiography coincides with the limit set between two kinds of soil depends in part upon the definition of the soil bodies concerned. It is possible that the exact criteria chosen to distinguish one soil from another in a taxonomic classification may lead to a systematic displacement, or 'error.' between the position of maximum physiographic change and the defined limit between the soil bodies. If at all, this situation will arise where transitions are gradual and, by recognizing the systematic pattern of the displacement it may still be possible to map the different soils by reference to changes in the physiography.

In part, the earlier question is already answered. Where external aspects of the soil change there are usually corresponding changes in the internal aspects. Therefore, a delineation of the external aspects will contribute to the purpose of the map by registering differences in the soil, although again it should be emphasized that such delineation does not pretend to register the exact nature of these differences. Differences relating to the internal aspects of the soil can only be, and must be, studied in the field.

We can now return to the first and most general consideration - that relating to the accuracy of air photo interpretation as a means of delineating soil bodies. The criteria used in air photo delineation of soil boundaries are selected on the basis of their known or expected relationships to soil differences. If the criterion used has a known relationship to soil differences, there is no problem. The criterion may be a single element, a combination of elements, or a physiographic pattern; as long as it is properly established that it is correlated with soil differences, its use in air photo interpretation for delineating soil boundaries does not differ essentially from its use in field work for the same purpose. Therefore, the resulting soil mapping units will be similar in extent and form to the ones determined by field work alone. In chapter 4 it has been claimed that whith air photo interpretation much greater accuracy is achieved but, leaving that claim aside for the moment, we arrive here at the conclusion that the use of external aspects of soil bodies as criteria for the delineation of those soil bodies should indeed be sufficiently accurate. The resulting soil mapping units should not be inferior to those arrived at by conventional field work.

Source of Inaccuracy

In the foregoing paragraphs mention has been made of criteria used in air photo delineation of soil boundaries. These criteria were said to be selected on the basis of their known, or expected relationship to soil differences, but in the discussion which followed it was assumed that the criteria used had a known relationship to soil differences.

Sometimes criteria are used, however, which have only an expected relationship to soil differences. In particular circumstances this could be a source of errors if controls were inadequate. This could easily happen if photo interpretation were to be executed on the assumption that no checking would be needed on the location of the soil boundaries. It is certainly true that a lot of routine-locating of soil boundaries in the field has become superfluous with the introduction of photo interpretation, but not to the extent that such work can be completely forgotten. Checking remains a scientific necessity, precisely to remove any inaccuracy due to the application of photo interpretation criteria which do not have the systematic relationship to soil differences which was expected of them. As a general rule, this checking is concentrated in the sample area, as explained in Chapter 4. If the checking is applied consistently this possible source of inaccuracy can be completely eliminated.

Impurity of mapping units

Some soil boundaries have no detectable reflection in the physiography. As a result they may be missed altogether in the air photo interpretation. As stated in Chapter 2, this is especially true of soil differences which are the result of some physiographic process which is no longer active and has been obscured by a second process. This, in itself, is so common that it is the rule rather than exception. Fortunately soils "react" rather quickly to physiographic changes and the soil bodies adjust themselves rapidly to most recent physiographic phenomena, although, of course, they retain reflections of the former processes in their internal characteristics. The boundaries of most units of soil classification are reflected, therefore, in the present physiography and it is only at the type, phase, or series level of soil classification that the boundaries may not be visible.

Because of this the units delineated by air photo interpretation will be of unknown purity. In other words, the content of each unit may well be composite. Usually more than one soil series will be found within each unit. Difficulty in separating them arises from the fact that no differences can be detected during the air photo interpretation. This being so it can be expected that the internal aspects of the soil will also have much in common. In other words, the soil series within one mapping unit will usually be closely related and in many aspects will be the same or similar. If no appreciable external differences exist in the drainage, relief, slope, geographic location and physiographic position, the group of soil series can very conveniently be called a 'soil association'. This is the most widely used unit for semi-detailed soil survey. It is a very convenient unit, because it often serves as a "management unit" at the interpretation stage of soil survey.

If it is desired to separate the individual soil series from each other and represent them on a soil map, then that soil map is a more detailed one and additional field work is required for its construction. For this reason, it was stated in Chapter 2 that air photo interpretation is less suited to detailed soil survey. It may very well be that with new "remote sensing" techniques such as radar and multi-spectral photography the separation of nearly alike soils will become more practical, but for the time being air photo interpretation for soil survey has the limitation that not all soil differences can be identified.

Does this mean that an essential feature of air photo interpretation is that the mapping units are more impure than in conventional soil survey through field work alone? The answer is, emphatically, "No!" Just as much as he did before the introduction of air photo interpretation, the soil surveyor has the task of checking the different soil mapping units with regard to their composition. He must register all possible variations in the field and if it becomes necessary to map a certain soil which he cannot delineate on the air photo, he must do so by conventional field survey. The fact that he can often reduce the number of checkpoints may give the impression that certain soils have been overlooked but, in reality, the surveyor has been able to make one observation (pit or auger) representative of a larger area by judicious selection of his observation point.

The soil surveyor using air photo interpretation has to be careful at this point. He must constantly ask himself, "How far can I go with the generalization of an observed element or pattern?" Constant checking is advisable, especially in the beginning of a survey. The soil surveyor has to guard against an overconfident approach, for this might be the source of many unchecked errors. But such dangers are not, of course, inherent in the method; they are related to failings in the human intellect rather than in any particular technique.

Physiographic Aspects of Soils

With the introduction of air photos in soil surveys more emphasis is placed on the study of the external, three-dimensional aspects of soil bodies. This is an advantage. Many soil maps have been constructed, on the basis of the detailed description and classification of a limited number of soil profiles; one soil being separated from another by a rather arbitrarily drawn boundary. The best maps were those which showed in the pattern of the soils the physiography of the area. In such cases the physiography often forms the constructional basis of the soil mapping legend, giving very valuable information which would be lost if the soil mapping units were only indicated by a taxonomic name based on the soil profile alone. That soils are landscapes as well as profiles is being increasingly recognized.

Problems in classification of landscapes

How to classify the landscapes often has been a problem to soil surveyors. The geomorphological genetic classification is not difficult in certain types of landscapes, such as the depositional landscapes of alluvial or aeolian origin, but in many erosional landscapes is not satisfactorily developed. Moreover soil surveyors are not always familiar with current geomorphological thinking.

As an alternative the morphometric approach can be applied, in which landscapes are grouped according to measurable characteristics.Slope, form of slope, length of slope, exposure, and density of gullies can all be measured, expressed in exact numerical values, and classified. Such a classification of landscapes is highly artificial. It may separate, at a high level of classification, landscapes which genetically belong together. A level terrace, and its severly dissected counterparts are very different in appearance, yet are close together in a genetic classification in which more emphasis is put on history of formation and composition of the material.

