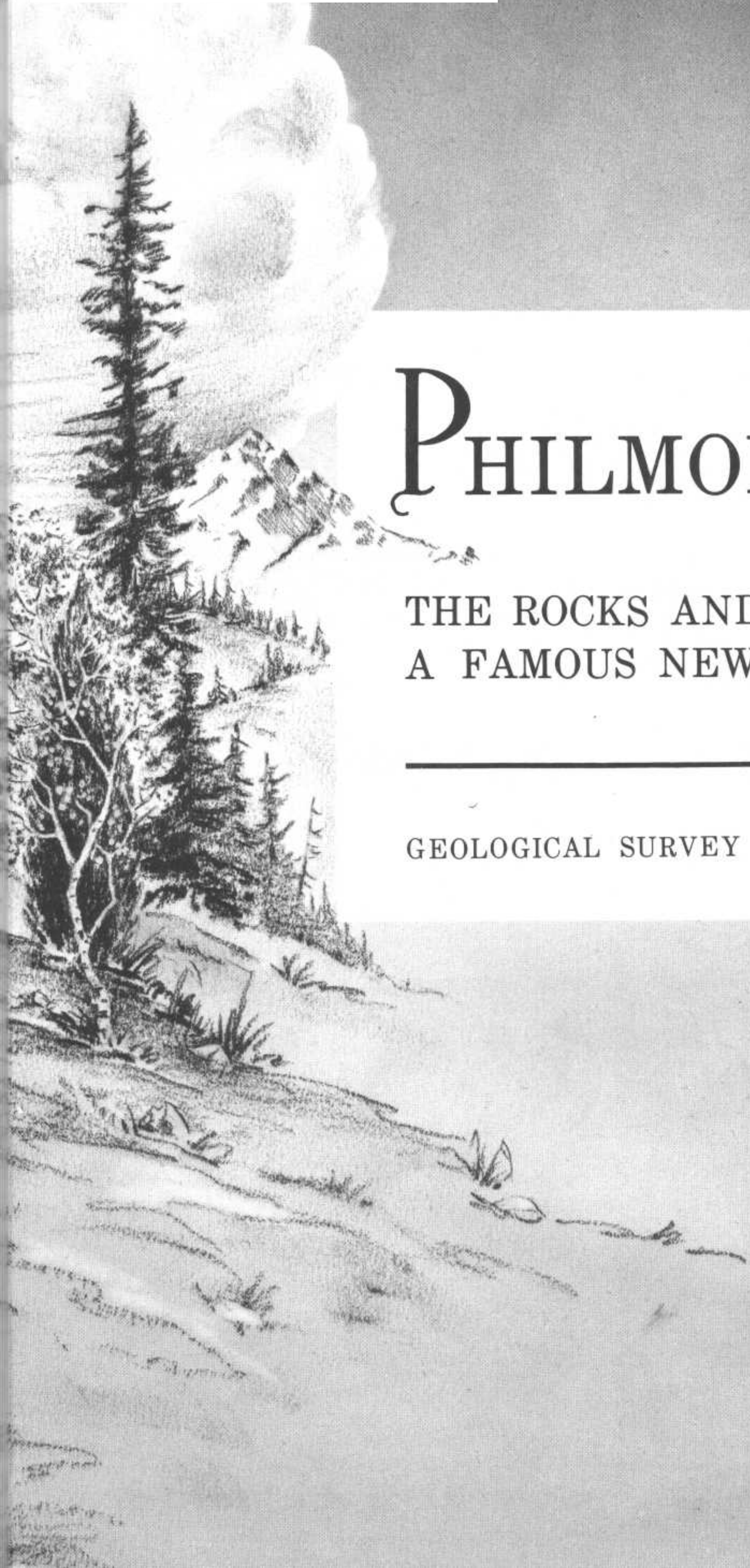

PHILMONT COUNTRY

THE ROCKS AND LANDSCAPE OF A FAMOUS NEW MEXICO RANCH

GEOLOGICAL SURVEY PROFESSIONAL PAPER 505

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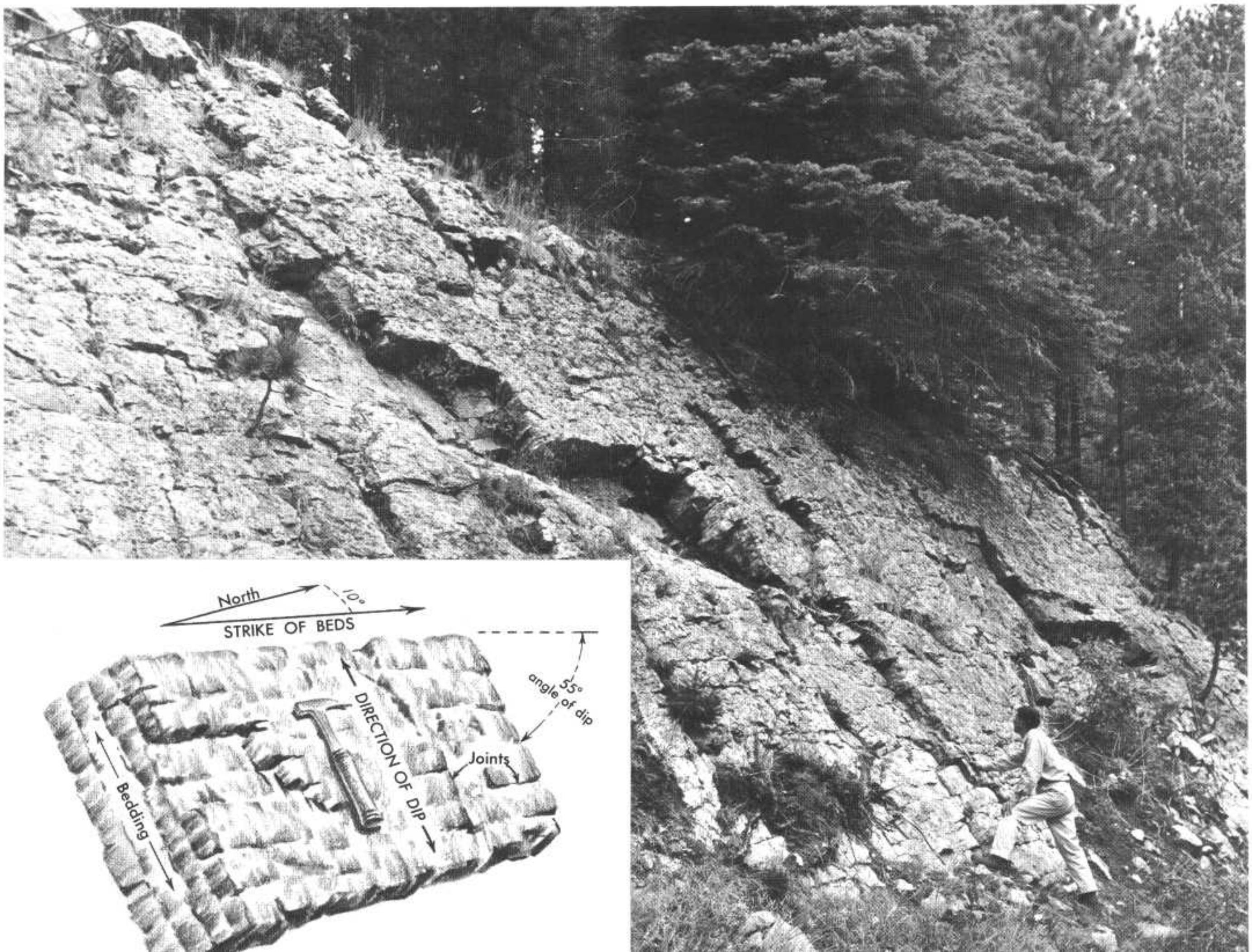
SUBSURFACE GEOLOGIC PROCESSES AT WORK

