Image (aerial photo)-Interpretation for Soil Survey

Subject to revision

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PREFACE

These lecture notes, when completed, are meant as a guide for ITC students following one of the courses under NRM and AES programmes, such as Soil Information System for Sustainable land Management (SISLM), in Sustainable Agriculture, or Geohazards (Applied Geomorphology), respectively. The notes are meant to cover the practical aspects of image interpretation for natural resources surveys, in particular, soil surveys. The term image is used here to imply both aerial photograph and Landsat data. This means that a number of related subjects, such as principles of aerial photography, photogrammetry, Satellite remote sensing instruments used in interpretation will be shortly dealt with too.

The notes, when completed, focus on systematic ways to carry out visual image (aerial photographic) interpretation in soil surveys. Despite all digital techniques applied to Landsat data interpretation aerial photo-interpretation has still its place in natural resources surveys, simply because aerial photographs show the third dimension. However, image-interpretation should be done by specialists, for instance, a soil surveyor trained in photo-interpretation. The soil surveyor, of our example, should be first and foremost a well-trained soil scientist (pedologist) familiar with the conventional aspects and methods of soil survey work (Bennema and Gelens, 1969). As soil survey is interwoven with geomorphology use of aerial photo-interpretation seems indispensable. The aerial photograph and the stereoscope should be considered as tools, in the same way as the soil auger and Munsell color charts are. In these notes, natural resource such as soil and its survey (e.g., soil survey) principles take a central place. The photograph or Landsat data and image-interpretation should be made subservient to them.

However, the very present notes compose only one part of the planned lecture-notes. The focus in the first part is on the aerial photo-interpretation for soil survey.
Besides the examples given in the text, mainly derived from different sources and in particular from **the original lecture-notes (Bennema and Gelens, 1969).** However, several other examples will be used in the class room while lecturing.

Introduction:

It is already more than 4 decades ago that the Manual of Aerial Photographic Interpretation, where Prof. Buringh (The Netherlands) and Prof. Frost (United States of America) had important chapters on aerial photo-interpretation in soil Survey, was issued.
This holds also true for the lecture-notes written by Prof. J. Bennema and Ir. H. Gelens, and the FAO Bulletin No. 6 written by Prof Goosen. These two publications were intensively used by the participants of the courses in soil survey division (ITC in Delft and then, as from 1970, in Enschede); the notes that have been referred to in many books and publications since then.
Those days, aerial photographs were taken using aerial films (eg., panchromatic, infrared) and analogue aerial camera installed in the aircraft, which could fly at different heights depending on the scale required.

In recent years with the technological advances in the field of photography, image acquisition has changed drastically. The change is not confined to the use of digital aerial camera (for single image and videography) but it also relates to GPS planning. Contrary to the conventional ground survey, where levels, tapes, etc were used to establish distances, elevations, and so on, in the Global Positioning (GPS methodology) an electronic receiver measures the distances between the ground point and a minimum of four satellites, and the intersection of the divergent rays establishes the spatial coordinates of the observing station (Falkner and Morgan, 2002).

In spite of all the advances in digital photography, once a digital photograph has been printed it is virtually no different than one printed from film, and can be viewed in the same fashion. However, when in digital form, stored in computer, it offers much advantages, as it can be manipulated and analysed using various software programmes (Graham and Koh, 2002). This means, in short, that much of the aids for photo-interpretation (eg., mirror stereoscope), and photo-reading aspects (eg., texture, pattern) remain still valid.

1. Soil survey phases and the role of aerial photograph

Before discussing the techniques of photo-interpretation in soil survey, the position that visual image-interpretation takes in a soil survey project, the role it could and should play in it and its advantages and limitations should be discussed. Usually, a soil survey consists of:

a) **Information collection**
All existing surveys, including reports, maps (also topographic), databases, DEM, etc are collected and studied in order to learn about the area.

b) **Stratification**
This comprises the division of the survey area into geographical units, normally done according to the understanding of geomorphology/soil relationships. This is exactly the phase where image interpretation plays an important role. On the map, where these units are presented, every unit is marked by a symbol. These units are described in a legend. The legend describes the basic elements on the basis of which the unit is demarcated

such as geomorphologic features and lithology. The construction of a legend is an essential part of soil mapping and often requires a greater mental effort than any other part of it. The legend in its layout usually gives a certain grouping of the units on different levels (landtype, sublandtype, and mapping units in physiographic analysis, or relief-type, lithology and landform when geopedologic approach to image interpretation is applied. In the coming chapters it will become clearer how the legend of the interpretation map is made.

c) **Soil description and characterization**

This involves the detailed description of representative profiles of the individual soils and a description of their range of characteristics. This is done on the basis of field observations in profile pits, road cuts, quarries and from auguring. A generally accepted guide for the description of soils is the Soil Survey Manual (U.S. Dept. of Agriculture, 1993) and the FAO Guidelines for Soil Profile Description (FAO, 1990).

d) **Soil classification**

The described soils should be placed in a recognized classification system, to enable a comparison with similar soils elsewhere and to assist in understanding and remembering the similarities and differences among the soils of the area. Such a classification system may be national, or international such as Soil Taxonomy (USDA, 1998).

e) **Soil survey interpretation**

A soil survey only has practical value if it is followed by interpretation, where the properties of the soils are expressed in terms of their suitability for agricultural or other purposes. In this way the conclusions of the soil survey can be made also available to the interested non-soil scientists, who need the soils data as an indispensable item in development planning of the surveyed area.

It is easily realized that remotely sensed data (and in particular, aerial photography) plays an important role in the 'stratification'. Many physical and cultural features visible on aerial photographs have a correlation with the soil conditions. They can therefore be an important aid in establishing the boundaries of the mapping units. In other words, remotely sensed data help better locating of the boundaries of the mapping units, which otherwise is a time-consuming and expensive process. Aerial photograph is also needed when Landsat data are used, simply because Landsat data cannot be <u>easily</u> studied stereoscopically (see the figures S1, S2, S3 and S4; of stereoscopes, and some other facilities such as making use of anaglyph glasses, below). In small scale mapping use can be made of DEM, which is produced using contour line map, superimposed by Landsat data (see the example of Hamadan, in Iran). High resolution DEM's produced from ASTER images, or in many cases downloading from SRTM (at http://srtm.usgs.gov/), are very useful. Later on in the text you will see that DEM if properly prepared (say from contour map with contour interval of a few meters) can be used to prepare (digital) stereo-pair, which can be put up on the monitor and interpret it using screen stereoscope (see appendix 1).

To what degree the use of aerial photographs is time-saving, depends very much on the scale of the mapping. It should be understood that apart from using photographs for interpretation, they can be used in every survey as base maps. Unless very accurate and detailed large-scale topographic maps are available, the photograph provides the best base for accurate plotting of observations.; This holds true even for very detailed surveys, provided that the quality of photographs is not impaired by enlargement to the size necessary for the plotting of the dense network off observations required by such a survey.

As a general rule we may say that, up to a certain point, the role of photo-interpretation in a soil survey increases as the scale of the map (to be published) decreases. However, other factors influence the gain in efficiency achieved by using aerial photo-interpretation. The characteristics of an area play an important role. Some areas, on the aerial photographs, show more features indicating soil boundaries than others.
It is also obvious that photographs are not as essential when an area is accessible and when good topographic maps of it exist than in the case of inaccessible, poorly mapped areas. Still, the general rule that photo-interpretation plays a greater role as the scale of the soil map (to be published) gets smaller, holds true.

Consider also the fact that aerial photographs cover a small part of the light spectrum (panchromatic) whereas Landsat data are advantageous in this respect.

2. Aerial photo-interpretation

Most of the notes concentrate on the use of (panchromatic) Black and White aerial photographs (data captured in analogue way), knowing that even when digital, once the data are printed there is no difference as compared to one printed from panchromatic film. Obviously, digitally collected data have some advantages when they are still stored digitally. For instance, in terms of manipulations (using a software such as ‘photoshop’ in improving the quality) digital photographs are advantageous.

2.1 History

The use of photographs, particularly aerial photographs, for interpretation purposes, dates back to the 1st World War (1914-1918). In this time, interpretation was only used for military intelligence. Between the two world wars photo-interpretation was used by foresters in forest inventories, and by geologists in the exploration studies. There are only a few articles about the use of aerial photographs in soil surveying (Bennema and Gelens, 1969).
Photo-interpretation received another great stimulus during the 2^{nd} World War (1939-1945). Aerial photographs were taken in order to obtain information about the enemy's positions, troop concentrations, etc. Besides, accessibility of the terrain for different types of vehicles, potential sites for landing troops, and location of future air-strips could also be studied in advance. Obviously, in such a study landforms were separated with regard to their soil material, drainage conditions, etc., but without field check.
The tendency of using patterns, developed under the name "<u>pattern analysis</u>" method was probably originated from the same way air photos were used during the war time. This method was developed when some people considered photo-interpretation as a science.

Once the value of aerial photo-interpretation was discovered in soil survey, many people started using it. Buringh, being the head of Soil Division at ITC (Delft, The Netherlands) introduced the method "the element analysis", which is based on a systematic analysis of relevant individual elements, visible on aerial photographs. Further in the text, it is explained how physiognomic analysis was resulted from the element analysis.

Another method, called "physiographic analysis" was worked out in different countries and by different people. This method paid due attention to the analysis of geomorphic processes and the resulted landforms, extracted or seen on aerial photograph. The units, delineated in this way, could be associated with some soil properties. The method is far more straight- forward and scientifically logical than the element analysis.

In the seventy's some people thought that the introduction of Satellite data might be an end to the use of aerial photographs. However, in the course of this lecture it will become clear that so far aerial photograph has not yet been fully replaced. There is no doubt that photogrammetry has entered a new era, from mechanical graphic mapping to more and more computer-supported data collection. The field of photogrammetry is in the digital mapping era, and the mapper of today is more scientifically oriented than those of yesteryear (Falkner, 1995).

2.2. Phases in the process of visual image (photo) -interpretation

Visual image (aerial photo)-interpretation, which is considered as both an art and a science, can be seen as a process, including a number of phases, covering subjective judgement on the one hand and objective analysis on the other. The ultimate goal is to obtain the maximum information from the image (photograph or Landsat) for the purpose for which the imagery is used. Generally three phases are distinguished:

a. Detection, recognition and identification (sometimes referred to as "photo-reading")

This concerns the direct observation of objects and features visible on the photographs (see also 2.3. Human aspects of photo-interpretation).
Detection is when one observes that there is something. In the second step "recognition", shape, size, tone, pattern, texture and other visible properties (see under 2.3.1) help the observer to recognize the object, thinking of the object as something familiar to him or her. Finally in the step of "identification" the object is identified and given a name.

The degree of achievement in photo-reading depends on the person's acuity of vision and reference level. Some objects - often cultural objects - are so familiar that they can be readily identified. No photo-interpreter would fail to recognize a house and identify it as such, but it is more difficult to identify certain landscape features such as point bars, eskers or drumlins, for which a specialized reference level is needed. For instance, the gilgai of Fig. 13, or the termite hills of two different sizes and shapes in Fig. 14 are characteristic of certain parts of the world, in this case of Iraq and some African countries respectively.

b. Analysis

Analysis basically means dividing the aerial photograph into constituent parts, which is done on the basis of a qualitative and quantitative evaluation of certain kinds of objects or features. This means that when starting with the analysis phase (of the interpretation) it is first necessary to select which objects and features are to be analyzed. This choice will depend on the field of science for which the

Fig. 13 : Gilgai on air photograph

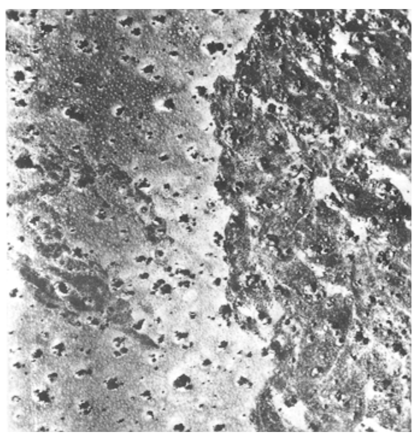


Fig. 14 : Termite mounds/ burnt bushes

photograph is employed. The geologist will start measuring strikes and dips of geological strata; the soil conservationist may analyze the pattern of soil erosion in terms of type and degree; the sociologist will probably delineate the areas of human settlement while differentiating them according to type and density.

There is no doubt that analysis should be done in a <u>systematic</u> way, and on the basis of pre-selected relevant objects or features. The kind of object or the particular features on which a particular analysis is based is usually called: "<u>element</u>" (Fig's S1, S2, S3, and S4).

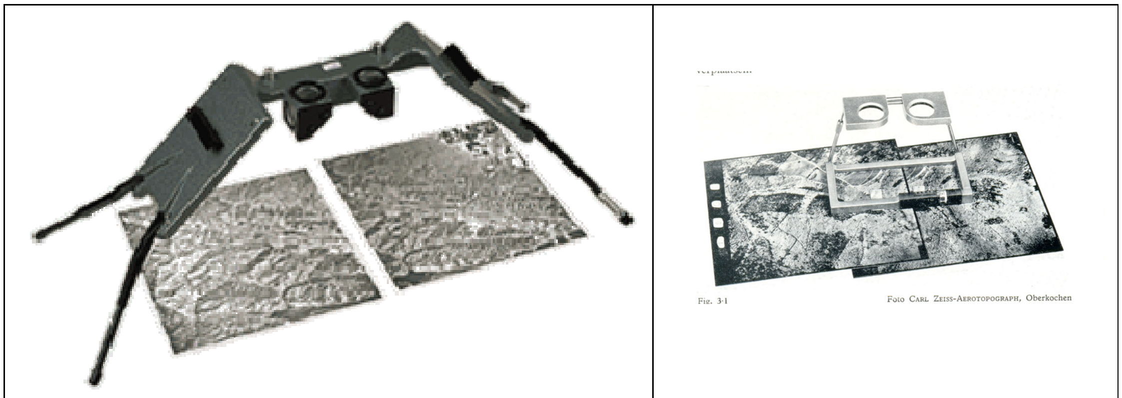


Fig. S1: Making use of (conventional) stereoscope (left: mirror stereoscope, and right: pocket stereoscope)

Fig. S2: Screen stereoscope on PC (left), and on laptop (right)

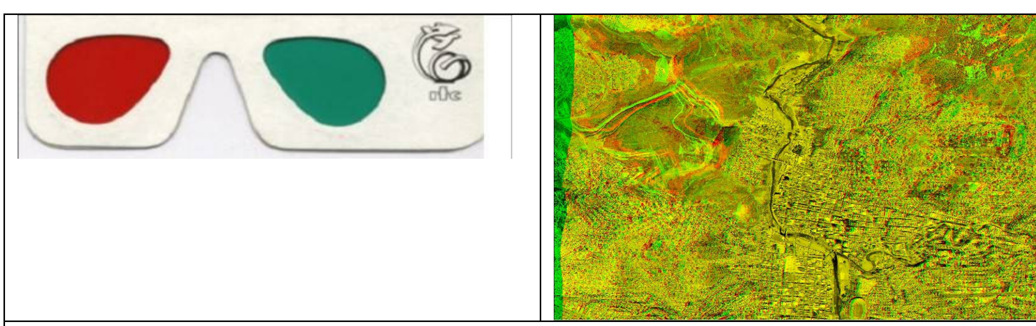


Fig. S3: Making use of anaglyph glasses

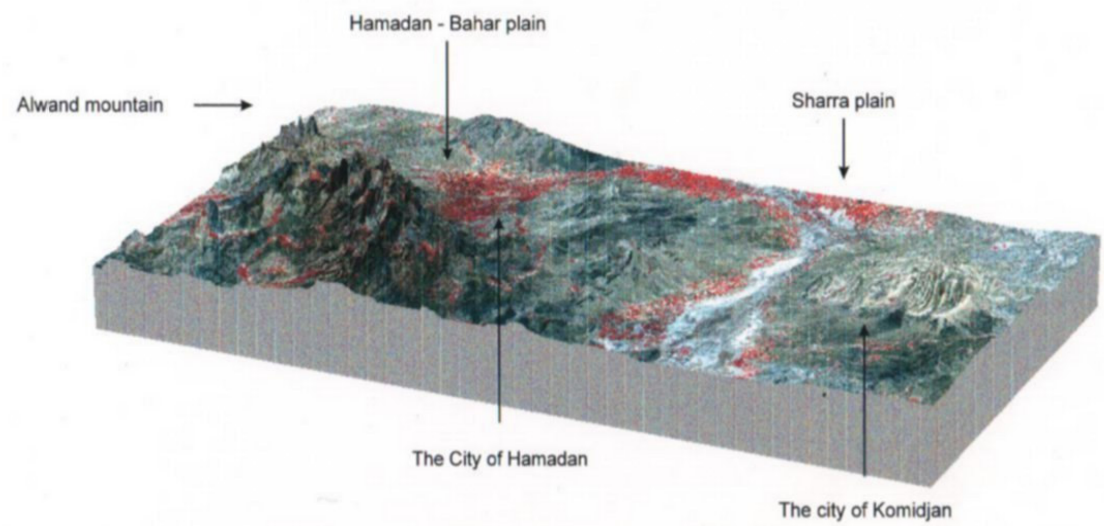


Fig. S4: Landsat (TM) laid over a DEM (made from topographic map with contour interval of 50m)

Classification

Photo-interpretation activities can be stopped after the analysis has been carried out, either because the analysis is the direct goal or because one wants to base all further information on field observations only. Soil surveyors may be satisfied to have delineated units which have a certain individuality, at least with respect to those elements on the photo on which the analysis was based. They are however never make any comparison between units, at least not in terms of soils content, before they have checked the units in the field.

A comparison based on the defined characteristics of the units resulting from the analysis will lead to the classification. In certain fields where aerial photo-interpretation is applied, this phase may give almost all the information required. This is not the case in soil surveying where a description and classification of the interpretation units still does not give the identity of the object of our study: the corresponding soil unit. For this we need the fieldwork and we then hope to find useful correlation between soil units and the classification of our interpretation units.

d. Deduction

Some authors consider deduction as a fourth phase in aerial photo-interpretation. Deduction is then seen as the phase dealing with the extraction of information that can not directly be observed in photo image itself, but can be obtained from the combination of observations on photographs and knowledge from other sources, that is, through "converging evidence".

Deduction, to us, is an inherent process of every phase of photo-interpretation except detection. How deduction plays a role in the phase of recognition and identification was already dealt with. The phases of analysis and classification also involve a good deal of deduction, a decision on which of the differences among units are the relevant ones for a classification is based on deduction and even the choice of elements used in our analyses might be seen as deduction.

2.3. Human aspects of photo-interpretation

Before discussing any principles or methods of photo-interpretation it is useful to consider what basically constitutes a photo. In other words: why do we see an image? And where we usually work with stereo pairs of photographs, why do we see a three-dimensional image?
A single photograph is basically a structure of grey tones. We perceive an image because there are grey tone differences. Spots of a particular grey tone become perceptible when this grey tone is different from its environment. Through the shape and size of a particular grey tone spot and through the kind of change-over of the grey tone into that of the environment, we may be able to identify it as a familiar object.
It may be easier to recognize it if we use two photographs taken from slightly different positions. Nearly always an object appears on a photograph not as an even spot but as a structure of grey tones which stands out as a whole against its environment. Between the different grey tone parts of the structure forming the object, there will also be parallax differences. These parallax differences bring us the third dimension. We should realize that this third dimension also can be seen only because of grey tone differences. Within an area which registers on a photo in an absolutely even tone, we can not perceive any height differences.

2.3.1 Summary: we may say that there are two basic components constituting a three- dimensional photograph image:

a. greytone (or colour tone) differences
b. parallax differences

There is no doubt that size, shape, and a number of other features such as shadows also help to visualize images

Size
The size is an important clue to the identity of an object. A canal has a much bigger size than a drainage ditch (Fig. 6A and B). Another example is at C (graves) as compared to D (houses)

*Fig. 6: Suburb of Utrecht, The Netherlands (Scale 1:5,000). **A** is a canal, **B** depicts drainage ditches. Note the boats in the canal. C might look to an inexperienced interpreter as streets with houses. Compare however with **D**, where we see the size of a real house. **C** in reality is a cemetery with tombstones.*

Shape

It is important to realize that we see our objects from above, thus they have a quire different shape from the one to which we are used. This is something to which one has to become accustomed. In Fig. 7, A is a road by its long narrow shape and B is a railroad because the latter is always straight or has very gradual regular curves while the former may have rather irregular curves or sudden changes of direction. The objects at C are recognizable as race track for horses because of its particular shape.

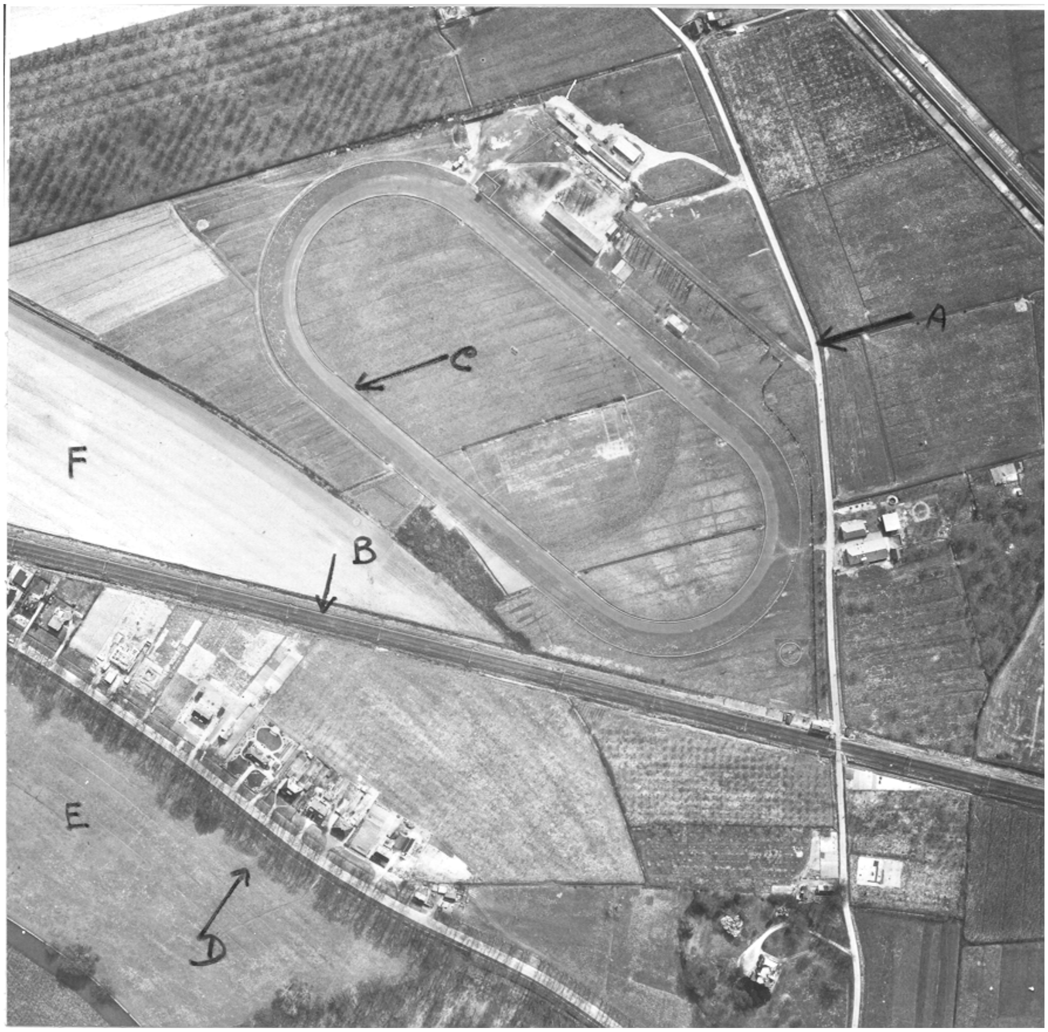


*Fig.7 : Suburb of Utrecht, The Netherlands (Scale 1:5,000). The photo illustrates the aspect shape of objects on photographs. **A** is a road: long, narrow, constant width but with rather abrupt curves. **B** is a railroad: abrupt curves do not occur. **C** is a race track for horses, recognizable by its peculiar shapes. The aspect shadow is demonstrated as **D**. The clear shadows of the trees along the road show better than the trees themselves.*
*Grey tone: the smooth road surfaces appear to reflect more light than almost any other object on the photograph (see **A**). See further the difference in grey tone between **E** grassland and **F** arable land.*

Shadows

Shadows are sometimes very helpful in photo-interpretation. For example, the shadows of the leafless trees at D in Fig. 7 tell us more than the images of the trees themselves.

Pattern

Pattern can be basically defined as the spatial arrangement of objects in a repeated sequence and/or in a characteristic order. The word pattern is applicable to the most divergent kind of objects. Descriptive adjectives may give an indication of what a particular pattern is like and in what way it distinguishes itself from another. By their pattern we may recognize many things on photographs. A few examples of patterns will probably clarify the concept better than descriptions can. The regular arrangement of trees at A in Fig. 10 makes it clear that we have orchards here, whereas at B we have forest. In Fig. 11 we can clearly distinguish a very regular rectangular pattern of land parcels in the parts marked with A, and a pattern of land parcels of irregular shape and size and under varying angles with the main road system (B). Note that the parcels in the A parts have generally a more even grey tone than the ones in the B parts. Nevertheless several of them show a pattern of spots, which could be called "mottled" (see mottling, below).

Fig. 10 : The Rhine river between Wageningen and Rhenen, The Netherlands (Scale 1: 20,000). At ***A*** *regular open pattern of trees characteristic for orchards. Compare with forest at* ***B****. At* ***C*** *a pattern of buildings characteristic for a brick factory in this area.*

Texture

Texture could be defined as a pattern, which is too fine to enable us to recognize the individual objects. It can also be expressed as follows: texture is created by repetitions in tone changes, caused by objects that are too small to be discerned as individual elements. Texture mainly plays a role in the recognition of different vegetation types covering the surface and in distinguishing the composition of forest stands. An example is Fig. 12, where 1 and 2 indicate two forest stands, which show different textures. We speak of fine and coarse textures. In our example we have at 2 a coarser texture than that of 1.

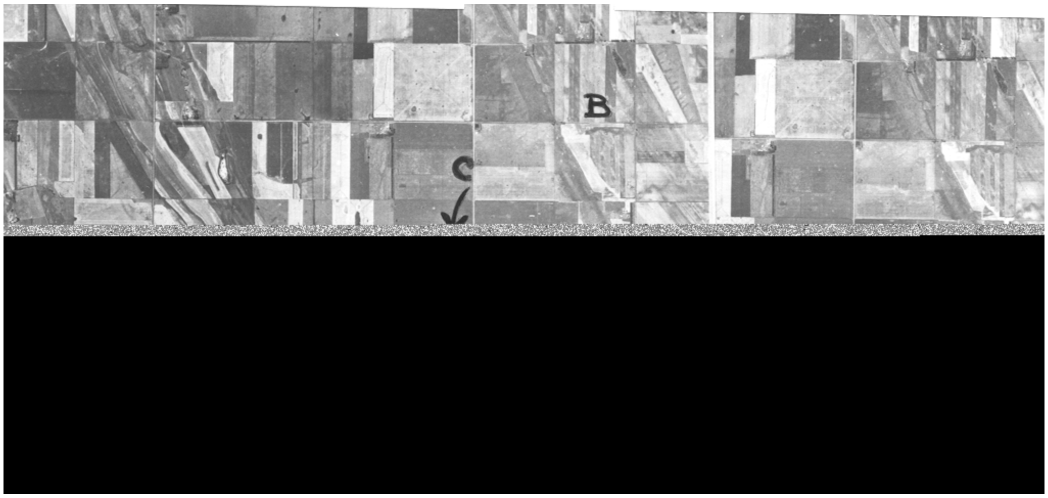


Fig. 11: Pattern: At A a regular rectangular pattern of land parcels. At B a pattern irregularly shaped parcels of varying size and at varying angles with the main road system. At C an example of mottling (see the photo-album).

