6. APPLICATION OF PHOTOINTERPRETATION TO GEOLOGY

Two types of geologic information can be obtained from aerial photographs: structural and lithologic. The kinds and amounts of information that could be obtained from aerial photographs depend primarily on: 1) type of terrain, 2) climatic environment, 3) stage of the geomorphic cycle.

1. Areas underlain by sedimentary rocks yield more information than areas underlain by igneous and metamorphic rocks. Because the sedimentary rocks have strongly differing physical characteristics, whereas plutonic rocks are relatively homogeneous over wide areas. Metamorphic rocks may show the least amount of information from aerial photographs.

2. Arid and semi-arid regions will yield the greatest amount of geologic information compared to the tropical regions. The arid and semi-arid regions might also show a greater number of significant plant-rock associations than other climatic areas, because weathered material in the arid and semi-arid regions is not excessively leached and a close relation of soil to parent rock formation exists. As a result of difference in vegetation growing on soils, closely associated to the bedrock, mapping of different rock types is possible in these areas. This association is less developed in tropical areas where rainfall is abundant. Aerial photographs yield more structural information in areas where vegetation cover is dense and superficial deposits is wide-spread.

3. During the mature stage of geomorphic cycle, at which time streams show their greatest adjustment to and reflection of structure, the amount of structural information will be greater.

Factors affecting the photographic appearance of rocks

Most photogeologic studies are designed to compile a geologic map of lithologic units and structures. The factors which affect the photographic appearance of a rock:

1. Climate
2. Vegetation cover
3. Soil cover
4. Absolute rate of erosion
5. Relative rate of erosion
6. Color and reflectivity
7. Composition
8. Physical characteristics
9. Depth of weathering
10. Structure
11. Texture
12. Factors inherent in the type and conditions of photography.

Use of aerial photographs in geology
1. Outline the structure and structural relationship in an area
2. Outline the stratigraphic succession
3. Preparation of a geologic map
4. Measurements of stratigraphic sections
5. Measurements of dip and strike and thickness of formations
6. Inferences about rock types present in the area.

6.1. STRUCTURAL ANALYSIS (INTERPRETATION)

The photogeologic interpretation of the planar structures like bed, foliation, joint and fault is termed as **structural analysis.**

6.1.1. Bedding

In structural analysis, to follow a resistant bed or complex is usually not difficult. The position of a bed in relation with the horizontal is called an **ATTITUDE.** The position of a tilted bed can be determined by the **DIP** and the **STRIKE**. The **DIP** is the direction of the maximum slope. It is the angle between the surface plane of bedding at its greatest value in degrees and the horizontal. It is a line the runoff takes flowing down the bedding plane. The horizontal line which can be constructed at right angles to the dip direction is the **STRIKE**. It can be said that the strike line is parallel to the intersection of the bedding plane with a horizontal surface (Figure 6.1).
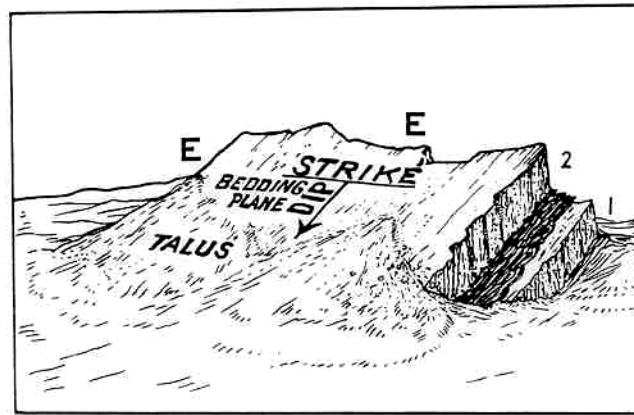

Figure 6.1. Relation between strike-dip-bedding plane and talus. The talus tends to reduce the angle of sloping. E-E is the edge or rim of a hard bed, usually marked on aerial photographs.

In the aspect of photointerpretation, the beds can be classified into three groups on the basis of dip amount:

1. horizontal and gentle dipping beds,

2. medium dipping beds,

3. steep and vertical dipping beds.

6.1.1.1. Horizontal and gentle dipping beds.

In deed, there are no perfectly horizontal beds. So, the beds with a very gentle dipping slope, not exceeding one degree is considered to be horizontal. Beds, having one to five degree dip amount are named as **horizontal beds**. Generally, alluvial deposits, terraces, talus and undisturbed deposits may display horizontal bedding. The appearance of a landscape with horizontal and low dipping beds is that of a **CANYON-MESA** type (Figure 6.2). The hills when isolated have the form of a flat table mountain or **MESA**. The valleys are deep dissected cut-in **CANYONS**. The slope of a mesa or sides of a canyon are step-like. The hard beds, like sandstone or limestone, form near perpendicular cliffs, the softer shales (or thin sandstone thick shale intercalations) form slopes.
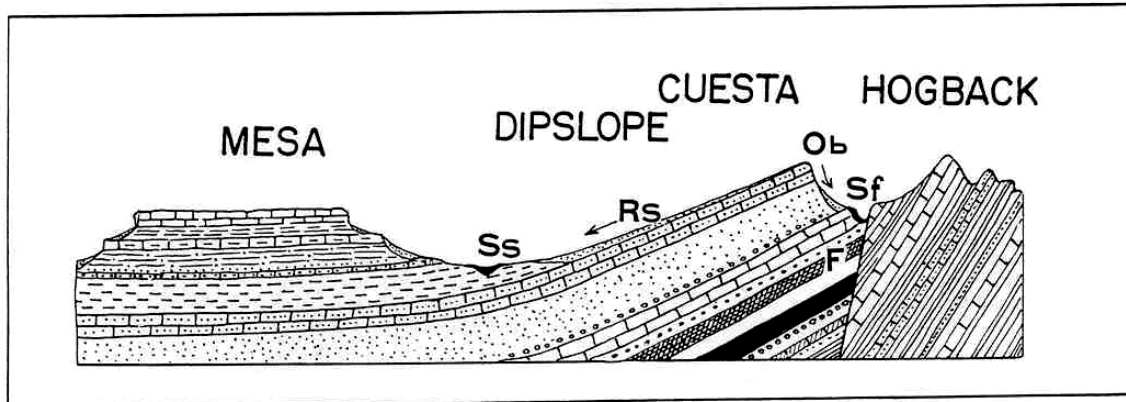
Figure 6.2. Relation of attitude of resistant beds to landform. Hard beds form a mesa when horizontal, a dipslope or cuesta when tilted, and a hogback when in steep attitude. Ss is a subsequent or strike controlled stream; Sf a fault controlled stream; Rs a resequent stream, and Ob an obsequent stream.

The conspicuous photographic characteristics of horizontal beds are as follows:

1. The flat lying or nearly horizontal beds are easily distinguished by tonal contrast and different resistance to erosion. The tonal contrast is expressed as bands following or extending parallel to the topographic contours. They are also loop-like shaped on the aerial photographs (Figure 6.3).

2. In the case of alternating resistant and non-resistant beds slope characteristics (breaks in slope) help in recognizing each unit.

3. The drainage pattern on flat lying beds is generally dendritic unless they are controlled by joint or fault.

4. A dip of half a degree can be observed on aerial photographs unless beds are obscured or obliterated by talus or scree.

5. The land shape of canyon-mesa type topography is underlain by horizontal or flat-lying sediments.

6.1.1.2. Medium dipping beds.

The beds with dips ranging from 5-35 degrees are considered to be **medium dipping beds.** Usually the hard bed forms a more or less even sheet. The top part of this layer, when hard, will resist erosion more than a weaker cover formation like shale or marl. When this is removed, the hard layer is exposed. A slope results, showing the inclination and direction of the dipping hard bed. This landform is called a **DIPSLOPE** or **CUESTA** (Figure 6.2), the most valuable element on a photogeologic map. because it indicates the attitude of the hard bed. The dipslope or questa is an asymmetric ridge with one slope is gentle, long and agree with the dip direction of the bed. Other slope is short and steep. The longer is called the **face slope**, which is parallel with the dip of the hard bed, and the other is the **scarp** or **steep slope**, which inclines away from the face slope.

Because the dipslope of a gentle or medium dip is attacked by erosion from two opposite quarters, the resulting watershed will shift. On the steeper slope the streams will erode with greater intensity, than on the side with a gentle slope. The divide will therefore shift gradually from the steeper slope towards the gentle or face slope until an equilibrium is reached (Figure 6.4).

Figure 6.3. Dendritic drainage patterns characteristically develop on horizontal strata and cut canyons or valleys in which progressively older rock units are exposed. As a result, the map patterns of horizontal strata parallel stream valleys and produce a dendritic pattern on the geologic map. Although topographic contour lines are not shown on all maps, the contacts of rock units of horizontal strata will parallel the contours. Escarpments and gentle slopes generally develop on resistant and nonresistant beds respectively and thus produce variations in the width of the map outcrop patterns. On steep cliffs the upper and lower contacts (as seen on the map) will be close together, whereas on a gentle slope of the same formation the contacts will appear further apart. It is apparent, therefore, that the map width of the outcrop belts of horizontal strata is no indication of the unit's thickness. Gently dipping strata will develop the same basic outcrop pattern as horizontal beds. The contacts between rock units in gently dipping strata, when traced far enough up a valIey, however, will be seen to cross topographic contours and form a large V-shaped pattern which points in the direction in which beds dip.
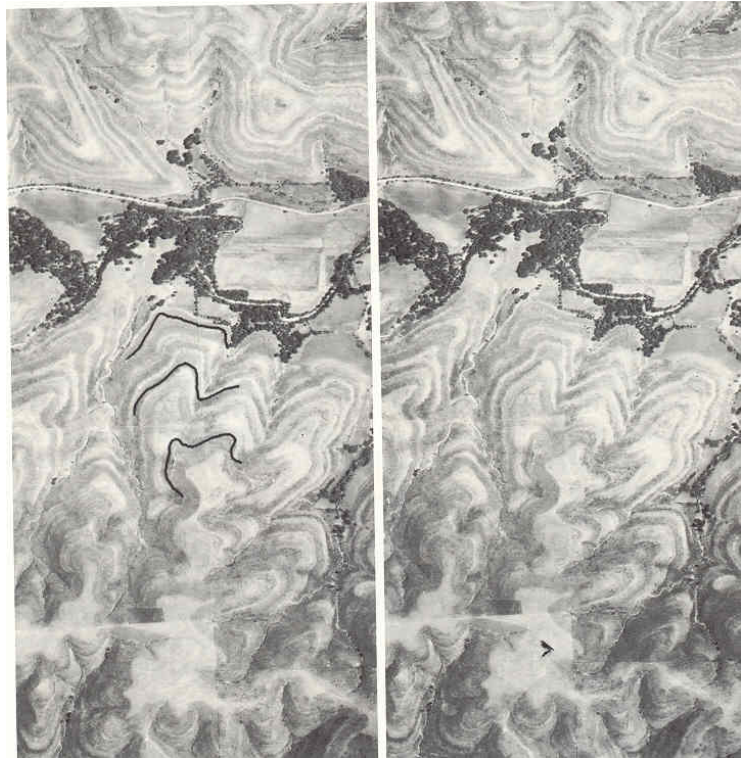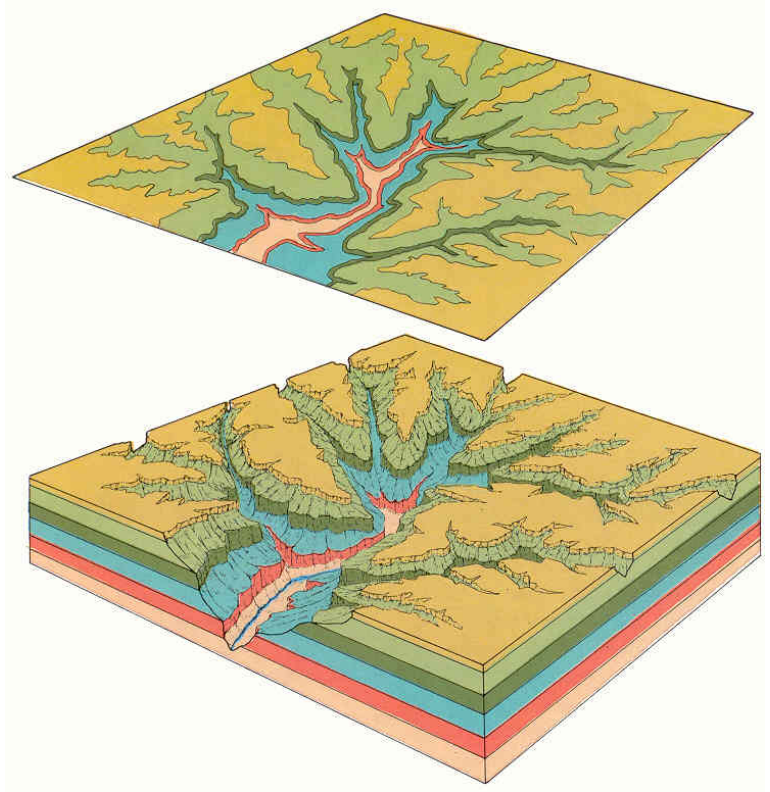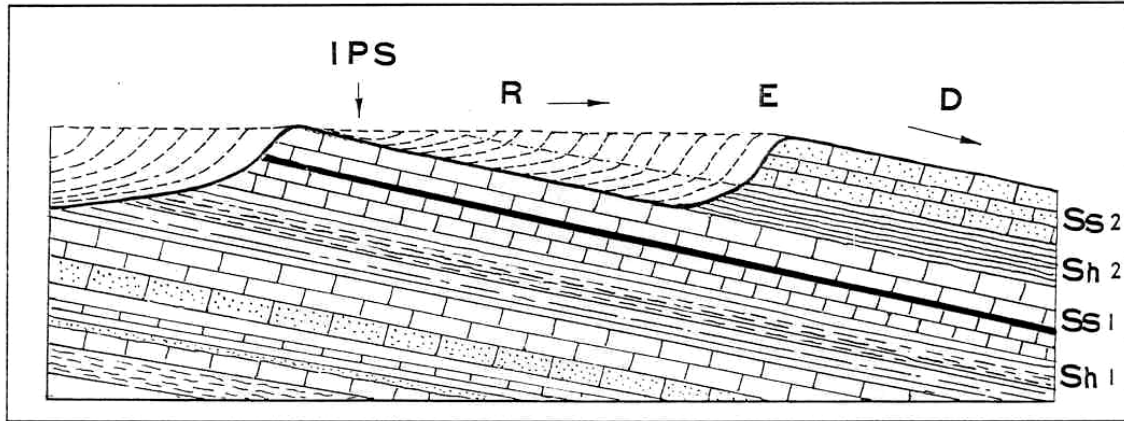
Figure 6.4. Recession of an escarpment. Escarpment (E) started at the initial position IPS where a strike controlled stream began to erode shake Sh2 which is overlying Ss1. R and arrow indicated direction of receding watershed. D is a dipslope of Ss2.

The main photo-characteristics of medium dipping beds are as follows:

1. The dip amount, dip direction and the strike can be determined well on these beds. Such beds are the most valuable sources of information to the photogeologist.

2. The outstanding land shape developing on the medium dipping beds is the **DIPSLOPE or QUESTA**.

3. Where bedding is expressed by bands of differing photographic tone or by topographic breaks in slope due to the resistance of beds, the rule of V's may be applied to determine the direction of dip; that is, where the trace of a bed intersects a stream valley a V in the outcrop pattern will point the direction of dip (Figure 6.5, 6.6).
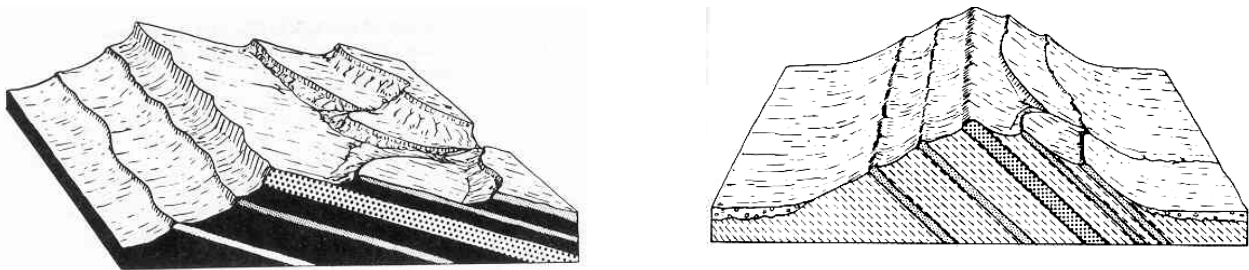

Figure 6.5

But if the direction of dip and direction of stream flow are the same and the stream has a gradient greater than the amount of dip, the case will be reverse.

