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Physiographic Surfaces and Weathering Near Butte

Gordon B. Brox

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PHYSIOGRAPHIC SURFACES AND WEATHERING NEAR BUTTE

By
Gordon B. Brox

A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science

Montana School of Mines
Butte, Montana
May 17, 1950
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>11</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>General Geology</td>
<td>2</td>
</tr>
<tr>
<td>Tertiary Erosion Surfaces</td>
<td>5</td>
</tr>
<tr>
<td>Ridge Level</td>
<td>7</td>
</tr>
<tr>
<td>Intermediate Level</td>
<td>7</td>
</tr>
<tr>
<td>Recent Level</td>
<td>11</td>
</tr>
<tr>
<td>Scattered Remnants</td>
<td>14</td>
</tr>
<tr>
<td>Effects of Weathering</td>
<td>15</td>
</tr>
<tr>
<td>Chemical Effects</td>
<td>15</td>
</tr>
<tr>
<td>Effects of Weathering Chemical Effects</td>
<td>15</td>
</tr>
<tr>
<td>Hydrothermal Alteration</td>
<td>17</td>
</tr>
<tr>
<td>Mechanical Factors</td>
<td>18</td>
</tr>
<tr>
<td>Jointing</td>
<td>20</td>
</tr>
<tr>
<td>Results</td>
<td>21</td>
</tr>
<tr>
<td>Effect on Physiography</td>
<td>23</td>
</tr>
<tr>
<td>Summary and Conclusions</td>
<td>25</td>
</tr>
<tr>
<td>Bibliography</td>
<td></td>
</tr>
<tr>
<td>Plate</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>I</td>
<td>Index map of Butte district</td>
</tr>
<tr>
<td>II</td>
<td>Relief map of Butte district</td>
</tr>
<tr>
<td>III</td>
<td>Elk Park surfaces. A, Intermediate bench land north of Elk Park Station; B, General view northward from Trask Station; C, General view southward from Trask Station</td>
</tr>
<tr>
<td>IV</td>
<td>A, Panaramic view looking east and southeast at East Ridge and Silver Bow Valley from Tramway Mine; B, Panaramic view looking south and southwest at Highland Mountain and Silver Bow Valley from Tramway Mine</td>
</tr>
<tr>
<td>V</td>
<td>Joint pattern along highway 10 south, southeast of Butte</td>
</tr>
<tr>
<td>VI</td>
<td>Weathering features. A, Balanced boulders seen near Pipestone Pass; B, Balanced boulders formed by diagonal joints near Rocker; C, Balanced, flat slabs near Donald</td>
</tr>
<tr>
<td>VII</td>
<td>Weathering features. A, Closely spaced, vertically jointed blocks near Donald; B, Weathered blocks in a road cut at Nine-mile house; C, Horizontal sheeting near Donald</td>
</tr>
<tr>
<td>Figure 1</td>
<td>Effect of hydrothermal activity at Pipestone Pass</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Large, resistant blocks outcropping near Donald</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Rounded surface with scattered outcropping boulders at Nine-mile house</td>
</tr>
</tbody>
</table>
ABSTRACT

Three cycles of erosion have modified the Boulder batholith. The earliest cycle produced a peneplanation that has been largely obliterated by a partially completed intermediate cycle, and the recent cycle now in progress.

Physical weathering facilitated by intensive jointing is the prime factor in the modification of the surface features, and this extensive disintegration is responsible for the rounded profile and lack of numerous outcrops on the old surfaces.

Jointing influenced the physiographic pattern. Persistent closely spaced fractures provided more susceptible paths for stream erosion, forming broad valleys and deeply dissecting the flanks of the more resistant and massively blocked areas. Modified by local faulting and regional uplift, the existing surface reflects the internal structure of the batholith.
INTRODUCTION

Why the boulders of the Boulder batholith? What conditions are responsible for their development? And what has been the physiographic history through which the present landscape has passed? The answering of these questions was chosen by the writer as the subject of an undergraduate thesis for the Department of Geology at Montana School of Mines. Field work was not begun until mid-winter, a most unfavorable time for such studies as the writer soon found, and the scope of the problem soon proved indeed large. But information was gained by a review of the literature, and numerous trips along the highways in the vicinity of Butte.

