3

DESCRIPTION OF FOLDS

Introduction

Folds (Frontispiece) are best displayed by stratified formations such as sedimentary or volcanic rocks or their metamorphosed equivalents. But any layered or foliated rock, such as gabbro or granite gneiss, may show folds. Some folds are a few miles across. The width of others is to be measured in feet or inches or even fractions of an inch. Folds of continental proportions are hundreds of miles wide.

Folds may be observed directly or may be inferred from various kinds of data. The size of the exposure determines the size of the folds that may be observed. Folds many thousands of feet across may be observed in regions of high relief. Conversely, where the exposures are small, only folds a few feet or tens of feet across may be observed.

Attitude of Beds

Attitude refers to the three-dimensional orientation of some geological feature, such as a bed, a joint, a hornblende needle, or a fold. The attitude of planar features, such as beds or joints, is defined by their strike and dip. The *strike* (Plate 1) of a bed is its trend measured on a horizontal surface. More precisely, strike may be defined as the direction of a line formed by the intersection of the bedding and a horizontal plane. In Fig. 3-1A the

te 1. *Measuring strike.* Measurement is made at base of a lstone in the Chinle Formation. Usually the geologist stands distance to eliminate effect of small irregularities in the bed. . Colfax County, New Mexico. Photo: J. R. Stacy, U. S. logical Survey.

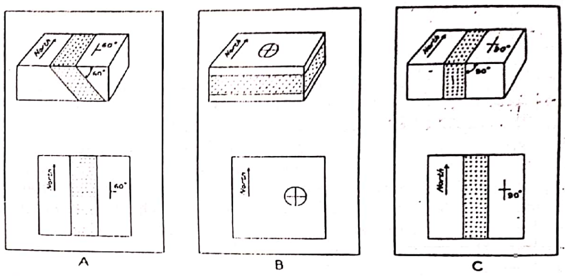


Fig. 3-1. Dip-strike symbols used for inclined, horizontal, and vertical strata. Block diagram above, map below. (A) Inclined strata. (B) Horizontal strata. (C) Vertical strata. The position of the 90° may be used to indicate the top side of the bed (see page 81).

strike is north; the upper part of the figure is a block diagram, the lower part a map or plan.

The *dip* (Plate 2) of a stratum is the angle between the bedding and a horizontal plane; it is measured in a vertical plane that strikes at right angles to the strike of the bedding. In Fig. 3-1A the dip is 60 degrees to the east.

A special *dip-strike symbol* is employed on geological maps to show the attitude of beds (Plates 3, 4, and 5). It is shaped somewhat like the capital letter *T*, but the relative lengths of the two parts are reversed (Fig. 3-1A). The longer line is parallel to the strike of the bedding, whereas the shorter line points in the direction of the dip, and a figure gives the value of the dip. For horizontal strata (Plate 6), a special symbol ⊕ may be used (Fig. 3-1B). For vertical strata a long line gives the strike, and a short crossbar extends on either side of the long line (Fig. 3-1C). Although most geological maps use symbols similar to these to give dip and strike of the bedding, the system is not standardized, and it is necessary to look at the legend accompanying the map in order to ascertain the meaning of the symbols employed.

Parts of a Fold

The *hinge* of a fold is the line of maximum curvature in a folded bed. It is characterized by orientation and position. There is a hinge for each bed. In the fold shown in Fig. 3-2A, the line *aa'* is the hinge on the top of the bed.

The hinges may be horizontal (Fig. 3-2A, D, E), inclined (Fig. 3-2B, F) or vertical (Fig. 3-2C).

The axial plane is the surface connecting all the hinges. It may be a simple

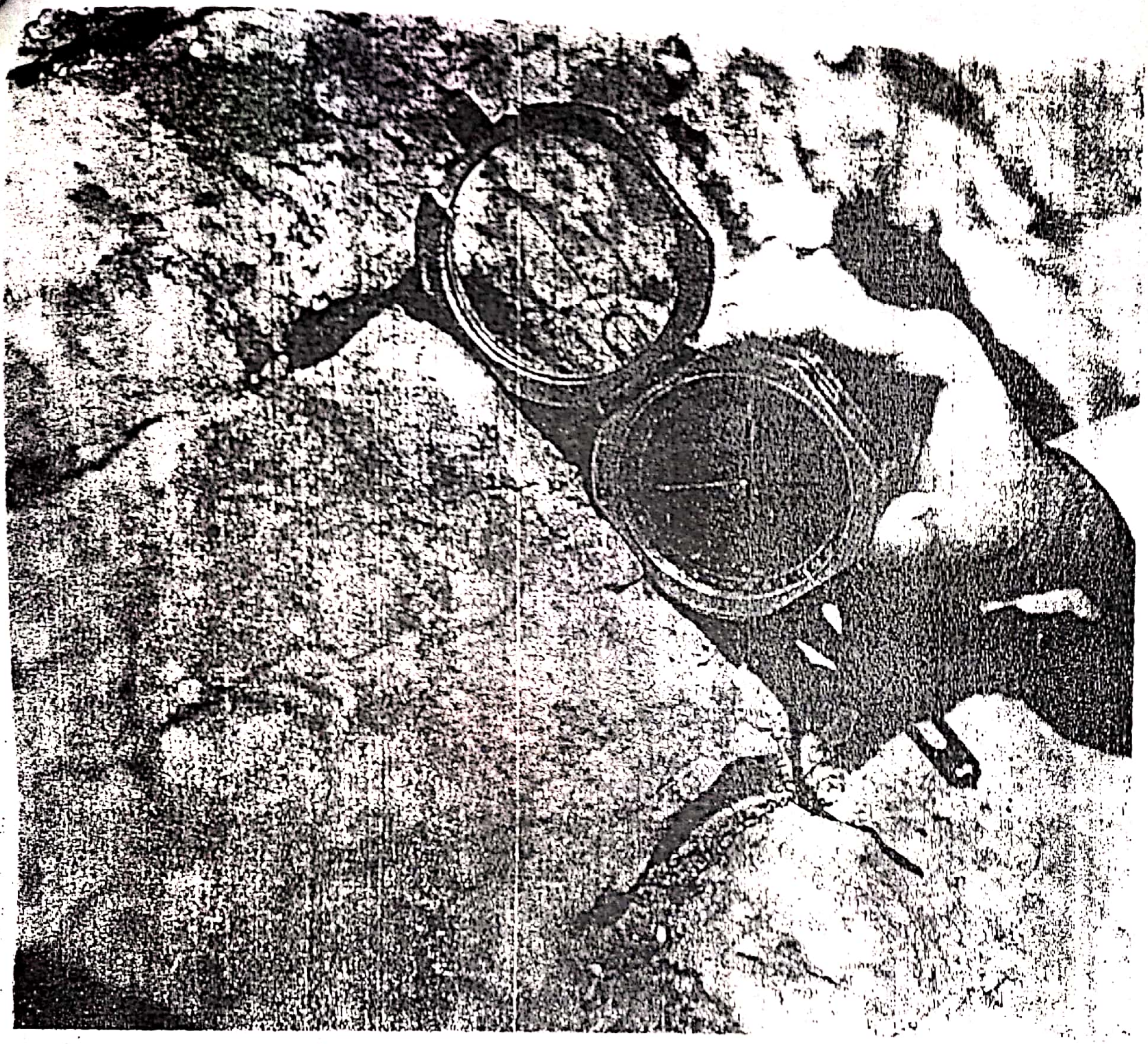


Plate 2. *Measuring dip.* Dakota Sandstone. Usually the geologist stands at a distance to eliminate effect of small irregularities in the bedding. Colfax County, New Mexico. Photo: J. R. Stacy, U. S. Geological Survey.

plane or a curved surface. In cross sections, the axial plane is represented by a line.

In some folds the axial plane is vertical (Fig. 3-2A, B, and C), in others it is inclined (Fig. 3-2D and F), and in still others it is horizontal (Fig. 3-2E). Although in many folds the axial surface is a relatively smooth plane, it may be curved. The attitude of the axial plane is defined by its strike and dip, just as the attitude of a bed is defined. In Fig. 3-2, north is toward the upper left-hand corner. In Fig. 3-2A, B, and C, the axial plane strikes north and has a vertical dip. In Fig. 3-2D, the strike is north, the dip 45° to the west. In Fig. 3-2F, the axial plane strikes north and dips 60 degrees to the west; in

Plate 4. *Dipping strata.* Alameda Parkway. Shows how to measure dip. Jefferson County, Colorado. Photo: J. R. Stacy, U. S. Geological Survey.