6.1.1.3. Steep and vertical beds.

The beds having dips more than 35 degrees are considered to be steeply dipping beds. In practice, steep or vertically dipping beds are seldom indicative to which side of the ridge the bed is dipping. Dips over 65 degrees seem vertical on photographs because of stereoscopic exaggeration.

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Figure 6.6. When a sequence of rocks is ti1ted and truncated by erosion, the outcrop patterns will appear as bands which, on a regional basis, are roughly parallel. Important variations in details of the basic pattern are developed in areas dissected by erosion and should be carefully analyzed, for they provide important information concerning the subsurface structure.

When dipping strata are traced across a valIey, a V-shaped outcrop pattern is produced which points in the direction of dip. Exception to the rule is possible if the degree of bedding dip is less than the gradient of the valIey, but such conditions are seldom encountered. The size of the outcrop pattern V is inversely proportion al to the magnitude of dip:

1. low angle dip -large V (front part of Figure)

2. high angle dip - small V

3. vertical dip - V is absent (back part of Figure)

Careful examination of Figure will reveal several additional relationships basic to geologic maps:

1. Older beds dip toward younger beds unless the sequence is overturned. 2. Outcrop width depends on a. thickness of the beds

b. dip of the beds (low dip maximum width)

c. slope of the topography (steep slope minimum width)
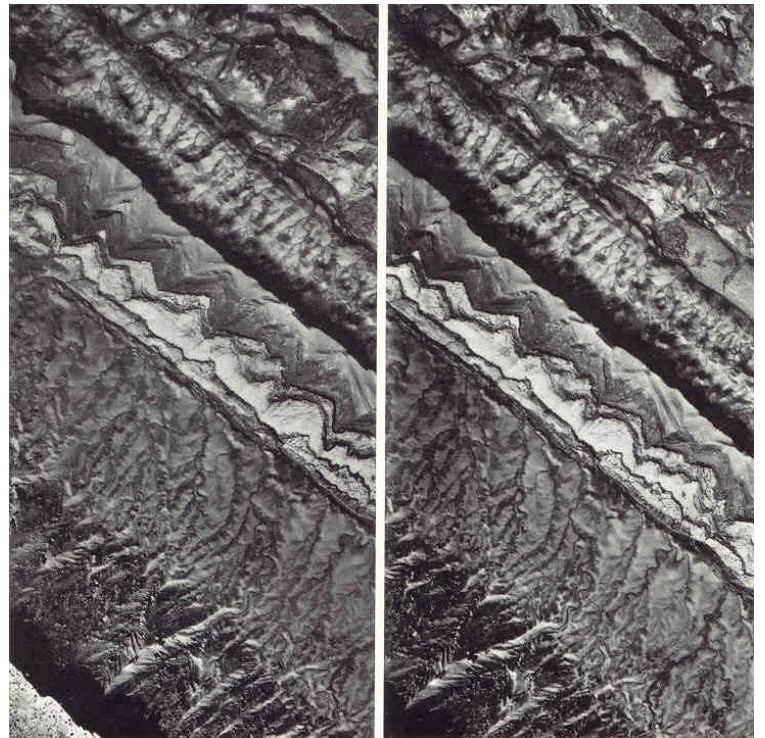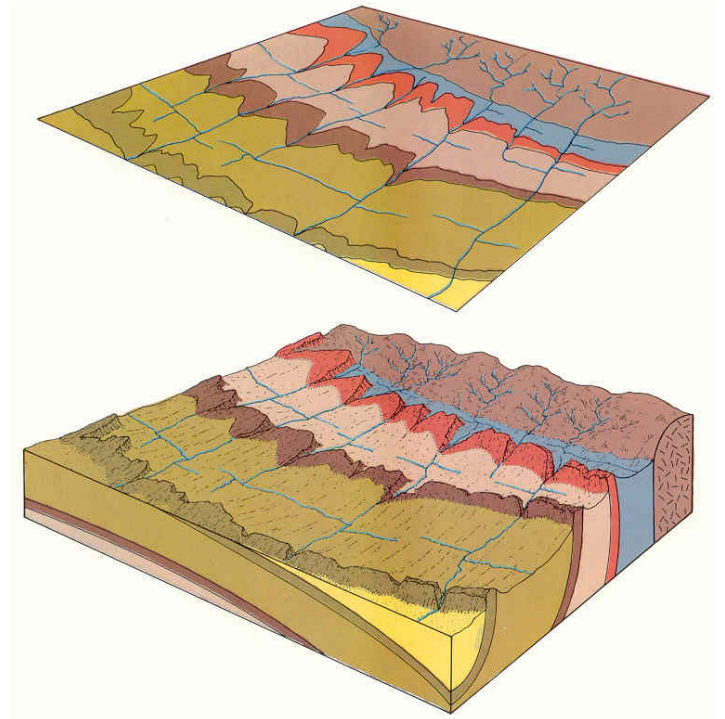
The main photo-characteristics of the steep and vertical dipping beds are as follows:

1. The diagnostic landshape developing on these beds is **HOGBACK** (Figure 6.2). Hogbacks are sharp, straight or slightly curved ridges with the two opposing slopes dipping at same angles.

2. Vertical beds are strongly eroded, worn, and often covered by talus on both sides of a hogback ridges.

3. The long axis of the hogback is parallel to the strike of the bedding. By using the long axis, one can easily determine strike direction.

4. Using the scale of the aerial photograph, the true thickness of vertical or nearly vertical bed can be measured directly without the aid of any formula.

6.1.1.4. Determination of the direction of dip of inclined beds from aerial photographs

1. Dip direction is readily apparent where topographic surfaces coincide with bedding surfaces (Figure 6.7).
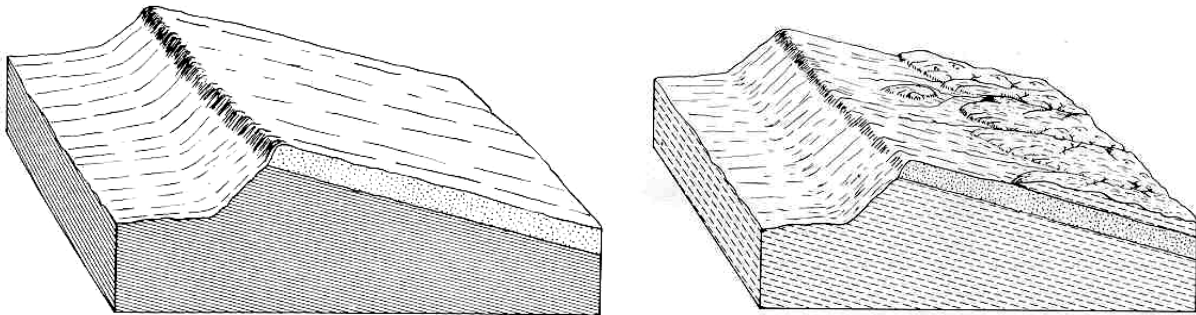

Figure 6.7

2. Dip direction can be determined using the rule of V (Figure 6.6, 6.9). The apex of V always points the dip direction. The long and narrow V shape shows less dip amount or gently dipping beds while short and wide V shape refers medium and steep dipping beds.

3. The drainage characteristics may also be used to find the dip direction in the areas, particularly those of low relief, where beds are obscured by surfical materials or vegetation. Where the dips are gentle the relatively long tributary systems commonly flow down the face slopes, whereas short tributary systems will characterized back slopes (Figure 6.8). When the dip is steep, in other words, it is over the 45 degrees, the rule is reverse (Figure 6.10).
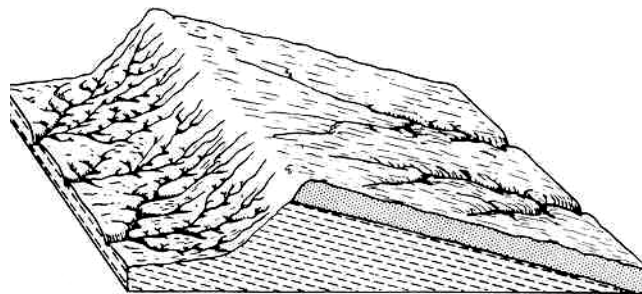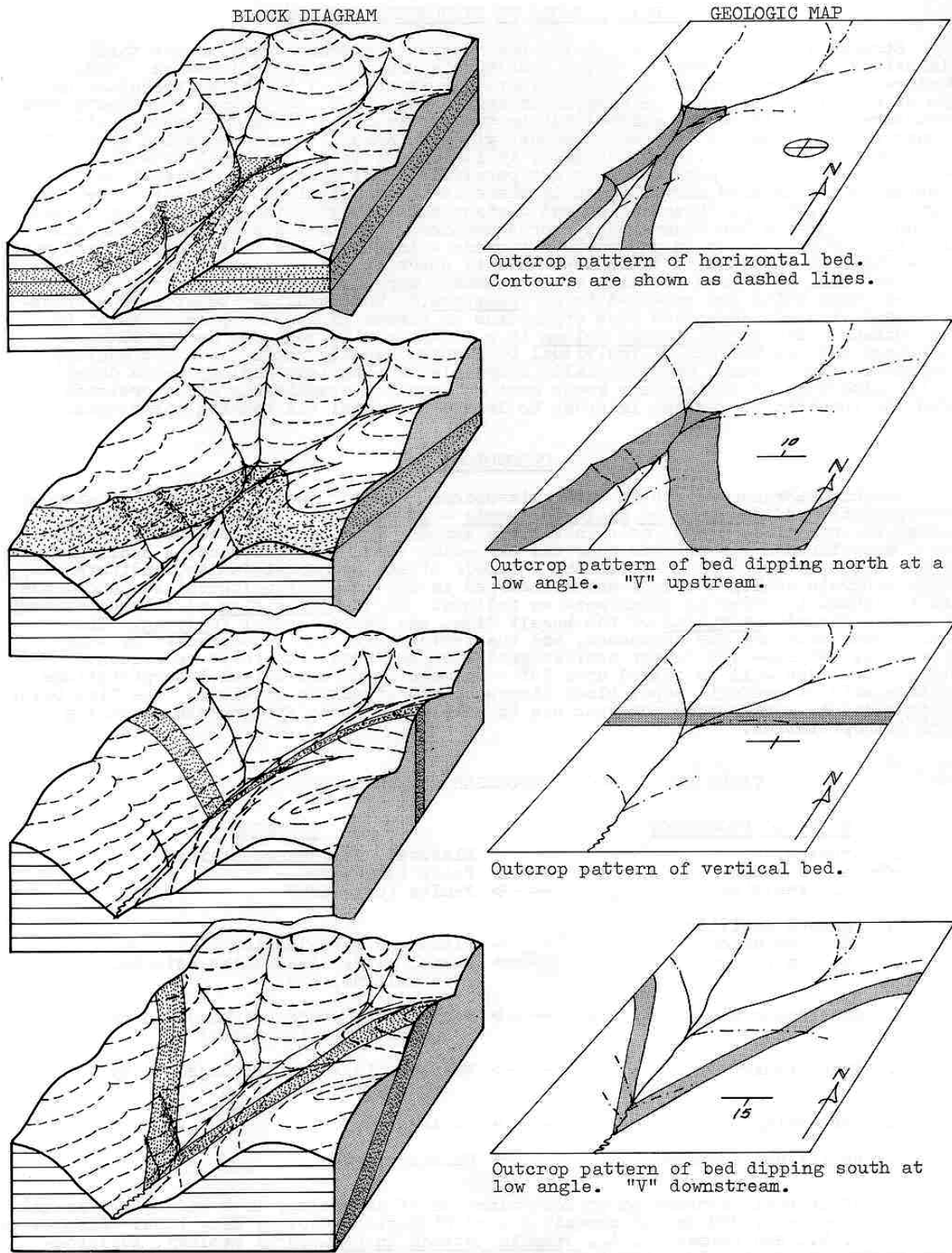

Figure 6.8

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BLOCK DIAGRAM   GEOLOGIC MAP

Outcrop pattern of horizontal bed. Contours are shown as dashed lines.

Outcrop pattern of bed dipping north at a low angle. "V" upstream.

Outcrop pattern of vertical bed.

Outcrop pattern of bed dipping south at low angle. "V" downstream.

Figure 6.9. Relationship between outcrop pattern and type of the bed

4. Slope asymmetry may be used to find the dip direction. The gentle slope of a questa or dip slope indicates dip direction (Figure 6.10).

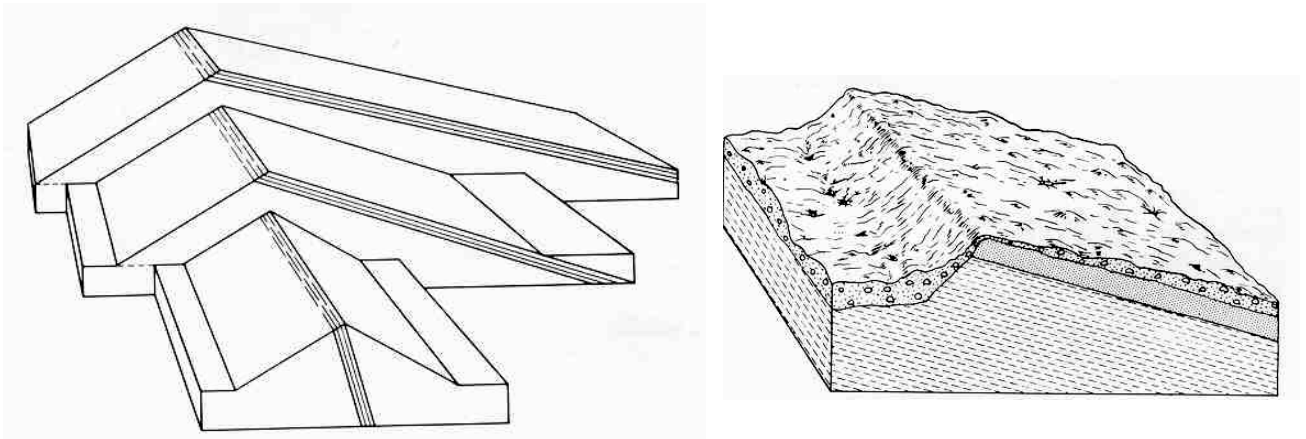5. In heavily vegetated areas the tree crowns fall in the direction of slope.

Figure 6.10

To interpret the lineaments resulting from the dipping beds, the following characteristics should be observed on aerial photographs:

a. They have to be persistent ridges when the bed is more resistant to the erosion than the adjacent bed or rock unit.

b. They have to be approximately parallel to one another. If there is an abrupt ending of this parallelism, it indicates a structural features like a fault.

c. Ridges of hard beds tend to be found in groups rather than single.

6.1.2. Folded structures

Sediments are deposited like pages of a book, in sheets. Sediment layers have various extensions, composed of different types of rock. Some are plastic, soft, like clays or shales; some are loose, granular, like sand and gravel; and some hard like sandstone and limestone. Layers of rock are laid down originally in a horizontal position. The process of sedimentation is continuous and may go on for ages, until it is interrupted by crustal movements. Sedimentary rocks, laid down in large basins of water, will eventually emerge from the sea and become exposed to denudation. When the horizontally deposited sedimentary sequences are compressed by the tangential pressure, which is the main force in the orogenesis or orogenic processes, they are tilted, warped, folded and fractured resulting the orogenic belts or terrain.

The difference in rigidity of layers, changing direction or intensity of pressure, causes fracturing of the strata. Rigid, hard beds, like sandstone or limestone, will break up into blocks when exposed to folding movements near the surface. But beds of greater softness or plasticity like shale or clay when compressed in depth, act just like viscous fluids. Folding and fracturing are processes linked closely to each other.

Since rock layers are deposited one after another, in horizontal bedding, the upper strata is the younger, the lower one the older. Evidence of stratigraphic sequence is of greatest importance in a photogeologic evolution of an area. Tectonic analysis without evidence of the age of a formation cannot be complete. In separating lithologic units on aerial photographs, the question arises continually which is older, which the younger? On areas with a low relief, dipslopes are often too

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indistinctive to obtain evidence of the sequence of certain strata. When the area is folded, the cores of the fold will expose the older, the flanks and troughs the younger beds.

The type or forms of the tectonic landforms and structural features depend on the intensity of tangential pressure. For example, slight tangential pressure on a horizontal strata will result in gentle warping or open folds. When the tangential pressure is high and continues, steep and overturned folds will form (Figure 6.11).

