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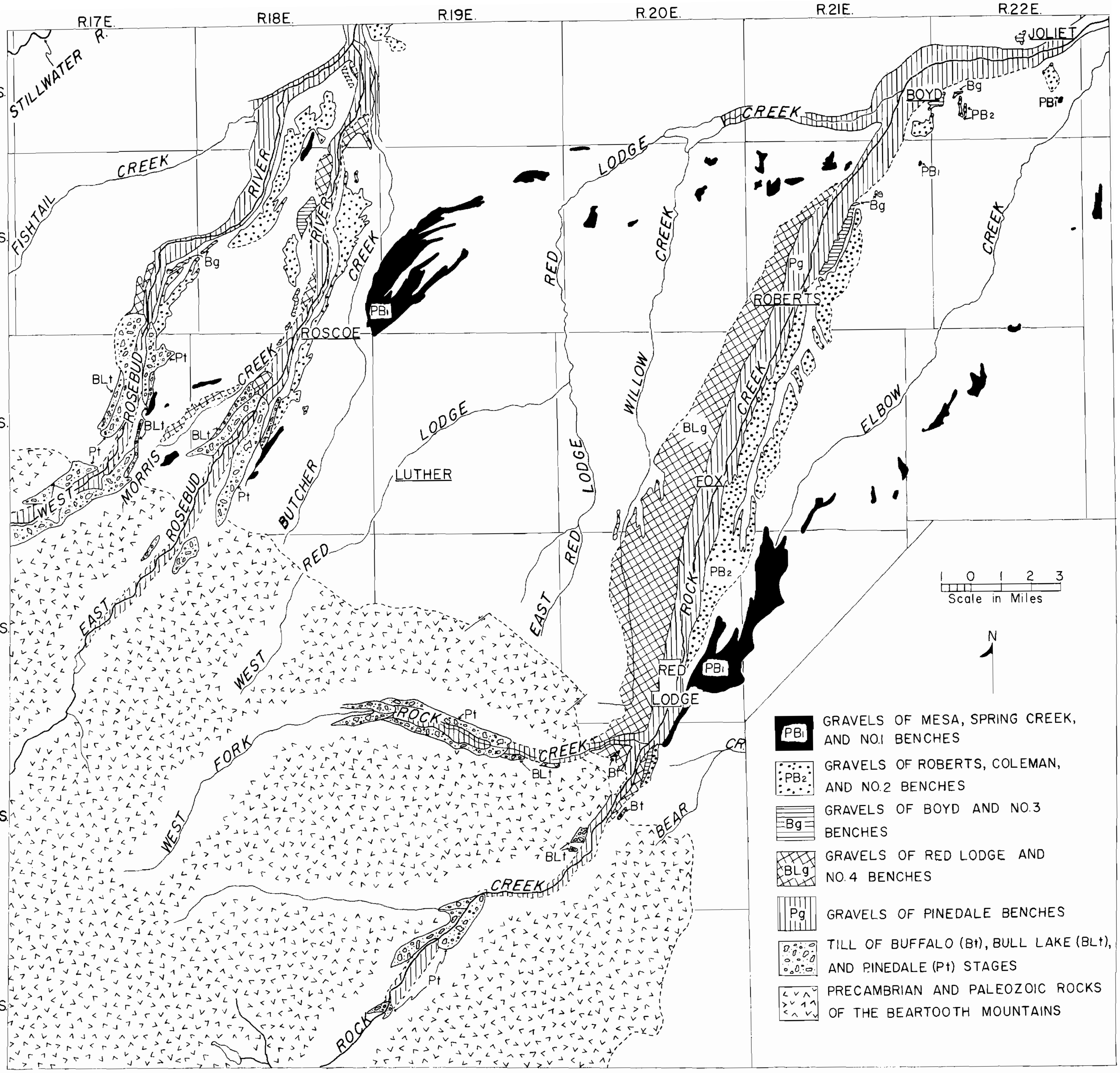

DISTRIBUTION OF GLACIAL AND TERRACE DEPOSITS OF THE MAIN STREAMS HEADING IN THE EAST FLANK OF THE BEARTOOTH MOUNTAINS, SOUTHERN MONTANA

Deposits of the tributary streams are not shown (*see* Fig. 1 for location).

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Terrace Development along the Front of the Beartooth Mountains, Southern Montana

Abstract: Each major stream rising in the Beartooth Mountains in southern Montana and flowing from the east flank of the mountains to the adjacent portions of the Great Plains formed five distinct, well-developed terrace levels during the Pleistocene Epoch. The terraces are capped by coarse gravel derived from the crystalline rocks of the high-standing mountains; all deposits are fundamentally the same, regardless of elevation above the present stream. The gravel may represent valley fills deposited as the result of stream captures or as outwash during periods of glaciation in the mountains. The origin of any terrace gravel may, therefore, be partly fluvial and partly glaciofluvial.

Piracy of the major rivers by tributary streams heading in the plains would initiate aggradation because the coarse loads of the mountain-bred rivers cannot be transported on the low gradients of the capturing tributaries. Some of the terrace gravels can be traced into and partially through moraines of late Wisconsin age.

During deposition of the highest terrace gravels the rivers in the area drained to the northeast. Before deposition of the gravel capping the next lower terraces, each major river was diverted to a more northerly position. Terraces in any one valley are seldom matched, indicating that downcutting usually occurred in the nonresistant bedrock along the edge of the valley rather than through the coarse gravel deposits. Much of the downcutting may have been accomplished by headwardly eroding tributary streams which subsequently captured the main rivers.

Excavation of the Big Horn Basin began in the late Tertiary, ending a long period of basin filling. This downcutting trend has continued to the present except for intervals of valley filling represented by the terrace deposits.

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INTRODUCTION

GENERAL SETTING: The Beartooth Mountains are an uplifted granitic block, rising abruptly from the Great Plains of southern Montana and northwestern Wyoming, and represent one member in a series of genetically related ranges which partially encircle the Big Horn Basin of Wyoming and Montana (Fig. 1). The northwest-trending Beartooth block, almost rectangular in outline, extends from the Clarks Fork River in northern Wyoming to the valley of the Yellowstone River in Montana. The range is bounded on the north and northeast by the northern portion of the Big Horn Basin and on the west and southwest by the volcanic rocks of the Absaroka Mountains and the Yellowstone Plateau.

The region studied here lies near the northeast corner of the Beartooth block in parts of Carbon and Stillwater counties, Montana. This region is divisible into two distinct topographic units: the high-standing, resistant mountains and the lower bench lands of nonresistant sedimentary rocks.

Several upland erosional surfaces between 9500 and 11,000 feet above sea level, collectively known as the "subsummit plateau" (Bevan, 1925), characterize the mountains and give the crest its remarkable flatness. These surfaces are now isolated into individual plateaus by the valleys of deeply incised rivers. The general level of the subsummit surface in places is broken by hills rising to higher elevations, including Granite Peak, the highest point in Montana (12,850 feet). Bevan (1925) interpreted these higher peaks as remnants of an old, once-extensive surface, the "summit plateau."