Fig. 3-2E, the axial plane is horizontal. If the axial plane is curved, the dip or strike—or both—may differ from place to place, as in the case of a curved bedding plane.

The *axis* is a line parallel to the hinges. It is that straight line moving parallel to itself that generates the fold. The term *fold axis* as thus used is an abstraction. The term axis has also been used as synonomous with hinge as defined above.

The sides of a fold are called the *limbs* or *flanks*. Terms used in the past, but now obsolete, were *legs, shanks, branches*, and *slopes*. A limb extends from the axial plane in one fold to the axial plane in the next. For example.

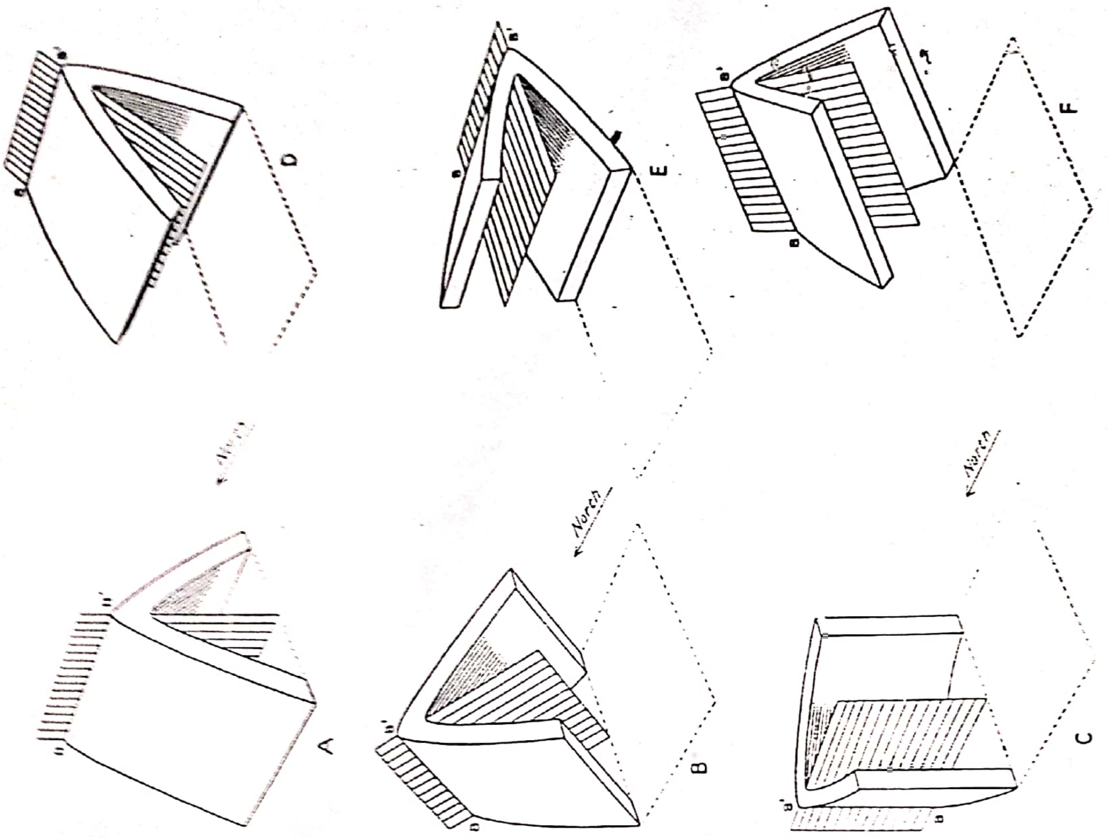


Fig. 3-2. A few of the different attitudes assumed by axial planes and hinges of folds. The axial plane is shaded in each diagram; aa' is hinge of fold.

In Fig. 3-3A, $a'b$ is the limb of a fold. It may be considered either the east

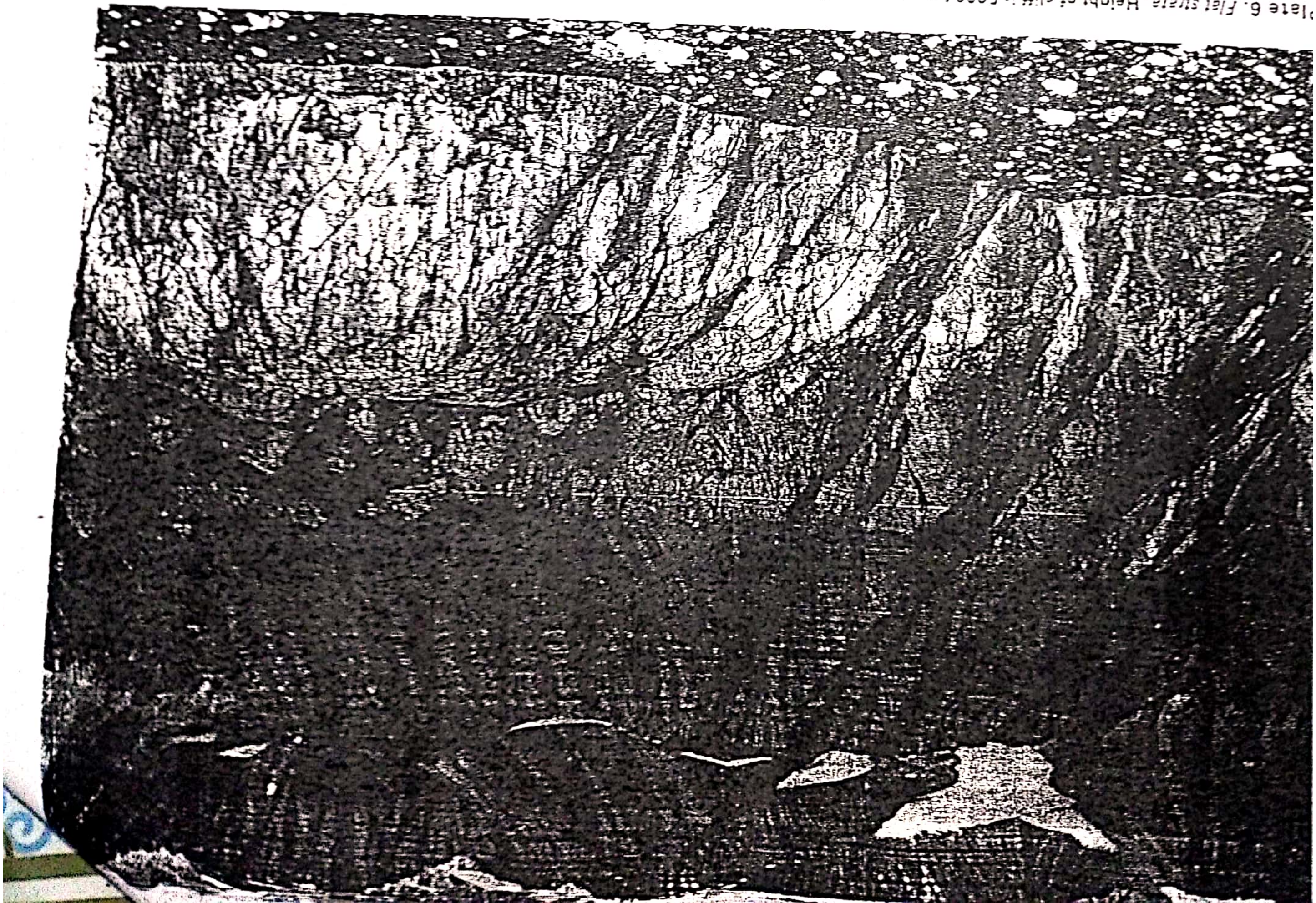


Plate 6. *Flat strata*. Height of cliff is 5000 feet. Early Tertiary basalts (black) and interbedded sedimentary rocks (light) resting unconformably on gneiss. Gaaserfjord, East Greenland. Photo: Lauge Koch Expedition.