As far as possible, the nomenclature of classification should be informative about the origin of the landscape. In general the soil surveyor can adhere to geomorphological usage, modified if need be by other aspects of physiography (vegetation, water regime and human activities) which are important to soil development. Where the genetic classification is not worked out sufficiently, the morphometric approach may play a supporting role.

To set up a good, universally applicable classification, the assistance of quaternary geologists and geomorphologists is often needed. However, some aspects of such a future classification can be usefully discussed here in relation to their importance in soil studies.

It is not always possible to use a geomorphological classification. Sometimes the mineralogy of the soils is more important than the form of the landscape, in other cases the character of the parent rock dominates other features of the landscape.

In areas where uniform processes of sedimentation and erosion have acted, such as in wide plains with alluvial terraces and in floodplains, the age and position of the different physiographic units play a prominent role in setting up a classification. A high alluvial terrace is usually the oldest formation and will present a more advanced soil profile development, absent in lower terraces. Irrigation as a rule is more difficult on higher terraces, simply because there is less water available and the technique of distributing it requires more effort,for higher terraces tend to be more dissected, and therefore their relief is often less well suited to irrigation. Higher terraces also are usually better drained than lower ones, which will influence soil formation.

Leaching will have had a greater accumulative effect in the higher positions, partly because of the greater age of the soils.

In this example, therefore, it is evident that the physiographic classification, which is going to serve as a backbone of the soil mapping legend, must be based primarily on two aspects; age and position. In naming a series of accumulation terraces the name "high" implies as a matter of course the meaning "old." so that an indication of position is at the same time an indication of the relative age of deposition of the material. Some care is needed here, however. In the first place it does not necessarily follow that the soils of the higher terraces are also the oldest pedologically speaking. It may very well be, that because of dissection, considerable rejuvenation of the soils has occurred; perhaps more so on the high than in the lower terraces. One could then find "older" soils on lower terraces.

Furthermore, the relation "highest position equals oldest material" is only valid in the case of accumulation terraces. Where erosion terraces are concerned, the position might not have this same relationship with age; in fact quite the reverse is possible.

In regions where differences in the character of parent material are more important than position and relative age it might be justified to have the structural arrangement of the soil map legend based on differences in parent rocks. Casual reference to an existing geological map would suffice for an indiscriminate use of this criterion but, in this context, it is well to realize that a geologist is not primarily concerned with mapping the parent material of soils. Indeed, he usually disregards the upper few meters as a disturbing and annoying factor in his studies. Furthermore, physiographic influences acting over long periods of time may well dissociate the solid geology at depth from the soil material at the surface. Faint rains of volcanic ash, for example, may have been incorporated in the soil without leaving any distinct layers which a geologist might record.

In hilly areas, it will be an exception to find a soil which is derived directly from the rock underneath. Usually the soil is derived from rock which originally occupied a higher position for, through soil creep and colluvation, the weathered rock and soil have moved down to their present position.

Geological maps which only show the composition of the solid rocks and their relative age, are often a poor guide for the soil surveyor if he wants to know about later physiographic processes which may have acted upon these formations. In many cases the soil surveyor must investigate the relationships between rocks and soil himself. As an example, the situation in the high Andes of northern South America can be quoted. Abundant information of admirable quality is available on the complex solid geology of these mountains, but soil scientists cannot use this information indiscriminately for, in areas above 2,700 - 3,000 metres, alpine glaciation during the Pleistocene has had a profound effect on physiography, and thus on the nature and distribution of soil parent material. Since the glaciation has not affected petrography its effects are not shown on the geological maps and must be recognized by the soil scientist himself.

The broader question, as to which aspect of physiography should take priority in a particular case in determining the structure of the soil mapping legend is not, as a rule, difficult to solve. Many investigators have found good and workable solutions.

One major difficulty remains in the general application of physiographic classifications, namely the present lack of an internationally agreed and defined nomenclature for physiographic processes and phenomena. This is of course the same difficulty as the lack of a generally accepted classification of landscapes. It is no easy task to find definitions and descriptions of landscapes, which together constitute a classification, and which, therefore, must be based upon logically arranged processes and phenomena. At the same time the definitions should not be ambiguous, that is to say, they must be mutually exclusive.

On most parts of the earth's land surface more than one physiographic process has acted or is still acting. The physiographic phenomenon, the landscape, the land unit, the land system, the landscape element, the facet, or whatever name one wants to apply, is the result of an interaction between those different processes. In some way account of this complexity has to be taken in landscape classification.

In developing such a classification, a connection must be sought with geomorphology, for, in effect, many physiographic processes and features have been studied and described already in that science. But for the purpose of soil survey we cannot rely completely on geomorphology. Many processes important to soil survey, have been neglected by geomorphologists and the systematic survey of large areas by soil scientists has revealed many interesting phenomena which have not been studied in geomorphology. Many aspects of microrelief, for instance, are much better known in soil science circles than amongst geomorphologists.

This does not disguise the fact that terrible confusion exists in present nomenclature. For a certain type of microrelief, the USDA Soil Survey Manual gives the following names: gilgai, hog-wallowed, crab-holey, hush-a-bye, buffalo-wallowed, Bay of Biscay, self-swallowing, self-mulching, tiger-striped, leopard-spotted, puffed, corrugated, pits-and-mounds. To this list can be added: zurales, tatucos, canalets, kawfoetoes, and perhaps many other names. Some of the names refer to effects produced by expanding clays, others by animal activities, still others by special types of erosion, but it is not easy to sort them out correctly.

Physiographic nomenclature has been very much neglected in soil survey. Only recently have attempts been made to introduce some system into it. Worthy of mention, however, are the many different papers presented on the subject at the Symposium of Photo Interpretation (Archives, 1962). These clearly demonstrate that workers in photo interpretation are very much interested in the problem.

The Structure of the Soil Map Legend

Many soil surveyors use a legend in which the individual mapping units are arranged according to different levels of some taxonomic soil classification. To the soil expert, such an arrangement has the advantage that the taxonomic names in themselves convey information on the properties of the soils and their arrangement at different levels of classification conveys information on the genetic relationships of the different mapping units. The layman, however, unfamiliar with such terms as "Orthic Grumustert" or"Brown Grumosol." will not derive these benefits. At the same time, such a legend provides little information concerning the three-dimensional configuration of each soil mapping unit in which many readers are likely to be interested.

