The Precambrian Geology of Casper Mountain, Natrona County, Wyoming

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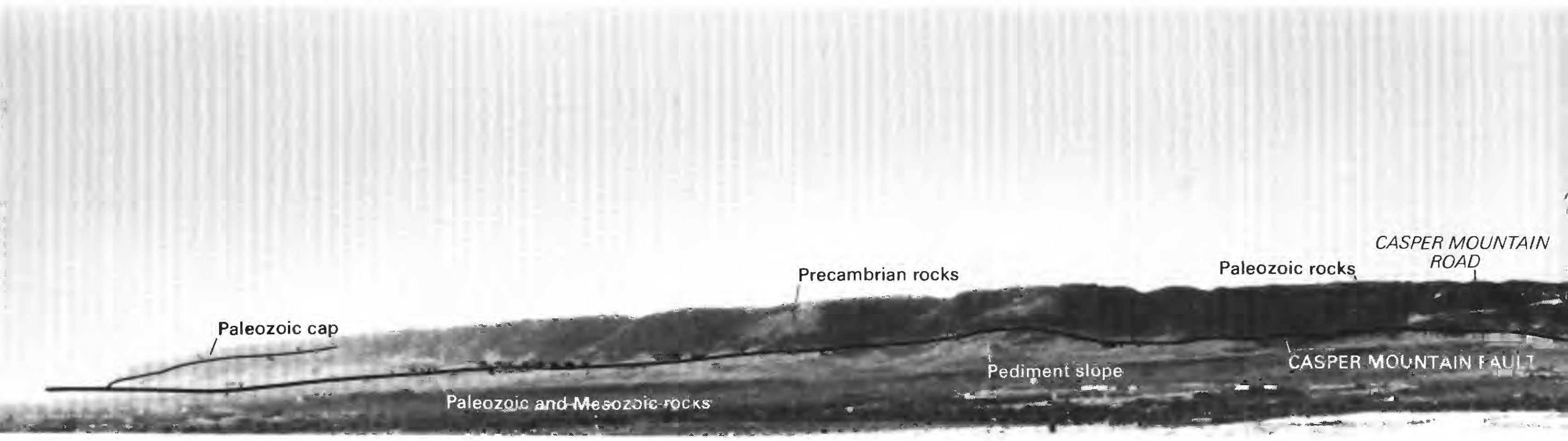
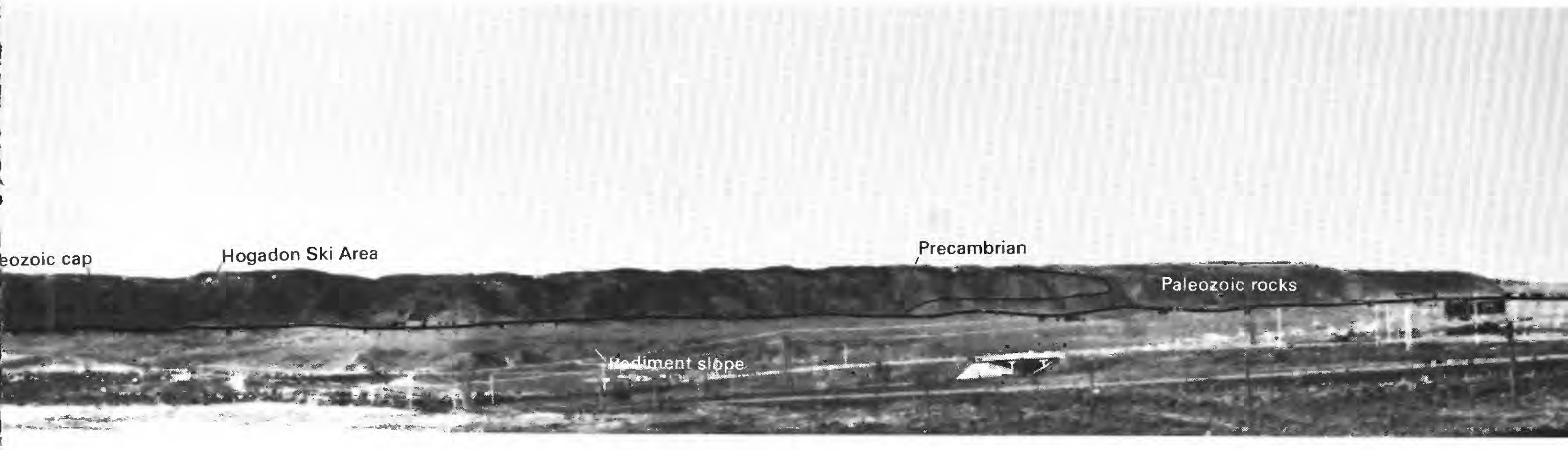


FRONTISPIECE (above and facing page).—View of Casper Mountain from Casper, Wyo. Photograph by A.E. Burford.



eozoic cap
Hogadon Ski Area
Precambrian
Paleozoic rocks
Pediment slope

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By DOLORES J. GABLE, ARTHUR E. BURFORD, *and* ROBERT G. CORBETT

With a section on THE GEOCHEMISTRY OF ITS GROUND WATER
By ROBERT G. CORBETT

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A mineral, geochemical, structural, and ground-water study of the Casper Mountain Precambrian terrain

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THE PRECAMBRIAN GEOLOGY OF CASPER MOUNTAIN, NATRONA COUNTY, WYOMING

By DOLORES J. GABLE, ARTHUR E. BURFORD[1], and ROBERT G. CORBETT[1],
with a section on
THE GEOCHEMISTRY OF ITS GROUND WATER
BY ROBERT G. CORBETT

ABSTRACT

The Precambrian rocks of Casper Mountain were mapped as part of the U.S. Geological Survey's studies of the geologic framework of Precambrian crystalline areas in Wyoming.

Casper Mountain, an east-west-trending, asymmetrical anticlinal flexure defined by its Paleozoic and Mesozoic sedimentary cover, is the northwest extension of the Laramie Mountains uplift. The area of the mountain has been topographically positive since Laramide time. Since then, erosion has stripped part of the overlying sedimentary cover from the mountain, exposing Precambrian rocks in its core. This Precambrian core is part of the Archean greenstone-granite belt of central Wyoming.

An early sedimentary sequence of sandstone and graywacke intruded by, and interlayered with, diabase, gabbro, and other mafic intrusive and extrusive rocks was subjected to regional dynamic metamorphism of high amphibolite grade 2.8 b.y. ago. This metamorphism converted the sedimentary rocks to quartzite, biotite schist, and gneiss and felsic gneiss, and the mafic rocks mostly to amphibolite. Intrusions of ultramafic, mafic, and granitic rocks and migmatite accompanied, or followed, metamorphism. A more recent (1.7 b.y.) thermal event resulted in a pervasive regional retrograde metamorphism recognizable in most rocks on Casper Mountain.

Precambrian structures south of the Casper Mountain fault include folds, joints, and faults that trend predominantly east-northeast. Many of these northeast-trending faults were reactivated during Laramide time when horizontal forces caused the area to be uplifted and folded on an east-trending axis into a doubly plunging fold. The anticlinal form of the mountain, however, is not reflected in its Precambrian core. The consistency of the Precambrian structure indicates the Precambrian rocks did not flex or deform plastically during Laramide time but did fracture. The flexure of the mountain was probably formed by a maximum principal stress oriented north-south, a mean principal stress oriented east-west, and a minimum principal stress oriented vertically. Pervasive joint sets in the Precambrian rocks may have developed during Precambrian time, but these were largely masked by a stronger Laramide joint pattern. Laramide-age movements on the major faults of the area thrust Casper Mountain northward, and the amount of horizontal transport may have been substantial.

Although prospecting for chromite and asbestos has been fairly extensive on Casper Mountain, the area has not shown potential for either mineral sufficient to support workings.

Geochemical studies of wells, seeps, and springs on Casper Mountain indicate that the quality of ground water is greatly influenced by terrain and rock composition. Water from granitic and metasedimentary terrain is a hard calcium bicarbonate water, and that from a serpentine terrain is a hard magnesium bicarbonate water.

INTRODUCTION

The core of Casper Mountain, at the northernmost tip of the Laramie Mountains in south-central Wyoming, is composed of a Precambrian metamorphic complex that has been intruded and deformed by a series of granitic and mafic-ultramafic intrusive rocks. This association of granite and mafic-ultramafic rock is similar to Archean greenstone belts elsewhere. The metamorphic sequence includes quartzite and metagraywacke interlayered with, and intruded by, the first of two recognizable generations of mafic-ultramafic lenses and dikes. Both the older mafic-ultramafic rocks and the metasedimentary rocks were cut first by granitic rocks and a second generation of mafic-ultramafic intrusive rocks and later by lenses and dikes of hornblendite, diabase, and rhyolite. The metamorphic complex is geologically interesting for the series of mafic-ultramafic intrusive rocks and the chromite and asbestos deposits associated with them.

Casper Mountain is an east-trending, doubly plunging anticline bounded by the high-angle Casper Mountain fault on the north. On the south, southeast, and west, a cover of Phanerozoic strata limits the exposures of the Precambrian rocks. Of considerable interest is the structure of Casper Mountain, especially the type and extent of thrusting on the Casper Mountain fault.

In the Precambrian rocks, mega- and micro-fractures trend predominantly east-northeast and less conspicuously north-south. These fractures suggest a complex

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structural pattern closely related to not only Precambrian tectonics but also to the Laramide orogeny, when vertical movement and thrust faulting modified the major crystalline terrains of Wyoming.

Casper Mountain is 10 km due south of the city of Casper, in east-central Wyoming. Casper Mountain Road, an extension of South Wolcott Street in Casper, crosses the central part of the mountain from north to south. A gravel road along the mountain crest provides access to the easternmost and westernmost exposures of Precambrian rocks on the mountain. Many parts of the north face of the mountain can be reached by unmaintained ranch roads, but ranchers' permission is necessary to use these roads or to enter the area.

Casper is at an elevation of 1,566 m above sea level; Casper Mountain ranges from 2,230 to 2,462 m. Due to this elevation difference, Casper Mountain averages 10–15 °F cooler than Casper. Casper's mean January temperature is 33.6 °F and its mean July temperature is 87.1 °F.

Elevation, precipitation, temperature, and soil type account for the variation in vegetation from the base to the top of the mountain. At the base, sagebrush grows in the dryer areas, and narrowleaf cottonwoods, boxelders, and willows grow in more moist areas adjacent to streams. Higher on the slope the sagebrush gives way first to juniper and ponderosa pine and then to lodgepole pine and subalpine fir. On the very top of the mountain, limber pine, subalpine fir, lodgepole pine, and quaking aspen predominate. Due to the high winds, low precipitation, low temperatures, and poor soils, large areas of the mountaintop are treeless. Infertile soils are underlain by serpentinite, which lacks alkali and lime, necessary ingredients for plant growth. Treeless areas underlain by granite are perhaps due to lack of soil and the harsh climate. These treeless areas are covered with grasses and dwarf shrubs and resemble tundra. Sagebrush is common in alluvial areas where some soil has built up.

Most previous work on the geology of the mountain and adjacent areas has been described in master's theses. A composite of these theses was published in a report entitled "The Precambrian Complex of Casper Mountain—A Preliminary Paper" (Burford and others, 1979). Earlier, Beckwith (1939) briefly described the geology of the mountain, emphasizing the asbestos and chromite deposits. In 1965, the Wyoming Geological Association published a geologic map of Casper Mountain, focusing primarily on sedimentary rocks. In 1978, the Wyoming Field Science Foundation published a "Field Guide to the Casper Mountain Area" (Knittel, 1978). This nature guide (in color) describes the geology, vegetation, and wildlife of the mountain and surrounding areas.

The Precambrian rocks of Casper Mountain were mapped as part of the U.S. Geological Survey's studies of the geologic framework of Precambrian crystalline areas in Wyoming. The data collected for this report, including those of economic importance, will be used to expand the framework studies.

The authors mapped and studied the Precambrian of Casper Mountain during the 1979–80 field seasons. A geologic map of the Casper Mountain Precambrian was subsequently published in 1982 as a U.S. Geological Survey Open-File Report, which this report supersedes. Subsequent laboratory studies done for this report include both rapid rock chemical analyses and semiquantitative spectrographic analyses, modal analyses, study of X-ray powder patterns and cathodoluminescence, probe work, and unit-cell measurements. The classification of rocks is based on modal analyses, aided by X-ray powder patterns for the identification of individual minerals, and rapid rock chemical analyses. Grain size in most cases allowed at least 800 counts per thin section, and this number was considered adequate to calculate relative mineral percentages.

Rapid rock chemical analyses, done according to the techniques outlined by Shapiro and Brannock (1962), and semiquantitative spectrographic analyses were used in determining rock composition. These analyses were made by the U.S. Geological Survey; individual analysts have been credited in the appropriate tables. For most samples analyzed by semiquantitative spectrographic methods, the precision of each result is defined by the standard deviation of any single determination and should be taken as plus 50 percent and minus 33 percent.

The authors acknowledge the contributions of the following researchers to this study: Richard Phillips identified the feldspar in the pebble conglomerate and determined its composition from unit-cell measurements. Lorraine Schnabel identified the mineral pseudoixiolite from a pegmatite mine by using X-ray powder patterns and microprobe analyses. Arthur Burford, University of Akron, studied the cathodoluminescence of the quartzite-pebble conglomerate. Field photographs used throughout the report were taken by Arthur Burford and Dolores Gable. The photomicrographs were taken by Dolores Gable.

The authors extend special thanks to the following people for their assistance and permission to map on their properties: Dr. Nat Fuller, Robert Brecker, Mrs. Percy Jones, Homer Lathrop, and Tom Milne (Hat Six Ranch).

PHYSICAL SETTING

Casper Mountain is an east-west-trending, 38-km-long, dissected ridge bounded on the southwest by Coal

Mountain; on the west by Rasmus Lee Lake, about 10.5 km west of Matheson Creek (west edge of area of fig. 1); on the north by the east-west-trending Casper Mountain fault; on the east by the Clear Fork of Muddy Creek and the Hat Six Hogback; and on the south by Muddy Mountain (fig. 1). The Precambrian of Casper Mountain is exposed on the eastern and central parts of the mountain only. Most streams in the Casper Mountain Precambrian trend north-south, in many places following joint or fault traces, and drain north, many dissecting pediment surfaces north of the mountain front.

GEOLOGIC SETTING

Although a prominent physiographic feature in the Casper area, Casper Mountain is one of the smallest of a series of Laramide uplifts in Wyoming (fig. 2). Actually, Casper Mountain is not a totally separate entity but is a part of the northernmost tip of the north-northwest-trending Laramie Mountains uplift that appears to have been separated from the main uplift. In general, the Laramide uplifts, extending from the Hartville Mountains on the east to the Wind River Mountains on the west, trend northwest across Wyoming into southwestern Montana. The uplifts are widely spaced, have Precambrian rocks exposed in cores, and are flanked and separated by broad areas of downwarped younger sedimentary rocks.

East of Casper Mountain the east-trending Casper Mountain fault supposedly swings in a more northerly direction (Stone, 1969). To the west, the fault is perhaps continuous with the east-trending fault that displaces the southern tip of the Rattlesnake Hills.

Precambrian metamorphic and igneous rocks, buried beneath thousands of feet of sedimentary rock in the Casper basin, north of the Casper Mountain fault, are exposed at Casper Mountain. The metamorphic rocks reflect an early period of sedimentation that included deposition of pebble conglomerate, sand, sandy clay, and silt. Interlayered with these sediments were minor basalt and some felsic tuff. The resulting sedimentary and volcanic rocks were metamorphosed and deformed by a regional high-grade metamorphism accompanied by migmatization, folding, and faulting along generally east-northeast axes. Intrusion of granitic rocks accompanied and followed this high-grade metamorphism. Most rocks now reflect a retrograde metamorphism that affects all but the youngest rocks of the area.

Sedimentary rocks, Middle Cambrian to Late Cretaceous in age, flank and drape over the exposed Precambrian mountain core and form an east-west-trending, doubly plunging anticline 38 km long. On the east, the anticline appears to be covered by Tertiary sediments, or it may die out just north of the Hat Six Hogback (pl. 1); on the west, it dies out just south of Rasmus Lee Lake (sec. 13, T. 32 N., R. 82 W.), 10 km west of the area shown in figure 1. Sedimentary rocks dip gently to the south off Casper Mountain and are abruptly cut off by the northeast-trending Muddy Mountain fault, which separates the main Laramie Mountain uplift from the Casper Mountain uplift (Knittel, 1978).

Faults that formed in Precambrian time were reactivated during the Laramide, and perhaps also during the Quaternary. In fact, movement may have been quite recent: the Casper Mountain fault appears in many places as a distinct line of depression on aerial photographs.

Much of the unraveling of the major events affecting central and eastern Wyoming can be credited to the geochronological studies in the Granite Mountains by Peterman and Hildreth (1978) and by R. E. Zartman and J. S. Stacey (U.S. Geological Survey, 1979, p. 190). Condie (1969, 1976), Johnson and Hills (1976), and Hills and Armstrong (1974) carried out similar studies in the northern Laramie Mountains.

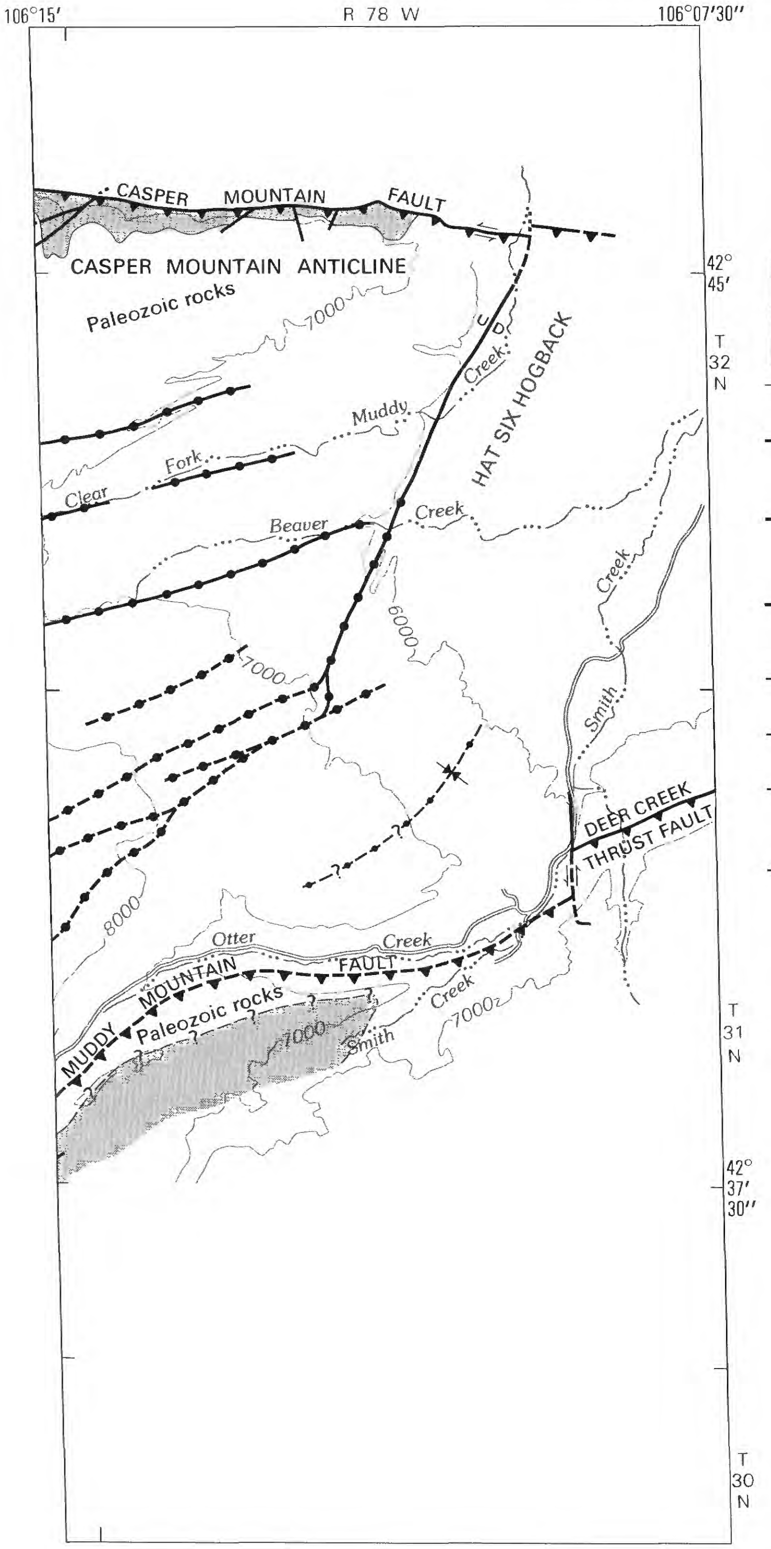
No radiometric ages are available for the metasedimentary rock of Casper Mountain. However, a minimum $^{207}Pb/^{206}Pb$ age of 3.2 b.y. was measured by R. E. Zartman and J. S. Stacey (U.S. Geological Survey, 1979, p. 190) for the western part of the Granite Mountains, due west of Casper Mountain. This metamorphic complex includes migmatite, amphibolite, biotite schist, and tonalite. While one cannot make a positive correlation between the sedimentary rocks of the Granite Mountains and Casper Mountain, similar metamorphic rocks in both locations may be the same age.

A rubidium-strontium age of 2.5 ± 0.06 b.y. is the only age determination that has been made on the Casper Mountain rocks. This age was determined by Hills and others (1968) using microcline and muscovite from pegmatite (probably an Ap pegmatite) in the central part of the mountain.

This 2.5-b.y. age corresponds to a postmetamorphic event that has counterparts in the Granite Mountains and the Laramie Mountains. For the Granite Mountains, Peterman and Hildreth (1978) obtained a rubidium-strontium date of 2.55 ± 0.06 b.y. for the main body of granite. Johnson and Hills (1976) reported a similiar rubidium-strontium age of 2.57 ± 0.03 b.y. for Laramie Mountains granite.

The oldest (Aam) and youngest (ꝒAdi) rocks that intrude the Precambrian rocks in the Casper Mountain area are diabase dikes, none of which has been age dated. Similar diabase dikes in central and western Wyoming have been dated as old as 2,600 m.y. (Stuckless and others, 1977) and as young as 700 m.y. (Condie and others, 1969). The 2,600-m.y. age on the

FIGURE 1 (above and facing page).—Map showing regional geologic setting for Casper Mountain, Natrona County, Wyo. Compiled by Burford and Gable with additions from Love and others (1979).



EXPLANATION

Mesozoic-Paleozoic rocks—Division shown in general way by labels on map

Precambrian rocks

Contact—Dashed where inferred; queried where uncertain

U D **Fault**—Dashed where uncertain; dotted where concealed. U, upthrown side; D, downthrown side; arrows show relative horizontal movement

Linear topographic feature interpreted from aerial photographs—Dashed where inferred. Arrows show relative horizontal movement

Thrust—Dashed where inferred. Sawteeth on upper plate; arrows show relative horizontal movement

Antiform—Showing approximate trace of axial plane

Synform—Showing approximate trace of axial plane. Dashed where inferred

?— **Synform interpreted from aerial photographs**—Showing approximate trace of axial plane. Dashed where inferred

Monocline or sharp flexure—Dashed where inferred

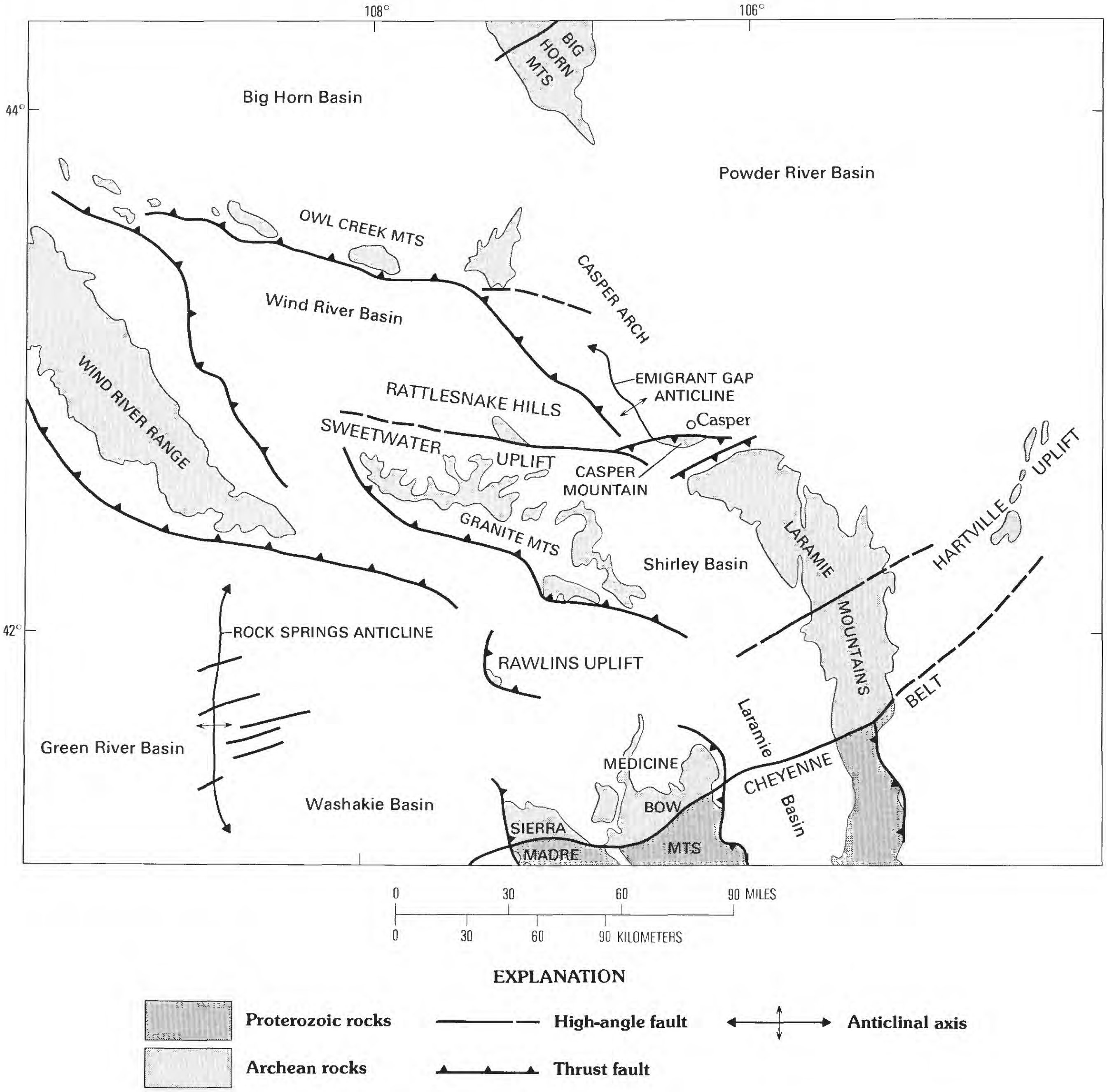


FIGURE 2.—Generalized structure map of east and central Wyoming.

older dikes indicates that some diabase was emplaced during regional metamorphism in Wyoming.