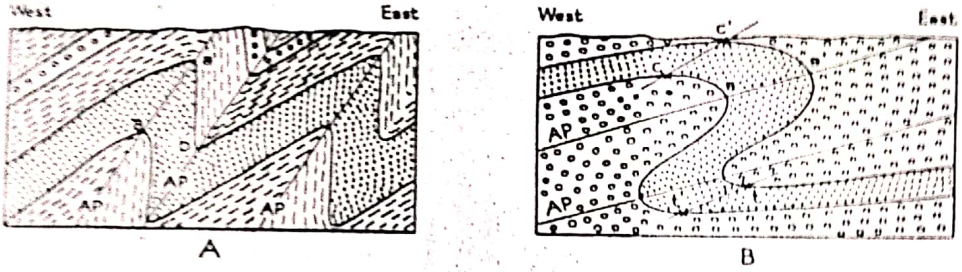


Fig. 3-3. Parts of a fold. *AP*, axial plane; *a'b*, limb of a fold; *c*, crest on one bed; *c'*, crest on another bed; *cc'*, crestal plane; *t*, trough on one bed; *t'*, trough on another bed; *tt'*, trough plane.

Although in many instances the hinge is at the highest part of the fold, as in Fig. 3-3A, this is not necessarily the case. In Fig. 3-3B, for example, *a* and *a'* are hinges, or, to be more precise, the intersection of hinges with the plane of the paper; *c* and *c'* are the highest points on the folds. The crest is a line along the highest part of the fold, or, more precisely, the line connecting the highest points on the same bed in an infinite number of cross sections. There is a separate crest for each bed. The plane or surface formed by all the crests is called the *crestal plane* (*cc'* of Fig. 3-3B).

In many phases of geology, the distinction between the crest and hinge is not important, either because the two correspond or, if there is a difference, because the distinction is of academic interest only. The same is true of the distinction between crestal plane and axial plane. In the accumulation of gas and petroleum, however, the difference is significant. The trapping of such materials is controlled by the crest and crestal plane rather than by the hinge and axial plane. In American oil fields, however, the crestal plane and axial plane are usually identical.

The *trough* is the line occupying the lowest part of the fold, or, more precisely, the line connecting the lowest parts on the same bed in an infinite number of cross sections. In Fig. 3-3B, *t* and *t'* are troughs. The plane connecting such lines may be called the *trough plane*.

Nomenclature of Folds

In general an *anticline* (Plates 7A and B and Plates 8A and B) may be defined as a fold that is convex upward; it may also be defined as a fold that has older rocks in the center. The word is from the Greek, meaning "opposite inclined," referring to the fact that in the simplest anticlines the two limbs dip away from each other (Fig. 3-4A). But the term has also been extended to folds such as that in Fig. 3-4B where the two limbs dip in the same direction at different angles. Normally this means that older rocks are in the center of the fold. Consequently the term has been extended to any fold where older rocks are in the center (Fig. 3-4C). The definition of antiform is deferred to page 66.

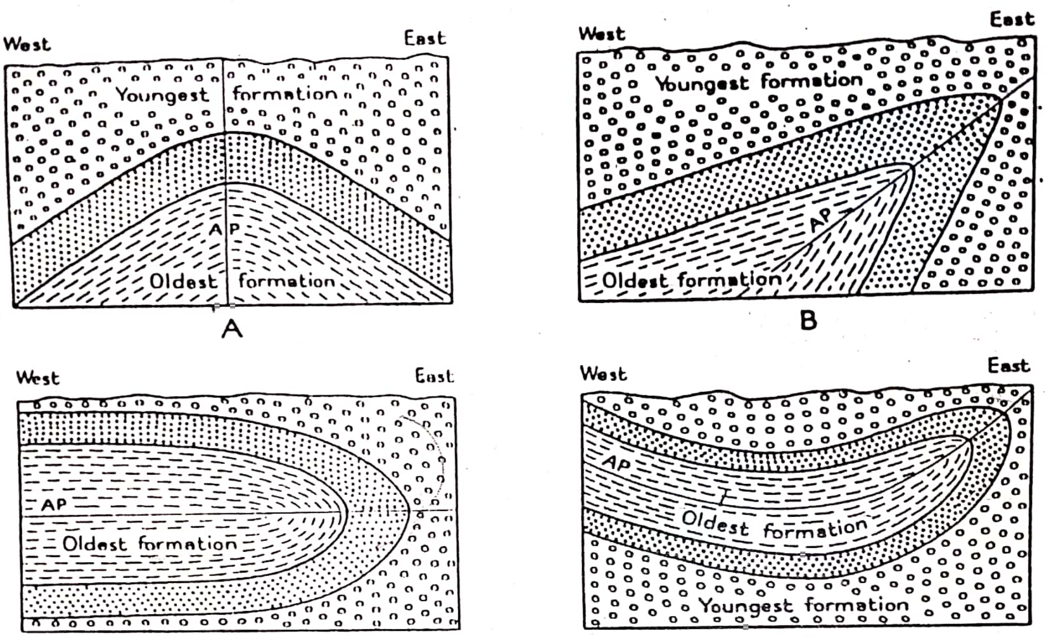


Fig. 3-4. Some varieties of anticlines. *AP*, axial planes.

In general a *syncline* (Plates 8A and B) may be defined as a fold that is convex downward. The word is from the Greek meaning "together inclined," referring to the fact that in the simplest synclines the two limbs dip toward each other (Fig. 3-5A). But the term has been extended to such folds as that in Fig.

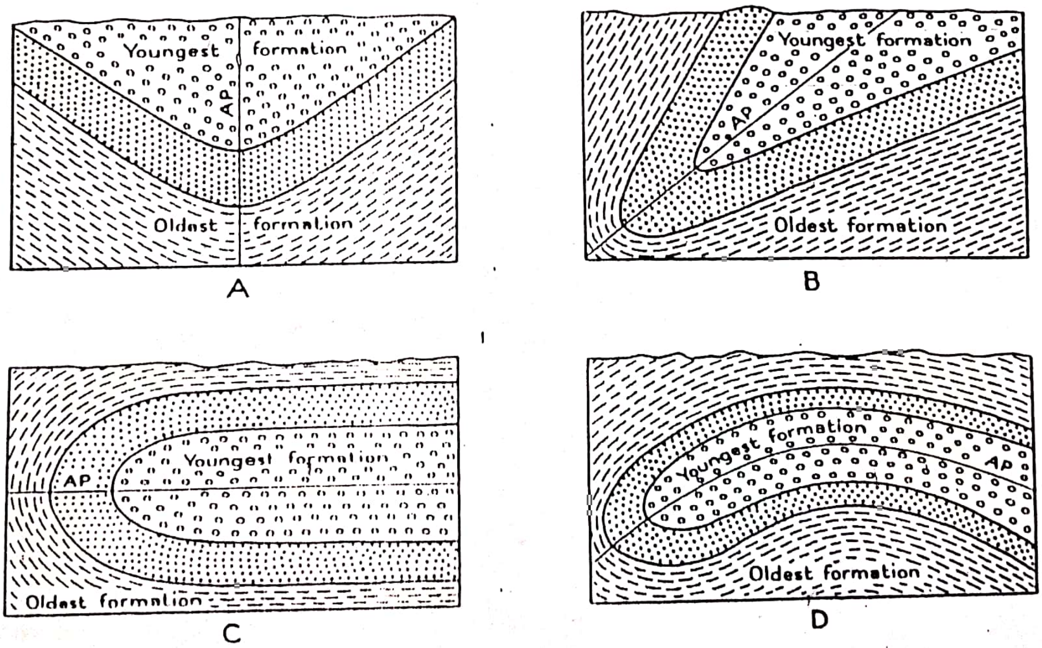


Fig. 3-5. Some varieties of synclines. *AP*, axial planes.

Plate 8B. Overturned syncline. Lower Cambrian limestone, York, York County, Pennsylvania.
Photo: C. D. Walcott, U. S. Geological Survey.

3-5B where the two limbs dip in the same direction at different angles. Normally this means that younger rocks are in the center of the fold. Consequently the term has been extended to any fold where younger rocks are in the center (Fig. 3-5C). The definition of synform is deferred to page 66.

A *symmetrical* fold is one in which the axial surface is essentially vertical (Fig. 3-6A); *upright* is also used. Conversely, an *asymmetrical* fold is defined as one in which the axial surface is inclined (Fig. 3-6B).

In the *overturned fold* or *overfold* (Plate 9) the axial plane is inclined, and both limbs dip in the same direction, usually at different angles (Fig. 3-6C). The *overturned, inverted,* or *reversed limb* is the one that has been rotated through more than 90° to attain its present attitude. A special dip-strike symbol is commonly used on modern maps to indicate overturned strata (Fig. 3-7). The *normal limb* is the one that is right-side-up.

