Paleozoic Rocks of Antelope Valley Eureka and Nye Counties Nevada

GEOLOGICAL SURVEY PROFESSIONAL PAPER 423

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By CHARLES W. MERRIAM

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Principles of stratigraphy applied in descriptive study of the Central Great Basin Paleozoic column

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By Charles W. Merriam

ABSTRACT

Antelope Valley is bordered by mountains of the Basin and Range Province that consist mainly of Paleozoic strata partly covered by Cenozoic volcanic rocks. The Paleozoic beds range in age from Late Cambrian to Early Permian; only the Pennsylvanian system is unrecognized.

Reconnaissance geologic mapping in the 1-degree Roberts Mountains quadrangle pointed up need for special studies of stratigraphy and paleontology relating principally to the Ordovician, Silurian, and Devonian systems.

Widespread thrusting coupled with later normal faulting so complicates stratigraphic study in this region that a simultaneous approach to problems of stratigraphy and structural geology is needed. To achieve a more comprehensive regional understanding of areal, stratigraphic, and structural relations, the Antelope Valley investigations were coordinated with work in the adjoining Eureka mining district.

Impressive manifestations of intense deformation are thrust outliers of Ordovician beds of the Vinini formation. These outliers rest upon Paleozoic rocks of different facies and range in age from Ordovician to Carboniferous. It has become reasonably certain that the graptolitic rocks were deposited in a western Great Basin depositional subprovince, whereas the pre-Carboniferous rocks over which they have been thrust accumulated in an eastern subprovince wherein carbonate sedimentation predominated. Immense horizontal displacement is clearly related to the Roberts Mountains thrust, earlier described in the region to the north. Thrusts of lower magnitude in the Monitor and Antelope ranges are possibly sympathetic to the main Roberts Mountains thrust.

Aside from the major facies changes of subprovincial magnitude, well-marked east-west differences are recognized within Ordovician, Silurian, and Devonian rocks of the eastern or carbonate subprovince itself.

Of 17 Paleozoic formations described in this report 14 are normally superposed at Antelope Valley. These range from Late Cambrian to Mississippian. The Ordovician is the most diverse in terms both of rock type and faunas. Twelve of the normal section formations at Antelope Valley are present also at Eureka, but the facies of several of these differ markedly.

Paleontologic research undertaken in conjunction with the stratigraphy was confined largely to preliminary identification of diagnostic fossils. Another major consideration in which fossils have played the significant role is that of system-boundary definition, which remains somewhat arbitrary. More detailed studies of the Helderberg and Oriskany Early Devonian faunas were also carried forward as part of this program.

Only a single unit of Cambrian age, the Windfall formation, is exposed at Antelope Valley. This Late Cambrian unit lacks the upper member of the type section near Eureka, and is overlain by dark carbonaceous shale containing only the small crustacean *Caryocaris*.

The normal Ordovician column including six formations is about 4,300 feet thick. Ranging in age from Early to Late Ordovician (Richmond), these units are in order from bottom to top as follows: Goodwin limestone, Ninemile formation, Antelope Valley limestone, Copenhagen formation, Eureka quartzite, and Hanson Creek formation. Limestones predominate, but the Eureka quartzite is a notable exception. Three of these Ordovician formations—Ninemile, Antelope Valley, and Copenhagen—have type sections in the Antelope Valley area. The richly fossiliferous Copenhagen, theoretically a facies of the lower part of the Eureka, is known only in the study area.

Thrust outliers of Ordovician graptolite shale, bedded chert, and sandstone occur in the northern Mahogany Hills, at the north end of Monitor Range, and in the vicinity of Charnac Basin. Where fossils are absent, these shales and sandstones of the Vinini are easily confused with similar beds of Carboniferous age.

The rocks of the Silurian system, about 2,200 feet thick, include the Roberts Mountains formation below and the Lone Mountain dolomite above. Limestone of the Roberts Mountains formation carries a *Monograptus* fauna in the Monitor Range; its base is there defined by a laterally persistent cherty zone. This formation changes to dolomite on the east side of Antelope Valley, where it is gradational above with the Lone Mountain dolomite. In the Monitor Range, where the Lone Mountain is unrecognized, the *Monograptus* beds are seemingly overlain disconformably by Early Devonian (Helderberg) Rabbit Hill limestone.

Silicified fossils, including the Late Silurian brachiopod *Howellella*, occur in the upper part of the Lone Mountain dolomite. These beds are disconformably overlain by Oriskany age Lower Devonian dolomitic limestone of the Nevada on the east side of Antelope Valley.

Devonian rocks of this area, about 4,000 feet thick, range in age from Helderberg to Late Devonian and are classified in four formations; only three of them—the Nevada, the Devils Gate, and the lower part of the Pilot—are superposed in a continuous section. The Rabbit Hill limestone seems to be confined to the west, where it occurs in the Monitor Range. On the contrary the Nevada formation of Early and Middle Devonian age and the Devils Gate limestone of late Middle and Late Devonian age are found only on the east and are not recognized on the Monitor Range side of the valley.

The Nevada formation has been zoned paleontologically and is subdivided lithologically into lower, middle, and upper divisions. Oriskany age spirifers of the *arenosa* and *murchisoni* types characterize the lowest zone, whereas the upper zone carries *Stringocephalus* and is of late Middle Devonian age. The Nevada changes lithologically and to some extent faunally eastward from Antelope Valley to the Eureka district, where it is divisible into five members. With the facies change eastward, the rich lower Nevada faunas disappear.

The upper Nevada *Stringocephalus* fauna does not extend into the overlying Devils Gate limestone, which is lithologically more uniform than the Nevada. Late Devonian faunas of the upper part of the Devils Gate include *Pachyphyllum, Manticoceras, Hypothyridina emmonsi* (Hall and Whitfield), and *Cyrtospirifer*. Gradationally above the *Cyrtospirifer* zone is the lower part of the Pilot shale bearing a Late Devonian conodont assemblage.

Mississippian shales and sandstones of Antelope Valley are classed as Chainman shale and Diamond Peak formation, undifferentiated. Closely associated with them in the northern Mahogany Hills are similar rocks of the overthrust Ordovician Vinini formation. Ely limestone of Pennsylvanian age, present in the vicinity of Eureka, was not recognized at Antelope Valley.

Uppermost Paleozoic rocks of the area are assigned to the Garden Valley formation of Wolfcamp Permian age. These beds appear to rest unconformably upon overthrust graptolite shale in the northernmost Monitor Range. Two divisions are described, a lower fossiliferous sandy and pebbly limestone and a much thicker limestone cobble conglomerate. Cobbles in this unit contain Ordovician fossils of the Pogonip group.

INTRODUCTION

GEOLOGIC SETTING

Nowhere in western North America are fossil-bearing middle Paleozoic rocks better shown than at Antelope Valley and in adjoining territory of Eureka and Nye Counties, Nev. (fig. 1). Within this area, situated north of parallel 39 and west of the important Eureka mining district, marine rocks of Ordovician, Silurian, and Devonian ages have a combined thickness of more than 10,000 feet. Strata of Late Cambrian, Carboniferous, and Permian ages are likewise present; but because they have a more restricted distribution, they can be studied to greater advantage in neighboring areas.

Antelope Valley has the north-south trend characteristic of the Great Basin. The valley is V-shaped and is formed by divergence of the Antelope Range on the east from the Monitor Range on the west. Antelope Range ends without completing the east arm of the V; to the north, beyond its tip, the adjacent Fish Creek Range swings northeastward to join the mountains that enclose Antelope Valley with those of the Eureka district.

Antelope Valley opens into a broad almost quadrangular basin known as Kobeh Valley, north of which lie the Roberts Mountains (fig. 2). Lone Mountain, with its unexcelled exposures of Ordovician, Silurian, and Devonian rocks, rises like an island near the margin of Kobeh Valley, a short distance northeast of its union with Antelope Valley.

Except for scattered small playas, the alluvial flats of the valley floor are clothed with sparse semidesert vegetation. Characteristic plants are greasewood, rabbitbrush, sage, white sage, and shadscale. Gentle sage-mantled slopes rise from the broad flats on either side to meet coalescent fans, with here and there an intervening pediment surface. At the valley edge there is abrupt change in acclivity where mountains characteristic of the Basin and Range Province rise as much as 4,000 feet above the valley floor. Summit Mountain and Antelope Peak in the northern Monitor Range reach 10,461 and 10,220 feet respectively.[1] These mountains, which are the highest in the area, consist of volcanic materials. The Mahogany Hills, Fish Creek Range, and Antelope Range to the east are composed largely of Paleozoic sedimentary rocks. Like the loftier Monitor Range to the west, they are clothed with forests typical of the central Great Basin comprising juniper, pinyon pine, and mountain mahogany.

The northern Monitor Range is within a belt of intense Tertiary vulcanism, and volcanic rocks cover most of the Paleozoic strata in this part of the Antelope Valley area (pl. 1). Well displayed in Summit Mountain and Antelope Peak is a succession of rhyolite, dacite and andesitic flows, together with tuffs and coarser pyroclastic rocks; the entire volcanic pile is about 4,000 feet thick. At Bald Mountain and Charnac Basin water-laid tuffaceous sediments contain fossil floras of undetermined age. Volcanic rocks have been completely eroded from the Twin Spring Hills on the north, where Permian and Ordovician strata are exposed. Volcanic cover has also been eroded from an area southeast of Charnac Basin, where much significant evidence on the Ordovician, Silurian, and Devonian systems was obtained.

The Paleozoic rocks are largely devoid of volcanic cover on the Antelope Range side of the valley, where outcrops of Paleozoic strata continue south through the Mahogany Hills and western Fish Creek Range. Across Fenstermaker Wash they extend south in the Antelope Range to meet partial volcanic cover at Ninemile Canyon.

Fresh-water Cretaceous sediments of the Newark Canyon formation (Nolan, Merriam, and Williams, 1956, p. 68) occupy a saddle on the northwest spur of Table Mountain, where they rest upon massive Devils Gate limestone (loc. 71). This small erosion remnant comprises yellowish gray, tan, and reddish sandstone, siltstone, and plant-bearing shale beds. Westernmost exposure of this unit thus far recognized is in the Twin Spring Hills (loc. 91) of the Monitor Range, where it rests unconformably upon the Permian Garden Valley formation.

Fanglomerate, gravel, sand, diatomaceous deposits, and volcanic ash compose the later deposits of Antelope Valley. White, poorly consolidated sand, silty and shaly diatomaceous beds, and loose white volcanic ash

[1] Altitudes from Antelope Park quadrangle, 1956; altitudes shown on pl. 1 are from Roberts Mountains quadrangle of 1929.

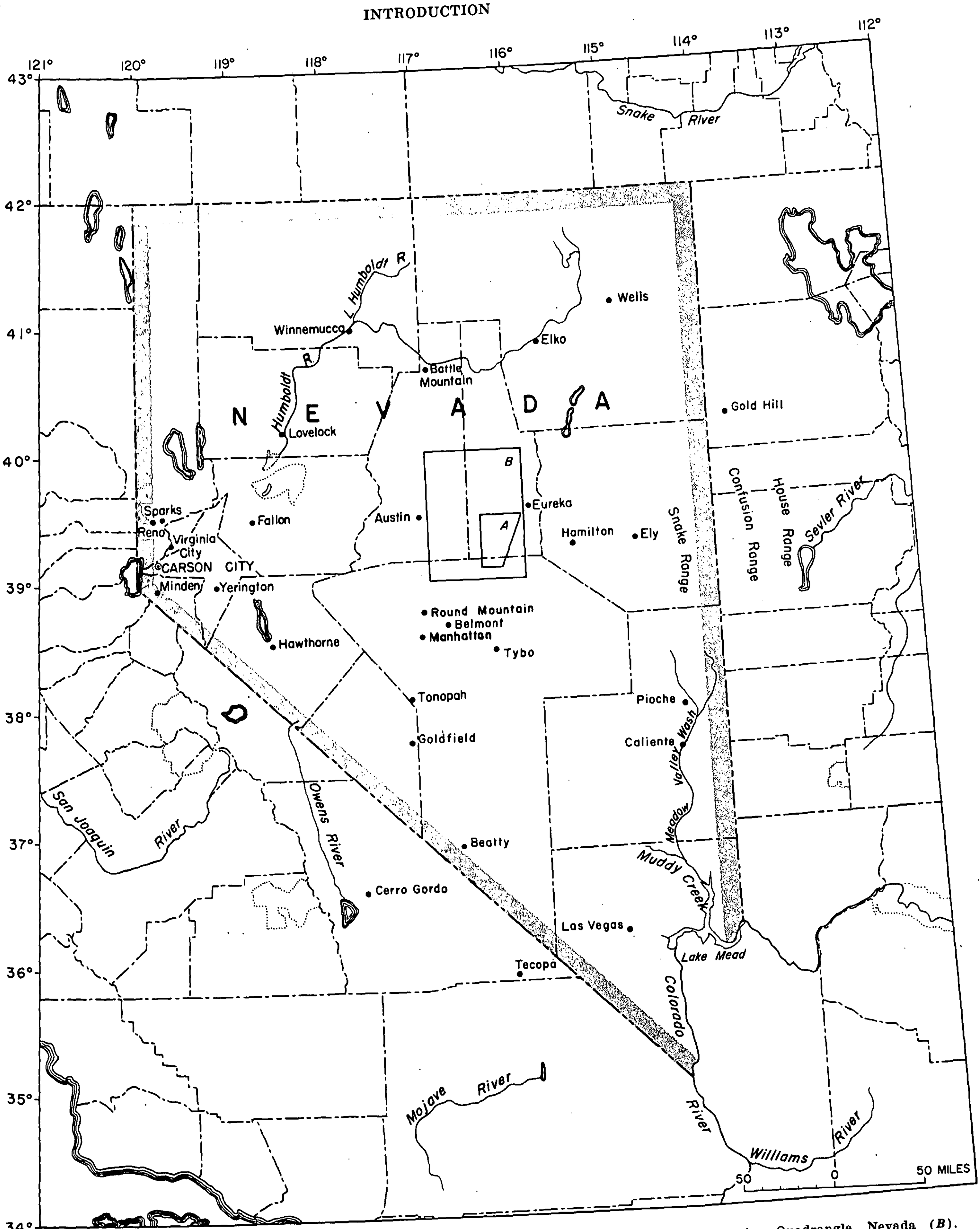

FIGURE 1.—Index map showing location of the Antelope Valley area (*A*) and the Roberts Mountains Quadrangle, Nevada (*B*).