Flanking the mountains on the northeast is the gently rolling terrain of the Great Plains, whose elevation is 6000–7000 feet adjacent to the mountain front and gradually decreases to the north and east. Much of the region has undergone an inversion of topography: old valley bottoms now stand as topographic highs, and old divides have been obliterated and in

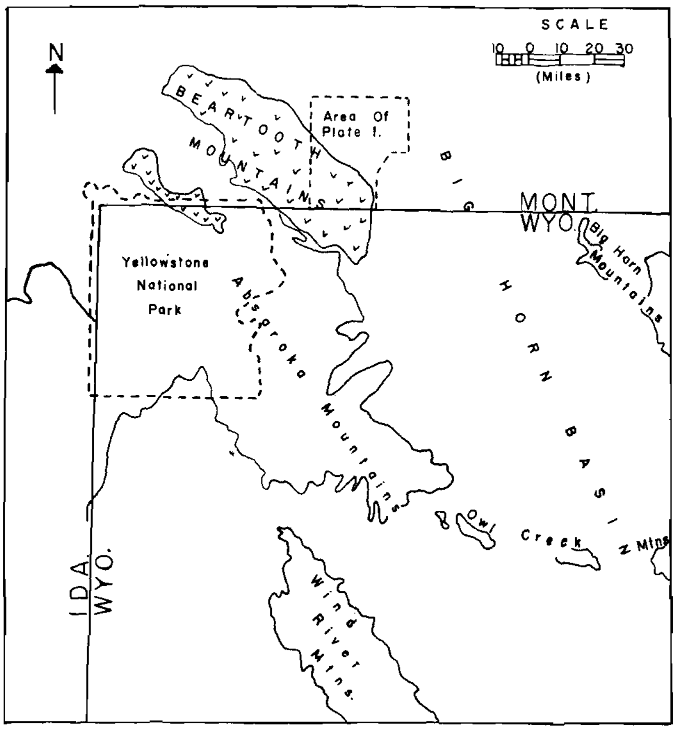

Figure 1. Index map of the region surrounding the Beartooth Mountains, Montana and Wyoming

places are now valley bottoms (Mackin, 1937). Three major drainages are included in the area investigated: Rock Creek, East Rosebud River, and West Rosebud River, all part of the drainage basin of the Yellowstone River (Fig. 2).

Every stream rising in the mountains has formed a series of gravel-capped terraces or benches[1] which extend, finger-like, away from the mountains. Bordering Rock Creek and the East and West Rosebud rivers are five distinct terrace levels, the origin of which is the principal concern of this paper. Remnants of these benches are distributed, in various states of preservation, from the mountains across the area studied.

The areas between the main rivers (Fig. 2) are dissected by small tributary streams also bordered by terraces. The exact relationship between the terraces of the tributary streams and those of the main rivers has not been studied in detail. Thus, the benches on the tributaries are not treated in this report.

STRATIGRAPHY AND STRUCTURE: The Precambrian crystalline rocks which form the core of the Beartooth Mountains were covered by sedimentary rocks when the block uplift began. Almost all this sedimentary pile has since been eroded. Thus, the mountain uplands are underlain primarily by granite gneisses, amphibolites, mafic intrusive rocks, and other resistant crystalline rocks.

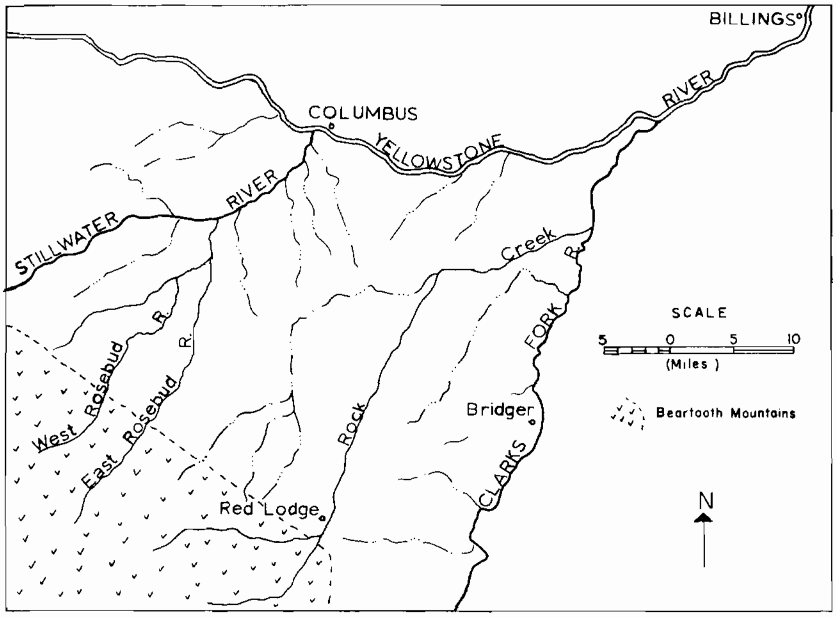

Figure 2. Drainage map of the region near the northeast corner of the Beartooth Mountains

Paleozoic and Mesozoic rocks are approximately 10,000 feet thick and consist mainly of limestones and dolomites (Paleozoic) and fine-grained clastic materials (Mesozoic). Along the mountain front these rocks draped rather passively over the ascending mountain block during orogeny and now dip at very high angles. The carbonates commonly form prominent hogbacks and vertical palisades which clearly delineate the mountain front. In contrast, the clastic rocks are weakly resistant to erosion and, thus, do not form pronounced topographic features. In the region fringing the mountains a thick wedge of nonmarine Tertiary rocks, deposited during and following the orogenic movements of the Beartooth block, overlies the older sedimentary sequence. For greater detail of the pre-Quarternary stratigraphy and struc-

[1] The terms *terrace* and *bench* are often given different connotations. Previous workers in this region, however, have used the terms interchangeably. This practice is followed in this report.

ture of this area the reader is referred to Foose and others (1961).

Quaternary deposits in this region consist of till and alluvium of various types. Alden (1932) correlated the high gravels fronting the Middle Rocky Mountains with the coarse-grained deposits of the Flaxville Plain in northeastern Montana (Collier and Thom, 1918), and hence, the highest benches were commonly thought to be remnants of an extensive late Tertiary erosion surface. Subsequent reports concluded that a late Miocene–early Pliocene age for the highest surface is unreasonable and indicated that a late Pliocene–early Pleistocene age for this surface is more tenable (Mackin, 1937; Horberg, 1940; Richmond, 1960). Recent work (Rohrer and Leopold, 1963) in the southern portion of the Big Horn Basin also strongly supports a Pleistocene age for all the high bench deposits. On the basis of pollen analysis and physiographic reconstruction, Rohrer and Leopold suggested a probable Pleistocene (possibly Pliocene) age for their Fenton Pass Formation which includes the coarse-grained andesitic gravel capping Tatman Mountain, the highest bench remnant in the Big Horn Basin. This gravel stands nearly 1200 feet above the nearby Greybull River. Previous to this and entirely on the basis of physiographic arguments, Alden (1932) dated the Tatman Mountain gravel as Oligocene and Mackin (1937), as Pliocene. If Rohrer and Leopold are correct, the gravels capping the high benches in the region of the present report, standing generally 300–600 feet above the present streams, are probably no older than early Pleistocene and possibly even younger.

No known way of assigning absolute ages to the gravel deposits exists, but relative stratigraphic positions may be related in a general way to the regional glacial sequence. Blackwelder (1915) described three distinct Pleistocene ice advances in western Wyoming, which he named, from oldest to youngest: Buffalo, Bull Lake, and Pinedale. On the basis of weathering characteristics and topographic expression, Blackwelder tentatively correlated the Pinedale with the late Wisconsin of the midwest region and the Bull Lake with the early Wisconsin. The Buffalo, he believed, was related to either the Illinoian or Kansan stage. These correlations are generally accepted.