Geologic events described for the Precambrian rocks of Casper Mountain fall into the same regional pattern as do those recognized for the Granite Mountains and the northern Laramie Mountains. Collectively, these Precambrian, or Archean (pre-3.2 to 2.5) and Proterozoic (1.6 to post-1.6), geologic events are summarized below:

Pre–3.2 b.y. ago

Basement composed of mafic and granitic rocks not exposed at Casper Mountain

3.2 b.y. ago

Deposition of grit or sand, silt, and clay accompanied by eruption of mafic extrusive rocks and emplacement of intrusive rocks consisting of dikes and sills of diabase and perhaps some gabbro (U.S. Geological Survey, 1979)

2.8 b.y. ago

Regional high-grade metamorphism (Peterman and Hildreth, 1978) of sedimentary pile into quartzite, schist, and gneiss and of diabase and gabbro into amphibolite. Large ultramafic-mafic intrusive bodies emplaced late in metamorphism but before intrusion of granitic rocks

2.6–1.8 b.y. ago

Major granite emplacement about 2.6 b.y. ago (Johnson and Hills, 1976; Peterman and Hildreth, 1978). Mafic-ultramafic magma in form of small lenses and pods and large, irregular masses intruded the granite. Diabase dikes associated with intrusive event yield ages of 2.5 b.y. (Johnson and Hills, 1976) and 2.6 b.y. (Stuckless and others, 1977). Rhyolitic dikes that cut hornblendite, gneissic granite, and granite gneiss and pegmatite are youngest granitic intrusive rocks, and diabase, intrusive throughout Precambrian core, is youngest mafic intrusive rock

1.8–1.6 b.y. ago

Thermal event 1.7 b.y. ago (Hills and Armstrong, 1974) brought about regional greenschist (retrograde) metamorphism

Post-1.6 b.y. ago

Emplacement of some diabase dikes?

THE METAMORPHIC COMPLEX

METASEDIMENTARY ROCKS

The metamorphic complex on Casper Mountain consists of a layered sequence that includes quartzite (Aq), biotite gneiss (Abg) and gneissic biotite schist (Abs), biotite-feldspar-quartz gneiss (Aqf), and metadiabase and metabasalt mapped as amphibolite (Aam), which appears to be part of a greenstone terrain. The metadiabase and metabasalt are interlayered with, and in some places crosscut, the metasedimentary sequence. The depositional sequence is uncertain because of poor exposures and poorly preserved sedimentary structures.

IMPURE QUARTZITE

Impure quartzite (Aq) that is gray to cloudy pinkish or greenish white and commonly stained reddish brown by hematite occurs in several distinct thick-bedded units in the Precambrian of Casper Mountain. Each unit consists of white quartzite alternating with bands of hematite-stained quartzite, amphibolite, and fuchsite schist. Quartzite also appears as thin distinct layers and as gradational lenses in the metamorphic sequence of felsic gneisses and schists (pl. 1). Quartzite is also present in several small unmapped enclaves in gneissic granite (Agn) in SW¼ sec. 8, T. 32 N., R. 79 W., where it is interlayered with metaconglomerate felsic gneiss, and gneissose and schistose amphibolite.

The largest quartzite outcrop is just northwest of the Eadsville site, in the central part of Casper Mountain. This outcrop is predominantly quartzite stained reddish-brown that is interlayered with white or gray quartzite and locally interlayered with amphibole-rich layers or amphibolite layers a few millimeters or centimeters thick (fig. 3*A*).

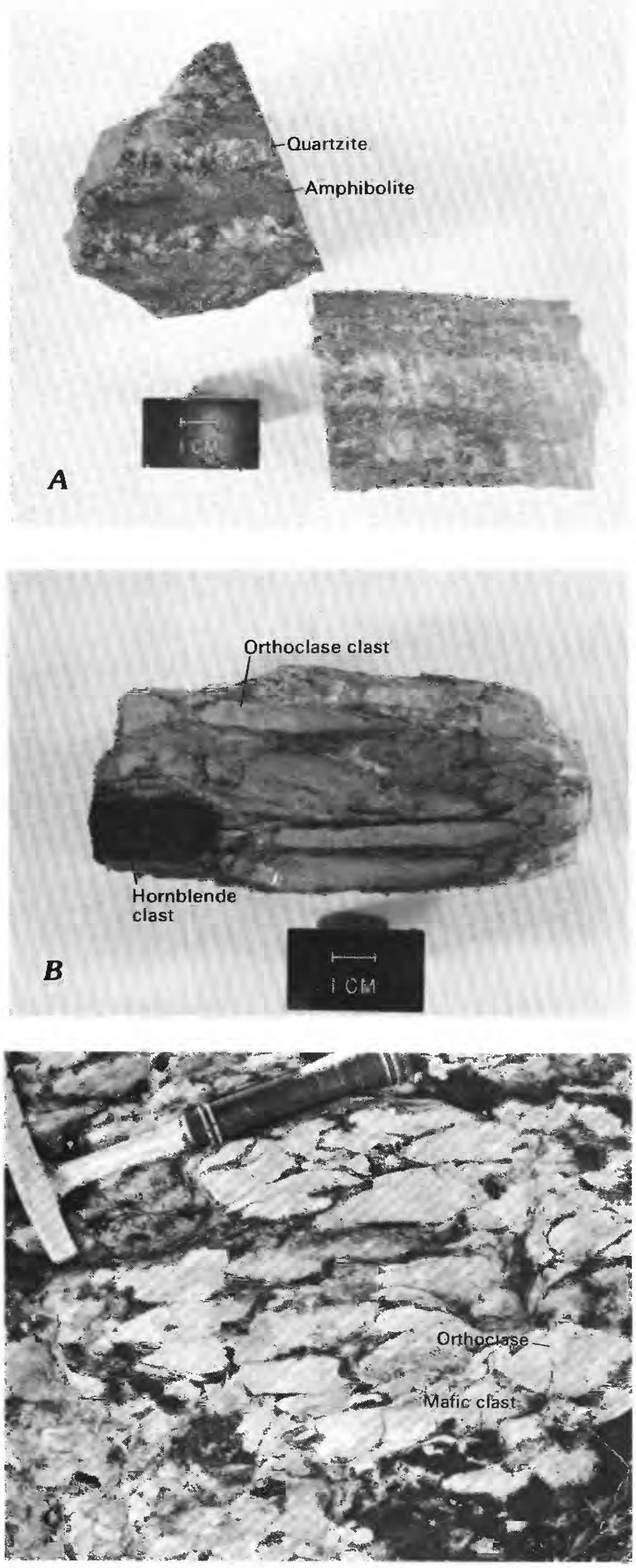
In this report we have treated the large outcrop of quartzite near Eadsville as part of the layered sequence, but because it is a topographic high and the quartzite is more resistant to erosion than surrounding rock and because contacts with the mafic-ultramafic rocks to the northeast are rather abrupt, the quartzite could unconformably overlie the mafic-ultramafic rocks. However, in the same general area, thin quartzite lenses interlayer with adjacent gneiss, and contacts in critical areas are poor due to vegetative cover and loose, unconsolidated sediments. Because of these last two factors, we have decided to consider the quartzite as part of the layered sequence.

As seen in thin section, the quartzite generally exhibits textures indicative of slight dynamic metamorphism or preferred orientation due to regional metamorphism. The quartz grain boundaries range from serrate to curved planar, locally showing cataclastic quartz between larger crystals. In amphibolite-bearing layers, the quartz is finer grained and has been elongated in the direction of bladed mafic minerals.

The quartzite contains as much as 5 percent accessory minerals; the accessories may be one mineral or a combination of several, including microcline, perthite, ores (chiefly magnetite altered along edges to hematite), and sheet silicates (chlorite, fuchsite, muscovite, and traces of biotite). Some quartzite also bears trace amounts of epidote, allanite, sphene, zircon, tourmaline, apatite, monazite (multizoned), amphibole (hornblende, tremolite-actinolite or cummingtonite), pyroxene (diopside), and garnet.

The black to greenish-gray streaks and wispy layers in the quartzite are commonly foliated, have a distinct mineral lineation, and have distinct mineralogies. Some layers are wholly amphibole-bearing, others pyroxene-bearing; still other thin layers and streaks consist of tiny oriented grains of magnetite, subhedral pyroxene crystals, and traces of anhedral amphibole.

Amphibolite layers, 1 mm to several tens of centimeters in width, in the quartzite contain hornblende, diopside, mica, opaque ores, and, locally, garnet. There is some alteration of hornblende to tremolite or actinolite,



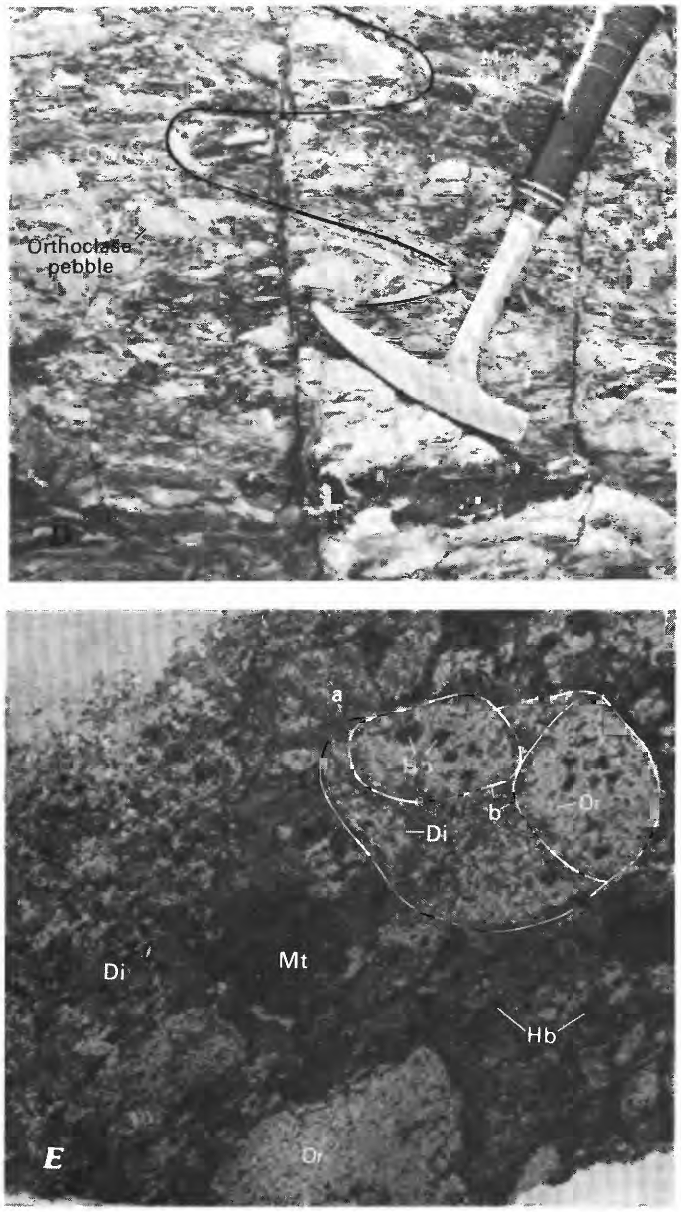


FIGURE 3.—Quartzite interlayered with amphibolite gneiss and metaconglomerate.

A, Hand specimens of medium- to coarse-grained quartzite interlayered with fine-grained amphibolite (dark layers). *B*, Hand specimen of a flattened-pebble metaconglomerate found interlayered with quartzite, Casper Mountain. Black elongate inclusion is hornblendite rich in magnetite. Light-colored, pebble-like elongated inclusions are orthoclase in a fine-grained, greenish-black, greenish-yellow, or pinkish groundmass commonly speckled with black and consisting of diopside, hornblende, and lesser amounts of quartz, poikilitic plagioclase, and magnetite. Traces of tiny orange garnet crystals, sphene, biotite, and allanite also present. *C*, Metaconglomerate outcrop. *D*, Folds in metaconglomerate; mixed mafic and leucrocratic groundmass present between orthoclase blebs. *E*, Cathodoluminescence photograph of metaconglomerate collected from area of *C*; × 3. Some well-rounded pebbles (a) are composed of smaller rounded pebbles or granules (b). Sand-size grains are rounded, subrounded, and angular. Di, diopside (medium-gray areas); Hb, hornblende (black areas); Mt, magnetite (also in black areas, but grains more rounded and smaller than hornblende); and Or, orthoclase (light-gray areas).

of magnetite to hematite, and of biotite to chlorite or, rarely, to epidote. Pyroxene layers are rich in diopside, magnetite, hematite, quartz, and tremolite or actinolite.

Exposures of metaconglomerate interlayered with quartzite in the several small unmapped enclaves in gneissic granite (Agn) are only about 2 m wide and several meters long, but they are the only metaconglomerate found in Precambrian rocks on Casper Mountain. There are also slightly larger outcrops of finely interlayered quartzite and amphibolite in this same general area. The metaconglomerate consists of black, partly angular hornblendite fragments and flattened, light-brownish-orange, feldspar-rich, pebble-like clasts in a sandy-textured groundmass; it is part of a layered sequence of quartzite and fine-grained rock rich in pyroxene, amphibole, and feldspar (fig. 3*B*). Thin sections show the mafic minerals in the hornblendite clasts to be hornblende and 15–20 percent magnetite. The minerals in other mafic clasts and lenses in the metaconglomerate are predominantly pyroxene (diopside) and hornblende and varying amounts of magnetite, garnet, allanite, biotite, and sphene. The mafic layers commonly contain large crystals and profuse small grains of magnetite. The groundmass consists of tiny subhedral pyroxene crystals and traces of anhedral hornblende, garnet, and untwinned poikilitic plagioclase or mixtures of orthoclase, pyroxene, and hornblende, as shown in figure 3*C–E*. Tiny euhedral to subhedral apatite crystals are associated with the most leucocratic parts of the groundmass. The large brownish-orange and pinkish, pebble-like clasts consist almost entirely of finely crystalline alkali feldspar, much with profuse inclusions of magnetite, hornblende, and some biotite. The alkali feldspar, identified from unit-cell measurements, is an intermediate orthoclase (Wright and Stewart, 1968; Afonina and others, 1979) that is Or_{92} as determined by the methods of Wright (1968). Cathodoluminescence studies clearly show sedimentary textures consisting of well-rounded clastic orthoclase grains within the pebble clasts (fig. 3*E*). Some orthoclase crystals luminesce with dark-maroon or reddish-brown cores but have light-blue rims, whereas others are medium blue with very dark overgrowths, and some luminesce from core to rim a medium bluish. In a study of cathodoluminescence in quartz crystals in sandstones, Owens and Carozzi (1986) suggest that the source rock for the sandstones can be determined using colors of luminescence. If the same principle can be applied to these large orthoclase crystals, the luminescence suggests the orthoclase is basically igneous in origin, but some crystals were subjected to low-grade metamorphism, perhaps contact, and all were finally subjected to a high grade of metamorphism. This series of events is also suggested by the minerals associated with the orthoclase.

GNEISS

The gneiss has been divided into two principal rock types, (1) biotite gneiss that is further divided into map units of biotite-quartz-plagioclase gneiss (Abg) and biotite-quartz-plagioclase schist (Abs), and (2) biotite-microcline-plagioclase-quartz gneiss (Aqf) (here referred to as "biotite-feldspar-quartz gneiss"). Biotite-feldspar-quartz gneiss is generally coarser and better foliated than the biotite gneiss and does not exhibit the large number of mafic layers and lenses seen in the biotite gneiss, but is readily differentiated only in thin section.

BIOTITE-QUARTZ-PLAGIOCLASE GNEISS AND BIOTITE-QUARTZ-PLAGIOCLASE SCHIST

Biotite-quartz-plagioclase gneiss (Abg), here referred to as "biotite gneiss," and biotite-quartz-plagioclase schist (Abs), generally referred to as "biotite schist," are mapped separately locally, but they are commonly interlayered on a scale too small to map separately; therefore, biotite schist is mapped in most places with the coarser biotite gneiss. When general statements are made throughout this report concerning biotite gneiss, it can be assumed that the name refers to the undivided unit unless the schist is specifically mentioned.

Biotite gneiss (Abg) and biotite schist (Abs) are predominantly fine- to medium-grained, equigranular, grayish or greenish-black and white, foliated rocks. Locally, biotite gneiss contains interlayered quartzite lenses 1 cm–1m thick. Adjacent to granitic intrusive rocks, biotite gneiss commonly contains single large pink feldspar crystals or feldspar veins that are of probable granite origin. Migmatite also developed in biotite gneiss adjacent to such intrusive rocks (fig. 4).

Interlayered with biotite gneiss are sparse, unmappable lenses of cordierite-, cordierite-garnet-, garnet-, anthophyllite-, or hornblende-bearing biotite gneiss and schist. Cordierite and garnet are recognizable only in thin section. Cordierite alters readily to pinite: in many thin sections its positive indentification is uncertain. Garnet generally occurs in the denser, fine-grained, commonly schistose rock east of Wolf Creek and is associated with cordierite only in the most gneissic rocks.

Amphibolite (anthophyllite- or hornblende-bearing amphibolite) and hornblende schist layers and lenses (fig. 5) in the map unit biotite gneiss (Abg) are more abundant than indicated on plate 1. Commonly, amphibolite lenses and pods crop out in generally the same area as hornblende schist; however, both hornblende- and anthophyllite-bearing amphibolites are coarser grained and less biotic than the hornblende schist layers. Nearly all the areas containing hornblende schist (not mapped separately) are in the vicinity of Wolf Creek.

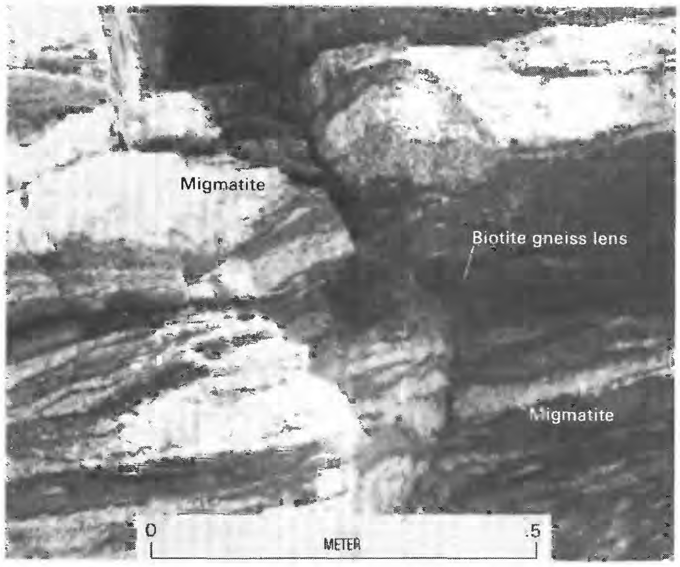


FIGURE 4.—Outcrop of migmatite in biotite-quartz-plagioclase gneiss (Abg), north-central part of Casper Mountain.

FIGURE 5.—Biotite-quartz-plagioclase gneiss (Abg) and hornblende schist in outcrop, Casper Mountain.

In thin section, the biotite gneiss is xenomorphic inequigranular (fig. 6); the dominant minerals are plagioclase, quartz, and biotite (table 1). In biotite-quartz-plagioclase gneiss (Abg) plagioclase is An_{27-34}, and plagioclase in schistose layers (Abs) is a little more calcic, An_{32-40}. Biotite gneiss (Abg and Abs) contains small to trace amounts of reddish to pinkish garnet, apatite, zircon, opaque oxides (chiefly magnetite), and xenotime-monazite (combined because the crystals are too small to identify). Secondary minerals include chlorite, epidote, allanite after biotite, sphene, muscovite after fibroid sillimanite(?), and hematite along edges of magnetite crystals and calcite.

Biotite stringers (in elongate aggregates and as single crystals) best define lineation in the rock. Golden-brown to red-brown biotite laths are either very small and stubby or slender bladed; some are ragged. Biotite is commonly partly altered to chlorite, magnetite, or epidote. Garnets are very small, anhedral, and clear of inclusions. The plagioclase shows moderate to strong alteration to sericite. Plagioclase and quartz are both commonly elongate in the plane of foliation and exhibit a mild to severe cataclasis. Biotite, quartz, and plagioclase may all mirror part of the cataclasis that occurred sometime after the thermal peak of regional metamorphism.

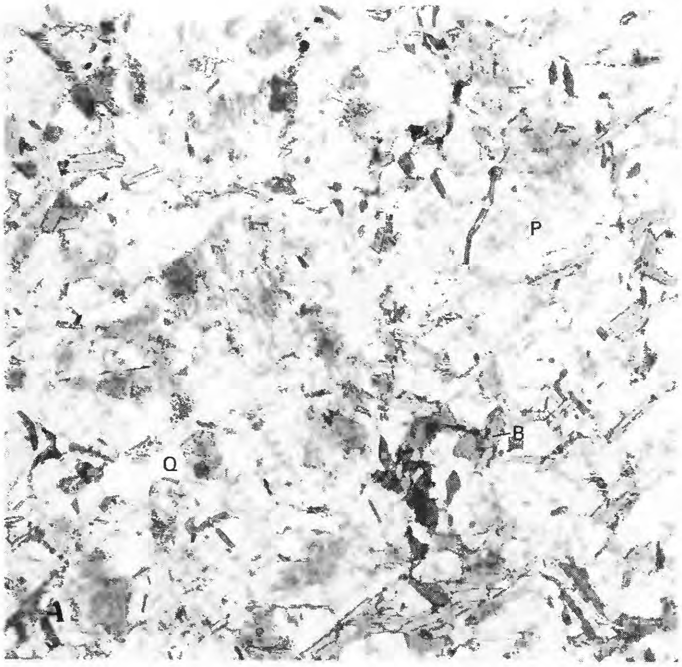
BIOTITE-FELDSPAR-QUARTZ GNEISS

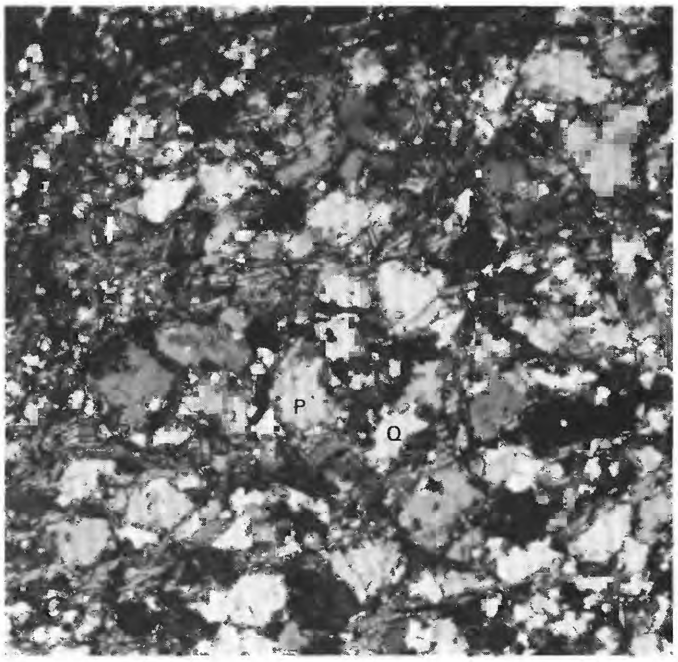
The map unit biotite-microcline-plagioclase-quartz gneiss (Aqf) will be referred to here as "biotite-feldspar-quartz gneiss." This gneiss is a fine- to medium-grained, leucocratic, inequigranular, buff-gray to gray, well-foliated rock that generally is micaceous on foliation planes. The foliation is defined by alternating layers of slightly different mineral composition, composed of quartz layers several millimeters thick, and thin streaks of biotite along the foliation planes. Lenses and pods of muscovite-bearing quartzite are common in this unit in the central part of Casper Mountain. Contacts with this quartzite appear to be gradational.

Thin sections show that the biotite-feldspar-quartz gneiss appears xenomorphic inequigranular (fig. 7); quartz, plagioclase, and microcline all form both large and small crystals in a similarly composed groundmass. The quantities of microcline and plagioclase in these feldspar-rich rocks vary greatly, but microcline averages 20 percent and plagioclase (An_{25-34}) 29 percent, quartz nearly 35 percent, and the micas about 15 percent (table 2). Apatite, zircon, xenotime-monazite, chloritoid(?), and the ore minerals rarely exceed 1 percent. Hornblende is found only locally and then only in the central and western part of the Casper Mountain Precambrian.

Secondary minerals include chlorite, hematite rims on magnetite, muscovite, pinite, rutile in altered biotite, epidote, allanite, and sphene. Plagioclase, cordierite, and biotite are commonly altered to sericite-muscovite, pinite, and chlorite-magnetite, respectively. Plagioclase and cordierite are pervasively altered, whereas microcline is generally fresh or only slightly altered.

From thin section, we find that cataclasis in the gneiss is represented by stretched quartz and feldspar crystals along the foliation, serrate and recrystallized quartz, and new muscovite laths that were bent around quartz grains. In several areas, muscovite appears to mimic sillimanite trains; however, no sillimanite has been found in the various kinds of gneiss at Casper





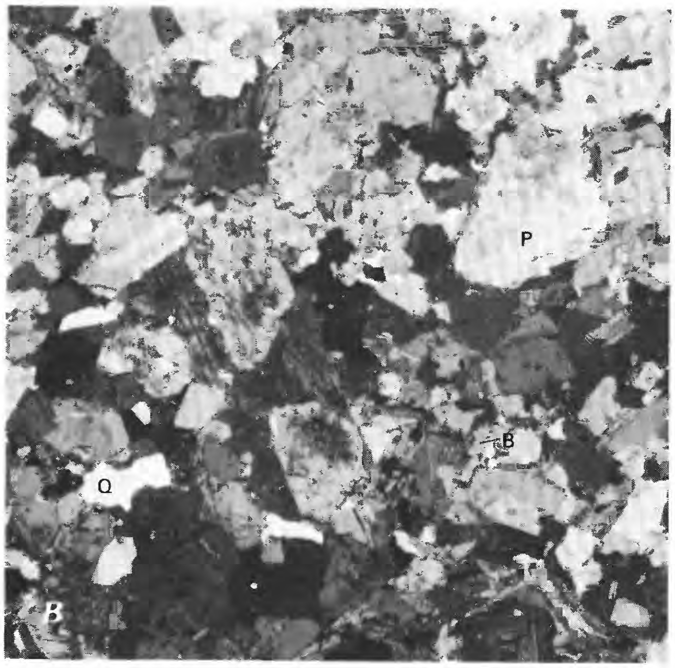


FIGURE 6.—Photomicrographs of inequigranular biotite-quartz-plagioclase gneiss (Abg) and biotite schist (Abs). *A*, Biotite-quartz-plagioclase gneiss (C18–80) showing generally random distribution of biotite; exception is small fold in lower-right corner, where biotite is shingled; plane-polarized light, ×15. *B*, Same section, all plagioclase shows alteration to sericite; crossed polars, × 15. *C*, Fine-grained, slightly schistose biotite gneiss (C–204); biotite laths in linear aggregates interstitial to quartz and plagioclase; crossed polars, × 40. B, biotite; P, plagioclase; Q, quartz.

Mountain, although it does occur in gneiss to the east, in Mormon Canyon, at the northeast tip of the Laramie Mountains. Sillimanite was probably destroyed by the pervasive retrograde metamorphism in the Casper Mountain area.

AMPHIBOLITE

At least two generations of amphibolite (Aam) are recognizable in some places on Casper Mountain: a younger, commonly nonconformable, sequence penetrates all Archean units, especially the granitic rocks, and generally retains a diabasic texture; an older sequence, widely exposed in the metasedimentary terrain, occurs in part as foliated pods and lenses elongate parallel to the regional foliation trend, but some of these metadiabase or metabasalt dikes crosscut the regional foliation locally. These older amphibolites represent metamorphism of remnant mafic extrusive(?) and intrusive rocks. Because we cannot always differentiate these generations of amphibolite, they are shown on plate 1 as a single map unit (Aam).

Much of the amphibolite is medium- to coarse-grained rock that consists mainly of hornblende and plagioclase. Most of the amphibolite is weakly foliated, displaying a weathered salt-and-pepper texture imparted by equigranular hornblende and plagioclase. Minor amphibolite is dark, schistose or massive, nonfoliated rock. The amphibolite occurs as dikes, lenses, and pods as much as 500 m long and several tens of meters wide.