Previous Work: Nearly all of the geological studies carried on near Butte have been devoted to the economic aspects, particularly as related to the fabulous ore deposits of the Butte district. They deal with physiography and weathering more or less incidentally. However, in 1916

(1)
Atwood (1) published the results of his physiographic studies of southwestern Montana and northeastern Idaho in which he emphasized that of the Butte district. Another by Perry (2) in 1934 revealed a slightly different interpretation for the region, although Perry did not work specifically with the Butte district.

**Acknowledgements:** The writer wishes to express sincere appreciation, particularly to Dr. E. S. Perry, and to Prof. Forbes Robertson for their interest, candid criticism, and expert guidance that made this research an adventure in geology. A special acknowledgement is extended, also, to the authors of the publications on physiography, Mr. W. W. Atwood along with Dr. Perry, without which this writer could not have completed the extensive field work in the limited time available.

**GENERAL GEOLOGY**

The area around Butte (Plate I) forms the south-central part of the Boulder batholith. This igneous mass is continually exposed from Highland Mountain on the south to Helena on the north, and from the Deer Lodge Valley on the west to Bull Mountain on the east, or roughly 70 miles long and 25 miles wide.

The prevailing rocks within 20 miles of Butte are igneous, ranging from coarse textured granites to fine-grained andesites, aplites, and rhyolites, with lake bed deposits in the valleys. Quartz monzonite predominates, and is
flanked by sediments and lavas of pre-Cenozoic age, which at the time of intrusion were structurally a syncline. Pre-Cambrian, Paleozoic, and Mesozoic sediments typical of southwestern Montana originally occupied the area now containing the batholith. Overlying these are andesite and latite lavas believed to be upper Cretaceous in age. These beds were later folded during the Laramide orogeny, and the batholith intruded high into the synclinal trough, to within, it is believed, 4000 feet of the surface. The intrusion occurred either in late Cretaceous or early Eocene time.

Subsequent erosion has cut into the mass to a depth in some valleys of over 2000 feet.

Following the intrusion of the batholith an extensive period of erosion began. Continuing until the cover was largely removed and the surface was reduced to a lowland, it possibly lasted through much of Eocene time. This peneplained surface probably was at or near the original surface, or roof, of the batholith. Numerous roof pendants of andesite, and several of recrystallized Madison limestone still persist at heights comparable to what is believed to be the remnants of this old surface, although earth movements and erosion make correlation difficult. No evidence of the most ancient stream channels remain. Widespread uplift interrupted this peneplaination, and a second cycle of erosion was inaugurated. This cycle was also of prolonged duration, apparently persisting throughout much of middle Tertiary time. It is possible that a mature topography or
one of late youth was attained before renewed uplift terminated this downcutting. Deep, broad valleys were cut, although the relief that existed then was not as great as that exhibited around Butte today; and the old surface was dissected, largely destroying evidence of the former plane, but still preserving scattered remnants of the early flat-lying surface. During this time, streams which occupied many of the existing valleys, locally the Elk Park Valley, flowed southward emptying into the headwaters of the Snake River in Idaho. Drainage in that direction was interrupted by regional tilting and block faulting, and in southwestern Montana extensive lakes developed, one of which was impounded in the Butte Valley. Fossil evidence dates the lake beds as Oligocene and Miocene in age. After an extended period of time, the lakes cut new channels through the divides and escaped, initiating the third and present cycle of erosion. The present cycle renews downcutting in the valleys formed during the intermediate cycle; the effects are a deepening and a widening of the valleys and a further dissection of the ridges and peaks. There has been a directional change of drainage as the present divide now runs just east of Butte through the center of the batholith. The present drainage is in part captured by the Clark Fork of the Columbia River on the west, and in part by the headwaters of Missouri River on the east. A remarkable example of this directional change is found 15 miles southwest of Butte near Feeley where one can cross
the Continental Divide, which extends across the valley east and west, completely unaware that he did so.