Although glacial events older and younger than those recognized by Blackwelder have since been reported (for a complete list *see* Richmond, 1965), Blackwelder's study more than half a century ago still provides the basic chronology of Rocky Mountain glaciation. In most areas of the Cordilleran region, three episodes of glaciation are known; most geologists equate these with the stages of Blackwelder's sequence.

In the Beartooth region also, deposits of three distinct glacial episodes have been recognized whose characteristics are similar in most respects to those deposits described by Blackwelder. Thus, the terms Buffalo, Bull Lake, and Pinedale are here retained and are used in the same sense as Blackwelder's original designations.

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DESCRIPTION OF THE TERRACES AND TERRACE DEPOSITS

General Statement

Five well-preserved terraces, at various elevations above the present stream level, characterize each major valley of this region (Table 1). The terraces of any valley are not, in most cases, physically continuous with the terraces in other valleys. The fundamental terrace features, however, are essentially the same for every bench in the region, and the sequence of terrace levels is similar in each valley.

The benches are capped by gravel derived from the crystalline rocks of the mountains. These deposits lie with angular unconformity on the underlying sedimentary rocks of Cretaceous and Tertiary age; but few, if any, of these sedimentary rocks are incorporated into the terrace deposits.

The upper surface of each terrace is flat when viewed across the bench. Exposures in the gravel indicate, however, that the deposits originally possessed minor relief. This relief was destroyed later by the deposition of wind-blown silts, slope-wash materials, flood deposits, or silts from laterally migrating streams.

TABLE 1. TERRACES OF THE MAJOR VALLEYS AND THEIR ELEVATIONS ABOVE THE MODERN STREAM, BEARTOOTH REGION, SOUTHERN MONTANA

Valley and related benches	Mountain-front remnants (in feet)	Basin remnants (in feet)
Rock Creek		
Mesa	275–325	500
Roberts	200–250	240–280
Boyd	150–200	120–160
Red Lodge	120–170	20
Pinedale	Floodplain–20	Floodplain
East Rosebud River		
Spring Creek	400–440	?
Coleman	260–300	240–280
No. 3	90–130	80–120
No. 4	30	20
Pinedale	Floodplain–30	Floodplain
West Rosebud River		
No. 1	400–440	?
No. 2	300–340	260–300
No. 3	150–190	80–120
No. 4	40–60	20
Pinedale	Floodplain–20	Floodplain

Rock Creek Terraces

The five terrace levels along Rock Creek are, from lowest to highest (and youngest to oldest): Pinedale, Red Lodge, Boyd, Roberts, and Mesa. Of these, Boyd Bench is poorly preserved, but the other four are nearly continuous for a distance of 25–30 miles from the mountain front. All the benches trend northward except Mesa Bench, the highest and oldest; its aberrant northeastward trend is important in the interpretation of the origin of the benches, which will be discussed further on.

Figure 3 shows the longitudinal profiles of Rock Creek and its related terraces. Near Red Lodge, 4 miles from the mountain front, all the profiles have similar slopes, but, as pointed out by Mackin (1937, p. 856) and as shown by this figure, the over-all slope of Mesa Bench and Roberts Bench is less than that of the present stream. In contrast, the gradient of Red Lodge Bench is greater than the present Rock Creek so that it merges with the Pinedale Bench north of Roberts. The Pinedale terrace on which the town of Red Lodge is located is not shown on this diagram because it stands only 6–20 feet above the present stream. The profile of Rock Creek represents that of the Pinedale bench, since the two are essentially equal.

East Rosebud Terraces

As in Rock Creek, five distinct terrace levels can be recognized in the valley of the East Rosebud River, although they are not as continuous nor as well preserved as their counterparts near Red Lodge. They are designated, from lowest to highest: Pinedale, No. 4, No. 3, Coleman, and Spring Creek. Their longitudinal profiles are presented graphically in Figure 4. All the benches trend northward with the exception of the highest and oldest, Spring Creek Bench. Calvert (1916) and Alden (1932), who described Spring Creek Bench, showed the large gravel surface northeast of Roscoe, Montana, as the only remnant of the bench. They assumed that during deposition of the Spring Creek gravel, the East Rosebud River flowed parallel to its modern position. Recent studies (Patterson, 1963) and Plate 1 of this investigation, however, show many additional high, flat surfaces northeast of the previously mapped remnant. These surfaces, underlain by crystalline gravel, represent the downstream portion of Spring Creek Bench and indicate that the course of the ancient East Rosebud River did not parallel its present position.

Spring Creek Bench can be traced to the valley of Rock Creek and, with some assurance, across this valley. East of Rock Creek Valley are two gravel deposits which correlate with Spring Creek Bench (Pl. 1): one is 4 feet thick and caps Stormitt Butte, 2 miles south of Boyd; the other is a thin deposit 2 miles south of Joliet. Spring Creek Bench, thus, represents a direct link between the terraces in the Rock Creek drainage and those of the East Rosebud drainage. This relationship gives Spring Creek Bench regional importance.

West Rosebud Terraces

The five bench levels recognized in the valley of the West Rosebud River are designated,

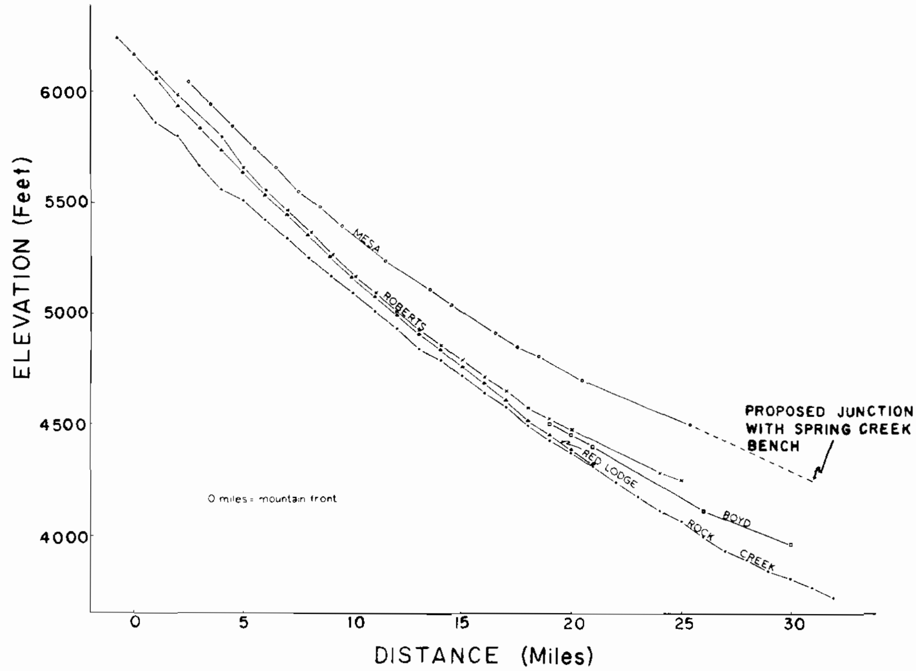

Figure 3. Longitudinal profiles of Rock Creek and related terraces. Pinedale Bench profile is essentially the same as that of Rock Creek.

from lowest to highest: Pinedale, No. 4, No. 3, No. 2, and No. 1. Their longitudinal profiles are presented graphically in Figure 5. It is generally more difficult in this valley than in the others to correlate the down-valley segments with their corresponding mountain-front segments where the terraces are not continuous, for glacial advances here have proceeded farther on to the piedmont region than in the other major valleys.

