Geology of the Atomic Energy Commission Nevada Proving Grounds Area, Nevada

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A CONTRIBUTION TO GENERAL GEOLOGY

GEOLOGY OF THE ATOMIC ENERGY COMMISSION NEVADA PROVING GROUNDS AREA, NEVADA

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ABSTRACT

The Nevada proving grounds area in Nye and Clark Counties, Nev., is about 700 square miles in size and lies about 70 miles northwest of Las Vegas in southern Nevada. It consists essentially of two large valleys, Yucca and Frenchman Flats, both surrounded and separated from one another by hills and mountains of variable relief.

Seventeen Paleozoic formations and one of Tertiary age have been recognized in the Nevada proving grounds area. The Paleozoic formations are Early Cambrian to probable early Permian in age and consist of 22,000 feet of limestone, dolomite, quartzite, shale, and conglomerate beds. The predominantly volcanic Oak Springs formation of Tertiary age is at least 2,000 feet thick and is the most widespread formation in the area. A granitic intrusion of probable Late Cretaceous to early Tertiary age has metamorphosed and mineralized some of the Paleozoic rocks, and dikes of middle Tertiary or later age occupy normal faults along the northeastern margin of the area. Quaternary deposits reaching a maximum thickness of more than 800 feet are mostly a heterogeneous mixture of detritus derived from bedrock areas. This fill contains some caliche and fanglomerates. Playas made up wholly of impermeable fine silt and clay are present.

During the Mesozoic era uplift and attendant folding and contemporaneous thrust faulting occurred, probably in Cretaceous time. Normal faulting began in early Tertiary time, followed by volcanic deposition and later by continued normal fault displacement.

INTRODUCTION

The Nevada proving grounds area is in southeastern Nye County and along the extreme northwest margin of Clark County, Nev., about 70 miles northwest of Las Vegas (fig. 57). The area is about 42 miles long and from 16 to 18 miles wide, comprising a total of about 700 square miles. The proving grounds lie in the Great Basin section of the Basin and Range physiographic province.

The proving grounds area consists of two major valleys, Yucca Flat to the north and Frenchman Flat to the south. These valleys are bordered by hills and ridges of moderate relief.

The geologic study of the Atomic Energy Commission Nevada proving grounds area, Nye and Clarke Counties, was made and the present

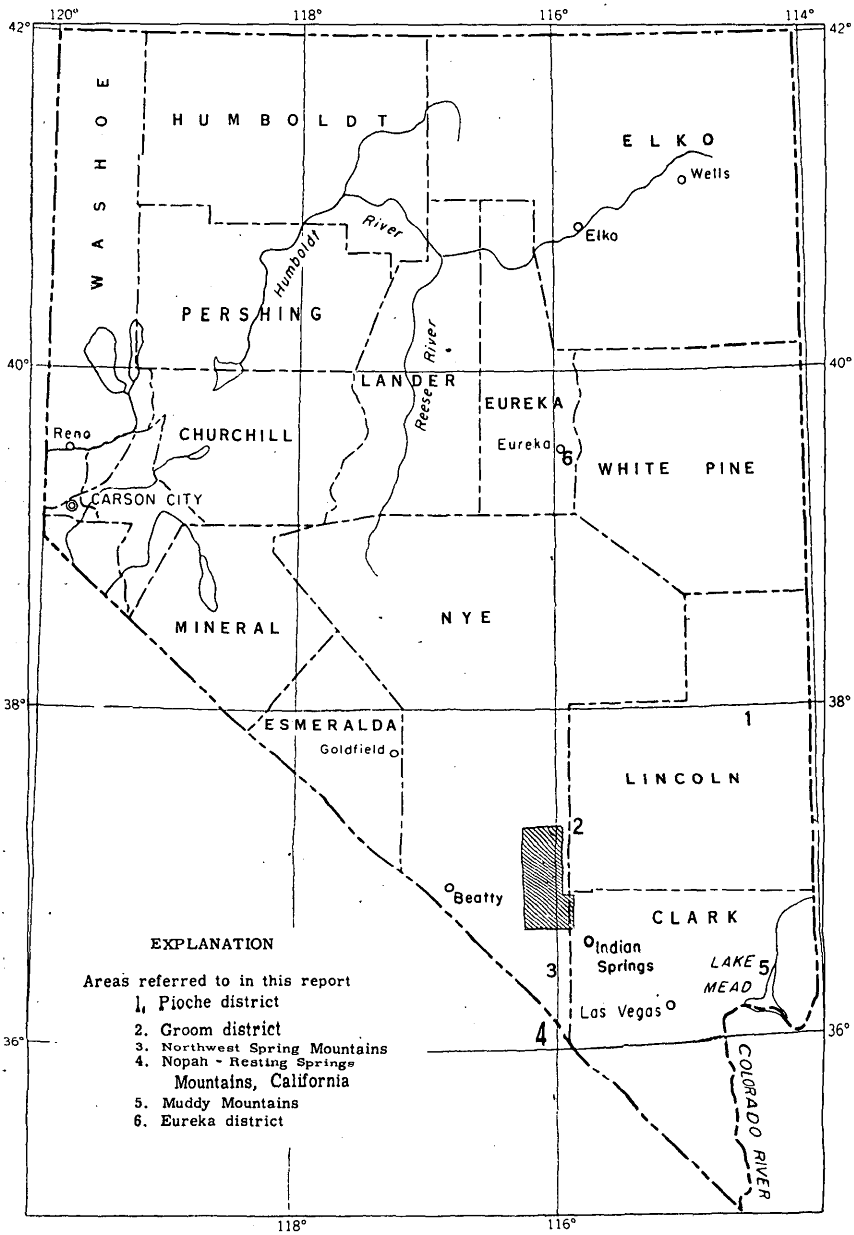

FIGURE 57.—Index map showing areas (cross ruled) described in this report and other areas.

report was written while the writers were in the U. S. Army stationed at the Mercury Test site. The report is being published by the Geological Survey so that geologic data for an area that is now inaccessible will be available to those interested in the geology of southern Nevada.

PREVIOUS INVESTIGATIONS

A brief mention of part of the Nevada proving grounds area is included in Ball's report (1907) on the geology of southwestern Nevada and eastern California. In 1951 A. M. Piper carried out reconnaissance investigations of Yucca Flat. The writers, who served as assistants to Piper on this project, have incorporated many of the results of his work in this report.

The southeastern part of the area lies within the Las Vegas quadrangle, which is being mapped by C. R. Longwell, who kindly supplied important information on parts of the area. Nolan (1929) has mapped the northwestern part of the Spring Mountains, about 15 miles south of the proving grounds. Hazzard (1937) has described the Paleozoic stratigraphy in the Nopah-Resting Springs Mountains, Inyo County, Calif., about 40 miles to the south. Ten miles northeast of the proving grounds, Humphrey (1945) reported on the geology of the Groom lead and silver mining district.

PRESENT INVESTIGATION

Reconnaissance was done in the Nevada proving grounds area in the fall of 1951 under the direction of A. M. Piper. The writers did the detailed mapping between February and mid-August, 1952.

ACKNOWLEDGMENTS

The writers wish to thank Col. Gordon B. Page, U. S. Army, who was in charge of the project, for his critical analysis of the written report.

We are indebted to the following for their contributions to this report: T. B. Nolan, C. W. Merriam, Allison Palmer, Helen Duncan, Josiah Bridge, Raymond Douglass, J. Steele Williams, J. Brookes Knight, Edwin Kirk, Arthur Boucot, and T. C. Yen of the U. S. Geological Survey and the U. S. National Museum, for identification of fossil collections and for assistance in the field; C. R. Longwell for his criticism and aid in the field and for his review of the manuscript; and C. W. Merriam and J. H. Wallace for revision of the manuscript.

STRATIGRAPHY

The exposed rocks in the Nevada proving grounds include a wide variety of sedimentary rocks of Paleozoic age, as well as Tertiary volcanic rocks and Quaternary valley fill (pl. 32).

The Paleozoic rocks have an aggregate thickness of about 22,000 feet of which more than 16,000 feet is limestone and dolomite. The rest is dominantly conglomerate, quartzite, and shale. Fossils occur in many beds of limestone, dolomite, and shale but are absent in the other rocks. These sedimentary rocks range in age from Early Cambrian to probable early Permian.

The Tertiary rocks have a minimum thickness of about 2,000 feet. They consist mostly of rhyolite and tuff but include many other igneous types. Locally, near the base, these rocks are interbedded with layers of conglomerate and fresh-water, marly limestone containing fossils of probable Miocene age.

Quaternary rocks form the valley fill of Yucca and Frenchman Flats. These rocks consist of a heterogeneous mixture of detritus derived from adjacent bedrock areas.

A stratigraphic column showing the exposed rocks in the area is included (pl. 33). This column is a composite of 10 partial sections measured at different localities in the area. It was not possible to obtain a stratigraphic section to include all units between the Cambrian and Permian(?), the oldest and youngest pre-Tertiary rocks exposed, because of faulting and cover by alluvium or Tertiary volcanic rocks. Correlation between the partial sections is based on distinctive paleontological and lithologic characteristics.

CAMBRIAN ROCKS

STIRLING QUARTZITE

The Stirling quartzite is restricted to several high hills northeast of Yucca Flat. The outcrops range in width as much as 3,000 feet and are traceable northwestward for about 4 miles. The type locality of the Stirling is in the northwest Spring Mountains, where it was originally defined by Nolan (1929).

That part of the Stirling quartzite exposed in the area consists of quartzite interbedded with a few layers of shale. The quartzite is light gray, lead gray, and brown but includes some beds exhibiting distinct color-banding. It is generally poorly bedded, granular in texture, and shows indistinct crossbedding. In a few zones, quartz pebble conglomeratic beds are interbedded with the quartzite. The shale is generally gray, brown, and greenish. Where examined, these shale beds are also hard micaceous thin-bedded and slope-forming. Characteristically, the Stirling forms hills of moderate to high relief that, in places, have talus-covered slopes.

The Stirling is well set off from, and conformably overlain by the Pioche shale. The nature of the lower contact is not known because the Stirling is the oldest formation recognized in the area.

This formation is only partly exposed. The exposure was not measured but the thickness was estimated to be at least 800 feet, of which 95 percent is quartzite. This figure is considerably less than the 3,700 feet exposed at the type locality south of the area (Nolan,

1929) or less than the 7,855 feet reported at the Groom district (Humphrey, 1945).

The Stirling quartzite is probable Early Cambrian in age for it conformably underlies shale beds containing late Early Cambrian fossils. It is similar in age and lithologic characteristics to the Stirling of the northwest Spring Mountains and hence is correlated with it. The Prospect Mountain quartzite of the Groom district also corresponds in lithologic characteristics and stratigraphic position to this unit and is considered as the probable correlative of the Stirling.

PIOCHE SHALE

The Pioche shale is recognized in several small hills and gullies about 1½ miles east of Banded Mountain in northeastern Yucca Flat. These exposures are separated by alluvium or Tertiary volcanic rocks making correlation between outcrops difficult. Many of these outcrops are not shown on the map because of their small size. However, in the field they may be recognized at a distance by their buff color and sharp contrast to the other beds. Walcott (1908) defined this formation from the Pioche district, Nevada.

The Pioche consists of buff to reddish-brown, highly micaceous shale containing thin interbedded limestone. The shale is generally flaky, slope forming, fossiliferous, and contains some silty beds. A few beds are ripple marked and some are foliated because of the large amount of mica in the shale. In places, the Pioche contains several beds of dark-gray hard micaceous, quartzitic shale in layers a few inches thick. Elsewhere, limestone is interbedded with the shale in layers a few feet or less thick. The beds are generally dark gray, buff weathering, thin bedded, fossiliferous limestone containing much buff to red clastic material. Because of faulting and incomplete exposures, the stratigraphic position of these limestone beds within the Pioche was not definitely established. However, they appear to be more common in the middle and lower parts of the formation.

Distinct lithologic breaks separate the Pioche from the overlying and underlying formations. The lower contact is at the base of the lowermost buff-colored shale bed, and the upper boundary is at the break between shale and overlying limestone.

Only the upper 150 feet of the Pioche was measured in the area because of faulting and inability to correlate between outcrops. At the Groom district, the Pioche shale is 961 feet thick (Humphrey, 1945). This figure probably approximates the thickness of this formation in the Nevada proving grounds.

Trilobites were found in the lower and middle parts of the Pioche

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shale. These fossils were examined by A. R. Palmer (written communication) who reports:

Olenellus gilberti Meek
fremonti Walcott
Paedumias transitans Walcott
Peachella sp.

This is a typical Lower Cambrian assemblage. *Peachella* is a striking olenellid trilobite that seems to be widespread in the Great Basin in the upper part of the Lower Cambrian.

Some of the same fossils are reported in the Pioche from the Groom district where fossils of Middle Cambrian age have also been found (Humphrey, 1945). By fossils, stratigraphic position, and lithologic similarity, the Pioche in the Nevada proving grounds is correlated with the Pioche of the Groom district and consequently is considered of Early and Middle Cambrian age.

LYNDON LIMESTONE

Exposures of the Lyndon limestone are limited to a discontinuous, faulted, narrow band about 1½ miles east of Banded Mountain. These outcrops are about 300 feet wide and are traceable northward for about 2½ miles. Westgate (1927) originally defined the Lyndon at the Pioche district, Nevada.

The Lyndon consists of light to medium-gray, mottled, generally finely crystalline, resistant limestone. Characteristically, it contains many oval and elongate, concentric algal masses, commonly an inch or more in size. These "*Girvanella*" beds occur throughout the formation. In some places the Lyndon contains pink to reddish-brown silty limestone and at those places may be less resistant. Some buff to reddish-brown oolitic material also occurs in a few of the beds.

The contact of the Lyndon limestone with the underlying and overlying formations is conformable and at both places is at the lithologic break between limestone and shale.

A total thickness of 245 feet was measured for the Lyndon limestone in the area.

