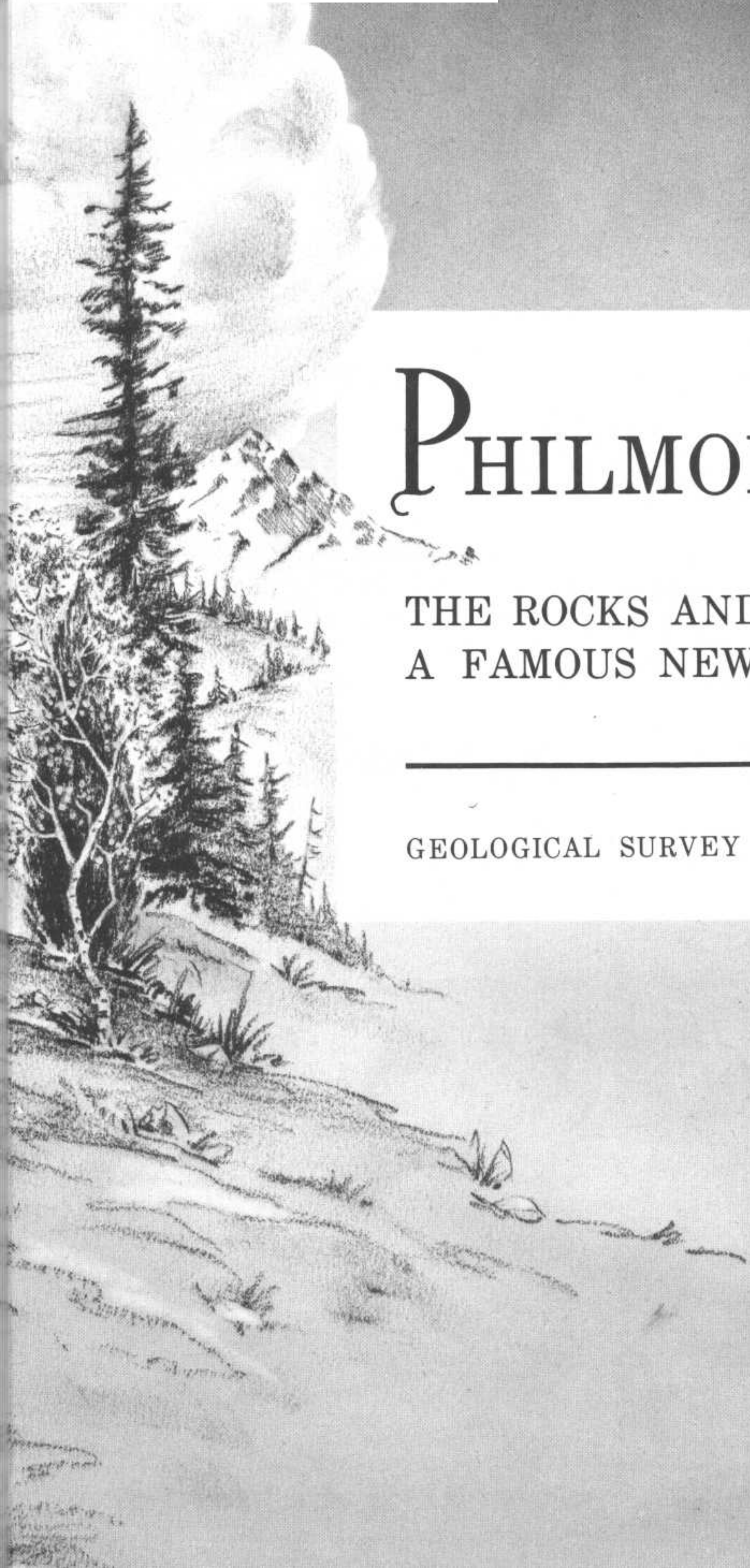

PHILMONT COUNTRY

THE ROCKS AND LANDSCAPE OF A FAMOUS NEW MEXICO RANCH

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SHAPING THE LANDSCAPE

So much for the tortured inner life of the Philmont cake during the past billion years or so. But what was happening on the surface while metamorphism and intrusion, folding, faulting, and uplift were going on below? We have had many hints along the way. Now to concentrate on the landscape and how it has evolved.

The scenery of Philmont, as we saw early, is made up of seven main elements, which are shown on the landform model (pl. 1): (1) steplike gravel-capped lowland plains which in most of Philmont flank the main streams in narrow belts but spread out to cover the southeastern part; (2) high steep-sided flat-topped hardrock benchlands that make almost the whole northern half, the southern edges, and a few scattered surfaces between, such as Deer Lake Mesa, Antelope Mesa, Urraca Mesa, Fowler Mesa, and Crater and Rayado Peaks; (3) rough hummocky hillsides along much of the mountain front and around the benchlands south of Cimarron Creek and in Ute Creek Valley; (4) rugged mountain country, without flatlands, in the western part; (5) high swampy meadows in the southwest corner and along Bonito and Agua Fria Creeks; (6) a network of streams that flow away from the crest of the Cimarron Range and join Cimarron Creek, which flows across the range; and (7) scattered natural lakes, most of which are on the high meadowlands.

We also realized that running water has been doing most of the work of carving the landscape, but just how the carving is done and why the scenery is very different in different parts of Philmont were mysteries. Now that we know something of the rocks beneath the land—how and when they were formed and how and when they were deformed—some of the mystery can be cleared away. To understand the scenery, look underneath the greenery.