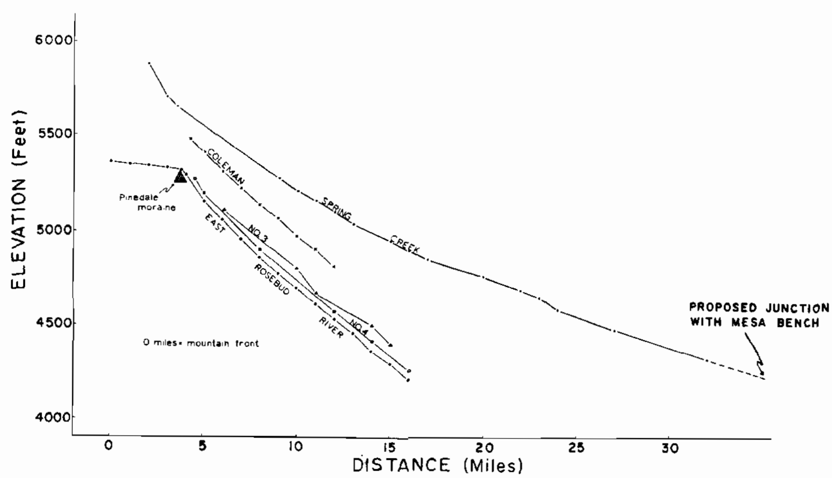

Figure 4. Longitudinal profiles of the East Rosebud River and related terraces. Pinedale Bench profile is essentially the same as that of the East Rosebud River.

Because they have been buried by drift, terrace remnants close to the mountain front cannot be recognized unless deep and properly placed exposures are present. The only known exposure is 2 miles north of the mountain front (NW¼sec. 23, T.6 S., R. 17 E.), where a postglacial landslide has exposed 170–200 feet of gravel and till which truncates the gently tilted early Tertiary sedimentary rocks. The lower 60 feet of this deposit is a coarse, crystalline gravel which represents the highest terrace level in the West Rosebud drainage. The top of the gravel stands approximately 420 feet above the present stream.

Only one isolated remnant of the highest bench is present along the proglacial portion of the stream valley. This surface, 6 miles north of Roscoe, Montana, may not even be related to the ancestral West Rosebud River, for evidence indicates that during deposition of the high-level gravel the river flowed northeast from the mountain front, joining the East Rosebud River somewhere southeast of Roscoe, Montana. The high, flat surfaces adjacent to Morris Creek, a tributary of the East Rosebud River, testify to this direction of flow. Projection of the gradients of these remnants toward the mountains suggests that these deposits are a continuation of the thick gravel in the landslide exposure referred to above. A northeastward direction of flow of the old West Rosebud River is, in addition, consistent with the ancient flow directions of Rock Creek and the East Rosebud River. If this were truly the flow direction, the high-level bench gravel north of Roscoe could not have been deposited by the West Rosebud River.

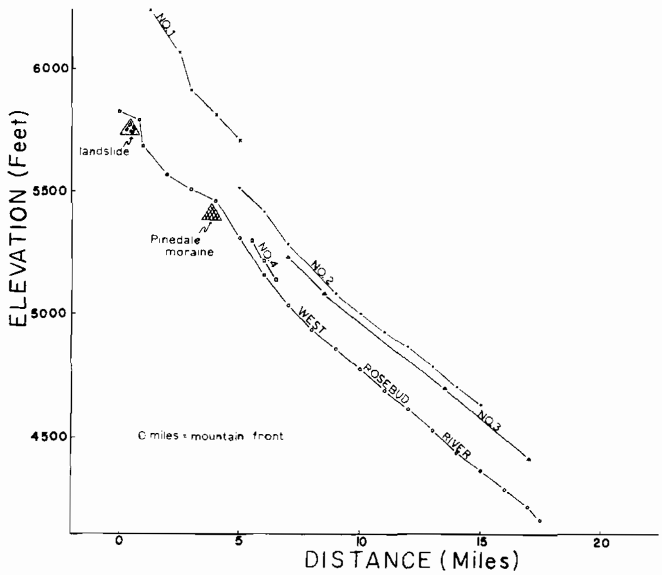

Figure 5. Longitudinal profiles of the West Rosebud River and related terraces. Pinedale Bench profile is essentially the same as that of the West Rosebud River.

Relationship of the Terrace Sequences

Projection of the longitudinal profiles of Mesa and Spring Creek benches (Figs. 3 and 4) indicates that the two would join 2 miles east of the town of Joliet. The projected elevation of Spring Creek Bench at the postulated point of juncture is approximately 4230 feet and Mesa Bench, approximately 4250 feet. This near equality of altitude strongly suggests that the gravels of the two benches were deposited at approximately the same time. In addition, projection of the gradients on the No. 1 Bench remnants of the West Rosebud River indicates a possible junction with Spring Creek Bench southeast of Roscoe.

Thus, Spring Creek Bench (East Rosebud), Mesa Bench (Rock Creek), and the No. 1 Bench (West Rosebud) may have defined a northeast-trending drainage system of which the ancestral Rock Creek, and East and West Rosebud rivers were integral parts (Fig. 6). This ancestral drainage represents the last period in which all the major rivers of this area were joined.

Terrace Deposits

The gravel deposits of the terraces in this region are similar in texture. They are generally unstratified although sand or silt lenses, which rarely exceed 3 feet in thickness, are interbedded with the coarse gravel at some localities. Where the gravels lack interlayered units, the gross textural aspect is uniform throughout. The deposits are predominantly coarse-grained, *i.e.*, material of pebble size or larger comprises the main framework of the deposit. Even within this coarse-grained fraction a large range in particle size exists. The matrix is largely sand, with silt and clay being present in minor amounts.

To emphasize the coarse nature of the gravel estimates of maximum boulder size in each terrace deposit were made at many localities by taking the average of the ten largest boulders measured along their greatest axis. The maximum boulder size on each bench near the mountain front is extremely large, commonly exceeding 5 feet in diameter. Although the boulders gradually decrease in size away from the mountains, they are still nearly 1 foot in diameter 25 miles from the mountain front.

In the past, few data were available concerning the gravel thickness, and these were confined mainly to localities along the exposed edges of the benches. Such measurements cannot indicate with assurance whether a constant thickness of deposits is maintained across the bench. Indeed, seismic studies farther south in the Big Horn Basin (Moss and Bonini, 1961) showed that gravel thickness can vary considerably across a bench even though it appears to be constant when measured longitudinally along the edge of the bench.

Additional information allows new estimates of gravel thickness for the entire region (Table 2)[2]. At each site where measurements were made the slope of the bench is in the downstream direction, and at each locality visited the gravel

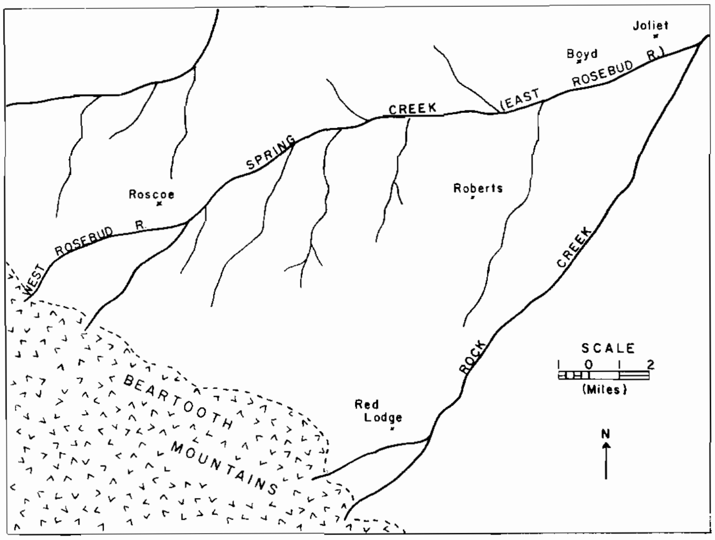

Figure 6. Regional drainage pattern during deposition of the gravels capping Mesa, Spring Creek, and No. 1 benches. Note the prevalent northeast trend. The tributary of Spring Creek (East Rosebud River) east of Roberts eventually diverted Rock Creek to the North.