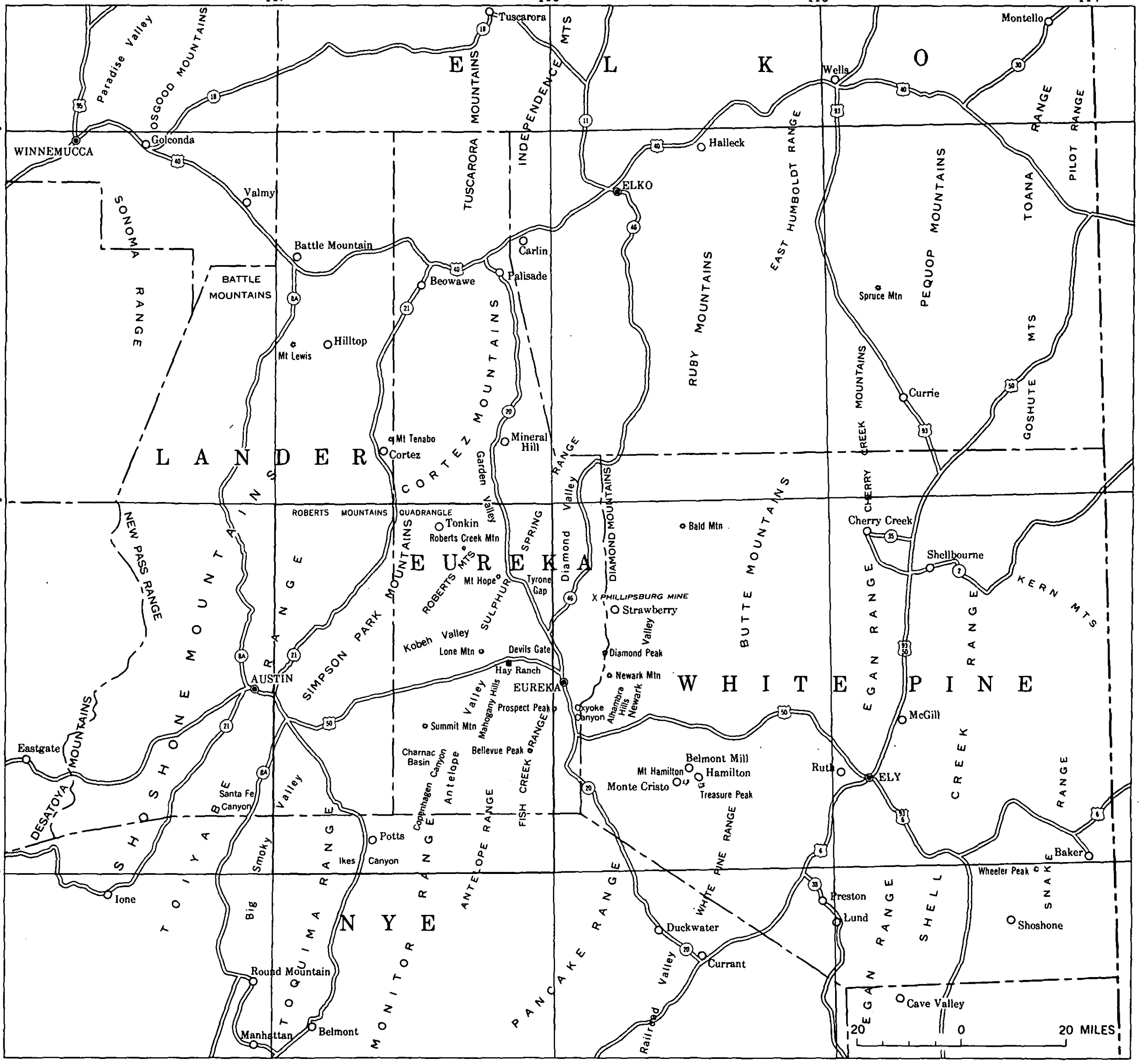

FIGURE 2.—Index map of central and eastern Nevada showing localities to which reference is made.

are well shown on the lower southwest and east slopes of Lone Mountain. At Lone Mountain the flat-lying white beds are at least 160 feet thick. Poor exposures of these strata are found northeast of the Twin Spring Hills, on the northwest side of Mahogany Hills, and at many places along the east side of Antelope Valley south to Fenstermaker Wash. Whether these diatomite and ash beds are partly late Tertiary or entirely Pleistocene has not been determined. In any case Antelope Valley undoubtedly held a southerly arm of Kobeh Valley Lake in Pleistocene time.

Geomorphically the mountains surrounding Antelope Valley are representative of the Basin and Range Province, as they are bounded for the most part by en echelon frontal faults. In fact the linear west front and abrupt rise of the Antelope Range clearly indicate the faultline influence. In the Devonian rocks at the northwest tip of this range, there is clear stratigraphic evidence of valley-side down throw on northeastward-striking normal faults near the valley edge (pl. 2).

HISTORY OF INVESTIGATION

Attention was first drawn to Paleozoic rocks of the Antelope Valley area by Henry Englemann, geologist and meteorologist of the Simpson Exploring expedition that crossed Kobeh Valley ("Kobah Valley") in 1859. According to the published route map (Simpson, 1876), the explorers skirted Lone Mountain ("Lowry Peak") on the south and followed Devils Gate Pass ("Swallow Canyon") to Diamond Valley ("Pah-hun-nupe Valley"). Englemann was especially attracted by the impressive exposures of Devils Gate limestone, from which Devonian fossils later identified by Meek (Meek and Englemann, 1860; Meek, 1876) were collected.

In the decade following 1868, the Geological Survey of the Fortieth Parallel examined and reported upon the Paleozoic rocks of neighboring areas, principally to the north but also east and west of Antelope Valley. Mountains stretching northward from the Mahogany Hills were at that time referred to as the "Pinyon Range." Although the richly fossiliferous rocks at Devils Gate were known to the Fortieth Parallel party (King, 1878, p. 211), most of the Devonian fossils collected by them in the "Pinyon Range" appear to have come from farther north, in that part today called the Sulphur Spring Mountains (fig. 2).

In 1880 and 1881 the rocks on the east side of Antelope Valley extending south from Devils Gate ("The Gate") through Wood Cone and Bellevue Peak were mapped by the U.S. Geological Survey party under Arnold Hague (1883; 1892). Walcott (1884) at that time investigated the stratigraphy and faunas of the mapped area with special reference to Upper Devonian rocks at Devils Gate, Middle Devonian at Combs Peak, and the Upper Ordovician near Wood Cone. Ordovician and Devonian collections from nearby Lone Mountain made by Walcott and other members of the Hague party provided an important part of the material described and figured in the Eureka paleontology memoir (Walcott, 1884). For 50 years the monographic studies by Hague and Walcott remained the most significant references on Paleozoic history and paleontology of the Great Basin, in fact of the entire Far West.

Little was added to knowledge of Paleozoic rocks in Antelope Valley and the neighboring Eureka district until 1928, when Henry G. Ferguson and Edwin Kirk of the U.S. Geological Survey visited these areas for geologic reconnaissance and fossil collecting. Kirk (1933; 1934) later discussed some aspects of the fossil record in the northern Antelope and Monitor Ranges, calling especial attention to the Ordovician sections, which beginning with his visit, have yielded a rich store of fossil material.

At the suggestion of Edwin Kirk, the Devils Gate and Lone Mountain sections were studied by Merriam (1940) and various stratigraphically significant Devonian fossils were described and figured. In 1939 and 1940, during the geologic investigations in the Roberts Mountains by Merriam and Anderson (1942), several Ordovician sections of Antelope Valley were visited in the hope of resolving local problems of stratigraphic correlation and geologic structure. Current study of Antelope Valley is in essence an outgrowth of these earlier geologic investigations of the Roberts Mountains 1-degree quadrangle initiated in 1939.

The present report embodies results of joint fieldwork undertaken near Martin Ranch by the writer in collaboration with C. M. Nevin and L. E. Nugent of Cornell University. A preliminary geologic map of Martin Ridge was contributed largely through the efforts of Nevin and Nugent during the summer of 1940. For brief periods in 1941, 1948, and 1950 the writer continued reconnaissance mapping and fossil collecting in the Antelope and Monitor Ranges.

Revision of Paleozoic stratigraphy in the Eureka mining district was undertaken jointly in 1951 by T. B. Nolan, J. S. Williams, and the writer (Nolan, Merriam, and Williams, 1956). Several of the stratigraphic and related structural problems dealt with briefly in this contribution are common to the Eureka district and Antelope Valley. These questions have in recent years been investigated further by Nolan and the writer. Among them are Cambrian-Ordovician boundary relations, phenomenal distribution of the Vinini graptolite shales, and westward facies change in the Ordovician, Silurian, and Devonian rocks.

This paper was in substance largely completed by 1943, but before it was published new field evidence made revisions necessary, and the paper was therefore withheld until changes and adjustments could be made.

Since 1945 growing interest in oil potentialities of the Great Basin has stimulated geologic activity. Consequently, the better exposed stratigraphic sections, including those in Antelope Valley and neighboring areas, have received attention from several oil companies. The economic interest drew response likewise from academic institutions, with the result that students in growing numbers have been attracted to the many stimulating field problems the region offers. In response to requests by scientific colleagues for stratigraphic information on the central Great Basin region, much of what is herein embodied was made available before 1950.

PURPOSE AND SCOPE

The main objective of the present study, begun in 1940, is to continue southward the reconnaissance geologic mapping in the Roberts Mountains region initiated by Merriam and Anderson (1942). The Paleozoic sections at Antelope Valley had previously been noted to differ appreciably from those at Eureka to the east and the Roberts Mountains to the north. These differences are best demonstrated by detailed comparative study and description of the Antelope Valley rocks and their contained fossil faunas. Scant geologic evidence from areas west of Antelope Valley indicates even more marked depositional changes in that direction, such as might be expected near the margin of a geosynclinal basin; this problem can best be attacked by first gaining as full an understanding as possible of the Antelope Valley rocks as a basis for extrapolation.

A major objective of the Antelope Valley program is to provide a sound stratigraphic and paleontologic basis for future detailed geologic mapping and structural study now in progress. Toward these ends, zoned fossil collections have been made from several of the formations, though much careful collecting remains to be done. These collections, it is hoped, will serve likewise as a basis for more refined paleontologic studies, as noted under the section on "Paleontologic studies."

As in the Roberts Mountains (Merriam, 1940; Merriam and Anderson, 1942) very general reconnaissance mapping was done in selected parts of the Antelope Valley area. The base map used for this purpose is a two times enlargement of the 1:250,000 Roberts Mountains quadrangle (pls. 1, 2). Several of the stratigraphic sections, which at the outset appeared relatively unbroken, were measured in detail with tape and Brunton compass. However, some thickness figures presented here must be regarded as rough approximations, having been scaled from reconnaissance maps in areas of strong deformation. Because of pervasive faulting, bed-by-bed measurement was in many sections found impracticable or unreliable. As in other parts of the Great Basin, detailed measuring of sections after preliminary areal mapping proved to be the most satisfactory method.

ACKNOWLEDGMENTS

The writer takes pleasure in acknowledging the encouragement and friendly counsel given by Thomas B. Nolan. After a long period of pleasant association on problems of central Great Basin geology it became the writer's privilege to collaborate with Nolan and James S. Williams on a revision of the stratigraphy of the Eureka district.

Since the outset of this program, G. Arthur Cooper of the Smithsonian Institution has helped greatly by his advice on fossil identification, and geologic correlation, and by criticism of manuscript. The late Rudolf Ruedemann kindly identified Ordovician and Silurian graptolites.

Acknowledgment is due the trustees of Cornell University for financial assistance during the summer of 1940, at which time valuable aid in the field was given by C. M. Nevin of Cornell and by L. E. Nugent, formerly of the same institution.

Among others who have given freely of valuable counsel on the problems of the Great Basin during this work are H. G. Ferguson, the late Edwin Kirk, C. A. Anderson, R. J. Roberts, and James Gilluly of the U.S. Geological Survey. A. R. Palmer and R. J. Ross, Jr. aided in determination of the Cambrian-Ordovician boundary. Finally, the writer expresses thanks to the late Mr. William Martin and Mrs. Martin of the Martin Ranch for many courtesies extended during the fieldwork.

GEOLOGIC STRUCTURE AS RELATED TO STRATIGRAPHY

The Paleozoic column in the Antelope Valley-Eureka region is about 25,000 feet thick, largely marine, and reflects the structural and stratigraphic setting of a classic geosyncline. A long-continued depositional history, well supported by the data of paleontology, parallels the established record in other and more fully studied major belts of geosynclinal accumulation.

Within the long interval from Late Cambrian to Mississippian the Antelope Valley strata reveal no clear structural evidence of strong compressional deformation. Broad regional uplift unaccompanied by appreciable warping of strata took place in the Ordovician near the end of Pogonip time and probably during deposition of the Eureka quartzite. Uplift and emergence are documented by local disconformity near the close of the Silurian. The Mississippian rocks manifest revolutionary tectonic and geographic changes with introduction of impure sandy and pebbly limestone, carbonaceous shale, coarse siliceous sandstone, and conglomerate. These Carboniferous siliceous clastics, though largely marine, contain remains of land plants indicative of nearby coal-swamp environments.

The present study does not shed light directly upon the problem of intense late Paleozoic crustal movement in the central and western Great Basin (Roberts and others, 1958). Date of the major Roberts Mountains thrusting remains uncertain in this area, where the Mississippian rocks of the Chainman shale and Diamond Peak formation are the youngest demonstrated by mapping, to have actually been overridden by Ordovician graptolitic deposits of the Vinini formation. However, the Permian beds of the Garden Valley formation and overlying sandstone beds assigned to the Cretaceous Newark Canyon formation are strongly deformed. Permian beds resting on the overthrust Vinini (loc. 82) may actually have been involved in the thrusting; if such eventually proves to be true the earliest thrusting in the Antelope Valley area came about after Wolfcamp (Early Permian) time.

Antelope Valley is probably situated near the west margin of the Great Basin prism of Paleozoic marine rocks in which the stratigraphic column and paleontologic record of this era are most nearly complete. Maximum stratigraphic continuity or completeness in the time and paleontologic sense does not necessarily denote maximum thickness of the column. Such a conclusion would perhaps be illogical because of phenomenal thicknesses known to have piled up locally in subsidiary basins during less than a single geologic period.

How far west of Antelope Valley this more continuous Paleozoic column extends in these latitudes cannot at present be determined. Westward, north of parallel 39 (fig. 2), through the Monitor, Toquima, and Toiyabe Ranges field evidence suggests attenuation of the column, accompanied by significant facies change and wedging out of stratal units within the stratigraphic interval ranging from late Middle Ordovician through Carboniferous time. Beyond the Toquima Range, exposures of unaltered Paleozoic strata are unfortunately few, because of plutonic intrusion and cover of later rocks, especially Cenozoic volcanic rocks. Yet farther west, through The Sierra Nevada belt in this latitude, intrusion, metamorphism, and burial by later rocks prevent elucidation of Paleozoic history, except in the broadest and most sketchy of inferential terms.

Lithologic facies changes from east to west, so well illustrated by Ordovician and Devonian rocks of this region, no doubt have paleotectonic significance. These changes may be related in part to rise and fall of a major geanticline to the west, as postulated by Nolan (1928).

Manifestations of intense post-Paleozoic deformation are widespread at Antelope Valley. The Paleozoic strata, including those of Permian age, are folded and thrust, and all rocks of the region have been cut by innumerable normal faults. Certain homoclinally tilted blocks of Paleozoic strata appear at least to represent normally faulted segments of north-south trending and rather open folds. Such are the eastward-dipping Ordovician section at Ninemile Canyon and the westward-dipping block that forms Martin Ridge. Rocks of the Pogonip group along the Antelope Range front west of Ninemile Canyon exhibit reversal of dip from east to west. There is evidence here of reverse faulting near the axis of this supposedly anticlinal flexure (fig. 3).

Simple, relatively uncomplicated symmetrical folds are not the rule in the central Great Basin. In Antelope Valley, the Dry Lake anticlinal arch and a similar structure at Bellevue Peak most nearly approach this ideal form.

As seen in the Mahogany Hills (pl. 1), the Dry Lake arch appears as a broad open anticline, for the greater part in low-dipping Devils Gate limestone underlain by Nevada formation. Between Dry Lake and Hay Ranch this almost domelike structure has distinct topographic expression, and the Devonian beds of the Devils Gate are traceable from east to west across the axial zone. Dip of the west limb is on the whole rather gentle toward Antelope Valley; here and there, the slope of the west limb is almost coincident with the dip. There are, however, many irregularities and local steepenings of dip due to faulting. The comparable flexure at Bellevue Peak, where the Pogonip group and Eureka quartzite are involved, may in fact be merely a southward prolongation in lower strata of the Dry Lake arch. Position of Ordovician strata in Martin Ridge and the opposing Antelope Range on the east suggest that southernmost Antelope Valley may be virtually synclinal (pl. 2).

