GRANITES, GRUSSES, AND THE SHERMAN EROSION SURFACE, SOUTHERN LARAMIE RANGE, COLORADO-WYOMING

D. H. EGGLER*, E. E. LARSON*, and W. C. BRADLEY**

ABSTRACT. Recent mapping of the southern part of the Laramie Range in Wyoming reveals that the smooth Sherman erosion surface there developed principally on one type of rock, the Precambrian Trail Creek granite facies of the Sherman Granite. Other crystalline rocks support a more rugged, parkland-tor topography.

A distinctive petrographic characteristic of the Trail Creek granite is extensive, high-temperature oxidation of Precambrian age. Minerals so affected were principally the opaques and biotite. In particular, formation of hematite along biotite cleavages expanded the mineral, although not enough to disrupt the rock. Later weathering processes have exploited the oxidized biotites to produce vermiculite, montmorillonite, kaolinite, and gibbsite, all contributing to additional biotite-expansion which has shattered the near-surface rock. Disintegration to gruss is so rapid and complete that outcrops are scarce, and a smooth, gently rolling topography results. Other crystalline rocks, lacking the early alteration, weather more slowly and selectively, providing the parkland-tor topography.

INTRODUCTION

The Laramie Range of southeast Wyoming possesses one of the classic high-level erosion surfaces of the Rocky Mountains, the Sherman surface. In its type area between Laramie and Cheyenne (fig. 1) it truncates Precambrian crystalline rocks and slopes eastward to blend without fanfare into a surviving remnant of the Pliocene depositional surface of the Great Plains (the Gangplank west of Cheyenne). An observer atop the Laramie Range is impressed with the remarkable flatness of the surface, although in the distance he notes monadnocks (inselbergs) which vary in size from small tors to mountains. Indeed, as a mountain range, this part of the Laramie totally fails to live up to emotional expectations, a testimonial to the perfection of the Sherman surface.

An early analysis of the Sherman surface was made by Blackwelder (1909) and Darton, Blackwelder, and Siebenthal (1910). A half-century passed before additional work was done (Moore, 1960). All workers have agreed that the Sherman surface is undiscriminating in its bevelling of diverse rock types.

Recent detailed mapping of the southern Laramie Range (Eggler, 1968) suggested that topography, after all, is closely related to bedrock lithology. This was investigated further, and the present paper reports the findings. We conclude (1) that the Sherman surface in its type area is associated almost exclusively with a single granite, whereas monadnocks are associated with other granites and crystalline rocks; (2) that this is because the Sherman surface granite disintegrates rapidly and totally to gruss under the expansive effects of altering biotites; and (3) that high-temperature alteration early in the history of this granite prepared it for later exploitation by surficial processes.

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THE AREA

General statement.—Figure 1 shows the portion of the Laramie Range that was studied in detail, although additional reconnaissance extended the area of observation well beyond the boundary shown. The Sherman surface occurs in the northern and eastern parts of this area. Average elevation for the area is about 7500 feet. At Laramie (elevation 7200 ft), mean annual temperature and precipitation are approximately 41°F and 10 inches (Darton, Blackwelder, and Siebenthal, 1910).

Bedrock geology.—Figure 2 is a geologic map of the area. Petrography and history of the units have been discussed by Egger (1968); this paper will focus on the Sherman Granite because of its intimate association with the Sherman surface. Sherman Granite in this area consists of two facies, Trail Creek granite and Cap Rock quartz monzonite, which are somewhat similar in appearance. Texturally, they are equally coarse grained, although the Cap Rock quartz monzonite is usually porphyritic and the Trail Creek granite is not; I. C. numbers, a common measure of grain size, are 12.5 and 11.5 respectively. Mineral make ups are not greatly different (table 1). Trail Creek granite is redder than the gray to pink Cap Rock quartz monzonite.

Important differences between the two units appear in polished sections under oil at high magnification (1000X). The Trail Creek granite displays extensive, pervasive alteration, even in fresh samples. Magnetite has been almost completely altered to hematite. Ilmenite has been highly altered to hematite, rutile, and pseudo-brookite. Biotite has been altered to hematite, which occurs in lenses and pods along cleavage planes and in aureoles around the biotite grains. Hematite has expanded the biotite in the c-direction, evidently contributing to the minute, iron-

![Fig. 1. Index map of northern Colorado and southern Wyoming. Area outlined shown in figure 2.](image-url)
stained fractures that radiate outward from the flared edges of some of the grains. Hornblende is only slightly altered, mainly along fractures. Hematite provides the coloring agent for the rock. It is worth emphasizing that, except for color, the alteration is not recognizable in hand specimen and is even easy to overlook in thin section.