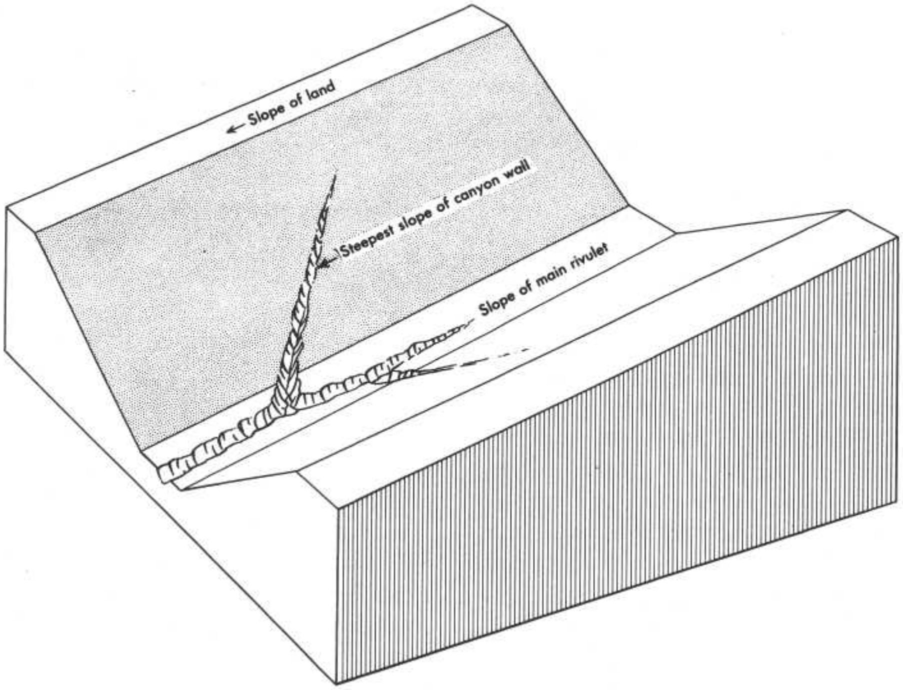
Compare the landform model (pl. 1) with the geologic model (pl. 4). Clearly, the larger landscape features are closely related to the underlying rocks and their structure. Beneath their veneer of sand and gravel, the broad lowland plains are underlain almost entirely by the soft shale formations of Late Cretaceous age: Graneros, Carlile, Niobrara, Pierre. The high benchlands are carved in hard rocks that have low dips or are flat. The northern benches are cut in sandstones and conglomerates of the Trinidad, Raton, and Poison Canyon Formations and in one great sill of dacite porphyry. The southern benchlands are cut in sheets of basalt. Long narrow ridges that stick out of the plains and benchlands are dikes of dacite porphyry, andesite, or lamprophyre. The hummocky hillsides appear only below steep hillfronts that expose shale, mostly the Pierre Shale. The rugged mountain front is carved on the upturned edges of alternate hard and soft folded and faulted rocks: the ledges are made mainly of dacite porphyry and of sandstones of the Sangre de Cristo, Dockum, Entrada, and Dakota; the valleys are are in soft shales of half a dozen formations. The mountain core is Precambrian metamorphic and igneous rocks. The streams flow away from the mountain core, which has been lifted up in a great arch. The swampy high meadows and natural lakes are nearly all on lava flows.

It may be interesting to look more closely at how running water and geology have combined to make each of the seven kinds of landforms. We will begin with the stream network.

The network of streams

The Cimarron Range was slowly arched up many thousands of feet in middle and late Tertiary time, and the large streams drain away from its crest simply because they are flowing downhill. The range itself, unlike many ranges, does not exist because of stream sculpture but in spite of it. The streams are destroying the range but have a long way to go. A look at the landform model and at the streams themselves shows that they are doing their destructive work not only by cutting both downward and sideways but also by growing longer and by adding tributaries. They have been doing this from both sides long enough to score the range deeply and to narrow its crest but not long enough to make sharp peaks—the summits are flat rather than pointed. The pattern the streams have made is like a great oak leaf, having Cimarron Creek as its stem: each stream junction is a V pointing downstream, except along the mountain front between Cimarroncito Creek and Ute Park Pass, where the large tributaries run parallel to the front and to each other, like a trellis.

How a leaflike, or treelike, drainage pattern starts is easy to observe at Philmont. Watch what happens in a heavy rainstorm to any smooth but sloping surface underlain by loose sand or soft shale, such as one of the drainage ditches along Highway 21 or the front of a bench on the lowland plains. At first the whole surface may be flooded by a sheet of water that soon becomes muddied by bits of shale. As the storm continues, the rushing water begins to scoop out the softest places, and tiny rills start to form parallel to the slope; once formed, such rills tend to deepen fast and become fixed because they are low places toward which more and more water flows. Soon some of the rills become rivulets, running in miniature V-shaped canyons. Then, in the same storm or later, tributary rills start to grow by branching from the rivulet and cutting back into the walls of the little canyons (fig. 122) not at random but angling downstream. This is because the tributary grows in the direction of fastest flow, which is down the steepest slope of the canyon wall. If the main rivulet had no slope, the path of the tributary rill would be at right angles to it; but the rivulet slopes downstream, so the steepest path for a tributary is not at right angles to it but slanting downstream. Before long the surface is cut up by a network of branching gullies, as in this view (fig. 123), just upstream from Webster Reservoir, of a lowland bench just starting to be dissected.



HOW LEAFLIKE DRAINAGE PATTERNS are formed by streams starting on smooth and uniform rock. Tributaries grow not at random but angling downstream, in the direction of steepest slope of the valley walls of the main stream. (Fig. 122)

GULLIES CUT BY SEASONAL STREAMS in the upper edge of the lowland plains east of Cimarroncito Creek just above Webster Reservoir. (Fig. 123)

It is not hard to visualize such a network extending itself over a plain of any size underlain by uniform rock, given enough time. But the exposed rocks of Philmont are wildly far from uniform. And, as every dacite ridge and sandstone cliff shows, where the rocks are not uniform the drainage becomes concentrated in the softer rocks, which wash out, leaving the harder rocks as ledges. The resulting drainage pattern is not leaflike but reflects the outcrop pattern of the resistant rocks. Thus, little streams run parallel along that part of the mountain front where the steeply upturned edges of dacite porphyry sills and sandstone formations are parallel, and some of the anticlines and synclines in southeastern Philmont are outlined by small streams.

If little streams are so much influenced by rock structure and grow to be big streams, how is it that the perennial main streams and their larger tributaries cut heedlessly in treelike drainage patterns across folds and faults over so much of Philmont and are affected, apparently, only by the largest structure, the arch of the Cimarron Range?

One possibility is that the large streams are older than all the structures but the main arch. Perhaps they began flowing in about their present course before the smaller structures formed and were so well entrenched that they were not diverted by folds and faults that grew slowly across their paths. This is an attractive idea that explains some puzzling stream patterns elsewhere, but it does not fit Philmont very well. If true, it would mean that the streams were well established not just on the plains but in the mountain core in early Tertiary time, for the main time of folding and faulting was well back in the Tertiary Period. By 20 or 30 or 40 million years ago, then, the heads of streams like Ponil, Urraca, and Rayado Creeks would already have reached within a few miles of the crest of the Cimarron Range. Now, of these streams, Ponil Creek, flowing over the Poison Canyon Formation, could not have existed at all, at least not as a carver of landscape, until after Poison Canyon time, 50 or 60 million years ago, as the Poison Canyon was originally deposited over a much larger area than it now covers, probably including southern Philmont; the same, no doubt, applies to all the other streams. The streams were able in a few tens of million years to extend themselves only tens of miles, from the original east limit of the Poison Canyon rocks into the mountain core. In a comparable length of time since the main deformation, they should have been able to extend a few miles farther and deeply notch the mountain crest; but only Cimarron Creek has done so.