Fossil fragments from the upper part of the Lyndon limestone establish it as Middle Cambrian. These fossils were examined by A. R. Palmer (written communication) who identified them as:

Kootenia sp.
Ptarmigania? sp.
"*Girvanella*"

From stratigraphic position, lithologic similarities and the abundant "*Girvanella*" beds, the Lyndon of the Nevada proving grounds area is correlated with the Lyndon limestone of the Groom district.

CHISHOLM SHALE

The Chisholm shale is exposed about 2 miles east of Banded Mountain. The outcrop extends for about 2½ miles as a narrow, northward-trending, discontinuous band a few hundred feet wide. Because of its nonresistant character, it forms gently sloping low hills. This formation was originally defined by Walcott (1908) at the Pioche district, Nevada.

The Chisholm consists of brown, buff-weathering, slightly micaceous shale. In places, the shale beds are silty. Some of the shale layers break into small, sharp, angular pieces and others weather into flat, platy fragments. One or two dark-gray, resistant limestone beds, a few feet or less thick, are exposed about 110 feet above the base of this formation.

The Chisholm shale is sharply set off from, and lies conformably over the Lyndon limestone and under the Jangle limestone. Each contact is at the lithologic break between shale and limestone. A complete thickness of this formation was obtained and measured as 320 feet.

No fossils were found in the Chisholm shale in the area. However, in the Groom district, the Chisholm is Middle Cambrian in age because it is underlain and overlain by beds containing Middle Cambrian fossils (Humphrey, 1945). The Chisholm shale of the Nevada proving grounds area is correlated with the Chisholm shale of the Groom district by lithologic similarities and stratigraphic position and is thus considered as Middle Cambrian in age.

JANGLE LIMESTONE

The section of beds which is here named the Jangle limestone crops out on Jangle Ridge and also occupies several of the hills a few miles to the south. The name Jangle limestone is substituted for the Peasley limestone of Wheeler (1940) in the Pioche and Groom districts because of differences in thickness, lithologic characteristics, and possibly in formational boundaries. In the field the Jangle may be identified by its prominent, ledge-forming upper and lower units and generally slope forming middle unit.

The Jangle is subdivided into three units, each of which consists of limestone.

The lower unit is 80 feet thick and consists of dark smoky-gray to steel-gray, prominent, ledge-forming limestone containing buff irregular silty partings. The lower 40 feet of this unit includes some well-bedded resistant finely crystalline limestone beds a few inches thick. The remaining 40 feet of the unit is dominantly resistant, calcitic, poorly to fairly well bedded limestone.

The middle unit is 115 feet thick. The beds consist of dark-gray limestone containing much buff to reddish-brown silty material which is distinctive for its slope-forming character.

The upper unit of the Jangle is 80 feet thick and consists of dark-gray to smoky-gray ledge-forming limestone containing a few buff silty partings and round, concentric algal masses. This formation is completely exposed on Jangle Ridge where it is 275 feet thick.

The Jangle limestone lies in conformity with the underlying Chisholm shale and with the overlying Yucca Flat formation. The lower boundary is at the lithologic break between shale and overlying limestone. The upper contact is at the break between the dark-gray limestone of the Jangle and the lowest, light-gray limestone bed of the Yucca Flat formation.

"*Girvanella*" were the only fossils found in the Jangle limestone. However, in the Groom district, the Jangle is lithologically similar to most of the Peasley limestone of Wheeler. At that locality, the Peasley of Wheeler directly overlies the Chisholm shale and is listed as Middle Cambrian in age (Humphrey, 1945). Because of the relationship, the Jangle is correlated for the most part with the Peasley limestone of Wheeler in the Groom district, and is assigned a Middle Cambrian age.

YUCCA FLAT FORMATION

The name Yucca Flat formation is hereby given to all beds lying between the Jangle limestone and the Dunderberg shale on the east side of Yucca Flat in the Nevada proving grounds area.

This formation is the most widely distributed Cambrian unit in the area. It crops out boldly along the northeast margin of Yucca Flat and occupies many hills and ridges of great relief. Banded Mountain obtains its name from the alternating beds of dark and light-colored limestone and dolomite so characteristic of parts of this formation. The most complete section of the Yucca Flat is exposed from Jangle Ridge to Banded Mountain. However, owing to faulting, this section is not continuous.

The Yucca Flat formation consists of limestone and dolomite and is subdivided into two parts. The upper part contains four recognizable units, *A* through *D* in ascending order.

The lower part is 395 feet thick, nearly all of which is limestone. The limestone beds are generally light to medium gray and weather a mottled buff to gray. Characteristically they form prominent ledges which weather into a rough, sharp surface. Commonly they contain stringers and specks of calcite. The upper portion of this part includes an alternating sequence of light and dark-gray, fine to medium crystalline limestone beds which have a subdued banded appearance. Interbedded with these banded beds are a few thin dark and light-gray finely laminated dolomite beds totaling about 15 feet in thickness. Sixty feet from the base of this part is a dark-gray and buff, silty limestone, 30 feet thick, similar lithologically to the underlying Jangle limestone.

About 355 feet of black to dark-gray, finely crystalline, fairly well bedded limestone comprise unit *A*, which overlies the lower part. This unit is easily recognized in the field by its sharp contrast to the lighter colored limestone beds directly above and below.

The basal 20 feet of unit *B* is made up of light-gray limestone. These beds are separated from the remainder of the unit by a large fault. Because of this faulting, the total thickness of this unit was not established but at least 1,450 feet of section was measured and the total thickness probably exceeds this figure by hundreds of feet. That part of unit *B* lying above the fault is made up dominantly of an alternating sequence of dark limestone and light dolomite. At a distance, these interbedded dark and light beds form a diagnostic banded color effect. The limestone is commonly dark gray to black finely crystalline and resistant. Many of the limestone beds emit a fetid odor upon being struck by a hammer. The dolomite beds are generally several shades of gray and buff. They are nonresistant finely crystalline to cryptocrystalline and many weather into tabular fragments or spalls. Some fragments ring like china when struck. Many rocks of this unit are of dark limestone and light dolomite in an alternating series of fine laminations, a fraction of an inch thick.

Unit *C* consists of 380 feet of light-gray to light-buff finely crystalline to cryptocrystalline very well bedded aphanitic limestone. It occurs in beds about 1–2 feet thick and is well exposed in bold, bare outcrops. The lower part of the unit weathers to a light yellowish brown which is easily identifiable on Banded Mountain. The remainder of this unit weathers light gray and lies in sharp contact with the overlying dark unit.

Unit *D*, the uppermost 235 feet of the Yucca Flat formation, is a dark-gray to black well-bedded fossiliferous resistant limestone. Generally it is finely crystalline but contains much calcite and in places has been recrystallized, probably from dolomite.

The underlying and overlying contacts of the Yucca Flat formation are conformable and are placed at distinct lithologic breaks. The lower contact is at the base of the lowermost, light-gray limestone bed of the Yucca Flat and the upper boundary is at the contact between dark-gray limestone and overlying Dunderberg shale.

The measured thickness of the Yucca Flat formation, including the lower member, the partial section of unit *B*, and the complete sections of the other three units, is at least 2,815 feet. The total thickness is considerably more.

The only faunal evidence for the age of the Yucca Flat was obtained from unit *D*. A. R. Palmer (written communication) reported on fossils collected from two zones within this unit as follows:

Collection from the upper part of the dark limestone unit below the 'Dunderberg':
Micromitra sp.
Pseudagnostus sp.
Acrotretid brachiopods
Two undescribed trilobite genera

This collection is late Dresbach (early Late Cambrian) in age. The fauna has never been reported from the Great Basin although it is now known to be present at several localities.

In the lower portion of the dark limestone unit below the 'Dunderberg', representatives of *Meteoraspis* and *Crepicephalus*, characteristic Dresbachian trilobites, were seen.

Although no fossils were collected in the units underlying unit *D*, their stratigraphic relationship with overlying and underlying fossil-bearing beds indicates these units are mostly Middle Cambrian in age.

Lithologically, the lower part of the Yucca Flat is similar to the Burrows dolomite of Wheeler (1940) in the Groom district. However, the lower part is much thicker and the lower contact is at a lithologic break unlike the lower contact of Wheeler's Burrows in the Groom district (Humphrey, 1945). Unit *A* is also lithologically similar to the basal part of the Highland Peak limestone, which overlies Wheeler's Burrows at Groom, and the color-banded beds of unit *B* are found in higher units of the same formation.

For these reasons, the stratigraphic interval represented by the Yucca Flat formation corresponds to most of Wheeler's Burrows and the Highland Peak limestone as used by Humphrey (1945) at Groom, and is assigned a Middle Cambrian to early Late Cambrian age.

DUNDERBERG SHALE

The Dunderberg shale is recognized on the lower slopes of the west side of Banded Mountain and is also exposed about a mile east of Paiute Ridge. It characteristically forms low, gently sloping hills or a break in slope below the resistant limestone beds of the overlying formation. This shale is generally exposed as a narrow northward-trending band. The Dunderberg was originally called Hamburg shale by Hague (1892) at the Eureka district, Nevada. Later, it was renamed Dunderberg shale by Walcott (1908) to eliminate confusion with the underlying Hamburg dolomite in that district.

The Dunderberg consists of brown and reddish-brown hard, fissile, nonresistant shale and several thin beds of dark-gray and reddish-gray argillaceous fine-grained fossiliferous limestone. The limestone commonly forms resistant ledges between the slope-forming shale beds.

Where measured on the west side of Banded Mountain, the Dunderberg is 195 feet thick.

The age of the Dunderberg is well established as Late Cambrian by a fossil collection from limestone in the upper part of that unit. Concerning the fossil collection, A. R. Palmer (written communication) reports as follows:

> Four trilobites are quickly recognizable—"*Pterocephalina*," *Pseudagnostus*, *Geragnostus*, and *Dunderbergia*. This is the same association found in the Dunderberg at Eureka. In that area, this association is considered to be latest Dresbach or earliest Franconia in age.

Palmer's findings indicate that this formation is correlated with the Dunderberg of the Eureka district and is assigned an early Late Cambrian age. Fissile green shale and limestone containing a similar Late Cambrian fauna are also found in the Las Vegas quadrangle (C. R. Longwell, oral communication).

UPPER CAMBRIAN ROCKS

In the Yucca Flat area post-Dunderberg, pre-Pogonip strata have a thickness of about 2,660 feet, part of which can be closely correlated with like strata in the Eureka district, Nevada. In redefining the "Pogonip limestone" at Eureka, Hague (1892) retained these rocks in that division. More recently they have been described (Nolan and others, 1956) as an independent Upper Cambrian formation comprising two members, and are excluded from the Ordovician Pogonip group. At Yucca Flat the limestone and dolomite of this interval are provisionally referred to as Upper Cambrian rocks. Four units, *A* through *D*, are described in ascending order.

Contact between Upper Cambrian rocks and overlying Pogonip is provisionally drawn at a break between dolomite and overlying limestone. (At this boundary limestone and dolomite are interbedded, the contact being placed at the top of the uppermost dolomite bed of the Upper Cambrian rocks.) The lower contact of Upper Cambrian rocks is conformable, being drawn at a break between limestone and the underlying Dunderberg shale.

Units *A*, *B*, and *C* of the Upper Cambrian rocks crop out on the high hill west of Banded Mountain. Southward, nearly all the overlying units are exposed on Paiute Ridge. Because of faulting at this locality the lower contact of unit *D* is not exposed. As it does not crop out elsewhere in the area, this division constitutes the only incompletely measured part of the Upper Cambrian strata.

Unit *A* consists of 80 feet of brownish-gray limestone containing buff to reddish-gray silty partings. These beds are fossiliferous, cherty, and nodular. They generally occur in well-defined beds a few feet thick which form alternating resistant and nonresistant ledges.

Unit *B* is a dark- to smoky-gray aphanitic limestone, 360 feet thick, containing many thin bands of reddish-gray silty material. It is characterized by extremely well defined beds 1–2 inches thick. Typically, the lower 150 feet weathers into a talus slope of thin flat plates which have a light-gray sandy surface. Locally these surfaces display indications of trilobites. The remaining upper 210 feet of limestone contains lenses and nodules of gray chert which weathers orange brown. Because of the chert, these beds are resistant and are prominent ledge formers.

At least 1,115 feet of poorly bedded massive gray, dark-gray, and black mottled limestone containing many thin calcite veinlets composes unit *C*. It is generally finely crystalline although some medium-crystalline beds are in the upper part. The lower 260 feet also contains many gray chert lenses a few inches thick and in places several feet long.

Unit *D* is 1,105 feet or more thick. This unit consists chiefly of medium-gray and dark-gray dolomite. The dolomite is finely crystalline and fairly well to poorly bedded. Characteristically, it contains thin bands of white to pink coarse dolomite crystals. Some beds are cherty and others show distinct crossbedding. In other places, the unit displays a rough, pitted sandy surface. About 200 feet from the top is a 55-foot bed of dark-gray finely crystalline calcitic limestone. Other thin dark-gray limestone layers, interbedded with the dolomite, are also in the lower part of this unit.

Unit *A*, basal division of the Upper Cambrian undesignated, contains fossils examined by A. R. Palmer (written communication), who reports as follows:

Irvingella major Ulrich and Resser
Geragnostus sp.
Pseudagnostus sp.
Kinbladia sp.
Litocephalus sp.
Pterocephalia sp.
Elvinia sp.
Dunderbergia sp.
Dellea sp.

This large fauna is characteristic of the *Elvinia* zone of Franconia age. Except for *Dellea* and *Kinbladia* the assemblage is the same as that in the basal beds of the (new post-Dunderberg, pre-Pogonip formation) at Eureka.

Unit *B* contains an unusual trilobite fauna and concerning them; A. R. Palmer states:

Bienvillia sp.
Loganellus sp.
Geragnostus sp.