By observing the rocks and their relations to each other, we have begun to see Philmont as a sort of gigantic layer cake. Badly made to begin with, our cake has endured unceasing troubles. It has, of course, been constantly attacked from without by weather and running water whenever it has been above the sea; more about this in the next chapter. Now we will consider troubles from within.

Many of the sedimentary layers at Philmont do not simply hug the surface, like the skin of an onion, but dip into the earth, in places very steeply; the exposed edges of such layers suddenly end in the air. But the rocks were not formed this way. Most sediments collect on the ocean floor or on river flood plains in almost flat-lying beds that taper gradually to their edges, so that each bed has the general shape of a pod or lens, whether it is small enough to hold in the hand or large enough to blanket half the United States. A few coarse-grained deposits have been seen to form at initial dips of several degrees, but such dips are out of the question for fine-grained soft sediments in water: until they harden they cannot maintain an upper surface that has much slope; rather, they flatten out by flowing and sliding. Therefore, beds of fine-grained waterlaid rocks having dips of as much as 1° (about 100 feet to the mile) or more must have been tilted or bent after the rock was solid.

A layer that is tilted or bent and then eroded appears as a strip or belt cutting across country. The trend of the edge of an eroded layer is called the strike, and its slope is the dip (fig. 94). Together, the strike and dip of a surface are called its attitude.

DIP AND STRIKE of a sandstone ledge. This outcrop, of Dakota Sandstone, is on the lowest switchback in the trail west of Crater Lake Base Camp. (Fig. 94)