Rayado Creek offers direct testimony that the main streams are not older than the mid-Tertiary deformation, but much younger. If there was an early Tertiary Rayado Creek system, it was buried under lava in late Tertiary time, and so were the eroded edges of folds in the sedimentary rocks. Yet in the few million years since the lava flowed, Rayado Creek has been able to establish a drainage system just as complex as that of its neighbors, Urraca and Cimarroncito Creeks, and to dig in just as deeply. The conclusion is hard to excape that the main streams of Philmont, except possibly Cimarron Creek, are no older than late Tertiary and are a great deal younger than the folds they cross.

Rayado Creek also shows how streams can turn the trick of avoiding control by structures older than they are. Rayado Creek clearly started its leaflike drainage pattern when it was running on basalt that dipped gently eastward. This pattern was so deeply grooved that it was preserved after the stream cut through the basalt, even after the basalt was stripped entirely away from the plains, and the creek now runs unconcernedly across prebasalt structures. The leaflike drainage of Rayado Creek is therefore inherited from a time when the creek ran on uniform rocks. To the stream, the folds and faults beneath the prebasalt unconformity *are* younger. On the other hand, the Rayado stream system has been much affected by faults younger than the basalt, as the zigzag courses of lower Agua Fria Creek and of part of Rayado Creek itself attest.

The drainage pattern farther north can be explained in a similar way. The basalt cap seems never to have extended much farther north, but other unfolded, fairly uniform rocks once did, as our discussion of "Missing Layers" brought out. The present oakleaf drainage pattern seems to have been first imprinted in late Tertiary time on thick unresistant sands and gravels that covered most, perhaps all, of Philmont. Once set, the large streams held their courses across the structures that were revealed as the unresistant blanket of loose sediments was stripped away. Only the paths of young tributaries that started after the folds and faults were exposed are controlled by these structures.

The general stream pattern at Philmont is not much influenced by the rocks that the streams are now running across, but each stream is. Its valley and channel respond strongly to the kind of rock the stream crosses, as we shall see in considering each landscape element.

The special history of Cimarron Creek

Cimarron Creek is different from the other creeks and must have had a different history. The other creeks are still chewing away at the east side of the Cimarron Range, but Cimarron Creek has cut clear through the range and has lowered its bed so much that it falls only about 70 feet per mile in crossing Philmont; nearby Cimarroncito Creek, in comparison, falls something like 250 feet per mile across Philmont.

How Cimarron Creek has been able to scoop its canyon so much deeper than other Philmont streams and why it is the master stream of the area seem plain: Cimarron Creek has so much more water to work with. The headwaters of the other creeks drain only a few square miles, but the headwaters of Cimarron Creek drain all of Moreno Valley—300 square miles of low country between the Cimarron Range and the Sangre de Cristo Mountains (fig. 124).

But how did Cimarron Creek manage to capture the waters of Moreno Valley? Where did the streams of Moreno Valley go before Cimarron Creek cut through the range? Or has the Valley been scooped out entirely since late Tertiary time? From what we have learned at Philmont alone, we cannot tell. Others have studied Moreno Valley briefly, however, and have sketched a remarkable story, that makes sense though many details are obscure.

In middle Tertiary time, Moreno Valley did not exist (fig. 124*A*). Instead, a vast blanket of Poison Canyon and younger streamlaid rocks stretched far to the east from the flanks of the Sangre de Cristo Mountains. Later, the Cimarron Range began to rise, and Moreno Valley formed where the land sank between two steep north-south faults (fig. 124*B*). Streams that had flowed far eastward from the Sangre de Cristo Mountains were blocked by the new range but found outlets at the south end of the valley. They began stripping the Tertiary gravel off valley walls and from the valley floor. Then, near the end of the Tertiary, the southern exit too was blocked, by floods of lava (fig. 124*C*). Trapped, the streams became sluggish, and the valley became a swamp or lake that began to fill with sediment.

Eventually, in early Quaternary time, Cimarron Creek, cutting steadily westward, breached the range. Why Cimarron rather than some other Philmont creek was the first to cut through the Range crest is not known. A fair guess is that Cimarron Creek was already the master stream during late Tertiary erosion, and it is shown this way in figure 124*B*; but this only pushes the question back in time. Perhaps the range was most easily breached here because it was broken by east-west faults; perhaps, too, a creek working eastward from about the site of Eagle Nest Dam helped to breach it. Before long the head of Cimarron Creek became the lowest place in Moreno Valley, for only its tributaries had much fall and could do much cutting. Soon all the streams in the valley became tributaries of the Cimarron. The waters that had once flowed east, and then south, again flowed east.

The now faster running tributaries in Moreno Valley began to dissect and remove the lake and swamp deposits and the bedrocks as well. By the time the first Indians came to Moreno Valley, an organized network of streams joined near what is now Eagle Nest and poured eastward into Cimarron Canyon.

Hundreds of years later, early in this century, European men, needing water for irrigation, mining, and recreation, built a dam across the upper canyon; and Eagle Nest Lake came into being (124*D*).