*Fig.12: Grebbeberg area, The Netherlands. Scale 1: 20,000 and f (focal length) =21cm. Texture differences in planted forest stands. At **1** we have a stand of scotch pine which has a finer (we might possibly say, a more cloudy) texture than the stand of Douglas fir at **2**.*
*The difference is caused by the more pointed crowns of the Douglas fir trees. Note the stand of larsh at **3** which distinguishes itself from the other two by a much lighter grey tone and the stand itself from the other two by a much lighter grey tone and the stand of Pinus Nigra at **4**, which is of still darker tone than 1 and **2**.*

Mottling

We often encounter in photo-interpretation the term "mottling" or expressions like a "mottled surface" etc. Mottled means: covered with spots which may be of darker or lighter tone than the main surface, which appear in an irregular pattern and which usually are of irregular shape and size. In Fig. 10 we see some mottling at C.

Association

Association is meant that the occurrence of some features can be brought in relation to others. For example, when a doubtful object, guessed as yacht, is parked next to a house in the middle of a town. The photo-interpreter will become sure when he finds out that the house is located in a marina or at a river side.

2.3.2 The perception

Visual perception is formed through a combination of physical and mental components, which is very decisive in the quality of photo-interpretation and the extracted information from aerial photograph.

A. The eye

The human eye is considered as the most perfect multispectral remote sensor which is able to register global images with a central perspective and also to scan features. The technical characteristics of eye are as follows :

* spatial resolution : at focal length (25 cm) = 0.08 mm or 6.25 lines/ mm
* focal length : 25 cm (read- distance)
* angle of view : vertical 140^0
  horizontal, 1 eye 150^0
  2 eyes 180^0
* spectral sensitivity : adaptable according to the temperature of the light :
  - maximum day : 550 - 600 nm
  - maximum night : 500 nm
* spectral resolution :
  - some 200 grey levels (= light intensivity levels)
  - some 10.000 colours

B. The mental perception

The human vision is not an objective-technical instrument but is integrated with the total human perception and psyche. The most important psychological aspects which play a role in photo- interpretation are as follows:

i. The concentration field

It is known that not all objects within our perception field can be perceived with the same accuracy. We can simultaneously perceive between 6 to 12 objects. It is also known that although we can detect 200 grey tone levels, we can only distinguish 20 classes simultaneously.

ii. The memory

Very often the problem in photo-interpretation is to extrapolate things from one photo to the other. These things can be patterns, topography features, height, texture, etc. This is not equally easy to all specialists, because capability of memorizing is different from one person to another. The highest possible number of grey tones to be memorized is 10 -12.

iii. Optical illusions

Optical illusions have important influences on pattern- recognition, contrast-effects, edge- effect and stereovision (Following figures: A1, A2 and A3).

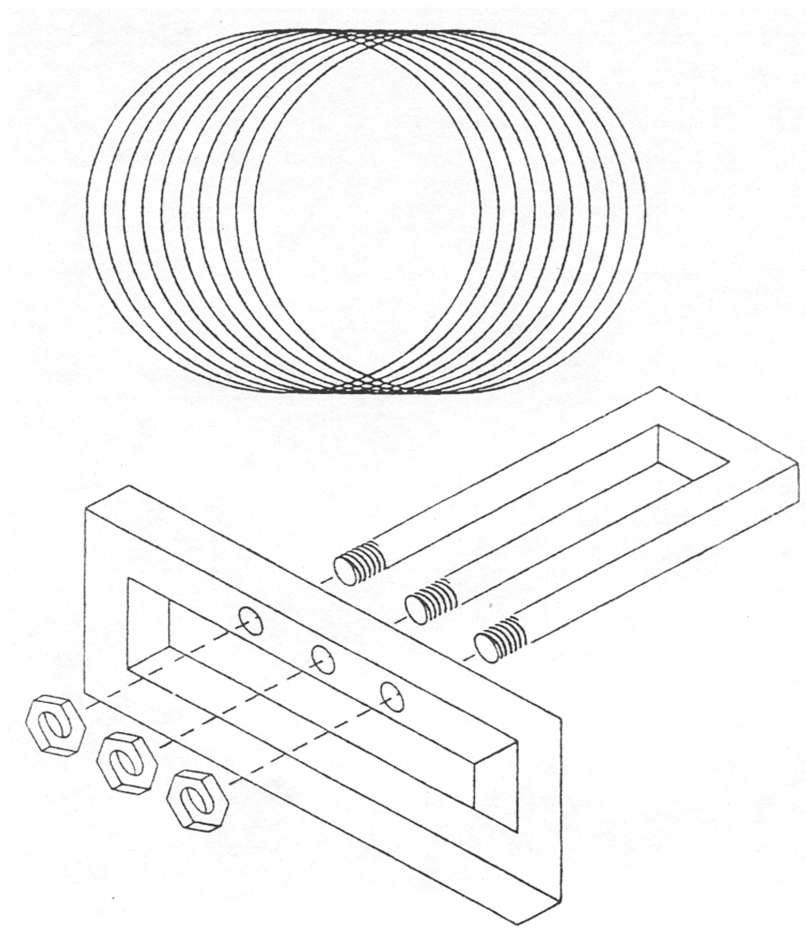


Fig. A1: Spiral looks like it changes direction. The three pins, block and nuts look like real, but in reality they are not.

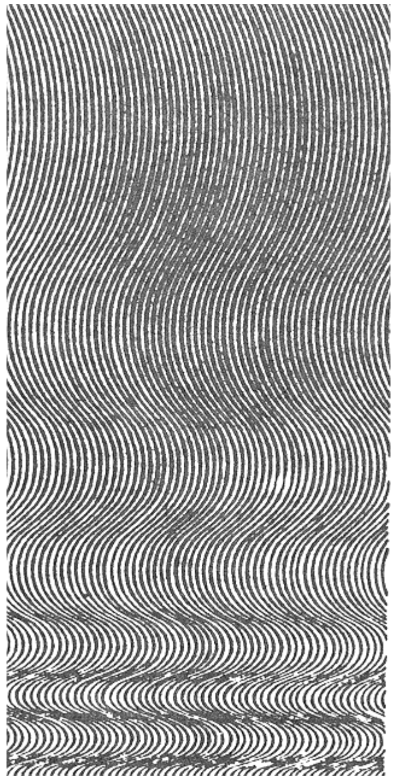


Fig. A2: This drawing gives the illusion like it is moving. The impression is stronger in the lower part, where lines are traced with closer interval.

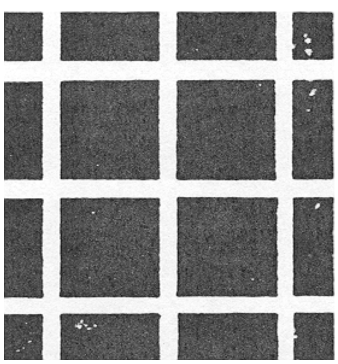


Fig. A3: In this plate: although we are sure that the white part is white the cross-points appear more grey than white.

iv. Affective influences

Affective influences are important because they have a deep, unconscious archetypical meaning and therefore are difficult to change by a training process. Most important effects for image interpretation are:

* warm and cold colour (red versus blue). Regarding colours; it is approved that working with false colours makes the interpreter earlier tired.

* relief effects : strong contrasts push foreword, low contrasts seem to be situated further away. The same feeling one has with coarse and fine texture. Coarse textures seem to be closer than fine textures.

* perfectness of objects or features such as polygons, circles, etc may lead to misinterpretation, simply because regular geometrical patters suggest an human action.

v. Image completion

The human perfection is finally made in the mind. All image - components are analyzed and compared to each other, making the human perfection one of the most powerful interpretation instruments (Fig.A4).

Fig. A4 : A perception test; try in your mind to complete the missing pieces. You will see then a horseman. Isn't it?

vi. Learned skills

Most people have been trained in reading since their childhood. Depending whether your alphabet is written from right to left, left to right or top to bottom, scanning of photograph will also be done in the same way (see also lettering in cartography).

2.3.3 Psychology of learning as a basis for visual interpretation

The methods for image interpretation can generally be grouped into associative (ideographical) and holistic or field theoretical (Daels and Antrop, 1980):

i. Associative: this starts with known samples (images) used for memory-training. It is making comparison between image- types (= reference material) and unknown image which leads to the interpretation of the unknown image.

ii. Field theoretical: forms the base for the holistic and structuralistic interpretation methods. It starts with the diffuse, complex totality of the unknown image. Stepwise and systematic analysis allows a gradual differentiation of this image into components, one can understand or recognize. Deduction, insight and reference level are vital.

2.3.4 Reference level

The more experience the soil surveyor has, the more reliable information about the soils he can deduce from the aerial photo. It is of importance to consider the "reference level" of the soil surveyor when assessing the possible advantages of the use of aerial photo-interpretation in a given case (Vink, 1964). Reference level may be discussed under the following headings:

i) general:

> Most educated people have a wide general knowledge including many facts, which may be quite useful in photo-interpretation. For instance the fact that man prefers to build his house on dry land is generally known. This fact may lead to the delineation of areas where we see permanent settlements concentrated on photographs and to further conclusions about such areas. The problem is to utilize such knowledge, which is often disregarded when conclusions have to be drawn from photographs. This knowledge should be activated and this is often attained by much work with photographs.

ii) scientific:

> Other things will draw the photo-interpreter's attention because he recognizes and understands them through a certain knowledge of such fields as geology, geomorphology, vegetation, etc. A reasonable knowledge of these, which can be called auxiliary sciences of soil science, is most important to the soil surveyor. He will with the aid of these auxiliary sciences, for instance recognize landforms and land systems and this will enable him to draw certain conclusions about the sedimentology and the parent materials of the area.

iii) specialized knowledge/ skills:

> There is also the specialized knowledge of the photo-interpreter as a soil scientist which may give him certain information about the area. E.g. from

the recognition of certain sediments such as wind blown sands, loess deposits or volcanic materials, he may draw preliminary conclusions about the fertility of the soils.

Apart from these, which could be called scientific reference levels, we should mention the local reference level. Familiarity with an area, country or region will enable an interpreter to gain more information from his photographs than if he was unfamiliar with the area. This applies not only to random features but also to many features, which have a relationship to soil conditions. In a given country a particular kind of land use may point to a particular soil condition.
The higher the reference level, the more preliminary conclusions the interpreter will be able to draw from the photographs.

2.3.5 Some (mainly) digital-specific terminology and activities

i. Image resolution theory: Resolution, although defined by physics, has strong foundations in human perception and visual visual acuity. For practical purposes it is possible to split image-resolution into two major parts: optics and sensors (Graham and Koh, 200). If two points on a photograph cannot be resolved they cannot be seen as two points but only as one. Although camera lens and sensor are the important factors determining resolution, other factors such as contrast play also role. Resolution can be increased artificially using the Photoshop software. This does not improve image quality, but preserve the original resolution. Three different methods of interpolation: Nearest Neighbor, Bilinear and Bicubic are available in the Photoshop software.

   Often when talking about high resolution the file size, file format, memory of the aerial camera-chip, the time required to load and download files, and data compression become vital issues to be considered (see Graham and Koh, 2002; pages 40 through 57).

   In summary, four types of resolution must be considered:

   - Spectral , that is, the specific wavelength intervals that a sensor can record. For example, SPOT panchromatic sensor records EMR between 0.51 and 0.73 μm (considered to have coarse spectral resolution), whereas band 3 of the TM Landsat sensor has fine resolution because it records between 0.63 and 0.69 μm.
   - Spatial, that is, the area on the ground represented by each pixel (example 79 is coarser than 10m)
   - Radiometric, that is the number of possible data file values in each band (indicated by the number of bits into which the recorded energy is divided). For example in 8-bit data , the data file values range from 0 yo 255 for each pixel, but in 7-bit data, the data file values for each pixel range from 0 to 128.
   - Temporal, that is, how often a sensor obtains imagery of a particular area. For example, the Landsat satellite can view the same area of the globe once every 16 days, whereas SPOT revisits the same area once each day.

ii. Aids for photo-interpretation: Traditional means such as magnifying glass, stereoscope, and parallax-bar are still very much used to do the interpretation. Depending on the scale of survey Epipolar Stereo Pair can be generated and studied digitally. Almost in all software programs such as ILWIS, ERDAS and PCI, offer the facilities to extract DEM, needed for making stereopairs as well as for orthophotos and perspective views (see the exercises' instruction papers; also http://www.uga.edu/~crms/gim.htm).

iii. Georeferencing: Probably, one of the most forthcoming terms in the field of digital mapping is the term 'image referencing. As remotely sensed data are affected by distortions caused by sensor geometry, scanner, earth rotation and curvature, etc georeferencing is a must (see ILWIS User's Guide, under 6.4).

3. Elements of photo-interpretation for soil surveys

3.1. General considerations about the elements used in photo-interpretation for soil surveys.

In our discussion of the different phases of photo-interpretation we have said that when starting the analysis of a photo, we have to make a choice of what we want to analyze. The kind of objects or features on which a particular analysis is based, is called an "**element**". If we made a list of all the elements which could possibly be analyzed on a photograph, we would find that they are numerous. Not all of them, however, are of equal interest to the soil surveyor. For example, we could make a detailed analysis of the houses on a photograph and group and classify them according to their size (small and big houses) or the density of their occurrence, and so on. We could do the same with roads: wide or narrow roads, straight or curving, etc. This kind of analysis would have no or only an incidental significance to learning something about the soil distribution.

A soil surveyor should therefore look for those elements that do have a relation to the soil. There are many physical and cultural features, visible on aerial photographs, which indeed have a correlation with soil conditions. Moreover, we shall see that in many cases we can see on the photographs something of the soil bodies themselves, such as their surface configuration or certain properties of the topsoil.

Often soil boundaries will neither directly, nor indirectly through correlated features, show at the surface. Such boundaries can not be expected to be traceable on aerial photos. Mostly this will concern soil differences based on the lower categorical levels of soil classifications. If, as in detailed soil surveys, such soil differences have to be mapped, we often have to do it fully through means of ground observations. It may, however, happen that boundaries required on semi-detailed or reconnaissance maps can not be traced from the photos. These also have to be located by means of ground observations. This will further be dealt with in soil survey methodology.

The elements that have a relation to the soil are often the elements that at the same time lead to the recognition of landscape units. Such landscape units usually constitute natural soils bodies, although they usually present a complex or an association of soils. It is therefore logical that the more experienced soil surveyor - photo-interpreter - will try to recognize and delineate these landscape units directly, as is done in the physiographic and physiognomic analysis, both of which will be discussed at length in the next chapter. Also these kinds of analysis basically rely on the elements. The elements therefore deserve our thorough attention. We will first give some general considerations here and next discuss a number of elements individually.

3.2. Grouping

Several authors have attempted to make a grouping of the elements. Buringh (1960) speaks of **physical**, **natural** and **cultural** elements. Vink (1964) developed a system of six groups.

It should be noted that some of the elements used in photo-interpretation for soil survey are visible as such on the photographs, whereas other either become visible through a complex of other elements or, by means of deduction, are inferred from other elements. This has led us to recognize three groups of elements (Bennema and Gelens, 1969).

3.2.1 Basic elements

These are elements visible as such on the photographs. We give the following examples among which one finds to be of importance for the soil surveyor:

a. surface configuration which may be described in terms of slope and relief.
b. natural vegetation
c. some crops
d. surface soil
e. rocks
f. water ice and snow
g. human constructions
h. animals
i. clouds

3.2.2 Compound elements

These are elements which are visible on the photographs through a combination of two or more of the elements of the first group, while often their occurrence in a pattern helps to recognize them. Elements belonging to this group are:

j. drainage ways, gullies and ditches
k. drainage pattern
l. land use
m. parceling
n. faults and joints
o. animal constructions

3.2.3 Inferred elements

These are elements which are not visible on the photographs, either as such or as a combination of elements, but which can through deduction be inferred from elements of the first two groups. Elements belonging to this group are:

p. drainage condition
q. parent rock and parent material
r. soil depth
s. erosion conditions

It is necessary to make some comments about the relation of the elements of these three groups. Elements are only of importance for the photo-interpretation for a certain soil survey if they have in one way or another a relation to these soil conditions, which we want to show on the pertinent soil map. Occurrences of a special kind of vegetation are not relevant if they are only due to human influences. They are also not relevant if they indicate soil differences, which can not be shown on the soil map because the scale does not allow it.

If required elements can be analyzed according to the following aspects (Buringh, 1960):

a. grade or density
b. type or shape
c. size
d. regularity
e. site or geographical position.

When analyzing an element on a photo one should consider all these five aspects in order to utilize the element to its full extent. Variations in each of the aspects contribute to the completeness of the analysis. The idea is demonstrated below for the element "slope".

a. **grade**
Slopes can be divided into different classes according to their steepness flat-nearly level, slightly sloping etc.

b. **type or shape**
There are convex slopes, concave slopes, straight slopes.

c. **size**
Slopes may be differentiated according to length; long-medium-short. The numerical values of such classes depend on the circumstances.

d. **regularity**
Slopes may be regular or irregular or any gradation in between

e. **site or geographical position**
Slopes may have different expositions, e.g. north and south slopes. Another possibility is that when level parts or slopes of the same grade in a mountainous landscape occur in the valley parts as well as near the summits, they can be distinguished according to elevation.

It should said that with certain elements one or several of the five aspects will prove to be irrelevant or will play an insignificant role.

A very practical way to analyze an element is the approach of Goosen (1967; FAO publication No. 6). He lists a number of elements and gives an evaluation in terms of high, medium and low for the following characteristics:

a. visibility in the stereo-image
b. relation to soil conditions
c. coincidence with soil boundaries

For an evaluation of the elements which discusses, we refer to his FAO publication.

4. Discussion of a number of individual elements

In the following, a few selected elements (of basic, compound and inferred groups) will be discussed. The same way can be applied to discuss the applicability of the other elements, listed in former chapter.

4.1 basic elements

a. slope and relief

Slope and relief (complex slope) are both elements, which are of great importance to soil surveyors. Both have a "high" visibility in the stereo-image, a "high" relation to the soil condition and a "high" coincidence with the soil boundaries. Of these, the high visibility in the stereo-image is quite obvious, as depth perception through parallax differences is one of the essential components of a stereo-image.
We should realize, however, that the stereo-image that we see through the stereoscope does not give a true impression of slopes and relief (Fig.15A, B and C). Generally slopes appear steeper than they really are and we speak of "**vertical exaggeration**".

The relation to the soil condition is of different kinds. First of all there is a direct relation because, soil is a three-dimensional body, the configuration of the surface can be considered as a soil property. Even with the same profile development, those differences in slope and relief among soil bodies, which have practical consequences, lead to a distinction being made between different slope phases. Such slope phases play an important role when it comes to land classification because they influence susceptibility to erosion, the possibility of using certain implements and machinery, etc.

Often, however, slope differences indicate more than a mere difference in slope phases.

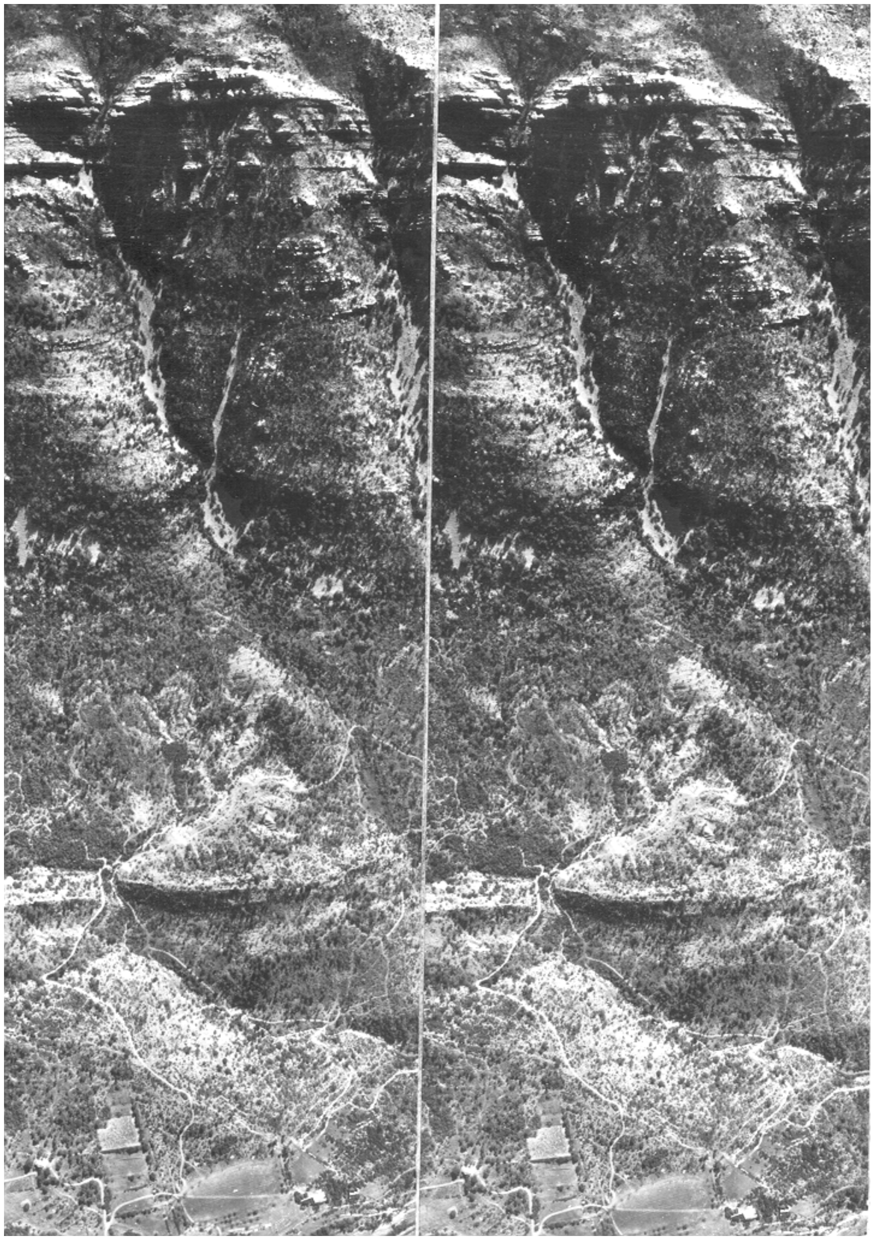


Fig. 15 A: An area in France, near Aix and Provence. This stereogram should be compared with Fig. 15 B and Fig 15 C, on the following pages. Three stereograms are made, using one and the same run of photographs. The overlap of consecutive photos was close to 90%, hence photos could be selected such that the air base of photos of Fig. 15B is three times that of Fig. 15 A, and that of Fig 15C is five times the one of Fig. 15 A.

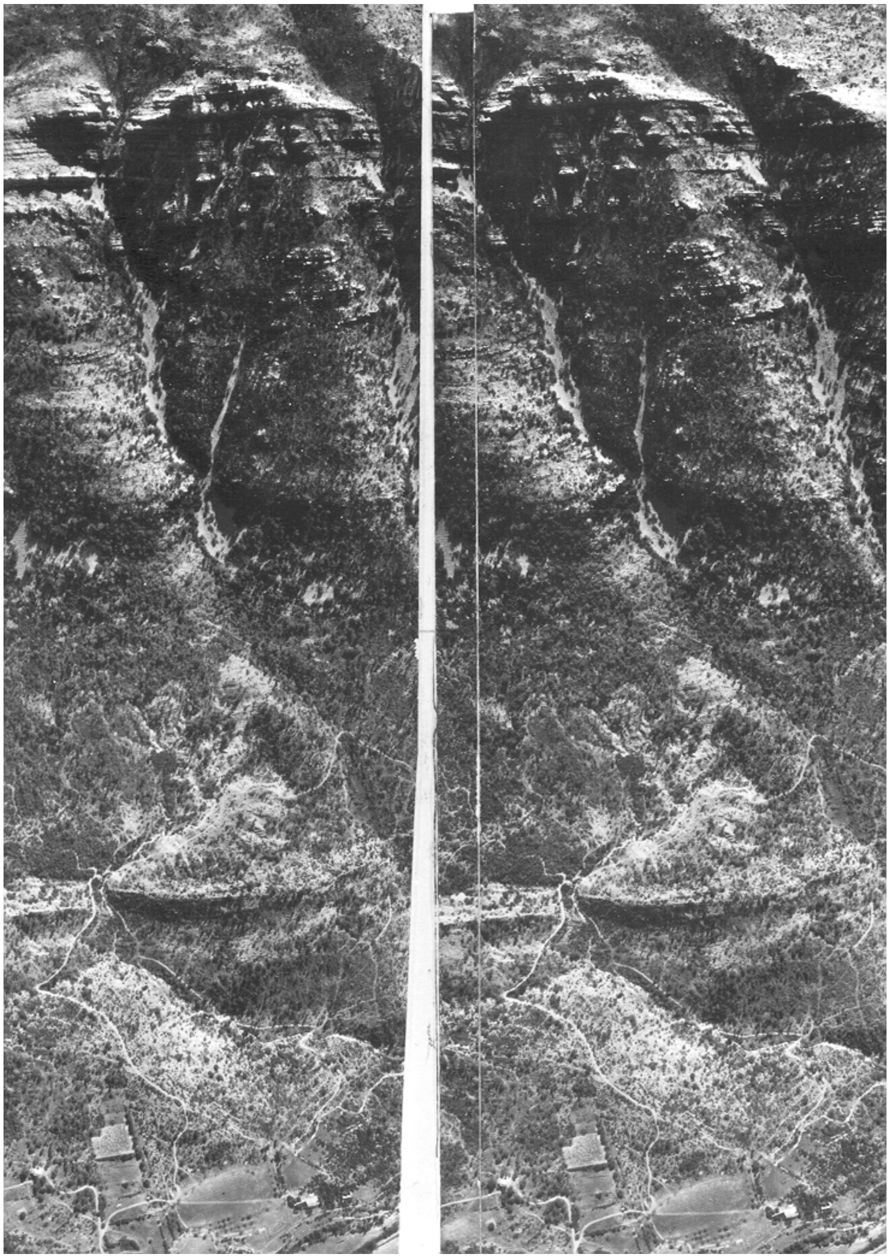


Fig. 15 B: Stereogram cover an area in France near Aix and Provence (See Fig. 15A).