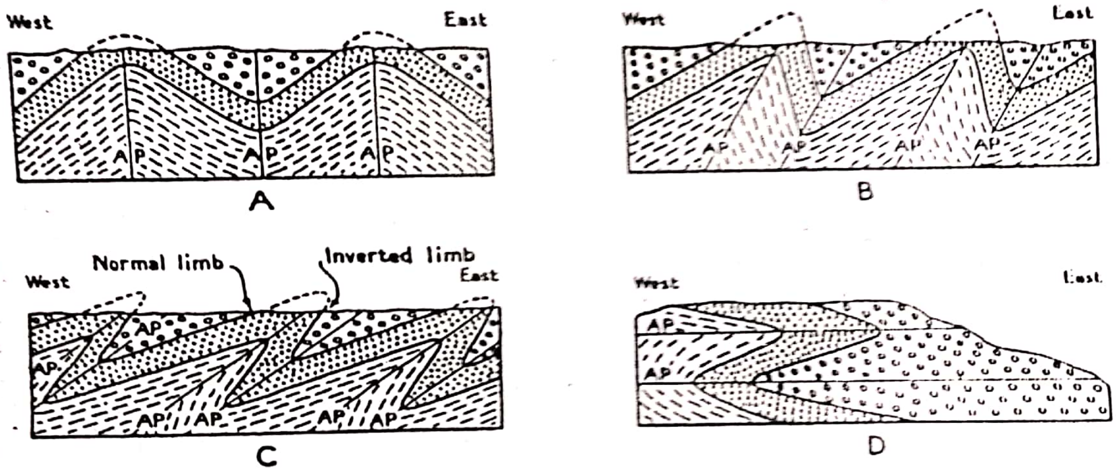
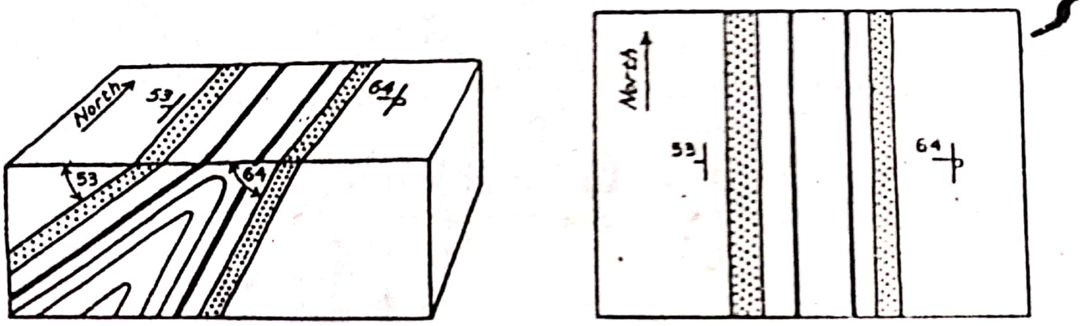
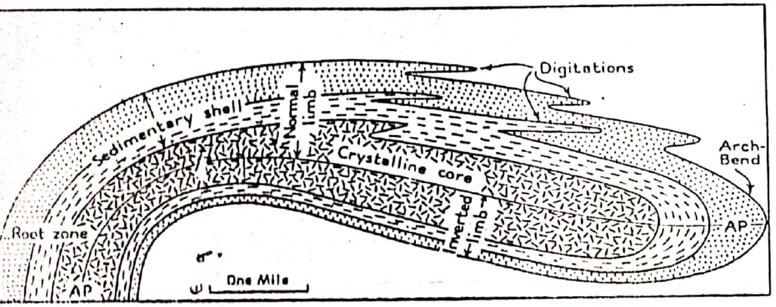


Fig. 3-6. Some varieties of folds. *AP*, axial plane. (A) Symmetrical (upright) folds. (B) Asymmetrical folds. (C) Overturned folds (overfolds). (D) Recumbent folds.



A *recumbent fold* is one in which the axial plane is essentially horizontal (Fig. 3-6D). Large-scale folds of this type are especially well exposed in the Alps.[1] Consequently, a rather elaborate terminology has been evolved by European geologists to describe such folds (Fig. 3-8). The strata in the inverted limb are usually much thinner than the corresponding beds in the normal limb. The term *arch-bend* has been used for the curved part of the fold between the normal and inverted limbs. It is synonymous with hinge. Many of the recumbent folds in the Alps have Paleozoic crystalline rocks in the center and Mesozoic sedimentary rocks in the outer covering. Thus there is a distinct core of crystalline rocks within a shell of sedimentary rocks. Even in a recumbent fold composed entirely of one kind of rock, the terms *core* and *shell* may be used to refer, respectively, to the inner and outer parts of the fold. Many recumbent folds have subsidiary recumbent anticlines attached to them; these subsidiary folds may be called *digitations* because they look like great fingers extending from a hand. All recumbent folds, if satisfactory exposures are available, may be traced back to the *root* or *root zone*—that is, to the place on the surface of the earth from which they arise; in other words, recumbent folds may be traced to the place where the axial plane becomes much steeper.



g. 3-8. Recumbent anticline with names of various parts.

An *isoclinal fold*, from the Greek meaning "equally inclined," refers to folds in which the two limbs dip at equal angles in the same direction (Fig. 3-9). A vertical isoclinal fold (Fig. 3-9A) is one in which the axial plane is vertical; an inclined or overturned isoclinal fold is one in which the axial plane is inclined (Fig. 3-9B). A recumbent isoclinal fold is one in which the axial plane is horizontal (Fig. 3-9C). Many recumbent folds are isoclinal.

A *chevron fold* is one in which the hinges are sharp and angular (Fig. 3-10A).

A *box fold* is one in which the crest is broad and flat; two hinges are present, one on either side of the flat crest (Fig. 3-10B).

A *fan fold* is one in which both limbs are overturned (Fig. 3-11A). In

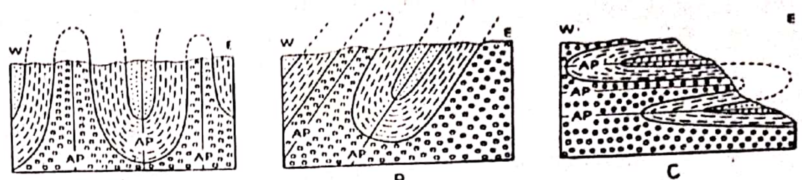


Fig. 3-9. Isoclinal folds. *AP*, Axial planes. (A) Vertical isoclinal folds. (B) Inclined isoclinal folds. (C) Recumbent isoclinal folds.

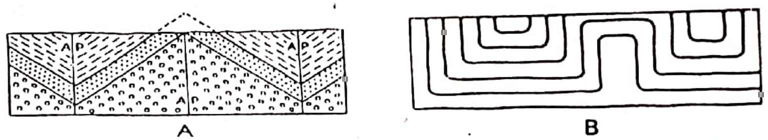


Fig. 3-10. Some varieties of folds. *AP*, axial plane. (A) Chevron fold. (B) Box fold.

the anticlinal fan fold, the two limbs dip toward each other; in the synclinal fan fold, the two limbs dip away from each other.

Kink bands (Fig. 3-11B) are narrow bands, usually only a few inches or few feet wide, in which the beds assume a dip that is steeper or gentler than that in the adjacent beds.

In plateau areas, where the bedding is relatively flat, the strata may locally assume a steeper dip (Fig. 3-12A). Such a fold is a *monocline*. The beds in a monocline may dip at angles ranging from a few degrees to 90° and the eleva-

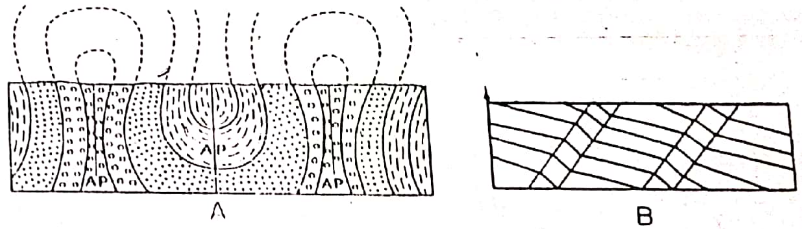


Fig. 3-11. Some varieties of folds. *AP*, axial plane. (A) Fan fold. (B) Kink bands. A fracture may separate the kink band from the rest of beds.