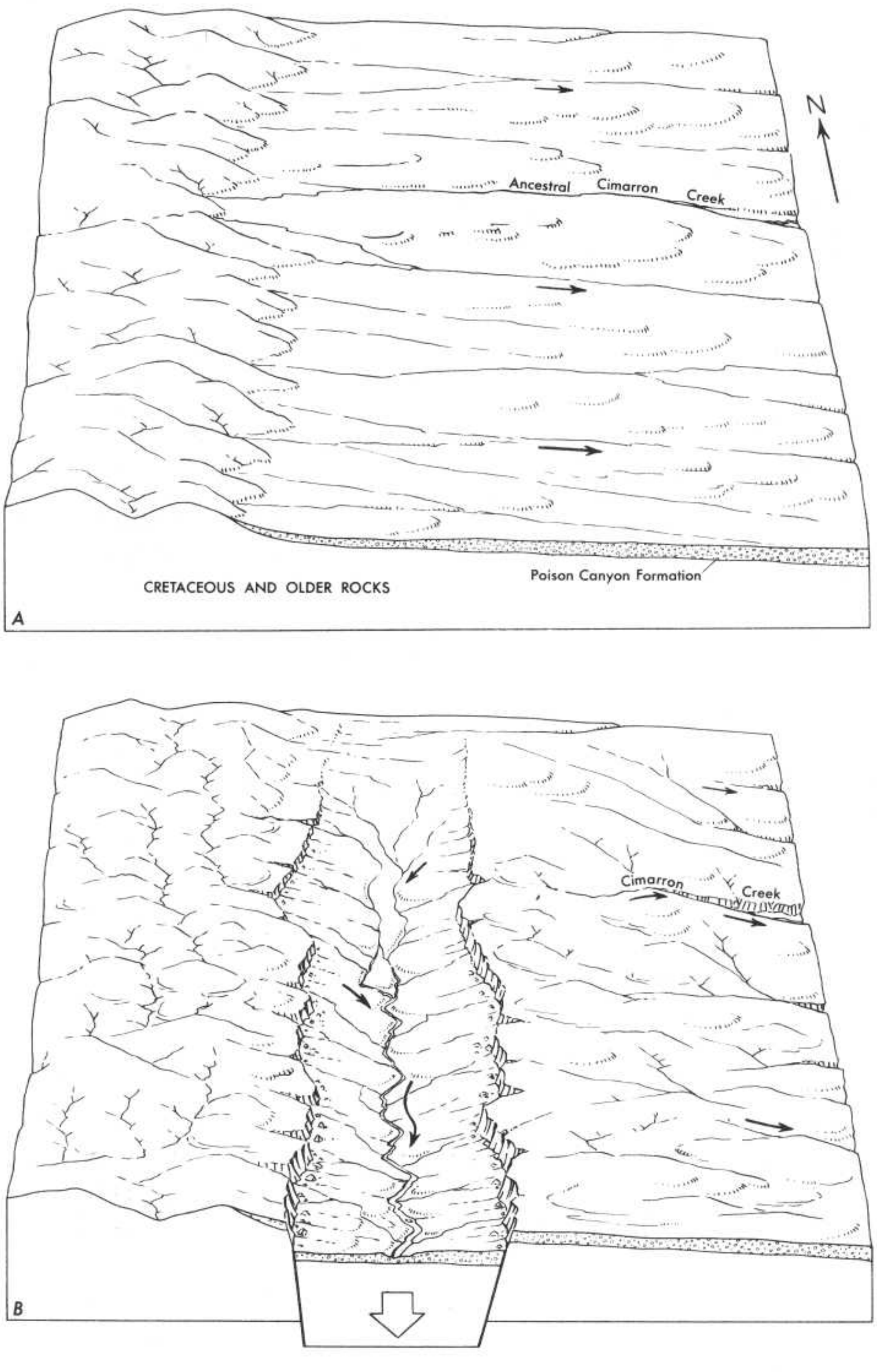
The high benchlands

Now let us consider the origin of the high benchlands, certainly the most widespread kind of landform at Philmont and perhaps the easiest to understand. Although they look much alike from afar, the northern benchlands are very different from the southern and will be discussed separately.

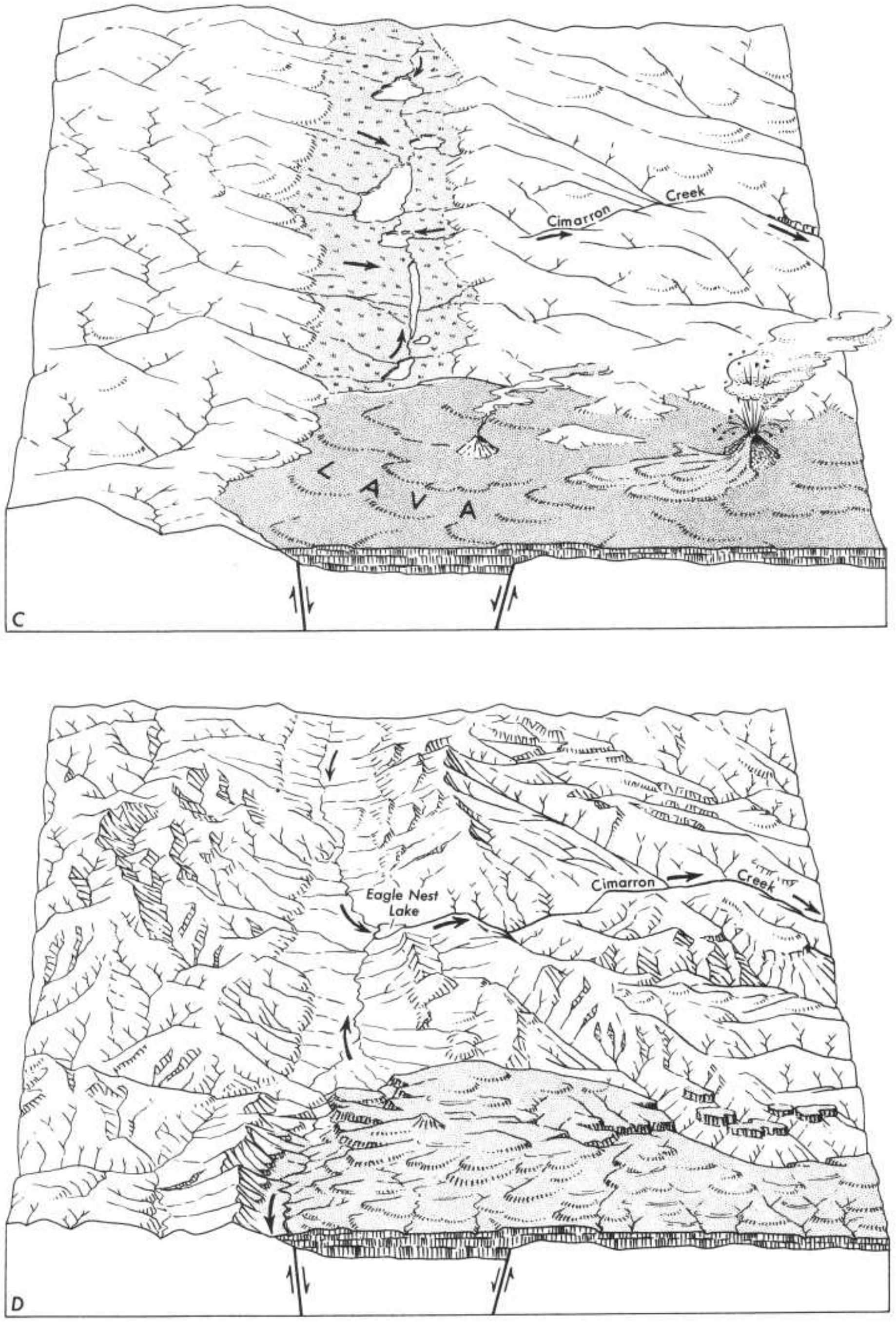
The northern benchlands

Each of the benches north of Cimarron Creek is topped by a layer of very hard sandstone or conglomerate, except for Wilson Mesa, which is topped by a sill of dacite porphyry. At the base of each bench is a thick soft shaly bed, usually concealed by brush or by slide rock. The shale, made of small soft particles that separate easily, has been rapidly excavated, so that a sandstone bench is left below; and the sandstone or dacite layer above is undercut. With its support gone, the hard rock has slabbed off along joints, making the steep bench fronts.