The modern tendency is for the definition of soil taxonomic units to become more precise and more exclusive, a trend greatly accelerated by the publication of the new system of soil classification (7th Approximation) of the United States Department of Agriculture (1960). This trend, whilst admirable in itself, creates difficulties in the use of the new taxonomic names to identify units in the legend of a soil map, for quite subtle changes in soil characteristics may place soils on one side or other of a precisely defined distinction between kinds of soil. As a result, a certain element of the landscape which can be conveniently mapped as a single unit is quite likely to include two or more of these precisely defined kinds of soil. Use of the name of one of these kinds of soil as the name of the unit as a whole, clearly does not do justice to the actual composition of the unit. Valuable information about the external, three-dimensional relationship of the individual soil is omitted.

The best way out of this problem is to name the mapping unit an "association" of soil kinds A and B (or, if need be A, B and C), the presence of transitions between A and B within the association being implicit. With the introduction of the association concept a new dimension, excluded in the taxonomic classification, is brought into the legend - that of the three-dimensional, geographic, arrangement of the individual soils. Taxonomic classifications do not pretend to express the relationships between kinds of soil found within a single physiographic unit. The concept of a soil association makes it possible to express these relationships.

To give a simple example, let us assume that on a natural levee of a river two soils occur:

A. a well-drained, deep sandy loam over loamy sand.

B. an imperfectly drained, mod. deep clay loam over sandy loam.

If these soils have to be mapped together, then the name of their association could be: soils of the natural levee, well to imperfectly drained with textured sandy loam to clay loam, association A - B.

In this case anyone familiar with the normal physiographic features of a natural levee, would know that soil A is situated at the crest, and soil B at the slope, that A and B grade into each other through soils of intermediate texture and drainage. It is unthinkable that an imperfectly drained soil would be found at the crest of a natural levee, in the immediate vicinity of a well drained soil on the lower slopes.

Thus, valuable information has been given by introducing a physiographic concept into the name of the mapping unit.

The author does not wish to imply that taxonomic names should be excluded from the legend. Taxonomic names at any required level of detail may be added to mapping unit descriptions based on physiographic concepts. It is very usual to add the series names. Whether the higher category names are also given will depend on the specific purpose of the map. If the map is to be used for soil correlation purposes full taxonomic names ought to be given; but when the map is intended mainly for farmers the need for higher category names is less obvious.

The arrangement of mapping units, defined and named according to physiographic elements within the mapping legend is not governed by any particular taxonomic classification of the soil. At present this is only an advantage, in view of the somewhat confusing situation existing in soil classification. Furthermore soils may be translated, or correlated, from one taxonomic classification into another, without actually changing the order of the legend. This has very decided advantages, the foremost of which is the possibility of establishing early in the survey both the general framework of the legend and the order in which the soils are going to be presented.

Care must be taken that the landscape classification is prepared at an appropriate degree of detail, comparable to the detail of the soil classification. Both aspects must be well balanced.

The following example is intended to illustrate the preceding discussion: From an aerial photograph (Fig. 52) and some field work, three maps were made (Figs. 53, 54, 55). All show the same area, but they differ in their degree of detail.

The map of Figure 53 is at scale 1:240,000 and may be regarded as a schematic, or exploratory, soil map. Three major landscapes are recognized and the soils in each of the landscapes have been indicated at a high level of generalization.

The map of Figure 54 is at scale 1:120,000 and the degree of subdivision corresponds to a general reconnaissance soil map. Two of the three landscapes are further subdivided, and the soils are indicated in more detail than on the schematic soil map.

The map of Figure 55, at a scale 1:75,000 can be regarded as a semidetailed soil map of the same area, although the scale is rather small in this particular example. The landscapes are subdivided in as much detail as the air photo permits, and the classification of the soils is at the family, sometimes at the series, level.

For the classification of the soils in this example the new system of the United States Department of Agriculture has been adopted, but it would be possible, of course, to express the profile descriptions and analysis in terms of other taxonomic soil classification systems. Some of the given names are tentative, because of lack of laboratory data and of adequate field control, but this does not affect the principles which are being demonstrated.

TABLE 3. (a, b, and c) - Comparative detail of structural components of soil map legends

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3a. SCHEMATIC SOIL MAP LEGEND

Symbol	Landscape	Soil profile
A	Alluvial plain	Entisol, and Inceptisol
E	Aeolian plain	Oxisol, some Inceptisol
G	Steep hills	Mainly rock outcrop

3b. GENERAL RECONNAISSANCE SOIL MAP LEGEND

Symbol	Landscape	Soil profile
Alluvial plain		
Ar	Recent floodplain	Psamment and Aquept
At	Terrace	Tropept and Aquept
Am	Riverdunes	Psamment
As	Swamps	Aquept and open water
Aeolian Plain		
Ed	Nearly level, convex divides	Orthox and Tropept
Ew	Level plain	Aquox, some Aquept
Ec	Valleys	Tropept and Aquox
Steep hills		
G	Steep granite-hills	Rock outcrop and some Psamment

3c. SEMI-DETAILED SOIL MAP LEGEND

Symbol	Landscape	Soil profile
Alluvial Plain Recent floodplain		
Ar1	Natural levees	Loamy sandy Aquic Quarzipsamment
Ar2	Complex of point-bars	Sandy Aquic Quarzipsamment and loamy Humic Normaquept
Ar3	Alluvial flat	Loamy to clayey Humic Normaquept
Terrace		
At	Subrecent low terrace	Loamy to clayey Oxic Tropept and Humic Normaquept
Riverdunes		
Am	Longitudinal river-dunes and swales	Typic Quarzipsamment and loamy Normaquept
Swamps		
As	Oxbow lakes and other depressions	Typic Humaquept bordering open water
Aeolian Plain Nearly level, convex divides		
Ed1	Smoothly convex divides	Psammentic Ustox
Ed2	Slightly dissected borders of ED	Sandy loamy Plinthic Tropept
Level plain		
Ew1	Level plain and some elongated depressions	Sandy loam to loamy Typic Albaquox
Ew2	Depressional broad drainage ways	Loamy to clayey Typic Humaquept
Valleys		
Ec	Colluvic-alluvial valleys	Sandy loam to clayey Aquic Tropept and Humic Normaquox
Steep hills Steep granite-hills		
G	Steep granite-hills and colluvial scree	Rock outcrop and some coarse sandy Lithic Quarzipsamment

In Table 3 the different components of the soil map legend are given for each of the maps.These components form the building stones out of which the soil map legend can be built up. The arrangement is according to the classification of the landscapes; starting with little detail and proceeding by means of subdivison toward more detail.