The origin of broad folds like the Dry Lake arch is probably related to compressional stresses, which are also responsible for thrusting. Ordovician beds of the Vinini on the east limb at Yahoo Canyon and Devils Gate with little doubt overrode the arch that

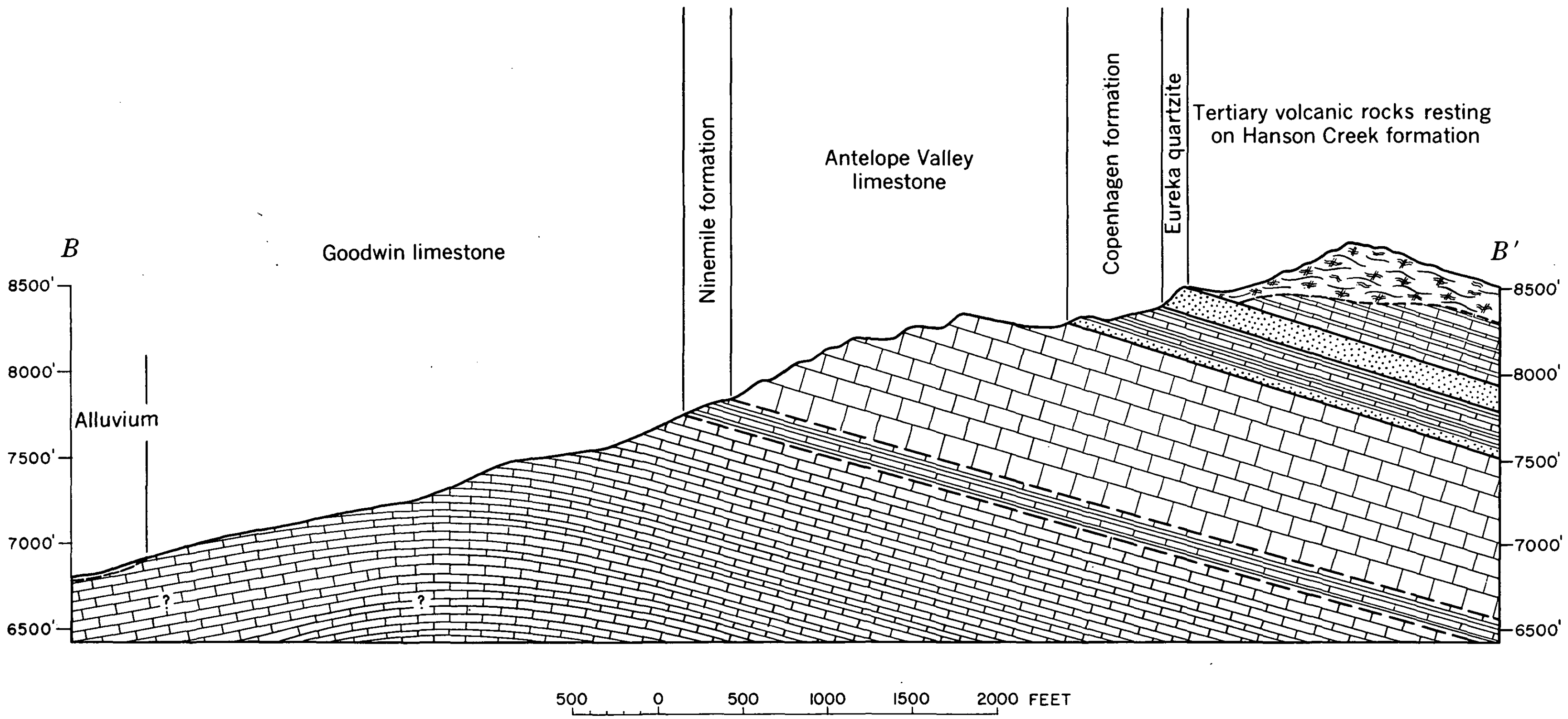

FIGURE 3.—Section along line *B–B'* south of Ninemile Canyon, Antelope Range, showing Ordovician formations. See plate 2 for location of section.

could have formed in the lower plate contemporaneously with the thrust movement.

Thrust faults, most important manifestations of compressional deformation in this area, range in magnitude from relatively minor ones that displace rocks normally present in the local stratigraphic section to at least one of far greater magnitude that introduced foreign sedimentary facies not present in the normal Antelope Valley column. It is probable that most of the minor thrusts were contemporaneous in origin and sympathetic with the major thrust movements.

In the category of minor thrusts is a low-angle thrust well shown on the west side of Copenhagen Canyon (pl. 2; fig. 4), where massive cliff-forming Antelope Valley limestone rode over less competent Lower Devonian beds of the Rabbit Hill limestone. Drag folds suggest west to east movement of the upper plate.

At locality 3 in Whiterock Canyon a thrust outlier of Pogonip rests upon Lower Devonian Rabbit Hill, east of the principal thrust contact. Comparable thrusting is evident on the east side of Antelope Valley; for example, in the northern Antelope Range the Cambrian Windfall formation and overlying Pogonip override the Nevada formation.

Between Charnac Basin and Devils Gate pass, a linear distance northeastward of 35 miles, there is abundant evidence of major thrust displacement. Beyond doubt these displacements are related to the widespread Roberts Mountains thrust (Merriam and Anderson, 1942, p. 1701). In most places the upper plate consists of Ordovician Vinini formation, which occurs in thrust relationship to other rocks at all known exposures. Garden Valley Permian strata may also have formed part of the upper thrust plate; this Permian unit rests unconformably upon the Vinini at Tyrone Gap and probably also in the Twin Spring Hills.

On the west side of Charnac Basin, at Whiterock Canyon narrows (loc. 13) and in the Twin Spring Hills, graptolitic shales and cherts of the Vinini override the Pogonip; near Devils Gate pass and in the Mahogany Hills the Vinini is thrust over Middle and Upper Devonian Devils Gate limestone and Mississippian rocks of the Chainman-Diamond Peak sequence. Details of these outliers and their stratigraphic relations are discussed below under description of western graptolitic facies.

The Vinini formation with its graptolitic facies was probably deposited in a western subprovince of the Great Basin wholly distinct from that in which the normal or eastern carbonate Ordovician was laid down. The writer's present paleogeographic and paleotectonic conception calls for great shortening of the Earth's crust west of the Antelope Valley belt. West to east movement of the upper plate is clearly to be measured in tens of miles, probably no less than 35 miles and possibly at least twice this figure.

Scattered masses of resistant silicified breccia with flat distribution mark the sole of the Roberts Mountains thrust at places where the upper plate has been almost entirely removed by erosion. Breccia masses of this kind are associated with the thrust west of Charnac Basin and in the Twin Spring Hills at the north tip of the Monitor Range. Large outcrops of unsilicified limestone breccia lie on the east side of Antelope Valley, 4 miles south of Lone Mountain (pl. 1., loc. 88). Flat distribution suggests that it also may be a product of thrusting. However, these isolated limestone breccias pertain to the Devils Gate limestone and, in part at least, represent the noncataclastic depositional limestone mud breccias so characteristic of that formation in the Mahogany Hills area.

Of innumerable high-angle and normal faults in this area, only those producing the most obvious stratigraphic displacements are shown on the accompanying reconnaissance maps (pls. 1, 2). Among these faults is the northwestward-striking Ninemile Canyon fault along which Goodwin limestone together with overlying Ninemile formation abuts against the Upper Cambrian Windfall.

In addition to range-front faults, like those along the western Antelope Range, several interior faults and fault zones have influenced geomorphic sculpture appreciably. Examples are the Ninemile Canyon fault zone and the Copenhagen Canyon fault zone. A geomorphically similar zone of late faulting probably follows Yahoo Canyon southward through Dry Lake.

PALEONTOLOGIC STUDIES

Nowhere in western North America is a record of Paleozoic marine life more amply preserved than in the region bounded on the north by the Roberts Mountains, on the west by the northern Monitor Range, and on the east by the Diamond Mountains (fig. 2). Within this broad region the Eureka district is known above all for its Cambrian and upper Paleozoic faunas and the Roberts Mountains especially for Silurian and Lower through Middle Devonian. Antelope Valley excells in the richness of its Ordovician and Devonian faunas, ranging in both systems from very early to late stages.

The stratigraphic paleontology of the Cambrian and upper Paleozoic are briefly touched upon in this report, as it has recently been dealt with in connection with the work at Eureka (Nolan, Merriam, and Williams, 1956, p. 5–23; 54–68). Large fossil collections were

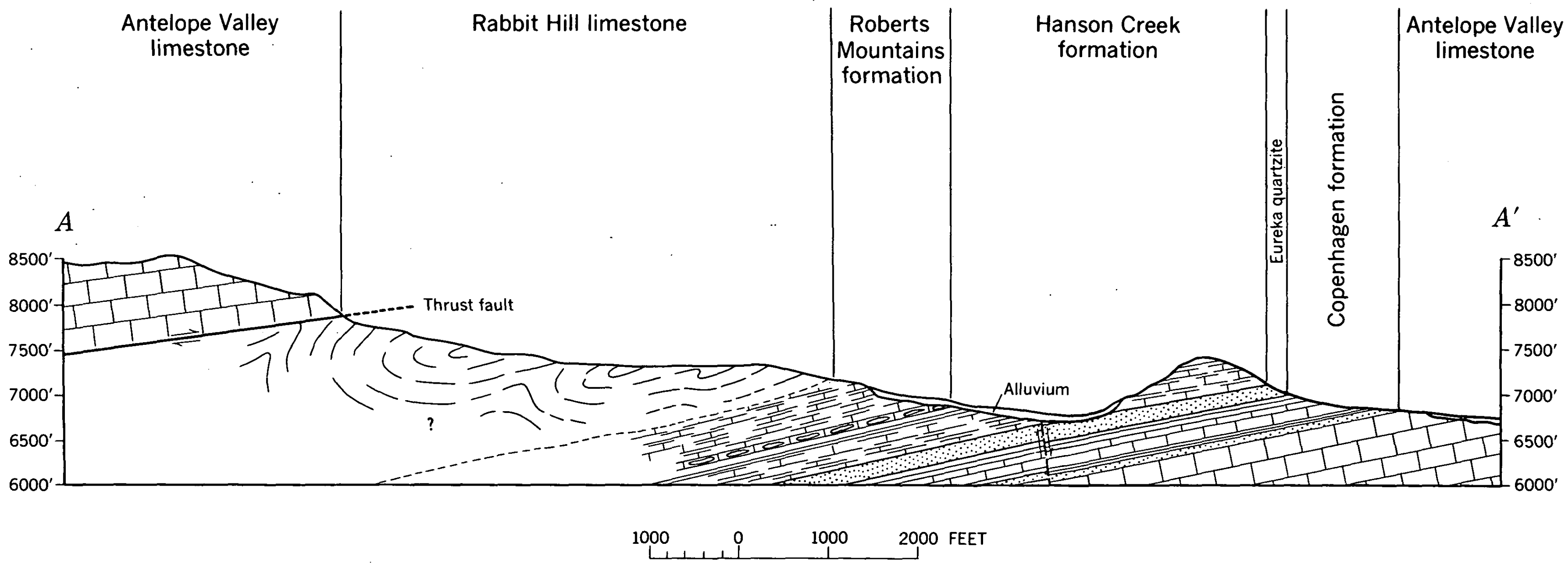

Figure 4.—Section along line *A–A′* at Copenhagen Canyon, Monitor Range, showing thrust relationship of rocks of the Pogonip group over Lower Devonian Rabbit Hill limestone. See plate 2 for location of section.

made from five Ordovician formations. A preliminary study of these fossils has been made to establish stratigraphic demarcation. Least fossiliferous are the Silurian rocks of Antelope Valley, which are in large part dolomite. Recently, however, small lenses of dark carbonaceous Silurian dolomite were found to contain excellent silicified material, which thus opens a new approach to study of these strata.

Walcott (1884, p. 4; p. 270–273; p. 284–285) called attention to the richly fossiliferous Ordovician strata ("Lower Silurian" of 1884) of this region, and as an outcome of his collecting near Wood Cone (pl. 1), appears to have been the first to record the presence of Late Ordovician (Richmond) fossils in the Far West. Beginning in 1928, with a visit by Edwin Kirk (1933; 1934), several Ordovician collections were made in the northern Antelope and Monitor Ranges by U.S. Geological Survey and Smithsonian Institution parties. Brachiopod materials collected by Edwin Kirk, G. Arthur Cooper of the Smithsonian, and the late Josiah Bridge of the U.S. Geological Survey, together with those obtained by the writer, have in part been treated by Cooper (1956) in a memoir on Chazyan and related brachiopods. An earlier contribution on Ordovician brachiopods by Ulrich and Cooper (1938) describes several species obtained from Pogonip rocks of Antelope Valley. Whittington (1948, p. 567) began detailed work on Antelope Valley Ordovician trilobites with a special study of the diagnostic Ninemile form *Kirkella vigilans*. A study by Kirk (1930) of the remarkable gastropod genus *Palliseria* from the Monitor Range and other Great Basin localities established the stratigraphic range of an important Ordovician indicator of the Cordilleran belt.

The practical objective of this report is to record the stratigraphic occurrence of common fossils that aid in establishing vertical order in the Ordovician column and in correlating with other western sections. Preliminary review of the Ordovician faunas shows that most of the systematic and descriptive work lies ahead. Distinctive forms in nearly all the Ordovician zones described bear morphologic resemblance to species described from eastern North America and more remote regions, thus providing a basis for provisional long-range geologic correlations.

During this investigation a great part of the paleontologic study was concentrated on three of the four Devonian formations, as part of a general program in progress since 1933. During this period an attempt has been made to establish workable faunal zones in the Roberts Mountains area, at Lone Mountain, and in the Eureka district (Merriam, 1940; Nolan, Merriam, and Williams, 1956). Systematic studies of special biologic groups have been undertaken, especially the brachiopods and rugose corals. Effort has been made to obtain stratigraphically zoned coral collections, relating the biologic changes to factors of ecology and sedimentation. Taxonomy of many of these Devonian corals has been treated in valuable contributions by Erwin C. Stumm (1937; 1938; 1940).

Brachiopods have proved thus far to be the most useful fossils for stratigraphic zonation and correlation of Devonian strata in this region. Dependable key forms of very wide geographic distribution are *Stringocephalus*, *Rensselandia*, the *Leptocoelia* group, and spirifers of the *arenosa* group. Of the many distinctive Devonian brachiopod species collected in the central Great Basin, only a small minority have been described or studied.

Other Devonian invertebrate groups present in abundance, but almost unstudied by specialists, are the stromatoporoids, Bryozoa, and Ostracoda. Conodonts, common in the lower port of the Pilot shale, are present also in lower horizons of the Devonian column. Except for routine determinations, these remain almost unstudied.

In conjunction with the Antelope Valley stratigraphic work, a monographic study of Lower Devonian faunas was undertaken, with special emphasis on the Rabbit Hill limestone of Helderberg age and Oriskany faunas of the lowermost Nevada. Initial objective of this project was to determine the stratigraphic position of the Rabbit Hill relative to the Nevada, for the two were not found in the same section.

Among unresolved paleontologic questions disclosed by this investigation are those of paleoecology. Foremost is that of the true significance of graptolite shale facies and the nature of physical and bio-environmental factors controlling loci of black shale deposition, while seemingly contemporaneous carbonate sediments with contrasting shelly faunas accumulate elsewhere. These problems are uppermost when attempts are made to equate the Ordovician Vinini formation with units of the Pogonip group, and are met again in connection with stratigraphy and correlation of the Copenhagen formation, the Hanson Creek formation, and the Roberts Mountains formation.

The richly fossiliferous Nevada formation and the Devils Gate limestone are likewise promising fields for biofacies and population study. As noted elsewhere the environments of sedimentation and faunas of the lower part of the Nevada change almost completely between the Diamond Mountains on the east and the Lone Mountain-Antelope Valley belt to the west. Restricted or local environments of profuse coral growth in both the Nevada formation and the Devils Gate limestone lend themselves to eventual biofacies research. Finally, the conodont facies of the Pilot shale indicate a special environment worthy of investigation.

Correlation of the Devonian rocks at Antelope Valley with other sections in the Great Basin and in the Far West has been facilitated by large collections made in other areas by the writer for purposes of comparison. Exclusive of many sections in central Nevada, these areas include the southern Shell Creek Range in Nevada, the Inyo Mountains in California, and the Klamath Mountains region of northern California.

Fossils collected during the field seasons of 1940 and 1941 form the principal basis for provisional faunal lists here included. These collections, originally at Cornell University, have been transferred to the U.S. National Museum through the courtesy of W. Storrs Cole. Additional collecting in 1948, 1950, and 1954 provided material now deposited in the Menlo Park laboratory of the U.S. Geological Survey.

THE PALEOZOIC COLUMN AT ANTELOPE VALLEY

Seventeen formations compose the Paleozoic column at Antelope Valley. Fourteen of them are normally superposed (table 1) and constitute what is here referred to as the normal stratigraphic section. Of the three remaining, the Vinini formation of Ordovician age occurs only in thrust outliers, the Lower Devonian Rabbit Hill formation is a western unit thus far recognized with certainty only in the Monitor Range, and the Permian Garden Valley formation makes up isolated exposures in the Twin Spring Hills and at Lone Mountain and is seemingly associated everywhere with overthrust rocks of the Vinini formation.

Distribution of the normal section formations with respect to geologic system is as follows: Upper Cambrian, 1 formation; Ordovician, 6; Silurian, 2; Devonian, 2; combined Devonian and Early Mississippian, 1; and Mississippian, 2. Of the systems well exposed in this belt, the Ordovician is the most diverse with respect to rock type and faunal differentiation.

Twelve of the normal Antelope Valley Paleozoic formations are present also in the Eureka mining district, although significant facies differences are introduced between the two areas. For example, dolomitization, which locally affects all parts of the carbonate Silurian section, makes it difficult to differentiate beds of the Roberts Mountains formation from the Lone Mountain dolomite. Such appears to be true at Eureka (Nolan, Merriam, and Williams, 1956, p. 37). Unrecognized in the Eureka area are the Copenhagen formation and the Rabbit Hill limestone (Helderberg). The western facies overthrust beds of the Vinini just reach the edge of the Eureka district near Devils Gate.