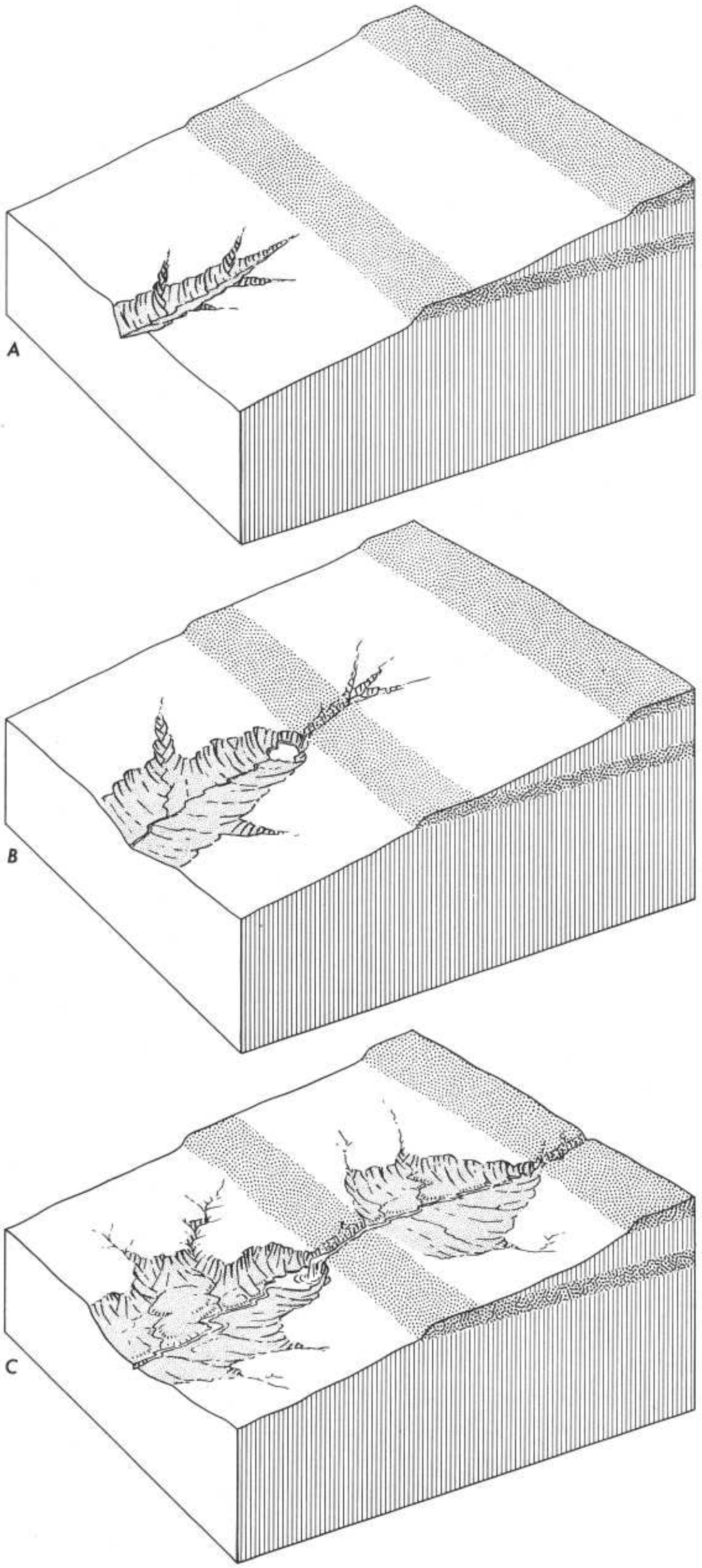
Very soon, the steep bench fronts would disappear, buried in their own rubble, if tremendous volumes of sandstone and shale were not constantly being removed from the scene. We already know one way this might be done: by the alternate sidecutting and downcutting of streams. Is this a workable explanation? To test it, we cannot actually watch a stream cut a bench, but we can do nearly as well by studying gullies of different lengths and depths in a benchland stream canyon.



HOW CIMARRON CREEK CAPTURED THE WATERS OF MORENO VALLEY. A, In middle Tertiary time, Moreno Valley did not exist. Streams flowed east over a blanket of Poison Canyon and older bedded rocks. B, Later, Moreno Valley was created by sinking along north-south faults as the Cimarron Range was rising. Streams that formerly crossed the site of the valley were blocked by the rising Cimarron Range and turned south.



C, Near the end of Tertiary time, the southern outlet was blocked by outpourings of lava. The trapped streams became sluggish, and the valley became a swamp or lake, slowly filling with sediment. But streams from the east, especially Cimarron Creek, were slowly working their way into the Cimarron Rqnge. D, Eventually, Cimarron Creek breached the range and captured the waters of the valley, allowing them once again to flow east. Recently, the outlet was dammed to make Eagle Nest Lake. (Fig. 124)



HOW STREAMS GROW IN THE NORTHERN BENCHLANDS. A, Gully starting in soft shale. B, Stream, growing longer, begins cutting in hard sandstone. C, Valley becomes steplike—wide and nearly flat in shale; narrow and steep in sandstone. (Fig. 125)

Start with a smooth canyon wall, such as a new roadcut. Exposed are the edges of alternating beds, each a few feet thick, of shale and sandstone, starting with shale at the base (fig. 125). Beginning in the soft shale, a new stream works rapidly and soon cuts a wide notch (fig. 125*A*). As the stream gets longer and climbs up the canyon wall, it reaches the sandstone above the shale. In the harder, better cemented rock, it cannot cut as rapidly, so it makes a narrow notch that has a much steeper slope than that in the shale (fig. 125*B*). As the growing stream, now carrying particles of hard sand, flows over the shale, it cuts even faster than before at the upstream edge of the shale and soon has scooped the shale out, except where it is protected by the sandstone, and a small waterfall forms (fig. 125*C*). Still growing, the gully meets another shaly bed in which the fledgling stream can again cut rapidly. The edge of the succeeding hard sandstone bed slows the flow so that the stream spreads out and cuts sideways in the shale as well as back.

In this way the stream lengthens its valley unevenly—cutting steeper narrower stretches across harder beds and flatter broader stretches across softer beds. Where the stream flows over the edge of hard layers, it makes little rapids or waterfalls; but across the shale it flows more quietly. At the bottom of its fall, where it is flowing fastest, the stream cuts fastest too, so that downcutting is greatest at the upstream edge of the shale outcrop and slowest at the downstream edge. Streams, then, can cut wide benches in nearly flat beds by stripping soft rock like shale off hard rock like sandstone.