Fig. 15 C: The stereogram covers an area in France, near Aix and Provence (See Fig. 15A).

As relief is a soil-forming factor, one can expect that differences in slope and relief bring about differences in profile development. Slope and relief are closely related to drainage conditions, the accumulation and sorting of parent material, whereas slope and relief are also expressions of the geogenesis of an area which is interrelated with the pedogenesis. A clear example is the different layers in sedimentary rock formation; these may have different hardness, and where their contact-line comes to the surface, there is often then a break of slope. This break of slope will most likely be a soil boundary, as the different parent materials give rise to the development of different soils.

Fig. **16** illustrates a situation where the occurrence of alternating hard and soft layers is marked by breaks of slope.

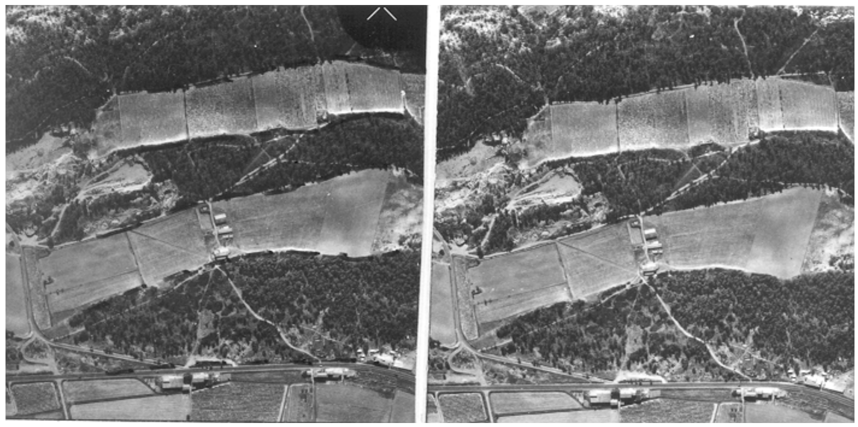


Fig. 16:layers of different parent material have different slopes. The Contacts of the layers are marked by rather sharp breaks of slope. The different parent materials give different soils.

Aspects of the element single slope

We will now consider the different aspects of the element "single slope". This is an expansion of what was discussed earlier in this chapter.

Grade

A slope can have different grades. Soils occurring on different segments of a slope can be different. It is important to pay attention to breaking point in a slope. The following 6 classes may be used:

Symbol	Lower limit	Upper limit	Descriptive terms
A.	O	- 1 to 3%	level, nearly level
B.	1 to 3	- 5 to 8%	gently sloping
C.	5 to 8	- 10 to 16%	sloping
D.	10 to 16	- 20 to 30%	moderately steep
E.	20 to 30	- 45 to 60%	steep
F.	45 to 60%	- up	very steep

There is a certain overlap in these classes so they can be adapted to a given situation. Depending on the situation we may, in an interpretation, often group two or more classes together. In actual practice we shall discover that rarely can an analysis be carried out on the gradient of single slopes alone. Usually complex slopes (relief) will have to be considered too.

Shape

The second aspect of the element slope is its shape or form. We can recognize three basic forms (Fig.19):

a. convex
b. concave
c. straight

The stereogram of fig.19 gives a good example of a convex slope between A and B and a concave one between C and D. Combinations of the basic forms often occur on one slope.

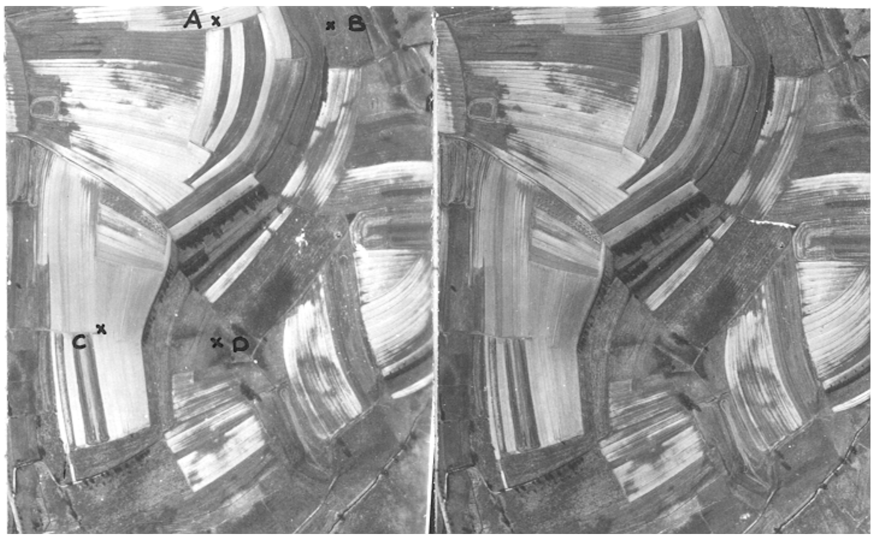


Fig.19 : An area in Luxemburg; Scale 1: 15,000 f (focal length)=15cm
Convex (A B) and concave (CD) slopes are depicted

Size

In many cases this aspect may be irrelevant but in other cases the length of a slope may have practical implications. Long even slopes may entail a greater erosion hazard than short ones. There is of course a practical limit to the length of a slope that can still be analyzed as a single slope. Depending on the circumstances - the scale of the photos and the map to be produced are in this case often decisive - one has to decide what slopes can be analyzed singly and where one has to see them as part of a complex, part of a relief class.

Regularity

Some slopes are very even and uniform, others have irregularities, a number of changes in the direction of the slope. These latter ones can, however, have the same overall slope as the even ones. Sometimes one could possibly say that the irregular slopes have a kind of superimposed micro relief. Fig. **22** shows different degrees of regularity, while the overall slope is the same.
The regularity of a slope may be a measure for its uniformity of parent material. The kind of irregularity which is caused by what we call a superimposed micro relief can in many cases be attributed to stoniness or rockiness and such irregular

slopes or slope parts should be separated from the regular ones which possibly have deeper profiles. Fig. **23** shows a slope on which two classes of regularity can clearly be distinguished. The two have been delineated on the overlay and marked A and B. The more irregular part B is a rather recent lava flow superimposed on an older one, still at the surface in A. An irregular slope may also be caused by recent erosion (Fig. **24)**.

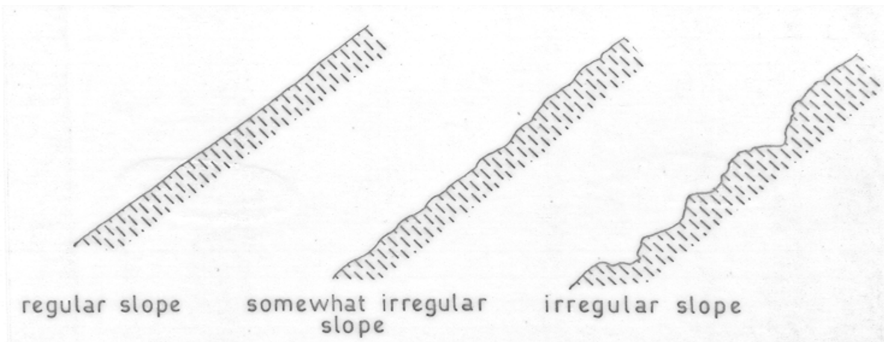


Fig. 22: Schematic view of regular/irregular slopes

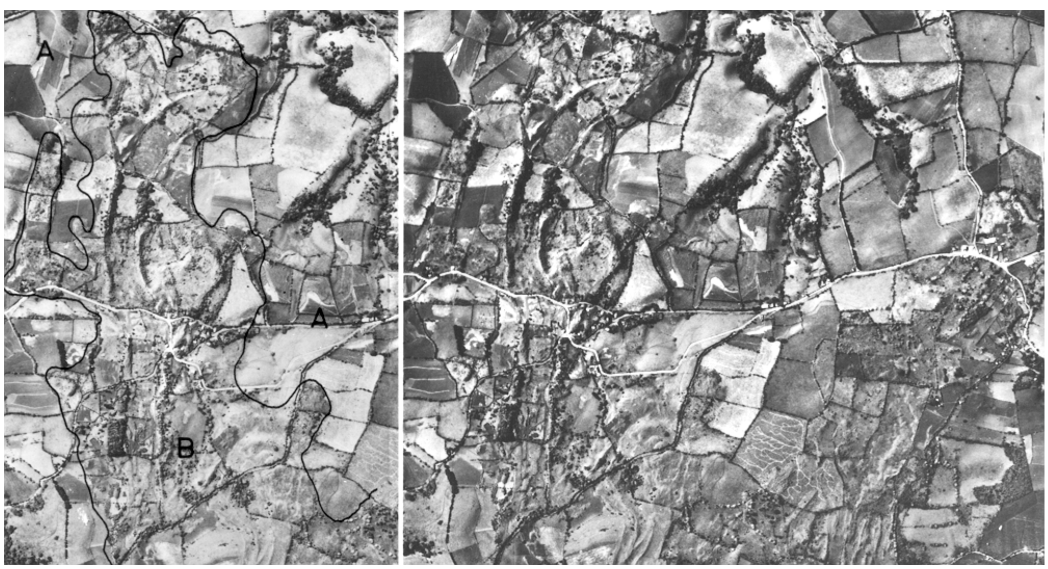


Fig. 23: Boqueron, Costa Rica;   Scale 1: 20,000   f (focal length)= 6"
***A** is more regular than **B**, which can be called irregular. **B** is a more recent lava-flow superimposed on an older one, which is still at the surface in the part marked **A**.*

Fig. 24: Irregular slopes caused by recent erosion.

Site

The site or geographical position of a slope may play a role in our interpretations. Two slopes may be the same in all four previously mentioned aspects: same gradient, same length, same type and of the same regularity and yet they may have different soils because of different exposition. The exposition may influence their climatic conditions so much that different profile developments result from it. Such a **25** at any rate demonstrates the different conditions prevailing on slopes different profile development cannot be illustrated on an aerial photograph but Fig. with north expositions and on slopes with south expositions as can be clearly seen from the tree growth.
The same kind of climatic differences may occur between two identical slopes with a considerable difference in elevation. It should be remembered that these considerations are also valid for flat parts of the terrain, for these can be considered as slopes with a zero gradient.
To be of importance to the soil surveyor, differences in geographic position do not have to entail climatic differences. In a system of river terraces the terraces should be analyzed according to their position, not because the differences in elevation has climatic consequences but because the different positions imply differences in the time factor in their soil development.
Finally the position of a slope may have an important relationship with the stratigraphy. Simplifying, we may say that one slope can be parallel to the strata of a geological formation and another perpendicular to them. (Fig. **26** demonstrates such a situation). Normally this will also have an effect on the form and regularity of the slope, while an identical gradient would be rather a coincidence. Often this special aspect in slope position is considered as part of a separate element: stratigraphy, which at times can very well be deduced from other elements visible on the photographs.

Aspects of the element relief

The world relief is used in many senses. It is "a pattern of slopes" or "a complex of slopes" or simply "complex slopes". We may say that relief is the configuration of the land surface and an integral part of the particular soil body to which it belongs

Fig. 25: Gallatan County, Montana, USA Scale 1: 20,000
This photo together with the adjacent one (numbers NE-58-88 and NE-58-89; see the album) are to be studied under stereoscope to see the different conditions on slopes with different exposition. The north slopes have a thick forest cover, while the south slopes are almost without.

(see Soil Survey Manual, pages 8-9, 64-70). Relief is the product of geological forces, climate and vegetation acting on a given pertain material during a certain period of time. The stereoscopic image shows its present stage of development.

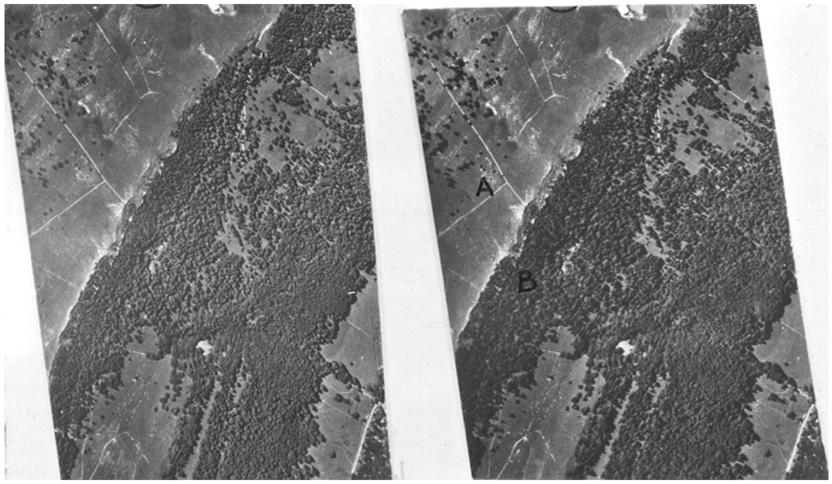


Fig. 26: Jura in Switzerland   Scale 1: 17,000   f= 21cm
*Different slope conditions as a consequence of stratification. The moderate slope as **A** is more or less parallel to the strata. The steep slope as **B** is perpendicular to them.*

Grade

This implies to the gradient of the slopes forming the major part of the relief. The six classes used in interpretation are:

Symbols	Lower limit		Upper limit	Descriptive terms
-------	-----------		-----------	------------------
A.	0	-	1 to 3%	level-nearly level
B.	1 to 3%	-	5 to 8%	undulating
C.	5 to 8%	-	10 to 16%	rolling
D.	10 to 16%	-	20 to 30%	hilly
E.	20 to 30%	-	45 to 60%	steep
F.	45 to 60%	-	up	very steep

Strictly speaking grade is not linked with particular differences in elevation between the tops and the depressions of the relief of a landscape. It is obvious that relief is normally too complex to be characterized by grade alone. Fig. **27**, however, illustrates a case where two kinds of relief can be distinguished mainly on the basis of grade. In the following we will see how relief can be different from case to case other than on the basis of grade.

Shape and type

The shape and position of the individual elevations or inequalities with regard to their environment will to a great extent characterize a particular kind of relief and mark it as a certain type.
In many cases there is a main level in a landscape (reference level) relative to which relief can be called positive or negative. Fig. **28** shows an example of negative relief.

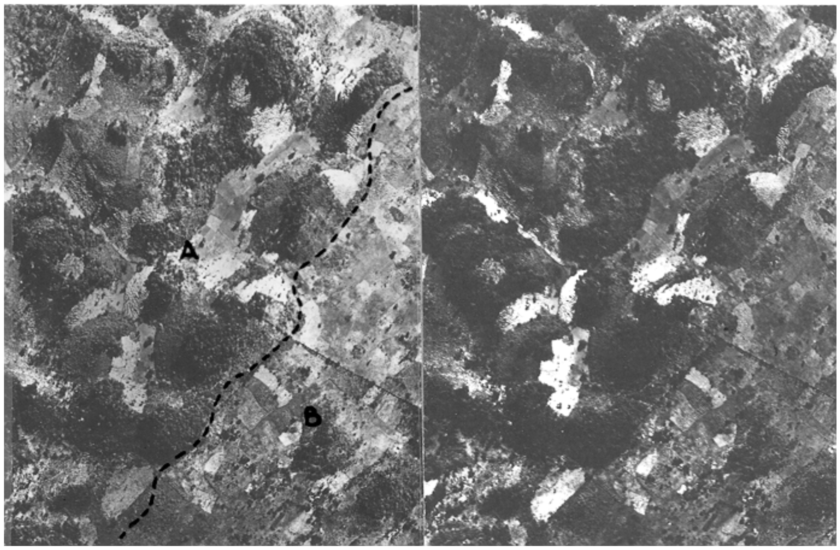


Fig. 27: An area in Jamaica   Scale 1: 14,000   f = 6″

*The areas **A** and **B** show two different types of relief. The difference is mainly characterized by a difference in grade. The slopes in the **A** are much steeper than in the areas indicated by **B**.*

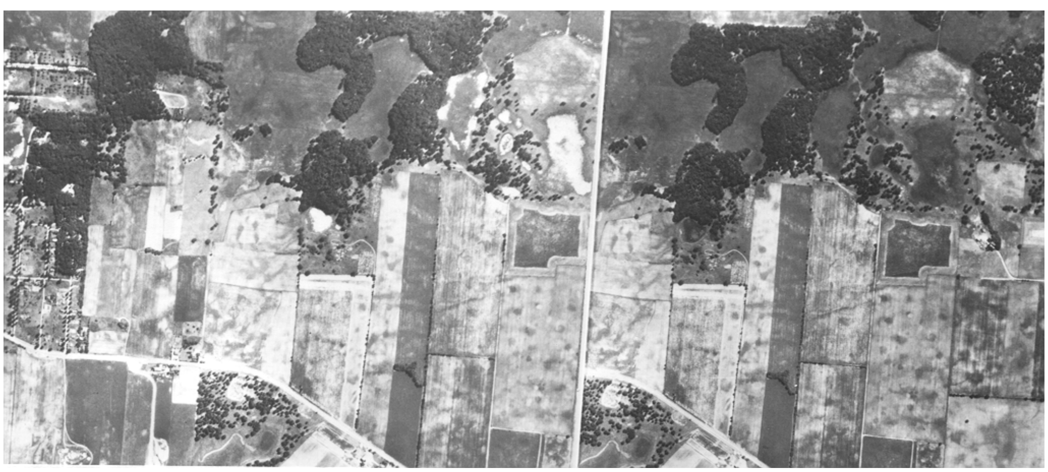


Fig. 28: Mc Henry County, Illinois, USA   Scale 1: 19,000   f = 8,25″
(stereogram by the University of Illinois).

A pitted outwash (glacial) plain is depicted. This can be used as an example of negative relief (if needed!!).

The shape and distribution of certain elevations or depressions may be so typical that the relief types formed by them have their own characteristic names such as barchan dunes, fans, glacis, etc.

Size

It is evident that a volcano and a mole-hill, although they may have the same slope gradient and about the same shape, can not be considered the same. From this example it becomes clear that relief has to be considered at different levels. We can see this as the "size" aspect of the element.

Regularity

When we have a regular repetition of the same relief form, we may speak of regular relief. When, on the other hand, the relief of an area is characterized by the fact that slopes are of different gradients and lengths, we may speak of irregular relief. In these cases we may have to use terms in the description such as: undulating to hilly. Fig. **31** illustrates what we mean in this respect.

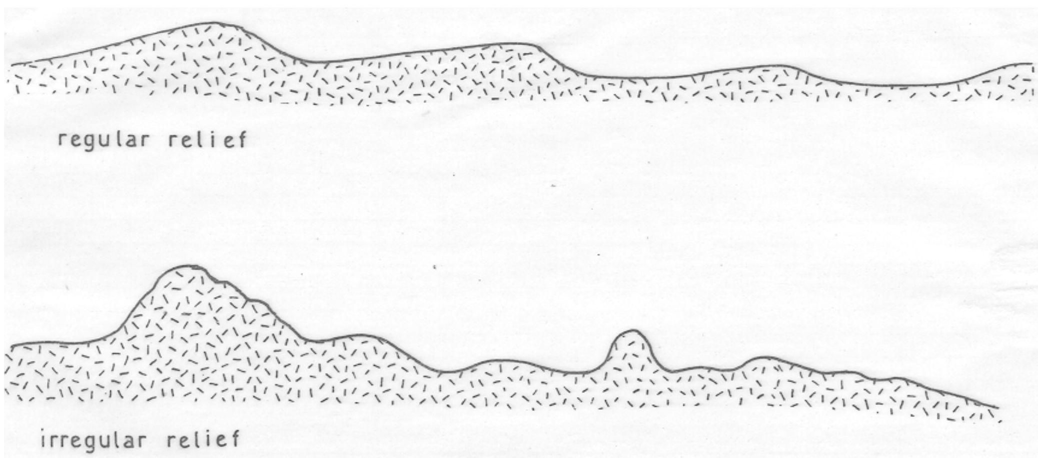


Fig. 31: Schematic illustration of regular and irregular relief

Site

The site or geographical position is important to soil surveyers. One of the methods in soil survey is the "toposequence or catena study" Both of these terms are used, sometimes interchangeably. However, they are not exactly the same, and defined as repetitive sequence of topography, with a significant difference, that is, if parent material remains the same along the slope (sequence) it is called catena and otherwise it is toposequence.

b. soil surface and rocks

Except when obscured by tall vegetation we can always see the relief or slope of a soil body. All the differences in surface soil are shown as differences in greytone or greytone pattern.

Fig. **38:** The light tone is sandy wind deposits, which gradually wedge out over soils of much heavier texture.

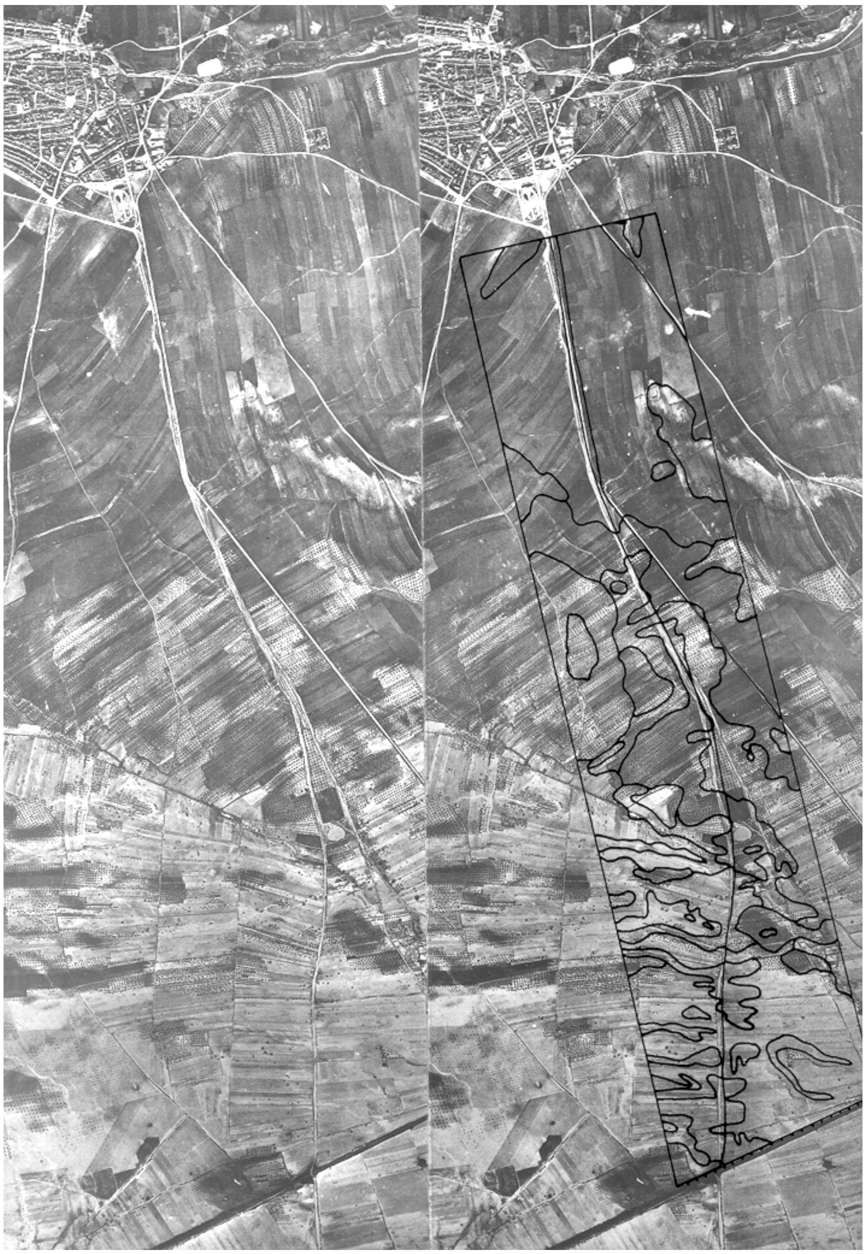


Fig. 38: Guarena area near Merida, Spain; Scale 1 : 32,000 f = 6″

An example of sandy soils distinguishing themselves on the photograph from the heavy clay soils by a lighter tone. The correlation between soil distribution and grey-tone pattern on photograph is well demonstrated by the overlay and the corresponding map (see the photo-album)

Fig. **39:** **S**oils with different topsoil texture can be delineated on the basis of greytone.

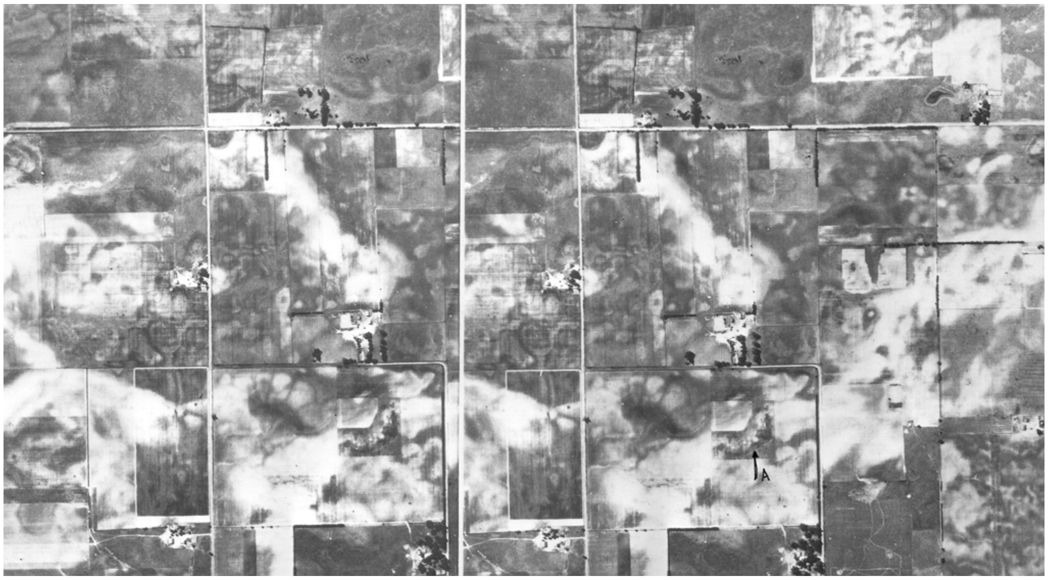


Fig. 39: Crescent City, Iroquis County, Illinois, USA. Scale 1: 20,000 f = 8,25"
*A portion of the bed of the glacial lake Watseka. Surface soils are developed from water and wind laid sands and sandy loam. A dune can be recognized at **A**. Highest positions are occupied by Hagener loamy fine sand and Anarga fine sandy loam. These have light colour tones. Dark coloured La Hogue loam and Drummer clay loam occupy the poorest drained positions. Ridgeville fine sandy loam and Wateska loamy fine sand are found in the intermediate positions*

Fig. **40:** Soils have a crust of secondary lime. The light patches indicate where the overlying soil cover is so shallow that by ploughing chunks of the lime crust have been brought to the surface.