Four of the units here described are either newly designated or have recently been defined in connection with the Eureka studies (Nolan, Merriam, and Williams, 1956). These divisions, each with type section designated in the Antelope Valley area, are the Ninemile, Antelope Valley, and Copenhagen formations of the Ordovician system, and the Lower Devonian Rabbit Hill limestone. Unrecognized thus far outside of the Antelope Valley area is the Copenhagen formation.

The Upper Cambrian Windfall formation and the Lower Ordovician Goodwin limestone were defined in revision of the stratigraphy of Eureka, Nev., where the Goodwin is the lowest unit of the emended Pogonip group.

The Ordovician, 4,300 feet thick, and the Devonian, about 4,200 feet thick, are in the physical and paleontologic sense especially full. The Silurian, 2,200 feet thick, about half the thickness of the others, shows far less faunal diversity, partly owing to the fact that most of it is dolomite and contains fewer identifiable fossils.

Carbonate rocks predominate in the normal stratigraphic column from Upper Cambrian through the Devonian system. The Eureka quartzite is a notable exception; in fact, the vertical change from limestone of the Pogonip to clean quartz sand is one of the more striking shifts of its kind in Cordilleran Paleozoic history. Following abrupt readjustment to marine carbonate conditions at the end of the Eureka cycle there were occasional but relatively rare and localized recurrences of pure quartz sand deposition in the Silurian and Devonian.

TABLE 1.—*Normal stratigraphic section at Antelope Valley, Nev.*

Age		Group or formation		Thickness (feet)
Mississippian		Chainman shale and Diamond Peak formation, undifferentiated [1]		
Devonian	Upper	Lower part of the Pilot shale [2]		75+
	———?———	Devils Gate limestone [2]		1,200
	Middle	Nevada formation [2]		2,500
	Lower			
		———Disconformity [3]———		
Silurian		Lone Mountain dolomite [2]		1,570+
		Roberts Mountains formation		600+
Ordovician	Upper	Hanson Creek formation		350
	———?———	Eureka quartzite		150+
	Middle	Copenhagen formation		350
	———?———	Pogonip group	Antelope Valley limestone	1,100
	Lower		Ninemile formation	550
			Goodwin limestone	1,800
Cambrian	Upper	Windfall formation		300+

[1] Upper part of the Pilot shale and Joana limestone unrecognized.
[2] Unrecognized on west side of Antelope Valley.
[3] Rabbit Hill limestone (Helderberg) unrecognized in normal stratigraphic section; present only on west side of Antelope Valley.

The Mississippian period brought a return to widespread and persistent deposition of silicious clastic sediments on a scale comparable to that of the Early Cambrian. In the central Great Basin these conditions persisted with only occasional deposition of impure sandy-silty carbonate into Permian time.

As our geologic understanding of this region increases with mapping progress, problems of sedimentary facies come increasingly to the fore. Our Antelope Valley studies, in conjunction with simultaneous work in the Eureka vicinity, elucidate certain of these lateral environmental changes, particularly in the Pogonip group, the Eureka quartzite, and the Nevada formation. For example, the interval occupied by most of the Eureka quartzite to the north and east is filled in Antelope Valley by partly calcareous beds. Again, highly fossiliferous lower shale and impure limestone beds of the Nevada in the Antelope Valley belt are replaced east of Eureka by nearly barren dolomite and quartz sand deposits, to which local member names have been given.

Germane to the facies problem is that of primary dolomitization. Areal and vertical changes from limestone to dolomite, or the reverse, enter into questions of stratigraphic differentiation and nomenclature in the Ordovician, Silurian, and Devonian, wherein carbonates predominate. For example, the Hanson Creek, typically a limestone, passes into dolomite eastward from Wood Cone toward the Eureka area. Similarly the Silurian Roberts Mountains formation, prevailingly limestone to north and west, becomes dolomite at Lone Mountain and eastward in the Eureka vicinity. Geographically shifting loci of dolomitic replacement in the Nevada and Devils Gate Devonian are treated elsewhere. Also considered below is the problem of possible westerly facies change from uppermost Lone Mountain dolomite into Rabbit Hill limestone.

System limits, subjective and discretionary at best, remain provisional in this belt of continuous geosynclinal accumulation. The Antelope Valley Paleozoic column clearly shows the period-to-period biologic changes, which are the traditional basis for rock system delimitation; the harmonizing of biologic changes and ranges with discrete rock boundaries, as conceived for the ideal world rock system, is less obvious in some places. Searching analysis and comparison of borderline faunas from this region with those of eastern America and the Old World are needed. Some border strata are subject to adjustment or possible system reassignment. An example is the borderline *Caryocaris* shale, placed tentatively in the Ordovician system on a paleontologic basis, but possibly in the physical sense a facies of a unit elsewhere classed as Late Cambrian.

Assignment of the Hanson Creek formation and its Richmond faunas to Late Ordovician rather than Early Silurian awakens an unresolved boundary question. The Silurian-Devonian boundary is likewise not well fixed at the Lone Mountain-Nevada contact, and may eventually be found to fall within the uppermost Lone Mountain dolomite. As viewed at present, the Devonian-Carboniferous boundary at Antelope Valley is more than ordinarily subjective and is based on questionable paleontologic criteria. It now falls at some indefinite horizon within the Pilot shale, where delineation would appear to depend on future studies of Pilot conodont assemblages.

CAMBRIAN SYSTEM

GENERAL FEATURES

The Cambrian system is poorly exposed at Antelope Valley. Only in the northern Antelope Range has erosional downcutting penetrated deep enough to reach the top of the system. Older Cambrian rocks are undoubtedly present in depth, for 25 miles northeastward at Eureka 8 formations, ranging from Early to Late Cambrian, constitute one of the more complete records of this system in western North America. That so full a column ends near Eureka is scarcely conceivable, yet to the west in these latitudes few outcrops of Cambrian strata have been identified. Westward continuity of the system in depth is suggested by Lower Cambrian rocks of the Toiyabe Range west of Round Mountain (fig. 2) as reported by Ferguson (1954) and in the Osgood Mountains and Hot Springs Range as reported by Roberts and others (1958).

Upper Cambrian beds of the Windfall formation are exposed on the east side of Ninemile Canyon, where they occupy a narrow strip bounded on the west by the Ninemile Canyon fault, and pass eastward downdip beneath Lower Ordovician Goodwin limestone (pl. 2; fig. 5). Sheared strata, which remain unidentified within the Ninemile Canyon fault zone, may well include Dunderberg shale, normally to be expected below Windfall.

WINDFALL FORMATION

GENERAL FEATURES

Type section of the Windfall formation is in Windfall Canyon, Eureka mining district, where it comprises 650 feet of limestone, shale, and chert resting conformably on Dunderberg shale; it is succeeded without discordance by the Goodwin limestone (Nolan, Merriam, and Williams, 1956). The type Windfall includes two units, the Catlin member below and the Bullwhacker above. Hague's (1883; 1892) "Pogonip limestone" embraced these Upper Cambrian strata, excluded by us from the revised Pogonip group. Beds in Antelope Valley assigned to the Windfall formation are similar lithologically to the Catlin member at Eureka (figs. 5 and 6). The Bullwhacker member has not been recognized. Instead, strata similar lithologically to the Catlin are overlain by a shale unit not recognized in the Eureka area.

LITHOLOGY AND STRATIGRAPHY

The Windfall formation as exposed in Ninemile Canyon consists largely of medium to fine-grained platy impure sandy and silty limestone beds of medium to dark-gray. Dark-gray to black chert occurs in fairly even interbeds several inches thick. An 8-foot chert zone, 90 feet below the top of the formation, includes a small amount of limestone. Especially distinctive of the formation at Ninemile Canyon, but of the lower or Catlin member only at Eureka, are laminated chert layers which reveal a rhythmic alternation of light and dark-gray millimeter-thick laminae. Laminated chert layers are most numerous in the upper part of the Windfall at Ninemile Canyon. In the type Windfall section at Eureka chert layers appear to be limited to the lower half of the lower or Catlin member.

Heavy-bedded highly fossiliferous rather coarse-grained limestone units that are prominent in the Catlin member at Eureka were not recognized in the section at Ninemile Canyon. One of these is the basal massive light-gray limestone of the Catlin bearing a fauna re-

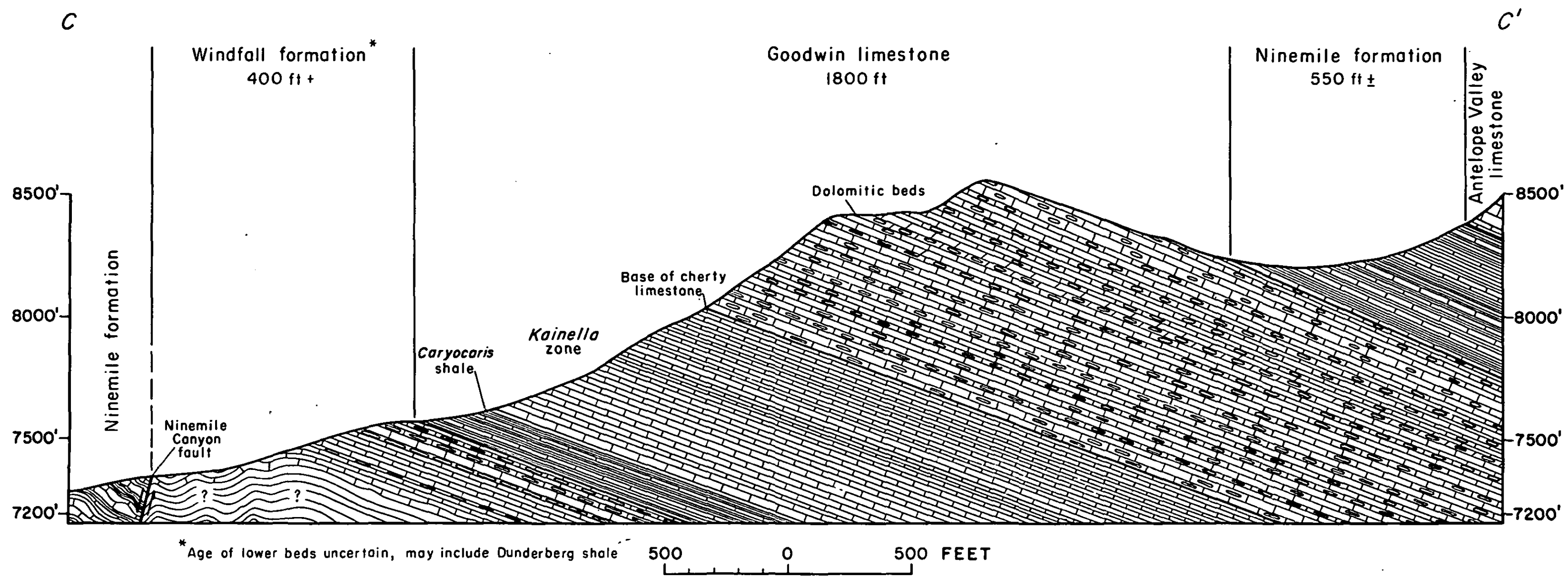

Figure 5.—Section along line *C–C'* at Ninemile Canyon, Antelope Range, showing Upper Cambrian and Ordovician formations. See plate 2 for location of section.

lated closely to that of the underlying Dunderberg shale.

Only about 300 feet of Windfall was measured in the Ninemile Canyon section, because the lower parts of these strata are deformed. Dislocated beds east of the Ninemile Canyon fault (fig. 5) may include over 250 feet of the lower part of the Windfall and possibly, Dunderberg shale.

AGE AND CORRELATION

Identification of these beds as Windfall formation is based largely on the distinctive laminated chert. Fossil collections made by A. R. Palmer (written communication, 1959) from the lower silty limestone layers at Ninemile Canyon contain *Bienvillia* cf. *B. corax* Billings, *Plicatolina* sp., and *Lotagnostus trisectus* (Salter). *Bienvillia* and *Lotagnostus*, although represented by different species, are common in the middle part of the Catlin member of the Windfall formation near Eureka (Nolan, Merriam and Williams, 1956, p. 22).

Studies of type Windfall fossils by G. Arthur Cooper of the U.S. National Museum and by A. R. Palmer of the U.S. Geological Survey (Nolan, Merriam, and Williams, 1956; Palmer, 1955) make possible a three-fold zonation. Two of the zones are in the lower or Catlin member, the third corresponds to the Bullwhacker member. According to Palmer massive limestones of the lowermost Catlin contain *Pseudagnostus prolongus* (Hall and Whitfield) together with species of *Elvinia* and *Irvingella*, a fauna differing but slightly from that of the underlying Dunderberg. Remainder of the Catlin bears a fauna with *Bienvillia corax* (Billings), *Tostonia iole* (Walcott), and species of *Eurekia*, *Lotagnostus*, *Geragnostus*, and *Pseudagnostus*.

Palmer regards the upper Catlin fauna as late Late Cambrian (*Trempeleau*); while the Bullwhacker, with *Elkia nasuta* (Walcott) and *Eurekia granulosa* Walcott, is considered by him to correlate with slightly younger horizons of the Trempeleau.

Catlin brachiopods determined by Cooper include species of *Lingulella* and *Finkelnburgia*. In the Bullwhacker he has recognized *Homotreta eurekensis* Ulrich and Cooper, *Elkania hamburgensis* (Walcott), *Westonia iphis* (Walcott), *Conodiscus burlingi* (Kobayashi), and *Xenorthis* n. sp.

The shale unit termed "*Caryocaris* shale", which overlies the Windfall formation in Ninemile Canyon, seems to occupy the interval of the upper part of the Windfall or Bullwhacker member in the Eureka district (fig. 6). Conceivably the shale may be either a Late Cambrian shale facies of Bullwhacker age, or alternatively, younger than Bullwhacker and therefore early Ordovician rather than Late Cambrian. Paleontologic evidence would favor Ordovician assignment, for *Caryocaris* is seemingly unknown in rocks of Cambrian age. No graptolites have been found in this black shale.

ORDOVICIAN SYSTEM

GENERAL FEATURES

The Ordovician system is especially well represented at Antelope Valley. Six formations, or about 4,300 feet of prevailingly carbonate sediments make up the normal section, and range from Early Ordovician to Late Ordovician (Richmond) age. Graptolite-bearing sediments not present in the normal carbonate sequence, comprise an additional major division known as the Vinini formation.

The normal Ordovician sequence is as follows:

		Feet
Hanson Creek formation	Late Ordovician	350
Eureka quartzite	Middle and Late Ordovician.	150
Copenhagen formation	Middle Ordovician	350
Pogonip group:		
Antelope Valley limestone.	Early and Middle Ordovician.	1, 100
Ninemile formation	Early Ordovician	550
Goodwin limestone	do	1, 800
		4, 300

At Antelope Valley no significant vertical discontinuities have been detected in this column. Elsewhere in the central Great Basin there is evidence of possible hiatus at the top of the Eureka, and particularly to the north, where the Eureka is separated by disconformity from underlying rocks of varying age.

ORDOVICIAN SYSTEM BOUNDARIES

Depositional history of the region reveals no evidence that either Cambrian or Ordovician were interrupted by diastrophic events. Failure to recognize physical boundary features and virtual continuity of marine deposition from one period to the other places the burden of system delimitation upon paleontological judgment. As here adopted the subjective system boundaries based on paleontologic evidence may sometimes require arbitrary adjustment to local requirements of geologic mapping on a strictly lithologic basis. In actual mapping, a system boundary determined by ranges of fossils is likely to fall somewhere within a formation, or lesser unit, rather than at its exact top or bottom.

In the Eureka district (Nolan, Merriam, and Williams, 1956, p. 23–25, 26–27) the lower limit of the Ordovician system may be interpreted paleontologically as falling somewhat above the base of the Goodwin limestone, for fossil holdovers of established Cambrian affinity cross the lithologic contact into the basal 20 feet or so of that formation. Above the lowermost Goodwin fossil zone there is no recurrence of fossils of Late Cambrian age and the acknowledged Ordovician *Kainella-Nanorthis* fauna is present. In mapping, the base of the Goodwin limestone is considered as base of the Ordovician system in spite of Cambrian holdovers.