Inasmuch as this collection is bracketed by fossiliferous beds of Franconia age, it can be placed definitely in that stage. The first two cited trilobites are known primarily from boulders in the Levis conglomerate in Quebec. *Bienvillia* also occurs in the Eureka district (near the middle of the new Upper Cambrian formationed mentioned above).

Float from an unknown zone in the lower 100 feet of unit *C* yielded fossils concerning which A. R. Palmer reports:

Pseudagnostus
Idahoia sp.
Wilbernia sp.

This collection represents a horizon in the *Ptychaspis* zone from the upper part of the Franconian stage indicating that there is still Upper Cambrian in the section [above unit *B*].

Fossils were not collected from the thick remaining part of unit *C* nor from unit *D*. Some doubt therefore remains as to the age assignment of these units.

CAMBRIAN ROCKS UNDIFFERENTIATED

Immediately west of Yucca Pass, the exposed rocks consist of strata assignable to the Lower, Middle, and Upper Cambrian formations. These rocks have been intensely deformed and in most places are not recognizable as mappable units. For this reason, these formations are grouped together and are mapped as Cambrian rocks, undifferentiated.

ORDOVICIAN ROCKS

POGONIP GROUP

King (1878) originally defined Pogonip as beds that conformably underlie the "Ogden quartzite" (later named Eureka quartzite) and conformably overlie "Cambrian quartzite" (Prospect Mountain quartzite). Hague (1892) later redefined "Pogonip limestone" as the beds overlain by the Eureka quartzite and underlain by "Hamburg shale" (later named Dunderberg shale).

In recent years the term "Pogonip" has been applied mainly to strata of Ordovician age. As redefined in the Eureka mining district, Nevada (Nolan and others, 1956), Cambrian strata have been excluded from the lower part of the group. Considered as a group the Pogonip of the Eureka area embraces several mappable formations falling between the top of the Cambrian system and the base of the Eureka quartzite. In the Nevada proving grounds area the latter definition is applied arbitrarily.

Reconnaissance of the present stratigraphic study does not favor the formal naming of new formational divisions within the Pogonip, though such procedure may eventually be called for. Accordingly a provisional subdivision is employed with nine minor units designated as units *A* through *I* in ascending order.

Rocks of the Pogonip group are exposed over large areas in the mountains surrounding Yucca and Frenchman Flats. East of Yucca Flat the section is essentially complete. Small outcrops are found along the southwest margin of Yucca Flat where the Pogonip is involved in complex thrust faulting. A single small exposure occurs in the northern part of the same valley. It is entirely surrounded by alluvium and lies about 1,000 feet from strata of Carboniferous age, offering one of the more puzzling structural problems in the area.

About 2 miles northeast of Oak Spring Butte unit *I* is exposed in steeply-dipping, northward-trending beds that are terminated on the east by Butte fault.

The west front of Ranger Mountains is made up entirely of Pogonip units *F*, *G*, *H*, and *I*. Except for *G*, these units are all very prominent and cliff forming.

The Pogonip is also exposed several miles northwest of Camp Mercury in the vicinity of Red Mountain. As elsewhere, these beds are resistant and are easily identifiable by their cliff-forming character and bluish-gray color.

Pogonip unit *A* comprises the lower 610 feet of the group. It consists of mottled and dark-gray finely crystalline fossiliferous limestone. The lower 175 feet contains a few interbedded layers of dolomite near the base and is massive. The remainder of the unit is made up of thin-bedded, silt or shale-parted, buff-weathering limestone. Some beds contain orange-brown weathering chert and a few near the top are platy bedded. Intraformational breccia occurs in some of the limestone indicating shallow water deposition.

Unit *B* comprises about 105 feet of medium- to dark-gray nodular fossiliferous, silty and shale-parted limestone and is interbedded with thin layers of buff flaky shale.

Unit *C*, the next unit, is 615 feet thick. The lower 250 feet is a light- to medium-gray, well-bedded limestone in beds that range from a few inches to 2 feet in thickness. It contains stringers and masses of dark-brown chert as much as 6 inches in diameter and forms a resistant ledge above unit *B*. These lower beds are separated from the next 270 feet of the unit by a resistant, 2-foot bed of gray chert that weathers dark brown to black. These beds are gray, thin-bedded limestone containing a few layers of interbedded brownish-gray limestone and a few stringers and masses of dark-brown chert. Above these beds are about 65 feet of gray, yellowish-buff weathering, shale-parted, nodular limestone layers 6 inches thick. The uppermost 30 feet of this unit is a brownish-gray limestone containing a few dark-brown chert masses. It is uniformly bedded in 6-inch layers and weathers into a rough sandy surface.

Unit *D* is a distinctive shale, 265 feet thick. It is a buff paper-thin flaky shale interbedded throughout with 1-inch layers of gray to reddish-buff highly fossiliferous clayey nodular limestone. This unit is recognized at a distance by its characteristic slope-forming appearance.

The shale is overlain by unit *E* which consists of 235 feet of gray limestone. This limestone along the east side of Yucca Flat contains irregular layers of buff silty and muddy material that weathers dark brown. This material gives these beds an alternating buff and gray appearance. The limestone occurs in beds 6 inches to a few feet thick and forms a resistant slope above the underlying shale unit. However, along the east side of Frenchman Flat, this unit is somewhat different lithologically. The unit contains a few shale-parted layers but lacks the characteristic silty and muddy material found in the area to the north.

Unit *F* comprises about 135 feet of gray to dark-gray finely crystalline limestone. It is characterized by large straight-coned cephalopods and prominent ledges which set it off from the slope-forming unit above and from the less resistant unit below. Commonly, fragments of this limestone emit a fetid odor if struck by a hammer.

Unit *G* consists of 195 feet of gray thin-bedded fossiliferous silty limestone and many buff to pink lenses of silty material. It is nonresistant and at a distance is recognized as the slope-forming unit lying between the cliff-forming beds above and below. Some beds contain abundant small brachiopods.

The overlying 535 feet of gray to dark-gray calcitic resistant, massive and cliff-forming limestone makes up unit *H*. The lower 300 feet contains many large gastropods as much as a few inches in diameter. These fossils seldom weather out but are generally seen in cross section.

Unit *I*, which is 455 feet thick, is the uppermost unit of the Pogonip. It is made up of interbedded limestone and dolomite and is characterized by alternating color bands. Shades of buff, gray, and brown are common and many of the beds weather an unusual rusty brown or bluish gray. This unit is uniformly bedded in layers 1 to 2 feet thick and contains many thin silty siliceous partings.

Contacts of the Pogonip group with underlying and overlying divisions are conformable. As drawn at the base of Pogonip unit *A* the lower boundary is somewhat arbitrary and provisional. Future work may demonstrate the desirability of including older rocks at present assigned without fossil evidence as unit *D* and upper unit *C* of the Upper Cambrian rocks.

The total thickness of the Pogonip is about 3,150 feet. This figure was obtained by combination of separate sections measured along the east side of Yucca and Frenchman Flats. Sections were correlated by lithologic characteristics and fossils.

Lowermost Ordovician fossils were found 185 feet above the base of Pogonip unit *A*. Faunas of unit *A* so far obtained apparently correlate with those from the *Nanorthis-Kainella* zone (lowermost

Ordovician) near the base of the lowest Pogonip of Eureka, Nev., as currently understood. However, before definite conclusions can be reached it will be necessary to collect distinctive fossils immediately above and below the base of Pogonip unit *A* in the Yucca Flat area.

Pogonip unit *A* yielded several fossil collections which were examined by Josiah Bridge (written communication) who states that these collections

contain a well-preserved pygidium of *Xenostegium* sp. together with spines and other fragments presumably belonging to the same form; poorly preserved brachiopods tentatively identified as *Nanorthis* sp.; a single well-preserved specimen of *Tetralobula* sp., and a large species doubtfully referred to *Nanorthis*.

Bridge also examined a collection from unit *B* and reports that this collection contains "the pygidium of a large but undescribed trilobite that is known from the Manitou formation of Colorado." Bridge further states that

all of the forms seen in these collections are characteristic of the lowest Lower Ordovician rocks in other parts of Nevada and adjoining states, and Palmer and I are convinced that the collections are of Lower Ordovician age.

A fossil collection from the lower part of unit *D* was also examined by Josiah Bridge. He comments that this collection "contains numerous specimens of *Protopliomerops* and is correlated with zone G of Ross's Garden City sections."

Fossils were also collected from unit *F*. They were examined by C. W. Merriam, who identified them as follows:

Orthidiella
Mitrospira?
Large holochoanate cephalopod

Merriam (written communication) considers these forms to be Early Ordovician in age.

Unit *G* yielded abundant small brachiopods. Concerning these, Bridge (written communication) remarks

the boundary between the Lower and Middle Ordovician is tentatively placed at the top of (unit *G*). This is done largely on the presence of the brachiopod *Orthidiella*, a very late Lower Ordovician form. (Unit *G*) is still Lower Ordovician, approximately equivalent to the Roubidoux or a slightly younger horizon in Missouri.

Unit *H* contains a fauna which C. W. Merriam places in the upper Pogonip. He identified these forms as:

Maclurites sp.
Mitrospira longwelli Kirk
Girvanella sp.
Receptaculites elongatus Walcott
  mammillaris Walcott

Bridge's comments concerning these fossils are: [This collection] "was not seen, but from the list on the columnar section, it is undoubtedly Chazy, Middle Ordovician of most geologists."

From the abundant fossil evidence, the Pogonip is placed as Early to Middle Ordovician in age.

EUREKA QUARTZITE

The Eureka quartzite is well exposed in the southeastern part of the area. Its nonresistant character in this area is well displayed in the Ranger Mountains where it has been eroded back from the steep cliffy outcrops of the underlying limestone of the Pogonip group. It crops out high in these mountains and can be easily traced as a complete unit northwestward across the entire length of the mountains.

The Eureka is also exposed in the high areas capping some of the hills in the vicinity of Red Mountain and may also be observed along Mercury Highway in the southernmost part of Frenchman Flat.

In the northern part of the area, the Eureka quartzite occupies a small area south of Paiute Ridge and occurs in small, patchy outcrops near the Mine Mountains. About a mile northeast of Oak Spring Butte, it crops out in steeply dipping beds and can be traced as a complete unit beyond the north margin of the area. The Eureka was originally defined by Hague (1892), at Eureka, Nev.

This formation is divisible into two lithologic units. The lower unit is 155 feet thick and consists of varicolored quartzite. Common colors of these beds are several shades of gray and brown which generally weather to darker tones and which sometimes are desert varnished. The formation is poorly bedded, well jointed vitreous nonresistant and fine grained. Near the middle of this unit are beds of mottled gray and buff finely crystalline thin-bedded dolomite about 5 feet thick.

The upper unit is 130 feet thick and consists of white to light-gray fine-grained quartzite which grades to medium gray at the top. It is characteristically nonresistant and lacks bedding. Many beds weather into small, thin chips an inch or less in size.

Carbonate rocks conformably underlie and overlie the Eureka quartzite. The lower contact is placed at the lithologic break between limestone and quartzite and the upper contact is at the break between quartzite and dolomite.

As measured in the Ranger Mountains, the Eureka is about 285 feet thick.

Although unfossiliferous, the age and correlation of the Eureka is well established by the underlying fossiliferous limestone of Chazyan age and by the overlying fossiliferous dolomite of Late Ordovician age. This relationship, in addition to lithologic similarity, allows little question as to the age and correlation with the Eureka quartzite of the Eureka district, Nevada. Kirk (1933) divided the Eureka into three units; a thin basal unit which he considered as Chazyan in age; a middle unit which constitutes the bulk of the Eureka and which is Middle Ordovician; and an upper unit only a few feet thick which he considered to contain the basal beds of the Upper Ordovician. Owing to the lack of definite evidence of this relationship, the Eureka quartzite in the Nevada proving grounds area is considered as Middle Ordovician in age.

ORDOVICIAN TO DEVONIAN ROCKS

DOLOMITE OF MIDDLE PALEOZOIC AGE, UNDIFFERENTIATED

In the Yucca and Frenchman Flats areas a dolomitic sequence more than 1,500 feet thick occupies the interval between Middle Ordovician Eureka quartzite and the Nevada formation of Devonian age. Comparison with similar sections in central Nevada leads to the conclusion that the dolomite in question includes time-stratigraphic intervals of Late Ordovician, Silurian, and possibly Early Devonian age. At Eureka, Nev., Hague (1892) described similar rocks as the "Lone Mountain limestone."

Middle Paleozoic rocks of central Nevada have more recently been reclassified (Merriam, 1940, p. 13–16) by restricting the name Lone Mountain dolomite to the higher part of this column. To the basal or Upper Ordovician part the term Hanson Creek formation was applied. The name Roberts Mountains formation was given to limestone and dolomitic limestone beds between Hanson Creek formation and Lone Mountain dolomite. Whereas both Hanson Creek and Roberts Mountains are commonly not dolomitized, the Lone Mountain is dolomitic throughout.

Except where detailed stratigraphic work has been done, the subdivision and correlation of this part of the Great Basin Paleozoic column is difficult, especially where it is mainly dolomitic and contains few determinable fossils. Such appears to be the case in the Yucca Flat area where for purposes of this report it seems desirable provisionally to employ the noncomittal term dolomite of middle Paleozoic age, undifferentiated.

Dolomite of middle Paleozoic age, undifferentiated is best exposed in the southeastern part of the area. It crops out in a large part of the Ranger Mountains where it is recognized as the dark- and light-colored, cliff-forming beds above the Eureka quartzite. The dolomite beds are also well displayed in the pass north of Camp Mercury as resistant hills consisting of poorly bedded dolomite which is typical of this division throughout the area. Elsewhere, a small outcrop is present about 2 miles east of Yucca playa and many hills north and northeast of Oak Spring Butte consist of this dolomite.

Seven unnamed lithologic units are recognized within the undifferentiated dolomite of middle Paleozoic age in the area.