At each level of detail the basic idea remains the same, namely that a landscape classification should provide the framework of the soil map legend. Within each classification the spatial aspects of the soil bodies are incorporated and indicated or implied in the name. When we talk of a natural levee in an alluvial plain, then we visualize an elongated, rather narrow strip of land, recently sedimented by a river; with a nearly level, somewhat convex relief; and with good external drainage, but seasonally susceptible to flooding when not protected by dykes. The soil profiles found in these physiographic units can be placed in a taxonomic classification, and this addition to the name of the soil mapping unit is of course essential for a soil map. This additional information serves to identify the soils in terms of their profile characteristics and to distinguish them from other soils. "Loamy sandy Aquic Quarzipsamment," for example, describes a very sandy soil, which is imperfectly to moderately well drained, with a sand fraction consisting predominantly of quartz, and with a soil profile that shows little development.

CHAPTER 6

PRACTICAL PROBLEMS IN SOIL SURVEYS WITH AIR PHOTO INTERPRETATION

The Organization of Field Work

With the introduction of air photo interpretation in soil surveys a few special problems have arisen. First of all there is the problem of deciding how to fit the air photo interpretation into the program of the conventional soil survey; or rather how to adjust the conventional soil survey in such a way that the photo interpretation finds its proper place. This problem relates to the execution of the soil survey.

From the previous chapters some general principles can be derived on the basis of which field work must be adapted to meet the needs of the new approach:

1. In the field work, relatively more attention can be paid to the study of soil profiles than to the location of soil boundaries.
2. The random, or grid, survey can usually be abandoned and replaced by the "selective" survey.
3. The distribution of observations need not be regular. In all but detailed surveys they may be concentrated in sample areas.
4. The photo interpretation must be done by soil surveyors who can later check the result in the field. For the sake of efficiency some specialization and task-division is needed.

The sample areas form an important element in the combination of photo interpretation and field work. Sample areas must fulfill a few conditions:

(a) They must be typical for a large area;

(b) They must collectively include all soil mapping units occurring in that survey area.

Theoretically one sample area per landscape would suffice. In practice, however, especially when the landscapes are large, more than one sample area within one landscape better serves the purpose of including all possible gradual changes.

The functions of a sample area can be summarized as follows:

(a) The study of the sample area must provide the photo interpreter/soil surveyor with a clear picture of the correlation between soil boundaries and photo image, since these soil boundaries also have to be traced in the rest of the area outside the sample area. Usually such soil boundaries are indicative of soil associations, but sometines individual series are mapped for the overall survey.

(b) The study of the sample area must also reveal the distribution and pattern of the soils which together compose one mapping unit. This pattern may not show up systematically in the photo image, but is extremely important for the knowledge of the interrelationship of the individual soils. This also applies for the whole survey area.

Based upon these principles, it is now possible to put down an operational sequence of photo interpretation plus field work:

1. Collecting material, data and information

   a. Photo coverage. This includes, as a minimum, some copies of photo indexes (small-scale uncontrolled mosaics with an indication of flight-lines and numbers); two sets of photos, one of glossy contact prints for office work, and one of matt or semimatt contact prints for field work; two copies of a semicontrolled or controlled mosaic.

   b. Topographic maps. Drawing facilities have to be provided to adjust topographic maps in such a way that they can serve as base maps for the soil survey.

   c. Control points. If no topographic maps are available, control points must be located with their coordinates on the aerial photos. These serve in the assembly of the base map by simple photogrammetric procedures.

   d. Relevant literature and other information. All available information on the area, whether published or not, whether written or in map form and on all subjects relevant to the survey (geology, vegetation, hydrology, etc.) must be collected.

2. Layout of photos or mosaics

   The purpose of this layout is to arrive at a small-scale map showing all landscapes. This map and a preliminary legend can also be prepared with the assistance of additional stereo study of representative photos.

3. General field reconnaissance

   In combination with stage 2 it is preferable to undertake a general field reconnaissance to become familiar with the area and to provide a check on the end result of stage 2.

4. Selection and study of sample area

   In each landscape one or more sample areas are selected, each satisfying the criteria described previously. A detailed photo interpretation of each sample area is then executed. The classification of the photo interpretation units must fit within the framework of the landscape map. A draft legend is set up.

5. Field work in sample areas

   For a proper correlation of the photo interpretation and the soil conditions as found in the field, the sample areas are studied in rather more detail than is needed to meet the purposes of the overall survey. Care must be taken to ensure that the two main purposes of the sample area, described previously, are achieved.

6. The photo interpretation of the whole area

   The soil boundaries which have been established by photo interpretation and field work in the sample area are systematically extrapolated or interpolated, as far as possible, on the remaining photographs of the area. Units which do not appear to correspond to units recognized in the sample areas and which do not appear, therefore, in the draft legend must be added and must be noted down for field checking.

7. Field checks outside sample areas

The density of field checking outside the sample areas varies according to the scale of map, the degree of change between sample areas, and the degree of correlation observed between soil boundaries and photo interpretation in the survey of the sample areas. Where necessary the photo interpretation is corrected.

8. Transfer of data to base map

The final corrected version of the photo interpretation, including the result of field work, is transferred to the final base map.

Remarks:

Stages 4, 5, 6 and 7 can be phased. When some sample areas have been interpreted, it may be desirable to start immediately on the systematic field work in these sample areas. Subsequently, a part of stage 6 can be executed, followed by stage 7 in the areas corresponding to the completed sample areas.

At an early stage of the survey it is desirable to have a draughtsman available. So that his work may be divided more evenly over the period of survey, stage 8 can be done in part during early stages of the survey, even if corrections are likely to be necessary later. This approach is likely to prove cheaper and more efficient than concentrating all the drawing work at the end of the survey.

Including the variations mentioned, the operational sequence of stages 1 to 8 is seen as the ideal procedure. It is at the same time the most efficient procedure, if trained personnel are available and limitations to field work are few.

In each individual situation, however, the survey leader may have to adjust his program to make allowance for:

- the scale requirements of the final map;
- seasons when field work is impractical;
- the coordinated timing of all stages;
- transport difficulties and the practical possibility of frequent journeys between the interpretation office and the field. (If only one long field visit is possible, as in a consulting job, for example, the photo interpretation should be completed as far as possible before the fieldwork starts);
- the experience of the surveyors. Surveyors with little experience in photo interpretation will need to make more frequent comparisons between photo interpretation and field work;
- the possible need for preliminary reporting.

The capacity of a survey party employing air photo interpretation is much greater than that of a party using only conventional soil survey methods. Time saving is estimated by Buringh (1960) at 400 to 1,000%, and in several cases these figures have proven to be on the conservative side. The increase in capacity puts more stress on the organizational talents of the survey leader if he is to arrange the survey in the most efficient way.