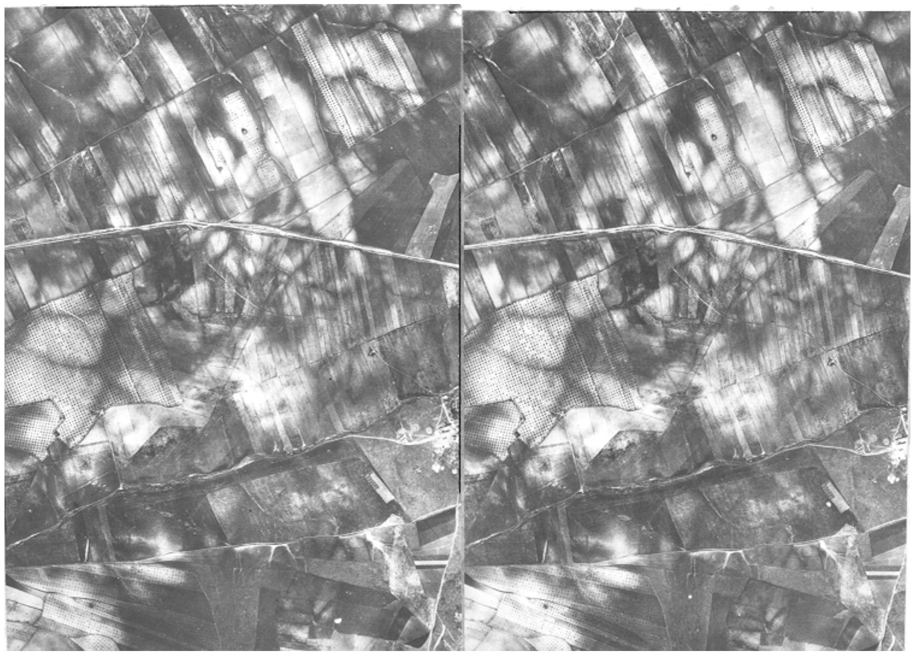
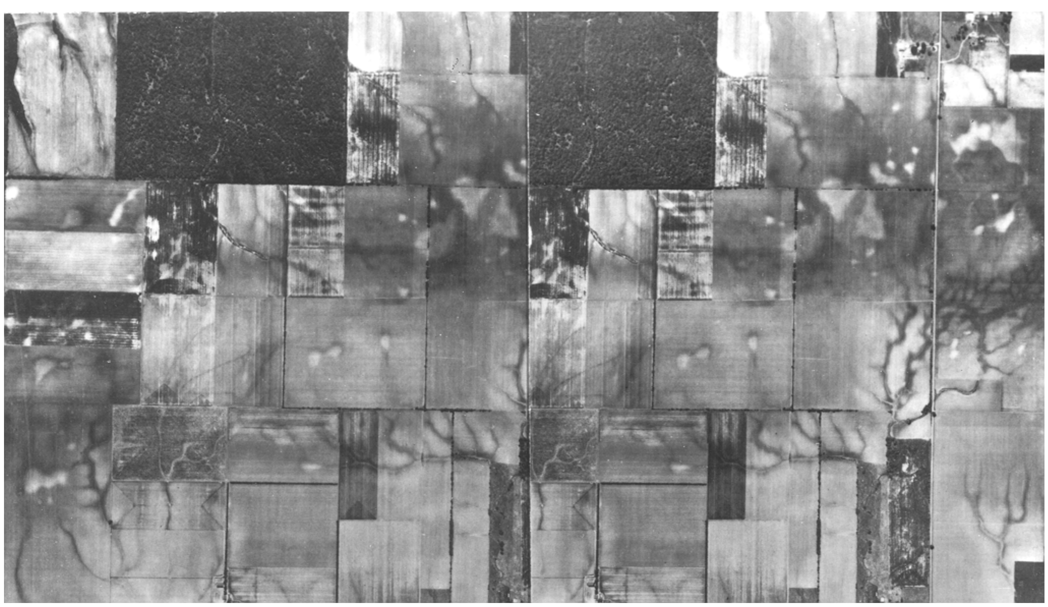


Fig. 40: An area in Merida in Spain. Scale 1 : 32,000 f = 6″
The stereogram shown light-toned spots where we have soils with a secondary lime crust near the surface. Chunks of the lime crust (petrocalcic) have been plowed up and are at the surface, causing the light tone. Studying soils in catena (summeit/shoulder, backslope and footslope) is remarkable.

Fig. **41 (below):** A gully pattern, which is partly visible as a dark greytone, that contrasts greatly with the environment. This dark tone is caused by an accumulation of humic topsoil material.



Another generally known phenomenon is that soils in wet condition show up darker on photographs than dry ones (other factors being equal).

4.2. compound elements

a. stream forms and drainage patterns

Streams and drainage patterns are visible to us on aerial photographs through a number of basic elements. These are:

-Relief Streams and drainage ways occur in the lowest places between adjacent relatively higher areas, thus at the bottom of every local valley. When the scale of the photo and the size of the stream permit, we may be able to see the shape of the actual bed of the stream.

-Water Water may be permanently or intermittently present in drainage way.

-Soil Dark lines caused by poor drainage conditions and/or accumulation of dark topsoil material may mark the course of a drainage way. Such long narrow strips are usually too small to be delineated as a mapable soil body.

-Vegetation Equally small strips of vegetation may mark the location of small streams or the configuration of a drainage system.

Figures **41** and **44** illustrate how several of the basic elements contribute to showing a drainage pattern.

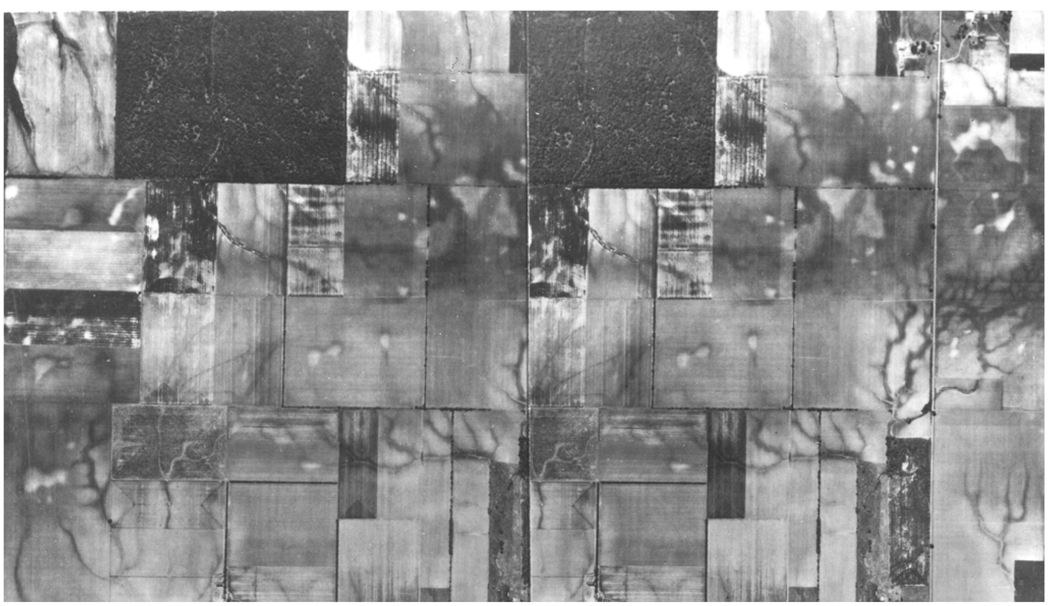


Fig. 41: Sangamon County, Illinois, USA. Scale 1:22,000 f = 8,25"

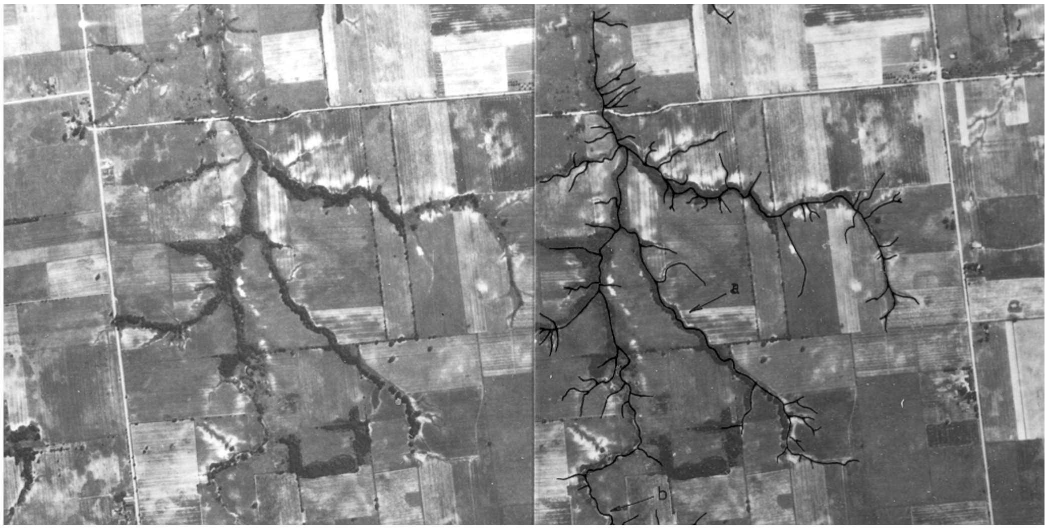
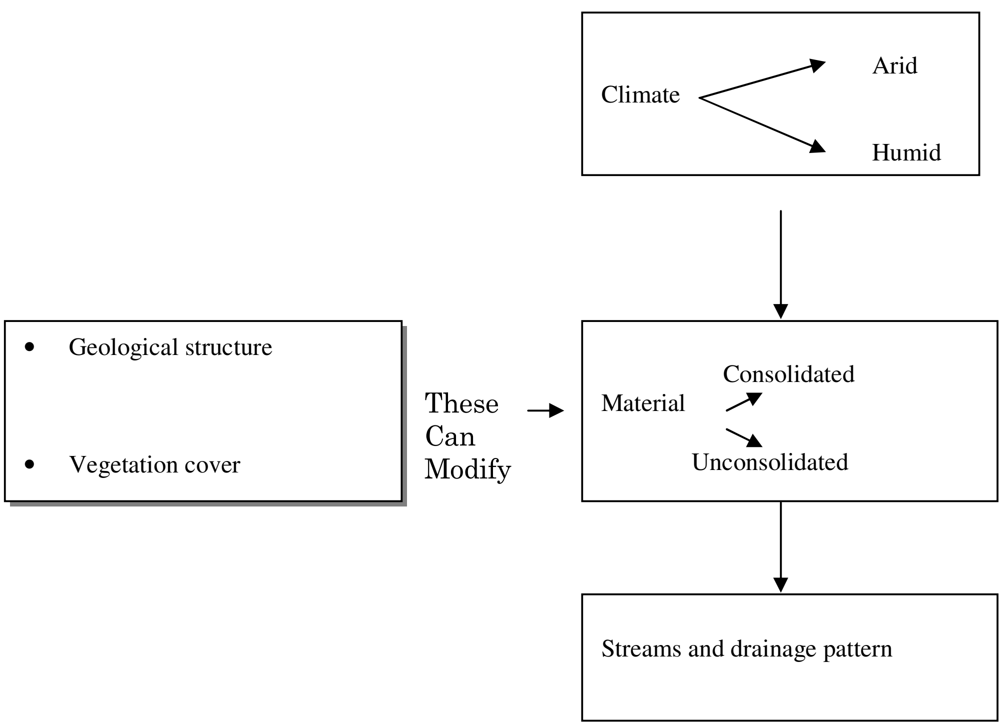


Fig. 44: Effingham County, Illinois, USA. Scale 1:20,000 f = 8,25"
A drainage system which for the greater part is clearly visible through vegetation in the gullies (a). In other parts it is the relief of the gully itself which marks the position (b). There are also places where the position of the gully is marked by a grey tone differing from that of the surrounding land. This may be a lighter tone where only the surface layer has been eroded away (c) or darker tone caused by accumulation of dark coloured humic material or wetness (d). The basic pattern of the drainage is dendritic.

Streams and drainage patterns form an important aspect of geomorphology, quite visible on air photo, thus intensively used by soil surveyors.



The major characteristics used to describe drainage patterns are : degree of integration, density, degree of uniformity, orientation, degree of control, angles of juncture, angularity and type and simile (Lueder, 1959).

i. Degree of integration : degree of unity exhibited by a pattern. Drainage patterns are either integrated (eg., highly integrated or weakly integrated) or non-integrated. Degree of integration is relative and is dependant largely on the size of area under study.

Degree of integration is indicative of :

a. uniformity and degree of erodibility (texture, perviousness, infiltration/ runoff ratio)
b. topography.

ii. Density : while dealing with patterns that are basically of the same type, one can have different densities. This can range from an almost complete absence of drainage pattern to one that is so dense that we can not fully represent all its details on a tracing of an average scale photograph. An example of an area with drainage patterns of varying density is Fig. **64**. It is possible to indicate the density of a drainage pattern by a numerical value. For this purpose one can give the ratio between total gully length and total area.

The density of a drainage pattern depends on the amount and concentration of precipitation, seen in connection with the external and internal drainage characteristics of the soil. The latter may be greatly influenced by relief and vegetational cover. When there is no drainage pattern at all, this usually means that all or nearly all the precipitation can be handled through internal drainage.

iii. Degree of uniformity (regularity): the more regularity a drainage pattern shows in type and density, the better are the chances that we are dealing with an area of homogeneous parent material. We should pay attention to anomalies in a pattern as they often indicate irregularities in the parent material conditions. In this respect we have already drawn attention to sudden changes in the type of individual streams.

iv. Orientation : implies direction. A pattern may have any combination of integration, uniformity and density and be oriented or non-oriented. Orientation indicates effect of geological formation, tectonic movements, shallow bedrock, etc.

v. Degree of control : refers to relative dominance of orientation. Degree of control provides clues concerning the geological factor causing orientation and also provides information on specific area characteristics such as relative depth to bedrock. terms such as low, moderate and high are used to show different degree of control.

vi. Angularity : refers to the abruptness of directional change. Angularity provides clues concerning the existence and location of erratic conditions and materials, hidden faults, fractures, underground structures, etc.

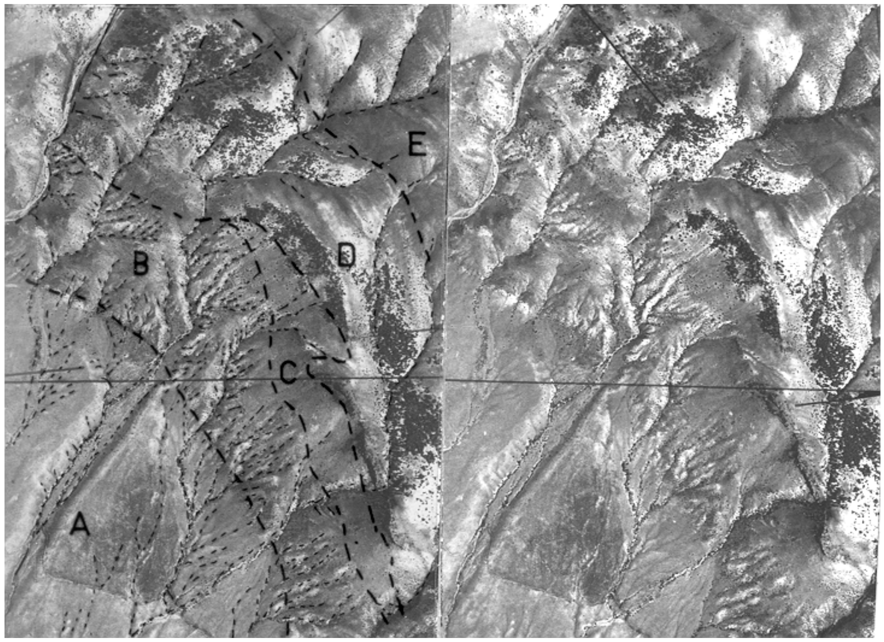


Fig. 64: Lewis and Clark County, Montana, USA. Scale 1: 20,000
Illustration of the fact that besides type of drainage pattern also the density of streams or gullies plays its role. A and B both have subparallel drainage pattern, but density is much higher in B. In C the drainage pattern is almost lacking.

vii. Angles of juncture : refers to the angle of juncture between a stream and its tributary.

viii. Types and simile : in the following pages you will see a number of drainage patterns.

When doing the exercises on drainage pattern analysis, you will realize that usually we can not draw sharp boundaries between areas covered by different patterns. Lines in our photo-interpretation based on differences of drainage pattern do not usually have a high accuracy as soil boundaries.
The most important stream types and drainage patterns, to give their most important characteristics and - as far as possible - to illustrate all this by a number of photographs.

The more important types of simple streams are:

The braided river

This is a stream type indicating that the river is not able to carry its bed load. Deposition of big parts of the load, usually consisting of coarse materials, continually force the river to change its course whereby an intricate pattern of small channels develops. The channels split and at other places cut through the river's own deposits, and join again which makes the term braided very appropriate (Fig. **45**).

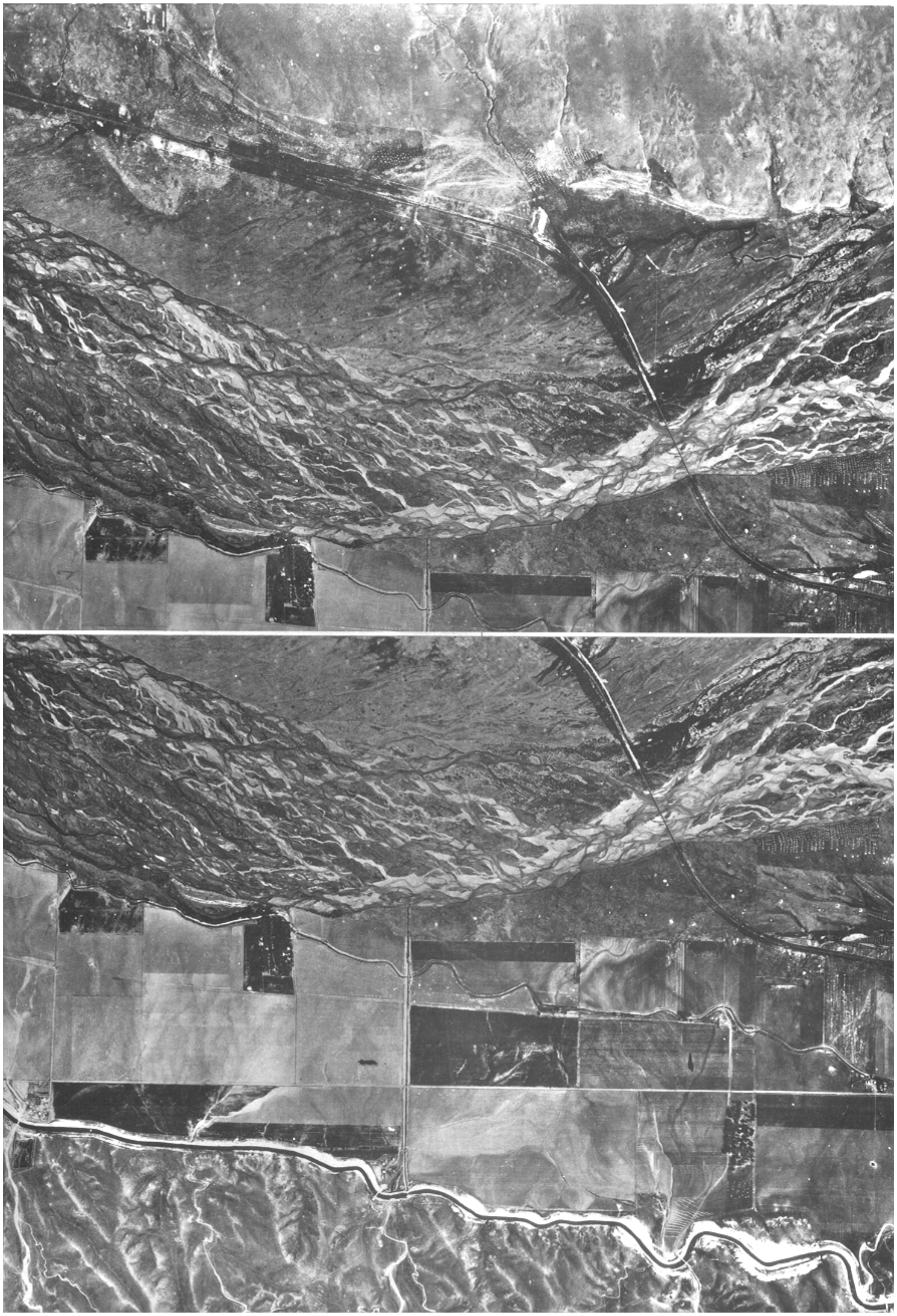


Fig. 45: North Platte River, Nebraska, USA. Scale 1: 34,000 f = 8.25″
Strongly braided channel of the North Platte River. Late tertiary sediments in an area with a semi-arid climate always provide an excess of available sediment.

The meandering river

This kind of stream moves with rather regular bends and loops through the landscape. It can normally carry its own bed load. Partly this type occurs it stretches of the river where it gradually cuts itself deeper into the formations through which it has taken its course (Fig. **46**).

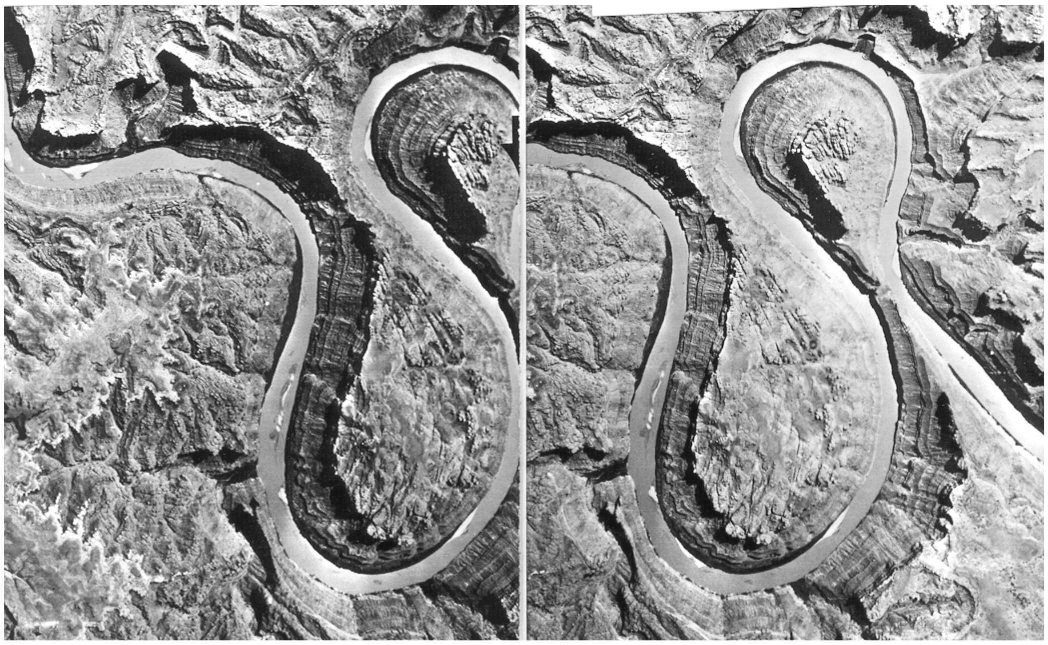


Fig. 46: The loop in the Colorado River, Utah, USA. Scale 1:42,000 f = 6"
Meandering channel of the Colorado River incised in Pennsylvanian strata of the Hermosa and Rice formations.

It often happens that the structure of the rock formations forces the river to follow a course deviating from the meandering pattern. It is exactly such changes in stream type which are of importance for the photo-interpreter because they indicate possible changes in the factor parent material.

There are a number of drainage patterns considered as basis because their characteristics readily distinguish them from other basic patterns. Those patterns deviated from the basic ones are the modified basic patterns which distinguish themselves from the type basic pattern by a special characteristic (Table ,below).

Table Drainage patterns and their characteristics. According to A.D. Howard, 1967

Basic	Significance	Modified basic /	Added significance or locale
Dendritic	Horizontally bedded sediments or beveled, uniformly resistant crystalline rocks.. Gentle regional slope at present or at time of drainage inception. Type pattern resembles spreading branches of oak or chestnut tree.	Subdendritic Pinnate Anastomotic and yazoo Distributary (dichotomic)	Minor secondary control, generally structural Fine-textured, easily erodable materials Floodplains, deltas, and tidal marshes Alluvial fans and deltas
Parallel	Generally indicates moderate to steep slopes but also found in areas of parallel, elongated landforms. All transitions possible between this pattern and dendritic and trellis types.	Subparallel Colinear	Intermediate slopes or control by sub-parallel landforms Between linear loess and sand ridges
Trellis	Dipping or folded sedimentary, volcanic, or low-grade meta-sedimentary rocks with different weathering; areas of parallel fractures; exposed lake of sea floors ribbed by beach ridges. All transitions to parallel pattern. Type pattern is regarded here as one in which small tributaries are essentially same size on opposite sides of long parallel subsequent streams.	Subtrellis Directional trellis Recurved trellis Fault trellis Joint trellis	Parallel elongated landforms Gentle homoclines Gentle slopes with beach ridges Plunging folds Branching, converging diverging, roughly parallel faults Straight parallel faults and/or joints
Rectangular	Joints and/or faults at right angles. Lacks orderly repetitive quality of trellis pattern; streams and divides lack regional continuity.	Angulate	Joints and/or faults at other than right angles. A compound rectangular-angulate pattern is common
Radial	Volcanoes, domes and erosion residuals. A complex of radial patterns in a volcanic field might be called multiradial. **Note:** In this concept, a radial pattern is a centrifugal system. Another classification is possible in which a radial pattern is a general term which includes two drainage systems; the centrifugal and the centripetal drainage system.	Centripetal	Craters, calderas, and other depressions. A complex of centripetal patterns in area of multiple depressions might be called multicentripetal.
Annular	Structural domes and basins, diatremes and possibly stocks		Longer tributaries to annular subsequent streams generally indicate dip of metamorphic layers and permit distinction between dome and basin.
Multibasinal	Hummocky superficical deposits, differentially scoured of deflated bedrock; areas of recent mass movements and volcanism, limestone solution, and permafrost. This descriptive term is suggested for all multiple depression patterns whose exact origins are unknown.	Glacially Disturbed Karst Thermokarst Elongated bay	Glacial erosion and/or deposition Limestone Permafrost Coastal plains and deltas.
Contorted	Contorted, coarsly layered metamorphic rocks. Dikes, veins and magmatised bands provide the resistant layers in some areas. Pattern differs from recurved trellis in lack of regional orderliness, discontinuity of ridges and valleys, and generally smaller scale.		The longer tributaries to curved subsequent streams generally indicate dip of metamorphic layers and permit distinction between plunging anticlines and synclines.