In contrast, fresh Cap Rock quartz monzonite shows much less alteration. Magnetite and biotite are little changed, and hematite is minimal.

Details of this alteration are given elsewhere (Egglar and Larson, 1968). It will suffice here to say that the oxidation is believed to have occurred at high temperature during late stages of crystallization of the Trail Creek granite. Evidence includes: (1) the oxidation is restricted to a single granite unit, (2) the alteration assemblage of hematite and pseudobrookite indicates high-temperature conditions (Lindsley, 1966),
and the Sherman erosion surface, Southern Laramie Range

![Diagram showing geological layers and contacts.](image)

ern Front Range. Topography from Army Map Service Cheyenne and Greeley

and (3) the magnetization provided by the hematite yields a good Precambrian paleomagnetic pole position. This early alteration is important because we feel it explains why Trail Creek weathers differently from the other crystalline units.

Topography and weathering.—Wherever the Sherman surface exists on the southern Laramie Range, bedrock is Trail Creek granite. Although in places the Sherman bevels small masses of other rocks, these situations are minor compared with the other association. So reliable is this relationship that where Trail Creek granite stops, the Sherman surface stops and is replaced by a more rugged, outcrop-dominated topography (see fig. 2).

Characteristically Trail Creek granite is deeply disintegrated to gruss; local thicknesses reach as much as 200 feet. Ghost dikes indicate that most of the gruss is in place, although on hill slopes it is overlain
by thin colluvial gruss, and in topographic lows poorly washed alluvial gruss is present. Disintegration is so complete that outcrops are scarce, and rarely do subsurface corestones survive to reach the surface. Typical Sherman topography is smooth, gently rolling, and gruss-covered, consisting of broad open valleys and even broader, low divides. What small tors are present usually mark the outcrops of dikes of aplite, pegmatite, or other crystalline rocks, or indurated fracture zones, as noted by Darton and others (1910). Trail Creek granite provides few outcrops except in areas of recently accelerated erosion.

Table 1

Average modal compositions of Sherman Granite facies

<table>
<thead>
<tr>
<th></th>
<th>Trail Creek granite</th>
<th>Cap Rock quartz monzonite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>26.4</td>
<td>26.1</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>23.0 (An16)</td>
<td>32.6 (An24)</td>
</tr>
<tr>
<td>Microcline</td>
<td>42.0 (Or67)</td>
<td>32.2 (Or79)</td>
</tr>
<tr>
<td>Biotite</td>
<td>2.0</td>
<td>8.1</td>
</tr>
<tr>
<td>Hornblende</td>
<td>6.0</td>
<td>trace</td>
</tr>
<tr>
<td>Opaque minerals</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Apatite</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Sphene</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Zircon</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Allanite</td>
<td>trace</td>
<td>trace</td>
</tr>
</tbody>
</table>

Cap Rock quartz monzonite, as well as other crystalline rock types, also disintegrate to gruss but more slowly and less completely than does the Trail Creek granite. Fresh rock often occurs at the surface in the form of tors. Indeed, the characteristic topography of the Cap Rock quartz monzonite and other crystalline units is a parkland-tor complex where open, grassy, gruss-floored parklands are interspersed with tor clusters. The change from parkland-tor topography to the Sherman surface is abrupt and coincides with the change in granitic rock types (pl. 1). Both topographies occur side by side and at the same elevations, indicating that they are contemporaneous and that the parkland-tor topography has not originated by recent dissection of the Sherman surface. The two contrasting topographies are similar to those described by Ollier (1965, p. 298-299) in Australia.

One further point will be sufficient to emphasize the relationship between topography and bedrock lithology. Wherever the Trail Creek granite crops out, topography typical of the Sherman surface appears. At the crest of the Laramie Range all such areas of similar topography are collectively called the Sherman surface. But there are nearby areas of identical topography, also associated with the Trail Creek granite,
which are not identified as part of the Sherman surface because they are topographically lower. Some of these may be contemporaneous with the Sherman, although others are undoubtedly younger. One is the open ring valley that follows the Trail Creek granite ring dike (fig. 2). Another occurs just a few miles farther southeast where U.S. Highway 287 follows a long outcrop of Trail Creek granite across a landscape that is distinctly Sherman-looking.