Unit *A*, the basal unit, consists of 95 feet of dark-gray to black aphanitic cherty gritty dolomite including some beds that contain thin veinlets of white dolomite crystals. This unit is easily recognized at a distance by the striking contrast to the light-colored beds of the underlying Eureka quartzite.

Unit *B* is made up of 130 feet of light- to medium-gray dolomite and a few darker beds of aphanitic hard dolomite. It occurs in beds several inches thick and in places contains veinlets of coarse dolomite crystals.

The overlying unit *C* is lithologically similar to unit *A*. It consists of 115 feet of dark-gray to black, gritty, aphanitic dolomite containing chert and dolomite veinlets.

About 270 feet of mottled-gray poorly bedded finely crystalline to cryptocrystalline, strong cliff-forming dolomite makes up unit *D*. It weathers to a light-gray sandy surface and at a distance is identified as the light-colored resistant ledges which overlie the dark dolomite beds of unit *C*.

Where seen, unit *E* is poorly exposed. The part measured is 365 feet thick, the upper beds are covered by alluvium. It generally consists of light- and dark-gray and some black beds of dolomite. Dark-brown and tan chert occurs in a few beds and others contain dolomite veinlets typical of many of the underlying units.

Unit *F* consists of about 340 feet of light-gray vuggy, medium to coarsely crystalline poorly bedded resistant dolomite. Characteristically, it weathers to a rough, saccharoidal surface and forms hills of high relief with prominent ledges.

Unit *G* is lithologically similar to unit *F* but is finer textured. The unit is made up of about 250 feet of medium to finely crystalline dolomite and a few interbedded coarsely crystalline beds.

The undifferentiated dolomite of middle Paleozoic age conformably overlies the Eureka quartzite and underlies the Nevada formation. The lower boundary is one of the most striking lithologic breaks in the area. It is placed at the contact between the light-colored quartzite beds of the Eureka and the black dolomite which forms the lowermost unit of the dolomitic sequence. The upper contact is placed at the top of the uppermost light-gray dolomite bed.

In the Ranger Mountains the undifferentiated dolomite of Paleozoic age was measured as 1,565 feet thick. This thickness represents the total for this division, except for a faulted interval of about 100 feet.

In the Pioche district (Westgate and Knopf, 1932) and the Death Valley region (McAllister, 1952) the lower part of a similar dolomitic sequence has been assigned to the Ely Springs dolomite. The Hanson Creek limestone of the Eureka district, Nevada (Merriam, 1940; Nolan and others, 1956) is about the same age.

The upper contact of the Ely Springs dolomite has elsewhere been placed at a lithic break between dark-gray to black dolomite and light-colored beds of the overlying Silurian. This procedure could not be followed in the Nevada proving grounds area, however, because of the interbedded and lenticular character of these dark- and light-colored beds.

Unit *B* yielded a few fossils which were examined by Josiah Bridge (written communication). He states that these fossils are

> possibly of Upper Ordovician age, but might be Silurian. Insoluble residues have yielded numerous brachiopods (and) a few silicified bryozoa belonging to the genus *Rhinidictya*, and several specimens of *Tentaculites*. Although this last named form has been reported from rocks of Richmond age, it is not common below the Silurian.

The brachiopods in this collection were examined by G. A. Cooper, who considers that they are Ordovician and Silurian types.

Although the evidence is not conclusive, the fossils and the Late Ordovician age generally assigned to the Ely Springs in other localities indicate that the lower part of the dolomitic sequence in question is probably Late Ordovician.

Poorly preserved colonial corals were collected from the upper part of unit *E*. These fossils were studied by Helen Duncan (written communication), who reports:

> The specimens of halysitid corals have mesopores and belong either to the subgenus *Halysites* or to the subgenus *Cystihalysites*, neither of which is known to occur in the Ordovician. The phaceloid coral has dissepiments and apparently is related to the post-Ordovician disphyllid or columnarid corals and not to the Ordovician favistellids, which have no dissepiments. The form characterized by a massive corallum and very small corallites is a squamulate favositid. According to two authorities on the tabulate corals, squamulae are not known to have developed in the favositids until 'upper' Silurian time (Wenlock, or approximately Niagaran which is considered to be Middle Silurian in the American classification). It is not particularly desirable to base an age determination on fossils that cannot be accurately identified. The corals in this assemblage, however, exhibit a stage of morphologic development that was not attained in the Ordovician. Further, at present it is believed that the halysitid corals are confined to pre-Devonian rocks. It is therefore reasonable to conclude that this particular coral assemblage is of Silurian age.

According to this report, these fossil-bearing beds are no older than Silurian in age. However, no attempt is made to locate the Ordovician-Silurian boundary in the area because fossils were not found in the interval between unit *B* and the upper part of unit *E*.

In central Nevada finely crystalline dolomite beds corresponding in lithology to unit *G* are considered as Middle to possible Early Devonian in age (Merriam, oral communication). This unit was examined in the field by Nolan and Merriam who consider it similar to beds at the base of the Nevada formation in the Eureka district. This fine-grained dolomite is also lithologically similar to the Sevy dolomite of western Utah. Presence of a distinctive lower Middle Devonian fauna 20 feet above the top of the undifferentiated dolomite of middle Paleozoic age further augments the possibility of Lower Devonian strata occurring between the Nevada formation and unit *E* of the dolomitic sequence which contains Silurian corals.

DEVONIAN ROCKS

NEVADA FORMATION

As defined by Hague (1892) in the Eureka district, Nevada, the Nevada limestone comprised Devonian strata occupying the interval between his Lone Mountain limestone and his Mississippian White Pine shale. In the original definition the Nevada included likewise an upper limestone later proposed as an independent formation, the Devils Gate limestone (Merriam and Anderson, 1942; Nolan and others, 1956). Both the Nevada formation (restricted) and the overlying Devils Gate limestone have been recognized in the Yucca Flat area.

The Nevada formation is recognized at several localities in the area. About 2 miles northwest of Captain Jack Spring, dolomite and limestone beds of this unit are well exposed. These beds form prominent, dark-colored, cliff-forming ledges unconformably overlain by Tertiary volcanic rocks.

At the Mine Mountains, the Nevada and overlying rocks have been thrust over Mississippian strata. The beds are exposed about 3 miles southwest of the Mine Mountains along the west margin of the area. They form areas of high relief and are recognized by their alternating dark- and light-colored steplike ledges. Tertiary volcanic rocks overlie these Devonian strata with angular unconformity.

The highest part of the southern Ranger Mountains is developed on the Nevada formation.

The Nevada comprises three units designated as unit *A* through unit *C* in ascending order.

Unit *A* consists of about 460 feet of dolomite, limestone, and quartzite. The basal 15–20 feet is a distinctive gray finely crystalline limestone which weathers buff to reddish brown. A few feet of dark-gray to black highly fossiliferous limestone overlies the basal limestone. Interbedded gray and dark-gray finely crystalline fairly well bedded limestone and dolomite beds comprise the next 175 feet of the member. It is slope forming except for the upper 50 feet which contains thin beds and nodules of tan and gray chert. These cherty beds are prominent and stand out as resistant ledges. Overlying these cherty

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beds are 95 feet of light-gray, brown-weathering, fine-grained, cross-bedded quartzite. Some beds are desert varnished and others are calcareous and sandy textured. A few thin black limestone layers occur near the top of these beds. The uppermost 175 feet of unit *A* consists of thin beds of black, gray, and brown dolomite. These beds are generally finely crystalline, well bedded and appear strikingly banded. Near the base and at the top, thin quartzite beds are interbedded with these carbonate rocks.

Unit *A* is overlain by unit *B* which consists of about 260 feet of interbedded light-gray and black dolomite. The light-gray dolomite makes up about 80 percent of this unit. It is a medium to coarsely crystalline, vuggy poorly bedded cliff-forming dolomite that weathers into a sugary texture. The black dolomite beds are finely crystalline poorly bedded and contain dolomite veinlets. Where struck by a hammer these beds emit a strong fetid odor.

About 350 feet of interbedded limestone and dolomite make up unit *C*, the next overlying unit. These beds are characterized by many poorly preserved twiglike fossils which have produced a spaghettilike white mottling in these beds. According to information received from Helen Duncan, many of the so-called spaghetti limestones that occur in the Devonian of the West were formed by concentrations of the rodlike stromatoporoid *Amphipora*, which flourished all over the world in Devonian time. These strata also contain other stromatoporoids that form concentric masses that range from a few to several inches in diameter. The limestone of this unit is dark gray to black, finely crystalline, well bedded, cherty and weathers to an irregular, sharp, rough surface. The dolomite is differentiated from the limestone by a generally lighter color and by weathering to a smooth sandy surface. At a distance this unit is recognized by prominent, dark-colored, steplike ledges, usually 5–10 feet thick.

Where measured the three units comprising the Nevada formation total 1,070 feet.

The lower age of the Nevada formation in this area is well established as early Middle Devonian by the presence of a highly fossiliferous limestone about 20 feet from the base of the formation. A cursory examination of fossils collected from this limestone was made by C. W. Merriam, who identified the following forms:

Large cyathophyllid coral
Favosites sp.
Syringopora sp.
Tentaculites sp.
Meristella sp.
Leptaena sp.
Chonetes macrostriata Walcott
Stropheodonta sp.

Atrypa sp.
Gypidula sp.
Platyceras sp.
Large *Loxonema*-like gastropod
Dalmanites meeki Walcott

Merriam (written communication) considers these fossils as early Middle Devonian in age.

The lower part of unit *C* yielded fossils reported on by Edwin Kirk and A. J. Boucot (written communication). They state that these beds "contain an unidentified cyrtinid brachiopod and finely plicated brachiopods belonging to the genus *Atrypa*. [The Atrypas] resemble forms elsewhere found in the Middle and Upper Devonian."

Unit *C* contains forms identified as *Cladopora* (a name also applied to *Amphipora* in other reports), Stromatoporoidea, and *Striatopora*, fossils commonly found in the Nevada formation in other localities (Nolan, oral communication).

From this faunal evidence the Nevada formation of the Yucca Flat area is considered as Middle Devonian.

DEVILS GATE(?) LIMESTONE

The Devils Gate limestone (Merriam, 1940) of the Eureka area, Nevada, was formerly included in the original "Nevada limestone" of Hague (1892). Because of distinctive lithologic characteristics and faunas it is now considered a separate formation. The formation is predominantly limestone, though it is locally dolomitized in parts of Nevada. Beds and lenses of dolomite or magnesian limestone are sometimes found in the lowermost part near the boundary with the dolomite of the underlying Nevada formation.

The Devils Gate(?) limestone about 1,380 feet thick is made up of limestone containing several quartzite interbeds. Whereas the beds are similar in surficial appearance to those in the topmost division (unit *C*) of the underlying Nevada formation, they differ in being all limestone. Within the upper 750 feet, the Devils Gate(?) limestone is sandier, containing sandy limestone, a few lenticular sandstone layers and several beds of quartzite. The sandstone, totaling about 10 feet in thickness, is tan to light brown medium to coarse grained crossbedded and has a "salt and pepper" appearance. The quartzite beds are light buff to orange brown and weather dark brown. They are fine to coarse grained, and include some sandy lenses. Characteristically they form a break in slope between the ledge-forming limestone layers.

Where observed, the contact of the Devils Gate(?) limestone with the overlying and underlying formations is conformable and is placed at distinct lithologic changes. The upper contact is conspicuous, owing to the slope-forming nature of the overlying formation. This contact is at the base of the lowermost buff nonresistant platy limestone of the Narrow Canyon.

This formation, like the underlying Nevada, contains fossils resembling cladoporoid corals (many of these are probably *Amphipora*) and stromatoporoids in some abundance. Its most distinctive fossil, however, is the gastropod *Orecopia mccoyi* Knight which characterizes a widespread zone in the upper part of the Devils Gate of the Great Basin. *Orecopia mccoyi* Knight probably indicates an early Late Devonian age. In the type area, however, a large part of the Devils Gate below this zone is considered late Middle Devonian.

DEVONIAN AND MISSISSIPPIAN ROCKS

NARROW CANYON LIMESTONE

The strata which are here named Narrow Canyon limestone crop out in Narrow Canyon, at the southeast margin of the area. These beds are well exposed about a half mile from the mouth of the canyon in a narrow, northeastward-trending band and are characterized by their typical buff-colored slope-forming appearance. This formation is not recognized elsewhere in the area.

The Narrow Canyon limestone consists of dark-gray silty limestone well defined in beds less than an inch thick. It weathers into thin buff-colored plates and forms talus-covered slopes.

The Narrow Canyon limestone conformably overlies the Devils Gate(?) limestone in sharp contact. The contact of the Narrow Canyon with the overlying formation is also conformable but is interbedded for an interval of about 10–20 feet.

At the type locality, the measured thickness of the entire formation is 175 feet.

No fossils were collected from this formation. However, in east-central Nevada, beds of lithologic similarity and stratigraphic position have been noted in the Narrow Canyon. These beds have been termed Pilot shale and are considered as Late Devonian to early Mississippian in age (Nolan, T. B. and Merriam, C. W., oral communication).

Because of lithologic similarities in these formations the Narrow Canyon is considered as a probable correlative of the Pilot shale.

MISSISSIPPIAN ROCKS

MERCURY LIMESTONE

The name Mercury limestone is here given to the beds exposed on Mercury Ridge that overlie the Narrow Canyon limestone, about 5 miles east of Camp Mercury. This formation is not recognized elsewhere in the area. It is traceable northeastward for about a mile as a prominent gray ledge but is terminated in both directions by a reverse fault.

In the small part of the area where the Mercury limestone is exposed, it consists of dark-gray, buff-weathering crinoidal limestone. It is generally poorly bedded cherty and forms resistant ledges above the slope-forming Narrow Canyon limestone.

The basal beds of the Mercury are interbedded with the buff platy limestone of the formation below and the upper contact is not exposed owing to faulting.

The complete thickness of the Mercury limestone in the area is not known. At the type locality, only the lower 115 feet of this formation was measured. The remaining part has been dropped under alluvium by faulting.

