ADVANCED PHOTOGEOLOGY

LECTURE NOTES

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1. INTRODUCTION

Photogeology is the interpretation of the geological and geomorphological features as well as various lithofacies on the aerial photographs. Some other terms such as "**aerogeology**" and "**airgeology**" are also used.

Aerial photographs are a source of geological information that may be unobtainable elsewhere. An **aerial photograph** is the picture of the ground surface taken from the air with a camera pointing downward.

The study of the aerial photographs can't substitute the field investigations but rather it helps and contributes to them. The advantages of the study of the aerial photographs can be listed as follows:

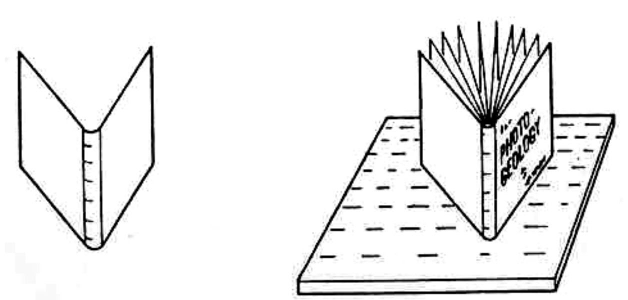
a. it saves time
b. it provides to observe a larger area
c. it has more detailed ground surface than maps
d. photographs can be studied anytime and at anywhere
e. studies carried out on the photographs are cheaper than studies in the field
f. studies carried out on the aerial photographs are easier than studies in the field

The only disadvantage of the aerial photographs is the absence of the topographic contours and the geographic names.

2. STEREOSCOPY

2.1. Stereoscopic Vision

The act of perception is a mental process; the mind invents a model to fit the data with which it has been provided. If Fig. 2.1A, is looked at persistently, it will appear as a book-like object alternately opened towards and away from the observer. The mind has insufficient data to decide between these two possibilities. Such illustrations are known as **alternating figures**. As soon as extra data are added to the illustration to make one interpretation more probable than another, the observer tends to see it in that way. Thus in Fig.2.1B, the addition of pages and a table top make the illustration appear permanently as a book opened away from the observer.



A B

Figure 2.1

The strength of the three-dimensional effect is the resultant of all the data presented to the mind. A simple experiment may convince the reader this. If a number of objects on a table are looked at with only one eye, after a short time, the field of view appears flat. If then the head is moved from side to side, an increase in the apparent solidity of the field of view occurs. The effect of moving the head from side to side is to provide the mind with additional data; these extra data lead to the production of a three-dimensional, rather than two-dimensional, mental model.

The factor that produces the strongest three-dimensional effect is **stereoscopic vision**. Stereoscopic vision depends upon having two view-points (the eyes), set about 6.3 cm apart in the head; this distance is known as the **eye base**.

2.2. Stereoscopes

Two photographs of the same terrain, but taken from different camera stations, generally permit three-dimensional viewing and are said to comprise a **stereoscopic pair**, also commonly referred to as a **stereo pair**. Normally a stereoscopic pair is considered to be made up of any two successive photographs along the flight line (a line on a map representing the track of the aircraft). Stereoscopic pairs typically are viewed under a **stereoscope**, a device constructed to force each eye to look essentially straight down and along lines that are parallel or nearly so. In stereoscopic viewing the lines of sight do not converge as they do in the normal viewing of any nearby object.

There are two basic types of stereoscopes. These are **simple lens or pocket stereoscopes** and the **mirror stereoscopes**.

2.2.1 Lens stereoscope

The lens stereoscope consists of two lenses mounted in a simple frame supported by short legs (Figure 2.2). The best separation for corresponding points of detail on a stereopair, is slightly less than the eye-base of the observer, about 5.72 cm. To view such photographs with a lens stereoscopes therefore, it is necessary to overlap them until the corresponding photographic images are at a suitable separation. When this done, a strip about 5.72 cm wide may be viewed stereoscopically. To view the whole overlap it is necessary to band back the edge of the overlapping photograph.

The lens stereoscope is advantageous to the field geologist because of its compactness and small size. Lens stereoscopes commonly magnify (usually two times) the photographic image and thus are helpful in viewing details of terrain. The principal disadvantage: photographs must be positioned in an overlapping position and as a result the edge of one photograph must be flipped or turned up in order to view some parts of the stereoscopic model. The entire model cannot be viewed at any one time.

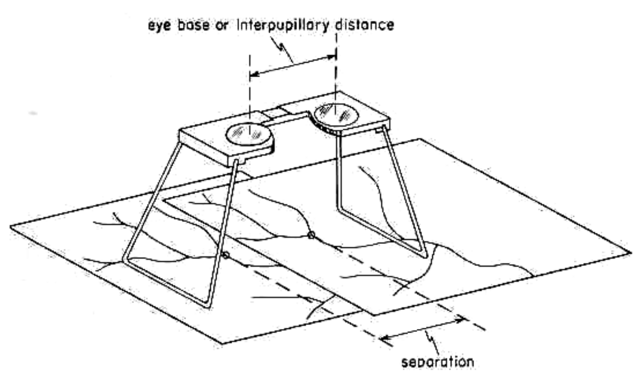


Figure 2.2. Diagram showing eye base (interpupillary distance) and the separation of photographs in stereoscopic viewing with a lens stereoscope.

2.2.2. Mirror stereoscope

Mirror stereoscope is illustrated in figure 2.3; their optical system is as shown in figure 2.4. Light rays coming from the photographs are reflected first by large, surface-silvered mirrors set at 45 to the horizontal and then again by small mirrors set parallel to the larger ones. After reflection by the small mirrors, the rays are parallel to their original direction, but are separated by a distance determined by the separation of the small mirrors.

It can be seen that, with this system the separation of the photographs, when they are set up for stereoscopic viewing, is determined by the separation of the large mirrors (20-25 cm).

The optical distance between the eyes and the photographs consists of the sum total of the distances between the eyes and the small mirrors, the small mirrors and the large mirrors and the photographs; it is thus very great compared with that for lens stereoscope. A stereopair viewed from such a distance would appear very small. To overcome this, lenses are inserted between the eyes and small mirrors. If higher magnification is required, binoculars may be inserted between the lenses and the eyes.

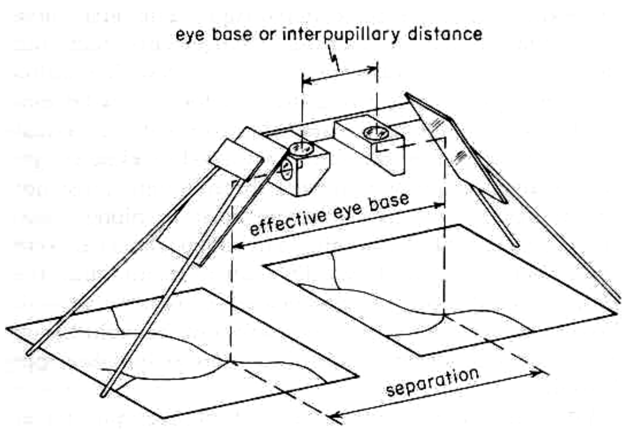


Figure 2.3. Diagram showing eye base, effective eye base, and separation of photographs in stereoscopic viewing with mirror stereoscope.

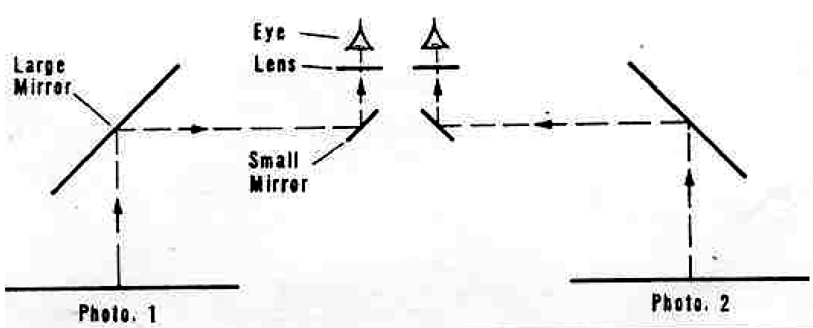


Figure 2.4.

The optical distance between the eyes and the photographs consists of the sum total of the distances between the eyes and the small mirrors, the small mirrors and the large mirrors and the photographs; it is thus very great compared with that for lens stereoscope. A stereopair viewed from such a distance would appear very small. To overcome this, lenses are inserted between the eyes and small mirrors. If higher magnification is required, binoculars may be inserted between the lenses and the eyes.

The mirror stereoscope has the advantage of allowing the entire stereoscopic model to be viewed at one time. But they, in contrast to lens stereoscopes, generally are not readily carried around on field traverses. Most mirror stereoscopes are equipped with auxiliary lenses in a binocular attachment that permits image magnification of several times. But magnification is itself of limited use because enlargement of the photographic image merely enhances the graininess which is present in all photographs. When magnification is greater than 4X, the grain of the emulsion may become conspicuous.

2.3. Radial displacement due to relief

Because of terrain relief, the images of ground positions are shifted or displaced, in the central projection of an aerial photograph. If a photograph is truly vertical, the displacement of images is in a direction radial from the photograph center. This displacement is called the **radial displacement due to relief**. Radial displacement due to relief is also responsible for scale differences within any one photograph, and for this reason a photograph is not an accurate map (Figure 2.5).

In an orthographic projection the true map position of some point A on the terrain appears at A', directly below point A as shown in Fig.2.5(a); the true map position of some point B is at B' directly above B. The difference in height between points A and B does not affect the map distance between them.

In the central projection characteristics of the vertical aerial photograph the map position of terrain point A does not appear at A' but rather at A" as shown in Fig.2.5(b). Point A has been displaced radially outward. On the photograph (negative or print) the image of terrain point A appears at a" rather than its correct position at a'. The distance from a' to a" is the **radial displacement due to relief**. Similarly, point B will be displaced inward on the film or print with respect to its correct relative map position; and point C will have no radial displacement due to relief at the selected datum. Points above the selected datum are thus displaced outward and points below the datum are displaced inward.

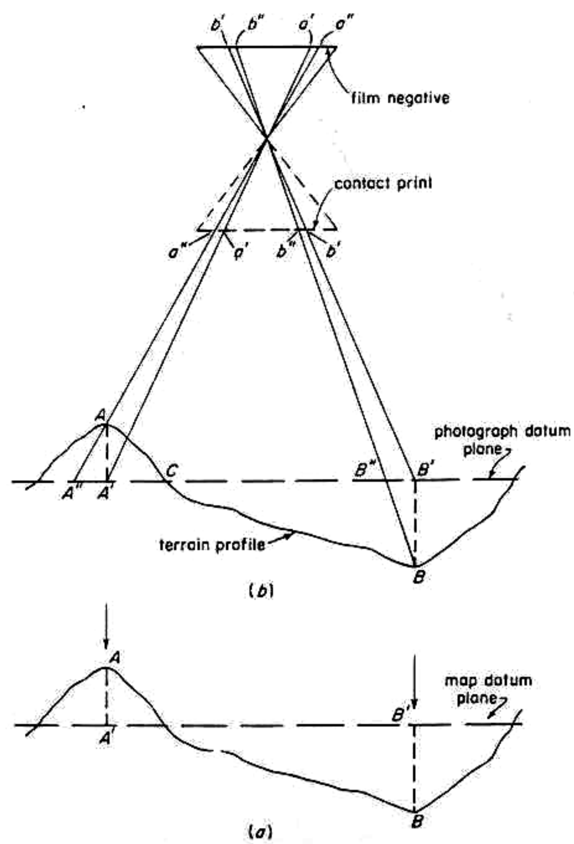


Figure 2.5. Diagram showing comparative positions of features as correctly plotted in the orthographic projection of a map (a) and as displaced in the central projection of a vertical aerial photograph (b).

On any one photograph the amount of displacement due to relief increases with increasing distance from the center point and with increasing difference in elevation between any point and the selected datum reference (Figure 2.6).

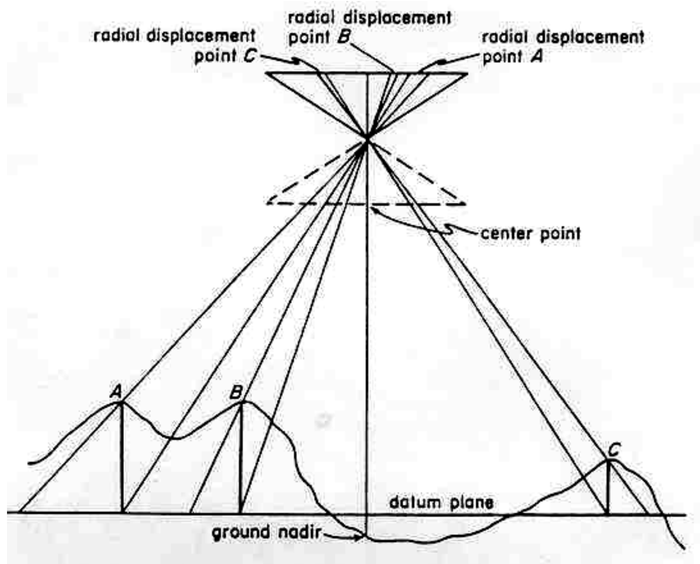


Figure 2.6. Diagram showing relative radial displacement of terrain features on a photograph. For points of equal elevation (A and B) radial displacement is greater for a point farther from the photograph center. For points of different elevation, but equal distance from the photograph center (A and C), radial displacement is greater for a point of higher elevation.

3. AERIAL PHOTOGRAPHS

3.1. Types of aerial photographs

The aerial photographs are classified on the basis of: Optical axis position, scale and film used.

3.1.1. Types of the photographs on the basis of optical axis position

Basic definitions:

Optical axis (OA): is a line passing through the camera lens and being at right angle to the camera film (Figure 3.1).

Vertical axis (LP): is a line passing through the camera lens and parallel to the earth's gravity. So it is perpendicular to the ground surface (Figure 3.1).

Pointing (sighting) angle: is the angle between the optical axis (OA) and the ground surface which is a horizontal plane (Figure 3.1).

Nadir: is the point on the terrain vertically beneath the center of the camera lens.

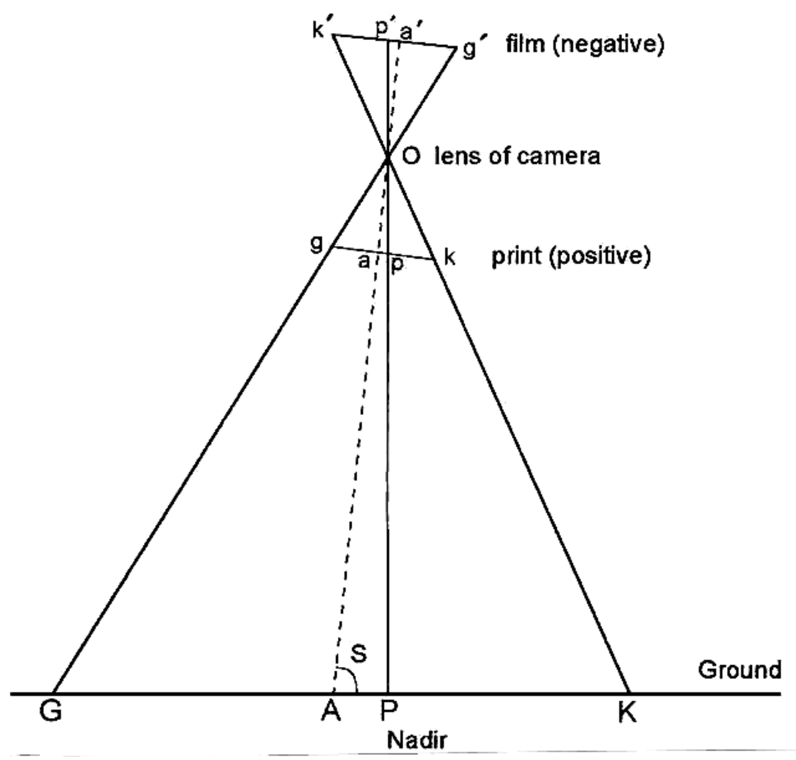


Figure 3.1. Relationship between the camera and the ground surface

The aerial photographs are grouped into two, on the basis of optical axis position (Figure 3.2):

a. Vertical aerial photograph

b. Oblique aerial photograph

a. **Vertical aerial photographs** are taken by the camera pointing vertically downward. Therefore the optical axis is perpendicular to the ground surface. In fact, the optical axis is not exactly vertical. There is a tilt of 1°-2°.

b. **Oblique aerial photographs** are taken by the camera which has the optical axis being oblique to the ground surface. The angle which is called pointing or sighting angle ranges from 20° to 60°. There are two types of oblique aerial photographs: Low oblique and high oblique aerial photographs.