Of the two primary minerals, hornblende is green and poikilitic with inclusions of subhedral quartz and traces

TABLE 1.—*Modes (volume percent) for biotite-quartz-plagioclase gneiss and schist and for schistose amphibolite, Casper Mountain, Wyo.*

[---, not found; Tr, trace]

	Gneiss (Abg)				Schist (Abs)						Schistose amphibolite (Aam)
Field No.--	C-217	C-244	C18-80	C-109	C-204	C107-80	C31-80	C79-80	C87-80	C115-80	C15-80
Plagioclase	38.9	46.1	74.0	39.1	42.2	59.4	40.0	41.0	26.0	*33.0	29.0
Quartz-----	26.6	27.8	13.0	32.0	20.5	19.0	27.0	26.0	46.0	34.0	3.0
Biotite----	30.4	25.4	12.0	27.8	36.4	11.3	32.0	31.0	27.0	31.0	---
Garnet-----	---	0.1	---	---	---	---	---	---	---	0.5	---
Epidote----	---	---	Tr	---	---	1.5	---	---	0.5	---	4.0
Ores-------	0.8	.4	Tr	Tr	0.9	1.6	0.3	Tr	Tr	.5	0.5
Zircon-----	Tr	Tr	Tr	Tr	Tr	---	Tr	Tr	Tr	.5	---
Allanite---	---	---	---	---	---	---	---	---	Tr	---	---
Chlorite---	3.2	---	0.5	---	Tr	1.9	---	---	---	---	---
Muscovite--	---	.1	Tr	0.8	---	---	.4	2.0	---	Tr	---
Calcite----	---	---	---	---	---	Tr	---	---	---	---	---
Hornblende-	---	---	---	---	---	3.6	---	---	---	---	63.0
Xenotime---	---	---	Tr	Tr	---	---	---	---	---	Tr	---
Apatite----	.1	.1	.5	.3	Tr	.7	.3	Tr	.5	.5	Tr
Sphene-----	---	---	Tr	---	---	.9	---	---	---	---	.5

* Total includes pinite, an alteration product of cordierite.

of plagioclase. Plagioclase, ranging in composition from An_{34} to An_{52}, is commonly completely sericitized in amphibolite but locally exhibits a few discontinuous lamellae of albite or pericline twinning.

Traces of apatite occur in hornblende and quartz, whereas traces of monazite and zircon, which show decay around crystal edges, are found throughout the rock. Magnetite may be profuse and is locally intergrown with, or rimmed by, hematite. Some magnetite is altered to sphene and possibly ilmenite. Hornblende is altered to cummingtonite, epidote, and a little biotite. Clinopyroxene was observed in a thin section of schistose amphibolite, where it appeared frayed and badly eroded, with fine-grained magnetite as streaks and blebs along cleavage and grain boundaries.

ORIGIN OF THE METAMORPHIC COMPLEX

The metamorphic complex is the result of a high-grade metamorphism that converted the rocks discussed below into gneisses, schists, and quartzites and produced some migmatites. Migmatites formed as a result of partial anatexis in the presence of H_2O probably derived from the sedimentary pile. Thus, assuming load pressure equals water pressure, in an area where migmatites formed, assemblages lacking muscovite but including quartz and plagioclase indicate pressures were greater than 3.5 kb and temperatures were approximately 650 °C (Winkler, 1979): The stable mineral assemblage representing this metamorphic grade in Casper Mountain rocks consists of cordierite-microcline-quartz-plagioclase ± biotite ± garnet.

The quartzite (Aq), biotite gneiss and biotite schist (Abg and Abs), and biotite-feldspar-quartz gneiss (Aqf) of Casper Mountain are mainly of clastic sedimentary origin, derived from weathered rocks from highlands of primarily crystalline rocks.

The quartzite represents impure sandstone that was deposited at a time when volcanism was active in the area, as suggested by the mafic layers and randomly distributed, sparse mafic minerals in the quartzite. These indicators of volcanic activity probably represent windblown ash as well as layers and lenses of intrusive and, possibly, extrusive rock in and along the bedding planes. No preserved extrusive structures, such as pillow lava, were found on the mountain, only the intermixing of quartzite and mafic layers that under both reducing and oxidizing conditions produced the orange-brown or reddish-brown limonite stain of the quartzite. The clasts in the enclave of pebble metaconglomerate and quartzite in gneissic granite are possibly debris from a mixed source; the large, pinkish, leucocratic, flattened, and generally smooth, pebble-like clasts of orthoclase may represent abraded fragments of an alkali gabbro intermixed with fragmented and less abraded ultramafic clasts. These mafic-felsic associations are indicative of an ancient greenstone terrain.

Biotite-feldspar-quartz gneiss is probably of graywacke origin. The dark, amphibolitic, fine-grained layers

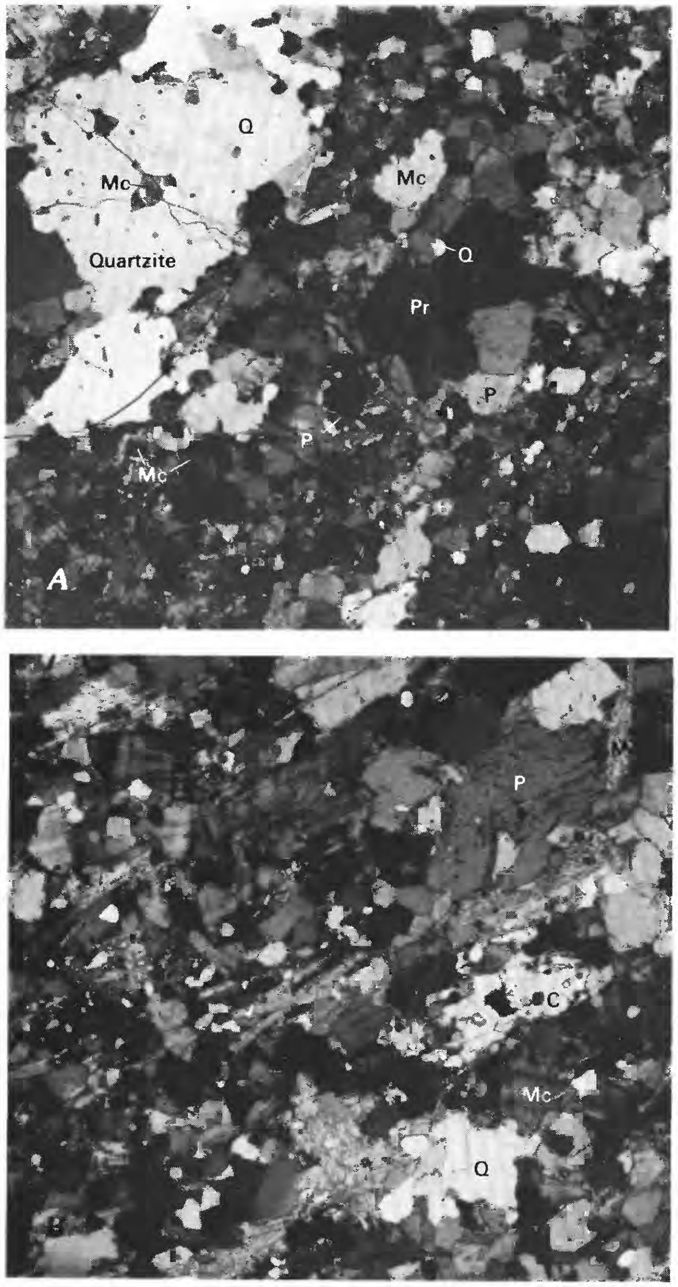


FIGURE 7.—Photomicrographs of biotite-feldspar-quartz gneiss (Aqf). *A*, Inequigranular, fine- to medium-grained gneiss (C-81). Shows quartzite layer in upper-left part of thin section. Microcline is fresh looking, but nontwinned plagioclase is altered to sericite; microcline rimmed by nontwinned, nonaltered albite; crossed polars, × 15. *B*, Well-foliated gneiss (C-58); crossed polars, × 40. B, biotite; C, cordierite; M, muscovite; Mc, microcline; P, plagioclase; Pr, perthite; Q, quartz.

in biotite-feldspar-quartz gneiss may, in part, represent small mafic intrusive or extrusive bodies. Micaceous quartzite is representative of an impure sandstone that is interlayered and gradational with the more common graywacke.

The amphibolite dikes, lenses, pods, and layers observed along foliation trends or crosscutting the foliation are of diabasic, gabbroic, or ultramafic origin. These mafic rocks probably represent magma that originated in the mantle or lower crust.

MAFIC-ULTRAMAFIC INTRUSIVE ROCKS

Mafic-ultramafic rocks intruded the Casper Mountain area intermittently during the Archean and possibly as late as the Proterozoic. They appear to have been emplaced as sills, pods, and dikes, many into east-northeast-trending structures. In the central part of Casper Mountain, adjacent to a large serpentinized peridotite mass, lenses and layers of mafic igneous rocks were forcefully emplaced for short distances in the metasedimentary sequence concurrently with peridotite emplacement.

The largest ultramafic body at Casper Mountain, now represented chiefly by serpentinized peridotite, is similar to the Preacher Creek intrusive body (Potts, 1972), on the east border of the Laramie Mountains, in southeastern Wyoming. The Preacher Creek intrusive body, a clinopyroxene-olivine peridotite with a marginal rim of orthopyroxene-plagioclase, is suprisingly unaltered in comparison to the large Casper Mountain ultramafic intrusive. Its fresh appearance may indicate a younger age (post-2.4–2.5 b.y.) for emplacement than that of the peridotite of Casper Mountain (Potts, 1972).

Most Casper Mountain ultramafic intrusive rocks are now serpentinized peridotite (formerly clinopyroxene- and in places olivine- and orthopyroxene-bearing rocks); however, less altered individual clots or pods of olivine-bearing and pyroxene-rich peridotite, many of them remnant, occur in or adjacent to the major serpentinite area. Chromite schist, possibly of dunite origin, is associated with the serpentinite.

The mafic intrusions include hornblendite, hornblende diorite, and diabase. All of the hornblende diorite and hornblendite dikes, sills, and pods have been metamorphosed; those that intrude granitic rocks display a thermal metamorphism only. While the hornblendite mineralogy generally suggests an ultramafic origin, the hornblende diorite, some still displaying relict textures, is of basaltic or gabbroic origin. The map (pl. 1) shows that outcrops of hornblende diorite and hornblendite are not consistently oriented with respect to the regional structure but instead tend to be randomly oriented in clusters throughout the central part of the Casper Mountain Precambrian.

Diabase, the youngest and least altered of the mafic intrusive rocks, cuts all Precambrian units but does not penetrate the younger sedimentary rocks. The diabase

TABLE 2.—*Modes (volume percent) for biotite-feldspar-quartz gneiss (Aqf), Casper Mountain, Wyo.*

[---, not found; Tr, trace]

Field No.---------	C-58	C-81	C-116A	C-152	C-215	C12-80	C26-80	C59-80	C95-80	C104-80
Potassium feldspar	24.4	39.8	10.7	0.2	1.6	26.9	---	31.0	24.0	25.0
Plagioclase-------	26.3	24.8	25.5	41.4	32.4	26.6	59.1	19.0	8.0	28.0
Quartz------------	35.3	31.8	38.8	45.4	45.2	31.7	13.0	35.0	36.0	32.0
Cordierite--------	Tr	---	---	---	---	---	---	---	---	---
Biotite-----------	7.2	1.2	7.7	.2	12.9	10.4	8.1	7.0	16.0	14.0
Hornblende--------	---	---	---	---	---	---	12.6	---	---	---
Allanite----------	---	---	---	---	---	---	0.1	---	---	---
Ores--------------	Tr	.5	Tr	.9	---	0.1	1.2	Tr	---	Tr
Zircon------------	Tr	Tr	Tr	Tr	Tr	Tr	---	Tr	Tr	Tr
Epidote-----------	---	---	---	---	---	---	1.0	Tr	Tr	---
Chlorite----------	0.3	1.9	15.0	11.9	0.2	.1	1.4	Tr	---	---
Muscovite---------	5.5	---	1.8	Tr	4.3	4.2	---	6.0	10.0	1.0
Pinite------------	1.0	---	0.5	---	3.4	---	---	2.0	6.0	---
Rutile------------	---	---	---	---	Tr	---	---	Tr	---	Tr
Xenotime-monazite	---	---	---	---	Tr	---	---	Tr	Tr	---
Apatite-----------	---	---	Tr	Tr	---	---	1.4	Tr	---	---
Sphene------------	---	---	---	---	---	---	2.1	---	---	---

dikes strike east-northeast generally and parallel structural trends recognized as of Precambrian origin.

ULTRAMAFIC INTRUSIVE ROCKS

Included here are rocks having relict mineral textures and a mineralogy similar to known ultramafic intrusive rocks. The ultramafic rocks include altered olivine-bearing and pyroxene-rich peridotites (Au, Asp) and chromite schist (Acs). They are dark-greenish-gray to black, dense rocks, some of which are massive and some schistose, that weather a yellowish brown, greenish gray, gray with white streaks, brownish, or brownish black. The more massive coarsely crystalline varieties have a hackly or rough surface. The rocks are locally strongly to weakly foliated.

The mineralogy of the ultramafic rocks, described below, is complex because of a pervasive high- and low-grade regional metamorphism. Magnetite in the ultramafic intrusive rocks is evidence that the magnetite and enclosing rock formed within a temperature range of 700–1,000 °C.

The ultramafic rocks are divided for the purposes of this report into serpentinite (Asp), chromite schist (Acs), and other ultramafic rocks (Au).

SERPENTINITE

Serpentinite (Asp), a serpentinized peridotite, is a dense, massive, aphanitic, black or greenish-black rock that weathers bluish gray to buff. It is highly fractured (fig. 8) and commonly fibrous and contains dark-brown or black iron-rich lenticular structures (fig. 9*A*) that are about 1 mm thick, discontinuous, and locally fractured and that weather rusty brown. Sheared serpentinite is crisscrossed by veinlets of calcite, quartz, dolomite, and magnesite(?). Asbestos commonly forms on shear and fracture planes. Locally, bladed asbestos forms crystals as much as 15–20 cm long in serpentinite. Rodingite, a garnet- and diopside-bearing rock described by Burford and others (1979), is present on the periphyry of the large serpentinite body in the central part of Casper Mountain.

FIGURE 8.—Outcrop of typically sheared and fractured serpentinite (Asp).

As seen in thin section, serpentinite consists of felted masses of the minerals antigorite, clinochrysotile, and lizardite. Associated ore minerals are magnetite, chromite, and some hematite (in polished sections hematite appears intergrown with the magnetite or it occurs along magnetite grain boundaries). Magnetite commonly outlines relict pyroxene and olivine crystals or occurs along cracks in these crystals, and it forms small patches in the altered crystals (fig. 9*B* and 9*C*). Biotite talc and clinochlore are present in minor amounts.

Serpentine, ubiquitous in the largest ultramafic intrusion, indicates that little or no CO_2 was present at the time of retrograde metamorphism and that large amounts of H_2O were available. Minor talc associated with serpentine indicates that the original rocks were dominantly pyroxene-bearing. Within the large ultramafic body and adjacent to it are masses and lenses consisting primarily of anthophyllite, ferrogedrite, and cummingtonite presumed to be of ultramafic and mafic origin. Some of these rocks appear to have intruded the layered sequence during and after emplacement of the peridotite; all were altered during the period of serpentinization but to varying degrees. Rodingite is assumed to have formed by the metasomatic addition of calcium and magnesium ions released during the serpentinization of pyroxenitic and dunitic rocks. Metasomatism may also have been related to hydrothermal solutions that accompanied the emplacement of pegmatite rocks adjacent to the large area of ultramafic rock and within it.

CHROMITE SCHIST

The chromite schist (Acs), exposed in roadcuts and rock outcrops in the vicinity of Camp Wyoba (pl. 1), occurs in a lens associated with serpentinite. The schist has been tightly folded and extensively faulted and sheared. It is a fine-grained, greenish-gray or bluish-gray rock containing brown or blackish-gray, chromite- and magnetite-rich blebs and streaks. It weathers to a rusty greenish gray or purple and has brownish-rust spots that are probably caused by the replacement of magnetite by hematite and by the presence of tiny, partly decayed disseminated chromite grains.

Chromite, magnetite, tremolite-actinolite, serpentine (antigorite), and chlorite (thuringite) make up the chromite schist. The chromite and magnetite occur as round to idiomorphic crystals, although some chromite has a ragged crystal outline; the cause of the raggedness is not clear. Magnetite and chromite are most abundant in short stringers within two elongate lenses in the chromite schist. Both minerals are much less abundant toward the outer edges of the lenses, where there are only small disseminated crystals. In thin section, anthophyllite-tremolite schist and talc schist present in the chromite schist are observed to be tightly folded on a microscopic scale, the anthophyllite occurring as acicular felted stringers along the folds (fig. 9*D*).

Associated with the chromite schist are thin lenses and layers of anthophyllite-chlorite-tremolite-magnetite-talc schist, chlorite-tremolite-talc-magnetite schist, and talc-chlorite-magnetite schist. Thin lenses of quartzite schist are common peripheral to the chromite schist, especially along its southern contact. The original mineralogies and textures of these various schists have been extensively altered by the high- and low-grade metamorphism of the area.

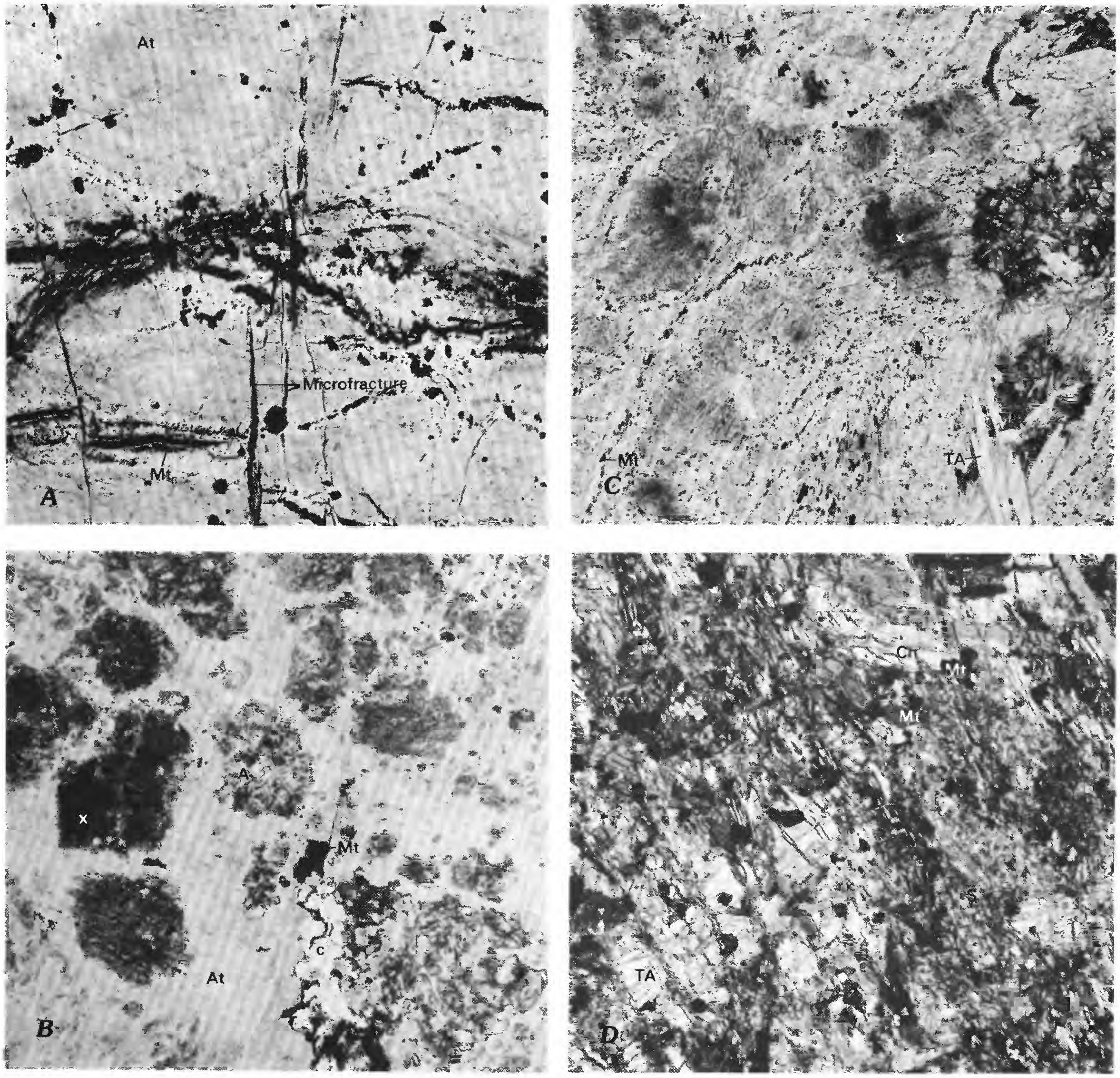
OTHER ULTRAMAFIC ROCKS

This map unit (Au) includes olivine-bearing and nonolivine-bearing ultramafic rocks that probably originated as peridotite. They are dark-gray to greenish-black, fine- to coarse-grained, massive, dense rocks that weather a brownish or reddish brown and have rough weathered surfaces.

These ultramafic rocks occur as pods, small tabular masses, plugs, and sills that alter readily to abestos minerals including clinochrysotile, lizardite, and antigorite. Within serpentinite, the ultramafic-serpentinite contacts are generally obscured by float. The ultramafic rocks appear to be slightly younger than the serpentinite; however, they may represent less altered serpentinite that still bears the ragged primary minerals olivine, augite, and hypersthene.

The mineral assemblages in these ultramafic rocks are complex. It is evident that augite, olivine, magnetite, and some chromite were among the original minerals. The association of hypersthene with augite in the rocks indicates that at least some of the peridotite contained two pyroxenes. Most of the rocks display abundant secondary and alteration minerals (fig. 9*E*). Assemblages include augite-ferrogedrite-hypersthene-olivine-magnetite ± chromite; anthophyllite-antigorite-chlorite(sheridanite)-magnetite; hypersthene-augite-tremolite-sphene ± calcite; and augite-tremolite-actinolite-magnetite.

As seen in thin section, the olivine is either partly altered to brownish iddingsite or is completely replaced by serpentinite. Radiating hypersthene crystals in one olivine-bearing rock sample are well developed and are considered primary, whereas radiating crystals of serpentine (clinochrysotile) are secondary. Augite and hypersthene are mostly altered to massive clots or single long blades of tremolite-actinolite. In augite-bearing rocks, tremolite and magnetite replace augite, leaving ragged anhedral relicts of augite. Plumose tremolite in schistose layers of serpentinite was also observed. The



magnetite in these rocks is tentatively identified as a maghemite that is partly altered to hematite. Serpentine, anthophyllite, ferrogedrite, and cummingtonite appear older than well-bladed tremolite and (or) actinolite, which chlorite and talc both cut and replace.

MAFIC INTRUSIVE ROCKS

The youngest mafic intrusive rocks at Casper Mountain include hornblendite, hornblende diorite, and diabase. Hornblendite and hornblende diorite (PAhd) crop out as irregularly shaped lenses and pods as much as 900 m long and 250 m wide in the central and west-central part of the mountain. The largest hornblendite outcrop occurs in granite gneiss and pegmatite just west of Wolf Creek. Hornblendite bodies have no preferred regional orientation. However, hornblende diorite lenses tend to be elongate parallel to the east-northeast regional foliation. Hornblendite mineralogy suggests that this rock is probably peridotite in origin, but that of the hornblende diorite, some still exhibiting remnant

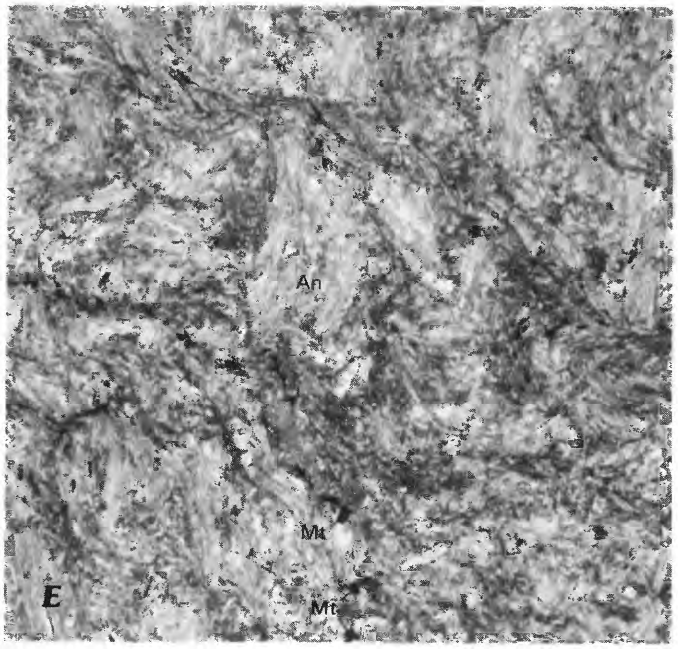


FIGURE 9 (above and facing page.—Photomicrographs of serpentinite, peridotite, and other mafic-ultramafic rocks.
A, Augite replaced by serpentinite (C–70), microfractures filled with magnetite; plane-polarized light, × 15. *B*, Altered peridotite (C–51); magnetite outlines former crystals of augite and olivine; plane-polarized light, × 15. *C*, Altered peridotite (C–73), showing relict augite; plane-polarized light, × 40. *D*, Tremolite-actinolite-serpentinite layer (BC–2); crossed polars, × 40. *E*, Felted and microscopically folded anthophyllite schist layer in chromite schist (chromite schist not shown) (C–86); plane-polarized light, × 15. A, augite; An, anthophyllite; At, antigorite; c, epoxy; Ch, chlorite; Mt, magnetite; O, olivine; S, serpentinite; TA, tremolite-actinolite; tw, twinning in augite outlined by magnetite; x, more massive, fine-grained magnetite in augite.

textures, is a hybrid of basaltic or gabbroic origin. The youngest diabase (pЄAdi), is the least altered mafic-ultramafic intrusive rock; it cuts all Precambrian units but does not penetrate younger sedimentary rocks. The diabase dikes generally strike east-northeast parallel to the trend of the Precambrian structures; there are even some diabase dikes in the trace of the faults.

HORNBLENDITE AND HORNBLENDE DIORITE

Hornblendite and hornblende diorite (pЄAhd) are generally massive, dark-colored rocks that bear hornblende as their major mineral (fig. 10). Hornblendite is a more massive, darker, and generally coarser grained rock than hornblende diorite and occurs more locally.

In thin section, the hornblende in hornblendite is olive green and euhedral to anhedral, and some of it is poikilitic. Large crystals have augite or aegirine-augite, magnetite, and some sphene at the centers. Augite or aegirine-augite, as eroded masses and some frayed crystals, represents no more than 10 percent of the rock. The poikilitic hornblende is younger than augite and commonly has overgrowths of cummingtonite. Plagioclase is sparse, occurring as tiny, barely recognizable saussuritized crystals. The hornblendite contains only traces of magnetite and quartz. Small magnetite crystals intergrown with hematite are present in the hornblende crystals and as trains that cross the crystal boundaries. Secondary minerals include chlorite and traces of epidote.

In addition to the large hornblendite outcrops, hornblendite occurs at the center of a funnel-shaped volcanic pipe in gneissic granite about the midpoint of the west edge of sec. 8, T. 32 N., R. 79 W. The pipe, which is about 15 m in diameter, has a core of hornblendite rimmed by anthophyllite that in turn is rimmed by impure quartzite in contact with the granitic country rock. The hornblendite is 75–85 percent hornblende, 10–20 percent pyroxene (aegirine-augite?), 2 percent magnetite, and about 5 percent epidote. The augite occurs in clots or at the centers of the hornblende crystals. The outer rim of the pipe consists of impure quartzite containing 35 percent hornblende, 2 percent plagioclase, and trace amounts of magnetite and epidote.