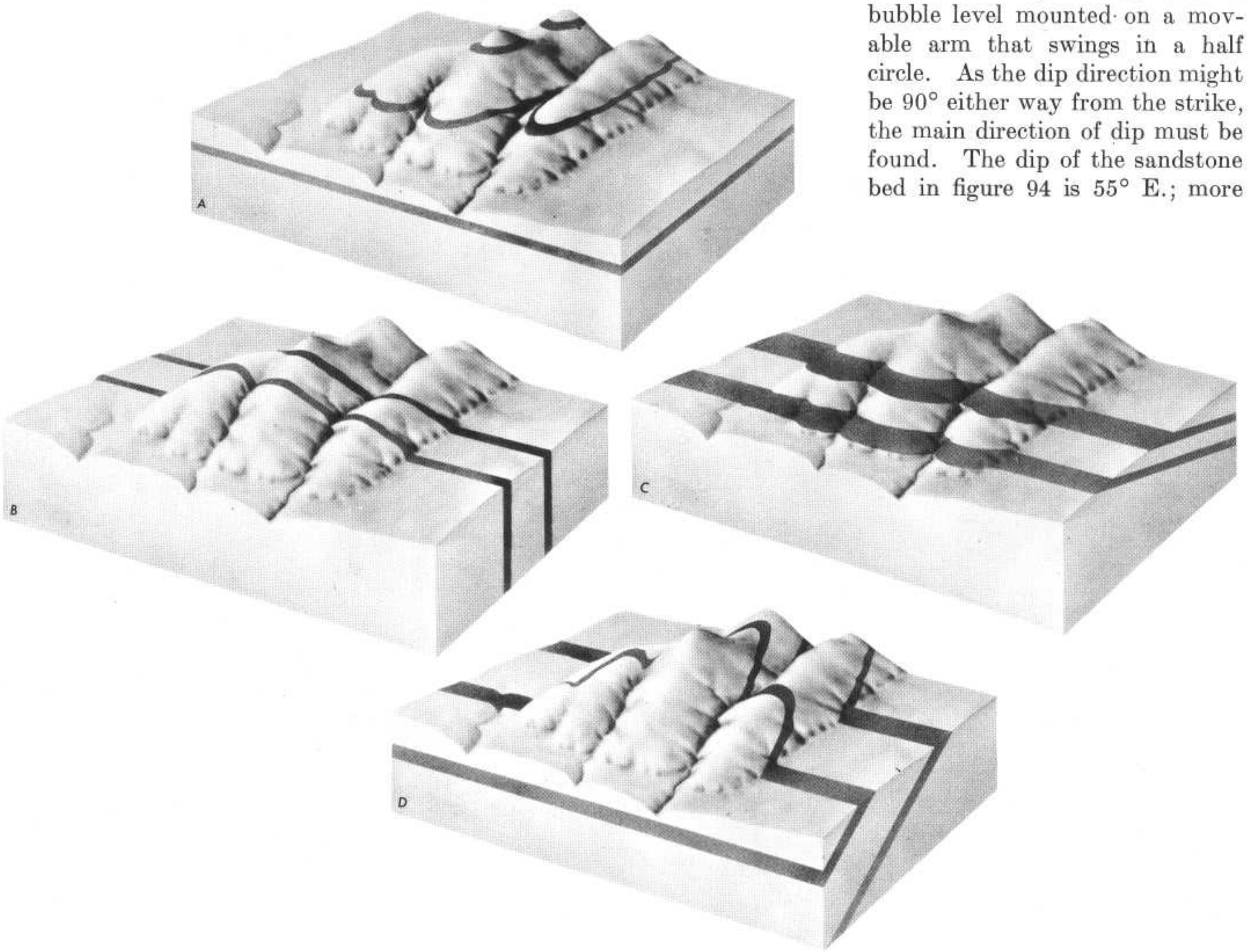


More precisely, the strike is the direction of the intersection between a dipping surface and a horizontal plane. The surface of a lake is a horizontal plane, and a good way to visualize strike is to imagine that the tilted bed forms the shore of a lake and dips beneath the lake, as in figures 97 and 98.

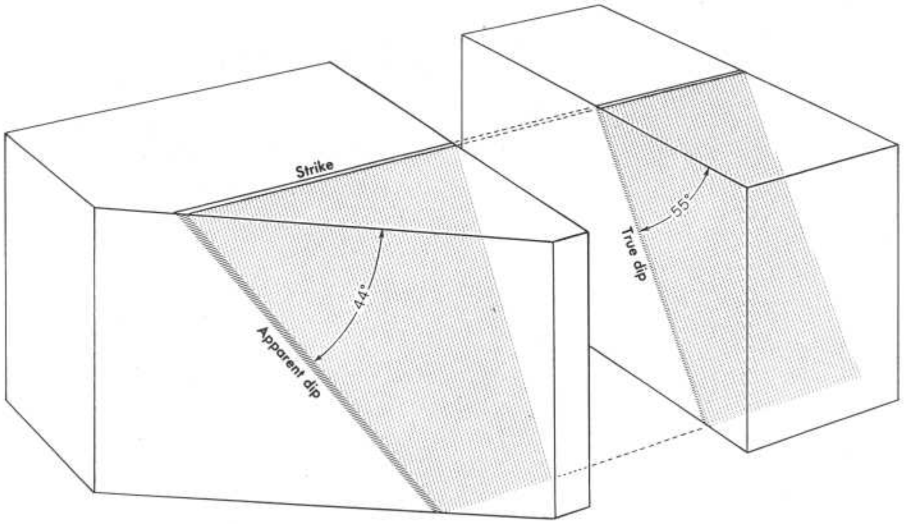
Measuring the tilt of beds

Measurements of strike and dip are the main tools used to learn about the kind and magnitude of rock deformation, or rock structure, in the earth's outermost skin. A good idea of the attitude of rock layers can be had by noting the shapes of outcrop belts in dissected country (fig. 95). More accurate measurements can be made with a compass and are usually expressed in degrees from true north. (Compasses in the northern hemisphere point to magnetic north, not true north, and allowance must be made for this magnetic deviation. At Philmont, the compass points 13° east of north.) The strike of the sandstone bed in figure 94 is north 10 degrees east, abbreviated N. 10° E.; the strike is also, of course, south 10 degrees west (S. 10° W.), but it is unnecessary to record this. The strike of east-west beds is N. 90° E. or N. 90° W.

Dip is measured at right angles to the strike, in degrees from zero (flat) to 90 (vertical), with a bubble level mounted on a movable arm that swings in a half circle. As the dip direction might be 90° either way from the strike, the main direction of dip must be found. The dip of the sandstone bed in figure 94 is 55° E.; more



TOPOGRAPHY AND DIP affect the outcrop pattern of layered rocks. A, Beds that lie flat or nearly so crop out in patterns that outline the land forms. In rough country, like most of Philmont, their outcrop patterns are intricately scalloped and patchy. B, Layers that stand vertically or nearly so run straight across the landscape, whether it is rugged or subdued. C and D, Layers that have moderate to steep dips make curved patterns somewhere between the scalloped and the straight. If the dip is opposite to the direction of streamflow, the outcrops of layers crossing valleys make V's pointing upstream (C). If the dip is in the direction of stream flow, the V's point downstream (D). (Fig. 95)



TRUE AND APPARENT DIP. The true dip is at right angles to the strike. Seen at any other angle, the dip appears lower. This makes it easy to underestimate dip. (Fig. 96)

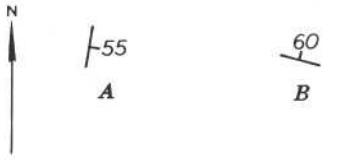
precisely, it is 55° in a direction 80° east of south, or S. 80° E., but this need not be stated, because dip is measured at right angles to strike, and this direction can be found simply by adding or subtracting 90° from the strike direction. It is enough, then, to state whether the dip is eastward or westward. Similarly, if a strike is nearer to east-west than to north-south, say N. 50° W., the dip is given simply as degrees north or south, for it must be either in a direction 90° north or 90° south of N. 50° W., that is, N. 40° E. or S. 40° W.

As shown in figure 96, the true dip can only be found by measuring at right angles to the strike: at less than a right angle, the apparent dip is progressively lower than the maximum or true dip until the dip seems to be zero parallel to the strike. This is why the rocks north of Cimarron look flat from Highway 64, though they actually dip northward: the road is nearly parallel to the strike.

A compass needle for measuring strike and a movable level for measuring dip are combined in the geologist's, or Brunton, compass. Figures 97 and 98 show this instrument and how it is used. It is better to stand away from the outcrop and take average measurements rather than to place the instrument against the outcrop. Dip and strike in disturbed rocks vary a lot in short distances, and "accurate" measurements on a very small part of an undulating surface would be meaningless.

It is also wise to measure dip on beds well within a formation. Measurements on the upper surface of a formation may be misleading, for the upper surface may slope more or less steeply than the bedding, as a result of later erosion; and the base may also slope, owing partly or wholly to deposition on an irregular or sloping surface, rather than to deformation.

Strike and dip are usually shown on a geologic map by a short-bar T. The top of the letter is the strike. The map symbol for the example we have been using—strike N. 10° E., dip 55° E.—is shown as *A* below, and another example—strike N. 75° W., dip 60° N.—is shown as *B*.