The beds of the large streams also steepen across sandstone and flatten across shale. This is not so obvious as on small streams, because the large streams, during floods, have dumped gravel in their flatter stretches, smoothing out and concealing changes of slope in the bedrock floor.

Ponil Creek and its tributaries surely have cut their own valleys. In doing so they have left gravel and sand on the valley floor and on the terraces—former valley floors—that wind along on both sides of each stream. But did these streams also cut the broad benches that now rise above them? If they did, the evidence is well hidden. Except next to flood plains, there is no sign that organized streams have ever been at work on the broad benches, for there are no abandoned stream channels and none of the kinds of deposits that streams make. In fact, there is little loose rock of any kind except for angular chunks of sandstone and conglomerate that have fallen from the cliff face and are nestled in little piles at its base.

By watching what happens during a summer storm or a heavy spring thaw, we see how the cutting and moving are done. Sheets of water, muddied by particles of shale, quickly collect at the base of the benches and sweep across them, picking up sand and pebble-size chunks and moving them a little toward the low edge of the bench. Remember that the benches, though they seem to be flat, actually have slopes of several degrees, or several hundred feet to the mile. This is greater than the slope of the bed of either Cimarron or Ponil Creek and is in the same class as the average slopes of Rayado, Cimarroncito, and Urraca Creeks, which are quite capable of moving pebbles.

Often, the water in the sheet disappears by sinking into the ground before it can flow over the edge of the bench; but in storm after storm the rock fragments move ever closer to the cliff edge, eventually falling over and then rolling or creeping to the next bench, to go through the sheetflood procedure again, and finally to reach the stream valleys. So, in a rainy spring, do autumn leaves on a sloping lawn move in a sheet toward the street, until they reach the stream channel of the gutter and are swept away. Rock fragments seem to break off the ledges of northern Philmont at such a slow rate and in such small sizes, and sheet floods are so many and so strong, that the benches are kept nearly free of debris, and their rocky fronts remain steep as they retreat.

The number and height of steps that form in this way depend entirely on the number and thickness of hard and soft layers. Because benches like these are controlled by the bedding and structure of the rocks, they are called structural benches.

We decide, then, that the northern benchlands are carved in gently dipping beds of varying hardness mainly by gravity alone, combined with seasonal sheet floods. The big job of streams has been to haul away the debris, though the streams have surely deepened and widened their own valleys.

As they climb westward, the benches change a good deal in detail. Lower down, in eastern Philmont, bench edges are sharp and clear, as figures 41 and 48*A* show. Because rainfall is sparse, there is little soil and vegetation to slow erosion and to round corners of the benches by chemical decay. Higher, where more abundant rain and snow support open forest (see figs. 7, 9), the sharp edges of the benches are rounded, and the bench fronts are less steep. Still higher, where the forest thins out, the bench edges are also rounded, even though the rocks are bare and there is little chemical decay. (See fig. 76.) Above timberline the temperature goes below freezing almost every night, and the rocks break up by frost action faster than sheetfloods or wind can remove the pieces; so the benches are swathed with sharp-edged rock chips and blocks.

Deer Lake Mesa: Hollowed by the wind?

The top of Deer Lake Mesa (fig. 3) seems not to have formed in the same way as the bench tops north of Cimarron Creek. It is capped by the same rocks that cap the other benches but, unlike them, does not slope smoothly toward the nearest large stream. Instead, Deer Lake Mesa slopes gently inward to form two shallow undrained depressions: Devils Wash Basin, an intermittent lake, and Deer Lake, which is permanent. These basins were certainly not made by running water, either in sheets or in organized streams. Running water does not make depressions but destroys them, either by filling or cutting. Earlier, we thought these depressions might reflect synclines. Are they, then, simply the direct result of downfolding? Possibly, but this would mean recent folding, which is unknown elsewhere at Philmont. More likely, the folds, if any, were made in late Tertiary time when all the other folds in the Poison Canyon Formation were made. Since then, most of the Poison Canyon has been removed (only about 500 feet of it is preserved on the mesa), and not wholly by running water.

If the depressions were not hollowed by streams or bent down by recent folding, perhaps they were made by wind, one of the very few surface agents that can move particles uphill and thus leave a depression. Strong winds, sweeping off the main range of the Sangre de Cristo Mountains and channeled by Cimarron Canyon, may have scoured out fine-grained beds that were once in the cores of the basins. Today, a thin but stubborn cover of soil and vegetation prevents much wind erosion around Philmont. If wind was responsible, it must have done the job when the climate was distinctly drier even than it is today and when the mesa surface was bare rock. Many wind-scoured depressions are forming today in the world's deserts.

The southern benchlands, their meadows and lakes

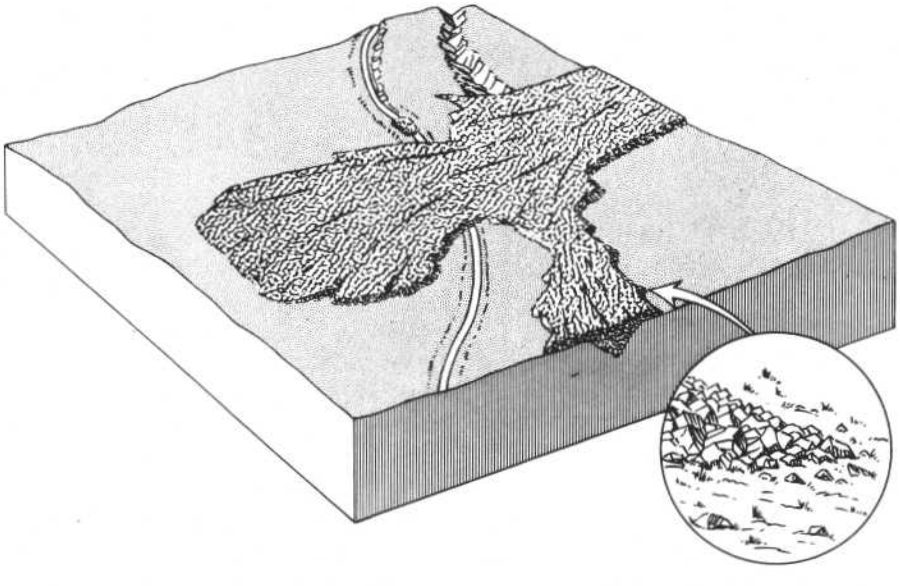
The southern benchlands are like the northern ones in some ways but unlike them in others. They have steep sides and are nearly free of stream deposits, but their tops are rolling rather than smooth, have much more soil and vegetation, and are dotted with marshy meadows and lakes (figs. 12, 20*B*, 20*C*); also, their streams are fewer and smaller. These differences reflect differences in both rocks and structure; the southern benchlands are in slightly tilted basalt rather than in gently folded sedimentary rocks.