The intrusive character and mineralogy of the hornblendite suggest that it is an altered ultramafic rock. The degree of alteration depends on the temperature of the hydrothermal fluids that accompanied the ultramafic emplacement.

Hornblende diorite is a medium- and coarse-grained, massive, dark rock containing light-colored crystals and clots consisting of quartz and plagioclase. The largest outcrops of hornblende diorite are in the serpentinite north of Eadsville in sec. 18 and in the biotite-feldspar-quartz gneiss along the intersection of secs. 17 and 20, T. 32 N., R. 79 W. It also crops out as dikes or in small oval lenses throughout the central area of the Casper Mountain Precambrian.

As seen in thin section, hornblende diorite consists principally of euhedral to anhedral hornblende that is partially altered to sphene and epidote. In porphyroblastic hornblende diorite, or so-called "leopard rock" (fig. 10), the predominant hornblende is subhedral and olive green. Younger anhedral, blue-green hornblende erodes and embays the olive-green hornblende and occurs in the matrix between the larger crystals. Hornblende commonly encloses single blebs, clusters, and feather-like sprays of magnetite. Some of the hornblende is poikilitic.

The plagioclase in the hornblende diorite is primarily equigranular, calcic andesine. Twinning, which is generally poorly developed, is either albite-pericline or

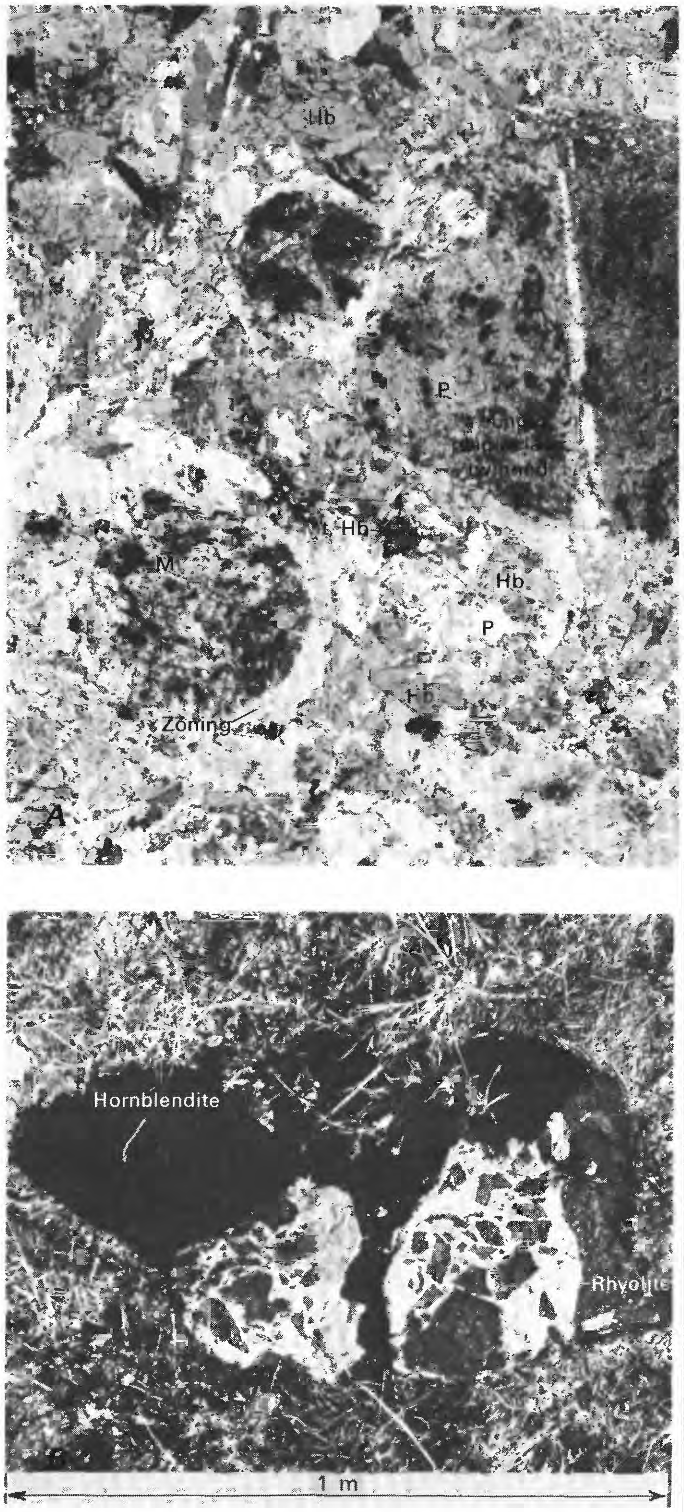


FIGURE 10.—Photomicrograph of hornblende diorite and photograph of hornblendite.

A, Photomicrograph of hornblende diorite, consisting of large zoned plagioclase phenocrysts with rinds of younger plagioclase in a matrix of plagioclase and hornblende; crossed polars, × 15. Hb, hornblende; Mt, magnetite; P, plagioclase. *B*, Boulder of hornblendite and brecciated hornblendite in rhyolite.

albite-Carlsbad-pericline. In porphyroblastic hornblende diorite, plagioclase forms huge zoned crystals (10 cm in diameter) altered to sericite, carbonate, and dusty clay minerals with clear, partly albite-twinned rims separated by interstitial nonzoned plagioclase crystals.

Quartz content ranges from none in hornblende diorite to at least several percent in porphyritic hornblende diorite. Magnetite in hornblende diorite, which is profuse and may account for at least 3 percent of the rock, contains only traces of hematite along the crystal edges. Apatite is rare.

DIABASE DIKES

Diabase dikes (₱Adi), 3–5 m wide and as much as 4 km long, that generally trend east-northeast are scattered throughout the Precambrian of Casper Mountain. This diabase may be the youngest Precambrian mafic rock intruding major northeast-trending faults. Diabase dikes are also common in the Granite Mountains to the west (Stuckless and others, 1977), in the Big Horn Mountains to the northwest (Osterwald, 1959), and in the Laramie Mountains on the south and east (Graff and others, 1982).

These diabase dikes are fine to medium grained, dark gray to black, blocky, and very hard. They weather chocolate brown to yellowish brown and impart a characteristic brown color to the soil. Diabase consists of calcic plagioclase, clinopyroxene, and hornblende and bears small amounts of quartz, biotite, ore minerals, and apatite.

As seen in thin section, the diabase dikes are highly altered. The primary minerals are clinopyroxene (augite or pigeonite) and zoned plagioclase (An_{35-65}). Accessory minerals consist of 2–3 percent quartz and 1.5–3 percent magnetite; the quartz occurs both as large crystals and tiny blebs. That the largest crystals are equal in size to plagioclase and pyroxene suggests they crystallized at about the same time as the primary minerals.

The least altered diabase has an ophitic to subophitic or diabasic texture that is characterized by subhedral, zoned plagioclase intergrown with subhedral clinopyroxene crystals. The plagioclase is generally altered and dusted by sericite and clay minerals although some fresh, clear albite-twinned crystals are present. The pyroxene is augite or pigeonite (Burford and others, 1979) and has been partially altered to hornblende and biotite.

Diabase displays sharp contacts with the country rock, is more resistant to weathering than the surrounding country rock, and commonly forms mounds and low ridges less than 1 m high. These dikes are believed to be Proterozoic in age. Age determinations on similar diabase dikes by Condie and others (1969) suggest they may be as young as 700 m.y.

GRANITIC ROCKS

Rocks that are granitic in appearance account for more than half of the exposed Precambrian of Casper Mountain. For the purpose of this discussion, we have divided the granitic rocks into two major rock types: a gneissic granite (represented by map units Agn and Agr) and a granite gneiss and pegmatite (represented by map units Ag, Agp, and Ap). Rhyolitic dikes (ꟼAr) in the western part of Casper Mountain are also discussed in this section.

As a whole, the granitic rocks of Casper Mountain range in composition from granite to granodiorite (Streckeisen's classification, 1976). The two principal types, gneissic granite and granite gneiss and pegmatite, are in some places difficult to distinguish in the field.

Gneissic granite comprises two map units, a binary granite (Agr) and a gneissic granite (Agn). Gneissic granite is generally more weakly foliated and coarser grained, contains many enclaves of biotite gneiss and amphibolite, and is more mafic than is the granite gneiss and pegmatite, especially in the western Casper Mountain Precambrian.

The granite gneiss and pegmatite comprises three mappable units: granite (Ag), granite gneiss and pegmatite (Agp), and pegmatite (Ap). These units are spatially associated with biotite-feldspar-quartz gneiss (Aqf) in the west-central part of the map area and are more localized than rocks in the gneissic granite units (Agr, Agn).

GNEISSIC GRANITE

As mentioned above, gneissic granite consists of a localized, coarse-grained, nonfoliated binary granite (Agr) and a medium- to coarse-grained, foliated to weakly foliated gneissic granite (Agn). Rock samples showing major physical characteristics of the two groups appear in figure 11.

Binary granite (Agr) crops out southeast of Eadsville, sec. 19 and 20, T. 32 N., R. 79 W., and east of the West Fork of Garden Creek, sec. 7, 8, and 16, T. 32 N., R. 79 W. As seen in outcrop, the binary granite is very coarse grained, nonfoliated, massive, pink granite that is mottled reddish and (or) grayish black. Borders of the granite are weakly foliated.

As seen in thin sections of the binary granite, plagioclase, microcline, and quartz occur in approximately equal amounts, and biotite and muscovite account for 1–7 percent of the rock (table 3). Monazite, apatite, magnetite, and zircon occur in trace amounts only. These minerals tend to cluster with the biotite. Samples with field numbers C–40, C–74, and C–75, table 3, are representative of the binary granite, although sample C–40 is atypically low in micas.

Gneissic granite, the most volumetrically important map unit in the Precambrian of Casper Mountain, is a pinkish, medium- to coarse-grained, poorly foliated to well-foliated rock that weathers buff and is commonly mottled with reddish brown stain caused by the disintegration of biotite and magnetite. It is ubiquitously, but moderately, cataclasized. Locally, large microcline crystals give this gneissic granite a slightly porphyritic texture.

Modally, gneissic granite (Agn) contains more biotite and plagioclase and less quartz than does the binary granite (table 3). On average, less than 5 percent of the gneissic granite is biotite.

Gneissic granite (Agn) crops out on both the western and eastern flanks of Casper Mountain. Some of the gneissic granite on the western flank contains hornblende and is nearly twice as mafic as that on the eastern flank. The hornblende occurs either in clusters with the other mafic minerals, including apatite, or in single ragged crystals, both small and large, scattered throughout the rock. In table 3, we show the differences in mafic content of gneissic granite from the eastern and the western flank. Rocks on the west vary from granite to granodiorite or quartz monzonite, whereas rocks on the east consistently have a granitic composition.

As seen in thin section, a typical rock from the gneissic granite (Agr and Agn) is allotriomorphic inequigranular; locally, microscopic quartz veins having a mortar texture cut across all other minerals. Most of the potassium feldspar is poikilitic microcline with inclusions of plagioclase, quartz, and altered biotite. Plagioclase inclusions in microcline are altered to sericite and some to epidote. Plagioclase crystals are oligoclase (An_{15-29}) that is ubiquitously dusted by alteration products consisting mostly of sericite, and traces of muscovite, epidote, and, rarely, calcite. Microcline and plagioclase are equigranular, whereas some of the quartz grains are nearly the same size as the feldspar grains, and some quartz occurs as small interstitial crystals. All of the biotite occurs as frayed, altered laths. Retrograde metamorphism is indicated by the partial alteration of biotite to chlorite, magnetite, or epidote and, locally, by epidote rims on allanite. Sphene crystals are zoned, and many are partly altered to an iron oxide. Epidote is common in the gneissic granite unit, particularly in shear zones on the west flank of the mountain.

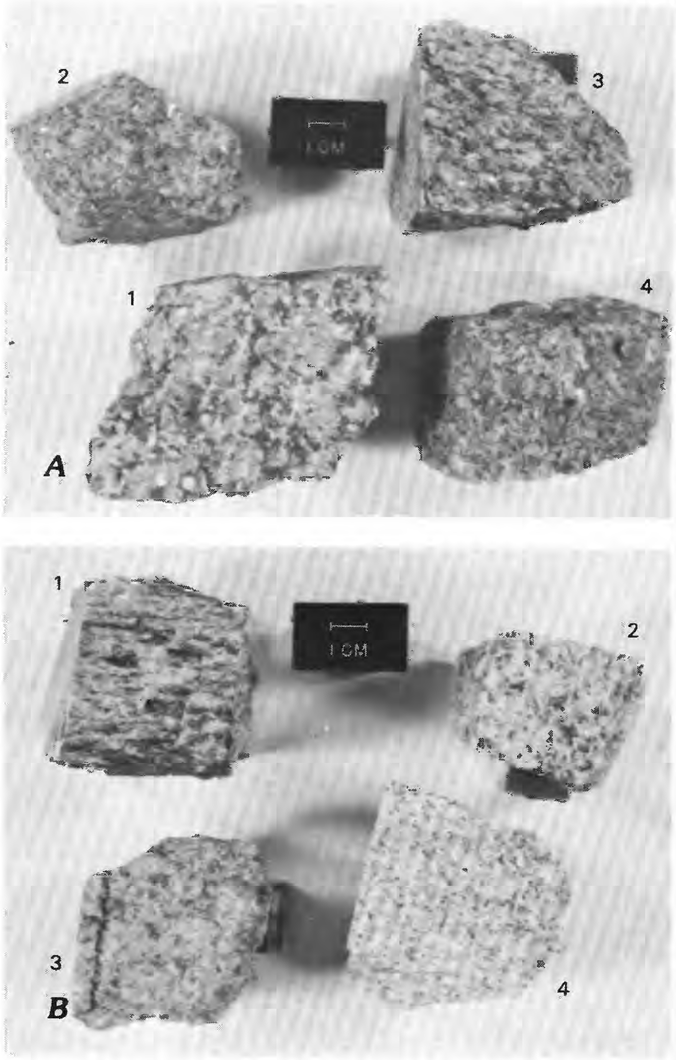


FIGURE 11.—Photographs of hand specimens of gneissic granite and granite gneiss and pegmatite.
A, Gneissic granite. 1, coarse, mica-bearing pink granite (Agr); 2, slightly foliated mafic gneissic granite (Agn); 3, medium-grained, slightly porphyritic gneissic granite (Agn); 4, medium-grained mafic gneissic granite (Agn). *B*, Granite gneiss and pegmatite. 1, foliated granite gneiss (Agp), biotite defining foliation; 2, binary granite (Ag); 3, leucocratic granite gneiss (Agp); 4, leucocratic granite (Ag), nonfoliated.

As seen in thin section, the binary granite (Agr) exhibits less cataclasis between plagioclase and quartz crystals than does gneissic granite (Agn) (fig. 12).

Just south of the Casper Mountain fault, enclaves in gneissic granite (Agn) are profuse and varied in composition. Still farther south, gneissic granite (Agn) is more homogeneous, perhaps indicating that the contact of the gneissic granite and country rock was at one time just north of the fault. Modes shown in table 4 typify the variation in the mineralogy found in enclaves in gneissic granite (Agn). The mafic minerals in the enclaves include hornblende, biotite, and ore minerals; the secondary minerals are epidote, chlorite, and some sphene. Sampled enclaves include remnants of metamorphosed diabase dikes (now amphibolite and related rocks), biotite gneiss country rock (C53–80), and gabbro (C128–80). The gabbro, now an epidosite, crops out just south of the Casper Mountain fault about 2,800 m due west of Wolf Creek. This gabbro is light-greenish-gray, dense, fine-grained rock that was not mapped due to poor exposure.

GRANITE GNEISS AND PEGMATITE

Granite gneiss and pegmatite, as indicated earlier, consists of three mappable units: granite (Ag); granite gneiss and pegmatite (Agp), a foliated rock associated with a mineralogically related pegmatite; and pegmatite (Ap). The granite (Ag) is present only in the Eadsville area in sec. 18 and 19, T. 32 N., R. 79 W. Granite gneiss and pegmatite (Agp) crop out mostly in the central and west-central part of the mountain, south of the gneissic granite (Agr and Agn) and adjacent to biotite-feldspar-quartz gneiss. Pegmatite (Ap) is represented by the large pegmatite bodies that intrude serpentinite in the central part of Casper Mountain.

The granite (Ag) is a leucocratic, nonfoliated, medium- to coarse-grained, buff to light-gray or white rock showing profuse muscovite flakes that glisten on fresh fracture (fig. 13). This granite is rich in quartz (table 5) and contains variable amounts of muscovite and nearly no biotite.

As seen in thin section, muscovite in the granite (Ag) appears in large, clear laths that cut and penetrate all other minerals. It also forms sericite in plagioclase. Plagioclase, because of its large size, crystal shape, and alteration, appears to have been the first mineral to crystallize; it is locally antiperthitic, has a composition of An_{23-30}, and commonly has clear albite-twinned rims. Microcline occurs as large crystals that are fresher than plagioclase. Cataclasis in the granite is slight and is characterized by microcline and quartz mortar between larger plagioclase crystals.

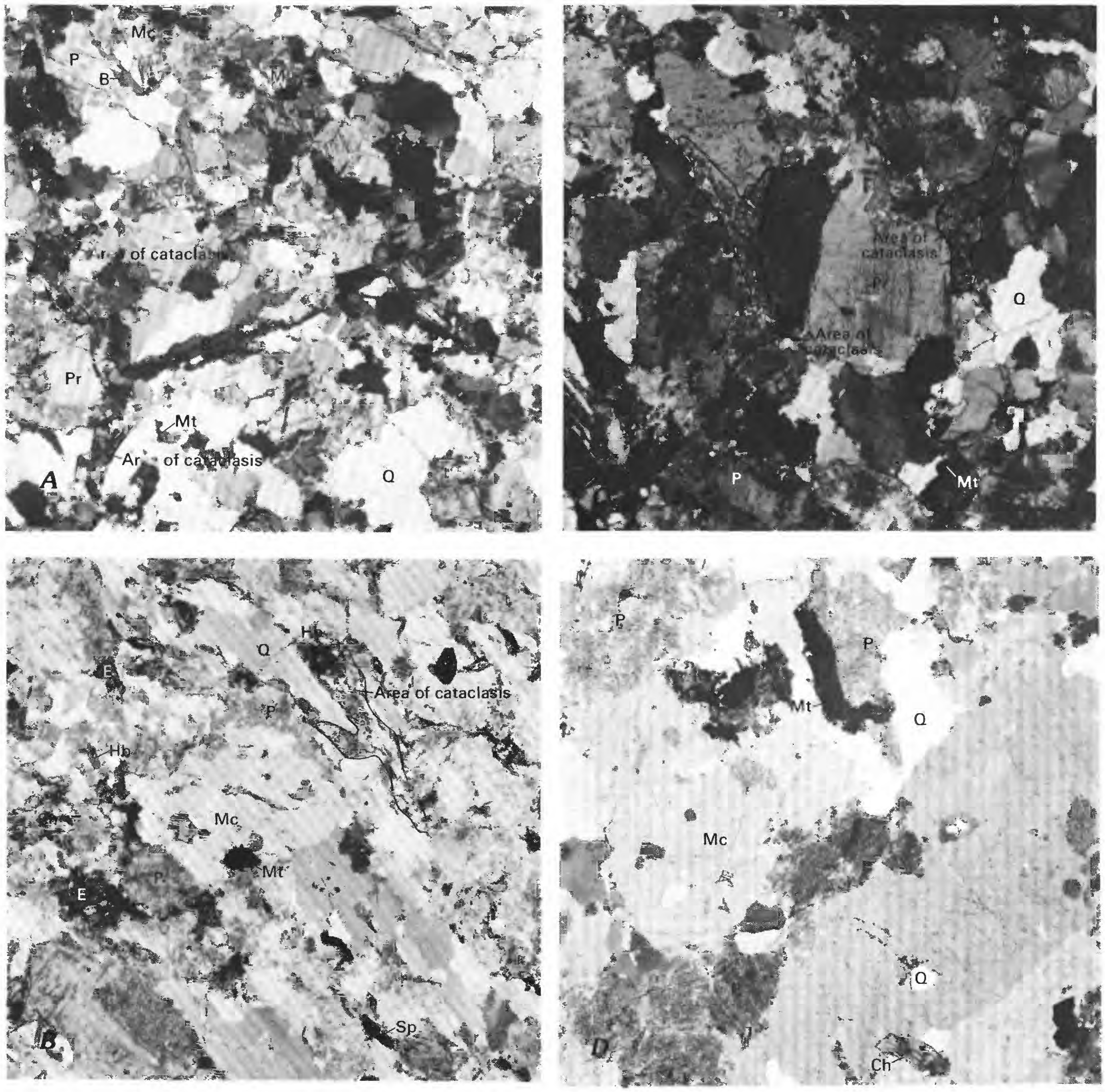
Granite gneiss and pegmatite (Agp) is a medium-grained, light-gray, poorly foliated to well-foliated paragneiss that weathers to a buff color. It is generally associated with a pegmatite that forms medium- to coarse-grained dikes or leucocratic pods in the granite gneiss.

As seen in thin section, granite gneiss and pegmatite (Agp) has the modal composition of a granite, and many of the same mineral characteristics as the granite (Ag). Granite gneiss and pegmatite rarely contains less than

TABLE 3.—*Modes (volume percent) for gneissic granite, Casper Mountain, Wyo.*

[---, not found; Tr, trace]

	Binary granite (Agr)			Gneissic granite (Agn)													
				Eastern flank of mountain						Western flank of mountain							
Field No.-------	C-40	C-74	C-75	C-2	C-138	C-145	C-157	BC-16	BC-62	BC-171	BC-212	JD-5	C44-80	C64-80	C121-80	C122-80	C124-80
Potassium feldspar	38.1	22.0	30.0	25.0	26.0	46.0	36.0	34.0	24.0	20.5	24.4	18.0	16.0	33.6	36.7	16.9	31.8
Plagioclase-------	27.5	37.0	33.0	40.0	38.0	27.0	31.0	32.0	39.0	46.9	40.6	47.1	40.8	36.2	45.4	45.4	32.5
Quartz------------	33.2	34.0	31.0	29.0	25.0	26.0	30.0	28.0	31.0	20.4	26.4	21.4	29.2	25.9	10.7	26.2	33.1
Biotite-----------	1.2	0.5	5.0	5.0	11.0	Tr	1.0	2.0	6.0	---	---	1.0	10.7	0.6	---	0.6	0.1
Hornblende--------	---	---	---	---	---	---	---	---	---	2.7	Tr	---	---	---	---	1.8	---
Ores--------------	Tr	---	---	Tr	Tr	1.0	1.0	1.0	Tr	1.2	1.5	0.9	0.7	.1	0.8	2.6	2.0
Zircon------------	---	---	Tr	---	---	---	Tr	Tr	Tr	---	---	.1	.1	Tr	.1	0.2	Tr
Epidote-----------	---	---	---	Tr	Tr	---	---	1.0	---	3.1	2.7	.4	.1	.1	.5	2.2	Tr
Chlorite----------	Tr	---	---	1.0	Tr	Tr	1.0	2.0	Tr	4.2	3.7	10.2	.1	1.5	4.4	2.8	.4
Muscovite-sericite	---	6.5	1.0	Tr	---	Tr	Tr	Tr	---	---	---	---	1.8	2.0	---	---	.1
Allanite----------	---	---	---	Tr	Tr	---	---	---	---	Tr	---	---	---	---	.1	---	---
Calcite-----------	---	---	---	Tr	---	---	---	---	---	---	---	---	---	---	---	---	---
Monazite----------	Tr	Tr	Tr	---	---	---	Tr	---	---	---	---	---	Tr	---	---	---	---
Apatite-----------	---	Tr	---	Tr	Tr	Tr	Tr	Tr	Tr	0.1	0.1	.3	.5	---	1.1	.5	Tr
Sphene------------	---	---	---	---	---	---	---	---	---	.9	.6	.6	---	---	.2	.8	---



20 percent microcline; whereas muscovite is the predominant mica, a few rock samples contain as much as 13 percent biotite. The accessory minerals are sparse, but include trace amounts of apatite, zircon, magnetite, and allanite. Garnet was observed as a single inclusion in plagioclase, and andalusite was confined to one muscovite lath. The alteration minerals are sphene, hematite (forms rims on magnetite), epidote (forms rims on allanite), rutile, chlorite, and sericite. Plagioclase has a composition similar to that in the granite (Ag), and it occurs in large crystals that are locally antiperthitic, containing patches of microcline. The alkali feldspar in the granite gneiss is microcline and film and bleb perthite. Microcline is less altered than plagioclase and occurs generally as larger crystals (fig. 13*A*).

Compositions for the gneissic granite (Agn and Agr) and granite gneiss and pegmatite (Ag and Agp) were plotted on a quartz–plagioclase–potassium feldspar

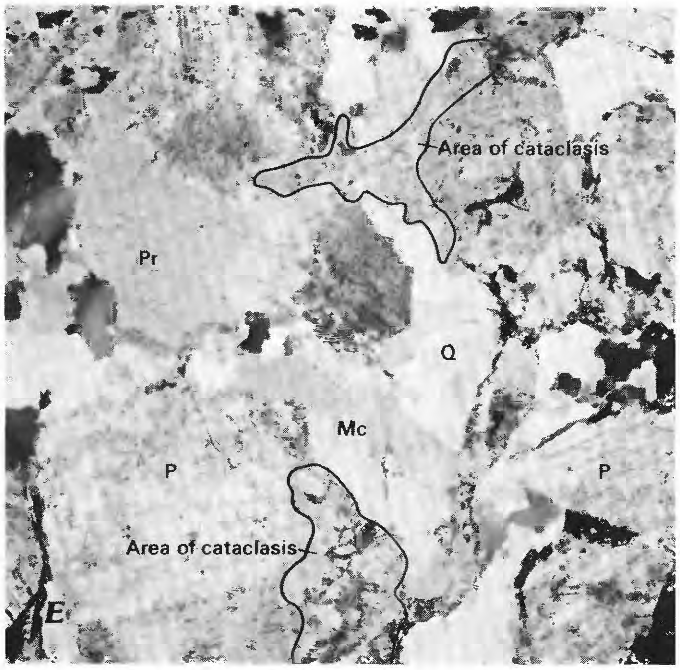


FIGURE 12 (at left and facing page).—Photomicrographs of gneissic granite.
A, Medium-grained binary granite (C–75; Agr); note areas of slight cataclasis between crystals; crossed polars, × 15. *B*, Sheared hornblende-bearing gneissic granite (BC–212; Agn), hornblende partially replaced by epidote; crossed polars, × 15. *C*, Medium- to coarse-grained gneissic granite (BC–171; Agn) showing considerable cataclasis in groundmass, crossed polars, × 15. *D*, Coarse-grained gneissic granite (C–157; Agn), plagioclase altered, crossed polars, × 15. *E*, Coarse-grained gneissic granite (C–120; Agn) showing cataclasis along grain boundaries, all major minerals found in areas of cataclasis; plane-polarized light, × 15. B, biotite; Ch, chlorite; E, epidote; Hb, hornblende; M, muscovite; Mc, microcline; Mt, magnetite; P, plagioclase; Pr, perthite; Q, quartz; Sp, sphene.

ternary diagram (fig. 14). The only noticeable difference is that granite gneiss and pegmatite is a little richer in quartz than is gneissic granite; otherwise their compositions are quite similar.