[2] Most data, determined from drillers' logs of seismic shot holes, were provided by the Gulf Oil Company and the Shell Oil Company. Some information was obtained from well logs of private drilling companies recorded at the Carbon County Courthouse. Additional data were derived by personal observations of the drilling of shot holes by the Texas Oil Company.

TABLE 2. THICKNESSES OF THE GRAVEL DEPOSITS CAPPING THE BENCHES IN THE BEARTOOTH REGION, SOUTHERN MONTANA

Terrace	Location	Miles from mountain front	Thickness (in feet)
	Rock Creek		
Mesa	NE¼sec. 34, T. 7 S., R. 20 E.	4	22*
	SW¼sec. 8, T. 7 S., R. 21 E.	6.5	25+*
	SW¼sec. 27, T. 6 S., R. 21 E.	10	8†
	SW¼sec. 25, T. 6 S., R. 21 E.	11.5	7*
	NE¼sec. 13, T. 5 S., R. 22 E.	22.5	30+*
Roberts	NW¼sec. 14, T. 7 S., R. 20 E.	7	30*
	SE¼sec. 30, T. 6 S., R. 21 E.	11	55–60**
	NE¼sec. 19, T. 6 S., R. 21 E.	12	40**
	NE¼sec. 4, T. 6 S., R. 21 E.	16	20*
	NE¼sec. 32, T. 5 S., R. 21 E.	17	15*
	NE¼sec. 15, T. 5 S., R. 21 E.	20	15*
Boyd	SE¼sec. 27, T. 7 S., R. 20 E.	4	25*
	NW¼sec. 28, T. 5 S., R. 21 E.	18	25+*
	SE¼sec. 16, T. 5 S., R. 21 E.	20	15+*
	NE¼sec. 30, T. 4 S., R. 21 E.	25	25*
Red Lodge	NE¼sec. 17, T. 8 S., R. 20 E.	0	110–115*
	SW¼sec. 5, T. 8 S., R. 20 E.	1	70+†
	SE¼sec. 15, T. 7 S., R. 20 E.	7	50*
	SW¼sec. 34, T. 6 S., R. 20 E.	9	45**
	SE¼sec. 23, T. 6 S., R. 20 E.	11.5	37**
	SW¼sec. 13, T. 6 S., R. 20 E.	12.5	35**
	NE¼sec. 12, T. 6 S., R. 20 E.	14	25+*
	NE¼sec. 31, T. 5 S., R. 20 E.	17.5	10–15*
Pinedale	Red Lodge	4	70††
	Red Lodge	4	45+††
	NE¼sec. 29, T. 5 S., R. 21 E.	18.5	16††
	Roberts	18	25+††
	Roberts	18	21††
	Joliet	31.5	15††
	Joliet	32	9††
	Joliet	32	8*
	East Rosebud		
Spring Creek	SW¼sec. 9, T. 5 S., R. 19 E.	12.5	25+*
	SE¼sec. 2, T. 5 S., R. 19 E.	15.5	30††
	NW¼sec. 7, T. 5 S., R. 21 E.	22	15+*
	SE¼sec. 1, T. 5 S., R. 21 E.	28	4*
Coleman	NE¼sec. 3, T. 6 S., R. 18 E.	6	20+*
	SE¼sec. 12, T. 5 S., R. 18 E.	11	15*
No. 3	NW¼sec. 34, T. 5 S., R. 18 E.	7	22+††
	SE¼sec. 33, T. 5 S., R. 18 E.	6.5	20*
	SE¼sec. 10, T. 5 S., R. 18 E.	10.5	15*
No. 4	SE¼sec. 4, T. 6 S., R. 18 E.	5	40**
Pinedale	SE¼sec. 4, T. 6 S., R. 18 E.	5	70**
	SE¼sec. 27, T. 5 S., R. 18 E.	8	20† ††
	West Rosebud		
No. 1	SW¼sec. 23, T. 6 S., R. 17 E.	2	60*
	NE¼sec. 14, T. 6 S., R. 17 E.	3.5	40**
	NE¼sec. 7, T. 6 S., R. 17 E.	4.5	35*
No. 2	NW¼sec. 36, T. 5 S., R. 17 E.	6	20**
	SE¼sec. 25, T. 5 S., R. 17 E.	6.5	65**
	NE¼sec. 25, T. 5 S., R. 17 E.	7	70**
	NE¼sec. 25, T. 5 S., R. 17 E.	7	50**
No. 3	NE¼sec. 33, T. 4 S., R. 18 E.	13.5	25*

* Estimate at terrace edge or in gravel pit
† Communication with owner
** Seismic shot hole
†† County Well Records

at the surface is composed of material derived from the mountains. Thus, the possibility that much of the measured thickness represents locally derived slope wash is remote. The data suggest two generalizations:

(1) Gravel deposits may vary in thickness across a terrace. Where this is the case, the eroded bedrock surface beneath the gravel probably has significant relief and does not reflect the surface on the overlying gravel.

(2) The terrace deposits gradually decrease in thickness away from the mountain front. This thinning is best seen in the deposits capping Red Lodge Bench and the Pinedale Bench in the valley of Rock Creek. These deposits appear to be continually thinning wedges of sediment rather than sheet-like bodies of uniform thickness.

Perhaps the best example of gravel-thickness variation is seen at Roberts Bench, east of Fox (Pl. 1). Here the gravel exposed on the terrace rim by the downcutting of Rock Creek and a small tributary is 20–30 feet thick. One-quarter mile east of this tributary, however, a driller's log has indicated a thickness of 55–60 feet; and several hundred yards farther east, the bench alluvium abruptly ends along a line separating the crystalline gravel from local bedrock. This lithologic line has no apparent relationship to the surface configuration, *i.e.*, the bench surface is formed on both gravel and local bedrock with little topographic expression along the line of lithologic transition (*see* Zeller, 1963). Thus, the surface of the underlying bedrock is not parallel to the surface on the covering gravel, a characteristic noted elsewhere in the Big Horn Basin (Swenson, 1957; Moss and Bonini, 1961).

In the absence of more data, other well-documented cases of considerable bedrock relief beneath the flat-topped benches cannot be cited. The wide variety of thickness measurements presented in Table 2, however, suggests that new data will provide additional examples.

ORIGIN OF THE TERRACES

Previous Investigations

Calvert (1916), Alden (1932), and Swenson (1957) briefly considered the origin of the Beartooth terraces. They proposed glaciation, aggradation during interglacial or preglacial times, and deposition in response to uplift. None of the above studies, however, was primarily directed toward the resolution of the origin of the benches; and, as a result, the problem received little critical examination from these workers.