The Mercury contains fossils identified by C. W. Merriam in the field as *Syringopora* and *Spirifer centronatus?* Winchell. This species of *Spirifer* is considered to be early Mississippian in age and is also found in the Joana limestone of east-central Nevada and in the Tin Mountain limestone of the Death Valley region (Merriam, C. W., oral communication).

J. Steele Williams (written communication) examined a collection obtained from the Mercury limestone and made the following report on the brachiopods:

> Collection 28 contains several specimens of a *Spirifer* that I believe is *Spirifer centronatus* Winchell as generally recognized in the West. It also has the brachial valve of a productid of the type Girty in 1899 referred to *Productus scabriculus* Martin. Fragments of brachiopods representing other productids, other Spirifers, possibly a *Chonetes* and a *Rhynchopora* are present. I believe that the most probable age of the collection is early Mississippian.

A few corals in the same collection were examined by Helen Duncan (written communication) who reports:

> This lot includes several pieces of *Syringopora* cf. *S. aculeata* Girty and fragments of clisiophyllid and caninoid horn corals. The specimens of *Syringopora* are recrystallized, but the characters of the coralla indicate that the species is comparable to a species that is very common in the lower Mississippian of the West. The horn corals, likewise, are Carboniferous types.

The faunal evidence indicates that the Mercury limestone is of early Mississippian age and a probable correlative of the Joana and the Tin Mountain limestone of nearby areas.

ELEANA FORMATION

The beds in the area to which the name Eleana formation is here given crop out in the Eleana Range and in other mountainous areas bordering Yucca Flat on the west. These beds are exposed on Quartzite Ridge, which topographically, is one of the highest peaks in the area. These strata are also present in the Mine Mountains where they consist mostly of reddish-brown shale. In the Mine Mountains, light-colored carbonate rocks of Devonian age have been thrust over these shale beds and in places the thrust-fault relationship between the Devonian rocks and the Eleana is well displayed and easily identified by the striking contrast of the beds.

Lithologically, the Eleana formation is the most diverse unit in the area. Abrupt facies changes from north to south prevent correlation of beds. However, the Eleana generally consists of a conglomerate, quartzite, and shale facies in the northern part of the area. Southward these grade into finer grained sediments.

On Quartzite Ridge, where the section was measured, the Eleana is subdivided into three units.

The lower unit consists of 1,000 feet or more of dark-brown to buff hard poorly bedded slope-forming argillite and shale. These beds break into small irregular flat fragments and contain a few thin beds of quartzite and conglomerate in the upper 100 feet. The base of this unit was not observed in the area.

The middle unit is composed of about 1,050 feet of interbedded quartzite, conglomerate, and argillite. The quartzite is generally brown, fine to medium grained, well cemented and fairly well bedded. The conglomerate is also brown and characteristically contains subrounded varicolored chert pebbles about one-fourth to one-half inch across, well cemented in a quartzite matrix. Generally, the quartzite and conglomerate beds do not form cliffy ledges. However, locally they may be cliff forming. The argillite is brown to reddish brown, platy, bedded, hard and makes up only about 100 feet of this unit. Many beds show evidence of cyclic deposition by the interbedded relationship and gradational change from one lithic type to another. They are probably the result of an oscillating sea that, while advancing and receding, deposited these alternatingly fine- and coarse-grained sediments.

The upper unit consists of about 760 feet of varicolored argillite. Generally it is slope forming and breaks into platy and blocky fragments. The colors are highly diverse and include shades of gray, brown, red, and yellow, which have a conspicuous color banding in the upper part.

These three units of the Eleana are traceable southward into the Eleana Range where they grade laterally into finer grained sediments. The most noticeable facies change is in the middle unit which is split by a shale tongue. The tongue thickens southward where it also contains interbedded thin limestone beds and occupies about a third of the middle unit. The remainder is conglomerate and quartzite. Similar changes occur in the upper unit. Whereas it is composed entirely of argillite on Quartzite Ridge, in the southern part of the Eleana Range the upper unit consists of an interbedded sequence of argillite and limestone. The lower unit is exposed only as far south as Captain Jack Spring and does not exhibit, in the area exposed, radical facies changes similar to the other units of the Eleana. South of the Eleana Range and in the Mine Mountains, the middle and upper units are not recognizable as units owing to abrupt lithologic changes, and are not differentiated on the geologic map. In these areas, this formation consists of interbedded conglomerate, quartzite, shale, and some limestone.

The lower contact of the Eleana formation was not observed in the area. The upper contact on the margins of Syncline Ridge, is placed at the lithic break between interbedded quartzite, argillite and overlying limestone and appears to be conformable.

The Eleana was measured on Quartzite Ridge where it is 2,810 feet thick. However, this figure does not represent a total thickness because the lower unit was not completely measured.

No fossils were collected from the Eleana formation in the area. However, clastic sedimentary rocks similar in lithologic characteristics and stratigraphic position to the Eleana are exposed in central Nevada. In the Eureka district, these beds are referred to as the Chainman shale and Diamond Peak formation and generally are assigned a Mississippian age. The White Pine shale of Hague (1893) has been subdivided in the Eureka district by Nolan, Merriam, and Williams (1956) into a lower unit, the Pilot shale; a middle unit, the Joana limestone; and an upper unit, the Chainman shale, formations originally defined by Spencer (1917) for the Ely district. As previously stated, the Narrow Canyon and Mercury formations of the Nevada proving grounds area probably correlate with the Pilot shale and Joana limestone of central Nevada. The lower unit of the Eleana is lithologically similar to the Chainman shale, considered as probable late Mississippian in age, and may correspond, at least in part, with that unit. Likewise by lithic similarities, the middle unit of the Eleana is considered as probably the approximate equivalent of the Diamond Peak formation.

From this reasoning, the Eleana is considered as probable Late Mississippian in age. The exact age limitation of the Eleana is not known owing to the absence of fossils in the upper unit and the inability to correlate it with known formations in other areas.

Of striking significance, are the radically different lithologic characteristics of strata of supposedly equivalent age in the Spring Mountains, less than 50 miles to the south. Whereas the strata are dominantly clastic in the Nevada proving grounds area, they are represented in the Spring Mountains entirely by limestone and dolomite. It is inferred that the sedimentary facies changed abruptly to the south.

The radical changes in lithology might be due in part to shortening of the earth's crust by thrust faulting (C. R. Longwell and T. B. Nolan, oral communication).

PENNSYLVANIAN AND PERMIAN(?) ROCKS

TIPPIPAH LIMESTONE

The name Tippipah limestone is hereby assigned to the beds of Pennsylvanian and probable Permian age that overlie the Eleana formation on Syncline Ridge, about a mile east of Tippipah Spring. These rocks are also exposed about one-half mile north of Syncline Ridge in a single outcrop which is surrounded by alluvium, and in a few small areas along the north end of the Mine Mountains. Also correlated with this unit are the beds that overlie the Eleana in the southern part of the Eleana Range and on the eastern slopes of Quartzite Ridge. At a distance, the Tippipah is recognized by its light-buff color and for the most part by slope-forming limestone zones 20–50 feet thick which are separated from one another by thin, resistant ribs of limestone 5–10 feet thick. West of Yucca Pass, the Tippipah is exposed on several hills which are entirely surrounded and, in places overlain by strata of Cambrian age in a thrust-fault relationship. The Tippipah exposures are interpreted as being fensters or the exposed parts of the underthrust block.

The Tippipah limestone is subdivided into four distinct units, *A* through *D* in ascending order, all of which consist of limestone.

Unit *A*, 295 feet thick, consists of four zones of alternating resistant and nonresistant limestone. The lower 95 feet is poorly exposed but generally consists of dark smoky-gray medium-bedded slope-forming limestone. It is overlain by about 130 feet of interbedded gray to dark-smoky-gray limestone in beds 1–3 feet thick, which contain thin buff and light-gray silty limestone partings. This zone is resistant and stands out as a prominent, gray cliff between the slope-forming units above and below. These resistant beds are overlain by 50 feet of light-gray and buff-colored nonresistant finely crystalline limestone. This zone is in turn overlain by the uppermost 20 feet of unit *A*, which is a dark smoky-gray well-bedded, resistant limestone containing large masses and lenses of brown chert.

Unit *B* consists of about 580 feet of light-gray, buff, lavender, and light-purplish silty limestone. The beds are slope forming and weather into small plates. These platy fragments generally have a gritty surface and a few ring when struck by a hammer.

About 2,035 feet of limestone make up unit *C*. This unit is an alternating sequence of resistant and nonresistant light- to medium-gray and brown limestone. The nonresistant zones are generally 20–50 feet thick and are separated by 5–10 foot ribs of resistant limestone. The resistant beds are medium to finely crystalline and are uniformly bedded in layers 2–4 feet thick. This unit contains many beds of pebbly limestone, the pebbles of which are made up of varicolored chert generally one-fourth to an inch across, cemented in a limestone matrix. The brown color prevalent in some of the beds is a result of the large amount of clastic material contained in the limestone. A few buff and lavender platy, silty limestone beds are exposed in this section.

Unit *D* is 1,195 feet thick. Like unit *C*, it consists of alternating resistant and nonresistant strata. The principal difference is that the beds of unit *D* are considerably thicker and definitely more massive than the beds of unit *C*. The resistant, ordinarily massive beds of unit *D* are light to medium gray, and some beds show a slight olive green tint on the fresh fracture. Some zones contain a few conglomeratic limestone beds and others are cherty or contain calcite stringers. The nonresistant zones are generally silty, thin bedded and often weather into platy fragments.

Collection 29A of *W* was taken from the Tippipah strata exposed west of Yucca Pass. Knight also examined these fossils and reports:

> There are two very interesting species here from which very tentative conclusions may be drawn. The most significant is *Neilsonia*. Poor preservation prevents close identification, but the species is very close indeed to an undescribed species from the Smithwick shale (early middle Pennsylvanian) of central and west Texas. Similar species are found as low as the New Providence shale (Mississippian) of Indiana, but I have never met with any specimens in beds higher than the Smithwick.
>
> There is in the same collection a euomphalid of undescribed genus and species. The genus is also best known in the Smithwick although the species seems to be different.
>
> There is a third gastropod, a high-spired one with a shape identical with an undescribed genus and species of murchisonid that I know only from the Smithwick and a little higher. Unfortunately the poor preservation of the growth lines does not permit confirmation of the identity suggested by the shape.

Fusulinids and corals were collected 750 feet from the base of unit *C*. The foraminifera were identified by Raymond Douglass (written communication) who reports:

> Fusulinids and smaller foraminifera occur abundantly in this sample but are poorly preserved due to silicification and distortion. Textularians, *Bradyina* sp. and *Staffella* sp. were recognized among the smaller foraminifera and ?*Pseudofusulinella* sp., *Triticites* sp. and ?*Schwagerina* sp. among the fusulinids. This assemblage does not allow an age determination closer than late Pennsylvanian or early Permian.

Concerning the corals from this collection, Helen Duncan (written communication) states:

> The coral-bearing rock is a limestone conglomerate and from the condition of the corals, I infer that the specimens must have been broken and worn before they

were incorporated in the conglomerate. All the pieces appear to have been derived from caninoid forms. Caninoid corals occur throughout the Carboniferous and range into rocks that are classed as Permian.

The collection also contains a single specimen of the bryozoan *Rhabdomeson*. This genus also occurs throughout the Carboniferous and ranges into the Permian.

A collection of fusulinids was made from a zone located about 1,060 feet from the base of unit *C*. Douglass (written communication) reported on these forms as follows:

This sample contains Tolypamminids, Calcitornellids, Textularians and *Bradyina* sp. among the smaller foraminifera. The fusulinids include an undescribed genus resembling *Fusulinella* and *Wedekindellina* and a *Triticites* aff. *T. notus* Thompson. Forms similar to this *Triticites* have been reported from the lower Wolfcamp equivalents in several areas.

Another fusulinid collection, located about 500 feet higher stratigraphically than the preceding one, was identified by Douglass who states:

This collection contains Calcitornellids, *Climacammina* sp., *Textrataxis* sp., *Bradyina* sp., *Endothyra*? sp., *Millerella* sp., *Pseudofusulinella*? sp., and *Triticites* sp. aff. *T. subventricosus* Dunbar and Skinner. This assemblage suggests lower Wolfcamp age.

Limestone beds about 200 feet above the base of unit *D* yielded the next fossil collection. The fauna obtained consists of several classes of fossils, which were examined by several specialists.

J. S. Williams (written communication) comments:

Although I have not studied this collection in detail, in general appearance its brachiopods resemble some of the Wolfcamp and Permian brachiopod faunules of the West. Contained in it are productoids of several types, including forms related to species of '*Productus*' and *Marginifera*. Also represented are types suggesting species of *Composita*?, perhaps *Martinia*, and *Chonetes*. Few specimens can be identified specifically and some not even generically. The basis for considering the collection to be of Wolfcamp or of Permian age is not very firm, but I believe it belongs in one of these divisions. More detailed study would be necessary before such assignment could be confirmed if the brachiopods would warrant a definite conclusion.

Concerning the bryozoans Duncan (written communication) states:

The single specimen of the bryozoan *Polypora* in this lot is specifically indeterminate. Representatives of this genus are common throughout the Pennsylvanian and Permian of the West. The coarse meshwork of this particular specimen suggests a form that occurs in rocks of Wolfcamp age in Nevada, but the actual ranges of comparable species are not well established in the West.

The gastropods were studied by J. B. Knight (written communication) who reports:

This collection contains *Straparollus* (*Euomphalus*) undescribed species. Although too imperfect for close work, this specimen resembles a species as yet undescribed that ranges through beds of Leonard to lower Word age in the west Texas Permian, I know of no similar species in any older beds.

Douglass, who examined the fusulinids, reports, "*Triticites* sp. advanced type resembling *T. ventricosus* but more elongate and with fewer volutions. Age: Virgil or younger."