Because of the way it forms, basalt lava can build benchlands without the help of water or wind merely by piling up on the surface after filling in the low places. The hot lava, though a liquid, is very much thicker than water and has a freezing temperature about 2000° F. above that of water, so it flows slowly and congeals quickly. No eye-witness accounts, or even legends, tell of lava flowing at Philmont; but eruptions of basalt are common affairs in many places, especially on the borders of the Pacific Ocean and on Pacific Islands, so we can be sure of what happens when lava makes benches.

Soon after a tongue of lava, white-hot, pours out of a crater vent or a fissure, its top, bottom, and sides freeze into a black crust. Insulated by this crust, the lava within stays molten and creeps downslope like a moving stone wall or a tractor, flowing over a floor of its own crust, here pushing blocks and plates of broken crust before it, there breaking through and gushing over the crust, only to freeze at once and make new crust. Before long, a big flow fills in the low places that guided it at first. It becomes a sticky river, flowing on a self-made bed and between self-made banks, perhaps many feet above the ground it started on (fig. 126). When it finally stops, because no more lava is supplied from below, it has formed a steep-sided bench or mesa and has a top that is rough and irregular and is pitted by many depressions that can hold rainwater. The edges too are a jumble of broken blocks; the familiar pencil-shape joint blocks on old flows are the sides of cooling columns from well inside the flow that have been exposed by erosion of the original rough edge. Later a flow may be buried by a larger flow, but successively smaller outflows may build a series of bench steps.

The single lava flow of which Rayado Peak, Fowler Mesa, and Urraca Mesa are the dissected remnants is such a constructional bench (fig. 45). The highest bench of the several that make Ocaté Mesa was also built rather than cut. The lower benches may have been also, but the evidence needed to be sure of this is hidden under soil, vegetation, and slide rock; possibly, some or all of these benches have been eroded from alternate resistant and unresistant layers of volcanic rocks and thus are structural benches like the northern ones.

Even the first lava flows were poured out on a smooth, gently dipping surface, for their floors are parallel to their smooth and gently dipping tops; and no lava seems ever to have flowed into any canyons, ancient or modern. Here and there, a little typical stream



RIVER OF LAVA freezes to make a bench. The inset is a close-up of the jumbled blocks of broken crust at the edge of a new lava flow. (Fig. 126) gravel is found between the lava and the underlying shale bedrock and is good evidence that the prelava plain was cut by streams—the same streams, no doubt, that stripped the Tertiary rocks from southern Philmont. The lava flows, therefore, not only made new benches but protected an old one.

The southern benchlands have more soil and vegetation partly because the basalt has low dips and many original depressions, so that rainwater stays longer and does more in the way of chemical decay than it does on the northern benches, but mostly, perhaps, because of the nature of basalt. Basalt is rich in magnesium, iron, calcium, and other metals needed to make fertile soil, and the glass of which it is mostly composed quickly weathers to clay if there is plenty of moisture. The small part of the Ocaté Mesa included in Philmont is high, fairly rainy country; so its basalt, which is probably a few million years old, is deeply weathered and supports much vegetation. (Just to the south, basalt flows extend several miles out onto the dry plains; and there the basalt, despite its age, is only slightly weathered and supports only a little grass.)

How is it that so many marshy meadows and lakes exist on the Ocaté Mesa although streams have been able to drain nearly all such places elsewhere on Philmont? It is partly a matter of time, for before any streams had started to run in the basalt, streams in northern Philmont were well organized and working away. It is partly a matter of surface slope also, for the streams in northern Philmont have always had steeper slopes to flow down than those in the basalt; therefore the northern streams could flow faster, cut more, and grow faster.

It is also a matter of the nature of the basalt itself. The new basalt was honeycombed with cooling cracks. Instead of running off the surface in sheets and streams, rainfall and melt water sank into these cracks and disappeared into the ground, so that streams formed slowly. And because the basalt weathered so easily, it soon grew a protective blanket of soil and plants that took over the job of slowing stream growth.

The lowland plains

The lowland plains are carved into giant steps like the benchlands that flank them (fig. 8). The steps are still forming on both benchlands and plains: bench fronts are slowly retreating, and the lowest steps—the flood plains of present streams—are being widened, lengthened, and coated with more and more gravel and sand. Plainly, the benches in both kinds of landscape have been growing side by side for a long time. Nevertheless, they are very different and cannot be accounted for in the same way. The steps on the plains are cut almost wholly in soft shale, so they are not due to differing resistance of bedded rocks. They cut smoothly across large folds that bring up not only shale but hard limestone, so they are not controlled by the dip of the bedded rocks. And they are covered by a thin but nearly continuous blanket of somewhat rounded gravel and sand of the sort deposited by organized streams, so they apparently are not the product of gravity fall and sheetfloods. They seem, then, to be stream terraces.

The origin of the plains comes down to two questions: what streams planed off the shale and veneered it with gravel and sand? Why, in fairly uniform material, did downcutting alternate with sidecutting to make steps? We have not done enough work to be sure of answers, but we can at least discuss some of the possibilities.

At first glance, the nature of the responsible streams seems obvious. Surely the same east-flowing streams that exist today cut and almost simultaneously capped the benches by wandering back and forth over the soft shale after leaving their canyons in the hard mountain rocks. The eastward slope of the terraces seems to fit this idea. But it is not that easy. We have already reasoned that the streams have a leaflike drainage pattern because they are a carbon copy of drainage that started on a surface of uniform unfolded rocks that are now washed away. If the mountain streams had slowed down enough to wander much from their early paths, they would have been influenced by the folded structures, especially where the folds bring up hard limestone; and the oak-leaf drainage would not have lasted very long—yet it has persisted long enough for many cubic miles of shale to wash slowly away in the cutting of the plains, and long enough for several cubic miles of sand and gravel to be dumped on the cut surfaces. The eastward slope, which is very steep for meandering streams on soft rocks, is very likely the result of Quaternary uplift of the Cimarron Range.

An alternative to east-flowing streams is the Canadian River, which flows south parallel to the mountain crest and is the master stream of a region much larger than Philmont (fig. 1). Suppose that the Canadian River, in early Quaternary time, flowed on a flood plain a mile or two wide close to the mountain front, and suppose also that the ancestors of the present streams emptied into it there. As the mountains rose on the west, the eastward slope caused the Canadian River and its flood plain to shift eastward; and the mouths of the tributaries also migrated eastward, across loose gravel of the earlier flood plain. If this is true, our ideas on the origin of leaflike drainage east of the mountains will need to be modified: the drainage has been inherited directly from a pattern formed on Quaternary rocks rather than on Tertiary ones.