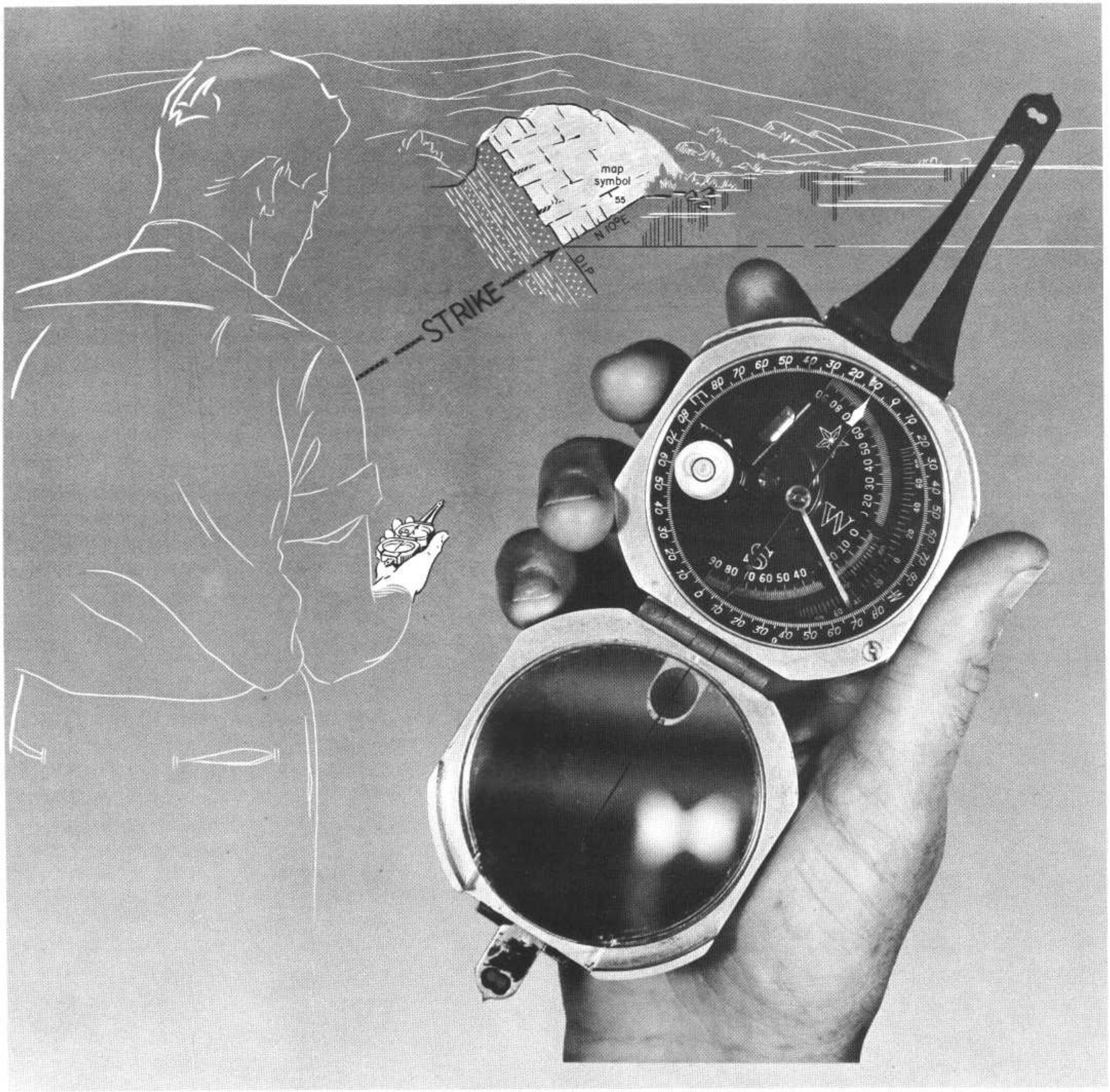
When later we speak of low or gentle dips, we mean dips of less than 10°; moderate dips are those between 10° and 40°; and steep dips are greater than 40°.

Only a few dips and strikes are shown on the geologic map (pl. 3). These were recorded to the nearest 5° except that dips of 1° to 3° are given as 2°. Although dip and strike are usually measured directly in the field, they can be measured on a carefully made geologic map that has an accurate topographic base (but not on quickly made plate 3!), or even on stereoscopic pairs of aerial photographs.

