Stratigraphy and Structure of the Antler Peak Quadrangle Humboldt and Lander Counties Nevada

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By RALPH J. ROBERTS

GEOLOGY OF THE ANTLER PEAK QUADRANGLE, NEVADA

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Descriptions and regional relations of geologic units in a complex mining district

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CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

STRATIGRAPHY AND STRUCTURE OF THE ANTLER PEAK QUADRANGLE, HUMBOLDT AND LANDER COUNTIES, NEVADA

By Ralph J. Roberts

ABSTRACT

The Antler Peak quadrangle in Humboldt and Lander Counties, north-central Nevada, includes Battle Mountain and parts of the valleys of the Reese and Humboldt Rivers and of Buffalo Valley. Battle Mountain is a range 18 miles long and 12 miles wide, and has a maximum relief of 4,200 feet. The highest point is North Peak, which rises to 8,550 feet, and the second highest is Antler Peak, which rises to 8,236 feet.

Battle Mountain is mainly underlain by sedimentary and volcanic rocks that range in age from Cambrian to Tertiary. Intrusive rocks of early Tertiary age cut the pre-Tertiary rocks, forming small stocks, sills, and dikes. Quaternary detrital rocks mantle the flanks of the range and partly fill some of the valleys.

The sedimentary and volcanic rocks of Paleozoic age in north-central Nevada may be divided into four distinct assemblages: an eastern or carbonate assemblage composed mainly of limestone and dolomite; a western or siliceous and volcanic that contains minor amounts of carbonate; a transitional, composed of interbedded limestone and clastic and volcanic rocks; and an overlap of coarse clastic rocks. The first three of these assemblages were deposited in distinct belts in a broad geosyncline—the Cordilleran geosyncline which extended through Nevada. During and following Late Devonian time, these rocks were folded and cut by thrust faults of great magnitude, and the thrust plates were brought together in a most complex manner. Subsequently they were overlapped by clastic rocks of Mississippian to Permian age, which rest unconformably upon the folded and faulted rocks and are therefore called the overlap assemblage. No rocks of the carbonate assemblage are exposed in Battle Mountain, but they have been found in the Shoshone Range, 10 miles southeast of the Antler Peak quadrangle. All the other assemblages are well represented in Battle Mountain.

Two Paleozoic units, the Pumpernickel and Havallah Formations, do not belong to any of the four assemblages; they were deposited in western Nevada in a separate basin during and after the Antler orogeny. These units are partly age equivalents of the overlap assemblage, but will be described separately under the Havallah sequence.

The oldest rock unit in the siliceous and volcanic assemblage in Battle Mountain is the Scott Canyon Formation of late Early or early Middle(?) Cambrian age. It consists of 5,000 feet or more of chert, argillite, and intercalated volcanic rocks and a little limestone.

The contact of the Scott Canyon and the next younger formation of the siliceous and volcanic assemblage, the Valmy Formation of Ordovician age, is concealed beneath a thrust fault and their relation is not known; it is inferred, however, that they belong to a more or less conformable sequence. The Valmy Formation has been subdivided into three units: members one and two of Early and Middle Ordovician age consist of interbedded quartzite, chert, and shale and intercalated mafic volcanic rocks at least 5,260 feet thick; member three is Middle Ordovician in age and is composed of interbedded shale and chert with a little greenstone estimated to aggregate more than 3,000 feet in thickness.

No siliceous and volcanic assemblage rocks of Silurian or Devonian age have been recognized in the Antler Peak quadrangle, but they have been found in the northern Shoshone Range and in other ranges in north-central Nevada.

The transitional assemblage is represented in Battle Mountain by the Harmony Formation of Late Cambrian age. The Harmony is found in a thrust plate that rests on the Scott Canyon and Valmy Formations. It consists of feldspathic sandstone, arkose, grit, shale, and limy shale and limestone which aggregate at least 3,000 feet and may be considerably thicker.

The overlap assemblage in the quadrangle is represented by the Antler sequence which includes, in ascending order, the Battle Formation, Antler Peak Limestone, and the Edna Mountain Formation. The oldest unit of the Battle Formation rests unconformably upon the Valmy and Harmony Formations. The Battle is largely made up of coarse red conglomerate, and a little sandstone, limy shale, and limestone aggregating about 730 feet in thickness. It was derived from a highland area nearby, and was probably deposited in both terrestrial and marine environments.

The Antler Peak Limestone rests disconformably upon the Battle Formation. It consists of thin- to thick-bedded limestone and a few shaly layers, and has a thickness of 625 feet at the type locality. Fusulinid, coral, and brachiopod faunas in the lower beds indicate that the limestone is Late Pennsylvanian and Early Permian (Missouri to Wolfcamp) in age.

The Edna Mountain Formation, which is exposed in a few places in the quadrangle, rests disconformably upon the Antler Peak Limestone. The Edna Mountain consists of limy shale, limestone, and a little chert conglomerate. It reaches a thickness of about 200 feet, and is of Late Permian (Word or Phosphoria) age. The Edna Mountain Formation is in thrust fault contact with the block containing the Pumpernickel and Havallah Formations, and is the youngest Paleozoic unit in the area.

The Havallah sequence, which includes the Pumpernickel and Havallah Formations, was deposited in western Nevada and was brought into north-central Nevada on the upper plate of the Golconda thrust. The Pumpernickel consists of interbedded dark shale, chert, and some greenstone (altered andesite), and pyroclastic rocks aggregating at least 5,000 feet in thickness in Battle Mountain. As the base is not exposed, the total thickness is not known.

The Havallah Formation has been divided into three members: the Jory, which consists mainly of pebbly sandstone, sandstone, and conglomerate, about 1,180 feet thick; the Trenton Canyon, composed of interbedded red, green, gray, and black chert, and shale, about 1,000 feet thick; and the Mill Canyon consisting of interbedded limestone, quartzite, chert, and shale more than 2,380 feet thick. The Jory contains fusulinids of early Middle Pennsylvanian (Atoka) to Permian age; no fossils have as yet been found in the Trenton Canyon; and the Mill Canyon contains fusulinids of Permian age (Wolfcamp and Leonard). No units resting on the Havallah have been found in Battle Mountain, but 8 miles west on the west side of Buffalo Valley, the Havallah is unconformably overlain by the Koipato Formation of Permian and Early Triassic age, which is succeeded by sedimentary rocks of Triassic age.

Deposits of Quaternary alluvium in the Antler Peak quadrangle include older gravels, older and younger alluvium in the fans that flank the range and in the valleys, shoreline deposits, and flood-plain deposits in the valleys of the Reese and Humboldt Rivers.

The Paleozoic rocks in Battle Mountain have been intruded by igneous rocks at various times beginning in the early Paleozoic and continuing intermittently until late Tertiary. The oldest intrusive rocks are plugs, sills, and dikes related to mafic volcanism during Cambrian and Ordovician time. Apparently little intrusive activity took place during the late Paleozoic and Mesozoic, but during the early Tertiary quartz monzonite and granodiorite stocks, dikes, and sills were injected. Related dikes include gabbro, diorite, and quartz diorite. Aureoles of contact metamorphism around the larger intrusive bodies are as much as a mile in width, but are generally narrower. The effects of the metamorphism include recrystallization of limestone to marble, shale to hornfels, sandstone to quartzite, and chert to a rock resembling quartzite. In addition, lime-silicate minerals were formed in the calcareous rocks. Pyritization, chloritization, silicification, and argillic alteration of wallrocks was widespread.

Mafic volcanism in the eugeosynclinal basin began in Cambrian time contemporaneously with the deposition of the Scott Canyon Formation, and continued at least through the Middle Ordovician; greenstones in the Pumpernickel Formation indicate volcanism also during Pennsylvanian(?) time.

A younger period of volcanism in Battle Mountain began in the Tertiary, possibly in the Miocene, and continued intermittently until late Pliocene and early Quaternary. The earliest volcanic rocks are quartz latite welded crystal tuffs and pyroclastic rocks which were followed by olivine basalt.

The present topography of Battle Mountain is partly the result of erosion during late Tertiary time, modified by subsequent erosion during the Quaternary. The range includes remnants of an upland surface of low relief, best developed between altitudes of 7,000 and 8,000 feet and best preserved in the central part of the range. This surface was formed in late Tertiary and since then has been largely dissected, so that rugged canyons and steep ridges predominate on the periphery of the range. The range is flanked locally by narrow pediments which pass laterally into fans that extend down into the Buffalo Valley and the valleys of the Reese and Humboldt Rivers. The drainage pattern of Battle Mountain is mainly radial, modified locally by a subsequent arrangement of tributaries that have worked headward along bedding or fault zones.

The structural features of Battle Mountain and the surrounding area are most spectacular and record evidence of recurring orogeny that began in the Paleozoic and continued intermittently until the Quaternary. In all, four major orogenic periods have been distinguished: two of these took place in the Paleozoic, the first in Late Devonian to Early Pennsylvanian time, the second in the Permian, the third was in the Mesozoic, probably in Jurassic and Cretaceous time, and the fourth began in the Tertiary and extended into the Quaternary. The first three periods were characterized by folding and thrust faulting, and the fourth by block faulting, tilting, and only minor folding.

The oldest structural features in the area are folds and thrust faults that are assigned to the Antler orogeny. The Battle Formation of early Middle Pennsylvanian (Atoka) age laps over the folds and faults, thus dating the orogeny as pre-Atoka. Orogenic movements of Late Permian age, the Sonoma orogeny, are recorded in folds in the Havallah and Pumpernickel Formations. Subsequent Jurassic and Cretaceous orogenic movements resulted in folding and thrusting of Paleozoic and Mesozoic rocks in four successive pulses.

High-angle faulting occurred during all the periods of orogenic movement. Because the Paleozoic and Mesozoic high-angle faults cannot be separated in most places, they are described together. The high-angle faults formed in Tertiary and Quaternary time can be divided into four subgroups: those that contain dikes, those that contain ore deposits, those that cut the ore deposits, and last, the range-front faults that outline Battle Mountain.

INTRODUCTION

The Antler Peak quadrangle covers the area bounded by meridians 117°00′ and 117°15′ and parallels 40°30′ and 40°45′, and includes the Battle Mountain range, the low foothills on its flanks, and parts of Buffalo Valley and the valleys of the Reese and Humboldt Rivers. The northeast boundary of the range is 4 miles southwest of the town of Battle Mountain and lies in Humboldt County (fig. 1). The Battle Mountain mining district, the leader in production in this part of Nevada, covers the range and includes Copper Canyon, Copper Basin, Galena Canyon, Iron Canyon, Snow Gulch, and Elder Creek areas. The main lines of the Southern Pacific Railroad and U.S. Highway 40 pass through the town of Battle Mountain and the northeast corner of the quadrangle; the Western Pacific Railroad is 6 miles north of the north border of the quadrangle. An asphalt-surfaced road extends from Battle Mountain southwestward along the east side of the range and secondary graveled roads extend from this road into Cottonwood, Galena, and Copper Canyons. Connecting roads that are, for the

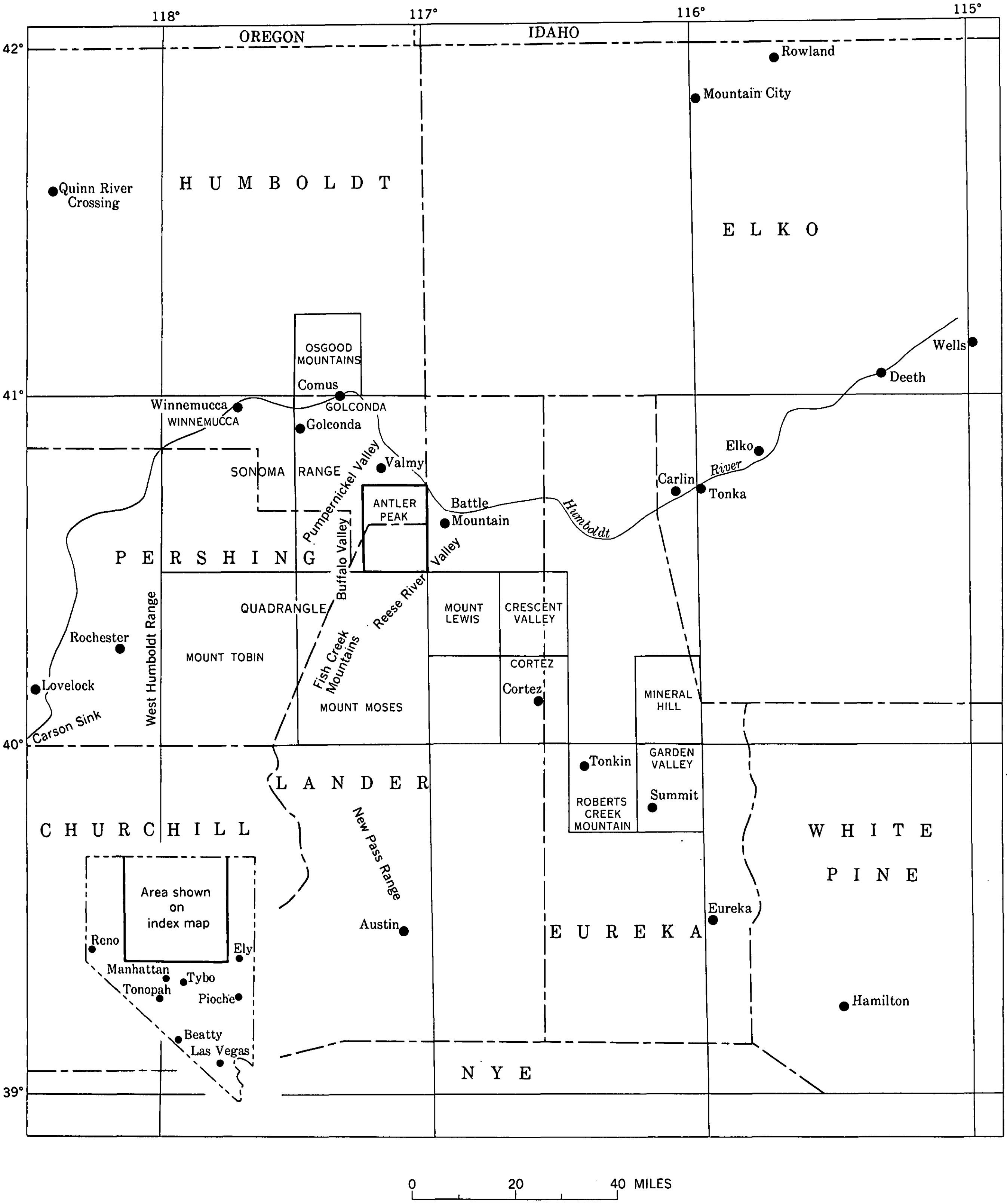
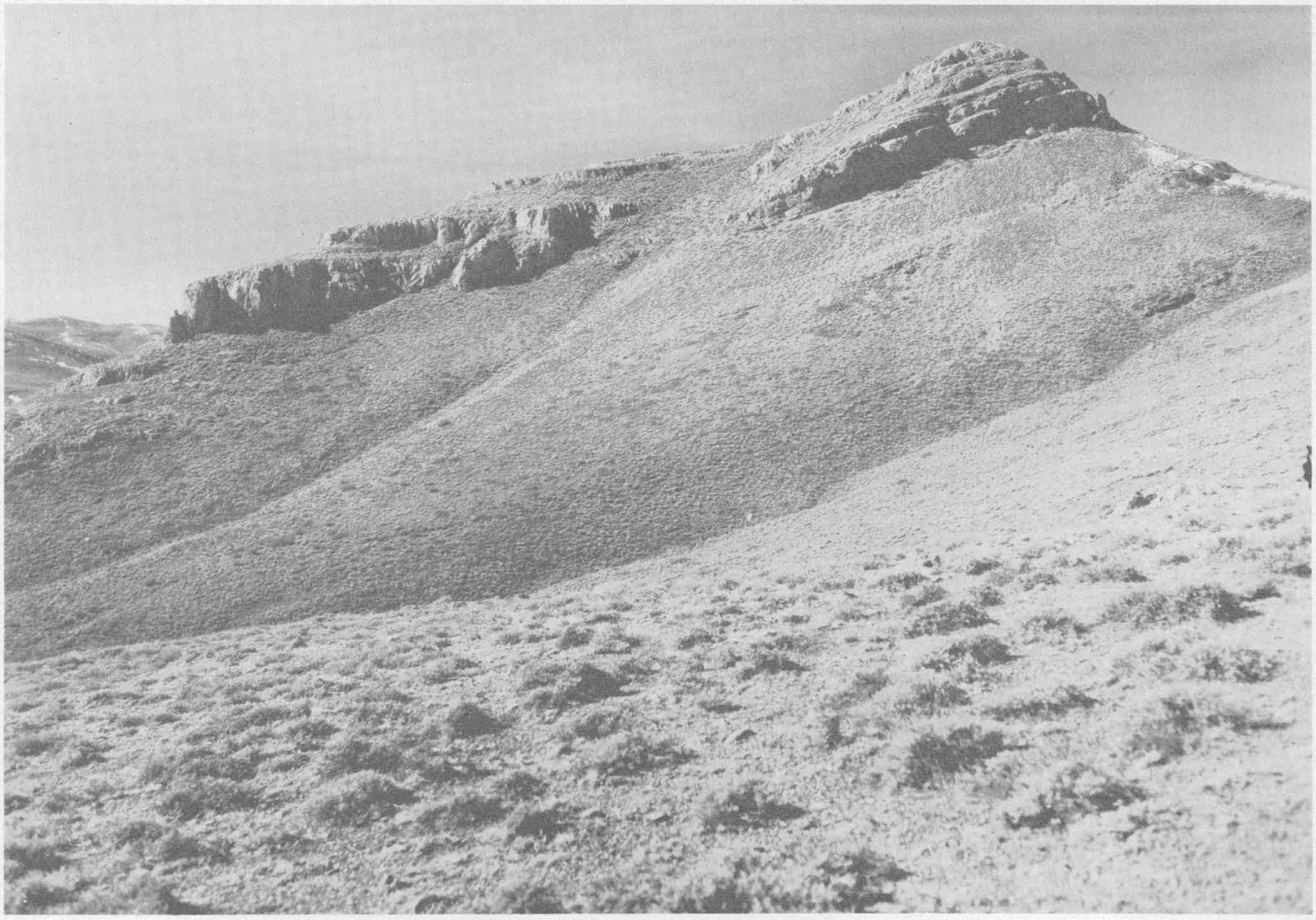


FIGURE 1.—Index map of north-central Nevada.



Antler Peak from the southeast. The base of the Antler Peak Limestone is just below the cliffs. The limestone beds on the left are separated by a fault from the sequence exposed on the peak. The smooth slopes in the middle distance and foreground are underlain by pebble and cobble conglomerates and shales of the upper part of the Battle Formation.

most part, unimproved have been built to mining properties. Only one road crosses the range; it is not shown on the topographic map but extends from the Antimony King mine westward past the Lucky Strike mine, then continues down the North Fork to the Oyarbide Ranch. The road shown on the map from Long Canyon to Cottonwood Creek no longer exists.

PHYSICAL FEATURES

Battle Mountain is one of the ranges in the north-central part of the Basin and Range province and is surrounded by alluviated valleys (Fenneman, 1931). Except for low hills in the southwestern, eastern, and southern parts of the range, the range is entirely within the boundaries of the Antler Peak quadrangle. The main axis of the range strikes northward, parallel to the general trend of the major ranges in this part of Nevada.

Viewed from the southeast, Battle Mountain is not impressive for it rises gradually from Buffalo Valley and the Reese River valley, but from the north and northeast the mountain presents a more imposing front that stands out above the Humboldt River valley. The highest peak is North Peak, rising to 8,550 feet above sea level. Antler Peak, which gives the quadrangle its name, is the next highest point, rising to 8,236 feet (see photograph above). The lowest point in the quadrangle is the valley of the Humboldt River at an altitude of 4,468 feet in the northeastern part of the quadrangle. The maximum relief is 4,082 feet, but the local relief is less; near North Peak it is 3,500 feet, but elsewhere it is generally less than 2,000 feet. The west and north slopes of the range are extremely rugged, but the south and east sides are less precipitous and slope smoothly down to the valleys.

On the north, Battle Mountain is bordered by the Humboldt River valley (fig. 1). At the town of Battle Mountain, the Humboldt River valley is 8 miles wide. The present river is obviously underfit and could not have carved its valley. The valley it follows is probably structural in origin, formed by block faulting during which the juggling of horsts and grabens deflected the river into its present zigzag course across northern Nevada.

CLIMATE AND VEGETATION

The climate in this part of Nevada is arid and the valleys normally receive only about 6 inches of rainfall annually, but the recorded range at Battle Mountain (alt., 4,513 ft.) is about 3 to 14.0 inches (Waring, 1918, p. 102–104). Most of the precipitation falls during the winter and spring months, largely as snow in the mountains and as rain and light snow in the valleys. During some years heavy rainfall has been recorded in June and September, but only local showers fall during July and August. Rainfall at higher altitudes is greater and averages about 12 inches annually at Austin (alt., 7,000 ft.), 80 miles to the south of Battle Mountain (Sager, 1941, p. 979).

The maximum temperature recorded at Battle Mountain is 112° F and the minimum −40° F. The January average is 28.4° F, and the July average is 74.7° F.

The vegetation in the range at altitudes above 5,000 feet is characterized by scattered juniper stands (*Juniperus scopulorum*), which extend as high as 7,700 feet and are best developed on the western and southwestern parts of the range. The junipers are accompanied by the characteristic sagebrush association (*Artemisia tridentata* and *Artemisia nova*), which is more luxuriant and thicker on the lower slopes and fans. On the valley bottoms the sagebrush gives way to shadscale (*Atriplex confertifolia*), which grows best on clayey, alkaline soils.

The Humboldt River flows in a meandering course in a broad flood plain 1 to 2 miles wide. Meander scrolls, cutoffs, and oxbow lakes form intricate patterns along the flood plain. The main channel is sluggish and has a gradient of about 2 feet per mile (T. W. Robinson, oral commun.); the flood plain has a gradient of about 4½ feet per mile, showing that the meanders covers more than two times the length of the valley along its axis. The river is at grade and carries a heavy load of silt in the flood season. Because of the relatively small supply of water, floods are rarely a problem in the Humboldt River valley. Low areas are commonly inundated in the spring, but no destructive floods have been recorded.

Battle Mountain is separated by the Buffalo Valley from the Tobin Range on the west and southwest, and from Buffalo Mountain on the northwest. A group of unnamed low hills connects the north ends of Battle and Buffalo Mountains. The Reese River valley on the east separates Battle Mountain from the Shoshone Range. This valley is 6 to 8 miles wide; the fans on the southeast side of Battle Mountain extend out from the range nearly to the river, whose channel cuts across the southeast corner of the quadrangle. The river flows northward in a broad arc, convex eastward, and joins the Humboldt River just north of the northeast corner of the quadrangle. South of Battle Mountain the Reese River valley opens westward into Buffalo Valley, a closed basin between Battle Mountain on the northeast, the Fish Creek Mountains on the east, and the Tobin Range on the west. The Buffalo Valley extends northward to a divide separating it from the Humboldt River valley near the northwest corner of the quadrangle.

WATER SUPPLY

The water supply of the Battle Mountain area is partly derived from surface waters and partly from ground waters. The surface water supply includes the Humboldt River, the small streams that head in Battle Mountain (fig. 34), and springs in and near the range. Because the rates of flow of all these vary seasonally, the principal water supply is gained by wells from the ground water in the valleys.

There are three major ground-water basins in the Battle Mountain area: Buffalo Valley on the west, the Reese River valley on the east, and the Humboldt River valley on the north. Little is known as to the configuration of the basins, but according to Waring (1918, p. 110), they are deeply filled with unconsolidated deposits in which ground water occurs. In the lower parts of these basins the water table is within 10 feet of the surface, and there are flowing wells at the town of Battle Mountain and at several places in the Reese River valley. Scant data indicate that the water table rises gradually toward the ranges, but at a lower gradient than the surface gradient.

Most of the wells dug in Buffalo Valley are shallow and are not heavily pumped. Mining operations in Copper Canyon and on the Copper Canyon fan require large amounts of water, and deep wells were drilled south of the canyon mouth just outside the quadrangle boundary. The collar altitudes ranged from 4,624 to 4,667 feet, and the water table ranged from 4,619 to 4,625 feet. The water-bearing units are mainly coarse gravel layers which are interbedded with silts and clays. According to Waring (1918, p. 113–114), many of the wells drilled in the Reese River valley have only small flows because the water-bearing beds are fine sands. A few have a small artesian head.

At Battle Mountain some wells yielded an artesian flow, but as water use increased through pumping, the flow from these ceased. Originally there were four horizons of flowing water at depths of 100, 180, 250, and 300 feet.

Analyses of water from wells and springs in the area show the water quality is good (table 1). It is satisfactory for domestic use and for irrigation but generally requires treatment for industrial use. In boilers the water would, in general, cause incrustation and foaming, and water from some wells would be corrosive.

TABLE 1.—*Typical analyses, in parts per million, of water from wells and springs in the Battle Mountain area*

[From G. A. Waring, 1918, p. 124-125]

Well or spring	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Carbonate radical (CO_3)	Bicarbonate radical (HCO_3)	Sulfate radical (SO_4)	Chloride (Cl)	Total dissolved solids at 180°C
1	70	Trace	40	11	35	0.0	142	45	41	340
2	65	do	30	1.0	50	.0	162	30	17	298
3	35	do	123	36	82	0	398	227	50	750
4	23	do	31	27	488	168	317	264	307	1,388

1. Land Development Co., Home Ranch, Humboldt Valley, 1 mile north of the town of Battle Mountain.
2. Farris Ranch, Humboldt Valley, 2½ miles east of the town of Battle Mountain.
3. Wilson Spring, Battle Mountain, mouth of Galena Canyon.
4. Picketts Spring, north end Fish Creek Mountains, Buffalo Valley.

PREVIOUS WORK

The first systematic geologic study of the Battle Mountain area was carried on by Hague and Emmons (1877, p. 666–672) under the direction of Clarence King. They mapped the range, grouping the Paleozoic rocks under two units, the Weber Quartzite and Upper Coal-Measure series, and also separated rhyolitic and basaltic flows. Emmons visited most of the operating mines and contributed significant information on early day mining. Hill was the next geologist to do systematic work in the area (1915, p. 64–91). In 1913 he examined most of the mines and made extensive notes on the geology of the adjacent areas. The writer has drawn on Hill's report for descriptions of several mines that were inaccessible during the time of the present study. In 1932 Frank C. Schrader visited the active mines in the district and wrote a short report on the mining activity. This report was never published, but was available to the present author and has been the source of much pertinent data. In addition, many geologists and engineers have published accounts of mining operations in the district which also have been drawn upon by the author.

FIELDWORK AND ACKNOWLEDGMENTS

The Antler Peak project was part of the Sonoma Range project, which was begun under the direction of H. G. Ferguson in 1939. Because the major producing ore deposits were in Battle Mountain, the Antler Peak quadrangle was topographically mapped at a scale of 1:62,500 to give a base map for study of the mining areas. The Antler Peak project was carried on under the supervision of Mr. Ferguson, who also participated actively in the early stages of the fieldwork. His broad experience gained from studies of the geology of central and western Nevada was of inestimable value in interpretation of the stratigraphic and structural problems encountered.

Mapping in the Antler Peak quadrangle was done in June to August 1941; September and October 1942; July to November 1946; July 1947 to March 1948; and again in 1951 and at intervals during 1952 and 1953.

For varying periods of time Claude C. Albritton, Wilfred J. Carr, Calvin C. Covell, Manning W. Cox, Arthur E. Granger, J. Frederick Maier, Paul D. Proctor, John L. Rich, Edgar A. Scholz, and Bryan Sorenson assisted in the fieldwork. David C. Arnold was associated with the project from 1952 to 1954; he was responsible for mapping the mines of the Elder Creek area, for the geochemical sampling and mapping of the metamorphic zones, and in addition he assisted the writer in geologic and underground mapping and with petrographic work in the office.

James Steele Williams, Lloyd G. Henbest, Mackenzie Gordon, Jr., and Helen Duncan of the U.S. Geological Survey visited the writer in the field, and in addition to making the determinations of the fossils collected, gave him the benefit of their knowledge of the succession of Paleozoic rocks elsewhere in the western states. Raymond Douglass, Josiah Bridge, W. H. Hass, C. W. Merriam, R. J. Ross, Jr., W. B. N. Berry, and Allison R. Palmer also made reports on fossils collected in the area. R. A. Gulbrandsen and Charles Milton assisted in mineral determinations.

The writer also owes a debt of gratitude to members of the U.S. Geological Survey who have worked in the nearby areas, and have exchanged visits and discussed problems of mutual interest. Among these are H. G. Ferguson, James Gilluly, Preston E. Hotz, S. W.

Muller, Roger S. Morrison, Donald E. White, P. E. Cloud, and S. Warren Hobbs.

Stanislaw Dzulynski of the Polish Academy of Science visited the area briefly in 1958 and made helpful suggestions concerning the origin of the siliceous and volcanic assemblage rocks.

Geologists of the Southern Pacific Land Department carried on an extensive mapping program in Battle Mountain in 1957–59 under the direction of George A. Kiersch to appraise the mineral resources. The writer has drawn on the detailed maps prepared by Frank Stejer, John T. Collier, and Robert F. Wilson for additions to the geologic map of the quadrangle.

It is a pleasure to acknowledge the cooperation and hospitality of Robert H. Raring, formerly General Manager of the Copper Canyon Mining Company. Permission was given to map the underground workings on property of the company, and all geologic data in files of the company were made available to the U.S. Geological Survey. The helpful cooperation of all the members of Mr. Raring's staff, especially Ralph Hayden, L. W. Snow, and William D. Kerns is also acknowledged.

REGIONAL SETTING

To adequately understand the significance of the geology of the Antler Peak quadrangle, it is necessary first to review the regional geology of central Nevada. The picture of this regional geology has been built up painstakingly and slowly from a great mass of complex and often fragmentary data. No one range offers a complete section of the rocks, or the solution to all the critical structural problems. It has therefore been necessary to assemble the data and then fit it into a picture that is similar to a jigsaw puzzle. Many of the pieces are still missing, but the major framework is now assembled, and the outlines of the picture are becoming clear.

From the time when geologists of the Fortieth Parallel Survey studied Paleozoic rocks in Nevada, it has been recognized that the stratigraphy and the structural history of the eastern part of the State differed strikingly from that of the western part (King, 1878, p. 247, 342). The geologists who mapped along the 40th parallel did not recognize many of the major stratigraphic and structural features in north-central Nevada, but they did record, for the first time, the major lithologic types and mapped their distribution.

Following the work of the Fortieth Parallel Survey, Turner (1909, p. 255–256) was probably the first to recognize facies changes in the Paleozoic rocks of Nevada. He pointed out that the Palmetto Formation of Ordovician age in the Silver Peak area is different in lithology from the Ordovician rocks in central Nevada. Nolan (1928) was the first, however, to call attention to the real significance of the differences; he pointed out that carbonate rocks predominate in eastern Nevada, and volcanic and clastic rocks predominate in western Nevada. Later, in a comprehensive summary of the regional geology of the Great Basin (1943, p. 141–158), he discussed in detail lithology of the Paleozoic rocks in Nevada and the structural history. Kirk (1933, p. 31) made a significant contribution when he recognized two distinct facies of Ordovician rocks in the Roberts Mountains; he noted that the two facies were separated by only a few miles and suggested that they had been brought together by thrust faulting. Merriam and Anderson (1942, p. 1701–1704) in the late 1930's confirmed Kirk's suggested explanation when they discovered and mapped the thrust between the two facies in the same area and named it the Roberts Mountains thrust fault.

Detailed mapping by personnel of the U.S. Geological Survey and others during recent years in north-central Nevada has revealed that the facies changes are regional in extent and that the facies are commonly separated by thrust faults. Clarification of the stratigraphy of this complex is the result of the work of many men. The basic data and concepts were developed by Ferguson and others and published in a series of papers dealing with central Nevada (1924, 1949, 1952). In 1939 Ferguson, Muller, and Roberts began geologic mapping in the Sonoma Range quadrangle (pl. 3). This work was published in 1951–52 as four 30-minute quadrangles, the Winnemucca, Mount Moses, Mount Tobin, and Golconda (Ferguson and others, 1951a, 1951b; Muller and others, 1951; Ferguson and others, 1952). The Antler Peak 15-minute quadrangle, in the southeast part of the Golconda quadrangle, was mapped by Roberts (1951). The Mount Lewis, Crescent Valley, and Cortez 15-minute quadrangles were mapped by James Gilluly in 1949–55 and the Osgood Mountains quadrangle by P. E. Hotz and Ronald Willden in 1951–55. Reconnaissance surveys of Elko County by Granger and others (1958), of Eureka County by R. J. Roberts and R. E. Lehner, and of Humboldt County by Willden (1961) have also contributed much pertinent data on Paleozoic stratigraphy.

The picture of the geology of north-central Nevada has been developed to the extent that the outlines of the regional stratigraphy and structure are now apparent. As mapping is continued, further clarification of details of stratigraphy and structure can be expected. In this paper the summary of the geologic history of north-central Nevada must be regarded as a progress report to be modified by further discoveries.

GENERAL CONCEPTS

CARBONATE (EASTERN) ASSEMBLAGE

In eastern Nevada, roughly east of an irregular line between meridians 116° and 117°, the Paleozoic rocks from Middle Cambrian to Late Mississippian time are composed mostly of limestone and dolomite with minor amounts of shale and quartzite (pl. 1). The stratigraphic section in the Eureka area, originally described by Hague (1892) and Walcott (1908) and recently revised by Nolan and others (1956), is the classic section of carbonate rocks for eastern Nevada. These rocks were deposited in a shallow miogeosynclinal environment (ensialic of Wells, 1949) that covered much of western Utah and eastern Nevada. In the Eureka area strata of Middle Cambrian to Late Devonian age aggregate about 14,500 feet. Of this thickness, limestone comprises about 50 percent; dolomite, 40 percent; shale, 8 percent; and quartzite, 2 percent. These proportions vary from place to place, but the general ratio of 90 percent carbonate rocks and 10 percent clastic rocks appears to hold over eastern Nevada. Locally the proportion of clastic rocks is higher. The shale units in the assemblage [1] are mostly fine-grained black shales or calcareous shales; they do not generally contain interbedded coarse clastic rocks. The quartzite units are commonly clean and are well sorted, and ones like the Eureka Quartzite have enormous areal extent (Kirk, 1933, p. 29). The limestone and dolomite units locally are shaly or sandy but are, on the whole, rather pure carbonate rock.

[1] Previously the Paleozoic facies in Nevada have been referred to as "eastern" and "western" (Merriam and Anderson, 1942, p. 1704; Nolan and others, 1956, p. 6, 23, 34; Roberts and others, 1958, p. 2816–2817). These terms served adequately in Nevada as the facies boundary extended medially north-northeastward through the State. However, as these facies extend into California on the west and south, and into Idaho on the north, these terms are no longer appropriate. Silberling and Roberts (1962, p. 5) used the term "detrital-volcanic" in place of "western" and "carbonate" in place of "eastern". Gilluly (oral commun., 1963) suggested that "siliceous" would be a more useful term than "detrital"; I would like to add the term "volcanic" and call it "siliceous and volcanic" facies. For convenience, the term could later be shortened to "siliceous" facies.

In order to deal with the large number of formational names in this region, formations that accumulated in a certain environment are grouped under the term "assemblage." Thus we have western or siliceous and volcanic (eugeosynclinal), transitional, and eastern or carbonate (miogeosynclinal) assemblages. Broadly speaking, assemblage is equivalent to facies, but it is not used here in the precise sense of facies in stratigraphic nomenclature. Subdivisions within assemblages will be referred to as "sequences" to designate rocks deposited in a certain part of a basin. For convenience, the sequences will be named after one of their component units.

The term "autochthon," which will be used frequently, refers to "a succession of beds that have been moved comparatively little from their original site of formation, although they may be intensely folded and faulted" (Howell, 1960, p. 19). The term "parautochthon" is applied to structural features that can be connected by their facies and tectonic features to the autochthon (Howell, 1960, p. 212). The term "allochthon" refers to rocks of one or more assemblages "that have been moved a long distance from their original place of deposition by some tectonic process, generally related to overthrusting or recumbent folding, or perhaps gravity sliding" (Howell, 1960, p. 7).

SILICEOUS AND VOLCANIC (WESTERN) ASSEMBLAGE

West of meridians 116°–117° in central and western Nevada, strata of early and middle Paleozoic age are predominantly clastic sedimentary rocks, chert, and intercalated volcanic rocks (pls. 1 and 2). The broad basis for our present knowledge of the lithology, extent, and thickness of the siliceous and volcanic assemblage comes mainly from the studies of Ferguson and his coworkers in the Manhattan district (1924), in the Hawthorne and Tonopah quadrangles (Ferguson and Muller, 1936, 1949), and in the Sonoma Range quadrangle (Muller and others, 1951; Ferguson and others, 1951a, 1951b, and 1952). In 1952 Ferguson (p. 73) pointed out that the siliceous and volcanic assemblage attains a great thickness in the Sonoma Range area. Subsequent studies there and in adjacent areas indicate that the pre-Mississippian rocks may aggregate more than 50,000 feet (pl. 1). These rocks were deposited in a eugeosynclinal environment (Stille, 1940, p. 40; ensimatic of Wells, 1949) far to the west of the shallow shelf seas. Few data as to the proportion of rock types are available, but it is estimated that shale makes up 20 to 40 percent of the section, sandstone and quartzite 10 to 30 percent, and chert with shale partings up to 30 percent; volcanic rocks range from a few percent to 30 percent. The units are characteristically lenticular and may thin or thicken abruptly. Limestone, generally shaly or sandy, is present locally as thin, discontinuous layers. The shale units commonly contain sandy layers and are rarely calcareous. The sandstone and quartzite are in places fairly pure, but generally they contain sufficient impurities to be classed as graywacke. The chert units range in thickness from a few inches to several hundreds of feet; individual chert layers are lenticular and range from a fraction of an inch to as much as 3 feet in thickness. The layers are separated by shaly partings which are also lenticular; laterally, the chert units grade into shaly units with subordinate chert. The volcanic rocks include flows, pillow lavas, and pyroclastic rocks that mainly accumulated in a marine environment. These units are also highly lenticular and probably formed around many source centers.

Locally, coarse clastic rocks are interbedded with siliceous and volcanic assemblage rocks. Carlisle and Nelson (1955) have mapped two units of Late Devonian age in the Sulphur Spring Range; the lower consists of limestone conglomerate, chert, black shale, and quartzite; the upper of chert conglomerate, clastic limestone, and quartzite. These appear to be of local extent and grade laterally into black-shale facies. The predominance of clastic rocks in these units indicates early orogenic activity to the west where these sedimentary rocks accumulated.

Merriam and Anderson (1942, p. 1702–1703) showed that the carbonate (eastern) and siliceous and volcanic (western) assemblages had been brought into juxtaposition in the Roberts Mountains along a thrust fault of great magnitude—the Roberts Mountains thrust fault (pl. 3). Gilluly (1954) mapped the thrust in the Cortez quadrangle in 1949, and in 1950 he recognized it in the Mount Lewis quadrangle. During the summer of 1954, Roberts and Lehner (1955) traced the thrust northward through Eureka and Elko Counties approximately along the 116° meridian and suggested that it continued into Idaho northeast of Rowland. The thrust also probably extends southward from Eureka County, but its course is conjectural. Frank J. Kleinhampl (oral commun., 1963) noted klippes of the upper plate in northern Nye County, and believes that the thrust extends southwestward towards Mina, where it is overlapped by younger thrust plates.

TRANSITIONAL ASSEMBLAGE

Generally a sharp and unequivocal distinction can be made between the carbonate and siliceous and volcanic assemblages above and below the Roberts Mountains thrust, and the two can be mapped separately without difficulty. Locally, however, a transitional assemblage is present (Hotz and Willden, 1955) that belongs to neither the carbonate nor siliceous and volcanic type but includes elements of both. These transitional rocks were originally included as part of the siliceous and volcanic assemblage because they resembled those units more closely than the carbonate. As investigations continued, additional faunal data and contrasts in lithology made it evident that rocks deposited in two different environments had been sandwiched into the same composite section. Therefore, a transitional group of rocks was separated. This transitional assemblage, shown on plate 3, is regarded as parautochthonous; it is part of the block overridden by the Roberts Mountains thrust plate which carried the siliceous and volcanic assemblage eastward. In places the Roberts Mountains thrust plate also carried slivers of transitional assemblage rocks eastward along with the siliceous and volcanic assemblage. Such slivers have been noted in the northern Shoshone Range, at Antler Peak, and in parts of Eureka and Nye Counties.

The transitional assemblage is characterized by clastic, volcanic, and carbonate elements. The proportion of carbonate rocks is generally less than 40 percent; the clastic rocks are mainly shale and sandy shale, in part calcareous. Sandstone and calcareous sandstone beds make up a part of the section, but coarser clastic units similar to those in the siliceous and volcanic assemblage are rare. Volcanic material is commonly fine-grained tuffs or tuffaceous shales. Chert and chert-shale units are less abundant than in the siliceous and volcanic assemblage. Some transitional units resemble the carbonate assemblage of rocks and others resemble the siliceous and volcanic assemblage; the boundary between the assemblages probably oscillated back and forth across central Nevada during lower and middle Paleozoic time, and local basins probably existed in which pockets of one assemblage accumulated in an environment predominantly like that of another assemblage.

The recognition of the transitional assemblage necessitates a major reinterpretation of the structure of north-central Nevada. The presence of transitional rocks in the Sonoma Range, Edna Mountain, and the Osgood Mountains has been interpreted (pl. 3) to mean that the root zone of the Roberts Mountains thrust fault lies to the west. The Adelaide thrust fault in the Sonoma Range (Ferguson and others, 1951a, 1951b), which separates siliceous and volcanic and transitional assemblages, may well be a part of the Roberts Mountains thrust fault. The width of the zone over which the siliceous and volcanic assemblage has been thrust would therefore be about 90 miles.

OVERLAP ASSEMBLAGE

The broad geosyncline in which the three assemblages were laid down persisted with only local disturbances until Late Devonian time, when orogenic movements began along a north-trending positive area (Nolan, 1928, p. 161) (fig. 2). These orogenic movements ultimately resulted in the formation of a belt of rugged highlands—the Antler orogenic belt—between the 116° and 118° meridians (Roberts, 1949a, 1949b, 1951). This belt was the locus of intense folding and faulting which culminated in the Roberts Mountains thrust fault in Early Mississippian time.

During the orogenic movements, which lasted into Early Pennsylvanian time, a broad apron of coarse clastic rocks was laid down over central and eastern Nevada (fig. 3). The full extent of the apron is not known, but sandstone and conglomerate deposited during this interval extended into southern Nye County near Beatty, as far east as Pioche and Wells, and as far north as Mountain City. Coarse clastic rocks derived from the highland were deposited in basins in western Nevada and locally accumulated in troughs within the highland. Away from the Antler orogenic belt (fig. 3, inset map) the clastic rocks grade laterally into finer sedimentary rocks that interfinger with the normal marine section; in the orogenic belt the clastic rocks and associated lenticular limestones overlap folded and faulted carbonate, transitional, and siliceous and volcanic assemblage strata that have been involved in the orogeny. The overlapping rocks constitute a distinct post-orogenic facies, which has been named the overlap assemblage by Roberts and Lehner (1955).

Following the Antler orogeny, north-central Nevada remained partly below and partly above sea level during the remainder of the Paleozoic (fig. 4). Sedi-

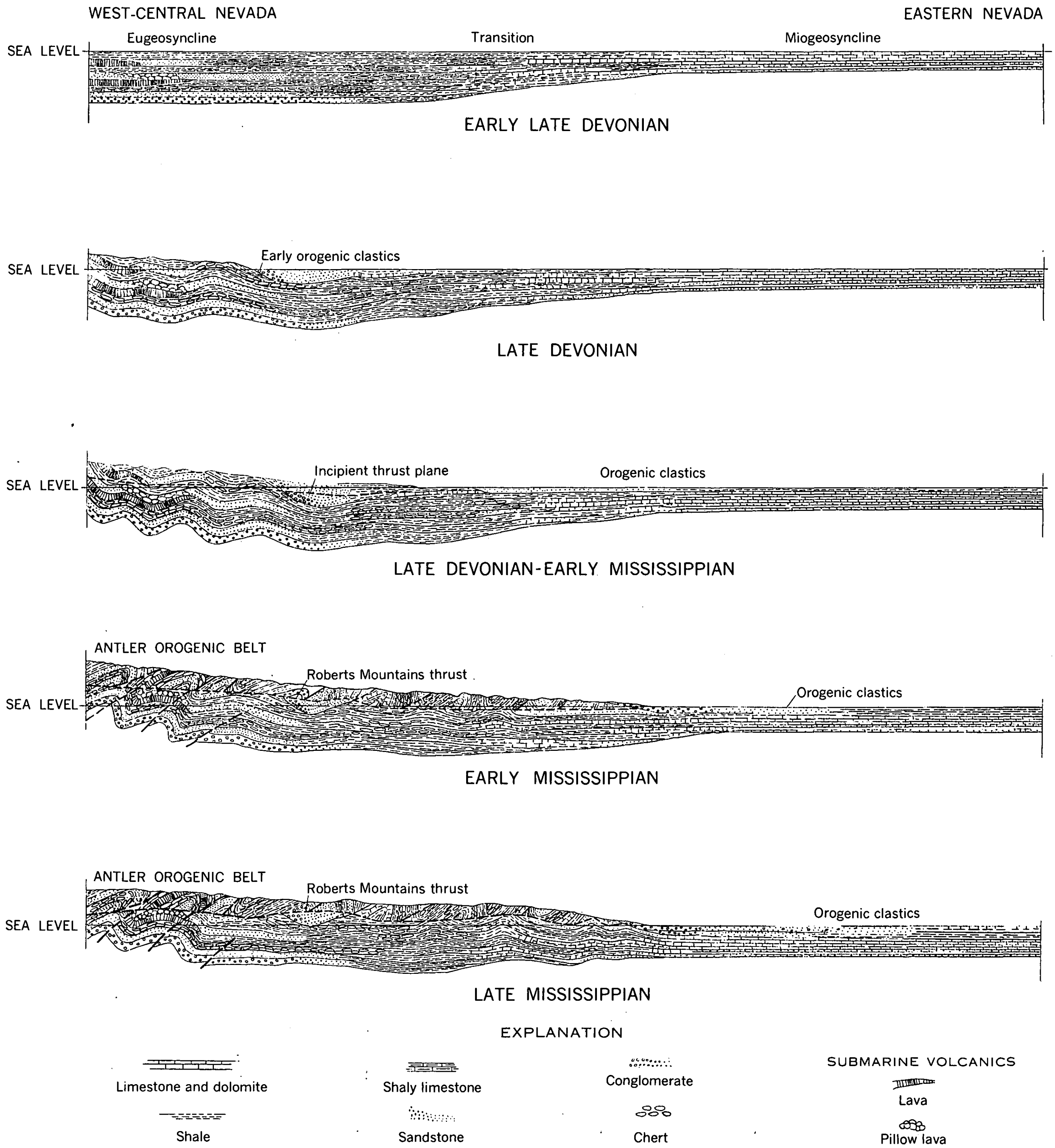


FIGURE 2.—Diagram showing inferred sequence of events during the Antler orogeny in north-central Nevada.

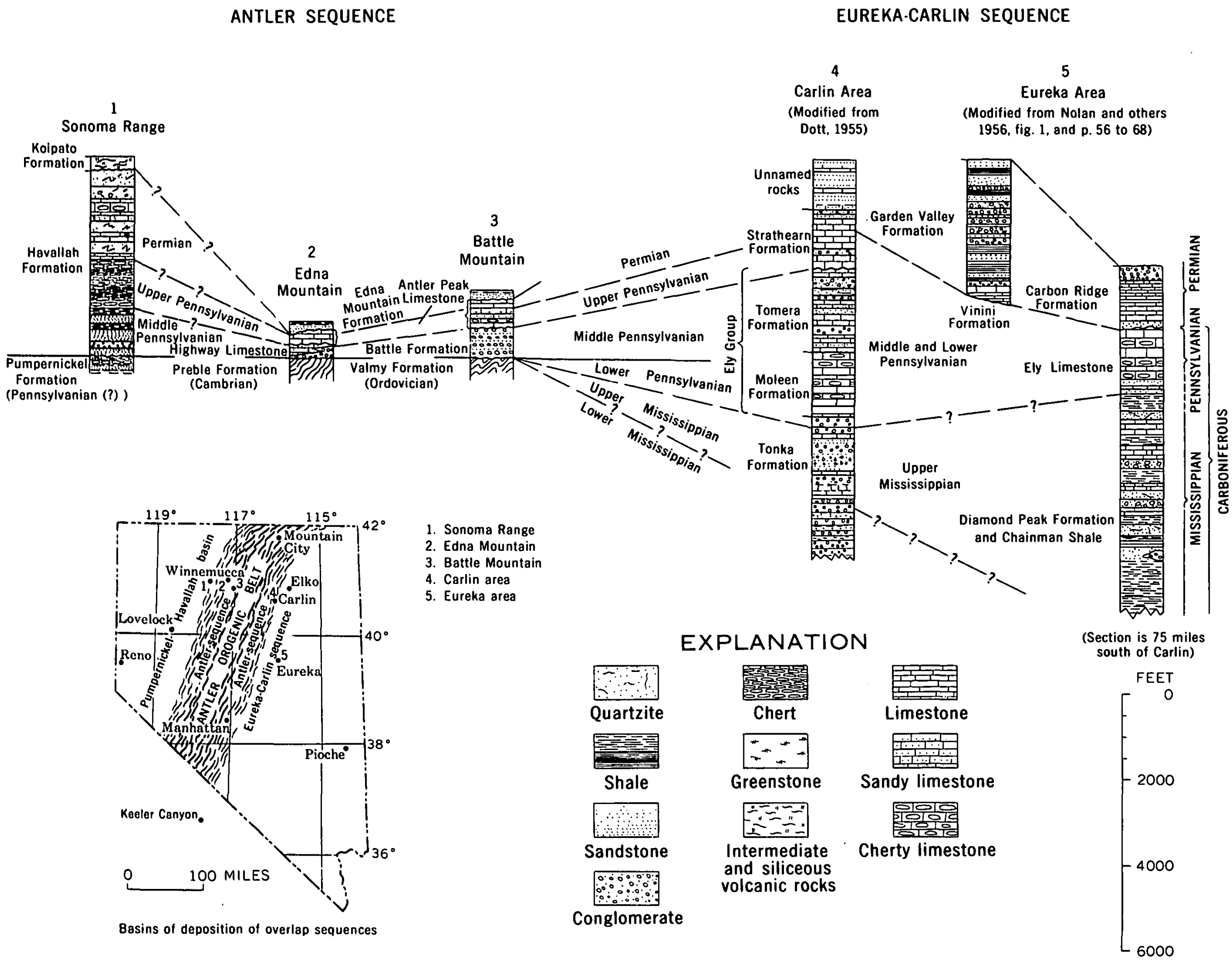


FIGURE 3.—Stratigraphic columns of the overlap assemblage, north-central Nevada.

mentation within the orogenic belt took place locally in straits and embayments, consequently the deposits are thin, lenticular, and vary abruptly in lithology along the strike.