Low oblique aerial photographs: S is between 30°-60°

High oblique aerial photographs: S is between 20°-30°

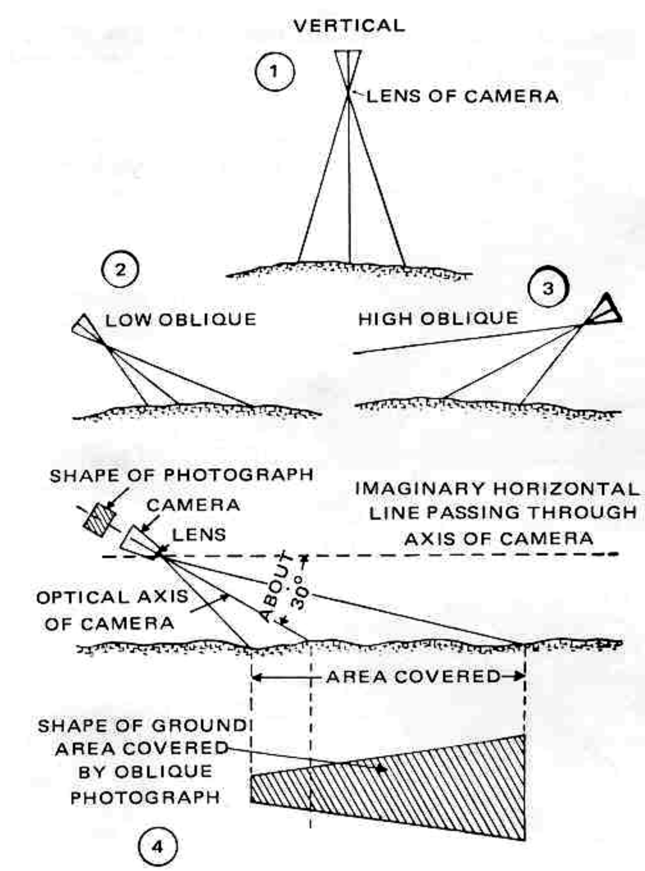


Figure 3.2.

The comparison of vertical and oblique aerial photographs:

a. No (or less) distortion on vertical, but quite large distortion on oblique ones (Figure 3.3).

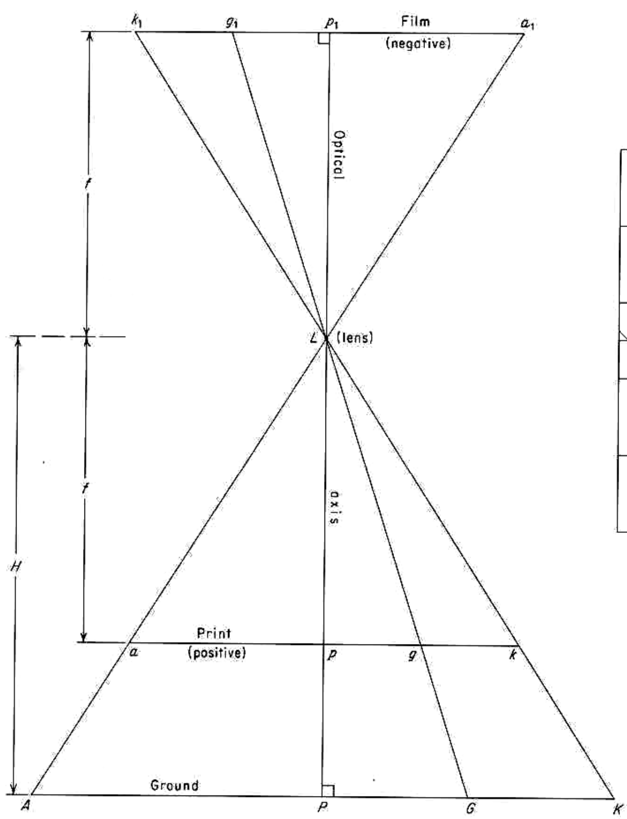
b. The front edge is the same in both, but back edge is different (in oblique greater) (Figure 3.4, 3.5).

c. The vertical photographs cover less area than oblique, that depends on the amount of sighting angle. With a less angle the larger area will be taken.

d. The horizon is generally seen on oblique photographs but not on vertical ones (Figure 3.4).

e. Oblique aerial photographs are not suitable to get 3-D view because of the scale difference between the front and back edges. Therefore, generally the oblique aerial photographs are used to study gentle dipping features such as unconformities and thrust.

f. Oblique aerial photographs are used to illustrate the reports to show the route of the proposed roads, while the vertical ones are used mainly for photogrammetry and photointerpretation.



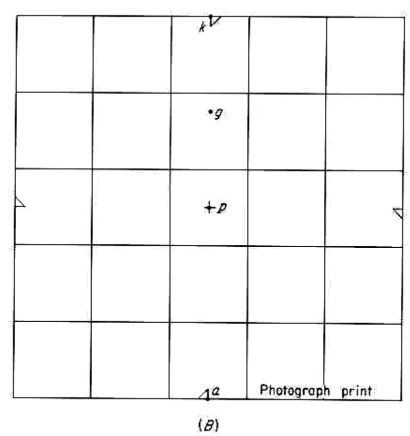


Figure 1-1. (*A*) The geometry of a *vertical aerial photograph*, and the basic relations of film negative, lens, positive print, and the ground. Photograph scale is equal to the ratio of camera focal length to camera height (f/H). Ground point *P* lies directly beneath the camera. It is called the *nadir point*. Point *p* is the principal point (center) of the photograph. In vertical photographs, the principal point and image of the nadir point coincide; on tilted or oblique photographs they are separated. (*B*) A vertical "photograph" of a square ground grid. The marks in the centers of the edges of this figure are called *fiducial marks;* lines connecting opposite fiducial marks intersect precisely at the principal point. The principal point is also marked on some photographs.

Figure 3.3

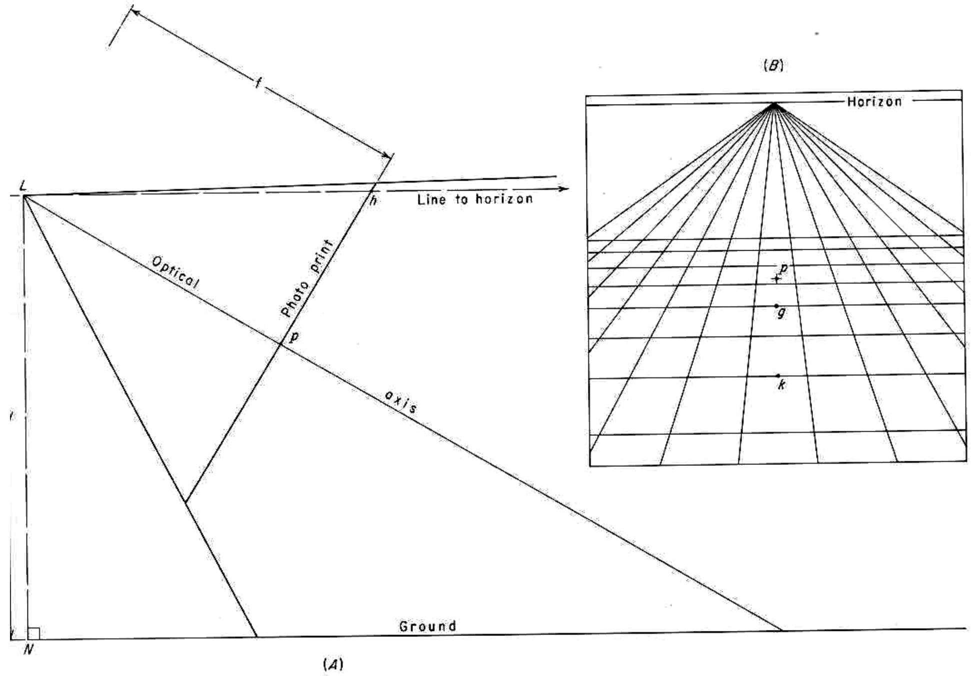


Figure 3.4. (A) The geometry of *high oblique photograph.* The optical axis is sufficiently inclined to permit the photography of horizon. The nadir point N is not photographed. (B) A high oblique "photograph" of a square ground grid. The ground squares are equal to those shown in Figure 3.2.

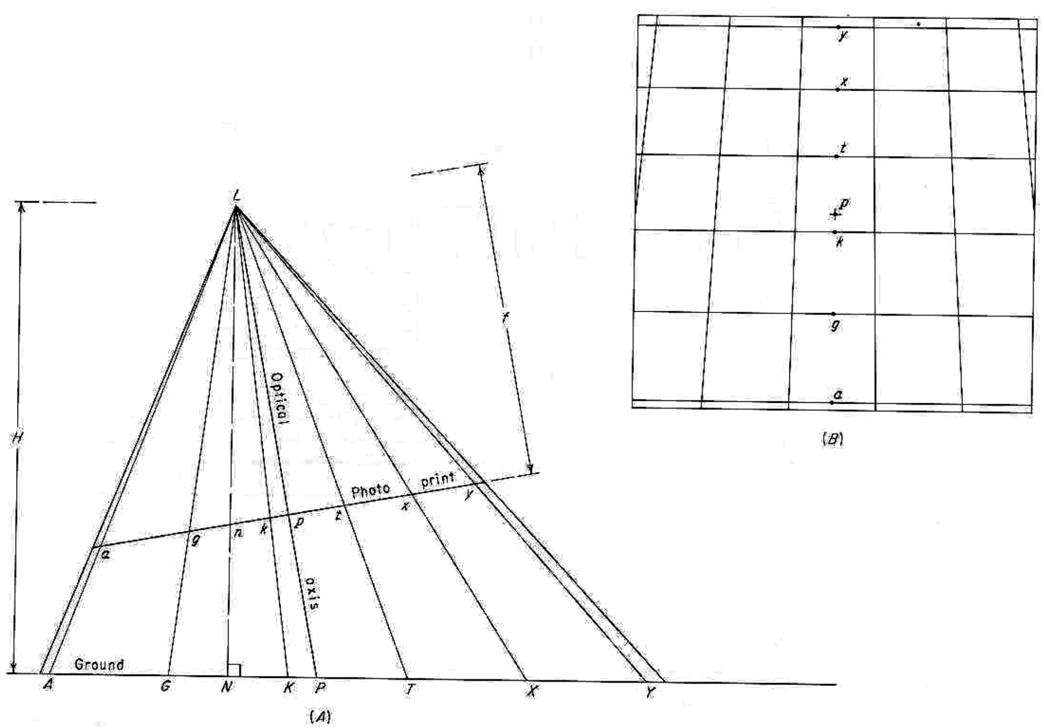


Figure 3.5. (A) The geometry of a low oblique photograph. Compare with Figures 3.3A and 3.4A. Camera height H and focal length f are same in all three illustrations. Equal ground distances AG, GK, etc. appear as unequal image distances ag, gk, etc. on the low oblique photographs. The nadir point n is shown on the photograph. (B) a low oblique photograph of a square ground grid. The ground surfaces are equal to those shown in Figures 3.3B and 3.4B

3.1.2. Types of aerial photographs on the basis of scale

a. large scale aerial photographs (1/5.000 to 1/10.000)

b. medium scale aerial photographs (1/10.000 to 1/20.000)

c. small scale aerial photographs (1/20.000 to 1/60.000)

d. very small scale aerial photographs (1/60.000)

The photographs used mostly are at the scale of 1/35.000, with a size of 18X18 cm.

The size of the photograph can not be greater than 25X25 cm, because stereographic viewing is only possible for these size.

3.1.3. Types of aerial photographs on the basis of film used

a. Panchromatic black and white photographs

b. Infra-red black and white photographs

c. Infra-red colored photographs

Black and white photographs are taken with a minus blue filter eliminating the scattering effect of the haze, and hence good quality photograph with high degree of resolution is obtained. This type of aerial photographs are also called "conventional black and white photographs". They are mainly used for mapping.

Colored photographs, on the other hand have some advantages over the first ones when they are used for special purposes such as to detect the mineralization zones. However, some details of the surface can not be resolved clearly on these photographs. Colored photographs have a common usage in forestry and pollution studies.

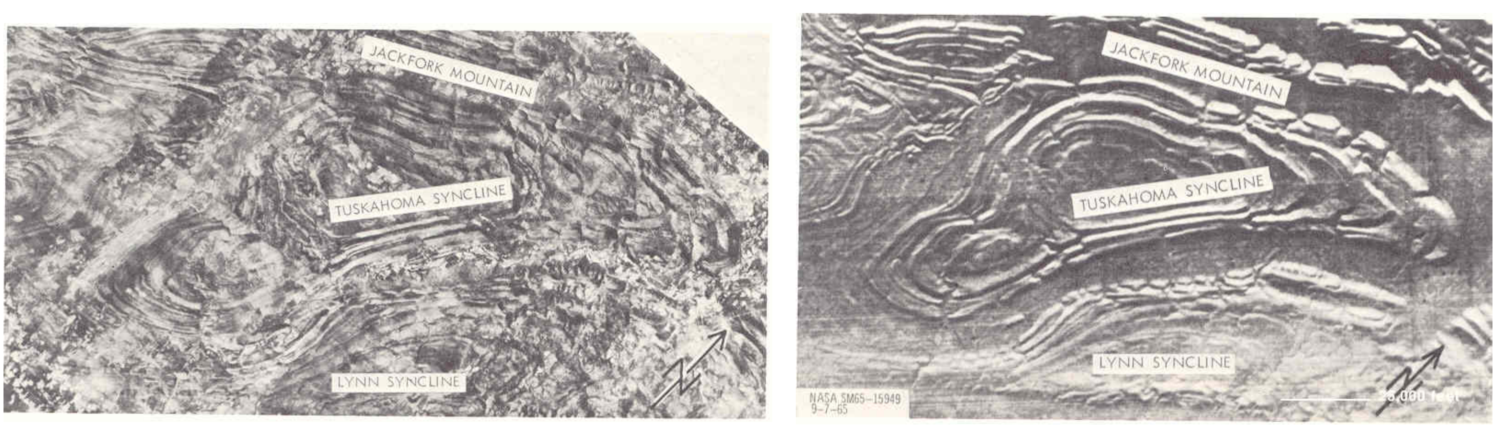


Figure 3.6. The photomosaic of the region (left figure) and radar image of the same region (right figure)