TERTIARY EROSION SURFACES

The topography of the general area surrounding Butte is mountainous, but not rugged; the rounded ridges that rise abruptly above the broad valley floors present the most characteristic physiographic feature of the region, and they trend north and south.

Correlation between the various erosion surfaces is difficult because accurate topographic maps and elevations are available for only the area north of Butte, and because the Butte Valley surface has been shifted by block faulting.

Atwood (1:706) has outlined the physiographic history of southwestern Montana as follows:

PHYSIOGRAPHIC EVENTS

Late Cretaceous

Early Tertiary

Eocene-Oligocene

Oligocene

Late Oligocene

Miocene

Early Pliocene?

Mountain growth.

Pre-peneplain stage.

Development of summit peneplain.

First cycle of erosion.

Uplift and deformation of peneplain.

Development of great intermontane troughs and a mature topography in the mountains. Deposition of lower Bozeman beds.

Second cycle of erosion.

Closing of drainage.

Third cycle of erosion in mountains.

Aggradation in lowlands. Deposition of upper Bozeman beds.

Development of local erosion plains at the "intermediate level."
Pliocene

- Uplift of mountain masses; tilting of Bozeman beds.
- Piracies of the Missouri, Columbia, and Salmon Rivers.
- Opening of drainage.
- Fourth cycle of erosion in mountains.
- Dissection of Bozeman beds.
- Superimposed drainage.
- Earlier glaciation.
- Pre-Wisconsin stage.
- Interglacial interval; weathering, erosion, and faulting.
- Later glaciation.
- Wisconsin stage.
- Postglacial interval.
- Stream erosion.
- Piracy of the Yellowstone.

Pleistocene

Recent

The writer is inclined to agree with the latter concept, because only the benches immediately surrounding Butte suggest four surfaces; and since this area is intensely faulted, and Elk Park Valley and Lower Pipestone Canyon exhibit only three levels, the overwhelming evidence suggest this interpretation.

The surfaces represented will here be referred to as the ridge level, the intermediate level, and the recent
level (Plate II).

RIDGE LEVEL

Evidence to substantiate the existence of this surface is meager. Western Montana attests an extensive early erosion of the cover under which the batholith was intruded; and the more or less even contour of the ridges with their rolling crests, and the plateaus, attest the flat nature of the surface when the intermediate cycle began. The only concrete evidence of this level is found on Table Mountain Plate II, 4), 18 miles south of Butte, where waterworn pebbles were found by Conlin Christie on this table-like platform. Atwood (1) considers this mountain a monadnock rising from the peneplain, but it seems more reasonable that it was a part of this level, later uplifted by faulting to its present dominating height. It seems unlikely that the Belt quartzite and argillite which makes up the Highland area would resist erosion to this degree; and furthermore, all evidence of an intermediate stream channel which probably passed just west of this peak (Plate II, 5) has been obliterated in this immediate vicinity.

INTERMEDIATE LEVEL

The pattern of stream erosion of this cycle is displayed prominently in the Elk Park Valley and in Lower Pipestone Canyon, but the Butte Valley presents a much more complex pattern (Plate II).
RELIEF MAP
of
BUTTE DISTRICT

1. Recent level.
2. Intermediate level.
3. Ridge level.
4. Highland mountains.
5. Wind gap where Elk Park drainage extended.
7. Rocker fault.

[Map details with annotated levels and features]
The Elk Park valley is broad, steep sided, and is evidently the work of stream erosion. The first evidence of this level of erosion is seen along the east side of the valley where low hills protrude flatly from the mountain side, and midway through the valley similar hills are visible on the west wall. Toward the north end of the valley, north of Elk Park Station (Plate I), a long, low bench land extends across the valley at about the same elevation as the low hills. It is also even-topped, and it appears to be a part of that surface not yet eaten away.