Figure 6.11. Types of folds. The type depends on the intensity of tectonic pressure. An is an anticline, with crest C and anticlinal axis, AAx. The two slopes are called limbs or flanks (L). The syncline (Sy) and its axis (SAx) indicate that the structure is symmetric. When the axial plane (O-FAx) is tilted, an assymetric or overfold, will result (OF). Continuous tectonic pressure will result in a recumbent or overturned fold (RF). This fold is usually connected with an overthrust (O-T) fault. Recumbent folds may become covers or nappes in intensively folded mountainous areas.
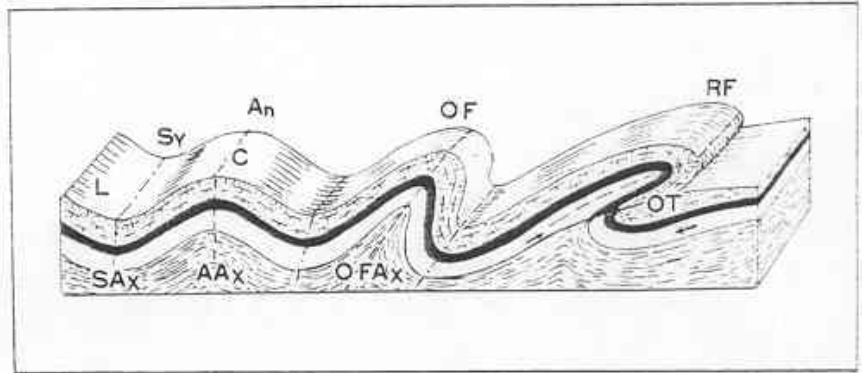
On the basis of dip amount of flanks or limbs, folds are classified into three groups, namely gentle folds, medium folds and steep folds.

a. Gentle folds. The dip amount of the limbs range from 2 to about 10 degrees. Folds in this range have long gentle dipslopes. Gentle folding is of great importance to the petroleum geologist because such structures are favorable for accumulation of oil.

b. Medium folds. The dip amount of the limbs range from 10 to 35 degrees. The landforms are medium grade dipslopes. Such folded belts follow orogenesis.

c. Steep folds have dips from 35 to vertical. When eroded and in the steeper range, it is often not possible to construct the approximate axial part of these folds. Metamorphics are almost everywhere strongly compressed to steep folds because several orogenic movements from different directions may have worked on the strata. Areas which have undergone several phases of tectonic pressure usually show steep folds with meandering axes. The highest grade of tectonic pressure causes over-thrusting. Layers are squeezed out into sheets or nappes.

There are several types and forms of folds namely, anticline and syncline.

a. Anticline. Anticlines are positive folds with bedding planes dipping away from a line called the **axis** of the structure (Figure 6.11). The dip amount increases towards the flanks and low or horizontal on or near the axis. The axis which runs with the highest part of the fold is a theoretical plane of vertical or tilted attitude cutting the anticlinal fold at its highest part. It is, therefore, marked with a line or symbol on maps. Axes do not continue horizontally along an anticlinal fold. They plunge according to the dip of the bedding planes, and are named as **plunging anticline** (Figure 6.12). Anticlines are of essential importance for petroleum prospecting.

Figure 6.12. Folding is one of the most common types of structural deformation and is found in complex mountain ranges and in less deformed lowlands and plateaus.

A convex upward fold is referred to as an anticline and in this structure the limbs dip away from the axis. Anticlines are characterized by having the oldest rocks in the core or center. Synclines are folds which are concave upward with limbs dipping toward the axis and are characterized by having the youngest rocks in the center.

In some folds the axis is horizontal but more commonly it is inclined. The inclination of the axis is referred to as plunge and is of importance in analyzing the three-dimensional aspect of the fold. Plunging folds which have been truncated by erosion form a characteristic zig-zag outcrop pattern. A plunging anticline forms a V -shaped outcrop pattern with the apex (or nose) pointing in the direction of the plunge. Plunging synclines form a similar pattern, but the limbs of the fold open in the direction of plunge.
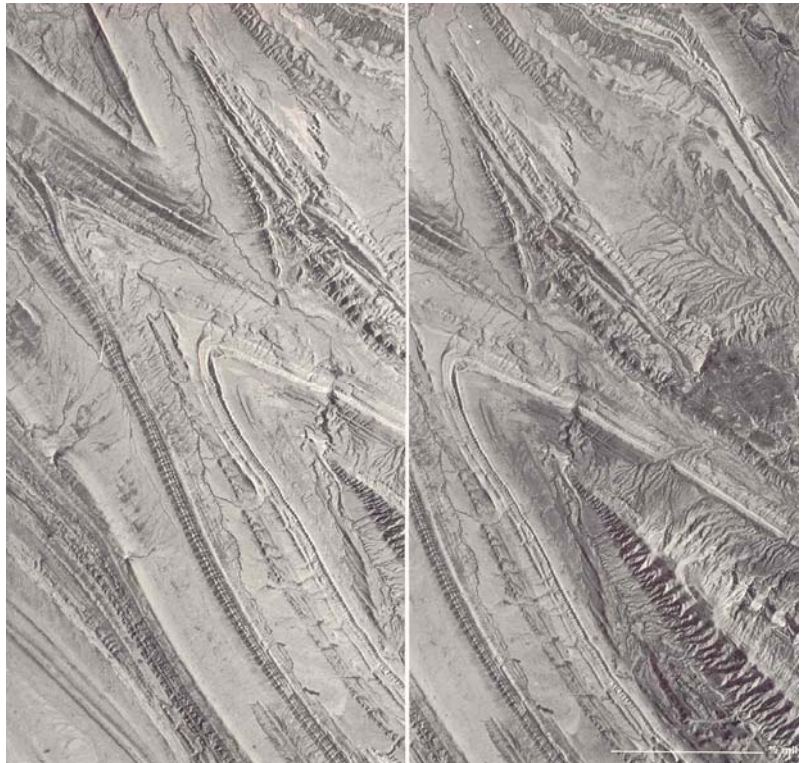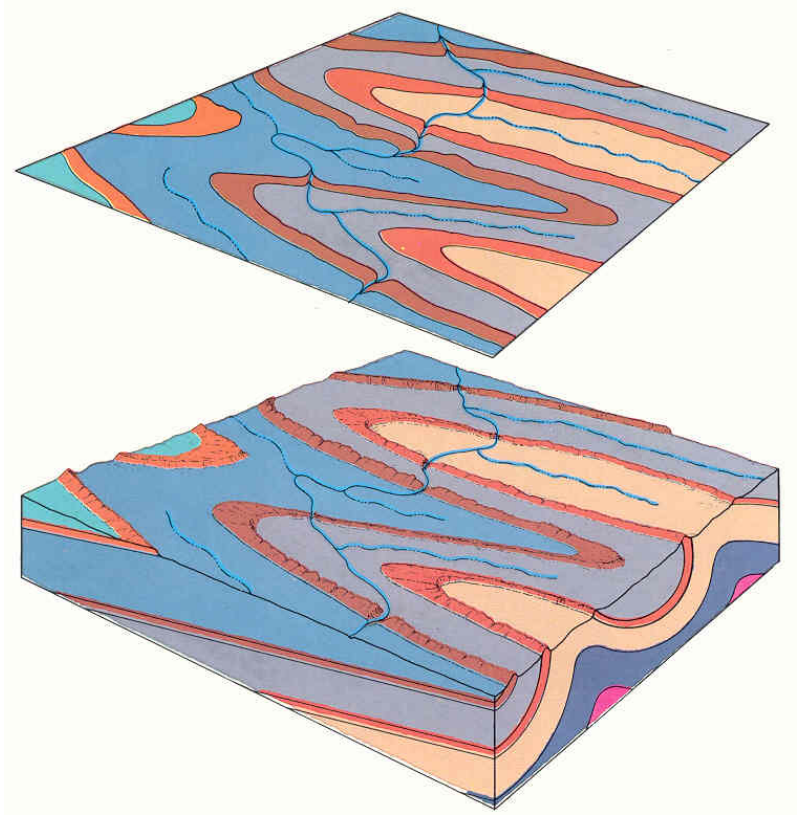
Figure 6.13. Eroded, dome-shaped structures form a roughly circular to elliptical outcrop with beds dipping away from a central area. These structures may range in size from small warps a few feet in diameter to regional features covers hundreds or thousands of square miles. As can be seen in Figure 157 the central part of an eroded dome is made up of the oldest bed with progressively younger rock units located outward from the center of the structure.

Drainage patterns are helpful in interpreting domal structures because (1) they tend to form a radial pattern as streams develop on the less resistant beds and (2) streams cutting across the resistant beds permit one to apply the rule of V's to interpret the direction of dip. If the relative ages of rock units are shown on the map, a dome is readily recognized by older rocks located in the center of the structure.
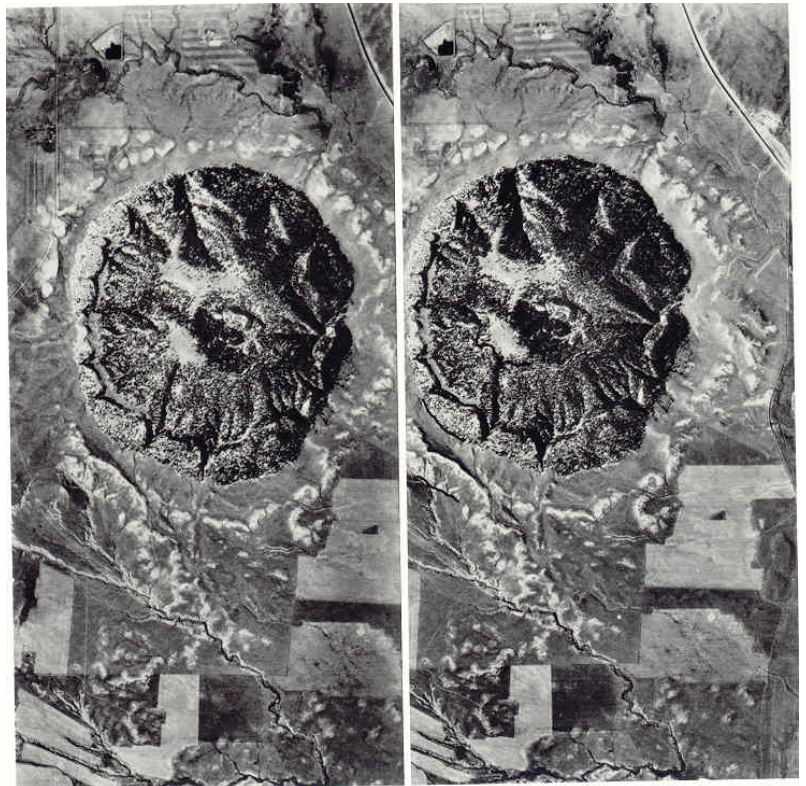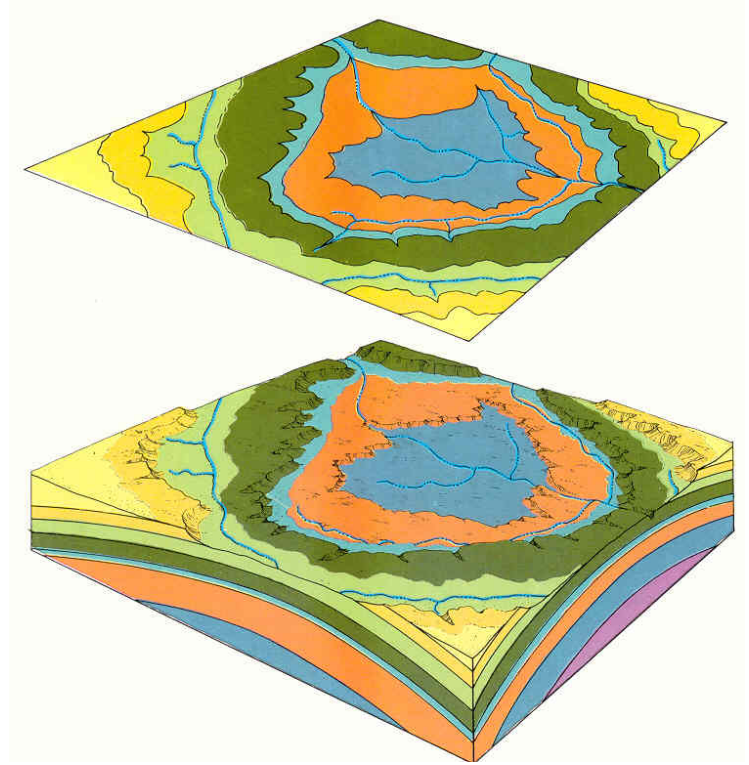
Figure 6.14. A structural basin, when eroded and ex- posed at the surface, displays an elliptical or circular outcrop pattern similar to that of an eroded dome. The general outcrop pattern of both structures is similar, but two major features enable us to distinguish readily a basin from a dome: (1) Younger rocks crop out in the center of a basin, whereas older rocks are exposed in the center of a dome. (2) If the structure has been dissected by stream erosion, the V in the outcrop points toward the center of a basin and away from the center of a dome. In addition, the cliff or scarp formed on the resistant rocks of a basin faces outward, and the dip slope is inclined toward the center of the structure. This is exactly the opposite of the direction in which the slope is inclined in an eroded dome.
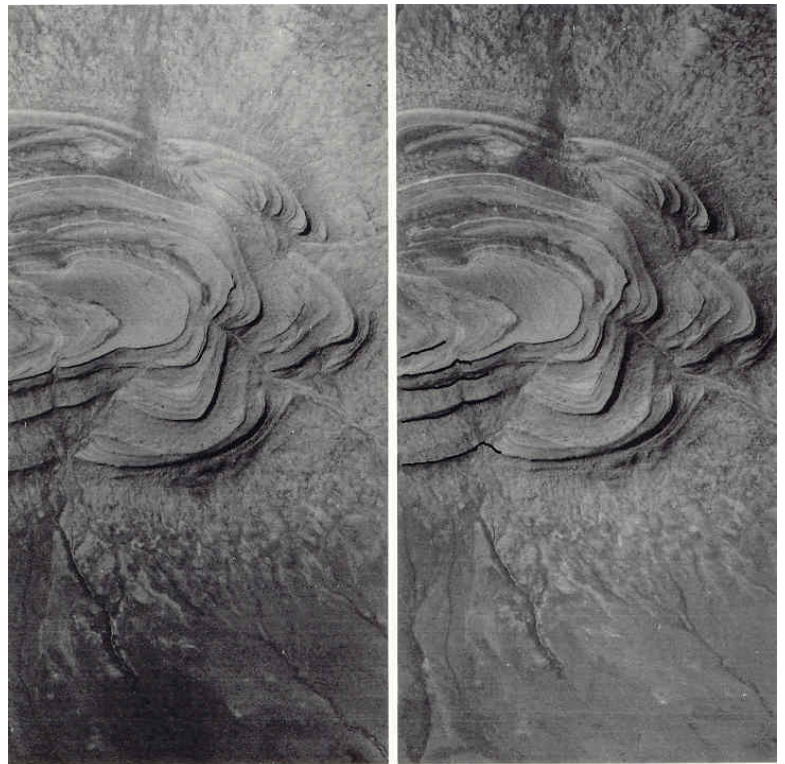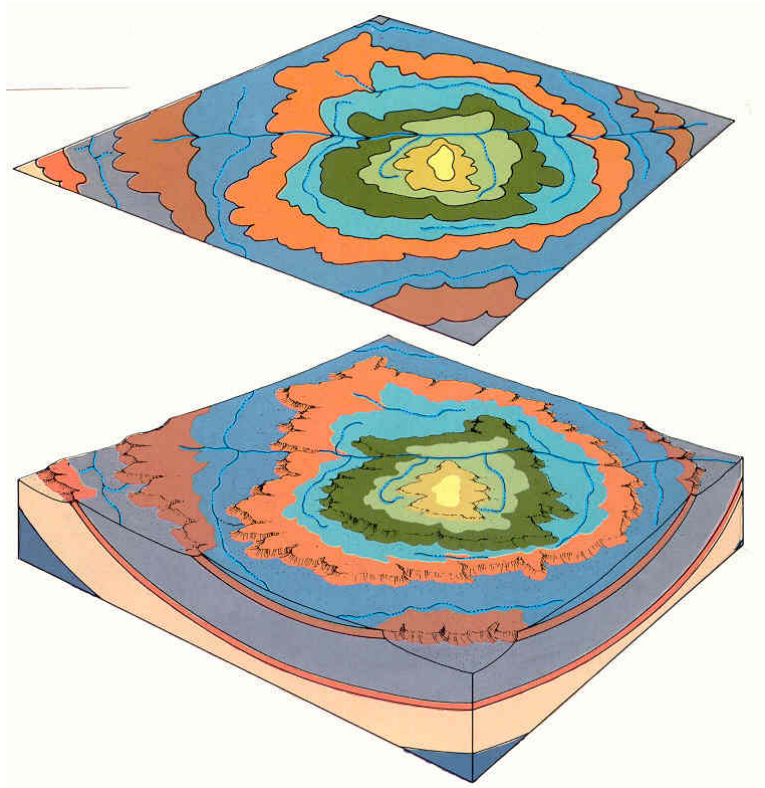
Every anticline, short or long, has a part where the beds are highest, or where, the oldest beds appear at the surface of a near level terrain. From such an area, the beds are dipping radially in all directions, and the axis shows two plunges at opposite areas away from this highest part. These types of features are called as **dome** due to their dome like shape (Figure 6.13). Such structural features are of great economic importance in the respect of petroleum accumulation.

b. Syncline. This structure is a negative fold. The beds on a syncline dip toward the central line, the synclinal axis, which runs along the deepest part of a tectonic trough. Synclines are of many types, similar to anticline. If the axis of syncline shows two plunges at opposite areas, these features are named as basin (Figure 6.14). Synclines have usually no economic interest for the oil geologist. For the hydrologist however, synclines are important because artesian wells can be successfully drilled in synclines.