The next fossil collection was made about 400 feet higher in unit *D*. It consists of fusulinids and corals. Douglass studied the fusulinids and states:

"This sample contains Tolypamminids, *Bradyina* sp., and *Triticites* sp. aff. *T. ventricosus* (Meek and Hayden). Lower Wolfcamp age is indicated."

Duncan's report on the corals is as follows:

A fragment of a syringoporoid coral was found in this collection. The specimen is not well preserved, but sections suggest that it may be a species of *Pseudoromingeria*. This genus was described originally from the late Upper Carboniferous of Asia (approximate equivalent of the Wolfcamp in America), but it apparently ranges well down in the Carboniferous in this country.

The highest fossil collection was taken from beds that occur about 450 feet from the top of unit *D*. This collection was reported on by Douglass as follows:

This collection includes *Bradyina* sp. and *Triticites* sp. aff. *T. subventricosus* Dunbar and Skinner. Lower Wolfcamp age is indicated.

The fossil evidence establishes the approximate age of the Tippipah. However, because of the absence of diagnostic fossils at the top and base of this formation, its range is indefinite. From the paleontologic data at hand, it is here considered to be as old as early Pennsylvanian and probably as young as early Permian.

The apparent absence of earliest Pennsylvanian fossils (Morrow equivalents) in the Tippipah may appear surprising as strata of that age are reported in the Nopah Range (Hazzard, 1937) and in the Spring Mountains (Hewett, 1931). It is entirely possible that the earliest part of the Pennsylvanian may be represented in these lower beds as no fossils were found in the lower 775 feet of the Tippipah.

Hewett (1931) assigned the name Bird Spring formation to rocks of Pennsylvanian age in the Goodsprings quadrangle, where the section is about 2,500 feet thick. Also rocks of early Pennsylvanian age in the Nopah Range have been correlated with the Bird Spring (Hazzard, 1937). Longwell and Dunbar (1936) reported fusulinids of Wolfcamp and probable Leonard age in the upper 2,950 feet of the much thicker section (5,000 feet) of Bird Spring formation in the Las Vegas quadrangle, thereby extending the age span of the Bird Spring.

At present, no detailed correlation of the Tippipah with the Bird Spring can be attempted. However, the Tippipah generally is comparable in age and lithology to the Bird Spring and probably correlates, at least in part, with that formation.

QUATERNARY ROCKS

ORIGIN

The fill which forms and underlies Yucca and Frenchman Flats is made up of detritus transported by the intermittent streams which flow only during and following torrential storms.

The size and amount of detritus that the intermittent streams of the area can carry depends upon the gradient and the amount of precipitation. Thus, during rains, the carrying power is great along the margins of the valleys where the alluvial fans have relatively steep slopes, about several hundred feet per mile, and gradually diminishes progressively towards the middle of the valley where slopes are only about 10 feet per mile.

Only a crude sorting of the debris takes place anywhere in the alluvial fans. However, a larger amount of coarse debris generally is deposited along the flanks of the valleys, where streams are more turbulent, than in the central part of the valley where carrying power of the streams is less.

COMPOSITION OF THE FILL

Large excavations and four test holes, dug in the northern part of Yucca Flat offered the writers an excellent opportunity to study in detail the valley fill in that area. Elsewhere in Yucca and Frenchman Flats, information was collected as it became available but was not equal in amount nor in detail, to the data compiled from northern Yucca Flat. This information was obtained from well logs, excavations dug in several parts of the valleys, and observations made at the surface.

The valleys are generally composed of an assemblage of interfingering and lenticular beds of unconsolidated detrital material. This material is unsorted and consists of the several lithic types exposed in the bedrock areas which border the valleys. The dominant rock types are limestone, dolomite, quartzite, conglomerate, shale, tuff, rhyolite, and other igneous rocks. From pebble counts made in parts of the valleys, it was determined that a direct relationship exists between the dominant lithic type of the alluvium in any part of the valley, and the immediately adjacent bedrock areas. For example, the dominant rock types present in the alluvium in the northern part of Yucca Flat are tuff and rhyolite, which also is the composition of the bedrock bordering Yucca Flat to the north. By this analogy, it would be possible to predict the composition of the valley fill by determining the rock types of nearby bedrock exposures. Thus, the west side of Frenchman Flat, which is bordered entirely by volcanic outcrops, is probably made up of alluvium containing mostly volcanic rocks; the northwest side of Yucca Flat, which is commonly bordered by exposures of the Eleana formation, consists of shale, quartzite, and conglomerate.

The texture of the alluvium is variable. It ranges from clay and silt-sized particles to cobbles and boulders. In northern Yucca Flat 60 alluvial samples were collected at random from depths of 5–35 feet and analyzed for particle-size distribution (Piper, oral communication). Fifty percent of the material ranges in grain size from 0.009 to 0.39 inch; the average is 0.082 inch. The corresponding range of largest particles is from 1 to 12 inches. The percentage of particles passing a 100-mesh sieve (size of opening 0.0058 inch or 0.15 mm) ranged from 3 to 31 and averaged 13. These variations in particle size appear to be random in geographic position and in depth below land surface within the area spanned by the data.

At a few localities in the western and northwestern part of Yucca Flat, many large boulders of quartzite and conglomerate lie directly beneath a thin surface veneer of finer textured alluvium. These boulders are particularly evident along the Five Mile road, west of the Jangle area, where they are more than a foot in diameter and lie only a few inches below ground surface.

The playas in Yucca and Frenchman Flats are lithologically different from the rest of the valley fill. They consist generally of compact fine silt and clay and are uniform, both laterally and vertically. The thickness of the playa deposits is probably variable. At one place, in the playa at Frenchman Flat, it was calculated by seismic methods to be about 175 feet thick (Farnham, oral communication).

THICKNESS OF VALLEY FILL

Only general limiting facts concerning the thickness of the valley fill in Yucca and Frenchman Flats are known. Along the valley margins and over many reentrants, the fill is only a veneer and locally, as in the washes, it has been removed, exposing the underlying bedrock. Away from the valley margins, the valley fill is hundreds of feet thick. A part of northern Yucca Flat was surveyed by a seismograph crew of the United Geophysical Co. (Rugg, oral communication). In this area, they report that the alluvial fill thickens towards the central part of the valley to about 800–1,000 feet. Elsewhere in the valleys, wells drilled in search of water have cut through hundreds of feet of valley fill before reaching bedrock.

Seismic survey (Farnham, oral communication) determined a depth to bedrock of about 650 feet in the playa in Frenchman Flat, which is the only other area where depth to bedrock is known.

Notwithstanding the lack of conclusive evidence, it is probable that the major part of Yucca and Frenchman Flats away from the valley margins contains alluvial fill exceeding 500 feet in thickness.

CALICHE

The term caliche is of Spanish origin and is commonly applied to a porous, earthy, calcium carbonate deposit containing soil, sand, and coarser rock fragments. There has been much speculation in regard to the origin of caliche. One of the early theories is the one expounded by Blake (1902). He considers caliche deposits the result of upward capillary flow of calcareous water, induced by constant and rapid evaporation at the surface in a comparatively rainless region. In the formation of caliche, two essential factors are necessary; a constant supply of phreatic calcareous water and a continuous dessicating atmosphere. Desert regions are characterized by the unusual dryness of the air and its capacity for absorbing moisture, and by maintenance of continued evaporation from the soil which determines a constant upward movement of the phreatic water. However, the great depth to water in the Nevada proving grounds area, at least several hundred feet, and the presence of caliche at the surface leaves some question as to whether capillary action could cause the rise of water from such a great depth. A more suitable explanation would be to consider the caliche as forming from evaporation of water which occupies the valley during infrequent downpours. The water, which contains calcium carbonate in solution, is absorbed by the upper few feet of the alluvium soon after the rains. Later, it evaporates and leaves the calcium carbonate as a deposit in the interstices of the valley fill.

The caliche in the area is generally chalky white to cream colored amorphous dull soft and very well cemented. It seldom occurs in beds more than a foot thick. More commonly it occurs as 1- to 2-inch stringers. Often it is indicated only by the firmly consolidated character of the alluvial fill. The caliche distribution vertically and horizontally is irregular, and the deposits may occur from the surface downward. However, wells dug in other parts of the area indicate that the vertical spacing between caliche zones increases with depth. In the excavations examined in the northern part of Yucca Flat, caliche is not present to a depth of about 18 feet.

INTRUSIVE ROCKS

Intrusive rocks are represented in the Nevada proving grounds area by a granitic intrusive mass south of Oak Spring Butte, and by many generally northward-trending dikes in the mountains bordering Yucca Flat on the east.

The granitic intrusive mass is bordered on the north by Tertiary volcanic rocks which lie in normal contact with the intrusion. East and west, the intrusion is bordered by Paleozoic rocks which have been altered and intruded by the granitic rocks, and to the south it is bordered by Butte fault.

The dikes are all dark colored which makes them easily identifiable on aerial photographs. They are generally 25–50 feet wide and in most places occupy preexisting normal fault zones.

The intrusion at Oak Spring Butte is a pink highly biotitic, granite porphyry which contains quartz and large phenocrysts of orthoclase. Typical of granite, it weathers to a sandy granular texture and into rounded jointed knobs or smooth-sloping hills. Wyant (oral communication) also reports granite pegmatite and diorite in this intrusion.

The dikes are aphanitic, and probably basic in composition. Generally, they are more resistant than the rocks which they intrude and stand out in thin resistant outcrops.

Age of the intrusion is not definitely known. However, Nolan (1943, p. 177) has suggested that granitic intrusive masses apparently marked the end of major compressional diastrophism in the Great Basin. Major compressional deformation in the area is dated as probably occurring between Cretaceous and early Tertiary time and thus conceivably the intrusion may lie within these time intervals. The dikes on the other hand, cut the Tertiary volcanic rocks and consequently are considered much younger, probably Miocene or younger in age.

METAMORPHIC ROCKS

Metamorphic rocks are recognized south of Oak Spring Butte where they occupy an area of a few square miles. The granitic intrusion separates the metamorphic rocks into an eastern and western block, both of which are highly folded, faulted, and intruded.

These rocks are made up dominantly of light-colored coarsely crystalline calcitic and dolomitic beds of marble. The western outcrop of metamorphic rocks contains, in addition to marble, a few quartzite and several conglomerate beds lithologically similar to the Eleana formation. Thus they are considered as possibly belonging to the younger Paleozoic rocks of the area.

In all probability, metamorphism of these Paleozoic rocks was contemporaneous with intrusion of the granite and therefore is considered as occurring in late Mesozoic or early Tertiary time.

EXTRUSIVE ROCKS

OAK SPRING FORMATION

The name Oak Spring formation is hereby assigned to the rocks exposed at Oak Spring Butte and to corresponding rocks in other parts of the area. These rocks are Tertiary in age, and nearly all are volcanic in origin. At one time, they probably masked the entire area, but subsequent faulting and erosion has exposed the older strata.

Many geographic landmarks in the area are evident on these beds. North of Yucca Flat, Oak Spring Butte and Twin Peaks, prominent topographic features are visible from great distances. In the mountains west of Frenchman Flat, where only volcanic rocks are exposed, prominent high peaks such as Skull Mountain, Hampel Hill, and Mount Sayler are easily identified.

In places the variations in color and lithology of the Oak Spring formation within a short stratigraphic distance makes them quickly recognizable. At French Mountain, white, gray, and black beds are interbedded and juxtaposed by faulting into several separate, color-banded blocks. In other places, the hills are composed of white slope-forming tuffaceous beds, interbedded with, or capped by, thin dark, resistant extrusive masses. At Tippipah Springs, the tuff beds, the color of which is unlike that of any other rocks in the area, form steep, high picturesque, white cliffs. Elsewhere, a thick series of dark lava flows blankets the area.

The Oak Spring formation consists of rhyolitic lava flows, tuff beds, and many other volcanic rock types. A few sedimentary rocks were noted near the base. No attempt was made to subdivide these rocks nor to correlate them for great distances. This was rendered impossible by the abrupt lateral changes of many of the units and by the interfingering with, and lensing out against, volcanic units derived from other "centers" of volcanism.

The tuff beds are generally chalky white, cream or light gray and highly variable. In places they may be noncrystalline earthy dull, porous tuff beds, whereas in other places the beds may consist of compact, hard, dense, welded tuff containing glassy quartz phenocrysts. Most of the tuff layers, indicate deposition in water, probably large lakes or basins which existed at the time of volcanism. Biotitic tuff, tuff breccia, and tuff containing shards of pumice are a few of the many tuffaceous rock types.

The extrusive rocks are also diverse in appearance and composition. These rocks are dominantly acidic although rocks of basic composition also occur. Colors are dominantly several shades of red, brown, black, or gray. Textures range from aphanitic to phaneritic. Some of the lavas are vesicular indicating rapid cooling at the time of extravasation. Dark schlieren and flow banding occur in some of these rocks. Rhyolites are probably the dominant extrusive type although dacite, latite and other more basic rocks are also present. Pumice and a few beds of obsidian were also observed but these rocks are not abundant.

Some of the extrusive masses are resistant and form steep ledges that can be traced for several miles. The rhyolite beds which form the cap and shoulder of Oak Spring Butte are so distinctive and widespread in the northern part of the area that the tops of these two flat-lying flows are shown on the geologic map (pl. 32) as mappable units.

A few sedimentary rocks are present near the base of the Oak Spring formation. These include some fanglomeratic deposits and well-cemented gravels. A few cream to light-gray fossiliferous, marly limestone beds are exposed at the base of the Oak Spring section in a few of the low hills along the south margin of Frenchman Flat.

About 2,000 feet of Oak Spring rocks were measured at Oak Spring Butte. However, this does not represent a maximum figure for this formation. Thicker sections of these rocks are exposed west of Frenchman Flat but were not measured because of faulting.