Southward, east of the city of Butte, low, triangular faceted spurs on either side of Columbia Gardens (Plate I) represent the old Elk Park channel where it extended southward. The Continental fault here truncated the valley, leaving a hanging valley east of the scarp. Corry (3) has found that the fault splits at Rampart Mountain. This may account for the absence of low hills for a distance on the west side of Elk Park Valley, and perhaps also the notch in the ridge just south of Sheepshead Mountain, west of Elk Park Station.

Lower Pipestone Canyon exhibits a somewhat similar topography to that of Elk Park. Rather than low hills, level terraces extend from both sides of the surrounding mountain walls at approximately the same elevation as those of Elk Park. Here waterworn cobbles of quartzite, subangular to subrounded, are sparingly found on the valley floor, and are probably wash material from the benches which range
some 200 feet above.

These are remnants of the same cycle of erosion by two different streams; this would seem to imply that the Continental Divide at the top of Pipestone Pass (Plate I) has been a constant feature during much of the Cenozoic period.

Surfaces near Butte are extremely complicated. The plateau area immediately north of Butte, and that just to the south and southwest (from which Timber Butte rises) are of about the same elevation, and are reasonably of the same height as the spurs around Columbia Gardens. Further south and east, beginning at the Nine-mile house (Plate I), and continuing through the southern half of Roosevelt Drive, a higher bench rises, although it is lower than the Continental Divide at Pipestone Pass, upon which stream worn material was observed.

As only a thin veneer of disintegrated granite covers the composite rock, the lower surface cannot be considered lake formed. It is the writer's conviction that they both represent the same surface, the former assuming its lower position as a result of earth movements.

Two large faults (Plate II), the Continental fault and the Rocker fault, outlined the block which constitutes this shifted surface. Probably as a result of horizontal compression, the homogenous body, resisting crumpling, sheared along these two planes, and the block hinging to the west near Rocker was depressed eastward, probably
2000 feet at the shear line along East Ridge. Although the northern and southern extent of these faults are unknown, it is the opinion of the writer that they are limited to the area of displayed scarp, and that at the extreme ends, there was no great fault zone, but a series of fissures developed which disturbed the surface to a lesser degree.

Apart from the two different elevations of this same surface, more definite evidence is available to support this conclusion. Corry (3:15) writes that the depression bordering East Ridge, known as the Flat, has been filled with alluvium to a depth of at least 600 feet, and that the basement of granite dips strongly to the east at a 30 degree slope. Along the Rocker fault, the block moved up relative to the west side of the fault, but to a lesser degree, which also supports the conclusion that the block hinged to the west. Here lake beds 400 feet or more in depth are present on the west side, but absent on the east side where granite is outcropping.

The major drainage probably did not follow that of Silver Bow Creek at that time. The spurs of East Ridge continue along that ridge to a point midway through the Flat area before they are truncated by the fault. This is well beyond the present channel into the Deer Lodge Valley, and the pattern of the valley wall above the spurs does not suggest there was a curve, but rather presents a rather straight pattern, suggesting that the river continued
through the valley. Northwest of Red Mountain (Plate II, 4) is a ridge level plateau with a ridge running north- westward. Near the southeast end of this ridge what appears to be a wind gap leads southward into Burton Park, west of Red Mountain.

The width of the Butte valley suggests, also, the possibility that this area was a junction for several branch streams, one through Elk Park from the northeast, another possibly entering the valley from the north, which united to form a trunk stream flowing southward through what is now Burton and Maloney Parks (Plate I), and between Red Mountain and Nigger Mountain, eventually emptying southward into some other larger stream.

RECENT LEVEL

Contemporaneous with the regional tilting of Oligocene time, local faulting took place in this area also. Movement along the Continental fault cut off the drainage from the north, while a similar disturbance in the Highland Mountain area uplifted that area retarding the southward drainage. The minor tributary creeks and streams found no avenues for escape and were impounded around the Flat, forming a lake which eventually cut the channel westward through which the present creeks flow. This was the beginning of the present cycle of erosion.