Dendritic pattern: This is characterized by irregular branching of tributary streams in all directions. It develops on uniformly resistant materials which have only a gentle regional slope (Fig,s **44,** on page….. , and **49).**

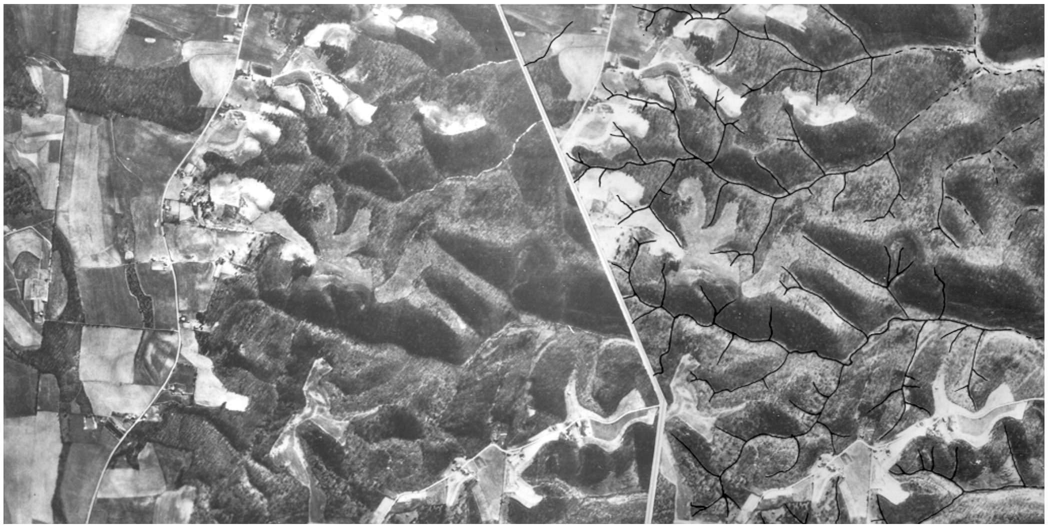


Fig. 49: Highland Rim Plateau, Tennessee, USA. Scale 1: 23,000 f = 6"
A level plain capped by a resistant chert formation. Where it is broken through, streams cut down rapidly in deep, v-shaped valleys, which form a dendritic pattern.

An important dendritic pattern modification is the **pinnate pattern**. The larger streams are dendritic but there are many closely spaced tributaries, more or less parallel to each other, joining the larger branches of the pattern at an acute to nearly right angle. The pattern has therefore a typical feather-like appearance. The pattern is characteristic of deep, easily eroded materials of rather fine texture, like loess (Fig. **50**).

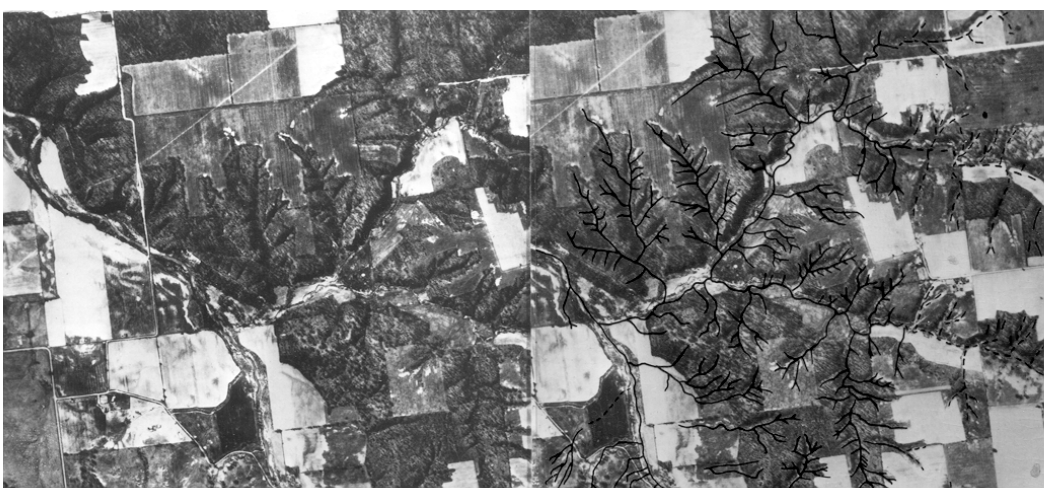


Fig. 50: Clark County, Illinois, USA. Scale 1: 21,500 f = 8,25"
Glacial drift area (Illinoian glaciation) covered by loess approximately 5 to 6 feet deep (1.50-1.80cm). The loess causes the modification to a pinnate type of the dendritic drainage pattern which is typical for the Illinoian drift plains

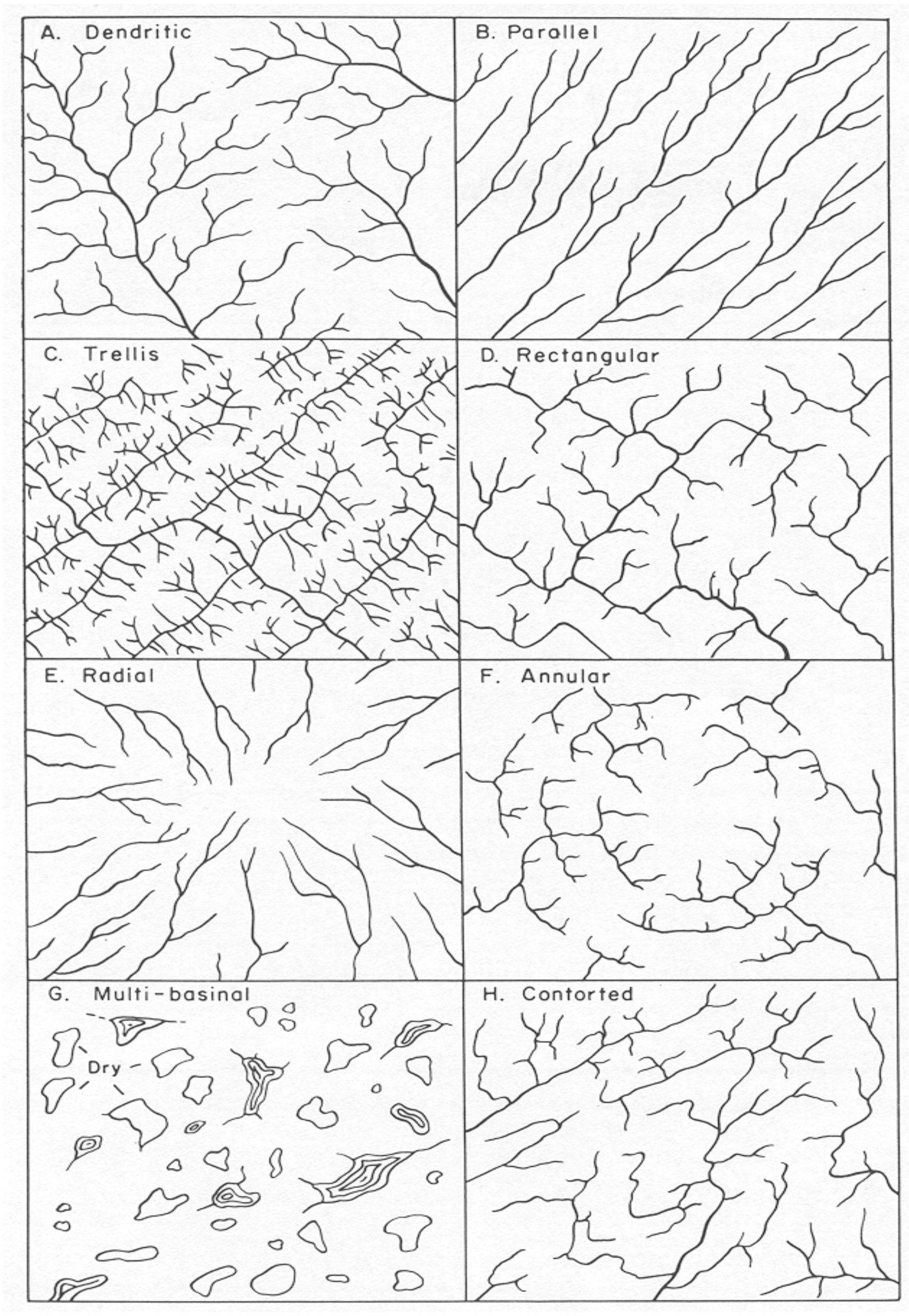


Fig. A5: Schematic examples of a number of drainage patterns mentioned in the text

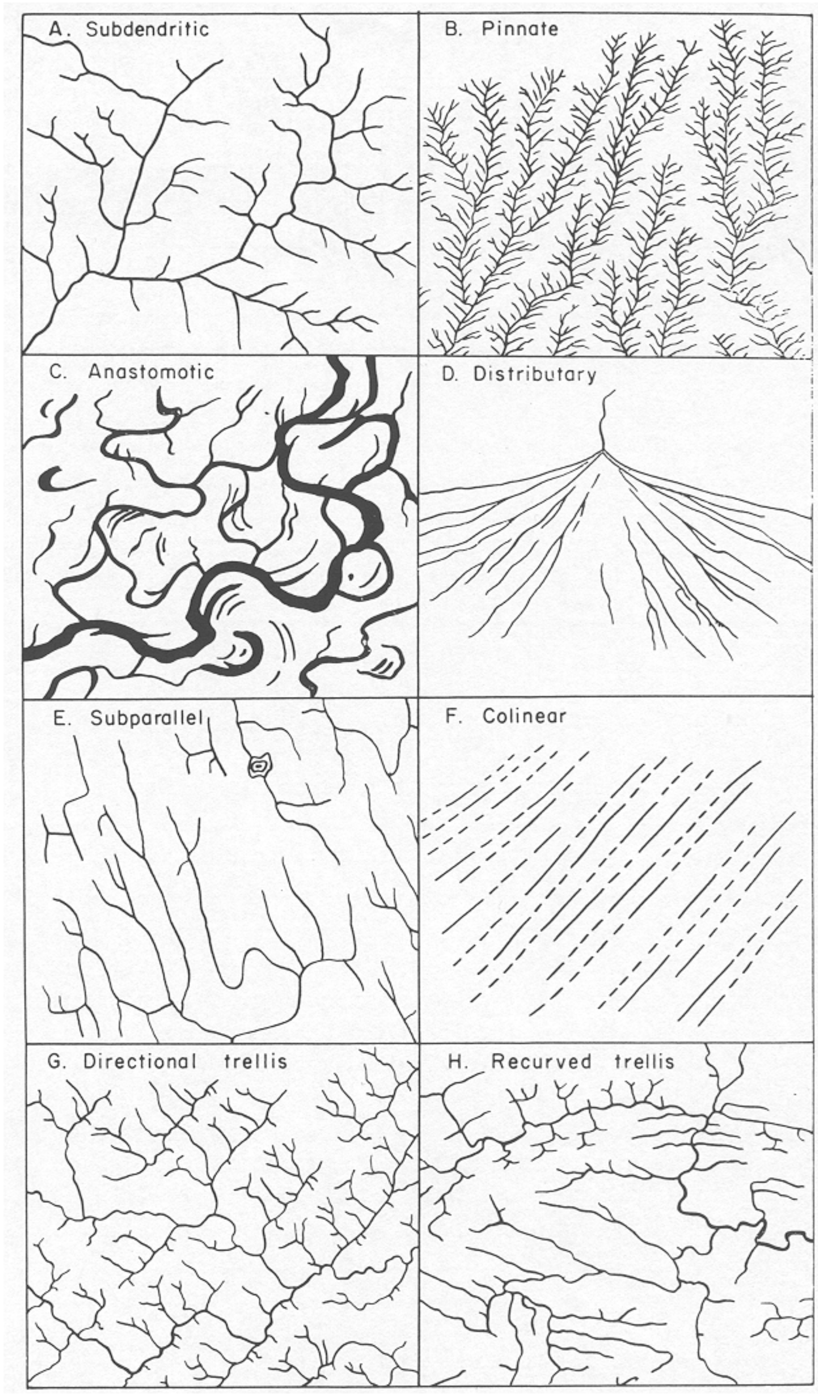


Fig. A6: Schematic presentation of a number of drainage patterns Mentioned in the text

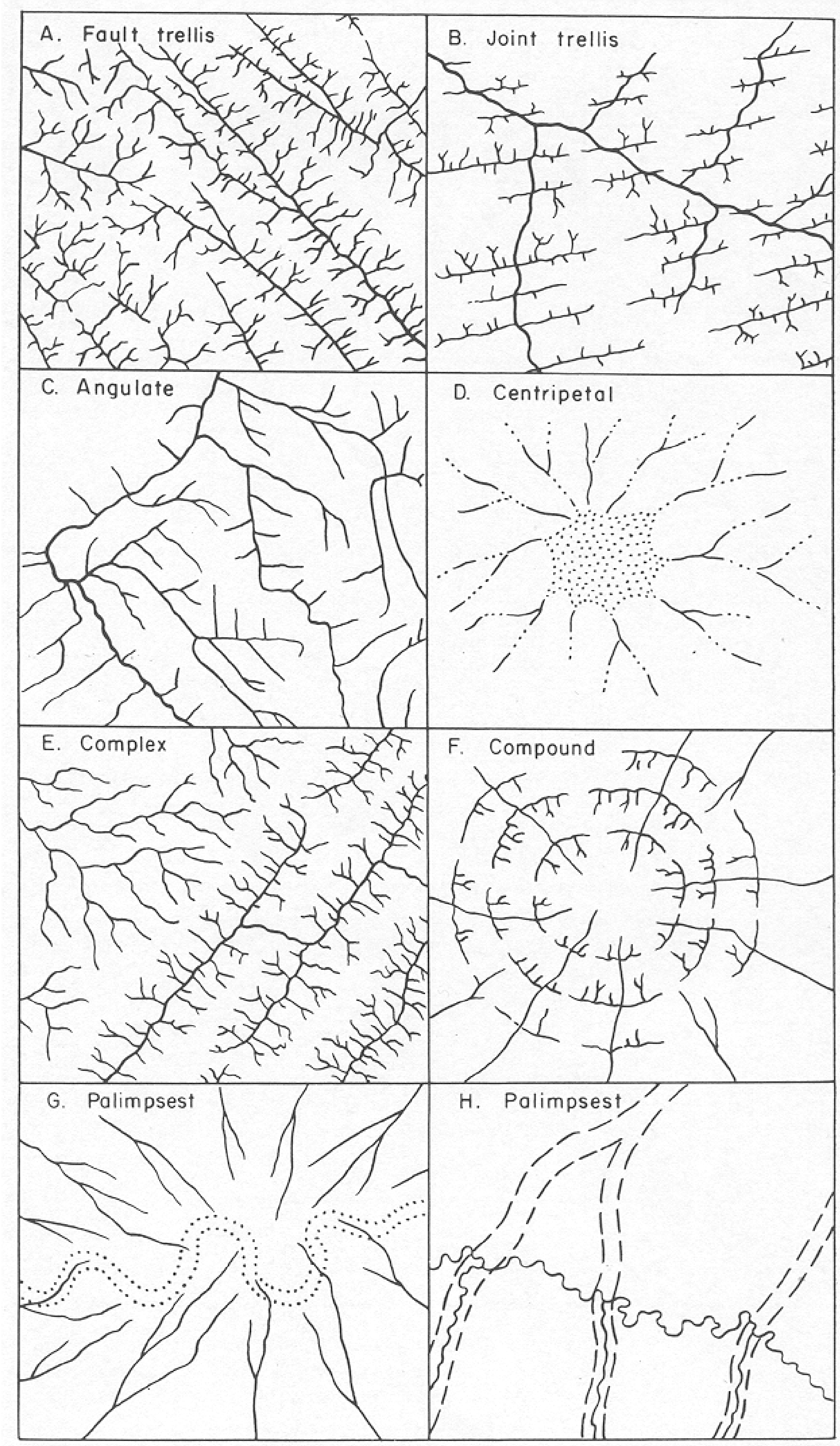


Fig. A7: Schematic presentation of a number of drainage patterns, mentioned in the text

Another kind of dendritic pattern modification found in areas of mainly deposition is the **distributary pattern** or dichotomic pattern. Instead of minor branches joining each other, as is the case with the type dendritic pattern, here streams or gullies usually split. The type is very characteristic of alluvial fans (Fig. **51**), but deltas also have a pattern that is basically the same.

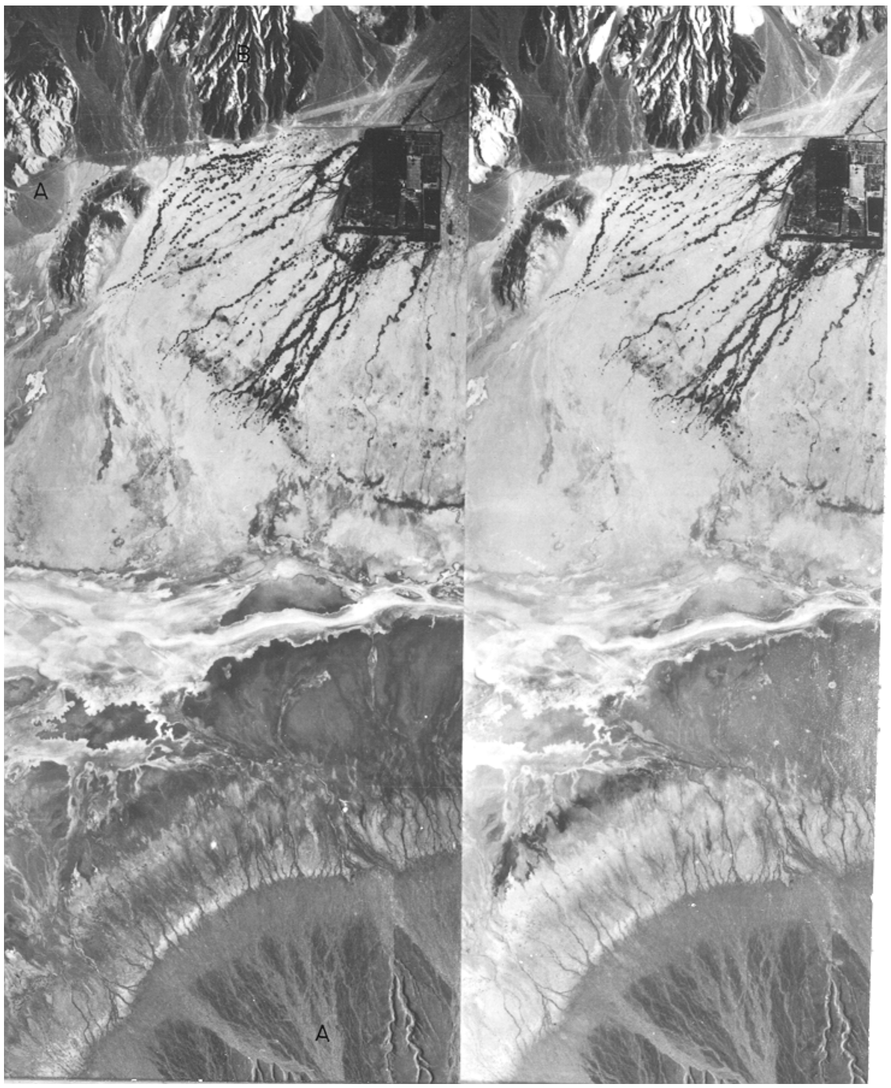


Fig. 51: Furnace Creek, California, USA.   Scale 1: 48,000   f = 155mm
The floor of the death valley with alluvial fans (dichotomic or distributary drainage pattern) and large piedmont encroachment.

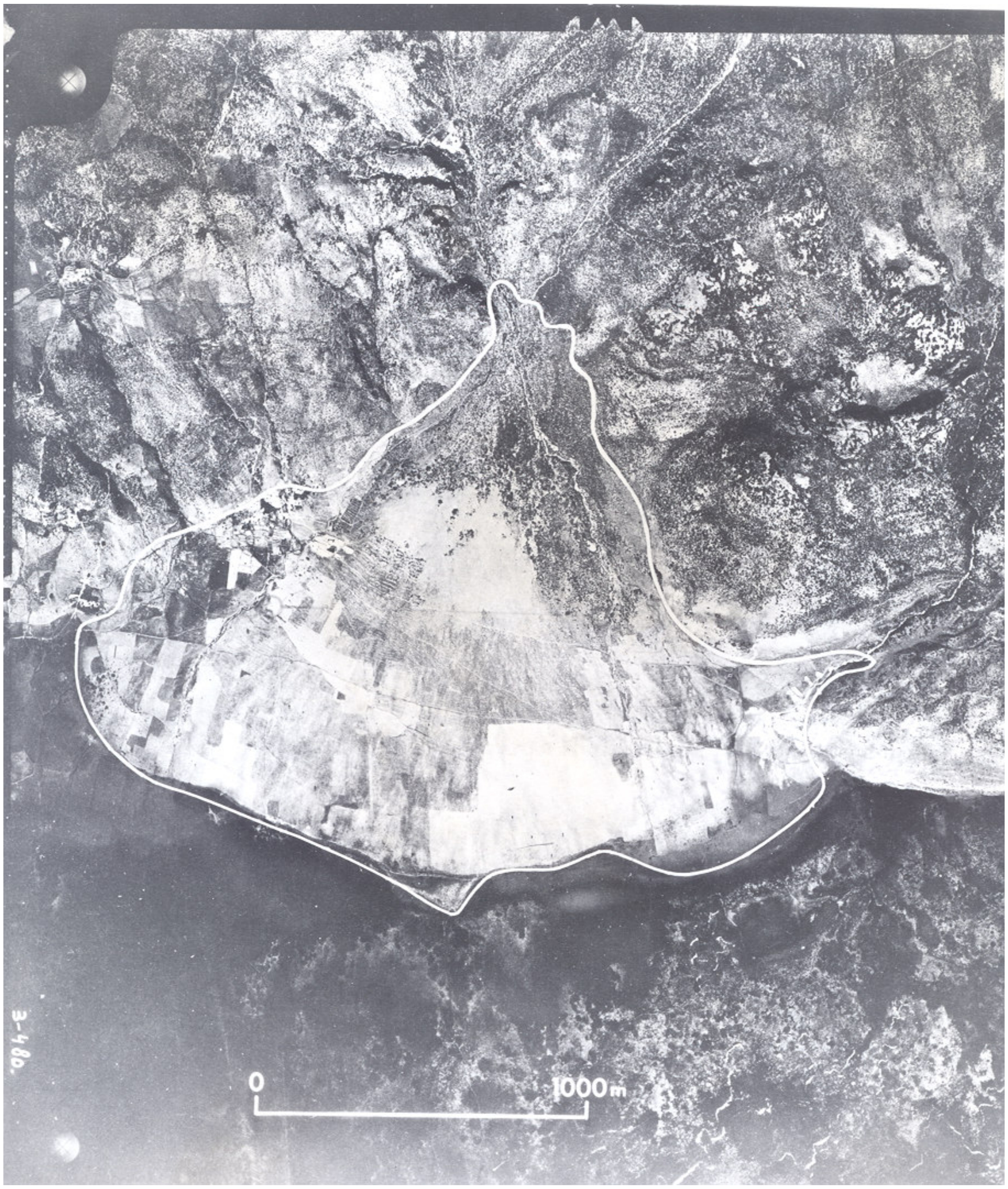


Fig. 48A: An alluvial fan in the ElGhab area, Syria.

Parallel pattern is a basic pattern again. It can be caused by the steepness of slope or structural control. Examples are shown in figures **52** and **53**. When the parallelism is not so strict, we speak of 'sub parallel", which is considered as a modified basic pattern. Another parallel pattern modification is the **collinear pattern**, found in areas of linear loess and sand ridges. The latter has remarkably straight parallel streams or channels, which may locally disappear and reappear again.

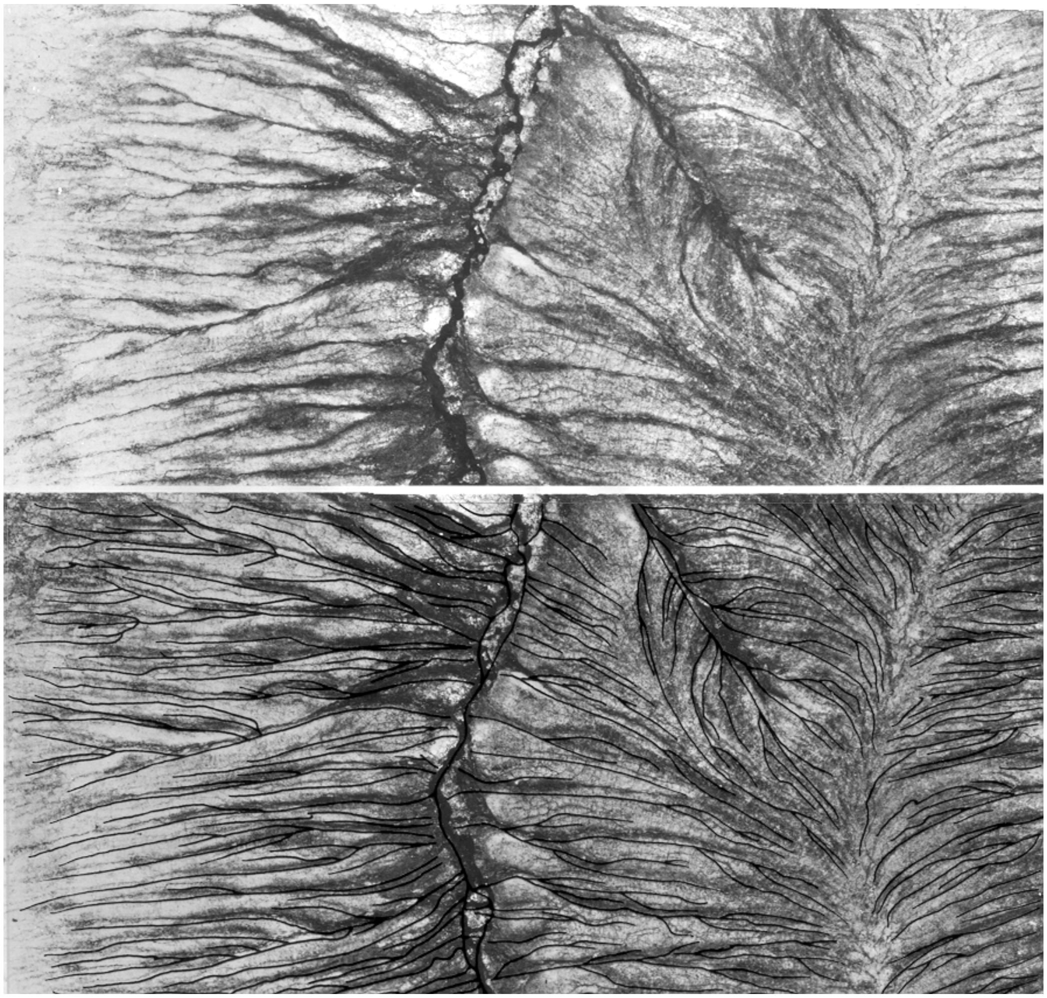


Fig. 52: Alaska, USA. Scale 1: 20,000 f = 6″
Parallel drainage pattern on solifluction slopes in the Arctic. There are no pronounced gullies
.

Trellis pattern is characteristic of folded or dipping sedimentary rock formations. It consists of a system or more or less parallel subsequent main streams with small tributaries , which join the main streams usually at right angles. **Directional trellis**, is when the tributaries are spread on one side of the main streams (Fig. 54).