6.1.3. Structural landforms

Every region of sedimentary rocks will be eroded during and after accomplished folding. Weak rock will be removed and the hard beds will remain as ridges or dipslope belts. The resulting landforms depend on the distributions of hard and weak strata. Positive forms will be mountains or ridges; negative forms will be valleys, troughs, or basins.

Tectonic terrace (tectonic bench or homocline). These are incomplete anticlinal structures. They have two flanks dipping in the same direction similar to a river terraces (Figure 6.15)

Figure 6.15

Anticlinal mountain. The axial part can be built up by a resistant and hard formation. Such a situation is rather frequent because along an anticlinal axis, older beds crop out, which are mostly harder and more resistant than younger formations which are not too well consolidated. The core part will, therefore, remain and **anticlinal mountain** will result (Figure 6.16). Such anticlinal landforms are frequent in areas of thick sandstone formations or where beds of hard limestone become exposed.

Anticlinal valley. When nonresistant and weak beds are exposed along an anticline and the flanks are of resistant material, the core of the fold will be carved out by subsequent stream and an anticlinal valley will result (Figure 6.16).

Synclinal valley. It is a type of landform which is associated with troughs (Figure 6.17).

Synclinal mountain. It is less frequent and occur when the core of the syncline is of hard rock and the older beds along the flanks are weak and removed by erosion (Figure 6.17).

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Figure 6.16. Block diagram of an anticlinal mountain and a synclinal valIey. The anticline (A.Mt.) forms a ridge. A thick sandstone bed (Ss2) is overlain by a sandy shale sSh. Consequent drainage C of sandy shale character forms dipslopes (D) which however do not conform with Ss2 below. The ‚watershed W, however, follows the axis of the structure. The synclinal valley (S. V.) is formed by sandstone Ss1. It forms a trough with dipslopes (D) and alluvial fill (A). The shale at the left shows a strike controlled strato subsequent river (sR). At the center, stream sR follows the scarp in a similar sense. The tributaries from the anticline are resequent streams; the steep short gullies from the scarp obsequents (O). CgI is a base coinglomerate; B is base rock.
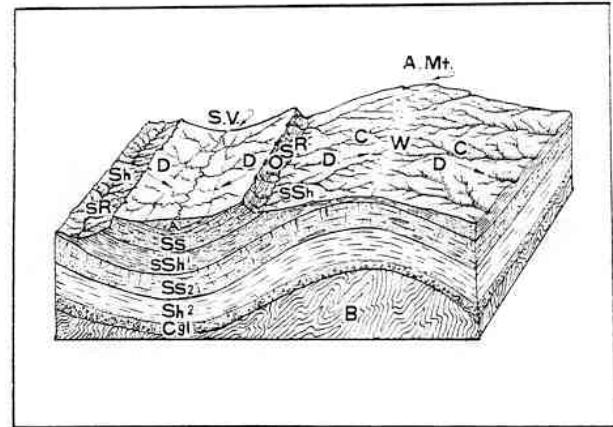

FIGURE 6.17. Block diagram of a synclinal mountain and anticlinal valIey. The beds: Ss, sandstone; Sh, sha1e;sSh, sandy shale; Lst, limestone; CgI, conglomerate; and B, basement rock. At D is a sinkhole-studded gently dipping limestone surface, with internal drainage. It forms dip- slopes (D-D). Since the anticlinal crest (AV) falls into a sandy shale, a valley is eroded by a strike controlled stream. The syncline (SM) is formed by several hard beds. It is a mesa-type fiat trough. Talus cones (Tc) fiat-tening the slope between sandstones 1 and 2, should not be confused with dipslopes. Note that shale at SM ex- presses the dip of beds. At sSh the shale is unconclusive to real dip of the complex.
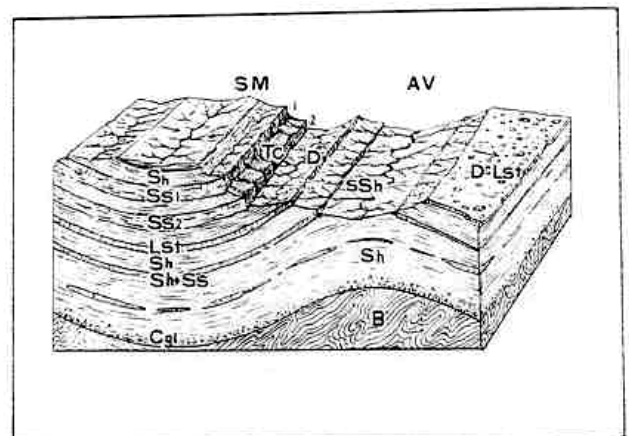
6.1.4. Fractures

Tectonic forces do not always cause the development of folds. Instead, the rocks may break or fracture. Faults and joints are examples of these types of deformational features.

6.1.4.1. Faults

Faults are the deformational features of the Earth's crust along which a measurable movement takes place (6.18).

On aerial photographs fault indications have one common property: they are always straight, or slightly curved. Straightness is inherent to all breaking phenomena of the crust. This stands mainly for resistant rocks, because, weak, plastic beds are bent rather than broken. The relative straightness of a fault indication is based on the straightness of the fault plane. This plane is always somewhat irregular or slightly curved. Normal faulting displays, as a rule, straightness along a certain length (Figures 6.18, 6.19). Curved fault traces are found only in reverse or overthrust fault.

Figure 6.18. Outcrop patterns of faults and Colorado Plateau

Fault patterns on geologic maps are distinctive; they appear as lines or zones of displacement that abruptly offset structures and terminate contacts between formations.

Thrust faults generally dip at a low angle. Because of the low-angle dip, the pattern of the fault trace is characteristically irregular and similar in many respects to the trace produced by low-dipping angular unconformities. In Figure 6.18, thrust faults are located at the base of the formations colored purple and blue. The trace of a thrust fault commonly forms a V across valleys, with the V pointing in the direction in which the fault dips.

Normal and reverse faults usually dip at a high angle, so their outcrop patterns are relatively straight. Since older rocks are generally exposed on the upthrown block, the relative movement on most high-angle faults can be determined from the map relations alone.

Thick, resistant sandstone formations in the Colorado Plateau commonly show the characteristics of fracture systems in remarkable detail. The sandstone formation in this area is nearly horizontal. Normal faults are shown where the surface is displaced vertically. Joint systems are accentuated by weathering and are expressed as cracks.
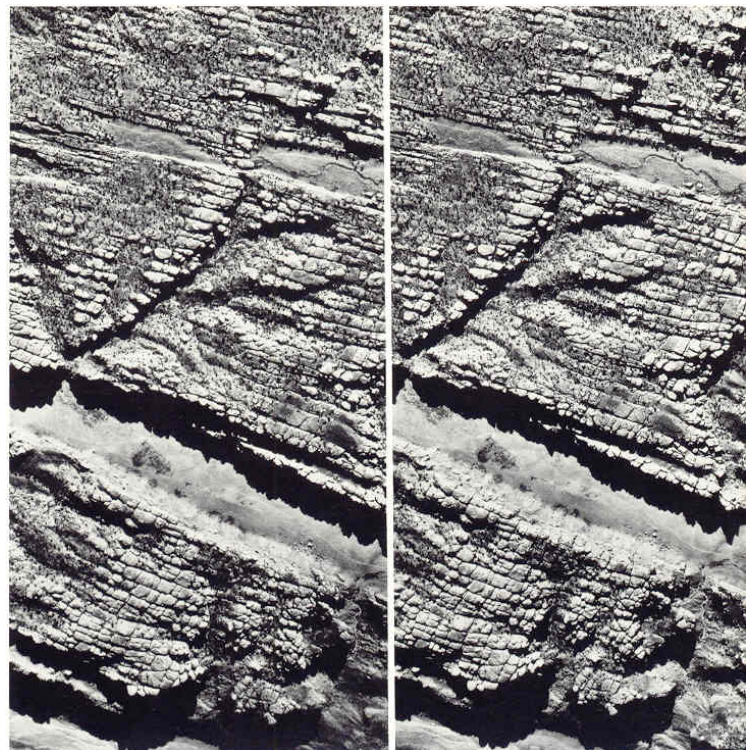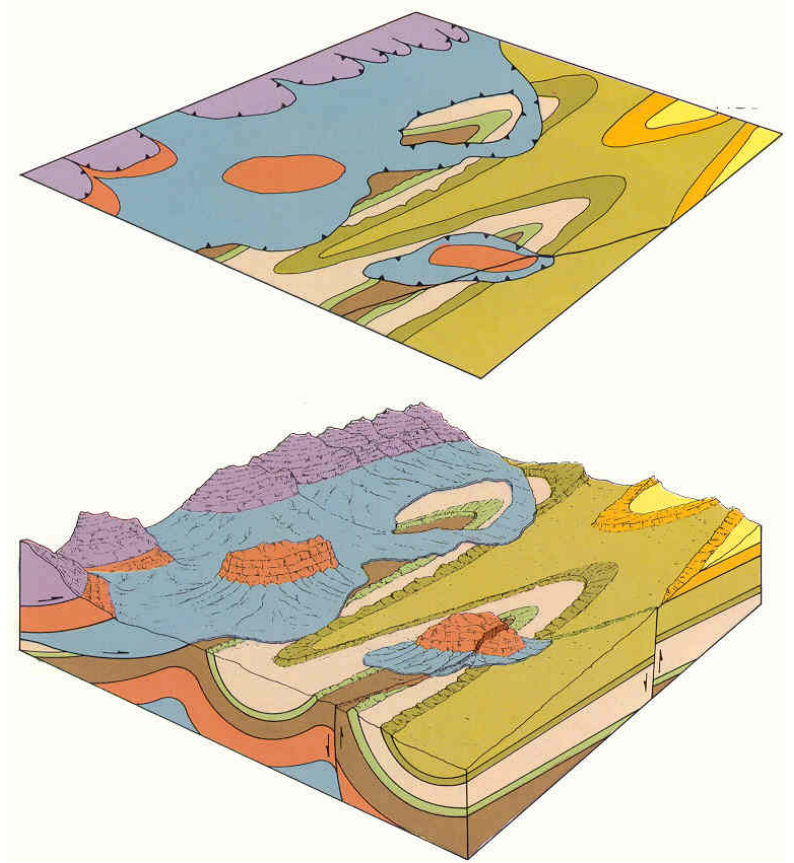
Figure 6.19. Outcrop patterns of strike-slip faults and strike-slip faults of California

In a strike-slip fault, the displacement is parallel to the strike of the fault plane. Displacement on strike-slip faults may reach several hundred miles, so rock types of very different structure and geologic characteristics may be placed side by side after prolonged periods of movement. The trend of strike-slip faults is typically straight, in contrast to the irregular trace of thrust faults and the zigzag trace of normal faults. Small slivers or slices of foreign rock bodies may be caught in the strike-slip fault zone and are commonly expressed either as elongate troughs or ridges.

The lateral displacement of the crust in strike-slip faults does not produce high scarps. The fault line is, however, commonly marked by structural and topographic discontinuities, linear ridges and rivers, and offset drainage patterns. The offset drainage is usually very significant, because it indicates the direction of displacement.
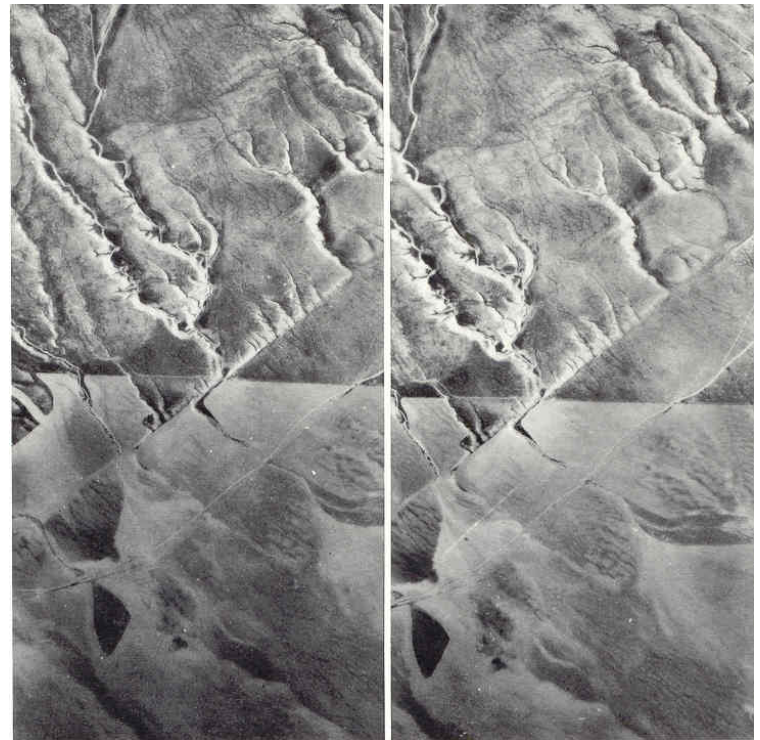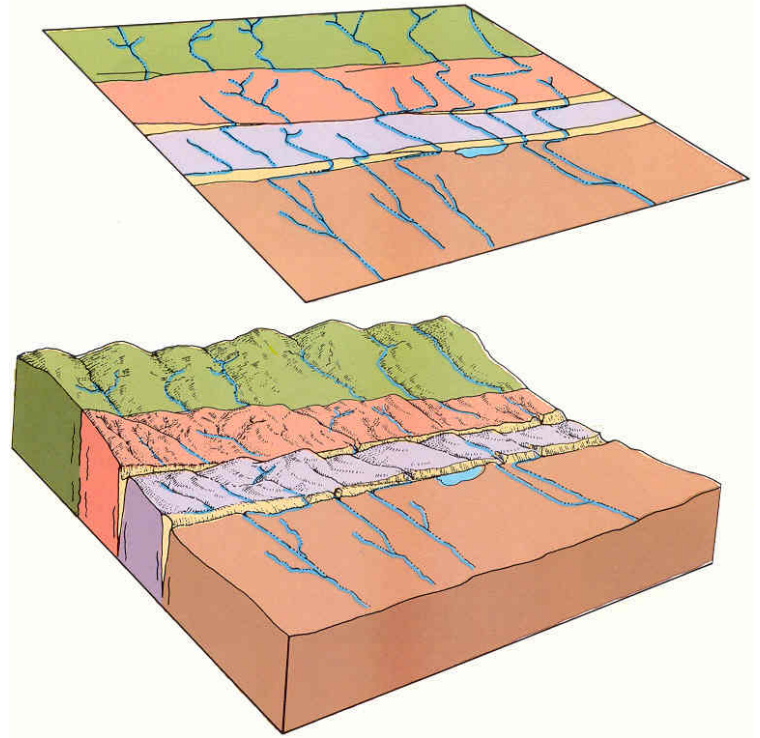
The main indications or features, which can be distinguished on aerial photographs to determine the faults are:

1. Scarps. Morphologically, the most common landforms are fault scarps. All types of faults may cause scarps but normal faulting will be the most frequent cause of scarp forming (Figure 6.20).

2. Triangular facets. When erosion advances and cuts up the fault scarp into residual landforms, parts of the original scarp will remain and indicate the original approximate position of the fault plane (Figure 6.20). These features are named as triangular facet and found along the foot of a fault scarp, following a more or less straight line. They are found mostly on active, reactivated or young faults.