Figure 3.7. Examples of aerial photographs

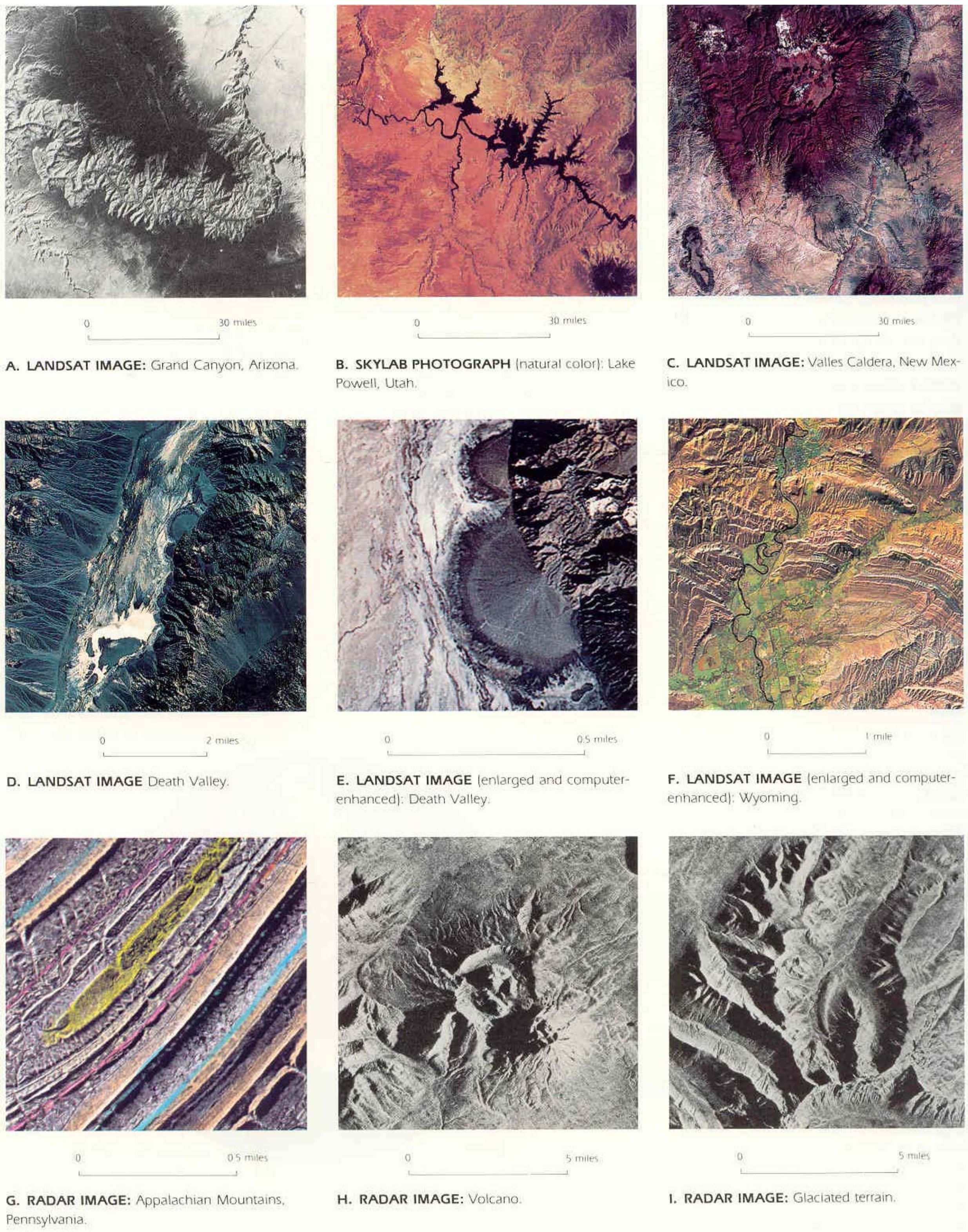


Figure 3.8. Types of remote sensing imagery

3.2. Uses of aerial photographs

Vertical aerial photographs are mostly used for two purposes, namely "photogrammetry" and "photointerpretation".

Photogrammetry is a science branch dealing with surveying and mapping using the aerial photographs. It is also used for drawing the contour maps and road schemes.

Photointerpretation, on the other hand, is the study of the character of the ground surface using the aerial photographs. It has been widely applied to many branches of science and engineering including: geology, civil engineering, pedology, hydrology, military science, land use, geography, forestry, and archeology.

It is widely applied to civil engineering problems, site investigations, route planning and reconnaissance studies.

In geology the photointerpretation is applied to: stratigraphy, structural geology, tectonics, sedimentology, geomorphology, glacial geology,

The widest application is in aerial geological mapping.

3.3. Informations printed on aerial photographs

A photograph contains the following information (Figure 3.9).

a. **Fiducal (collimation) mark**. These marks are used to determine the principal point (fiducal center) of the photograph. The principal point is the geometric center of a photograph. It is the intersection point of two straight lines joining pairs of opposite fiducal marks. Because of 60% overlap of the photographs every principal point lies on an adjacent photograph. These points are called '**conjugate principal point**' or '**transferred principal point**' (Figure 3.10). Therefore each photograph contains one principal point and two conjugate points.

b. **Serial number**. All the photographs included in the same strip along the flight lines have a number called '**serial number**'. Serial numbers are recorded at the end of each strip in the flight index or flight plan (Figure 3.11).

c. **Film (or photograph) number**. All the photographs taken from the airplane are numbered separately. These numbers are called '**film number**'.

Serial number and film numbers are recorded side by side on each photograph.

In a flight index, on the other hand, the serial number is recorded at the end of each strip, while the film numbers are recorded in brackets on the flight index (Figure 3.11).

d. **Focal length (or principal distance) 'f'**. It is the distance between the film used and lens of camera (Figure 3.12),and it is recorded automatically on the film during exposure.

The modern cameras have a focal length of 152 mm.

e. **Camera number**. It is the number of the camera, which takes the picture. It is also printed automatically on the photograph.

f. **Clock**. It shows the time, when the picture was taken. The time interval between two successive photographs is used to determine the speed of the airplane.

g. **Date.** It shows the day, month and the year when the photograph was taken.

h. **Altimeter**. It shows the flight height from the mean sea level.

g. **Spirit level**. It shows tilting . The tilt is the deviation of vertical axis, when the plane is not horizontal because of some effect, such as wind.

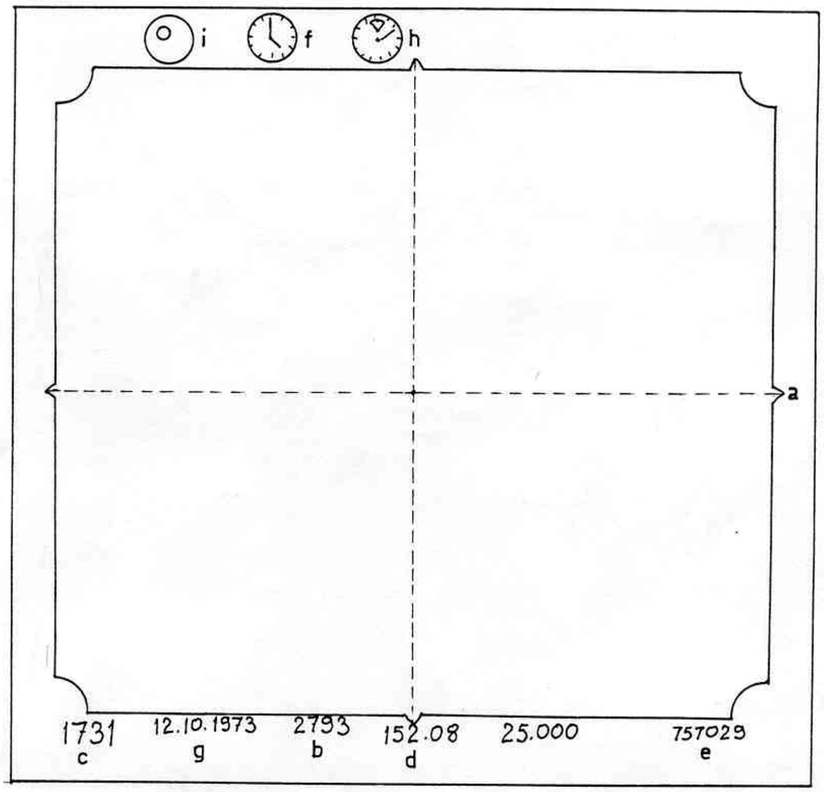


Figure 3.9. A schematic aerial photograph showing the information printed on it.

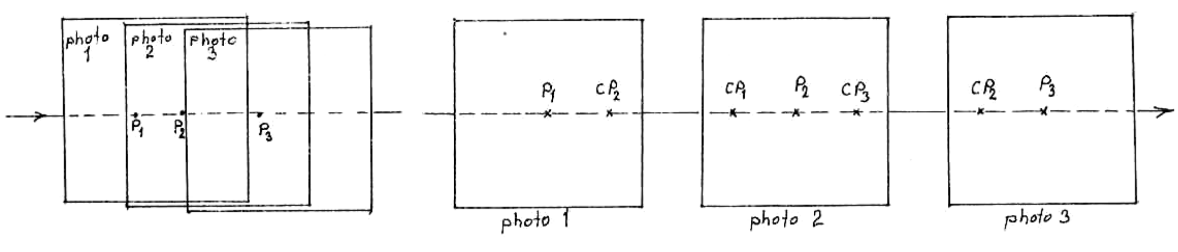


Figure 3.10.

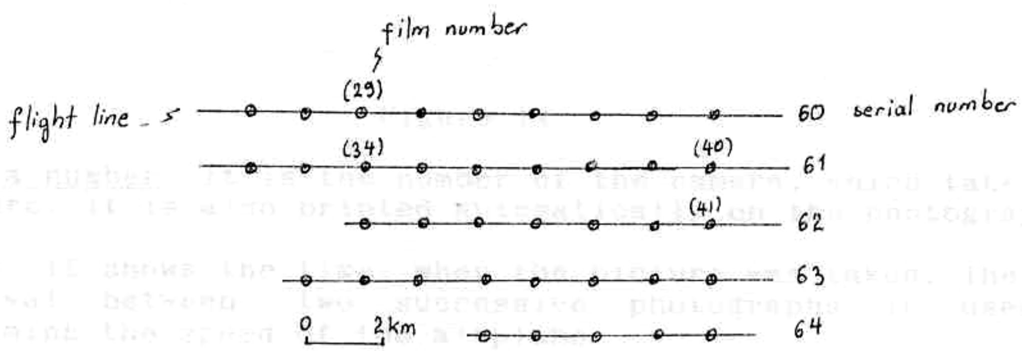


Figure 3.11.

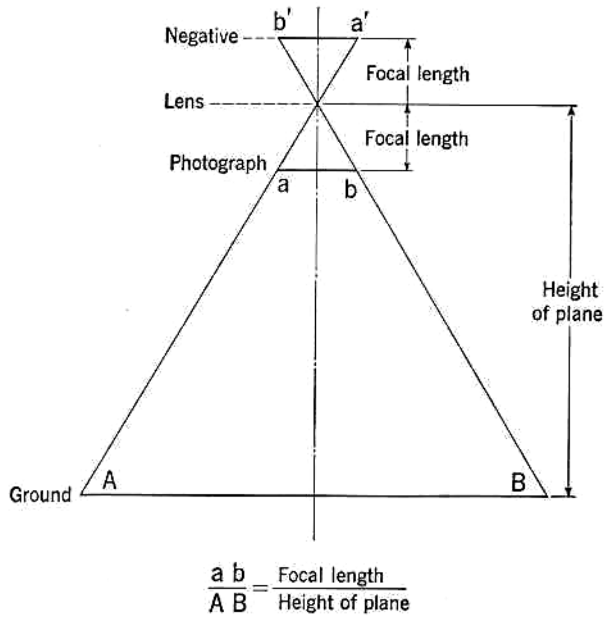


Figure 3.12.

3.4. Taking aerial photographs

3.4.1. Principles.

The photographs are generally taken in spring or autumn, when the ground is not covered by vegetation. The pictures are taken at series of parallel lines so that it provides overlapping in order to obtain stereoscopic viewing.

When two pictures of the same area, taken from two different positions, are studied simultaneously with a stereoscope, a solid model of the ground can be seen. This solid model is called '**stereomodel**'. Two adjacent photographs are called '**stereopair**'.

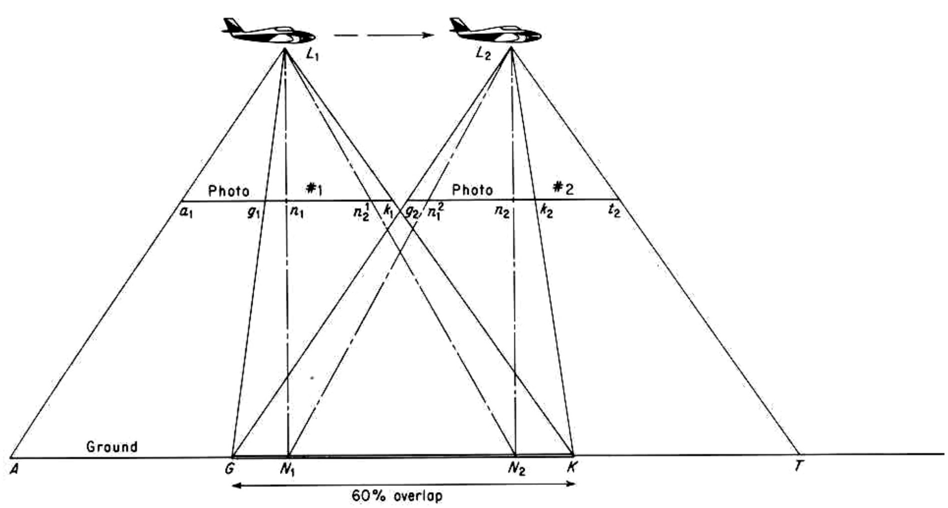


Figure 3.13

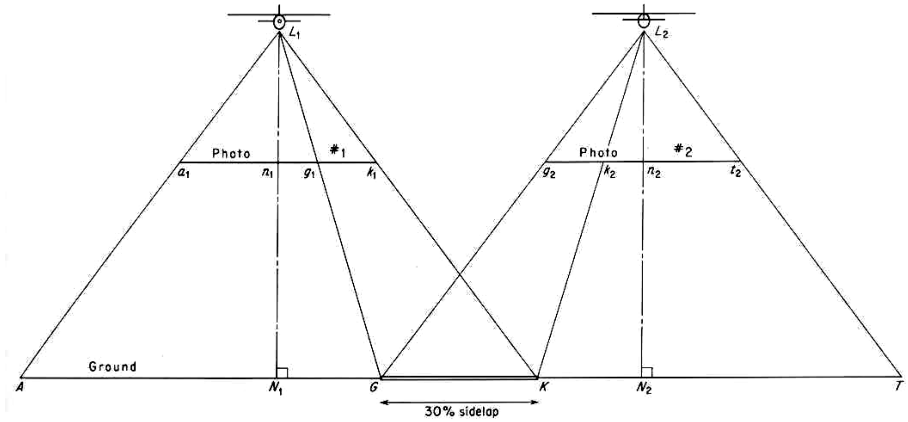


Figure 3.14

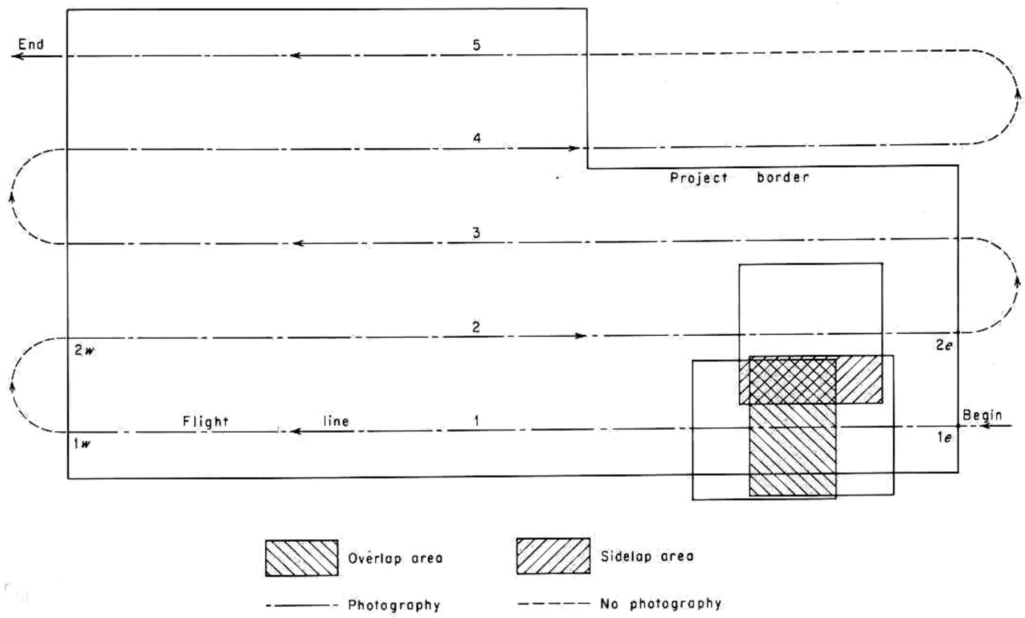


Figure 3.15.