Summary.—We have established a relationship between the Sherman surface on the southern Laramie Range and the Trail Creek granite. What needs elaboration now is how the Trail Creek weathers to gruss and how the early alteration facilitated this weathering.

GRUSS DEVELOPMENT

General statement.—Grain size of Trail Creek gruss varies widely and shows some relationship to mineralogy. Fine gravel and coarse sand fractions are composed largely of quartz and microcline, with some plagioclase and minor hornblende and biotite. Finer sand and silt are similar except they contain somewhat more hornblende and biotite. Clay mineralogy is complex and will be discussed more fully in the next section. Thin sections show that quartz and microcline are fresh, plagioclase is slightly altered to clay and calcite, hornblende is slightly altered to clay, but that biotite is extensively altered to a variety of minerals. Thin section evidence is supported by X-ray patterns which commonly show strong plagioclase and hornblende peaks but only minor, diffuse biotite peaks. This association of mineral stability is similar to that re-
ported by Wilson (1967) but different from that of Harriss and Adams (1966) and Wolff (1967). Because it is by far the most weathered mineral, biotite and its weathering products will now be discussed in detail.

**Biotite alteration and clay mineralogy.**—Oriented tile mounts were made of biotite from seven grusses, four from Trail Creek granite and three from Cap Rock quartz monzonite, using the technique of Schultz (1964). From the X-ray diffractograms, some of which are shown in figure 3, and corresponding thin sections it is possible to delineate arbitrarily three stages of weathering.

Stage one is characterized by biotite in which the dark-brown color of the fresh mineral is only slightly bleached, and the principal diffraction peak at 10 Å is strong although somewhat reduced in height.

In stage two (samples R-54 and R-50, fig. 3) biotite is mottled and bleached to a red-brown color. Individual grains still exhibit pleochroism and bird's-eye texture, but they possess irregular extinction, numerous cracks, and a disrupted internal structure. Thin pods of clay are present along cleavage planes. The diffractogram of sample R-54 (fig. 3), typical of this stage of weathering, indicates biotite that has partially altered to vermiculite. Vermiculite is indicated by the 14 Å peak which remains after glycolation. Although vermiculite is difficult to differentiate from montmorillonite by swelling tests alone, it is generally conceded that if the clay does not expand beyond 14.5 Å it is a vermiculite, probably with Mg as the exchangeable cation (Walker, 1958). In thin section lemon-yellow vermiculite is present both at the edges of biotite grains and in zones parallel to cleavage within the grains. Sample R-54 also seems to contain a little kaolinite-group clay as indicated by the 7 Å (basal reflection) and the 1.49 Å (060 reflection) peaks. In thin section this is probably represented by the fine-grained, low-birefringent clay present along some cleavage planes. The relatively narrow basal peak (7 Å) and the poorly resolved but distinct peaks at and less than 4.43 Å suggest that the mineral is disordered kaolinite (Brindley, 1961). Gibbsite (4.8 Å peak) is present in small quantities and may be present with the kaolinitic clay.

Sample R-50, another biotite of stage two, is grossly similar to R-54 in that it contains bleached biotite, kaolinite, and gibbsite, but it differs in that the 14 Å peak is split. This could indicate a lateral mixing of vermiculite layers with greater and lesser charges or an interstratification of vermiculite and montmorillonite.

Stage three biotite flakes (sample R-53) are golden red and commonly curled. In thin section they are extremely bleached, only faintly

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Fig. 3. X-ray diffraction patterns of weathered biotites from Sherman Granite using Ni filtered, CuKα radiation. All samples from Trail Creek granite gruss, except R-50 from Cap Rock quartz monzonite gruss. Locations: R-54, 1.5 miles south of Virginia Dale, Colo.; R-50, 0.25 mile northwest of Virginia Dale; R-53, 2.3 miles east of Hermosa Tunnel, Wyo.; HT samples, Hermosa Tunnel.