3. Block forming. Relatively elevated and depressed surfaces can form a pattern called a block mosaic. Such an area is called block faulted. These blocks are mostly connected with multiple scarping (Figure 6.19)

4. Truncation. Abrupt termination of landforms, or drainage pattern or sudden changes in photographic tone, texture along a straight line or linear feature (Figure 6.18, 6.19).

5. Trenches or linear depressions. Straight, incised narrow valleys or grabens in hard rock like igneous, dissolved cracks in limestone (Figures 6.19, 6.20)

6. Controlled drainage. Every straight, angular stream course if not strato-subsequent, should be considered fault controlled (Figures 6.19, 6.20).

7. Axial shift of structures. Right or left stepping in the fold axes indicates faulting.

8. Abrupt changes of dip on monoclines, or a sudden change of dip, strike or both, along a line.

9. Igneous features. Linear arrangement of extrusives and dikes where magma intrudes into major fractures or extrudes along them.

10. Alignment of sinkholes and vegetation, springs.

11. Tone changes along a linear feature due to vegetation or high water content.

12. Offset streams, rock units, and other linear features Figure 6.19, 6.20).

13. Lineaments. These are large scale linear features, which are the topographic expression of underlying structural features such as fault-controlled valley (Figure 6.18, 6.19, 6.20), joint controlled valleys or streams, fronts of mountain ranges, straight and narrow mountain or hill ranges, ridges (Figure 6.20), lines of isolated hills, linear igneous intrusions, and lines of volcanoes.

14. Straight boundaries of cliff coasts or straight contacts between erosional (hills) and depositional (alluvial) area.
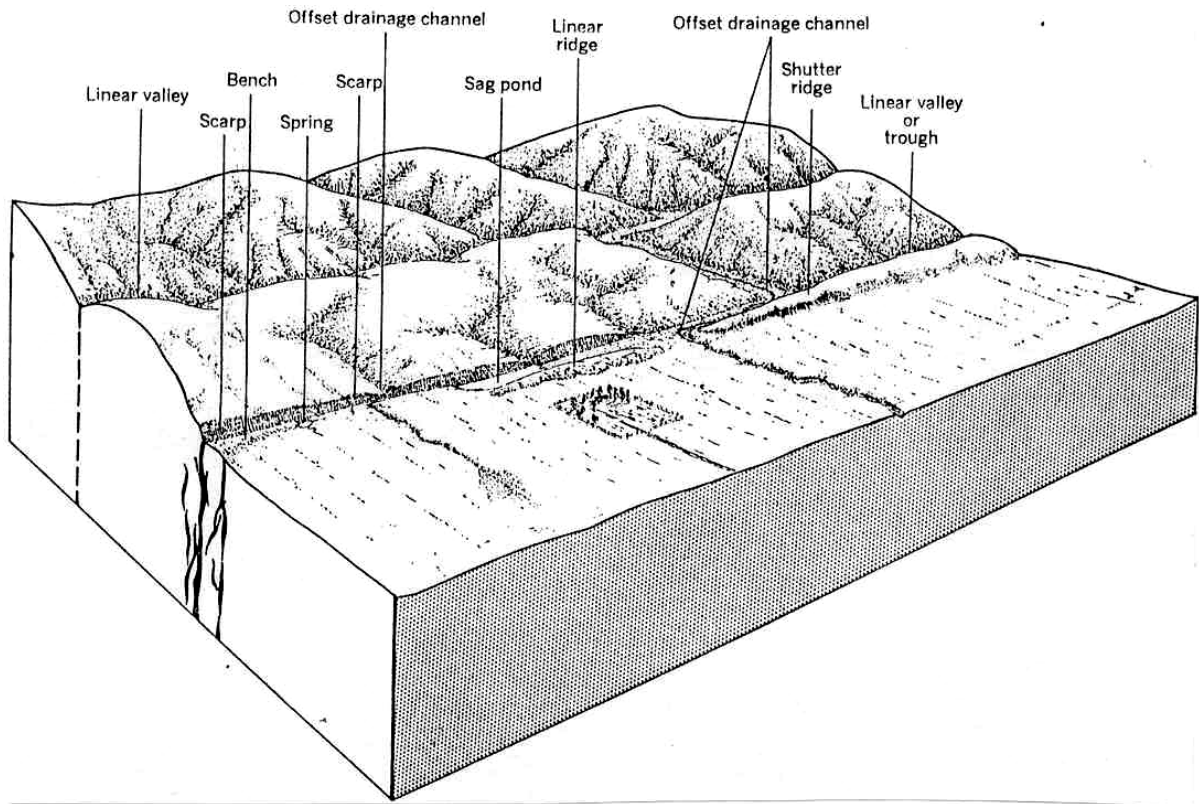
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Figure 6.20. Block diagram showing landforms developed along recently active strike-slip faults.

6.1.4.2. Joints

Joints are also expressed as linear features, similar to faults, on aerial photographs (Figure 6.18). So, the same features or criterias which are used to detect faults on aerial photographs can be used also to detect joints. The main differences:

1. there is no displacement along the joint planes,

2. the lengths and the spaces of the linear features caused by the joints are less than that of faults.

Joints in sedimentary rocks develop as regularly spaced parallel sets with equal separation. Generally two closely spaced sets form at an certain angle to each other. But in igneous rocks more than two joint sets may occur, and the separation between joints are unequal. Therefore, joint sets developed on igneous rocks may produce a criss-cross pattern.

In fine grained sedimentary rocks like clay, shale and marl joints are relatively closely and regularly spaced, while they are widely spaced in coarse grained hard rocks, like sandstone and limestone.

6.1.5. Unconformities

Deposition of beds in a body of water is a continuous process. Layer by layer is deposited in succession, the older covered by the younger. Such beds have parallel bedding planes and the strata are called **conformable**. When the deposition of sediments is interrupted, and the sedimentary rocks is lifted above water and consequently becomes exposed to erosion, an erosional surface will develop. When the depositional cycle is terminated, it will be replaced by an erosional cycle. The eroded or abraded surface may eventually sink again. A new sedimentary period will start The relationship between the old and the new deposit cycle is called **unconformity.** The beds of old cycle may be

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tilted, broken or folded during the process or in later periods. When a following submergence is followed by a new sedimentation, the relation between the two sedimentary groups is called an **angular unconformity** (Figure 6.21, 6.22, 6.23).

On aerial photographs, unconformities can be directly observed when the contact is along a tilted plane. When the contact is horizontal, it is usually cannot be observed, because of scree or a soil cover. Usually, the unconformity contact is an irregular plane in a horizontal rather than a tilted position. In intensely folded areas, however, the unconformity plane may become tilted or vertical and the contact may appear somewhat straight, when the topography is taken into consideration. When plotting unconformity contacts, which appear as irregular lines on photographs, care should be taken not to confuse them with fault contacts. The main character of a contact line is its irregularity. If straight lines are observed, it should be considered as a fault contact.

Since the unconformity contact is seldom directly visible on aerial photographs, the contact line must be plotted between two areas of different attitudes or lithology. Angular contacts can be observed rather easily, provided no fault contact is present between two members. Erosional contacts can be plotted rather easily when marine sediments, igneous and alluvials are involved.

Figure 6.21. Two types of unconformities. The formation (S) shows conform bedding C-C. Formation B is folded and angular unconform with S. Unconformity plane is at A-A. The tilted formation S became eroded, and on the eroded surface, formation T deposited horizontally. The contact between S and T along line E-E (the old eroded surface of S) is *erosional.* This is an erosional unconformity, though an angular as well.
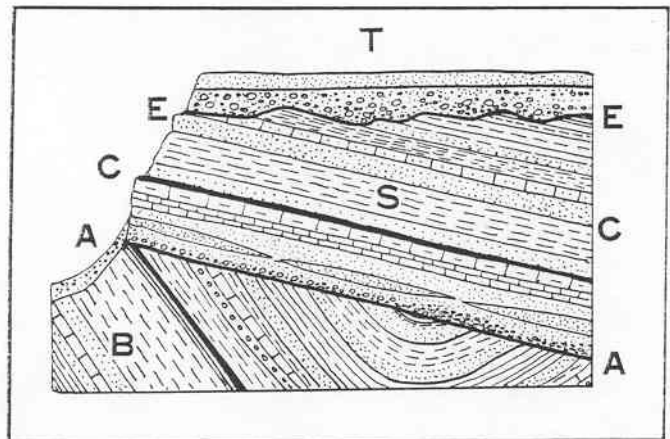

Figure 6.22. Morphologic expression of unconformities. B is a folded base rock. Supposedly homogenous, the out- cropping formatian shows a dendritic drainage. (A) denotes an angular unconformity. The outcropping sediments of S form dipslope rows. There is an erosional unconformity at E between S and horizontal terrace T.

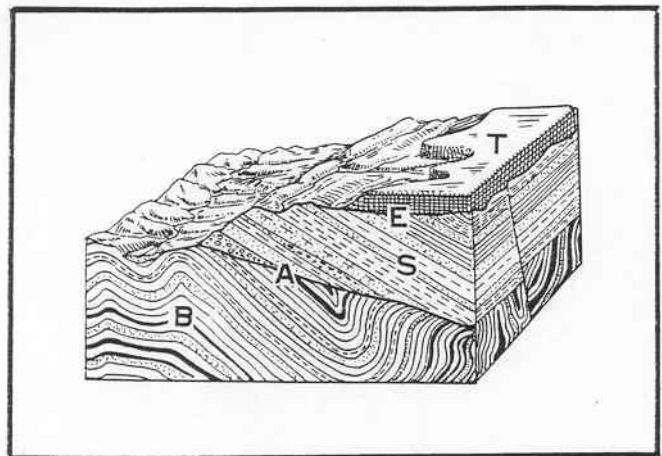İleri Fotojeoloji Ders Notları, Kadir Dirik, 2006

Figure 6.23. Outcrop pattern of unconformity and aerial photograph of an angular unconformity in the Montana region

Angular unconformities can be recognized on geologic mars by interruptions, or discontinuities, in the outcrop patterns. The outcrop pattem of older structures is partly covered by younger strata, so on the geologic map, the contacts of the older structures will terminate abruptly against the patterns of the overlying younger beds. In the diagram shown here, the oldest sequence has been warped into plunging folds, eroded, and subsequently covered by a younger sequence of strata. A second period of erosion has partly removed the younger strata and exposed segments of the older folds. The angular unconformity is located at the base of the sequence of younger horizontal strata. All of the map patterns of the older strata terminate against this contact. V s in the trace of the unconformable surface indicate the direction in which the unconformity dips
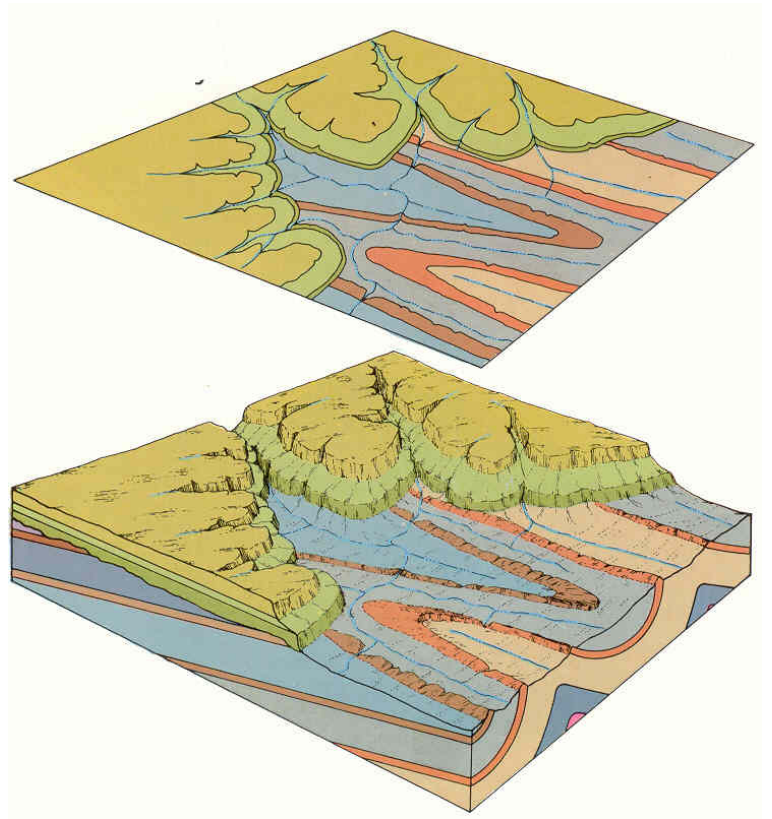
6.2. LITHOLOGIC INTERPRETATION

Lithological interpretation refers to the recognition of rock types from photogeological data alone, rather than from photogeological data supported by local field experience. A combination of geomorphological and structural analysis must be undertaken. Each outcrop seen on the stereomodel must be considered on its local and regional geological environment, and the final lithological interpretation must not be made until the other studies are completed.

The photographic appearance of a particular rock type may be quite variable, depending especially on the climate and the amount of relief. It is not possible to establish a set of criteria for the recognition of rock types that would be applicable to all areas. However, certain lithologic information can be obtained by using certain photocharacteristics of different rocks.

The following procedure may be used in lithologic interpretation:

1. Determine the climatic environment (e.g. desert, arid, semi-arid, humid, temperate, tropical),

2. Determine the type of erosional environment (e.g. active, very active, inactive),

3. Recognize and mark the bedding traces of the sediments or metasediments,

4. Recognize and mark the areas of outcrop that do not have any bedding (these may be intrusions, or horizontally bedded sediments),

5. Recognize and mark the areas of superficial cover that do not indicate bedding,

6. Re-study the bedding traces determined at (3) around fold noses and determine the approximate position of the axial traces,

7. Study the lineaments to determine whether they represent faults, dykes, joints, or combinations of these.

To differentiate different lithologies, the following observations should be made on aerial photographs:

1. The photographic tone of the rock mass in relation to the neighboring rocks,
2. The resistance to erosion of the rock mass in relation to the neighboring rocks,
3. The boundary of whole rock mass,
4. The topographical expression of whole rock mass,
5. The boundaries of the individual outcrops,
6. The gully analysis,
7. The joint pattern,
8. The fault pattern,
9. The drainage pattern,
10. The vegetation cover,
11. The bedding or the relic bedding lineaments,
12. The foliation lineaments,
13. The regional geological environment.

6.2.1. Sedimentary rocks

6.2.1.1. Consolidated sediments

The most prominent feature of sedimentary rocks is **bedding**. As a result of differential erosion of sedimentary rocks, beds appear as banded patterns on aerial photographs. Banding due to vegetation or soil differences expressed by topographic tone can also be used to recognize and mark the beds in absence of topographic expressions. Bedding may be most prominent in the mature stage of geomorphic cycle. However, bedding may be masked in the case of massive sedimentary rocks, such as certain sandstones, and these appear as uniform masses and similar to some igneous and metamorphic rocks. In massive limestones sinkhole develop.

Table 6.1. Summary chart of sedimentary rocks (Way, 1973)

Landform	Topography	Drainage*	Tone	Gullies	Vegetation/Land Use
Sandstone					
Humid	Massive, steep slopes	Dendritic, C	Light	Few (V-shaped)	Forested
Arid	Flat table rocks	Angular dendritic, M-F	Light (banded)	Few to none	Barren
Shale					
Humid	Soft hills	Dendritic, M-F	Mottled-Dull	Soft U-shaped	Cultivated
Arid	Steep, rounded hills	Dendritic, F	Light (banded)	Steep-sided	Barren or badlands
Limestone					
Humid	Karst topography	Internal	Mottled	White-fringed	Cultivated
Arid	Flat table rocks	Angular dendritic, M-F	Light	Few to none	Barren
Tropical	Tropical karst	Internal	Uniform light	None	Barren or forested
Dolomite					
Humid**	Hill and valley	Angular dendritic, M	Light gray	Soft U-shaped	Cult. & forested
Coral					
Tropical***	Terraced or reef	Internal	White to gray	None	Barren or forested
Flat, interbedded (thick bedded)					
Humid	Terraced hillsides	Dendritic, M-C	Subdued bands	Varies	Cult. & forested
Arid	Terraced hillsides	Dendritic, M-F	Banded	Varies to few	Barren
Flat, interbedded (thin bedded)					
Humid	Uniform slopes	Dendritic, M	Med. gray	Soft U-shaped	Cult. & forested
Arid	Minor terraces	Dendritic, F	Faint, thin bands	Few to none	Barren
Tilted, interbedded					
Humid	Parallel ridges	Trellis, M	Faint banding	Varies	Forested & Cult.
Arid	Saw-toothed ridges	Trellis, F	Banded	Varies	Barren

*C, coarse; M, medium; F, fine.