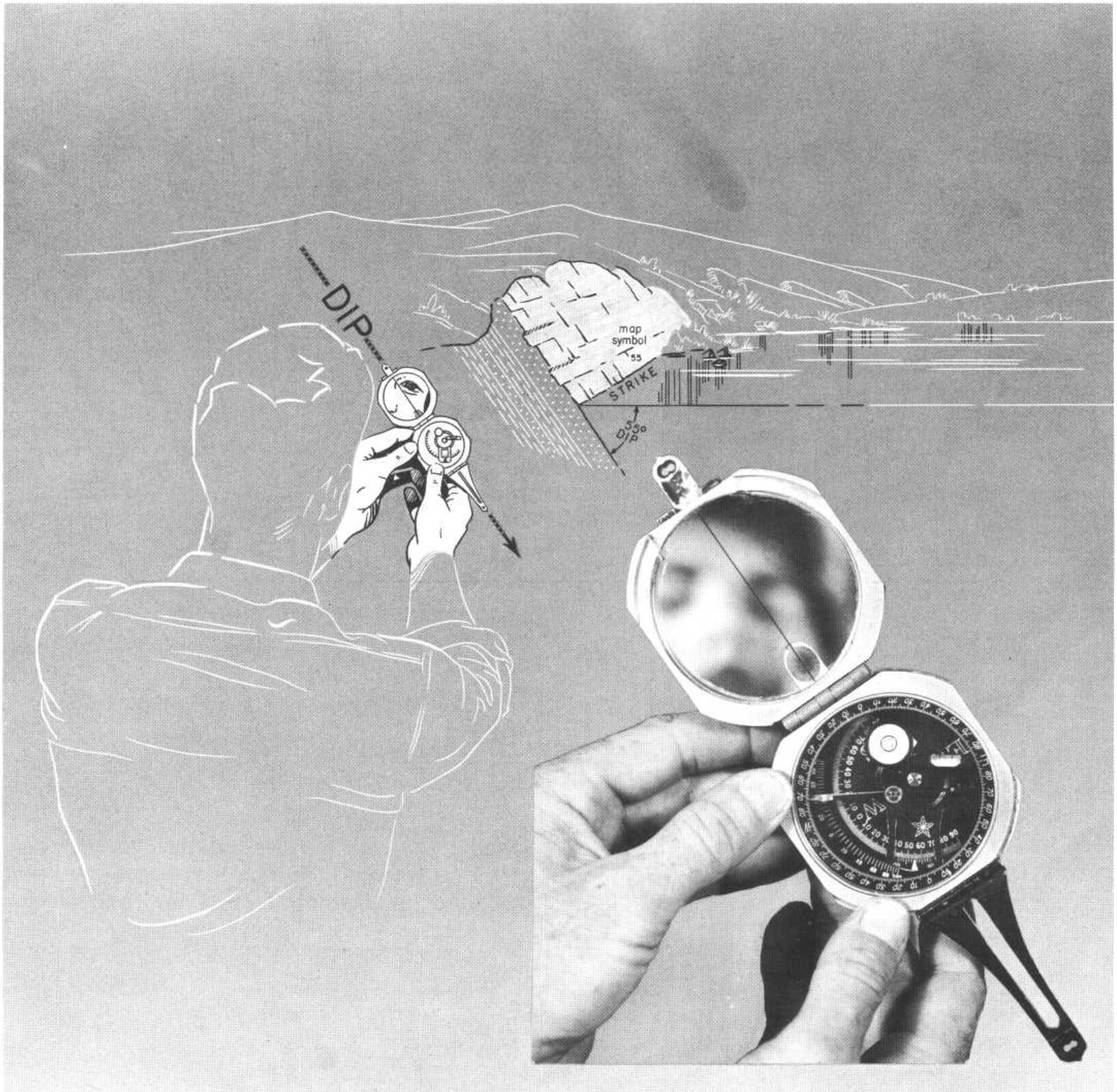
With the help of dip-and-strike information, we can learn something of the earth movements that have interrupted the piling up of layers at Philmont. Knowing the geologic ages of the rocks, we can also decide when these movements happened.

Deformed layers: Tilted and folded rocks

If layered rocks are deposited on the earth's surface nearly flat, we realize that all the named formations at Philmont must have been disturbed, or deformed, to some extent after they became solid, for most of them have marked dip. A reasonable prediction would seem to be that the older the rocks, the greater the deformation. Using the steepening of dip as a fair guide to the degree of deformation and taking the scattered attitude symbols on the map as representative, we can quickly visualize where and



USING THE GEOLOGIST'S COMPASS TO MEASURE STRIKE. First the compass is set for the average magnetic declination by turning a set-screw on the side; at Philmont, 13° E. Then it is leveled by centering the bubble in the bull's-eye and is lined up parallel to the strike. The strike, read directly from the dial marked in degrees, is N. 10° E. in this example. Note that the symbols for east and west are reversed: to take a reading, the body of the compass is turned while the magnetized needle stands still, so that rotating the compass to the east, as in this example, makes the needle seem to move west. Any compass can be used to measure strike. This kind is simply more accurate than most and gives a direct reading. (Fig. 97)



USING THE GEOLOGIST'S COMPASS TO MEASURE DIP. The compass, turned on edge, is lined up parallel to the dip. Then, by means of a lever on the back, a movable arm that has an attached bar level is rotated until its bubble is centered. The angle between the centerline of the compass and the axis of the bar level is the dip—in this example, 55°—which is read directly from the innermost scale, marked in degrees. A simple dip measurer can be made with a protractor, a string and a small weight. One end of the string is attached to a hole at the center point, the other end to the weight which is allowed to hang free. The protractor is rotated until it is parallel to the dip, and the angle of dip can be read directly. (Fig. 98) how much the sedimentary rocks are deformed. By doing so, we find that the "reasonable prediction" is a bad guess. The solid rocks of the northern benchlands are the least deformed, having dips generally under 10°; those of the mountain front are the most deformed, having dips typically 25° to 45° and many much steeper; and those of the plains and along upper Cimarron Canyon are somewhere between. This is not at all the order of relative age of the rocks in those areas. Furthermore, some of the same formations that crop out both in the plains and in the mountains have widely varying dips. It is even true that certain younger formations in some places have much steeper dips than older ones elsewhere; for example, the Dakota Sandstone (Cretaceous) on upper South Fork Urraca Creek is turned up to vertical, whereas the much older (Permian and Pennsylvanian) Sangre de Cristo Formation on Cimarroncito Creek has moderate dips.

Yet it is hard to deny that, where movements are going on, only rocks that have not yet formed can escape being deformed. Some kinds of deformation must, therefore, be confined to narrow belts of country and not be felt elsewhere, so that the degree of deformation in rocks is not a sure guide to relative age. Anyone who likes puzzles will see at once that the study of rock disturbances or deformations—structural geology—can be fascinating.

The Philmont area has its share of structural puzzles. Before we get to them, let's look at some of its least puzzling structures, starting with the simplest.