In northwestern Nevada thick clastic and volcanic units accumulated during the late Paleozoic, mostly in a marine environment, indicating westward migration of the eugeosyncline. In latest Permian these rocks were moved eastward on the Golconda thrust and piled up on the west margin of the Antler orogenic belt.

During early Mesozoic most of north-central Nevada was probably emergent (Silberling and Roberts, 1962), but by late Early Triassic the seas again covered part of the Antler orogenic belt. Sedimentation probably continued until Late Jurassic. During the Cretaceous, deformation in the orogenic belt and in western Nevada caused local folding and thrusting (Willden, 1958, p. 2396).

GENERAL GEOLOGY

SEDIMENTARY ROCKS

The sedimentary rocks of Paleozoic age in the Antler Peak quadrangle include representatives of three of the four assemblages discussed in the preceding section on "Regional setting" (pl. 4). The transitional assemblage is represented by the Harmony Formation; the siliceous and volcanic assemblage by the Scott Canyon and Valmy Formations; and the overlap assemblage by the Antler sequence, which includes the Battle Formation, the Antler Peak Limestone, and Edna Mountain Formation. The Havallah sequence includes the Pumpernickel and Havallah Formations, which were deposited in western Nevada and were brought into this area on the Golconda thrust fault. The siliceous and volcanic and transitional assemblages are separated from each other by major thrust faults and their present juxtaposition is due to

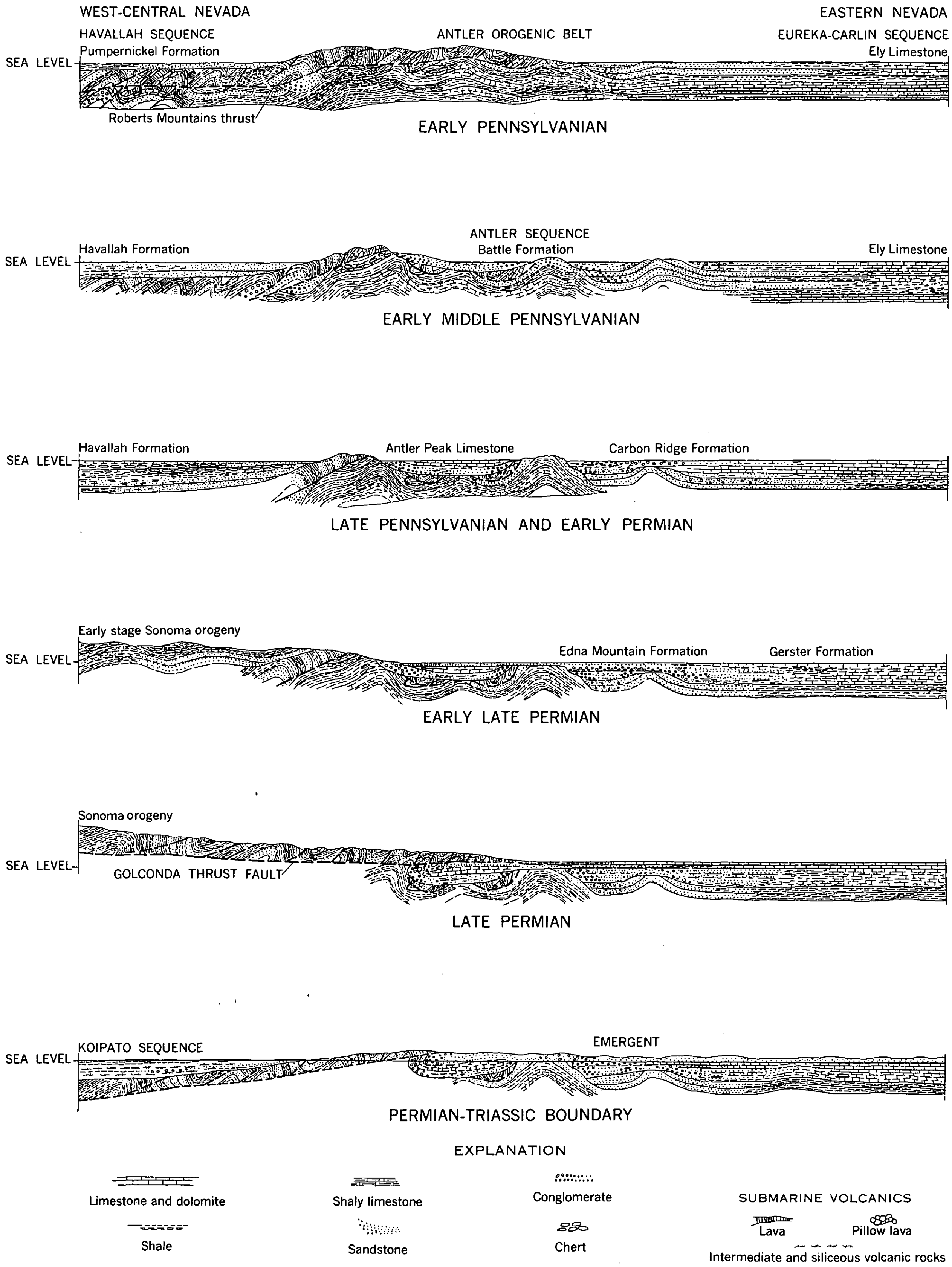


FIGURE 4.—Diagram showing inferred sequence of events following the Antler orogeny in north-central Nevada.

telescoping on these thrust faults. Because parts of many units are cut out by the thrusts, no accurate idea of the total thickness of the Paleozoic section can be given. It is estimated, however, that the section exposed in the quadrangle is at least 30,000 feet thick, and it may be considerably thicker.

During geologic work that was carried on in the Antler Peak, Mount Tobin, Winnemucca, Mount Moses, and Golconda quadrangles by Ferguson, Muller, and Roberts, a sequence of the Paleozoic rocks in the area was determined (Muller and others, 1951; Roberts, 1951; Ferguson and others, 1951a, 1951b; and Ferguson and others, 1952). In all, 15 Paleozoic formations were defined, of which 8 are exposed in the Antler Peak quadrangle.

The stratigraphic succession of the Paleozoic units in the Antler Peak quadrangle is summarized in the following table.

Summary of the sedimentary rocks of Paleozoic age, Antler Peak quadrangle

Age	Formation and member		Assemblage and sequence	Thickness (feet)	Lithology
Early Permian (Wolfcamp and Leonard)	Havallah Formation	Mill Canyon Member	Havallah sequence (allochthonous)	2, 386+	Quartzite and calcareous sandstone, gray, brown-weathering, fine-grained; fine conglomerate; thin- to medium-bedded limestone; shale; chert.
Early Permian	Havallah Formation	Trenton Canyon Member	Havallah sequence (allochthonous)	1, 000	Shale, red, green, and gray; red, green, and gray chert.
Middle Pennsylvanian and Early Permian	Havallah Formation	Jory Member	Havallah sequence (allochthonous)	1, 272	Sandstone, greenish-brown, coarse-grained with local pebbly beds, limy in places; characterized by graded bedding.
	Disconformity (?)				
Pennsylvanian (?)	Pumpernickel Formation		Havallah sequence (allochthonous)	5, 000+	Shale, black, gray, green, and red; gray, green, red, and black chert with a little sandstone and intercalated greenstone (altered andesitic volcanic and pyroclastic rock).
	Golconda thrust fault				
Late Permian (Word)	Edna Mountain Formation		Overlap assemblage, Antler sequence (autochthonous)	100–200	Shale, gray, limy; chert conglomerate; medium-gray limestone.
	Disconformity (?)				
Late Pennsylvanian and Early Permian (Missouri, Virgil, and Wolfcamp)	Antler Peak limestone		Overlap assemblage, Antler sequence (autochthonous)	625–1, 750	Limestone, light- to medium-gray, fine- to medium-grained, commonly medium- to thick-bedded.
	Disconformity				
Middle Pennsylvanian (Atoka)	Battle Formation		Overlap assemblage, Antler sequence (autochthonous)	730	Conglomerate, red to brown with interbedded red sandstone and shale; thin limestone layers in upper part. Crossbedding and current bedding common.
	Angular unconformity				
Late Cambrian	Harmony Formation		Transitional assemblage (allochthonous)	3, 000+	Micaceous sandstone, feldspathic sandstone, arkose, shale, calcareous shale, and limestone. Graded bedding is characteristic.
	Roberts Mountains thrust fault				
Middle Ordovician	Valmy Formation	Member 3	Siliceous and volcanic assemblage (allochthonous)	3, 000+	Shale, black and gray; dark-gray, green, or black chert.
Middle Ordovician	Valmy Formation	Member 2	Siliceous and volcanic assemblage (allochthonous)	3, 675+	Chert and shale, light- to dark-gray, green, and black; quartzite; lenticular greenstone (altered basaltic pillow lavas and pyroclastic rocks).
Early Ordovician	Valmy Formation	Member 1	Siliceous and volcanic assemblage (allochthonous)	1, 785+	Quartzite, light-gray to brown; dark-shale and chert; greenstone (altered pillow lavas and pyroclastic rocks).
	Contact concealed				
Early to Middle Cambrian	Scott Canyon Formation		Siliceous and volcanic assemblage (allochthonous)	5, 000+	Chert, argillite, and greenstone, interbedded, dark (altered basaltic lavas and pyroclastic rocks); some massive gray limestone lenses, black quartzite, brown sandstone, and limy sandstone beds in upper part.

SILICEOUS AND VOLCANIC ASSEMBLAGE

The siliceous and volcanic assemblage is represented in the Antler Peak quadrangle by two formations, the Scott Canyon and Valmy. The Scott Canyon Formation of late Early or early Middle(?) Cambrian age consists of chert, shale, greenstone, and a little limestone. The Valmy Formation of Early and Middle Ordovician age includes three units: two lower units of quartzite, shale, chert, and greenstone, and an upper unit of chert and shale. These two formations were originally deposited far to the west and were brought into their present position in the upper plate of the Roberts Mountains thrust fault, which probably passes beneath Battle Mountain at no great depth.

CAMBRIAN SYSTEM

SCOTT CANYON FORMATION

The oldest formation exposed within the Antler Peak quadrangle is the Scott Canyon Formation, which underlies most of the southeastern part of Battle Mountain in Philadelphia Canyon, Iron Canyon, Galena Canyon, and Little Cottonwood Canyon. The type locality is in Scott Canyon, a tributary that enters Galena Canyon about a mile east of the settlement of Galena. The area underlain by the Scott Canyon Formation has the following limits: it is bounded on the west by the Trinity-Plumas fault system that drops the younger Harmony Formation down; on the north in the Little Cottonwood Canyon and on the ridge to the south, the Scott Canyon Formation is also in fault contact with the Harmony Formation, but the fault zone, for the most part, dips at low angles and is considered to be the eastward continuation of the Dewitt thrust fault. The Scott Canyon Formation has been pressed into tight, north-trending folds that show steep dips. Near the Dewitt thrust these folds are locally overturned to the east.

Lithology

The Scott Canyon Formation is composed predominantly of chert, argillite, and greenstone with minor amounts of sandstone, quartzite, and limestone. No detailed section has been measured, but rough estimates made from cross sections indicate that the aggregate thickness may be more than 5,000 feet.

The chert units in the formation range from a few feet to 200 feet in thickness. They are made up of thin- to medium-bedded chert layers 1 to 18 inches thick with thin shale partings. The predominant colors are gray, green, brown, and black, and locally white; some layers show fine laminations in lighter and darker shades. In many places the fine laminations are offset on breaks along which beds have been displaced a fraction of an inch to a few inches, and locally the beds are contorted into sharp, but discontinuous folds, both concentric and similar types. This faulting and folding probably took place soon after deposition and before complete consolidation of the material, possibly during compaction or as a result of slumping on the sea floor.

Microscopic examination of the chert reveals mostly cryptocrystalline siliceous material so fine that it shows only faint aggregate polarization. This is interlayered with fine-grained chalcedony whose grain size averages about 0.002 mm in diameter. Some layers contain grains of clastic quartz that measure as much as 0.04 mm in diameter and average 0.02 mm. Shreds of carbonaceous material and a micaceous mineral occur in the groundmass. The cherty and argillitic layers generally show gradation from one rock type to the other.

The argillite units in the Scott Canyon are mostly drab in appearance; gray, black, and brown hues predominate. In places they are thinly laminated, but commonly they are medium bedded. As the argillite generally weathers to low relief, the best exposures are found in stream channels and on ridge tops.

The greenstone units that make up a considerable part of the Scott Canyon Formation do not crop out prominently; they generally weather to smooth slopes and are well exposed only on steep slopes and in canyon bottoms. The greenstone includes flows, which are in part massive and in part pillow lavas, and pyroclastic rocks ranging from fine tuffs to coarse breccias. The relative proportion of flows to pyroclastic rocks is not known, but pyroclastic rocks appear to predominate. Originally the greenstones were probably mafic andesites or basalts, judging from the remnants of calcic plagioclase found in some flows. Subsequent alteration has changed the plagioclase to more sodic varieties, and the augite to actinolite and chlorite. These changes are common in volcanic rocks that have been extruded in a submarine environment (Turner and Verhoogen, 1951, p. 208–209; Park, 1946, p. 320; Gilluly, 1935, p. 228–234; Pettijohn, 1943, p. 962).

The massive lavas are generally altered; under the microscope they appear as a disordered group of secondary minerals. The mafic minerals are largely altered to aggregates of serpentine, chlorite, epidote, and zoisite. The plagioclase is largely albitized, but it is crowded with inclusions—probably relicts of the intermediate products formed during alteration of the original calcic plagioclase. Needles of actinolite are scattered throughout the rock and also occur in veinlets of albite. A secondary carbonate mineral is a significant constituent of most lavas, replacing other minerals and occurring as vein fillings.

The greenstones of pyroclastic origin generally contain some nonvolcanic material; the finer tuffs appear to grade into shale of sedimentary origin. The tuffs contain small fragments of lava, crystals of plagioclase and mafic minerals, and their alteration products. The breccias are made up largely of angular volcanic fragments. The pyroclastic rocks are less albitized than the flows, but some units contain considerable albite, of partly clastic and partly secondary origin.

Massive lavas, which are well exposed at the east front of the range about a mile northeast of the mouth of Philadelphia Canyon, show less alteration. The lavas rest with apparent conformity on thin-bedded chert. A specimen collected across the contact shows fine-grained basaltic lava and argillitic chert (fig. 5). The base of the flow evidently was chilled at the time of eruption and consisted of glass with a few plagioclase and augite phenocrysts. Subsequently, the glass was devitrified and altered to a reddish-brown material that shows subrounded areas with a radial structure similar to that of variolites. Originally the plagioclase was a calcic variety, but it has been largely replaced by calcite, sericite, and albite. The albite laths (about An_5) are generally fresh and are 0.05 to 0.6 mm long; they are scattered throughout the groundmass and also occur locally in aggregates. A vein of chalcedony about 1.5 mm wide along the contact of lava and chert also contains small albite crystals; the chalcedony forms radial envelopes around some of the crystals. Albite is also present in some of the

FIGURE 5.—Photomicrograph showing contact of spilitic greenstone flow and argillitic chert, Scott Canyon Formation south of Duck Creek. Shows variolitic structure in chilled border of greenstone (center), chert (right); secondary albite (left center and upper right center). Plane-polarized light, × 53.

carbonate veinlets in the rock. The augite crystals are from 0.10 to 0.90 mm long. Some of the smaller ones are largely serpentinized, but the larger ones are fresh or only slightly serpentinized.

An analysis of this massive lava made by the Geological Survey (3, table 5) shows 4.5 percent Na_2O, nearly twice the normal amount for typical olivine basalts of the Pacific (9, table 5). The additional sodium probably was derived from sea water. Analyses of the average Columbia River Basalt and tholeiitic basalt are also included in table 5 for convenience in comparison.

The sandstone and quartzite beds in the Scott Canyon Formation make up only a small part of the formation. In the sandstones feldspar, principally plagioclase, is a notable constituent, and is the most abundant after quartz; these rocks also contain fragments of chert and volcanic material. Near the Butte mine a black quartzite layer about 5 feet thick crops out prominently. This quartzite resembles the black quartzite near the top of the lower member of the Valmy formation both megascopically and microscopically. It is medium grained and made up of well-rounded quartz grains ranging from 0.15 to 0.4 mm in diameter and averaging about 0.3 mm. The grains are tightly cemented with quartz and only a few have quartz overgrowths; they generally show smooth borders, but some are sutured. Locally the rock shows shearing. A few wisps of muscovite and biotite occur between the quartz grains. The dark color appears to be due to carbonaceous material that coats the grains.

Limestone lenses, commonly associated with greenstone, occur in the upper part of the formation near the mouth of Galena Canyon and on the south side of Little Cottonwood Canyon. The lenses are as much as 500 feet long and 200 feet thick; some of them are composed largely of algae and sponges together with archaeocyathids and a few trilobites; others are composed of recrystallized limestone and show no recognizable fossils. Helen Duncan (written commun., 1960) has studied the fauna and suggests that the lenses may represent bioherms. This indicates accumulation in fairly shallow water, possibly as fringing reefs.

Conditions of deposition

The Scott Canyon Formation consists predominantly of volcanic and fine clastic rocks. A high proportion of pillow lavas indicates marine vulcanism, and the volcanic rocks interfinger with marine chert, shale, and limestone. This suggests that the environment may have been a volcanic archipelago similar to the East Indies island arcs. The occurrence of thick chert and shale units suggests that long stable periods intervened between volcanic outbursts.

Age and correlation

The age of the Scott Canyon Formation was originally considered by Helen Duncan, of the U.S. Geological Survey, to be Carboniferous on the basis of poorly preserved fossils collected in 1947. Subsequently, when better preserved material containing recognizable archaeocyathids and algae was found in 1953, the age assignment was changed to late Early or Middle Cambrian. One collection, from a limestone unit on the north side of Galena Canyon near the Iron Canyon mine, was described as follows by Miss Duncan (written commun., 1953):

The most abundant and conspicuous fossils in USGS 3181–CO (collection 305 of 1947) (SE¼ sec. 6, T. 31 N., R. 44 E.) * * * are called *Archaeosycon*, one of the most spongelike of the archaeocyathids * * * a rare and poorly known archaeocyathid; the few American species are described on very meager material. In Russia Vologdin has used the name *Eucyathus* for a form that is much like *Archaeosycon*, and in Australia the archaeocyathid specialists have still other names for about the same sort of fossil.

The next most common form in your 1947 collection is *Protopharetra*, which as its name implies is another genus originally considered to be an early sponge. The thin sections show also traces of other genera identified as *Syringocyathus* and *Pycnoidocyathus?* as well as algae. One of the algae is *Renalcis* and another is *Epiphyton*, which Vologdin records as a genus commonly found in the archaeocyathid beds and reefs of Russia and Asia.

According to published statements, the archaeocyathids are supposed to be confined to the Lower Cambrian in the Cordilleran province. They occur at Silver Peak, Nevada, and Waucoba Springs, California, and at a few other localities in that general region, which is almost directly south of Battle Mountain. Small faunules have been described. The archaeocyathid facies appears to be fairly restricted in North America, so this occurrence is of considerable interest. In Asia and the Mediterranean region archaeocyathids are supposed to persist into the Middle Cambrian.

Archaeocyathids have been included in faunal lists from Lower Cambrian strata near Barrel Spring, 16 miles south of Silver Peak (Walcott, 1908, p. 189). Here they occur mainly in a massive blue mottled limestone member 737 feet thick with 50 feet of sandy limestone in the middle. Walcott (1908, p. 187) also mentions archaeocyathids from the Waucoba Springs section in unit 3c, which consists of 575 feet of alternating arenaceous limestone, shale, and sandstones; the fauna was collected at a point 275 feet from the base. Unit 3d, shaly indurated sandstone about 450 feet thick, also yielded archeaocyathids from its lower part. As the lithology of the stratigraphic sections at Waucoba Springs is quite different from the lithology of the Scott Canyon Formation, no direct correlation can be attempted.

Subsequently, another limestone lens containing algae and archaeocyathids was discovered in 1953 near the Iron Canyon mine. Miss Duncan (written commun., 1954) reported on collections from the lens as follows:

USGS 3180–CO (field No. 53–F–8)—SE¼ sec. 23, T. 31 N., R. 43 E.

Algae:
- *Epiphyton* sp.
- *Renalcis* sp.

Archaeocyatha:
- *Ajacicyathus* sp.
- *Ethmophyllum* sp.
- *Ethmophyllum?* sp. (parieties abundantly perforated)
- *Sajanocyathus* sp.
- *Archaeopharetra?* sp.
- *Protopharetra* sp.
- *Pycnoidocyathus* sp.
- *Syringocnema* sp.
- *Eucyathus* sp.

So far as is known, *Epiphyton* and *Renalcis* first appear in the upper part of the Lower Cambrian. These algae are particularly characteristic of deposits assigned to the latest Early or the earliest Middle Cambrian. The association of the algae with an archaeocyathid fauna containing several relatively advanced genera suggests that the Scott Canyon archaeocyathid beds belong somewhere in this interval and that they are younger than the "zone of *Olenellus*."

In 1958 additional collections were made at locality 53–F–8, yielding a brachiopod, *Rustella*, and trilobites of late Early to early Middle Cambrian age, according to A. R. Palmer (written commun., 1959).

The Scott Canyon Formation is the only unit of Cambrian age belonging to the siliceous and volcanic assemblage that has been found so far in north-central Nevada. It is lithologically similar to the associated Valmy Formation of Ordovician age and was probably deposited in the same seaway under similar environmental conditions. In the Mount Lewis quadrangle to the southeast, Gilluly (Roberts and others, 1958, p. 2829) reports a unit of greenstone flows intercalated with pyroclastic rocks, phyllite, and limestone. The limestone contains Middle Cambrian fossils and is correlated with the Secret Canyon Shale of the Eureka district. The presence of greenstone in the Mount Lewis quadrangle suggests kinship with the Scott Canyon Formation, but the Secret Canyon, which consists largely of shale and limestone, lacks the bedded chert and sandy units of the Scott Canyon, and the two formations are clearly of different facies.

The sedimentary section of Cambrian rocks in the Osgood Mountains, about 30 miles to the west of the town of Battle Mountain, has been studied by Hotz and Willden (1964). Here the section consists of the Osgood Mountain Quartzite, about 5,000 feet thick, which is presumed to be of Early Cambrian age; this quartzite is overlain by the Preble Formation of Middle and Late Cambrian age—mainly shale with a little limestone—about 6,000 feet thick; this is followed successively by the Paradise Valley Chert of early Late Cambrian age (shown as unnamed unit on pl. 1), which is approximately 2,000 feet thick, and the Harmony Formation of Late Cambrian age, which is 3,000 feet thick.

The Osgood Mountain Quartzite is probably regional in extent; it resembles the Prospect Mountain Quartzite of the Eureka district and may be equivalent in age (Roberts and others, 1958, p. 2826). The other units contain lithologic elements that belong to both the siliceous and volcanic and carbonate assemblages and are considered transitional between them. The Preble Formation rests with gradational contact on the Osgood Mountain Quartzite, thus spanning the time interval during which the Scott Canyon Formation was deposited. As the Scott Canyon Formation is also quite different in lithology from the Preble and other Osgood Mountains formations, it is clear that they must have formed in different parts of the geosyncline under entirely different conditions.

ORDOVICIAN SYSTEM

VALMY FORMATION

The next oldest formation of the siliceous and volcanic assemblage exposed within the quadrangle is the Valmy Formation, which crops out in the northwestern part of the area on North Peak and in the valleys of Cottonwood Creek, Trout Creek, and the North Fork. The Valmy Formation generally forms steep slopes broken by ledges of quartzite and chert (fig. 6). Cliffs formed by the quartzite ledges are in places more than 100 feet high, and cliffs formed by chert units are as much as 50 feet high. The shaly layers commonly form smooth slopes locally broken by outcrops of interbedded chert layers. The terrain underlain by the Valmy Formation is therefore alternately rugged and smooth. Streams cutting the resistant units of the formation for the most part flow in narrow canyons with extensive bedrock outcrops on the valley floors. Slopes that are protected from the sun on the north and east sides of the valleys generally are covered by talus slides below prominent outcrops.

The Valmy Formation has been subdivided into three members in the quadrangle: the oldest, member 1, of Early Ordovician age, consists mainly of gray quartzite, chert, and shale with some greenstone; the middle, member 2, of Middle Ordovician age, is largely interbedded shale and chert, and greenstone with thick quartzite units at the base and top; the youngest, member 3, of Middle Ordovician age, formerly mapped as the Comus Formation (Roberts, 1951), is composed of chert and shale with a little greenstone.

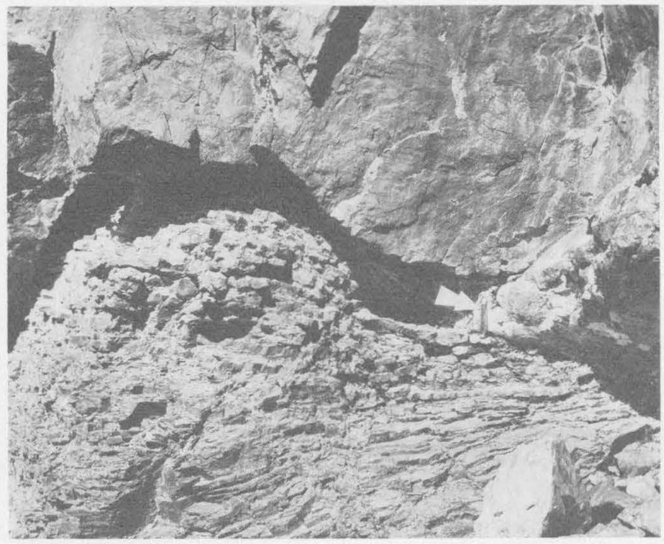


FIGURE 6.—Thin-bedded chert and shale overlain by massive quartzite, Valmy Formation. Shearing at the base of the quartzite has cut out the upper chert and shale beds. Scale is indicated by the knife, right center, 4½ inches long.

The Valmy Formation has been complexly folded and faulted, and in no single block were complete sections of the members exposed. The sequence of beds in members 1 and 2 was worked out, however, and a composite section was measured; as member 3 consists mainly of nondescript chert and shale beds in thrust slices, no section was measured.

Member 1 underlies the lower slopes on the west side of North Peak. The base of the member is not exposed. The lowest beds consist of quartzite, which weathers gray, buff, and reddish brown to dark brown; on fresh surfaces it is generally light to medium gray, but in places it is dark gray to black. The quartzite is generally thick bedded to massive, but where it intertongues with chert and shale, it is locally thin bedded. The thickness of the beds ranges from a fraction of an inch to as much as 50 feet and probably averages more than 10 feet. In most places bedding in the quartzite units can be discerned only with careful study, for outcrops commonly show only faint banding (fig. 7*A*).

The seriate texture of the quartzite of the Valmy Formation is very distinctive; the grains show fairly large size range, but the rock is characterized by a scattering of the larger grains in a matrix of medium-sized grains. This texture is helpful in differentiating the Valmy quartzite from quartzite beds in the Haval-

Composite section of members 1 and 2, Valmy Formation, Antler Peak quadrangle, Nevada

[Section measured on south side of Cottonwood Creek (SW¼ sec. 7, T. 32 N, R. 43 E., and SE¼ sec. 12, T. 32 N., R.42 E.); on south side of Trout Creek (SW¼ sec. 8 and NE¼ sec. 7, T. 32 N., R. 43 E.); range front northwest of North Peak (NW¼ sec. 4, T. 32 N., R. 43 E.)]

	Feet
Golconda thrust fault.	
Member 2:	
J. Quartzite, black, medium- to thick-bedded; cliff former	1, 200+
I. Quartzite, massive, gray and brownish-gray; 15-foot green shale unit 50 feet above base of unit	90
H. Chert, gray, black, and green, thin-bedded; and gray siliceous shale; lower part of unit contains numerous 1- to 3-foot gray and brownish-gray quartzite beds; middle and upper parts of unit contain a few gray quartzite beds	825
G. Shale, gray, siliceous	365
F. Quartzite, thick-bedded to massive, gray	195
E. Chert, green and gray; and gray and black siliceous shale; upper and middle part of unit contains a few gray and white mottled quartzite beds	435
D. Greenstone (altered pillow lava)	0–365
C. Quartzite, massive, light-gray; middle of unit contains 60-foot layer of chert and shale	200
Total member 2	3, 310–3, 675+
Member 1:	
B. Shale, dark-gray and black; contains a few thin beds of gray and black quartzite and thin layers of black chert	660
Chert, black, 1-inch to 12-inch beds; some thin-bedded dark-gray and greenish-gray chert; lower part of unit dominantly shale	525
Greenstone; altered pillow lavas and pyroclastic rocks interfingers laterally with chert and shale	0–200
A. Quartzite, massive, brownish-gray and dark-gray; red-brown weathering quartzite in middle of unit contains some interbedded chert and shale	400+
Total exposed member 1	1, 585–1, 785+
Base not exposed.	

lah and Osgood Mountain Quartzite because the latter rocks are composed of more uniformly sized grains. Microscopic examination reveals subangular to rounded grains ranging in size from 0.1 to 1 mm; the median-grain size is from 0.3 to 0.4 mm (fig. 7*B*). The cementing material is fine-grained quartz; in places a little iron oxide or carbonaceous cement is associated with the quartz. The quartz grains locally

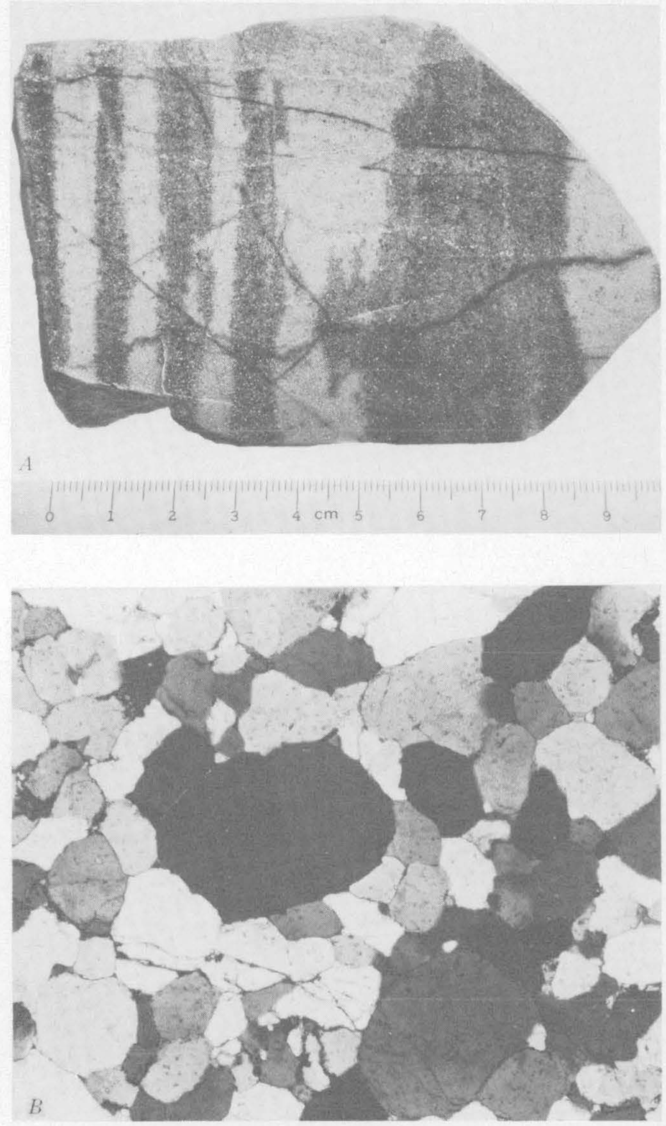


FIGURE 7.—*A*, banded quartzite, Valmy Formation. Shows the characteristic well-sorted texture and irregular banding of the quartzite. *B*, photomicrograph of quartzite, Valmy Formation. Shows seriate quartz grains; grain boundaries generally unsutured. Cross-polarized light. × 75.

penetrate each other, probably because of solution due to pressure during folding and thrusting.

Because of the high purity of the quartzite from member 1, a sample was collected for analysis from an outcrop on the north side of the North Fork, sec. 5, T. 32 N., R. 43 E. This sample (lab. No.—145668; field No.—55AP 3) was analyzed by the U.S. Geological Survey [2] with the following result:

[2] P. L. D. Elmore, K. E. White, and S. D. Botts, analysts. The quartzite would meet the requirements for metallurgical quartzite as outlined by Murphy (1954, p. 21). The locality that yielded the sample is about 9 miles from Valmy, the nearest shipping point, but other quartzite layers in the Valmy Formation are as close as 4 miles to the railroad.

SiO_2	98.3
Al_2O_3	.74
Fe_2O_3	.32
FeO	.04
MgO	.05
CaO	.10
Na_2O	.02
K_2O	.14
TiO_2	.04
P_2O_5	.00
MnO	.00
H_2O	.18
CO_2	.05
Sum	100
BaO	-------
Total S as S	.02
Sp gr (powder)	2.60
Sp gr (lump)	2.56

The Valmy quartzite contains only minor amounts of accessory minerals. In most slides studied, a few well-rounded grains of tourmaline and zircon were found, but these minerals total less than 0.1 percent of the rock. Locally, secondary pyrite is a minor constituent of the quartzite.

The lower quartzite unit is overlain by a lenticular greenstone mass as much as 200 feet thick which includes a volcanic plug in the SE¼ sec. 5, T. 32 N., R. 43 E. The plug is a coarsely crystalline gabbro; it is surrounded by pillow lava and breccia which grade outward into fine-grained tuff and shale within a distance of about 2 miles. Chemical analyses of the gabbro and related pillow lava are included in table 5, nos. 1 and 2. The pillow lava is chemically similar to the gabbro, but has a somewhat lower alumina and soda content and a higher calcium carbonate content, which is probably owing to alteration caused by reaction with sea water. The lava pillows have a dense outer layer from 1 to 1½ inches thick that was formerly glass and that contained scattered varioles 2 to 4 mm in diameter; this outer layer grades inward to fine-grained basalt cut by veinlets of calcite and albite.

The upper part of member 1 is predominantly gray to black shale containing thin chert and quartzite beds. The shaly beds weather to small flakes or pencil-shaped fragments; the beds are poorly exposed in most places. The chert beds are highly lenticular and interfinger with shaly beds along the strike. The quartzite beds are on the whole less pure than the beds of unit A, and locally grade into sandy shale along the strike.

Member 2 is made up of rock units that are generally similar to those of member 1; quartzite, chert, shale, and greenstone are the principal rock types. The basal quartzite of the unit forms prominent outcrops on the south side of Trout Creek. The overlying greenstone consists mainly of greenish-brown pyroclastic material ranging from breccia to fine-grained tuff and with well-developed pillow lava in places. Microscopic studies show that the tuffs are composed mainly of clay minerals, sericite, chlorite, serpentine, and secondary biotite. The outlines of feldspar grains can be seen in some fragments. Pillow lavas are well exposed on the ridge between Trout and Cottonwood Creeks near the range front. The overlying chert and quartzite beds of units E through I are not particularly distinctive, but unit J is a highly characteristic dark-gray to black quartzite that forms bold cliffs in the eastern part of sec. 13, T. 32 N., R. 42 E. The black color is due to finely divided carbonaceous material that coats the quartz grains.

Member 3 is exposed on the northeast side of the North Peak and extends southward in a belt as much as a mile wide to the valley of Cottonwood Creek. It is in fault contact with member 1 on the west and with the Harmony Formation on the east; on the south it is overlain unconformably by conglomerate of the Battle Formation. On the original Antler Peak geologic quadrangle map (Roberts, 1951), member 3 was referred to in part as the Comus Formation of Early Ordovician age. During the more detailed study of the Antler Peak quadrangle, the unit was found to contain fossils of Middle Ordovician age (R. J. Ross, Jr., and W. B. N. Berry, written commun., 1959), and therefore is younger than the Comus Formation at the type locality. Moreover, the Comus contains a significant proportion of limestone, whereas member 3 contains only a few limy lenses. Accordingly, the name Comus Formation is now dropped in the Antler Peak quadrangle, and the unit is made member 3 of the Valmy Formation.

Member 3 consists of interbedded chert and black shale, and a little greenstone; it generally forms smooth slopes except locally where thick chert units crop out (figs. 8 and 9). The cherts of member 3 are generally dark in color, green, gray, or black, and like the chert of the lower units, are characteristically thin bedded. The chert layers range from a fraction of an inch to as much as 18 inches in thickness and are separated by thin shale partings. The shaly layers interfinger with the chert layers and are gradational along the strike. The shale units in member 3 are not well exposed, but on the steep slopes northeast of North Peak, black shale beds from 10 to 15 feet thick are interbedded with dark gray and black chert. These beds are highly sheared.

Member 3 of the Valmy Formation has been complexly folded and is highly sheared in most places. Consequently, no attempt has been made to measure a section of the formation, but it is estimated that the strata aggregate more than 3,000 feet in thickness.

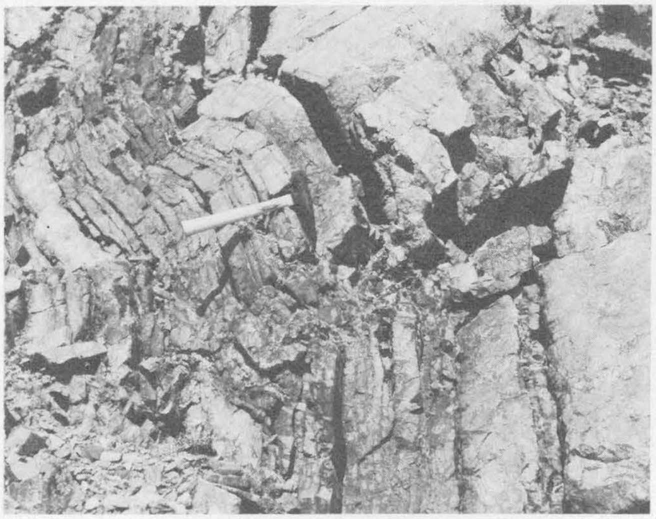


FIGURE 8.—Folded chert of member 3, Valmy Formation. Chert beds are 1 inch to more than 2 feet thick. Note absence of shaly partings between beds.

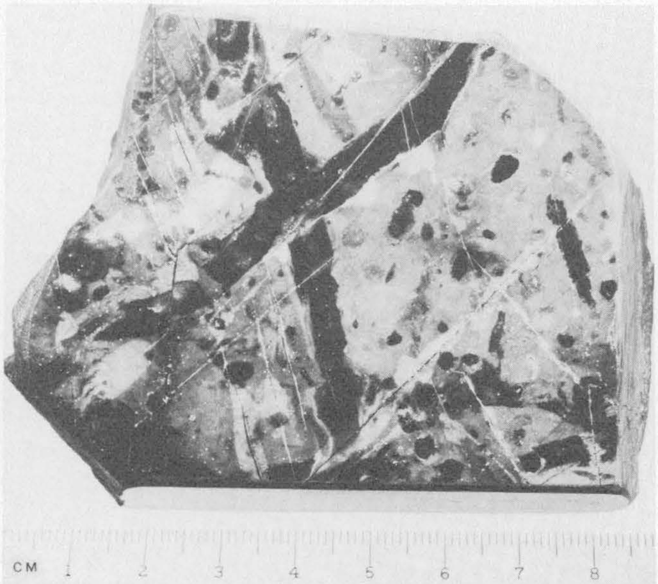


FIGURE 9.—Chert, Valmy Formation, showing nodules and rods (worm trails?) of dark-gray chert in a light-gray to white groundmass.

Age and correlation

Collections of graptolites from the Valmy Formation have been studied by the late Josiah Bridge, R. J. Ross, Jr., and W. B. N. Berry; these indicate that the Valmy contains beds of Early and Middle Ordovician age in this area. R. J. Ross, Jr., and W. B. N. Berry have written as follows concerning graptolites from member 1 (written commun., 1959).

USGS Colln. D489 CO. North side of North Fork, altitude 6350 feet. SW¼SW¼ sec. 5, T. 32 N., R 43 E. Antler Peak quadrangle, Nevada

Adelograptus, sp.
Didymograptus sp. (extensiform type)
Didymograptus patulus Hall?
Tetragraptus fruticosus (Hall)

The above species indicate a probable age equivalent to the zone of *Tetragraptus fruticosus* (Early Ordovician).

Cryptograptus tricornis Carruthers
Lasiograptus cf. *L. pusillus* Ruedemann
Retiograptus geinitzianus Hall
Dicellograptus sp.
Dicellograptus sextans (Hall)
Climacograptus sp.
Nemagraptid?

The latter group of species are from the zone of *Nemagraptus gracilis* or of *Climacograptus bicornis* (Middle Ordovician).

Because all these species came from one outcrop it is extremely likely that there is a tectonic cause for the lack of intervening faunas.

USGS Colln. D499 CO. North side of North Fork of Trout Creek, SE¼SW¼SW¼SW¼ sec. 5, T. 32 N., R. 43 E., Antler Peak quadrangle, Nevada

Tetragraptus fruticosus (Hall) (3 branched forms)

Age: Zone of *Tetragraptus fruticosus* (3 and 4 branched forms) (or zone 4 of Elles and Wood) (Early Ordovician).

USGS Colln. D434 CO. South side of North Fork of Trout Creek at range front. SW¼ sec. 6, T. 32 N., R. 43 E. Antler Peak quadrangle, Nevada

Didymograptus cf. *D. similis* (Hall) (immature)
Tetragraptus fruticosus (Hall) (4 branched forms)

Age: Late Canadian (zone 4 of Elles and Wood) (Early Ordovician).

USGS Colln. 1292 CO. Valmy Formation. South side of North Fork of Trout Creek at range front, SE¼SW¼ sec. 6, T. 32 N., R. 43 E., Antler Peak quadrangle, Nevada

Didymograptus sp. (extensiform type)
Tetragraptus fruticosus (Hall) (3 branched and 4 branched forms)
?*Tetragraptus*. (If a *Tetragraptus* this may be *T. denticulatus* (Hall))

Age: Zone of *Tetragraptus fruticosus* (3 and 4 branches) (approximately equals zone 4 of Elles and Wood or Arenig) (Early Ordovician).

Collection D 489 contains both Early and Middle Ordovician faunas; the suggestion by Ross and Berry that there might be a tectonic cause for the lack of intervening faunas was subsequently checked in the field and found to be the most likely explanation.

Member 2 has yielded seven collections; these have been determined by Ross and Berry as belonging to zones 8 to 11 of Elles and Wood (1901–18) (Middle Ordovician).

USGS Colln. D500 CO. North Fork of Trout Creek, NE side, C, N½NE¼NE¼ sec. 8, T. 32 N., R. 43 E. Antler Peak quadrangle, Nevada

Orthograptus aff. *O. quadrimucronatus*?
Glyptograptus? sp.
Glossograptus hincksii (Hopkinson)

Age: Possibly zone of *Climacograptus bicornis* (Middle Ordovician).

USGS Colln. 1293 CO. Valmy Formation. On north side, North Fork Valley at 7100 feet; NE¼ *sec. 8, T., 32 N., R. 43 E., Antler Peak quadrangle, Nevada*

Diplograptus cf. *D. multidens* var. *diminutus* Ruedemann
Glyptograptus cf. *G. teretusculus* (Hisinger)
Climacograptus cf. *C. scharenbergi* var. *stenostoma* Bulman.

Age: Probably zone of *Climacograptus bicornis* (zone 10 of Elles and Wood) (Middle Ordovician).

USGS Colln. 1949 CO. Valmy Formation. On ridge east of North Peak at altitude of 8250 feet, SW¼ sec. 3, T. 32 N., R. 43 E., Antler Peak quadrangle, Nevada

Dicellograptus sextans? Hall

Age: Possibly zone of *Nemagraptus gracilis* or of *Climacograptus bicornis* but may not be this restricted (Middle Ordovician?).

USGS Colln. D 495 CO. South shoulder of North Peak, 700 feet east of quarter corner between sections 3 and 4, T. 32 N., R. 43 E. Altitude 8150 feet, Antler Peak quadrangle, Nevada

Dicellograptus intortus Lapworth
Dicellograptus sextans Hall
Corynoides aff. *C. curtus* Lapworth

Age: Zone of *Nemagraptus gracilis* or of *Climacograptus bicornis* (Middle Ordovician).

USGS Colln. D 504 CO. Altitude 7700 feet, on ridge west from 7900 peak, SW¼ sec. 9, T. 32 N., R. 43 E., Antler Peak quadrangle, Nevada

Climacograptus aff. *C. scharenbergi* Lapworth
Glyptograptus cf. *G. euglyphus* (Lapworth)

Age: Probably in range from zone of *Glyptograptus teretusculus* to zone of *Climacograptus wilsoni* (zones 8–11 of Elles and Wood) (Middle Ordovician).

USGS Colln. D 496 CO. South Fork of Trout Creek, nose running northwest. SW¼NE¼SW¼ sec. 9, T. 32 N., R. 43 E., altitude 7675 feet, Antler Peak quadrangle, Nevada

Climacograptus aff. *C. scharenbergi* Lapworth
Climacograptus sp. (new?)
Glyptograptus? sp.

Age: Early to Middle Caradoc. Zone of *Nemagraptus gracilis* to zone of *Climacograptus wilsoni* (zone of *Orthograptus truncatus intermedius*) (zones 9–11 of Elles and Wood) (Middle Ordovician).

USGS Colln. 1950 CO. On ridge east of North Peak, SE¼ sec. 3, T. 32 N., R. 43 E., Antler Peak quadrangle Nevada

Climacograptus sp.
Glyptograptus sp.
Orthograptus quadrimucronatus var. *angustus* Ruedemann
Orthograptus truncatus cf. var. *intermedius* Elles and Wood
Orthograptus truncatus cf. var. *pertenuis* Ruedemann
Orthoretiolites hami Whittington
an archiretiolitid

Age: Zone of *Climacograptus wilsoni* (=zone of *O. truncatus* var. *intermedius*) (zone 11 of Elles and Wood) (Middle Ordovician).

Member 3 has yielded only two determinable collections; these have been determined as Middle Ordovician age (zone 9 or 10 of Elles and Wood) by Ross and Berry. Member 3 is approximately the same age as member 2; the two units differ in lithology, however, and therefore were separately mapped.

USGS Colln. 1953 CO. Valmy Formation. SW¼ sec. 21, T. 32 N., R. 43 E., altitude 7050 feet on knoll south of road. Antler Peak quadrangle, Nevada

Dicellograptus sextans (Hall)
Dicellograptus sp.

Age: Zone of *Nemagraptus gracilis* or of *Climacograptus bicornis* (zone 9 or 10 of Elles and Wood) (Middle Ordovician).

USGS Colln. 1952 CO. Valmy Formation. NE¼ sec. 20, T. 32 N., R. 43 E., altitude 6850 feet. NE side of Cottonwood Creek about 200 feet above road. Antler Peak quadrangle, Nevada

Dicellograptus smithi Ruedemann
Dicellograptus sextans var. *exillis* Elles and Wood

Age: Zone of *Nemagraptus gracilis* or of *Climacograptus bicornis* (Middle Ordovician) (zone 9 or 11 of Elles and Wood).

Member 1 of the Valmy Formation is correlative in part with the beds assigned by Merriam and Anderson (1942, p. 1694) to the lower Vinini Formation of Early Ordovician age in the Roberts Mountains. These units are lithologically similar; both contain quartzite, chert, and shale beds together with lava flows and pyroclastic rocks. Member 1 of the Valmy Formation, however, contains a much larger proportion of quartzite than the lower Vinini and the beds in the Valmy are much thicker. For this reason a new formation name was applied to the units in the Antler Peak quadrangle. Fossils found in member 1 of the Valmy Formation are of Early Ordovician age and contain the same faunal elements as the lower part of the Vinini Formation; fossils from members 2 and 3 of the Valmy Formation are of Middle Ordovician age and are therefore partly equivalent to those found in the upper part of the Vinini Formation.

Near Summit, Nevada, in the Sulphur Spring Range north of the Roberts Mountains, graptolites of zones 7 and 8 have been collected from the Vinini Formation (R. J. Ross, Jr., written commun., 1960). The Vinini Formation in this latitude is mainly shale and chert; equivalent rocks farther west include much quartzite, which indicates westward coarsening toward Battle Mountain. This is in accord with the concept that the upper plate of the Roberts Mountains thrust carried units transitional in aspect near the toe or eastern front, and that the rocks graded westward into coarser clastic rocks (Roberts and others, 1958).

The relation of the Valmy Formation to the Comus Formation in Edna Mountain (Ferguson and others, 1952) is not definitely known because the two units have not been found in contact. As they are roughly equivalent in age, but different in lithology, it is inferred that they belong to different facies, deposited in different parts of the geosyncline.

In the Winnemucca quadrangle, about 25 miles to the northwest, rocks assigned to the Valmy Formation rest with apparent conformity upon intercalated chert, greenstone, and argillite which have been named the Sonoma Range Formation (Ferguson and others, 1951a). In 1955, the contact between the Sonoma Range and Valmy Formations was proved to be a thrust fault. It now seems likely that the Sonoma Range Formation is equivalent to the upper part of the Valmy Formation.

Conditions of deposition

The Valmy Formation contains a large proportion of marine clastic rocks and intercalated volcanic materials. This suggests that the environment of deposition may have been in or near a volcanic archipelago similar to that proposed as the environment in which the Scott Canyon Formation was deposited. The abundance of spilitic pillow lava and the interfingering of lava and marine chert, shale, and tuff are clear evidence that the volcanic rocks were largely extruded on the sea floor. The thick chert and shale units accompanying the lavas are representative of worldwide association characteristic of eugeosynclinal deposits.