Cartographic Problems

Choice of publication scale

It is generally recognized that as a result of correctly applied air photo interpretation soil survey maps of better quality are produced. They show the soil boundaries more reliably than on most soil maps produced by conventional field methods. They also show much more detail than was formerly practical.

In this connection, it is an important consideration that the increased detail and accuracy of soil maps produced using air photo interpretation is achieved with a lower density of field observation than would be considered necessary for soil maps at equivalent scales produced by field methods alone. In the past, certain minimum standards for the density of observations in relation to the scale of the published maps have been applied to conventional soil surveys in different countries. It would be unrealistic, however, to apply these same standards to surveys in which photo interpretation was efficiently employed, for in such a survey each field observation can be expected to be more informative and representative of a much larger area than was the case in the past. This is partly because the site of each observation can be carefully chosen from the photographs as representative of a specific section of the landscape, and partly because air photo interpretation itself has greatly increased our knowledge of the relationship between soils and physiographic elements, thus providing a sounder basis for selecting observation sites.

By using modern mapping techniques, therefore, a similar standard of reliability, or of scientific honesty, can be maintained with a lesser number of observations in each unit area of the final map. Needless to say this is only true up to a point and it is important to emphasize that the smaller the experience of a surveyor in photo interpretation the larger is the number of field observations he must make in order to produce a reliable map.

Although there may be little technical reason for reducing the publication scale of a modern soil survey much below the scale used for field work or for photo interpretation, there may be practical reasons for doing so. At a large scale the map of a reasonably large area may have to be printed in several sheets and this may be a severe disadvantage in terms of both cost and convenience. If coloured maps are required cost may be a major reason for reducing the publication scale and a map at reduced scale may also be desirable to provide a broad, panoramic view of the soils of the area surveyed.

Knowledge that the survey is to be published at a small scale can affect the method employed in photo interpretation, for two alternative approaches are possible:

1. The photo interpretation can be carried out with a clear idea in mind of the amount of detail it will be possible to show on the final maps, introducing simplification into the choice and drawing of boundaries from the outset.

2. The photo interpretation can be carried out in as much detail as possible, using all the units identified in the sample areas. The resulting map can be reduced photographically to the required final scale and then simplified by a draughtsman who follows standard rules in the elimination of excessive detail. The original detailed photo interpretation remains available for reference in the file. Simplification may lead to the elimination of certain small but important mapping units. The complex mapping units so formed will require new names and the legend of the final map will have to be adjusted accordingly.

The first of these methods has the advantage of speed but, in practice, it is often difficult to maintain the same standards of simplification systematically on all the photographs of a large survey.

The second method takes considerably longer but it provides a much better map and the more detailed interpreted information remains available on the file.

Topographic base maps

In connection with the scale of the final map some attention should be given to the accuracy of the topographic base. Many areas of the world, although photographed, do not yet have reliable topographic maps.

Sometimes the available maps made from photos show so much detail that any additional information on them (soil boundaries and symbols) would result in a very confusing picture. In other words the cartographers have used the space available on the map sheet to its maximum capacity. Naturally, this occurs when the cartographer sees his map as an end product and not as the starting point for other users.

Problems caused by insufficiently accurate maps, or by maps, or by maps which, although accurate, show too much detail, occur frequently and cause many delays in the publishing of soil surveys. These problems merit special mention here for they can be solved through the use of aerial photographs.

1. Insufficiently accurate maps.

In this case a soil surveyor is faced with the problem of having to transfer his information to a map on which lines and symbols are less accurately located than is the case with his own work. The inferiority of older maps is often most clearly demonstrated when they are compared with aerial photographs.

A soil surveyor, who tries to compile a soil map using an inferior base map, can spend much effort in either:

(a) trying to locate common features of map and photograph.

(b) deliberately distorting his soil boundaries to "fit" the map pattern.

Neither occupation is rewarding and it is much better to prepare a new base map by simple photogrammetric means than to attempt to use an old inaccurate one.

It may be that the soil survey organization concerned has no qualified personnel to execute even a simple map production, and may need to seek the aid of a photogrammetrist. Now here may be a tricky problem, for photogrammetrists are trained to work to degrees of accuracy never dreamt of by a soil surveyor. It is becoming customary in photogrammetric circles to talk of errors of less than 1 meter, whilst a soil surveyor, making a general soil survey, might well be satisfied with an accuracy 100 times less. If a map at the same level of accuracy as the soil survey itself can be produced in one tenth of the time it would take to produce a map satisfying the professional standards of accuracy of the photogrammetrists, the situation is ripe for conflict. It usually takes a soil surveyor considerable persuasive effort to convince the photogrammetrist of the laudable function he would fulfill by producing a map quickly even at the sacrifice of some of his standards.

This difficult situation is so common in so many countries, that its recognition as an international problem led to the formulation of a resolution which was adopted by the Commission on Photo Interpretation at the 1962 Lisbon Congress of the International Society of Photogrammetry:

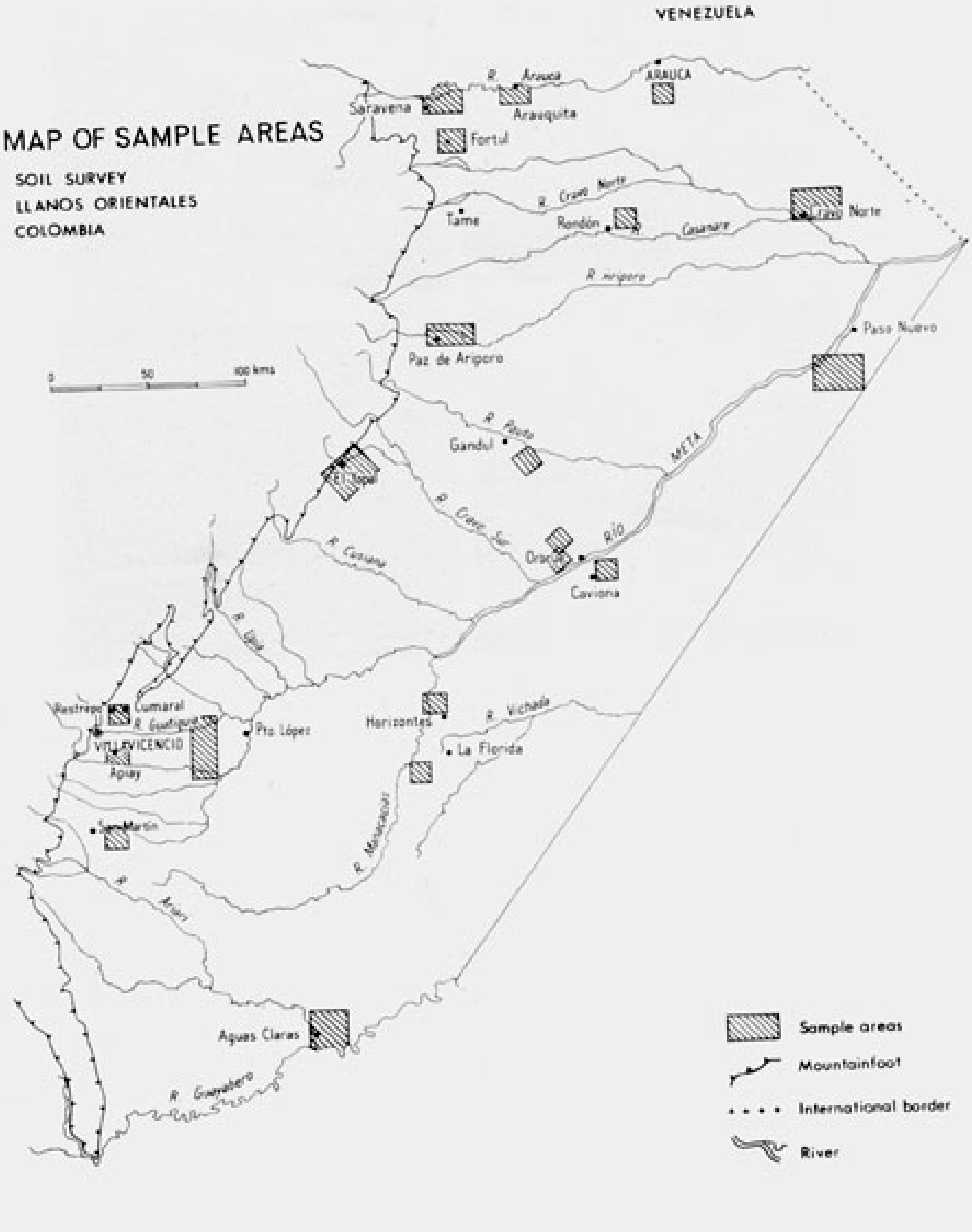

Fig. 56. Map of sample areas in a region of 13.000.000 hectares in the Llanos Orientales, Colombia.

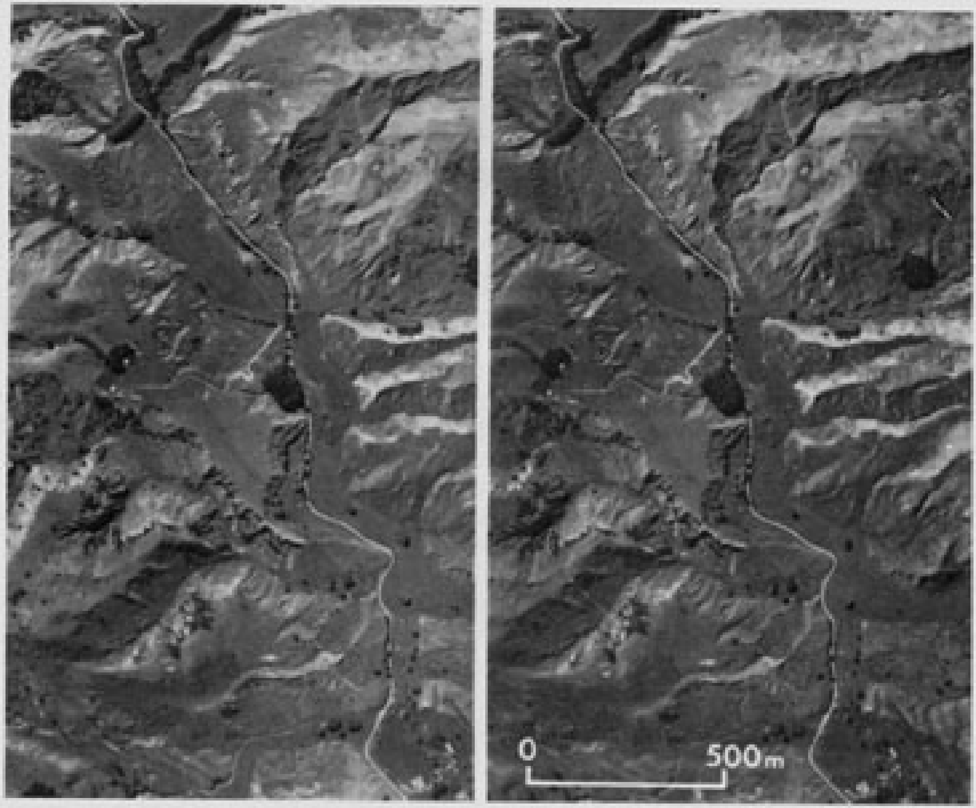

Fig. 57. *Stereogram of part of the Ngatapa area, North Island, New Zealand. This volcanic area shows various kinds of landform, not easily identified from a topographic map. (Courtesy Lands and Survey Dept., Wellington, New Zealand)*