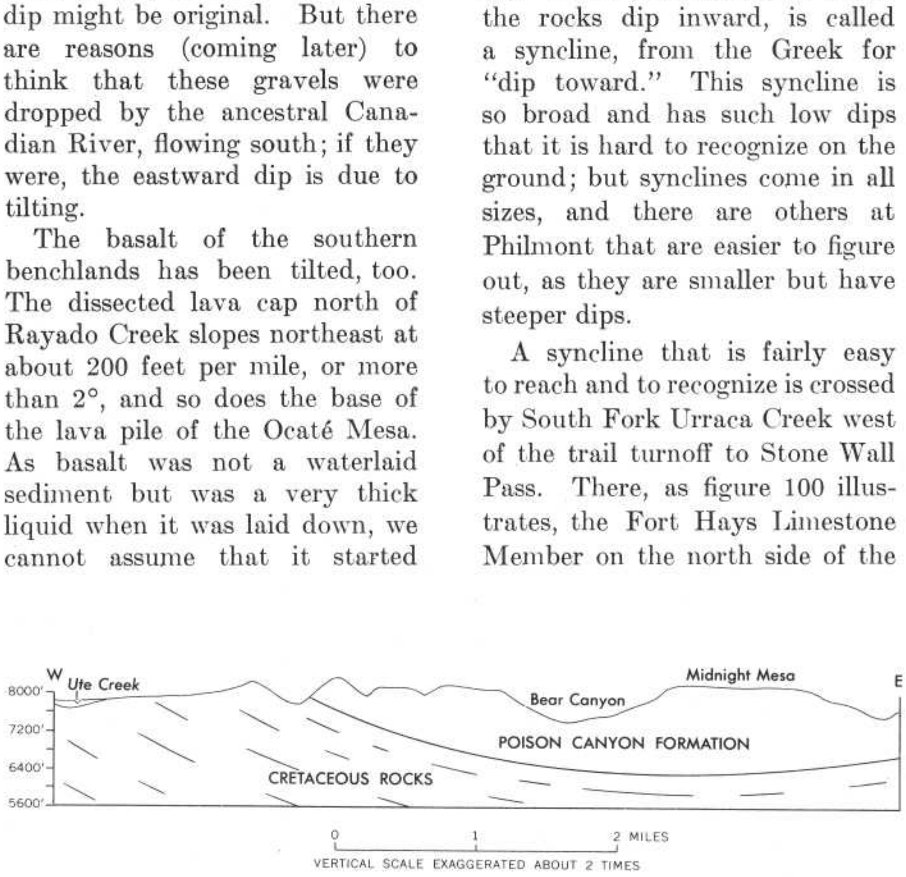
If the dip of a slab of sedimentary rock is uniform and all in one direction, the slab has probably been tilted. The gravel caps of the lowland benches seem to have been tilted slightly down to the east. The base of the cap that extends almost unbroken for 4 miles from Webster Reservoir near Cimarroncito Creek to Highway 21 drops 400 feet in that distance, or 100 feet per mile. The cap that extends many miles eastward from the conspicuous white buildings of Nairn Place, near Urraca Creek 1.2 miles east of the Stockade, has about the same slope, or a little steeper, and so does the cap along the north side of lower Rayado Creek.

Of a still higher graveled bench level, only scraps are preserved at such places as the east end of Horse Ridge and on Kit Carson Mesa, south of Carson Maxwell Base Camp; this slope is hard to measure, but it seems to be well over 100 feet per mile. If these gravels were deposited by streams flowing east, some or all of this dip might be original. But there are reasons (coming later) to think that these gravels were dropped by the ancestral Canadian River, flowing south; if they were, the eastward dip is due to tilting.

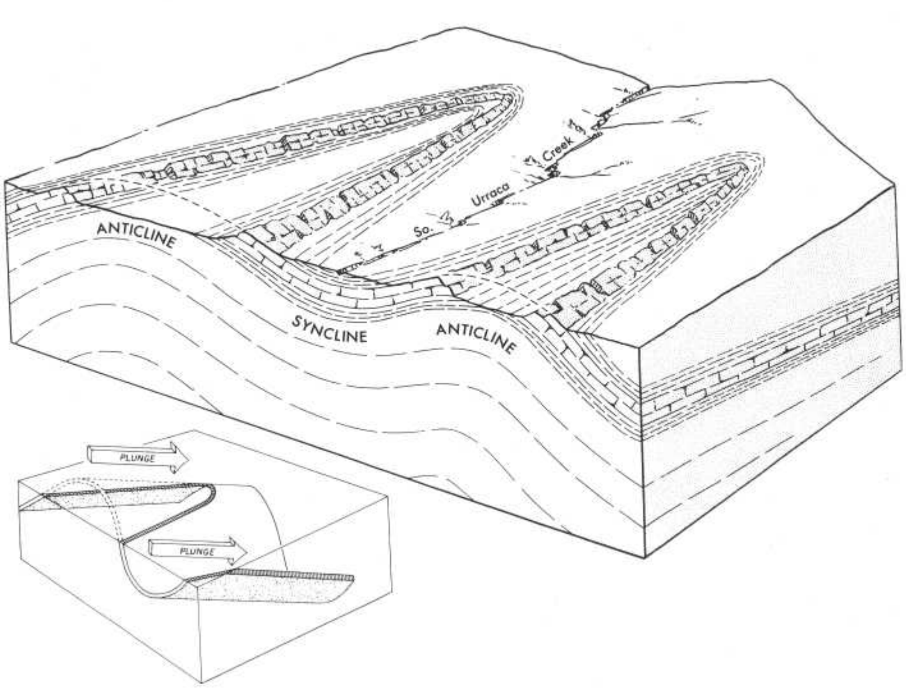
The basalt of the southern benchlands has been tilted, too. The dissected lava cap north of Rayado Creek slopes northeast at about 200 feet per mile, or more than 2°, and so does the base of the lava pile of the Ocaté Mesa. As basalt was not a waterlaid sediment but was a very thick liquid when it was laid down, we cannot assume that it started flat; at least some of its dip was the dip of the surface on which it flowed. At any rate, the basalt, being older than the gravel caps but near them, has surely been tilted eastward as much as the gravel.

At first sight, simple tilting seems also to explain the steady northeasterly strike and low northwesterly dips—all near 2°—in rocks of the Raton and Poison Canyon Formations along Ponil Creek between Highway 64 and Ponil Base Camp. But to the west the strike and dip of these rocks change, so that along Ute Creek valley they strike west of north and dip 5°–10° NE. These changes show that the Raton and Poison Canyon Formations north of Cimarron Creek are not merely tilted but are folded into a broad shallow scoop shape (fig. 99). Such a downfold, in which the rocks dip inward, is called a syncline, from the Greek for "dip toward." This syncline is so broad and has such low dips that it is hard to recognize on the ground; but synclines come in all sizes, and there are others at Philmont that are easier to figure out, as they are smaller but have steeper dips.