**Characteristics of dolomite in arid climates appear similar to those listed for arid limestone.

***For all practical purposes coral formations are found only in tropical climates.

Coarse grained rocks (sandstone). Porosity and permeability are variable. The individual beds are generally thin and occur interbedded with shale. Differential erosion is an important recognition factor. Cross bedding features might be observed in the photographs taken in arid regions. The joints and fissures may be visible on photographs. In spite of their porosity and permeability they develop a drainage pattern (dendritic). It is partly an internal drainage and streams often follow lines of dislocations (angular drainage). Gullies are generally short, steep, V-shaped and widely spaced. The tone is usually light gray, ferruginous types may become dark. Sandstones support little or no vegetation, less dense than on shales. In humid climates sandstone-shale are usually vegetated and cultivated.

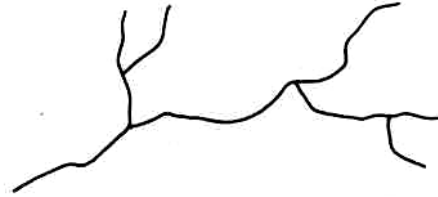**Table 6.2. Sandstone (humid and arid) (Way, 1973)**

Humid

Topography
Massive, steep slopes

Drainage
Dendritic: Coarse
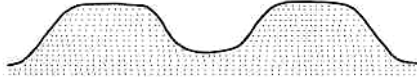
Sandstones tend to be relatively resistant to weathering because of the strength of their cementing agents. Therefore, in humid climates they produce a massive, bold topography with steep sideslopes. The residual soils tend to be very shallow along the ridgelines but thicker at lower elevations, owing to the accumulation of colluvium. Since sandstone is usually the most resistant sedimentary rock in humid climates, it tends to occur as an overlying cap rock. Where sandstones encounter other sedimentary rocks, there is generally a sharp boundary.

In humid climates the drainage pattern for sandstones is generally dendritic although, depending on the influence of the jointing pattern, it may also be somewhat angular or even rectangular. The drainage system texture is usually coarse but may also be medium, with minor tributaries joining the next higher stream order at right angles.

Arid

Topography
Flat table rocks

Drainage
Angular dendritic
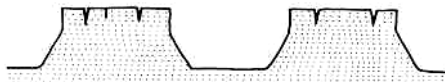
Sandstone deposits in arid climates are resistant to the forces of weathering and form dominant formations in the landscape. Fracture or joint patterns, having the appearance of rectangular blocks, can be readily observed since there is little soil cover. Cliffs may occur where sandstones overlie weaker sedimentary rocks, and wind erosion and blowing sand may modify these vertical elements, rounding and carving them into streamlined shapes. If the beds are flat, the hilltops tend to be of equal elevations.
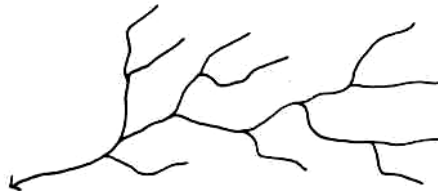
In arid climates the lack of residual soil cover allows the joints in sandstone to have maximum control over the drainage pattern. Thus, it is usually an angular dendritic or even rectangular pattern, medium to coarse in texture. Many streams are intermittent, so large areas of no apparent drainage may be observed.

Shale and similar fine grained sedimentary rocks. Shales are the most common and wide spread sediments. They exhibit dark tones, a fine-textured drainage, and relatively closely and regularly spaced joints. Dark tone of shales is due to absorbed water (but it is impervious to it). As a result of very poor permeability no internal drainage develops on shales (or unconsolidated equivalents, clays). Erosion is intense, typical drainage pattern is closely spaced tree-like (dendritic), and when steep-sloped and silty, is dendritic-parallel. Gullies in shales are long, more open with more gentle gradient than in sandy beds. In most places shales are interbedded with more or less sandy beds or sandstone. Sand content influences the drainage pattern. Strike controlled subsequent pattern may form. Faulting can rarely be observed in shales, because the fissure is soon closed and joined together by clay.

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Table 6.3. Shale (humid and arid) (Way, 1973)

Humid

Topography
Soft Hills

A smooth, sag-and-swale topography occurs, appearing as soft hills and mounds. Sharp breaks in slopes are neither common nor stable. The attitude of the bedding layers does not affect the appearance of the topography, and it is difficult to observe bedding planes, because of the deep soil profiles found in this climatic zone.
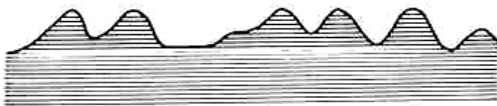
Drainage
Dendritic: Medium to fine
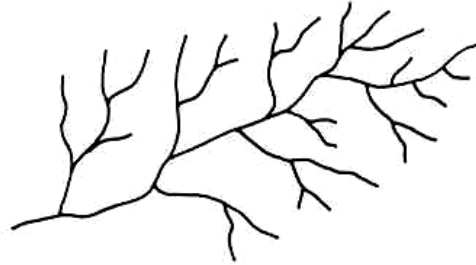
The soft materials exert no control over the drainage system, allowing a medium to fine dendritic pattern to develop freely. No angularity is found, and tributaries enter streams of the next order at acute angles.

Arid

Topography
Steep sideslopes

The topography is characterized by steep sideslopes and is highly dissected, reflecting the soft nature of the rock. Ridgelines are rounded, and faint bedding planes may be observed along the sides of hills.

Drainage
Dendritic: Fine

Shale regions show a very finely dissected pattern, dendritic in nature, reflecting rapid runoff and the impervious nature of the shale.

Very coarse grained rocks (conglomerate and breccia). These seldom show a great degree of permeability. Permeability depends on the grade of cementation and the type of solubility of the matrix. They are usually lenticular and almost always associated with sandstones. It is difficult to separate conglomerates from sandstones on the basis of drainage since they differ from sandstones only in the size of fragments. In deserts the surface of beds are disintegrated to gravel deposits giving a rough surface and darker tone (shadow effect). Cataclastic breccias and conglomerates occur in crush zones.

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Limestones have light tones with dissolution forms like rills, channels, trenches and sinkholes. Dolomite is less soluble than limestone. Different types of limestones have sinkholes different size and distribution. Fractures are broadened by solution. The drainage is internal. Marls are light in tone, have drainage patterns similar to shales depending on their clay content. In tropical regions they support dense forest vegetation.

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Table 6.4. Limestone (humid and arid) (Way, 1973)

Humid

Topography	Drainage
Karst	Internal
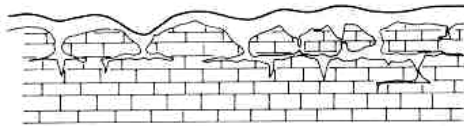
Chemical weathering dissolves the rock along jointing and bedding planes, thus developing a collapsing surface of sinkholes and depressions known as "karst topography." The ground surface is undulating and forms indistinct transitional boundaries with other, associated sedimentary rocks. Sinkholes are rounded in flat-laying beds, elongated in tilted beds.
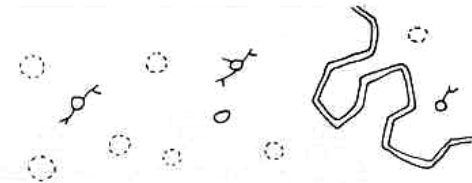
The solution cavities within the rock and the high permeability of the residual soil cause humid limestone regions to be drained internally, leaving little water to be collected in a surface water system. Major streams follow angular alignments of old jointing patterns. Typical sinkholes average 10 to 40 feet in depth and 50 to 500 feet in width.

Arid

Topography	Drainage
Table Rocks	Angular dendritic: Medium to fine
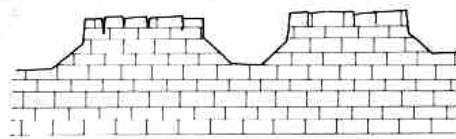
Since little moisture is available for chemical weathering in arid climates, the limestones present erode very little. Pure, thick limestone deposits form cap or table rocks, developing none of the characteristics associated with karst topography.
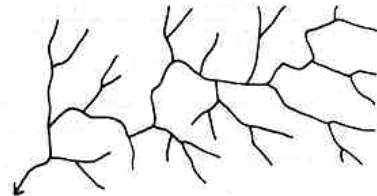
The surface drainage system is well developed (karst topography does not exist in arid climates.) The pattern is very angular, following jointing alignments in the bedrock, and is medium to fine textured. All but major streams are intermittent.

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Table 6.5. Tropical limestone, dolomite or cherty limestone (humid and arid) (Way, 1973)

Tropical limestone

Topography
Tropical karst
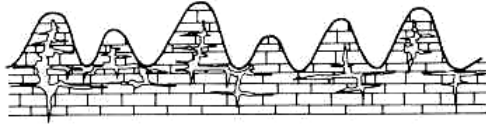
Drainage
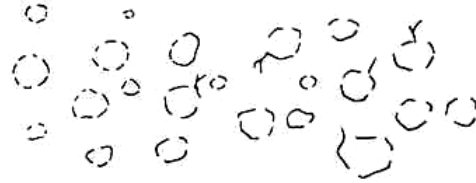Internal

A very rugged, tropical karst topography is developed with conical hills and large depressions (up to 1000 feet deep and 1 mile in diameter).

All drainage is internal through the highly permeable soil and bedrock.

Dolomitic or cherty limestone

Topography
Hill and valley

Drainage
Angular dendritic: Medium

These areas are similar to sandstone in appearance, with little or few solution cavities or sinkholes. Nodules of chert can be observed in open fields.

A dendritic pattern of medium texture is characteristic in humid climates, with angularity reflecting jointing control.

Coral

Topography
Terraced

Drainage
Internal

Elevated reefs appear flat, with a steep, jagged cliff along the seaward edge. Sea-level reefs either encircle (barrier type) or appear as a white, discontinuous fringe along the edge of an island.

Coral is very porous and spongy and therefore does not develop either a surface drainage pattern or sinkhole topography.

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Table 6.6. Thin bedded sedimentary rocks (humid and arid) (Way, 1973)

Humid

Topography
Uniform slopes

Thin, interbedded sedimentary materials do not have terraced slopes, although faint banding may be observed. Sandstones have steeper slopes than shale or limestone masses. Hilltops throughout such regions have approximately the same elevations.
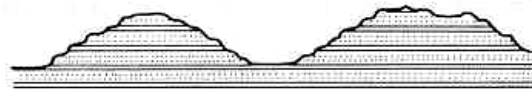
Drainage
Dendritic: Medium
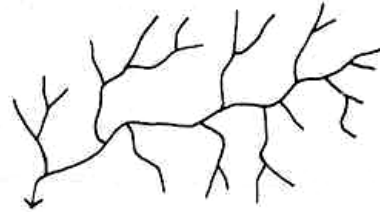
The drainage pattern in thin, interbedded sedimentary rocks is dendritic and of medium texture, similar to shale drainage in humid climates. The presence of shale in the interbedding, however, increases surface runoff, resulting in a more dissected topography.

Arid

Topography
Minor terracing

The well-dissected topography shows very narrow terracing, following hillside contours. Sandstones and limestones have vertical cliffs, while shale forms more gradual slopes.

Drainage
Dendritic: Fine
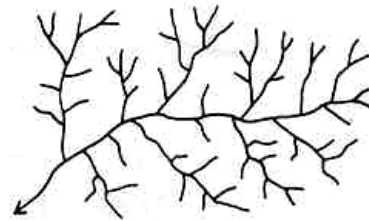
Interbedded sedimentaries in arid climates form dendritic patterns with fine textures. If shales are present, they provide impervious layers which increase surface runoff and dissection.

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Table 6.7. Thick bedded sedimentary rocks (humid and arid) (Way, 1973)
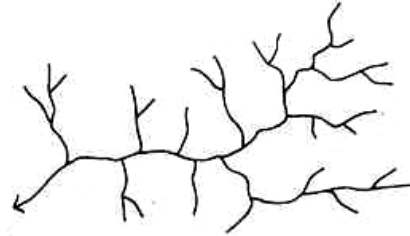
Topography

Terraced hillsides
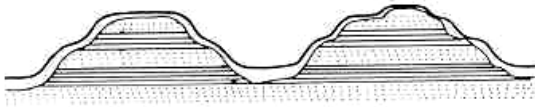
Hillsides in thick, interbedded sedimentary rock regions appear terraced; hilltops are at the same elevations. In sandstone-shale combinations the more resistant sandstone remains as a cap rock with steep sideslopes; the underlying shale has a more gradual sideslope. In limestone-shale combinations the limestone occupies the hilltops and uplands and may have solution features.
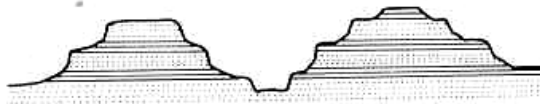
Drainage

Dendritic: Medium to coarse

The drainage pattern is commonly a medium dendritic system and tends to be controlled by the most resistant rock in the series, commonly sandstone. Thick, limestone cap rocks may be characterized by solution sinkhole topography, with major streams following angular alignments.

Topography

Terraced hillsides

As in humid climates, hillsides appear terraced and hilltops are at the same elevations. The more resistant rocks occupying table rock positions, such as limestone and sandstone, maintain steep escarpments. Shale, usually underlying more resistant rock, is characterized by more gradual slopes.

Drainage

Dendritic: Medium to fine
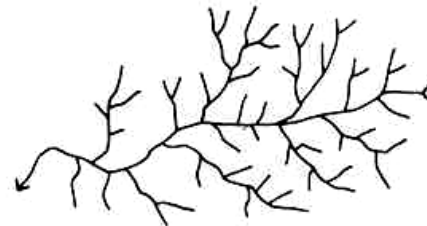
A dendritic drainage system of medium to fine texture is common, reflecting the nature of the upper strata of bedrock. Limestone does not develop solution cavities but may control surface drainage and valley alignments through its angular jointing system.

Table 6.8. Tilted sedimentary rocks (humid and arid) (Way, 1973)

Humid

Topography
Parallel ridges

Drainage
Trellis and dendritic
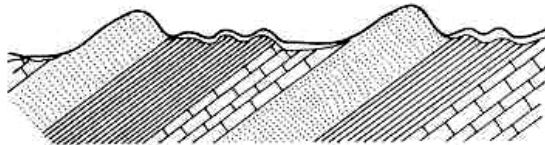
In sandstone-shale combinations sandstone forms resistant, sharp, parallel ridges; shale forms soft, rounded hills in the lowlands. Limestone-shale forms low, rounded hills in shale formations, and karst topography with rounded or oval sinkholes in limestone areas. Thin beds give the ridge topography a saw-toothed appearance.
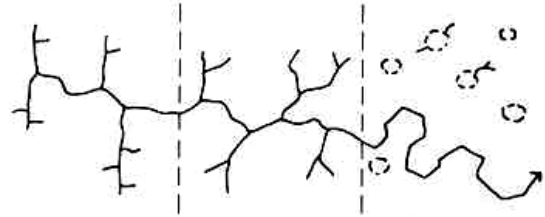
In most situations a trellis drainage pattern of medium to fine texture exists, controlled by the tilted rock structure. Interbedded limestone and shale may have a dendritic pattern and solution topography with internal drainage. Stream courses are generally located in shale lowlands; if they are located in limestone low-lands, some angularity should occur as a result of jointing influence.
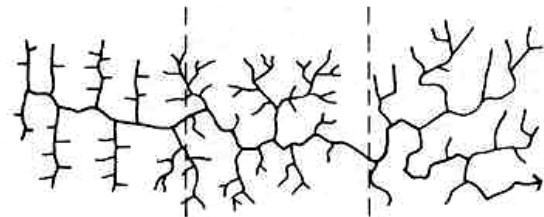
Arid

Topography
Saw-toothed ridges

Drainage
Trellis: Fine
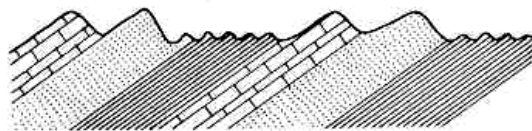
Ridge crests in arid climates are much sharper, and the ridges develop a saw-toothed appearance. The V's formed between the teeth point down the dip of the rock strata. Sandstone and limestone both form resistant ridges; shale forms conical lowland hills. Thin beds give the ridges a finer saw-toothed appearance.

In arid climates tilted sedimentary rocks are identified by a trellis drainage pattern which is normally fine-textured. If there is a regional uniform slope, the trellis pattern may be modified, showing some parallelism.

6.2.1.2. Unconsolidated sediments

Most unconsolidated sediments are readily differentiated from consolidated sedimentary rocks on aerial photographs. Land-form is the significant element in recognizing surficial sediments; because many surficial deposits have diagnostic topographic form, e.g. sand dunes, alluvial fans, river terraces, eskers. In the absence of a diagnostic landform, their character can be inferred from drainage characteristics, tone, slope analysis, and related criteria.