Ground samples were mounted on ceramic tiles. Symbols indicate: unt = untreated sample; gly = glycolated tile; 550 = sample heated to 550° C. Some peaks indicated by: Q = quartz, H = hematite, G = gibbsite, K = kaolinite, B = biotite, D = dolomite, C = calcite, V = vermiculite.
pleochroic, retain only a vestige of the bird’s-eye texture, and have very disrupted internal structure and cleavage. Pods of kaolinite, commonly large, are conspicuous along cleavages. This sample retains only a broad and subdued 10 A biotite peak (fig. 3). This may indicate partial hydration of the biotite to vermiculite (D’Yakonov, 1965), but the lack of a strong 14 A vermiculite basal peak is contradictory. More probably, the biotite has been altered to an intralayer mixture somewhere between vermiculite and an interstratified vermiculite-biotite. Considerable kaolinite and a small amount of gibbsite are also present.

Although most heat-treated samples are not shown, all weathered biotites collapsed to a sharp, single 10 A biotite peak when heated to 550°C. R-50 and R-54 collapsed to this peak when heated to 300°C, indicating a lack of brucite or gibbsite-like intersheet material.

Table 2
Mineralogy of <2μ fraction of grusses from which biotites were extracted, estimated from X-ray diffractograms*

<table>
<thead>
<tr>
<th>Trail Creek granite</th>
<th>Cap Rock quartz monzonite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R-54</td>
</tr>
<tr>
<td>Weathering stage</td>
<td>2</td>
</tr>
<tr>
<td>Depth below surface (ft)</td>
<td>6</td>
</tr>
<tr>
<td>Hornblende</td>
<td>0</td>
</tr>
<tr>
<td>Biotite</td>
<td>8</td>
</tr>
<tr>
<td>Montmorillonite</td>
<td>4</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>0</td>
</tr>
<tr>
<td>Chlorite</td>
<td>22</td>
</tr>
<tr>
<td>Interstratified clay mineral</td>
<td>0</td>
</tr>
<tr>
<td>Talc</td>
<td>54</td>
</tr>
<tr>
<td>Hematite</td>
<td>2</td>
</tr>
<tr>
<td>Calcite</td>
<td>0</td>
</tr>
<tr>
<td>Dolomite</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

* Quartz and feldspar neglected because of interfering peaks from ceramic tiles.

The clay mineralogy of the minus-2-micron fractions of grusses, from which the biotites described above were separated, is given in table 2. The principal minerals are chlorite and talc. However, since the exact source of the minerals in the clay-size fraction is unknown, these minerals may or may not be the product of biotite weathering.

Biotites in Trail Creek granite gruss are always weathered, generally to the degree of stages two and three. Biotites in Cap Rock quartz monzonite are weathered only to stages one and two. Even where the two facies are side by side, the grusses show different degrees of biotite al-
teration. For example, biotite from Trail Creek gruss (HT-1C and HT-30, fig. 3) is considerably hydrated and altered to expanding lattice minerals, whereas gruss at the top of a cross-cutting dike of Cap Rock quartz monzonite at the same location contains only fresh biotite.

Discussion.—Our observations on biotite weathering agree generally with those of others (for example, Walker, 1949; Raman and Jackson, 1965; Wahrhaftig, 1965; Wilson, 1966). Alteration of biotite to vermiculite (Walker, 1949), montmorillonite (MacEwan, 1954), or intergrade aluminous vermiculite-chlorite (Wilson, 1966) have been reported, and Wilson (1966) found epitaxial zones of kaolinite and gibbsite within biotite grains.

In detail, however, biotite alteration in the Sherman Granite is not identical to that of previous studies, and its development is not fully understood. Apparently, biotite weathers to vermiculite through processes involving the leaching of potassium, movement of magnesium and water to intersheet positions, and oxidation of some Fe$^{2+}$ in octahedral positions. However, in only one sample was the development of identifiable vermiculite extensive. Most commonly, the alteration produces a biotite-vermiculite mixture, probably with greatest removal of potassium near grain edges or in zones near open cleavage planes.

At the same time, kaolinite and gibbsite apparently crystallize along cleavage planes, possibly in the manner described by Wilson (1966) in which progressive expansion and splitting of the flakes present fresh surfaces and open spaces for continued precipitation of hydroxyaluminum, in the case of gibbsite-growth, and aluminum gel, in the case of kaolinite-development. Unlike Wilson's process, intersheet areas do not also aluminate to an intergrade vermiculite-chlorite mixture.