A syncline that is fairly easy to reach and to recognize is crossed by South Fork Urraca Creek west of the trail turnoff to Stone Wall Pass. There, as figure 100 illustrates, the Fort Hays Limestone Member on the north side of the



GIANT SHALLOW DOWNFOLD, or syncline, in Poison Canyon rocks north of Cimarron Creek. Dips exaggerated. (Fig. 99)



FOLDS IN SEDIMENTARY ROCKS on lower South Fork Urraca Creek. Stream and landslide deposits omitted. (Fig. 100)

creek dips moderately south, and the Carlile Shale, cropping out on the hillside to the north, and dips beneath the limestone. These south-dipping rocks are also shown in figure 30*A*. The shale in the creek bed to the south lies on top of the limestone and is, therefore, the upper part of the Niobrara Formation. A little farther upstream, outcrops of the limestone on the south side of the creek dip toward the trail, or northeastward. The limestone, then, dips toward the creek from both sides: it has been folded into a trough shape.

Other, somewhat broader but shallower synclines have been mapped in the Cretaceous rocks of the plains to the south. Probably, too, the rocks beneath Deer Lake Mesa are folded into two shallow bowl-shaped synclines, each marked by a surface basin—Devils Wash Basin and Deer Lake—but we did not make enough dip and strike measurements to prove this.

If rocks can be folded down into trough, scoop, canoe, or bowl shapes, we would suspect that they can also be folded up into matching shapes, for folding a pile of layered rocks ought to be much like folding a pile of paper. (Remember that a pile of paper can be folded in several ways: pushing from one side or from several sides is perhaps the most obvious, but putting weight on part of the pile or pushing up on part of it will also serve.) It is no surprise, then, that a little west of the syncline where the Urraca trail turns sharply southwest, the dip of the limestone is again reversed so that it is southwest. These opposing dips outline an archlike upfold called an anticline, from the Greek for "dip away." The sides or limbs of this pair of folds are not parallel but make a zigzag pattern, as shown in figure 100. This outcrop pattern means that the trough of the syncline and the crest of the anticline are plunging toward the plains. If the crests and the troughs of the folds were flat, the beds would crop out in parallel stripes.

Some broader and shallower anticlines than the one we have just noticed can be recognized in the Cretaceous formations to the south.

If Devils Wash Basin and Deer Lake are truly in the troughs of separate small synclines, then there must be a low anticlinal arch between. Also, at least one anticline must be concealed by the landslide between Deer Lake Mesa and Midnight Mesa, for the dips seem to be in opposite directions on the mesa flanks that face each other.

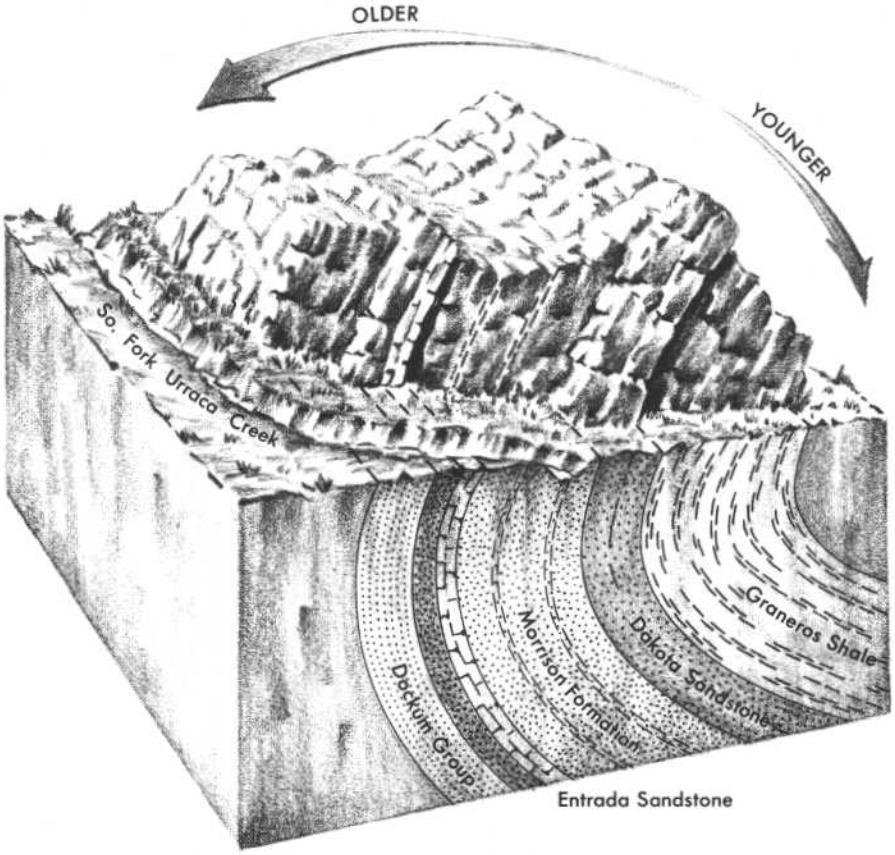
The ledge of Fort Hays Limestone Member on the north limb of the syncline sketched in figure 100 is on the south limb of a much larger domelike anticlinal structure. This limestone ledge makes a nearly unbroken loop that is 2½ miles long, extending from near the Shaefers Pass Trail to just east of the Stockade, and 1½ miles wide, from Urraca Trail to the middle of Tooth of Time Ridge; the limestone dips outward from the center of the loop, which is filled not by Carlile Shale, the next underlying sedimentary formation, but by dacite porphyry. Many of the mountain peaks flanking Highway 64 are near the crests of similar but much larger broad domes in which the sedimentary rocks are spread apart by sheets of dacite porphyry. More will be said about this kind of anticline when the structures of the igneous rocks are discussed.

From the traverses up Rayado Creek and across the Cimarron Range, we saw that the whole range is a huge anticlinal arch, being broader even than the syncline north of Cimarron Creek and having much steeper dips on the flanks. The small folds east of the mountain front may be thought of as wrinkles on this superfold, or ripples on the side of a giant frozen wave.