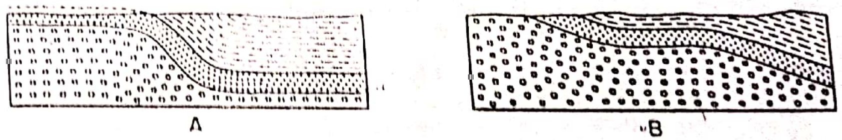


Fig. 3-12. Monocline and terrace. (A) Monocline. (B) Structural terrace.

tion of the same bed on opposite sides of the monocline may differ by hundreds or even thousands of feet.

The term *homocline*, from the Greek meaning "one inclination," may be applied to strata that dip in one direction at a relatively uniform angle. Although many homoclines are, if large areas are considered, limbs of folds, the term is useful to refer to the structure within the limits of a small area. But many geologists use the term monocline to refer to rocks that dip uniformly in one direction.

In areas where dipping strata locally assume a horizontal attitude, a *structural terrace* is formed (Fig. 3-12B). This usage should not be confused with that of the physiographer, who employs the term to refer to terraces that are structurally controlled.

A *closed* or *tight fold* is one in which the deformation has been sufficiently intense to cause flowage of the more mobile beds so that these beds thicken and thin (Fig. 3-13B). Conversely, an *open fold* is one in which this flowage has not taken place (Fig. 3-13A). Although the more extreme cases of these two types may be readily distinguished from each other, there are intermediate examples that are difficult to classify.

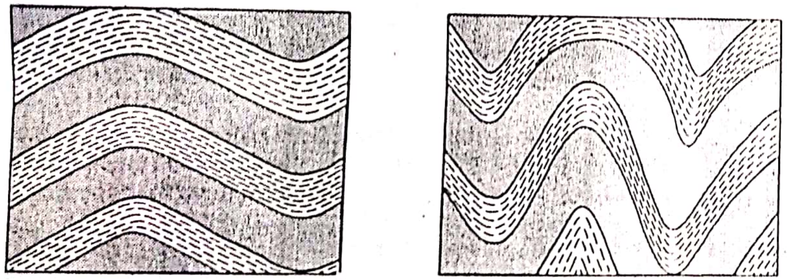


Fig. 3-13. Open and closed folds. (A) Open folds. (B) Closed folds.

Drag folds form when a competent ("strong") bed slides past an incompetent ("weak") bed (Fig. 3-14). Such minor folds may form on the limbs of larger folds because of the slipping of beds past each other, or they may develop beneath overthrust blocks (Chap. 10). The axial planes of the drag folds are not perpendicular to the bedding of the competent strata, but are inclined at an angle. Under a couple, of the type illustrated in Fig. 3-14, an imaginary circle in the incompetent bed would be deformed into an ellipse. The traces of the axial planes of the folds are parallel to the long axis of this ellipse. The acute angles between the axial planes and the main bedding plane point in the direction of the differential movement. Such structural features may form during sedimentation, when a sheet of sediment slides over a weaker bed.

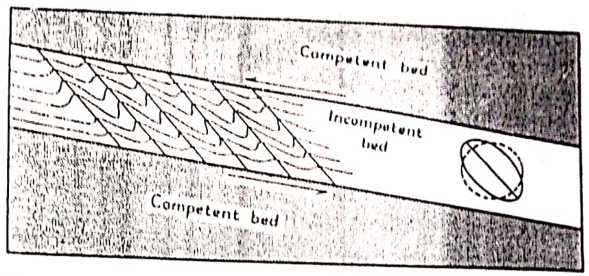


Fig. 3-14. Drag folds resulting from shearing of beds past each other.

The shape of folds may vary along the axial plane at right angles to the fold axes. A theoretical approach sheds some light on the problem. Figure 3-15A illustrates *similar folding*. Line *a* is taken as the form of the fold shown by one bedding plane. The other lines have been drawn on the assumption that they have the same form as line *a*. In this way the form of the fold is propagated indefinitely upward and downward. Moreover, lines *b* and *c* have the same length as *a*. In this type of folding every bed is thinner on the limbs and thicker near the hinges. To produce folds of this type there is considerable plastic movement of material away from the limbs and toward the hinges. In natural folds the stronger or more competent beds preserve a relatively uniform thickness, but the weaker, less competent beds adjust themselves by flowage and drag folding.

Figure 3-15B illustrates *parallel folding* (*concentric folding*). Line *a* is taken as the form of the fold shown by one bedding plane. The rest of the figure has been constructed on the assumption that the thickness of the beds

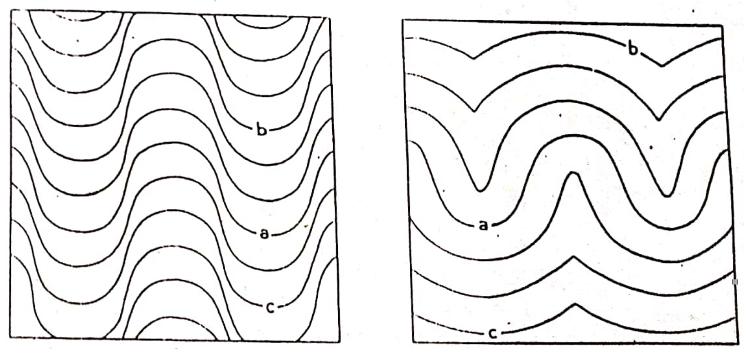


Fig. 3-15. Types of folding. (A) Similar folding. (B) Parallel folding.

has not changed during the folding. It is apparent that, under such conditions, the form of the fold must change upward and downward. The anticlines become sharper with depth, but broader and more open upward. Conversely, the synclines become broader with depth, but sharper upward. The folds die out downward and upward. In regions of gentle folding, where the dips do not exceed 10 or 20 degrees, the folding may well approach the parallel type. In Fig. 3-15B, lines *b* and *c* are shorter than *a*, but in the original basin of deposition, they must have had the same length as *a*.

The examples of similar and parallel folds in Fig. 3-15 are ideal and limiting cases. Most folds are a combination of the two extremes. Moreover, the axial planes shown in Fig. 3-15 are vertical, but, of course, may assume any attitude.

Where unusually good data are available, it is clear that most folding is disharmonic; that is, the form of the fold is not uniform throughout the stratigraphic column. Figure 3-16 shows a structure section in the Northern Anthracite Basin of Pennsylvania, based on data obtained from mines and drill holes.[1] A symmetrical anticline between two bore holes passes downward into an overturned anticline at 400 feet above sea level. At 400 feet below sea level the fold has disappeared. Disharmonic folding is well displayed on some of the great cliffs in the Alps. Figure 3-17 is one example, but inasmuch

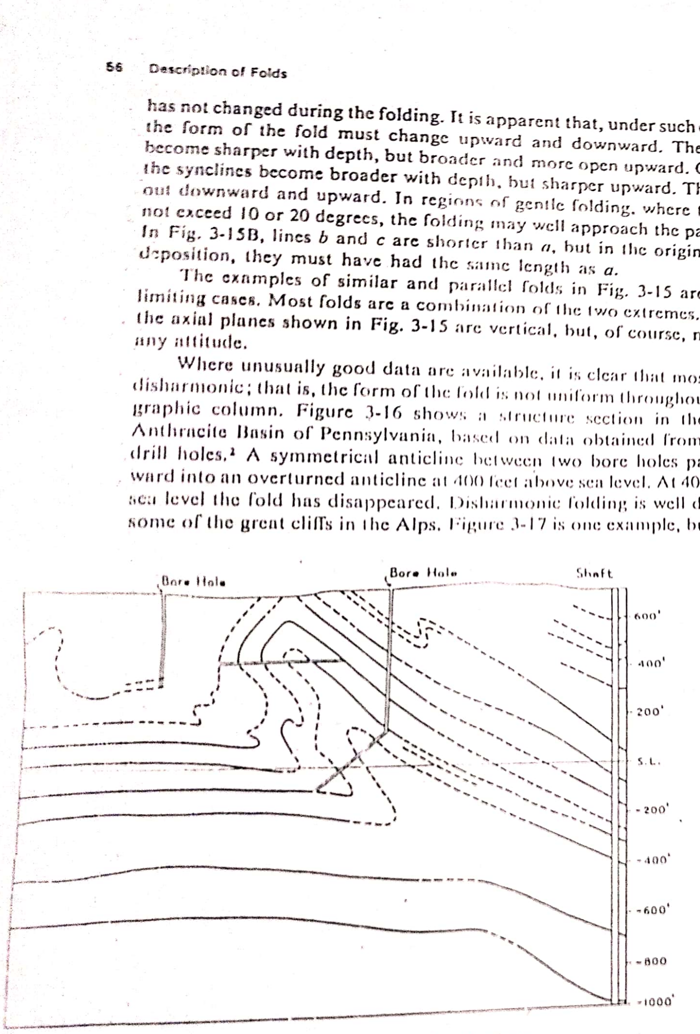


Fig. 3-16. Cross sections of disharmonic folds in the Northern Anthracite Basin of Pennsylvania. Solid lines represent beds of coal that have been mined out. Broken lines represent beds of coal based on drill records. (After N. H. Darton.[2])

as the folds are recumbent, the change of form takes place in the horiz[illegible] direction rather than with depth. The formation labeled *Jd* shows four recu[illegible]bent synclines approximately equal to each other in size, whereas the top (north) of formation *Ja* shows folds of very different form.