Rectangular type is a basic type, which we find in areas with joints and faults at right angles. The drainage pattern reflects this. Streams make right angle bends and join each other at right angles. A modification is the **angulate type** in which

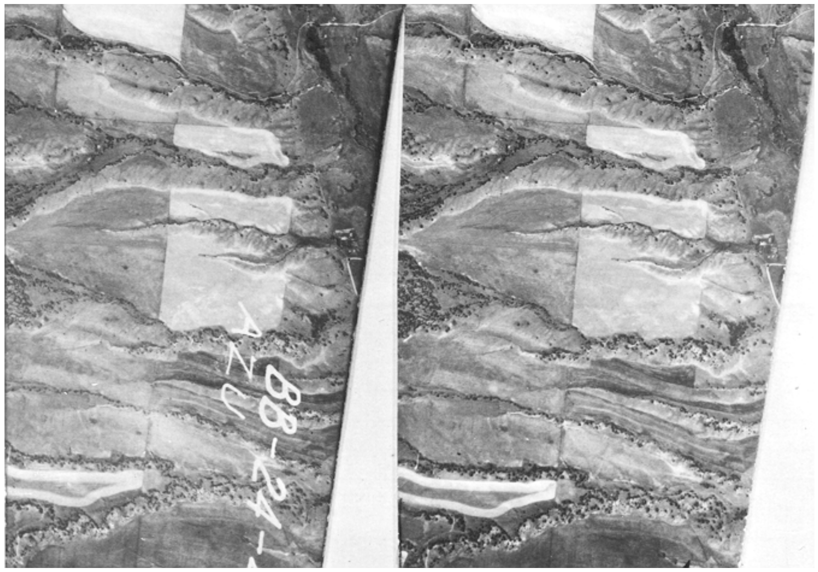


Fig. 53: Lewis and Clark County, Montana, USA. *Scale 1: 20,000*
Parallel drainage pattern. Deeply incised gullies.

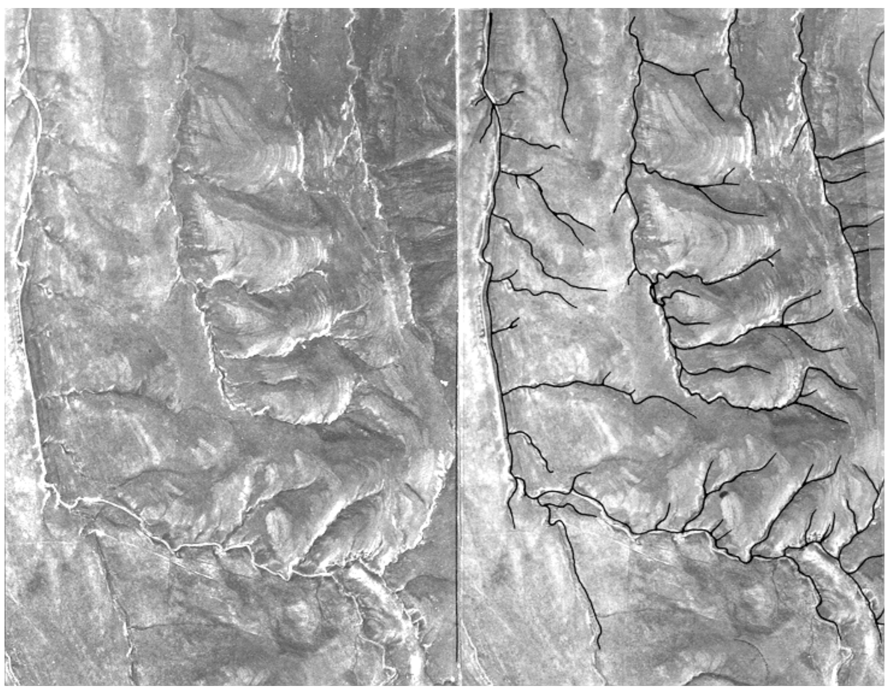


Fig. 54: Broadwater County, Montana, USA. *Scale 1: 20,000*
Example of a directional trellis pattern.

joints and faults are at other than right angles. An example is given in Fig. **56**, where actually more than two directions of joints can be recognized and where therefore characteristics of both the rectangular type and angulate type can be recognized.

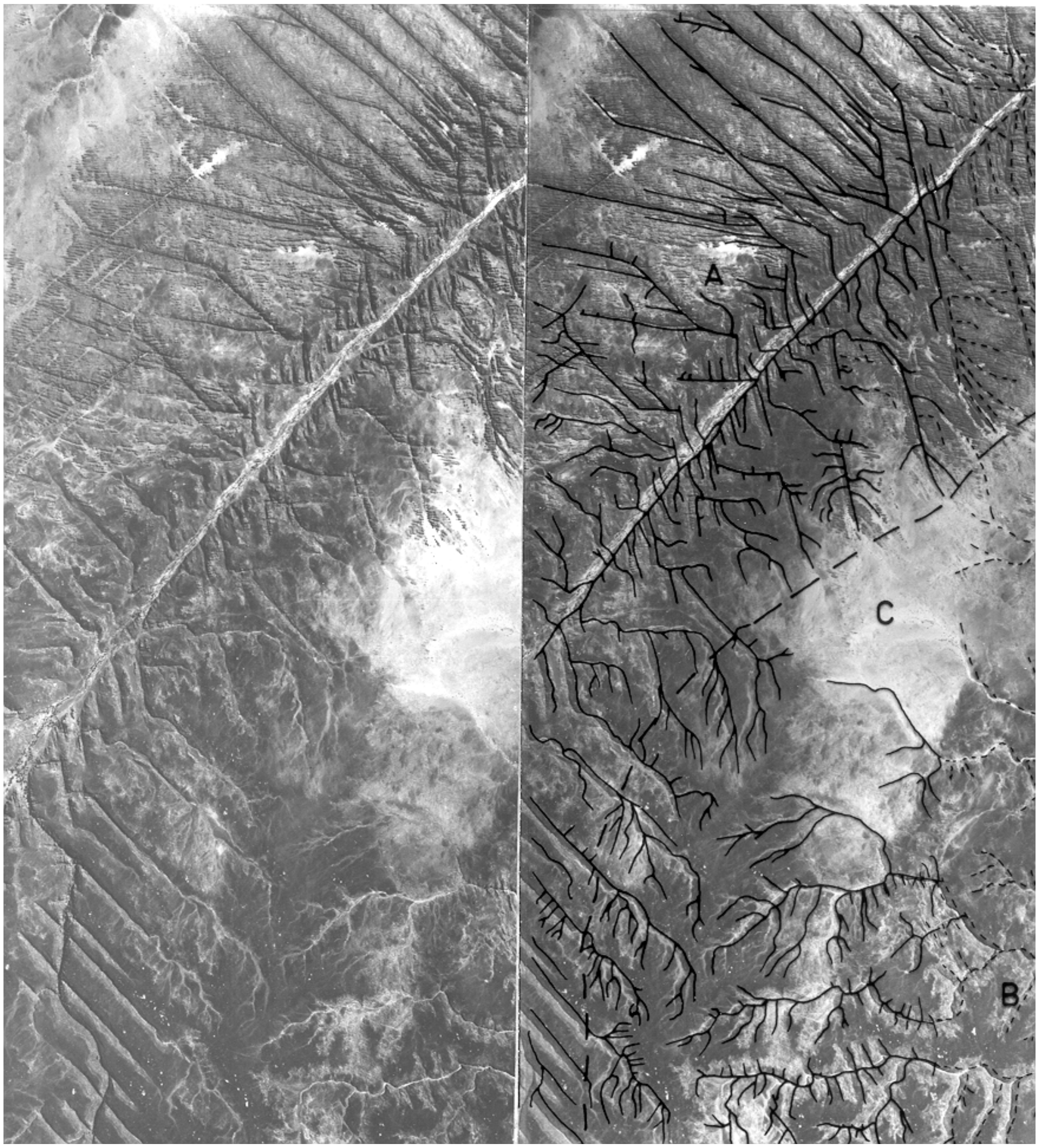


Fig. 56: Tibesti region, Tchad, Africa. *Scale 1: 20,000*
A drainage pattern which is a combination of the rectangular and angulate type has developed in an area of sandstone of Ordovician age (A). The main stream runs through a fault, while in addition three main directions of joint and fracture systems can be recognized. The area B which has a completely different drainage system (dendritic) may be argilaceous. The light toned area at C consists of wind blown material. (see the photo-album)

Radial and **annular:** The radial pattern we find on volcanoes and domes (Fig. **57**). A modification is the **centripetal pattern** in which the streams flow inward to a closed or nearly closed depression. The annular pattern can be found on domes with concentric rock formations.

The term **multibasinal pattern** is applied to those patterns in which a number of not well-coordinated depressions occur. They may develop under many different conditions. For many modifications and varieties of the pattern genetic names

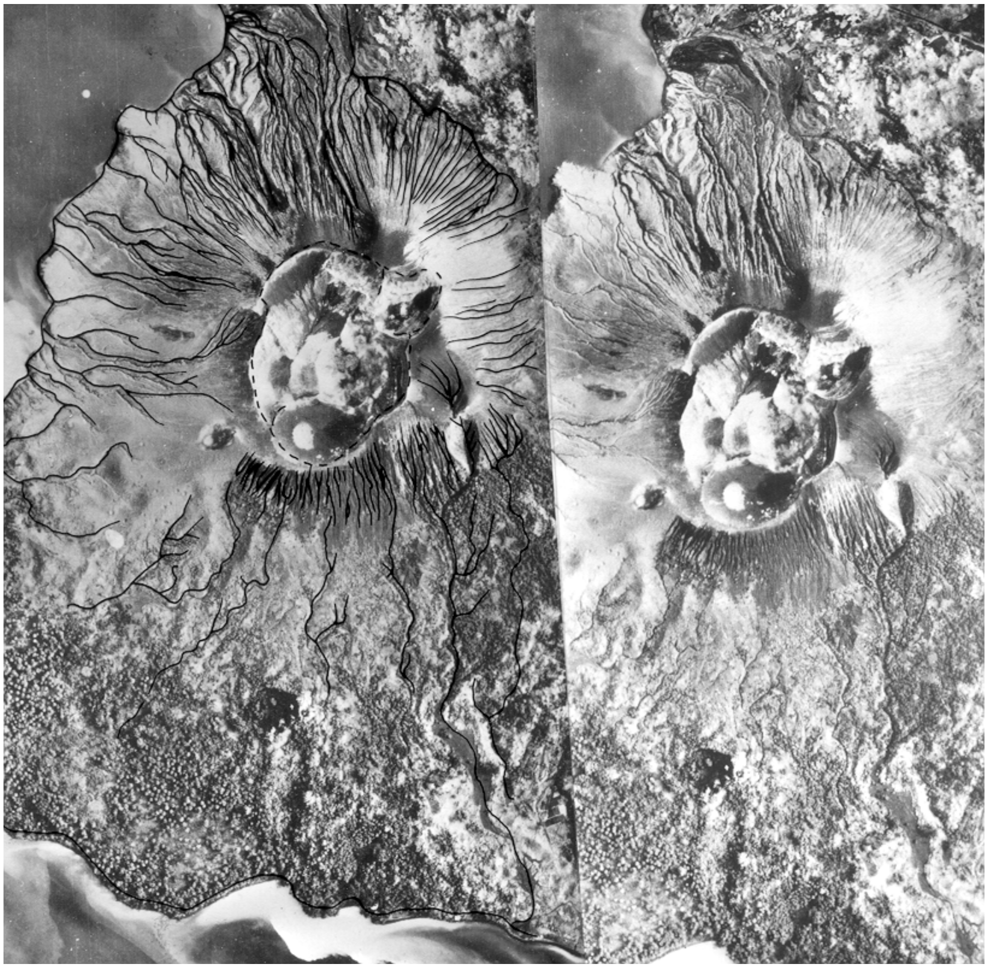


Fig. 57: Mt. Tavurnur, New Britain. *Scale 1: 15,000* *f = 24"*
A volcanic cone which as a whole demonstrates a radial drainage pattern.

have been suggested: knob and kettle, deranged, glacially disturbed, karst etc. Two examples are shown in figs. **59**, **60**.

A rather rare basic type is the **contorted pattern** occurring in contorted, coarsely layered, metamorphic rocks.

A few patterns, which Howard treats as modifications of the dendritic type, still deserve attention. It may be preferable to consider these ones under a separate basic group as they differ basically from the type dendritic pattern:
-Anastomotic type is a network of diverging and joining channels with many oxbow lakes and cut-off channels of varying width. The type is found in flood plains.

-Interlocking type is the type which we find in tidal marshes. The term reticular has been used for this type but it appears that most channels, although they run intricately one between the other, have no connection with each other. The term interlocking therefore seems more appropriate.

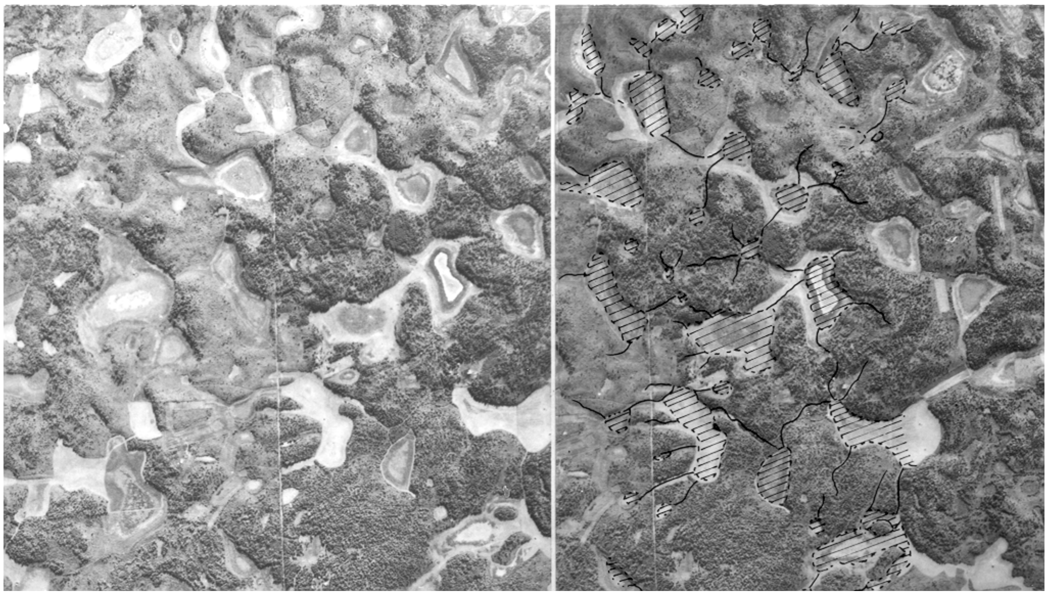


Fig. 59: North Dakota, USA.　　　　　Scale 1: 21,000　　　　　f = 8,25"
Glacial landscape with very uneven and poorly drained surface. The photograph shows a good example of what is known as knob and kettle topography. This is an example of a non-integrated drainage pattern.

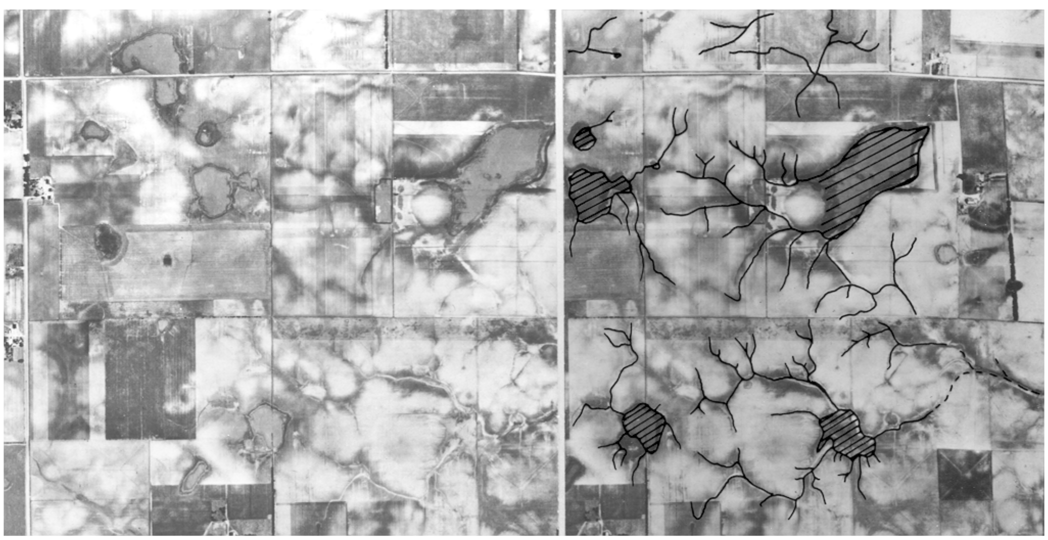


Fig. 60: Illinois, USA.　　　　　Scale 1: 20, 000　　　　　f = 8,25"
Another area with a glacial landscape. Glaciation has deranged the drainage pattern which however is more integrated in the landscape than in Fig. 59.

Individual gullies

It seems within the scope of the element stream form and drainage pattern to say a few words about the individual gullies of a drainage pattern. We think here of dry gullies and it is in particular the shape of their cross sections, which deserves

our attention. Often this aspect of dry gullies is considered as a separate element but we see it rather as a part of the compound element drainage pattern.
Gully type or gully forms are often related to climate and parent material and certain handbooks draw far-reaching conclusions from the form of a gully and may even provide keys in this respect. A few examples of the shape that the cross section of a gully may take are indicated in Fig. **65**. Not only parent material influences the gully form but also the climate, the already existing soil profile development and the depth to bedrock. So different gully forms may develop in the same parent material under different climatic conditions. The soil profile may have a hardened or more coherent layer, which disturbs the normal cross section and whether such a layer is a clay-pan, a caliche or a plinthite crust can not be seen from the photograph.

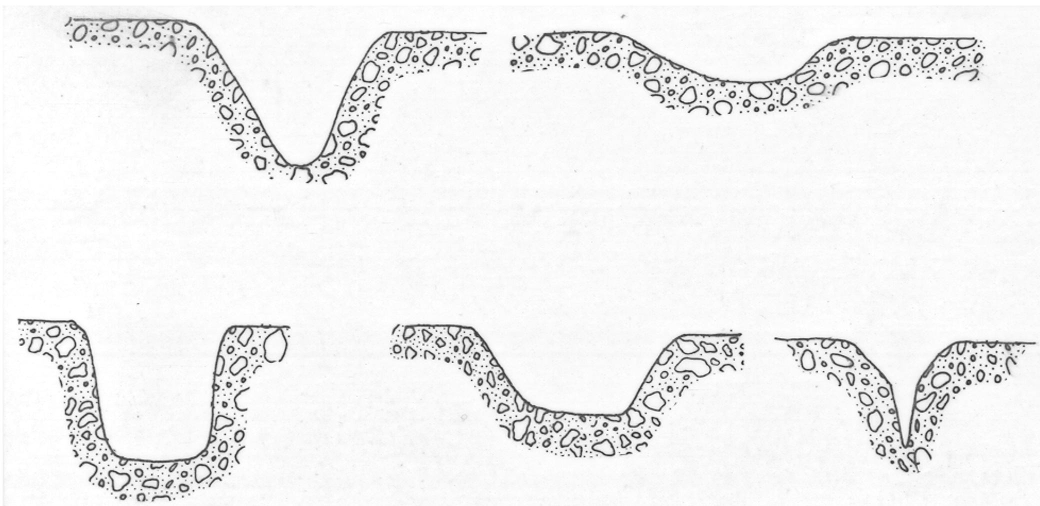


Fig. 65: Some possibilities of the form of the cross section of individual gullies

b. land use

Land use here does not mean so much the individual crops but rather a general division into arable land, pastures, orchards, planted forest etc.

Land use in the general sense is an element, which has a "high" visibility in the aerial photograph. The relation of the element land use to soil condition is quite variable. In certain areas of traditional agriculture the farmers have adapted their land use very much to the soil conditions. When they settled in the areas many centuries ago, hydrological conditions always played a very important part. Soils for arable land had to be neither too wet nor too dry. The wetter areas were used as grazing land and land which was excessively drained, was left with its natural vegetation, used for grassing sheep or - in certain periods - was transformed into planted forest (Fig. **66**). However, land ownership could upset the general rule e.g.

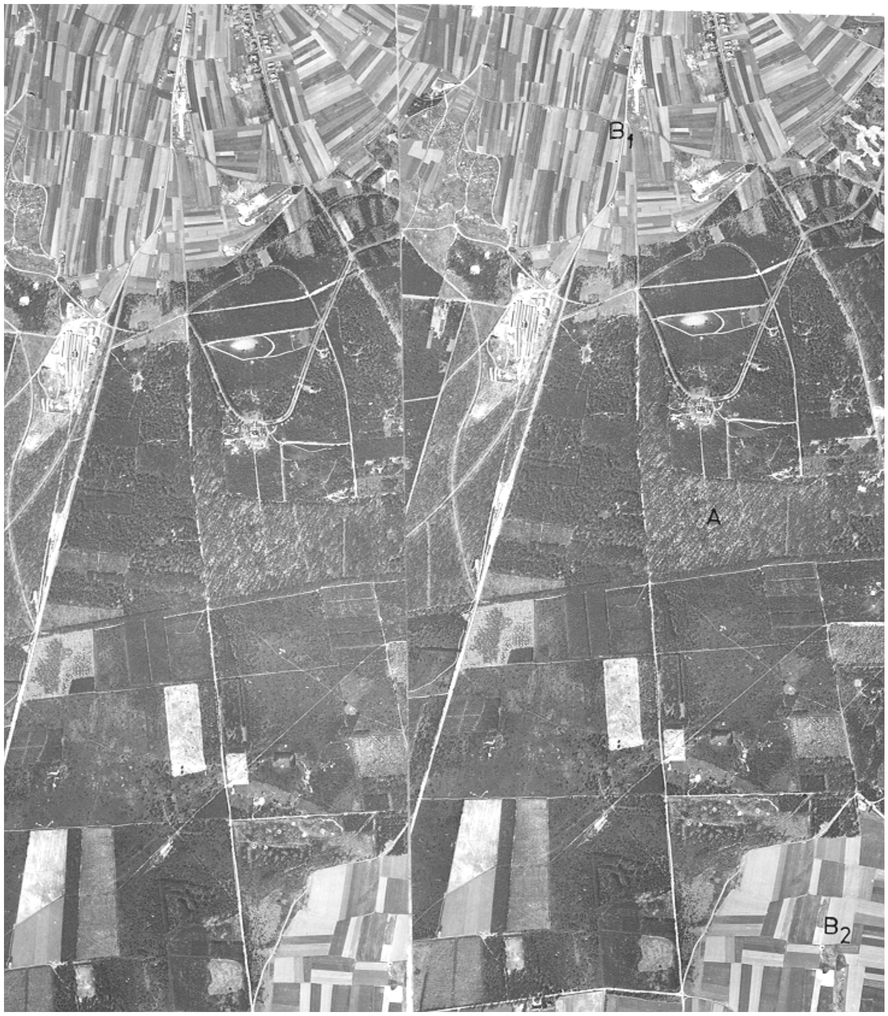


Fig. 66: An area in the south of Rijssen, Twente, The Netherlands. Scale 1: 20,000 f = 21cm
The stereogram depicts an area in a sandy region of The Netherlands. The land use distinguished are:
A - mainly planted forest
B1 and B2 are areas of arable land. The different grey tone s are due to different crops in different stages of development.
C - Pasture; has a much more even grey tone, situated in lower parts and with more poorly drained soils.

where big landowners kept land regardless of the soil conditions as hunting grounds.

In newly developed areas the relation of land use to soil condition is not so "high", simply because in large-scale developments land use often does not follow the soil pattern in detail.
The coincidence of land use boundaries with soil boundaries is generally low (Goosen, 1967). Certainly one should not expect the parcel boundaries, which constitute land use boundaries, to be also the exact soil boundaries. Several aspects of the element land use are illustrated in Fig. **68 (**see the album for more details).

Fig. 68: Maas region near Boxmeer (North Brabant), The Netherlands.
A-Pasture; B arable land; C- mixture; D Pasture with arable.

c. Parceling

Closely connected with land use is the element parceling. It is not the single parcel which interests us but the pattern. Shape and size of the individual parcels, their arrangement and regularity, these together give us a particular pattern. Apart from the historical value that such clearly recognizable patterns have, they may be of significance to the soil surveyor because of their relation to soil conditions.
An example is given in Fig. **69**, where we find two distinctly different parceling systems; at A and B the differences are mainly in the size of the individual parcels. The system at A is on high river loam deposits, soils with a high suitability for arable land and traditionally used for that purpose. At B we have sandy deposits of lower fertility and with less favorable physical properties. These soils were only brought under cultivation with the advent of artificial fertilizers. Another difference in parceling pattern can be seen between A and C. Comparison with existing soil maps of the area shows that in C we have low heavy river loam soils and low grey loamy river sand soils, which, particularly because of their hydrological condition, are less attractive for agriculture. More recent reclamation is therefore the probable explanation for the more regular arrangement of the parcels.

d. fault and joints

Faults and joints manifest themselves on aerial photographs through the relief features, which they cause in the landscape and the more or less rectilinear arrangement. Fault and joint systems may at the same time constitute a drainage system, but not necessarily so. For illustrations of joints and faults see Figs. **71** and **72 (**in the album**)**. Also Fig. **56** may be viewed in this context.

4.3. Inferred elements

a. Drainage condition

The drainage condition is an important property of a soil and it is therefore useful for the soil surveyor if this element can be incorporated in his analysis of the aerial photographs. Drainage condition is an inferred element, which means that it has to be deduced from other elements. This is not always possible, thus its visibility on the aerial photograph is not high. A number of elements that may give us a clue as to the drainage condition in an area are:
-Water: an area may be really waterlogged and the water surface may be visible in the photo as such.
-Topography: compare higher areas to lower lying areas
-Special kind of vegetation: poor drainage may be indicated by special kinds of vegetation or by the fact that vegetation is lacking. In certain regions the fact that an area is covered only by grass or by low brushes may mean poor drainage (Fig. **32**) but depending on the climate the opposite can also be true. Pastures are usually on the more poorly drained soils as compared to the arable land (Figs. **68** and **69)**.

Fig. 69: The Niers river, east of Gennep, Northern Limburg, The Netherlands. Scale 1:20,000; f= 21cm.
A and B are arable land, but different in parceling. A is high river loam soil and B is high river sand soil (see in the album).