During the period of faulting just considered, the area to the east, including Elk Park, was tilted slightly
to the east. This forced drainage eastward and westward from the fault scarp near which passes the present Continental Divide. The streams in both areas, cut off from the larger area of drainage, were relegated to creeks, and their reduced carrying power has resulted in less modification of the features than occurred during the intermediate cycle.

The Elk Park and Lower Pipestone Canyon drainages follow the pre-existing valleys, but the creeks of the Butte valley have assumed new channels through the Flat, and now pass westward into the Deer Lodge Valley following the escape route of the lake waters.

The recent cycle has cut a valley not more than 200 feet below the intermediate level in the Elk Park Valley. But this is a considerable amount when the size of the draining stream, Bison Creek, is taken into consideration.

Bison Creek, a small creek less than 20 feet in width, flows northward in a series of meanders and oxbows similar to a larger mature stream, and empties into the east-flowing Boulder River.

Just north of Elk Park Station, headward erosion into the intermediate surface is now in progress. Here the creek has incised itself deeply into this older surface, and extensive gullies are gradually removing this feature.

The question naturally arises as to whether a stream this small is capable of this amount of corrosion of the composite quartz monzonite. The answer is yes, as this
valley floor has but a thin cover of disintegrated granite, and no other features suggest the former presence of a stream much larger than the one now at work.

Little Pipestone Creek, on the contrary, has by no means approached its profile of equilibrium. It is a very youthful stream cutting rapidly into the granite, but it is of an intermittent nature, and also has had its progress retarded until recently when the swampland there was drained to facilitate the re-routing of highway 10 south. It seems probable that the stream of the intermediate cycle was deprived of many of its headwaters by earth movements, and was rapidly reduced in size, and consequently in carrying power.

Little modification has been produced in the Butte valley. Headward erosion, the removal of much lake bed material and weathered debris, and a further dissection of the ridge level, are the effects of the small creeks that drain the valley.

A more recent phase, the carving of surfaces by glacial activity has been studied by Atwood (1) who finds evidence particularly abundant in the vicinity of Grace (Plate I) and in the Deer Lodge Valley. The writer has observed no occurrences of this type close to Butte, but the cirques and deep gullies on the sides of Red Mountain, 20 miles southward, are the result of glaciation.
Remnants of the ridge level are the mountain ridges (Plate II). Common levels are noticed in the plateau area just below Highland Mountain, the ridge running northwest from this plateau, the ridge east of Butte along which the Continental Divide follows, and the ridges that bound the Elk Park Valley. The photographs, Plate III and Plate IV, show the relation of this surface with those of the intermediate and recent levels. This surface, although highly dissected, can be traced along its eastward dip to the border area.

The most striking result of the intermediate cycle of erosion is the north-south valley pattern that exists throughout western Montana today. The stream terraces found along the valley walls are positive evidence of these former streams, and indicate that they are responsible for the present physiographic pattern. In the plateau areas, many knobs rise to slightly higher elevations. Timber Butte, immediately south of the city of Butte, is an example of a conspicuous monadnock of this level.

Recent erosion has emphasized, as well as modified, the former surfaces. Streams in recent headward erosion cut narrow, V-shaped gorges into the flat-lying plateau areas. Such examples are seen in Blacktail Canyon, and along Bison Creek north of Elk Park Station.
PLATE III

Elk Park Surfaces

A. Looking northward from Elk Park Station. The snow covered surface is a part of the Recent Level. The dark, higher surface that extends across the valley, and merges with the ridges on both sides, is the "intermediate" bench land.

B. General view looking northward through Elk Park from Trask Station, midway through the valley.

C. General view looking southward through Elk Park from Trask Station.
A. Panaramic View Looking East and Southeast at East Ridge and Silver Bow Valley From Tramway Mine North of Butte.