The most penetrating inquiry into the origin of the Rock Creek terraces is included in Mackin's (1937) study of the erosional history of the Big Horn Basin. Mackin asserts that the Rock Creek benches, and all the other terraces of the Big Horn Basin, were formed by laterally corrading streams. In his discussion of Mesa Bench he states (p. 848):

"This uniformity in gravel thickness throughout the length of the bench and the neat beveling of bed-rock structures indicates that the surface on which the gravel rests was formed by the lateral corrasion of the same swinging river (or rivers) that deposited the gravel, that is, the Mesa Bench is a surface of stream planation."

Such a mechanism demands that the gravel be deposited at the same time that the suballuvial bedrock surface is cut. Stream incision of the valley bottom subsequently formed Mesa Bench by leaving the gravel elevated relative to the degrading stream. Incision continued until a pause in the downcutting allowed a new period of lateral planation and deposition of gravel at the level of the next lower bench. This mechanism accounts for each successively lower bench, with the exception of the lowest terrace which he felt differed from the others in that it was partly aggradational. Thus, as visualized by Mackin, each bench level represents a cessation in the general downcutting by Rock Creek, a cessation which allowed time for the stream to cut laterally. While the stream migrated across the valley, it simultaneously laid down a thin cover of crystalline gravel over the planed bedrock underlying the valley bottom.

Gravel Distribution in the Rock Creek Area

Plate 1 shows that the remnants of Mesa Bench and Roberts Bench in the Rock Creek area are in close proximity only in the region near the mountain front. Four miles north of Red Lodge the terraces begin to diverge in the downstream direction. Elbow Creek, which drains much of the area between the two benches, is clearly closer to the remnants of Mesa Bench than those of Roberts Bench (Fig. 7). The differences of the material on either slope of Elbow Creek valley strongly indicate that the gravel of Mesa Bench extended only to the position of Elbow Creek, never across the valley.

The slopes on the southeast, which lead up to the Mesa remnants, as well as the channels of each minor tributary heading in the uplands southeast of Elbow Creek, are covered with crystalline gravel, obviously derived from the terrace deposits and presently in transit to the valley bottom. Even where no remnants of the bench are preserved the slopes and stream bottoms are still mantled with crystalline particles. This indicates that although the gravel-covered bench has, at places, been completely undermined and removed, the erosive forces have been unable to eliminate all the crystalline components from the vicinity.

Bench has no material derived from the Beartooth Mountains.

The distribution of the crystalline gravel suggests that the modern position of Elbow Creek marks the former western margin of the valley in which the Mesa gravel was deposited. If this is correct, the breadth of the valley floor during deposition of the Mesa gravel was probably about 2 miles.

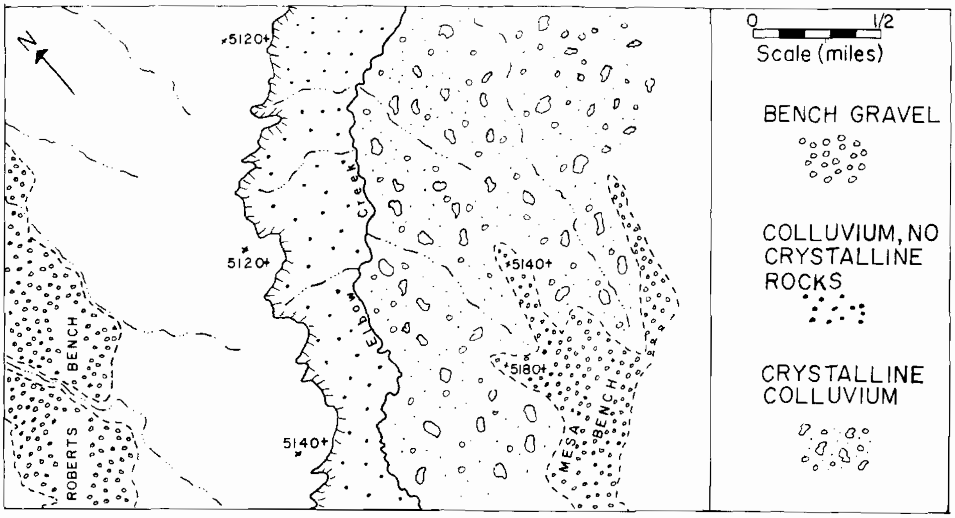

Figure 7. Map of the area between Roberts Bench and Mesa Bench, east of Fox, Montana. Note the lithologic change in the colluvium across the valley of Elbow Creek. Blank areas represent bedrock

In contrast, the uplands overlooking Elbow Creek on the northwest side of the valley are underlain entirely by local Tertiary sandstones and siltstones (Fig. 7); no terrace remnants are preserved. Although the bedrock surfaces do not stand as high as the Mesa remnants directly across the valley, at places the difference in elevation between the two is only about 20–40 feet. Careful examination of the slopes on the northwest side of the valley and the streams transecting these slopes revealed no traces of crystalline gravel.

The area farther to the northwest, between Roberts Bench and Elbow Creek, is drained by tributaries flowing northwest and is also mantled entirely by local, angular sandstone and siltstone components. The streams truncating Roberts Bench transport no crystalline particles in their reaches which are east of the Roberts Bench gravel. Thus, the area between Elbow Creek and the eastern boundary of Roberts

Stream Capture

If Elbow Creek defines the western extremity of the Mesa gravel, one must inquire as to the mechanism which shifted the course of the mountain-bred stream into its position represented by Roberts Bench. One of the distinctive features of piedmont areas is the significant variation in the gradients of streams: rivers originating in crystalline rocks of mountains have high gradients; in contrast, the gradients of streams which originate in softer basin rocks transport finer material and are usually more gentle. This variable nature of stream gradients in piedmont regions has been recognized by many authors in both arid and humid regions (Rich, 1935; Hunt and others, 1953; Hack, 1960; Denny, 1965) and, specifically, in the Big Horn Basin by Mackin (1936; 1937).

It was proposed above that the remnants of Mesa Bench and Spring Creek Bench present circumstantial evidence of a former, neatly integrated, northeast-trending drainage. With such a drainage pattern in the piedmont locale, the diversion of the ancestral Rock Creek which formed Mesa Bench would have been imminent. During deposition of Spring Creek and Mesa gravels the position of Roberts Bench was probably occupied by a tributary to the river depositing the Spring Creek gravel (Figs. 6 and 8).

This tributary, because it did not head in the resistant crystalline rocks of the mountains, carried no coarse material in its load. Therefore, its gradient was lower than that of the ancient major stream which was carrying the coarse gravel which now caps Mesa Bench. Progressive headward erosion of this low-gradient tributary culminated in the piracy, near the mountain front, of the major river. At this position, the channel of the major stream would have stood at a much higher elevation than the plundering tributary because of the dissimilar gradients of the two streams.

This drainage diversion prior to deposition of the gravel of Roberts Bench explains the aberrant trend of Mesa Bench and the absence of crystalline pebbles in the area between Roberts and Mesa benches (Figs. 6 and 8). A similar process apparently operated in the other major valleys at approximately the same time. The bold remnants of Spring Creek Bench demand a northeastward direction of flow for the ancient East Rosebud River. The orientation, however, of the next lower bench, Coleman Bench, requires a rather drastic change in the direction of the river before the deposition of its gravel cover (Pl. 1). Examination of the surface between Coleman Bench and the western margin of Spring Creek Bench reveals this region to be barren of crystalline material. Thus, the situation simulates that of Rock Creek: an abnormal northeastward trend of the high bench, a lower second bench extending northward, and the area between the two benches completely devoid of lithologic components derived from the mountains. It is most probable, therefore, that the East Rosebud River was also captured by a small, headward-eroding stream which originated in the piedmont noncrystalline region.