Pegmatite (Ap) as separate bodies and pegmatite intimately associated with granite gneiss and pegmatite (Agp) are believed to be the same age. These pegmatite bodies are in the central part of the Casper Mountain Precambrian; they are white, gray, or pinkish-buff leucocratic rocks that occur as small stringers or as lenses in granite gneiss and pegmatite or that form very large dome-like masses that intrude, and have sharp contacts with, serpentinite. Local residents claim that large perthitic microcline crystals weighing more than 450 g have been found in this massive pegmatite. Included with the pegmatite are bodies of white, gray, or pinkish-buff, fine- to medium-grained aplite that grade into coarse-grained and very coarse grained pegmatite. As observed under the microscope, the huge perthitic feldspar crystals in the pegmatite contain trains of smaller crystals of microcline and plagioclase that crisscross the perthite crystals along fractures. Besides microcline, the coarse pegmatite consists of varying amounts of quartz, plagioclase, muscovite, and, locally, biotite, tremolite, and traces of garnet. Accessory minerals are rare but include crystals of yellowish-green beryl nearly 1 m long (Burford and others, 1979), pseudo-ixiolite (a disordered tantalite) as much as 304 cm long, apatite, and muscovite, some in large sunburst-like masses (fig. 15). Locally, pods of muscovite-rich pegmatite are deformed into tight chevron folds, some of which form a plumose-muscovite rock.

As seen in thin sections of aplite, plagioclase is generally subordinate in crystal size to microcline or perthite, is slightly antiperthitic, is albite twinned, and generally has been only slightly altered to sericite. Plagioclase ranges in composition from albite to oligoclase. The alkali feldspar is microcline or patch, vein, string, or film perthite containing some graphic intergrowths of quartz. Muscovite is the youngest mineral; it either replaces the microcline or forms boxwork-like structures in microcline. Two modal analyses of the aplite are similar to those of the unit granite gneiss and pegmatite (table 5).

RHYOLITIC DIKES

Rhyolitic dikes (ꟼAr), generally too small to map, crop out mostly on the west flank of the mountain. These dikes form low, discontinuous ridges along faults, fractures, and joints in gneissic granite (Agn). The dikes occur within hornblendite (ꟼAhd) as crosscutting veinlets that have brecciated margins (fig. 10). The rocks are dense, fine to medium grained, fractured into blocks, and commonly sheared. Some of the dikes are slightly pegmatitic and light to bright pink on fresh fracture but weather dark pink or dark reddish brown.

Thin sections show that the dikes contain 36 percent microcline, 33 percent plagioclase, 30 percent quartz, and less than 2 percent accessory and alteration minerals that include biotite, ore minerals, apatite, allanite, chlorite, and epidote. Modal composition suggests these are potassic rhyolite dikes.

ORIGIN OF THE GRANITIC ROCKS

Granitic rocks dominate the Precambrian of Casper Mountain, and most are believed to be related to the Laramie batholith to the south and southeast. The map

TABLE 4.—*Modes (volume percent) for enclaves (inclusions) in gneissic granite (Agn), Casper Mountain, Wyo.*

[---, not found; Tr, trace]

Field No.---	C-165	C236A	C28-80	C53-80	C128-80	BC-156
Potassium feldspar--	2.1	---	11.6	38.9	23.0	5.8
Plagioclase	46.8	55.2	48.3	25.5	Tr	46.0
Quartz------	25.8	25.6	13.2	28.9	---	14.3
Biotite-----	25.0	---	14.9	4.6	---	---
Hornblende--	---	---	7.1	---	---	20.0
Ores--------	Tr	1.9	2.0	Tr	Tr	2.1
Zircon------	Tr	Tr	---	Tr	---	---
Epidote-----	---	5.6	0.4	---	77.0	5.8
Chlorite----	0.2	8.9	.2	0.1	---	4.9
Muscovite-sericite--	.1	0.1	---	2.0	---	---
Allanite----	---	.1	---	---	---	---
Xenotime-monazite--	---	---	---	Tr	---	---
Apatite-----	Tr	1.5	.7	Tr	Tr	0.3
Sphene------	---	1.1	1.6	---	Tr	.8

TABLE 5.—*Modes (volume percent) for granite gneiss and pegmatite, Casper Mountain, Wyo.*

[---, not found; Tr, trace]

	Granite (Ag)			Granite gneiss (Agp)					
Field No.--	C-60	C-245	BC-52	C16-80	C22-80	C42	C96-80	C101-80	C108-80
Potassium feldspar	22.0	30.0	31.0	37.7	46.4	11.7	43.0	27.0	26.9
Plagioclase	26.0	35.0	21.0	27.7	25.5	40.0	25.0	32.0	31.0
Quartz-----	39.0	34.0	46.0	33.6	27.1	33.6	27.0	40.0	36.1
Biotite----	Tr	Tr	---	---	Tr	12.3	1.0	---	5.8
Ores-------	Tr	Tr	Tr	0.3	Tr	---	Tr	Tr	---
Zircon-----	---	---	Tr	Tr	---	Tr	---	Tr	Tr
Allanite(?)	---	---	---	.1	Tr	---	---	---	---
Chlorite---	---	1.0	Tr	.5	1.0	0.4	---	1.0	0.1
Muscovite-sericite	13.0	Tr	2.0	---	---	2.0	4.0	---	---
Epidote(?)	---	---	---	Tr	Tr	---	---	---	.1
Xenotime-monazite	---	Tr	Tr	---	---	---	---	---	---
Apatite----	---	---	---	.1	---	Tr	---	---	Tr
Sphene-----	---	---	Tr	---	---	---	---	Tr	---

unit granite gneiss and pegmatite (Agp), however, has a mineralogy more nearly that of the Granite Mountains batholith to the west. The granitic rocks on Casper Mountain represent two separate granitic phases, and the location of Casper Mountain does not rule out the possibility that they are granitic phases of both the Laramie batholith and the Granite Mountains batholith.

Gneissic granite (Agn and Agr) contains large enclaves of metasedimentary rock; this unit probably represents the foliated northernmost exposure of the Laramie batholith. The binary granite (Agr) may represent a more massive and slightly later injection of magma.

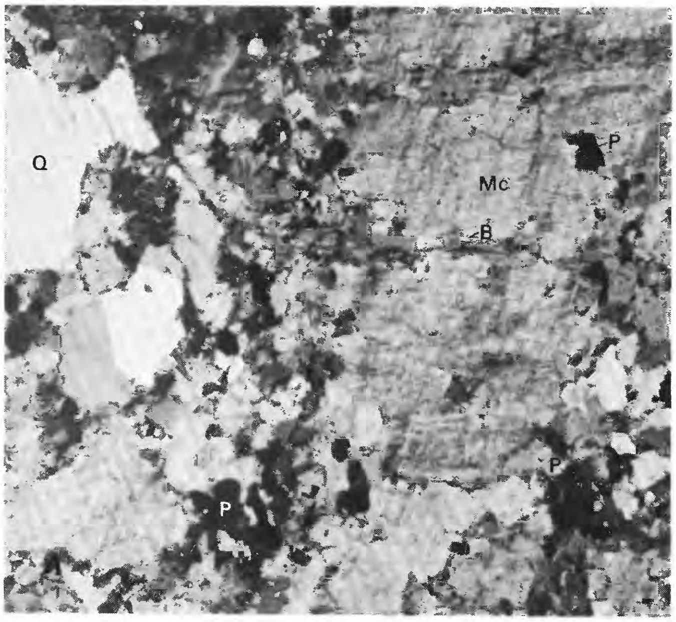
Although gneissic granite may be related to the Laramie batholith, granite gneiss and pegmatite (Ag, Agp, Ap) appears to be of mixed origin and more closely related to the Granite Mountains batholith. The several small bodies of granite associated with this unit exhibit the same bluish-gray, less commonly gray-black perthitic microcline similar to some granite in the Granite Mountains batholith to the west and may represent a small satellite pluton of the latter granite.

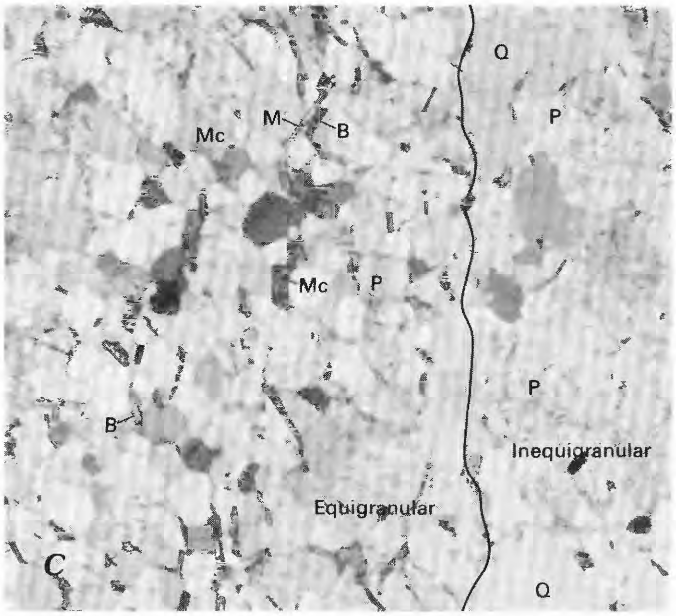
The granite gneiss and pegmatite may have been produced in part by metasomatism associated with emplacement of the granitic magma of the Laramie batholith or the Granite Mountains batholith, or both. An indication of the metasomatism can be seen on the west side of Wolf Creek, where biotite-feldspar-quartz gneiss gradually coarsens in texture across a zone several meters wide into typical granite gneiss and pegmatite (Agp). This occurrence of granite gneiss and pegmatite (Agp) contains dark-gray or bluish-gray-black perthitic microcline crystals about 1 cm long, set in a lighter quartz-plagioclase groundmass, similar to those in the map unit pegmatite (Ap) and to rocks in parts of the Granite Mountains batholith. This is an unusual occurrence for microcline and diagnostic for these rocks.

These dark-bluish-gray, almost black, microcline crystals are also found in the large pegmatite mine in the central part of Casper Mountain, where pseudo-ixiolite crystals have been found. Crouse and Cerny (1972) and Cerny and Turnock (1971), from their research on this mineral, proposed that pegmatite bearing pseudo-ixiolite in a mineral assemblage similar to that of Casper Mountain represents a product of advanced differentiation of a granitic magma. This suggests that the units granite gneiss and pegmatite (Agp) and pegmatite (Ap) were produced by a combination of partial melting and metasomatism, perhaps brought about by emanations from a granite intrusive, in this instance from a pluton more closely related to the Granite Mountains batholith than to the Laramie batholith.

GEOCHEMISTRY OF THE IGNEOUS AND METAMORPHIC ROCKS

Rapid rock chemical analyses of 14 rock samples and semiquantitative spectrographic analyses of 28 rock samples, done for this report, appear in tables 6–12. The samples represent most of the major rock types on Casper Mountain. The major differences noted are contrasts in trace element content between gneissic granite (Agr and Agn) and granite gneiss and pegmatite units (Ag, Agp, and Ap). However, we could not find for comparison a full range of trace element data for either the





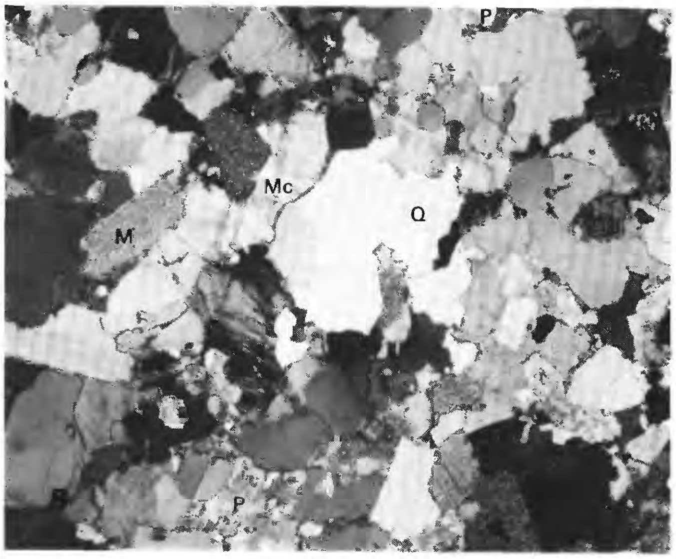


FIGURE 13.—Photomicrographs of granite gneiss (Agp). *A*, Inequigranular, nonfoliated granite gneiss; microcline and quartz megacrysts set in a leucocratic groundmass of quartz and plagioclase; crossed polars, × 15. *B*, Inequigranular granite gneiss; plagioclase partly altered to sericite; crossed polars, × 15. *C*, Foliated, equigranular granite gneiss (left) in contact with inequigranular gneiss (right); biotite defines foliation; plane-polarized light, × 15. B, biotite; M, muscovite; Mc, microcline; P, plagioclase; Q, quartz.

Granite Mountains or the Laramie batholith. Therefore, it is impossible to relate to either batholith the significant and distinct differences observed in these trace elements in the granitic rocks, even though the whole-rock chemical analyses are similar in many ways.

Gneissic granite (Agr and Agn) is commonly slightly more mafic and contains slightly larger than average amounts of potassium and aluminum, and slightly less silica, than the batholithic rocks to the south and west (Stuckless and others, 1977; Condie, 1969). The compositions of granite (Ag) and granite gneiss (Agp) is more variable on Casper Mountain than is the composition for granitic rocks in the northern Laramie Mountains metamorphic complex (Condie, 1969).

Distinct chemical differences between gneissic granite (Agr and Agn) and granite gneiss and pegmatite (Ag, Agp, and Ap) lie in the trace elements (tables 6 and 7). Gneissic granite contains more trace elements, in higher concentrations, than found in granite gneiss and pegmatite. Boron, cerium, cobalt, lanthanum, and neodymium are below limits of detection in granite gneiss and pegmatite but measureable in gneissic granite. Barium, strontium, vanadium, zinc, and zirconium occur in much greater amounts in gneissic granite than in granite gneiss and pegmatite.

Biotite gneiss and biotite schist (Abg and Abs) and biotite-feldspar-quartz gneiss (Aqf), the two major types of metasedimentary rocks in the area, form modally and chemically distinct populations (tables 8–10), even though they are locally gradational and interlayered with each other. Both units contain nearly the same amount of potassium feldspar, but only biotite-feldspar-quartz gneiss contains microcline. The trace elements, except strontium, vary within each rock type as much as between rock types. However, strontium is about six times more abundant in biotite gneiss and biotite schist (average 500 ppm, table 9) than in biotite-feldspar-quartz gneiss (average 80 ppm, table 10).

Biotite gneiss contains twice as much iron and

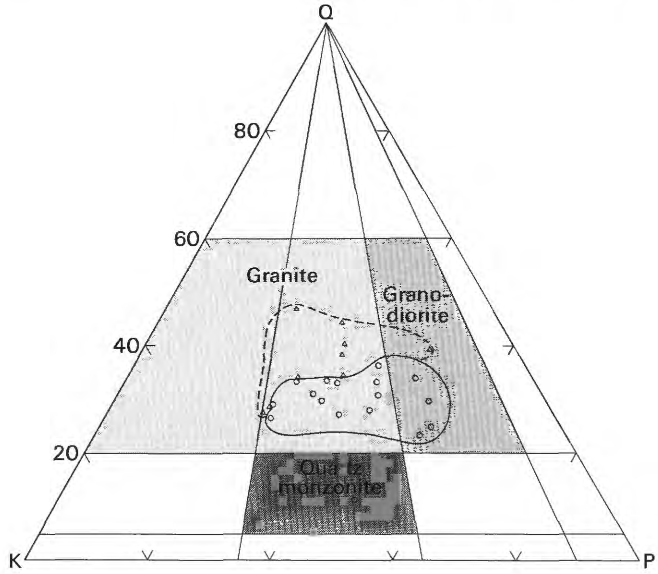


FIGURE 14.—Ternary diagram comparing composition (volume percent) of gneissic granite (Agn and Agr) with that of granite gneiss and pegmatite (Ag and Agp), Casper Mountain. P, plagioclase; K, potassium feldspar; Q, quartz; circle, gneissic granite (Agn); triangle, granite gneiss and pegmatite (Agp).

titanium and considerably more calcium than does biotite-feldspar-quartz gneiss, displaying a composition more like the average Wyoming Archean graywacke (Condie, 1967). Garnetiferous biotite gneiss has more magnesium and less calcium and sodium than the average graywacke, representing a graywacke in which more mafic source rocks were contributing to the sedimentary pile. Excess iron and titanium in the biotite gneiss appear in biotite and muscovite.

Leucocratic biotite-feldspar-quartz gneiss (Samples C–58, C–152, and C95–80, table 8) has a composition more nearly that of a calc-alkali rhyolite (Nockolds, 1954) except for excess magnesium and less calcium, sodium, and potassium.

Three rapid rock analyses of mafic-ultramafic rocks, including amphibolite and serpentinite (table 8), suggest that the amphibolite has a composition similar to that of an olivine-rich basalt, whereas the serpentinite is more representative of peridotite (Nockolds, 1954). The serpentinized rocks also have chemical characteristics not too different from peridotitic komatiite (Arndt and others, 1977), except for low silica, calcium, and aluminum, but these elements may have been systematically removed during serpentinization.

Spectrographic analyses of trace elements and rapid rock analyses from sampled mafic-ultramafic rocks (tables 8, 11, and 12) show them to be high in chromium, manganese, and nickel. Titanium is less than 1 percent in all samples and this low a concentration is characteristic of basaltic komatiites (Jahn and others, 1980). The high concentration of zinc and nickel in chromite schist cannot be related to mineralogy observed in thin section, suggesting that the zinc and nickel may occur in solid solution, perhaps in the silicate mineral structure.

SEDIMENTARY ROCKS

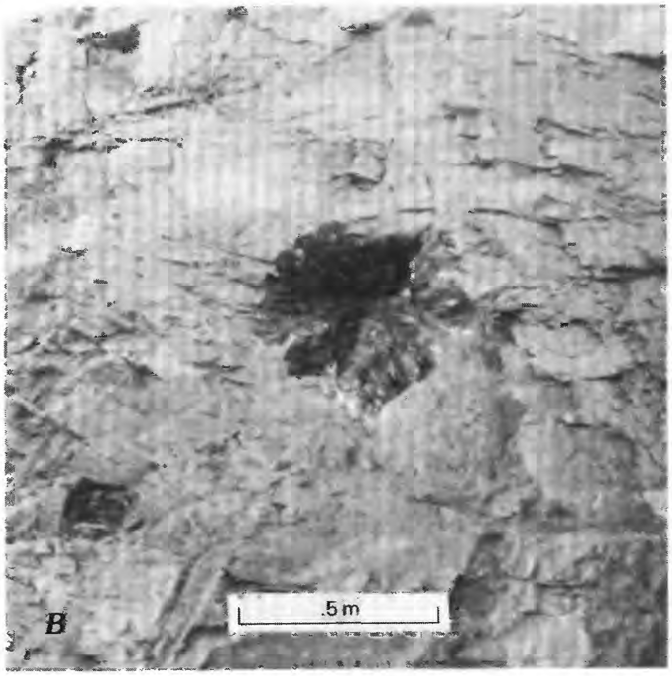
In the Casper Mountain area, limestone, dolomite, and clastic rocks of all periods except Ordovician, Silurian, and Devonian unconformably overlie a basal sandstone of Cambrian(?) age. If rocks of Ordovician, Silurian, and Devonian age were deposited, they have subsequently been removed by erosion and are no longer present. However, recent work by Sando and Sandberg (in press) suggests that rocks unconformably overlying the Precambrian near Casper Mountain are Late Devonian. The sedimentary rocks in the vicinity of the Casper Mountain Precambrian were not mapped or studied in detail for this report. A summary of characteristics of the sedimentary rocks in the area is provided in table 13.

STRUCTURAL GEOLOGY

REGIONAL SETTING

The central Rocky Mountains of the North American Cordillera, in which Casper Mountain lies, is a region of uplifts and downwarps of considerable magnitude. Casper Mountain is a northwest extension of the Laramie Mountains uplift that is southwest of the Powder River Basin, north of the Shirley Basin, east of the Wind River Basin and the Sweetwater Uplift, and south of the Casper Arch (fig. 2).

The profound structural relief that is characteristic of the central Rocky Mountains has been recognized by many, including Eardley (1963), Keefer and Love (1963), and Stearns and others (1975). The uplift mechanisms have variously been ascribed to (1) the German tectonic style (Blackstone, 1963), which is characterized by crystalline basement uplift and intervening basinal downwarp; (2) horizontal or tangential crustal movements and wrench-fault tectonics (Sales, 1968, 1971; Stone, 1969; Thomas, 1971); or (3) widespread tangential or horizontal principal compression related to the alpine or subalpine-type thrusting in the Cordilleran orogen to the west. Detailed COCORP data (Allmendinger and others, 1982; Brewer and others, 1982) and



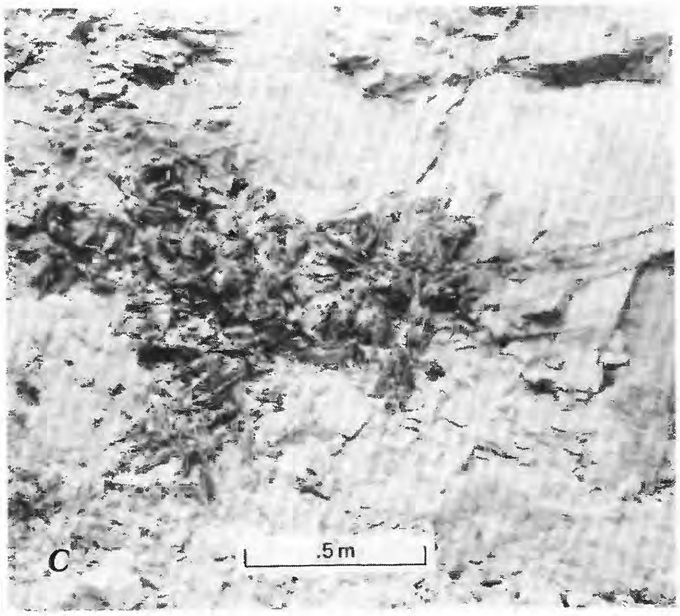


FIGURE 15.—Large pegmatite quarry on Casper Mountain. *A*, Rock strongly fractured by faulting. *B*, Mica sunburst, about 3 m in diameter, undeformed in jointed and fractured microcline pegmatite. *C*, Mica growths in microcline pegmatite; these growths are uncommon in the quarry.

other data for the subsurface (Blackstone, 1980; Gries, 1981, 1983) suggest the importance of thrust uplift of many ranges in Wyoming.

The general structure of Casper Mountain is both anticlinal and thrust as indicated by dips of surrounding sedimentary strata and the south-dipping reverse border fault of the north flank of the mountain. Sedimentary rocks of Paleozoic and Mesozoic age dip gently south off the back of the mountain, dip steeply north off the north face, and plunge east and west, respectively, off the east and west ends of the mountain. The anticlinal structure of the mountain trends east-west and is strongly asymmetric toward the north. The north flank is cut by a south-dipping, moderate- to high-angle reverse or thrust fault, known as the Casper Mountain fault. Along this fault, the abuttal of Precambrian and Paleozoic rocks of the mountain mass against Mesozoic strata indicates considerable displacement. This thrust extends beyond the west and east ends of the mountain and is a major structural feature of the region. High-angle faults of small displacement cut the east end of the mountain, the west end several kilometers west of the Precambrian exposures, and even the gentle south flank of the structure.

PRECAMBRIAN STRUCTURES

Precambrian structural features include foliations, lineations, folds, faults, and joints. Many appear to have

TABLE 6.—*Semiquantitative spectrographic analyses for gneissic granite (Agn), Casper Mountain, Wyo.*

[Analysts: C-145, N. M. Conklin; all others by J. L. Harris. ---, not found; >, greater than; <, less than; G, greater than 10 percent]

Field No.	[1]C-120	[2]BC-62	BC-212	C121-80	C-145
Lab No.--	W212743	W212736	W212751	W212752	D225938
Major elements, in percent					
Si-----	>34.0	>34.0	29.0	28.0	G
Al-----	8.6	8.3	7.4	9.9	7.0
Fe-----	2.0	2.8	2.5	1.9	1.5
Mg-----	0.61	0.69	0.68	0.69	0.07
Ca-----	1.8	.89	3.1	1.5	.3
Na-----	4.6	3.7	5.8	7.5	3.0
K------	3.8	3.6	3.2	5.2	5.0
Ti-----	.08	.16	.15	.08	.03
P------	<.07	.09	.11	.17	---
Mn-----	.03	.03	.04	.03	.07
Trace elements, in parts per million					
B------	30	14	8	11	15
Ba-----	1,900	1,100	1,600	1,500	700
Be-----	2	3	2	1	2
Ce-----	<43	110	<63	<43	---
Co-----	4	5	9	6	---
Cr-----	11	9	5	2	2
Cu-----	6	6	5	37	3
Ga-----	20	24	17	20	30
La-----	26	80	30	<10	---
Nb-----	4	7	4	<3	---
Nd-----	<32	77	<32	<32	---
Ni-----	7	6	6	5	---
Pb-----	43	25	34	40	30
Sc-----	4	5	5	6	2	---
Sn-----	3	5	<2	3	---
Sr-----	510	220	610	440	300
V------	19	30	45	28	20
Y------	6	14	7	6	10
Yb-----	1	2	1	1	2
Zn-----	44	20	36	51	---
Zr-----	54	290	150	31	70

[1]West slope, Middle Fork Elkhorn Creek, SW1/4 sec. 3, T. 32 N., R. 79 W.
[2]East slope, Middle Fork Elkhorn Creek, NE1/4 sec. 10, T. 32 N., R. 79 W.

TABLE 7.—*Semiquantitative spectrograhic analyses for granite gneiss and pegmatite, Casper Mountain, Wyo.*

[Analysts: C-60 and C-74 by N. M. Conklin, sample C96-80 by J. L. Harris. ---, not found; G, greater than 10 percent; <, less than; >, greater than]

	Granite (Ag)	Granite gneiss (Agp)	
Field No.-	C-60	C-74	C96-80
Lab No.---	D225935	D225936	W212750
Major elements, in percent			
Si--------	G	G	33.0
Al--------	5.0	7.0	6.4
Fe--------	0.3	0.7	0.59
Mg--------	.07	.15	.16
Ca--------	.2	.15	.20
Na--------	3.0	3.0	7.0
K---------	3.0	3.0	5.1
Ti--------	.015	.03	.01
Mn--------	.07	.07	.02
Trace elements, in parts per million			
Ba--------	70	150	200
Be--------	---	---	2
Cr--------	---	7	1
Cu--------	3	10	3
Ga--------	30	20	30
Nb--------	10	15	9
Ni--------	---	7	2
Pb--------	30	30	41
Sc--------	5	7	2
Sn--------	---	---	6
Sr--------	30	30	60
V---------	---	---	3
Y---------	70	15	11
Yb--------	7	2	2
Zn--------	---	---	19
Zr--------	70	30	18

formed at different times in the Precambrian; many were probably periodically reactivated.

FOLIATION

Foliation in the Casper Mountain Precambrian rocks has a fairly consistent orientation, striking east-northeast and dipping southeast (fig. 16). Foliation is defined by compositional layering or banding and by alignment of mafic or leucocratic minerals. The mafic-ultramafic rocks generally are nonfoliated or at best are poorly foliated, except for the oldest mafic schistose lenses. In the amphibolite, mineral alignment and slight differential layering define the foliation. The leucocratic Precambrian rocks are foliated to varying degrees. The metasedimentary rocks display a good foliation, whereas foliations in the granitic rocks range from good to fair to poor. Foliation in the metasedimentary rocks is defined mainly by light and dark compositional banding and by parallelism of minerals and elongate quartzose lenses. Foliation in the granitic rocks results from the parallelism of biotite stringers and aligned tabular feldspars. The foliation pattern in the gneissic granite suggests that these rocks are part of a steep-sided batholithic mass.