B. Panaramic View Looking South and Southwest at Highland Mountain and Silver Bow Valley From Tramway Mine North of Butte.
EFFECTS OF WEATHERING

The main rock of the Boulder batholith is a homogeneous quartz monzonite. As in many igneous bodies of this type, the border presents a more basic facies of dioritic composition, and the interior is marked by a profusion of aplitic and pegmatitic material in the form of dikes and irregular masses. In the vicinity of Butte, seven different rock facies are found—quartz monzonite, diorite, rhyolite, aplite, granite, pegmatite, and lamprophyre, given in the order of decreasing abundance. However, except for the occasional occurrence of lamprophyre, no distinction can be made as to which facies is the more resistant, in fact it is a difficult task to distinguish the point of changing composition even by careful scrutiny.

It is not surprising that, in this rigorous, semi-arid climate of western Montana, physical forces are the most active agents of weathering; but chemical decomposition also is partially responsible for the major and minor features that characterize the landscape. They function jointly in producing these features that make the name Boulder batholith very appropriate.

CHEMICAL

Mechanical disintegration of the rocks near Butte proceeds with but slight chemical action. Limited rainfall, long periods during which freezing is continuous, and other conditions favorable to extensive mechanical weathering,
such as exfoliation, all exceed greatly the chemical process of decomposition in their speed of reaction.

The extreme effects of chemical action are produced in the thin cover of disintegrated material that accumulates between the outcrops, and in the crevices and joints. Immature soil develops. It contains little actual clay material, however, and granitic particles, still quite fresh, compose more than 50 per cent of the cover. The proportion of clay is sufficient, nevertheless, to support a luxurious growth of pine and aspen.

Effects: Chemical break-down of the individual grains is slight. Kaolin is present as a light-brown coating on the feldspars, but even on the intensely disintegrated material, it is insignificant. The most obvious modification is the liberation of iron oxide in increasing amounts as weathering progresses. Much of the ferrous type was later oxidized, and the excess of iron oxide produced commonly gives the outcrop a reddish appearance. Generally, as weathering proceeds, the feldspars become dull and somewhat bleached; and the biotite and hornblende, although commonly fresh in appearance, partially alter to green chlorite and iron oxide.

This minor decomposition does, nevertheless, perform an important function in facilitating active corrasion. The rotting rock so commonly seen is traceable, mainly, to hydration. As decay progresses, the iron oxide liberated invades the grain boundaries, and crystallizing there wed-
ges the grains apart, aiding in the further disintegration of the rock.

**Hydrothermal Alteration:** Some localities show evidence of hydrothermal alteration. Usually the evidence is seen over small areas, but one large area at Pipestone Pass, over a mile across is consistently affected. Hot waters have produced a decided bleaching of the granitic rocks, giving them a "chalky" appearance. Fissures, which seem to have provided the channels, are marked by a rich iron stain, and by stringers of vein quartz. Along the fissure walls, a clay has been formed which appears to contain a high amount of sericite. The blocks between the joints are reduced to cores (Fig. 1), and this phenomenon is generally observed here only after the fine material has been removed, thereby causing the blocks to be exposed. How-

![Fig. 1. Effect of Hydrothermal Activity at Pipestone Pass.](image)

ever, a suite of thin sections made from samples taken
from a road cut at Pipestone Pass reveals that in spite of the outward appearance, the blocks actually have suffered relatively little mineral alteration. Kaolin and sericite are present, but not in appreciable quantities, and the biotite appears to be still fresh, altering partly to chlorite and iron oxide in the outer zones.

A heavy mineral analysis of the freshest material and the most altered material, likewise showed there was little alteration. The apatite-zircon ratio did not change appreciably (from 3:1 to 2:1).

Hydrothermal activity is both an aid and a hindrance to weathering. Generally, it serves to soften the rock, leaving it more susceptible to the physical agents and to erosion. Locally silicification has developed along the cracks, and these areas now protrude from the surface of the exposure, resisting weathering more than the surrounding granite.

MECHANICAL

The mountain topography and the climate favor extensive mechanical disintegration. Temperature changes producing exfoliation, frost wedging, wind, plants, and even gravitative force work together in causing the rock to crumble, particularly along joint planes.