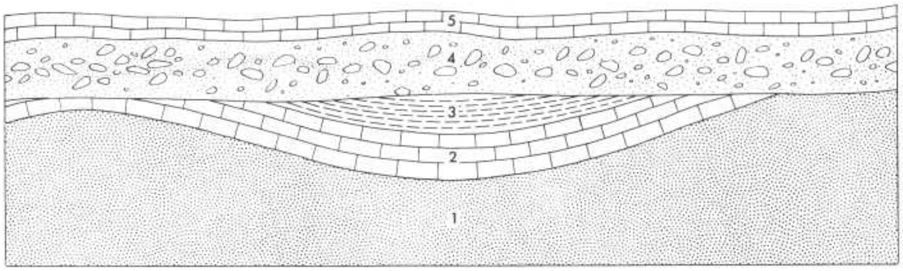
In a few places these wrinkles have been so tightly folded that the rocks are overturned. For instance, at the mountain front on the South Fork Trail, the sedimentary formations are bent so steeply that they are overturned, dipping 70° W. (fig. 101). We can tell that the Dockum Group in figure 101 is overturned, top to the east, and not simply in a fold, top to the west, because the beds that are below it to the east (fig. 102) are not the coarse-grained red rocks of the Sangre de Cristo Formation but are successively the white Entrada Sandstone, the red Morrison Formation, the ridge-making Dakota Sandstone, and the black Graneros Shale, all of which are known, from many observations where the rocks are less disturbed, to be above and younger than the Dockum Group. By climbing the hill north of the trail and walking along the strike, we can see the overturned beds change to vertical and then to their usual east dip, in normal sequence.

The geologic age of tilting and folding can be decided in a simple way. Any tilt or fold must be younger than the youngest rocks in it and older than the oldest rocks in the same area that are not tilted or folded (fig. 103). Between the deformed and undeformed rocks in figure 103 is, to recall the discussion of "missing layers," an unconformity, which represents a period of erosion that occurred after the tilting or folding and before the next rocks were deposited. When the unconformity is the result of deformation, so that there is an angle between the bedding above and below, it is an angular unconformity. The unconformity beneath the Poison Canyon and

SHALE AND SANDSTONE of the Dockum Group standing nearly vertical on South Fork Urraca Creek trail. (Fig. 101)



BEDS OVERTURNED at the mountain front on South Fork Uracca Creek. For a short distance on the north side of the creek, younger rocks dip under older rocks. (Fig. 102)



GEOLOGIC AGE OF FOLDING. In the drawing, formations 1, 2, and 3 are deformed but 4 and 5 are not. The rocks must have been disturbed and then eroded to a smooth surface after 3 was deposited but before 4. If 3 is Jurassic and 4 is Cretaceous, the folding happened late in Jurassic or early in Cretaceous time. (Fig. 103)

Raton Formations in northwestern Philmont described earlier is evidence of slight eastward tilting before Raton time but after Vermejo time and is therefore an angular unconformity.

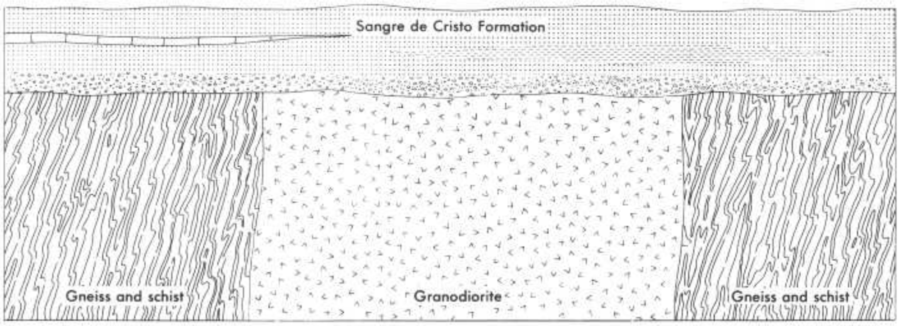
Using the simple guide of angular unconformity, we can decide that the broad syncline north of Cimarron Creek is younger than the Poison Canyon Formation but older than the landslides and all the loose sand and gravel on the plains and valley floors. The great Cimarron Range anticline is also younger than the Poison Canyon Formation. The main arching probably occurred in middle Tertiary time, but the tilting of the basalt flows and of the higher graveled benches shows that arching continued or recurred until fairly late Quaternary time; indeed, sensitive instruments might show that it is still going on.

The smaller anticlines and synclines south of Cimarroncito Creek are younger than the Pierre Shale and older than the unfolded basalt. These small folds, incidentally, are not easy to recognize because so much of them is covered by unfolded younger deposits. The folds must be reconstructed by piecing together scattered dips and strikes and, in imagination restoring parts planed off by erosion.

A reasonable guess is that the metamorphic rocks were tightly folded in Precambrian time before and during metamorphism; the layers in the metamorphic rocks are almost at right angles to the bedding in the Sangre de Cristo Formation, making the break between an extreme angular unconformity (fig. 104).

Anticlines do not necessarily mean bulges on the landscape, nor synclines depressions. Probably, folding is often so slow that erosion keeps up with it, and folds forming at depth may never appear as bulges or sags on the surface. The landform that grows on an eroding fold depends on the resistance of the different rocks to erosion. If the core of an anticline is made of rocks more resistant than those of the flanks, then it makes a high part of the landscape, like the Cimarron Range itself; but if the core rocks are less resistant, then the heart of an anticline may wind up at the bottom of the local scenery, like the valley of Urraca Creek between Shaefers Pass Trail and the Stockade. The same, in reverse, is true of synclines. Fold structures, then, are revealed in the dips of the rocks. They may or may not be shown by the landscape that forms on them.

Most of the world's mineral deposits are in folded rocks: metal ores are mainly in tightly folded rocks; fuels—coal, oil, gas, uranium—are mostly in gently folded ones. Modern mineral industries employ many thousands of geologists to find favorable-looking structures that might be explored for new deposits as well as to guide the development of known deposits. Mineral exploration demands special skill and imagination if the ore- or fuel-bearing structure does not crop out but is buried beneath an unconformity—or is the unconformity itself. To meet the increasingly heavy demands of industry, the ores and fuels, which are unreplaceable, are being dug and pumped out of the ground faster and faster. More and more new deposits must be found, and the search grows increasingly difficult and challenging. As time goes by, more and better geologists will be needed to find and to develop hidden mineral wealth.



ANGULAR UNCONFORMITY between Precambrian rocks and the Sangre de Cristo Formation. (Fig. 104)