The presence of thick, poorly bedded quartzite units in the Valmy in such an environment poses a problem. The quartzites are unusually free of feldspar and other detrital material, suggesting that the quartz grains were furnished by a terrain composed largely of quartzose beds—sandstone, quartzite, or quartzitic gneiss. The sparseness of accessory minerals also is indicative of such a terrain, although in part the sparseness may be due to solution of grains after burial (Bramlette, 1941, p. 35). The quartzites have a seriate texture; the range of grain size is not large, and the rocks can be considered well sorted. The absence of bedding and crossbedding in the thick quartzite units, and alternation with finer materials, suggests that an unusual agency, such as density currents, may have transported the sand to its place of deposition. A similar explanation was suggested by Cline (1959) for sediments deposited in the Ouachita Mountains. Except for the volcanic outbreaks, which were probably short in duration, the bulk of the Valmy was laid down in relatively quiet water. The cherts (figs. 8 and 9) are finely laminated and regularly bedded, suggesting stable conditions when little coarse clastic material was being carried into the basin. The chert beds are interbedded with shale and the chert laminae are locally separated by thin shale partings. In places thin quartzite beds interfinger with the shale beds, but this is not the rule. The conditions under which all these units may have been deposited might best be met in a trough, such as those adjacent to East Indian island arcs today.

SILURIAN SYSTEM

No rocks of Silurian age have thus far been recognized in the Antler Peak quadrangle. Silurian graptolites have been found in Eureka County near McCluskey Pass by C. A. Merriam (oral commun., 1954), in the Sulphur Spring Range 20 miles south of Carlin by C. A. Nelson (written commun., 1956) and in the Shoshone Range by Gilluly (Roberts and others, 1958). Shale and chert units, the source of graptolites, closely resemble the strata of the Vinini Formation and it would be difficult to map them separately. Graptolites that extend into the Silurian were found by Roberts while mapping in northern Eureka County 10 miles northwest of Carlin during 1954. From these data it may be inferred that Silurian rocks are a significant part of the siliceous and volcanic assemblage and are probably widespread in extent.

DEVONIAN SYSTEM

No rocks of Devonian age have been recognized in the Antler Peak quadrangle, but Gilluly (Roberts and others, 1958) has reported about 4,000 feet of sandstone, shale, and chert of middle Devonian age in Slaven Canyon in the northern part of the Mount Lewis quadrangle. These Devonian rocks are assigned by Gilluly to the siliceous and volcanic assemblage, and it seems likely that the Devonian was likewise deposited over a wide area.

TRANSITIONAL ASSEMBLAGE

The Harmony Formation of Late Cambrian age is the only unit in the Antler Peak quadrangle that belongs to the transitional assemblage. The type locality of the Harmony Formation is in Harmony Canyon, Sonoma Range, in the Winnemucca quadrangle, where it was estimated to exceed 5,000 feet in thickness (Ferguson and others, 1951a). As far as is known, the Harmony crops out in the East, Sonoma, and Hot Springs Ranges, the Osgood Mountains, and Battle Mountain. In these areas it is found in two kinds of structural settings: as parts of a folded block comprising the Hot Springs Range and northern part of the Sonoma Range, and in thrust sheets of Paleozoic and Mesozoic age in the East and Sonoma Ranges, Osgood Mountains, and Battle Mountain. The folded block appears to be a structural unit of transitional assemblage rocks that is considered to be autochthonous or parautochthonous (Roberts and Hotz, *in* Roberts and others, 1958). The thrust sheets are thought to have moved slivers of the Harmony eastward along with siliceous and volcanic assemblage rocks during Paleozoic thrusting and westward during Mesozoic thrusting. In the Sonoma Range, the folded block is separated from the thrust sheets by the Adelaide thrust fault, which is considered to be the westward extension of the Roberts Mountains thrust fault, the sole thrust of the siliceous and volcanic assemblage.

CAMBRIAN SYSTEM

HARMONY FORMATION

The Harmony Formation in Battle Mountain is present in the upper plate of the Dewitt thrust, one of the Paleozoic thrusts related to the Roberts Mountains thrust fault. The Dewitt thrust plate covers most of the northeastern part of Battle Mountain and is also present locally in downfaulted blocks in the southeastern part (pl. 6). The Harmony Formation is composed principally of sandstone and shale and a little limestone. The best exposures are near the north crest of the range at the divide between the North Fork, Elder Creek, and Snow Gulch and on the east side of the range at the head of Little Cottonwood and Long Canyons. Estimated total thickness of the formation in the quadrangle is about 3,000 feet.

Lithology

The Harmony Formation is composed of interbedded sandstone, feldspathic sandstone, arkose, granule and pebbly sandstone, shale, calcareous shale, and limestone. The relative proportions of these units are variable from place to place, but it is estimated that sandstone makes up about 70 percent of the formation, and shale and calcareous shale the bulk of the remainder; limestone probably makes up less than 2 percent of the formation exposed in the quadrangle. The sandstone is commonly dark green on fresh surfaces where unmetamorphosed and weathers brownish green to brown. The shale is generally green or brown but includes gray, red, and black units. Near granitic intrusive bodies the shale is metamorphosed to hornfels and the sandstone to quartzite; the hornfels is generally dark reddish brown, and the quartzite is gray to brown.

The rocks of the Harmony Formation are generally not resistant to erosion and commonly form smooth slopes in upland areas, broken locally by outcrops of thick sandstone beds on the ridges and steep slopes. The sandstone and pebbly sandstone beds disintegrate readily and weather to sandy soils. However, adjacent to intrusive bodies where the rocks of the Harmony Formation are indurated and metamorphosed, they break down into angular blocks that form extensive talus slopes.

The sandstones of the Harmony formation range from fine, fairly well sorted silty sands to coarse grits (fig. 10). They are generally composed of angular to subrounded grains in a matrix of clay minerals, quartz, calcite, mica, and iron oxides. Coarse conglomerate beds are absent, and thick granule or pebble beds are rare, but many of the grit beds contain scattered pebbles. One of the consistent features of the Harmony is well-developed graded bedding. Most of the sandstone layers show this graded bedding whether they are 4 inches or 10 feet thick. The grading is of the type in which the fines are distributed throughout the bed; Pettijohn (1957, p. 171) suggests that this type is produced by differential settling from turbidity flows.

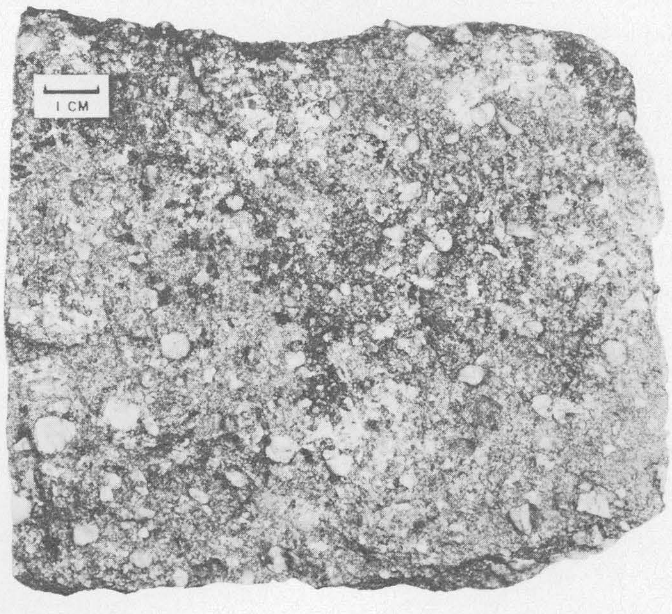


FIGURE 10.—Pebbly sandstone of the Harmony Formation. Pebbles are mostly vein quartz and some feldspar set in a sandy micaceous matrix.

The sandstone units are characteristically lenticular and pinch out along the strike, interfingering with shales. Marker beds are few and cannot be traced far because of structural complexity. Accordingly, no attempt was made to measure a section of the formation.

From the study of thin sections, the composition of the sandstone was found to be variable; the quartz content ranges from 60 to 80 percent, feldspar 10 to 20 percent, mica 2 to 5 percent, and the remainder, the matrix of cementing material, 20 to 30 percent. Some of the sandstone contains considerable calcite as cementing material, and such rock locally grades into sandy limestone. Where the percentage of feldspar exceeds 20 percent, the rock is called feldspathic sandstone; where the percentage of feldspar exceeds 40 percent, it is called arkose.

The quartz grains average nearly 2 mm in diameter. They are of three types—clear, smoky, and milky quartz. The clear quartz grains are either parts of a single crystal or crystal aggregates and are believed to have come from pegmatitic or granitic source rocks. The smoky quartz contains numerous minute opaque inclusions and probably came from veins. The milky quartz grains may be rounded fragments of quartzite or of vein quartz (fig. 10). The fragments of quartzite range from finely granular material, which may have been formed by recrystallization of chert, to coarsely crystalline schistose quartzite in which the quartz grains show marked elongation. The fragments of vein quartz contain abundant vacuole inclusions and show characteristic undulatory extinction.

The feldspars include orthoclase, microcline, and sodic plagioclase (fig. 11). These, for the most part, are fresh and unaltered. The total feldspar content averages about 15 percent; this normally includes about 55 percent orthoclase, 33 percent plagioclase, and 12 percent microcline. The orthoclase grains are as much as 7 mm in diameter and average about 2.5 mm; many of the grains show Carlsbad twinning. The microcline grains are somewhat smaller, averaging about 1.7 mm in diameter. The plagioclase is generally sodic and ranges from An_{10} to An_{30}, corresponding to oligoclase and sodic andesine.

The quartz fragments in the Harmony Formation are of three types: clear, smoky, and milky quartz. The clear quartz grains are either rounded parts of a single crystal or of crystal aggregates; they are believed to have been derived from pegmatite and granitic source rocks. The smoky and milky quartz grains owe their opacity to minute opaque inclusions and were probably derived from veins.

The cementing material in the sandstones generally makes up about 20 to 30 percent of the rock and consists of clay minerals, calcite, quartz, and finely divided rock detritus. This material has been partly reconstituted in places and finely crystallized sericite has formed. It is often difficult to determine quantitatively how much of the mica in the groundmass is secondary and how much was of clastic origin.

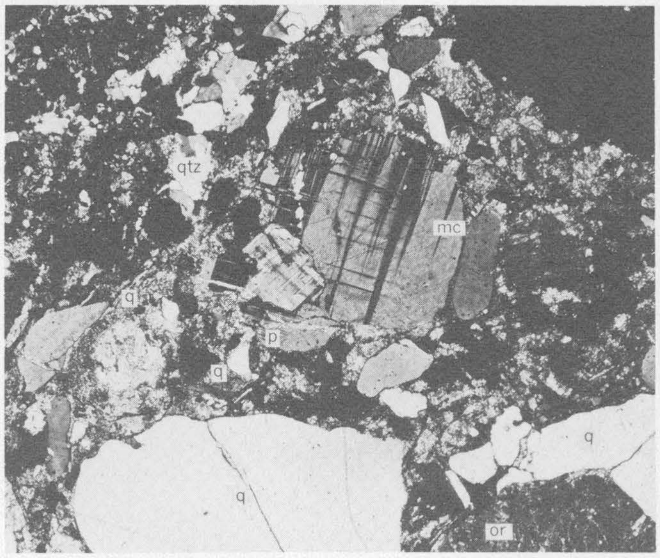


FIGURE 11.—Photomicrograph of sandstone, Harmony Formation. Shows microcline (mc), quartz (q), orthoclase (or), plagioclase (p), and quartzite (qtz) grains in groundmass of mica and argillaceous material. Cross-polarized light. × 53.

Some of the sandstones contain considerable calcite as cementing material, and these rocks grade into sandy limestone locally. The limestone beds contain as much as 85 percent calcite with the remaining 15 percent mainly quartz, feldspar, and mica. The feldspar grains are relatively more abundant in the limestone than in the feldspathic sandstone and appear to be more highly altered.

Muscovite and biotite flakes are present in approximately equal amounts in most of the sandstone and shale beds. These minerals are of clastic origin; their borders are frayed and uneven owing to abrasion during transportation. Elongate flakes commonly curve around other clastic grains; they were probably bent during deposition and compaction. The flakes are generally alined parallel to the bedding planes; in places the flakes are so abundant that rock fragments split parallel to bedding have a sheen like schistose rocks. Where the rocks are metamorphosed the micas are recrystallized to secondary muscovite and feldspar.

Typical samples of unmetamorphosed sandstones from the Antler Peak quadrangle were analyzed by rapid methods to give the composition of the Harmony Formation. The analyses are given in table 2.

The coarse-grained sandstone contains a lower percentage of aluminum and potassium than the medium-grained sandstone. This probably reflects a higher clay-mineral content in the matrix of the medium-grained sandstone. The percentage of other elements is comparable.

TABLE 2.—*Analyses of sandstones of the Harmony Formation*

[Analysts: K. E. White, P. W. Scott, H. F. Phillips, and F. S. Borris, U.S. Geol. Survey, by rapid methods]

	1	2
SiO_2	84.4	78.2
Al_2O_3	7.0	9.0
Fe_2O_3	.7	.8
FeO	1.0	2.0
MgO	.72	1.0
CaO	1.0	1.2
Na_2O	2.0	1.8
K_2O	.66	2.2
H_2O+	1.0	1.6
H_2O-	.05	.06
TiO_2	.25	.36
P_2O_5	.11	.10
MnO	.04	.06
CO_2	.82	.64
Sum	100	99

1. Feldspathic sandstone (lab. No.—53-543C; field No.—53-AP-14), medium-grained, Harmony Formation, Duck Creek, NW¼ sec. 15, T. 31 N., R. 43 E.
2. Feldspathic sandstone (lab. No.—53-545C; field No.—53-AP-16), coarse-grained Harmony Formation, Cow Canyon, NW¼ sec. 3, T. 31 N., R. 43 E.

Stratigraphic and structural relations

The Harmony Formation has been found only in the upper plate of the Dewitt thrust fault in the Antler Peak quadrangle. Therefore, its stratigraphic relations within the quadrangle are not definitely known. The formation is widely distributed throughout the Golconda and Winnemucca quadrangles (Ferguson and others, 1951a; 1952), but wherever exposed in these quadrangles it rests on thrust faults. The formation in the Antler Peak quadrangle must therefore be considered to be an allochthonous mass which has moved eastward into its present position. From evidence discussed by Roberts and Arnold (1952), it appears to have moved eastward at least 30 miles, and the total movement may be much more.

In the Hot Springs Range on the west side of the Osgood Mountains quadrangle, Hotz and Willden (1964) have found that the basal unit of the Harmony Formation is red and green shale 100 to 300 feet thick. The shale rests with apparent conformity on the Paradise Valley Chert which contains trilobites of early Late Cambrian age. Because the Hot Springs Range is separated from the Osgood Mountains by an alluviated valley, the relation of these units to the older Cambrian units in the Osgood Mountains is not known. The major structure in the Osgood Mountains is a northward-plunging anticline with the Osgood Mountain Quartzite and Preble Formation exposed in the core. The Paradise Valley Chert and overlying Harmony Formation in the Hot Springs Range would therefore be on the west flank of the anticline, in the normal position for beds of Late Cambrian age. These formations are not present on the east flank of the anticline. They are absent there owing to faulting that drops the Comus Formation of Ordovician age down against the Middle Cambrian Preble Formation, thus concealing the intervening units. To show the kinship of the Harmony and unnamed formation to the transitional assemblage, they are shown together on plate 1, but are offset slightly to indicate uncertainty as to the actual stratigraphic relation.

Conditions of deposition

The source rocks that furnished material for the Harmony Formation are not now exposed, but inferences may be drawn concerning the rock types that furnished material to the basin of deposition. Granitic rocks must have been present to furnish the feldspar—especially the microcline, microperthite, and plagioclase—and part of the quartz. The muscovite and biotite could have come from either a metamorphic or an igneous source. The quartzose grains were derived partly from quartz veins or pegmatites, and partly from quartzite and chert beds. Some of the quartzite fragments show deformation and recrystallization—to a much greater extent than the grains in the Osgood Mountain Quartzite—and they are evidently from source units more highly metamorphosed than those of the Osgood Mountain.

The freshness of the feldspars and micas and slight rounding of the minerals indicates rapid transport over a short time to the basin of deposition. The conditions of deposition are not entirely clear, however, but some inferences may be drawn from the character of the sediments. A few trilobite fragments have been found in limy beds, which signifies that the environment was marine. The predominant rock types are shaly sandstone with interbedded shale. The sandstone contains considerable argillaceous and calcareous cement, and on the whole is poorly sorted. Graded bedding is generally well developed; crossbedding and ripple marks are rare. These features all point to deposition in relatively deep water where normal wave or current action is slight or absent (Kuenen, 1953, p. 1045), and suggest that transportation by density currents was an important process in the accumulation of the Harmony Formation.

This sudden influx of clastic debris into an offshore environment suggests orogenic activity in the source area. No accurate idea of the magnitude of the orogeny or its position can be given as yet. The most likely area lies to the northwest or north.

Age and correlation

No fossils have been found in the Harmony Formation at the type locality in the Sonoma Range or in the Antler Peak quadrangle. Late in 1954, however, P. E.

Hotz collected trilobites in strata assigned to the Harmony Formation in Gough's Canyon, Osgood Mountains quadrangle. According to A. R. Palmer (written commun., 1955), the fauna is of Late Cambrian age. No other formation of similar age is known in north-central Nevada, but the Windfall Formation of the Eureka district (Nolan and others, 1956, p. 19) contains a correlative fauna.

ORDOVICIAN SYSTEM

No rocks of the transitional assemblage of Ordovician age are known in the Antler Peak quadrangle. In Edna Mountain, Ferguson, and others (1952) described the Comus Formation of Early Ordovician age, which consists of dark slate, chert, impure limestone, and quartzite. Hotz and Willden (1964) have mapped a northern continuation of these beds into the southern part of the Osgood Mountains quadrangle and found that the proportion of limestone increases and that strata of Middle Ordovician age also are present.

SILURIAN SYSTEM

No rocks of Silurian age have been mapped in the Antler Peak quadrangle, but Gilluly (Roberts and others, 1958) found Silurian graptolites in rocks of transitional aspect in the Mt. Lewis quadrangle in the Shoshone Range. These rocks include yellowish-weathering limy sandstone and platy shaly limestone estimated to aggregate about 2,000 feet.

DEVONIAN AND MISSISSIPPIAN SYSTEMS

No transitional assemblage rocks of Devonian or Mississippian ages have been recognized so far in north-central Nevada, but it seems likely that rocks of these ages were deposited throughout the region and that sedimentation continued until the beginning of orogenic movements, probably in Late Devonian time.

OVERLAP ASSEMBLAGE

Ferguson (1924, p. 37) was the first to discuss late Paleozoic orogeny in Nevada when he described the unconformable contact between Permian rocks and folded and eroded Ordovician rocks in the Manhattan area. Later Ferguson and Cathcart (cited in Nolan, 1938, p. 158) reported late Paleozoic orogeny in the Candelaria Hills in the Hawthorne quadrangle. Nolan (1928, p. 158; 1943, p. 171–172) showed that this orogeny was related to geanticlinal warping on an axis extending northward through Nevada between the 116° and 117° meridians (see Nolan, 1943, fig. 12). The geanticlinal axis was the site of major orogeny during Late Devonian to Early Pennsylvanian time which ultimately divided the former broad geosyncline into two distinct seaways.

Roberts (1949b) proposed that this orogeny be called the Antler orogeny, and the orogenic belt was named the Antler orogenic belt (see fig. 3, inset map). The orogeny brought to an end the geosynclinal cycle that had persisted in central and western Nevada from Cambrian to Late Devonian time and ushered in a new cycle. Coarse clastic rocks derived from the orogenic belt were deposited to the east and west; overlapped the carbonate, transitional, and siliceous and volcanic assemblage rocks on the flanks of the belt; and locally accumulated within the belt. Roberts and Lehner (1955) proposed that these clastic rocks be called the overlap assemblage. In the zone of acute orogeny, the overlap assemblage rests with pronounced angular unconformity upon the folded rocks; away from the orogenic belt the unconformity gradually fades out with increasing distance, and the coarseness of the sediments is the only clear-cut evidence of the orogeny.

The basal beds in the overlap assemblage are coarse conglomerate near and within the orogenic belt and grade laterally and upward into finer conglomerate and sandstone, then into silts, clays, and limestone. In fact, the coarse clastic beds may be terrestrial in part where they were deposited within the orogenic belt, but they were mainly formed in a marine environment adjacent to the belt. At times the belt may have been largely submerged, for widespread marine limestone units interfinger with clastic rocks. The lenticular nature of the larger units of the overlap assemblage, however, indicates deposition in many separate basins, possibly in a series of straits separated by peninsulas and islands. Local deposition of coarse clastic rocks throughout the early part of the Pennsylvanian indicates continued orogenic activity.

In Eureka County near Carlin, coarse conglomerates were being deposited during Early Mississippian time. By Early Pennsylvanian time limestone was being formed near Carlin, and the area of conglomerate deposition had shifted to the west in the Battle Mountain area. In the Late Pennsylvanian and Early Permian, limestone was being formed in the Battle Mountain and surrounding areas; indicating lower relief in the emergent area, and westward migration of the basin of deposition.

The full extent of the clastic apron derived from the orogenic belt is not yet known. James (1954) reports pebbly sandstone in the southern Egan Range near Ely. Dott (1955) has discussed the regional distribution of Upper Mississippian, Pennsylvanian, and Permian rocks in northeastern Nevada, pointing out that the clastic rocks of these ages make up a significant part of the section. Ball (1907, p. 120–121) reports sandstone and pebbly sandstone 800 to 1,000 feet thick in the Belted Range about 35 miles northeast of

Beatty. Westgate and Knopf (1932, p. 21) described the Scotty Wash Quartzite about 1,000 feet thick near Pioche. Sharp (1942, p. 669–670), mentions chert pebble conglomerate 4,000 to 10,000 feet thick in the southern Ruby Mountains. K. P. Bushnell (oral commun., 1956) reports thick clastic units of Pennsylvanian age at Gold Creek near Mountain City. These occurrences indicate that the clastic apron covered much of eastern Nevada. Less is known of the Post-Mississippian stratigraphy of western Nevada. During Late Mississippian and Early Pennsylvanian, erosion of the orogenic belt resulted in deposition of clastic rocks to the west. The best clues as to the history of western Nevada during the late Paleozoic are to be found in the thrust plates of Paleozoic rocks which moved eastward during Late Permian time.

As the lithology of the overlap assemblage is markedly different from place to place, various names have been given to correlative units. In order to more conveniently discuss the local sequences, they have been designated by locality names (Roberts and others, 1958). In the east, the name Eureka-Carlin sequence has been used; it includes the Chainman and Diamond Peak Formations, Ely Limestone, and Carbon Ridge and Garden Valley Formations in the Eureka area; and the Tonka, Moleen and Tomera, Strathearn, and unnamed permian rocks of Dott in the Carlin area (Dott, 1955). In the west, the name Antler sequence is used to include the Battle Formation, Highway Limestone, Antler Peak Limestone, and Edna Mountain Formation. Because of local variations in source areas, conditions of deposition, and the subsequent history of these rocks, precise correlations of the units in the different sequences cannot be made. Regional lithologic similarities indicate, however, that similar environmental conditions, prevailed over broad areas.

ANTLER SEQUENCE

The Antler sequence in Battle Mountain includes three units, the Battle Formation, the Antler Peak Limestone, and the Edna Mountain Formation. The Battle Formation of Middle Pennsylvanian (Atoka) age is composed mainly of coarse conglomerate and sandstone and some thin limestone beds in the upper part. The Antler Peak Limestone of Late Pennsylvanian and early Permian age consists largely of massive limestone containing a few shaly and sandy layers. The Edna Mountain Formation of Late Permian age is composed of interbedded limy shale, limestone, sandstone, and a little chert conglomerate. These formations are separated by erosional breaks, but form a conformable sequence that rests with angular unconformity upon rocks of the siliceous and volcanic and transitional assemblages. The Antler sequence is therefore an autochthonous sequence, deposited within the Antler orogenic belt during postorogenic submergence.

730–670 O—64——3

BATTLE FORMATION

The Battle Formation is a unit of great regional importance; its coarse boulder beds resting unconformably on rocks of both the transitional and siliceous and volcanic assemblages gave the first clear-cut evidence of major Paleozoic orogeny in Battle Mountain. In addition, the Battle Formation is the host rock for the most productive primary ore deposits in the quadrangle. The type locality of the Battle Formation is the east slope of Antler Peak, and the formation was named after Battle Mountain (figs. 2, 33).

The Battle Formation is exposed in three areas: the principal one, a belt ranging from 100 feet to 1 mile in width, extends from the southeast edge of the range with minor interruptions to the northwest edge of the range; the other two consist of several small erosional remnants in the vicinity of Copper Basin and a small outcrop in a narrow fault sliver in Rocky Canyon. The principal belt of outcrops has an erratic exposure pattern owing to displacement on faults. The best exposures are southeast of Antler Peak on the west side of Cow Canyon, a tributary of Galena Canyon, where the lower two-thirds of the formation makes nearly vertical cliffs (fig. 33). The upper third of the formation crops out on the north and east slopes of Antler Peak (fig. 2). These exposures aggregate about 730 feet in thickness and are designated as the type section.

In Copper Basin the Battle Formation has been complexly faulted and only small erosional remnants remain. The thickest part of the section appears to be on the ridge northwest of the Copper King mine, where the beds, chiefly conglomerate, total about 150 feet in thickness.

The narrow outcrop of the Battle Formation near the head of Rocky Canyon is in a fault sliver. The exposures are not continuous, but the formation can be traced about a thousand feet by float.

Lithology

At the type locality the Battle Formation is composed chiefly of interbedded conglomerate and sandstone, together with some shale, calcareous shale, and limestone. These beds are highly resistant to weathering, and throughout most of the quadrangle the formation is generally well exposed where it is present. For purposes of description, the formation has been divided into three parts.

The lower part (398 ft thick) is medium- to thick-bedded conglomerate, characteristically medium to deep red where unmetamorphosed. The rock fragments are poorly sorted; they range from boulder to granule size in a sandy to silty matrix containing iron oxide and locally calcite cement. The rock types found include sandstone, quartzite, chert, limestone, greenstone, and jasper. For the most part, the fragments can be classed as subangular, but in places they are subrounded to well rounded (figs. 12 and 13).

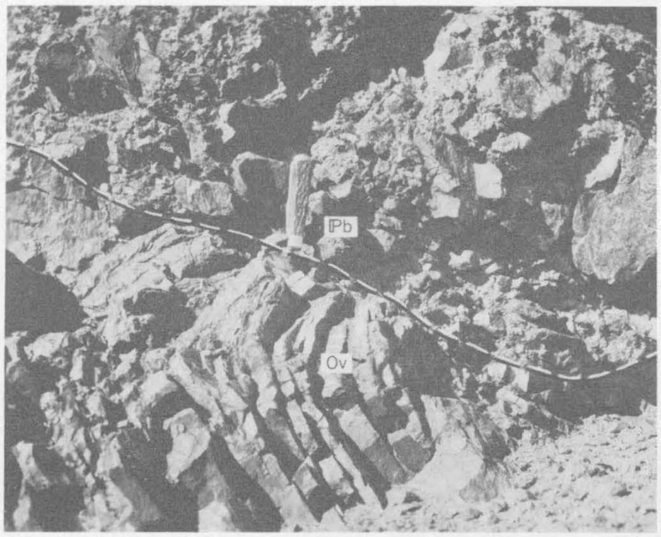


FIGURE 12.—Base of Battle Formation (Pb) resting with angular unconformity on chert of the Valmy Formation (Ov) at the head of Cottonwood Canyon.

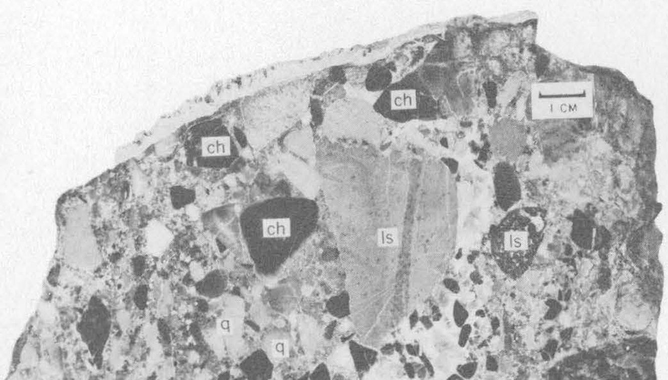


FIGURE 13.—Conglomerate of the Battle Formation made up of pebbles of limestone (ls), chert (ch), and quartzite (q). The chert and quartzite were derived from the Valmy Formation. The source of the limestone is uncertain.

Locally, plant fragments have been found near the base of the lower unit. Features such as current bedding and torrential bedding are found in places in the lower part of the formation, but are not common. They usually are restricted to a single bed or group of beds and indicate minor variations in conditions of deposition. The beds in the upper part of the lower unit show better sorting and are more uniform than in the lower part and include fewer boulder beds. Cobble and pebble conglomerate beds and sandstone are predominant; some shaly beds are present.

The middle part (74 ft thick) consists largely of pebble and granule conglomerate interbedded with sandstone, shale, calcareous shale, and limestone. The conglomerates and sandstones are generally lighter red than the lower beds and show better sorting. The shale and calcareous shale are light red, yellow, brown, or buff. The limestone is gray to buff and commonly has a sugary texture; limestone beds grade into calcareous sandstone and shale along the strike. Most of the fossils thus far discovered are in the middle part.

The upper part (258 ft thick) is composed of interbedded fine sandstones, pebble conglomerate, and shaly layers, locally calcareous. The sandstones are mostly red, yellow, and buff and are commonly coarse grained. The pebble conglomerates are composed mainly of subangular to rounded quartzite, chert, and jasper pebbles. The shaly layers, which predominate in the upper part, are mostly reddish to buff and contain limy lenses. Only a few fossils have been found in the upper unit.

The lithology of the formation in the vicinity of Copper Basin is locally obscured by contact metamorphism and subsequent hydrothermal alteration, which have silicified the conglomerate and leached it light gray. It is mostly composed of pebble and granule conglomerate with a few cobble beds, interlayered with sandstone. Commonly it is medium to thick bedded and is generally well stratified. The fragments are subangular and subrounded for the most part and are embedded in a sandy matrix. Part of the material is sandstone and argillite derived from the underlying Harmony Formation, but most of the cobbles, pebbles, and granules were derived from the more resistant chert and quartzite units of the Scott Canyon and Valmy Formations.

No single exposure shows a continuous section of the formation. Accordingly, a composite section was measured at the type locality. Section A represents the upper part of the type section on the southeast side of Antler Peak. Section B represents the lower part of the type section at the head of Cow Canyon.

Composite section of the Battle Formation

Section A, measured 500 feet southeast of Antler Peak (pl. 4)

	Feet
Shale, siltstone, fine sandstone; red, thin-bedded. Shale layers average one-eighth to one-fourth inch thick. Upper beds are red, yellow, and brown calcareous shale	140
Conglomerate, light brick-red. Pebbles chiefly chert, quartzite, and some limestone in coarse sandy matrix	98
Sandstone, pebbly sandstone, shale, and limy shale. Sandstone, light to dark reddish-brown grading into yellow sandstone at top, thin- to medium-bedded, containing limy nodules and layers. Shale and limy shale, gray to yellowish, thin-bedded	20
Total, upper part	258

Section B, measured due east from ¼ cor. between secs. 3 and 4, T. 31 N., R. 43 E.

	Feet
Break in section.	
Limestone, light-gray with abundant fossil fragments including crinoid stems, brachiopods, and gastropods	6
Conglomerate, siliceous shale, and sandstone. Siliceous shale, red, green, and gray, locally calcareous. Conglomerate, generally leached gray; massive to thick-bedded. Sandstone, red, fine to coarse, in beds 2 to 24 inches thick; thin-bedded near top. Sandstone grades laterally into siliceous shale, and pebbly sandstone into conglomerate	60
Limestone, reddish-gray, mottled red brown in places in medium to thick beds with wavy bedding; grades into reddish-yellow shale and sandstone at base and top; contains *Productus*, *Fusulinella*, and *Chaetetes*	8
Total, middle part	74
Conglomerate and sandstone. Conglomerate, reddish-brown, medium- to thick-bedded; pebbles and cobbles chiefly gray, red, and brown chert, some quartzite; well bedded for most part; generally good sorting. Sandstone, pale to dark reddish-brown, generally thin- to medium-bedded; locally calcareous. Sandstone and conglomerate interfinger along the strike	97
Conglomerate, reddish-brown, thick-bedded. Cobbles, pebbles, and boulders of gray, green, brown, and white chert, quartzite, and sandstone. In places contains sandy partings and layers of thin-bedded reddish-brown and green sandstone. Generally well bedded, but not well sorted	147
Conglomerate and sandstone. Conglomerate boulders, cobbles, and pebbles of sandstone, limestone, greenstone, chert, and quartzite. Boulders up to 3 feet in diameter, commonly angular, poorly sorted. Matrix pebbly sandstone; cement calcareous, ferruginous, and argillaceous; lenticular bedding; in places calcareous, shaly. Sandstone, reddish-brown, generally well bedded; locally shows torrential crossbedding	68
Conglomerate, medium to dark reddish-brown, thick-bedded to massive. Conglomerate contains boulders, cobbles, and pebbles of sandstone, quartzite, chert, limestone, and greenstone. Boulders up to 3 feet in diameter, commonly angular to subangular. Torrential crossbedding common; sorting poor except in pebble conglomerate. Matrix is reddish-brown sandstone with calcareous, ferruginous and argillaceous cement; locally contains plant fragments	86
Total, lower part	398
Unconformity.	
Base, folded strata of Harmony Formation.	
Total, Battle Formation	730

The Battle Formation is the host of the principal ore bodies in the Copper Canyon area. Because the chemical composition of the rocks was partly responsible for localization of the ore, representative samples of unaltered conglomerate and shale were analyzed to determine their initial composition. The analyses are given in table 3. The two specimens analyzed are highly calcareous and contain a considerable amount of clay minerals. The lower conglomerate is distinctly more ferruginous, owing largely to ferric iron oxide in the cement. The middle shale has a somewhat higher ferrous iron content. The calcium and magnesium content of the shale is higher than that of the conglomerate, and the CO_2 content is correspondingly higher indicating that these elements are mainly in the carbonate. The other constituents are normal for rocks of these kinds except for potash, which seems to be abnormally high. The potash is probably in clay minerals in the cementing material of the two rocks.

TABLE 3.—*Analyses of calcareous conglomerate and shale from the Battle Formation, Antler Peak quadrangle, Nevada*

[Analysts: K. E. White, H. F. Phillips, P. W. Scott, and F. S. Borris, U.S. Geol. Survey, by rapid methods.]

	1	2
SiO_2	62.0	53.0
Al_2O_3	6.6	7.8
Fe_2O_3	4.1	1.4
FeO	.81	1.7
MgO	2.8	4.6
CaO	9.6	13.2
Na_2O	.14	.20
K_2O	1.8	3.2
H_2O+	2.0	2.3
H_2O-	.11	.10
TiO_2	.80	.46
P_2O_5	.18	.23
MnO	.13	.08
CO_2	7.5	10.3
Sum	99	99

1. Conglomerate (lab. No.—53-544C; field No.—53-AP-15) from lower member, Battle Formation, SW¼ sec. 15, T. 31 N., R. 43 E.
2. Calcareous shale (lab. No.—53-546C; field No.—53-AP-18) from middle member, Battle Formation, NW¼ sec. 22, T. 31 N., R. 43 E.

Stratigraphic relations

The Battle Formation rests unconformably on rocks of the Scott Canyon, Valmy, and Harmony Formations. The unconformity is marked by angular discordance throughout the quadrangle, for the Battle Formation in most areas dips gently westward, and the older units were highly folded and thrust faulted prior to the deposition of the Battle Formation (fig. 12).

Where the Battle Formation rests on rocks of the Harmony Formation, the lower beds of the former contain a large proportion of boulders of Harmony sandstone in a matrix of sand grains also derived from the Harmony Formation. In addition, pebbles of greenstone, quartzite, chert, and jasper, presumably derived from the Scott Canyon and Valmy Formations, and pebbles of reddish and yellowish shaly limestone of unknown origin are also present. Where the Battle Formation rests on rocks of the Scott Canyon and Valmy Formations in the northwestern part of the quadrangle, the basal beds contain chert and quartzite pebbles derived directly from these formations (fig. 13). The conglomeratic beds in the middle unit contain a greater proportion of chert and quartzite pebbles, and in the upper unit the conglomerate beds are made up almost entirely of chert and quartzite. This indicates that either the sources of rocks other than chert and quartzite were eroded as time went on, or that they were gradually covered by the overlapping conglomerate beds. The upper Battle beds locally contain gray crystalline limestone pebbles which are similar in lithology to the limestone units interbedded in the Battle Formation; some of these pebbles contain fossils, but those found thus far are too fragmentary for age determination.

The Battle Formation originally was probably highly variable in thickness. The deepest part of the basin of accumulation in this area was apparently near Galena; from there the formation appears to thin to the northwest and north, either mostly because of nondeposition or in part perhaps because of erosion prior to the deposition of overlying units. To the northwest, the thinning seems to have been mainly in the lower units, for the limestone units of the upper part of the section are still present in the headwaters of Cottonwood Canyon. The lower units seem to end successively northwestward, possibly owing to overlap on a seaward-sloping land area; at the northwesternmost outcrop in the quadrangle, near the Marigold mine, the Battle Formation is only 50 to 200 feet thick.

In Copper Canyon, as at the type locality, the Battle Formation has been subdivided into three units. These units, in general, correspond with those of the type section, but are probably not precisely correlative because contact metamorphism and hydrothermal alteration at Copper Canyon have changed the color and general appearance of the rocks. The lowest unit, about 120 feet thick, at Copper Canyon is a chloritic conglomerate which was derived from a calcareous conglomerate. It is overlain by calcareous and siliceous hornfels about 150 feet thick, which was derived from the middle unit. The upper unit is composed of interbedded quartzite conglomerate, quartzite, and siliceous hornfels; its top is not exposed in the workings and its thickness cannot be measured but is estimated to be more than 300 feet.

Origin

The Battle conglomerate is a striking and distinctive lithologic unit. Hague and Emmons (1877, p. 688) referred to it as follows: "A prominent stratum consists of a coarse conglomerate of quartz and jasper pebbles, held firmly together by a binding material of fine ferruginous sand." Lawson (1913, p. 328, 329, 330, 332) described the formation in more detail, and discussed the genesis of the unit as follows:

> Resting unconformably on the upturned edges of these strata [Harmony Formation], and occurring chiefly as a mesa-like cap on various hilltops, is a later formation composed of angular fragments of the underlying rocks, but so thoroughly silicified and cemented that it is one of the hardest and most resistant formations of the district. * * * Except for the fact that it is thoroughly cemented and indurated, the rock is very similar to the detritus which flanks the margins of the mountain in the form of alluvial fans. There can be little doubt but that the formation is the remnant of an alluvial fan deposit spread over the region in the remote past. * * * I hesitate to call the rock a conglomerate because that * * * suggests an erroneous conception of the mode of deposit and the climatic conditions which determined that mode. * * * I propose that this and similar rocks be known as fanglomerate. * * * In defining the term I must first make clear that it is not intended to include the finer sediments on the lower flanks of alluvial fans, but only the coarser deposits in the upper parts. * * * In many alluvial fans the constituent blocks are of extraordinary size near the apex, and sporadic blocks several feet in diameter are by no means uncommon far down the slope where the average size of the fragments may be less than an inch. * * * Apart from its interest as a type of sedimentary rock the fanglomerate of Battle Mountain is significant of the existence of conditions in the far past similar to those which prevail in the Great Basin today. Those conditions are bold relief and aridity. * * * Bold relief is the immediate result of acute diastrophism.

Thus the term "fanglomerate" came into existence, and it has been widely used since then to designate rocks that generally conform to Lawson's definition. Judging from Lawson's description, he visited localities only in Copper Basin where the Battle Formation is exposed. Here it is medium- to thick-bedded conglomerate made up of subangular to rounded chert, sandstone, and some limestone cobbles and pebbles in a silicified sandy matrix. The conglomerate is for the most part well bedded; channeling, crossbedding, and similar features are rare.

Parts of the basal unit of the Battle Formation have features that bring to mind the deposits in present-day fans. The material in this basal unit shows poor sorting and some crossbedding, current bedding, channeling, and abrupt changes in lithology. Study of the formation on a regional basis, however, gives a somewhat different impression. Taken as a whole, the middle and upper units of the Battle Formation contain a large proportion of marine beds. Therefore, it seems likely that the formation was deposited under a combination of marine and terrestrial conditions.

Some clues to the conditions of deposition can be obtained from the textures and structures of the rocks. In the lower beds the rock fragments are mostly subangular and subrounded; crossbedding, current bedding, and channeling are present in places but characteristic of only a few beds. On the whole, the bedding is uniform and tends to be gradational from one bed to another without abrupt changes. The sorting is poor in the lowest beds, which were probably deposited by streams of high competency adjacent to a rugged upland. The sorting becomes fair to good stratigraphically upward, suggesting that relief in the source area gradually diminished.

The source area was comparatively close, judging from the coarseness and angularity of the material and relative fragility of some of the limestone, greenstone, and sandstone fragments. In addition, erosion and transport probably were rapid, because unweathered rock was carried by the streams. The climate in the upland was probably hot and humid with seasonal rainfall (lateritic conditions) as is indicated by iron oxide cement in part of the conglomerate (Krynine, 1938). The conglomerates exhibit some of the features of sedimentary rocks related to faulting (Longwell, 1937, p. 440) and seem comparable to some of the Triassic rocks in New England.

Merriam and Berthiaume (1943, p. 149, 165) noted a boulder conglomerate in the Pennsylvanian rocks of central Oregon, which are associated with plant-bearing rocks as well as marine facies. They considered that the conglomerate was deposited on a delta plain by streams of great carrying power during flood periods; crustal instability caused oscillation from subaerial to estuarine or marine conditions. Similar oscillations probably took place in the basin where the Battle Formation was deposited.

Age and correlation

The faunas from the Battle Formation have been assigned to the Atoka Epoch of the Pennsylvanian by L. G. Henbest and R. C. Douglass (written commun., 1953), who wrote as follows concerning the fauna:

USGS f6085—Pennsylvanian, Battle Formation (type locality), limestone lens in conglomerate. Antler Peak quadrangle, Nevada; half a mile S. 35° E. from Antler Peak, sec. 3, T. 31, N., R. 43 E. Collected by L. G. Henbest, R. J. Roberts

Hydrozoan(?) (Atokan and early Des Moines fossil)
Climacammina sp. (common)
Endothyra sp. (common)
Bradyina sp. (common)
Tetrataxis sp. present
Fusulinella sp. present
Chaetetes sp. (loose specimen collected by Roberts)

At the outcrop *Fusulinella* sp. and *Chaetetes* sp. were recognized and determined as representing Atoka age. Subsequently several thin sections have been prepared because of occasion to refer to this formation and fauna (Henbest to Nolan 7/20/51, p. 9; and Douglass to Hotz 2/24/53) and F9668 below. The more comprehensive list of species supports the original determination.

Areas underlain by rocks assigned to the Battle Formation in Edna Mountain have been described by Ferguson and others (1952). Here the Battle Formation is a thin, lenticular conglomerate 20 to 100 feet thick. It is overlain by about 300 feet of limestone and interbedded conglomerate that has been named the Highway Limestone; the limestone beds contain a fauna similar to the fauna collected from the limestone beds about 400 feet above the base of the Battle Formation at the type locality. The Highway Limestone therefore appears to be a limestone facies equivalent to the middle and upper parts of the Battle Formation that was deposited in a basin receiving little clastic material. In figure 14 this relation is shown diagrammatically.

In the Osgood Mountains, S. W. Hobbs, P. E. Hotz, and Ronald Willden studied rocks that have been assigned to the Battle Formation. Hobbs (1948) did not describe the section in detail, but Hotz and Willden (1964) state that on Lone Mountain on the east side of the range more than 200 feet of conglomerate and limestone is present that is probably correlative with the Battle Formation. In addition, Hotz has found small, discontinuous outcrops of conglomerate and limestone that probably belong to the Battle Formation and Highway Limestone in highly faulted areas on the west side of the Osgood Mountains.

James Gilluly (oral commun., 1954) has mapped thrust slices containing masses of conglomerate in the Shoshone Range east of the Battle Mountain Range (Mount Lewis quadrangle). No fossils have been found in these units, but on the basis of lithologic similarity and the fact that they underlie Antler Peak Limestone, they are correlated with the Battle Mountain Formation.

The correlatives of the Battle Formation in eastern Nevada are mainly carbonate formations such as the

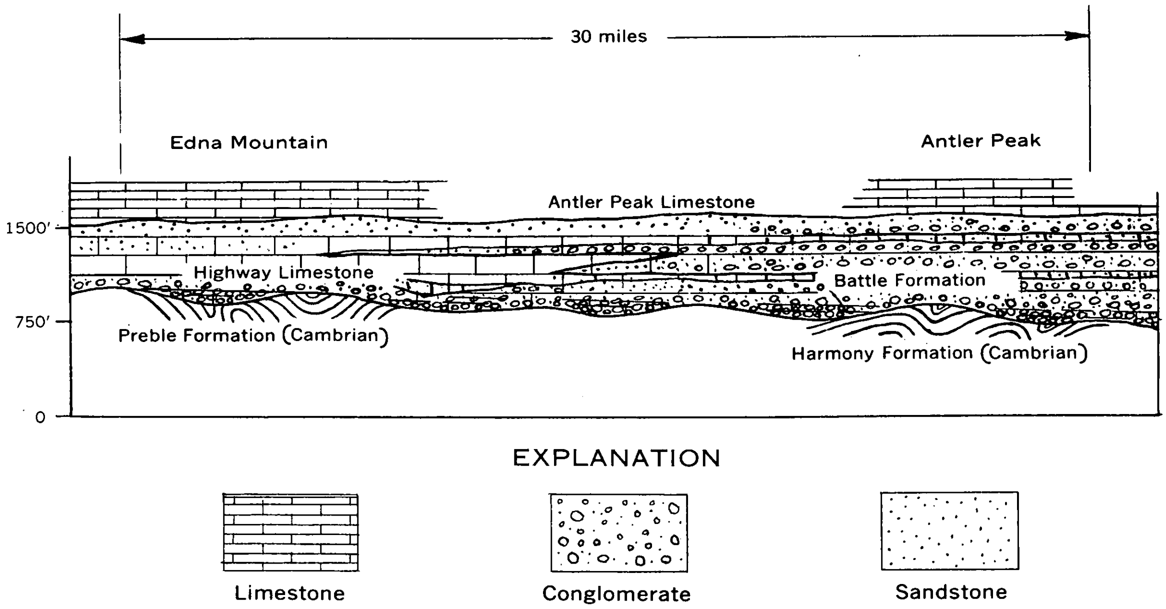


FIGURE 14.—East-west section showing relation of Highway Limestone to Battle Formation.

Ely Limestone (Lawson, 1906, p. 295; Spencer, 1917, p. 27) and the Bird Spring Formation (Longwell and Dunbar, 1936, p. 1204). The Ely Limestone is nearly free of clastic interbeds in the Ely district, but in the Eureka area it contains layers of sandstone and locally conglomerate (Nolan and others, 1956, p. 62) near the base. The faunas in the upper part of the Ely Limestone contain fusulinids of early Middle Pennsylvanian (Atoka) age according to L. G. Henbest (cited in Nolan and others, 1956, p. 63). These fossils are approximately correlative with the fauna of the Battle Formation. Dott (1955, p. 2234) has described the Moleen and Tomera Formations in the Elko area as being virtually equivalent to the Ely limestone. His Moleen Formation is 1,270 feet thick at the type locality and consists of limestone, in part sandy and shaly with a few sandstone and conglomerate beds; the proportion of clastic rocks increases westward; correlative beds in Carlin Canyon, 5 miles to the west, contain prominent conglomerate and sandstone, and silt interbeds (Kay, 1952). Dott's Tomera Formation of Middle Pennsylvanian age, 1,700 to 2,000 feet thick, overlies the Moleen Formation and is composed of chert-pebble conglomerate and interbedded limestone. The Tomera contains fusulinids of late Atoka and early Des Moines time and is correlative with the upper part of the Ely Formation in the Eureka area. The time span of the faunas in the Battle Formation is not known, but the *Fusulinella-Chaetetes* zone about 400 feet above the base is apparently equivalent with the upper part of the Moleen Formation. Des Moines time is not represented by beds in the section at Antler Peak and presumably was an interval of erosion of nondeposition.

ANTLER PEAK LIMESTONE

The Antler Peak Limestone, which underlies Antler Peak, the second highest point in the quadrangle, is the only thick extensive limestone unit in the area (fig. 2). It is the middle unit of the Antler sequence of the overlap assemblage, which formerly covered most of north-central Nevada. The Antler Peak Limestone is a distinctive unit; it is easily recognizable even where found in small fault slivers. Moreover, it contains a distinctive fusulinid and coral fauna that has permitted accurate dating of the unit and widespread correlation with units in other parts of Nevada.

The Antler Peak Limestone is best exposed on Antler Peak, where the type section is located. Outcrops of the limestone extend from this area northwestward 2 miles to the headwaters of Cottonwood Creek and southeastward to Galena; the outcrop belt has a maximum width of a little more than a mile in secs. 32 and 33, T. 32 N., R. 43 E., at the head of Willow Creek; in places the limestone has been cut out entirely by faulting. Two isolated exposures are present along the strike of the belt to the south in Copper Canyon, one on the east side of the canyon near the range front and the other at the Nevada mine. There are three more exposures in the northern part of the range near the Marigold mine, and two slivers were mapped in the headwaters of Rocky Canyon. Elsewhere, to the west, the limestone is cut out by the overriding Golconda thrust fault probably of Permian age. Another belt of Antler Peak Limestone is on the east side of Copper Basin. The formation extends northward for 3 miles underneath the quartz latite that caps Elephant Head and has a width of nearly 2 miles at the Copper King mine, where it extends east beyond the quadrangle to the edge of the range.

Because of the varying resistance to erosion of the members of the Antler Peak Limestone, the outcrops show steplike breaks and the slopes are divided into alternating treads and risers. Where the beds are nearly horizontal or dip into the slopes, the treads are narrow and the risers are clifflike, ranging from a few feet to 50 feet in height. Locally, as on the southeast slope of Antler Peak where faulting has repeated massive members, cliffs 100 feet or higher have been formed.

Lithology

The Antler Peak Limestone in the Antler Peak quadrangle consists of medium- to thick-bedded limestone beds ranging from 15 to 155 feet in thickness. The limestone is light to dark gray and black and commonly weathers medium gray. Some of the limestone beds contain discontinuous beds and nodules of chert. Interbedded shaly limestone and shale are found at a few places in the section; these units are generally light gray to brown and weather tan to brown. Some limestone beds are sandy or pebbly. The sand grains and pebbles are mostly chert and quartz or quartzite and probably were derived from the same source rocks that furnished the clastic material to the Battle Formation.