Gastropods were collected from the fresh-water, marly, limestone beds. These fossil-bearing beds were found along the south margin of Frenchman Flat. Although restricted in distribution, the age of these beds, and consequently the age of the overlying volcanic rocks at that locality, seems to conform with age assignment given to similar rocks in other areas.

Teng-Chien Yen (written communication) examined these fossils and reports as follows:

Valvata sp. undet.
Lymnaea cf. *L. meekiana* Evans and Shumard
cf. *L. shumardi* Meek
Menetus cf. *M. retulus* Meek and Hayden

The fossil specimens are represented by internal molds, and they are not well enough preserved to yield desirable features to establish identification of species. Therefore, a definite age assignment cannot be given at present. Judged by the fossil findings available in comparison with the known records of freshwater molluscan faunas in the Western Interior, the fossil-bearing beds are probably of late Tertiary age and possibly of Miocene deposition.

According to Nolan (1943, p. 165), beds of Miocene age appear to be the most widely distributed of the Tertiary sedimentary rocks in the California and Nevada parts of the Great Basin. Thick accumulations of surficial volcanic rocks and local small intrusive bodies are commonly associated with these sedimentary beds.

No definite age assignment can be given to the Oak Spring formation owing to the lack of diagnostic fossils. However, evidence indicates that it is probably Miocene or younger in age.

STRUCTURAL GEOLOGY

The Nevada proving grounds area is structurally complex, corresponding to other areas in southern Nevada where intense crustal deformation has been the rule. Six significant folds, five in the Paleozoic rocks and one in the Tertiary volcanic rocks, and several thrust faults, and many normal faults have been mapped. Most of the folds and all the thrust faults are exposed in the bedrock areas surrounding Yucca Flat. The Paleozoic bedrock of the Yucca Flat area is broken into two main blocks; a western block consisting of folded upper Paleozoic rocks and an eastern block of westward-dipping lower Paleozoic strata. The lower Paleozoic rocks of the eastern block are believed to overlie the upper Paleozoic rocks in a thrust-fault relationship. A small granitic mass has been intruded into the north end of the western block.

Normal faults occur in almost every part of the area. They cut the Paleozoic sedimentary rocks and Tertiary volcanic rocks, producing in several localities, a series of tilted, repeated, fault blocks. This is strikingly displayed at French Peak, where light, varicolored tuffaceous sedimentary rocks and dark extrusive masses are repeated many times by faulting. Northwest of Yucca Flat, postvolcanic normal faults have broken the bedrock into two structurally different areas; an eastern area which has been thoroughly cut and broken by faulting and a western stabilized area, which has remained almost completely uncut by faulting. The bedrock of the Frenchman Flat area is extensively broken by normal faults into a series of fault blocks. Several dikes, which occupy preexisting normal fault zones, crop out northeast of Paiute Ridge.

The valley fill of Yucca and Frenchman Flats is broken by faulting. Yucca Flat is cut by a southward-trending normal fault which extends throughout the valley. Frenchman Flat contains many southward to southwestward-trending small faults of an indeterminate structure.

FOLDING

After deposition of the Paleozoic sedimentary rocks compression produced an uplift of the land surface with concurrent formation of folds and contemporaneous thrust faults. The fold axes and thrust traces trend southward, and conform to the general pattern of Great Basin structure. To produce this pattern, compression was applied along an east-west plane, perpendicular to the resulting fold and fault trends. Evidence, such as the overturned limb of the syncline north of Oak Spring Butte and overturned beds of the overthrust block north of Tippipah Springs, indicates that the active compression was applied from the west. This evidence is further corroborated by the westward-dipping surfaces of the thrust faults west of the Eleana Range and north of Tippipah Springs. The one anomalous example is the syncline southeast of Frenchman Flat, the overturned southeastern limb of which indicates an active application of compression from the southeast. This latter overturned, northeastward-plunging syncline is one of the most conspicuous folds in the area because of its abrupt structural transition in a northeasterly direction from a normal, symmetrical syncline to an asymmetrical, axial-faulted syncline with an overturned southeastern limb to a gently-dipping syncline with a small anticline formed on the southeastern limb. Still farther northeast the two folds die out, and the projected trend of the two axes is represented by a gently to steeply southeastward-dipping homocline. This syncline is exposed in the bold, prominent outcrops of Mercury Ridge, a high dark-colored ridge 1 mile east of Camp Mercury, and is in limestone of Devonian age.

Almost all the folds of the Yucca Flat area are in the Carboniferous Tippipah and Eleana formations exposed west of that valley. In the Mine Mountains, clastic rocks of the Eleana formation are folded into a northward-plunging anticline. Although the fold is largely covered by a thrust plate of limestone of Devonian age, both anticlinal limbs are exposed on either side of the thrust plate. Moderate dips have been recorded on these limbs, which extend about 1 mile from the axis before being covered by volcanic rocks.

Two miles to the northwest of the Mine Mountains is Syncline Ridge, where rocks of the Tippipah limestone have been folded into one of the two longer folds in the area. This fold is a northeastward-trending syncline, 5 miles long and symmetrical in cross section. An axial fault drops the western limb with a displacement of about 100–200 feet. A later cross fault transects the synclinal axis and the axial fault, and drops the northern part of the fold. The northernmost part of the syncline is overturned, possibly by a smaller unexposed thrust fault.

Quartzite Ridge, a prominent topographic feature north of Yucca Flat, is on the eastern flank of a southward-plunging anticline where clastic rocks of the Eleana formation are present. It is the second of the two longer exposed folds in the area, and has an axial length of 5 miles. This fold is broad at the northern limit, where it appears from beneath the volcanic rocks. To the south, the fold becomes more compressed before disappearing beneath the alluvium.

In the small mineralized area just south of Oak Spring Butte, metamorphosed Paleozoic rocks are folded and faulted into a sharp, northward-plunging syncline. The possible northern extension of this structure is a northward-plunging syncline, which reappears from beneath the volcanic rocks north of Oak Spring Butte. The western limb is overturned. Unmetamorphosed limestone of the Pogonip group, Eureka quartzite, and dolomite of middle Paleozoic age have been recognized on the limbs of this possible synclinal extension. From there, the syncline is traceable beyond the northern boundary of the area.

One long northeastward-trending syncline in Tertiary volcanic rocks is in the Belted Range in the northwest corner of the area.

The flank dips are no more than 5°–10°. Also several small folds are present in the volcanic rocks.

FAULTING

THRUST FAULTS

The thrust faults of the area appear to be concentrated in the vicinity of Yucca Flat where at least four thrusts have been observed. The first thrust indicates that Carboniferous strata have been thrust from the west over younger Carboniferous rocks. Two widely-separated thrust faults reveal limestone and dolomite of Devonian age resting on clastic rocks of Carboniferous age. The fourth thrust fault reveals Cambrian sedimentary rocks thrust on Carboniferous strata. Contact relationship in the vicinity of the Mine Mountains, combined with evidence from this fourth thrust and the areal distribution of lower and upper Paleozoic rocks surrounding Yucca Flat indicate that at least two of the above mentioned thrusts may be segments of a very large thrust fault in that area. Almost all the Paleozoic rocks which make up the western bedrock rim of the valley are Devonian to Carboniferous in age. Most of the Paleozoic sedimentary rocks bordering the valley on the east are of Cambrian and Ordovician age, and the writers believe that these rocks comprise a thrust plate which rests on the Carboniferous rocks cropping out west of the valley.

Four miles north of Tippipah Springs, the first thrust relationship reveals overturned quartzite and conglomerate of the Carboniferous Eleana formation thrust from the west over shale of the same age on the east. One-half mile east of Tippipah Springs, overturned clastic rocks of the Eleana and limestone of the Tippipah have been thrust over limestone higher in the Carboniferous section. The relationship of these two thrusts is not definitely known. However, they are probably parts of the same fault because of the similarity of rocks displaced in the thrusting and the similarity in thrust trends.

A northeastward-trending thrust fault, which dips 45° W., is immediately west of the Eleana Range. Fractured, westward-dipping dolomite beds of Devonian age are thrust against folded, clastic rocks of the Eleana. The minimum displacement is 2,800 feet. This thrust is traceable for only 1 mile. The southern extension is covered by volcanic rocks and the northern extension is covered by alluvium. A cross fault in the northern part of the Eleana Range and the peculiar occurrence of Devonian rocks in this vicinity indicate that the northern part of this thrust is offset to the east by the cross fault.

The most apparent thrust in the area is the low-angle Mine Mountains thrust fault. It may be easily detected by the conspicuous contrast between the overthrust plate and underlying block. The Devonian rocks of the overthrust plate are resistant, highly distorted dark to light-gray dolomite, limestone, and quartzite. In contrast, the underlying block is made up of anticlinally folded relatively nonresistant reddish-brown clastic rocks of the Eleana formation. The overthrust plate crops out for more than half the area occupied by the Mine Mountains. Evidence indicating the direction of thrusting in this area is lacking.

Southeast of the Mine Mountains is a northeastward-trending normal fault. It displaces the clastic rocks of Mississippian age and overlying thrust plate of Devonian strata, which crop out at the Mine Mountains, and is downthrown on the southeast. The downthrown block is almost completely covered by alluvium in that vicinity except for small protruding bedrock "islands." The highest strata exposed in these "islands" are Devonian in age, thus revealing the probable existence of the Mine Mountains overthrust plate southeast of the normal fault. No Eleana rocks crop out in this vicinity.

On the largest of these "islands," a few patches of the thrust plate of Devonian rocks lie, not on the underlying block of the clastic rocks of the Eleana as at the Mine Mountains, but on limestone of the Ordovician Pogonip group and on Eureka quartzite. Although the contacts are by no means clear cut, the presence of another thrust fault displacing Ordovician rocks is indicated. The clastic rocks of the Eleana are dropped from the Mine Mountains along the normal fault, but are not exposed in the area to the southeast. Thus they conceivably may underlie the Ordovician rocks in a thrust relationship. If this is true, two overlapping thrust faults may exist in this area as follows:

1. A lower thrust, in which a plate of Ordovician sedimentary rocks has been thrust over an underlying block of Carboniferous rocks.
2. An upper thrust, in which a plate of Devonian strata has been thrust over the clastic rocks of Carboniferous age (Mine Mountains thrust fault) and onto the lower thrust plate of Ordovician sedimentary rocks.

In the bedrock area southeast of the Mine Mountains and west of Yucca Pass, the exposed formations are of Cambrian age but are undifferentiated because of the extreme structural complexity and lithologic changes from other known Cambrian formations in the area. This undifferentiated Cambrian section and the Ordovician section of the "islands" are essentially continuous stratigraphically from Yucca Pass northwestward to the normal fault southeast of the Mine Mountains, where the section abuts against clastic rocks of the Carboniferous Eleana formation. These Cambrian and Ordovician sedimentary rocks therefore probably make up the lower thrust plate which overlies

Carboniferous sedimentary rocks, as postulated in the preceding paragraph.

Positive evidence for the existence of this thrust plate of Cambrian and Ordovician rocks lies in the fensters about 2 miles west of Yucca Pass. Normal faults have brought rocks containing fossils of very probable Carboniferous age (Knight, written communication) against fractured Lower Cambrian strata. The lithology and fossil content of the rocks in the fensters and units *A* and *B* of the Tippipah formation are almost identical. If this thrust fault of Cambrian on Carboniferous rocks is continuous northwestward from these fensters to the Mine Mountains, as is postulated, the movement along the fault would be at least 8 miles.

The area adjacent to the Quartzite Ridge in northern Yucca Flat acts as a focal point for all the structure of the Paleozoic rocks in the northern part of that valley. The western mountainous rim of the valley from the Mine Mountains to Quartzite Ridge is almost completely composed of clastic rocks and limestone of Carboniferous age. On the contrary, the Paleozoic bedrock east of the valley is Early Cambrian to Silurian in age. The Eleana and Tippipah(?) formations of Quartzite Ridge are separated from limestone beds of the Pogonip group, about 10,000 feet lower in the section, by only a 1,000-foot interval of alluvium. Butte fault cuts this interval but its relative displacement is exactly opposite that necessary to produce this 10,000-foot displacement in the Paleozoic rocks. It is postulated that a thrust plate of Cambrian and Ordovician sedimentary rocks is dropped on the southeast along Butte fault against Carboniferous rocks of the underthrust block on the west.

This structural relationship is analogous to that of the Mine Mountains, where a known thrust plate of Devonian strata is dropped on the southeast along a normal fault against the underlying block of clastic rock of the Eleana. Thus all the lower Paleozoic formations exposed east of Butte fault and east of the Mine Mountains probably make up a large thrust plate, which has been thrust over the Carboniferous strata that crop out only west of the valley.

The displacement of this thrust fault would be along at least an 18 mile front from Quartzite Ridge to Yucca Pass. The direction of thrusting is not positively known, although evidence indicates it was from the west. The overthrust plate is exposed in the bedrock areas north, east, and south of Yucca Flat, and the underlying block occupies the areas only to the west, but this evidence does not imply that the thrust originated from the east. Many normal fault blocks in this area are dropped on the east. Consequently, the overthrust plate has been repeatedly dropped to the east along these normal faults, thus explaining its eastern exposure.

Whether this large thrust is related to the thrust fault north of Tippipah Springs and to the one west of the Eleana Range is unknown.

NORMAL FAULTS

Almost every part of the Nevada proving grounds area has been affected by normal faulting. Most of these faults have a southerly trend similar to most of the Great Basin normal faults, and the trend of the mountain ranges in the area has been largely determined by this faulting. Consequently the Great Basin ranges have been likened to a group of "caterpillars crawling southward." This pictorial comparison holds true for most of the Nevada proving grounds area except in the southern part where the trend gradually changes westward. South of the area the mountain ranges and normal faults resume their southerly trend.

One of the most conspicuous structural features of the area is in the vicinity of western Yucca Flat. A line drawn from Butte fault trending S. 20° W. and passing just west of the Mine Mountains would divide the Yucca Flat area into two postvolcanic structural blocks. West of this line, the volcanic rocks remain essentially unfaulted. This area of structural stability is separated by Butte fault from an area of instability east of this line, where the normal fault pattern is extremely detailed and complex.