This idea also can be used to explain the steps. Suppose that the Quaternary rise of the range was not smooth but was in a series of jerky steps, having long pauses between. Each pause would produce wide gravel-clad flood plains. Each rise, by increasing the slope of the tributaries as well as by shifting the main river eastward, would cause the streams to dissect their flood plains, leaving terraces.

This sounds fine, and it may even be true; but there are other ways besides steplike uplift to make streams alternate between downcutting and sidecutting, ways that cannot be disregarded in our state of ignorance. Consider a few.

Suppose, for example, that a steep fault having many feet of vertical movement broke across the Canadian River not far downstream from Philmont. If the downstream side rose, the river might be dammed to form a lake. As long as the lake existed, the speed of the stream and its tributaries would be greatly reduced; and the streams would start cutting sideways, drop their loads, and produce a gravel-topped flood plain. When the lake was destroyed, by filling or by breaching, the main river would resume speed and begin cutting down; the tributaries would do the same, leaving the old flood plain as a terrace. A lava flow across the river could have the same effect.

If, however, the downstream side of our hypothetical fault dropped, the result would be a waterfall or a rapid. The fall of the river upstream would increase, and general downcutting by both river and tributaries might follow, until the waterfall had been reduced to a normal slope for the river. If downstream faults or lava flows are responsible for the terracing of the plains, they have so far escaped detection.

Persistent changes in climate, either to wetter or drier, can also cause streams to cut and build terraces. Suppose, after a single broad flood plain was built in a dry climate, that the rainfall increased markedly. More and higher floods would lead at first to more erosion, and the flood plain might be dissected, leaving a terrace. But heavy rainfall continued for centuries would lead to deep weathering, thick soil, and dense plant cover. In turn, soil and plants would retard erosion and lead to another episode of side cutting.

Now suppose that the building of a single broad flood plain in a rather damp climate is followed by long drought. At first stream flow would be reduced and deposition increased, merely extending the flood plain or thickening its gravel cover. Soon, however, the plant cover would thin, and erosion would become easier. As the use of water by plants declined, the amount of water in the streams would actually increase, and the flood plain would be dissected to become a terrace. In a small way this is now happening at Philmont, which, like the rest of the Southwest, is in a dry period that started about 1850; many streams have cut down several feet, and hosts of new gullies have scarred the plains. (See fig. 123.)

Long wet periods alternated with long dry ones in earlier Quaternary time as vast ice sheets from centers in Canada advanced and retreated on the Great Plains. These climatic changes may have been responsible for some or all of the terrace steps, after the highest plains surface was cut.

It is even conceivable that, despite the evidence of the stream gravel cover, the higher benches of the plains were not cut by streams at all. Perhaps, as the range rose, shale between stream canyons was stripped by sheetfloods and slow earth flow, just as on the northern benches, and wandering streams dumped gravel on them later.

Landscape puzzles can be as difficult and intriguing as structural puzzles.

Waterfalls and mountain meadows

In the mountain core, stream valleys flatten and widen out in the metamorphic rocks upstream from hard-rock ledges of sandstone and dacite porphyry; stream channels are shallow and broad, and the streams wander sluggishly across the valley floor. Bonito Creek, the largest stream that heads in metamorphic rocks and crosses the mountain front, has cut down so far in the metamorphic rocks near the front that its valley has become a long meadow (fig. 127). But the stream valleys narrow and steepen abruptly where they cross the hard-rock ledges. Stream channels become narrow and deep, and the water, swift; rapids form where the channel crosses narrow ledges, and waterfalls form where it crosses wide ones. This suggests that the metamorphic rocks are more easily eroded by streams than are the sandstone or dacite porphyry. In turn this seems to tell the same story that the benchlands told: the waterfalls at the mountain front and the ledges that extend beyond the waterfalls may be structural benches cut on the bias.

The evidence of geologically late uplifts in the region, however, leads to a different possible explanation of the mountain meadows along middle Bonito Creek. Perhaps Bonito Creek once reached a stage at which it flowed through an ever widening valley across metamorphic, sedimentary, and igneous rocks alike to its junction with the Canadian River. Then a pulse of mountain uplift started a wave of downcutting that has worked its way headward only as far as the present mountain front, so that the meadows are the remnants of an older, interrupted episode of valley widening.

The future of waterfalls is interesting to consider. The waterfall best known to Americans is Niagara Falls, which is in flat rocks; everyone has heard or read that it is retreating upstream, and it is natural to assume that all falls do the same. Waterfalls in flat-lying rocks *do* retreat upstream. But in rocks that dip, the matter is more complicated. If the dip is upstream, or is downstream but at an angle lower than the slope of the stream channel, falls retreat as in flat beds. If the dip is downstream, though, as it is along nearly all the mountain front, the falls will advance. Falls across vertical beds, as on South Fork Urraca Creek, will not migrate at all.

The marshy meadows along lower Agua Fria Creek (fig. 10) at the junction with Rayado Creek look like those on upper Bonito Creek, but they cannot have had the same origin; for there are no hard sandstone or dacite ledges just downstream, and Rayado Creek valley does not have a broad meadow reach near the junction. Agua Fria Creek has been able to cut its bed down faster than other streams in the Rayado Creek system, so that it meanders sluggishly on a marshy flood plain, partly because it is running in crushed rocks along a fault and partly because it drains a much larger area than the other creeks and so has had more water to work with. Agua Fria Creek is reminiscent of Cimarron Creek, which has cut its bed much lower than neighboring streams for apparently the same reasons.

MOUNTAIN MEADOWS where Bonito Creek runs on metamorphic rocks, upstream from hardrock ledges at the mountain front. (Fig. 127)

The rugged mountain country

The mountains begin where hard layered rocks—Dakota Sandstone and dacite porphyry sills—crop out and dip 25° or more. The most rugged mountains are not deep in the range but at the very front, where these same moderately to steeply dipping hard layers alternate with soft ones of shaly rocks. The highest part of the mountain country, Touch-Me-Not Mountain, is held up mostly by thick sills of hard dacite porphyry that have moderate to low dips near the crest of the Cimarron Range anticline. Even the shale between the sills is a fairly hard rock, because it has been baked and hardened by the intrusions. It seems clear that the mountains exist because their hard rocks have been arched up, faster than streams could strip them away, in a great surge in middle Tertiary time and in many lesser pulses since.

At first glance, the Precambrian metamorphic and igneous rocks in the mountain core do not seem very resistant to erosion, judging by the general roundness of the terrain, the scarcity of outcrops, and the many small closely-spaced streams. All this surely means that weather and water easily attack these rocks at the surface through the countless openings