LINEATION

Lineations are most obvious in the metasedimentary and granitic rocks of Casper Mountain, especially in the

TABLE 8.—*Rapid rock chemical analyses (in weight percent) for representative gneissic granite, granite gneiss and pegmatite, amphibolite, and serpentinite, Casper Mountain, Wyo.*

[Analysts: Deborah Kobilis for samples C-145–C-51 and J. R. Gillison for samples CA-2 and CA-3; n.d., not determined; <, less than]

	Gneissic granite (Agn)	Mafic gneissic granite (Agn)		Granite gneiss and pegmatite (Agp)		Migmatitic granite gneiss and pegmatite (Agp)	Amphibolite (altered diabase) (Aam)	Serpentinite (altered ultramafic rock) (Asp)	
Sample No.	[1]C-145	[2]BC-212	[3]C121-80	[4]C-60	[5]C-74	[6]C96-80	[7]C-51	[8]CA-2	[9]CA-3
Lab No.--	D225938	W212752	W212752	D225935	D225936	W212750	D225940	D253287	D253288
SiO_2-------	76.1	69.1	63.6	76.1	74.9	75.5	53.0	39.6	36.0
Al_2O_3------	13.5	15.1	18.3	13.2	13.6	14.2	4.5	2.3	1.9
Fe_2O_3------	1.2	2.3	1.5	0.65	0.40	0.39	2.1	9.5	17.9
FeO--------	0.10	1.1	1.2	.14	.26	.40	7.1	0.60	1.1
MgO--------	.09	1.1	1.2	.13	.21	.30	17.8	35.0	32.2
CaO--------	.16	2.6	1.3	.33	.00	.43	12.3	.06	<0.01
Na_2O-------	2.8	3.6	3.9	2.5	3.7	3.8	0.38	.03	.03
K_2O--------	5.3	4.0	6.6	5.0	4.7	5.0	.26	.04	<.01
H_2O^+ ------	.64	1.1	1.2	.01	.63	.43	.97	11.7	10.8
H_2O^- ------	.30	0.27	0.28	.90	.16	.16	.25	.58	.80
TiO_2-------	.08	.76	.25	.06	.09	<.01	.43	.03	.03
P_2O_5-------	.01	.13	.44	.03	.03	<.01	.01	.06	.06
MnO--------	.00	.07	.07	.00	.00	.04	.19	.06	.03
CO_2--------	.01	.04	.06	.01	.01	.10	.02	.03	.04
F----------	n.d.	.04	.06	n.d.	n.d.	.02	n.d.	.02	.03
Cl---------	n.d.	.006	.012	n.d.	n.d.	.003	n.d.	.01	.01
S----------	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total	100.	101.	100.	99.	99.	101.	99.	100.	101.

[1]East end of Casper Mountain, NW1/4SW1/4 sec. 9, T. 32 N., R. 78 W.
[2]On ridge, SW1/4NE1/4 sec. 11, T. 32 N., R. 80 W.
[3]On slope east of stream in NW1/4NW1/4 sec. 11, T. 32 N., R. 80 W.
[4]Northeast of Eadsville, SE1/4SW1/4 sec. 18, T. 32 N., R. 79 W.
[5]Southeast of Eadsville, SE1/4NE1/4 sec. 19, T. 32 N., R. 79 W.
[6]On slope west of Wolf Creek, NE1/4 sec. 13, T. 32 N., R. 80 W.
[7]On ridge in NW1/4 sec. 18, T. 32 N., R. 79 W.
[8]East of Garden Creek, on ridge NE1/4 sec. 17, T. 32 N., R. 79 W.
[9]Small lens intersects road on dividing line between NE and SE sections of sec. 7, T. 32 N., R. 79 W.

metasedimentary rocks in the south-central part of the Precambrian rock mass. Lineations are defined in the schistose rocks by elongate groups of platey micaceous minerals, in the amphibolite rocks by hornblende crystals, and in the granitic rocks by parallel feldspar laths, biotite stringers, and hornblende. In addition, lineations are defined by the axes of small folds and crenulations.

A synoptic plot of all types of lineations suggests polyphase folding (fig. 17*A*). While the lineations measured from metasedimentary rocks vary substantially (fig. 17*B*), a major maximum plunges 2°, N. 88° E. and is subparallel to the axis of a fold in the Precambrian rocks in the south-central part of the area, and to the regional trend in general. A lesser maximum that plunges 28°, S. 76° W. may result from the faulting and tilting of fault blocks in the area. Two other, weaker maxima that plunge 56°, S. 18° W. and 73°, S. 25° E. may be associated with secondary structures to the major folds.

Mineral lineations in granitic rocks (fig. 17*C*) are subparallel to the regional trend shown in figure 17*B* but plunge 10° more steeply. Two maxima defined by these lineations, but not seen in the metamorphic rocks, are assumed to be related to the granite emplacement: these are 17°, S. 59° W. and 15°, S. 65° E.

TABLE 9.—*Rapid rock chemical analyses (in weight percent) for representative samples of biotite schist and biotite-feldspar-quartz gneiss, Casper Mountain, Wyo.*

[Analyst: Deborah Kobilis; n.d., not determined; <, less than]

	Biotite schist (Abs)		Biotite-feldspar-quartz gneiss (Aqf)		
Field No.--	[1]C-204	[2]C-45	[3]C-152	[4]C95-80	[5]C-58
Lab No.----	D225939	D22593	D225937	W212749	D225934
SiO_2---------	65.3	68.0	75.8	70.4	74.4
Al_2O_3--------	15.0	12.4	11.1	13.5	12.8
Fe_2O_3--------	1.3	1.4	0.51	1.2	0.55
FeO----------	4.2	3.2	3.0	1.3	1.0
MgO----------	3.0	5.3	2.0	6.3	1.5
CaO----------	1.7	0.68	.22	0.59	.87
Na_2O---------	3.1	.78	3.3	.8	2.0
K_2O----------	3.2	3.6	1.6	4.2	4.3
H_2O^+ --------	1.5	2.5	1.7	2.2	.72
H_2O^- --------	0.39	.35	.33	.56	.26
TiO_2---------	.65	.54	.35	<.01	.14
P_2O_5---------	.17	.18	.11	.02	.02
MnO----------	.06	.03	.03	.03	.07
CO_2----------	.02	.04	.02	.11	.04
F------------	n.d.	n.d.	n.d.	.06	n.d.
Cl-----------	n.d.	n.d.	n.d.	.009	n.d.
Total-----	99.	99	100.	101.	99.

[1]Asbestos Springs area, NE1/4 sec. 17, T. 32 N., R. 79 W.

[2]Garnet-bearing biotite schist from ridge west of West Garden Creek, NW1/4 sec. 18, T. 32 N., R. 79 W.

[3]East end of Casper Mountain, SE1/4 sec. 9, T. 32 N., R. 78 W.

[4]Slope west of Wolf Creek, NW1/4 sec. 13, T. 32 N., R. 80 W.

[5]Slope east of Wolf Creek, SE1/4 sec. 13, T. 32 N., R. 80 W.

FOLDS

The largest and only mappable flexure lies in the south-central part of the map area, where serpentinite and biotite-feldspar-quartz gneiss are folded about an east-northeast-trending axis into a syncline 3 km long. Other folds broader than several hundred meters occur mainly in biotite-feldspar-quartz gneiss near the east end of the mountain. Many small flexures in the schist and gneiss, most too small to map, follow the general foliation trend (fig. 17*B*).

Crinkles and small disharmonic, chevron folds occur in the most incompetent schistose gneiss and micaceous pegmatite. The height of these chevron folds is as great or greater than their breadth.

FAULTS

Faults are common in the Casper Mountain Precambrian. Generally associated with staining and local quartz veining, they are marked by mylonite and (or) gouge or by shear zones and slickensides.

High-angle reverse faults.—Several high-angle faults cut across Casper Mountain and can be traced for from 1 km to almost 10 km. Most of these faults strike from about N. 55° E. to N. 90° E.; the southeast and south sides of most are relatively upthrown, displacements probably reflecting Laramide movement. The faults may have originated as strike-slip or normal faults.

Although the planes of the high-angle reverse faults and related small faults are generally not well exposed, where they are exposed, they dip steeply south. The faults cut both Precambrian and Phanerozoic rock, and displacement is as much as several hundred meters. Faults either parallel the major Precambrian structural grain of the mountain or follow its east-west trend. Because the northeast trend of these faults parallels the Cheyenne belt (formerly called Mullen Creek–Nash Fork shear zone) 140 km to the south, we interpret them to have a Precambrian origin and to have been reactivated in Laramide and possibly later times. In addition, numerous very small unmapped high-angle reverse faults occur throughout the Precambrian terrain. Most trend east-west and dip steeply south.

High-angle normal faults.—At least one east-northeast-trending normal fault, having a relatively small displacement, can be traced for 8 km across the central part of the mountain. Other normal faults that have short traces are common but are too small to map. The northward dip of many of these suggests they formed as antithetic faults in Laramide time.

Strike-slip faults.—Numerous steeply dipping faults, having mainly strike-slip displacement, cut all rocks. Predominant strike-slip movement is indicated by low-plunge fault striae; many faults are probably related to the later Laramide deformation.

Other high-angle faults.—Innumerable high-angle faults, most either too short or too indistinct to map, cut the Precambrian rocks. Amounts of displacement cannot be determined. One set of relatively small faults, however, is apparent throughout much of the Precambrian; these faults are especially abundant in sec. 10 and 11 of T. 32 N., R. 30 W. They are almost universally marked by quartz veins that vary in thickness from less than 1 cm to several centimeters, by banded granitic veins, by red hematite staining, and by epidote and specularite coatings. The faults range in strike from N. 70° E. to N. 90° E. and dip mainly south at from 70° to 90°. The faults are confined to the Precambrian terrain and may be related to the dominant east-northeast structural grain.

JOINTS

All of the Precambrian rocks are highly fractured,

TABLE 10.—*Semiquantitative spectrographic analyses for biotite gneiss (Abg and Abs), Casper Mountain, Wyo.*

[Analysts: C-204 and C-45, N. M. Conklin; all others by J. L. Harris. ---, not found; L, detected but below limit of determination; >, greater than; G, greater than 10 percent; n.d., not determined]

Field No.--- Lab No.-----	[1]C18-80 W212745 (Abg)	[2]C87-80 W212747 (Abs)	C-204 D225939 (Abs)	[3]C-27 W212737 (Abs)	[4]C-109 W212742 (Abg)	[5]BC-22 W212735 (Abs)	C-45 D225933 (Abs)
Major elements, in percent							
Si----------	33.0	34.0	G	23.0	>34.0	>34.0	G
Al----------	12.0	11.0	10.0	8.9	10.0	9.8	7.0
Fe----------	1.7	6.5	7.0	6.7	5.2	5.7	3.0
Mg----------	0.98	2.4	0.7	3.0	1.8	2.0	3.0
Ca----------	3.7	3.1	2.0	1.6	2.9	2.5	0.3
Na----------	7.0	2.7	3.0	3.2	3.2	3.2	.7
K-----------	1.4	2.4	3.0	3.3	2.1	2.2	3.0
Ti----------	.23	0.22	.3	0.28	0.23	.23	.3
P-----------	.09	.09	---	.11	.13	.07	---
Mn----------	.03	.10	.07	.10	.06	.08	.03
Trace elements, in parts per million							
B-----------	20	<7	---	11	7	6	15
Ba----------	380	560	700	460	530	690	700.0
Be----------	2	4	1	2	2	2	1
Ce----------	<63	<43	---	<43	<43	51	150
Co----------	5	19	20	34	17	21	15
Cr----------	10	250	300	250	230	180	70
Cu----------	3	41	70	26	42	40	30
Ga----------	24	22	20	26	18	22	15
La----------	33	31	30	22	15	16	70
Nb----------	11	8	L	6	7	11	15
Nd----------	<32	<32	---	<32	<32	<32	<32
Ni----------	7	63	70	110	42	68	70
Pb----------	18	14	20	15	39	30	15
Sc----------	6	15	20	22	16	16	7
Sn----------	3	2	---	<2	<2	<2	---
Sr----------	730	650	700	400	450	500	70
V-----------	42	100	150	130	99	99	70
Y-----------	14	7	15	8	6	9	70
Yb----------	2	1	2	1	1	2	7
Zn----------	48	79	---	110	80	140	---
Zr----------	88	150	150	73	91	120	300
Major elements recalculated as oxides, in percent							
SiO_2--------	71.0	>73.0	n.d.	49.0	>73.0	73.0	n.d.
Al_2O_3-------	23.0	21.0	n.d.	17.0	19.0	19.0	n.d.
[6]Fe_2O_3------	2.4	9.3	n.d.	9.6	7.4	8.2	n.d.
MgO---------	1.6	4.0	n.d.	5.0	3.0	3.3	n.d.
CaO---------	5.2	4.3	n.d.	2.2	4.1	3.5	n.d.
Na_2O---------	9.4	3.6	n.d.	4.3	4.3	4.3	n.d.
K_2O----------	1.7	2.9	n.d.	4.0	2.5	2.6	n.d.
TiO_2---------	0.38	0.37	n.d.	0.47	0.38	0.38	n.d.
P_2O_5---------	.20	.21	n.d.	.25	.30	.16	n.d.
MnO----------	.04	.12	n.d.	.13	.07	.10	n.d.

[1]Ridge west of Wolf Creek,SE1/4 sec. 12, T3. 2 N., R. 79 W.
[2]Ridge west of West Garden Creek, SE1/4 sec. 7, T. 32 N., R. 79 W.
[3]Slope west of Elkhorn Creek, NE1/4 sec. 9, T. 32 N., R. 79 W.
[4]Garnet-bearing biotite gneiss from Elkhorn Creek, NW1/4 sec. 16, T. 32 N., R. 79 W.
[5]Garnet-bearing biotite schist from ridge east of West Garden Creek on north half of N-S line separating sections 17 and 18, T. 32 N., R. 79 W.
[6]Total iron recalculated as Fe_2O_3.

TABLE 11.—*Semiquantitative spectrographic analyses for biotite-feldspar-quartz gneiss, Casper Mountain, Wyo.*

[Analysts: C-60 and C-74, N. M. Conklin; C95-80 and C62-80 by J. L. Harris. ---, not found; <, less than; >, greater than; G, greater than 10 percent; n.d., not determined]

	Biotite-feldspar-quartz gneiss (Aqf)			Cordierite-biotite-quartz-feldspar gneiss (Aqf)
Field No.-	C95-80	C-152	[1]C62-80	C-58
Lab No.---	W212749	D225937	W212746	D225934
Major elements, in percent				
Si	34.0	G	>34.0	G
Al	7.0	7.0	8.2	7.0
Fe	2.0	3.0	1.5	1.5
Mg	2.2	1.5	1.8	0.7
Ca	0.11	0.3	0.09	.7
Na	.84	3.0	.42	3.0
K	3.4	1.5	2.3	3.0
Ti	.07	.15	.08	.07
P	<.07	---	<.07	---
Mn	.02	.03	.03	.07
Trace elements, in parts per million				
B	10	---	17	---
Ba	530	500	550	700
Be	2	2	3	1
Ce	<43	---	61	---
Co	3	15	2	7
Cr	2	100	15	2
Cu	12	15	4	20
Ga	20	15	14	20
La	26	30	60	---
Li	78	---	<68	---
Nb	12	10	26	10
Nd	<32	---	40	---
Ni	3	30	17	3
Pb	10	---	11	30
Sc	2	7	3	---
Sn	10	---	3	---
Sr	31	200	21	70
V	11	70	5	---
Y	10	20	21	20
Yb	2	2	3	2
Zn	46	---	32	---
Zr	60	150	96	70

[1]Ridge west of Squaw Creek, NW1/4 sec. 13, T. 32 N., R. 80 W.

joints being the primary form of fracture. Many of the joints are systematic, others are nonsystematic, and some are curved, especially those in the eastern half of the Precambrian core. Some joints are slickensided, and some are mineralized by quartz, specularite, red hematite, and calcite.

Joints of apparent Precambrian origin are much less obvious than those related to the Laramide. The description and analysis of most joints is therefore deferred to the later section on Laramide structure. However, one system that apparently originated in Precambrian time appears in the analysis of all joints (fig. 18). This Precambrian system has only two moderately developed sets that have preferred orientations of strike N. 67° W., dip 86° SW. and strike N. 84° W., dip 80° NE. (*F* and *G*, fig. 18). Because all possible interpreted stress axes are plunging and none is horizontal, it appears that the system was probably tilted and reoriented after its formation.

LARAMIDE STRUCTURES

During Laramide time some of the Precambrian structures were reactivated, especially many faults. It is also possible that some reactivation and deformation occurred during post-Precambrian, pre-Laramide, and post-Laramide time. However, the dominant structural elements belong to either the Precambrian or the Laramide, or both. Structures of Laramide origin overprint those of Precambrian origin.

FOLDS

Casper Mountain is a major east-west-trending asymmetric anticlinal flexure, defined by its Paleozoic and Mesozoic sedimentary strata (pl. 1). The flexure is deeply breached, exposing the Precambrian core in the east and central part of the mountain. Sedimentary strata of the north flank dip steeply north; those of the south flank dip very gently south. The east-west-trending Casper Mountain fault cuts the north flank of the anticline throughout its length, and the entire flexure is highly fractured and faulted.

The anticlinal form of Casper Mountain is not reflected within the Precambrian core. Rather, foliation of the core strikes mainly east-northeast and dips generally steeply south. The constancy of the foliation pattern indicates that the Precambrian rocks did not flex or deform plastically during the formation of the Casper Mountain anticline in Laramide time, but must instead have yielded by fracture. The blocks and slices within the mountain accommodated uplift along more-or-less parallel faults without appreciable rotation. A similar mode of deformation is suggested by Stearns and others (1975) for uplifts of southwestern Wyoming. Some of the local divergence of the general foliation pattern may have resulted from differential movement, tilting, or minor rotation of the individual blocks or slices during uplift.

The flexure of Casper Mountain was probably formed by a maximum-principal-stress axis oriented north-south, a mean-principal-stress axis oriented east-west, and a minimum-principal-stress axis oriented vertically.

TABLE 12.—*Semiquantitative spectrographic analyses for mafic-ultramafic rocks, Casper Mountain, Wyo.*

[Analysts: C-51, CA-2, CA-3, N. M. Conklin; all others by J. L. Harris. ---, not found; H, occurrence of unresolved interference; <, less than; >, greater than]

	Ultramafic rocks (Au)		Amphibolite (Aam)	Serpentinite (Asp)			Amphibolite layer in chromite schist (Aam)	Chromite-rich schist (in Acs)	Interlayered fuchite schist and quartzite (in Aq)
Field No.-	[1]C-213	[2]C79A	[3]C-51	[4]C-70	[5]CA-2	[6]CA-3	[7]C-86	[8]C-92	[9]C-105A
Lab No.---	W212744	W212739	D225940	W212738	D253288	D253288	W212740	W212741	W212748
B--------	25	10	---	18	30	---	---	---	13
Ba--------	---	8	30	---	7	7	---	4	150
Co--------	75	75	70	81	70	150	55	190	---
Cr--------	810	2,700	1,500	3,000	2,000	2,000	1,800	6,800	110
Cu--------	4	12	70	3	---	7	7	84	4
Ga--------	---	3	10	---	---	---	7	53	4
La--------	---	---	---	---	---	---	---	---	15
Nb--------	---	5	---	---	---	---	5	10	5
Ni--------	2,800	880	300	2,500	1,500	1,500	400	1,200	2
Pb--------	---	---	---	---	---	---	---	12	9
Sc--------	---	18	70	---	---	---	9	4	2
Sn--------	---	3	---	---	---	---	---	H	---
Sr--------	---	---	15	---	---	---	---	---	---
V---------	8	67	150	29	---	30	62	500	15
Y---------	---	---	15	---	---	---	---	---	14
Yb--------	---	---	2	---	---	---	---	---	3
Zn--------	78	110	---	65	---	---	140	1,200	---
Zr--------	---	10	20	---	---	---	6	36	200

[1]Hogadon ski area, NE1/4 sec. 18, T. 32 N., R. 79 W.
[2]South edge of map area NW1/4 sec. 20, T. 32 N., R. 79 W.
[3]Ridge east of Wolf Creek, NW1/4 sec. 18, T. 32 N., R. 79 W.
[4]Camp Sacajawea area, NW1/4 sec. 20, T. 32 N., R. 79 W.
[5]East of Garden Creek, on ridge NE1/4 sec. 17, T. 32 N., R. 79 W.
[6]Small lens intersects road on dividing line between NE and SE sections of sec. 7, T. 32 N., R. 79 W.
[7]West of Casper Lions camp, SW1/4 sec. 16, T. 32 N., R.79 W.
[8]West of Camp Wyoba, NE1/4 sec. 20, T. 32 N., R. 79 W.
[9]West of Casper Mountain drive, NW1/4 sec. 16, T. 32 N., R. 79 W.

FAULTS

High-angle reverse faults.—The long and prominent Casper Mountain fault extends along the entire north flank of the mountain. Its trace is marked by much hematite staining, by fault breccia, and by slope change from pediment to steep mountain slope. The remarkable straightness of the general trace of the fault indicates that the fault dips steeply. Locally, however, the trace is irregular, suggesting that the dip may be more moderate. The south dip of the fault is demonstrated by a petroleum exploration well, Government-Donley Well No. 1, spudded in Precambrian rock in SW¼NW¼, sec. 7, T. 32 N., R. 78 W., approximately 100 m south of the interpreted trace of the fault. Sedimentary strata were encountered beneath Precambrian rocks at a depth of about 175 m; the fault dip, as calculated, is 50° to the south.

The above data suggest the main mass of the mountain was thrust up and to the north along the Casper Mountain fault against the Mesozoic strata of the Powder River Basin and the Casper Arch. This thrusting is similar to that of the north end of the main part of the Laramie Mountains that lies southeast of Casper Mountain (Gries, 1981). The thrusting along the Casper Mountain fault suggests a southward-plunging maximum-principal-stress axis, σ_1; an east-west, horizontal mean-principal-stress axis, σ_2; and a north-plunging minimum-principal-stress axis, σ_3. Most of the previously discussed Precambrian high-angle reverse faults, and some of the longest faults on Casper Mountain, cut and displace the overlying sedimentary

TABLE 13.—*Sedimentary rocks cropping out at Casper Mountain, Natrona County, Wyo.*

[>, greater than]

System or series	Formation	Thickness of Casper Mountain exposure	Characteristics of unit at Casper Mountain	Location of relevant formation description (source of description)
Upper Cretaceous	Cody Shale	>1,000 m	A soft bentonitic shale containing calcareous concretions, very minor lenticular, dark-gray sandstone and numerous thin bentonite layers.	Shoshone River, Cody, Wyo. (Lupton, 1916).
	Frontier Formation	270 m	Dark, bentonitic, carbonaceous shale, silty sandstone, sideritic nodular layers and zones, and minor siltstone and thin bentonite layers. The upper part of the formation contains flaggy to massive, ridge-forming, fine- to medium-grained sandstone. The Frontier appears to interfinger with Cody Shale.	Near Frontier, Wyo. (Knight, 1902).
Lower Cretaceous	Mowry Shale	50 m	A distinctive siliceous shale that weathers a bright and reflective silvery color. Fish scales common in some zones. Several bentonite beds occur within the unit. A 1-m-thick Clay Spur Bentonite Bed is present at the top of the Mowry Shale.	Mowry Creek, northwest of Buffalo, Wyo. (Darton, 1904).
	Thermopolis Shale	70 m	Characterized by dark-colored shale, interbedded thin sandstone and siltstone, some bentonite layers, and some minor, discontinuous calcareous layers. The Muddy Sandstone Member occurs near the top of the formation and varies in thickness from less than 1 m to several meters.	Thermopolis, Wyo. (Lupton, 1916).
	Cloverly Formation	25–35 m	Three recognizable units occur in the general area of Casper Mountain, where the formation conformably overlies siltstone of the Morrison Formation. The upper unit consists of thin-bedded, fine- to medium-grained, tan and white lenticular sandstone and some interbedded shale. The upper unit, which is generally about 5 m thick, has been correlated with the Fall River Sandstone (Hooper, 1962). The middle unit contains carbonaceous and variegated red, purple, green, brown, and gray shale and interbedded silty sandstone and is about 10 m thick; it resembles the Fuson Shale in the Black Hills first described by Darton (1901). The basal massive, crossbedded, conglomeratic sandstone that averages 10 m thick is correlated with the Lakota Sandstone in the Black Hills (Darton, 1899).	East side of Big Horn Basin, Wyo. (Darton, 1904).
Upper Jurassic	Morrison Formation	60 m	The upper one-third is dark-brown carbonaceous shale and siltstone. The lower two-thirds of the unit consists of variegated green, purple, and gray mudstone, siltstone, sandstone, and limestone. At Casper Mountain the Morrison Formation conformably overlies the Sundance Formation.	First described by Cross (1894) and shown on his map of the Pikes Peak area, Colorado, but was named by Emmons and others (1896).
Upper and Middle Jurassic	Sundance Formation	70 m	Distinct units of green to yellow-white or red-brown sandstone and gray-green to medium-gray fossiliferous and argillaceous siltstone and thin limey layers and nodules.	South-central Wyoming (Pipiringos, 1968).

System or series	Formation	Thickness of Casper Mountain exposure	Characteristics of unit at Casper Mountain	Location of relevant formation description (source of description)
Upper Triassic	Jelm Formation	20 m	Sequence of interbedded brick-red, reddish-brown, or white siltstone, claystone, and sandstone.	South-central Wyoming; described by Knight (1917) and defined by Pipiringos (1968).
Triassic	Alcova Limestone	7 m	A gray algal and thin-bedded limestone; forms ridges.	Alcova, Wyo. (Lee, 1927).
Lower Triassic	Red Peak Formation	220 m	Interbedded red-brown sandstone, siltstone, and silty claystone.	East of Red Creek in the southern margin of the Absaroka Range (Love, 1939). Raised to formation status by High and Picard (1967). Chugwater Group of Triassic age includes Red Peak Formation, the Alcova Limestone, and the Jelm Formation.
Lower Triassic to Lower Permian	Goose Egg Formation[1]	120 m	A sequence of redbeds (shale and siltstone) interlayered with thin limestone, dolomite, gypsum, and anhydrite. The Goose Egg unconformably overlies the Casper Formation and conformably underlies the Chugwater Group (Oriel and Craig, 1960).	Goose Egg Post Office, Wyo. (Burk and Thomas, 1956).
Lower Permian to Middle Pennsylvanian	Casper Formation	100 m	Dolomitic and calcareous, crossbedded sandstone. On Casper Mountain, fusulinids identified as *Triticites kelleyensis* occur near the base of the unit; higher in the unit are fusulinids identified as *Triticites planus* and *Triticites nebraskensis* (R. F. Nanna, unpub. research, 1979).	Originally described by Darton (1908); included all sedimentary rocks of Carboniferous age cropping out on the west flank of the Laramie Mountains.
Upper and Lower Mississippian	Madison Limestone	100 m	A sequence of thin-bedded, pink, purple, and gray dolomitic limestone and dolomite unconformably overlying the basal clastic Flathead(?) Sandstone. The lowermost dolomite is overlain by thin beds of sandstone and sandy dolomite. A resistant, thick-bedded dolomite forms a prominent ridge in the middle part of the formation. Near the upper contact, a well-developed karst zone is marked by solution or collapse breccia in a red sand and silt matrix. Brachiopods and pelecypods are common in the upper 15 m of the formation.	"Madison Limestone" first applied to a 456-m-thick section of limestone in the central part of the Three Forks quadrangle, Montana (Peale, 1893).
Cambrian	Flathead(?) Sandstone	20–100 m	The basal Flathead(?) Sandstone, exposed on the northern slope of Casper Mountain, unconformably overlies weathered Precambrian rocks. The basal 7–15 cm is a very coarse arkosic conglomerate containing quartz and feldspar pebbles. Overlying the conglomerate is light-brown, well-sorted and crossbedded, medium- to coarse-grained sandstone. The unit becomed more massive and friable higher in the section, where it is interlayered with reddish-brown sandstone.	"Flathead quartzite" first applied to a 46-m-thick section of quartzite and sandstone exposed at Flathead Pass, northern part of the Bridger Range, Montana (Peale, 1893); also reported in northwestern Wyoming (Balster, 1971). In both areas Flathead overlies the Precambrian. In a new interpretation, Sando and Sandberg (in press) call this basal sandstone the "Fremont Canyon Sandstone," a name they apply to outcrops in the canyon 9.9 km south of Alcova on Wyoming State Highway 220. They have assigned a Late Devonian age to the sandstone without fossil evidence.