Consider figure 3.13, which represents a vertical section in the line of fight of the plane. A photograph taken from Air Station 1 (L1) covers the ground A-K. The plane flies to Air Station 2(L2), and photograph 2 is taken, which covers the ground G-T. The ground G-K, known as the **overlap**, is thus represented on both photographs.

The amount of overlap depends on the **air base** B, which is the distance between the air stations. If the overlap were 50 per cent, G-K would be half G-T, when photograph 3 was taken from Air Station 3, the new overlap would be K-T; thus the whole of the area covered by photograph 2 would appear on two photographs and could be viewed stereoscopically using first photographs 1 and 2 and then 2 and 3. If the overlap were less than 50 per cent there would be a gap in the center of photograph 2, which was not included in either overlap, and which could not be viewed stereoscopically; to avoid this, an overlap of 60 per cent is usually aimed at.

If the overlap is 60 per cent, every point on the ground is represented on at least two consecutive photographs; it is therefore possible to divide the photography into two sets of photographs, each of which covers the whole area; one set will consist of photographs 1,3,5, etc., and the other of photographs 2,4,6,etc. Either set can be referred to as a set of **alternate photographs**; the other set is then referred to as the **conjugate photographs**.

To photograph a large block of ground, it is necessary to fly a number of parallel strips; these must overlap laterally to ensure that no area between them is left unphotographed. This lateral overlap, known as **side-lap**, is usually about 30 per cent. If the terrain is flat, a smaller side-lap of (say) 20 per cent would be suitable (figure 3.16, 3.17); but if the terrain is mountainous, and particularly if the photographs are likely to be required for mosaicing, a larger side-lap would be desirable.

3.4.2. Errors in flying

Ideally each flight line is a straight course and each photograph has 60% overlap and 30% sidelap (figure 3.14, 3.15). But this is not always achieved and some errors occur, because of cross winds other problems of aircraft navigation. These errors are namely: Crab, drift, tilt and differential overlap.

3.4.2.1. Crab

It occurs when the plane is corrected for the wind effects but the camera left unoriented (figure 3.14). The resulting photographs will not be parallel to the correct flight course. But the actual and correct flight courses will coincide.

3.4.2.2. Drift.

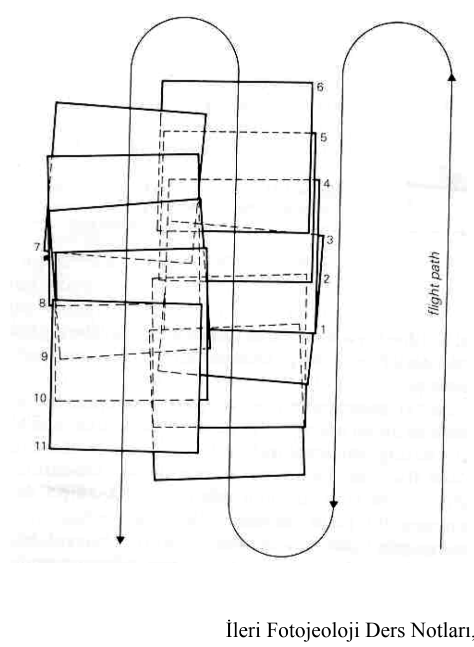
If the plane is affected by cross winds and no correction is made for the wind effect, **drift** occurs (figure 3.14). The edges of the photographs remain parallel to the correct flight course, but the plane drifts further from its course.

3.4.2.1. Tilt

It occurs when the plane is not horizontal at the time of exposure. Stereoscopic viewing will be difficult and forms, produced on the stereoscopic image will be unreal. In extreme cases tilt effect shows rivers flowing uphill.

Tilt angle is the deviation angle between the horizontal surface and the flight line, measured on the vertical section (Figure 3.15). On the other hand, drift and crab angles are deviations measured on the horizontal plane.

Fig.3.16.



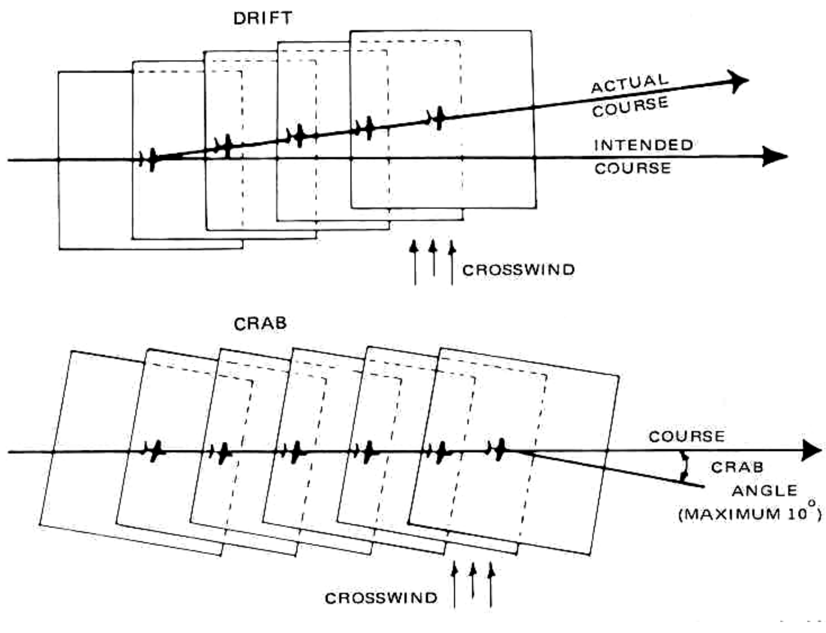


Figure 3.17.

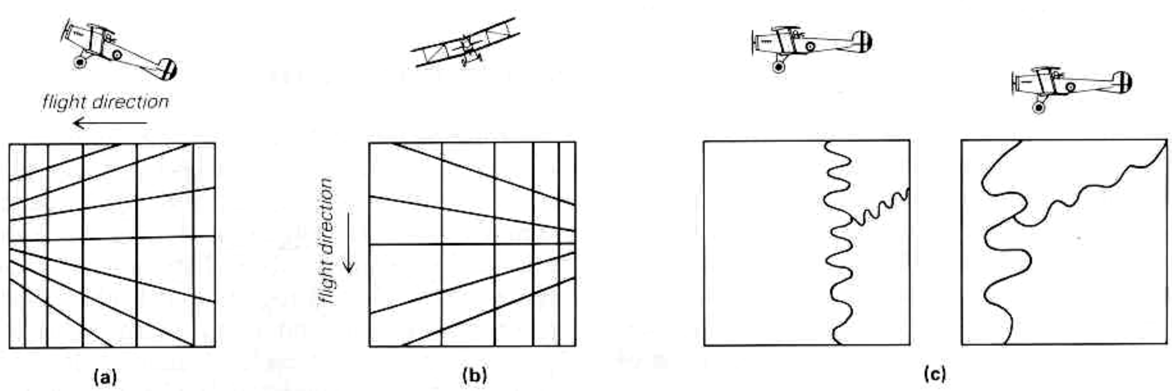


Figure 3.18. Apart from distorsions in scale due to varying elevations of the surface, the main distortions in aerial photographs are due to tilting of the aircraft, (a) and (b), so that the view is slightly oblique. Convection cells in the atmosphere may cause the aircraft to change altitude so that adjacent images have different scales (c).

3.4.2.4. Differential overlap

It is caused by the speed of the plane. If the plane is not adjusted to the time interval between the exposures, the resulting overlaps will be either small or great. In both case an ideal stereo-viewing can not be obtained.

These affects can be overcome by modern navigational devices.

3.5. Handling of aerial photographs

We can come-across with two main problems during the studies on the aerial photographs: 1) to determine which photographs are required for the study area, 2) how to select quickly, the particular photographs required for a study from a large collection.

The first of these problems is solved by the use of either a **'cover diagram'**, **'print laydown'**, **'photo index**' or '**mosaics**'.

In order to solve the second problem, it is necessary to file the photographs according to a definite system. If all photographs for the area are numbered in a consistent manner, it is possible, and very convenient, to store them in a pile in strictly numerical order. For instance, if all the photographs are marked with flight and serial numbers, they are obviously amenable to filing in strict numerical order.

3.5.1. Cover diagram.

A cover diagram shows the approximate latitude and longitude of the area covered by each strip of photography; the photograph numbers are recorded at either end of each strip on the diagram, so that it is possible to estimate the approximate serial number of the photograph corresponding to any point within the strip.

3.5.2. Print laydown

A print laydown consists of a single photograph of the alternate prints of the original photographs, which have been laid down in approximately their correct relative positions. Print laydowns are of great value to geologists because they:

a. give him a "bird's eye" view of the area
b. indicate areas of particular interest
c. show the access routes to these special areas
d. indicate the most probable positions of outcrops
e. simplify the planning of traverse
f. indicate the serial numbers of the photographs required for a particular traverse, or for any particular area under discussion
g. simplify the selection of camp sites
h. provide illustrative material for scientific papers, and committee discussions.

3.5.3. Photo index.

A photo index is very similar compilation to the print laydown, in which all the prints are laid down before being photographed. The photograph serial numbers are printed at the end of each strip of photography on the print laydown, and on each photograph of the photo index. Print laydowns or photo indexes of an area enable the serial number of the photograph corresponding to any particular part of the area to be determined instantaneously; they are therefore much more useful than cover diagrams.

3.5.4. Mosaics.

The more advanced and attractive form of print laydown is **uncontrolled mosaic**. The differences between mosaic and print laydown:

a. In mosaic all photographs (not only alternate) are stuck down with glue. In print laydown they were attached.
b. In mosaic all the corners and edges are cut away before sticking, so that only the central portion of each photograph is used.
c. The serial numbers, like in print laydown, are printed at the end of each strip.
d. Mosaic, as an advantage over the others, seems to be a continuous photograph.

3.5.5. Flight index.

Flight index is a sketch map showing the flight lines, their senses, photograph serial numbers, film numbers and the main geographic features such as highways, towns, lakes, large rivers etc (figure 3.19).

Preparation of flight index, showing the outline of the photographs on a plan is very useful before starting to study on the aerial photographs. On the flight index aerial photographs are arranged in the same manner as they were taken by the plane. Flight lines are also plotted and labeled with the photograph serial number. On the other hand, the individual exposures or individual photograph numbers are marked on the flight lines and the sense of flight lines are indicated. The major geographic features such as villages, roads, etc. are also marked on the flight index to show the relative position of the photographs to such known features.

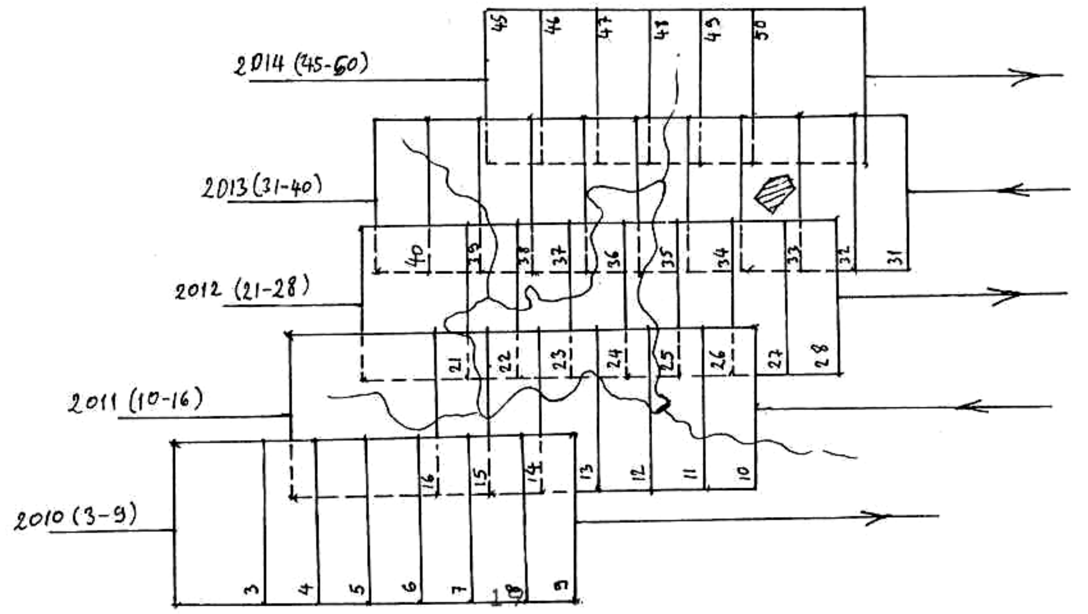


Figure 3.19

Requirements for Stereoscopic Viewing:

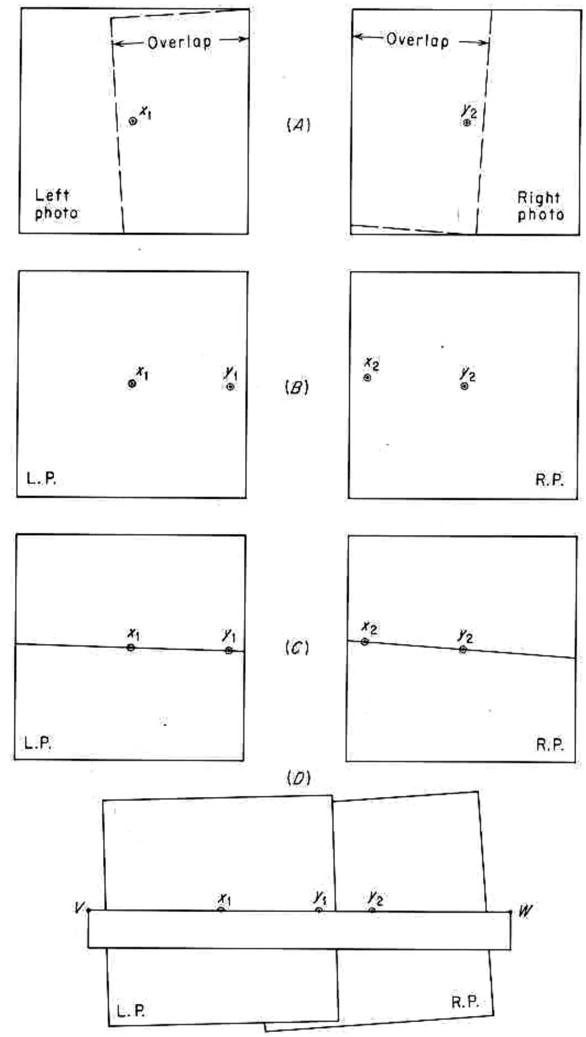
1) proper spacing of exposures during flight of the aircraft (60% overlap, 20-30% sidelap),

2) proper spacing of photograph in viewing (separation is about 5.7-6.0 cm for lens stereoscope, 20-25 cm for mirror stereoscope),

3) proper orientation of photographs in viewing (Figure 3.20),

4) the ability of observer to view the photographs at close range along essentially parallel lines of sight, either with or without the aid of stereoscope.

Figure 3.20. Arranging photograhs for viewing with lens stereoscope. (A) Mark principal point of each photograph (x_1 and y_2). (B) Transfer principal points y_1 and x_2. (C) Establish line through principal point transferred (conjugate) principal points of each photographs. (D) Adjust lines to single control line (VW), separation to be determined by eye base and instrument used.