The section at Antler Peak was measured in detail; the lower two-thirds of the formation was measured on the south slope of Antler Peak, and the upper one-third on the west side. The formation has been divided into 12 units, which are listed in descending order.

Section of the Antler Peak Limestone on Antler Peak

		Feet
Erosion surface.		
O.	Limestone and shaly limestone, banded light-gray to dark-gray and buff; weathers to brown, brownish gray, and yellowish brown. Lower 60 feet of beds characteristically have striped appearance; contain abundant small brachiopods and conglomerate and intraformational limestone conglomerate up to 40 feet thick near middle of unit; local crossbedding in sandy and shaly layers	155
N.	Limestone, light-gray, thick-bedded to massive; sandy partings which weather in relief; upper beds sandy and pebbly in places. Lower beds form cliff as much as 80 feet high	140
M.	Limestone, medium-gray, and conglomeratic, generally crossbedded. Basal layers contain well-rounded chert and quartzite granules and pebbles in sandy limestone matrix. Upper beds sandy and shaly, form smooth slopes	40

Section of the Antler Peak Limestone on Antler Peak—Continued

		Feet
L.	Limestone, dark-gray; gray sandy limestone in central part. Wavy bedding. Contains *Syringopora* sp. in upper part. In places forms cliff	25
K.	Shale, light greenish-gray and brown, shaly limestone at base. Forms smooth slope above limestone; in places forms nearly flat terrace	20
J.	Limestone, gray, thin-bedded; thin cherty bands at top. Lower 4 feet sandy limestone, less resistant than upper	15
I.	Limestone, lower 20 feet thin-bedded, dark-gray, cherty with brown-weathering shaly limestone at base; chert concretions locally, small and irregular. Upper 50 feet gray, brown-weathering, shaly and sandy limestone; platy parting in places. Generally forms cliffs made up of many narrow treads and steep risers	70
H.	Limestone, thin- to medium-bedded, gray, brown-weathering. Generally forms smooth slope	10
G.	Limestone, medium- to thick-bedded, dark blue-gray. Forms cliffs up to 40 feet high. Wavy bedding; in places contains shaly partings 4 to 12 inches apart. Contains chert nodules scattered throughout the unit. Silicified *Caninia* bed at base	45
F.	Limestone, medium- to thick-bedded, dark-gray. Shaly parting 6 inches thick at base. Chert nodules and layers occur in some beds, but are nowhere abundant. *Syringopora* and *Caninia* 5 feet below top. Beds form irregular outcrops	20
E.	Limestone, thin- to medium-bedded, light-gray to brownish-gray, shaly. Thin beds generally separated by shaly partings which weather brown. Near center of bed fusulinids (*Triticites* sp.) and associated fossils abundant. Wavy bedding; chert nodules in upper part. Forms smooth slope, broken by minor steps	25
A–D.	Limestone, brownish-gray, brown-weathering, thick-bedded, interbedded with sandy limestone. Upper beds show crossbedding in places. Two beds at base contain abundant *Caninia*-type corals. Forms prominent ledge	60
	Total	625

In the Copper Basin area, the lower beds of the Antler Peak Limestone are absent. No detailed section has been measured there, but careful comparison disclosed that the lowest beds are in unit G of the section at Antler Peak; unit M is well developed in Copper Basin and so are the overlying units N and O. Higher beds than the O unit are present just east of the edge of the quadrangle, where the O beds grade into shaly limestone and shale not found in the section at Antler Peak. These upper shaly beds weather buff to darker shades of brown. The section in Copper Basin as given by H. G. Ferguson (written commun., 1951) is as follows:

Section of Antler Peak Limestone in Copper Basin

		Feet (estimated)
Q.	Limestone, gray, thin-bedded and shaly in places; irregularly mottled with chert; locally dolomitic	300
P.	Limestone, brown, shaly; poorly exposed	100
O.	Not exposed. Float of bluish-gray shaly quartzite and shale	50
N.	Limestone and dolomite, thin-bedded, gray with brown chert lenses and layers. Upper part poorly exposed, but calcareous sandstone, chert, and quartzite conglomerate float noted	270
M.	Limestone, gray, massive, sandy and pebbly layers	30
L.	Not exposed.	
K.	Limestone, gray and brown, thin-bedded; sandy limestone and calcareous shale in lower part. Irregular brown chert layers abundant near top	500
J.	Limestone, brown, shaly, thin-bedded	50
I.	Limestone and dolomite(?), gray; cherty near top	100
H.	Limestone, brown, blocky, and thin-bedded; some calcareous shale interbeds	50
G.	Limestone, shaly, poorly exposed	300
Base:	Conglomerate of Battle Formation.	
	Total	1,750

To obtain an idea of the purity of the Antler Peak Limestone, a sample was collected from the N unit in Copper Basin. This sample (lab. No.—145669; field No.—55AP4) was analyzed by P. L. D. Elmore, K. E. White, and S. D. Botts, of the U.S. Geological Survey with the following results:

SiO_2	6.1
Al_2O_3	.36
Fe_2O_3 } FeO	.20
MgO	.52
CaO	52.3
Na_2O	.08
K_2O	.08
TiO_2	.02
P_2O_5	.04
MnO	.00
H_2O	.40
CO_2	40.1
Sum	100
BaO	
Total S as S	.02
Sp gr (powder)	2.68

In the Sonoma Range the Battle Formation and Highway Limestone are absent (Ferguson and others, 1951a), and the Antler Peak Limestone rests directly on the Harmony Formation in Clear Creek Canyon. The basal beds of the Antler Peak Limestone are absent in this area; the lowest unit on the west side of Clear Creek is probably equivalent to beds about 100 feet above the base at the type locality. Other exposures of Antler Peak Limestone are so incomplete that no sections were measured. The lithology and faunas of these exposures are similar to those of the type section, indicating that the conditions of deposition were similar throughout the belt.

Conditions of deposition

The fauna of the Antler Peak Limestone indicates deposition in a marine shallow water environment. The basal units are shaly but grade upward into limestone containing only thin cherty, shaly, sandy, or pebbly layers. The highest beds, which are exposed only in the Copper Basin area, are characterized by a dwarf fauna, which indicates shallowing of the basin of deposition and possibly a change to brackish water conditions.

A long interval of nondeposition followed Antler Peak time; it lasted from Early Permian (Wolfcamp) to early Late Permian (Word or Guadalupe) when the Edna Mountain Formation overlapped the area. The area probably remained near sea level most of this time, though at times parts of the area may have been uplifted above sea level and eroded.

The Antler Peak Limestone rests with paraconformity on the Battle Formation at the type locality on Antler Peak (Dunbar and Rodgers, 1957, p. 119). The basal beds of the Antler Peak in the central part of Edna Mountain contain the same fauna as at the type locality, but rest on the Highway Limestone in that area. On the west side of Edna Mountain, the Highway is missing and the Antler Peak Limestone rests with angular unconformity directly on folded rocks of Cambrian age. The Highway Limestone probably covered this area, but was eroded prior to Antler Peak time.

Age and correlation

The Antler Peak Limestone was first designated as Carboniferous by geologists of the 40th Parallel Survey (King, 1878, p. 670). King collected the following fossils from Willow Creek at Battle Mountain:

	Equivalent modern name
Productus semireticulatus	*Dictyoclostus semireticulatus*
prattenianus	*Linoproductus prattenianus*
Eumetria punctulifera	*Hustedia mormoni*
Athryis incrassata	*Composita* sp.

About 100 feet below the summit of Antler Peak, the following fossils also are listed as having been collected by King:

Fusulina cylindrica
Campophyllum sp.?

In 1940, the late James Steele Williams of the U.S. Geological Survey visited the Antler Peak quadrangle with the author and collected fossils from several localities. Williams wrote (1949) as follows:

> Other duties have prevented me from making more than a cursory examination of most of these collections, and I have not been able to study others at all. I have recently started on a more comprehensive study of all the collections from this and adjoining areas and hope to have more definite data soon.

Soon after I first visited this general region in 1938 on the basis of the study of a limited number of collections I agreed with Mr. Henbest in assigning the age of the formation as late Pennsylvanian. Later in 1945 I noted in a memorandum to Mr. Ferguson that I had in mind that the fauna may be as young as Wolfcamp in age. The age designation will have to rest in this uncertain [Pennsylvanian and (or) Early Permian] category until I have had more time to study the fauna.

The fauna has several species and genera of productoid brachiopods, several species of spiriferoid brachiopods, chonetids, and other brachiopods. Many of these belong to new or little known species, and I should not like to attempt to name them without more study. In addition, there is a considerable coral element in the fauna. Miss Helen Duncan, who is studying it, has recognized large *Caninia*, syringoporoids, and other types. Fusulinids are also very common, and Mr. Henbest has found time to report on only a relatively few of them.

The faunal facies and some of the species remind me, as I noted in 1940, of some of the Alaskan collections from beds that have been called Permian there. Resemblances to Russian species and faunules have also been noted. Further and more detailed conclusions must await further progress toward completion of the extensive investigations that I am making of the upper Pennsylvanian and Permian formations and faunas of the northwestern United States and Alaska.

Williams' tentative comparison of the Antler Peak fauna with faunas of Alaska and Russia rather than with the Rocky Mountain faunas opens up an interesting line of speculation; a seaway may have extended northward from central Nevada through Idaho and British Columbia, thus permitting the migration of Alaskan forms into Nevada. A connection eastward to the Rocky Mountain geosyncline during Late Pennsylvanian and early Permian time is also suggested, as beds of Virgil and Wolfcamp age also crop out in the ranges in eastern Nevada and western Utah. Eardley (1947, fig. 2) has shown the possible extent of the Pennsylvanian seas in Nevada.

Lloyd G. Henbest and R. C. Douglass (written commun., 1953, 1960) have studied fusulinid collections from the type locality of Antler Peak limestone and determined them as follows:

USGS f9661—Antler Peak quadrangle, southeast slope of Antler Peak, SE¼ sec. 33, T. 32 N., R. 43 E.
- *Triticites* sp. 1 (an elongate form, poorly preserved)
- *Triticites* sp. 2 (representing a variety of a species in f9653).

The known range of species of *Triticites* in the group represented by *Triticites* sp. 2 is Virgil to basal Hueco inclusive. The nearest species to this we have seen occurs in the lower Wolfcamp beds of West Texas. *Triticites moorei* of Dunbar and Condra also has some points of similarity.

Species 1 is poorly preserved and so far as it is identifiable in the existing thin sections, the nearest comparable forms are found in rocks of late Missouri and of Hueco age; so it adds little to the evidence from species 2.

Fusulinids have also been found in a thrust sliver of Antler Peak Limestone in Rocky Canyon. Henbest and Douglass prepared the following list of species in material from this locality:

USGS f9653—Antler Peak quadrangle, Rocky Canyon, NW¼ sec. 7, T. 31 N., R. 43 E.
- Textulariidae
- *Climacammina* sp.
- *Bradyina?* sp. (Microspheric?)
- *Bradyina* sp.
- *Triticites* 2 sp.

The exact correlation of this fauna is problematic. The maximum known range for *Triticites* of the kind represented here is in beds of Upper Missouri(?), Virgil, and basal part of Wolfcamp age.

Fusulinid collections that are found somewhat higher in the section are not earlier than middle or late Missouri, and more likely are of the Virgil Series of Late Pennsylvanian age.

The basal limestone of the Carbon Ridge Formation of Hueco age exposed at several places near Eureka contains a fusulinid fauna similar to the fauna of the Antler Peak Limestone (Nolan and others, 1956, p. 66), and it seems likely that they were deposited in the same basin, representing transgressive overlap from the east.

The limestone and dolomite in Copper Basin are in part equivalent to the upper beds at Antler Peak, and the fauna in the Copper Basin is similar. Williams noted that the limestone and dolomite in the upper beds contain more clay and silt, and that the fauna is dwarfed, but reported that the faunas are about the same age as the Antler Peak faunas or slightly younger.

Limestone fragments collected from the northernmost outcrops along the range front in sec. 22, T. 32 N., R. 44 E., were examined by the late Wilbur Hass of the U.S. Geological Survey who reported as follows (written commun., 1955):

Collection 54 F–2, herein reported on, comes from the SE¼ sec. 22, T. 32 N., R. 44 E., in the low hills at the edge of the range northeast of Copper Basin and at an elevation of 4,700 feet.

The observed material consists of approximately 50 fragmentary specimens. It is my opinion that if these specimens occur naturally in the rocks from which collection 54 F–2 came, they indicate a probable Permian age. A more precise age determination is not possible because few Late Paleozoic and younger conodont faunas are as yet known to science. The following genera are recognized:
- *Gondolella*
- *Streptognathodus*
- *Icriodus*
- Fragment of a blade-like conodont

Specimens of *Gondolella* completely dominate the fauna. This genus is known to range from the Pennsylvanian (Des Moines) into the Lower Triassic. Specimens of this genus in collection 54 F-2 most closely resemble the gondolellids described by Youngquist, Hawley, and Miller (Journal of Paleontology, vol. 25, pp. 356-364, p. 54, 1951) from the Phosphoria Formation of southeastern Idaho. They are smaller in size and less ornamented than those reported from Pennsylvanian formations; on the other hand, they are more linguiform than those present in the Lower Triassic Thaynes Limestone of southeastern Idaho.

Collection 54 F-2 contains six small specimens of *Streptognathodus*. This genus, according to the literature, ranges from the Lower Pennsylvanian into the Lower Triassic. Pennsylvanian representatives of the genus tend to be large whereas those from the Permian and Triassic are small.

Icriodus is represented by two specimens. This genus does not range naturally above the Devonian; its presence in collection 54 F-2, therefore, resulted from contamination.

This would seem to indicate that the uppermost beds in the Antler Peak Limestone are definitely Permian. Perhaps these beds should be mapped as a separate unit and defined as a new formation, distinct from the Antler Peak Limestone.

P. E. Hotz has found limestone and conglomerate on the west side of the Osgood Mountains that are correlative with the Antler Peak Limestone (Hotz and Willden, 1964). The units are thin and lenticular and they are always found in thrust slices. They contain a fauna that is the same age but contains elements quite different from the fauna collected from the type section at Antler Peak. One explanation of the difference in fauna and lithology is that the section on the west side of the Osgood Mountains may be allochthonous and may have been thrust into the area on Permian or post-Permian thrusts, possibly from the west. On the east side of the range the limestone section is about 1,200 feet thick; it is very similar to the type section on Antler Peak in lithology and fauna, and therefore probably belongs to the same facies.

In the Mount Lewis quadrangle, Gilluly (oral commun., 1954) has found limestone and conglomerate units in thrust slices that contain an Antler Peak fauna. These rocks more nearly resemble the limestone units on the west side of the Osgood Mountains than in the Antler Peak Limestone at the type locality, and also may have come from the west.

Partly correlative units in the Eureka area include the Carbon Ridge and Garden Valley Formations (Nolan and others, 1956, p. 67-68) of Wolfcamp and Leonard age.

EDNA MOUNTAIN FORMATION

The Edna Mountain Formation was named for Edna Mountain in the Golconda quadrangle (Ferguson and others, 1952). At the type locality the formation consists largely of brown sandstone, calcareous sandstone, and calcareous shale and reaches a maximum thickness of about 400 feet. Rocks assigned to the Edna Mountain Formation are exposed in only a few places in the Antler Peak quadrangle where they crop out just below the Golconda thrust fault. The principal exposures are in Galena Canyon and at the Nevada mine near the head of Copper Canyon. With the exception of a chert conglomerate unit that crops out prominently, the other rocks of the Edna Mountain Formation commonly form smooth slopes.

Lithology

The Edna Mountain Formation is this area is mostly interbedded limy shale, limestone, sandstone, and chert conglomerate. The limy shale is generally gray, brownish-gray, or greenish-gray and weathers gray and buff. The limestone is bluish gray and weathers light to medium gray. The sandstone is brown and weathers dark brown. Chert conglomerate as much as 20 feet thick that contains pebbles and granules ranging from one-fourth to one-half an inch in diameter is a prominent member near the divide between Copper Canyon and Galena Canyon. The chert pebbles are black, gray, brown, and green in a siliceous cement (fig. 15).

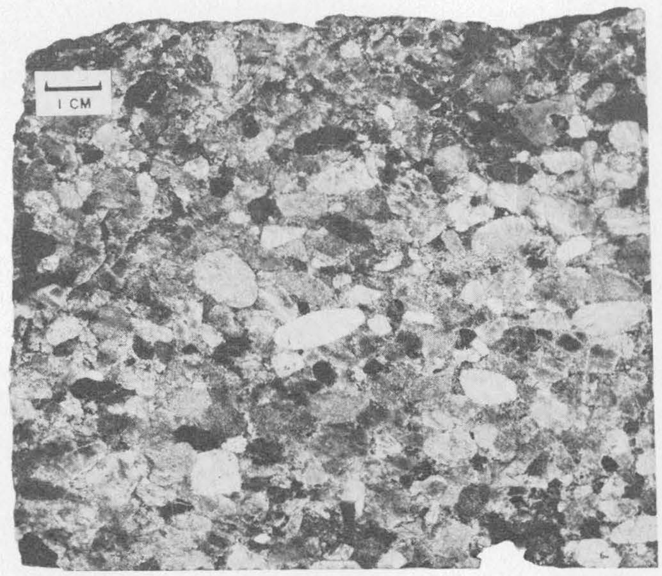


FIGURE 15.—Conglomerate of the Edna Mountain Formation. Composed chiefly of well-rounded pebbles of quartzite (white and gray) and chert (black), probably derived from the Valmy Formation.

Because the outcrops of the Edna Mountain Formation are small and widely separated, and because they are faulted, no clear idea of the sequence of units could be obtained. The actual thickness was not measured; it is estimated, however, that the aggregate thickness of the units present in the area is at least 100 feet and may be as much as 200 feet.

The relation of the Edna Mountain Formation to the underlying Antler Peak Limestone in Galena Canyon is unclear, but the contact appears to be an erosional unconformity. At one point the basal Edna Mountain unit rests on unit O, and at another point half a mile away on unit Q. This means that about 150 feet of Antler Peak beds were eroded at the latter place. In Edna Mountain, during post-Antler Peak erosion, in places the Battle Formation and Highway and Antler Peak Limestones were entirely removed and the Edna Mountain Formation rests with angular unconformity directly on Cambrian or Ordovician rocks.

Age and correlation

Brachiopod collections were made by J. S. Williams in the limy shale unit of the Edna Mountain Formation that is exposed 200 feet north of the Nevada mine. Williams did not report on these collections, but stated informally that they contained many of the same species found in the type section in Edna Mountain, concerning which he wrote the following report to H. G. Ferguson in April 1949:

> The best collections from the Edna Mountain Formation came from four localities (8725, 8726, 8727, and Muller 7/24/41). All these localities are close to Highway 40 about 4 miles east of Golconda. The fauna, as shown by these collections contains "*Neospirifer*" *pseudocameratus* (Girty) in abundance. The individuals show a very wide range of variation, and more than one species may be represented. Also present in the fauna are many individual specimens of a *Chonetes* that may be a variety of *C. ostiolatus* (Girty), a very fragmentary linoproductid identified very tentatively as *Linoproductus* cf. *L. eucharis* (Girty), a large *Hustedia* represented by molds, which is probably *H. phosphoriensis* of Branson, and also represented by molds of one kind or another, forms very tentatively identified as belonging to *Wellerella?*, *Cleiothyridina?*, a large *Composita*, *Juresania?*, *Rhynchopora?*, and *Conocardium?*. There is also a mold of a small *Punctospirifer* which cannot specifically be identified but which has some resemblances to a young *P. pulcher* (Meek).
>
> The fauna as shown by the above mentioned collections, through lacking good representatives of several important elements of the Phosphoria fauna, is nevertheless more closely related to this fauna and to its equivalent, the Gerster Formation, than to any other faunas of the Rocky Moutains. The age is therefore thought to be Phosphoria. The resemblances are slightly more with the lower part of the Phosphoria than with the upper part, but it would be unjustified to attempt to refer the fauna definitely to any part of the Phosphoria. In fact, it might be slightly older than typical Phosphoria.

A few corals that were collected from the Edna Mountain Formation at locality 8726 were studied by Miss Helen Duncan, whose remarks concerning them are as follows: "The specimens are columellate horn corals, mostly molds or crushed specimens. The genus might be the laphophyllilid *Stereostylus*, which is apparently not uncommon in Pennsylvanian and Lower Permian rocks and probably will be found to range into beds of Leonard or younger age, though it has not been reported hitherto from beds so young."

The Edna Mountain Formation correlates with part of the Phosphoria and Gerster Formations and is therefore considerably younger than the Antler Peak Limestone. The unconformity between the Antler Peak and Edna Mountain Formations represents a distinct stratigraphic break. Between Wolfcamp and Guadalupe time this part of Nevada probably remained at or near sea level, but local warping and uplift caused erosion of part of the Battle Formation and the Antler Peak Limestone in places; locally as much as 1,500 feet of strata is missing below the Edna Mountain Formation, suggesting uplift of this magnitude. The erosional unconformity at the base of the Edna Mountain Formation may reflect Permian orogeny in the west.

Rocks correlative with the Edna Mountain Formation are widespread throughout Nevada. Such units have been recognized in the valley of Clear Creek in the Sonoma Range (Ferguson and others, 1951a, 1951b) where they consist mainly of sandstone, slate, and limestone. The sandstone is in part feldspathic and micaceous, and resembles sandstones of the Harmony Formation. It seems likely that either the source of the Harmony Formation was again exposed during Edna Mountain time, or the Harmony Formation itself was a source rock for the Edna Mountain Formation in this area. A correlative unit in the Toyabe Range and Coaldale and Mina quadrangles is the Diablo Formation (Ferguson and Cathcart, 1954; Ferguson and others, 1953, 1954), which consists mostly of sandstone, dolomite, limestone, shale, and conglomerate.

HAVALLAH SEQUENCE

The Havallah sequence consists of two formations, the Pumpernickel and Havallah Formations, which were deposited in western Nevada and were brought into the Antler Peak quadrangle on the Golconda thrust (Silberling and Roberts, 1962, p. 16). The Pumpernickel Formation of Pennsylvanian(?) age is mostly dark chert, shale, and greenstone, and it resembles the siliceous and volcanic assemblage. The Havallah Formation of Pennsylvanian and Permian age is mainly calcareous sandstone, quartzite, and shale with some chert and sandy limestone. The lower and middle units resemble the siliceous and volcanic assemblage, and the upper unit the overlap assemblage. For this reason it seems best to assign them to a separate sequence, not directly related to the major assemblages or early and middle Paleozoic time.

PENNSYLVANIAN(?) SYSTEM

PUMPERNICKEL FORMATION

The Pumpernickel Formation is composed of shale, chert, and greenstone with some limestone, sandstone, and pebbly conglomerate. In general appearance it strikingly resembles the Scott Canyon Formation and member 3 of the Valmy Formation. This characteristic lithology definitely establishes the Pumpernickel as related to the siliceous and volcanic assemblage. However, it most likely was deposited in a separate basin, probably to the southwest or west of the basin in which the other units of the siliceous and volcanic assemblage accumulated, and was brought into juxtaposition with them on the Golconda thrust fault. The Pumpernickel is overlain with possible disconformity by the Jory Member of the Havallah Formation of early Middle Pennsylvanian to Permian age.

The term "Pumpernickel Formation" was first applied to chert, shale, and greenstone units exposed west of Pumpernickel Valley on the east side of the Sonoma Range (Ferguson and others, 1951a, 1951b). The formation is widespread throughout the Winnemucca, Mount Tobin, and Golconda quadrangles, where it everywhere forms a part of the upper plate of the Golconda thrust.

In Battle Mountain the Pumpernickel Formation underlies a belt that extends northward along the valleys of Willow Creek and Copper Canyon through the headwaters of Mill and Trenton Canyons, then along Trout and Cottonwood Creeks to the north edge of the range. At the south end the belt is 2 miles wide, but it narrows to about 1 mile at the north end of Willow Creek valley. Movement along strike faults in the headwaters of Timber, Mill, and Trenton Canyons has caused the repetition of the beds and has caused the outcrop to widen to as much as 2 miles; the outcrop is interrupted by intrusive granodiorite and by an upfaulted block of Battle Formation at the head of Trenton Canyon. At Trenton Canyon the belt extends westward to the range front; here it is displaced northeastward on the Oyarbide fault, and then continues northward along the valleys of Cottonwood and Trout Creeks to the Humboldt Valley.

Lithology

The Pumpernickel Formation in Battle Mountain consists largely of interbedded chert and argillite; some limestone, sandstone, conglomerate, and intercalated greenstone are minor constituents in places. The base of the formation has been cut off along faults that intersect younger beds progressively from north to south. The base of the formation is nowhere exposed, but the oldest beds are to be found in the southern part of the quadrangle in Copper Canyon and Willow Creek valley. Folding, presumably related to the Golconda thrust, and strike faulting have made measurement of a detailed section extremely difficult; the sequence of units is known, however, and rough estimates indicate that the beds total at least 5,000 feet in thickness.

The oldest unit is exposed near the Nevada mine and consists of gray and black argillite with thin chert lenses. This unit has a maximum thickness of about 500 feet; it is soft and easily eroded, and valleys such as Copper Canyon and the headwaters of Galena Canyon are cut in it. The lower argillite is overlain by a middle unit of interbedded chert and argillite that crops out prominently and underlies the ridge west of Copper Canyon. Detailed mapping of the ridge has proved that the chert and argillite layers are isoclinally folded, but it seems likely that they aggregate at least 1,000 feet in thickness. The middle chert and argillite unit is overlain by a thick argillite unit that contains thin chert beds. This upper unit probably is thickened by folding and faulting, but it appears to be about 3,500 feet thick.

The upper part of the Pumpernickel Formation is best exposed on the floor and west side of the valley of Willow Creek. The upper beds are estimated to be about 2,000 feet thick in this area and consist chiefly of argillite, siliceous argillite, and chert. The argillite is generally dark red, locally grading into purplish red and brownish red, or dark green. The argillite grades into red and green siliceous argillite and chert along the strike and downdip. Typical samples of the argillite and chert were analyzed chemically. One of the samples was from within the aureole of the Copper Canyon intrusive where it had been subjected to hydrothermal metamorphism; three were from outside the aureole. The analyses are shown in table 4.

Samples 1, 2, and 3 show increasing silica in transition from siliceous argillite to dense chert. The decrease in alumina, iron oxides, sodium, potassium, and other constituents from argillite to chert is notable. Apparently, sample 4 was originally much like sample 1, but during metamorphism considerable potassium was added by solutions from the stock in Copper Canyon.

All gradations can be found between argillite and chert. In the argillite the grains are principally quartz and calcite, together with small amounts of heavy minerals, cemented by argillaceous material. In addition to these minerals, fresh oligoclase grains were noted. The clastic calcite is generally rounded, but some of the grains are subhedral and show rhombohedral faces. The recognizable grains are embedded in a groundmass that appears to be nearly isotropic, but contains cryptocrystalline to finely crystalline material; in part at least, it is chalcedony; with diminution of the proportion of fragmental material the rock would grade into vitreous chert. Wisps of sericite and a green chloritic material also occur in the groundmass. These minerals are partly of clastic origin, but the chlorite was probably formed by alteration of biotite. X-ray studies of argillite specimens by R. A. Gulbrandsen have shown that some of them contain considerable plagioclase feldspar and most of them contain a chlorite fraction, suggesting that they are in part derived from volcanic material. Whether tuffaceous material predominated originally is not definitely known; the fine laminations in most of the units indicate that they were deposited in a marine environment below wave base.

TABLE 4.—*Analyses of argillite and chert of the Pumpernickel Formation, Antler Peak quadrangle, Nevada*

[Analysts: M. K. Carron (samples 1 and 2), K. E. White, H. F. Phillips, P. W. Scott, and F. S. Borris (samples 3 and 4, by rapid methods), U.S. Geol. Survey]

	1	2	3	4
SiO_2	75.28	89.15	94.6	77.0
Al_2O_3	10.22	3.45	1.8	7.8
Fe_2O_3	1.99	.58	.36	.8
FeO	2.24	2.19	.28	2.0
MgO	2.00	1.05	.64	2.5
CaO	.84	.24	.49	1.8
Na_2O	.82	.22	.15	.73
K_2O	2.30	.53	.37	4.6
H_2O+	2.14	1.17	.77	.83
H_2O-	.33	None	.09	.13
TiO_2	.66	.22	.07	.52
P_2O_5	.10	.04	.24	.20
MnO	.02	.03	.03	.04
CO_2	.54	.11	.60	.31
S	.04	.14		
BaO	None	.59		
Sum	99.52	99.71	100	99
Less O	.02	.07		
	99.50	99.64		
Sp. gr	2.73 (powder)	2.73 (powder)		2.56 (bulk)

1. Red argillite (field No.—48-R4-03), Pumpernickel Formation, Willow Creek, near center sec. 32, T. 32 N., R. 43 E.
2. Red and green chert (field No.—48-R4-04); same locality.
3. Black chert (field No.—53-AP-1), from adit in Copper Canyon in SE¼ sec. 16, T. 31 N., R. 43 E.
4. Brown recrystallized chert (field No.—53-AP-19), Farren adit, Copper Canyon mine, NE¼ sec. 28, T. 31 N., R. 43 E.

Thin conglomerate beds are scattered throughout the Pumpernickel Formation and are probably more abundant in the upper part. The beds range from a few inches to as much as 10 feet in thickness. They are composed mainly of grains of chert, quartzite, greenstone, and argillite of pebble and granule size. The cement is mostly argillaceous material, a little iron oxide, and possibly quartz and a carbonate mineral.

In the upper part of the Pumpernickel Formation in Mill and Trenton Canyons, thin-bedded limestone interbedded with chert and shale make up a unit as much as 100 feet in thickness. These limestone beds are absent south and north of this area, possibly because of erosion prior to the deposition of the overlying basal beds of the Havallah Formation. The limestone beds are light to dark gray and are fine to medium grained; they commonly range from a few inches to 1 foot in thickness. Thin limy shale beds also are present throughout the Pumpernickel Formation, but they are generally not persistent along the strike.

Near the top of the Pumpernickel Formation, greenstone flows and associated pyroclastic rocks are a distinctive unit. In Willow Creek Canyon this unit is thin, probably not more than 20 feet thick, but it thickens northward. On the north side of Timber Canyon in sec. 1, T. 31 N., R. 42 E., and on the west side of Trout Creek, half a mile west of the Marigold mine, it is well exposed. In Timber Canyon it includes pillow lavas and massive lava; near the Marigold mine it consists of massive lava and pyroclastic rocks more than 100 feet thick.

The massive lava in Timber Canyon is a dense, dark-greenish rock that weathers reddish brown. Microscopic examination of the rock reveals mainly plagioclase laths averaging about 0.3 mm in length, chlorite, and a little quartz, calcite, and pyrite. The plagioclase has been albitized and is near An_{10} in composition. Most of the crystals are poorly twinned and contain inclusions of chlorite. The chlorite is in plates and fibrous crystals that are probably derived from the alteration of mafic minerals, but in addition it occurs as vesicle fillings with calcite. Scattered throughout the rocks are patches of a mineral that is probably secondary after ilmenite and is thought to be leucoxene.

The pyroclastic rocks associated with the lava range from fine tuffaceous rocks to coarse breccias containing some fragments more than a foot in diameter. Generally the tuffaceous rocks are associated closely with the flows and pillow lavas, but have much greater extent, suggesting transportation away from the volcanic centers. The pyroclastic units are commonly thin, a few feet to 20 feet in thickness, and are lenticular. The proportion of volcanic rocks is much lower in the Pumpernickel Formation in Battle Mountain than in the Sonoma Range, where they make up 20 percent or more of the formation.

Coarse sandstone layers are in places interbedded with the chert and argillite. One persistent layer from 8 to 12 inches thick is exposed on the ridge west of Copper Canyon. The sandstone is brown and contains visible clastic mica flakes; it bears a striking resemblance to the coarse sandstone of the Harmony Formation. Microscopic examination of the rock reveals quartz, abundant feldspar and calcite. The feldspar is largely orthoclase and microperthite and some plagioclase; most of these minerals are fresh, but some are partly replaced by calcite. This layer, because of its feldspar content, is the only lithologic type of the Pumpernickel Formation whose material is sufficiently distinctive to permit inquiry as to the source. Two possible sources are: the feldspathic sandstone of the Harmony Formation and the granitic terrain from which the sandstone was originally derived. There is no way to evaluate these two possibilities at the present time, and no decision can be made as to the more likely explanation.

The chert beds in the Pumpernickel Formation are of two distinct types that appear to be different in origin: thick-bedded chert containing abundant organic remains (fig. 16*A*); and thin-bedded chert containing sparse organic remains (fig. 16*B*). Both types have wavy, lenticular bedding, although the thin-bedded units tend to be more evenly bedded than the thick-bedded units.

The thick-bedded chert beds are found mainly in the middle unit of the Pumpernickel Formation. Individual beds range from 2 to 24 inches in thickness and average about 6 inches. Some layers are thinly laminated and consist of alternating light and dark layers that resemble varves (fig. 17*A* and *B*); others are nodular or show indistinct bedding or mottling (fig. 17, *B* and *C*). The light layers are composed largely of monaxial sponge spicules and generally a few radiolaria set in a matrix of fine-grained chalcedony. Under the microscope in plain light the sponge spicules are scarcely discernible, but in the dark field they show plainly (fig. 18). Thin sections containing sponge spicules have been studied by M. W. de Laubenfels (written commun., 1958), who reports that the spicules are typical of those produced by shallow-water *Demospongea* that thrive in water less than 300 feet deep. The dark layers also contain carbonaceous material and iron oxides that may represent seasonal or rhythmic accumulations. During diagenesis, the thick-bedded cherts were extensively recrystallized; bedding laminations became less distinct (fig. 17*B*) and in places nearly disappeared. All traces of organic remains have vanished from the chert in the advanced stages of recrystallization.

On bedding surfaces the thick-bedded cherts commonly show well-preserved invertebrate tracks. Most resemble markings commonly attributed to helminthoidal worms (fig. 19*A*) (Abel, 1935, p. 334–335; Häntzschel, 1962, p. W–200, Fig. 122), but others may have been made by gastropods (fig. 19, *B* and *C*) (Abel, 1935, figs. 179, 195; Häntzschel, 1962, p. W–205, Fig. 127–6), crustaceans (fig. 19*D*), and by organisms that cannot be identified with certainty (fig. 19*E*).

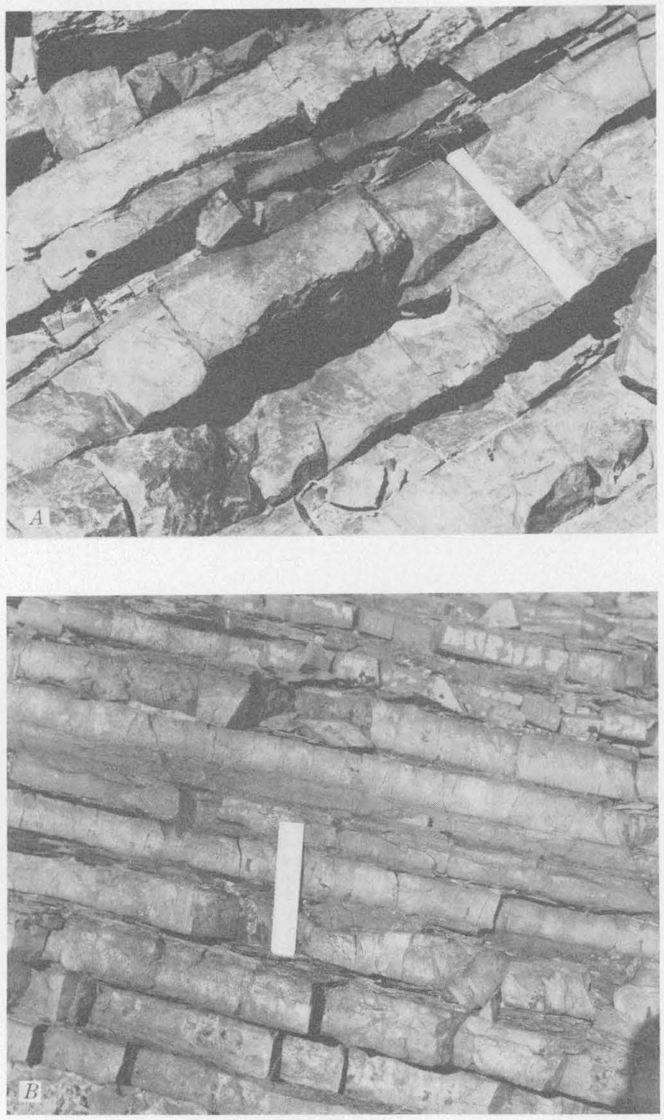
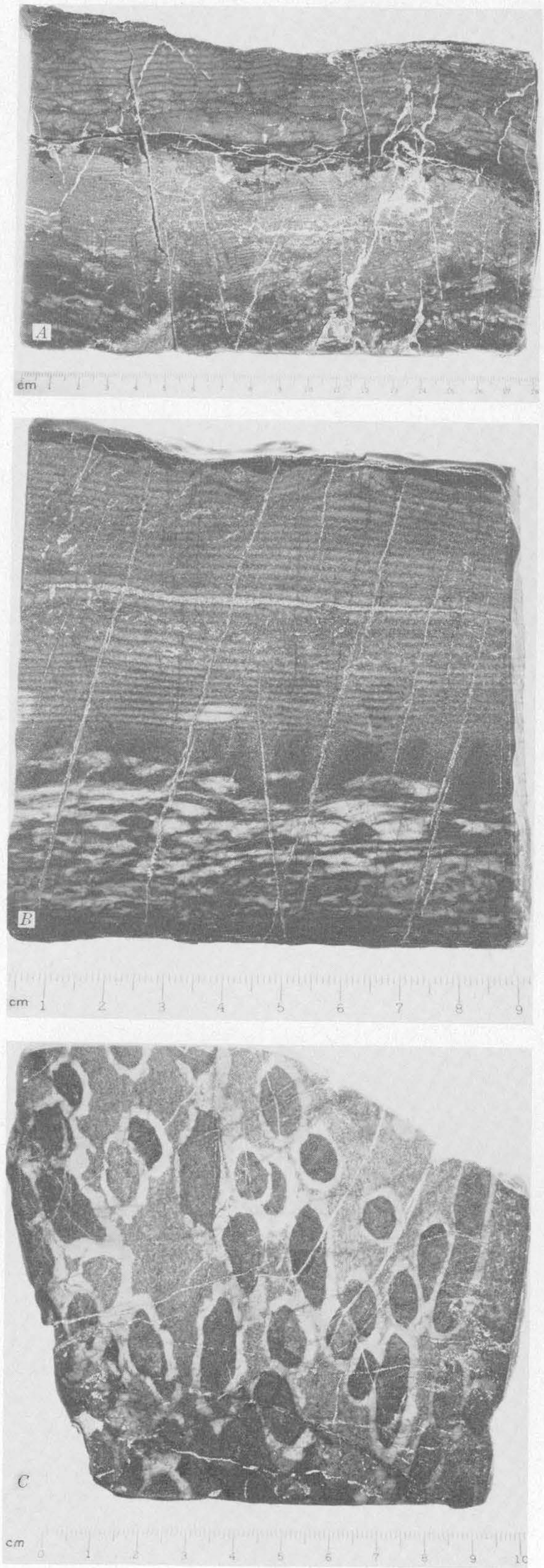


FIGURE 16.—*A*, thick-bedded chert of the middle unit of the Pumpernickel Formation on the ridge west of Copper Canyon. The beds average about 6 inches thick. The pick is 13 inches long. *B*, thin-bedded chert with shaly partings from the upper unit of the Pumpernickel Formation on the west side of Willow Creek valley. The beds average about 2 inches in thickness. The scale is 6¾ inches long.

According to P. E. Cloud (written commun., 1960), the markings may have been made by soft bodied, possibly wormlike, animals (Lophoctenium?) that tunneled just under the surface of the bottom mud by means of an extensible proboscis (Häntzschel, 1962, p. W–201–202). Preservation of such delicate surficial markings implies deposition of this part of the Pumpernickel below wave base, but not necessarily in abyssal depths.

The thin-bedded chert is mainly in the upper unit of the Pumpernickel Formation. The layers range from a fraction of an inch to 8 inches in thickness and



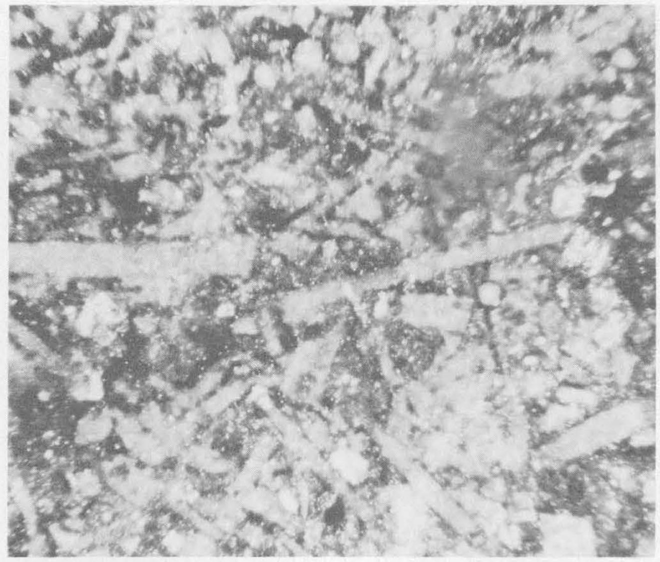


FIGURE 18.—Photomicrograph of chert, middle unit of Pumpernickel Formation showing sponge spicules (light-gray rods) in a dark groundmass. Plain light, dark field, × 75.

average about 3 inches (fig. 16*B*). Commonly a thin shaly parting is present between the layers. Along strike the cherty beds grade into siliceous silty argillite and silty argillite (fig. 20). Organic remains such as radiolaria and sponge spicules are sparse in the chert of the upper unit, but have been found in a few specimens that have been studied (fig. 20*B*). Microscopic examination of the chert reveals mainly quartz, chlorite, and sericite fragments set in a chalcedonic matrix. Interbedded argillites contain a higher proportion of clastic material and correspondingly less chalcedonic matrix.

Origin of the chert

The two kinds of chert in the Pumpernickel Formation—thick-bedded, containing abundant organic remains; and thin-bedded, containing sparse remains—were probably formed in dissimilar environments under different conditions.

The thick-bedded chert contains abundant spicules of *Demospongea*, which generally lives in water less than 300 feet deep; associated tracks of gastropods and worms indicate an abundant bottom fauna. The chert probably accumulated in an offshore environment in

←FIGURE 17.—Chert, middle unit of the Pumpernickel Formation. *A*, fine laminations in the upper part and lenticular structure in the lower part. The darker layers are in general finer grained than the light layers. *B*, minor folds and faults, probably formed before consolidation. Highly recrystallized during diagenesis. *C*, nodular chert. The groundmass is medium-gray chert with ovoid masses of darker gray chert surrounded by light-gray chalcedony rings. The dark-gray chert fills worm tubes in the rock; the white rings represent the original tube walls.

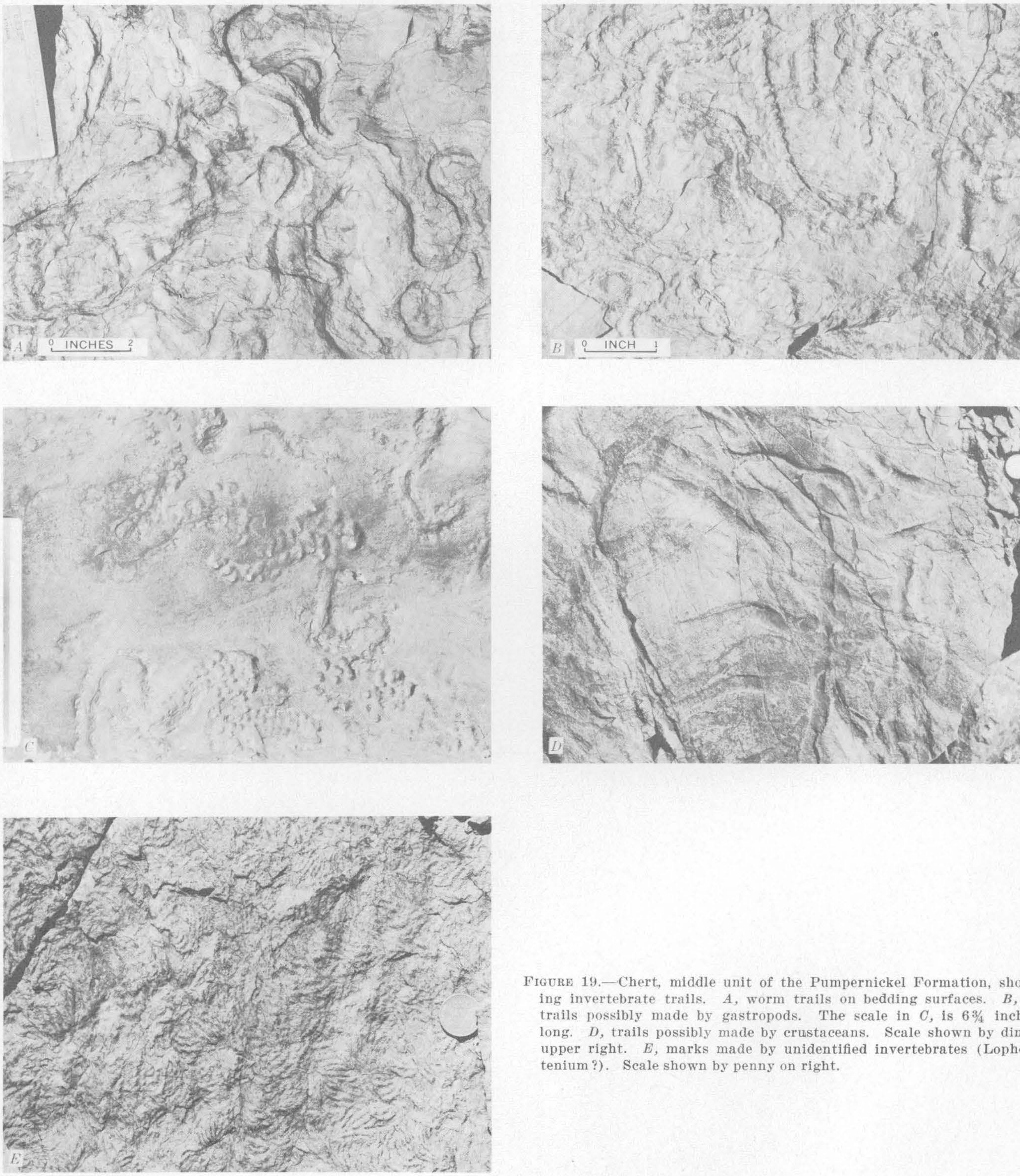


FIGURE 19.—Chert, middle unit of the Pumpernickel Formation, showing invertebrate trails. *A*, worm trails on bedding surfaces. *B*, *C*, trails possibly made by gastropods. The scale in *C*, is 6¾ inches long. *D*, trails possibly made by crustaceans. Scale shown by dime, upper right. *E*, marks made by unidentified invertebrates (Lophoctenium?). Scale shown by penny on right.

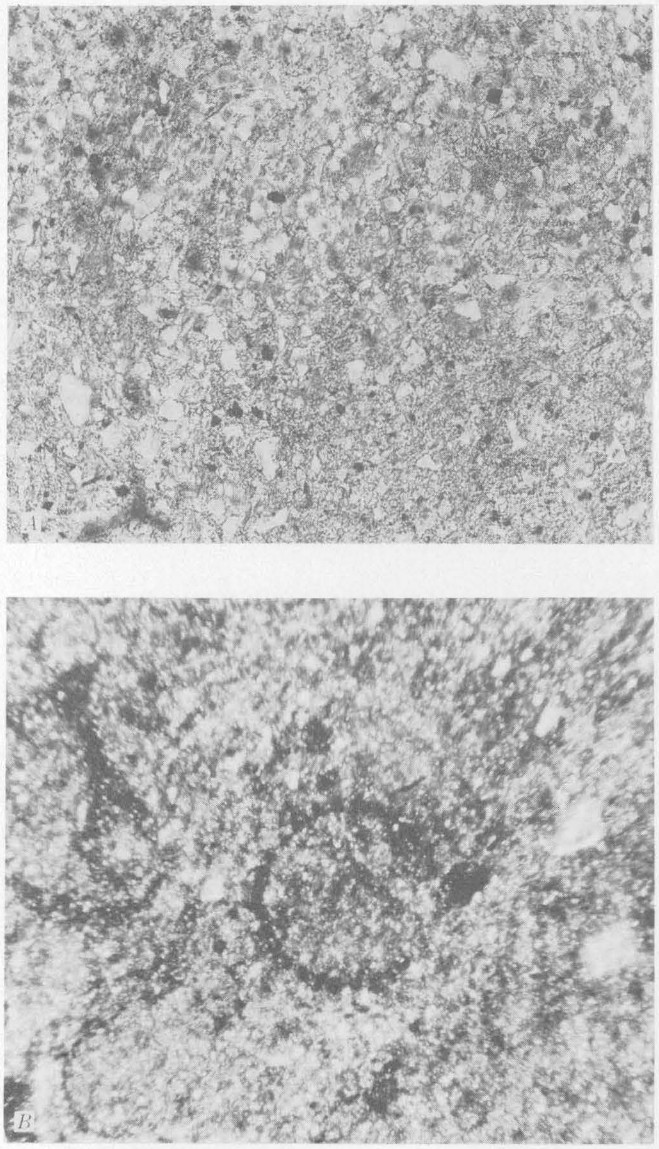


FIGURE 20.—Photomicrographs of upper-unit rocks of the Pumpernickel Formation. *A*, silty argillite from west side of Willow Creek valley. Shows angular quartz grains in an argillaceous groundmass. Plane-polarized light, × 75. *B*, chert, in dark field, showing radiolaria (rounded and ringlike bodies) in a chalcedony groundmass. Dark grains are phosphorite. Plain light, × 75.

water of moderate depth. The origin of the thick-bedded chert presents no serious problem, because opaline sponge spicules and radiolaria make up a large part of the rock. These may have been partly dissolved and reconstituted during diagenesis, forming chert in the manner suggested by Bramlette (1946, p. 41–45) for the Monterey Formation.