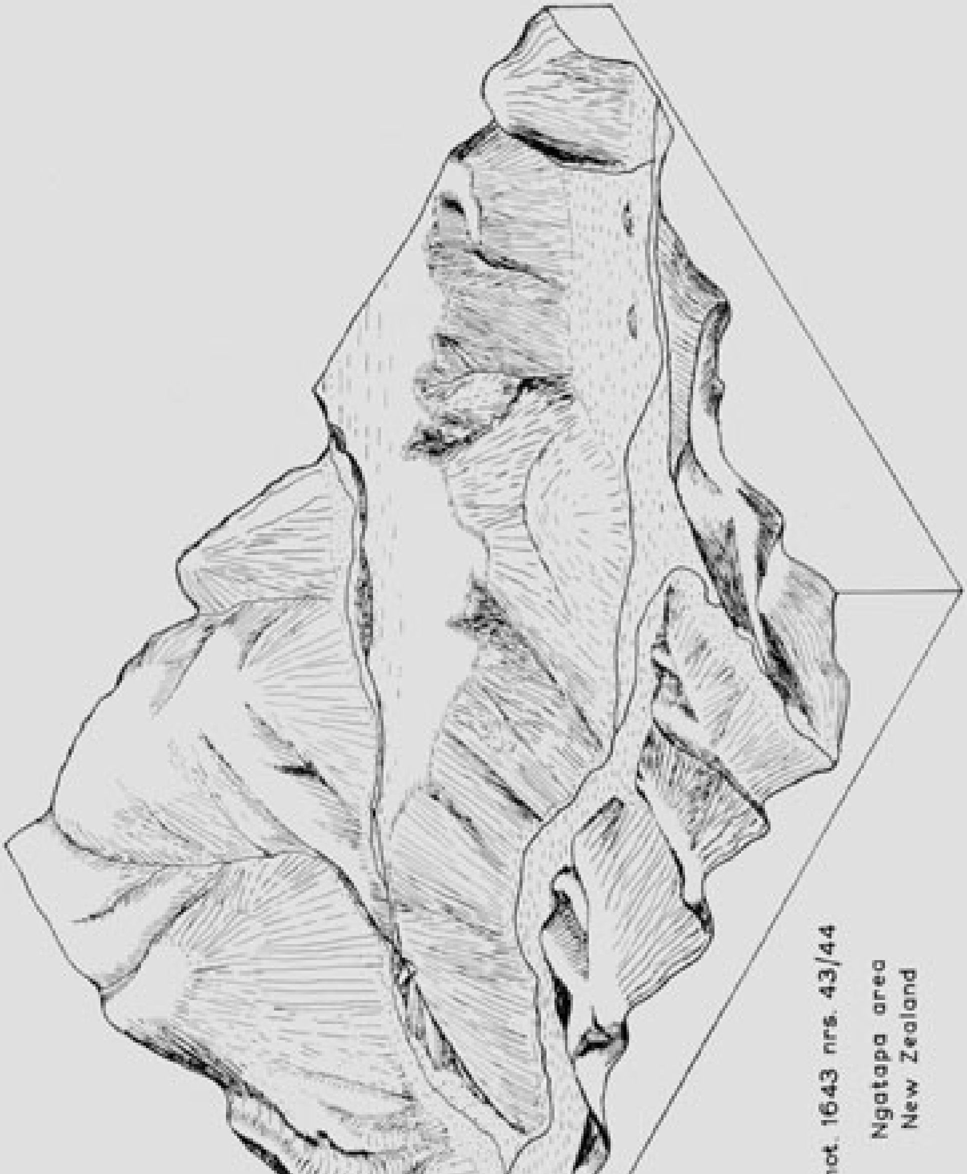

Fig. 58. Block diagram drawn from part of Fig. 57.

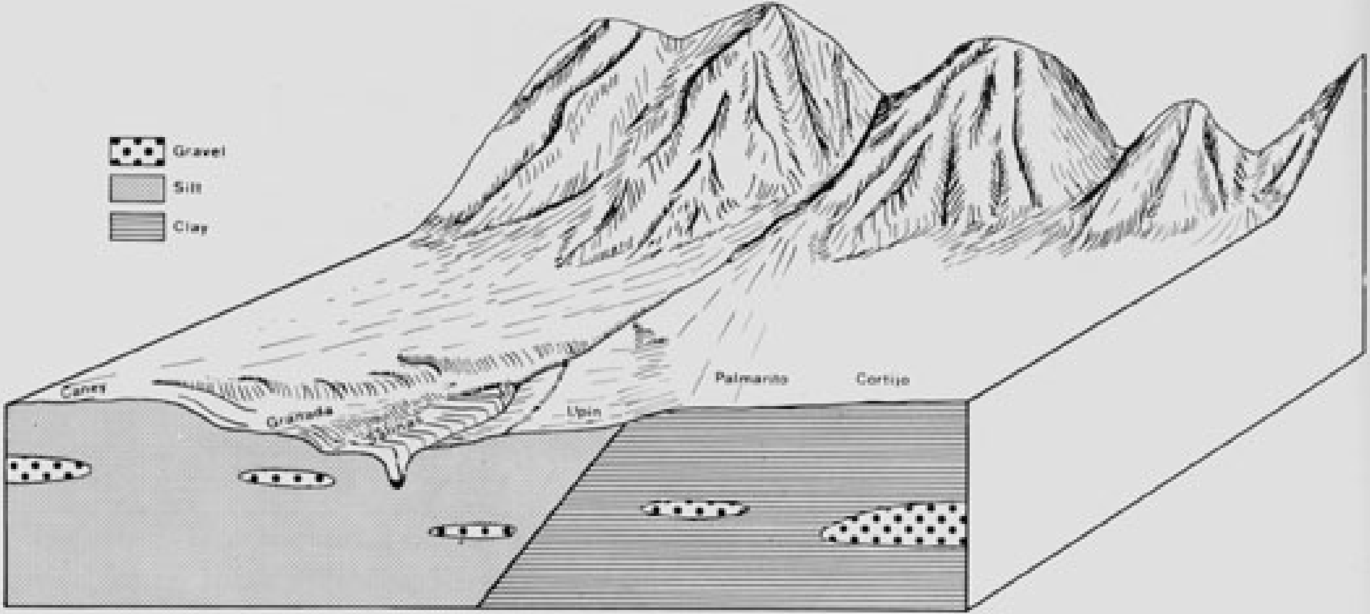

Fig. 59. Block diagram showing the location of soil series for the purpose of explaining how a certain soil association of a general reconnaissance soil map is composed.

> "Commission VII, during its final meeting on the 18th September 1962 at the Lisbon Congress, decides that for photo interpretation work in surveys of natural resources in large parts of the world, especially in developing areas, quick small-scale planimetric mapping techniques, including assembly of semi-controlled mosaics, is of the utmost importance, and recommends this aspect to the attention of the I.S.P."

At the same time, developing countries cannot afford to rely upon the assistance of expatriate photogrammetrists for their map production and must make determined efforts to have their own personnel trained in photogrammetry. Training facilities for this purpose are becoming more abundant each year in different parts of the world and, in the first instance, such training need only be at a relatively elementary level. Men capable of making simple planimetric maps, by the slotted template or even simpler methods, would be invaluable to many developing countries. Readers who are interested in the techniques involved in such work are referred to the Manual of Photogrammetry of the American Society of Photogrammetry (1965).

If mosaics of air photos are available, the cartographic problem is very much simplified. The lines of photo interpretation and field work can be transferred on a transparent sheet overlaying the mosaic, using a sketchmaster or even by direct visual comparison. Tytherleigh (1966) describes a method in which mosaics are constructed using only the odd-numbered (alternate) photos. The even-numbered photos are used in combination with the mosaic for obtaining stereoscopic vision, and the photo interpretation is traced directly onto the mosaic.

The tracing on the mosaic or on the overlay can be reduced photographically to the desired map scale.

2. Maps with too much detail.

Quite another problem has to be faced when accurate maps are available, but show too much detail for use by the soil surveyor as base maps.