In Antelope Valley, where the boundary rocks differ from those at Eureka, the Cambrian-Ordovician line is placed between the Windfall formation and the overlying dark-gray shale with *Caryocaris*, a unit not found in the Eureka area (fig. 6). Though provisicnally classed as Ordovician and included with the Goodwin, the systemic position of these dark shale beds is inconclusive. The small phyllocarid crustacean *Caryocaris*, which these shales contain, is unknown in rocks of Cambrian age, but occurs generally in association with the Vinini Ordovician graptolite faunules.

The Ordovician-Silurian boundary is likewise drawn mainly on faunal criteria, the appearance of *Monograptus* and pentamerid brachiopods. Although not everywhere recognizable in the Great Basin, a highly distinctive cherty limestone commonly marks the basal Silurian in the area under consideration.

FACIES PROBLEMS

Study of Antelope Valley Ordovician rocks in comparison with those of adjoining areas brings sharply in focus the complexities of lateral facies change. As areal mapping becomes more refined and brings fuller appreciation of the intricate relations of deposition there is a corresponding need for realistic nomenclature to express these complexities. The scheme of stratigraphic classification inevitably becomes more involved.

Between Eureka and Antelope Valley, a distance of about 12 miles, significant lateral changes are evident in most of the Ordovician units. Facies changes became evident in the boundary rocks when an attempt was made to relate the Cambrian-Ordovician boundary at Eureka with that in Antelope Valley (fig. 6). With reference to the Eureka quartzite-Copenhagen interval, the lithologic changes are especially remarkable as these rocks are followed westward. Lithologic boundaries shift vertically up or down relative to imaginary time-stratigraphic datum planes postulated on a paleontologic basis.

Normal marine carbonate facies predominate in the Antelope Valley Ordovician rocks. With these may be contrasted the little-understood marine depositional environments represented in graptolitic shale outliers. A third distinctive facies is the vitreous Eureka quartzite. These unfossiliferous partly crossbedded sands may represent very shallow marine or marginal beach-dune accumulation, but the possibility of continental depositation is also not unreasonable.

A provocative facies problem of this region involves the Vinini formation of Early and Middle Ordovician age in relation to the normal carbonate sequence. The Vinini strata comprise graptolitic shale, chert, arenaceous deposits, limestone, and basic volcanic rocks that occur as thrust outliers. Depositional interrelations of the Vinini and the normal carbonate facies remain to be worked out. On the basis of paleogeography the Vinini facies probably represent a western Great Basin marine subprovince, whereas the normal carbonate facies are probably characteristic of an eastern subprovince.

Great geographic extent is noteworthy in connection with certain Ordovician rock units of the Antelope Valley area. This applies to the remarkable Eureka quartzite and especially to the overlying carbonate formation of Late Ordovician age, traceable throughout most of the Cordilleran belt. Strata of the Pogonip time interval, though widely recognized in the Great Basin outside of the central Nevada region, vary lithologically from place to place to such extent that we hesitate to apply the central Nevada or type area formation names. On the other hand most of the major Pogonip faunal zones recognized at Antelope Valley and Eureka are traceable throughout the extent of these rocks in the Great Basin and adjacent regions (fig. 6). Several of these faunal zones have in fact been correlated rather closely with stages in eastern North America.

POGONIP GROUP

The Pogonip group, which is mainly limestone at Antelope Valley, comprises some 3,450 feet of strata classified in three formations as follows:

	Thickness (feet)
Antelope Valley limestone	1,100
Ninemile formation	550
Goodwin limestone	1,800
	3,450

Pogonip group as adopted conforms to a redefinition at nearby Eureka, Nev. (Nolan, Merriam, and Williams, 1956, p. 23–29), which includes only those Ordovician rocks between the top of the Late Cambrian Windfall and the base of the Eureka quartzite.

Clarence King (1878, p. 187–189) introduced the name "Pogonip limestone" for an estimated 4,000 feet of strata at the north end of Pogonip Mountain, White Pine mining district. These strata overlie quartzites correlated by King with what is today known as Prospect Mountain quartzite at Eureka, Nev. King was unable to assign a specific upper limit to the type Pogonip, because of alluvial cover. He therefore alluded in the initial description to the Eureka, Nev., section (King, 1878, p. 189), where the base of a conspicuous

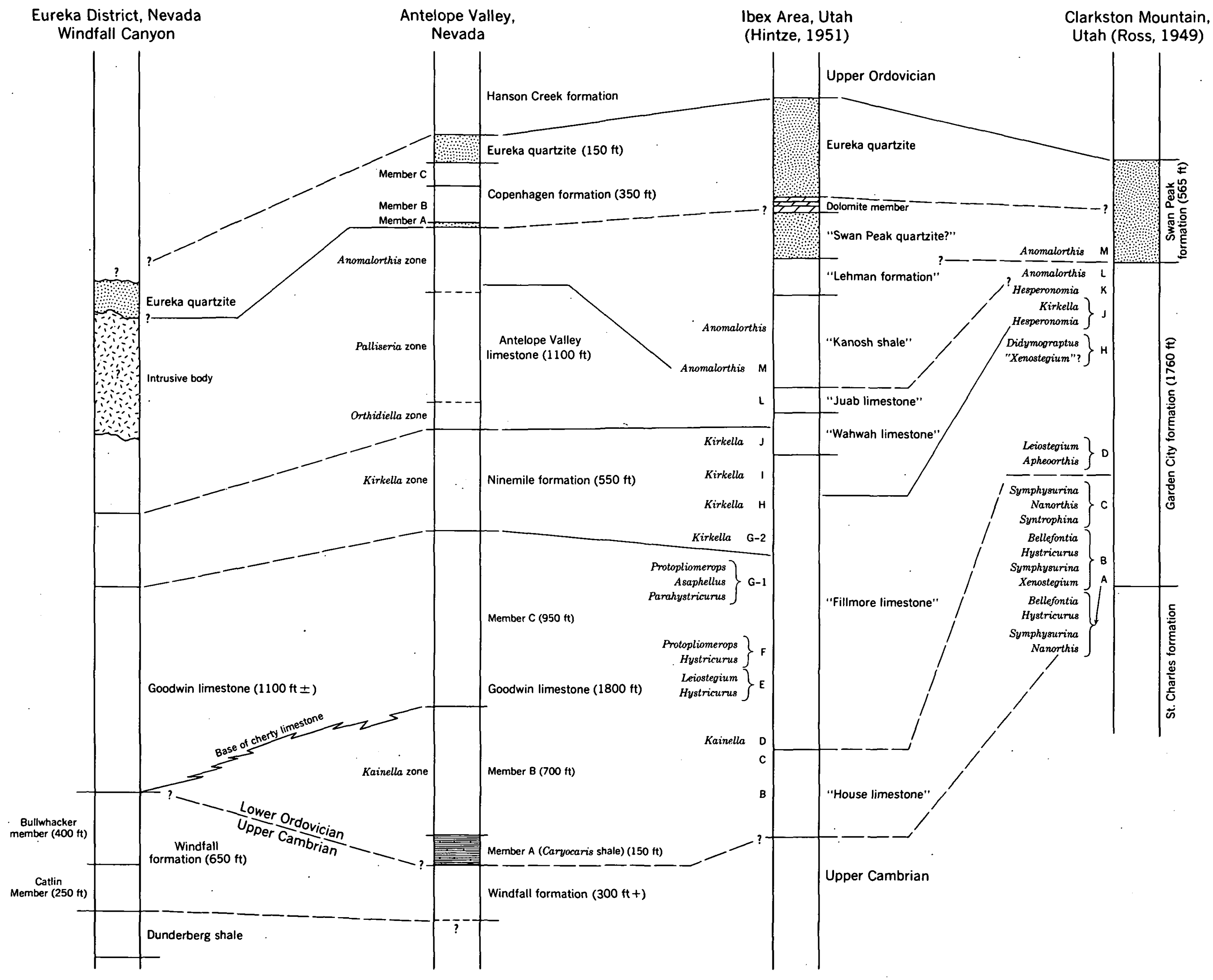

FIGURE 6.—Correlation diagram showing possible age relationship of Ordovician rocks of Eureka and Antelope Valley, Nev., to those of described sections in Utah.

upper quartzite, termed by him "Ogden quartzite," formed a natural top. In the Eureka district, the "Ogden quartzite" of King is the Eureka quartzite of present-day usage. At other localities, such as the Sulphur Spring Mountains south of Mineral Hill (King, 1878, p. 191, 193), the "Ogden quartzite" mentioned by King is probably in part the Devonian Oxyoke Canyon sandstone member of the Nevada formation (Nolan, Merriam, and Williams, 1956, p. 43). Occurrence of Devonian fossils at that locality may have led King to a general Devonian age assignment for those rocks in central Nevada classed by him as "Ogden quartzite" (King, 1878, p. 195).

King believed the original "Pogonip limestone" to be 4,000 feet thick and divisible into a lower and an upper half; the lower half containing "Primordial," or Cambrian, fossils seemingly passed below into shale and quartzite. Near the top of the upper division 2,000 feet thick, these rocks yielded "Quebec" faunas, today regarded as Ordovician.

At Pogonip Mountain and at Eureka, the definition of "Pogonip limestone," as presented by King in his Systematic Geology can be interpreted as broadly applicable to all rocks that lie between Prospect Mountain quartzite of Early Cambrian age and the Eureka quartzite of Middle to Late Ordovician age. Such broad and inclusive usage has not, however, been generally adopted.

Disadvantages of King's original definition of the Pogonip as well as his untenable use of "Ogden quartzite" were evidently understood by Arnold Hague, also of the Fortieth Parallel Survey. Hence, a few years later, describing the rocks of the Eureka district in more detail, Hague introduced appropriate emendations and adjustments, wisely excluding most of the "Primordial" or Cambrian half of the original "Pogonip limestone" as defined by King.

Experience has demonstrated that the Cambrian part of King's type Pogonip would have been ill chosen as a standard Cambrian column for the central Nevada region. Compared with the 6,000-foot Cambrian section overlying the basal quartzite at Eureka, the Pogonip Mountain Cambrian measured by King would appear greatly thinned, probably by faulting and subsequent erosion.

Hague (1883, p. 260; 1892, p. 48) thus applied the emended name Pogonip limestone to strata underlain by what is now called Dunderberg shale of Late Cambrian age (Wheeler and Lemmon, 1939, p. 26) and overlain by the Ordovician Eureka quartzite. The redefinition by Hague at Eureka, Nev., has been the only generally accepted interpretation.

Revision of the Eureka district Ordovician (Nolan, Merriam, and Williams, 1956, p. 23–36) and the coordinated Antelope Valley study depart narrowly from the Hague definition, mainly by restricting the name Pogonip to post-Cambrian rocks and by elevating it to group rank with three mappable formations. We have accordingly excluded from Pogonip those Late Cambrian rocks now called Windfall formation, which constituted the lowermost part of Hague's Pogonip limestone at Eureka.

Many years of accepted usage of Pogonip, as redefined by Hague, would favor retention of the name in application to a group. Such a course seems preferable in this case to complete abandonment of the name, or its restriction to one of the three described formations.

In Antelope Valley, though not at Eureka, about 350 feet of shale, siltstone, and limestone, herein named Copenhagen formation, occupies an interval between Eureka quartzite and the uppermost formation of the Pogonip group (figs. 6 and 7). The Copenhagen is excluded from the Pogonip group because of its absence in the Eureka district, where the standard section of the redefined Pogonip is located. Moreover, the Copenhagen is probably a facies equivalent of the middle and lower parts of the Eureka quartzite.

GOODWIN LIMESTONE

GENERAL FEATURES

As the lowermost formation of the Pogonip group at Eureka, the Goodwin limestone emended lies between the Windfall formation of Late Cambrian age and the Lower Ordovician Ninemile formation. The type section (Nolan, Merriam, and Williams, 1956, p. 25) is in Goodwin Canyon 1½ miles southwest of Eureka.

Goodwin limestone, redefined as a lithologic division, is less inclusive than the original Goodwin limestone of Walcott (1923, p. 466–467, 475), which was never actually used as a map unit. As originally proposed, the formation consisted of approximately the lower 1,500 feet of Hague's Eureka district "Pogonip limestone," or that part which in Walcott's view represented the vigorously sponsored but never widely acknowledged "Ozarkian System." In conformity with accepted American standards our paleontological studies indicate that Walcott's Goodwin embraced several hundered feet more of Ordovician than of Upper Cambrian. The Cambrian part consisted mainly of beds that are here called Windfall formation and which are poorly exposed in Goodwin Canyon. On the other hand those Lower Ordovician rocks that comprise emended Goodwin are very well shown in that locality.

As emended, the Goodwin limestone is a mappable lithologic unit carrying highly distinctive faunas; these appear to characterize a natural faunal unit of province-wide distribution. Although the Windfall-Goodwin contact is lithologically sharp at Eureka, it does not coincide precisely with the paleontologic boundary between Cambrian and Ordovician. As indicated above, a few Late Cambrian fossils linger on into the basal 20 feet of the emended Goodwin.

Kainella-bearing Goodwin limestone at Ninemile Canyon is underlain by carbonaceous shales of uncertain age. These boundary beds are provisionally included with the Ordovician as the basal part of the Goodwin.

AREAL DISTRIBUTION

The largest exposures of Goodwin limestone at Antelope Valley occur in the northern Antelope Range, where these beds underlie a wide belt along the lower western slopes from Ninemile Canyon southward, and occupy much of the higher medial part of the range north and east of Ninemile Canyon (pl. 2). West of Antelope Valley known Goodwin is limited to a small area at the north end of Monitor Range, small exposures at Whiterock Canyon narrows, and an outlying hillock at the extreme northern tip of Martin Ridge (loc. 49). For continuity of section the Goodwin exposures east of Ninemile Canyon are among the best to be found in central Nevada and worthy of more careful study than has thus far been possible.

LITHOLOGY AND STRATIGRAPHY

Smooth, dark-gray carbonaceous clay shales and calcareous shales with *Caryocaris* compose the lower part of the Goodwin at Ninemile Canyon (fig. 5). On weathering these become light gray, resembling organic upper shales of the Vinini formation, but unlike the upper part of the Vinini are not known to contain chert. These shales are lithologically distinct from cherty shales of the Vinini in the range front outlier 1¼ miles northwest of the measured section (loc. 67).

Fairly pure, fine-grained subporcellaneous limestone predominates in the Goodwin of this area. This limestone is commonly of light to medium gray color on fresh fracture, but in some places is cream colored or pinkish. Weathered surfaces are light tan, buff, and limonite brown. The formation is on the whole well bedded; individual layers range from less than half an inch to about 2 feet thick. A few thinly laminated interbeds and argillaceous shale partings are light gray or greenish gray. Thin platy weathering is characteristic of the lower half of the formation. Interfaces between limestone layers and shale partings show lumpy and pitted features; at certain horizons worm tracks and castings are abundant.

Light-gray to whitish chert lenses and nodules become abundant near the middle of the formation. The chert-bearing lime tends to be thicker bedded than the chert-free variety with fewer shale partings. In the lower platy part of the formation, phosphatic and calcareous brachiopods and trilobite shells are common, becoming scarce in the heavier bedded cherty limestone beds above.

Although depositional contacts were not observed the *Caryocaris*, shale appears to be conformable with beds above and below in a continuous stratigraphic succession. As presently interpreted, the Cambrian-Ordovician boundary is either within or at the base of these shales (fig. 6).

Top of the Goodwin is marked in the Antelope Range by an abruptly gradational change to greenish-blue and dark-gray shale and limestone beds of the Ninemile formation.

Three lithologic subdivisions are distinguishable in the Goodwin limestone of Ninemile Canyon. In ascending order they are: member A, a basal dark-gray carbonaceous and partly calcareous shale, 150 feet thick, called the *Caryocaris* shale; member B, a middle thinly bedded, platy weathering limestone, 700 feet thick, containing very little chert; and member C, an upper interval, 950 feet thick, in which light-gray and white chert is fairly abundant and the thicker limestone beds form steep bold outcrops.

The middle thinly bedded unit resembles lithologically the Late Cambrian Bullwhacker member of the Windfall formation near Eureka, but it carries the distinctive Early Ordovician *Kainella* fauna. Scarcity of chert distinguishes these beds from the lower few hundred feet of Goodwin at Eureka which contain an abundance of light-gray chert. At Ninemile Canyon, cherts of this kind appear only in the upper 950-foot thick-bedded unit. Beds that are about half chert occur 1,000 feet stratigraphically above the *Caryocaris* shale. Evidently the bottom of the cherty facies transgresses time, becoming much younger westward from Eureka towards Antelope Valley (fig. 6).