The pattern of the normal faults east of Yucca Flat is uniform. The faults generally dip to the east and are downthrown on the east. The displacements, about ten to several hundred feet, produce a series of tilted fault blocks in which Paleozoic and Tertiary rocks dip westward. Much repetition of strata is thus produced. The general fault trend is southward.

Another pattern of normal faults occurs 6 miles southwest of Yucca Pass. The pattern is opposite that east of Yucca Flat. Western fault blocks are dropped relative to eastern blocks along westward-dipping faults, producing a series of repeated, eastward-dipping, tilted fault blocks. Displacements as much as 100–200 feet occur, and again repetition of strata is caused.

In the area southwest of Frenchman Flat, no definite pattern of fault trends or displacements is present. A change in trend of the faults to the southwest may be seen.

Butte fault, as mentioned previously, is a major fault which separates areas of structural stability and instability in northern Yucca Flat. A displacement of 1,200 feet has been measured from two prominent extrusive flows, which form the cap and shoulder of Oak Spring Butte, to their dropped counterparts east of the fault. The fault trends northward beyond the limits of the area and southwestward along the southeast side of Quartzite Ridge. Displacement along this fault resulted in the dropping of the eastern block which is made up of the granitic intrusion, the mineralized and metamorphosed rocks, and the Tertiary volcanic rocks. The downthrown extension of the tungsten-bearing strata, should be present beneath the volcanic tuff extrusive mass east of Butte fault. Further to the southwest Butte fault disappears beneath the alluvium.

Yucca fault is the major structural feature of Yucca Flat. This fault has the largest displacement and is the longest normal fault in the Nevada proving grounds area. This southward-trending normal fault divides the valley about in half. The fault block is downthrown on the east and at one locality dips 60° to the east.

By its well-defined scarp in the valley deposits Yucca fault is traceable southward across most of Yucca Flat. In the northern part of the valley, the height of the scarp is greatest and exceeds 75 feet. Unconsolidated valley fill on the east is faulted against compact fanglomerate on the west. Northward, Yucca fault terminates against the northeastward-trending Butte fault at the boundary of the valley and bedrock areas.

From the point where the scarp attains its maximum height, Yucca fault is traceable southward by its gradually diminishing scarp for about 12 miles. It is then impossible to recognize the fault farther to the south in the valley deposits. However, if the fault trend were projected southward 2 miles, it would cut Yucca Pass. Geologic mapping in this vicinity has proved the existence of a normal fault, which has dropped volcanic rocks on the east against limestone of Cambrian age on the west with a displacement of about 1,000 feet. This relationship indicates that Yucca fault extends across the entire 18-mile length of Yucca Flat, cuts the bedrock of Yucca Pass, and continues into Frenchman Flat.

No evidence of Yucca fault was uncovered south of Yucca Pass in either the alluvial deposits of Frenchman Flat or in the adjacent hills and ridges. However, because Yucca fault has displaced the bedrock of Yucca Pass, it most probably continues from the pass into Frenchman Flat but is covered by alluvium.

Other normal faults may exist along mountain fronts which rise abruptly from the alluvium. One example is the Ranger Mountains, east of Frenchman Flat. The homoclinal strata of these mountains are remarkably unbroken by faults. However, the abrupt rise from the alluvium, the linear front of the mountains, and the dip of the strata away from the valley strongly indicate a typical Basin and Range block fault.

Several faults have displaced the playa and alluvial fan deposits in eastern and southern Frenchman Flat. These faults are generally small, extending only short distances laterally and apparently do not have large displacements. All the faults in the alluvial fans are upthrown to the southeast. When the sun is at the right angle in the late afternoon, these faults may easily be detected even from considerable distances by their sunlit scarps and by the shadows cast on the dissected upthrown block.

Probably the most recent valley fault is one which strikes S. 20° W. for about one-half mile across the extreme eastern margin of Frenchman playa. The fault trace is a crevice in the silt and clay playa sediments about 15 feet deep and 10 feet wide. No vertical displacement is apparent. This crevice represents the fault's surface displacement, which probably has been produced as a result of relatively large displacement in the compact underlying bedrock.

Several linear sagebrush growths on Frenchman playa trend about parallel to this recent playa fault crevice and suggest the existence of similar faults in that vicinity. The growth of some type of vegetation along fault traces seems a natural consequence. Any fault rift in the playa surface would act as an ideal collecting trough for plant seeds and for water. These factors lead to the belief that the linear sagebrush growths across Frenchman playa are probably along recent faults, but older than the fault crevice at the eastern edge of the playa.

The pattern of valley faulting shows a gradual change of trend from S. 20° W. in the eastern part of Frenchman Flat to S. 60° W. in the southern part. This pattern is parallel to the normal faulting of the Paleozoic and Tertiary rocks of the adjacent mountainous rim. The relative fault displacement of the valley and bedrock areas is generally the same, the southeastern blocks are upthrown in relation to the northwestern blocks.

DATING OF STRUCTURAL DEFORMATION

Owing to the absence of reliable reference features in the Nevada proving grounds area, only generalized age determinations of the structural events may be made. In succession, the compressional deformation, intrusion of the granitic mass, and initiation of normal faulting followed upper Carboniferous or early Permian(?) time and preceded Miocene(?) time. The localized intrusion of dikes followed the Miocene(?) or later deposition of tuff beds and extrusions of flow rock, and also followed the faulting of the volcanic section in that area. Normal faulting has continued to the present day.

Dating of the compressional orogeny within the Nevada proving grounds area is impossible. However, detailed mapping in adjacent southern Nevada areas has provided an approximate dating for the thrust faulting. In the Muddy Mountains (Longwell, 1949) about 90 miles southeast of the area, a thick fanglomerate was deposited in front of the Glendale thrust as the thrust plate advanced. The age of the fanglomerate is Late Cretaceous. However, because it was deposited while the thrusting was in progress, the beginning of the thrust faulting may date back to middle Cretaceous or earlier. Final stages of the thrusting in the Muddy Mountains occurred sometime near the end of the Cretaceous. Possibly thrust faulting in the Nevada proving grounds area, although not definitely dated, can be correlated with Cretaceous thrusting. However compressional deformation resulted, in its early stages, in the uplift of the land surface and subsequent folding before the formation of thrust faults. Thus the inception of deformation was probably earlier in the Mesozoic era than the Cretaceous dating of the thrusting.

As in many other localities in the Great Basin, a granitic mass has been intruded into the Paleozoic country rock north of Yucca Flat. The age relationship of this intrusion is not clear. However, Nolan (1943) states, "the emplacement of these granitic bodies everywhere in the Great Basin appears to have marked the end of major (compressional) diastrophism" and thus the intrusion conceivably could be of Late Cretaceous or early Tertiary age.

Normal faults have displaced the folds and thrust faults exposed in the Paleozoic rocks, and the granitic mass which has intruded them. The normal faulting had therefore been initiated subsequent to the compressional deformation and the intrusion. Three evidences for the upper age limitation of the inception of the faulting exist within the Nevada proving grounds area.

1. An unconformity of Tertiary age occurs within the tuffaceous section at four localities from Twin Peaks to French Peak in the Yucca Flat area. The strata underlying these unconformities are not folded, but are merely tilted, and beveled by erosion before continued deposition of the volcanic rocks of the Oak Spring formation. As disruption of the Tertiary strata by simple compression during this period was unlikely, possibly the tilting of the strata underlying the unconformities was produced as a result of normal faulting. This is analagous to the tilting of normal fault blocks as observed in the area today. Normal faulting, which was in progress during deposition of the Tertiary volcanic rocks, is thus implied.
2. Immediately east of the southern part of Paiute Ridge, the Paleozoic formations are cut by a large normal fault. This fault projects into an area where Tertiary volcanic rocks come in contact with Paleozoic rocks, and form a scarplike feature in the volcanic rocks along the line of projections. However, where this scarp was studied, evidence indicates that the Tertiary volcanic rocks merely lap onto and dip in the same direction as the scarp. Also in one small outcrop, tuff beds lie on the Paleozoic rocks of the scarp in a sedimentary contact and no fault relationship between the two exists. At least some of the normal faults in this locality, therefore, appear to have been formed before deposition of the Tertiary volcanic rocks.
3. The Tertiary Oak Spring formation in most of the Nevada proving grounds area and adjacent areas is composed of tuff and extrusive rocks. The only

exception occurs in southern Frenchman Flat, where interbedded tuff and fresh-water limestone beds of Miocene(?) age unconformably overlie the eroded Paleozoic rocks and make up the basal 100 feet of the Tertiary section. Overlying this are 100–200 feet of interbedded volcanic tuff and conglomerate layers bearing cobbles of quartzite and limestone of Paleozoic age.

Similarly, the major exception to the southerly trend of the fault pattern occurs in the mountainous areas south of Frenchman Flat, where the fault traces swing abruptly to the southwest and almost attain a westerly trend. This coincidence in structure and stratigraphy suggests the following hypothesis: Normal faulting attained a southwesterly trend in the vicinity of southern Frenchman Flat, and created a bedrock "dam" before Miocene time. The drainage of surface waters was impeded resulting in a fresh water lake, in which a few limestone beds were deposited in an interbedded sequence with volcanic tuff. Continued uplift along the southwestward-trending normal faults transformed the "dam" into a high area of Paleozoic rock subject to erosional forces. From this bedrock high area, cobbles and boulders of limestone and quartzite were eroded and washed into the basin where a predominance of volcanic rocks was being deposited. Thus, if this hypothesis is valid that faulting actually preceded the limestone and conglomerate deposition, a pre-Miocene(?) age of the inception of normal faulting is implied. Normal faults, which cut the valley alluvial deposits, attest to the recency of some of the faulting.

References from literature concerning dating of normal faulting substantiate an even earlier pre-Miocene inception of the faulting. Nolan (1943) presents a summary of the several publications concerning this subject and states:

> Ferguson (1926) and Ferguson and Cathcart (1924) . . . found that . . . (block faults) both preceded and followed the deposition of sediments belonging to the Esmeralda formation (late Miocene and early Pliocene) . . . Westgate (1927, p. 44) has also found evidence for block faulting of pre-Pliocene(?) age in southeastern Nevada, and Longwell (1936, p. 1456) has described block faulting in the Boulder Dam region that preceded, accompanied, and followed the deposition of his Muddy Creek formation, of questionable Pliocene age.
>
> . . . The evidence provided by the Tertiary sedimentary rocks, however, appears to be conclusive that the block-faulting movements started early in the Tertiary period, probably in late Eocene or early Oligocene time, and were widespread through the later Miocene and early Pliocene.

In the Muddy Mountains, Nevada (Longwell, 1949) and Gold Hill, Utah (Nolan, 1935) the stage of normal faulting is not distinctly separated from the compressional phase, as evidence of contemporaneous normal faulting and thrusting has been found.

Nolan (1943) also writes:

> Finally, there appears to be a suggestive connection in time between the block faulting and preceding folding and thrusting. Thus, block faulting is believed to

have been in progress in early Oligocene time and thrusting seems to have continued well into the Eocene epoch, a relation that may be interpreted as sequential and implying continuity in action of the same causative forces . . . the block faults thus represent the final and declining stages of (the compressional) revolution.

Thus, the foregoing discussions and references indicate that normal faulting in the Nevada proving grounds area began at least as early as Miocene time and probably as early as early Tertiary time, soon after the completion of folding and thrusting, and the intrusion of the granitic body. The normal faulting has continued to recent time.

One of the latest structural developments of the area is the localized intrusion of a series of dikes in the Paleozoic and Tertiary country rocks northeast of Paiute Ridge. Dating was made possible by the linear alinement of some of the dikes along preexisting normal faults, which cut the Tertiary volcanic rocks. In places the dikes have completely occupied the fault zone. Thus, intrusion of dikes in this locality followed the Miocene(?) or later volcanic deposition and the normal faulting.

ECONOMIC GEOLOGY

The tungsten mine at Oak Spring and the Hornsilver mine west of Frenchman Flat, now abandoned, are the largest mines in the area. Many smaller abandoned mines are in other parts of the area, particularly in the Mine Mountains, but information concerning them is not available. No mines are operating in the area.

The tungsten mine has been described by Wyant (1941). He states that scheelite ($CaWO_4$) and powellite ($CaMoWO_4$) occur in large masses of tactite, formed by granitic intrusion into limestone, and occupy premineral faults and dikes. Most of the tactite masses have been found parallel to bedding or premineral faults from 100 to 500 feet from any granite contact. Minerals found in the tactite in approximate order of abundance are garnet, quartz, pyroxene(?), calcite, idocrase, scheelite, powellite, and epidote. Control of the scheelite concentrations with tactite bodies is obscure; probably cross fractures and irregularities of the contact are factors in localization.

The original discovery of scheelite at Oak Spring was made in 1936 by individuals who immediately interested Goldfield Consolidated Mining Co. in the claim. This company optioned the claim to U. S. Vanadium Corp. for exploitation. However, U. S. Vanadium Corp., after thoroughly sampling the tactite masses dropped their option. Later, exploratory work was done by Goldfield Consolidated Mining Co., Pacific Bridge Co., Nevada Massachusetts Co., and I. Foster Smith. Returns were small and further work was frustrated by the incorporation of the Oak Spring area into an Air Force gunnery range. Total extraction of ore amounted to about 7 to 8 tons of concentrate containing 50 percent WO_3. Estimated tungsten reserves include 35,000 tons of probable and possible ore containing 0.5 percent or higher of WO_3 and 60,000 tons of possible marginal and submarginal ore containing 0.1 to 0.49 percent WO_3.

Very little is known concerning the Hornsilver mine. Minerals occur in volcanic rocks and probably include gold as well as silver. Production figures for the mine are not known, however, judging from the size of the shafts, the mine operated on a fairly large scale at one time.

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