Table 6.9. Summary chart of glacial landforms (Way, 1973)

Landform	Topography	Drainage	Tone	Gullies	Vegetation & land use
Till					
Thick					
Young	Flat plains	Deranged	Mottled	Few to soft	Cultivated, gridded*
Old	Dissected plateaus	Dendritic, medium	Subdued mottles	Box-shaped**	Cultivated, forested*
Thin					
Young	Rock-controlled	Rock-controlled	Light gray	Vary	Cult. and/or forested*
Old	Rock-controlled	Rock-controlled	Dull Gray	Vary**	Cult. and/or forested*
End moraine	Undulating to rugged	Deranged	Light to dark	Vary	Cult. and/or forested*
Drumlin	Drumlin-shaped	None	Light gray	None to few	Cult. and/or forested*
Glaciofluvial					
Esker	Snakelike ridges	None	Light	None	Natural cover
Kame	Cone or ridged hills	None	Light	Few V-shaped	Natural cover
Outwash					
Plain	Flat plains	Internal-channel scars	Light	None	Cult. or natural*
Pitted	Pitted plains	Internal	Light	Few V-shaped	Cult. or natural*
Valley train	Flat valley bottom	Internal	Light	None	Cult. or natural*
Glaciolacustrine					
Lake beds					
Sandy	Flat plains	Internal and ditches	Light dull gray	None	Cultivated
Clay	Flat plains	Broad meanders	Dull gray	Ditches	Cultivated

 * Semiarid or arid climates may have some grain crops but land is typically in natural cover of scattered grasses.

** White-fringed gullies are direct indicators of Illinoian age till.

Table 6.10. End moraines (humid and arid) (Way, 1973)

Topography	Drainage
Undulating and rugged	Deranged

End moraines create a topography with a linear, discontinuous band of hills and depressions, whose elevation differences seldom exceed 500 feet. Softly rounded, undulating hills (a) indicate fine soils (common in the Midwest); rugged, steep-sided, sharp-ridged hills (b) indicate coarse soils. Hill masses are relatively small when compared to bedrock formations.

Unless soils are very coarse or the climate is arid, many ponds and swamps are found in depressions at varying elevations. Small dendritic patterns drain into these depressions. Fine soils may have greater drainage development with a finer pattern texture, indicating higher runoff coefficients.
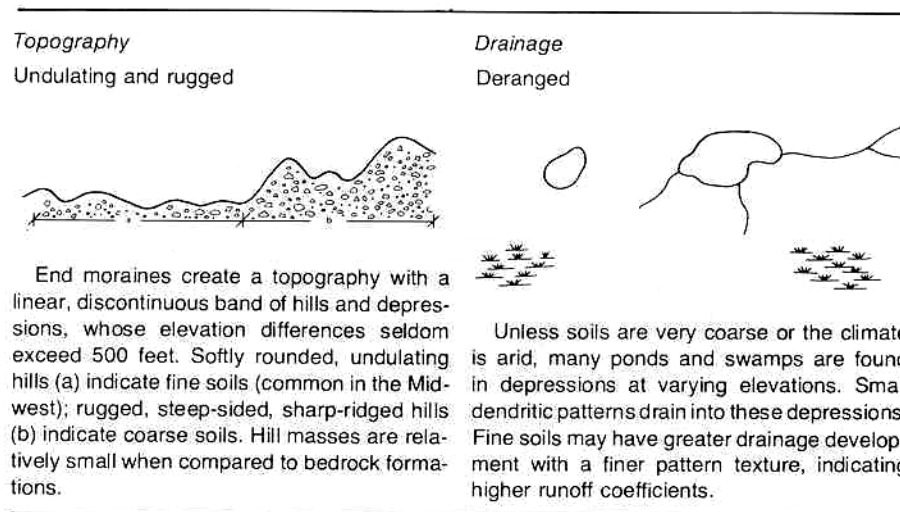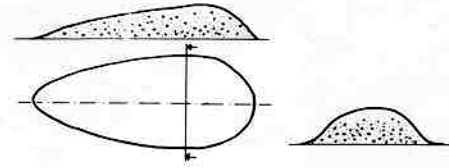
Table 6.11. Drumlins (humid and arid) (Way, 1973)

Topography
Drumlin-shaped

Drumlins are characterized by smooth, oval, cigar-shaped hills whose axes show the direction of glacial flow. Ideally, the side facing the glacier is steeper than the more tapering lee side. Lengths are typically ½ to 1 mile, widths, 500 to 1500 feet, and heights 60 to 200 feet.

Drainage
None

These formations are relatively small and do not develop their own characteristic drainage patterns. Some gullying may be apparent along the base edge and helps in identifying the composition of the soils.

Table 6.12. Glacial till Thick young till; thick old till   (Way, 1973)

Thick, young till

Topography
Flat plains

Thick, young till deposits of Wisconsin age are usually described as till plains but may also be mapped as ground moraine. The topography is very flat and undulating, typically not changing more than a few feet in elevation over an area of several square miles.

Drainage
Deranged
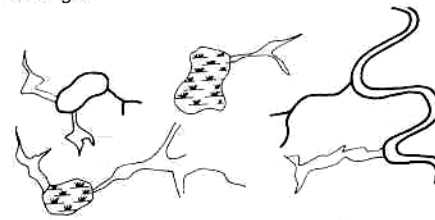
Since this formation is geologically young, runoff systems have not yet been established in well-defined, integrated dainage networks. Many depressions and swamps are found along with a few, meandering regional rivers.

Thick, old till

Topography
Dissected plains

Old, thick deposits of Kansan and Illinoian age till were originally flat plains in form, but age has allowed erosion to dissect the topography. Undissected portions of the topography appear as flat plains.
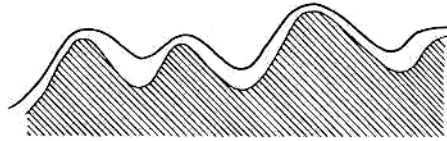
Drainage
Dendritic: Medium

Illinoian and Kansan tills develop integrated dendritic drainage systems of medium texture. Illinoian tills can be identified by the occurrence of white gullies feeding the drainage pattern; these are caused by exposure of the light-colored topsoil.

Thin, young till

Topography
Varies

Drainage
Rock-related

The drainage system is a significant indicator of shallow till deposits over rock structures, and angular alignments or other characteristics of rock-controlled drainage are apparent. Unlike deep, young till formations, these deposits have integrated drainage systems resulting from their slightly greater relief.

Table 6.13. Glacial till Thin young till; thin old till (Way, 1973)

The land surface should show characteristics of form or drainage related to the underlying rock strata. In New England the topographic form generally reflects the massive character of the crystalline rock.

Thin, old till

Topography
Varies

Drainage
Rock-related
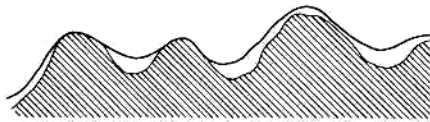
The sedimentary rocks found in southern Illinois, Indiana, and Ohio under Illinoian till do not control the topographic relief significantly. The topography is moderately undulating and dissected.
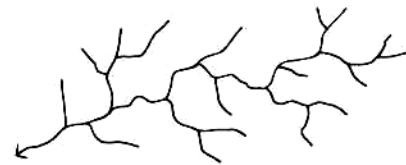
Drainage systems with angular alignments or other rock control patterns indicate till cover of insufficient depth to mask characteristics of the underlying rock structure. White gullies and gray tones indicate Illinoian or Kansan tills, respectively.

Topography
Snakelike Ridge

Drainage
None

Table 6.14. Eskers (humid and arid) (Way, 1973)
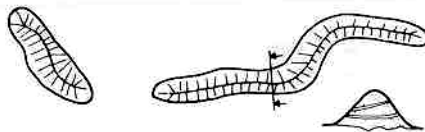
Eskers are primarily identified by the presence of snakelike ridges which do not follow a constant elevation. Typically, these formations are ½ to 1 mile in length, less than 200 feet in width, less than 100 feet above adjacent elevations, and have sideslopes of approximately 30 degrees.

Drainage patterns do not develop on eskers because of their small areal extent. Rainfall runs off the steep slopes and/or percolates into the granular subsoils. Eskers perpendicular to drainage courses develop seepage zones on their opposite sides which continue the drainage system. Eventually, breaks may develop where the esker is eroded.

Table 6.15. Summary chart of fluvial landforms (Way, 1973)

Landform	Topography	Drainage	Tone	Gullies	Vegetation & land use
River-associated forms					
Flood plains					
Meander	Flat	Broad Meanders	Complex	Vary	Cultivated or natural
Covered	Flat	Flood plain features*	Complex	Vary	Cultivated or natural
Terraces	Terraced valley sides	Internal-dendritic	Light	V-or U-shaped	Cultivated or natural
Deltas	Flat, slight slope	Numerous channels	Light to mixed	None	Natural or developed
Alluvial forms					
Alluvium					
Fans	Fan-shaped	Radial-braided	Light gray	None	Scattered scrub & grass
Valley fill	Filled valley bottoms	Parallel-braided	Uniform lt. gray	None	Natural or cultivated
Continental	Flat level plains	Internal(depressions)	Uniform lt. gray	Few, U-shaped	Grain or natural cover
Freshwater deposits					
Lake beds(playas)	Flat plain, basin	None-evaporation	Light-scrabbled	None	Barren to cultivated**
Organic deposits	Flat, depressions	None-dendritic	Dark to light	None(ditched)	Vegetated to cultivated
Marine forms					
Coastal plains					
Young	Flat, undulating	Parallel-dendritic, coarse	Mottled	Soft,U-shaped	Cultivated and forested
Old	Dissected, cuestas	Dendritic, medium to fine	Uniform light	U-shaped(V)	Forested, some agric.
Beach ridges					
Sand	Soft, parallel ridges	Internal	Light	None,V-shaped	Natural cover to cultiv.***
Gravel	Sharp, parallel ridges	Internal	Light	None,V=shaped	Natural cover to cultiv.***
Tidal flats					
Marsh	Flat	Tidal, dendritic	Vary	None	Marsh grass
Mud	Flat	Tidal, dendritic	Vary	None	Little vegetation
Sand	Flat	Tidal, parallel channels	Light to dark	None	None

* Flood plain features include old meander channels, oxbow lakes, meander scrolls, natural levees, slack-water areas, bars, and so on.

** Cultivated if under irrigation.

***Ancient glacial beach ridges are commonly cultivated in humid, subhumid climates.

Table 6.16. Delta (Way, 1973)

Topography
Delta outline

Drainage
Numerous channels

Deltas have planimetric shapes characteristic of their type: (a) arc, (b) estuarine, or (c) bird's-foot. Their surfaces, or topset beds, are generally flat, with a slight slope toward the water.

Arc deltas (a) generally have many radial drainage channels which may show some braiding. Estuarine deltas (b) contain many interconnecting channels which carry the drainage around the many islands. Bird's-foot forms (c) typically contain two or three major channels in a branching alignment.
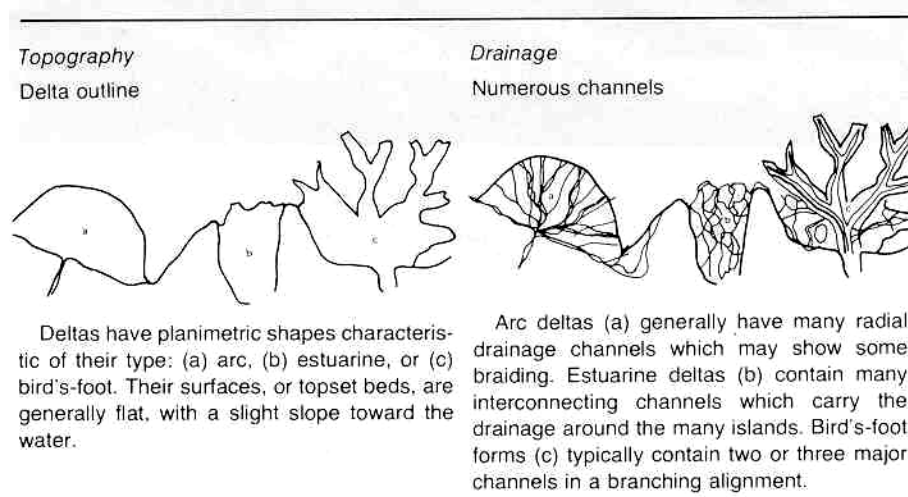
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Table 6.17. Tidal flats (marsh, mud, sand) (Way, 1973)
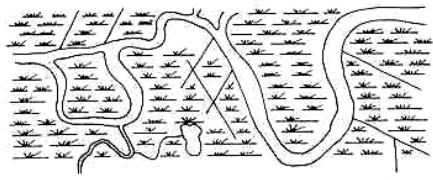
Marsh

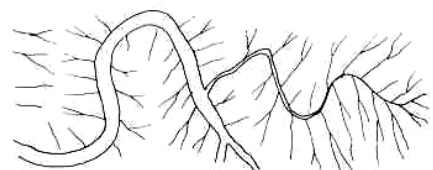| Topography	Drainage
Flat	Tidal, dendritic

The topography is flat and is bounded by land and water.

Wide, broad channels, forming a dendritic pattern, typify tidal marshes. Smaller channels occasionally close upon themselves, forming many irregular islands. Ditching is common for mosquito control.

Mud

Topography	Drainage
Flat	Tidal, dendritic

The topography is flat and is bounded by land and water.

Wide, broad channels form a dendritic pattern which also has many hairlike channels.

Sand

Topography	Drainage
Flat	Few, parallel channels

Since the sand is internally well-drained, few drainage channels are developed. Some short, parallel channels without tributaries are found.

The topography is flat and is bounded by land and water.

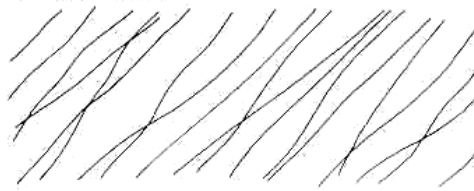# Table 6.18. Alluvium (fans, valley fills, continental) (Way, 1973)
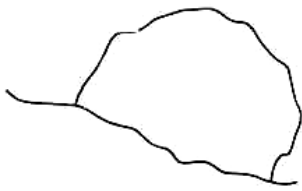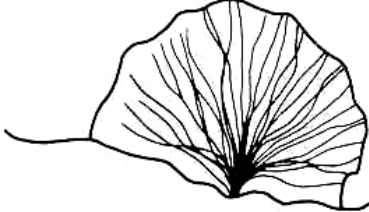
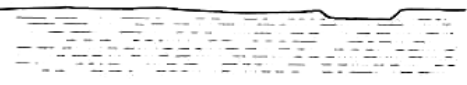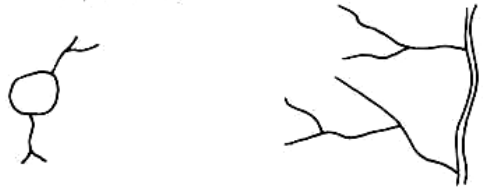| *Topography*	*Drainage*
Fan-shaped	Radial, braided

Alluvial fans have a fan-shaped outline with distinct boundaries. They slope 1 to 10 degrees toward the apex, the fan being convex in cross section.

Generally, drainage is active only during severe storms, but the dry channels are readily observed and form, from the apex, a radial pattern of braided streams.

Topography	*Drainage*
Filled valley bottoms	Parallel, braided

The topography may appear flat, but there is actually a gradual slope away from the highlands. The flat plain may be interrupted occasionally by resistant rock islands.

Valley fills are characterized by many dry, parallel, braided drainage channels. These are active during severe storms, when they shift channels and deposit vast amounts of alluvial sediments.

Continental

Topography	*Drainage*
Broad, flat plains	Internal, dendritic

The characteristic broad, flat plains covering vast regions are occasionally broken by small, circular, flat-bottomed depressions caused by wind erosion which has enlarged ancient buffalo or cattle dust wallows.

Drainage is mostly internal. Drainage features are neither apparent nor well-developed, owing to the low rainfall. Regional systems may dissect these forms, in which case the alluvial material easily erodes.