Factors

The direct effects of temperature changes produce a
spalling off of the rock surfaces. Extreme changes between day and night are the rule rather than the exception here. The quartz monzonite is heterogenous, and the individual minerals expand and contract in different amounts, setting up stresses within the rocks which upon repeated subjection develop fatigue, and fracture. Exfoliation is a common occurrence. Another factor is frost wedging. Although precipitation in this area ranges from only 10 to 20 inches per year, water is retained in the soils and crevices in sufficient amounts to permit frost wedging during the night when the temperature often drops below freezing. Hydration facilitates disintegration. By hydration the affected portion of the boulder swells slightly. At a slight depth where the water is not quickly evaporated, this slow swelling causes a disruption of layers which spall off the mass. The nature of jointing largely determines the extent to which disintegration has proceeded. Where huge blocks form (Fig. 2), destruction is slight,
but where fractures are closely spaced, the mass of rock is largely destroyed, or reduced to a rounded profile from which a few scattered boulders protrude from the mantle of disintegrated granite (Fig. 3).

![Rounded Surface With Scattered Outcropping Boulders at the Nine-mile House.](image)

**Jointing**: Joints are plentiful, but assume no regular pattern of spacing over the area as a whole; they range from closely knit fractures to breaks well over ten feet apart. In consequence, the granitic blocks also differ in size and shape. At one outcrop huge blocks, nearly square, may form, and in others where a finer spacing is dominant, parallel, tabular blocks result. Where the fractures are extremely fine, or where joints are lacking, no blocks develop, and weathering and erosion have more or less obliterated any trace of their existence. At some points, sheeting has produced nearly horizontal fractures, somewhat curved, resulting in flat slabs. Plate V shows the average joint pattern developed southeast of Butte.
Joint Pattern along Highway 10
Results

The mantled slopes and the rounded ridges are the result of extensive disintegration. The rock exposed to physical and slight chemical attack along joint planes and smaller fissures suffers a crumbling effect, or disintegration. The loose debris produced is moved downslope, leaving the larger, less vulnerable, boulders either standing above the surface, or else lying along the slope below the outcrop. Although these are more resistant, and are often still quite large, they, themselves, have been attacked extensively too. They exist as weathered cores that characteristically develop concentric bands of progressively more unconsolidated material outward from the fresh solid core. Their layers are susceptible to mechanical wedging, and scale off in small curved slabs that quickly crumble to a granitic gravel. Because the streams are unable to remove this weathered material as fast as it forms, much of it accumulates on the slopes where it retains the rain water. This further promotes hydration and rock rotting in place beneath this mantle.

Countless different scenic features are developed, ranging from aggregates of sharp, vertical pinnacles to horizontally sheeted slabs (Plates VI and VII). Perhaps the most interesting of these is the occurrence of one boulder balanced perilously upon another. Aside from the mystery of how they maintain this position, their existence
has a simple explanation.

Two nearly vertical joint sets, and one set nearly horizontal, formed a series of rectangular or square blocks in the granite. The forces of weathering then began to attack the rock beginning along the joints, and progressing downward as the joints were forced further apart by wedging. The first noticeable effect is a rounding of the corners which receive simultaneous attacks from all outward directions. Many of the blocks within the set contain cracks not related to the major jointing, and they may have been produced by some other form of physical force, perhaps from the seasonal expansion and contraction of the block itself; also the major joints are not consistently spaced within the same area. Consequently, the smaller blocks, and those with auxiliary cracks, succumb more rapidly than the large composite blocks; and they, together with the products of weathering, are removed from the block set, leaving the huge boulders of the set boldly standing above the material accumulated at the base. Continued weathering further rounds the corners, and many of the boulders lose their equilibrium and fall from their pedestal. From these result the egg-shaped masses which lie scattered along the slopes, the products of exfoliation. Eventually the rock mass has been reduced to a smoothly rounded surface from which isolated boulders rise, several of which may maintain their original position of one block supporting another.
PLATE VI

Weathering Features

A. Balanced boulders seen near Pipestone Pass. Two nearly horizontal joint sets at right angles, and one set nearly horizontal, outlined the blocks.