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-Greytone: All other conditions being equal - wet soils show darker on photographs than dry ones. The grey tone is therefore sometimes an indication for drainage condition (Fig. **74).**

-Drainage ditches (Fig. **76**): the fact that ditches are there may mean that soils are not well drained. Although digging of ditches may cause a substantial improvement in the drainage condition, it usually can not fully remedy the original

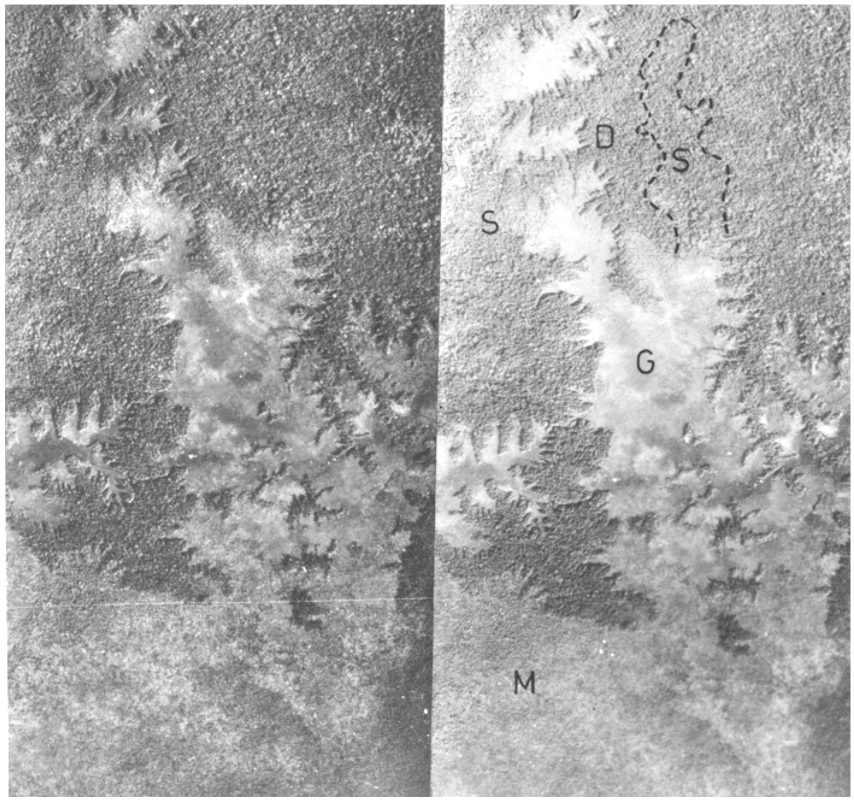


Fig. 32: Far East, Scale 1: 40,000. Vegetation types on aerial photographs.
G- large grass swamps, which will be covered by forest. One of the stages of colonization by forest is shown in (M). These trees have open crowns: also because of the low contrast with the background they are difficult to distinguish in the photograph. Swamp forest (S) has already occupied some water courses between the islands of forest on drier soil (D).

condition and certainly can not obscure the influence of the original situation on the profile development.

In general, to arrive at different grades or classes of drainage in a photo-interpretation is rather arbitrary. Often we have to limit ourselves to delineating those spots that are more poorly drained than the rest of the area. In some cases it may, however, be possible to recognize systematically three or even more classes.

b. Parent material

Many of the boundaries at which we arrive by means of basic and compound elements are at the same time boundaries between different parent materials. Differences in parent material may be inferred from differences in relief type, a break in slope, or difference in drainage pattern, etc. This does not yet mean that we are able to identify the parent material so easily. Sometimes, however, certain properties are so characteristic of a particular kind of parent material that we can identify it. This in turn may lead to certain speculations regarding the soils

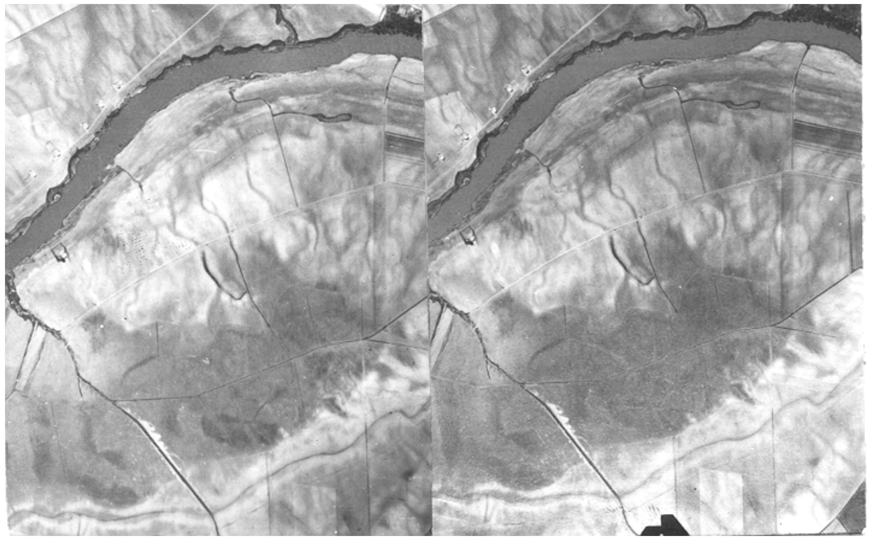


Fig. 74: Drainage condition. The dark grey tone indicates poor drainage condition of a basin-like area some distance away from the river. The conclusion that the dark grey tone means poor drainage is supported by the drainage ditch through the dark area and the depression, visible in the stereo-image.

developed on them, provided we have also data on other soil forming factors (climate, time etc).

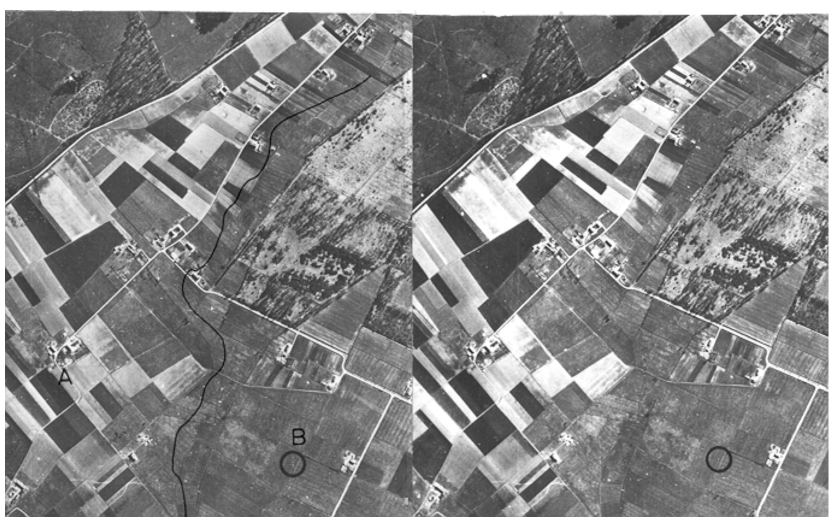


Fig. 76: Groesbeek area, east of Nijmegen, The Netherlands. Scale 1: 20,000
*Natural drainage conditions can to a certain degree be deduced from the fact that part of the area **(A)** has no drainage ditches, while the other part **(B)** has a systematic network of them. Although the drainage ditches will have improved the actual drainage condition, the original situation must have had a lasting influence on the profile development, which will distinguish the soils in **B** and **A**.*

c. Soil depth

With conventional photography we register the surface, and the photograph does not therefore give a single definite fact about the soil depth at a particular place. Nevertheless there may be many indications which may enable us to hazard reasonable guesses about the average soil depth of an area.
The relief is often a good indicator. Flat areas usually point to alluvial deposits, which are generally deep, although not necessarily of uniform parent material composition. Relief may be clearly a result of aeolian deposition and then also usually indicates deep soils. Mostly, however, relief is caused by underlying rock formations. Then the kind of relief, together with rock outcrops or visible stoniness, may give a clue as regards the soil depth.

d. Erosion

When we speak of erosion as an element in interpretation for soil survey purposes, we are referring to accelerated erosion as caused by human interference in the natural development of landscapes. Erosion is divided into different forms of erosion(e.g., sheet, rill, gully), and a distinction is also made as to the erosional agent: water or wind. Forms of erosion usually show up reasonably well on photographs and can be distinguished from each other. Greytone, relief, vegetation are a few useful elements in the recognition of erosion on aerial photograph (Fig. **78)**.

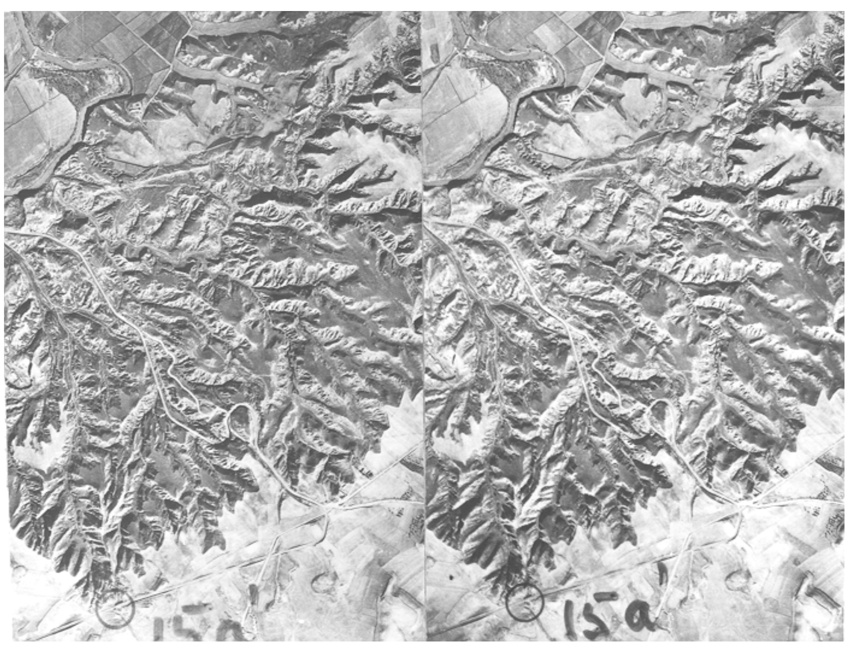


Fig. 78: Guadalajara, Spain. Scale 1: 32,000 f = 6″
Example of accelerated erosion in the form of gully erosion.

5. Use of the elements – methods of photo-interpretation

In the historical outline of photo-interpretation the manes pattern analysis, element analysis and physiographic analysis were mentioned. In the previous chapter some of the elements, which are the basis of interpretation, were discussed. In this chapter, a few methods of photo-interpretation for soil survey, will be discussed.

5.1. Element analysis

The method was developed at ITC, by Buringh (1960). It is based on the analysis of a number of individual elements, which are known or assumed to have a correlation with the soil condition. The correlation can be explained by the relationships which individual elements have with the soil condition. A few examples of these relationships were pointed out when discussing elements in the former chapter.
When applied really systematically the element analysis means that a number of elements are analyzed completely separately. Each analysis yields a map and the eventual result is a series of maps. These maps combined constitute the photo-interpretation map.
Obviously, not all elements are used everywhere. The analysis starts by eliminating those elements that in the given case have no relationship with the soil at all. Some elements are always of importance but the value of others may differ from area to area. The value may also differ according to the time of the year.

When combining the maps of the individual analyses some lines are the same for every one of them, other lines are repeated a few times and there will probably also be some that occur only once. Generally, the more often a line is repeated, the more likely it is a significant line on the final photo-interpretation map. It should be kept in mind, however, that some elements have a better correlation with soil conditions than others. The lines resulting from the analysis of such elements should consequently be given more "weight".

An example of the element analysis will be given in the class room. For this illustration we selected purposely a rather simple situation. Besides the analysis of a few elements, an analysis has also been made according to "homogeneous regions"[1] . When applying the element analysis, we first divide the survey area into a few homogeneous areas. It will appear that the boundaries between these relatively large units are the lines of which we said that they had the most "weight". This is a logical consequence of the fact that homogeneous regions distinguish themselves from each other because each has its own complex of characteristics and these characteristics manifest themselves in the photographs through the individual elements which we use for our analyses.
The combined map (analyses of the elements) will however, not only emphasize the main division in such homogeneous regions but will also yield a number of units

[1] In the original text the term landtype is used which is confusing, hence replaced by homogeneous area, a region throughout which recurring pattern of topography, soils and vegetation/ land use is observed.

within them. These units can be described in terms of the elements used and be classified accordingly.

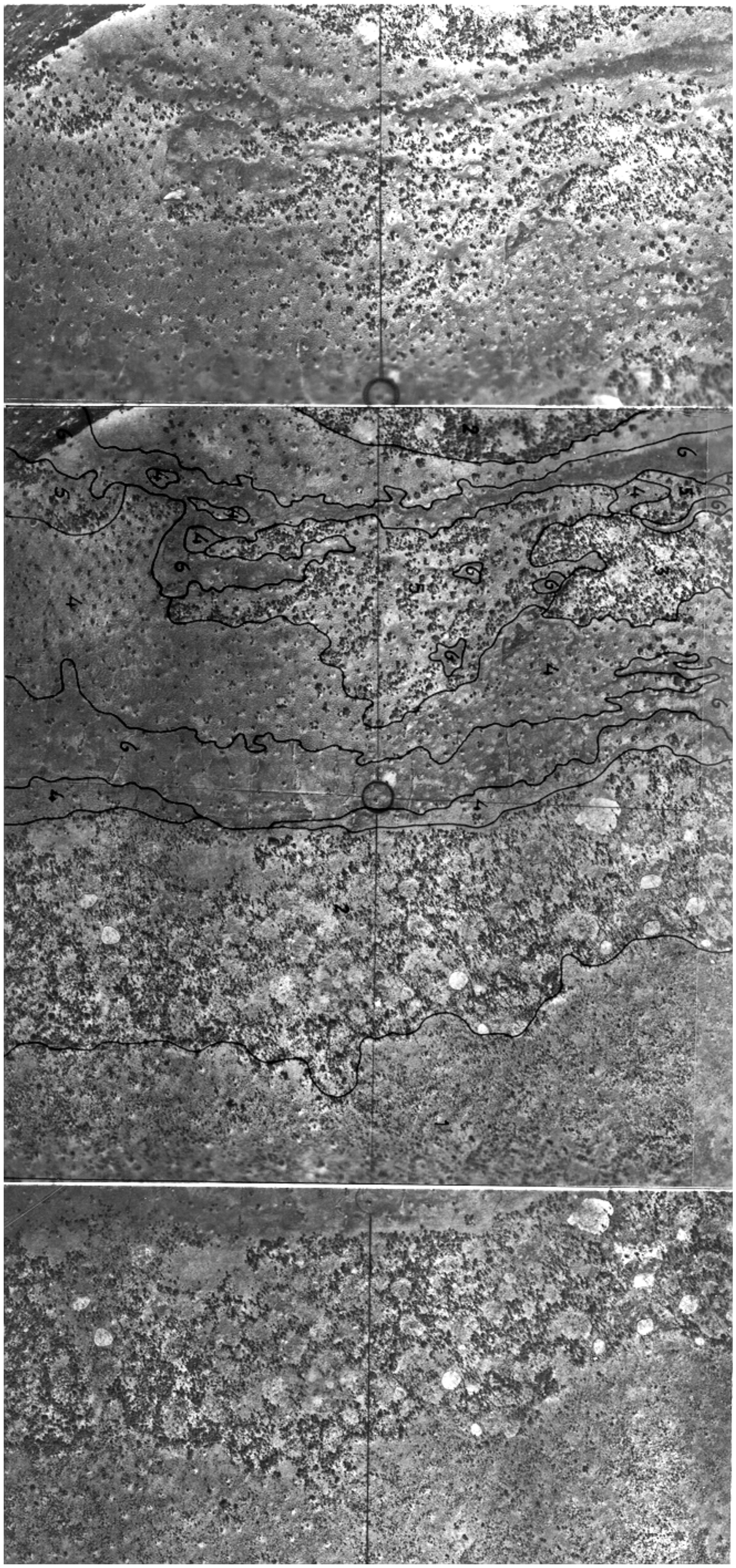
It is obvious that a field check will have to be carried out to find out which are the soil conditions in the individual units of the interpretation map. The field check will then also prove which of the lines of the interpretation map really have significance from the point of view of soil surveying and can therefore be accepted as boundaries between soil mapping units.
This method resembles the overlay making procedure within the modern GIS, where layers (of infrastructure, vegetation, land use, etc) are superimposed to come to a single map. However, there are some limitations in the pure form of the element analysis, a few of which are as follows:

- It is said that a number of elements should be analyzed separately. This sounds like if you are asked to look at only the binocular of your stereoscope, without looking at the stereoscope itself. Things are sometimes so integrated that one cannot separate them.
- It is very time-consuming, because a number of maps have to be made from the photographs and then combined. It may be applicable as an exercise, but imagine if you want to do it for a vast area, where tens of aerial photographs form the coverage.
- That the method takes "homogeneous area" (originally known as landtype) is confusing, simply because any homogeneous region (landtype) is a combination of elements.

More direct ways of producing a photo-interpretation are possible. After some experience a photo-interpreter will be able to arrive more directly at the delineation of terrain units each characterized by a certain combination of elements. He will realize that his lines are at certain points based on a difference in one element only, in other places he knows them to be supported by differences in two, three or more.

5.2. The physiognomic analysis

The term physiognomy is used here as an adjective of the word physiognomy, meaning appearance, resulted from the combination of a number of external features. In the physiognomic analysis method we limit ourselves strictly to the external features of an area as shown in the stereo-image, knowing that in some cases external and internal properties may be related.
In the Manual of Aerial Photo-Interpretation (1960), Buringh points out that "there is also a possibility of identifying specific terrain units, which will be important for the soil survey, as it is expected that these units will show different or similar soil conditions. Instead of an analysis of a number of single elements these terrain units are directly identified, analyzed and classified according to the specific characteristics as shown in the photo-stereo-image". He then adds that this is a more difficult approach than the pure element analysis. An example of a physiognomic analysis is given in Fig. **80**.



5.3. Physiographic analysis

When we carry out a physiographic analysis of an area, it means that we distinguish units not only on the basis of their appearance but also on the basis of the processes, which have shaped these units. Of course, as in the physiognomic analysis, the elements again form the medium through which the units are visible on the photograph and recognizable to the interpreter who has a sufficient knowledge of physiography.

For a good understanding of the physiographic method it is necessary to point out that physiography comprises the study and understanding of all the features determining the outlook and characteristics of a landscape. Most important in this respect is of course the ***geomorphology*** of the area but other factors such as the hydrology and the vegetation play a role. Moreover physiography implies that we can identify the processes " geomorphic[2] processes", which have shaped the area and that we have an understanding of how these processes have brought about the forms we see on the photograph.

The understanding of the geomorphic processes will be the guide to the delineation of the physiographic units which in turn will provide a good basis for the pattern of soil mapping units.

The units which we analyze on the photo will, as far as possible, be described in generally known terms, mostly derived from the terminology of geomorphology. Examples are: river levees, point bars, eskers, drumlins, kame terraces, beach ridges, etc. Such terms will join to qualitative differences between the units distinguished on the photo. However, as in the other methods a full quantitative description of the profiles and a more exact description of the composition of the mapping units has to be obtained by means of field work. Sedimentation and erosion are the geomorphic processes most important in relation to soil. Each of this can be subdivided as there are many forms of sedimentation and several kinds of erosion. Geomorphic processes that are less important for the soil surveyor are tectonic movements and volcanism. Example of a physiographic analysis will be shown in the class room. As it is the case in the two previously discussed methods, in this method too, one starts with the main landscape units and next proceeds to further subdivision.

An example of a legend made for a photo-interpretation map, where the physiographic analysis has been applied, is as follows.

- M	*Mountain, slightly eroded, sacredly vegetated*
- H	*Hilly area, steep sided, weakly gullied*
- P	*Piedmont plain*
- P1	*Old surfaces, gently sloping elevated parts*
- P2	*Alluvial fans, gently sloping*
- P2.1	*Old surface, smooth, extensive*
- P2.2	*Recent surfaces, showing relief of braided stream (superimposed)*
- L	*Lacustrine plain*
- L1	*Lake flats*
- L2	*Swamps*
- L2.1	*Permanent ones*
- L2.2	*Seasonal ones*

[2] In the original text and also in Goosen (1967) the term physiographic process have been used which is not a known term, hence replaced.

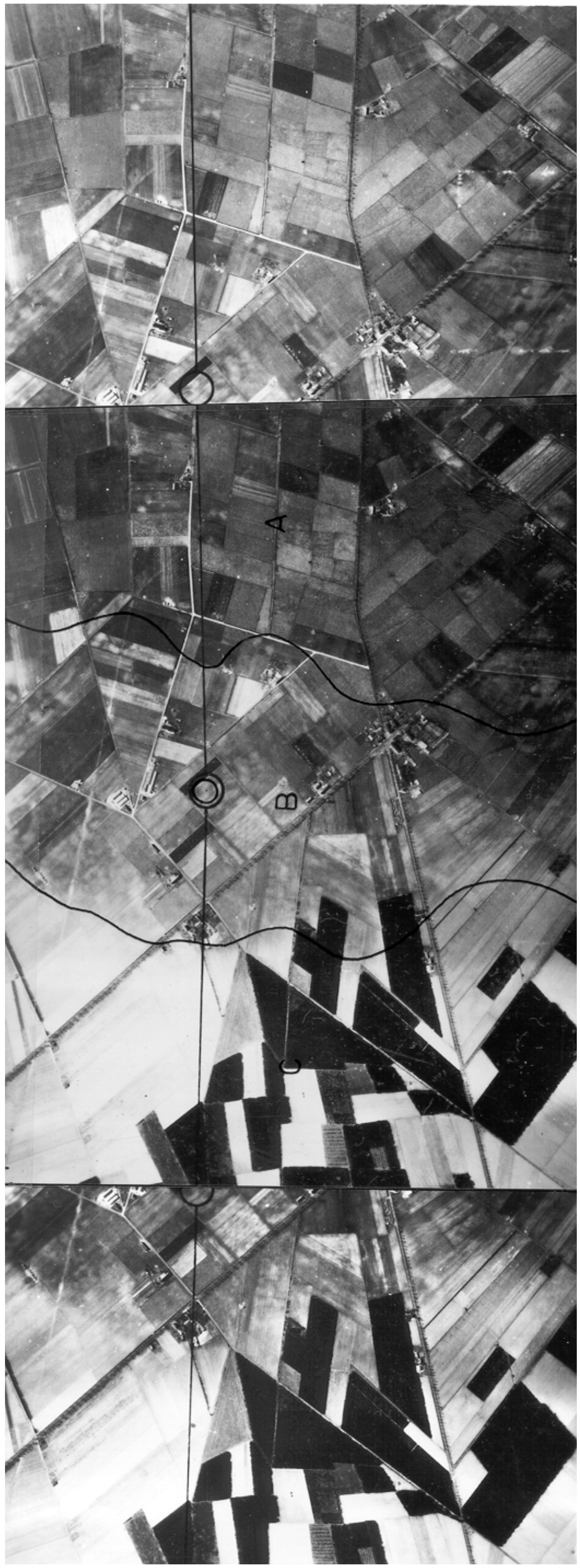


Fig. 85 : An example of transitional boundary

5.4. Pattern analysis

Frost (1960) has described this method extensively in the chapter "Photo-interpretation of soils" of the Manual of Photographic Interpretation. As a basis of the interpretation of soils on aerial photographs he mentions the "study of patterns created by the nature of parent rock, the mode of deposition, and the climatic, biotic, and physiographic environment". Interpretation of the soils is then based on "the following three important principles":

a. "Similar soils appear in similar patterns
b. Dissimilar soils appear in dissimilar patterns
c. Once the photographic image characteristics have been correlated with soil properties observed in field and laboratory, the sequence of events which formed a particular soil can often be reconstructed by means of photo-interpretation, and many important properties of similar soils can be inferred".

The correctness of these principles must remain the author's responsibility. However, Bennema and Gelens (1969) and Goosen (1969) argue against the above statements.
An example of a pattern analysis is given in Fig. P1, below.

5.5. Geopedologic approach to soilscape analysis

The basis of the geopedologic approach to aerial photo-interpretation is described in the lecturenotes on physiography and soils (Zinck, 1988).
Aerial photo- interpretation is carried out stepwise according to the hierarchical levels of the systems. The following steps are involved in the process of photo-interpretation :

1. Photo- lecture: this simply means studying the photo-pair under the stereoscope,
2. Tracing master-lines: having studied the photos often a few distinct lines, separating major units can be traced,
3. Sketching: based on the delineated units a number of cross-sections can be selected,
4. Pattern recognition: a number of units can often be recognized along each of the selected cross- sections,
5. Delineation: at this phase units are delimited while one fills in the legends' columns,
6. Composition of legend: by having gone through the above mentioned phases a coherent legend can be designed,
7. Interpretation of landscape: this is where the physiographic logic is applied. To do this well a thorough knowledge of geomorphology is required.