The West Rosebud River was apparently affected in a like manner. As described previously, the remnants of the No. 1 Bench of the West Rosebud drainage clearly follow the present northeast-trending valley of Morris Creek; and probably the bench merged with Spring Creek Bench somewhere southeast of Roscoe (Pl. 1). Prior to the deposition of the gravel capping the No. 2 Bench, however, the river was diverted to a new position. As before, the land between the remnants of the two benches completely lacks crystalline particles.

These drainage adjustments characterize a

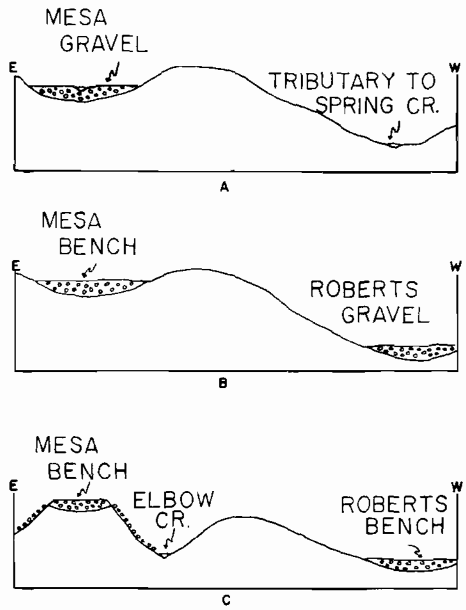

Figure 8. Physiographic evolution of the area between Mesa Bench and Roberts Bench, looking south toward the mountains. Diagram not to scale. A, During deposition of Mesa gravel; ancestral Rock Creek represented by small tributary of the East Rosebud River (Spring Creek). B, After capture of Rock Creek and during deposition of Roberts gravel. C, Headward erosion of Elbow Creek adjacent to Mesa gravel; slopes southeast of Elbow Creek are covered with crystalline boulders.

particular period in the geomorphic evolution of this area, *i.e.*, the time between deposition of the gravels veneering the highest benches and those of the second benches (Figs. 6 and 9). There is every reason to believe, however, that stream piracy is a very normal process in this region and has occurred many times in the past and, indeed, will occur in the future (Mackin, 1936; 1937). Thus, stream capture may have been a dominant factor in the development of this region.

It is important at this point to note that in each river valley in this area, remnants of the same bench are seldom found on both sides of the valley. Only three unquestioned examples of matched terraces can be cited: (1) Red Lodge Bench near the mountain front; (2) Red Lodge Bench near Roberts, where 10 feet of Red Lodge gravel on the east side of the present valley is buried by younger Pinedale gravel; and (3) Coleman Bench north of Roscoe. This pattern suggests that in most cases the downcutting which formed the terraces did not take place through the thickest parts of the valley fills, and possibly not in the gravel at all, but along the valley sides or in the thin gravel near the valley sides. The degrading streams were perhaps more effective in incising the nonresistant Mesozoic and Tertiary rocks of the area than the thick bouldery deposits of the valley bottom.

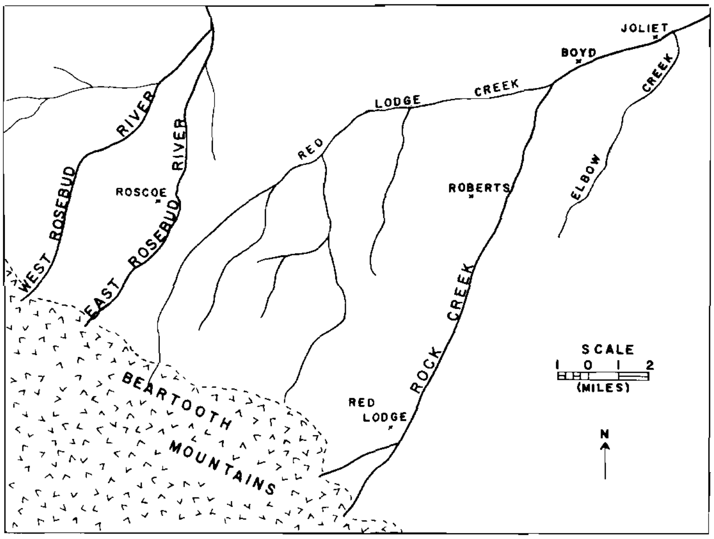

Figure 9. Regional drainage pattern during deposition of the gravels capping Roberts, Coleman, and No. 2 benches. Note that each major drainage has been diverted to the north from its earlier position as represented in Figure 6.

Exactly how the rivers accomplished their placement along the valley sides is debatable. It is probable, however, that headward erosion by tributaries flowing along or near the valley sides was responsible for some or all of the degradation. During the slow downcutting, the valley of the tributary stream may have been widened by lateral corrasion and by normal valley-side backwasting. The amount of downcutting would be controlled by the base level of the tributary stream and the channel declivity necessay to transport its fine-grained load. Subsequently, the small tributaries captured the main rivers and placed them along the valley sides, adjacent to the abandoned and now higher gravels of the main valleys.

The changes which would occur in the tributary valleys as the result of these captures are clear. At the time of capture the small pirating stream is burdened by a sudden influx of coarse detritus representing the load of the captured river which rises in the mountains. Unable to transport the coarse material on the low gradient of the former tributary channel, the river would deposit much of its load. This aggradation would fill the valley, partially modifying and burying the pre-existing topography. Presumably the filling would continue until the gradient of the channel increased enough to permit movement of the coarse load.

The process described above is similar in most respects to those reported elsewhere in the Rocky Mountains by Rich (1935), Hunt and others (1953), and Denny (1965). Mackin (1937, p. 883) recognized as an important process the ability of piracies to shift the position of the major rivers in this area. He did not stress, however, the probability that pre-existing valley topography was buried by this process or that the erosion of the bedrock beneath the terraces and the deposition of the overlying gravel were two separate events.

sult of deposition by streams characteristic of normal climatic conditions.

Evidence suggests that much of the gravel on the Pinedale benches and on Red Lodge Bench and its equivalents is glaciofluvial in origin. The

Table 3. Location of Till and Moraines of the Different Glacial Episodes

Location	Glacial episode	Description
	Rock Creek	
SE¼sec. 17, T. 8 S., R. 20 E.	Buffalo	Smooth slopes, crystalline debris
NE¼sec. 8, T. 8 S., R. 20 E.	Buffalo	Smooth slopes, crystalline debris
Sec. 19, T. 8 S., R. 20 E.	Bull Lake	Lateral moraines
10–13 miles SW. of Red Lodge, near junction of Lake Creek	Pinedale (main)	Complex terminal zone choking valley
16 miles SW. of Red Lodge, 1 mile S. of junction with Hellroaring Creek	Pinedale (recessional)	End moraine choking valley
½ mile S. of Buena Vista Park	Pinedale (recessional)	End moraine choking valley
½ mile SE. of Glacier Lake dam near edge of cirque floor	Temple Lake	End moraine
Crossing cirque floor	Cirque moraines or protalus ramparts	Fresh, bouldery deposits
	West Fork of Rock Creek	
NW¼sec. 11, T. 8 S., R. 19 E.	Bull Lake	Lateral moraine
6–10 miles SW. of Red Lodge	Pinedale (main)	Lateral moraines and complex terminal zone choking valley
Sec. 31, T. 8 S., R. 19 E.	Pinedale (recessional)	End moraine choking valley
	East Rosebud	
NE¼sec. 16, T. 6 S., R. 18 E.	Buffalo	Buried till
2–4 miles SW. of Roscoe	Bull Lake	Lateral moraines
2–10 miles SW. of Roscoe	Pinedale (main)	Lateral moraines and well-developed terminal moraine choking valley
	West Rosebud	
NW¼sec. 24, T. 6 S., R. 17 E.	Buffalo	Buried till
10–14 miles SW. of Fishtail	Bull Lake	Lateral moraines
9–17 miles SW. of Fishtail	Pinedale (main)	Lateral moraines and terminal zone choking valley