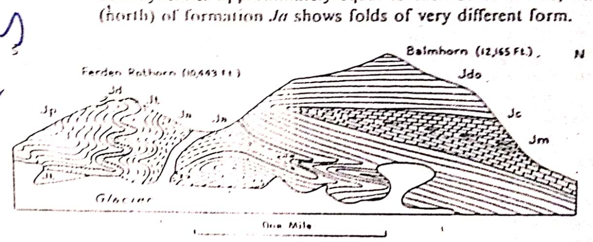


Fig. 3-17. Folds in the Ferden Rothorn and Balmhorn, Switzerland. Sketched by author from the Hockenhorn. The cliff on the east face of the Balmhorn is about 4000 feet high; that on the east face of the Ferden Rothorn is about 1600 feet high. *Jp*, Pliensbachian limestone; *Jd*, Domerian quartzite; *Jt*, Toarcian formation; *Ja*, Aalenian shale; *Jdo*, Dogger shale; *Jc*, Callovian shale; *Jm*, Malm limestone.

An extreme case of disharmonic folding is inferred for the Jura Mountains (Fig. 3-18). The Mesozoic and Tertiary strata are thrown into a series of anticlines and synclines that do not affect the underlying Paleozoic crystalline rocks. The weak shales and salt beds near the base of the Mesozoic served as a lubricant over which the higher strata slid, to form a *décollement*, that is, a "shearing off." Although most geologists agree with this interpretation, a few do not.

Piercing or diapir folds are anticlines in which a mobile core—rock salt in many cases—has broken through the more brittle overlying rocks. (See also Chap. 16.)

Fig. 3-18. *Décollement* of the Jura Mountains. The lowest formation, with nearly vertical structure, consists of Paleozoic crystalline rocks. Directly above these is a thin bed of flat-lying Triassic quartzite, left blank. The lower, solid black formation, which is very incompetent, consists of anhydrite, shale, and salt. The higher beds are Triassic, Jurassic, and Tertiary sedimentary rocks. (After A. Buxtorf.)

nge of Folds

In the preceding section, emphasis has been placed upon the appearance of folds in cross sections. But folds, like any geological structure, must be considered in three dimensions. The attitude of the hinge is of the greatest importance in describing the third dimension (Plate 10).[1,4]

In some folds the axis is horizontal (Plate 11 and Fig. 3-2A, D, and E); in other folds the hinge is inclined (Fig. 3-2B and F); in one (Fig. 3-2C) it is vertical. The attitude of the hinge of a fold is defined by two measurements: the *bearing* or *strike of its horizontal projection* and the *plunge*. It must be remembered that a hinge is a line, such as *FD* in Fig. 3-19. Of all the possible vertical planes in the figure, only one, *ADFG*, contains the line *FD*. The intersection of this plane with the horizontal plane *ABCD* is the line *AD*. The line *AD* is the horizontal projection of *FD*. In Fig. 3-19 the line *AD* bears northwest, and this is therefore the bearing of the horizontal projection of *FD*. The plunge of *FD* is the angle *P*, which is the angle between *AD* and *FD* measured in the vertical plane *ADFG*.

Although the larger plunging folds cannot be directly observed, they are easily recognized from their outcrop pattern. Figure 3-20 is a block diagram of a fold that does not plunge. On the map, the beds on the opposite

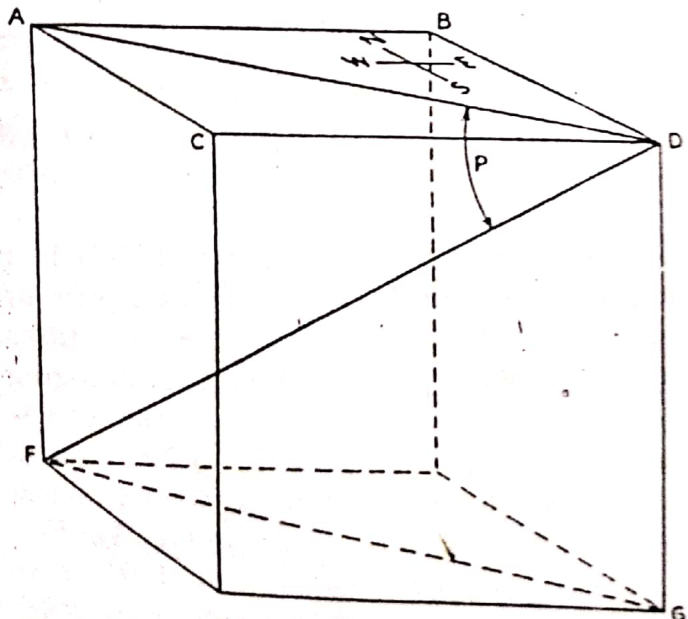


Fig. 3-19. Attitude of hinge of a fold. If *FD* is the hinge, *AD* is the bearing of the horizontal projection of the hinge; the angle of plunge is *P*.

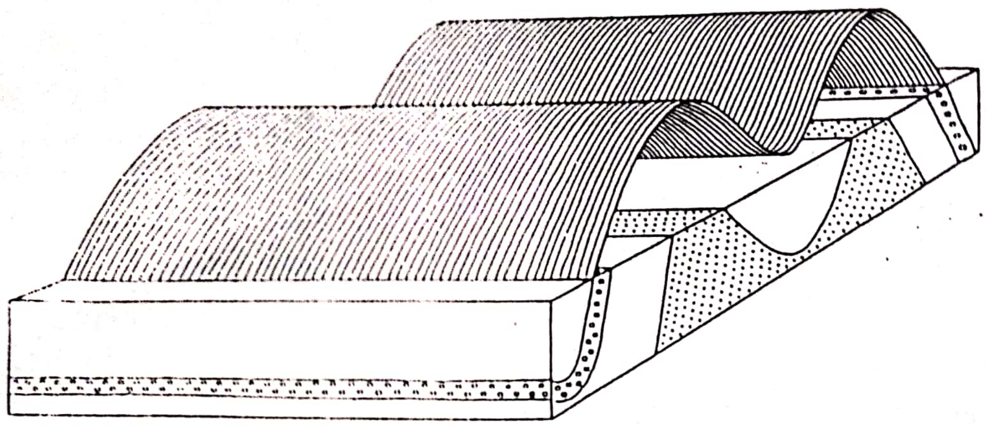


Fig. 3-20. Nonplunging folds.

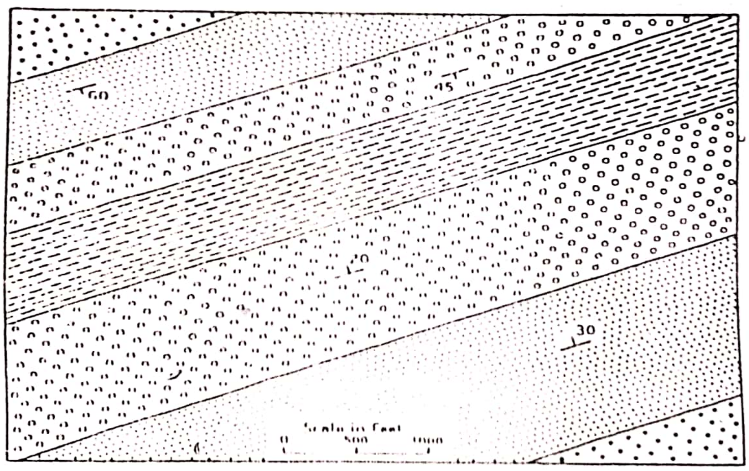


Fig. 3-21. Geological map of nonplunging fold.

limbs strike parallel to each other; they do not converge. Figure 3-21 is a geological map of a nonplunging syncline. Figure 3-22 is a block diagram of plunging folds and shows that on the map the beds converge; the formations have a zigzag pattern. Figures 3-23 and 3-24 are geological maps of plunging folds; the beds on the opposite limbs strike toward each other and the formations converge. Figure 3-23 shows a plunging anticline; Fig. 3-24 shows a plunging syncline. The *axial trace* of a fold connects the points where, on the map, each bed shows the maximum curvature (Figs. 3-23 and 3-24). For symmetrical folds or nonplunging folds, the axial trace and the horizontal projection of the hinge coincide, but this is not true if the axial plane is inclined and the fold plunges. A plunging fold is shown in Plate 10.