4. PHOTOGEOLOGICAL SYMBOLS AND ABBREVIATIONS

The use of proper and clear symbols on group tracing and maps saves work and makes map assembly easier. The use of standard symbols and legends in state and large private organizations, is a matter of efficiency and convenience for the author of aerogeologic maps and the reader in the field and office. The suggested symbols in this notes are based on the original Shell-Standard code with some adjustments taken from the geologic symbols used by U.S.Geologic Survey (Figure 4.1)

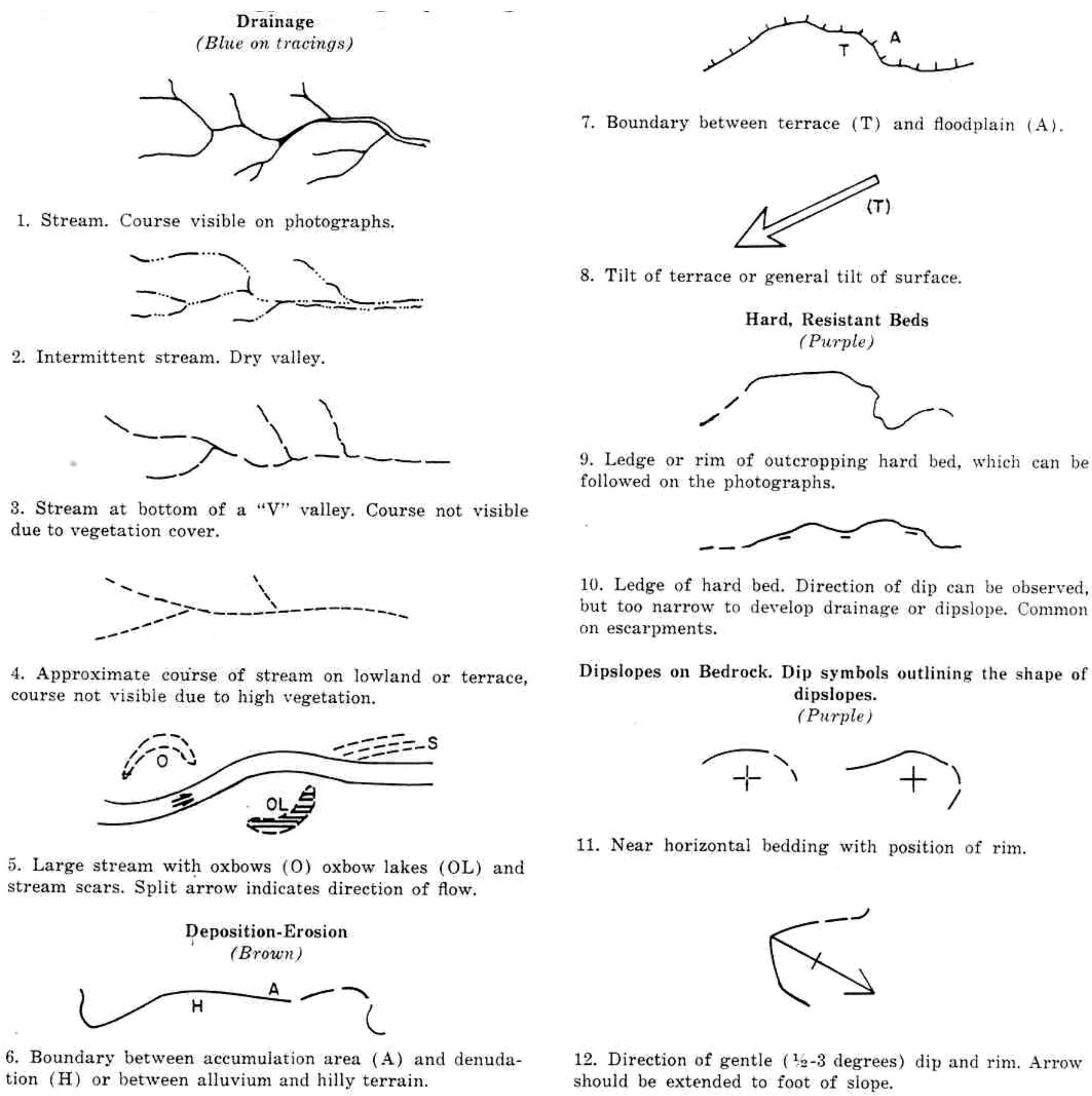
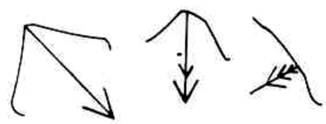
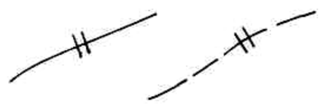


Figure 4.1. Symbols used on aerogeologic maps



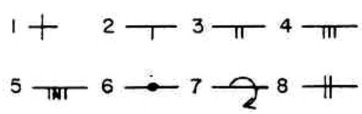
13. Moderate (3-10 degrees), medium (10-40 degrees) and steep (more than 40 degrees) dipslopes. With one, two and three barbs.

14. Short, narrow dipslopes, when arrows cannot be used.

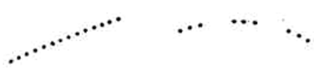


15. Hard bed of steep attitude, when direction of dip cannot be observed or may be to both directions. Frequent on hogbacks.

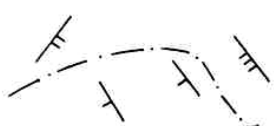
Strike symbols, to indicate strike of bedding plane without outlining shape of dipslope, with classification of dip group.



16. 1, horizontal; 2, ½-10 degrees; 3, 10-40 degrees; 4, 40-70 degrees; 5, 70-near vertical; 6, vertical; 7, overturned; 8, dip direction uncertain.

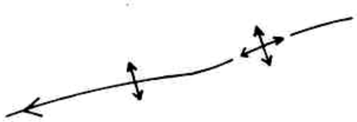


17. Lithologic boundary, certain or supposed; followed on photographs.

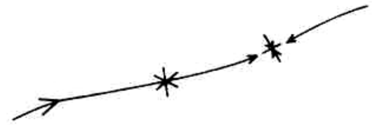


18. Boundary of unconformity with strike symbols.

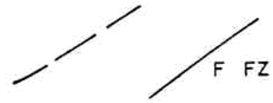
Structural Symbols
(Red)



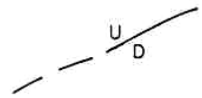
19. Anticline axis with dome and plunge.



20. Syncline, with plunge and deepest axial part (blue or green).



21. Fracture or inferred fault. F, known or certain fault. FZ, fault or fracture zone.

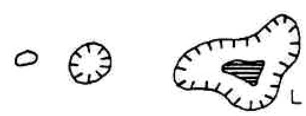


22. Fault with upthrown (U) and downthrown (D) side.

23. Downthrown side of fault with direction of fault plane, dip and facet (f).

24. Horizontal displacement.

Subsurface Drainage
(Blue)



25. Small, medium and large sinkholes (with pool) in limestone, dolomite or gypsum.

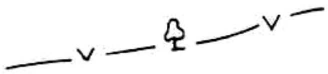
26. Infiltration center; large or small in granular material, marking kettles in glacials, small infiltration pans on terraces (T).

27. Hillslide, with head scarp, sliding masses and boundary (brown).

Figure 4.1. Cont'd.

Vegetation and Culture
(Green)

28. Boundaries of vegetation, (trees, shrub, grass, reed).



29. Alignment of vegetation.

30. Cultivated and abandoned fields in tropical rain forest.

Figure 4.1. Cont'd.

Frequently used features on oblique and stereo photographs are marked with letters. In order to simplify lettering and to avoid repetitions, the following abbreviations are used:

Lithologic abbreviations:

Sand	s	Sandstone	Ss	Conglomerate	Cgl	Clay	Cl
Shale	Sh	Limestone	L	Gypsum	Gy	Dolomite	Do
Lava	Lv	Agglomerate	Ag	Tuff	Tf	Basalt	B
Igneous	Ig	Granite	Gr	Serpentine	Sp	Slate	Sl
Gneiss	Gn	Schist	Sc				

Landforms, Miscellaneous

Dyke D, Facet f, River R, Terrace T, Talus Tc, Sinkhole Sk, Alluvium A

Tectonics

Anticline An, Syncline Sy Fault F, Important fault FF, Fault zone Fz, ,
Downthrown D, Upthrown U

Points of interest: X,Y,Z

Locations with numbers instead letters: 1,2,3

5. PHOTOINTERPRETATION IN GEOLOGY

5.1. Fundamentals of photointerpretation

Basics problems of photogeologic interpretation are:

1. A given feature is viewed on aerial photographs; what is it?

2. How was the structure produced? (structure, history, and erosion or deposition)

3. What is the geologic significance of the feature?

To answer these questions the following procedure may be followed:

A. **Geographic and geologic locations**. Recognizing the general geographic and geologic location of a project area, limits the types of feature which could be present. Once the area is defined, the structure and rock types can usually be determined. For example, in an area in SW New Mexico, sedimentary and crystalline rock units would be expected. Thrust faulting would not be expected in stable basin and shelf areas.

B. **Literature survey**. Research into literature, before a photogeologic study is undertaken, will determine the general sequence of rock units and their types if published data are available. Some of the major tectonic elements can also be learned. Published geomorphic information should be studied.

C. **Climate of the past and present**. Weathering will affect the rocks in different climates. For example, carbonate rocks are easily dissolved in the humid climates, in the arid climates they stand out as ridges.

In addition to these general considerations, specific topographical form, photographic characteristics, vegetation, location and relation to other objects are used in the identification and interpretation of features seen on aerial photographs.

When analyzed within the above framework, 1) shape, or form, 2) tonal and textural relations, and 3) drainage will permit recognition, delineation and analysis of the geologic features within most photogeologic project areas. Photointerpretation involves observing certain tones, shapes, and other characteristics of photographic images and determining their geologic significance by a combined deductive or inductive reasoning.

5.2. Essential interpretation elements in photointerpretation

Essential interpretation elements in photointerpretation are: tone, texture and pattern, shape or form, and drainage.

5.2.1. Tone

Photographic tone is a measure of the relative amount of light reflected by an object and recorded on a black and white photograph. Photographic tones are usually shades of gray, but may be black or white.

Photographic tone is a useful interpretation element. Three aspects of tone used in photointerpretation are (Table 1):

1. Relative tonality (white, light gray, dull gray, dark gray or black)

2. Uniformity of tone (uniform, mottled, banded, scrabbled)

3. Degree of sharpness of tonal variations (sharp, gradual)

TABLE 1. THE RELATION OF TONE TO SOIL OR ROCK CHARACTERISTICS

Tone Property	Soil or rock properties
A. Tone variation	
White	: Well drained, coarse, dry soil materials e.g. sand or gravel.
Light gray	: Soils of mainly coarse textures mixed with some fines. contain little organic matter.
Dull gray	: Generally fine material with good profile development and organic content. Poor drainage.
Dark gray or Black	: Poor internal drainage and/or, a water table near the surface. Organic content is high. Fine textures predominant.
B.Tone Uniformity	
Uniform	: Typified by, continental alluvium, lake beds and thickly bedded sedimentary rocks; indicate uniform soil texture and moisture conditions.
Mottled	: Significant changes in soil moisture and/or texture within short distances. Darker tones indicate depressions, lighter tones slightly drier areas. Coastal plains, till plains, limestone in humid climates and infiltration basins in terraces, flood plain or outwash all typically exhibit mottled tone.
Banded	: In areas of linear shaped differences in soil or rock texture and drainage or moisture availability. In transported soil landforms, banded tones indicate wet and dry areas and are associated with meander scrolls in flood plains, ancient outwash channels, ripple marks in lake beds, linear sand dunes and interbedded sedimentary rocks or highly foliated metamorphic rocks.
Scrabbled	: Common in arid regions of alkali deposits. The pattern is irregular, blocky and fine textured. Young volcanic lavas might have the same tone.
C. Sharpness of tone boundary	
Sharp, distinct	: Indicate quick changes in moisture content. Related to coarse soils of high permeability. Drainage is rapid, causing low areas near the water table to be wet and higher areas dry.
Gradual, **fuzzy**	:Light and dark tones with fuzzy, indistinct gradual boundaries indicate fine- textured soils and gradual changes in moisture content.

Dark gray-black : red marls, red sandstone, lava of basic or intermediate composition, basics, ultrabasics, conglomerates with dark components, coal, asphaltic layers, peat.

There are two main factors affecting gray tone namely, terrain factors and external factors.

5.2.1.1. Terrain factors affecting gray tone

Usually tone and texture are products of numerous independent and dependent variables. Three major elements of the ground surface are bedrock, soil and vegetation. Some physical characteristics of those elements such as color directly determine the tone. Other elements which are dependent on the physical characteristics of the bedrock and soil are topography and moisture content. Moisture also determines the density of vegetation. Important terrain factors affecting gray tone are: a) bedrock color, b) outcrop surface, c) orientation of the surface, d) soil and mantle, e) moisture, f) vegetation.

a) Bedrock color. The color of a particular rock unit will produce a distinctive photographic tone. Color of a rock depends on color components, sandstone, for example, may be light gray, brown, dark red-brown or dark gray. In general, a rough generalization of rocks with respect to tone is:

White to light gray: sand bar, shifting dune sands, coral sand, evaporites, gravel banks, granular deposits, some limestones, snow and ice.

Light gray : quartzite, sandstone

Medium gray : dolomite, limestone, gypsum, clay, shales, granitoid family (acidic rocks)

An abrupt change in tonality is usually a change in lithology, but may be due to changes in rock composition or water content. Weathering can produce tonal variations of the same rock unit in different areas.

b. Outcrop surface. Some rocks are weathered and eroded into smooth, uniform slopes and surfaces. Others, perhaps as a result of jointing, fracturing, or bedding separation, or combinations of these, appear as a blocky, irregular, or grooved features. The more regular exposed surfaces are recorded as lighter and more uniform photographic tones. The more irregular surfaces, especially if the scale of irregularities is small, will tend to produce darker tones. This is due to the fact that an extremely irregular surface affords numerous possibilities for local shadows which effectively reduce the total amount of light which could be reflected to the camera.

c. Orientation of surface. A slope or escarpment which lies in a shadow is noticeably darker than one exposed squarely to the sun's rays. Naturally, a rock unit exposed on two such surfaces would be recorded with contrasting tones. Nevertheless, in many areas the topographic relief, the orientation of topographic features, and the latitude are such that some shadows will always be present. A photogeologist must be able to work with shadows.

d. Soils and mantle. The term mantle is usually applied to any layer of unconsolidated rock material that lies on consolidated bedrock. Mantle may consist of particles of the underlying rock, either weathered or unweathered, and may be of any grain size or combination of grain sizes. It may also consist of materials transported from one place and deposited in another, by wind, running water, ice, or gravity.

Mantle formed in situ may be called **residual mantle.** That brought into an area from another area may collectively be called **transported mantle**.

Mantle which is in any way modified, altered, or weathered by chemical, physical, or biological processes or agents, is called **soil**. Soils developed in residual mantle are thought of as **residual soils**. Soils which have developed and have been moved by any agent may, also be called **transported soil**. Variations of tone in residual soils may reflect variations in the physical characteristics of bedrock. Variations in soil color, composition and texture are often apparent on aerial photographs. One of the advantages of photogeologic mapping over field mapping is that completely covered and obscured bedrock units can be differentiated since residual soil reflect the bedrock characteristics. However, soils may not always reflect underlying rock characteristics. Climate, time and general geographic conditions may combine to produce uniform soils which does not reflect the underlying bedrock characteristics or variations.

e. **Moisture**. The relative amount of moisture in the soil or mantle, and in some cases in the bedrock, frequently produces noticeable variations in tonal intensity on aerial photographs. The effect is sometimes direct and sometimes indirect. Relatively dray areas tend to appear a lighter gray, whereas the more nearly saturated areas tend to be darker. This is the direct effect of moisture content.

The indirect effect principally involves vegetation. In areas consistently arid or semiarid, a sparse growth of grasses, shrubs, and trees may be present. In extremely arid areas, little or no vegetation can exist. In humid areas a greater density of vegetation growth is possible. These variables produce pronounced effects in tonal variations.