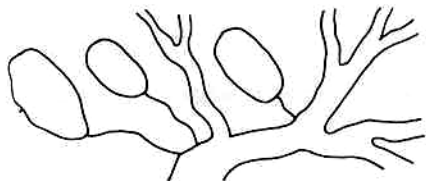**Table 6.19. Flood plains (Meander, covered composite) (Way, 1973)**

Topography
Flat

Drainage
Meanders or channels
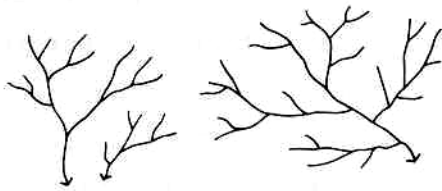
Flood plains are characterized by their predominantly flat topography, although there may be some surface irregularities caused by abandoned channels. Natural levees occupy slightly elevated positions; slack-water deposits are found in lower areas. Terraces may be found along valley walls.

Most flood plains contain a major drainage channel which either meanders through the valley bottom or is braided. Many undrained swamps and ponds may exist, indicating a deranged pattern. In some arid and semiarid regions, drainage patterns may not even be apparent, but this does not necessarily indicate porous materials.

Young

Topography
Flat, undulating

Drainage
Parallel, dendritic: Coarse

Table 6.20. Coastal plains (Young and old) (Way, 1973)

The topography is rather flat and softly undulating. Many swamps and organic deposits occupy depressions. The upland boundaries of these formations may be difficult to discern, but the lower edges are clearly defined by tidal flats or water.

A coarse, parallel, regional pattern develops on coastal plains; however, a local, coarse, dendritic pattern with wide channels indicates abandoned tidal marshes. Many swamps or Carolina bays occupy depressions. Ancient shoreline landforms (beach ridges) may modify the regional drainage to a trellis form.

Old

Topography
Dissected, cuestas

Drainage
Dendritic: Fine

Old coastal plains are highly dissected but do not have the steep slopes associated with more consolidated sediments. The stratified materials are unconsolidated and readily erode, forming gentle, moderate slopes. Regionally, cuestas may be observed where more resistant beds are exposed.

The unconsolidated soils readily erode and develop a fine-textured dendritic drainage pattern with major channels following the broad valleys of abandoned tidal flats. Cuestas may develop some localized trellis patterns.

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6.2.2. Igneous rocks

Table 6.21. Summary chart of igneous rocks (Way, 1973)

Landform	Topography	Drainage*	Tone	Gullies	Vegetation & Land Use
Intrusive granite (large masses)					
Humid	Bold, domelike hills	Dendritic curved ends, M	Uniform, gray	U-Shaped	Forested & Cultivated
Arid	A-Shaped hills	Dendritic curved ends, F	Light, fractures	Few to none	Barren, grass cover
Intrusive granite (linear dikes)					
Humid & arid	Narrow, linear ridges**	None	Light or dark	None	Natural cover
Extrusive volcanic	Cinder cones	Radial, C-F	Dark gray	Vary	Barren, natural cover
Extrusive basalt flows	Level plain	Regional parallel, C-F	Dark, flow marks	Soft, U-shaped	Cultivated/Barren
Extrusive inter-bedded	Terraced hillsides	Parallel dendritic	Banded	Vary	Cultivated or natural
Extrusive tuff	Sharp ridged hills	Dendritic, F	Dull, lt. gray	Vary	Natural cover

* C, coarse; M, medium; F, fine.

** Ring dikes, a variation of this landform, are found with a circular narrow, sharp ridge.

6.2.2.1. Intrusive igneous rocks

These can be recognized by drainage, texture, massive character of the rock, and cross-cutting relations with country rocks. Igneous rocks particularly those forming stocks and batholiths reveal a criss-cross pattern of joints. This pattern is seen in good exposure areas and it is due to the rock type and mode of origin and is independent of climate and erosional cycle. Vegetation will be more or less uniform. The rocks have rather uniform appearance in aerial photographs. Unless fracture controlled, dendritic drainage pattern will develop in large areas covered by uniform igneous masses. If the intrusion is dome shaped radial-annular drainage patterns occur.

Topographic and erosional characteristics of some igneous rocks may be used in interpretation. At low altitudes in some tropical areas granite shows hummocky, rounded topography with uniform vegetation and dendritic drainage. Angular topography might be expected in high altitudes.

Acidic intrusions can be differentiated by large scale rectangular jointing from the basic intrusions or relative tone may be used. But igneous mass should be mapped as an intrusion if there is not sufficient evidence.

Intrusive dykes stand out as ridges or when they are less resistant than the country rock, they appear as linear depressions; these may also display distinct tonal contrast. Sills are more difficult to interpret since they are parallel to bedding.

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Table 6.22. Granitic forms: Linear, Dykes (Humid and Arid) (Way, 1973)

Topography
Straight, narrow ridges
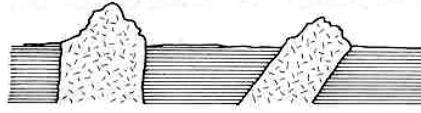
Drainage
None

Igneous material injected into fault zones is generally more resistant than the surrounding rock and therefore forms sharp or rounded ridges. In rare instances the material composing the dike is less resistant and in this case linear depressions result. Occasionally, circular ring dikes are found; these are formed by the intrusion of igneous material along the faces of a circular fault. Commonly, the interior area has dropped down during the faulting process.
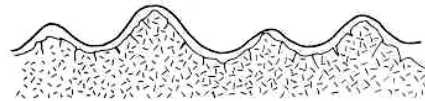
The forms are generally too small to develop any discernible drainage patterns. The steep slopes facilitate runoff to surrounding landforms.

Humid

Topography
Bold, domelike hills

Drainage
Dendritic: Medium

Table 6.23. Granitic rocks: Large, massive(Humid and Arid) (Way, 1973)

The topographic relief of granitic intrusions typically shows as massive, rounded, domelike hills. The tops of the hills are softly rounded; the sideslopes are steeper. The weathering processes of pressure-release and exfoliation tend to maintain the domelike appearance. Debris and large boulders weathered into rounded shapes accumulate in drainage courses and depressions.
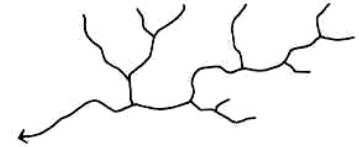
A dendritic drainage pattern of medium texture is common in humid climates and indicates the uniform materials of which the forms are made. The domelike hills cause curvilinear alignments to develop, and these are important evidence in the identification of granite. Intersections of tributaries occur at right angles or may be slightly acute upstream.
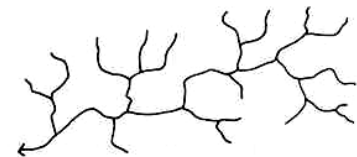
Arid

Topography
A-shaped hills

Drainage
Dendritic: Fine

Bold, massive, domelike hills also occur in arid granitic regions. Many rounded boulders and rock outcrops can be observed as microfeatures, but these are not concentrated in depressions and drainage courses as in humid climates but rather tend to form large mounds as the surrounding residual soil is removed by wind erosion. Highly dissected areas appear, having A-shaped hills with steep sideslopes.

Drainage patterns in arid granitic regions are commonly dendritic and fine-textured. Granitic rock materials are massive and impervious to water, so a large amount of runoff can be expected. Curvilinear alignments are formed by the domelike hills and resemble sickle shapes in the drainage system. Intersections of tributaries occur at right angles or may be slightly acute upstream.

6.2.2.2. Extrusive igneous rocks (Lavas and pyroclastics)

These might be acidic, intermediate or basic in composition. They have diagnostic landforms. Relatively young lava flows show lobate patterns of topography and vegetation and association with volcanic cones. The surface of a flow may be hummocky and irregular in comparison to the surfaces of sedimentary rocks. Basic lavas may show dark tones, whereas acidic (rhyolitic, or silicic) lavas show light photographic tones. Intermediate lavas (andesitic) have medium gray tones. Tuffs and tuffaceous clays have a dendritic surface drainage. Flow structures may be present. Vegetation is rather poor due to internal drainage.

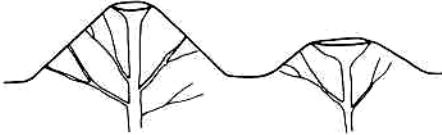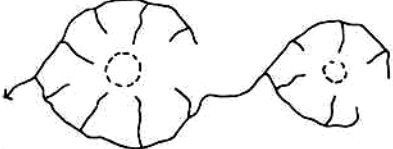**Table 6.24. Volcanic forms: Young; basaltic flows (Humid and Arid) (Way, 1973)**

Volcanic forms

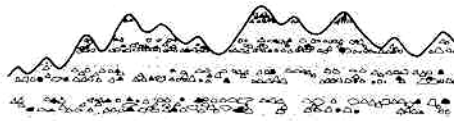| Topography	Drainage
Cinder cones	Radial

Rounded cinder cones are clear indicators of recent volcanic activity. Both mature and old dissected cones have some or all of the internal structure exposed, including the volcanic neck and radiating dikes.

As the formation is dissected over time, a radial drainage pattern is developed around the circular volcanic cone. The texture of the pattern is dependent upon the climatic zone; the finest textures are found in arid climates. Many tributaries along the slopes appear parallel.

Basaltic flows

Topography	Drainage
Level plain	Regional parallel: Coarse

Young basaltic flows form level or gently sloping, broad plains as a result of the fluid nature of the material. Mature and old dissected areas have many mesas or plateaus, with some pear-shaped appendages. Microfeatures of flow lines or gas pocket depressions may be observed on very young deposits. Vertical escarpments with columnar jointing develop along major drainage courses.

Basaltic rock itself is impervious to internal drainage, but the many joints and fractures create high permeability. Because of its gentle, uniform slope, the lava flow develops a coarse, regional, parallel drainage pattern.

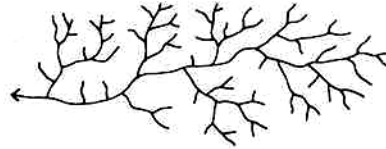**Table 6.25. Fragmented tuff and bedded flows (Way, 1973)**

Fragmental tuff

Topography	Drainage
Sharp-ridged hills	Dendritic: Fine

Tuff formations in all climates erode quickly and form sharp, knife-edged ridges within a highly dissected topography having characteristics similar to clay shale. Unlike the shales, however, hilltops do not occur at equal elevations. Sideslopes are very steep and of uniform slope, indicating homogeneity of materials.

An extremely fine dendritic drainage pattern develops in tuff formations, indicating a uniform composition. Welded tuffs are more resistant and do not show this extremely fine pattern.

Interbedded flows

Topography	Drainage
Terraced hillsides	Parallel dendritic

A dissected topography exposes stratified layers and interbeddings along the sides of hills. Parallel ridges with convex sideslopes are common. In those areas not highly dissected, flow lines, similar to those associated with basalt, may be apparent.

Interbedded deposits commonly develop dendritic patterns with parallel tributaries. The drainage systems in rhyolitic and andesitic materials tend to be parallel, with sicklelike, first-order tributaries.

6.2.3. Metamorphic rocks

It is difficult to identify metamorphic rocks from aerial photographs because large-scale distinguishing characteristics are generally absent. It may be difficult or impossible to recognize the bedding because of physical changes in the rock units due to high pressure and/or high temperatures of the metamorphism. Structural trends obtained from aerial photographs are foliations rather than bedding. Parallel alignments of ridges and intervening low areas may reflect regional cleavage, foliation or fold axis and may suggest metamorphic rocks. In these sort of areas the occurrence of widely spaced lineations at right angles to the regional trend support the presence of metamorphic rocks. The lineations represent regional cross-joints and may be reflected in abrupt deflections of drainage along conspicuous straight stream segments of major streams or in the development of tributary streams along these joints.

**Table 6.26. Summary chart of metamorphic rocks (Way, 1973)**

Landform	Topography	Drainage*	Tone	Gullies	Vegetation and Land use
Slate Humid and arid	Many sharp ridges	Rectangular, F	Gray	Short, parallel	Natural cover

Schist
  Humid
  Arid
	Rounded, steep hills
	Parallel laminations
		Rectangular, M to F
		Rectangular, M to F
			Uniform lt. gray
			Banded
				Parallel, U-shaped
				Few, parallel,
				  U-shaped
					Cult. & forested
					Barren and grass

Gneiss
  Humid and arid
	Steep, parallel ridge	Angular, dendritic,
		  M to F
			Light uniform	U-shaped, few	Natural cover

Schists are metamorphic rocks with highly foliated structures (Table 25). Not much resistant to weathering and erosion. They develop landforms similar to the original rocks they are derived from. Because they have been repeatedly folded and fractured they are usually in steep attitudes and folded into undulating lamellations. Drainage in uniform schists is dendritic, close-spaced in phyllites and widely spaced in quartzite schist. Fault control is prominent. In humid climates schists tend to form rounded crests as a result of intense weathering.

Table 6.27. Schist (Humid and Arid) (Way, 1973)
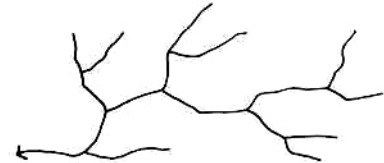
Humid

Topography
Rounded crests, steep sideslopes
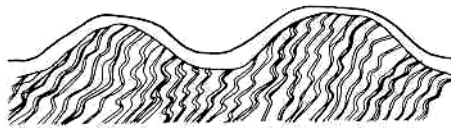
In humid climates schist formations develop deep residual soils reflected by rounded hills with steep sideslopes. The overall appearance of the topography is that of smooth, undulating hills.

Drainage
Rectangular dendritic: Medium to fine

A rectangular, dendritic drainage system of medium to fine texture, having many long, deep, parallel gullies, develops in humid climates. The drainage pattern is developed and controlled by the parallel foliation structure of the parent material, whose weaker materials are more easily eroded to form valleys and whose more resistant materials form ridges.

Arid

Topography
Parallel laminations

In arid climates schist formations develop topography that appears fairly rugged, the form of the ridges and valleys being controlled by the obvious foliation of the material. When residual soils are thin, the characteristic banding may be seen.

Drainage
Rectangular dendritic: Fine

A rectangular, fine-textured drainage system develops in arid climates. Many gullies exist, and tributaries are angular, reflecting the structural control of the rock.

Slates have rugged topography and have very characteristic drainage, angular and most often rectangular. The hills are rounded, the slopes are very steep. Tone is usually dark.

Gneiss is a massive foliated rock of granitic character with high erosion resistance. **Orthogneiss** is derived from granite and morphologically similar to it in appearance and landform, showing rounded forms. **Paragneisses** derived from sediments show sharp crested parallel ridges when they are derived from massive sandstone; smooth and irregular in case of metamorphosed shales, tuffs, lavas or marls. The tone varies widely depending on the composition.

Marbles, crystalline limestones have granular structure and have fine to coarse textures. Marble shows a massive appearance with smooth rounded forms. Development of sinkholes depend on the attitude, character, purity and mineral composition of the rock.

Serpentinites (metamorphic basic igneous rocks) occur in roundish or lenticular masses; compact resistant and impervious. Resistance to erosion varies, but not too high. The tone is dark. Poor soil cover, vegetation sparse, drainage is radial, fracture controlled.

Table 6.28. Slate (Humid and Arid) (Way, 1973)

Topography
Many sharp ridges

Drainage
Rectangular: Fine
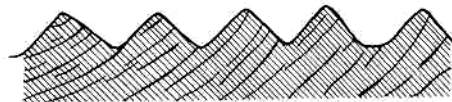
Slate weathers quickly by mechanical means, developing a very rugged topography with sharp ridges and steep hillsides. The small ridges and valleys tend to be parallel to one another. Elevations of the hilltops and valley bottoms tend to repeat over the region.

The drainage pattern developed in slate regions is a rectangular dendritic system, very fine in texture. The thin foliations or cleavages of the slate provide initial planes of weakness which control the drainage system. The drainage pattern found in slates is finer than the similar pattern found in schist.

Table 6.29. Gneiss (Humid and Arid) (Way, 1973)

Topography
Sharp, steep-sided, parallel ridges

Drainage
Angular dendritic: Fine to medium
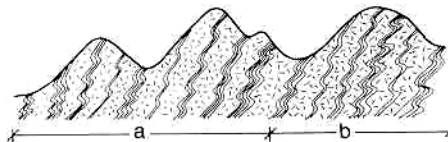
Gneiss formations develop parallel, sharp-ridged hills with steep sideslopes; this topography is the result of differential weathering of the foliations within the rock structure (a). Glaciated regions (b) develop the same topography, except that ridgetops may be rounded as a result of glacial scouring.
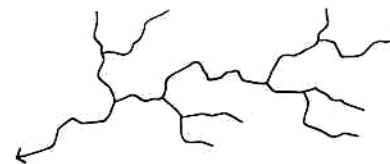
The weathering of the rock foliation initiates and controls the placement of the drainage system which is angular and dendritic. In regions where parallel ridges and valleys are developed, the system appears rectangular. The texture is generally fine or medium.

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