The thin-bedded chert consists mainly of fine particles of quartz, chlorite, and clay minerals in a chalcedonic groundmass. Included sparse organic remains consisting of radiolaria and occasional worm tracks are not diagnostic of any particular environment, but the absence of an abundant bottom-dwelling fauna suggests a deeper water offshore environment than the one in which the thick-bedded cherts accumulated.

The origin of chert in this kind of environment has been discussed by Davis (1918), who described the chert of the Franciscan Formation in California and emphasized the relation of siliceous sediments and volcanic rocks. He suggested that silica was supplied to the sea by emanations accompanying volcanism and accumulated as layers of silica gel. Analyses of sea water show, however, that the silica content is generally less than 10 parts per million, far below saturation (about 75), possibly because organisms extract the silica as fast as it accumulates. It is therefore unlikely that direct precipitation, even from submarine spring sources as suggested by Davis, would be possible.

Another possibility is that the chert represents lithified radiolarian oozes or volcanic muds. Revelle (1944, p. 58, 67) has shown that these contain only about 60 percent silica (table, p. 44, Nos. 3 and 4), about the same as terrestrial shales (table, p. 44, No. 7), and would not be particularly good source rocks.

Other investigations that may shed light on the problem have been carried on by Rubey (1929) and Goldstein and Hendricks (1953). The siliceous Mowry Shale of Wyoming and South Dakota has been interpreted by Rubey (1929, p. 153–170) as altered volcanic ash; he suggested that silica derived from the alteration of ash in the Mowry and overlying beds moved laterally and downward, replacing adjacent layers. Similarly, Goldstein and Hendricks (1953, p. 440) consider that silica of the siliceous shales of the Stanley, Jackfork, and Atoka Formations, Oklahoma, was derived from submarine weathering of volcanic ash.

Comparison of analyses of the siliceous shale and thin-bedded chert of the Pumpernickel Formation (table, p. 44, Nos. 1 and 2) with the Mowry Shale shows significant similarities. The siliceous shale (No. 1) resembles bentonite from Wyoming, and the chert (No. 2) resembles the Mowry siliceous shale. Rubey's interpretation that the Mowry Shale was formed on the sea floor by the decomposition of volcanic ash seems to serve equally well for the Pumpernickel Formation.

Direct evidence that siliceous volcanics formed a significant part of the Pumpernickel Formation is as yet lacking because diagenetic changes have obscured the original mineralogy. X-ray diffraction studies of the clay minerals in the argillites by R. A. Gulbrandsen (oral commun., 1956) indicate that they contain chlorite and illite; in addition, one sample contained a mixed layer illite-montmorillonite. This clay mineral

730-670 O—64——4

assemblage is comparable to that described by Weaver (1953) from Ordovician bentonite in Pennsylvania, which was considered to have been derived from volcanic ash.

To account for the thin-bedded cherts, the following mechanism is suggested. After burial, when free access of sea water is no longer possible, the silica content of entrapped sea water in sediments would increase by reaction with the fine mineral grains, glass shards, and siliceous organic remains in the sediment. These materials are all soluble in varying degrees; opaline tests, sponge spicules, and glass shards are among the most unstable constituents; quartz grains and other silicate mineral grains are more stable (Emory and Rittenberg, 1952, p. 796). After the interstitial water becomes saturated, silica can be readily transferred by flow and diffusion from place to place within the layer where it was dissolved or into another layer; highly organic layers on the bottom might absorb silica from solutions or hydrosols driven upward during compaction. After a time, such hydrosols change spontaneously to hydrogels (Hurd, 1938; Krauskopf, 1956, p. 16) which, during aging and compaction, systematically become dehydrated and gradually change to opaline material. Crystallization eventually would change the opaline material to more stable forms such as chalcedony and quartz.

Age and correlation

The Pumpernickel Formation was originally assigned by Muller and others (1951) and Roberts (1951) to the Pennsylvanian(?) because it was overlain by the Havallah Formation, which at that time was considered to be Permian(?). In 1958 conodonts were discovered in the middle part of the unit in Willow Creek; they were studied by W. H. Hass, who reported as follows:

None of these collections contains many conodonts but some of the fossils in collection 58 AP 3 * * * could be important in dating at least a part of the Pumpernickel * * *.

58 AP 3 SW¼SW¼ sec. 32, T. 32 N., R. 43 E., Willow Creek Valley at 6,500 feet on east side of valley

Gondolella sp. (6 specimens)

Hindeodella sp. (few specimens)

Conodont fragments (indeterminable)

58 AP 5 (same locality as 58 AP 3)

Hindeodella sp.

Indeterminate conodont fragments

The genus *Gondolella*, according to the published record definitely ranges from the Pennsylvanian (Des Moines Series) into Middle Triassic.

As early Middle Pennsylvanian fusulinids have been collected from the lower part of the overlying Jory Member of the Havallah, it appears that the two faunas overlap in age. The only way of rationalizing this overlap is the suggestion by Douglass that the lower Jory fauna may be redeposited from older beds (p. A48). Definite age assignment of the Pumpernickel must await further study; for the present, it seems best to consider the Pumpernickel as Pennsylvanian(?).

Typical analyses of siliceous rocks

	1	2	3	4	5	6	7
Lab No.	[1] 48R403	[1] 48R404	56	57	--------	--------	--------
SiO_2	75.28	89.15	60.18	60.66	70.98	84.14	58.38
Al_2O_3	10.22	3.45	13.62	13.48	11.47	5.79	15.47
Fe_2O_3	1.99	.58	5.88	5.92	2.48	1.21	4.03
FeO	2.24	2.19			--------	--------	2.46
MgO	2.00	1.05	2.32	2.41	1.38	.41	2.45
CaO	.84	.24	4.20	2.06	.26	.13	3.12
Na_2O	.82	.22	1.12	1.90	1.69	.99	1.31
K_2O	2.30	.53	.74	.12	.75	.50	3.25
H_2O+	2.14	1.17	5.42	6.89	11.32	5.56	5.02
H_2O-	.33	None					
TiO_2	.66	.22	.48	.57	.10	.22	.65
P_2O_5	.10	.04	.11	.13	(2)	(2)	.17
MnO	.02	.03	.10	.31	--------	--------	Trace
CO_2	.54	.11	1.72	.46	None	None	2.64
S	.04	.14	.01	.02	--------	--------	[3] .65
BaO	None	.59	None	None	--------	--------	.05
C	--------	--------	--------	--------	--------	1.21	.81
Sum	99.52	99.71	95.90	94.93	100.43	100.16	100.46
Less O	.02	.07					
	99.50	99.64					

[1] Analyst, M. K. Carron, U.S. Geol. Survey.
[2] Included with Al_2O_3.
[3] S as SO_3.

1. Siliceous shale, Pumpernickel Formation, Antler Peak quadrangle, Nevada.
2. Chert, Pumpernickel Formation, Antler Peak quadrangle, Nevada.
3. Gray siliceous volcanic mud, lat. 34°44′ N., long. 141°04′ E.; depth 2,911 meters; Revelle (1944, p. 58, 67).
4. Radiolarian ooze, lat. 37°40′ N., long. 145°26′ E.; depth 5,396 meters; Revelle (1944, p. 58, 67).
5. Bentonite from Clay Spur, Wyo.; Rubey (1929, p. 157).
6. Mowry Shale, sec. 7, T. 48 N., R. 65 W., near Thornton, Wyo. Rubey (1929, p. 157).
7. Average analysis of 78 shales; Clarke (1924, p. 631).

The Pumpernickel Formation has been tentatively correlated with the Leach Formation in the East Range (Muller and others, 1951). The two formations are in general similar in lithology, for they both consist largely of shale, chert, and greenstone; but the Leach also contains much dark vitreous quartzite, which is not a constitutent of the Pumpernickel. The quartzite is identical with the quartzite of the Valmy, however, and it seems likelier that the Leach and Valmy are correlative.

Dibblee (Dibblee and Gay, 1952, p. 15–19) has described the Garlock Series in the El Paso Mountains near Randsburg, Calif. This series has an amazing lithologic similarity to the Pumpernickel and Havallah Formations. The Garlock Series aggregates about 35,000 feet; the lower 9 members consist of interbedded shale, chert, greenstone, limestone, and sandstone with a little conglomerate totaling about 11,000 feet that resemble the Pumpernickel Formation; the upper 12 members consist of quartzite, shale, chert, and limestone with a little conglomerate, totaling about 14,000 feet that resemble the Havallah Formation.

PENNSYLVANIAN AND PERMIAN SYSTEMS

HAVALLAH FORMATION

The Havallah Formation rests with possible disconformity on the Pumpernickel Formation; the disconformity represents a break of unknown length. The Havallah Formation was first described by Muller and others (1951) and was named from exposures in the Tobin Range, which was formerly called the Havallah Range. The type section is near Hoffman Canyon in the southwestern part of the Golconda quadrangle (Ferguson and others, 1952).

The lower part of the Havallah Formation contains sandstone, deposited from density currents, and chert and shale, indicating little change from the eugeosynclinal environment of Pumpernickel time; the upper part, however, consists mostly of thick quartzites, limy quartzites, shale, and chert, suggesting a gradual shallowing of the Pumpernickel and Havallah basin to a miogeosynclinal environment.

The Havallah Formation underlies the west side of Battle Mountain and extends from the southwest corner of the range northward to the edge of the quadrangle. The formation attains its maximum width of outcrop in Rocky Canyon where it is about 4 miles wide and is repeated by strike faults; from Timber to Trenton Canyons it is about 2 miles wide. The formation is absent from Trenton Canyon to a point about 1½ miles north, where it appears in two narrow belts separated by strike faults. Another belt more than 3 miles long extends along the east side of Cottonwood Creek almost to the Marigold mine. At the north border of the quadrangle, the Havallah underlies the low hills west of the Valmy-Buffalo Valley road.

The Havallah Formation, as originally defined, comprised the rock units above the Pumpernickel Formation and below the Koipato. Fusulinid collections from the upper part of the Havallah were determined by Lloyd Henbest to be of Wolfcamp or Leonard age; consequently, the whole formation was assigned to the Permian. Subsequently in 1953, fusulinids that were found in the basal unit were determined to be early Middle Pennsylvanian and Permian age. This raised a question as to whether the term Havallah should be restricted and a new formation proposed for the lower beds, or whether Havallah should be retained as a group term. Inasmuch as large areas of the published Winnemucca, Mount Tobin, Golconda, and Mount Moses quadrangles were mapped as Havallah and as these areas presumably include all the units, it seems more logical to retain the name as originally defined and subdivide the Havallah into members. Accordingly, the Havallah rocks in the Antler Peak quadrangle are herein assigned to three members, the Jory, Trenton Canyon, and Mill Canyon. The Jory Member of Middle Pennsylvanian and Permian age is composed chiefly of coarse sandstone and limy sandstone with pebbly beds in places. The Trenton Canyon Member is interbedded dark chert and shale; thus far, no fossils have been found in it and its age is unknown. The Mill Canyon Member is composed of interbedded quartzite, thin-bedded limestone, chert, and shale. The lower beds contain fusulinids of Wolfcamp and Leonard (Early Permian) age. There is no striking evidence of breaks between the members, but the time interval represented is large and it is likely that the contacts may in part represent erosional disconformities. The members of the Havallah Formation were mapped separately on plate 4.

Jory Member

The lowest unit, here named the Jory Member, consists of sandstone and pebbly sandstone and interbedded minor amounts of conglomerate, shale, and chert (fig. 21). The sandstone beds are generally coarse and contain considerable calcareous material; locally they grade into sandy limestone beds. They are generally gray to brownish, and weather dark brownish gray to black. Grains of quartz, quartzite, and chert make up the bulk of the rock, but in addition, orthoclase, plagioclase, microcline, biotite, collophane, and muscovite are locally abundant (fig. 21*B*). The grains are subrounded to well rounded and average 1–2 mm in diameter. Quartz and calcite are the cementing materials. Studies of the thin sections show that the relative abundance of the minerals that make up the quartzite varies widely. In places the collophane content is significant; X-ray studies by R. A. Gulbrandsen (oral commun., 1956) indicate as much as 5 percent P_2O_5 in some specimens.

The type section of the Jory Member is on the west side of Willow Creek, where it has been named from the nearby Jory Ranch. A measured section gave a total thickness of 1,272 feet.

Poorly developed sole markings on the bottoms of beds in the Jory Member are alined uniformly north-south. These markings, together with the absence of crossbedding, ripple markings, and other shallow water features, suggest that the Jory Member was deposited below wave base. As most of the material in the unit is coarse sand and pebbly beds, it is suggested that deposition was mainly by density currents. This explains the anomaly of a sandstone unit in an environment where normally shale and chert were previously and subsequently deposited. The Jory also is suggestive of orogeny in the source area.

Jory Member of Havallah Formation measured in secs. 7 and 18, T. 31 N., R. 43 E.

	Thickness (feet)	Cumulative total (feet)
Fault (exact location indefinite).		
Sandstone and conglomerate; sandstone is pebbly	100	1, 272
Sandstone, pebbly, medium-bedded	40	1, 172
Shale, greenish-gray and siliceous; contains thin quartzite beds	10	1, 132
Sandstone, coarse-grained to pebbly and well-bedded; interbedded with calcareous sandstone	30	1, 122
Sandstone, brownish-gray, weathers dark brown, calcareous, well-bedded; some beds are quartzitic	130	1, 092
Sandstone, greenish-gray, weathers brown, coarse-grained, medium-bedded, locally laminated; forms smooth slopes with ledge outcrops at intervals	260	962
Sandstone, conglomeratic, with pebbles of chert and quartzite	85	702
Sandstone, medium- to coarse-grained, poorly exposed	100	617
Sandstone, coarse-grained, thick-bedded, granular in places	120	517
Sandstone, conglomeratic, and medium- to thick-bedded pebbly sandstone	25	397
Sandstone, with pebbly layers; poorly exposed	210	372
Conglomerate, pebbly, dark brownish-gray, weathers brown, forms prominent ledge, contains chert pebbles in sand matrix, in layers in some places but is commonly massive	22	162
Covered interval: Along strike this unit is a dense gray quartzite	140	140
Base: Pumpernickel Formation.		
Total	1, 272	

Trenton Canyon Member

The middle unit, here named the Trenton Canyon Member for the canyon of the same name, is composed of interbedded chert and shale that resemble the chert and shale units of the underlying Pumpernickel Formation. The chert layers are mostly red, green, purple, or gray and are generally thin bedded. The individual layers range from 1 to 12 inches in thickness and average about 4 inches. The shale forms thin partings between chert layers, and also distinct layers ranging from a fraction of an inch to 6 inches in thickness. The shale layers show the same color range as the chert.

The Trenton Canyon Member has not been measured in detail, but the section in the canyon just north of the Black Rock mine was estimated to be 1,000 feet thick and is designated the type section. In the vicinity of the intrusive body in Trenton Canyon, the chert and shale have been converted to hornfels, North of Trenton Canyon the outcrop narrows, probably because the member thins somewhat. To the south, the outcrop widens, in part owing to repetition caused by strike faulting, but perhaps partly because of a thickening of the member in that direction.

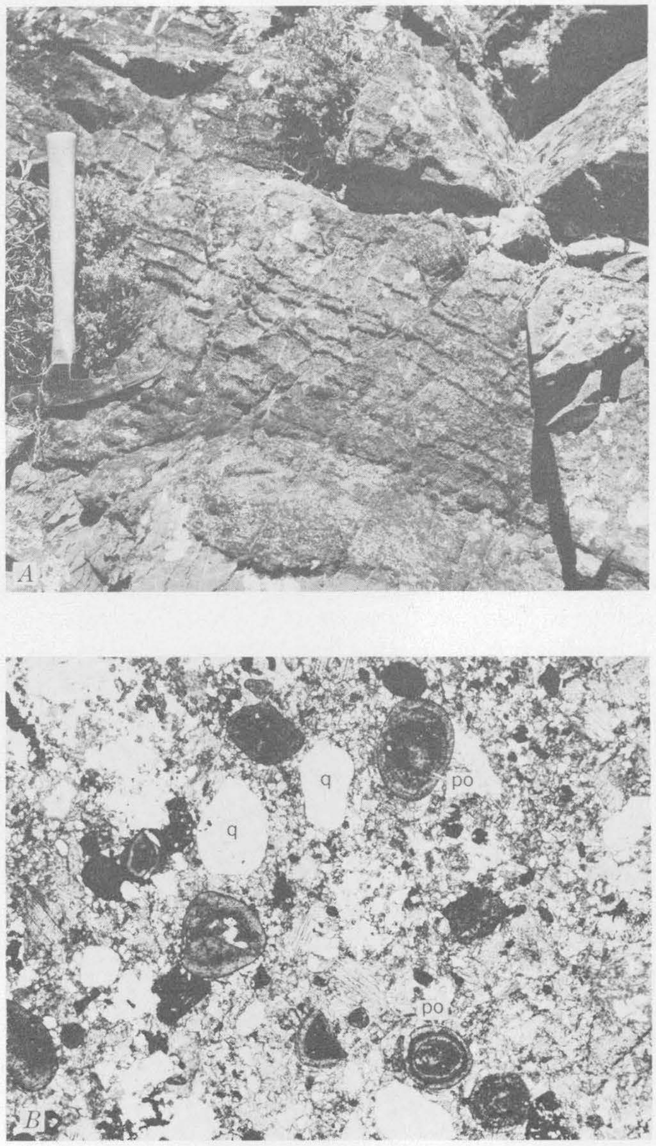


FIGURE 21.—*A*, pebbly limestone of the Jory Member of the Havallah Formation. The pebbly layers weather in bold relief. The white patches are lichen. *B*, photomicrograph of pebbly sandstone of the Jory Member of the Havallah Formation, showing phosphorite nodules (po) and quartz grains (q) in calcareous sandstone matrix. Plane-polarized light. × 14.1.

The similarity of the lithology of the Trenton Canyon Member to the Pumpernickel suggests a temporary return to the quiet offshore depositional environment that prevailed during most of Pumpernickel time.

Mill Canyon Member

The upper unit, here named the Mill Canyon Member, underlies most of the upland area of the west flank of the range; the type locality is in Mill Canyon. Quartzite, sandy limestone, shale, and chert are the dominant rock types in this member. The quartzite beds are medium to dark gray and weather brownish gray, tan, or white. They are resistant to erosion and form bold outcrops, especially in Timber and Mill Canyons. The quartzite is commonly medium bedded, ranging from a few inches to 2 feet in thickness, but some layers are thinly laminated with shaly partings, and others are thick bedded to massive. The rock units are generally thin, from 10 to 25 feet thick, but some are 100 feet or more thick. Most of the quartzite layers are calcareous and locally grade laterally into limestone. The quartzite beds weather to tan or brown angular blocks from a fraction of an inch to 1 foot in diameter, forming a distinctive float in the soil.

Limestone layers in the Mill Canyon Member are generally dark gray on fresh surfaces and weather light to medium gray. They range from a few inches to as much as 50 feet in thickness and average about 10 feet. Laterally the limestone interfingers with shale and locally grades into shale along the strike. Likewise, the limestone is sandy in places and grades into limy sandstone or quartzite. Microscopic examination shows it to be clastic and to contain much bioclastic material.

Shale also makes up some thick units in this member. The shale is generally gray and weathers tan to brownish gray. In some places the shale is also calcareous and grades into shaly limestone (fig. 22*A*). Chert units in the Mill Canyon Member are in part thick bedded and dark colored, like those in the middle part of the Pumpernickel Formation, and in part thin bedded. These units are persistent over wide areas and seem to maintain fairly uniform thickness throughout the quadrangle. Worm and invertebrate trails are locally abundant in the Mill Canyon Member (fig. 22, *B* and *C*).

Near the granodiorite in Trenton Canyon the quartzite and limestone units are bleached white and recrystallized, and the chert and shale units are metamorphosed to dark-brown or black hornfels.

Conglomerate layers occur locally in the Mill Canyon Member as well as in the Jory Member. The conglomerate in the Jory Member contains pebbles of chert and quartzite as much as 4 inches in diameter in a sandy matrix. The conglomerate in the Mill Canyon Member is composed predominantly of chert and quartzite pebbles, but in addition contains a large proportion of limestone pebbles in a calcareous matrix.

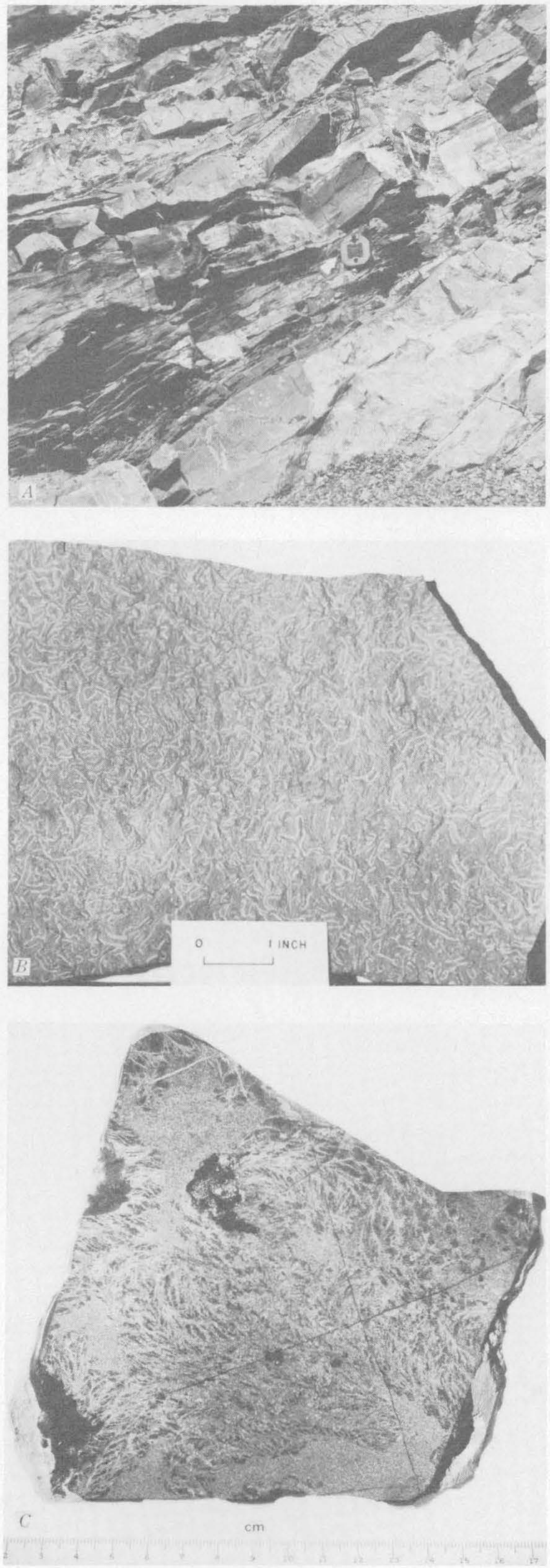


FIGURE 22.—Mill Canyon Member of the Havallah Formation. *A*, interbedded limestone and shale. The shaly layers show indistinct slaty cleavage. *B*, worm trails on sandstone. *C*, invertebrate(?) trails in limestone.

Only a small part of the total thickness of the Mill Canyon Member is exposed in the Antler Peak quadrangle. Ferguson and others (1952) estimate that the total thickness of the Havallah Formation may be 10,000 feet, leaving a considerable thickness of beds above the Jory and Trenton Canyon Members. Of this thickness, 2,386 feet was measured in the low hills south of Timber Canyon in the following section:

Partial section, Mill Canyon Member of Havallah Formation, measured in canyon south of Timber Canyon S½ sec. 15, T. 31 N., R. 42 E.

	(Feet)
Limestone, sandy and locally pebbly with thin quartzite beds	110
Quartzite, in part conglomeratic; brownish-gray, weathers dark brown	37
Limestone, sandy and locally pebbly; dark gray-brown, weathers dark brown. Some layers medium gray and contain only sparse sand grains A few pebbly layers interbedded	74
Chert and shale interbedded, green and gray; some black shale beds in upper part. Pebbly quartzite at 170 feet above base	620
Limestone, interbedded with chert	200
Quartzite, locally calcareous, interbedded with chert, brownish-gray, weathers brown; medium-bedded, locally thin-bedded	460
Limestone, gray with black chert at base and top; grades upward into brownish-gray, medium-bedded quartzite	45
Chert and shale, interbedded; gray and green; shaly partings and layers in chert	170
Chert and limestone, interbedded in part; in part pods and layers of limestone in chert; some of the limestone beds show mottling. Five feet of brown and gray chert bed in middle of unit	220
Quartzite and limestone, cherty. Quartzite very fine grained; grades into chert and limestone. Chert generally dark gray or black; contains shale partings locally; locally finely layered or laminated	155
Quartzite, medium-gray, weathers light brown; contains calcareous pods and layers; medium- to thick-bedded; some cherty layers associated with limestone	95
Quartzite, dark brownish-gray, weathers medium dark-brown; medium- to thick-bedded, commonly fine-grained; indistinctly layered. Locally calcareous	200
Base: Gray and green chert and shale of Trenton Canyon Member.	
Total	2,386

Age and correlation

The Jory and Mill Canyon Members of the Havallah Formation have yielded fusulinid faunas that have been studied by Lloyd Henbest and Raymond Douglass, who reported as follows on faunas from the Jory Member:

USGS f9668, Antler Peak Quadrangle, three-fourths of a mile northwest of Marigold Mine. Pennsylvanian, lower part Jory Member Havallah Formation, SE¼ sec. 12, T. 33 N., R. 42 E.

Bradyina sp.
Pseudostaffella sp.
Fusulinella sp.

* * * Contains an assemblage that indicates Atoka, early Middle Pennsylvanian age. It belongs in the same epoch of the Pennsylvanian as the lens of limestone in the conglomerate (Battle Formation) at Antler Peak though it might be slightly younger than that lens.

USGS f9773, Pennsylvanian, Antler Peak quadrangle, west side of Willow Creek, SE¼ sec. 19, T. 31 N., R. 43 E.

* * * The age suggested is early Middle Pennsylvanian, Atoka age.

USGS f9667 Antler Peak quadrangle, upper part of Jory Member NE¼ sec. 26, T. 32 N., R. 42 E.

Two or possibly three species of *Schwagerina* are represented. Permian is definitely indicated, but whether late Hueco or Leonard is represented is not clear.

Douglass pointed out, however, that the fusulinids in the lower part of the Jory Member showed abrasion, and evidently were transported from the source area along with the sands. The Atoka fusulinids are therefore not necessarily indicative of the age of the unit. The Hueco and Leonard fusulinids in collection f9667 from the upper part of the Jory Member may therefore represent the age of the unit. For the present it is suggested that the age be left indefinite and be designated as Pennsylvanian and Permian (?).

No fossils have been found thus far in the Trenton Canyon Member, but as it is bracketed by Permian beds above and Pennsylvanian to Permian below, it may also be Permian.

The basal part of the Mill Canyon Member has yielded an abundant fusulinid fauna. Lloyd Henbest and Raymond Douglass reported on sixteen collections of which the following are typical:

USGS f9655, Antler Peak quadrangle, west side of Rocky Canyon in NW¼ sec. 23, T. 31 N., R. 42 E.

Pseudofusulinella (?) sp.
Schwagerina or *Parafusulina* sp.
Parafusulina sp.

Permian is definitely indicated. Leonard age (early Permian) seems more likely, but might be late Hueco.

USGS f9656, Antler Peak quadrangle, same locality as f9655 but about 30 feet higher in section.

Parafusulina sp. (early form)
Schwagerina or *Parafusulina* 2 sp.

This is definitely Permian and probably Leonard in age. Late Hueco could not be disproved at this writing; late Leonard or Word age seems unlikely.

The three members of the Havallah Formation are partly correlative with the Antler sequence. The Mill Canyon Member (Hueco to Leonard(?)) apparently is younger than the Antler Peak Limestone, but the Jory and Trenton Canyon Members may be partly equivalent in age to the Antler Peak, though of different facies. During the deposition of the Havallah the basin gradually shallowed, and the environment changed from deep sea to shallow sea.

Dibblee (Dibblee and Gay, 1952, p. 15–19) has described the Garlock Series in southeastern California, of which the upper members resemble the Havallah Formation. Member 10 of the Garlock consists of tan quartzite 700 feet thick; member 11 is tan to brown shale and chert 700 feet thick; member 12 is composed of limestone, shale, and conglomerate and contains fusulinids of Wolfcamp (Early Permian) age. Dibblee's member 10 may be roughly equivalent to the Jory Member, his member 11 may be equivalent to the Trenton Canyon Member, and his member 12 may be equivalent to the Mill Canyon Member. Aside from differences in the thickness of units and minor differences in lithology, the general resemblance of the units is remarkable. Close kinship of the Havallah and the upper members of the Garlock Series is indicated, and it is suggested that the Havallah and Garlock may have accumulated in different parts of the same seaway.

In the southern Inyo Mountains, Calif., beds correlative with the Havallah Formation include the Keeler Canyon and Owens Valley Formations of Pennsylvanian and Permian age (Knopf, 1918, p. 37–41; Merriam and Hall, 1957, p. 5–12). The Keeler Canyon consists of about 2,300 feet of silty and cherty limestone and 1,700 feet of arenaceous, silty, and pebbly limestones with shale intercalations. The Owens Valley is mostly silty and sandy limestone, biogenic limestone, shale, siltstone, sandstone, and conglomerate aggregating about 1,800 feet. These two units lack the bedded chert characteristic of the Havallah Formation and Garlock Series and therefore belong to a different facies.

Originally Muller and others (1951) suggested possible equivalence of the Havallah and Inskip Formations. It was pointed out that the Inskip contained a greater proportion of graywacke and conglomerate than the Havallah, and that they are lithologically unlike, but they were provisionally correlated because they overlie similar formations, the Pumpernickel and Leach. Recently, corals of probable middle Mississippian age (Helen Duncan, written commun., 1957) have been found in the Inskip Formation, thus clearly establishing it as pre-Havallah.

Hobbs (1948, p. 27) and Hotz and Willden (1964) have mapped sandstone, sandy limestone, and limestone beds in the Osgood Mountains that are lithologically similar to the Havallah Formation. No fossils have been collected in these rocks.

Willden (oral commun., 1959) reports limestone, limy shale, and shale beds near Quinn River Crossing in Humboldt County that contain a fauna similar to the Edna Mountain fauna.

Dott (1955, p. 2261) mentions siltstones and dolomitic rocks near Carlin Canyon that may include beds as young as Guadalupe.

Ferguson (1924, p. 25, 26; Ferguson and Cathcart, 1954) has described sandstone of Phosphoria age in the Manhattan district and in the Toyabe Range. The thickness of the beds exceeds 3,000 feet in Toyabe Range, where the unit consists of conglomerate, grit, quartzite, and slate with a little dolomitic limestone. Correlative beds are also reported by Ferguson (Ferguson and Muller, 1949) from the Candelaria Hills in the Hawthorne quadrangle.

QUATERNARY SYSTEM

QUATERNARY DEPOSITS

Battle Mountain is mantled on all sides by Quaternary deposits. Adjacent to the range, alluvial fans and cones with steep gradients flank the bedrock and extend outward with gradually lessening gradients until they finally interfinger with the finer deposits of the valleys of the Reese and Humboldt Rivers and Buffalo Valley playa. The deposits have been divided into five units: Older gravels, older alluvium, younger alluvium, shoreline deposits, and flood-plain deposits. The older gravels are scattered remnants above the fans on the periphery of the range and in the range. The older alluvium comprises the fans that surround the range, and also some terraces and valley fill within the range. The younger alluvium is material eroded from the fans and valley fill that has been redeposited in stream channels and on aprons that cover the lower parts of the fans. The shoreline deposits are gravels and sands laid down in pre-Lahontan lakes in Humboldt Valley. Flood-plain deposits in the valleys of the Reese and Humboldt Rivers consists mainly of silts and clays that cover the shoreline deposits and the aprons of the fans.

Older gravels.—The older gravels generally crop out above the alluvial fans and in the range. They appear to be composed of well-washed and fairly well rounded cobbles and boulders, mainly of quartzite and chert, and form thin caps on Tertiary and pre-Tertiary rocks. They may have been deposited on alluvial fans or pediments during early stages in uplift of the range, but they occur only as scattered remnants and only a general idea of their original form and extent can be inferred.

Two deposits of gravel have been found high in the range, one about three-fourths of a mile west of Antler Peak at an altitude of 7,196 feet and the other on the 7,954-foot hill north of Trenton Canyon. This gravel contains boulders as much as 3 feet long and evidently was deposited by powerful streams. The remnants probably were channel deposits that were preserved on divides after uplift of the range. They may also be in part erosional remnants of the prevolcanic units. Coarse gravel is highly resistant to erosion because of percolation through pore spaces (Rich, 1911), and therefore has been preserved into the present cycle.

Another remnant assigned to the older gravel unit is half a mile north of the Buffalo Valley mine. This gravel contains large bolders of conglomerate of the Battle Formation. A drainage system considerably different from the present one must have existed to connect outcrop areas of Battle Formation with this remnant. The gravel, now at an altitude of about 5,700 feet, was probably downdropped along the faults that bound the range on the west. If so, the altitude of the gravel furnishes an index of the amount of displacement on the range-front faults—about 2,200 feet of dip-slip movement.

The gravels capping terraces between the Oyarbide Ranch and the Marigold mine are older deposits dissected during the uplift of the range. They are poorly exposed in most places, but include fairly well rounded and sorted material.

Older alluvium.—The older alluvium that comprises the alluvial fans and terraces and valley fill within the range is mainly unsorted coarse gravel with a sandy and clayey matrix. The gravel is composed of angular fragments near the range and contains boulders as much as 5 feet in longest dimension. Away from the range front, the fragments gradually become smaller and rounder. In the upper parts of the fans the gravel consists of rudely bedded coarse and fine layers (fig. 23). Both types contain considerable sandy and clayey material and probably represent a series of mud flows interlayered with fluviatile deposits. In the lower layers of the fans, which are exposed locally in placer workings, the gravel is washed and fairly well sorted (fig. 23). Moreover, the gravel in the lower layers is better rounded than that in the upper layers, suggesting that the supply of water was greater when the lower layers were deposited.

FIGURE 23.—Opencut in auriferous gravel in older alluvium, Copper Canyon fan, half a mile south of the range front. The gravel in the lower part is washed and well sorted; the gravel in the upper part is poorly sorted, suggesting mudflow origin. The lower gravels have yielded placer gold valued at several million dollars.

On the south side of Galena Canyon about 1,500 feet east of Galena townsite, a mass of rubble composed mostly of angular blocks of Battle Formation is jumbled together in a manner suggesting that it has slid from nearby outcrops. For convenience it is included here with the unit of older alluvium.

Younger alluvium.—Younger alluvium veneers the floors of the present valleys that have been incised in the fans and older valley fill and also forms the alluvial aprons covering the lower parts of the fans. The younger alluvium was in part formed during postfan dissection, which probably began in late Quaternary time and is continuing at the present time. The amount of incision is variable, ranging from a few feet to as much as 100 feet. Incision has been comparatively rapid and has produced stream channels generally less than 200 feet wide. The gravel in the channels is mostly subangular, but it is distinctly more rounded than the gravel in the upper parts of the fans. The channels widen out from the range fronts, forming the broad aprons that cover the lower parts of the fans. The aprons probably do not exceed 20 feet in thickness in most places.

Loeltz and others (1949, p. 26) studied the geology of the Paradise Valley northeast of Winnemucca and found the valley fill to consist of two units; deep valley fill and shallow valley fill. The deep valley fill, consisting of interbedded clay and silt, was penetrated in a well that reportedly reached a depth of 800 feet; they considered that this material might belong to the Humboldt Formation of Miocene or Pliocene(?) age. The shallow valley fill, consisting of stream or delta sand and gravel, was deposited in channels cut in the deep valley fill during Quaternary time.

Shoreline deposits.—On the south edge of the town of Battle Mountain, well-washed gravel and sand that appear to be shoreline deposits are exposed in a gravel pit about 200 feet east of the Austin Highway (Nevada Highway 8–A). Similar gravel and sand are also exposed in pits west of Battle Mountain along U.S. Highway 40 in sec. 28, T. 33 N., R. 44 E. The top of the gravel and sand is at an altitude of 4,500 feet, approximately the same altitude as a wave-cut ridge 5 miles northwest of Valmy in the Golconda quadrangle. Both the gravels and the wave-cut ridge probably are features formed along a pre-Lahontan lake in the valleys of the Humboldt and Reese Rivers and in Pumpernickel Valley. The age of the shoreline deposits is not known, but the deposits probably are partly equivalent to the older alluvium unit.

The full extent of the lake is not known, but the minimum length along the Humboldt River valley is inferred to have been about 50 miles, and the width at least 30 miles near Iron Point (in Golconda quad.; Ferguson and others, 1952). As no trace of this lake has been recognized in the Humboldt River valley west of Comus, it is inferred that the lake was formed when the valley near Comus was dammed by faulting or by a lava flow. To the east, the shoreline deposits are covered by flood-plain silt and clay in the valleys of the Humboldt and Reese Rivers. In Pumpernickel Valley, the lake terraces are somewhat dissected, and are well developed in the vicinity of Brooks Springs.

Flood-plain deposits.—The valleys of the Reese and Humboldt Rivers are covered by white to light-gray and buff flood-plain deposits that intertongue with the lower fan aprons. These deposits are mainly silts and clays that coarsen toward the range; locally they have been transported by wind, forming deposits of loess. The silts and clays range from a few inches to 40 feet in thickness. Wells in the valleys commonly enter gravel below this veneer.

IGNEOUS ROCKS

The igneous rocks in the Antler Peak quadrangle include volcanic and intrusive rocks that range in age from Cambrian to late Tertiary or early Quaternary. The oldest igneous rocks are basic andesite or basalt flows, pillow lavas, and pyroclastic rocks intercalated with sedimentary rocks of Paleozoic age. Such igneous rocks make up a considerable part of the Scott Canyon Formation of Cambrian age, and similar ones were also extruded in the Ordovician during Valmy time and in the Pennsylvanian(?) during Pumpernickel time. Diabase sills and dikes cut the rocks of the Harmony Formation, but no related flows have been recognized. The major period of intrusive activity was probably during the early Tertiary when magma, mainly of quartz monzonitic and granodioritic composition, invaded all the older rock units in the quadrangle. The youngest igneous rocks include welded and unwelded tuffs of quartz latitic composition, and olivine basalt flows of late Tertiary and early Quaternary age.

IGNEOUS ROCKS OF PALEOZOIC AGE

The igneous rocks of Paleozoic age are mainly mafic flows, pillow lavas, and pyroclastic rocks that were either extruded on the sea floor or on nearby land areas and were subsequently carried into ocean basins. The igneous rocks are intercalated with chert and clastic sedimentary rocks forming a typical eugeosynclinal sequence. As these igneous rocks are part of the stratigraphic sequence, they are described in the section on stratigraphy along with the sedimentary rocks. The igneous rocks in the Scott Canyon Formation are discussed on pages A14–A15, those in the Valmy Formation on page A19, and those in the Pumpernickel Formation on page A37.

Associated with the volcanic rocks are related make intrusive bodies, which are mainly diabase dikes, sills, and small plugs. As these rocks cut across the enclosing rocks, they will be described separately below.

DIABASE

Diabase dikes and sills are locally abundant in the Harmony Formation. They are involved in the folding of the formation and are therefore pre-early Middle Pennsylvanian in age. Despite their long and complex histories, many of the diabase sills are surprisingly fresh and unaltered. They range in width from a few inches to 20 feet and zones of them have been traced intermittently for several miles along the strike. The diabase is dark greenish gray to black. Near the contacts it is fine grained, and in the centers of the dikes or sills it is generally medium grained. The diabase is composed of zoned plagioclase phenocrysts (An_{75-37}) as much as 1.3 mm long in a groundmass of plagioclase laths (about An_{50-40}) ranging from 0.05 to 0.6 mm in length and averaging about 0.3 mm. The phenocrysts are largely replaced by sericite, but the laths are only slightly altered. Augite grains as much as 0.5 mm in diameter and averaging about 0.15 mm are scattered throughout the rock and form an intergranular texture with the plagioclase. Some of the larger grains show distinct zoning. On the whole, the augite is quite fresh, but it is locally altered to chlorite. There is a considerable amount of a carbonate mineral in the rock. An analysis of one of the sills is given in table 5, No. 4.

GABBRO

A gabbro plug, thought to be the neck of an Ordovician volcano, is exposed in the valley of the North Fork. The plug, about 50 feet in diameter, is surrounded by pillow lava and by basaltic breccia that grades outward into fine-grained tuff.

The gabbro is a coarse-grained greenish-black rock composed principally of augite and plagioclase. The augite is in large fresh grains as much as 5 mm long that enclose plagioclase laths in ophitic intergrowth, and also occurs in grains 0.1 to 0.5 mm in diameter scattered throughout the groundmass. The plagioclase laths range from 0.5 to 2 mm in length and are largely altered to sericite and a clay mineral. Scattered patches of chlorite and serpentine are thought to be alteration products of augite and possibly olivine. Other alteration products are zoisite, epidote, and a little calcite.

An analysis of the gabbro shows that it is normal in most respects, but the sodium content is high, suggesting introduction of sodium after emplacement (table 5, No. 1). No albite was seen in the rock and it is presumed that the sodium is contained in the clay minerals.

INTRUSIVE ROCKS OF TERTIARY AGE

GRANODIORITE AND QUARTZ MONZONITE

The major intrusive bodies that have been mapped in the Antler Peak quadrangle are stocks of granodiorite and quartz monzonite. The principal stocks are in Trenton Canyon, near the mouth of Elder Creek, in Snow Gulch and Copper Basin, and in Copper Canyon. The largest body is in Trenton Canyon and is 2 miles long and 1 mile wide. Apophyses, dikes, and sills extend out from the stocks, and dikes and sills occur in separate masses throughout the quadrangle. Contact metamorphic zones occur peripherally around the intrusive bodies and extend into areas not known to be underlain by intrusive rock; it is inferred from this that large areas in the quadrangle are underlain by intrusive rock at depth. Most of these intrusives are porphyritic and consist of conspicuous phenocrysts of plagioclase, orthoclase, and quartz in a fine- to medium-grained groundmass. In the larger bodies, the central parts are medium to coarse grained. Two of the intrusive bodies have been dated as late Eocene to early Oligocene by the lead-alpha method, and the others are thought to be of the same age.

The analyses of the intrusive rocks have been assembled in table 6. In addition, calculations of the norms according to the C.I.P.W. system (Cross and others, 1903), calculations of the Niggli numbers (Niggli, 1954), and of the Rittman values (Rittman, 1952, p. 93) are included in the table for convenient comparison of the chemical characteristics of these rocks. In figure 29, the Niggli k values (the ratio of K_2O to Na_2O and K_2O combined) have been plotted against the silica percentage for comparison of differentiation trends. In the upper right diagram in figure 29, the differentiation index of Thornton and Tuttle (1960) is plotted against silica percent.

Granodiorite at Trenton Canyon.—The granodiorite stock at Trenton Canyon is funnel-shaped in plan and has a length of about 2 miles and a width of as much as 1 mile at the northwest end. The stock is elongate in a northwest direction, and because it is less resistant to erosion than the enclosing Pumpernickel and Havallah Formations, it underlies a broad basin beginning about 1 mile east of the range front and extending nearly to the divide with Rocky Canyon.

The granodiorite (fig. 24*A*) is medium-gray rock that weathers light brown to light reddish brown. The peripheral parts of the intrusive consist of porphyritic rock containing phenocrysts of feldspar and quartz as much as 5 mm long set in a groundmass of quartz, feldspar, biotite, and hornblende. The central parts of the intrusive are generally equigranular, and the grain size averages about 2 mm.

The feldspar crystals include both plagioclase and

TABLE 5.—*Analyses and calculations of mafic igneous rocks, Antler Peak quadrangle, Nevada*

[Analysts: P. L. D. Elmore, S. D. Botts (samples 1-3); K. E. White (samples 1-6); H. F. Phillips, P. W. Scott, and F. S. Borris (samples 4-6); U.S. Geol. Survey, by rapid methods]

	Paleozoic intrusive and volcanic rocks				Tertiary volcanic rocks				
	1	2	3	4	5	6	7	8	9
Field No.	55-AP-1	55-AP-2	46-A-50	53-AP-20	53-AP-10	53-AP-11	----	----	----
Lab. No.	145664	145665	145666	53548C	53539C	53C540C	----	----	----
Chemical analyses									
SiO_2	48.6	48.8	49.9	49.1	46.8	46.6	52.31	50	47.0
Al_2O_3	14.4	12.3	13.8	15.2	15.8	15.9	14.38	13	15.1
Fe_2O_3	2.2	2.4	3.7	1.7	4.3	3.0	2.47	} 13	3.7
FeO	7.2	5.6	7.2	8.6	6.9	8.2	9.95		8.1
MgO	7.9	6.1	4.8	6.2	7.7	7.6	4.46	5	7.9
CaO	10.2	15.2	6.7	8.8	9.9	8.9	8.37	10	10.9
Na_2O	3.2	2.5	4.5	2.2	3.2	3.4	2.94	2.8	2.7
K_2O	.53	.07	1.2	.62	.54	1.0	1.26	1.2	1.0
H_2O	3.2	2.4	3.3	3.11	.72	.35	1.13	----	----
TiO_2	1.5	1.2	2.7	1.6	2.2	2.4	2.10	----	3.0
P_2O_5	.20	.18	.56	.28	.66	.73	.36	----	----
MnO	.17	.18	.16	.20	.20	.20	.21	----	.2
CO_2	.10	2.9	.73	2.1	.12	.23	----	----	----
Total	99.40	99.83	99.25	99.7	99.0	98.5	99.94	95.0	99.6
Sp gr lump	2.96	2.98	2.83	----	2.87	2.82	----	----	----
Sp gr powder	2.90	2.98	2.66	----	----	----	----	----	----
Norms									
Quartz	----	4.9	.5	6.7	----	----	----	----	----
Orthoclase	3.1	.41	7.1	3.67	3.2	5.9	----	----	----
Albite	27.5	21.3	38.1	18.60	27.1	28.7	----	----	----
Anorthite	23.2	22.0	13.9	28.8	27.1	25.1	----	----	----
Corundum	----	----	----	3.4	----	----	----	----	----
Wollastonite	10.7	14.2	5.3	----	----	5.38	----	----	----
Enstatite	6.8	15.3	12.0	15.5	9.8	4.3	----	----	----
Ferrosilite	3.2	6.7	6.0	12.1	6.5	2.0	----	----	----
Fayalite	2.2	----	----	----	2.3	5.3	----	----	----
Forsterite	6.3	----	----	----	6.6	10.3	----	----	----
Magnetite	3.3	3.5	5.36	2.46	6.2	4.3	----	----	----
Ilmenite	2.9	2.3	5.12	----	4.2	4.6	----	----	----
Apatite	.4	.40	1.21	.62	.43	1.6	----	----	----
Calcite	----	6.6	1.6	4.70	.27	.52	----	----	----
Niggli numbers									
al	19.7	17.4	25.9	23.3	21.1	21.5	----	----	----
fm	45.8	37.5	34.2	45.4	47.1	47.6	----	----	----
c	26.4	39.1	23.4	24.7	24.1	21.9	----	----	----
alk	8.1	6.0	16.3	6.6	7.7	9.0	----	----	----
Total	100	100	100	100	100	100	----	----	----
si	1.13	1.17	1.60	1.28	1.06	1.07	----	----	----
k	.09	.02	.16	.16	.09	.16	----	----	----
mg	.60	.58	.66	.54	.61	.56	----	----	----
Rittman values									
k	0.10	0.02	0.12	0.06	0.06	0.16	----	----	0.15
an	.45	.49	.10	.55	.45	.41	----	----	.47
p	56.1	53.2	40.0	61.5	53.8	51.7	----	----	----

1. Gabbro from plug in Valmy Formation, north side 7,000-ft knoll, SE¼ sec. 5, T. 32 N., R. 43 E.
2. Greenstone (altered pillow lava), Valmy Formation, North Fork, SE¼SE¼ sec. 5, T. 32 N., R. 43 E.
3. Greenstone (altered massive lava), Scott Canyon Formation, W. center sec. 25, T. 31 N., R. 43 E.
4. Diabase from sill in Harmony Formation, Cow Canyon, NW¼ sec. 3, T. 31 N., R. 43 E.
5. Basalt from canyon south of Box Canyon, NW¼ sec. 35, T. 31 N., R. 43 E.
6. Basalt from south side Box Canyon, NW¼ sec. 34, T. 31 N., R. 43 E.
7. Average Columbia Plateau Basalt of Waters (1955, p. 705). See also analysis cited by Anderson (1941, p. 404).
8. Kennedy's tholeiitic magma type (Kennedy, 1933, p. 241).
9. Average Pacific olivine basalt of Poldervaart (1955, table 21, No. 22, p. 134).

orthoclase. The plagioclase is mainly in large subhedral crystals that are complexly twinned (fig. 24*B*). These crystals are highly zoned; the interior parts show oscillatory twinning in the general range of An_{45-40}; the outer zones are as sodic as oligoclase, and some crystals have outer rims of myrmekite. A few small crystals of plagioclase occur in the groundmass and as inclusions in orthoclase crystals and have a composition of about An_{35}. The orthoclase occurs in two generations: As large crystals as much as 3 mm long, some of which are perthitic; and in fine-grained intergrowths with quartz in the groundmass (figs. 24*B* and 25). The larger crystals are partly sericitized and kaolinized; the smaller crystals are, on the whole, quite fresh. The perthite intergrowths follow cleavage lines or are irregularly distributed throughout the crystal.

Quartz is present also in two generations: Early subhedral bipyramidal crystals as much as 3 mm long, and later crystals averaging about 0.5 mm in diameter in the groundmass. The larger crystals commonly are fractured or show strain shadows. In part, the later quartz crystallized simultaneously with the fine-grained orthoclase as the two minerals are complexly intergrown.

The mafic minerals are biotite and hornblende, which together make up about 5 percent of the rock. The biotite is in anhedral plates as much as 2.5 mm long and in fine-grained aggregates in the groundmass. The variety in anhedral plates is a high-iron variety with 2V nearly 0°, and pleochroism X=light yellow and Z=dark reddish brown. The fine-grained variety apparently formed later and contains less iron; its pleochroic formula is X=light greenish yellow and Z=greenish brown. These two biotites appear analogous to two varieties of biotite in altered intrusive rock noted by Anderson and others (1955, p. 52) at Bagdad, Ariz. The hornblende is in subhedral crystals as much as 3 mm long. It is moderately pleochroic with X=brownish green and Z= clear green; $Z \wedge c = 22°$. To some extent, the hornblende is intergrown with and replaced by biotite, which has been partly altered to chlorite. The hornblende is generally fresh, but some crystals have been altered to chlorite, epidote, and zoisite.