Effects of Glaciation

As suggested above, diversions of the major rivers may be the dominant process involved in the formation of the terraces in this region. Determining the exact origin of the gravel capping the benches, however, is complicated by the probability of periodic floods of glacial outwash into the main valleys. The time at which these glaciofluvial incursions occurred may or may not have coincided with the time of the stream diversions. Thus, it is possible that any or all of the terrace gravels may have accumulated under diverse hydraulic conditions, *i.e.*, they may be partly glaciofluvial and partly the re-

low terrace in each valley can be traced into terminal moraines (Pl. 1; Table 3) which are comparable in every respect to the Pinedale moraines described by Blackwelder (1915). The topography on these moraines is extremely irregular, consisting of numerous small hills and depressions; many of the depressions are poorly drained and are thus marked by small lakes and swamps. The surface of the drift is covered profusely with large, unweathered, erratic boulders. Terminal ramparts are still intact, and these choke the valley such that the present rivers traverse the terminal zones in small V-shaped ravines incised in the bouldery till. The low benches pass into and partially through the terminal zones but are not present in those portions of the valleys behind the morainic topography.

Till similar to Blackwelder's Bull Lake drift is also preserved in every major valley of the area (Pl. 1; Table 3). The Bull Lake deposits possess enough morainal characteristics to indicate a glacial origin, even though terminal zones have been destroyed in each valley by subsequent erosion. Lateral moraines remain as long, narrow ridges which, in the piedmont, often form the divide between two adjacent valleys. The surface of the Bull Lake deposits is only sparsely covered with erratic boulders; thus, where Bull Lake and Pinedale moraines are juxtaposed, the difference between the two with respect to surface expression is striking.

Part of the gravel capping Red Lodge Bench and the No. 4 benches in the other main valleys may represent outwash of the Bull Lake glaciation. Although the gravel of Red Lodge Bench cannot be traced directly into a Bull Lake terminal zone, a genetic relationship can be reasonably demonstrated near Piney Dell Lodge 1.5 miles south of the mountain front, where the Bull Lake lateral moraines are clearly in the proper position to have served as the source for a portion of the gravel. A glaciofluvial origin for some of the gravel capping the No. 4 Bench in the East Rosebud valley is even more evident; 2 miles south of Roscoe, this gravel grades into the till of the Bull Lake moraines (Pl. 1).

Boyd Bench and its correlatives in other valleys cannot be traced directly into morainic deposits, but in every valley pre-Bull Lake (Buffalo?) till is at the proper elevation and in the proper geographic position to indicate a genetic relationship with these terraces.

Although striated boulders have been found in the gravel capping Mesa Bench (Paul MacClintock, personal commun., 1961), no till is present which has the proper age or geographic position to correlate with Mesa Bench, Roberts Bench, or their equivalents in other valleys. Very old till could not persist on the steep slopes of the mountain valley sides and may well have been removed by the many processes causing downslope movements which were certainly more vigorous during the Pleistocene than before or after. The possibility of older glaciations in the Beartooth Mountains exists, since at least three pre-Wisconsin glacial episodes have been recognized at several widespread localities in the Rocky Mountains (Richmond, 1965). It is probable, therefore, that a glacial environment prevailed simultaneously in the Beartooth Mountains, but the post-depositional conditions necessary for the preservation of the remains of the early advances have not existed.

Furthermore, the high bench gravels resemble in most details (thickness, boulder size, texture) those deposits which are almost definitely partly glaciofluvial in origin.

Thus, much of the gravel capping the benches in the Beartooth region may have been deposited during periods of mountain glaciation, at which time large amounts of coarse detritus were released from the wasting ice. Meltwater floods and floods caused by the destruction of ice-dammed lakes transported the coarse-grained load on to the fringing plains. The effects of these floods, however, could not be sustained, and gradually the streams became incompetent to move their coarse loads. Thus, aggradation occurred and persisted until the sudden influx of coarse debris was arrested, and the melting ice was no longer able to provide flows adequate to move all the channel material.

SUMMARY AND CONCLUSIONS

During the Pleistocene Epoch, each major stream crossing the Great Plains from the east flank of Beartooth Mountains developed five terrace levels, each capped by very coarse gravel composed of crystalline rocks derived from the mountains. Drill records suggest that some of the gravel deposits vary in thickness across the terrace, indicating that the eroded bedrock beneath the gravel is not a mirror image of the flat bench surface. Generally the gravel thins gradually away from the mountain front.

The terraces of the Beartooth region developed in a distinct and orderly manner. Excavation of the Big Horn Basin began in the late Pliocene (Mackin, 1937), ending a long period of basin filling. This erosional phase has persisted to the present, interrupted only by short periods of aggradation. The valley filling, represented in this area by the gravel capping the terraces, was initiated by a combination of two processes: stream piracy and glaciation.

Rivers crossing the Big Horn Basin which head in the surrounding crystalline mountains transport coarse particles and, therefore, are required to maintain steep gradients. Streams rising in the plains, however, carry less coarse material and flow on more gentle slopes. In such a fluvial environment capture of the mountain-bred rivers by the low-gradient tributary streams is a natural and common result (Mackin, 1936; 1937). At the time of capture, aggradation will occur because the diverted major rivers cannot transport their coarse loads on the low declivities of the former tributary channels. The topography developed in any tributary valley prior to capture is buried as the coarse gravel is deposited.

Evidence of stream capture is prevalent in the Beartooth area. The orientation of the terrace gravels indicates a northeasterly drainage pattern at the time of the deposition of the highest terraces and diversion of each major river to a more northerly direction of flow prior to deposition of the next lower terrace gravels. The terrace distribution within each valley also suggests the possibility of additional piracies. The scarcity of matched terraces indicates that, wherever possible, downcutting has occurred in the less-resistant bedrock near the edge of the gravel fills rather than through the fills themselves. Much of this downcutting was accomplished by headwardly eroding tributary streams which, by virtue of their low gradients, subsequently captured the main river. Thus, each successive gravel fill is adjacent to and lower than its immediate predecessor.

In addition to aggradation as a result of stream piracy, much, if not most, of the gravel capping the terraces was deposited as outwash during episodes of mountain glaciation. The lowest bench deposits in each valley can be traced into and partially through a Pinedale moraine of late Wisconsin age. Red Lodge Bench and its correlatives in other valleys can be reasonably related to moraines of the Bull Lake (early Wisconsin) glacial advance. No till is preserved which can be correlated with the gravel on the high benches. These gravels, however, have the same characteristics as those capping the lower benches which are almost certainly glaciofluvial in origin.

The proposed terrace development requires that any or all of the terrace gravels may be partly fluvial and partly glaciofluvial in origin. The erosion of the bedrock beneath the terrace gravel, however, occurred some time prior to the aggradation of the valley and may have been accomplished by some stream other than the one responsible for the subsequent gravel deposition.

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