[1]Goose Egg Formation does not crop out in map area of Casper Mountain.

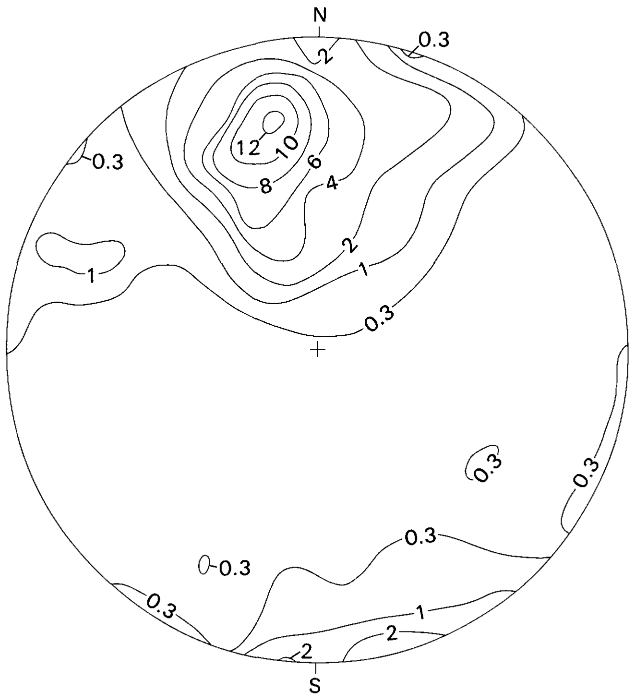


FIGURE 16.—Synoptic equal-area, lower-hemisphere projection of 346 poles to foliations for all Casper Mountain Precambrian rocks. Contours, 12, 10, 8, 6, 4, 2, 1, and 0.3 percent per 1 percent of area.

rocks and also the Casper Mountain fault, indicating minor reactivation in Laramide time.

High-angle normal faults.—Some north-dipping high-angle faults occur near south-dipping high-angle reverse faults in the north half of the mountain and appear to be antithetic in nature, related to the Laramide deformation.

Strike-slip faults.—Several strike-slip faults displace the Casper Mountain fault; some are right-lateral and strike north-northwest, some are left-lateral and strike north-northeast. The orientation and traces of many are best determined by interpretation of aerial photographs. Displacements on these faults are commonly as much as 100 m.

These strike-slip faults appear to belong to a conjugate system that formed by a maximum-principal-stress axis oriented north-south, a mean-principal-stress axis oriented vertically, and a minimum-principal-stress axis oriented east-west.

Other high-angle faults.—A north-south high-angle fault cuts across the Precambrian rocks and adjacent sedimentary rocks of the north and south mountain flanks. Its displacement, although small, appears to divide the mountain into an east half and a west half that are displaced, more or less, as units. The relative displacement is left lateral. Because the fault is approximately perpendicular to the axis of the anticlinal fold of the mountain, it probably formed as an extensional fracture compatible with the north-south orientation of the maximum principal stress suggested by the fold.

Low-angle reverse faults.—One east-northeast-trending fault plane is exposed in the NE¼ sec. 9 and in the NW¼ sec. 10, T. 32 N., R. 80 W. In section 9 it dips 49° south-southeast; near the common border of sections 9 and 10, it dips 35° south-southeast. Although most of the east- and northeast-trending faults are high-angle as inferred from straight traces, some of the accessory shears may in part be of low angle.

Other low-angle reverse faults in the Precambrian core are too small to map. These trend mainly easterly and dip to the north and to the south. The low-angle faults were probably formed by a maximum principal stress oriented generally north-south, a mean principal stress oriented generally east-west, and a minimum principal stress oriented vertically.

JOINTS

Most of the prominent joint sets in the Precambrian rocks appear to be of Laramide age. They overprint older sets of Precambrian and Phanerozoic ages. Two sets are recognized as of probable Precambrian age. The orientations of 390 joints from prominent or dominant sets are shown in figure 18. Seven joint sets having maxima of more than 2 percent are labeled "A" through "G." Of these, two maxima, A and C, are exceptionally well developed, accounting for as much as 6 or 7 percent of the total. Two of the minor joint sets having maxima of less than 2 percent, represented by "h" and "i," are possibly related to one or more of the major maxima A–C.

The preferred orientation of each joint set and the interpreted conjugate joint systems appear in table 14.

The orientations of these joint sets are diagrammatically shown in the block diagrams of figure 19. Figure 19*B–D* shows sets that intersect or very nearly intersect along mutual lines; these are interpreted to be related to the same joint system. When subjected to differential stress, rocks tend to fracture along three planar orientations: two complementary shears intersect at an acute angle that is bisected by the third extension joint and the axis of maximum principal compressive stress, σ_1 (Nevin, 1949; Anderson, 1951; Billings, 1972). The axis of minimum principal compressive stress, σ_3, bisects the obtuse angle of the complementary shears. The axis of mean principal compressive stress, σ_2, completes the stress field, is perpendicular to σ_1 and σ_3, and is defined by the intersection of the

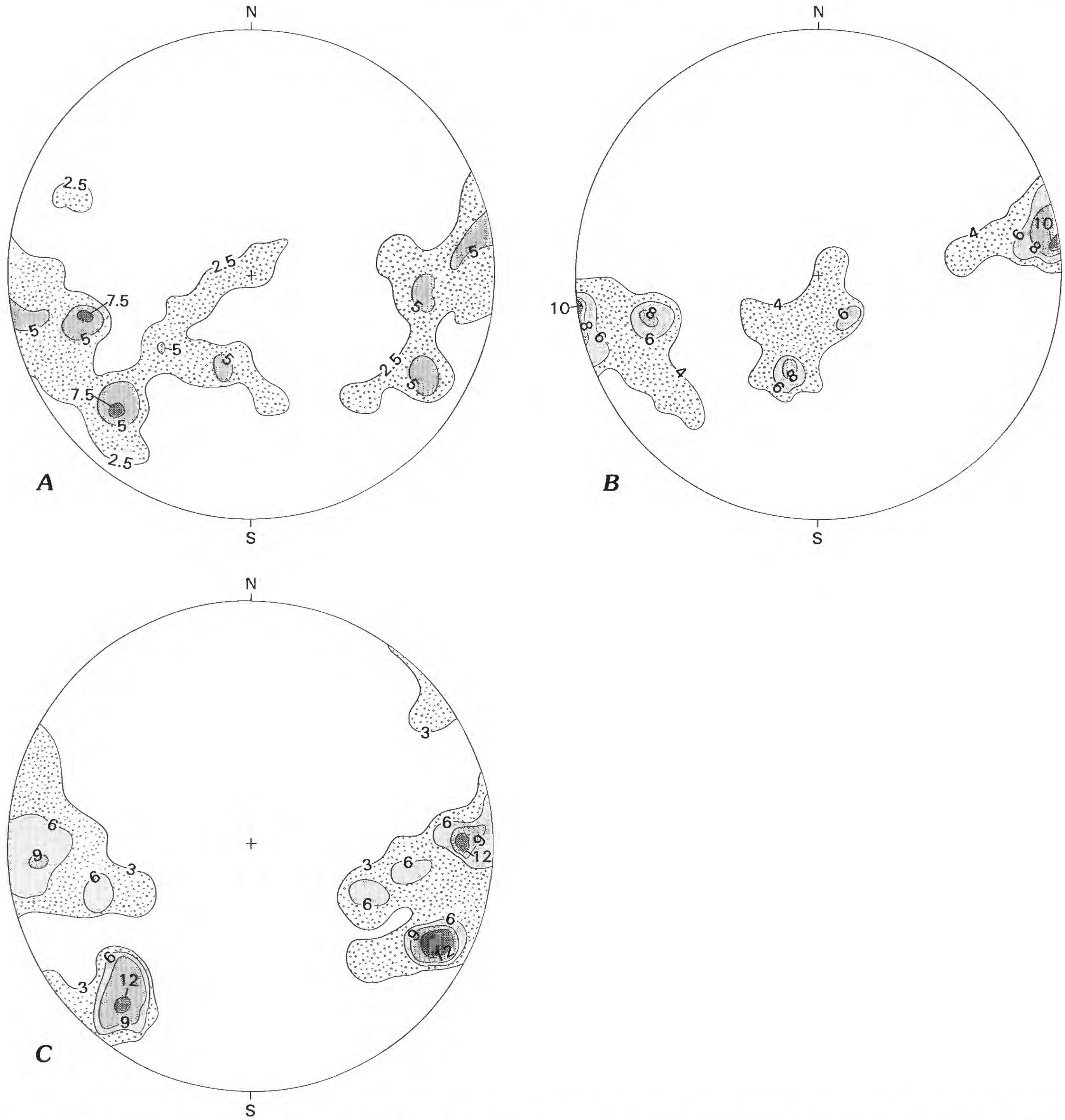


FIGURE 17.—Orientation diagrams of lineations for Casper Mountain Precambrian. Lower-hemisphere plot; equal-area net, contoured in percent points per one percent of area.

A, All lineations (85 points). *B*, Axes of crinkles and folds in metasedimentary rocks (50 points). *C*, Lineations defined by alignment of feldspar, hornblende, and biotite in granitic rocks (35 points).

two complementary shears and extension fracture. It is common for only one of the complementary shears and the extension fracture to predominate in some areas.

As shown by figure 19*B*, maxima A and B, along with the minor concentration i, form one probable system (I), in which maximum principal stress is north-south and

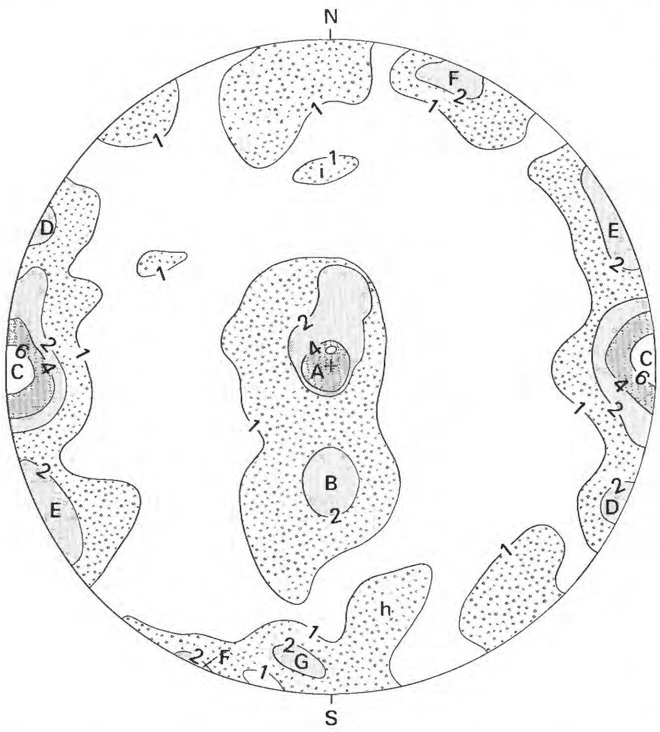


FIGURE 18.—Orientation diagram of joints in Precambrian rocks, Casper Mountain. Lower-hemisphere, equal-area projection of 390 poles to prominent or dominant joints. Contours are 6 percent, 4 percent, 2 percent, and 1 percent per 1 percent of area. Prominent or dominant sets are represented by maxima A–G. Maxima h and i represent less common orientations that may be related to maxima A and B and to F and G, respectively.

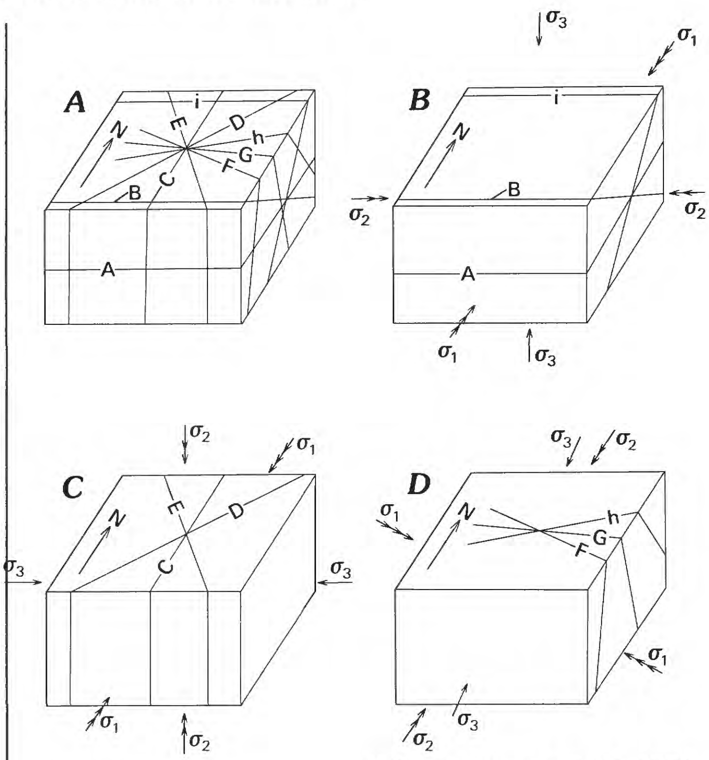


FIGURE 19.—Block diagrams of joint sets defined in Casper Mountain Precambrian rocks. Letters refer to joint sets shown in figure 18. Arrows indicate directions of principal compressive stresses $\sigma_1 - \sigma_3$. *A*, Block diagram of all joint sets represented by lettered maxima and concentrations shown in figure 18. *B*, Block diagram of interpreted joint system I showing inferred axes of principal compressive stress. σ_1 is north-south, horizontal; σ_2 is east-west, horizontal; σ_3 is vertical. *C*, Block diagram of interpreted joint system II showing inferred σ_1 as north-south, horizontal; σ_2 as vertical; σ_3 as east-west, horizontal. *D*, Block diagram of interpreted joint system III showing inferred σ_1 as plunging moderately to east; σ_2 as plunging steeply to west; σ_3 as almost horizontal.

minimum principal stress is vertical. North-directed thrusting of Casper Mountain Precambrian rocks along a south-dipping Casper Mountain thrust fault during Laramide deformation would probably have produced such a joint system.

System II, shown in figure 19*C*, is composed of vertically dipping fractures represented by maxima *C–E*. In this joint system, maximum principal stress is oriented north-south, but the minimum principal stress is oriented east-west. The strike-slip faults of Casper Mountain probably formed with this stress relation; therefore, system II is probably also of Laramide origin.

System III is not as prominent as systems I and II and bears no similar relation to the orientation of the main flexure of the mountain nor to any of the Laramide faults. As shown in figure 19*D*, the planes of maxima F and G, and the probably related minor concentration h, intersect along the west-northwest-plunging σ_2 axis. Stereographic solutions of paired plane intersections are shown in table 15. The close agreement of the intersects of the three pairings strongly suggests one origin and one stress field that resulted in one joint system. Whether this system is related to Laramide deformation or to an older brittle failure is not known. Because system III is less prominent than I and II and because of the lack of compatibility with the structural features of Laramide origin, we conclude that system III probably formed before Laramide time, probably in the Precambrian. Inasmuch as most systems form with σ_2 plunging either 0° or 90°, the approximately 50° plunge of the σ_2 axis strongly suggests rotation after deformation, the rotation further indicating pre-Laramide, and probably Precambrian, origin.

TECTONIC SYNTHESIS

Precambrian rocks on Casper Mountain were first deformed about 2.5–2.8 b.y. ago during a regional pervasive tectonic event that affected both the sedimentary

TABLE 14.—*The preferred orientations of joint sets and interpreted conjugate joint systems to which they belong*

Maxima	Value in percent per 1 percent of area	Approximate preferred orientations
	System I	
A	4-7	E.-W., 5^{o} S.
B	2-3	E.-W., 30^{o} N.
i	1-2	E.-W., 50^{o} S.
	System II	
C	4-7	N.-S., 90^{o}
D	2-3	N. 25^{o} E., 90^{o}
E	2-3	N. 28^{o} W., 90^{o}
	System III	
F	2-3	N. 67^{o} W., 86^{o} SW.
G	2-3	N. 84^{o} W., 80^{o} NE.
h	1-2	N. 76^{o} E., 65^{o} NW.

TABLE 15.—*Paired stereographic solutions of plane intersections*

Paired maxima and minor concentrations	Plunge of line of intersections (σ_2)
F, h	N. 72^{o} W., 48^{o}
F, G	N. 72^{o} W., 53^{o}
G, h	N. 77^{o} W., 46^{o}
Average =	N. 73^{o} W., 49^{o}

rocks and the syntectonic intrusive rocks. In general, many of the linear elements in the Precambrian rocks were formed by secondary flowage during plastic deformation that accompanied the regional metamorphism.

Foliation trends in the schist and gneiss of the Casper Mountain Precambrian indicate that folding occurred along east-northeast-trending axes. This folding is indicated on the map (pl. 1) by the flexure of the schist-gneiss-serpentinite complex in an area otherwise dominated by regular, steeply dipping foliation trends. Because the much less deformed Cambrian Flathead(?) Sandstone overlies the Precambrian sequence, we conclude that this folding occurred during Precambrian time. Subsequently, the Precambrian rocks were displaced mostly along major high-angle faults of east-northeast trend.

The dominant Precambrian structural grain on Casper Mountain also probably controlled or influenced the emplacement of the granitic bodies on the mountain as well as the ultramafic parent rock (now serpentinite). This structural grain, which is subparallel to the grain of other Precambrian rock masses in southeastern Wyoming, was overprinted by the Laramide deformation. On Casper Mountain, the anticlinal axis and the Casper Mountain fault of Laramide time trend east-west across this Precambrian grain. That the Precambrian structures have influenced the Laramide deformation is indicated by the reactivation or formation of many east-northeast-trending faults. Whereas some dislocation may be very recent, offsets of pediment gravels and alluvium are not apparent.

Strongly manifested, locally horizontal tectonic forces were responsible for the Laramide folding, probable thrusting, strike-slip faulting, and much of the jointing. Regionally vertical tectonic forces, attested to by the magnitude of the structural relief between Casper Mountain and the adjacent basins, were also important.

The east-west trend of the anticlinal axis of Casper Mountain indicates north-south maximum compressional stress. The two most prominent joint systems, I and II, are compatible with this stress. System I was probably directly related to the folding, but system II probably formed after the folding and probable thrusting. The strike-slip faults related to system II offset the reverse faults related to system I.

ECONOMIC GEOLOGY

Since the 1890's, prospectors have looked for mineable quantities of chrysotile asbestos, chromite, beryl, copper, gold, feldspar, and other minerals (Beckwith, 1939; Osterwald and others, 1959). Although prospecting for chromite and asbestos has been fairly extensive, the area has not shown potential for either mineral sufficient to support workings. Except for feldspar mined from one of the largest pegmatite bodies, little production has been recorded for the area (Burford and others, 1979). As a result, the economic importance of Casper Mountain lies not in its sparse mineral wealth, but in its climate as compared to Casper, its ski area, and in the forest that partly covers the mountain.

SUMMARY AND CONCLUSIONS

The exposed Precambrian (Archean and Proterozoic) igneous and Archean metasedimentary rock core of

Casper Mountain is flanked by sedimentary rocks of Cambrian(?) through Upper Cretaceous age, forming an asymmetric anticline. The geologic events that affected this area fall into the same regional pattern as that described for the Granite Mountains (Peterman and Hildreth, 1978) and the northern Laramie Mountains (Hills and Armstrong, 1974).

The Wyoming basement that is older than 3.2 b.y., consisting of mafic and granitic rocks, is not exposed on Casper Mountain, where the first event to be recorded is the deposition of sediments. Sedimentation resulted in a layered sequence of sandstone, siltstone, shale, and graywacke that were derived from a weathering foreland of probable granitic origin. This sedimentation was accompanied by eruption and emplacement of minor mafic extrusions and intrusions that included mafic dikes and sills of diabase and perhaps some gabbro. Younger granitic rocks replaced nearly all of the older sedimentary record. In the Granite Mountains area a minimum age of 3.2 b.y. was determined by R. E. Zartman and J. S. Stacey (U.S. Geological Survey, 1979, p. 190) for a series of metasedimentary rocks similar to those on Casper Mountain.

At about 2.8 b.y. a regional high-grade dynamic metamorphism (Peterman and Hildreth, 1978) transformed the sedimentary pile into metasedimentary quartzite and foliated schist and gneiss. The mafic-ultramafic igneous rocks in the sedimentary pile were transformed into amphibolite or schistose amphibolite and epidosite. This regional metamorphism was accompanied by the emplacement of new and larger mafic-ultramafic bodies and associated lenses in the central part of the mountain. Cummingtonite, ferrogedrite, and anthophyllite formed in appropriate mafic and ultramafic rocks during the waning stages of this high-grade metamorphism. Granite emplacement took place at about 2.6 b.y. (Peterman and Hildreth, 1978; Johnson and Hills, 1976). Granite gneiss and pegmatite, dated at 2.56 b.y. (Hills and others, 1968), formed closely following emplacement of the granite intrusions. Diabase dikes, associated with this intrusive event, yield ages of 2.5 b.y. (Johnson and Hills, 1976) and 2.6 b.y. (Stuckless and others, 1977). Late mafic-ultramafic magma in the form of lenses and pods and irregular masses intruded the granite, granite gneiss, and serpentinite; these are now recognized mostly as hornblende diorite and hornblendite. The youngest leucocratic intrusive rocks (not dated in the Casper Mountain area) are rhyolitic dikes that intrude hornblendite, gneissic granite, and granite gneiss and pegmatite. The rhyolitic dikes not only caused the breccia in hornblendite but intruded along faults west of Wolf Creek. At approximately 1.7 b.y. a thermal event (Hills and Armstrong, 1974) brought about a regional retrograde metamorphism of greenschist facies. In the Casper Mountain area this retrograde metamorphism is recognized only by the generation of retrograde minerals. The youngest and least altered diabase intrusions entered the area following the retrograde metamorphism. Some dikes intruded along Precambrian east-northeast-trending faults and fractures. Similar mafic dikes as young as 700 m.y. (Condie and others, 1969) occur in central and western Wyoming.

The multiple injections of mafic-ultramafic magma into the Casper Mountain area over an extended period of time indicates the area was open to emplacement of what is believed to be magma derived from the mantle. Deep subcrustal thrusting along fractures or zones of weakness extending along the northern Laramie Mountains may have provided the access the magma needed to penetrate the area. This supposition is supported by textural patterns in olivine (Augustithis, 1979, p. 37) in the Casper Mountain serpentinized peridotite. This early fracturing may have been the forerunner to the larger Proterozoic fracturing and uplift postulated by Peterman and Hildreth (1978). They suggest this event occurred along a major discontinuity extending from the southeastern tip of the Wind River uplift across Wyoming through the Granite Mountains and across the northern Laramie Mountains. According to Peterman and Hildreth, Casper Mountain and the northern fringe of the Laramie Mountains are now part of a stable block north of the uplift. The Archean of Casper Mountain and the northern Laramie Mountains is 3.0–3.2 b.y. old (Johnson and Hills, 1976), whereas just south of this major discontinuity in the Laramie Mountains, rocks yield increasingly younger ages, decreasing southward to 1.6–1.4 b.y.

The structural grain of the area is attributed to the pervasive regional high-grade plastic deformation during the Precambrian. This Precambrian structural grain is mostly defined by foliations, lineations, faults, some jointing, and minor folds. It runs approximately east-northeast. Superimposed on this Precambrian fabric is a very strong east-northeast to east-west Laramide structural pattern that has reoriented much of the Precambrian regional structural pattern of Casper Mountain and surrounding areas. Both horizontal and vertical tectonic forces related to Laramide deformation are important in determining the present structural pattern. During Laramide time, the youngest sedimentary rocks on Casper Mountain were folded, forming an asymmetrical anticline. However, Precambrian rocks along the crest of the Casper Mountain anticline and on its least deformed limb were not refolded. It is probable they were deformed by brittle fracture. During this time of uplift and downwarp, regional thrusting caused large blocks of country to move north, Casper Mountain among them. Precambrian rocks in Casper

Mountain have been thrust northward over the younger sedimentary rocks along the Casper Mountain fault.

The amount of horizontal displacement is uncertain. Horizontal transport of several hundred meters is suggested by the stratigraphy in the area immediately north of the Casper Mountain fault. Movement on the order of 10–15 km is suggested by the structures east of Casper Mountain (Love and others, 1979). It is also possible the movement was in a north-northeasterly direction sandwiched between the Casper Mountain fault on the north and the Muddy Mountain–Deer Creek fault on the south (fig. 1).

GEOCHEMISTRY OF GROUND WATER
By Robert G. Corbett

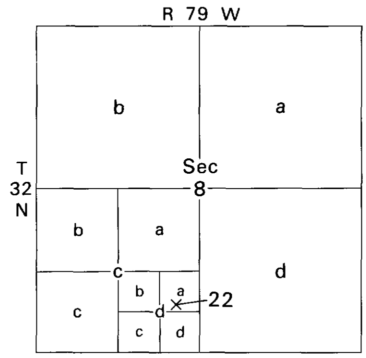
According to Crist and Lowry (1972), who provide the only information concerning the composition of ground and surface water in Natrona County, less than 10 percent of the county is underlain by igneous and metamorphic terrain, and only two water samples from such terrain were analyzed. They provide no data concerning the nature and composition of groundwater in the igneous and metamorphic terrain of Casper Mountain.

Samples from 34 wells, springs, and seeps in the immediate area of Casper Mountain were collected in the summer of 1979. The pattern of sampling was determined solely on the basis of availability. Local residents were helpful in identifying the location of many of the springs.

FIELD COLLECTION AND ANALYSIS

Seeps, springs, and wells were sampled as close to the water source as was practicable. All seeps and most springs were sampled at the point of emergence of the water. Most wells were sampled between pump and the pressure tank. Because of the probable contamination of water by pump, pipe, and tank, not all of the wells sampled are included in this report. New 1-L, collapsible polyethylene containers (cubitainers) were used to store the samples. One sample from each site was acidified with doubly distilled nitric acid to preserve the sample until laboratory analysis. A second nonacidified sample was also collected. Alkalinity and pH were determined in the field by electrometric titration to end points at pH 8.3 and pH 4.5 as soon after collection as possible. In every instance the analysis was completed within 2 hours of collection. The temperature of water at most sites was recorded.

Sample localities shown in figure 20 and in table 16 represent only springs and seeps associated with known bedrock. Codes shown in table 16 for localities follow the scheme given below; for sample 22, the code 32–79–8 cda refers to a locality in sec. 8, T. 32 N., R. 79 W. Following the convention of the Federal system of land subdivision in Wyoming, the letter "a" refers to the northeast quadrant and the remaining letters "b," "c," or "d," going in a counter-clockwise direction, indicate northwest, southwest, and southeast quadrants, respectively.



LABORATORY DETERMINATION

Cation analysis was by direct atomic-absorption spectrometric methods, using a [2]Perkin-Elmer model 460, a procedure similar or identical to methods described by Brown and others (1970) and by Skougstad and others (1979). Concentrations of chloride were determined by the Mohr titrimetric method; of sulfate by the barium-sulfate turbidimetric method, using the SulfaVer modification of the Hach Chemical Company; and of fluoride by the ion-selective electrode method, using an Orion 409 water fluoride system. Specific conductance was measured in the laboratory using a Beckman Conductivity Bridge, model RC–13C, and the result computed for 25 °C.