TABLE 6.—*Analyses and calculations of intrusive rocks, Antler Peak quadrangle, Nevada*

Analysts: M. K. Carron (samples 1-3), K. E. White (samples 4-7, by rapid methods), H. F. Phillips, P. W. Scott, F. S. Borris (sample 4, by rapid methods), P. L. D. Elmore and S. D. Botts (samples 5-7, by rapid methods), U.S. Geol. Survey]

	1	2	3	4	5	6	7
Field No.	48-R-112	68-259	48-R-341	53-AP-21	55-AP-5	52-R-82	52-R-149
Lab. No.	----------	----------	----------	53-549C	145670	145671	145667
Chemical analyses							
SiO_2	70.25	66.43	68.33	64.0	66.1	63.0	47.3
Al_2O_3	13.46	14.47	15.22	15.2	16.9	16.3	13.8
Fe_2O_3	[1] 3.42	[1] 4.29	.28	1.4	1.8	2.0	1.8
FeO			2.28	2.4	1.7	2.6	9.8
MgO	1.46	2.70	1.86	2.7	1.1	2.4	7.7
CaO	2.32	2.52	3.20	3.8	3.9	4.8	10.2
Na_2O	2.02	2.52	3.23	3.2	4.1	3.6	3.0
K_2O	4.88	4.22	2.92	2.8	2.9	2.6	1.0
H_2O+	.45	.30	.45	.12	.72	.74	2.0
H_2O-	.90	1.12	1.46	2.2		----------	.21
TiO_2	.36	.42	.33	.41	.45	.57	1.9
P_2O_5	.15	.13	.10	.16	.19	.18	.7
MnO	.02	.03	.06	.08	.06	.06	
CO_2	.08	.12	.34	1.7	.05	.30	.14
S	.51	.81	.03	----------	----------	----------	----------
BaO	None	None	None	----------	----------	----------	.14
Total	100.28	100.08	100.09	100	100	99	100
Less O=S	.25	.40	.01				
	100.03	99.68	100.08				
Sp gr (bulk)	2.66	2.62	----------	2.59	2.66	2.70	2.97
(powder)	2.66	2.66	2.65	----------	2.57	2.67	2.96

TABLE 6.—*Analyses and calculations of intrusive rocks, Antler Peak quadrangle, Nevada*—Continued

	1	2	3	4	5	6	7
Norms							
Quartz	31. 98	24. 99	31. 50	26. 29	21. 1	21. 6	
Orthoclase	28. 88	24. 96	17. 27	16. 57	17. 2	9. 8	6. 0
Nephelite							1. 0
Albite	17. 07	21. 25	27. 30	26. 58	34. 6	26. 0	23. 5
Anorthite	10. 13	10. 92	15. 56	7. 37	18. 5	20. 9	21. 4
Corundum	1. 13	2. 29	1. 47	4. 20	2. 5	. 7	
Enstatite	3. 65	6. 74	4. 65	6. 75	2. 75	6. 0	6. 6
Ferrosilite	1. 65	4. 20	2. 77	2. 72	. 94	1. 8	4. 1
Wollastonite							11. 3
Forsterite							8. 9
Fayalite							7. 3
Magnetite	1. 39	. 46	. 46	2. 03	2. 62		2. 62
Hematite							
Ilmenite	. 67	. 79	. 61	. 77	. 91	1. 1	3. 95
Apatite	. 31	. 30	. 24	. 38		. 3	. 37
Pyrite	. 96	3. 00	. 06	. 38	. 31		2. 6
Calcite	. 18	. 27	. 08	3. 86		. 7	4. 7
Classification according to Johannsen	(226″/7″) Adamellite	(227″) Adamellite	(226″7″) Granodiorite	(226″)			
Niggli numbers							
al	39. 2	37. 0	34. 4	36. 0	40. 8	36. 0	19. 0
fm	23. 7	30. 0	34. 1	29. 0	18. 3	27. 4	48. 0
c	12. 2	11. 0	12. 8	16. 0	17. 1	19. 3	25. 0
alk	24. 9	22. 0	18. 7	19. 0	23. 8	17. 3	8. 0
Sum	100	100	100	100	100	100	100
si	3. 47	2. 79	2. 57	2. 55	2. 71	2. 33	1. 07
k	. 62	. 53	. 37	. 37	. 32	. 62	. 18
mg	. 46	. 54	. 31	. 56	. 37	. 49	. 54
Rittman values							
k	0. 62	0. 53	0. 37	0. 37	0. 41	0. 43	0. 18
an	. 21	. 24	. 27	. 27	. 29	. 29	. 69
p	63. 9	66. 4	66. 2	62. 1	65. 4	61. 5	65. 4

[1] Total Fe as Fe_2O_3; presence of considerable sulfur in pyrite renders determination of FeO impractical.

1. Quartz monzonite, 200 ft. from portal of Farren adit, Copper Canyon mine, NE¼ sec. 28, T. 31 N., R. 43 E.
2. Quartz monzonite porphyry from dike cut at 250 ft. from collar of DDH. 68, Copper Canyon mine, NW¼ sec. 27, T. 31 N., R. 43 E.
3. Granodiorite, west side Snow Gulch, NW¼ sec. 18, T. 32 N., R. 44 E.
4. Granodiorite porphyry, Little Cottonwood Canyon, NW¼ sec. 1, T. 31 N., R. 43 E.
5. Granodiorite, Trenton Canyon, sec. 24, T. 32 N., R. 43 E.
6. Quartz diorite, sec. 15, T. 31 N., R. 42 E.
7. Gabbro, Mill Canyon, center sec. 36, T. 32 N., R. 42 E.

The accessory minerals are sphene, which occurs in irregular plates and wedges as much as 2 mm long, abundant apatite, sparse zircon, and magnetite partly altered to hematite.

The granodiorite at Trenton Canyon is intermediate in silica content (table 6, No. 5) as compared to the other granodiorites that have been analyzed (table 6, Nos. 3 and 4). The sodium content is much higher than that of the other two, reflecting a more sodic plagioclase and giving an albite: anorthite ratio of nearly 2:1. The Niggli k value of the granodiorite at Trenton Canyon is 0.32 (table 6 and fig. 29), lowest of the granodiorites. The granodiorites on the west side of Battle Mountain form a group whose Niggli k values are below those of the quartz monzonites on the east side of Battle Mountain, suggesting that the two groups were formed from somewhat different magmas.

Augite granodiorite near Trenton Canyon.—Augite granodiorite is an unusual facies of the granodiorite noted near the forks of Trenton Canyon at the SE cor. sec. 23, T. 32 N., R. 42 E. This facies cuts calcareous quartzite of the Havallah Formation and contains abundant augite as the sole mafic mineral. The augite is colorless in thin section. As $Z \wedge c$=about 40°, it is probably near diopside in composition. Calcareous material from the intruded Havallah Formation may have been assimilated by the granodiorite, thereby favoring the formation of augite. In other respects the augite granodiorite resembles the main mass of the granodiorite, except that it has an unusually large proportion of sphene.

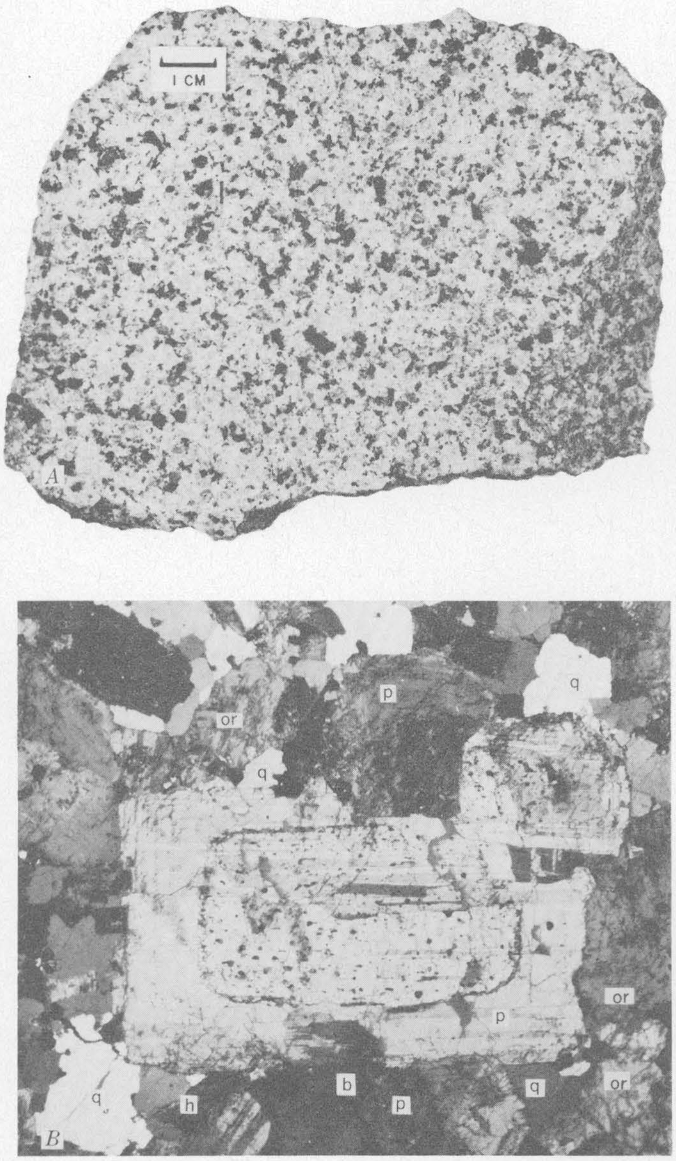


FIGURE 24.—*A*, granodiorite, Trenton Canyon. Consists mainly of plagioclase (white), quartz (light gray); the dark minerals are principally biotite and hornblende. *B*, photomicrograph of granodiorite., Trenton Canyon; plagioclase (p), orthoclase (or), quartz (q), biotite (b), and hornblende (h). The oriented inclusions in the plagioclase (lower center) are mainly apatite and biotite. Cross-polarized light, × 75.

Granodiorite at Elder Creek.—The granodiorite at Elder Creek comprises two stocks, each less than a mile long, together with several smaller bodies and dikes. The stocks are half a mile apart and are alined northeastward parallel to two tributaries that join Elder Creek at the range front. The dikes are mainly in the area around Healey Cabins and on the divide between Elder and Trout Creeks.

The stocks are made up of porphyritic granodiorite, a medium-gray rock containing prominent brownish plagioclase crystals as much as 5 mm long. The grain size of the groundmass ranges from very fine at the borders (1 mm) to medium coarse (about 2 mm) in the central parts.

Under the microscope the granodiorite at Elder Creek closely resembles the granodiorite at Trenton Canyon. The two rocks differ in that the granodiorite at Elder Creek has no large orthoclase crystals; staining by sodium cobaltinitrite (Chayes, 1952) shows that the orthoclase is fine grained (0.02–0.08 mm) and is intimately intergrown with quartz in the groundmass. The orthoclase also replaces phenocrysts of plagioclase and, to a lesser extent, early quartz. It occurs in veinlets and irregularly shaped masses that cut across and border the phenocrysts. The plagioclase in the Elder Creek group is a little more calcic with oscillatory zoning in the range An_{45-30}. The quartz crystals are present in two generations as early subhedral phenocrysts and later anhedral crystals in the groundmass. Accessory minerals are apatite, zircon, pyrite, and iron oxides. On the whole, the rock is quite fresh, but the biotite has been largely altered to chlorite, epidote, zoisite, and calcite.

A prominent granodiorite porphyry dike north of the Copper King mine in Copper Basin (fig. 25) is typical of the dikes in the north end of the range. Where fresh, the dike rock is dark gray and has phenocrysts of plagioclase, quartz, and hornblende set in a nearly granular groundmass. Microscopic examination of the groundmass reveals intergrown plagioclase, quartz, and orthoclase.

The plagioclase and quartz phenocrysts are as much as 5 mm long and the hornblende phenocrysts are as much as 2.5 mm. The plagioclase (An_{37-33}) is partly replaced by veinlets of orthoclase (fig. 25) and is peripherally altered to clay minerals. The hornblende is in fresh euhedral crystals, many of which are twinned. It is strongly pleochroic with X=light yellowish green, Y=brownish green, and Z=medium green. Remnants of biotite crystals, now altered to chlorite, epidote, zoisite, and sphene are also present.

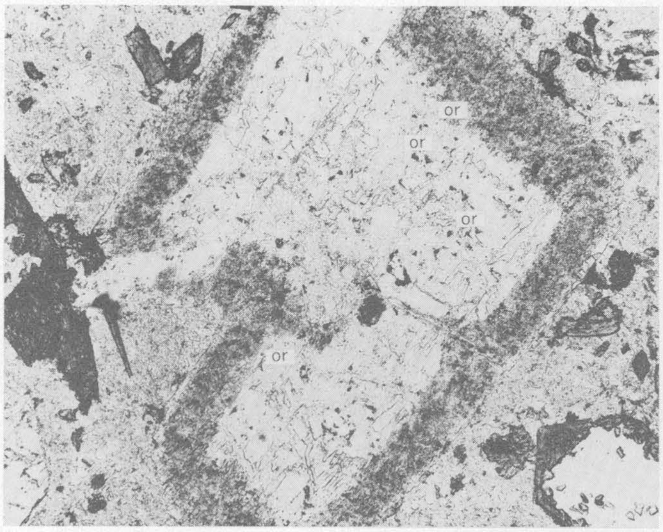


FIGURE 25.—Photomicrograph of granodiorite porphyry, Little Cottonwood Canyon, showing plagioclase phenocrysts partly replaced by orthoclase (or) in veinlets and with an outer turbid zone of alteration to clay minerals. Cross-polarized light. × 53.

The groundmass is a complex intergrowth of plagioclase, orthoclase, and quartz crystals all averaging about 0.03 mm in diameter. The quartz and orthoclase form aggregates and irregular intergrowths that have simultaneous extinction over areas as much as 1 mm in diameter. The plagioclase crystals in the groundmass are in small laths.

The plagioclase phenocrysts are complex crystals of andesine that show oscillatory zoning in the range of An_{50-30}. Some of the plagioclase crystals are partly replaced by fine aggregates of sericite and radial muscovite crystals.

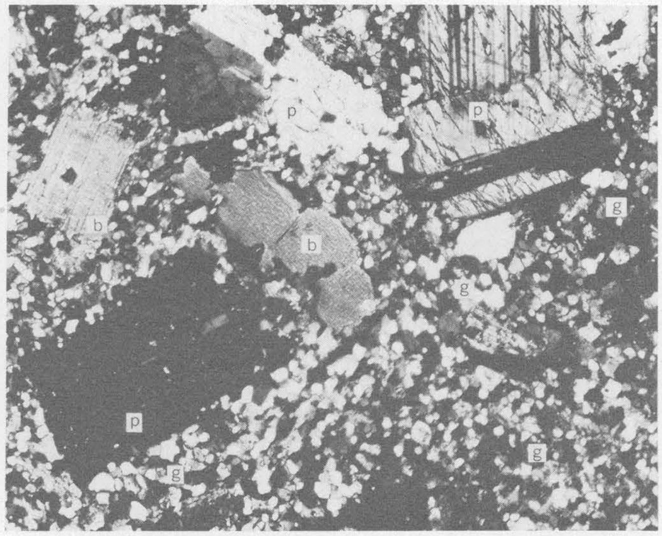


FIGURE 26.—Photomicrograph of quartz monzonite porphyry, Copper Canyon. Shows early plagioclase (p) and biotite (b) phenocrysts in a fine-grained groundmass (g) of quartz and orthoclase. Note subhedral form of early phenocrysts and anhedral form of groundmass crystals. Cross-polarized light. × 53.

The orthoclase phenocrysts are partly perthitic. The perthitic crystals have fine submicroscopic plagioclase intergrowths that do not follow any systematic crystallographic feature. The quartz occurs in phenocrysts that are mostly subhedral bipyramidal and also fresh these dikes are dark greenish gray and contain phenocrysts of microperthite, plagioclase, and bipyramidal quartz (fig. 27 *A*, *B*). Biotite is the principal mafic mineral, but hornblende is also a constituent of most dikes.

Quartz monzonite in Copper Basin.—The quartz monzonite in the Copper Basin area includes several small stocklike bodies and large dikes. These intrusive bodies are in a belt about 2 miles wide and 5 miles long extending from Snow Gulch to Little Cottonwood Canyon. Throughout much of the belt, and especially in the Copper Basin and Vail Canyon area, the intrusive rocks have been highly altered and bleached.

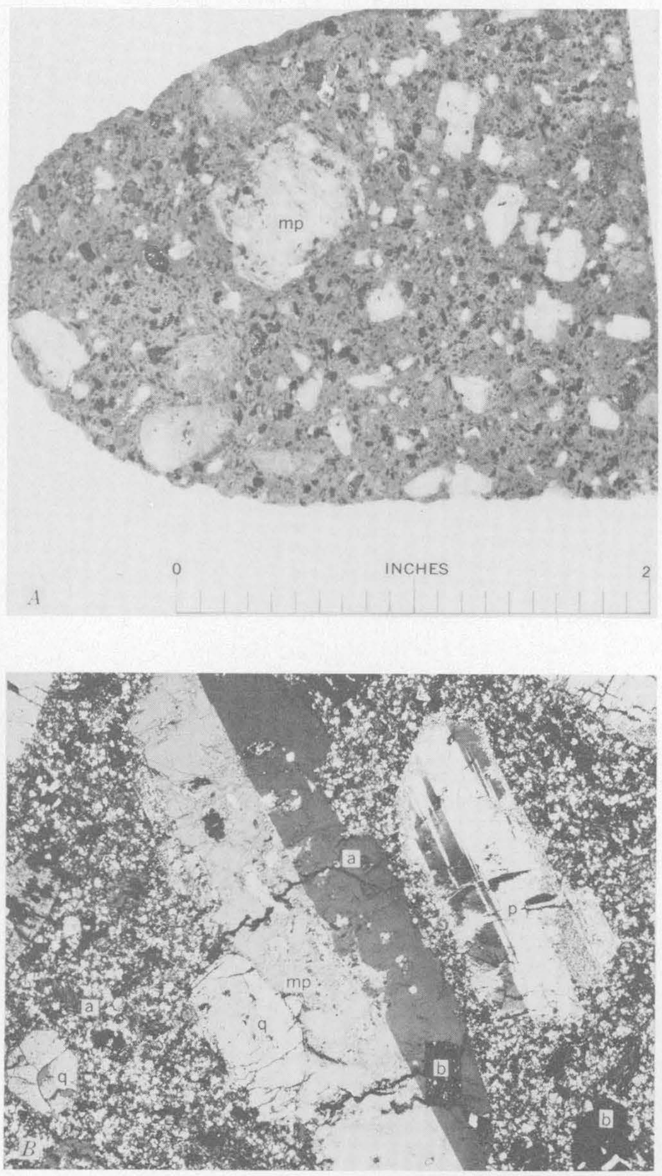


FIGURE 27.—Quartz monzonite porphyry dike, Copper Canyon mine. *A*, hand specimen showing large phenocrysts of microperthite (mp), and smaller phenocrysts of plagioclase, quartz, and biotite. *B*, photomicrograph showing early microperthite (mp), plagioclase (p), and biotite (b) with quartz (q) and quartz-orthoclase intergrowths (a). Plane-polarized light, × 22.9.

The intrusive bodies trend generally northward, parallel to the trend of the belt, except in Copper Basin where dikelike bodies strike northwestward. The northward trend was probably controlled by faults or fractures. Dikes mapped near the head of Little Cottonwood Canyon follow faults along which there has been little displacement.

The rock is porphyritic; plagioclase and quartz phenocrysts as much as 2.5 mm long are set in a groundmass of finely granular quartz and orthoclase, mostly smaller than 0.1 mm. The plagioclase crystals are replaced to a considerable extent by orthoclase, which is seemingly continuous with the orthoclase in the groundmass and also is slightly sericitized. The orthoclase follows cleavage lines in part but also cuts irregularly across the plagioclase.

The mafic mineral was formerly biotite; it is now altered to chlorite and a little secondary epidote, zoisite, and calcite. Iron oxide in irregularly shaped aggregates is scattered throughout the groundmass.

An intrusive body at the top of Long Peak about a mile east of the Lucky Strike mine is composed of porphyritic quartz monzonite containing both biotite and hornblende. From the large size of the metamorphosed aureole surrounding Long Peak, it is inferred that the exposed rock is an apical part of a larger intrusive.

The quartz monzonite contains phenocrysts of plagioclase (An_{55-53}) set in a groundmass composed mainly of finely granular quartz, plagioclase, orthoclase, and scattered crystals of biotite and hornblende. The plagioclase phenocrysts are partly shattered and are cut by orthoclase veinlets. The orthoclase is crowded with dustlike inclusions, which are probably clay minerals; some of the orthoclase veins contain similar inclusions, others are clear. It is noteworthy that in this rock, plagioclase (about An_{40}) is an abundant constituent of the groundmass. It has about the same composition as the outer zones in the phenocrysts.

QUARTZ DIORITE

Two small intrusive bodies of quartz diorite were mapped in the quadrangle. One of them is in a canyon west of Rocky Canyon, and the other is on the divide between Copper and Galena Canyons near the Nevada mine.

Quartz diorite west of Rocky Canyon.—The quartz diorite body in sec. 15, T. 31 N., R. 42 E. is typical of the diorite intrusives in the area. The rock in fresh hand specimens is medium gray in color and is fine to medium grained. On weathered surfaces it is light gray with reddish patches of iron oxides.

Microscopic examination of the rock reveals plagioclase, hornblende, biotite, and intergranular quartz and orthoclase. The plagioclase is in crystals averaging about 0.5 mm in length with a few as much as 1 mm long; it is strongly zoned with An_{45-20}. Hornblende in crystals as much as 1.5 mm long and somewhat smaller biotite plates are intergrown with the plagioclase. In part, the biotite is intimately associated with the hornblende and appears to replace it.

The quartz and orthoclase are mostly in grains 0.05–0.1 mm in diameter between plagioclase laths. A few of the orthoclase grains are as much as 0.5 mm long. The quartz is locally subhedral, but the orthoclase is distinctly anhedral, fitting into irregularly shaped spaces between grains. The orthoclase in part replaces the plagioclase along its borders and also occurs within the plagioclase grains.

Quartz diorite east of the Nevada mine.—The small quartz diorite intrusive body on the ridge east of the Nevada mine is similar to the quartz diorite west of Rocky Canyon. In hand specimens the rock is fine to medium grained and is greenish gray in color owing to the presence of much chlorite. Microscopic examination of the rock reveals mainly plagioclase laths (An_{40-30}) partly altered to sericite, which average about 0.20 mm in length, and chlorite that is pseudomorphic after augite, hornblende, and biotite. A clay mineral, probably of the montmorillonite group, occurs locally with the chlorite. Zoisite, epidote, and calcite are also present as alteration products. Quartz in small grains and in micrographic intergrowths with orthoclase fills intergranular spaces.

ANALYSES AND CALCULATIONS OF INTRUSIVE ROCKS

Chemical analyses of samples from two quartz monzonite bodies were made in the Geological Survey laboratories. The analyses and the norms calculated from them are shown in table 6, and they are also plotted on the variation diagram and plot of Niggli k values (figs. 28, 29). One of the analyses (table 6, No. 1) is representative of the larger intrusive masses; the other is of a dike which is probably an offshoot of the stock from which sample 1 was taken. The potassium content of sample 1 is higher than that of 2 and sodium is correspondingly higher in sample 2. This is interpreted to mean that as crystallization continued in the stock, part of the sodium may have passed off in a vapor phase; the remaining magma was therefore

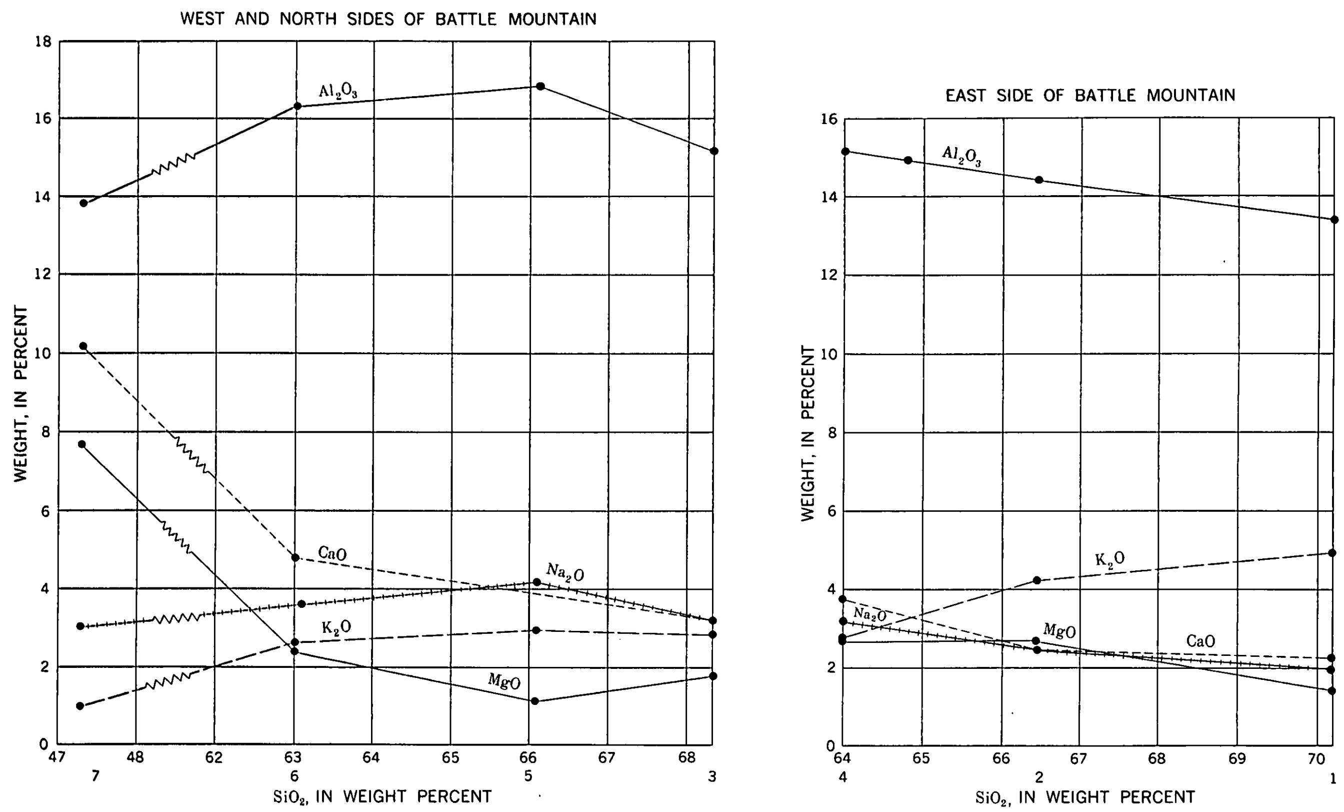


FIGURE 28.—Variation diagrams of intrusive rocks, Antler Peak quadrangle, Nevada. Numbers 1–7 below diagrams refer to analyses in table 6.

730-670 O—64——5

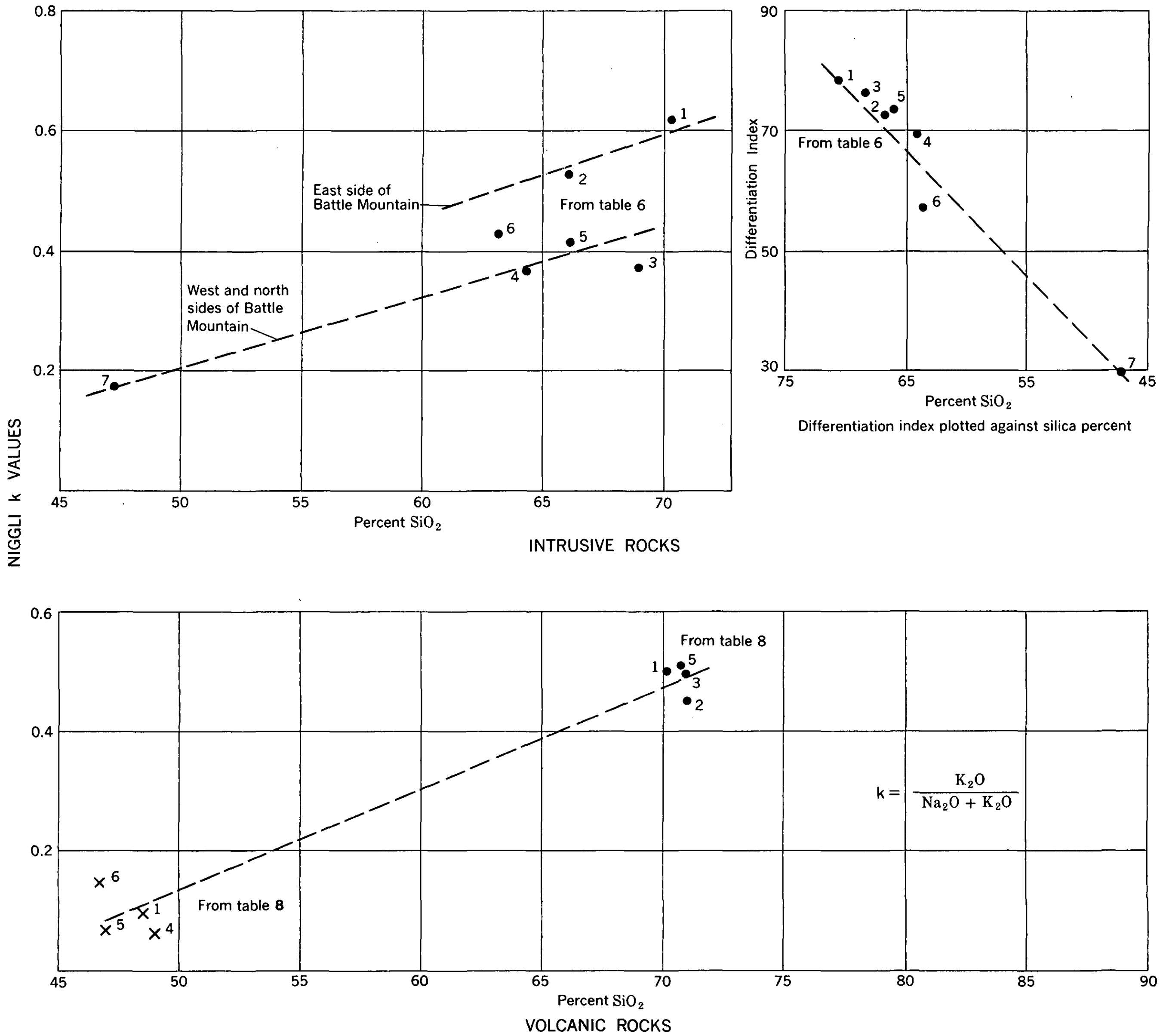


Figure 29.—Diagrams showing Niggli k values plotted against silica percentage, intrusive and volcanic rocks, Antler Peak quadrangle, Nevada. Diagram at upper right shows differentiation index of Thornton and Tuttle (1960) plotted against silica.

relatively enriched in potassium. In the dike, which was much smaller and therefore chilled faster, crystallization was more rapid, and the sodium crystallized in plagioclase in the groundmass.

The modal analyses given in table 7 correspond fairly well in composition to the norms. If there is any consistent difference, it is in the higher silica shown in the norms and possibly a higher potassium content. This is indicated by relative displacement of the plotted points of the norms toward the orthoclase corner of the triangular diagram (fig. 30).

DIKES AND SILLS

Most of the dikes that have been mapped in the quadrangle are composed of granodiorite or quartz monzonite porphyry and are offshoots from the stock-like bodies. Some of the dikes are distinctly different in lithology and composition; they may in part be equivalent in age to the main intrusives, but are in part considered to be older and to belong to somewhat earlier intrusive epochs. They include gabbro, diorite, granite porphyry, diabase, and lamprophyre (kersantite).

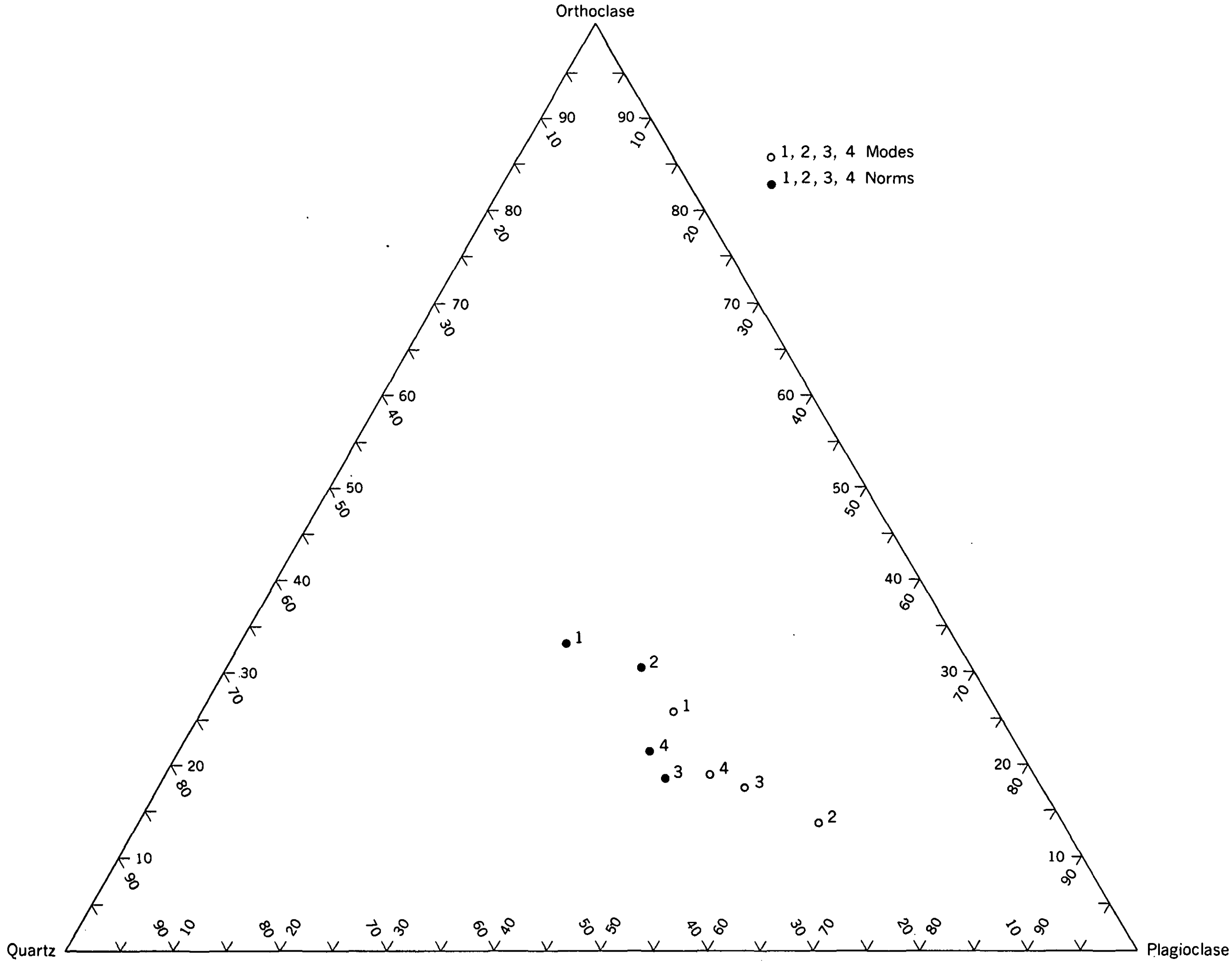


FIGURE 30.—Diagram showing modes (from table 7) and norms (from table 6) of intrusive rocks, Antler Peak quadrangle, Nevada.

TABLE 7.—*Modal analyses of silicic intrusive rocks, Antler Peak quadrangle, Nevada*

	1	2	3	4
Plagioclase	37. 8	56	48. 5	46. 0
Orthoclase	25. 6	12	15. 5	17. 2
Quartz	27. 2	20	24. 3	27. 1
Biotite	5. 2	7	6. 6	6. 6
Hornblende	4. 2	5	5. 1	3. 1
Total	100. 0	100	100. 0	100. 0

1. Granodiorite (field No.—46–A200), canyon west of Elder Creek, NE¼ sec. 2 T. 32 N., R. 43 E.
2. Quartz diorite (field No.—52–R–82), west of Rocky Canyon, NE¼ sec. 15, T. 31 N., R. 42 E. (sample 6 of table 6).
3. Granodiorite (field No.—48–R–384), head Trenton Canyon, SE¼ sec. 25, T. 32 N., R. 42 E.
4. Granodiorite (field No.—46–A–143), Trenton Canyon, NW¼ sec. 24, T. 32 N., R. 42 E.

GABBRO

Dikes and small intrusive masses of gabbro crop out in the upper part of Mill Canyon. The largest dike was traced for half a mile along the strike and is as much as 300 feet wide. The plug is about 200 feet in diameter.

The gabbro is medium to coarse grained and is dark greenish gray to black. Plagioclase laths and augite grains can be recognized in hand specimens. Under the microscope the augite is seen to enclose plagioclase laths in sub-ophitic texture. The plagioclase laths average about 1 millimeter in length and are as much as 2.5 mm long; the augite grains are as much as 2 mm long. The plagioclase (An_{45-35}) is moderately zoned and is partly altered to sericite and muscovite. The augite is in plates and subhedral grains. It is partly altered to fibrous green hornblende, biotite, and chlorite. These alteration products also to some extent replace the plagioclase. The hornblende occurs as peripheral shells around the augite and along cleavages. The biotite is in patches throughout the hornblende and in fibrous intergrowths with chlorite. Ilmenite partly altered to leucoxene and a sulfide that is probably pyrrhotite are the most abundant accessory minerals.

A sample of the gabbro plug was collected for analysis (table 6, No. 7). Although the sodium content is high, the rock clearly falls in the gabbro family.

DIORITE

In the Elvira adit near the Copper King mine, a diorite dike cuts quartzite of the Harmony formation. The diorite is a medium grained, dark-green rock composed of plagioclase (about An_{50}) and hornblende. Both of these minerals are partly altered, the plagioclase to clay minerals and the hornblende to secondary actinolite, biotite, chlorite, and zoisite. Pyrite is locally abundant. Leucoxene(?), which is probably secondary after ilmenite, and a carbonate mineral are scattered throughout the rock.

GRANITE PORPHYRY

A dike exposed in Trout Creek valley in the NW¼ sec. 17, T. 32 N., R. 43 E. is classed as a granite porphyry. It is aphanitic, light brownish gray, and contains sparse phenocrysts of feldspar and quartz. Microscopic examination of the groundmass reveals finely granular quartz, feldspar, and muscovite. The phenocrysts are perthitic orthoclase, plagioclase (An_{40}), and quartz. Quartz, in myrmekitic intergrowths with orthoclase, was noted in a few places.

DIABASE

Diabase dikes were mapped on the north side of Timber Canyon in sec. 3, T. 31 N., R. 42 E., and on the slope a few hundred feet west of Galena townsite. These dikes were originally composed largely of plagioclase and hornblende, which are now altered to clay minerals and chlorite.

LAMPROPHYRE (KERSANTITE)

A kersantite dike crops out on the south side of Mill Canyon near the center of the N½ of sec. 35, T. 32 N., R. 42 E. A similar dike was found in the valley south of Mill Canyon. These dikes are dark greenish brown, contain abundant biotite flakes, and weather readily. Microscopic examination of the rock reveals mainly biotite in large flakes and plagioclase. The biotite is highly pleochroic with X=light yellow and Z=dark reddish brown. It is in two generations, plates and laths as much as 0.5 mm long and laths about 0.05 mm long in the groundmass. The plagioclase is mostly altered to sericite and clay minerals; its composition could not be determined accurately but appears to be in the andesine range. Relicts of a mineral thought to have been hornblende are scattered throughout the rock in the form of secondary chlorite and biotite.

EMPLACEMENT OF INTRUSIVE ROCKS

The granodiorite and quartz monzonite bodies in the Antler Peak quadrangle were injected as partly crystalline magma along zones of weakness that were in part faults. The magma contained 20 to 40 percent of crystals that had formed intratellurically, mainly plagioclase, perthitic orthoclase, and quartz, in an alkali- and silica-rich melt which also contained considerable water and mineralizers.

Many intrusive bodies, especially the dikes, show a marked northerly trend, parallel to the most prominent set of high-angle faults in the range. Other intrusive bodies trend northeastward or northwestward, parallel to other fault sets. This close spatial relation strongly suggests that the high-angle faults were important in localization of the intrusive bodies. In addition, other structural elements may have played a significant role in localization of the intrusives—namely thrust faults. For example, two of the major intrusive bodies, the stocks in Trenton and Copper Canyons, are closely associated with the Golconda thrust fault. Both intrusive bodies cut across the thrust and may have followed the thrust plane in part. The Dewitt thrust fault, which is present at relatively shallow depths throughout the northeastern part of the quadrangle, may have to some extent controlled the localization of the larger intrusive bodies in Elder Creek, Snow Gulch, and Copper Basin. Such control is not clean cut like that of the normal faults in controlling the dikes. The Dewitt thrust fault appears to be a regional structural zone of weakness that in part broadly controlled the localization of the intrusive belt.

AGE OF THE INTRUSIVE ROCKS

The intrusive rocks in the Antler Peak quadrangle cut sedimentary and volcanic rocks of Paleozoic age and are overlain unconformably by volcanic rocks thought to be of Miocene or Pliocene age. Thus from stratigraphic relations their age would be between Permian and Miocene. In order to date the intrusive rocks more closely, samples of two stocks, the Copper Canyon and Trenton Canyon, were collected and lead-alpha ratios of the zircon in them were determined by Howard Jaffee, U.S. Geological Survey. The determinations are as follows:

Sample	Alphas (mg per hr)	Pb (ppm)	Age (millions of years)	Epoch
1	199	3.7	45	Eocene.
2	387	7.6	47	Do.
3			37	Early Oligocene(?).

1. Granodiorite, Trenton Canyon.
2. Quartz monzonite, Copper Canyon.
3. Quartz monzonite, Copper Canyon. At edge of Copper Canyon ore zone; sample contained considerable pyrite and barite.

Samples 1 and 2 agree fairly well and correspond to a date of late Eocene (Eocene-Paleocene span 40–60 million years). Sample 3 gives a distinctly younger date. The lead-alpha ratio probably was affected by alteration during the mineralization, thus resulting in a later apparent age determination.

IGNEOUS METAMORPHISM [3]

The sedimentary and volcanic rocks of Paleozoic age in Battle Mountain have been cut by many intrusive bodies (Roberts and Arnold, 1964, pl. 1, fig. 4). In their aureoles the sedimentary rocks have been metamorphosed, partly by heat and partly by the introduction of fluids derived from the igneous bodies and from related deeper sources. The metamorphism caused reconstitution of the original minerals in the sedimentary and volcanic rocks and in the igneous rocks as well. The changes in the aureoles are commonly called exomorphism, and the changes within the igneous bodies are called endomorphism. The ore deposits may be a late phase of igneous metamorphism following contact metamorphism without a significant break in time.

METAMORPHISM OF THE IGNEOUS ROCKS

The intrusive rocks in the Antler Peak quadrangle have undergone endomorphic alteration that began at the time of consolidation and extended into the hydrothermal stage. The earliest stage of alteration was propylitization, which accompanied or was followed by potassic metasomatism and later, silicification. In igneous bodies far from areas of ore deposits, propylitization and potassic metasomatism are the only effects of endomorphic alteration, but near ore deposits silicification also is widespread.

Propylitization includes alteration of the original biotite and hornblende to chlorite, epidote, clinozoisite, zoisite, and carbonate. Commonly hornblende is more intensely altered than biotite. Potassic metasomatism, during the late magmatic stage, was accomplished by formation of orthoclase, muscovite, and sericite. As the other silicates crystallized, the potassium content was relatively enriched in the late magmatic liquid. This liquid reacted with earlier feldspars and replaced them peripherally along crystallographic planes or fractures. Silicification is mainly confined to the vicinity of the ore deposits; elsewhere a few narrow quartz veins occur along fractures, but their bulk is small.

METAMORPHIC ZONES

Aureoles of contact metamorphism surround the larger intrusive bodies. These aureoles may be divided into an inner zone of intense metamorphism, an immediate zone of less intense metamorphism, and an outer zone in which the rocks are merely more indurated. The aureoles are as much as 2 miles wide but commonly are narrower (Roberts and Arnold, 1964, pl. 3). The inner zone, which is only a few tens of feet wide in most places, was included with the intermediate zone by Roberts and Arnold (1964, pl. 3). In calcareous rocks the minerals of the inner zone include garnet, wollastonite(?), diopside, actinolite, tremolite, biotite, and orthoclase; in argillaceous rocks the minerals are biotite, muscovite, sericite, cordierite, and orthoclase. In the intermediate zone calcareous rocks are metamorphosed to tremolite- and actinolite-bearing hornfels; argillaceous rocks are metamorphosed to biotite hornfels. Monomineralic rocks, such as limestone, quartzite, and chert, were changed by additive metamorphism in the inner zone, but except for recrystallization they are little changed in the intermediate and outer zones.

METAMORPHISM OF THE SEDIMENTARY ROCKS

The sedimentary rocks vary greatly in their susceptibility to metamorphism. Some units, such as the quartzites in the Havallah Formation, were bleached near contacts but remain unchanged in mineralogy. Other units, such as the Harmony and Havallah, were recrystallized over wide areas.

Battle Formation.—The Battle Formation was extensively metamorphosed by the stock in Copper Canyon. The lower calcareous conglomerate unit and middle calcareous shale were most sensitive to contact metamorphism, whereas the upper quartzose conglomerate was affected only slightly. The lower conglomerate contained limy pebbles as well as limy matrix, both of which were reconstituted forming garnet-diopside-actinolite conglomerate. Chert and quartzite pebbles were little changed. The middle calcareous shale was changed to diopside-actinolite hornfels and tactite.

Pumpernickel Formation.—The Pumpernickel Formation is also cut by the stock in Copper Canyon.

[3] Igneous metamorphism is treated only briefly here but is discussed in more detail in Prof. Paper 459–B, "Ore Deposits of the Antler Peak Quadrangle, Humboldt and Lander Counties, Nevada."

The normal grain size of the chert is 0.001–0.01 mm and the rock has a vitreous luster. At a point 1,200 feet from the contact the luster is dull, and the dark beds are somewhat bleached; the grain size averages 0.01–0.03 mm, and some of the argillaceous material in the rock has changed to a fibrous mineral, possibly hydromica or sericite. Chert collected a few feet from the contact is completely recrystallized. The rock is brown or reddish-brown and resembles a fine-grained quartzite. Under the microscope the quartz grains show sutured borders; the grains range from 0.01 to 0.2 mm in diameter. Biotite, muscovite, and orthoclase grains of the same size range are scattered throughout the rock.

Hornfels and siliceous hornfels are also extensively developed around the granodiorite stock in Trenton Canyon in the northwestern part of the range. The mineralogical changes are similar to those in the aureole of the stock in Copper Canyon.

Havallah Formation.—The Havallah Formation is cut by a major intrusive body only in Trenton Canyon. On the ridge south of Trenton Canyon the Trenton Canyon Member, which is mainly chert and shale, has been converted to biotite hornfels adjacent to the intrusive. The quartzite, sandy limestone, chert, and shale of the overlying Mill Canyon Member have reacted in quite different ways. The quartzite is bleached over a wide area; near the contact it is recrystallized. The sandy limestone layers contain pods and layers of fibrous tremolite and also are recrystallized. The chert and shale have been converted to biotite-cordierite hornfels, similar to the hornfels of the Pumpernickel Formation.

Scott Canyon Formation.—The Scott Canyon Formation is not in contact with any of the larger intrusive bodies, but the small mass of quartz monzonite at the Buzzard mine on the 6,573-foot hill south of Iron Canyon is probably a cupola of a buried mass. Chert and shale nearby are metamorphosed to biotite hornfels. Volcanic rocks in the Scott Canyon Formation were susceptible to metamorphism, forming diopside-actinolite-tremolite hornfels in the inner zone and chlorite-mica hornfels in the intermediate and outer zones.

Harmony Formation. The Harmony Formation contains much feldspathic sandstone and shale, both of which were highly susceptible to metamorphism. These rocks contain both orthoclase and sodic plagioclase grains, and much biotite and muscovite. The cementing material is composed of carbonate, clay minerals, chlorite, shredded biotite and muscovite, and iron oxides. These minerals are an unstable assemblage, and the metamorphic zones are commonly wider in the Harmony Formation than in the other units. In the outer zone the main effect of metamorphism is induration due to the formation of fine-grained quartz(?) and mica(?) in the cementing material. In the intermediate zone the shaly rocks become brown biotite hornfels, and the sandstones become biotite quartzites with crystalloblastic texture. In the inner zone the original clastic texture is nearly gone, and the micas have partly changed to orthoclase, which is intergrown with quartz in the groundmass. Sheaves and grains of diopside have formed in beds containing carbonate.

VOLCANIC ROCKS OF TERTIARY AGE

Volcanic rocks of Tertiary to early Quaternary age are scattered throughout the quadrangle and underlie a total area of about 4 square miles. Of this area, slightly more than half is underlain by welded tuffs, pyroclastic rocks, and quartz latite, and the remainder is underlain by basalt.

WELDED TUFF AND ASSOCIATED PYROCLASTIC ROCKS

Welded tuffs and associated pyroclastic rocks crop out at the Oyarbide Ranch, in narrow belts and isolated outcrops along Trout Creek for 1½ miles north of the ranch and in a belt as much as a quarter of a mile wide extending discontinuously for about 2 miles southeast of the ranch. The volcanic rocks are in the downfaulted hanging-wall block of the Oyarbide fault and range in altitude from 5,700 to 6,050 feet. Similar pyroclastic rocks also are exposed near the Buffalo Valley mine.

These volcanic rocks consist mainly of quartz latitic vitric tuff and welded tuff. At the Oyarbide Ranch the volcanic section totals about 125 feet in thickness and consists of a basal unit, 25 feet thick, of pinkish-gray slightly welded tuff; a middle unit, 75 feet thick, of pinkish-gray nonwelded vitric tuff; and an upper unit, 25 feet thick, of gray and purplish-gray moderately welded tuff. These rocks are petrographically similar to vitric tuffs described by Marshall (1935), Mansfield and Ross (1935), and Gilbert (1938). Except for variations in the degree of welding, the units are similar in appearance and all contain fragments of pumice, shale, quartzite, and chert.