The deficiencies of this kind of map are of two kinds:

a. The map space is full of symbols and names, so that any additional information (e.g. soil boundaries and symbols) would confuse the picture.

b. The map gives information relevant to soil conditions, in a way that is not satisfactory to the soil surveyor. For example, by use of symbols the map may indicate marshes, sandsheets, dunes and similar features, not sufficiently accurate, or unambiguously, as to meet the needs of a soil survey.

In both cases the soil surveyor is faced with the problem of how to simplify the map. Several possible methods exist:

a. To draw a simplified map on a transparent overlay.

b. To eliminate from the original map all nonrelevant features.

c. To print the topographic map in a different (subdued) colour than that used for the soil boundaries and symbols.

The most suitable method in each individual case will depend upon the availabilty of equipment and of technical knowledge. The first method may be preferred when good draughtsmen are available. It is time-consuming, but can be done completely under the direction of the soil surveyor. The second method needs a lot of cartographic skill, but can give very good results, while the third method is only possible when the necessary equipment is available.

Whilst there is no simple, universal, solution for the preparation of ideal base maps it is probable that much more suitable maps for this purpose could be obtained by closer collaboration between photogrammetrists and cartographers on the one hand, and soil surveyors (together with geologists, ecologists, etc.) on the other. Draft maps produced at an intermediate stage in the preparation of a topographical map might be more suitable as a base map, for example, than the final product.

For the sake of illustration, the stages in the preparation of a topographical map might be listed as follows:

1. Determination of control points on air photos.
2. Drawing of main topographic features.
3. Drawing of contour lines.
4. Addition of topographic detail.
5. Addition of nomenclature.
6. Printing of final map.

This is, of course, a simplified sequence. In reality many more operations may be involved, possibly in a different order. Nevertheless it serves to illustrate the point that, although the photogrammetrist regards only the final stage as leading to his product, draft maps produced at intermediate stages (stage 2 or 3, for example) might serve as ideal base maps for the soil surveyor.

A comparable solution has been in use for a long time in some large oil companies. There the cartographic departments have been established with the requirements of photogeologists in mind. The photogrammetrist and cartographers prepare base maps on which appear only the central points of the photos; rivers and strams visible on the photos; and the main roads. The map sheets produced in this way may not be pleasing to a professional cartographer but they suit the purpose of the photogeologist excellently. He has no trouble in locating the position of any photograph, and no trouble in drawing any geological detail he may wish to show.

By including the principal points of aerial photographs a major improvement can be made in topographic base maps from the point of view of the photo interpreter. Other improvements can be achieved simply by persuading photogrammetrist-cartographers to release certain intermediate phases of their work. Some progress has been made, and in some countries it is already possible to obtain simple black and white copies of maps formerly only available in at least 4 different colours.

If these relatively simple needs of the soil surveyor are not always fulfilled it is partly because of their own failure to recognize and express them.

Base maps derived from air photographs

It is possible to use copies of the air photos themselves, inscribed with soil boundaries and symbols, as maps accompanying the soil survey report. This method is already adopted in some countries, notably the U.S.A., and many excellent examples have been published (e.g. "Soil Survey of Lancaster County, Pennsylvania," published by the United States Department of Agriculture, 1959).

The advantage of using aerial photographs directly as a mapping base for the soil survey is obvious - all details of the ground are pictured on the photo and location is very easy. That this method has not found a wider application is due to a few disadvantages.

In the first place it is not possible to use colours to indicate the soil mapping units. For that reason the soil map, published on the photo map, does not give a ready overall picture of the soil distribution. In studying how a certain soil is distributed on the whole area, one must compare symbols, rather than colours, and this is less convenient. Still, for the user who wants to know what particular soil occurs in a particular place, reference to such a soil photo map is very easy. It can be said, therefore, that "the photo soil map is excellent for people interested in points, but rather poor for people interested in areas."

The second disadvantage arises when the photo is used as a base map for small-scale surveys of large areas, for then the general advantages of easy location are lost. The reduction of aerial photographs to scales 1:500,000,, 1:1,000,000 or even smaller results in the blurring together of individual objects (forests, agricultural fields, houses, towns, etc.) into an indistinct pattern. In such cases a topographic map is more valuable.

If the advantages of topographic maps and of aerial photographs were to be combined in one new type of map, many problems would be solved. Recently the Army Map Service of the U.S. Army ("Map substitute products," Corps of Engineers, Washington D.C. 20315) has obtained some very interesting results. Through an ingenious photographic laboratory process, this Service has developed the so-called "pictoline" method. The pictoline image is derived directly from aerial photographs, and produces a print on which the high contrasts between different areas are reduced and almost eliminated, while conserving the boundary between different areas of high contrast. For instance, in Figure 42 the various canefields contrast strongly in colour, ranging from nearly white to nearly black. A pictoline reproduction of such a photo would show only the field boundaries, and the white and black field would all show up in white, or at the most a light grey. It will be interesting to await the results of further research in this direction, especially with regard to its application in areas, where usually the limit between two contrasting areas is not so sharply defined as in cultivated areas.

Block diagrams

Soil maps transmit information about the soils. A flat soil map of an area cannot include much information on the physiography. The spatial aspects of the soils and the position of the soils with respect to the landforms is usually obscured and it takes a keen student of soils to understand directly these relationships from soil maps. For that purpose additional ways of representing soil bodies can be used.

In this respect the best method is the block diagram. Figure 57 shows a stereogram of a steeply sloping terrain in the north island of New Zealand. There is a close relation between landforms and soils, but that would not be expressed on the soil map. From part of this area a block diagram has been constructed, using the air photos. (See Fig. 58). A method of transforming a photo image into a block diagram is described by Goosen (1962).

The use of block diagrams is especially valuable for small-scale surveys, where the mapping units are soil associations, but where the individual members of a soil association do not appear as such on the soil map. In order to know the relative position of the individual soils (e.g.,soil series) a block diagram can serve better than a detailed map. An example is given in Figure 59 in which, firstly, the general position of the soil association is given with respect to the mountains and the location of soil series within the association is given on the surface of the block. The side of this block diagram shows the general composition of the parent material of the soils on an enlarged scale, below which a few important characteristics of the soil profile can be sketched.

This sort of information is not meant to replace the soil map but rather to provide additional information. The use of such block diagrams during general discussions with the users of a soil map or a soil survey report (including economists, politicians, and of course especially those working in, and for, agriculture), can often be a substitute for lengthy explanation. This will speed up the transmission of information from soil surveyor to agriculture, a consideration which should be of interest to every soil surveyor.

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