In the preceding paragraphs it has been tacitly assumed that the plunge is constant. In most instances, however, the value of the plunge changes along the bearing and the direction of plunge may even be reversed. Figure 3-25A

Plate 11. *Minor folds.* Interbedded impure marbles and quartzofeldspathic schists of Lower Paleozoic Age. Godøstraumen, Saltfjord, Northern Norway. Photo: J. Haller.

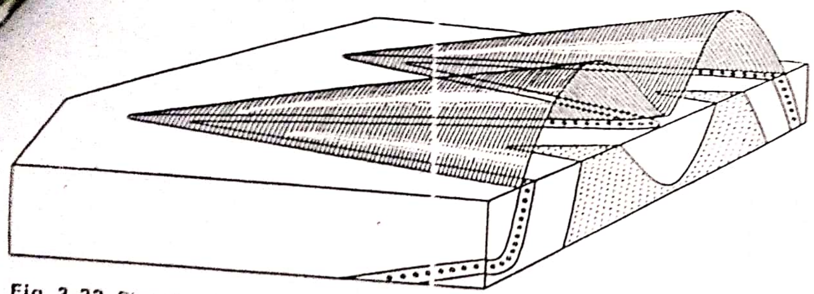


Fig. 3-22. Plunging folds. Plunge is about 10° to the left. One bed is shown by open circles; the part of this bed that has been removed by erosion is shown by lining.

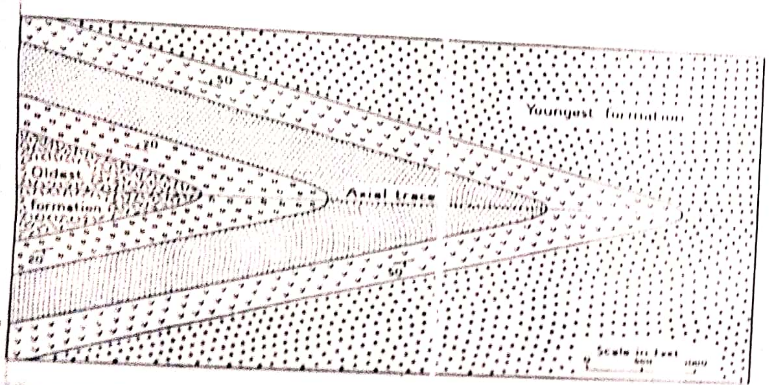


Fig. 3-23. Geological map of an anticline plunging east (to the right).

is a geological map of an anticline, the axial trace of which trends northeast. In the northeast corner of the map, the fold plunges 10 degrees to the northeast, and the strata converge northeastward. Toward the southwest, the value of the plunge decreases, and in the center of the map it is zero; here the strata on opposite limbs are parallel in strike. In the southwest corner, the anticline plunges 15 degrees to the southwest. Figure 3-25B shows a syncline that plunges southwest at the northeast corner of the map, and northeast at the southwest corner.

A *doubly plunging fold* is one that reverses its direction of plunge within the limits of the area under discussion. Most folds, if followed far enough, are doubly plunging.

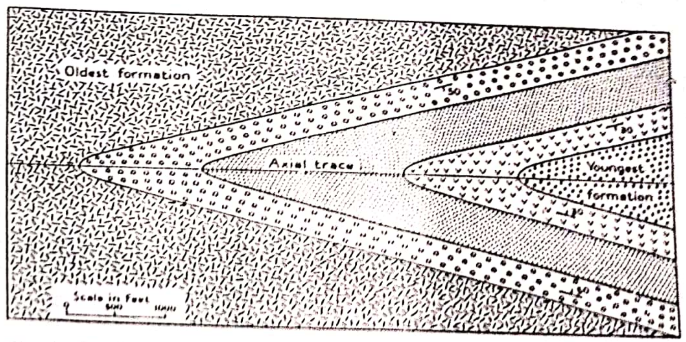


Fig. 3-24. Geological map of a syncline plunging east (to the right).

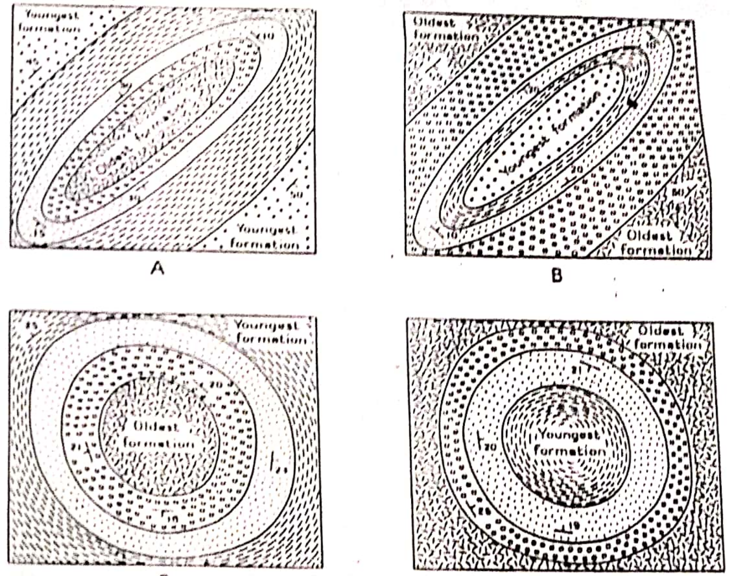


Fig. 3-25. Maps of plunging folds. (A) Doubly plunging anticline. (B) Doubly plunging syncline. (C) Dome. (D) Basin.

A *dome* is an anticlinal uplift that has no distinct trend (Fig. 3-25C).

A *basin* is a synclinal depression that has no distinct trend (Fig. 3-25D).

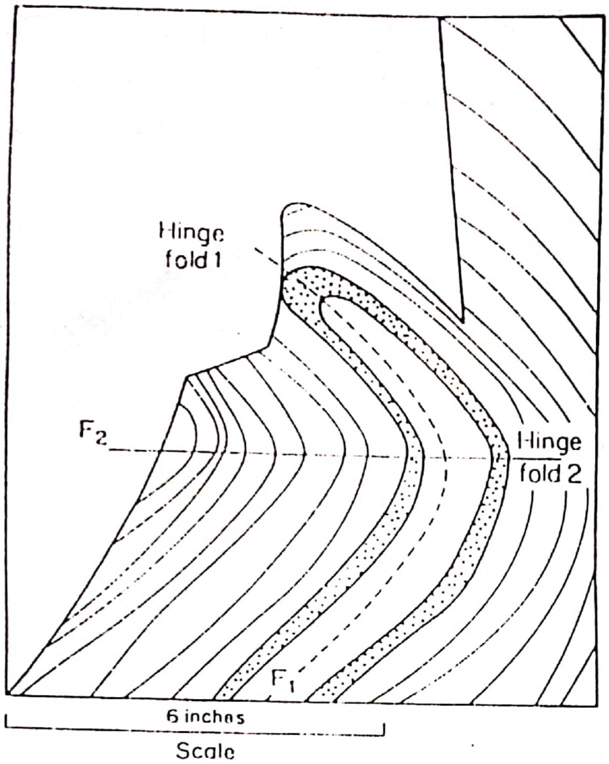


Fig. 3-26. Refolded isoclinal fold. (After G. E. Moore.[6])

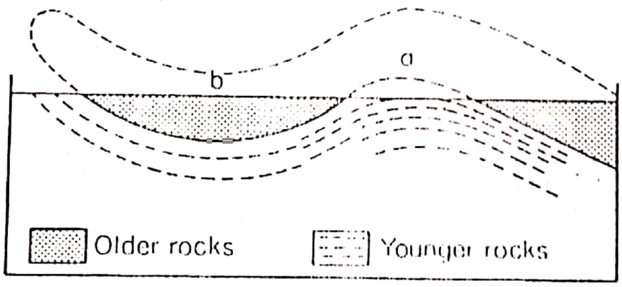


Fig. 3-27. Antiform and synform. *a*, Antiform; *b*, Synform.