Dolomitization is relatively unimportant in the Goodwin. Patches occur in a 130-foot interval of the upper cherty subdivision at Ninemile Canyon, beginning 450 feet below the top of the formation (fig. 5). In the Eureka area dolomite occurs about 300 feet above the bottom of the Goodwin.

THICKNESS

The measured Goodwin section at Ninemile Canyon is 1,800 feet thick, or about 800 feet thicker than the measured section at Eureka. Thicknesses of individual subdivisions in the Ninemile Canyon section are as follows: Lower *Caryocaris* shale (member A), 150 feet;

middle thinly bedded limestone unit (member B), 700 feet; and upper cherty limestone unit (member C), 950 feet. No measurement was possible on the west side of Antelope Valley, because of incomplete exposure of the Goodwin.

AGE AND CORRELATION

Only the small phyllocarid crustacean *Caryocaris* was found in member A, the lower shale unit. Fossils are numerous and diverse in member B but rather uncommon in member C.

As crustaceans of the *Caryocaris* type are unknown in the Cambrian and especially characteristic of Ordovician graptolite shales, the beds in question are provisionally classified as Early Ordovician. Previously it was considered likely that the shale beds were a facies of the upper part of the Windfall of Late Cambrian age (Nolan, Merriam, and Williams, 1956, p. 21). *Caryocaris* is abundant, unaccompanied by other forms. The phyllocarid is referred to *Caryocaris curvilata* Gurley, resembling most closely a variety in the graptolite shales of the Hailey guadrangle, Idaho, and figured by Ruedemann (1934, pl. 22). Comparison of the species from Ninemile Canyon with specimens of *Caryocaris curvilata* from the Garden Pass graptolite beds of the Vinini reveals notable differences. Those from Garden Pass are larger and have a proportionately longer carapace.

Absence of graptolites in the *Caryocaris* shale at Ninemile Canyon is difficult to explain, if these shale beds are actually of Early Ordovician age.

Early Ordovician age of member B, the 700-foot middle Goodwin zone, is established by the abundantly represented trilobite *Kainella.*

Common fossils of the *Kainella* fauna are:

Kainella cf. *flagricaudus* (White)
Apatokephalus finalis (White)
Moxomia cf. *angulata* (White)
Agnostus sp.
Nanorthis multicostata (Ulrich and Cooper)
Acrotreta cf. *eurekensis* (Ulrich and Cooper)
Obolus sp.
Lingulella sp.

R. J. Ross, Jr., (written communication, 1956) has recently made zoned fossil collections from Goodwin limestone at Ninemile Canyon, comparing them with Garden City faunas. A collection (USGS, D288 CO) from the lowest 20 feet of member B contains *Kainella* sp., *Apatokephalus* sp., and *Parabolinella* cf. *P. argentinensis* Kobayashi. It represents zone D or possibly an older horizon of the Garden City. From the top 30 feet of the Goodwin (USGS D297 CO) Ross obtained *Leiostegium* cf. *L. manitouenses*, *Hystricurus*? sp., *Apatokephalus* sp., and *Pseudonileus*? sp., an assemblage with zone D affinities. However, fossils that show affinities to Garden City zone F were collected 250 feet above the base of member B. This assemblage (USGS, D295 CO) listed below might be expected higher in the section, above rather than below that previously mentioned from the top 30 feet.

Goodwin limestone collection D295 CO

Kainella flagricaudus (White)
Apatokephalus sp.
Shumardia sp.
unidentified olenid trilobite
several agnostid trilobites
Protopliomerops cf. *P. superciliosa* Ross
Hystricurus sp., aff. *H. ravni* Poulsen

Fossil collections representing either high Goodwin or lowermost Ninemile formation were made from badly disturbed dark-gray limestone in Whiterock Canyon narrows on the west side of Antelope Valley. These deformed strata appear to underlie beds of the Ninemile. The assemblage includes: *Xenostegium*? cf. *X*? *belemnura* (White), small *Leiostegium*-like pygidia, *Obolus* sp., and *Nanorthis hamburgensis* (Walcott).

Zoned collections of Goodwin limestone fossils were made by the late Josiah Bridge of the U.S. Geological Survey and by G. Arthur Cooper of the Smithsonian Institution in Windfall Canyon, Eureka district (Nolan, Merriam, and Williams, 1956). These came mainly from the lower 130 feet of the formation, in which interval two faunal zones were recognized. The lower zone, occupying a few feet of fairly massive limestone at the base of the Goodwin, is characterized by the trilobite *Symphysurina* and a form related to the genus *Eurekia.* Brachiopods from this zone include *Nanorthis*, *Obolus*, *Plectotrophia*, and *Apheoorthis* (Cooper *in* Nolan, Merriam, and Williams, 1956, p. 26–27). As noted by Cooper, the *Eurekia*-like trilobite and possibly *Apheoorthis* suggest Late Cambrian, whereas *Symphysurina* and *Nanorthis* are regarded as Early Ordovician elements. Thus it seems appropriate to consider this basal zone, which could include roughly the lower 20 feet of Goodwin limestone, as latest Cambrian or earliest Ordovician.

The overlying faunal zone at Eureka is unquestionably Ordovician, yielding among the trilobites *Kainella*, *Apatokephalus*, *Symphysurina*, *Hystricurus*, and *Leiostegium* and the brachiopods *Nanorthis hamburgensis* (Walcott), *Punctolira punctolira* Ulrich and Cooper, and a *Syntrophina.*

The lowest or *Symphysurina* faunal zone with a holdover Late Cambrian *Eurekia*-like trilobite was not recognized in the Antelope Valley Goodwin section. It is older than the *Kainella* zone, which begins just above the *Caryocaris* shale (member A) in the Ninemile Canyon section. Hence the *Symphysurina* zone at Eureka is conceivably equivalent to some part of the *Caryocaris* shale (member A), which seems likewise to straddle the Cambrian-Ordovician boundary.

Most of the fossil collections made in the Eureka area came from the lower 130 feet of the Goodwin limestone. At Ninemile Canyon the upper cherty division, 950 feet thick, also yielded few fossils.

The Goodwin limestone may be correlated with *Kainella*-bearing beds in the lower part of the Pogonip group in the Ruby Mountains, Nev. (Sharp, 1942, p. 659). It correlates also with the lower part of the Ordovician section in the Ibex Hills, Utah (Hintze, 1951, p. 14, 36, 40), where beds with *Symphysurina*, *Kainella* and *Leiostegium* are present (fig. 6). Also correlative with Goodwin is the lower third, and possibly more, of the Garden City formation of Utah up through zone F (Ross, 1949, p. 479–481). *Nanorthis* and *Kainella* of the Goodwin indicate relation to the Mons and Chushina formations of the Canadian Rockies (Walcott, 1928, p. 224–226; Ulrich and Cooper, 1938, p. 23–26). Correlation with part of the Manitou formation of Colorado is also suggested. Of interest is evidence for correlation of the Mons and Chushina with the Cass Fjord formation of Greenland summarized by Poulsen (1937, p. 65–67).

Faunal evidence given by McAllister (1952, p. 11) suggests that the Goodwin interval is represented in Early Ordovician rocks of the northern Panamint area, California.

NINEMILE FORMATION

GENERAL FEATURES

The term Ninemile formation has been proposed (Nolan, Merriam, and Williams, 1956, p. 27) for Early Ordovician (approximately upper "Canadian") limestone and shale beds cropping out in the vicinity of Ninemile Canyon, Antelope Range. Type section of the formation is located 2 miles southeast of the mouth of Ninemile Canyon (pl. 2, loc. 56), where the formation rests conformably, and with apparent gradation upon Goodwin limestone and is in turn gradationally overlain by Antelope Valley limestone (fig. 5).

The shaly Ninemile formation, which is relatively unresistant to erosion, is inclined to occupy saddles or to form gentler slopes below cliffs and more rugged exposures sculptured in the overlying Antelope Valley limestone.

AREAL DISTRIBUTION AND LITHOLOGY

The most continuous Ninemile outcrops are found in the eastward-dipping section that forms the upper west slope of northern Antelope Range. From Ninemile Canyon the formation has been traced southward a distance of about 4 miles. Along the west foot of the range, smaller exposures lie in a separate westward-dipping structural block, which appears to represent the west limb of a faulted anticline. Ninemile exposures of smaller extent occur in the Monitor Range, where they are involved in structural complexities at the Whiterock Canyon narrows, 1.8 miles west of the Martin Ranch road. At locality 13, about 200 feet of dislocated beds of the Ninemile, dipping at low angles to the west, occupy a position near the base of a thrust plate. As Whiterock Canyon is traversed for half a mile east of locality 13, other exposures of deformed Ninemile are observed in fault contact with Lower Devonian Rabbit Hill limestone.

The Ninemile formation comprises medium-gray to olive-greenish-gray limestone beds, with gray to bluish-green partings and interbeds of calcareous shale and highly argillaceous limestone. The impure limestone beds are of fine-grained to porcellaneous texture. Also present are somewhat coarser grained light-grayish to tan crystalline sandy limestones and interbeds several inches thick of fine-grained calcareous quartz sandstone. In Whiterock Canyon narrows, east of locality 13, much of the exposed Ninemile is dark-gray argillaceous and calcareous shale. Fossils are fairly numerous and well preserved throughout most of the Ninemile formation at Antelope Valley, often weathering free from the olive-green argillaceous layers that separate limestone beds.

THICKNESS

At the type section on the east side of Ninemile Canyon, 550 feet of the Ninemile formation was measured (fig. 5). Elsewhere, as on the Monitor Range side of Antelope Valley, the thickness appears to be considerably less and nearer 200 feet, but these figures are unreliable because of the manner in which this incompetent shaly unit responded to deformation.

STRATIGRAPHY

Upper and lower limits of the Ninemile formation are gradational. As is well shown in the Whiterock Canyon narrows (loc. 13), the more shaly dark-gray Ninemile is separated from massive cliff-making limestones of the Antelope Valley by a tan or yellowish-weathering argillaceous limestone 75-feet thick, carrying the distinctive *Orthidiella* fauna. The *Orthidiella*-bearing limestone beds are regarded as the lowest division of the Antelope Valley limestone, although lithologically they appear to be intermediate. The fauna, however, is more closely allied to that of the overlying limestone than to the Ninemile below. In the Eureka area, the Ninemile is lithologically difficult to differentiate from rocks above and below, though it constitutes a readily recognizable faunal unit.

AGE AND CORRELATION

Early Ordovician age of the Ninemile formation is based on a large, well-preserved fauna, as yet only partially studied. A few of the common forms are listed below:

Kirkella vigilans (Whittington)
?*Isoteloides* n. sp.
Pliomerops n. sp.
?*Illaenus* n. sp. (large form)
?*Petigurus* sp.
encrinurid n. sp.
raphiophorid n. sp.
Agnostus sp.
Hesperonomia antelopensis Ulrich and Cooper
Archaeorthis elongata Ulrich and Cooper
Syntrophopsis polita Ulrich and Cooper
Leptella nevadensis Ulrich and Cooper
Tritoechia sinuata Ulrich and Cooper
Rhynchocamara sublaevis Ulrich and Cooper
Rhynchocamara cf. *R. breviplicata* (Billings)
Lingula sp.
Helicotoma sp.
Eccyliopterus sp.
Raphistomina cf. *R. latiumbilicata* Poulsen (large form)
?*Maclurites*, at least two small species
?*Protocycloceras foerstei* Butts
cystoids and cystoid plates numerous
Didymograptus sp.

No ostracodes or bryozoans have been recognized.

The small trilobite *Kirkella vigilans* (Whittington) is diagnostic of the Ninemile. Discovered by Walcott (1884, p. 98) in the Eureka district, this form was identified by him as "*Asaphus? curiosa* Billings"; subsequently, the beds under discussion came to be known as the "*Asaphus curiosus* zone." The generic name "*Billingsura*" applied to the typical form of this trilobite by Ulrich and Cooper (1938, p. 23) was superseded by *Kirkella* (Kobayashi, 1942, p. 118–121), whereas "*Ptyocephalus*" of Whittington (1948, p. 567–572) was suppressed (Ross, 1951, p. 91) as a synonym of *Kirkella* (Hintze, 1952, p. 181).

As noted by Whittington, the peculiar *Kirkella* is known from "Upper Canadian" rocks over a very wide area in North America, extending from Nevada to Alberta on the west and from Quebec to Arkansas in the east.

The *Kirkella vigilans* zone is recognized west of the Pioche district, where the upper part of the Yellow Hill formation (Westgate and Knopf, 1932, p. 14) bears a fauna similar to that of the Ninemile (Kirk, 1934, p. 454). In the Ibex Hills of western Utah (Hintze, 1951, p. 15–17), comparable faunas with *Kirkella* are reported to have a vertical range of at least 500 feet (fig. 6). The upper beds of the Garden City in the Randolph quadrangle, northern Utah (Ross, 1949, p. 480) have likewise yielded *Kirkella* cf. *vigilans*. Similar forms have been observed in Lower Ordovician strata of the Ubehebe area, Inyo County, Calif.

Brachiopod studies by Ulrich and Cooper (1938, p. 24, 26) indicate partial equivalence of the Sarbach formation in the Canadian Rockies to the Ninemile. Strata of about the same interval as the Ninemile *Kirkella vigilans* zone occur also in Texas and the midcontinent (Kirk, 1934). A possible correlation with the Nunatami beds of northwest Greenland is also of interest (Poulsen, 1927, p. 246, 342).

The Ninemile formation may be roughly correlative with western facies lower graptolite beds of the Vinini, but the upper part of the Vinini is probably no older than Chazyan and possibly younger. In the Roberts Mountains the typical lower part of the Vinini contains *Phyllograptus*, *Tetragraptus*, *Didymograptus*, and *Cardiograptus* (Merriam and Anderson, 1942, p. 1695). Immediately above this generic assemblage in the Vinini type section occur trilobites of the *Pliomerops* group, also present in the Ninemile. In Whiterock Canyon narrows (loc. 13), the Ninemile includes noncherty dark-gray argillaceous and calcareous shale with *Didymograptus*. These shale beds differ greatly in lithology from the overthrust graptolitic shale and chert of the Vinini immediately west of locality 13. *Phyllograptus* cf. *P. loringi* (White) is reported in beds of the Ninemile of the Antelope Range by Kirk (1934, p. 455). Whereas the Ninemile includes local graptolite-bearing shale interbeds, no physical evidence was found to show that this Pogonip unit intertongues with or passes westward into the lower part of the Vinini as might in theory be expected.

ANTELOPE VALLEY LIMESTONE

GENERAL FEATURES

Making rugged cliffy slopes in many places, the thick upper limestone beds of the Pogonip group are appropriately named for Antelope Valley. Conspicuous gray cliffs on the west side of Copenhagen Canyon (loc. 1) illustrate well the erosional expression of this unit, as do similar features on the higher west flank of Antelope Range where the type section of the formation is designated (loc. 58).

AREAL DISTRIBUTION AND LITHOLOGY

Underlying the less obdurate beds of the Copenhagen, the Antelope Valley limestone forms much of the east slope of Martin Ridge, extending thence southward to disappear beneath the volcanic rocks of Butler

Basin (pl. 2). West of Copenhagen Canyon and north of Whiterock Canyon, Antelope Valley limestone occurs in a thrust plate (fig. 4) which has ridden over the Lower Devonian beds of the Rabbit Hill limestone. In fact east of the main exposure of Antelope Valley, a small outlier of this formation appears to rest upon Rabbit Hill limestone at locality 3. To west and northwest the overthrust exposures are terminated by volcanic rocks.

Antelope Valley limestone forms the line of cliffs along the upper west slopes of the Antelope Range, from Ninemile Canyon to Blair Ranch (Segura Ranch). In the Fish Creek Range, these limestone beds have extensive distribution and may be observed to advantage at Bellevue Peak. The formation is fairly well exposed in the Eureka district, where it has been followed from Goodwin Canyon and McCoy Ridge southward to Windfall Canyon. Northernmost outcrop of this formation thus far recognized is at Lone Mountain, where it directly underlies Eureka quartzite; where the Eureka next appears at Roberts Creek Mountain, it is underlain disconformably by Goodwin limestone.

The Antelope Valley limestone is prevailingly a medium to heavy-bedded medium-bluish-gray fairly pure limestone that is fine grained. Calcite veinlets are numerous. The deposits often weather to a rough pointed surface. Projecting brownish silicified shell fragments are numerous at several horizons. Although fossils tend to be silicified in all parts of the formation, only a small amount of chert or jasperoid was observed.