CHEMICAL COMPOSITION OF SEEPS AND SPRINGS

Data are grouped in table 15 by geologic source associated with the water. For purposes of this study, samples were related to geology using the preliminary map of Burford and others (1979) and of Gable and Burford (1982). The general categories for geologic source of the water are (1) granitic rocks and soils, (2) serpentinite and related rocks and soils, and (3) sedimentary

[2]Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

TABLE 16.—*Chemical and physical characteristics of seeps and springs from granitic rocks and soil derived from granitic rocks, serpentinite and soil derived from serpentinite, and sedimentary rocks*

[<, less than value shown; n.d., not determined; concentrations in mg/L]

Source	Field No.	Sample locality	Chemical composition (mg/L) Ca	Mg	Na	K	Cu	Fe	Zn	Mn	Cl	SO_4	CO_2	HCO_3	F	Specific conductance (μ hos/cm at 25°C)	pH	Temperature (Celsius)	Owner or tenant
Spring in granitic rock	6	32-79-7 baa	36	10	4.2	2.1	0.003	0.01	0.01	<0.01	1.6	12	0	155	0.12	279	7.68	6.3	Whittaker
Seep in granitic rock	7	32-80-12 aad	6.7	2.1	2.5	1.9	<.003	.77	.01	.04	3.6	2.0	0	35	.088	66	7.01	n.d.	n.d.
Spring in granitic rock	22	32-79-8 cda	4.5	2.4	2.4	0.6	<.003	.32	<.01	.01	0.03	4.0	0	36	.064	52	6.55	7.5	n.d.
Spring in granitic rock	30	32-79-20 aac	45	26	0.8	.6	<.003	<.01	<.01	.01	3.4	0	0	265	.16	379	7.70	5.0	n.d.
Spring in granitic rock	34	32-79-12 daa	56	14	.7	.5	<.003	.02	.04	.01	3.7	1	0	232	.17	333	7.74	n.d.	n.d.
Seep in granitic soil	23	32-79-8 cdc	13	4.1	3.4	0.8	<.003	.6	<.01	.17	0	4	0	66	.11	102	7.21	24.0	Calvert
Spring in serpentinite rock	17	32-79-17 bcb	11	7.8	2.0	1.3	<.003	.13	.01	<.01	11	5	0	65	.11	119	6.23	7.5	Whitcomb
Spring in serpentinite rock	25	32-79-17 aaa	24	17	1.2	.5	<.003	.03	.04	n.d.	3.6	0	0	156	.14	227	7.80	13.0	n.d.
Spring in serpentinite soil	21	32-79-18 cab	23	30	.5	.3	.004	.01	<.01	<.01	1.4	3	0	207	.15	307	8.30	15.6	n.d.
Seep in serpentinite soil	27	32-79-18 bad	36	24	1.1	.4	<.003	<.01	.01	.01	1.8	0	0	218	.14	308	7.62	7.0	n.d.
Seep in serpentinite soil	29	32-79-19 bcd	25	30	.6	.2	<.003	.01	<.01	.01	2.2	0	0	270	.14	324	7.53	9.5	n.d.
Spring in sedimentary rock[1]	1	32-78-10 dad	49	22	1.7	.7	<.003	<.01	<.01	<.01	4.4	7	0	244	.12	417	7.25	8.9	Chaput
Spring in sedimentary rock[1]	2	32-78-10 ddd	54	21	3.1	1.6	<.003	.01	<.01	<.01	7.4	32	0	238	.18	448	7.30	13.0	Mosteller
Spring in sedimentary rock[2]	3	32-78-15 dca	49	20	2.9	1.5	<.003	<.01	<.01	<.01	5.2	22	0	222	.16	408	7.50	18.2	Mosteller
Spring in sedimentary rock[1]	4	32-78-21 dcd	53	20	1.0	.4	<.003	<.01	<.01	<.01	.4	2	0	268	.12	412	7.60	9.2	Mosteller
Spring in sedimentary rock[3]	33	32-79-10 ccd	62	17	.8	.7	<.003	<.01	<.01	<.01	6.9	1	0	269	.09	387	7.65	6.0	Mills Camp

[1]From Casper Formation.
[2]From Casper and Goose Egg.
[3]From Flathead(?).

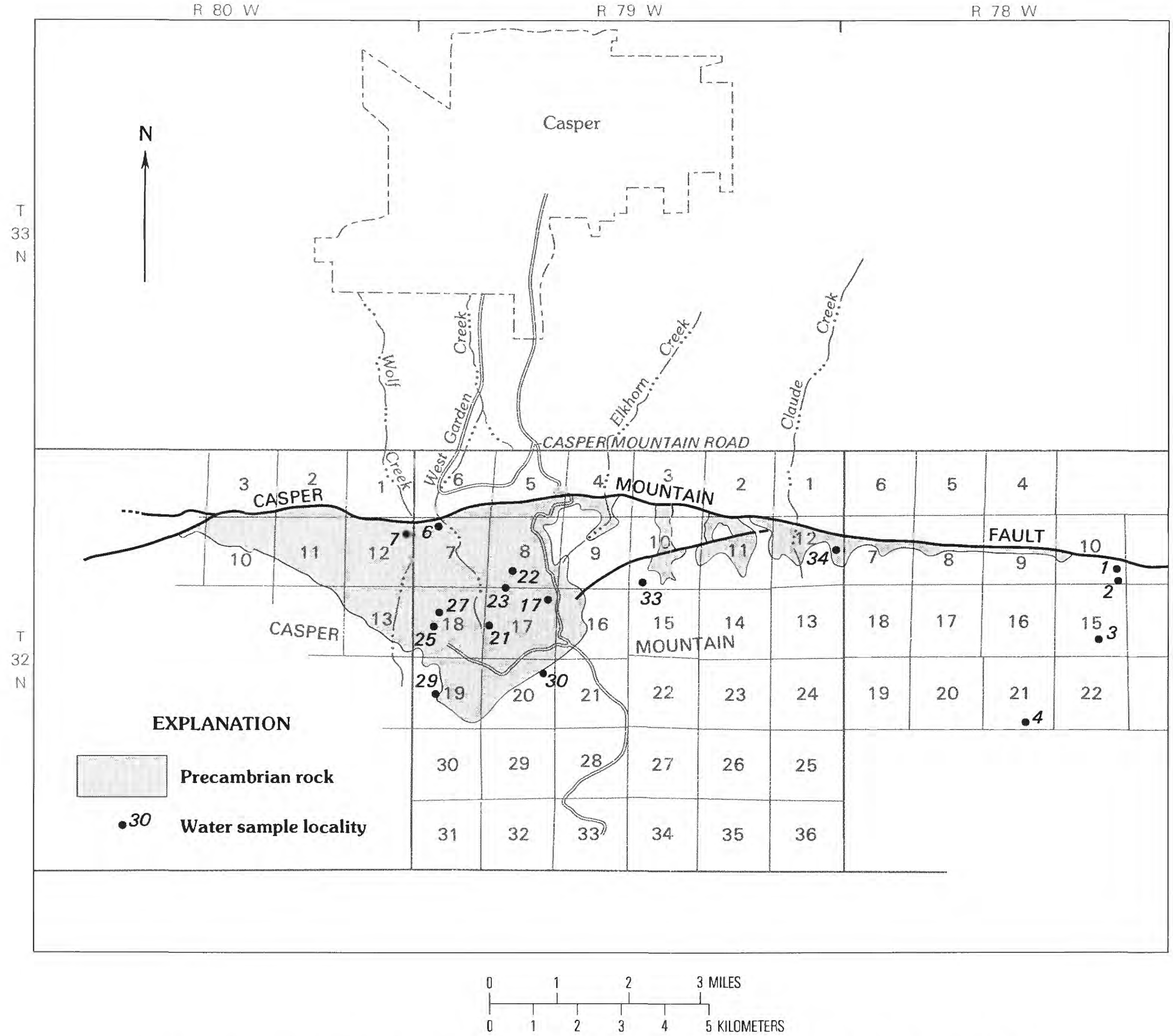


FIGURE 20.—Map showing localities of samples of seep and spring water from Casper Mountain, Wyo.

rocks; within each category, samples are ordered in table 15 according to increasing conductance. The dominant anion for all samples is bicarbonate, and the cation concentration order is either Ca>Mg>Na>K or Mg>Ca>Na>K. After conversion from mg/L, units of concentration shown in table 15, to me/L, the association between the cation concentration order Mg>Ca>Na>K and water from serpentinite and serpentinite soils appears. Equally strong is the association of the cation concentration order Ca>Mg>Na>K and water from granitic rocks and soil and from sedimentary rocks.

HARDNESS AND SPECIFIC CONDUCTANCE

A scatter diagram may be useful to establish the relationship to geologic source of water samples collected from a given area (Hem, 1959). Hardness and specific conductance for samples collected from the several geologic sources are plotted in figure 21.

Calculations of hardness are based on analytical data for calcium and magnesium. Hardness values based on equivalent $CaCO_3$, in mg/L, range from about 20 to 220 mg/L $CaCO_3$. Specific conductance ranges from about 50 to 450 μmho/cm. Four samples are soft (≤60

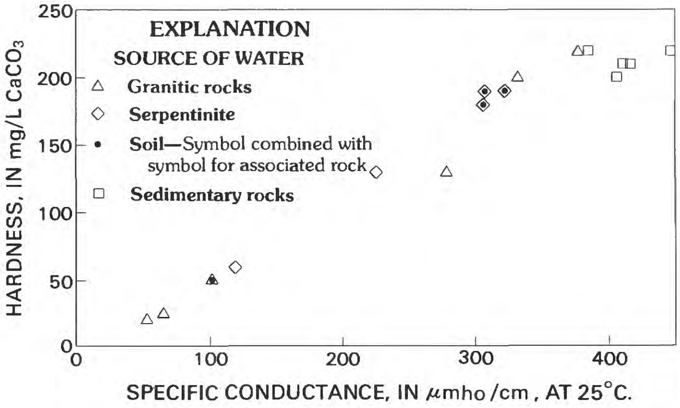


FIGURE 21.—Hardness versus specific conductance of water samples from springs and seeps from granitic rocks, serpentinite, and sedimentary rock, Casper Mountain, Wyo. Sample localities shown in figure 20; data plotted are shown below.

Sample No.	Hardness (mg/L $CaCO_3$)	Specific conductance (μmho/cm at 25° C)
Water from granitic rocks		
6	130	279
7	25	66
22	21	52
[1]23	49	102
30	220	379
34	200	333
Water from serpentinite		
17	60	119
[1]21	180	307
25	130	227
[1]27	190	308
[1]29	190	324
Water from sedimentary rocks		
1	210	417
2	220	448
3	200	408
4	210	412
33	220	387

[1]Soil.

mg/L $CaCO_3$), having a specific conductance less than or equal to 120 μmho/cm. No samples are both moderately hard (61–120 mg/L $CaCO_3$) and have specific conductance in the range of 120–220 μmho/cm. The remaining samples plot as a generally linear trend of increasing hardness and specific conductance. The break in the scatter diagram suggests a difference between the soft samples of low specific conductance and the harder samples of higher specific conductance. The former are shown to have compositions somewhat different from the majority of the samples, as discussed in the following section.

CHEMICAL COMPOSITION IN RELATION TO GEOLOGIC SOURCE

Data for samples of the hard to very hard water of high specific conductance associated with specific rock types (table 15) have been averaged and the results portrayed on a Piper (1944) diagram (fig. 22).

The average composition for water from the granitic rocks, calcium bicarbonate water, is quite similar to water from the sedimentary rocks. The composition of water from the serpentinite and related rocks and from soil associated with such rocks is magnesium bicarbonate water.

The greatest distinction for averaged water samples from each source is the ratio of calcium to magnesium. Water samples from granitic rocks, from soil associated with granitic rocks, and from sedimentary rocks have ratios of calcium to magnesium of 1.66, 1.61, and 1.92, respectively, whereas water samples from serpentinite and from soil associated with serpentinite have ratios of 0.86 and 0.6l, respectively. This relationship is consistent with mineralogy and bulk chemistry of the host rocks.

Chemical data for the major elements are presented graphically in Piper diagrams, figures 23 and 24. Samples of hard water having high specific conductance from granitic and sedimentary rocks are a calcium bicarbonate water, in which sodium and potassium compose no more than 9 percent of the cation concentration and bicarbonate no less than 82 percent; samples from serpentinite and soil associated with serpentinite are a magnesium bicarbonate water, in which sodium and potassium compose no more than 3 percent and bicarbonate no less than 96 percent.

Of two samples of soft water having low specific conductance collected from similar granitic rocks, one is a bicarbonate water that has no dominant cation and the other is a calcium bicarbonate water; the total of sodium and potassium in each sample exceeds 20 percent of the total cation concentration, and bicarbonate is not more than 82 percent. Sodium and potassium in a sample from serpentinite is 9 percent of the total cation content, and bicarbonate is only 72 percent. In these samples of soft water of low specific conductance, the absolute values of sodium and potassium and of sulfate and chloride are generally within the range exhibited by the samples of hard water of high specific conductance. This finding suggests that water chemistry is partly related to short residence time, composition of rainfall, or readily soluble components of soil and rock; given longer residence time in contact with the rock, the water would presumably become harder, would be higher in specific conductance, and would contain more calcium and (or) magnesium and bicarbonate.

These analyses demonstrate that the Precambrian terrain of Casper Mountain has a measurable and

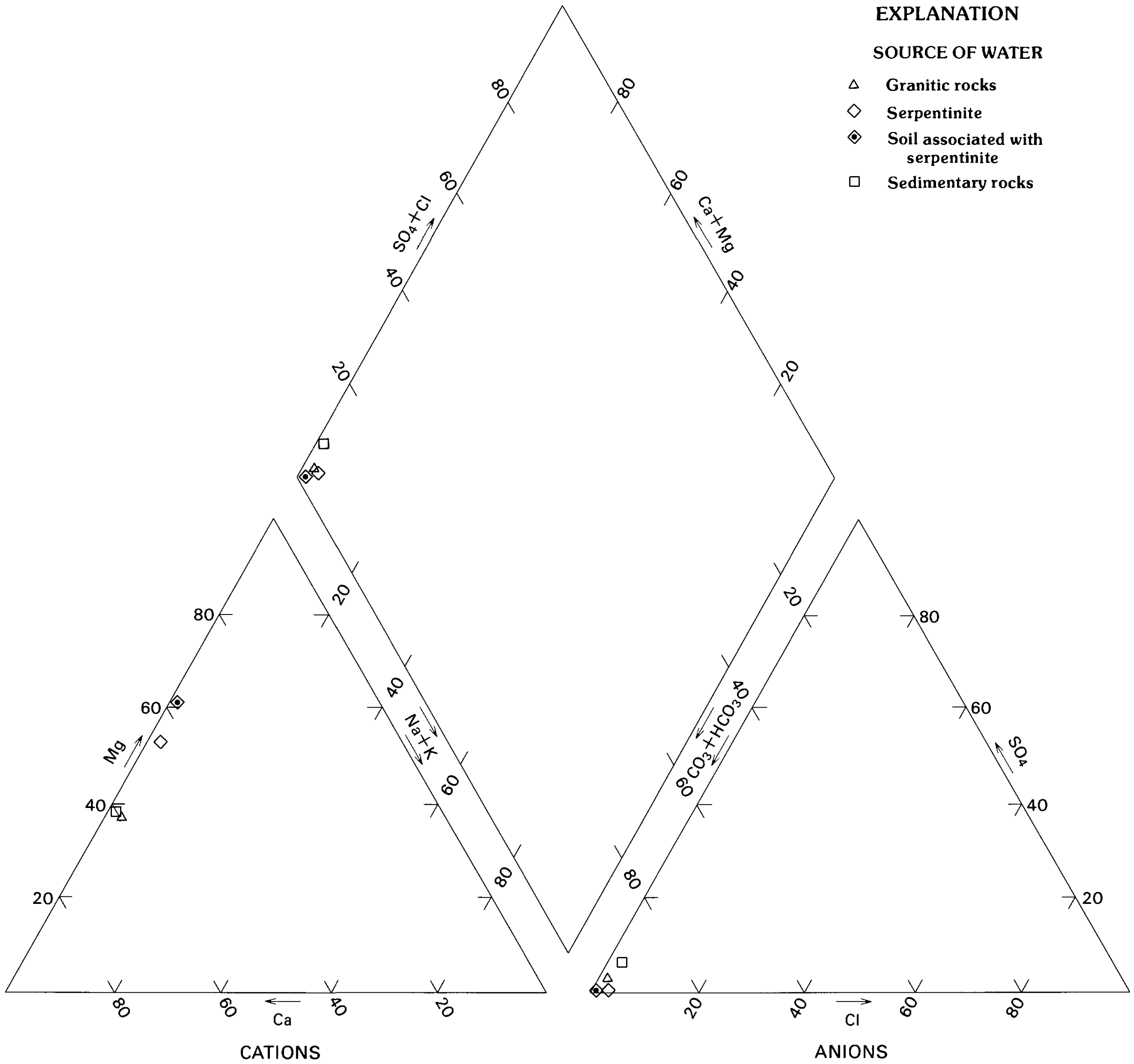
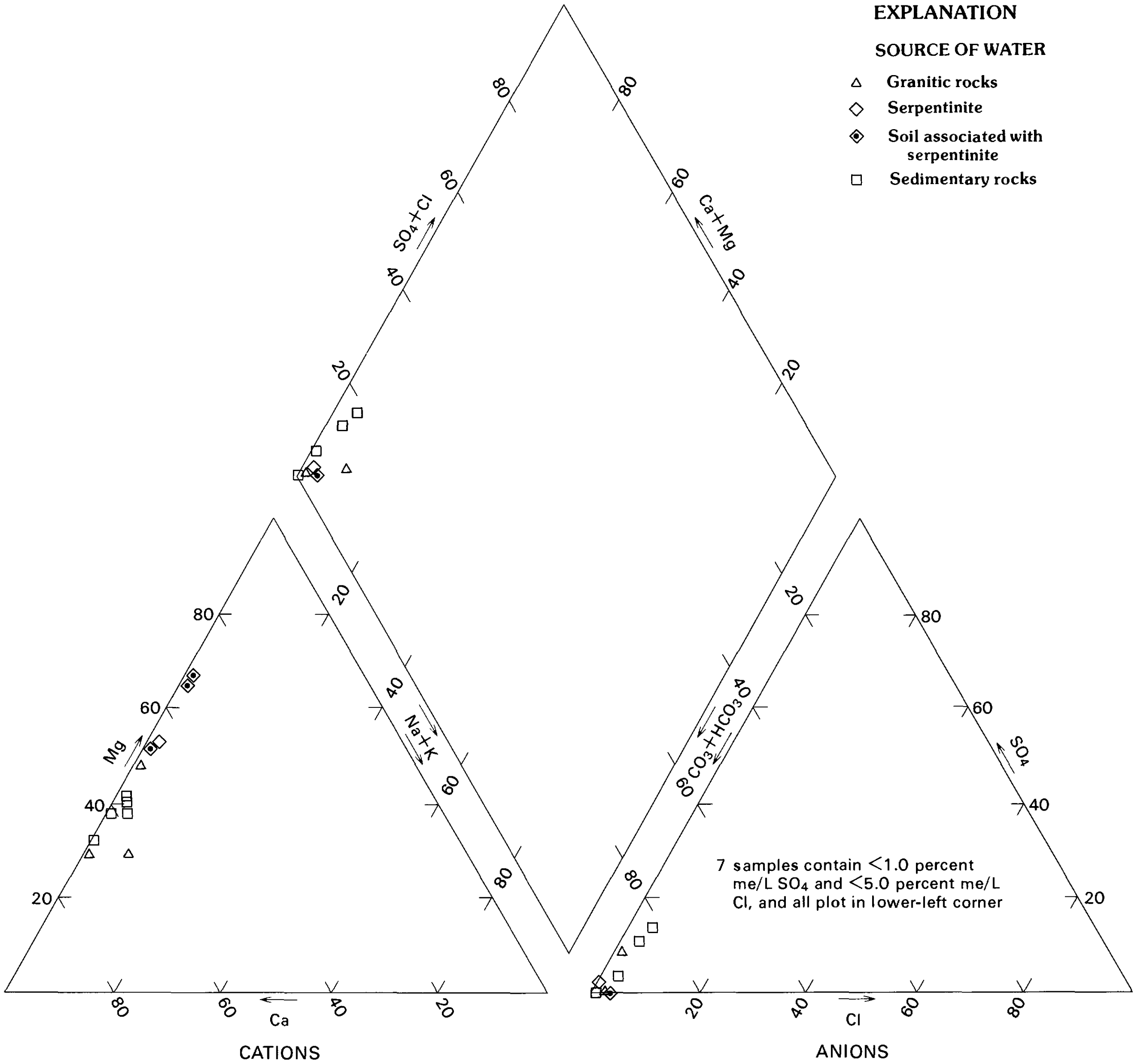


FIGURE 22.—Piper diagram showing average composition of water from granitic rocks, serpentinite, sedimentary rock, and soil associated with serpentine bedrock. Ternary diagram showing variation in cation composition (milliequivalents per liter) on lower left; ternary diagram showing variations in anion composition (milliequivalents per liter) on lower right; summary diagram (center diamond) representing overall composition of water samples. Data plotted are shown below.

Source of Water	Percent milliequivalents per liter					
	Cations			Anions		
	Ca	Mg	Na+K	Cl	SO_4	HCO_3+CO_3
Granitic rock	60.6	36.4	2.9	2.2	2.4	95.4
Serpentinite	45.0	52.6	2.4	3.8	0	96.2
Sedimentary rock	60.2	37.4	2.4	3.1	6.0	91.0
Soil associated with serpentine bedrock	37.4	61.6	1.1	1.3	0.5	98.1



consistent influence on the composition of springs and seeps. With sufficient residence time, water from granitic and sedimentary terrain becomes a hard calcium bicarbonate water, whereas water from the serpentinite terrain becomes a hard magnesium bicarbonate water.

FIGURE 23 (facing page).—Piper diagram showing composition of hard (> 120 mg/L $CaCO_3$) water of high specific conductance (>220 μmho/cm) from granitic rocks, serpentinite, sedimentary rocks, and soil associated with serpentinite. Data plotted are shown below.

Sample No.	Percent milliequivalents per liter					
	Cations			Anions		
	Ca	Mg	Na+K	Cl	SO_4	HCO_3+CO_3
			Water from granitic rocks			
6	62.9	28.8	8.2	1.6	8.8	89.6
30	50.6	48.2	1.1	2.2	0	97.8
34	70.0	28.9	1.1	2.7	0.5	96.8
			Water from serpentinite			
[1]21	31.5	67.7	0.8	1.1	1.8	97.1
25	45.0	52.6	2.4	3.8	0	96.2
[1]27	46.9	51.6	1.5	1.4	0	98.6
[1]29	33.3	65.9	.8	1.4	0	98.6
			Water from sedimentary rocks			
1	56.3	41.6	2.1	2.9	3.4	93.7
2	58.6	37.6	3.8	4.4	13.9	81.7
3	57.5	38.7	3.8	3.5	10.8	85.7
4	60.9	37.9	1.2	0.3	.9	98.8
33	68.1	30.8	1.2	4.2	.5	95.3

[1]Soil.

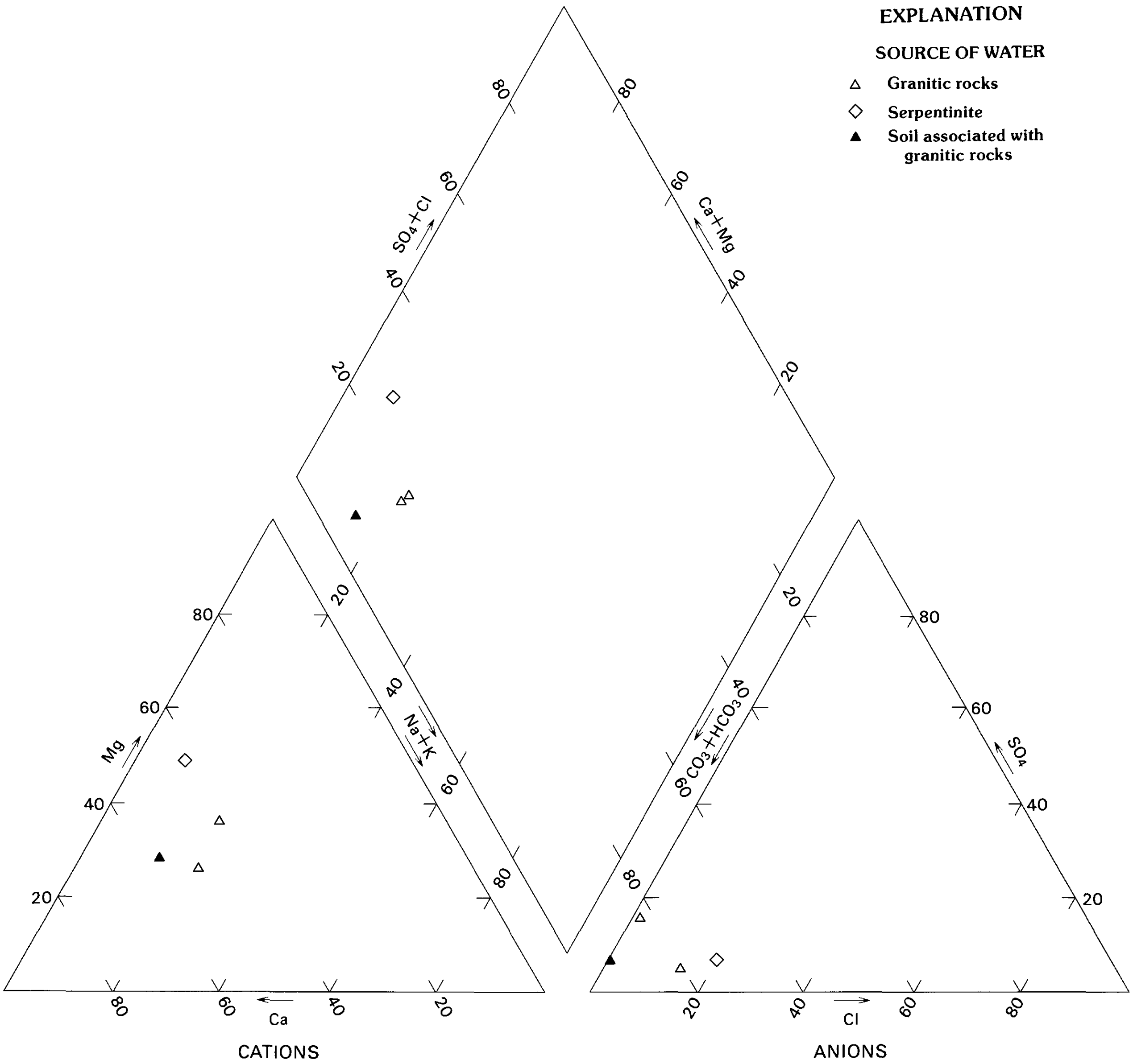


FIGURE 24.—Piper diagram showing composition of soft water of low conductance (≤1,200 μmho/cm) from granitic rocks, serpentinite, and soil associated with granitic rocks.

Sample No.	Source	Percent milliequivalents per liter					
		Cations			Anions		
		Ca	Mg	Na+K	Cl	SO_4	HCO_3+CO_3
7	Granitic rocks	50.3	26.0	23.7	14.2	5.8	80.0
22	.. do	41.5	36.4	22.1	1.6	16.1	82.3
17	Serpentinite	41.9	49.0	9.2	20.0	7.0	72.0
23	Soil	56.2	29.2	14.6	0	7.1	92.9

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