Even the same area can show tonal variations depending on the variations in temperature and precipitation. There two factors which determine the moisture content of soils: depth of water table and grain size.

In general coarse grained rocks or soils appear in lighter tones, because capillary zone is much narrower than in fine grained rocks or soils. Under similar conditions a shale will appear darker than a sandstone or gravel because it holds more water.

Tonal variations due to moisture change will be sharp in a coarse-grained material. Whereas in a fine grained soil the tonal variations due to the changes in moisture content will be gradual.

f. Vegetation. Vegetation may obscure significant geologic relations or it may be useful in the detection and mapping of geology. Two factors, namely color and shadows determine the tone produced by vegetation. These in turn are determined by various properties, e.g. spacing of the individual plants or trees, density of trees, type of trees, etc. Vegetation is controlled to a greater extent by the climate and soil type.

Vegetation displays a definite geologic preference or selectivity. This may be due to topographic, soil, or moisture factors. In many cases, where the mineral content of the rock influences the composition, texture and other characteristics of the soil, a definite correlation between the vegetation and rock type can be established. Certain plants or trees may grow on certain soils. Type and density of vegetation is also influenced by the magnitude and orientation of slope which contribute to tonal quality resulting from differences in light intensity, e.g. different growths on north and south sides of hill. Slope magnitude is mostly a function of bedrock type and structure. Bedrock may determine slope; slope may influence soil development; bedrock may influence soil composition; soil and slope may influence vegetation; and only differences in vegetation may be noted on the aerial photograph.

Sinkholes in limestones appear darker as a result of concentration of silty and clayey materials leached from the carbonate rock and different type of vegetation growing on them. Faults and joints may be indicated by the alignment of dark toned spots which correspond to vegetation.

5.2.1.2. External factors affecting gray tones

A. Technical factors: 1. Characteristics of the material and equipment
2. Techniques of exposures
3. Techniques of processing

B. Climatic factors: 1. Regular variations in the nature of daylight
2. Haze, mist, and clouds; reduction of contrast
3. Seasonal variations; surface moisture

5.2.2. Texture and pattern

Texture was defined as the frequency of tone change within the image and it is produced by the aggregation of unit features which are too small to distinguish individually on the photographs. Therefore the scale of photograph is important for the textural studies. The texture that shows differences because of the tone change of the image is called **photographic texture**.

Density of a drainage network or the relative spacing of streams is called **drainage texture.** **Topographic texture** is used to describe the degree of dissection of the land surface. In general fine grained materials such as shales, have a fine surface texture, whereas coarse grained materials such as gravel have a rough or coarse surface texture.

Pattern is the orderly arrangement of geologic, topographic and vegetation features. This arrangement is generally a two dimensional or plan view arrangement of features. If the features, that make up the pattern are too small to identify (because of the scale of the photograph) they may then form a photographic texture. Patterns resulting from particular distribution of gently curved or straight lines are common and are of structural significance. They may represent faults, joints, dykes or bedding. A single line or lineation is also an illustration of pattern and may result from an orderly arrangement of stream segments, trees, depressions or other features.

Drainage patterns are important in the geologic interpretation of aerial photographs; they may reflect underlying structure or lithology. Vegetation patterns may reflect structural features or lithologic character of the rock types.

Soil pattern used in engineering geology refers to the combination of surface expressions, such as landforms, drainage characteristics, and vegetation, that are used in the interpretation of ground conditions.

5.2.3. Shape or form

Shape or form is an important factor in geologic interpretation of photographs. Numerous geologic features can be identified primarily by their shape alone. Some examples are alluvial fans, sand dunes, glacial deposits, volcanoes (constructional land-forms, formed by deposition), and strike ridges, zigzag or parallel-subparallel valleys and ridges, linear valleys and ridges (erosional landforms, formed by erosion of existing bedrocks).

Differential erosion is considered the first key to bedrock identification and interpretation on aerial photographs. In any area subjected to prolonged erosion (principally by running water), resistant rock may be expected at or near the surface of higher topography, with less resistant rocks in lower topographic position (i.e., sandstone ridges and shale valleys) (Figure 5.1).

Dykes may extend across an area, either as prominent wall-like ridges or as continuous or discontinuous trench-like depressions. Their positive or negative expression is a function of their resistance to erosion and weathering relative to that of the surrounding rock. Similarly, sills may produce benches along the sides of escarpment or valley walls. Some veins which are composed largely of resistant minerals, such as quartz, may be traced across an area of less resistant rock by their positive topographic expression. Conversely, veins consisting largely of nonresistant minerals may be eroded easily and appear as linear depressions or trenches.

A series of plunging folds, involving strata of various relative resistance, is frequently represented by zigzag valleys and ridges. Where the folds do not plunge, parallel or sub-parallel valleys and ridges are found.

Volcanic necks or plugs, the resistant solidified central cores of maturely eroded volcanoes forms high topography above the less resistant country rock.

In some areas, isolated mountain masses may be observed to stand above former ancient erosional surfaces or peneplanes because of their greater resistance to weathering and erosion. These isolated remnants, called **monadnocks.**

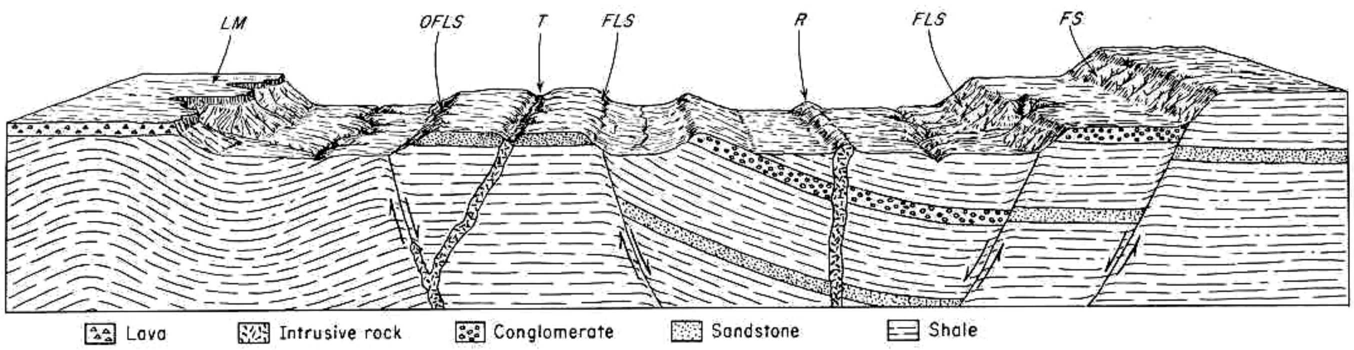


Figure 5.1. Composite block diagram showing several examples of correlation between rock resistance and differential erosion. LM, lava-capped mesa; FLS, fault-line scarp; OFLS, obsequent fault-line scarp; T, trench; R, ridge. FS (fault scarp) is an exception. Recent faulting has raised nonresistant shale above adjacent resistant conglomerate (Miller , 1981).

Intrusive rocks may stand topographically higher than the country rock into which they were emplaced (Figure 5.1. 'R'). If they are made of less resistant components, they may appear on aerial photographs as trench, circular, oval, or irregular shaped depressions.

Since fault zones and major fracture zones are frequently extensively ruptured and deformed and hence more susceptible to erosion, they may be detected by noting the presence of linear valleys or lowlands.

5.2.4. Drainage

Since erosion, transportation, and deposition by running water occur in most areas, a study and understanding of stream activity and resulting landforms is essential in photogeologic analysis. The important aspects of drainage are:

1. Genetic classification of streams; the relation of a stream to original slope, underlying bedrock, and structure.
2. The stage of development of a stream
3. Drainage patterns
4. Detailed drainage (or erosional) characteristics
5. Stage of landmass dissection

5.2.4.1. Genetic classification.

Streams are generally classified in the following manner (Figure 5.2): consequent, subsequent, resequent, obsequent, insequent, superposed or superimposed and antecedent.

A **consequent stream** is one which develops on some initial topographic slope (Figure 5.3).

A **subsequent stream** is one which has developed a course adjusted along some line or zone of least resistance (Figure 5.4).

A **resequent stream** is one which flows down the dip of the formation. The streams flowing down the steep obsequent faces of the several asymmetric ridges are also classified as obsequent streams.

An **obsequent stream** is one which flows in a direction opposite to the dip of the formation. The streams flowing down the back or dip slopes of the ridges are classified as obsequent streams.

An **insequent stream** is one which follows a course which is apparently not controlled by any factor of original slope, structure or rock type (Figure 5.4).

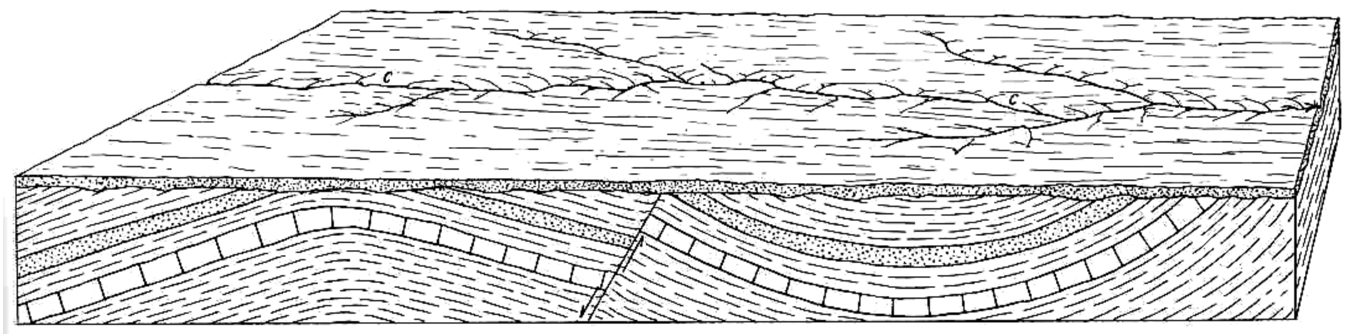


Figure 5.2. A block diagram showing an angular unconformity. A consequent stream (c) flows eastward down the gently sloping surface (Miller, 1981).

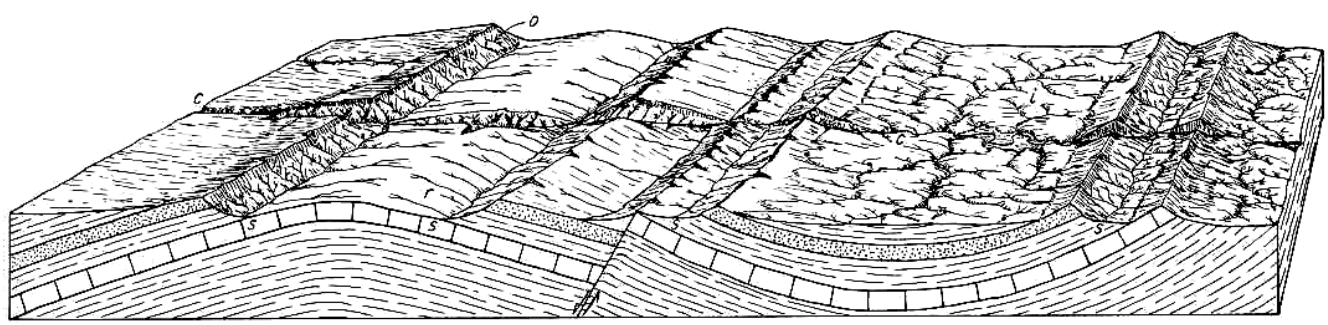


Figure 5.3. A block diagram of the area shown in Figure 5.2. following superposition of the major consequent stream (c) and extensive erosion. The tributary drainage is adjusted to the lithologies and structures formerly beneath the angular unconformity. Genetic classification is based on this adjustment and has no relation to original consequent stream direction. Symbols are as follows: *c*. original consequent stream (superposed); *s*. subsequent stream; *r*. resequent stream; *o*. obsequent stream; *i*. insequent stream (Miller, 1981)

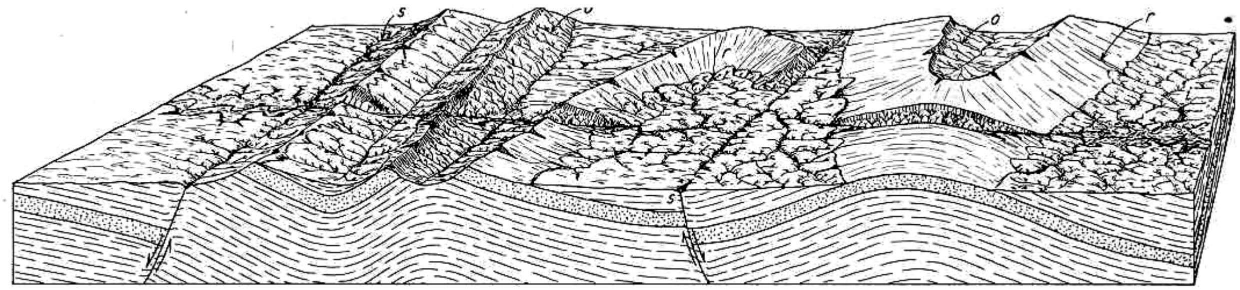


Figure 5.4. A block diagram of a maturely eroded area of moderately complex structure. The tributary streams can be classified with respect to structure. The master east-flowing stream is of unknown origin. It may be suporposed from a former higher surface. It may have been antecedent, having maintained its course during structural deformation (Miller, 1981).

A **superposed (or superimposed) stream** is one which has formed on one surface and structure and has since cut down through an unconformity, to flow across lower rock units which have a structure discordant with that above the unconformity (Figure 5.3). The materials lying above the unconformity may either be bedrock or unconsolidated material.

Antecedent stream A stream that continued to downcut and maintain its original course as an area along its course was uplifted by faulting or folding.

5.2.4.2. Stage of Stream development.

The following stages may be identified: initial stage, youthful stage, maturity, old age and rejuvenation (Figure 5.5 and Table 2).

Initial stage. The initial stage of a stream is usually characterized by a lack of order and organization. Falls, rapids, and variable stream gradients are typical. Initial drainage may develop on uplifted coastal plains and peneplains, in glaciated plains, on young lava surfaces and volcanoes, and on pediment surfaces.

Youthful stage. During the youthful stage, the major observable activity of a stream is that of downcutting. The stream occupies the entire valley floor. Frequently, the valley profile is V-shaped (Table 2) and stream course is relatively straight. Waterfalls and rapids persist well in this stage.

Mature stage. Downcutting is diminished and lateral erosion becomes dominant. Valley floor is wider than stream channel. In **full maturity**, a stream flows in a well established meandering course, sweeping back and forth across a flood plain sufficiently wide to accommodate the entire meander belt. **Early maturity** is characterized by the partial development of a flood plain. In **late maturity**, the flood plain is noticeably wider than the meander belt of the stream.

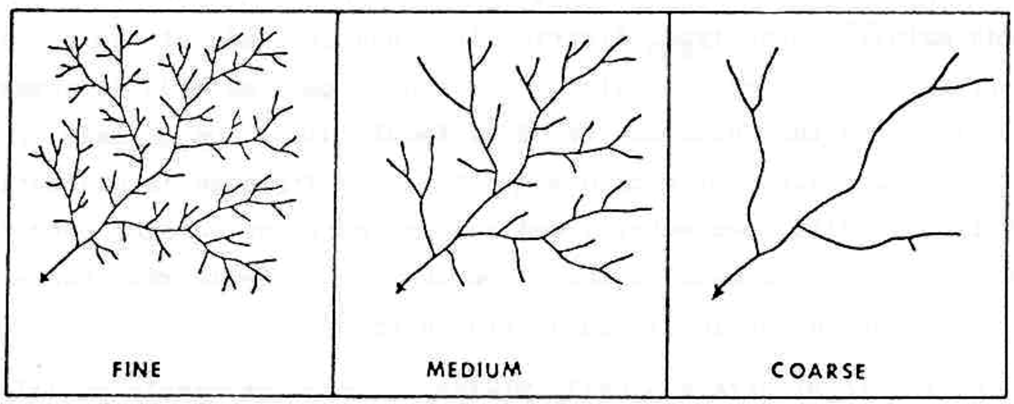
Old age. In old age the flood plain is so extensive that the entire meander belt has enough room to follow a gross meander like course. Lateral erosion and point bar deposition dominates. Oxbow lakes are common. The width of the flood plain is many times that of the meander belt and natural levees are present along much of the stream channel.