Based on a strong integration of geomorphology and pedology the former can be used as a tool to improve and speed up the soil survey (Farshad et al., 2005a and b). The discipline of geomorphology as used in this approach operates through a taxonomic system comprising six categorical levels. The six levels are:

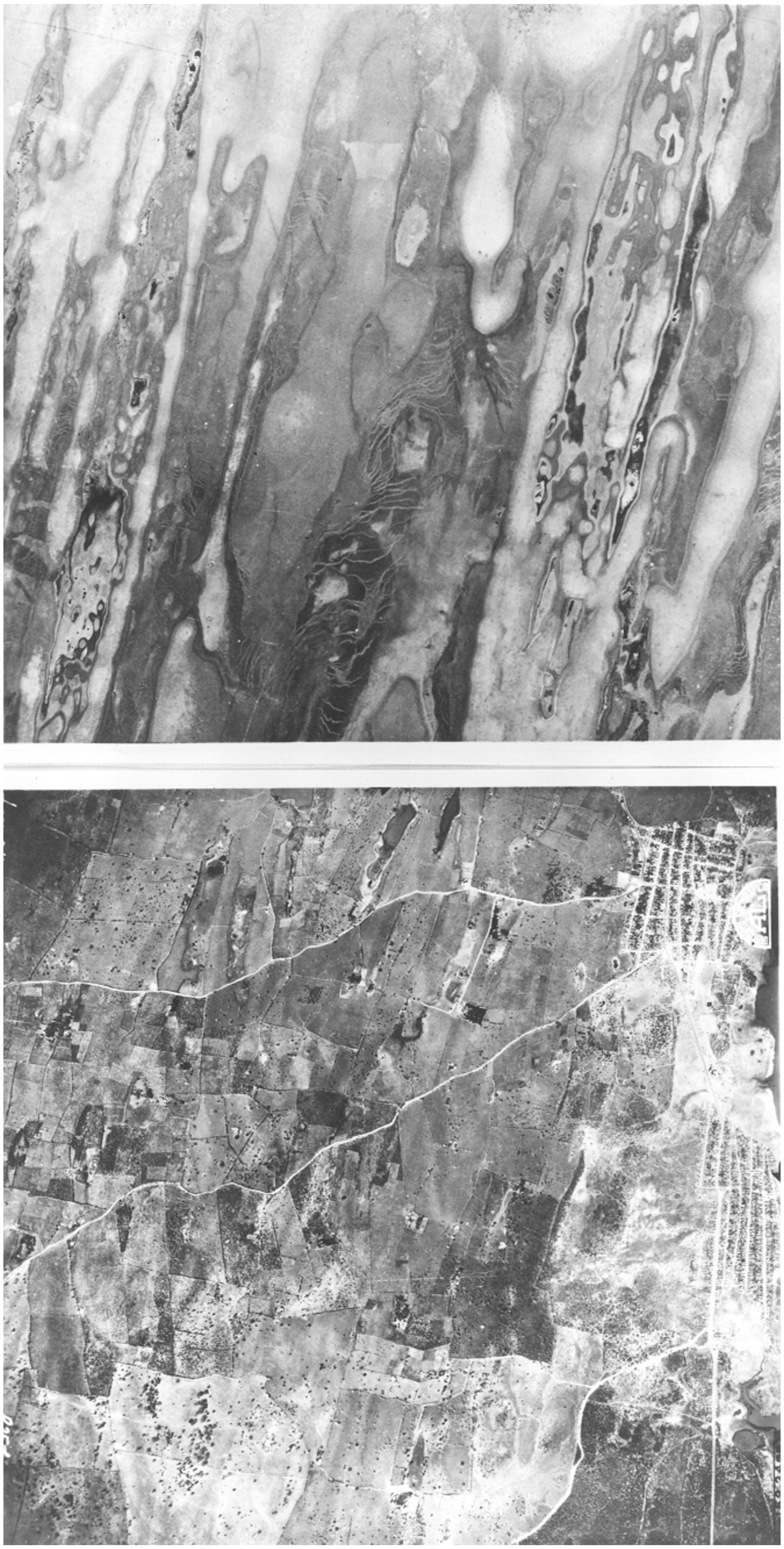
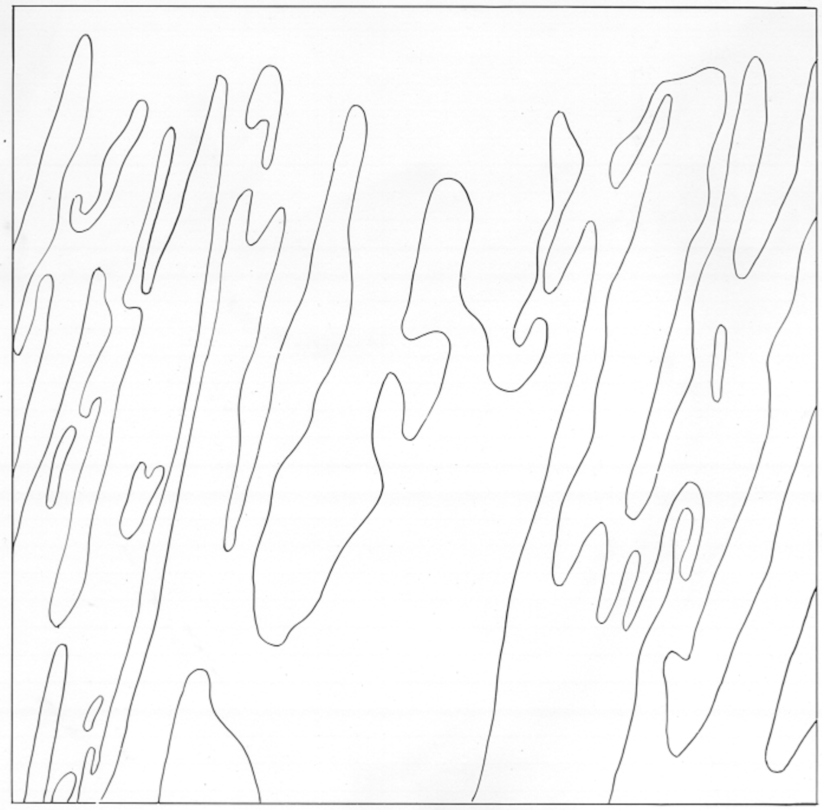
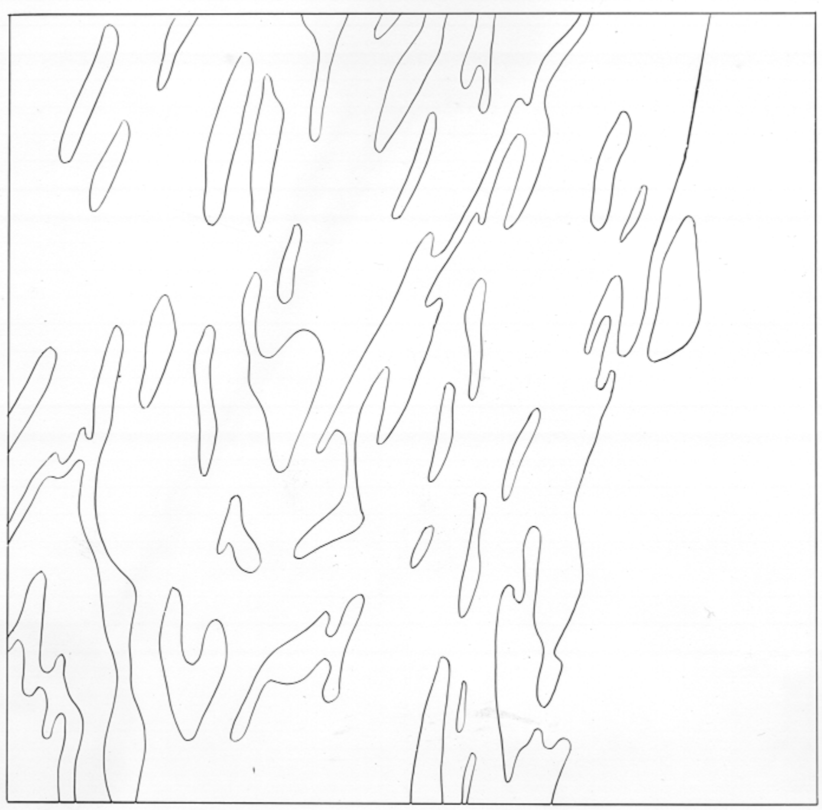


Fig. P1: Two examples of air photos where parallel patterns are Depicted: Above is river-dunes and below is coastal dunes. Interpretation Maps are given on the next page.





6 - Geostructure
5 - Morphological environment
4 - Landscape
3 - Relief type or molding type
2 - Lithology/ facies
1 - Landforms

The first two levels - geostructure and morphogenetic environment - are not used in our exercises. We will limit ourselves to the columns of landscape (level 4), relief/ molding (level 3), lithology/ facies (level 2) and landform (level 1). On level 4 the following six landscapes (incl. the mapping symbols) are used.

- Mountain: Mo Hilland: Hi Piedmont: Pi
- Plateau : Pl Peneplain: Pe Plain : Pl
- Valley : Va

Each landscape can be composed of a number of relief-types. The following table shows a number of taxa used at this level.

Structural	Erosional	Depositional	Dissolutional (Karstic)	Residual planation Surface
Depression Mesa Cuesta Creston Hogback Bar Flatiron Escarpment Graben Horst Anticline Syncline Excavated anticline Hanging syncline Combe Cluse Ridge Cone Dike	Depression Vale Canyon Glacis Mesa Hill Crest Chevron (rafter) Ridge Dike …	Depression Swale Floodplain Flat Terrace Mesa Glacis Delta Estuary Coral reef Atoll .. …. …	Depression Dome Tower Hill (um) Polje Blind vale Dry vale Canyon (=collapse vale) … … …	Dome Inselberg Monadnock Tors (=boulders field)

Here, a distinction is made between structural, erosional, depositional, karstic and residual types. As it is seen from the table some of the terms such as glacis, mesa, ridge, etc. are repeating in more than one column. In these instances terms must be prefixed with the name of process(es) involved in shaping the relief such as depositional glacis, erosional glacis, and so on. At level 2 (lithology/facies) the hard rocks or the facies of the soft cover formations (mostly of quaternary age; alluvial, colluvial aeolian, etc.) are mentioned. Very often lithology can be inferred from aerial photograph at higher level of rock classification such as sedimentary or igneous rocks. To distinguish between metamorphic and sedimentary rocks, or to

make a distinction between different types of any of the above mentioned rock types is not always as easy task in aerial photo-interpretation.
Lithology is normally deduced from a geological map which may be in some cases absent. However, it is often possible to recognize different appearances (physiognomic features) where an estimation of the type of rock can be made.
If lithology is not known and it can not be inferred from aerial photographic interpretation then a question mark is placed in this column meaning that it should be checked and completed in the field. At level 1 different landforms are distinguished. For the depositional landforms
the terminology has been more developed than for the erosional and structural ones. The following depositional landforms are very common (for further details see he lecturenotes on physiography and soils, Zinck):

- levee	- overflow mantle	- overflow basin
- decantation basin	- splay mantle	- crevasse splay, splay fan
- abandoned meanders	- oxbow lakes	- terrace front (riser)
- terrace tread		

For the erosional and structural landforms the simplified model of Rhue, with five facets (summit, shoulder, backslope, footslope and toe- slope), is used here. landform is the lowest level of the hierarchical (geopedological) system, and can only be subdivided by means of phases.

Using phases is not restricted to the landform level, but at any level of the legend can be used, the same way as the USDA Soil Taxonomy does.

An example of the legend is given hereafter (for more details see the lecturenotes on physiography and soils (part 2), and the exrcises which will be done during the exercise hours. The legend here is not constructed as in the physiographic analysis, where subdivision is done vertically as follows :

As you notice, legend of a geopedologic map shows a horizontal way of subdivision (see the following simplified example):

- Mo Mountain
- Mo1 Hill
- Mo11 Limestone
- Mo111 Summit/shoulder complex
- Mo112 Backslope
- Mo113a footslope, slightly eroded
- Mo113b footslope, severely eroded
- Mo12 Sandstone (where Mo121, Mo122, etc may be the subdivisions)
- Mo2 Ridge (which may have further subdivisions as Mo21, Mo22, Mo23, etc.)

In the above example landscape (mountain), relief type (hill), lithology (limestone), and a few landforms (Mo111, Mo112,....) are shown. The lower case letters **a** and **b** added to Mo113 are the phases. The legend may continue further for other landscapes, etc.

I also feel obliged to make it clear that contrary to what is sometimes thought, geopedology is not only an image-interpretation map, with a tabulated legend wherein map units are described in geomorphologic terms, or a well organized application of geomorphology to soil survey. Geopedology is a conceptual approach, which fortifies a scientific framework for soil resource inventory and its interpretation/ evaluation for various uses. In other words, it is a science and, at the same time, an art of modelling the occurrence of soils in landscape, a process which is based on (mental) integration of knowledge on climate, geology, geomorphology, sedimentalogy, hydrology, vegetation, and pedology (Wainwright and Mulligan, 2005). A geopedologic map is a soil map, which includes much facts and understanding about the landscape.
A well prepared geopedologic map, in a GIS environment, and if it is well attributed (in a database) can be digitally re-classified to extract different soil attributes, among others for salinity (EC).

6. The photo-interpretation map

We assume that a geopedologically well-trained soil surveyor with some experience in photo-interpretation will usually apply one of the methods fortified by geomorphology (eg., physiographic analysis, geopedologic approach), or where not possible the physiognomic analysis. We may now put the question: what are the units which we delineate on a photo-interpretation map and what do they represent in terms of soils? this question is important in view of what has to be done after the completion of the interpretation map viz. the transformation of the interpretation map into a soil map.
Before endeavoring to answer the question we will first try to obtain a better understanding of the problem by discussing the more basic problem of how soils occur in nature (see also lecture-notes on soil survey methodology). When a soil surveyor starts his work in an area, he does so by studying in the first place a number of soil profiles or pedons in the field.
These profiles or pedons are not defined soil units. We can study them at almost any place in the field and determine for ourselves the boundaries of the profile or pedon.
Studying profiles in the field, we usually find that in certain zones the profile or pedon characteristics stay more or less the same or change very gradually, while on the other hand there exist zones in which characteristics change more rapidly.
On grounds of this observation we can construct the following model of a soil(land)scape. There are areas where soil profiles or pedons and also external soil characteristics change very gradually or stay almost the same. These areas are bounded by transition zones with a more marked change in profile or pedon characteristics and external characteristics, followed once more by a zone of relative uniformity. An area bounded by a zone of rapid change can be called a geographical soil body, a natural soil body or in short: a soil body (for further details, see the lecturenotes on soil survey methodology).
Profiles or pedons then are *Samples* taken either from these soil bodies or from the transition zones between them.
The zone of transition between two soil bodies may in some extreme cases be very small. In this case there is an abrupt change from one soil body into the other and the delineation between the two can be put only at one certain place. However, the transition from one body to another often occurs within a somewhat wider zone. If the zone is small in relation to the scale of the soil map, which is being prepared,

then we split it between the two bodies which it separates. If the zone is still wider, then we might show it separately on the map as a mapping unit (Fig. **85**).

If the transition zone becomes wider and wider, it tends to lose its characteristics as a transition zone, because the changes of profile or pedon characteristics and the changes of external soil characteristics become more and more gradual. The transition zone will no longer exist if the changes become very gradual, it will in this case be just a part of a larger natural soil body.

The maximum width of a transition zone in any given case depends on the bodies between which it is a transition zone. The largest possible width of a transition zone between strongly contrasting bodies is certainly greater than the largest width between bodies having much in common.

A difficult question which will be discussed here only very briefly is: what changes do we mean, when we speak of changes of soil characteristics? These are in general the changes in the characteristics normally used in description and classification of the profiles or pedons. But also changes in the external features such as surface colour, kind of tilth and topography should be taken into account.

Natural soil bodies can sometimes be very large e.g. some of the young sea clay polders and in the lowland peat area in the Netherlands, and very old stable land surfaces in the tropics. In other landscapes they are often very small e.g. in areas of ground moraines or in general in undulating landscapes where groundwater is relatively high. Small bodies can occur side by side with small or large bodies, or as inclusions in larger bodies.

Natural soil bodies and broader transition zones can be delineated without having any specific soil classification in mind. This was actually done in the Netherlands in the first years of soil mapping, during and just after the last World war. No soil classification was present as a base, and there was no knowledge of other classification systems. The soil bodies might consist of soil profiles and pedons which are all very similar; another possibility is, however, that the profiles and pedons have a relatively wide range of characteristics. This is frequently the case in a large soil body where there is a gradual change of profile (or pedon) characteristics over relatively large distances. If we apply a soil classification (like the one of the 7th approx.) then we will find that such body consists of more than one kind of profile; it will include profiles belonging to different classes e.g. to two or perhaps even more soil series.

The bodies which are more homogeneous in their profile characteristics will often include only profiles (pedons) belonging to one class e.g. to one series, but this need not always be the case. We might have a soil body in which the profile characteristics of different profiles (*Samples*) are clustered around the limit of two classes. They might belong in this case to two related series. However, out with a classification system we would regard the profiles as similar, and the unit as homogeneous.

Large bodies which are not homogeneous will have to be split up in detailed surveys. Because no natural boundary is present, this division will be arbitrary. The sub-division of the body might be based on a soil profile (or pedon) classification system or it might be based on practical considerations as is done if, for example, phases are used.

Soil bodies will be grouped together in one mapping unit if the single soil bodies are too small to be mapped on the pertinens soil map. The mapping unit will in this case consist of an association of soil bodies forming composite soil bodies.

These composite soil bodies can be of different kinds: either the single bodies of the association have soil profiles which show a strong relationship with each other, or the soil profiles in the single bodies are more contrasting.

Composite soil bodies of more contrasting pedons are acceptable as mapping unit on the grounds that they form geomorphologically a definite landscape element. They will further show a certain homogeneity in their variety of pedons and external soil features.
We may go back now to the question: What are the units on our photo-interpretation map and What do they represent in terms of soils?
The units which we delineate as physiographic or physiognomic units may be said to correspond with the natural soil bodies which we have just discussed. We have seen in previous chapters that the physiographic and physiognomic units can be delineated on the photographs by the elements, which are either external characteristics of the soils in such a unit, or features which have a correlation with these soils.
If we can delineate physiographic units, whose formation processes are well understood, then we already have much information about the soils to be expected in a particular unit. Yet, the detailed facts can only be provided by digging, auguring and other kinds of observations in the field. This is even more true when the interpreter does not comprehend the physiography and therefore resorts to the physiognomic analysis, because in that case we do not have so much qualitative information about the soils as would be available in the case of an geomorphological - supported analysis.

Validity and accuracy of boundaries

Not all the boundaries with which a soil surveyor will have to deal have the same value and significance. Because this fact gains importance during completion of an interpretation map, we give here a general outline of the possibilities. We do not limit ourselves to the boundaries on the interpretation map, but consider also boundaries on photographs and on the eventual soil map. Two aspects of boundaries are important in this connection, viz. validity and accuracy.

Validity

The boundaries can be grouped in this respect as follows:

a. Boundaries visible on the photograph, and are definitely valid for the relevant soil map.
b. Boundaries visible on the photograph, but are definitely invalid for the relevant soil map. They may be invalid because:
    *. of having no relation to soil differences e.g. vegetation differences due to human influences
    *. merely indicate minor soil differences which are not important for mapping. Boundaries based on differences in greytones due to differences in soil surface colour may not coincide at all with boundaries of mapable soil bodies.
    *. they are too detailed for the scale of the relevant soil maps.
c. Boundaries visible on the photographs of questionable validity for the relevant soil map. These will be boundaries about which the soil surveyor is uncertain until he has checked them in the field. How many of these boundaries will occur, depends on the reference level of the surveyor and also on the kind of survey. In small-scale surveys a skilled surveyor will in general have no great difficulty establishing which boundaries are the valid ones, although he might in some cases have some difficulty in choosing

correctly. In photo-interpretation for large-scale soil maps more boundaries which need checking might appear.

d. Boundaries visible on the photographs but missed during photo-interpretation because the soil surveyor has not enough insight into the relation between landscape features and soils. He might be aware during the photo-interpretation that some boundaries are lacking, e.g. because the delineated areas are not very homogeneous in their external features. Probably however this lack will not be detected until the fieldwork.

e. Boundaries which are not visible on the aerial photograph, but which are still important for the soil map, especially for soil maps of large scales, and sometimes in surveys for a special purpose. These boundaries have to be found in the field by auguring.

Accuracy

In this respect the following may be considered:
Sometimes boundaries can only be drawn at one more or less fixed place on the photograph; then they are accurate. In other instances, however, they can be drawn anywhere within a zone. A boundary drawn during photo-interpretation might not be accurate. Fieldwork has to be done to ascertain whether this was the right place or not, or whether it matters much where in the zone the boundary is placed.

7. From photo-interpretation map to soil map (we also use the term geopedologic map)

There is no doubt that a photo-interpretation map gives valuable information about the soils in an area. This information will concern mainly the distribution of the soils and possibly information about their relative qualities. Nevertheless the results of the photo-interpretation will depend on the area mapped (some areas are more difficult to understand than others), on the amount of information which is already available and on the skill and knowledge of the surveyor-interpreter. This last point will always provide a subjective element in the photo-interpretation and this subjectivity may be very marked when the reference level of the surveyor is low. To reduce this subjectivity to an acceptable level is one of the reasons why fieldwork has to be done for obtaining a soil map (the photo-interpretation map is transformed to a soil map). The picture of the distribution of soils as given on the final soil map should be a natural picture; errors and omissions made during the photo-interpretation should be corrected. The fieldwork is further needed to obtain full information about the soils found within the natural soil bodies (discussed in the previous chapter); these are generally the mapping units delineated on the interpretation map.
Reducing the subjectivity on the final soil map does not mean that there is only one final map possible. If another surveyor were to map the same area, (s)he might arrive at a somewhat different soil map which could be equally true. The same is of course true for soil maps based fully on fieldwork. Such a divergence is of course not acceptable if more than one surveyor is working on the same survey, or if the survey is to be a part of a greater soil survey scheme. In that case a strict correlation is needed. This applies to surveys based on fieldwork only, and also to surveys in which photo-interpretation is being used. In the latter case correlation is needed throughout all the phases of photo-interpretation and fieldwork. It

should be understood that for the different aspects of the fieldwork, it makes a great difference whether the surveyor is entirely free to make his own map and report, or whether he is bound by decisions taken as a consequence of the correlation in the above-mentioned cases.

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Appendix 1:

Exercise - Generating Stereo-Pairs, using satellite images and contour-lines; an example of Tancitaro, Mexico[1]

For this exercise, it is assumed that the student knows ILWIS. The exercise deals with the generation of a stereo pair using a Digital Elevation Model (DEM*) and a single raster map. The map is displayed over the terrain (DEM) and can be viewed in stereo using a screen stereoscope device. The DEM is generated form a contour-lines map (of the study area) whereas the raster maps are false colour composites (FCC) derived form ASTER images and a shaded relief model (generated). The contour-line map is generated through digitisation of the topographic maps of the study area at scale 1: 50 000. The acquisition dates of the ASTER images are: May 12, 2003 and October 18, 2000. The images depict a recent volcanic area in Central Mexico. The area comprises some mountains, a large number of monogenetic cones and several lava and pyroclastic flows, some of which correspond to recent volcanism (Quaternary). The main land cover types are natural forest and irrigated agriculture.

Procedure:

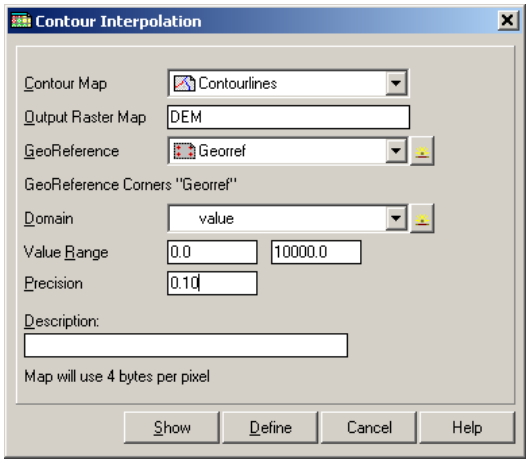
1. Display the false colour composites and observe the different land covers such as forest, rain-fed agriculture and urban areas. Identify the most recent volcanic structures and the recent lava flows and ash fields.

2. Observe the resolution of the "colourf" composites and notice the cartographic properties of the coordinate system (datum, ellipsoid, etc).

3. Display the contour lines on the false colour composites (as background) and try to identify some cones, mesas and mountains.

4. Create a DEM using the contour-lines map applying the contour interpolation function. Fill up the blank spaces using the following data:

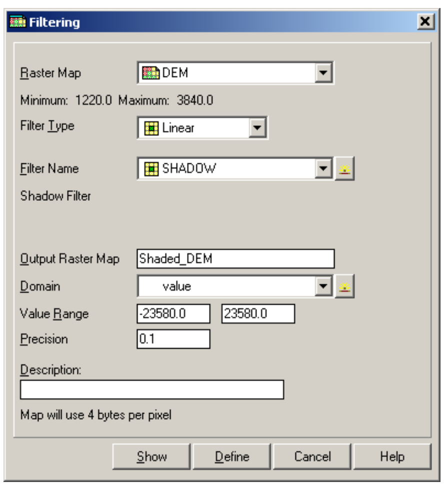
[1]Garrido, A.2004. MSc thesis. ITC, Enschede, The Netherlands



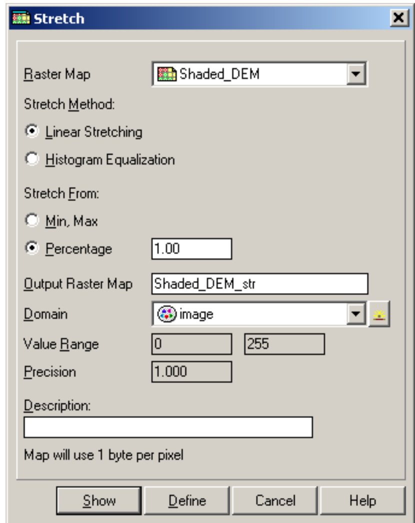
Notice that the georeference for the DEM will be the same as that used by the satellite images.

5. Display the resulting DEM using the CLRSTP10 representation. Find the highest and the lowest elevation values in the area.

6. Create a shaded relief model using the DEM applying the filtering function under image processing. The filter type is 'linear' and the filter name is 'shadow'. Accept the rest of parameters suggested by the program. This procedure is shown in the following figure.

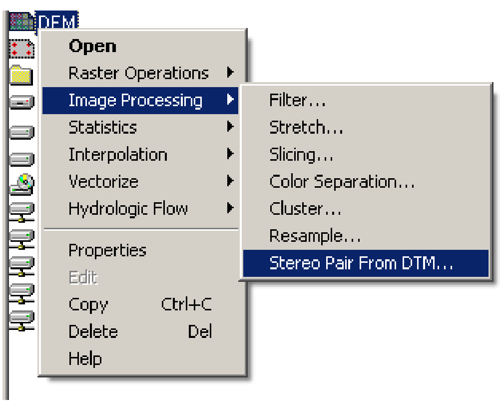


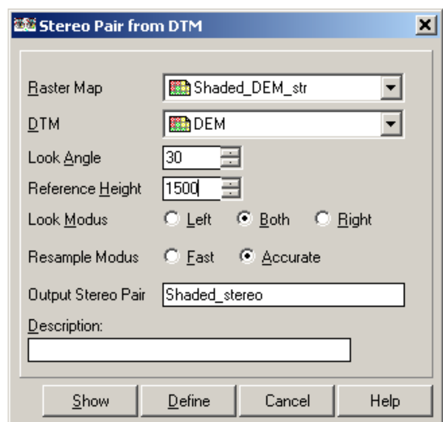
7. Display the DEM using the 'Gray' representation and observe the result. In order to enhance the result, an 'stretch' operation must be performed, thus, using the right button of the mouse and, under image processing function, select stretch command and fill up the options as follows:



Observe the results and recognize the different relief features in the area.

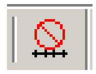
8. Select the stretched Shaded DEM and with the right button of the mouse, under image processing function, select ‘stereo pair from DTM’ function in order to create a stereo pair in the screen. You should be provided with a screen stereoscope device. Fill up the parameters as follows:





As you notice there are some parameters that you can modify. In this case, the parameters suggested for visualizing the stereo pair can be modify according to the preferences of the user. If you are more interested for knowing them it is advisable to follow the help on line of this window. Run the operation and display the result. Once the model is ready, adjust the stereoscope in order to have a comfortable position. Maximize the screen of the stereo pair image and, using the ‘zoom in’ tool of the tool bar make zoom windows in order to increase the level of detail of the image. When you use Zooming, Panning, Entire map or Redraw or when you scroll in one of the displayed photographs, this will be applied to both panes. Notice that both images have georeference.

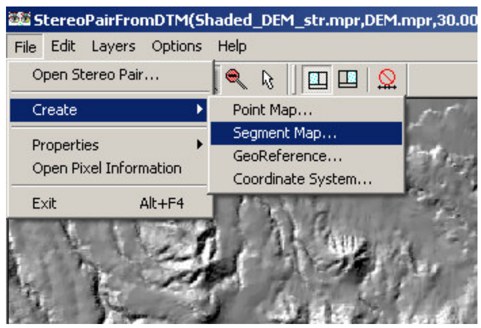
9. To improve the stereo vision, move one or both photographs a little to the left or to the right, you may unlock the left pane and right pane from each other using the following icon of the tool bar:



The Unlock Horizontal Scroll button in the toolbar will appear down. You may now use the horizontal scroll bar below the image for moving the image a little to the left or to the right.

10. Repeat the same procedure of the steps 8 & 9 but in this case, use the false colour composites in order to create a stereo pairs. Visualize them and select one of the models since a segment file will be created.

11. From the menu 'File', select create 'segment map':



Create a class domain containing the name of the classes to be used in the digitisation exercise. Fill up the coordinates spaces with the same coordinates as the georeference used by the DEM and satellites images (consult the georeference properties). Start the digitisation operation of the screen in a appropriate scale of detail.