Many samples contain montmorillonite or an interstratified montmorillonite mineral. In thin section it commonly appears in ribbons or pods along cleavage planes, accompanied by kaolinite and gibbsite, but in some cases it is present in large blebs replacing biotite. Kaolinite in these samples could be derived from montmorillonite-alteration rather than by precipitation (Poncelet and Brindley, 1967). Some of the montmorillonite may actually be vermiculite of variable layer charge, but since the division between vermiculite and montmorillonite is essentially arbitrary (Walker, 1961), the distinction is unimportant.

Effect of earlier alteration.—Biotite of Trail Creek granite weathers more rapidly than other biotites, even though the mineral is less abundant than in other units (table 1). This is attributed to Precambrian alteration. Under the influence of relatively high oxygen fugacity and elevated temperatures, probably in the presence of an aqueous phase, oxidation of certain minerals occurred (Eggler and Larson, 1968). Magnetite, ilmenite, and biotite show the greatest effects, but only in biotite was the oxidation disruptive. Hematite formed along biotite cleavages, expanding the mineral in the c-direction and producing a wedging effect which minutely fractured adjacent silicate grains. Alteration was not
sufficient to disintegrate the rock at that time but did provide an open structure for easy access of later weathering solutions. In Cap Rock quartz monzonite, Precambrian oxidation was minimal, and there was less acceleration of later weathering processes.

GRUSS AND THE SHERMAN SURFACE

The smooth, gently rolling topography that typifies the Sherman surface results from rapid and complete disintegration to gruss of the Trail Creek granite. Such detritus can be removed by water and wind without great difficulty. Principal culprit in the process is biotite which alters to secondary minerals of larger volume, thereby fracturing the rock along grain boundaries, feldspar cleavages, and preexisting fractures, all similar to the granite disintegration described by Wahrhaftig (1965). In Trail Creek, the whole process has been facilitated by Precambrian oxidation.

Cap Rock quartz monzonite and other crystalline units disintegrate to gruss by the same mechanism but at a much slower rate and more selectively along fractures, producing the parkland-tor topography. We concur with others that there is a disparity in rate of weathering between buried granite and exposed granite (Barton, 1916; Twidale, 1962; Wahrhaftig, 1965; Thomas, 1965; and others), which tends to maintain parklands and tors (although the dimensions and positions of the units may change as degradation proceeds).

From the foregoing, it is possible to conclude that the parkland-tor topography and Sherman topography are naturally coexisting topographic facies. Had the compound Sherman-Great Plains surface remained stable throughout the late Cenozoic, instead of undergoing recent dissection, it is doubtful that the Sherman surface would have gotten any flatter, or that the parkland-tor topography would look much different. Verification comes from those areas (generally in the interior of the range) that have not yet felt the late Cenozoic accelerated erosion; here, the two topographic facies have continued to evolve without major interruption right up to the present time, and hence are modern topographies. Nearer the range fronts, the principal effects of late-Cenozoic valley cutting have been to increase relief and amount of outcrop; even here, however, the contrasting topographies of the Trail Creek and other units can be distinguished. Pleistocene periglacial processes may have affected rates of disintegration but appear not to have produced any fundamental differences in the topographies. Finally, going backward in time, it seems likely that the parkland-tor and Sherman topographies would have been readily apparent to an observer atop the Laramie Range throughout much of the middle Cenozoic. This could also have been true at earlier geologic times when these rocks were exposed, as during the Pennsylvanian and late Precambrian-early Cambrian.

SUMMARY AND CONCLUSIONS

This study confirms the importance of biotite-alteration in granite disintegration. Precambrian oxidation expanded biotites in the Trail
Creek granite by formation of hematite along cleavages. This alone did not cause disintegration, but it did weaken the mineral’s resistance to later attack by surficial processes. Biotite then weathered to vermiculite, montmorillonite, kaolinite, and gibbsite, with a resulting expansion that shattered the otherwise comparatively fresh rock. Rapid and total disintegration to gruss were the conditions needed for development of the Sherman surface.

As many have observed, there are granites and granites in the way they weather. Events early in their history can provide a legacy that influences later behavior. The early changes may be subtle and difficult to recognize. We have here reported the legacy of early high temperature oxidation. With some other granites, the early events might be deuteric or hydrothermal alteration (Fuller, 1938; Mackin, 1947, 1954).

**References**