Rejuvenation. At any time in a stream's development from one stage to the next, changes may occur which produce a return to the dominantly downcutting youthful stage. Thus, a fully mature stream may rapidly become incised a second time. Rejuvenation may be produced one ore more of the following: uplift, tilting, lowering of base level, increase in a volume of stream by capture, increase in volume through change in climate. Entrenched meanders, broad and flat peneplain (partly dissected, relatively steep gradients are very common.

5.2.4.3. Drainage pattern

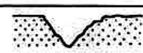
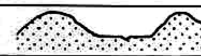
A **drainage pattern** may be defined as the planimetric arrangement of several streams which are usually adjusted to certain topographic, structural, or lithologic controls. The streams which comprise a pattern may be of any genetic type: insequent, consequent, subsequent, resequent, or subsequent. Frequently, the noting of a stream pattern in an area is helpful in the identification and interpretation of geologic features and structures. Similarly, the analysis and determination of genetic type is of great importance in the evaluation of the meaning of a stream pattern.

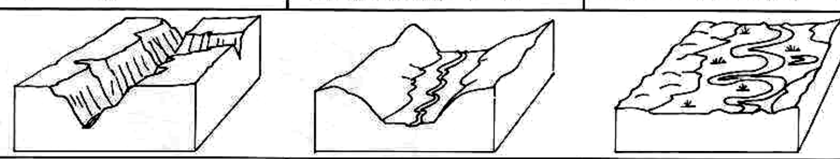
Drainage texture refers to the frequency or density of streams and tributaries in an area. A **fine drainage texture** indicates a high frequency, a **coarse drainage texture** refers to a low frequency. Drainage texture is closely related to the permeability of the underlying material. Materials with high permeability exhibit a coarse drainage texture, because most of the water drains down into the ground and the water flowing on the surface is limited, e.g. coarse-grained sandstones, sand and gravel, limestone. Fine-grained materials such as clay and shales have a low permeability and hence only a very limited amount of water seeps down. sandstones, sand and gravel, limestone. Fine-grained materials such as clay and shales have a low permeability and hence only a very limited amount of water seeps down.



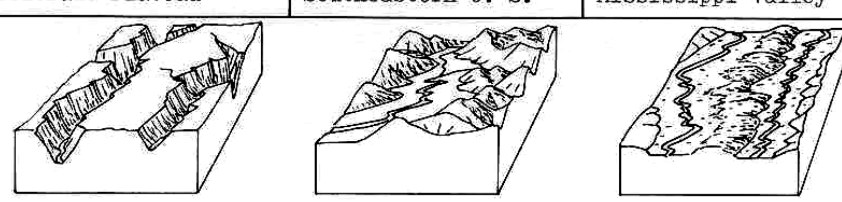
Sketches of drainage density variations.

TABLE 2. Valley development

VALLEY FEATURE	YOUTH	MATURITY	OLD AGE
Channel	nearly straight	some meanders	widely meandering
Valley walls	steep	moderate	gentle and low
Cross-section			
Width	narrow	medium	broad
Depth	deep	deepest to moderate	shallow
Deposition	little	narrow flood plain	much deposition; broad flood plain
Erosion	downcutting	lateral cutting begins	lateral cutting in alluvium
Gradient	steep	moderate	low
Other features	falls, rapids	sometimes rapids; small meanders	swamps, oxbow lakes, natural levees
Examples	Grand Canyon	Susquehanna River	Lower Mississippi R.



REGIONAL FEATURE	YOUTH	MATURITY	OLD AGE
Relief	high in valleys; low on divides	great (1000-3000')	least (< 1000')
Streams	few - most in youth	many - youthful and mature	few - most in old age
Tributaries	small, short, youthful	abundant - youthful	few
Divides	high, flat, broad	high, rounded, narrow	few, low, broad
Lakes	on uplands	few	on lowlands
Drainage	poorly developed	excellent	poor and swampy
Topography	rugged canyons - flat plateaus	hilly, land mostly in slopes	peneplain
Level Areas	on divides	in valleys	all over
Examples	Colorado Plateau	Southeastern U. S.	Mississippi Valley



Youthful stage

Mature stage

Old stage

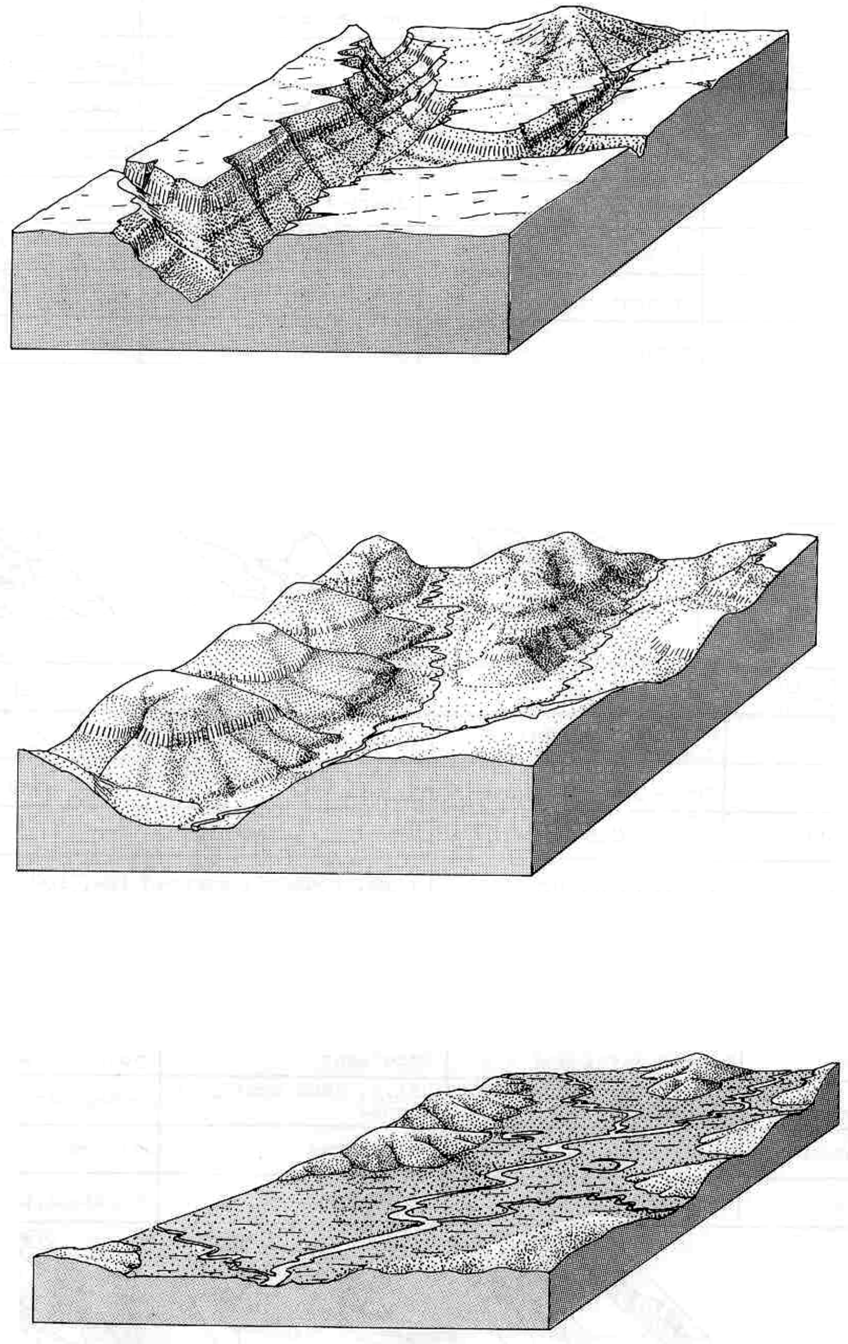


Figure 5.5. Block diagrams illustrating stages in the fluvial cycle of erosion

The important drainage patterns are as follow:

Dendritic drainage pattern. This pattern resembles the complex branching of a tree and is principally a collection of insequent streams (Figures 5.6, 5.7). Homogeneity (uniformity)-no structural control-is characteristic. There is no line of structural weakness, and no steeply dipping, nonresistant stratigraphic interval along which a stream can cut more rapidly than elsewhere. Dendritic drainage pattern is to be expected in the following areas: unconsolidated sands, silts, clays, gravels; in areas underlain by fine grained, gently sloping shales, tuffs; uniformly resistant crystalline rocks; highly metamorphosed rocks; horizontal or nearly horizontal rocks.

The main factor influencing the development of dendritic drainage pattern is the type and the attitude of the rock on which drainage develops. In fine grained and impermeable rocks or layers, the pattern becomes closely spaced and more divided (ramified), whereas, in coarse grained and permeable rocks, it becomes wide spaced and less ramified.

Modifications of dendritic drainage pattern: pincer-like drainage pattern, subparallel-dendritic pattern, dendritic-pectinate pattern (featherlike), dendritic-pinnate.

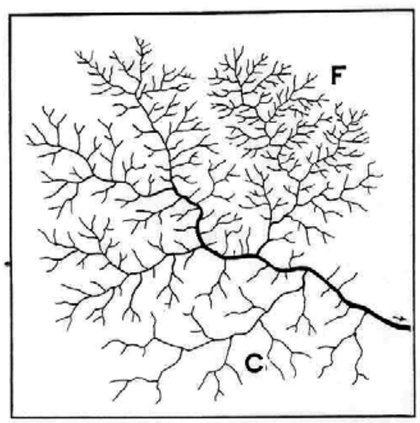


Figure 5.6. Dendritic drainage pattern. Also called tree-like or arborescent. Most common basic pattern. F is fine texture; C is coarse texture. No structural control. Occurs on fine textured impervious material.

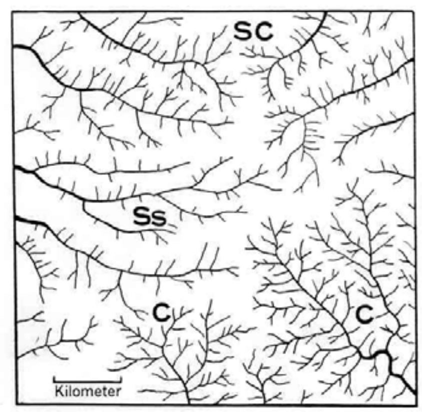


Figure 5.7. Modification of dendritic pattern. Different designs develop in claystone (C), sandy or silty clay (SC), and sand or sandstone (Ss). The difference is in shape, remification, type, texture and length of gullies. C is most remified, tree-like, fine textured. Ss is more wide spaced. Less remified with short straight gullies. SC is finer textured with longer remified gullies; a type between C and Ss.

Parallel drainage pattern. Extensive unidirectional slopes, such as those along a broad coastal plain or an elongate linear homoclinal ridge underlain by gently dipping strata or other tabular rock, are often drained by relatively uniformly spaced parallel or subparallel streams. When such streams constitute the principal drainage of an area, they may be referred to as forming a parallel drainage pattern (Figure 5.12) or subparallel drainage pattern (Figure 5.13). In general, this type of drainage pattern develops on fine textured material with steep slopes. Parallel drainage pattern is derived from dendritic and becomes dendritic, when the slope flattens out.

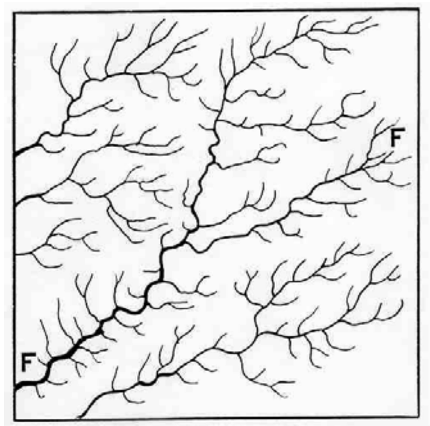


Figure 5.8. Modification of dendritic pattern

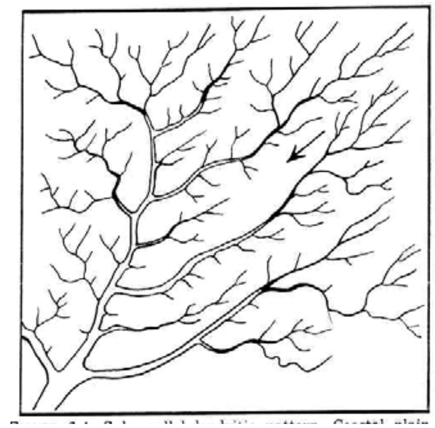


Figure 5.9. Subparallel-dendritic pattern

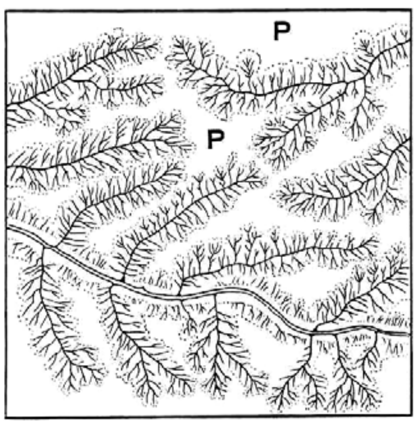


Figure 5.10. Dendritic-pectinate pattern.
The material is loses.

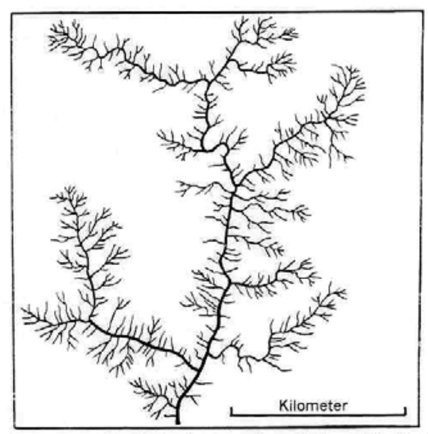


Figure 5.11. Dendritic-pinnate pattern.
The material is sandy and clayey silt

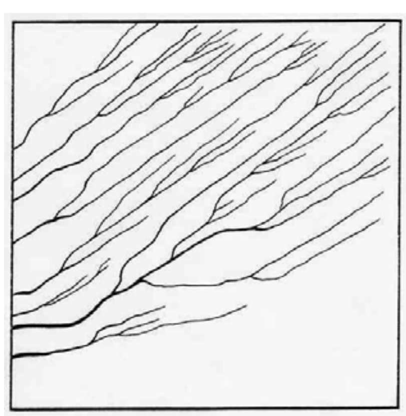


Figure 5.12. Parallel pattern

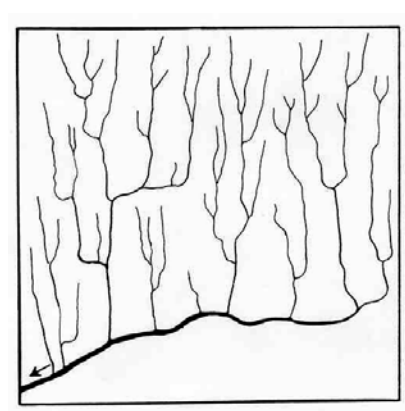


Figure 5.13. Subparallel pattern

Trellis drainage pattern. This pattern in contrast to dendritic drainage pattern is controlled structurally, and is produced in areas in which structural complexities or differences in rock resistance have directed stream development and location along a single major trend (subsequent stream), with smaller tributaries largely at right angles to the main units (obsequent and resequent streams) (Figure 5.14). Parallel folds of beds of different resistance, dipping sedimentary rocks generally exhibit trellis pattern.