THICKNESS

On the east side of Martin Ridge near the northern tip the Antelope Valley (loc. 27) measured 1,000 feet thick. True thickness is, however, somewhat greater as the lowermost beds of the formation are not exposed near the valley margin. In all probability the formation exceeds 1,200 feet. A rough estimate of thickness in the steep cliffy slopes at the type section just south of Ninemile Canyon agrees with this figure.

STRATIGRAPHY

In Whiterock Canyon narrows (loc. 13), the lower 75 feet of the Antelope Valley is thin-bedded argillaceous limestone, which appears to be gradational with underlying Ninemile formation. However, this zone, known as the *Orthidiella* zone (fig. 6), bears a fauna distinct from the Ninemile. The thin-bedded limestone grades upward into the heavy-bedded nonargillaceous middle part of the formation. Whereas in its argillaceous character the lower 75-foot division is lithologically somewhat closer to the Ninemile, it differs in weathering tan or yellowish and lacks the dark-gray and bluish-green coloration of the Ninemile.

Near its top, the Antelope Valley limestone becomes platy or flaggy and mottled with irregular argillaceous patches that weather tan or limonitic brown. Relationship to the overlying Copenhagen formation appears conformable. Possibility of an undetected break should nonetheless be entertained, for to the north (fig. 7) an important unconformity separates Eureka quartzite from lower units of the Pogonip group. The theoretical horizon of this break is the base of the Copenhagen.

On a faunal basis the Antelope Valley limestone may be partitioned in three well-defined zones; these correspond fairly well to lithologic divisions. The faunal zones are in stratigraphic order as follows:

3. *Anomalorthis* zone
2. *Palliseria* zone
1. *Orthidiella* zone

The lower or *Orthidiella* zone is especially well shown in the narrows of Whiterock Canyon at locality 13, where it corresponds to the lithologically distinctive lower 75-foot interval above the beds of the Ninemile. A large and unique fauna from which species of the Ninemile fauna are absent favors inclusion of this zone with the Antelope Valley limestone. The *Orthidiella* fauna is significant paleontologically, for it introduces the earliest ostracodes and bryozoans found in the Pogonip group. Characteristic fossils of the *Orthidiella* zone are listed below:

Orthidiella striata Ulrich and Cooper
Orthidiella longwelli Ulrich and Cooper
Orthis sp.
Pliomerops nevadensis (Walcott)
Pliomerops cf. *P. barrandei* (Billings)
Illaenus sp.
Asaphus cf. *A. quadraticaudatus* Billings
Ectenonotus cf. *E. westoni* (Billings)
Ischyrotoma cf. *I. twenhofeli* Raymond
Leperditia sp. (small form)
slender branching cyclostomate Bryozoa with habit of *Coeloclema*

The *Palliseria* zone embraces some 650 feet of the more massive, cliff-forming part of the formation. Gastropod facies crowded with silicified *Palliseria longwelli* (Kirk) and subordinate large *Maclurites* are characteristic. *Palliseria longwelli*, a large hyperstrophic gastropod (Knight, 1941, p. 199), was described by Kirk (1930) as "*Mitrospira*" on the basis of material that came in part from Martin Ridge. As shown recently by Yochelson (1957), "*Mitrospira*" appears to be a synonym of *Palliseria* (Wilson, 1924). At locality 27 in our measured section the limestone beds of this zone are crowded with *P. longwelli*, almost to exclusion of other forms. Commoner fossils of the zone are listed below:

Palliseria longwelli (Kirk)
Maclurites cf. *M. magnus* LeSueur
Endoceras sp.
Orthoceras sp.
Orthis cf. *O. tricenaria* Conrad
Receptaculites mammillaris Newberry
?*Calathium* sp.
algal nodules

Thick beds containing abundant ovoidal algal nodules are common in the *Palliseria* zone. The nodules, to which the name *Girvanella* is usually applied, average about 6 millimeters in long diameter and show concentric lamination. They are similar to such bodies occurring abundantly in the Middle and Late Cambrian of the Great Basin region, but uncommon above the Middle Ordovician.

At Bellevue Peak in the Fish Creek Range and on McCoy Ridge in the Eureka district, strata of the *Palliseria* zone are represented by a *Receptaculites* facies with two distinct types, *R. mammillaris* Newberry and *R. elongatus* Walcott, in great abundance. Only *R. mammillaris* Newberry was found in Antelope Valley, where it is apparently not a common form.

The *Anomalorthis* zone occupies roughly the upper 350 feet of the Antelope Valley limestone, as measured on Martin Ridge. The zone comprises platy and flaggy brown-mottled grayish limestone crowded with small high-spired gastropods, small orthoid brachiopods, large *Leperditia*, and hemispherical stony bryozoans. At many exposures the brachiopods are silicified. Beds with concentrically laminated algal nodules similar to those of the *Palliseria* zone occur here. Characteristic fossils of the *Anomalorthis* zone are:

Anomalorthis nevadensis Ulrich and Cooper
Anomalorthis lonensis (Walcott)
Orthis sp.
Pliomerops sp.
Illaenus sp.
Subulites sp.
Lophospira sp.
"*Murchisonia milleri* Hall?" Walcott
Leperditia cf. *L. bivia* White
stony bryozoans
algal nodules
cystoid plates

AGE AND CORRELATION

The large *Maclurites*, *Pliomerops*, and *Receptaculites* give the middle part of the Antelope Valley a Chazy aspect in terms of the eastern Ordovician. Equivalent deposits are found in Newfoundland (Kirk, 1934, p. 458). The similarities are especially notable in the *Orthidiella* zone, where certain undescribed trilobites resemble species in divisions K to M of the Table Head formation (Schuchert and Dunbar, 1934, p. 68–69).

The fauna of the *Palliseria* zone with *Maclurites* and various types of *Receptaculites* is widely recognized in the Cordilleran belt from the Death Valley-Inyo area northward. In fact, several earlier reports of "Pogonip limestone" are based on this assemblage.

Representing the upper part of the Antelope Valley interval, the *Anomalorthis* faunas are becoming known in various parts of the West (fig. 6), such as the Ibex Hills, Utah (Hintze, 1951, p. 19), and upper part of the Garden City and lower part of the Swan Peak quartzite of northeastern Utah (Ross, 1949, p. 479).

At Ikes Canyon in the Toquima Range, an unusual sponge fauna occurs in beds of Antelope Valley age (Bassler, 1941). These partly argillaceous sponge beds are characterized by Archaeoscyphidae and are reported to yield "*Pliomerops barrandei*". Whereas the lithology is suggestive of the lower part of the Antelope Valley limestone and the fauna seems to have affinities in Newfoundland with the Table Head, brachiopod studies by Cooper (1956, p. 127) indicate a closer relationship to the *Anomalorthis* zone.

The Antelope Valley limestone is, in the time sense, equivalent to the proposed "Whiterock stage" of G. A. Cooper (1956, p. 7–8, chart 1), the name "Whiterock" having been taken from a canyon in the Monitor Range that joins Copenhagen Canyon (pl. 2). Cooper's paleontologic characterization of the stage is in part as follows:

> The brachiopod fauna taken from rocks deposited during this stage is characterized by numerous orthids, the early stophomenids, plectambonitids, and the decline of the Syntrophiacea. Correlative rocks appear in the Arbuckle Mountains of Oklahoma, and the Table Head series of Newfoundland * * *. Equivalents of these beds in Europe are not clearly understood, but some related forms have been taken in Norway and Estonia.

According to Cooper (1956, chart facing p. 130), the "Whiterock stage" is older than Chazyan.

Cooper's "*Orthidiella* zone" and "*Palliseria* zone" are in virtual agreement with those of the same name here adopted. In the upper part of the column embraced by the "Whiterock stage" Cooper recognizes two additional brachiopod zones, a "*Desmorthis* zone" below his "*Anomalorthis* zone" and a "*Rhysostrophia* zone" above. *Anomalorthis* zone as used in the present paper would seemingly include also the "*Desmorthis* zone" of Cooper.

COPENHAGEN FORMATION

GENERAL FEATURES

The name Copenhagen formation is here applied at Antelope Valley to richly fossiliferous limestone, siltstone, and sandstone beds that occupy an interval between Eureka quartzite and the *Anomalorthis* zone of the uppermost Antelope Valley limestone. Type section of the new formation is on the west side of Martin Ridge, 1 mile southeast of the union of Ryegrass Canyon with Copenhagen Canyon (loc. 10). These fossiliferous strata and their correlation have been discussed heretofore by Kirk (1933, p. 28–31), by Merriam and Anderson (1942, p. 1684), and more recently by Cooper (1956, p. 126–128). Beds of the Copenhagen are not present in the adjoining Eureka district, where the Pogonip group has been redefined (Nolan, Merriam, and Williams, 1956, p. 23–29). Accordingly, the Copenhagen is not classified as part of the Pogonip group.

AREAL DISTRIBUTION

The Copenhagen formation is seemingly restricted to the vicinity of Antelope Valley. It does not extend northward as far as Lone Mountain, nor has it been recognized to the east in the Fish Creek Range between Antelope Valley and Eureka. Beds of the Copenhagen are best exposed beneath Eureka quartzite along the crest and east slope of Martin Ridge. Good exposures are present also on the west side of the Antelope Range north of Blair Ranch (Segura Ranch), where the formation is capped by thinned Eureka quartzite.

LITHOLOGY AND STRATIGRAPHY

At Martin Ridge the Copenhagen is about 350 feet thick and lends itself to threefold subdivision on the basis of lithology and faunas (fig. 6). These subdivisions are referred to as member A, member B and member C in ascending order. Whether or not the three divisions can be differentiated lithologically in the Antelope Range has not been ascertained.

Member A at the base of the formation is a fine-grained calcite-cemented light-gray quartzitic sandstone, 25 feet thick, which weathers light grayish brown. It contains abundant straight-shelled cephalopods of the *Endoceras* type, earlier having been referred to as the "*Endoceras* sand." This unit rests with seeming conformity upon the *Anomalorthis* zone of the uppermost Antelope Valley limestone.

Member B, the middle division, with estimated thickness of 200 feet, is yellowish-brown to buff-weathering well-bedded impure limestone that is medium to fine grained, with argillaceous and silty partings and interbeds. On fresh break, the limestone is medium gray. A large and varied fauna weathers free from the shaly layers.

Member C, the upper division, roughly 125 feet thick, comprises dark-gray silty limestone, calcareous siltstone, and exceedingly fine-grained calcareous sandstone. Dark-gray to black carbonaceous shale interbeds are fissile or flaky. Member C appears to intergrade upward with the Eureka quartzite.

AGE AND CORRELATION

Comparison of the excellently preserved and highly differentiated Copenhagen B and C faunas with those from formations of upper Chazy to about middle Trenton age in eastern North America discloses rather close specific resemblances; most of the western species appear, however, to be new.

Provisional identifications of fossils from member B of the Copenhagen formation are as follows:

Valcourea n. sp. (large form)
Rafinesquina n. sp.
Sowerbyites sp. a (small form)
Sowerbyites sp. b (large form)
Isotelus n. sp.
Illaenus cf. *I. americanus* (Billings)
Receptaculites cf. *R. occidentalis* Salter
Stromatotrypa sp.
Monotrypa sp.
Trematopora sp.
Stictoporella sp.

Quite characteristic of this assemblage are species of *Valcourea* and *Rafinesquina* with a large *Receptaculites* similar to *R. occidentalis.* One bed contains several genera of massive hemispherical stony bryozoa in abundance. Also common are *Cyrtoceras*-like cephalopods.

The fauna of member C of the Copenhagen formation differs sharply from that of underlying member B; few, if any, of the species appear to carry through. Of especial interest is the occurrence in member C of *Climacograptus* associated with the trilobite *Lonchodomas.* The faunal changes passing from B to C seem to harmonize with the less calcareous and more silty-argillaceous character of member C. Fossils listed below were collected from member C in the type area of the Copenhagen formation:

Climacograptus cf. *C. parvus* (Hall)
Strophomena n. sp.
Oxoplecia n. sp.
Cyclocoelia n. sp.
Lonchodomas sp.
Pterygometopus n. sp.
Bumastus sp.
Illaenus sp.
Isotelus sp. (large form)
Cryptolithus sp.

From beds of the Copenhagen of undetermined horizon on the Antelope Range side of the valley, Kirk (1933, p. 33) lists the following forms not recognized by us in the typical exposures of the formation. These are:

Remopleurides sp.
Thaleops sp.
Ectenaspis cf. *E. homalonotoides* (Walcott)

Special studies of Copenhagen brachiopods have been made by G. A. Cooper of the Smithsonian Institution. Similarities are noted to species from the Lincolnshire limestone and Oranda formation of Cooper and Cooper (1946, p. 86–89) in Virginia and the Bromide formation of Oklahoma (G. A. Cooper, written communications, 1947, 1948).

From member B of the Copenhagen formation or the "Yellow limestone," Cooper (1956, p. 127–128) lists the following brachiopods, most of which are described as new:

Camerella umbonata Cooper
Camerella sp. 3
Eoplectodonta alternata (Butts)
Isophragma ponderosum Cooper
Lingulasma occidentale Cooper
Macrocoelia occidentalis Cooper
Multicostella parallela Cooper
Multicostella rectangulata Cooper
Oxoplecia monitorensis Cooper
Sowerbyella sp. 4
Sowerbyites lamellosus Cooper
Valcourea plana Cooper

According to Cooper "the zone in question cannot be lower than Lincolnshire or higher than Benbolt * * *." A correlation of member B of the Copenhagen formation with the Arline formation of Cooper (1956) in the Southern Appalachians is suggested by his brachiopod studies.

In member C of the Copenhagen formation, or "dark shale with *Reuschella*," Cooper lists the following brachiopods:

Bilobia hemispherica Cooper
Bimuria sp. 1
Cristiferina cristifera Cooper
Eoplectodonta alternata (Butts)
Glyptorthis sp. 1
Hesperorthis antelopensis Cooper
Leptaena ordovicica Cooper
Leptellina incompta Cooper
Oxoplecia nevadensis Cooper
Paurorthis gigantea Cooper
Plectorthis obesa Cooper
Reuschella vespertina Cooper
Rostricellula angulata Cooper
Sowerbyella merriami Cooper
Sowerbyella sp. 1 and 2
Strophomena sp. 1

According to Cooper this division is correlative with his Oranda formation of Virginia, and may, therefore, be as young as middle Trenton.

The richly fossilierous beds of the Copenhagen formation are younger than the *Anomalorthis* zone, which characterizes higher strata of the Pogonip group. At Lone Mountain the brown quartzite in the lower part of the Eureka rests upon these *Anomalorthis*-bearing limestone beds; but southward in Antelope Valley, it is the lower part of the Copenhagen that occupies this position, whereas a thinned Eureka, agreeing lithologically with the light-colored upper part of the Eureka rests upon the Copenhagen (fig. 7). These factors, weighed in conjunction with a rather high content of quartz sand in the Copenhagen itself, strongly suggest that the Copenhagen is a restricted depositional facies occupying the time-stratigraphic interval of at least the lower brown part of the Eureka quartzite. Further support is given by virtual absence of this lower brown unit, where the Copenhagen is present. As an alternative explanation, it has been suggested that the localized Copenhagen might represent a depositional pocket above a Pogonip-Eureka disconformity, which after truncation was buried by the Eureka. However, the upper part of the Copenhagen is seemingly graditional with overlying light colored Eureka, the lower brown unit of the Eureka is unrecognized, and there is in this vicinity no physical evidence of a Pogonip-Eureka unconformity either beneath the Copenhagen or beneath the thinned Eureka over the Copenhagen. Evidence of lateral gradation or intertonguing of Eureka and Copenhagen is needed, but proof of this nature seems unlikely because of lack of outcrop in critical areas.

Lateral change of the lower part of the Eureka quartzite into shaly and calcareous deposits may well have taken place locally at many places in the Great Basin. For example, in the Inyo Mountains, Calif., there are sporadic occurrences of limy-argillaceous beds between vitreous Eureka quartzite and the upper limestone beds of the Pogonip. At Mazourka Canyon these strata were named Barrel Spring formation (Phleger, 1933, p. 5) and contain a fauna of Trenton affinites, suggesting correlation with the Copenhagen. Such deposits are absent at the base of the Eureka in the adjacent Ubehebe district of the northern Panamint Range (McAllister, 1952, p. 12).