B. Balanced boulders formed by diagonal joints near Rocker.

C. Flat slabs resting precariously on rounded pedestals near Donald.
PLATE VII

Weathering Features

A. Closely spaced, vertically jointed blocks outcropping near Donald. Further weathering will produce the "pinnacle" effect.

B. Weathered blocks found in the road cut at Nine-mile house. Outcropping boulders lean from 10 to 15 degrees from the vertical.

C. Horizontal sheeting seen in the road cut at Donald.
If the two sets other than the persistent vertical set dip toward each other at moderate angles, residual boulders that crop out (after extensive disintegration) commonly lean at angles even less than 80 degrees from the horizontal.

Another common feature, the spire-like pinnacles, form on steep slopes, such as the East Ridge scarp, when the persistent vertical joints are closely spaced in relation to the other two sets. All of the fractures may not be attacked equally, and a rectangular block may be left in relief. Later weathering attacks the remaining fractures, rounding the thin sheets until the pinnacle effect is developed. Further weathering will of course destroy these features.

Horizontally sheeted blocks occasionally develop another interesting feature. Preferential weathering of the blocks, which have developed secondary fractures, produces a feature similar to the balanced boulders; but here large slabs like a table top are supported by smaller legs remaining from the eroded slabs below.

The many other features which occur are too numerous to elaborate on, but they, too, are merely expressions of the attitude of the joint sets.

**EFFECT ON PHYSIOGRAPHY**

It has been pointed out that the features developed are mainly expressions of the attitude of the joints, and that the joint spacing largely determines the extent to
to which weathering and erosion proceeds. Hence jointing exerts a profound influence on the existing physiographic pattern. Because the persistent joint set, which strikes nearly north and south, is more commonly closely spaced, it is possible that the major valleys that extend in this direction also have been influenced by this structure.

For example, let us assume that erosion begins along paths of less resistance, provided here by this north-south striking joint pattern. As erosion develops, these more susceptible paths become the channels for streams, and the capture of drainage of tributary streams which are disecting other similar susceptible paths, such as a hydrothermally altered area, or a local occurence of closely spaced fractures of another joint set. Such streams would then become incised deeply into the terrane, removing the products of weathering, and exposing fresh surfaces of the more massively blocked areas to renewed attack.

Eventually the surface becomes generally rounded, and the tributary streams of adjacent valleys succeed in cutting through the minor divides; and one stream capturing the drainage of the other becomes a main drainage system of the area. This ideal example is complicated by regional up-lifting, such as local faulting and tilting, which interupted the cycle at various stages of completion, forced the rivers to abandon some old channels or reversed the drainage of others, thus causing them to form new avenues of escape.
SUMMARY AND CONCLUSIONS

Because the batholith is a more or less homogenous body of quartz monzonite, the surface features we see today are the result of structures of the batholith, such as jointing, sheeting, and fissuring, which provided zones favorable for the attack of weathering and erosion.

Three cycles of erosion have altered the original surface of the region near Butte. The ridge level represents the old peneplained surface of the earliest level. The intermediate level, conspicuously represented by spurs, benches protruding midway from the mountain slopes, and upland valleys, has been complicated in the Butte area by earth movements. Recent surfaces have been formed by small creeks in the Butte area, some of which now flow in a reversed direction; the Elk Park and Little Pipestone Canyon drainage is eastward, and the Butte valley drainage is westward.

The erratic nature of the joint pattern, and the extent to which weathering effects rocks along joint planes, have combined to cause characteristic features on the surface. Where huge blocks are formed, relatively little disintegration is effected, but where blocks are small, no outcrop remains. Mechanical forces attack the individual blocks, rounding and reducing the outcrop until the surface is smooth, with only scattered boulders lying on the slope or cropping out insignificantly. The mantle of dis-
integrated granite absorbs water readily. Hydration within these boulders causes further break-down, and beneath the mantle the rock is rotting in place.

Jointing exerted a basic influence upon the present physiographic pattern. Persistent closely spaced fractures of the north-south joint set provided vulnerable channels for debouching streams, forming a series of valleys and ridges that extend for the most part in a north to south direction.
BIBLIOGRAPHY