Rectangular drainage pattern. Rectangular drainage patterns (Figure 5.17) usually develop along intersecting fault or joint systems. The adjusted streams or stream segments which define the pattern are all subsequent streams. This pattern occurs in areas underlain by large bodies of homogeneous crystalline rock, and regional plateaus underlain by horizontal or gently dipping resistant sedimentary rocks. Adjustment along one set of joints or faults is more pronounced.

Combinations of dendritic and rectangular drainage patterns may occur in an area where the rock mass contains widely spaced fractures.

Angular drainage pattern. Joint and fault systems rarely intersect at exactly at 90 . The term rectangular is therefore usually extended to include large acute intersections. Angular drainage pattern occurs when the joints or faults cross each other at an angle (Figures 5.15, 5.16).

Radial drainage pattern. Most circular or oval topographically high areas are drained by streams which radiate outward from the central part, and flow down the flanks in all directions (Figure 5.18). Such radially drained topographic features may be underlain by horizontal strata, by dipping strata, by anticlinal or synclinal folds, by crystalline or sedimentary rocks, or by unconsolidated residual or deposited materials. Radial drainage alone cannot be assumed to indicate any particular structure.

However, many structural domes rise as topographic domes, Radial consequent drainage develops around their flanks. Volcanoes also display radial drainage.

Annular drainage pattern. Maturely dissected domes and basins are frequently expressed topographically by a series of concentric circular or arcuate ridges and lowlands. The lowlands, which are developed on nonresistant beds, are usually occupied by subsequent streams. These streams, if sufficiently well defined and restricted to the nonresistant belts, form what is called an annular drainage pattern (Figures 5.19).

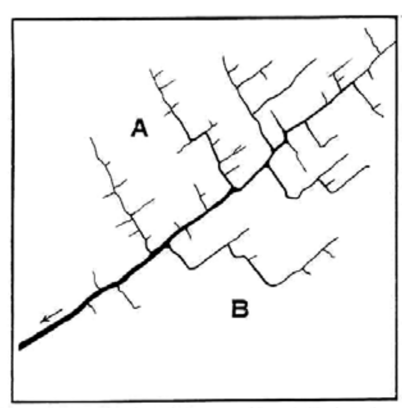


Figure 5.14. Trellis pattern

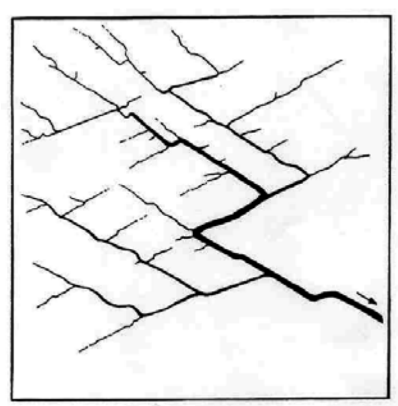


Figure 5.15. Angular pattern

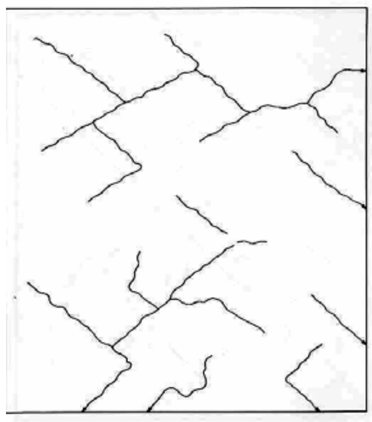


Figure 5.16. Angular pattern

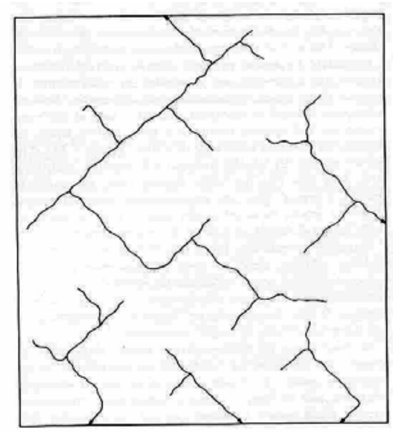


Figure 5.17. Rectengular pattern

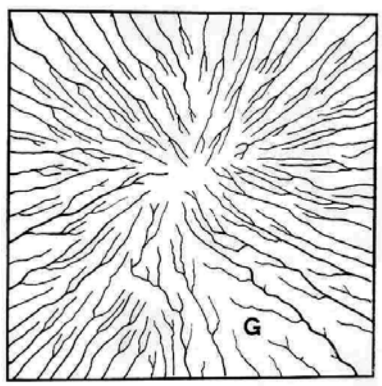


Figure 5.18. Radial drainage pattern

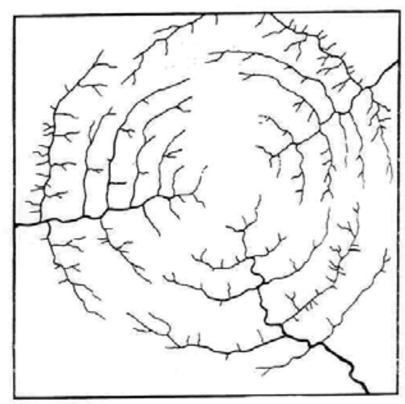


Figure 5.19. Annular drainage pattern

Patterns of internal drainage

The patterns of internal drainage occur in soluble rock like limestone or gypsum (**sinkhole pattern**) or in insoluble porous material like sandstone or conglomerates. The sinkholes on soluble rock have a roundish outline (Figure 5.20, 5.21). They may be round, oval or irregular curved, even somewhat angular when fault controlled. On insoluble, granular rocks, internal drainage patterns develop which are similar to sinkholes. They are roundish or irregular shaped depressions, where the rainwater percolates into the porous rock beneath.

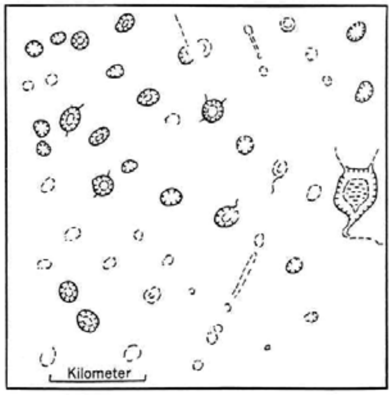


Figure 5.20. Sinkhole pattern.

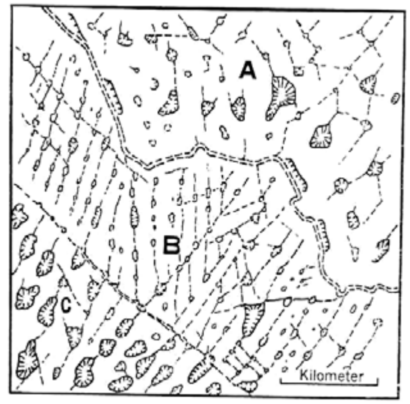


Figure 5.21. Drainage pattern in tropical karst. Three different types of limestones (A,B,C) show three types of sinkholes and dissolved fractures.

Special patterns

Besides the basic drainage types and their modifications, special patterns are known. They are indicative as to the material in which they develop. The following are the most common or significant types.

The **deranged pattern** is a common type of combined surface and subsurface drainage of glacial drift regions (Figure 5.24).

The **dichotomic**, is a pattern found on alluvial fans or on deltas. It is controlled by depositional material. This pattern occurs in coarse granular material as shown in Figure 5.25.

Alluvials, flood-plains with meandering streams, show a pattern of meander scars and oxbow lakes left by abandoned channels called **anastomotic** (Figure 5.22).

A stream pattern controlled by its own deposited load is called **braided** (Figure 5.23). It is most common in broad streams which emerges abruptly from high mountains to plains.

Other special drainage patterns are: **lacunate pattern**(Figure 5.26) and **barbed pattern** (Figure 5.27).

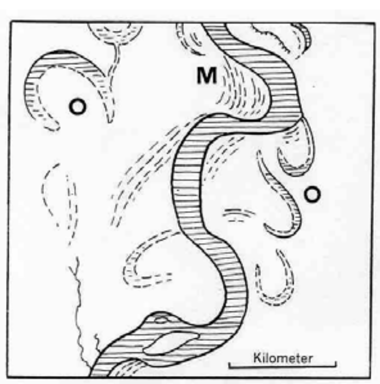


Figure 5.22. Anastomotic drainage pattern

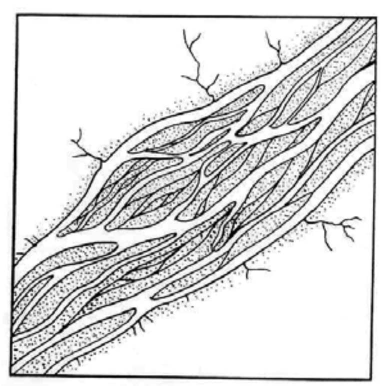


Figure 5.23. Braided drainage pattern

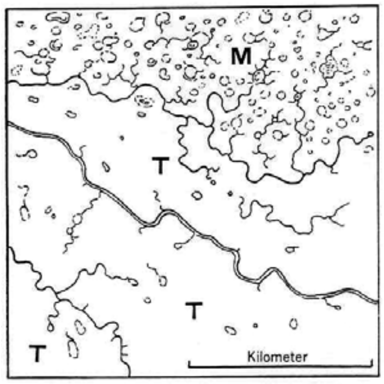


Figure 5.24. Deranged pattern develops on glacial till.

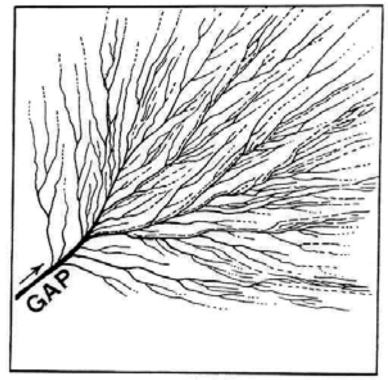


Figure 5.25. Dichotomic pattern develops on alluvial fans

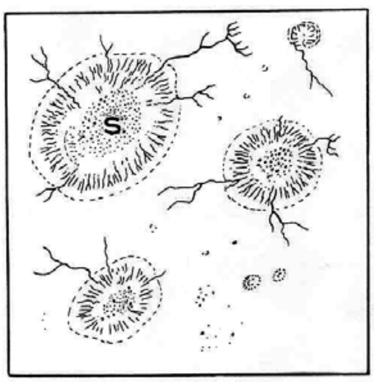


Figure 5.26. Lacunate drainage pattern.

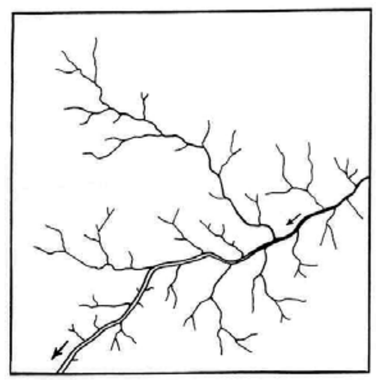


Figure 5.27. Barbed pattern.

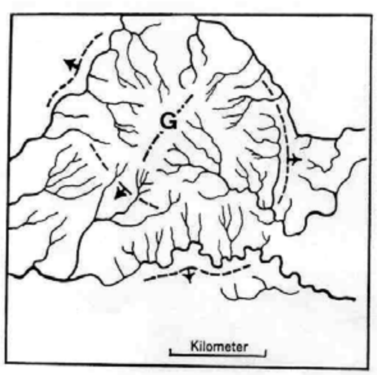


Figure 5.28. Radial, pincerlike-dendritic and annular drainage patterns on a small granitic dome.

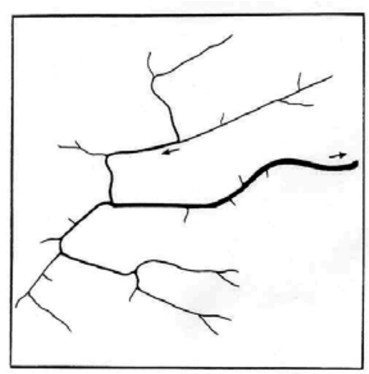


Figure 5.29. Contorted drainage pattern.

5.2.4.4. Detailed erosional characteristics

During the course of drainage development, several factors determine the ultimate type, density, and other characteristics of the stream systems of an area. The more significant of these are rock type, structure, climate, and vegetation.

Resistant rocks, such as sandstones, quartzites, and conglomerates, prevent the development of many small tributaries. Areas underlain by such rock units are usually drained by a relatively few widely spaced, large tributary streams. Soluble rocks, such as limestones and dolomites, in humid and semihumid climates, accommodate within themselves a large portion of the precipitation and permit less surface runoff in the form of streams. Areas underlain by such rocks are, therefore, frequently characterized by low drainage density and large tributaries. Conversely, such rocks as shales and clays, being dense and impermeable, have a greater surface runoff and allow the formation and maintenance of many closely spaced small finger-tip tributaries.

Distinct contrasts in rock type are clearly reflected in the minor drainage characteristics. A plateau underlain by extremely resistant quartzites is easily distinguished from one underlain by either porous limestones or dense clays. But, such differences may not be uniform over great areas, since various climatic, topographic, soil, and vegetation factors produce variations which must be taken into account. Within any one relatively restricted area, however, certain recognition criteria, which are very helpful in lithologic recognition, can be established.

5.2.4.5. Stage of landmass dissection

A landmass, like a stream, may be said to pass through several stages of development from initial form, through youth and maturity, to old age.

The **initial stage of dissection** of any area may be considered that stage in which drainage is just beginning to develop or has recently developed. Much of the initial block surface remains undissected and undrained.

The **youthful stage** is characterized by active stream development and dissection, though most of the original surface remains.

The **mature stage** may be described as consisting of slopes, resulting from the almost complete dissection of the original landmass. Little or no original upland surface remains.

In the **old-age stage**, a large number of the interfluvial spurs and divides have been removed by erosion and much of the lower topography is adjusted to a new base level. The original upland surface is reflected only by a relatively few remaining hills or outliers which rise above the new well-developed lower surface.

5.2.5. Gully and gully analysis

Drainage ways of the fourth order, or initial features running water cuts into consolidated or unconsolidated material are called **gullies**. Like the drainage pattern of streams and tributaries, gullies have characteristics which refer to the type of material in which they develop. The geologist will find some valuable detail information in studying them, because it shows the type of rock in more detail.

Physical characteristics of gullies refer to the material with their length, width, depth, shape, cross section and gradient. All those characteristics, are combinations of composition of the rock, climate, water velocity and vegetation cover. Length of the gullies depend on age (maturity) but material is a greater influence. In clay, shale and silt gullies are longer than in granular material as sand, gravel or agglomerate. Width and depth depend on age and erodibility. Wide gullies are common in arid regions, sand deserts and loess. They seem not always connected with the type of the rock.

The cross section depends on the material. Here, the two factors are the critical height of the gully and the shape of the bottom. Relationship between the two characteristics and the material are complicated. The component of "softening" of the sides of the gully is less in granulars than in fine cohesive loess or silts. Clays are softened in higher degree and will have longer, more shallow and less steep sided gullies than granulars or silts. Bottoms on sand or gravel are more narrow than those of shales which have a variable "soft" bottom. Sandy clay, silty or loess tend to produce broad flat bottomed gently sloped gullies. These relationships can be summarized as follows:

A. Non-cohesive porous soils (sands, gravels)

length: short
depth: rather shallow, variable
width: variable, but rather narrow
cross-section: straight V-shaped
gradient: steep
plan: simple, direct with few short branches

B. Cohesive, low porosity material (shales, clays, marls)

length: long
depth: variable, tend to be shallow or moderate
width: variable, tend to be wide
cross-section: broad round V
gradient: uniform
plan: smoothly curving, gentle slopes with many branches

C. Intermediate material (sandy shale, silt, flysch)

length: rather long
depth: extremely variable, not shallow
width: moderate
cross-section: uniform U or V-shaped
gradient: gentle
plan: intricate branching