Near the Buffalo Valley mine, the volcanic material is composed mostly of pinkish-gray, nonwelded tuff containing numerous pumice fragments and a few glassy sanidine crystals. Chert and shale fragments occur throughout the section, but are more abundant near the top. The tuff layer is highly lenticular, ranging from a few feet to 75 feet in thickness, and in places it has been entirely removed by erosion. The lenticularity is partly due to the relief of the surface on which the tuff was deposited and is partly the result of erosion subsequent to deposition. A thin veneer of fan material covers some of the tuff, which forms the low ridges northeast of the Buffalo Valley mine.

QUARTZ LATITE WELDED CRYSTAL TUFF

Quartz latite welded crystal tuff at one time probably covered most of the range, but has been largely eroded except for small patches at Elephant Head on the east side of Copper Basin and in the headwaters of Rocky Canyon (fig. 32*A*, *B*). Hague and Emmons (1877, p. 671) referred to this rock as rhyolite, and this name was also used in the early stages of the present study.

Recent chemical analyses (table 8) show that it is more accurately classified as quartz latite, however, and this name will be used in this report.

The quartz latite welded crystal tuff resembles flows but was probably formed by some type of explosive eruption. It differs markedly from the vitric tuff near the Oyarbide Ranch in that it is characterized by a high crystal content and is therefore described separately.

Quartz latite at Elephant Head.—The quartz latite at Elphant Head caps the ridges east of Copper Basin near the east side of the quadrangle. The base of these volcanic rocks is found at altitudes ranging from 4,750 feet to 5,650 feet, but as faulting has displaced and tilted them subsequent to their deposition, the amount of relief of the original surface cannot be determined. The volcanic rocks at Elephant Head and in Rocky Canyon are similar in lithology and are also closely related chemically (table 8). They are thought to have been derived from the same or related sources.

The quartz latite at Elephant Head includes three gradational units: a lower tuff about 20 feet thick, a middle vitrophyre 20–30 feet thick, and an upper aphanitic or stony quartz latite about 120 feet thick. These volcanic rocks rest on the Harmony and Battle Formations, Antler Peak Limestone, and on quartz monzonite porphyry dikes that cut these rocks. A reddish iron-stained soil layer 2–5 feet thick is commonly found at the base of the volcanic section. The red color is probably due to baking by the volcanic rocks.

The basal unit is a slightly welded light-gray tuff composed of rock fragments and crystals in an ashy matrix. The tuff is soft and porous and generally does not crop out except on steep slopes. Microscopic examination of the tuff reveals largely fragments of pumice and glass of lapilli size in a matrix of fine glass shards. The pumice fragments have been partly collapsed, indicating that they were slightly plastic after coming to rest (fig. 31*A*).

The basal tuff layer is overlain by a dark-gray to black vitrophyre (fig. 31*B*). Its contact with the lower unit is not well exposed, but is thought to be gradational, changing from the partly welded lower unit into the more completely welded glassy layer. At the outcrop the vitrophyre appears faintly banded, largely owing to variations in the proportions of crystals in different layers and also to flowage. Microscopic examination of the rock reveals lapilli-size fragments of pumice and glass which have been highly welded, drawn out, and bent around less plastic rock fragments and crystals. Locally, bleblike projections of glass have been forced into fractures in the fragments and crystals, indicating that the glass was still plastic after coming to rest. No matrix can be distinguished, probably because the material was so thoroughly welded that shard structure has been obliterated. It is even difficult in places to discern the fragmental nature of the rock. The fragments have been drawn out by flowage, which seems best explained as plastic flow of very hot glass. Although flow lines are discontinuous and crystals are broken, the rock resembles a flow (fig. 31*B*).

The biotite crystals in the vitrophyre commonly are fresh and unaltered. They are strongly pleochroic with X= dark greenish brown, Y nearly opaque, and Z=medium greenish brown. Hornblende is a minor constituent in several thin sections examined under the microscope. It is generally present as subhedral or euhedral grains of dark green or brown color. The low extinction angle ($Z \wedge c = \pm 5°$) and dark color suggest that the hornblende is of the variety oxyhornblende (basaltic hornblende). The pleochroism is X=greenish brown, Y=brownish green, Z=dark reddish brown.

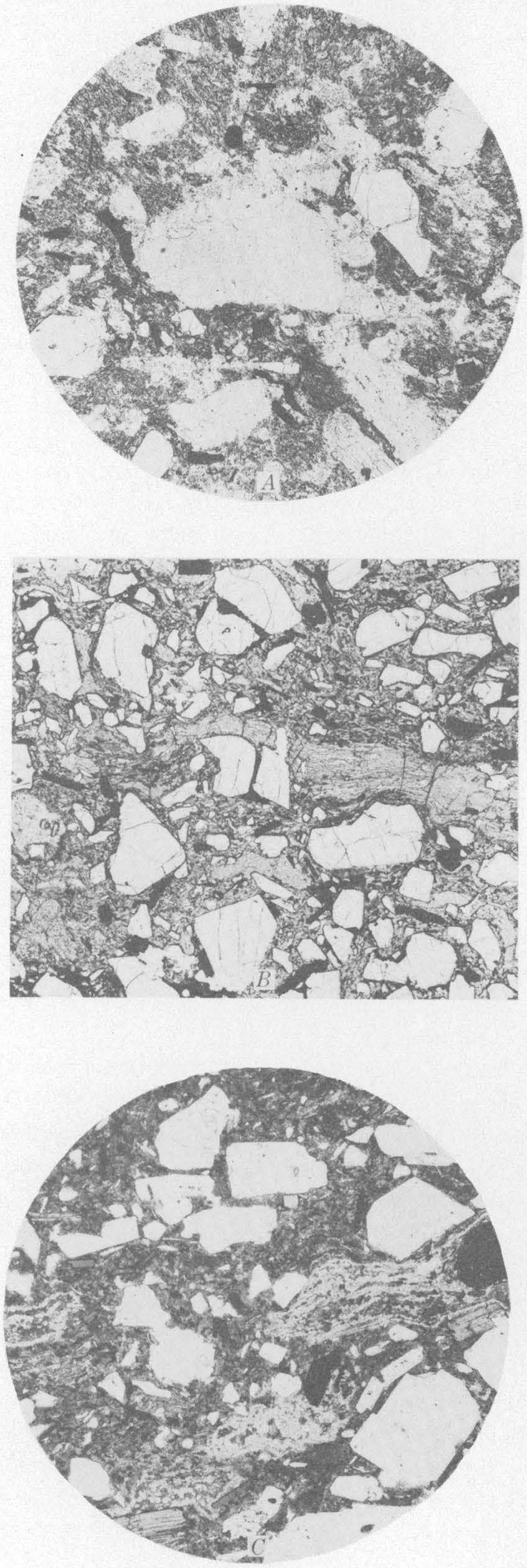
The upper aphanitic quartz latite is the thickest unit in the sequence. It weathers to rounded forms and commonly shows well-developed columnar jointing. In outcrop it appears to be homogeneous, but locally it is indistinctly layered parallel to the surface on which it rests. In thin sections it is similar to the vitrophyre of the upper part of the lower unit in that it is made up largely of lapilli-size rock fragments and crystals. The glassy matrix is partly devitrified, however, and the rock has a stony rather than glassy appearance. In hand specimens the upper stony quartz latite shows more distinct banding than the vitrophyre. Microscopic examination reveals this banding to be due to alternations of dark-brown and nearly colorless layers. The dark-brown layers are glassy with only partial devitrification, and the nearly colorless layers are crowded with spherulites (fig. 31*C*) ranging in size from 0.03 mm to about 0.2 mm. Because of their small size, the composition of the spherulites could not be definitely determined, but they have an index less than balsam and are probably composed of a feldspar

TABLE 8.—*Analyses and calculations of quartz latite, Antler Peak quadrangle, and other localities in Nevada*

[Analysts: H. F. Phillips, P. W. Scott, F. S. Borris (samples 1-4), K. E. White (samples 1-5), P. L. D. Elmore, S. D. Botts (sample 5), L. Shapiro, S. M. Berthold, E. A. Nygard (sample 6), by rapid methods, and F. H. Neuerburg (sample 8), U.S. Geol. Survey; G. Kahan (sample 7)]

	1	2	3	4	5	6	7	8
Field No	53-AP-3	52-AP-4	53-AP-13	53-AP-12	55-W-99	484-A	3	--------
Lab. No	53-537C	53-538C	53-542C	53-541C	----------	52-881CW	--------	--------
Chemical analyses								
SiO_2	70.2	71.0	70.7	71.2	70.1	71.4	69.35	71.82
Al_2O_3	14.7	15.1	14.2	14.6	14.2	14.2	15.22	14.44
Fe_2O_3	1.3	1.0	1.2	1.8	2.0	1.4	2.50	1.50
FeO	1.0	1.4	.86	.56	.90	.50	.38	.35
MgO	.56	.62	.50	.49	.68	.46	.51	.34
CaO	2.1	2.2	1.8	2.0	1.8	1.8	2.4	1.16
Na_2O	3.2	3.5	3.0	3.2	3.2	3.0	3.25	3.9
K_2O	4.6	4.3	4.8	4.4	5.1	5.2	4.48	4.88
$H_2O\pm$	1.6	.49	2.14	1.01	.64	2.8	1.33	.95
TiO_2	.33	.33	.28	.32	.43	2.5	.40	.61
P_2O_5	.14	.14	.11	.12	.18	.07	.15	.26
MnO	.04	.07	.06	.07	.06	.11	.02	.06
CO_2	.20	.04	.07	.19	.07	----------	--------	.01
Total	99.97	100.19	99.72	99.96	99.36	103.44	99.99	100.28
Sp gr	----------	----------	2.34	2.35	2.35	----------	--------	--------
Norms								
Quartz	----------	23.6	25.9	27.5	24.4	26.0	27.21	25.9
Orthoclase	----------	25.5	28.4	26.0	30.1	30.7	26.13	29.5
Albite	----------	29.6	30.6	27.1	27.0	25.4	31.44	35.5
Anorthite	----------	9.7	7.3	8.7	7.7	8.5	2.78	5.5
Corundum	----------	1.8	.4	1.4	.57	.50	3.06	1.0
Hypersthene	----------	----------	----------	----------	----------	----------	1.30	--------
Enstatite	----------	1.5	1.3	1.2	1.7	1.15	--------	--------
Ferrosilite	----------	1.3	.2	----------	----------	----------	--------	.85
Magnetite	----------	1.6	1.74	1.11	1.85	1.25	.23	.3
Ilmenite	----------	.62	.53	.61	.82	.47	.76	.4
Hematite	----------	----------	----------	1.0	.72	.54	2.40	--------
Apatite	----------	.31	.4	1.55	.40	.16	.34	.9
Calcite	----------	.1	.2	.44	.20	----------	--------	.3
Niggli numbers								
al	----------	44.7	45.8	46.6	43.4	45.8	45.7	47.2
fm	----------	12.7	10.6	10.1	13.4	9.5	10.5	7.6
ca	----------	11.8	10.3	11.4	10.0	10.5	13.1	6.8
alk	----------	30.8	33.3	31.9	33.2	34.2	30.7	38.4
Sum	----------	100	100	100	100	100	100	100
si	----------	3.57	3.77	3.86	3.65	3.83	3.54	--------
k	----------	.45	.49	.48	.51	.53	.47	.45
mg	----------	.37	.37	.39	.40	.40	.36	.37
Rittman values								
k	0.49	0.45	0.51	0.48	0.51	0.54	0.48	0.45
an	.17	.18	.16	.17	.11	.14	.19	.09
p	61.1	62.5	60.8	62.0	57.1	59.8	61.8	57.0

1. Vitrophyre, Rocky Canyon, ½ mile south head of Timber Canyon, NE¼ sec. 12, T. 31 N., R. 42 E.
2. Quartz latite, Rocky Canyon, ½ mile southeast head of Timber Canyon, SE¼ sec. 1, T. 31 N., R. 42 E.
3. Vitrophyre, Elephant Head, Copper Basin, SE¼ sec. 34, T. 32 N., R. 44 E.
4. Quartz latite, Elephant Head, Copper Basin, SE¼ sec. 34, T. 32 N., R. 44 E.
5. Quartz latite, Martin Creek, Humboldt County, T. 42 N., R. 42 E. (unsurveyed). Collected by Ronald Willden.
6. Quartz latite, Virginia City area. Collected by D. E. White.
7. Quartz latite, Roberts Mountains, Eureka, Eureka County, Nev. Collected by C. A. Anderson.
8. Quartz latite, Ione quadrangle. Collected by C. J. Vitaliano.



(sanidine?) and silica (tridymite?). The larger spherulites commonly show a distinct radial structure and locally have concentric rings.

It is noteworthy that the biotite crystals in the aphanitic quartz latite have undergone more alteration than in the glassy phase. This is attributed to a late-stage alteration, which resulted in nearly complete destruction of most of the smaller laths (less than 0.4 mm long and 0.1 mm wide) and in peripheral alteration of many of the larger laths. Generally the biotite laths in the glassy part of the groundmass are more altered than the ones in the spherulitic layers, but this difference is not consistent. The alteration products formed include a fine-grained mica (sericite?), dusty hematite, and quartz. These minerals form finely granular aggregates. Most of the hematite is disposed radially around the periphery of the crystals.

Because of the variation in the lithology of the quartz latite in different parts of the section, suites of specimens were collected at two places on Elephant Head to determine if there were any consistent variations in specific gravity. The results are given in table 9. There is little varation in the samples collected on the west side, whereas there is a consistent increase in specific gravity going upward in the samples collected on the east side.

TABLE 9.—*Specific gravities of quartz latite at Elephant Head*

West side		East side	
Altitude above base	Specific gravity	Altitude above base	Specific gravity
120	2.46	120	2.49
100	2.49	75	2.45
80	2.49	60	2.42
60	2.48	50 [1]	2.43
30	2.48	36	2.22
		30	<2.1

[1] Obsidian (vitrophyre).

Quartz latite at Rocky Canyon.—A group of isolated outcrops of quartz latite cover an area of about 2 square miles near the headwater drainage of Rocky Canyon in the southwestern part of the range. They occur on the divide between Rocky and Mill Canyons, near the head of Trenton Canyon (fig. 32*A*), and on

←FIGURE 31.—Photomicrographs of volcanic rocks at Elephant Head. *A*, basal layer, crystal tuff. Porous, nonwelded tuff that contains deformed pumice fragments. Plane-polarized light. × 14.1. *B*, vitrophyre about 30 feet above base. Welded crystal tuff with fragments of quartz latite showing collapsed pumiceous structure. Plane-polarized light. × 14.1. *C*, aphanitic quartz latite about 50 feet above base. Welded and devitrified crystal tuff. Plane-polarized light. × 14.1.

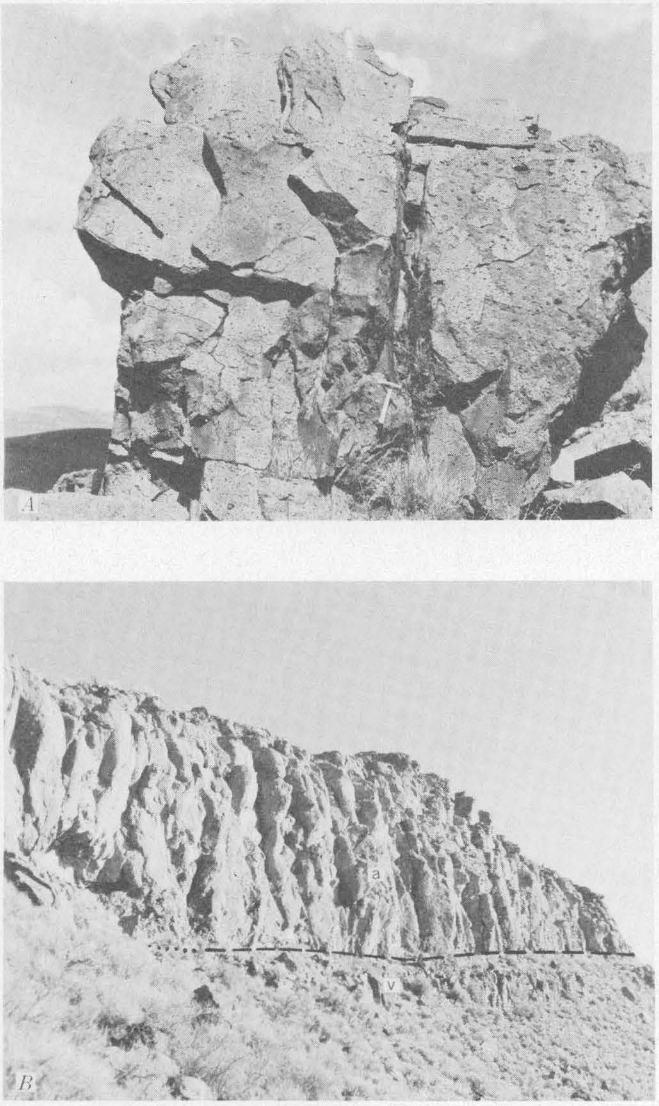


FIGURE 32.—*A*, porous quartz latite near head of Rocky Canyon. *B*, quartz latite at head of Rocky Canyon; a narrow ledge has formed at contact between lower vitrophyre (v) and upper aphanitic unit (a) owing to difference in weathering of the two units.

the divide between Willow Creek and Copper Canyon. All these remnants probably were once parts of a continuous unit that covered much of the southwestern part of Battle Mountain. The base of the outcrops ranges in altitude from 5,850 to 7,300 feet. The volcanic rocks rest on a surface of moderate relief that dips generally southwestward.

These volcanic rocks consist of two units: A lower tuff 10–100 feet thick which is a light-gray, slightly welded lapilli tuff containing numerous fragments of chert, shale, and pumice, and an occasional fragment of dense quartz latite; and an overlying black vitrophyre 20–30 feet thick (fig. 32*B*), which grades upward into quartz latite welded crystal tuff.

The lower unit of slightly welded tuff at Rocky Canyon is not resistant and is exposed at only a few places. The basal part is a crumbly, light-gray tuff with pumice fragments as much as 1 inch long. This grades upward into a light-gray rock with local medium-gray glass streaks that are probably the result of flowage.

The overlying vitrophyre is a medium-gray rock containing even more conspicuous dark-gray glass streaks. Under the microscope the rock resembles the Elephant Head vitrophyre very closely; the only significant difference is a notably higher proportion of discernible rock fragments in the vitrophyre in Rocky Canyon. The aphanitic upper unit at Rocky Canyon (fig. 32*B*) is very similar to the aphanitic unit at Elephant Head. Crystals, in part fragmental, make up as much as 40 percent of the rock and range from euhedral to anhedral. A majority are subhedral or anhedral. They range in size from less than 0.05 mm to more than 3.2 mm and average about 0.7 mm in diameter. Elongate biotite crystals are likely to show bending around crystals and fragments.

Modal analyses of quartz latite from the west side of Willow Creek show the following composition:

Crystals	*Percent*		*Size (mm)*
Plagioclase	12	(An_{29-37})	0.10–3.2
Quartz	11		.10–2.5
Sanidine	11		.1 –2.2
Biotite	5		.05–1
Total	39		

Matrix, 61 percent of the rock, is glass with rock fragments and inclusions of apatite, zircon, magnetite, and other accessories.

Chemical characteristics of the quartz latites.—To compare the volcanic rocks at Rocky Canyon and Elephant Head chemically, samples of vitrophyric and aphanitic quartz latite were collected from each area and were chemically analyzed by the rapid method. The results of the analyses are given in table 8.

The uniformity in composition is very striking and confirms the impression received from the microscopic study that the rocks from the two areas may have the same source. The norm and Niggli calculations also show only minor differences in mineral composition and molecular proportions. The Niggli k values range from 0.45 to 0.49, a relatively narrow range compared with the range of k values of rocks from many other areas. Analyses of similar quartz latites from other localities in Nevada are also listed. The regional chemical similarities of these rocks is remarkable considering their wide geographic distribution.

Origin of the quartz latite welded crystal tuff.—The origin of the welded crystal tuff warrants discussion, for this rock does not fit the usual concept of welded tuffs. The crystal tuff was probably formed by a mechanism similar to the one that formed the welded vitric tuff, but there are lithologic and physical differences that suggest a fundamental difference in their origin. It is therefore proposed to separate the welded crystal tuff as a distinct rock group to emphasize the differences between it and the vitric welded tuff. The author and Donald W. Peterson have discussed these two kinds of volcanic rocks in more detail in another publication (1961).

BASALT

Erosional remnants of basalt flows occur in three areas on the periphery of the range. The largest remnants are in the Philadelphia-Box Canyon area, where basalt covers about 2 square miles and extends southward beyond the quadrangle boundary. One of the other localities in on the ridge just east of the mouth of Rocky Canyon in the southwestern part of the quadrangle, and the other is near Cottonwood Creek in the northwestern part of the quadrangle.

Philadelphia-Box Canyon area.—Basalt flows cap the lower part of the ridge between Philadelphia and Box Canyons and occur along the range front at the mouth of Philadelphia Canyon. The flows overlap the older rocks where the basalt flowed into old valleys. The basalt flows dip gently southward and have a maximum thickness of about 150 feet. At least four separate flows having vesicular lower parts, dense central parts, and scoriaceous upper parts can be differentiated. The thickest flow is about 60 feet thick, and the thinnest is 25 feet. The flows form steep cliffs along the valley sides and are capped by narrow ledges where the less resistant lower and upper parts weather out. In places, the central parts show rude columnar jointing.

The basalt is black on fresh surface and weathers reddish brown. In dense parts of the flows the groundmass is aphanitic and contains prominent phenocrysts of plagioclase and olivine. The vesicular and scoriaceous parts are glassy and contain few phenocrysts. Microscopic examination of the basalt reveals mainly plagioclase laths and grains of olivine and augite forming an intergranular texture. The plagioclase is in two generations, phenocrysts as much as 3 mm long, averaging about 0.8 mm, and laths in the groundmass averaging about 0.2 mm in length. The phenocrysts are strongly zoned; they have cores of An_{60-75} and borders about An_{50}; the groundmass laths are An_{50-55}. The olivine grains are also in two generations; the phenocrysts are as much as 1 mm across, and the grains in the groundmass average about 0.2 mm. Many of the olivine crystals are rimmed with a reddish alteration product which is probably iddingsite. Augite occurs mainly as grains and microlites in the groundmass, but there are a few phenocrysts as much as a millimeter long. Augite microlites also occur in the central zones of some plagioclase phenocrysts.

The basalt on the ridge near the mouth of Rocky Canyon is very similar lithologically and petrographically to the basalt in Philadelphia and Box Canyons and will not be described separately. It seems likely that the basalts of these two areas have a common source.

Analyses of two samples of basalt from the Philadelphia-Box Canyon area are shown in table 10. These basalts are typical of olivine basalts of north-central Nevada.

TABLE 10.—*Analyses of basalts, Antler Peak quadrangle, Nevada*

[Analysts: K. E. White, H. F. Phillips, P. W. Scott, F. S. Borris, U.S. Geol. Survey, by rapid methods]

	1	2
Lab. No	53–539C	53–540C
Field No	53–AP–10	53–AP–11
Chemical analyses		
SiO_2	46. 8	46. 6
Al_2O_3	15. 8	15. 9
Fe_2O_3	4. 3	3. 0
FeO	6. 9	8. 2
MgO	7. 7	7. 6
CaO	9. 9	8. 9
Na_2O	3. 2	3. 4
K_2O	. 54	1. 0
H_2O+	. 58	. 29
H_2O-	. 14	. 06
TiO_2	2. 2	2. 4
P_2O_5	. 66	. 73
MnO	. 20	. 20
CO_2	. 12	. 23
Sum	99	99
Rittman values		
k	0. 06	0. 16
an	. 45	. 41
p	53. 8	51. 7

1. Canyon west of Philadelphia Canyon, NW¼ sec. 35, T. 31 N., R. 43 E.
2. South side Box Canyon, NE¼ sec. 34, T. 31 N., R. 43 E.

In comparison with the Columbia River Basalt (No. 7, table 5), they are lower in silica and higher in alumina, magnesia, lime, and soda. They more closely resemble the normal alkali basalt of Nockolds (1954, p. 1021).

Basalt at Cottonwood Creek.—The basalt near Cottonwood Creek is about 3 miles south of the Marigold mine in the northwestern part of the quadrangle. Four separate outcrops have been mapped, two a mile west of Cottonwood Creek at the range front, and two on the 6,036-foot hill on the east side of the valley. This basalt is less conspicuously porphyritic and is finer in grain size than that in the Philadelphia-Box Canyon area. Under the microscope it shows distinct flow structure by parallel alinement of plagioclase laths. The laths range from 0.05 to 0.2 mm in length, averaging about 0.1 mm and show a narrow range of zoning from An_{58-54}. Olivine is present as partly serpentinized phenocrysts and as grains in the groundmass. Augite is abundant in fresh phenocrysts as much as 2.5 mm long and as grains in the groundmass; some of the phenocrysts show distinct zoning. The 2V is low, ranging from 50° to 58°.

Basalt dikes.—Dikes of basaltic composition were noted at two places in the quadrangle, cutting the basalt flows in the Philadelphia-Box Canyon area and in the Bentley mine.

The dikes that cut the basalt flows are exposed on the ridge east of Box Canyon. They are 5–15 feet wide; one of them was traced for 500 feet along the strike. Flow structure generally parallels the vertical walls, but flattens and becomes horizontal where the basalt poured out on the surface.

The basalt dike in the Bentley mine follows a fault zone striking north and dipping steeply westward. The dike appears to be post-ore for its contacts are chilled against mineralized rock. The dike is altered to some extent, but not as much as the wallrock of the ore deposit.

The dike is composed of olivine, plagioclase, and augite and shows distinct flow structure. The olivine occurs as phenocrysts and as grains in the groundmass; it is now largely altered to serpentine and is partly replaced by calcite. The plagioclase is mostly in laths 0.15–0.3 mm long, and is partly altered to a clay mineral, probably of the montmorillonite group. The augite is quite fresh; it occurs as phenocrysts as long as 1.5 mm and as grains in the groundmass. On the whole, the rock resembles the Philadelphia-Box Canyon basalt microscopically, and the two rocks are probably related in origin.

Age and correlation.—The basalt rests upon the quartz monzonite with angular unconformity, and is therefore post-Eocene in age. The upper limit of its age is not definitely known, but as the basalt is covered with fan gravels south of Box Canyon, it is partly older than the fan gravels. Therefore, the basalt is most likely late Tertiary or early Quaternary in age.

Similar basalts have been mapped near Golconda and have been assigned by Ferguson and others (1952) to the late Tertiary or early Quaternary. Younger basalt cinder cones have been mapped in the Fish Creek Mountains; these cones have been only slightly dissected and have been assigned to the Quaternary as some were built up on the alluvial fans that flank the range and were eroded by wave action during late Pleistocene time.

AEROMAGNETIC SURVEY OF THE ANTLER PEAK QUADRANGLE

By Don R. Mabey

In 1947 an aeromagnetic survey of the Antler Peak quadrangle was flown along east-west flight lines spaced a quarter of a mile apart. The flight level was generally about 1,000 feet above the surface but was not constant because of the sharp relief. The magnetic data were contoured at 20- and 100-gamma intervals and plotted on the same base as the geologic map. (See pl. 5.)

The positions of the more extensive magnetic anomalies in the Antler Peak quadrangle suggest intrusive and extrusive igneous-rock sources, but some of the more local anomalies may be produced by mineralized zones in the sedimentary rocks. W. J. Dempsey (written commun., 1961) measured the magnetic susceptibility of samples of the principal rock types and found that the intrusive rocks, quartz monzonite, granodiorite, and related porphyries measure less than 50×10^{-6} cgs units; the most magnetic material was found along contact zones between intrusive and sedimentary rocks where sulfides, such as pyrrhotite and pyrite, and magnetite, are present. The susceptibility of these rocks was as much as $4{,}000\times10^{-6}$ cgs units.

The low susceptibilities reported for the intrusive rocks are too low to explain the observed anomalies. It is very probable, however, that the susceptibility of these rocks covers a wide range and averages higher than the values given. Because of the generally low susceptibility of the intrusive rocks, the magnetic anomalies produced by them may be small and the interpretation subject to more uncertainties than if the rocks were more magnetic.

The most intense local magnetic relief is produced by the basalt flows exposed near the mouth of Philadelphia Canyon. The anomaly pattern over this area is typical of that produced by basalt flows. The presence of a similar pattern over the younger sediments to the east of the basalt outcrops indicates that the basalt underlies these sediments at shallow depths. East of this area of intense magnetic relief is an area of moderate relief. The magnetic variations in this area may be produced by more deeply buried basalt.

A paired magnetic high and low occur over the exposed quartz latite at Elephant Head and probably are produced by the quartz latite.

Four areas of generally high magnetic intensity are believed to be areas underlain by abundant intrusive rocks. Because of the low average susceptibility of the intrusive rock, it is not possible to determine if these areas are underlain by extensive intrusive bodies at depth or by numerous smaller bodies.

The magnetic high in the Trenton Canyon area is produced by the granodiorite stock exposed there. The magnetic anomaly indicates that the stock extends to the southeast for about one mile beyond the surface exposures. Some of the local magnetic variations in the area of sec. 6, T. 31 N., R. 43 E., are produced by the quartz latite, but a more extensive anomaly is probably produced by the stock.

The high magnetic intensity over the area east of Antler Peak is probably produced by quartz monzonite. The broad magnetic high could be produced by a large mass of quartz monzonite or by several smaller masses. The local high between the Lucky Strike and Little Giant mines is a near-surface feature and in an area where the Harmony Formation has been altered to quartzite and hornfels. This local magnetic anomaly is probably produced by magnetite enrichment associated with this alteration.

The area of high magnetic intensity around the Copper Canyon mine is also probably produced by quartz monzonite with generally low susceptibility either as a single mass at depth or several smaller masses. The local highs probably represent magnetite-rich zones either in the quartz monzonite or adjacent rock.

Another area of abundant intrusive rock with generally low susceptibility is indicated near Healey's Cabin in an area of generally high magnetic intensity.

The narrow east-trending magnetic high across the northern part of the map indicates a dikelike body. Because the anomaly is parallel to the flight lines, the character is not well defined; however, the dike appears to be nearly vertical and nearer the surface on the west but more deeply buried to the east. Two small patches of Tertiary basalt occur along the trend of the inferred dike in the western part of the quadrangle. The magnetic anomaly may be produced by a basalt dike which locally reached the surface in the western part of the quadrangle. Similar magnetic anomalies have been observed associated with basalt dikes in the Cortez Range southeast of the Antler Peak quadrangle.

GEOMORPHOLOGY

The Antler Peak quadrangle is in the northern part of the Basin and Range province. Battle Mountain, a complex range made up of folded and faulted rocks, underlies most of the quadrangle and is bordered by waste-mantled slopes leading down into Buffalo Valley and the valleys of the Reese and Humboldt Rivers. The principal geomorphic features in the quadrangle can be separated into three major groups: (1) The mountains, a rugged upland area; (2) the pediments and fans that border the range; (3) the valley floors. The drainage of Battle Mountain is radial. Some of the streams flow into the interior basin, Buffalo Valley, and the others into the Reese and Humboldt Rivers, which drain westward into Carson Sink.

MOUNTAINS

Battle Mountain is a central upland surrounded by a rugged canyon and ridge topography. The upland comprises about 25 percent of the range. The area is broadly crescentic in shape, opening northwestward; it is a mature surface of low to moderate relief and is best developed at altitudes of between 7,000 to 8,500 feet (fig. 33). It is now being dissected from all sides by streams working headward and therefore antedates the last uplift of the range. Here and there the surface is capped by lava or gravel. The lava caps blend in with the surface and therefore probably predate it. The gravel rests on the surface and was deposited by the streams that assisted in forming the upland. The upland was probably formed by a combination of weathering and altiplanation during Pliocene and Pleistocene time.

The rugged canyon and ridge topography surrounding the central upland resulted from headward erosion of streams. The canyons show marked asymmetry; those on the west side are youthful with rock-strewn ridges and narrow floors, whereas those on the east side are more mature in development. Generally, the valley sides are bare or are only thinly veneered by debris, but some slopes are covered by colluvial deposits, thin near the ridgetops and thickening downward to the valley bottoms.

PEDIMENTS

Pediment surfaces have been formed at the heads of some of the fans on the north and east sides of the range and also within the range. In general, the pediments on the periphery of the range are narrow and are best developed on weak rocks, especially tuffs and sediments of Tertiary age. The pediments within the range are highly dissected, and only small remnants are preserved.

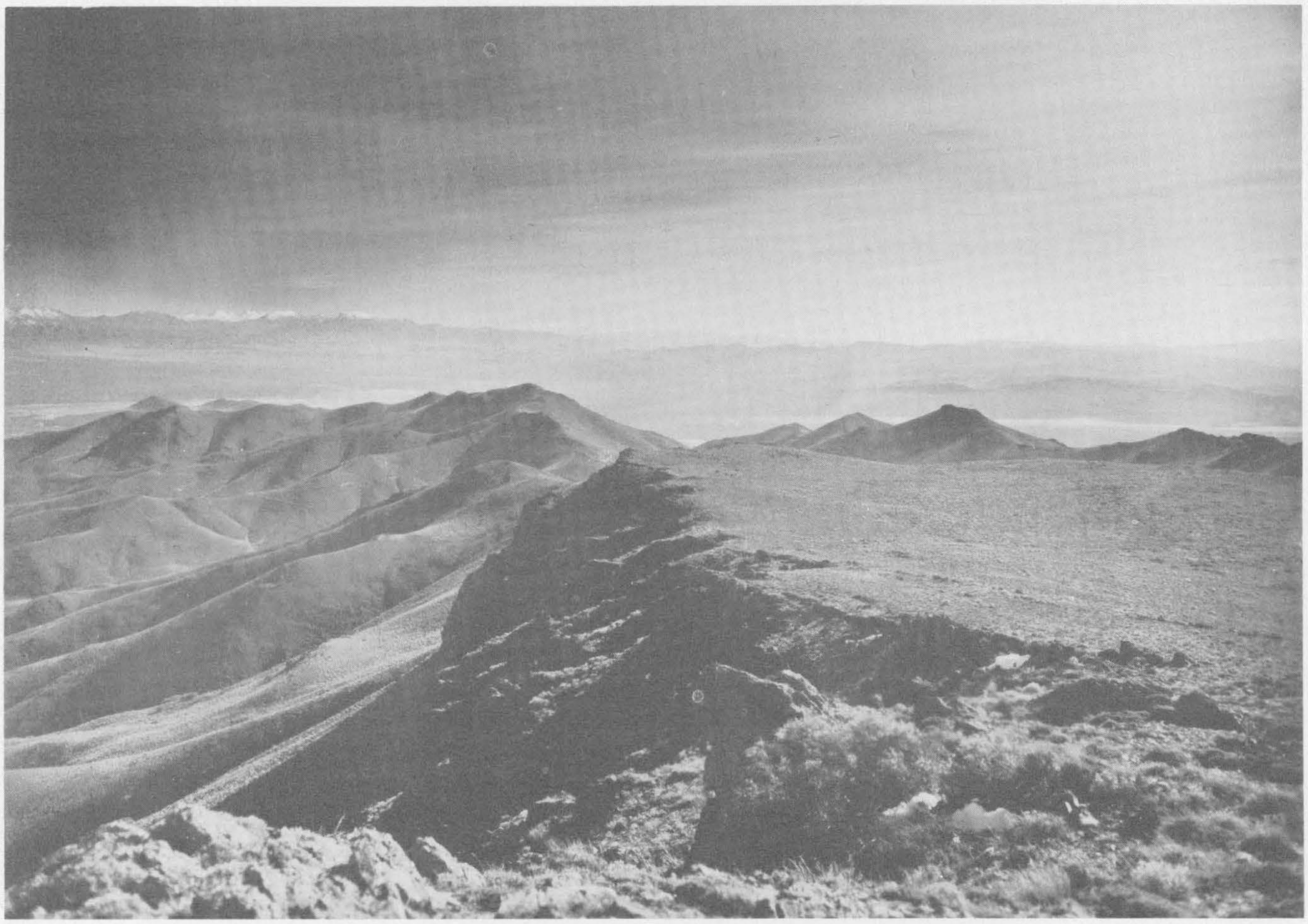


FIGURE 33.—Mature upland south of Antler Peak in center of range cut on Battle Formation in right foreground; slopes leading down into Galena Canyon on left. The Reese River valley extends south between the Shoshone Range on the east and the Fish Creek Range on the west. Part of Buffalo Valley can be seen between Battle Mountain and the Fish Creek Range. View looking south from Battle Mountain.

The peripheral pediments are relatively smooth slopes at the heads of the fans that are capped by thin gravel veneers. One of the best developed pediments is cut on Harmony Formation on the slope a mile northwest of the mouth of Elder Creek. Here the fan has been highly dissected, and adjacent to the spring near the center of sec. 35, T. 33 N., R. 43 E., bedrock is exposed in most of the gullies. Bedrock outcrops on the low hills in section 36 suggest that the alluvium in the intervening area may be quite thin and that the pediment area is more than a mile wide. Elsewhere on the northeast side of the range bedrock exposures are found here and there in gullies along the foot of the range, but commonly the belt of exposures is narrow and discontinuous. Pediment formation is going on during the present erosion cycle; as long as the range remains stable, the pediments will be extended headward.

Other pediments have been noted near the Oyarbide Ranch and Buffalo Valley mine where gravel rests on the beveled surface of gently dipping Tertiary volcanic rocks. Evidently the gravels once formed a more continuous cover, which has since been dissected by downcutting streams.

Small gravel remnants noted at two places in the range are dated as early Quaternary. These are well-washed stream gravels and their coarseness indicates that they were deposited by powerful streams.

FANS

Alluvial fans surround Battle Mountain on all sides, except for a narrow strip west of the Marigold mine. Some fans around the range differ from others in form or degree of dissection; such differences are helpful clues in working out the evolution of the fans and deciphering the history of the range. Two of the fans have been worked successfully as placer gold deposits.

The streams that flow intermittently on the fans on the north and east sides of the range drain into the Humboldt River and its major tributary in this area, the Reese River (fig. 34). The gradients of the stream channels on the lower part of the fans in the valleys

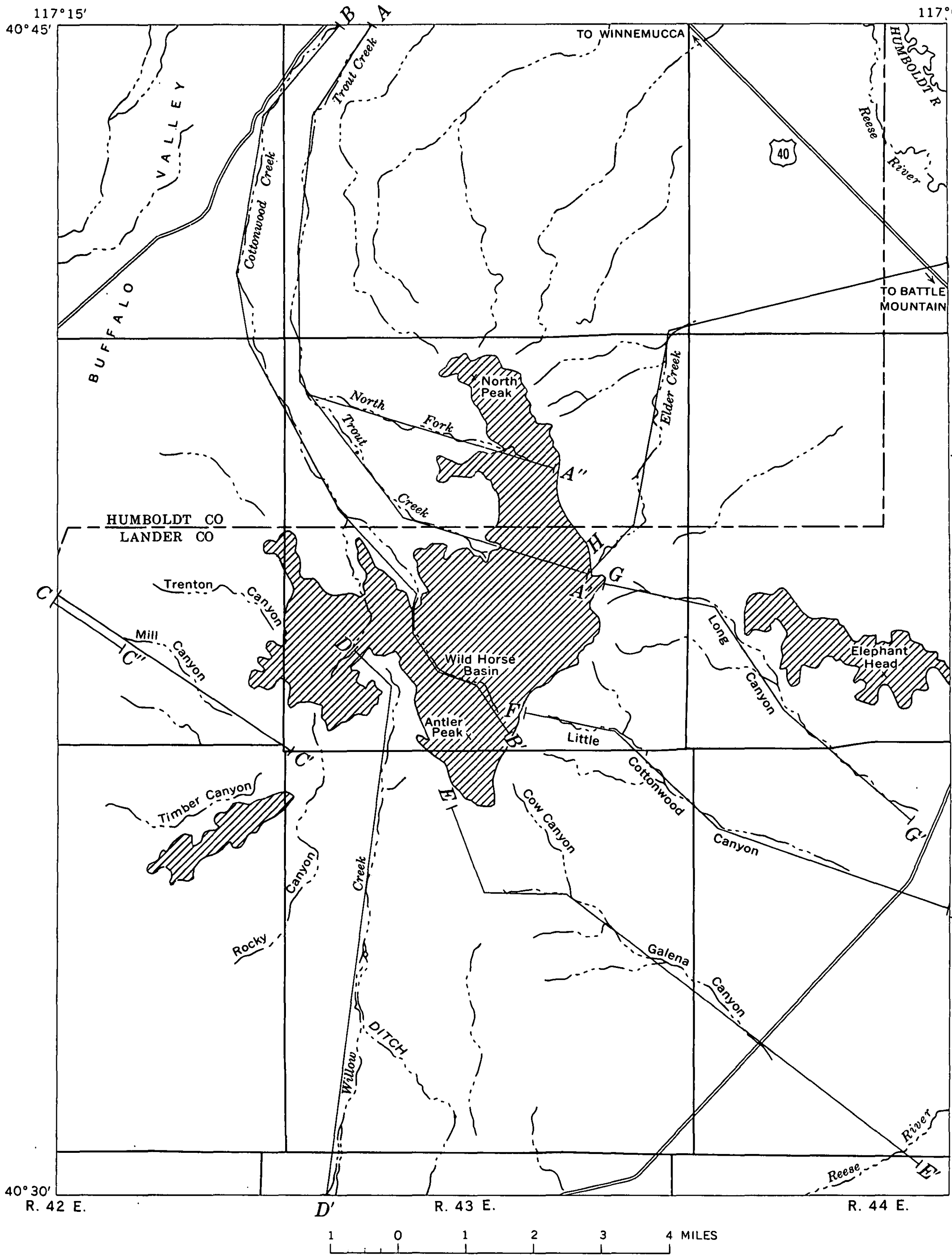


FIGURE 34.—Map showing major streams and mature upland surfaces (lined pattern) in the Antler Peak quadrangle, Nevada. Letters along stream courses designate longitudinal profiles shown on figure 35.

at the flood plains are as little as 40–50 feet per mile. They steepen headward to 200–370 feet per mile at the range front; within the range the gradients steepen to 500 or more feet per mile. As can be seen in figure 35, there is no sharp increase in declivity of the streams as they enter the range, but rather a gradual increase to the headwaters. The longitudinal profiles of all the streams on the north and east sides of the range are similar in gradient (compare profiles for Elder Creek, and Long, Little Cottonwood, and Galena Canyons).

The streams that flow on the fans on the south side of the range also drain to the Reese-Humboldt River system. The longitudinal profile of Willow Creek (fig. 35) is therefore similar to the profiles of the streams on the north and east sides of the range, but because Willow Creek is longer, the average declivity is less. About a mile south of the quadrangle, the gradient is about 50 feet per mile; at the range front, the gradient is only about 180 feet per mile; and at a point 4 miles north of the Jory Ranch, the gradient is about 300 feet per mile.

The fans on the west side of the range drain into Buffalo Valley with much steeper gradients than the fans on the other sides of the range. At the west edge of the quadrangle, the gradient of Mill Creek is about 330 feet per mile, and 2 miles east of the range front, the gradient is about 400 feet per mile. The reason for the higher than normal gradient is that faulting during Quaternary time has caused relative uplift of the range on the west, thus rejuvenating the streams and accelerating erosion of the west side. The streams here have had difficulty cutting down to maintain grade as is indicated by the narrow mouths of Trenton, Mill, and Timber Canyons.

Trout and Cottonwood Creeks drain to the Humboldt River, but as they have been involved in the uplift of the west side of the range, they show some features common to the streams of the west and north sides. The lower parts of the fans have about the same gradients as the Elder Creek fan, and are similar in form to it. Between the Marigold mine and the Oyarbide fault, the fans have now been largely removed, leaving terrace and fan remnants along the sides of the valleys.

One of the notable features of the Battle Mountain fans is that they have been dissected; on the north and east sides of the range the dissection is shallow, but on the west and south sides the major streams have cut down as much as 100 feet below the tops of the fans, and in places the fan itself is nearly destroyed.

The dissection of the fans on the north and east sides of the range is not spectacular when viewed from the valley, but it shows distinctly on aerial photographs of the flanks of the range. The surface of the upper parts of the fans are cut by rills a few inches to a few feet deep, and the major streams are incised from 5 to 25 feet. The deepest dissection of the fans is at the range front. The incision extends headward from the range front; much of the fill within the valleys has been eroded, leaving terraces or remnants of fans. The material eroded was redeposited on the lower parts of the fans or carried into the Humboldt and Reese River flood plains.

The fans of Willow Creek on the south and Timber, Mill, and Trenton Canyons on the west were deeply incised by their major streams after the fans reached maximum development. The incision is deepest at the range front and decreases toward the valley (plate 4).

Recent faulting parallel to the range front has dislocated the fan surface near the Buffalo Valley mine. The scarp formed along the trace of the fault can be recognized at several places to the north and is most conspicuous at the mouth of Mill Canyon, where it is about 12 feet high. The block to the east has been uplifted and tilted eastward relative to the west side. In the vicinity of the Buffalo Valley mine much of the unconsolidated fan material has been eroded from the uplifted block, exposing rocks of the Havallah Formation and tuffs of Tertiary age.

Formation of the present fans probably began in Pliocene time, prior to the last uplift of the range. At this time the range had probably reached a mature stage of dissection as is indicated by the well-sorted, clean gravel in the basal layers of the fans. These gravels are characteristic of perennial streams, and indicate that the climate was more humid then. In the upper parts the fan material is poorly sorted, with coarse angular gravel in a sandy and clayey matrix. Such deposits are more characteristic of the present arid climate.

Bradley (1936, p. 176) has discussed the deposition of the Bishop Conglomerate in Utah and Wyoming and pointed out that a slight change toward greater aridity caused aggradation.

> Diminished rainfall would decrease the volume and hence the capacity of the streams, which, by reason of their continued tendency to maintain a balanced or graded condition would drop some of their load and build up their gradients so as to increase the velocity and tend to compensate for loss of volume. Other factors commonly attendant upon a change to greater aridity would also accentuate the process of aggradation. After such a change the rainstorms become less frequent, but correspondingly more violent.

In central Nevada such a decrease in rainfall has been suggested by Axelrod (1939; 1956, p. 267), who estimated that the annual rainfall during the Pliocene

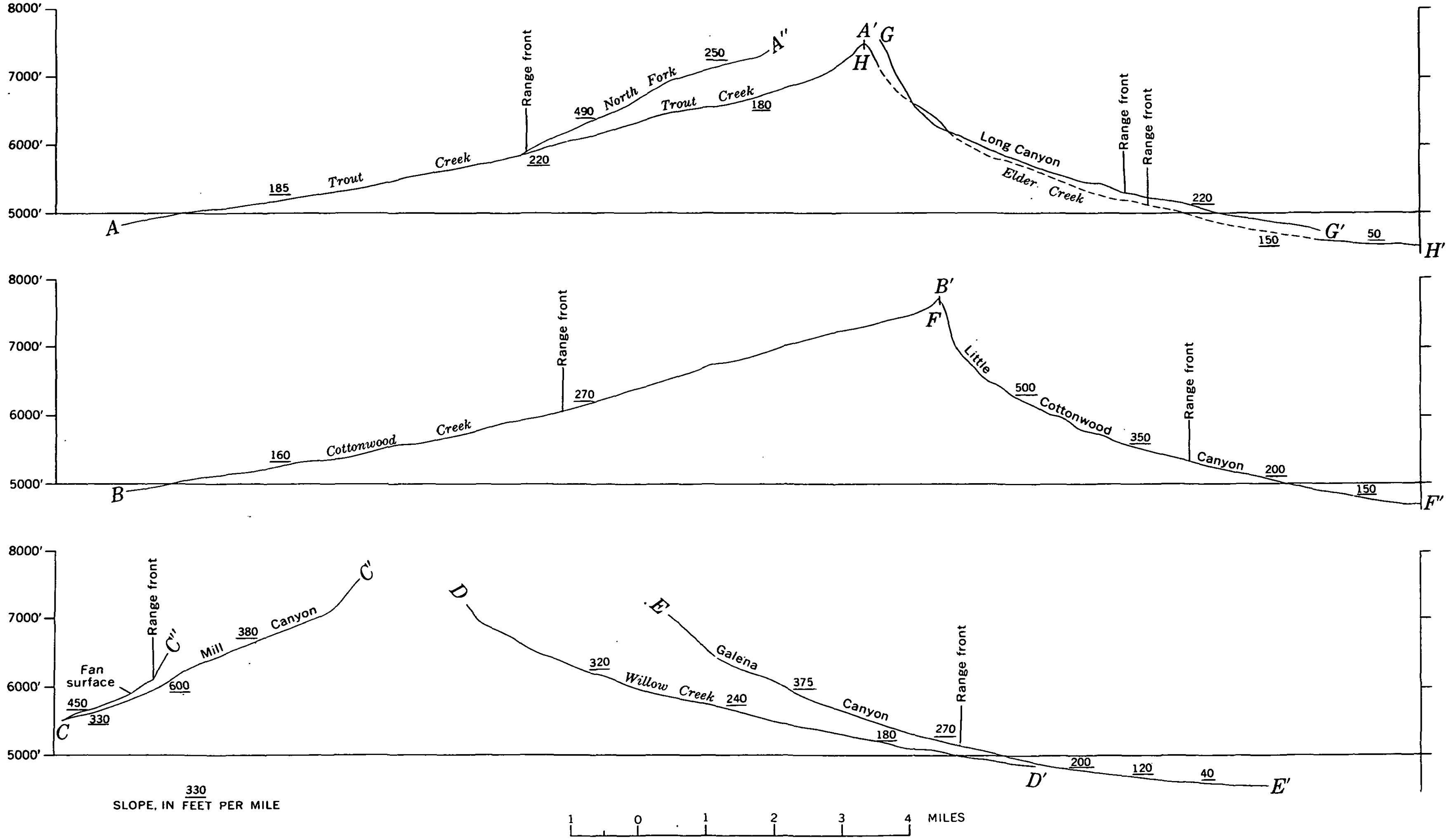


Figure 35.—Longitudinal profiles of major stream valleys, Antler Peak quadrangle, Nevada. Lines of profiles shown in figure 34.

was 20–25 inches as contrasted to about 6 inches in the Battle Mountain area now. The arid cycle probably continued throughout the fan-building stage but was interrupted by the glacial periods.

During these periods lakes formed in the valleys, and the lake sediments interfingered with the gravels deposited on the lower parts of the fans. The earliest lake of which any trace remains is near the town of Battle Mountain just east of the quadrangle limits. Excavations on the southeast side of Highway 8A in the SE¼ sec. 19, T. 32 N., R. 45 E., show well-washed and well-rounded gravels with foreset bedding. Gravels of this type are commonly found in beach bars along lakeshores in Nevada.