Refolding

Folds may be refolded (Plate 12). One of many possible examples is illustrated in Fig. 3-26. A vertical isoclinal fold has been refolded by an open fold with a horizontal axial plane.[6]

Figure 3-27 illustrates the complexity that may occur in highly folded areas. Fold *a* appears to be an anticline, fold *b* appears to be a syncline. But it is possible, of course, that the surface of the earth here truncates the refolded inverted limb of a recumbent fold with the normal limb removed by erosion;

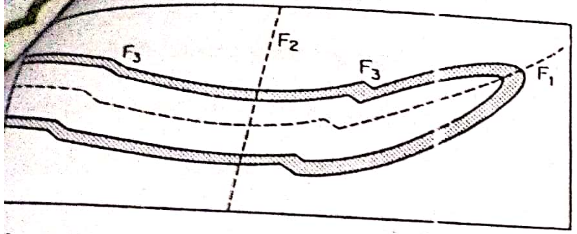


Fig. 3-28. Three stages of folding. Isoclinal recumbent fold, F_1, is oldest; broad open syncline, F_2, is intermediate in age; kink bands, F_3, are youngest.

that is, the shaded rock is the older. Fold *a* is not an anticline in the sense that older rocks are exposed toward the center of curvature. *Antiform* and *synform*[5] are often used as geometrical terms when the stratigraphic succession is unknown. The terms are also often used for cases such as that illustrated in Fig. 3-27, when the stratigraphy is known, but younger rocks appear in the center of what appears to be an anticline.

A *reclined fold* is one in which the axes plunge directly down the dip of the axial surface. Many reclined folds form when steeply dipping beds are subjected to shearing parallel to the strike of the beds.

In some areas the refolding may be deduced from the map pattern.[7] Figure 3-28 shows three stages of folding. F_1 is the axial surface of a recumbent fold. This was then refolded into an open synform (F_2) with gentle limbs. Finally, the kink bands (F_3) developed. Although a sequence of folds may be observed and deduced in the field, the dating of the various phases may be very difficult. Often the dating must be based on a thorough knowledge of the regional geology, which in turn is based on stratigraphy and paleontology. Theoretically radiogenic dating may be used, but to date little of this has been done.

Fold Systems

The preceding discussion has not been concerned with the structure of entire mountain ranges or large parts of continents. But folds are generally part of a larger system of folds, and this subject will be treated briefly here.

The wavelength of folds is the distance from one anticlinal hinge to the next anticlinal hinge (or between synclinal hinges). The wave lengths may range from a fraction of an inch to many miles. In many instances folds of various sizes are superimposed on one another. The amplitude of folds is the distance between a bed on an anticlinal hinge and the same bed in an

adjacent synclinal hinge, the distance to be measured parallel to the axial surface and perpendicular to the fold axes.

A major anticline that is composed of many smaller folds is called an *anticlinorium*. The term is restricted to large folds that are at least several miles across. Similarly, a *synclinorium* is a large syncline composed of many smaller folds; it should be at least several miles across.

Geosyncline literally means an "earth syncline," but should not be used for large synclines. It is a large depression, hundreds of miles long and tens of miles wide, in which many thousands or tens of thousands of feet of sediments accumulate.[8,9] Although the sediments deposited in the Appalachian geosyncline during the Paleozoic Era were 40,000 feet thick in places, the water was usually not very deep and at times deposition went on above sea level. The floor of the depression sank while the sediments were being deposited. In other geosynclines the water may have been deep at times. But the evolution of geosynclines has been so complex and varied that further generalizations here would be misleading.

A *geanticline* is a broad uplift, comparable in size to a geosyncline. It may lie either outside or inside a geosyncline.

The interior of the United States, between the Appalachian Highlands on the east and the Rocky Mountains on the west, is characterized by broad folds. The limbs of these folds have very low dips, rarely exceeding one or two degrees. The wavelengths are hundreds of miles and the amplitudes are many thousands of feet.

In orogenic belts, such as the Valley and Ridge Province of the Appalachian Highlands, the California Coast Range, and the Jura Mountains, the limbs of the folds dip more steeply, and may even be vertical or even overturned. The axial traces of the folds are generally parallel in any one part of the belt. But, over the folded belt as a whole the axial traces sweep in broad arcs or garlands. In Pennsylvania, the axial traces swing from almost north-south in the southern part of the state, through northeast-southwest, to nearly east-west in the northeast part of the state.

Figure 3-29 is a geological map of an area in which the axial traces are curved. Along the line *cc'* they are convex toward the north, and they diverge toward the east and west. In a *salient* the axial traces of the folds are convex toward the outer edge of the folded belt. Along the line *cc'* the folds are in a salient. In a *recess* the axial traces of the folds are concave toward the outer edge of the folded belt. Along the lines *dd'* the folds are in a recess.

In many areas all the folds plunge in the same direction. In Fig. 3-30 the folds between *cc'* and *ee'* plunge toward the east. East of *ee'* the folds plunge to the west. West of *cc'* but east of *dd'* the folds plunge west. West of *dd'* the folds plunge to the east. The line *cc'* is on a *culmination*, whereas *dd'* and *ee'* are on *depressions*. The folds plunge away from a culmination and toward depressions.

Salient and recess refer to the plan. Culmination and depression refer to

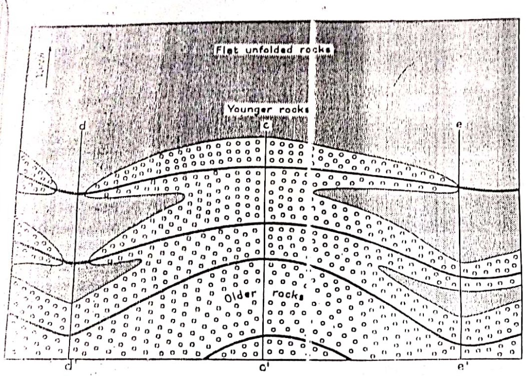


Fig. 3-29. Convergence and divergence of axial traces of folds. The axial traces (axes) are shown as heavy black lines. These lines diverge from one another on either side of *cc'*, and converge toward *cc'* if approached from *dd'* or *ee'*.

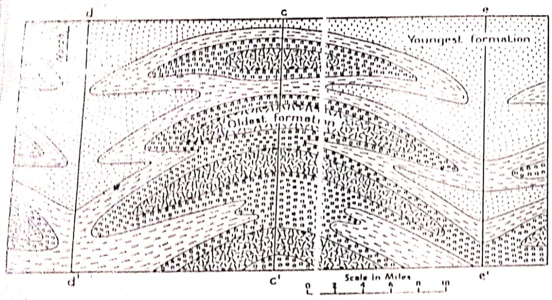


Fig. 3-30. Culmination and depression. The line *cc'* is a culmination, away from which the folds plunge; *dd'* and *ee'* are depressions, toward which the folds plunge.

the plunge in longitudinal section. Salients generally correspond to culminations. Along a line of maximum compression at right angles to the fold belt the folds are pushed forward the greatest amount and the anticlines are uplifted the most.

In some localities individual folds do not extend any great distance, but overlap one another, *en échelon*, as shown in Fig. 3-31.

An entire orogenic belt may show a sharp bend, which is called an orocline.[10] Some believe that these oroclines result from the bending of the whole folded belt.

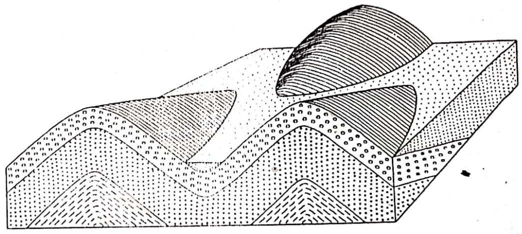


Fig. 3-31. *En échelon* folds. The anticlines hold up anticlinal mountains rising above a flat plain. The axial trace of the fold in the background is *en échelon* relative to the folds in the foreground.

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