DRAINAGE CHANGES

Some of the valleys that drain Battle Mountain show evidence of stream capture of changes in the drainage pattern during their development. Of these changes the most noticeable is the capture of the headwaters of Cottonwood Creek and Rocky Canyon by Willow Creek; another is the capture of the headwaters of Copper Canyon by Duck Creek; and others are the diversion of Cottonwood and Trout Creeks to the Humboldt River valley.

Willow Creek, a steam that flows parallel to the strike of the Pumpernickel Formation (pl. 4), extends much farther into the range than do most of the other streams. In addition, Willow Creek has opened a broad valley in its lower reaches, but has a narrow canyon in its upper reaches. The drainage patterns in this area indicate that Willow Creek has captured part of the headwaters of Cottonwood and Rocky Canyons. The tributary of Cottonwood Creek, which formerly headed just west of Antler Peak, has been cut in sec. 32, T. 32 N., R. 43 E. (pl. 4). This tributary originally flowed northwestward past the 7,196-foot ridge; a small remnant of the coarse gravels deposited before the early uplift of the range is still preserved on the ridgetop. Where the tributary now joins Willow Creek, a gorge with precipitous falls is cut into the Antler Peak Limestone, and a sharp elbow of capture leads to Willow Creek.

The causes of the capture are not entirely clear, but three factors probably played a part. The most important was that Willow Creek worked headward along a belt of weak rock—an argillitic unit of the Pumpernickel Formation. Because the stream in Cottonwood Canyon flows across resistant quartzite and chert beds of the Valmy Formation, it has had much greater difficulty in cutting its valley. The other factors are: (2) The canyon cycle had not reached the headwaters of Cottonwood Creek; and (3) eastward tilting of the range may have decreased the gradient of Cottonwood Creek, which flows northwestward, thus slowing its incision.

An upper tributary of Duck Creek flows southward parallel to the course of Copper Canyon and may well be a beheaded former extension of Copper Canyon; the elbow of capture is at Galena. The reason for this capture is probably that Duck Creek had a greater gradient than the stream formerly flowing in Copper Canyon and thus was able to effect the capture. Another capture was noted in the Box Canyon area. Philadelphia Canyon captured the headwaters of Box Canyon, probably because the former, which flows directly into the Reese River, has a base-level advantage over the latter, which flows into the lake in Buffalo Valley.

The main divide of the range is being shifted westward by the streams draining to the north and east. These streams all have steep gradients in their upper courses; they are consequently cutting down more rapidly than the westward-flowing streams, and are therefore capturing the headwaters. When the canyon-cycle incision reaches the upper courses of the westward-flowing streams, the divide will become stabilized along a line about midway across the range.

GEOMORPHIC HISTORY

Little is known about the geomorphic history of Battle Mountain prior to the extrusion of the Tertiary volcanic rocks. The oldest volcanic unit, the quartz latite welded crystal tuff, was apparently laid down on terrain characterized by rolling hills rather than the rugged terrain of today. The quartz latite in some places rests on soils developed on the older rocks, and in other places rests on washed gravels. At one time the quartz latite probably covered most of the range, judging from the erosional remnants on the west, southwest, and northeast parts of the range and in the foothills (pl. 4).

Remnants of quartz latite in the Reese River valley just south of the quadrangle and near Elephant Head east of Copper Basin are probably parts of a blanket that once flanked the range on the southeast. Although most of this area is now mantled by alluvium, the quartz latite may be present at depth; this is indicated by the higher than normal magnetic anomaly of the flank of the range (pl. 5). Basalt may also be present below the alluvium, but anomalies along the range front are even higher than shown over the basalt at the southeast end of the range and suggest the presence of a large mass of volcanic rock.

The basaltic volcanic rocks occur only on the flanks of the range and evidently were extruded along its margin; locally, the basalt flowed short distances into some of the valleys. The range probably was higher than during the extrusion of the quartz latite and was virtually blocked out in its present form. Remnants of basalt flows on the ridge between Trout and Cottonwood Creeks on the northwest part of the range are found as high as 6,036 feet; this is more than 500 feet above the valley of Trout Creek and gives a measure of postbasalt erosion at this point.

The postbasalt history may be deciphered from the landforms now preserved in the range and from the alluvial deposits that occur within and around the range. Five major stages in the development of the range can be recognized, beginning probably in the late Pliocene and extending to the present time. From oldest to youngest, they are: (1) Mature upland stage, (2) canyon-cutting stage, (3) fan-building stage, (4) fan-dissection stage, and (5) lake stage.

Mature upland stage.—The mature upland stage is best preserved in the central parts of the range (fig. 34). The upland has been dissected to some extent and has no doubt been lowered somewhat since formation, but it is still a rolling upland that contrasts strikingly with the steep-walled valleys and sharp interstream ridges cutting into the range. The local relief on the broad valleys and ridges of the upland does not exceed 1,500 feet and is generally less than 1,000 feet. An old soil profile—much deeper than present desert soil profiles—was developed on the younger volcanic rocks as well as on the older rocks. This old soil is now preserved on the broad interstream areas and divides in the central part of the range, but has been stripped from the dissected canyon areas. Probably the rainfall was higher during the formation of the soil and creep was the main process of surface modeling in contrast to washing under present conditions.

Canyon-cutting stage.—The canyon-cutting stage was probably started by relative uplift of the range, causing streams to cut down and carve deep valleys into the deeply weathered mature upland. The debris carried out into the surrounding basins was deposited as broad fans on the flanks of the range.

Fan-building stage.—During the initial part of the fan-building stage, the streams presumably were competent to carry all the available debris into the surrounding basins. As time went on, the streams began to aggrade, forming fans. The cause of the aggradation is not entirely clear, but two possible causes may be suggested: (1) A rising base level in the surrounding basins, and (2) climatic change to greater aridity. It is evident from the Golconda quadrangle topographic map that the base level has not risen sufficiently to be a controlling factor. The streams on the fans at the north and east sides of the range are at or near grade, but the streams on the fans on the west side have steep gradients. All the valleys in the range contain alluvial deposits so the alluviation was controlled by a factor independent of the topography. The other possibility is that as the area became more arid, the power of vegetation to hold soil and rocks decreased, so when heavy rainstorms did strike the area, great masses of mud and rock moved down the slopes. The streams were consequently overloaded, and deposition took place in the channels and partly filled the valleys. This caused building up of the fans and an increase in their declivities to provide a steeper gradient for transportation of coarse debris available to the streams.

Uplift of the ranges probably continued during the fan-building stage. Uplift along a range-front fault caused incision, first noted at the canyon mouth, followed by deposition of alluvial cones at the mouths of the canyons. Later as the valley was regraded the cones were incised. Such older cones are visible at the mouths of canyons on the west side of the range, as in Mill and Trenton Canyons, where uplift went on concurrently with fan building. On the other sides of the range, conditions were more stable during late stages of fan building, and cones are absent.

Fan-dissection stage.—After the fans reached their maximum development, most of the streams draining the range began to cut down into the fans as well as into bedrock in the range. The smaller streams formed an anastomosing pattern of shallow rills in the surfaces of the fans, and the larger streams became incised in the fans. The larger streams, such as those in Timber, Mill, and Trenton Canyons, have cut down into the fans as much as 100 feet. The canyons are deepest at the range front and become shallower both downstream away from the range and upstream from the range front. The date of major downcutting is not precisely known, but the streams that dissected the fans also dissected the bars formed along the lake in Buffalo Valley, a feature thought by Meinzer (1922, p. 550) to be of Wisconsin age. More recently, Roger Morrison (oral commun., 1956) has studied the history of Lake Lahontan and suggests that the latest of the lakes may have extended into Recent time, and the bars may also be Recent in age. Fan dissection is still continuing at the present time. The principal agents of dissection are flash floods, which are caused by cloudbursts. After a flood in July 1952, gullying as much as 4 feet deep was noted in the valley bottoms of Timber and Rocky Canyons, and Willow Creek Canyon. As the storm that was the source of the flood was confined to the headwaters of these streams, none of the other valleys in the range show similar downcutting.

Lake stage.—Following the maximum development of the fans, lakes were formed in many of the closed basins in Nevada (Russell, 1885, pl. IV). One of these lakes partly filled Buffalo Valley (Meinzer, 1922, p. 550) and had an outlet into Reese River valley. Another lake existed in the Humboldt Valley and its tributaries and extended from a point 5 miles east of Golconda to Battle Mountain. The lake stage was, in part at least, coincident with the fan-dissection stage previously described, but in places lakes have persisted into the present cycle.

GEOLOGIC STRUCTURE

North-central Nevada is tectonically one of the most spectacular areas in the world. In geologic structure it offers an unusual opportunity to study thrust faulting of cyclic nature with displacements along many thrusts measured in tens of miles and along two approaching a hundred miles. The evidence for postulating such large-scale telescoping of rock units in the earth's crust lies in the study and mapping of the rock facies deposited in the Cordilleran geosyncline that once extended over this part of Nevada.

The salient features of the regional distribution of Paleozoic rock facies in north-central Nevada have already been discussed and will be summarized here. On the east in central Nevada, the carbonate assemblage predominates (pl. 3). Beginning at about long, 116° W. klippen of siliceous and volcanic assemblage rocks appear. These klippen are erosional remnants of a formerly continuous thrust plate whose former eastern extent is indicated on plate 3. The plate rode eastward on the Roberts Mountains thrust fault, probably in Early Mississippian time. Although the continuity of the thrust fault has been broken locally by later orogeny and block faulting, the distinction between assemblages of the upper and lower plates is so clear that there is no question that the Roberts Mountains thrust fault was formerly continuous over the region. The thrust plane itself is well exposed at many places in Eureka County, in the northern part of the Shoshone Range, and in the Sonoma Range (Adelaide thrust fault). Rocks of the transitional assemblage appear in windows below the Roberts Mountains thrust fault in the Osgood and Sonoma Ranges and elsewhere on later thrust sheets. West of this area the siliceous and volcanic assemblage of Paleozoic rocks predominates.

The major structural features of north-central Nevada were formed during four major orogenic periods. Two of these took place during the Paleozoic, the first in Late Devonian to Early Pennsylanian time, and the second in the Permian. The third was in the Mesozoic, probably in Jurassic and Cretaceous time. The fourth period began in the early Tertiary, continued intermittently until late Tertiary, and culminated in the block faulting in the early Quaternary that outlined the present ranges.

The Battle Mountain area has a complex structural history that began with sinking below sea level by Cambrian time. Sedimentation initially consisted of carbonate assemblage rocks, which probably accumulated without any great disturbance, at least until Late Devonian time, in a miogeosynclinal environment. Sometime in the Late Devonian or Early Mississippian coarsening of the sediments in north-central Nevada heralded the beginning of orogeny in western Nevada. The orogenic movements spread eastward, eventually involving the shelf areas in which the transitional and carbonate assemblage rocks were laid down. The orogeny culminated in thrusting in Early Mississippian time when a great sheet of siliceous and volcanic and transitional assemblage rocks moved eastward over rocks of the carbonate assemblage. During later pulses other plates were also thrust eastward, resulting in most complex thrust relations.

Uplift and erosion of the Antler orogenic belt followed, but by Atoka time (early Middle Pennsylvanian) subsidence permitted the westward transgression of shallow seas into the Battle Mountain area. Orogenic movements continued farther to the west, and a broad apron of coarse clastic rocks was spread eastward, overlapping the orogenic belt and interfingering with marine limestones in central and eastern Nevada. The Battle Mountain area apparently received no sedimentary deposits between Atoka and Missouri (Middle to Late Pennsylvanian) time and may have been at or just above sea level. Subsidence again in Missouri and Wolfcamp time was accompanied by deposition of marine limestone. Local uplift resulted in erosion during the middle Permian followed by widespread deposition of sandstone, shale, and shaly limestone in Guadalupe (Early and Late Permian) time.

The Late Permian and Early Triassic history of the area is less well known. Silberling and Roberts (1962) suggest that folding and uplift in post-Edna Mountain time in western Nevada culminated in the Golconda thrust fault during the Sonoma orogeny. Following this, the orogenic belt was locally emergent and furnished sediments to the flanking seas during latest Permian and early Mesozoic time. In Early Cretaceous time the Jurassic and Triassic rocks were thrust from the west, piling up on the west flank of the orogenic belt. Orogenic movements continued into the Cretaceous, resulting in block faulting and the formation of local basins where continental Cretaceous rocks accumulated (Nolan and others, 1956, p. 60–70; Willden, 1958; McNeil, 1939). Intrusions of granite and related rocks in the Late Cretaceous and early Tertiary accompanied continued orogenic movements. Ore deposits were formed in the contact zones of some of the intrusives and along some faults. Volcanism, which began in early Tertiary, took place spasmodically throughout much of the region. The uplift of Battle Mountain that outlined its present form probably began in late Tertiary and continued into the Quaternary.

STRUCTURE IN THE ANTLER PEAK QUADRANGLE

Battle Mountain lies amidst a structurally complex region and the rocks there doubtless were involved in all the orogenic movements that affected the region. The type locality of the earliest, the Antler orogeny, is in the quadrangle, and the effects of the orogeny are well displayed on Antler Peak. The second period of orogeny, the Sonoma orogeny, affected the rocks in the upper plate of the Golconda thrust on the west side of the quadrangle. The Jurassic and Cretaceous orogeny apparently caused minor dislocations of blocks in this region, mostly in a westward direction (Silberling and Roberts, 1962).

The structural features in Battle Mountain were formed over a long period of time. Each successive disturbance affected the rocks older than that movement to some extent, but as the major structural features were, in part, formed outside the limits of the quadrangle prior to movement of the blocks into the area, structural features found in one block may be missing in another.

To illustrate the major structural features of Battle Mountain, structural maps have been prepared that show the major facies of the Paleozoic rocks, and the principal folds, thrust faults, and high-angle faults (pls. 6 and 7). The rocks of Battle Mountain have been broken along thrust faults into three principal structural blocks, which will be described separately; the structural features in them will be keyed to the major orogenic episodes that have been discussed in the previous section on regional structure. These blocks are: (1) The Valmy and Scott Canyon blocks in the north-central and southeastern parts of the range which include the Cambrian and Ordovician rocks of the siliceous and volcanic assemblage; (2) the Dewitt block which is composed of the Harmony Formation and underlies much of the eastern part of the range; and (3) the Golconda block which forms the western part of the range. Another block, the Antler block, which has undergone deformation unrelated to thrusting, has been broadly warped along a northwestward-trending axis and has been cut by high-angle faults.

VALMY AND SCOTT CANYON BLOCKS

The Valmy and Scott Canyon blocks form a structural unit. The Valmy block, on the north end of the range, is about 4 miles wide and extends from the Marigold mine southward for about 8 miles to the vicinity of the Dewitt Mill; a small segment of the block has been mapped in Galena Canyon. The Scott Canyon block is from 1½ to 2 miles wide and 6 miles long and is in the southeastern part of the range, mainly in Little Cottonwood Creek and Galena Canyon and in their tributary valleys. The contact between the two blocks is covered by the Dewitt thrust plate in most places, but a thrust contact is exposed in Galena Canyon. On the west, the Valmy and Scott Canyon blocks are overlapped in most places by a belt as much as 1½ miles wide of the Antler sequence, which includes the Battle Formation, Antler Peak Limestone, and Edna Mountain Formation. Locally, the Valmy block is directly in fault contact with the Golconda block.

Except for minor thrusts and considerable local folding and crushing in the Scott Canyon and Valmy blocks, there is no direct evidence in the quadrangle that they are allochthonous. From regional relations, however, and the fact that rocks of the siliceous and volcanic assemblage have been thrust over autochthonous calcareous rocks of the carbonate assemblage in the nearby Mount Lewis quadrangle, it is concluded that the sole thrust of the siliceous and volcanic assemblage—the Roberts Mountains thrust—probably passes beneath Battle Mountain at no great depth. The Valmy and Scott Canyon blocks then have no roots; they are parts of allochthonous blocks whose structural features were formed elsewhere, partly during folding and thrusting, and partly after they reached their present position.

VALMY BLOCK

The Valmy block, which forms the north-central part of Battle Mountain, is commonly bounded on the west by the Golconda thrust fault and on the south and east by the Dewitt thrust. A small segment of the block has been downfaulted in Galena Canyon near the Butte Mine; this segment is also in thrust contact with the Valmy block. The Valmy block has been folded and faulted during several periods of deformation.

Folds.—A major structure in the Valmy block is an anticlinal fold that is complexly faulted; the axis appears to trend southward and the plunge is about 30° S. The east limb of the fold on the west side of North Peak parallels the range front and dips 30°–60° SE.; the west limb dips 20°–70° SW. and is cut off by the Oyarbide fault. Because of poor exposures, the axis of the fold cannot be traced with certainty north of the Oyarbide fault, but consistent westward dips near Mud Spring indicate that the anticlinal axis probably passes to the southeast. Thrust and high-angle faulting to the south of the Oyarbide fault make it difficult to trace the axis south of the south side of sec. 17, T. 32 N., R. 43 E. Many minor folds were noted and some of the fold axes were plotted, but the difficulty of tracing stratigraphic units through complexly faulted areas discouraged attempts to work out the system of folds. It is possible that there is another southward-plunging anticline on the north side of North Peak, as indicated by dips in fawn-colored quartzite. If so, North Peak and the 7,900-foot peak to the south may be underlain by a southward-plunging syncline.

Thrust faults.—The thrust faults in the Valmy block probably developed during movement on the Roberts Mountains thrust which underlies the range. They may be subsidiary thrusts that have not had any great displacement, and formed in response to stresses developed during major thrusting. Three of them have been mapped in the Valmy block.

One thrust fault is exposed in the North Fork area about a mile east of the Oyarbide Ranch; it apparently crops out on both sides of a normal fault that passes through secs. 18, 8, and 5 of T. 32 N., R. 43 E. The thrust separates members 1 and 2 of the Valmy formation, and its displacement is probably small.

A second thrust, about 2 miles southeast of the Oyarbide Ranch, has a highly sinuous course from Cottonwood Creek in sec. 18, T. 32 N., R. 43 E., northeastward across Trout Creek and the North Fork, finally ending against another thrust on the south side of North Peak. Beds in the upper part of member 2 of the Valmy Formation are repeated on this thrust, greatly complicating the measurement of the stratigraphic section of the Valmy.

The third thrust extends northeastward from Cottonwood Creek across Trout Creek, the North Fork, and along the east side of North Peak to the range front in Humboldt Valley. At the south, the thrust dips 20°–30° SE. and has member 3 of the Valmy Formation in its upper plate; northeast of North Peak the thrust dips northwest and has member 2 of the Valmy in its upper plate. A possibility exists that segments of separate thrusts are involved, but a more likely explanation is that the thrust is folded and is partly overturned. The place of overturn is probably in a poorly exposed area southeast of North Peak (pl. 7).

At most places the thrust faults in the Valmy block dip eastward at moderate angles. This prevailing eastward dip is probably due largely to post-thrust folding and tilting.

High-angle faults.—High-angle faults have been mapped in both the Valmy and Scott Canyon blocks. In the Valmy block they trend northeastward, northwestward, and northward. In the Scott Canyon block, most of them trend northward. Some of the high-angle faults may be of Paleozoic or Mesozoic age, but most of them are probably Tertiary.

Only one high-angle fault in the Valmy block can be definitely assigned to pre-Tertiary age. This fault crosses Trout Creek about a mile east of the Oyarbide Ranch; it strikes N. 20° E. and dips about 60° SE., and cuts diagonally across the nose of the major anticline in the Valmy Formation here. To the southwest, the fault does not displace the basal contact of the Battle Formation in sec. 19, T. 32 N., R. 43 E., and it is therefore inferred that the fault is pre-Atoka (pre-Middle Pennsylvanian) in age. No other faults of any significance that end against the basal contact of the Battle Formation have been mapped. Doubtless others exist, but they could be discovered only by large-scale mapping of the Valmy Formation.

The Oyarbide fault, which passes just southeast of the Oyarbide Ranch, is a range-front fault that divides the Valmy block into two parts. Near the ranch the fault strikes about N. 60° E. and dips 55° NW.; to the northeast the strike swings to about N. 45° E. The dip-slip displacement on the fault cannot be accurately calculated, but appears to be about 2,500 feet. It cuts across the major anticlinal axis of the Valmy Formation at a low angle and continues into the Golconda block. Several faults of small displacement that parallel the Oyarbide fault on the southeast cut the Valmy Formation. These faults dip northwestward and are normal faults.

Another northeast-trending fault probably follows the valley in which Mud Spring is situated. Evidence for this fault is the apparent displacement of the trace of the Golconda thrust fault, downthrown on the northwest. To the west, the fault in Mud Spring Valley probably ends against a north-striking fault that follows Trout Creek.

Northwestward-trending, high-angle faults cut the blocks between the northeasterly faults and commonly end against the northeasterly set. In general, the northwesterly faults have small displacements and they appear to have formed in response to stresses during movement on the northeasterly set. One possible exception to this is the inferred fault on the northeast side of the range that is thought to parallel the range front. The location of this fault is uncertain, but may be about 2 miles northeast of the range front.

Several other north-trending faults cut the northern part of the Valmy block. One of these is a reverse fault that extends from the range front southward along a fork of Cottonwood Creek and displaces the base of the Battle formation about 2,000 feet. Other north-striking faults, which were mapped in areas underlain by the Antler Peak Limestone and Battle Formation, were followed for short distances into the Valmy-Scott Canyon blocks, but eventually were lost because there are so few distinctive units in the upper part of the Valmy Formation that show fault displacement.

SCOTT CANYON BLOCK

The Scott Canyon block is bounded on the north by the Dewitt thrust and on the west by the Plumas and Trinity faults. In Galena Canyon a segment assigned to the Valmy block has been mapped near the Butte Mine. The contact with the Scott Canyon block appears to be a thrust, possibly a subsidiary of the Dewitt thrust. Many steep faults, mostly trending from N. 20° W. to N. 20° E. and dipping west, cut the block. With few exceptions, their downthrown sides are on the west. Most of them have normal displacements of a few feet to 500 feet, but a few of them have displacements of 1,000 feet or more. Many of the north-striking faults contain mineral deposits; these will be described in more detail in the section "Ore-bearing faults."

Folds.—Little is known concerning the major folds in the Scott Canyon block. Many minor folds were noted, however, suggesting that the Scott Canyon Formation has been highly folded. Below the Dewitt thrust, minor folds in chert units are commonly overturned to the east.

DEWITT BLOCK

The Dewitt block, which underlies the east side of the range, is overlapped on the west by the autochthonous formations of the Antler sequence except where the contacts are faulted. On the north and south it is bounded by the Dewitt thrust fault; and on the east it is overlapped by the Antler sequence and by Tertiary volcanic rocks and alluvium. Because there are no sizable distinctive units in the Harmony Formation that can be mapped separately, the block was not subdivided and not a great deal is known about its internal structure.

The Dewitt block is similar in many respects to the Valmy and Scott Canyon blocks, for it has been highly folded and faulted and is also overlain by the Battle Formation of Atoka age. The Dewitt block, named after the gold mill of that name in the central part of the range, is made up wholly of the Harmony Formation, which was moved into the Battle Mountain area on the Dewitt thrust, a subsidiary thrust related to the Roberts Mountains sole thrust. Whether the Dewitt thrust moved along with the sole thrust or at a distinctly later date is not known. Possibly the easier mechanism would have been to move them together; but friction within the block may have caused the two plates to move independently, owing to local differential stresses.

The Dewitt thrust in general strikes a little east of north from the point where it is first exposed at the northeast side of Battle Mountain to the Dewitt Mill area and dips 30°–50° SE. Near the mill it is broken by north-striking normal faults and the strike changes first to northwest and then to west with southward dips until it is overlapped by the Battle Formation. This suggests that the thrust plate has a broadly anticlinal structure, somewhat asymmetric, whose axis strikes about N. 20° W., more or less coincident with the Antler anticline. This anticlinal structure is also shown in Little Cottonwood Canyon. The axis, complexly broken by high-angle faults, lies a little east of the Antimony King mine; from the mine the axis appears to extend southward across Galena Canyon near the mouth of Butte Canyon. The Dewitt thrust plate formerly covered all the southeastern part of the range, and remnants of the plate have been downfaulted in Iron Canyon and on the east side of Philadelphia Canyon.

The Dewitt thrust fault cuts across the bedding, and the beds are highly folded and locally overturned. The major structural feature seems to be a series of overturned folds whose axes trend northward and pass just east of the Dewitt mine (sec. 23, T. 32 N., R. 43 E.); they can be traced northward into the head of Elder Creek and southward into Cow Canyon.

Folds.—Many minor folds whose western limbs dip gently and whose eastern limbs are steep were noted in the Dewitt block; most of these trend northward. This suggests oversteepening or overturning to the east in accordance with the movement of the upper plate. An overturned syncline, marked by folded diabase sills, was mapped at the head of Cow Canyon about a mile east of Antler Peak (fig. 36*A*). Otherwise, even though a large number of strikes and dips were recorded, no major structures were worked out. The syncline may be the principal structural feature of the Dewitt block. It can be traced northward to the vicinity of Long Peak in sec. 26, T. 32 N., R. 43 E., where it is lost because of metamorphism near the quartz monzonite stock.

In Copper Basin, the Harmony Formation strikes northward and dips eastward. No folds of any consequence were noted. In the Galena-Copper Canyon area the Harmony Formation is metamorphosed, and structure has been obscured by recrystallization and faulting.

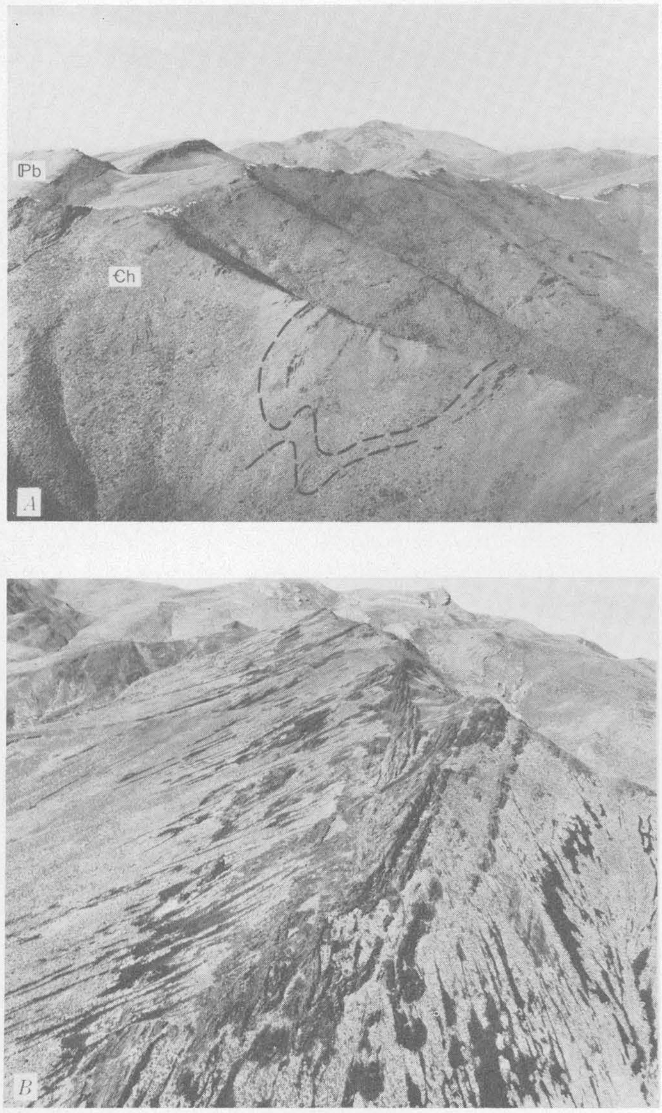


FIGURE 36.—*A*, aerial view north from the head of Cow Canyon showing fold in the Harmony Formation (Ꞓh) overturned to the east; on the west, the massive cliffs are conglomerate beds of the Battle Formation (IPb) dipping gently westward. *B*, aerial view north along the ridge between Willow Creek and Galena Canyon showing overturned folds in chert of the Pumpernickel Formation. Antler Peak is on the skyline, a little right of center.

ANTLER BLOCK

The Antler block includes the areas underlain by the Antler sequence: the Battle Formation, Antler Peak Limestone, and Edna Mountain Formation. The principal areas are a northwest-trending block that extends diagonally across the range and a small area on the east side of Copper Basin.

The Antler sequence rests unconformably upon the Valmy, Scott Canyon, and Dewitt blocks; the older structures that affect these blocks naturally did not disturb the Antler block. A useful purpose is achieved, however, in describing the blocks separately, as the Antler block records younger deformation that also affects the others.

Folds.—The Antler block has been folded into a broad northwestward-trending anticline about 8 miles wide whose axis passes about 2 miles northeast of Antler Peak; the central part is now largely eroded. The western limb of the anticline is the northwestward-trending belt that extends diagonally across the range, swinging in a broad arc, roughly parallel to the Golconda thrust fault. The rocks in the western limb dip 10°–40° W. or SW. for the most part, except where steepened along the Golconda thrust. The eastern limb, which generally dips 10°–30° NE., is exposed only in the east side of Copper Basin; elsewhere it has been eroded or is downfaulted. There is a suggestion of a southward plunge in the outcrops, but the evidence is not conclusive.

The folding of the Antler anticline has also caused warping of the Dewitt thrust. The axial part of the fold in Trout Creek has been broken by high-angle faults, but the broad form of the fold is clearly shown.

High-angle faults.—As the stratigraphy of the Antler sequence is well known, it has been possible to detect even minor displacements by offsets of key beds. Consequently, many high-angle faults have been mapped and are shown on plates 4 and 6. These faults cut units of the Antler sequence, but have not been traced far into the more homogeneous Harmony, Scott Canyon, and Pumpernickel Formations.

Most of the high-angle faults that cut the Antler sequence are normal faults that strike northward and dip steeply westward, but a few are reverse faults that dip steeply eastward. Locally, as in Copper Basin, there are also normal faults that strike northeastward and northwestward.

The northward-striking normal faults cut the intrusive rocks as well as the Antler sequence, and some contain ore bodies. They are therefore late Eocene or post-Eocene in age. These faults parallel the western limb in the southern part of the quadrangle, cut it diagonally, and parallel it again near the Marigold mine. The principal effect of these faults is to repeat the Antler sequence and widen the outcrop from Antler Peak northwestward to Cottonwood Creek. In all, possibly 15 faults have played a significant part in the widening. Near the head of Trenton Canyon, a reverse fault with a steep westward dip, possibly a continuation of the Rocky Canyon reverse fault, repeats the Battle Formation, narrowing the outcrop.

A number of northwestward- and northeastward-striking faults of small displacement cut the western limb, but aside from small displacements of contacts, they do not seem to have any great significance.

In Copper Basin on the eastern limb of the anticline, four sets of faults have been mapped. The oldest set strikes east-west; younger sets strike north-south, northeast, and northwest. Some faults belonging to the east-west set dip at a low angle and may be thrust faults related to the Dewitt fault. The Sweet Marie fault is one of these, and others were mapped in the Contention mine and north of Elephant Head. None of the north-striking faults mapped has any great continuity, although one that separates the Harmony and Battle Formations west of the Elvira adit was traced for more than a mile, and it may connect with faults north of the Carissa mine that extend to the Sweet Marie mine.

The northeasterly fault set is cut by the northwesterly set, which appears to have smaller displacements on the whole and to be less continuous. The principal northwest fault has been traced from Willow Creek across the head of Rocky Canyon and down into Timber Canyon. This fault drops the Mill Canyon Member against the Pumpernickel Formation, requiring a minimum dip-slip displacement of 3,000 feet.

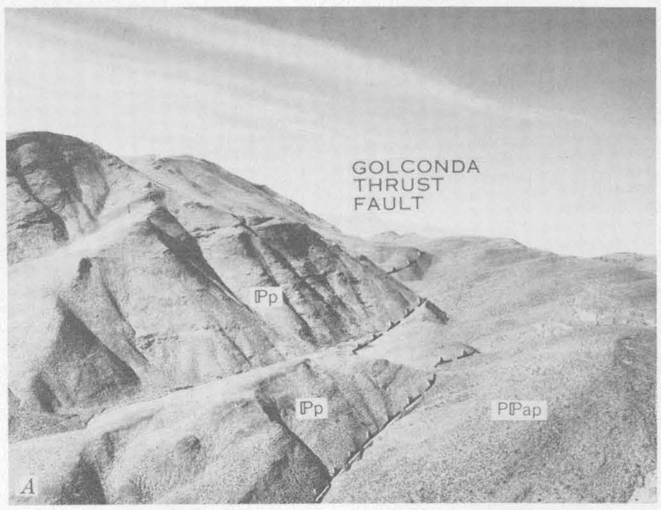
The youngest faults, the range-front faults, cut the Golconda block, but as they are not particularly related to the structures within the block, they will be described separately.

GOLCONDA BLOCK

The Golconda thrust fault, which forms the sole of the Golconda plate, has been mapped, with interruptions, through Battle Mountain, Edna Mountain, and the Sonoma Range. The plate appears to be a southward-plunging synclinal block about 25 miles wide; it is known to extend 60 miles south to Augusta Mountain, and it may extend 25 miles farther south into the New Pass Range.

The Golconda block is made up of folded strata of the Pumpernickel and Havallah Formations which are in part correlative with the units of the Antler sequence, but which were deposited in western Nevada and were thrust into this area in Late Permian or Mesozoic time. Thrusting in Late Permian seems more likely because Triassic strata involved considered (Silberling and Roberts, 1962) to be parautochthonous appear to be little disturbed; contrariwise, both the Pumpernickel and Havallah Formations in the Golconda block have been folded and sheared along faults.

The Golconda block covers the western flank of Battle Mountain (pls. 6 and 7). In the southern part it is as much as 7 miles wide, and it narrows northward to less than 2 miles at the Marigold mine. The block is bounded on the east by the Golconda sole thrust; in the southern half of the range it has been downfaulted. From south to north, the Golconda block is successively in contact with the Dewitt block, the Antler autochthonous sequence, and the Valmy block; near the Marigold mine the Antler sequence is again present (fig. 37). The Golconda block is structurally discordant with all the other blocks, for it has been involved in orogenic movements outside the area. It was the



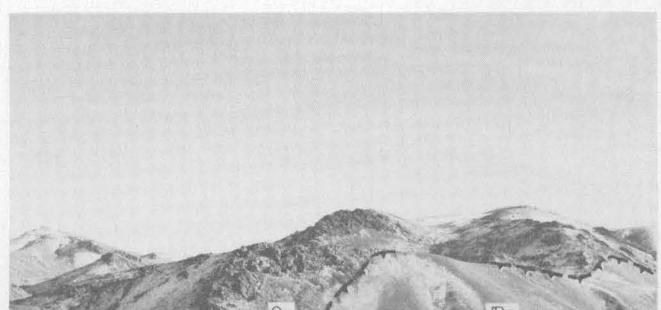


FIGURE 37.—*A*, aerial view north up Willow Creek showing trace of Golconda thrust fault. Upper plate is Pumpernickel Formation (ℙp) and lower plate is Antler Peak Limestone (PℙPap). *B*, aerial view south from the western front of Battle Mountain showing the trace of the Golconda thrust fault. The lower plate is chert and quartzite of the Valmy Formation (Ov) and the upper plate is shale of the Pumpernickel Formation (ℙp).

last major block to be transported into the Battle Mountain structural complex.

The structural features of the Golconda block have been mapped in more detail than those of the Valmy, Scott Canyon, and Dewitt blocks because it has been possible to subdivide the predominant formation in the block, the Havallah, into three members, the Jory, Trenton Canyon, and Mill Canyon, and map them throughout the block. This has assisted in bringing out the structural features and aided in their interpretation.

The Golconda thrust fault strikes N. 20°–40° W. throughout most of the quadrangle and dips 25°–60° SW. where measurements can be made (fig. 37). The best accessible exposure of the thrust plane is along the road about 150 feet north of the Nevada mine shaft. Here the lower plate rock is quartzitic conglomerate of the Edna Mountain Formation in which are preserved grooves that pitch 30° W. The broken zone along the thrust fault can be seen at many places; commonly, rock in the upper plate is highly fractured throughout a zone from a few feet to 30 feet thick. The lower plate is generally less fractured, but locally has widely spaced shears that are presumably related to thrusting. Fragments of broken rock derived from formations other than those in direct contact along the thrust may be seen locally. For example, fragments of Antler Peak Limestone and conglomerate of the Battle Formation may be found along the ridge about a mile southwest of the Oyarbide Ranch. These formations are probably present at depth in the lower plate of the thrust.

Folds.—The folds in the Golconda block are north-striking anticlines and synclines. Some of these folds are broad, open symmetrical folds, but most are asymmetrical and some of them are overturned.

The major fold appears to be a broad syncline whose axis strikes northward and northwestward and plunges gently southward. The syncline is best shown in Trenton Canyon and is therefore called the Trenton Canyon syncline. To the north, between Trenton and Mill Canyons, the axis of the syncline strikes about S. 30°–40° E.; south of Mill Canyon it swings into a southward trend which apparently continues to Timber Canyon, then turns to S. 10°–15° W. to the alluvial contact in Rocky Canyon. Much of the western limb of the syncline has been cut out along a reverse fault and is clearly observable only near the head of Mill Canyon. The eastern limb, on the other hand, has been repeated by reverse faults so that it can be seen on the ridge west of Willow Creek and at the head of Mill Canyon.

The anticline that flanks the Trenton Canyon syncline on the west is exposed in Timber Canyon, after which it is named. The northward extension of the anticline has been obscured by range-front faulting, but its general form is indicated on the north side of Timber Canyon by the contact between the middle and upper members of the Havallah Formation. The eastern limb of the anticline is likewise partly cut out on the reverse fault.

A highly significant fold in the Golconda block is the overturned northward-striking syncline on the ridge west of Galena (fig. 36*B*). The axis of the syncline is well exposed on the west side of the ridge, and it seems likely that it is only one of several parallel isoclinal folds that characterize the lower part of the Golconda thrust plate in this area.

A related fold has been mapped in the lower plate block at the Copper Canyon mine; core drilling in the workings indicates that the Battle Formation has been overturned to the east in a manner similar to the overturning in the upper plate. The northerly trend of overturned folds and westerly pitch of grooving on thrust surfaces at the Nevada mine also indicate that the upper plate of the Golconda thrust plate moved eastward.

Thrust faults.—Except for the sole thrust, the Golconda thrust fault, no other thrusts were mapped in the Golconda block. Doubtless there are others, but they do not appear to cut the Havallah formation, and therefore were not recognized. High-angle reverse faults, which may be related to thrusting, are described in the following section.

High-angle faults.—High-angle faults that cut the Golconda block can be conveniently divided into four principal sets: (1) Northward-trending reverse faults, (2) northeastward-trending normal faults, (3) northwestward-trending normal faults, and (4) range-front faults.

The northward-trending reverse faults in the block dip westward, like the dip of the thrust. Three of them are broadly arcuate in plan and are concave westward, parallel to the trend of the thrust. Because of this parallelism and as they are the oldest set of faults, they are believed to have formed during thrusting. Some of the reverse faults have large displacements; the one in the upper part of Rock Canyon repeats the Antler Peak Limestone and the Battle Formation and has a minimum dip-slip displacement of 4,000 feet. The two to the west, one on the west side of the 7,270-foot hill and the other passing about half a mile east of the Black Rock Mine, have smaller, but significant displacements.

Northeastward-trending normal faults were mapped at several places in the block. One in Mill Canyon cuts diagonally across the Mill Canyon syncline and is responsible for the downfaulted block of Havallah Formation north of Trenton Canyon. Another repeats the Jory Member on the north side of Timber Canyon about 2 miles from the mouth. Still another on the north side of Rocky Canyon, mostly in secs. 12, 13, and 14, T. 31 N., R. 42 E., displaces one of the principal reverse faults.

HIGH-ANGLE FAULTING

High-angle faults in the Antler Peak quadrangle were formed during several periods beginning in Mississippian time and extending through the Mesozoic and Tertiary, and into the Quaternary. Those of Paleozoic and Mesozoic age can be recognized locally, but they apparently are not abundant; some may have been masked by later faulting. High-angle faults of the greatest interest to the mining industry are those of Tertiary age, these contain ore deposits. Quaternary faults outline the Battle Mountain block.

HIGH-ANGLE FAULTS OF PRE-TERTIARY AGE

High-angle faults that were formed during Paleozoic and Mesozoic orogenies can be recognized because they cut older structural features and are cut by younger ones or are overlapped by rock units of pre-Tertiary age. The principal high-angle faults of Paleozoic age are in the Valmy block and were briefly described in the discussion of that block. Many others doubtless formed at the same time, but as they do not displace key beds, they have not been recognized. Still others may have undergone recurrent movement at later times and are therefore classified according to their youngest displacement. High-angle faults of probable late Permian age that were formed in the Golconda block have been described in the discussion of that block. These faults are mainly high-angle reverse faults related to movement on the Golconda thrust.

HIGH-ANGLE FAULTS OF TERTIARY AGE

The high-angle faults of Tertiary age probably formed over a long period of time and during several distinct cycles, the youngest of which extended into the Quaternary. For convenience in description, the faults will be divided into four groups: The oldest includes the faults that contain intrusive rocks; the second, the ore-bearing faults; the third, the post-ore faults; and the fourth, the faults that border the range.

FAULTS CONTAINING INTRUSIVE ROCKS

Some intrusive bodies in Battle Mountain follow high-angle fault zones that were in existence prior to intrusion of the bodies. The igneous rocks have been dated as late Eocene or early Oligocene, so it is presumed that the high-angle faulting began in the Eocene. For the most part, the dike-bearing faults strike northward, but there are many exceptions to this trend in the Copper Basin area (pl. 4). The displacement on the faults ranges from a few feet to many hundreds of feet, but generally appears to be small.

ORE-BEARING FAULTS

The second group of faults, the ore-bearing faults, cut the intrusive bodies and are therefore younger. This group is believed to be closely related in age to the major period of intrusion and may have formed in part during and as a result of intrusive activity. The ore-bearing faults strike northward for the most part and dip steeply westward. They generally are normal faults with the downthrown block on the west; the dip-slip displacements range from a few feet to more than a thousand feet. As many of these faults are economically important, they have been mapped in detail in the mines. The most productive ones are the Virgin, Plumas, Trinity, and Butte faults.

Virgin fault.—The Virgin fault, which was named for the Virgin shaft of the Copper Canyon mine, where it was first explored, can be traced from the south end of the range northward through Galena, past Antler Peak and Wild Horse Basin, and down into Trout Creek, where it can no longer be followed in the chert and shale of member 3 of the Valmy Formation. Along the southern part of its course, the Virgin fault separates the Pumpernickel Formation on the west from the Harmony and Battle Formations, Antler Peak Limestone, and Edna Mountain Formation on the east. It is thus the principal boundary between the Golconda block and the Antler and Dewitt blocks. Near Antler Peak it cuts diagonally across the Battle Formation, which then is the west-bounding rock for nearly a mile before the fault cuts through the Dewitt thrust and is lost in the chert of member 3 of the Valmy Formation.

The throw on the Virgin fault can best be measured near the Nevada mine. Here the Edna Mountain Formation is in contact with the lower part of the Battle Formation, a stratigraphic throw of at least 650 feet and perhaps as much as 1,000 feet. Northward near Antler Peak, the displacement appears to be less, possibly about 400 feet.

The Virgin fault contained copper ore bodies on the upper levels at the Copper Canyon mine, and lead-zinc ore bodies at the Nevada mine and in the vicinity of Galena. Between these areas only shallow exploratory work has been carried on. The deepest workings on the fault are in the Copper Canyon mine, where the fault has been explored to the 530-foot level.

Plumas fault.—The Plumas fault has been mapped from Philadelphia Canyon 3 miles northward to Galena Canyon, half a mile east of Galena, where it apparently dies out near its intersection with the Trinity fault. Along most of its course, the Plumas fault separates the Harmony Formation on the west from a block of Scott Canyon Formation on the east. At the Plumas mine, the minimum displacement is about 150 feet, and the maximum displacement is probably much greater. The fault zone is intensely sheared over a width of as much as 30 feet where it is exposed in underground workings.

The Plumas fault has been productive at the Plumas and Humbug-Lucky Chance mines, where it contains arsenical and pyritic gold ore. There are many exploratory pits along the fault zone elsewhere, but apparently no ore bodies have been discovered.

Trinity fault.—The Trinity fault has been mapped from its intersection with the Plumas fault in Galena Canyon for more than 2 miles N. 15° E. into Little Cottonwood Canyon. Near the Trinity mine the fault splits into two strands which dip 55°–75° NW. Most of the exploratory work in the Trinity mine has been carried out on the western strand. Like the Plumas fault, the downdropped western block is Harmony Formation; the eastern block is Scott Canyon Formation.

The Trinity fault has been productive only at the Trinity mine, but the eastern strand has not been explored to any extent south of the mine.

Butte fault.—The Butte fault has been mapped from the south side of Iron Canyon northward into Scott Canyon on the north side of Galena Canyon. The Butte fault strikes a little west of north and dips 50°–65° SW. Although it has been prospected at many places, the only significant production has been at the Butte mine, where it was stoped from the surface to the Butte Canyon floor.

POST-ORE FAULTS

The third period of Tertiary faulting followed ore deposition and may be dated as Miocene and Pliocene. The faults of the third period in part may represent renewed movements along the older faults, resulting in brecciation and fracturing of vein fillings, but in part they appear to represent new breaks.

Faults of the third period can be recognized where they cut and displace the volcanic and pyroclastic rocks of Tertiary age. One of them bounds the basalt cap in the southeastern part of the range in sec. 35, T. 31 N., R. 43 E. It strikes N. 45° E., dips steeply southeast, and has a dip-slip displacement of at least 200 feet. Other faults that cut the volcanic rocks east of Elephant Head strike both northwestward and northeastward; none of them appear to have significant displacements.

RANGE-FRONT FAULTS

The fourth period of high-angle faulting includes the youngest set of faults that bound the range and cut rock units as young as the bench and fan gravels. Some of these faults follow highly silicified breccia zones, and may well have originated at an earlier date, but the latest movement took place in late Tertiary or Quaternary. These faults are part of the pattern of block faulting that characterizes the Basin and Range province.

Since the 1870's, when King (1878, p. 451–453) first discussed the origin of the mountain ranges along the 40th parallel, the nature and origin of basin and range structure has been a subject for discussion and speculation. King thought that the ranges were eroded folds. Gilbert (1874, p. 50) was the first to point out that faults bordered many ranges and that vertical movements were concerned, but Dutton's explanation of the origin of the ranges (1880, p. 48) included both folding and later faulting and suggested that erosion had largely eliminated relief owing to folding before faulting.

Louderback (1924, p. 38) considered that basin and range faulting took place in Pliocene and post-Pliocene, but Ferguson (1924, p. 47; 1926) showed that block faulting began prior to late Miocene time and took place in distinct stages. Nolan (1943, p. 178–187) ably summarized the literature pertinent to basin and range structure, and emphasized that faulting began in early Oligocene and has continued intermittently since that time.

Louderback (1904, p. 305; 1926, p. 4–5) showed that in the West Humboldt Range, which adjoins the East Range on the west (pl. 3), basin and range faulting commonly resulted in tilting of late Tertiary volcanic caprocks, indicating greater movement on one of the bounding faults than the other. Throughout the Sonoma Range quadrangle, the Mount Lewis and Crescent Valley quadrangles, and Eureka County, the capping volcanic rocks generally dip eastward or southeastward suggesting regional tilting of the individual ranges. Some of the ranges, such as the Tobin, Buffalo, and the West Humboldt, have steep scarps on both sides, but most of them show steep scarps and evidence of recent movement only on the western side. This is further evidence of the general regional habit of eastward tilting of the ranges. Shoshone Mesa, north of the town of Battle Mountain on the north side of the Humboldt River Valley, is capped by nearly horizontal lavas; it is postulated that the valley is a structural trough separating the tilted blocks on the south and less deformed block on the north.

Only one side of Battle Mountain, the west side, is bounded by visible fault scarps. The westernmost fault, the Buffalo Valley fault (pl. 6), is exposed in the workings of the Buffalo Valley mine where it strikes north and dips 50° W. The hanging-wall block consists of fan gravels that are dropped down against rocks of the Havallah Formation. This fault can be traced only for about 1½ miles, but a poorly defined scarp in gravel indicates that it extends a mile farther north across the wash of Mill Canyon. The main fault, the West range-front fault (pl. 6), is 1 mile to the east. It strikes N. 10° E. and dips 55°–65° W. The fault plane is extensively silicified over a width of as much as 20 feet locally, and is brecciated, indicating recurrent movement. The hanging-wall rocks in most places are fan gravels, but as suggested by the presence of Tertiary and older rocks at the Buffalo Valley mine and in the southwest corner of the quadrangle, the fan gravels may be only a relatively shallow cover, possibly a few hundred feet thick. The West range-front fault has been mapped with fair continuity for about 12 miles, and it doubtless extends northward into Humboldt Valley beneath the alluvium along the course of Cottonwood Creek. No accurate idea of displacement can be given, but the local relief, thought to be due mainly to faulting, is more than 3,000 feet. This is probably a minimum rather than a maximum figure. The downthrown block has been partly buried in alluvium and the upthrown block has been dissected.

The Oyarbide fault, which passes half a mile southeast of the Oyarbide Ranch and separates the northwest corner of the range from the main range, also belongs to the fourth period. The fault strikes N. 60° E.–N. 30° E. and dips 55° NW. It extends from the range front on the west to the range front on the north, a distance of nearly 7 miles. The Oyarbide fault is a normal fault with an estimated dip-slip displacement of about 3,500 feet. The intersection with the Buffalo Valley fault is poorly exposed, but it is inferred that the Oyarbide fault ends against the Buffalo Valley fault and is therefore older.

The northeastern side of Battle Mountain (see northwestern extension on map by Ferguson and others, 1952) appears to be relatively straight. This suggests structural control and a buried fault or set of faults may parallel the range front between the range and U.S. Highway 40. No evidence of Recent or late Quaternary movement has been noted on this postulated fault system, and its presence is conjectural. Likewise, there may also be buried faults in the Reese River Valley and Buffalo Valley parallel to the southeast and south sides of the range, but there is no direct evidence to substantiate them other than the intriguing alinement of these fronts with other nearby range fronts or sharp breaks in range fronts (see maps by Ferguson and others, 1951b; and Muller and others, 1951).

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INDEX

[Italic page numbers indicate major references]

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