EUREKA QUARTZITE

GENERAL FEATURES

The Eureka quartzite, one of the conspicuous and widely distributed Paleozoic key formations of the Great Basin was named by Hague (1883, p. 253, 262; 1892, p. 54) and later made the subject of special studies by Kirk (1933) and by Webb (1956). Clarence King (1878) in the "Systematic Geology" included what is now called Eureka quartzite in his "Ogden quartzite," erroneously dated as Devonian. Thugh named by Hague for the town of Eureka, Nev., exposures in that vicinity and the northern Fish Creek Range are badly disturbed. Accordingly, the less deformed beds of this

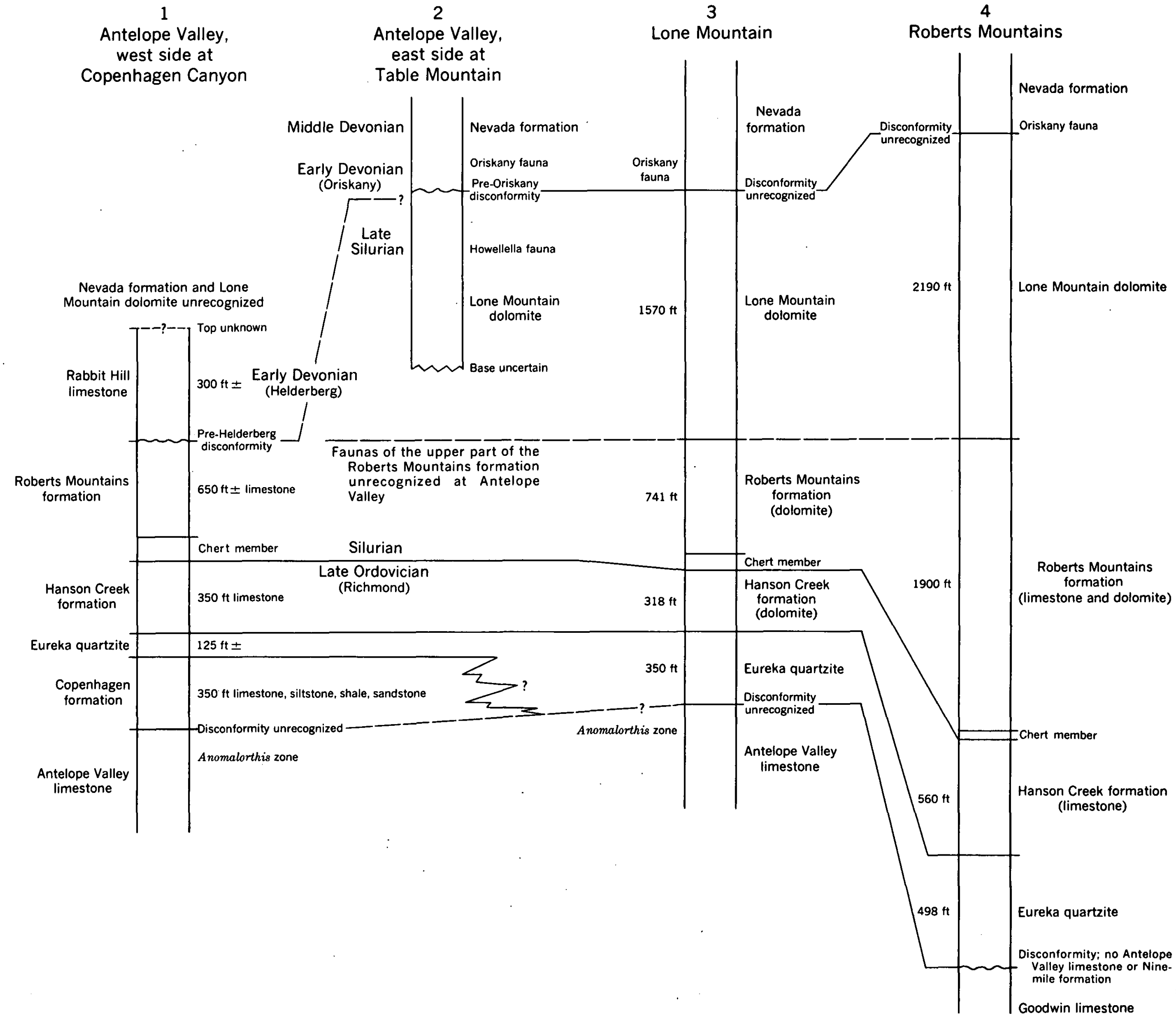

FIGURE 7.—Correlation diagram showing possible age relations of Ordovician, Silurian, and Lower Devonian rocks in the Antelope Valley area. See figure 2 for location.

unit at Lone Mountain came to be regarded as a standard section (Kirk, 1933, p. 30). In this region, the Eureka is overlain conformably by the Upper Ordovician Hanson Creek formation. Relations with underlying strata are far less uniform. Whereas at Lone Mountain the Eureka lies on Antelope Valley limestone, to the south the Copenhagen formation is introduced between the quartzite and the Antelope Valley limestone. North of Lone Mountain, the Eureka is above a significant disconformity. There are also notable changes in thickness, the quartzite thinning southward and thickening northward from Lone Mountain.

AREAL DISTRIBUTION AND LITHOLOGY

Eureka quartzite crops out almost continuously above the Copenhagen in westward-dipping fault blocks, which form Martin Ridge (pl. 2). In the Antelope Range, it is exposed below Tertiary volcanic rocks south of Ninemile Canyon near the top of the main eastward-dipping block; to the southwest the quartzite carries over in several cap-rock erosion remnants of a west-dipping block, which makes the lower west flank of the range.

Eureka quartzite forms a considerable part of the surface in the Fish Creek Range (pl. 1), extending northeastward toward the town of Eureka and northwest a short distance into the Mahogany Hills. North of Antelope Valley it reappears in the homoclinal Lone Mountain block and also 20 miles north at Roberts Creek Mountain (fig. 2).

Areal distribution of the Eureka quartzite is probably the greatest of any single continuous Paleozoic formation in the Great Basin region, with possible exception of the Upper Ordovician (Richmond) unit, which overlies the Eureka. As at present known with assurance, it extends from Cortez, Nev., eastward into western Utah and southwestward to the Inyo Mountains of California. In all probability, its northward and eastward extent will ultimately be shown to be much greater. Absence of Eureka in the southern Ruby Mountains (Sharp, 1942, p. 680) and in the northern Toquima Range (Kay, 1955) indicates that this formation is not a continuous blanket throughout its vast extent.

Normal Eureka quartzite comprises pure dense gleaming white sugary varieties and darker, brownish-gray less pure phases. These rocks are orthoquartzite with usually clear, fairly well rounded and in many places well-sorted quartz grains of fine to medium grain size. Petrographic studies by Webb (1956, p. 29–32) indicate that the larger grains have moderate to low sphericity, the finer grains have high sphericity and that there is sometimes minor iron oxide cementation. Heavy detrital minerals are generally lacking. Cement normally consists almost entirely of silica and only rarely of carbonate where the formation includes limestone or dolomite layers. No pitting or frosting of grains has been detected. Sedimentary nature of the Eureka is not uncommonly obscured and original texture obliterated where affected by hydrothermal activity.

There are no wholly reliable lithologic criteria that, exclusive of stratigraphy, serve to distinguish Eureka quartzite from other quartzites of the Great Basin Paleozoic column. Similar arenaceous deposits occur in the Lower Cambrian, the Ordovician Pogonip interval, the Silurian, and in the Devonian (Merriam, 1951). Unlike most of the Eureka the Devonian and Silurian quartzites commonly reveal original calcite or dolomite cement that remains unreplaced by silica. Cambrian quartzites like the Prospect Mountain include minor coarse pebbly facies and are commonly pinkish, maroon, or reddish in color; these characteristics are generally lacking in the Eureka.

THICKNESS

In Antelope Valley the average thickness of the Eureka quartzite is about 150 feet, much below normal for the formation as a whole. The Eureka thickens progressively northward, increasing to 350 feet at Lone Mountain and reaching 500 feet at Roberts Creek Mountain, 40 miles north of the Antelope Range. Between the Roberts Mountains on the north and the Inyo Mountains of California on the south, thicknesses of Eureka vary characteristically from 300 to 400 feet and are exceeded at only a few places.

STRATIGRAPHY

As pointed out by Kirk (1933, p. 28) the thicker Eureka sections show two lithologic divisions in many places: An upper white vitreous massive part and a lower phase of slightly darker brownish color, with cross lamination. These lithologic differences are not local, as they have been noted in areas separated as widely as the Roberts Mountains and the Inyo Mountains.

Stratigraphy of the Eureka quartzite and of the strata on which it rests involves both disconformity and lateral facies change. Northward from Lone Mountain, disconformity is the more evident factor, whereas southward from Lone Mountain facies analysis provides an explanation of observed changes. Northward between Antelope Valley and the Cortez area, Nevada, the quartzite rests successively on upper Middle Ordovician, Lower Ordovician, and Upper Cambrian beds. Where the Eureka is unusually thick at Roberts

Creek Mountain, it lies disconformably on the lower part of the Goodwin limestone (fig. 7). Missing units of the Pogonip group are the upper part of the Goodwin, Ninemile, and the Antelope Valley limestone. The hiatus is much greater at Cortez, where the Eureka lies on dolomite that has the appearance of Upper Cambrian Hamburg dolomite in the Eureka district (Nolan, Merriam, and Williams, 1956, p. 30). Evidence for this important unconformity is stratigraphic and paleontologic; no significant features of erosion or angular discordance have been noted. No positive indication of this stratigraphic break has been found at Lone Mountain or at the Copenhagen-Pogonip boundary in Antelope Valley.

Southward from Lone Mountain, facies changes bring about appreciable rise in section of the quartzite base, as explained previously under Copenhagen formation (p. 27). It is likewise possible that excessive thickening of the Eureka to 500 feet in the Roberts Mountains may be explainable by descent in section of the lower quartzite boundary, whereby quartz sands took the place of higher carbonate sediments of the Pogonip group. Elsewhere quartz sands actually appear in the upper part of the Pogonip before normal deposition of Eureka, as shown in the Inyo Mountains of California and as illustrated by the lower part of the Swan Peak quartzite of late Pogonip age in Utah (fig. 6).

Significant depositional changes are observed in passing northeastward from Antelope Valley to the Fish Creek Range. Thus, on the east side of Bellevue Peak, within 14 miles of the nearest Copenhagen exposures, strongly crossbedded Eureka quartzite rests on Antelope Valley limestone, with no trace of Copenhagen between. At the Bellevue Peak locality, pre-Eureka emergence is suggested by edgewise mud-breccia between the Eureka and the brown-mottled, grayish upper part of the Antelope Valley limestone.

In Antelope Valley the quartzite is relatively thin, fairly uniform, and seemingly conformable with rocks above and below. It is, moreover, largely the white variety and lacks the lower dark member. At Lone Mountain the Eureka is about 350 feet thick, or over twice that to the south, and is divisible into two members, of which the lower dark phase is roughly 100 feet thick. It is inferred that where the Eureka has thinned, as in the Monitor and Antelope ranges, and the lower phase is lacking, the place of the lower phase and part of the upper white phase is occupied by the Copenhagen formation (fig. 7).

The Chazyan *Anomalorthis* zone serves as an important datum between Lone Mountain and the area to the south, for at Lone Mountain this key zone underlies the lower brown part of the Eureka and in the Monitor Range it is beneath the Copenhagen formation. In summary, absence of the lower brown part of the Eureka and thinning of the upper light colored phase where Copenhagen is present suggest that the Copenhagen facies laterally replaces the brown lower part of the Eureka.

Depositional environment of the Eureka is problematic, for normally this formation yields no fossils. Only where vitreous quartzite changes to limy fossiliferous Copenhagen do we find unmistakable evidence of marine accumulation. Lack of fossils, crossbedding, and the nature of the clean quartz sand itself have suggested that the normal Eureka formed as a wind-transported sediment that accumulated under beach-dune or perhaps even continental conditions. Therefore, it may be reasoned that the carbonate-rich marine Copenhagen was forming offshore, while concurrently the clean shifting sand of the Eureka proper was deposited within near-shore intertidal and possibly contiguous landward belts. Scarce layers of dolomite in the vitreous Eureka quartzite of the northern Inyo Mountains of California, together with an exceptional occurrence of corals at Cortez, Nev. (James Gilluly, oral communication, 1952; Helen Duncan 1956, p. 217) demonstrate that the siliceous deposit interfingers here and there with undoubted marine beds.

AGE AND CORRELATION

A late Middle to early Late Ordovician age assignment appears reasonable for the Eureka quartzite. Its upper age limit is fixed by the Late Ordovician Richmond faunas of the Hanson Creek and its dolomitic equivalents, which accompany the quartzite throughout its distribution. A significant criterion of age is the probable laterally replacing facies relationship with the Copenhagen; if a valid concept, this would date the Eureka as about middle Trenton.

Relation of the Eureka quartzite to the Swan Peak quartzite of Utah remains somewhat uncertain (fig. 6). The presence of *Anomalorthis* suggests that the lower part of the Swan Peak is older than the lowest Eureka (Ross, 1951, p. 21, 27). In central Nevada this brachiopod genus characterizes the higher part of the Antelope Valley limestone. This would not eliminate possible equivalence of the higher part of the Swan Peak and the Eureka, both overlain by seemingly correlative Richmond strata. As noted by Hintze (1951, p. 20–22), Ordovician quartzite of the Ibex Hills, Utah, is divisible into an upper unit over 500 feet thick and a lower unit about 250 feet thick, with a dolomite member between them (fig. 6). It is possible that the lower quartzite may be correlative with the lower part of the Swan Peak, whereas the upper is with little doubt the Eureka. Fine-grained sandstone or quartzite beds similar to the Swan Peak are found here and there in the upper few hundred feet of the Inyo Mountains Pogonip and elsewhere in the Great Basin. It is, therefore, certain that quartz sand began to accumulate locally in late Pogonip time, before Eureka deposition.

Quartzites of possible Eureka age are present in Idaho, although little is yet known of their relationships. The Wonah quartzite of British Columbia (Walcott, 1924, p. 9–14; Walker, 1926, p. 31) is a possible northern Eureka correlative in the Canadian Rockies. Like the Eureka it underlies strata with a Late Ordovician (Richmond) fauna, but unlike the Eureka it overlies graptolite-bearing Glenogle shale.

HANSON CREEK FORMATION

GENERAL FEATURES

The name Hanson Creek formation was first applied to Upper Ordovician limestone beds in the Roberts Mountains (Merriam, 1940, p. 10), where the type section is situated on Pete Hanson Creek. In Antelope Valley this formation rests without obvious discordance upon the thinned Eureka and is overlain gradationally by cherty basal limestone of the Silurian Roberts Mountains formation.

Hague (1892, p. 58, 136) regarded beds here called Hanson Creek as the lowermost or "Trenton" part of the "Lone Mountain limestone," an inclusive division subsequently partitioned into three formations (Merriam, 1940, p. 8). Differentiation of these units in the Roberts Mountains, although basically lithologic, is supported by paleontologic evidence. Throughout much of the Great Basin these formational distinctions are on the other hand less clear cut, for this part of the column is generally dolomite and fossils are less numerous. In areas of Upper Ordovician and Silurian dolomite, the names Fish Haven dolomite or Ely Springs dolomite have been applied to rocks of the Hanson Creek interval.

In the Monitor Range, the Hanson Creek is, like the type section, a limestone but includes graptolitic facies not recognized in the type area nor on the east side of Antelope Valley itself.

AREAL DISTRIBUTION AND LITHOLOGY

The Hanson Creek is well exposed along the west slope of Martin Ridge and appears in a small area at the junction of Whiterock and Copenhagen Canyons (loc. 53). Small outcrops are found south of Ninemile Canyon just below Cenozoic volcanic rocks; several erosion remnants rest upon Eureka quartzite of the westward-dipping block along the west flank of the Antelope Range. The formation crops out again at Wood Cone near the south edge of the Mahogany Hills, where some of the more fossiliferous limestone exposures are located (loc. 76). Unlike the occurrence in the Monitor Range, the Hanson Creek is here partly dolomitic; northward to Lone Mountain and eastward to the vicinity of Eureka, it changes entirely to dolomite.

The Hanson Creek of the Monitor Range consists in part of dark-gray very fine grained platy and flaggy limestone that commonly weathers light gray and more rarely pinkish. There are scattered fissile shaly partings. Individual limestone layers range in thickness from less than 1 inch to 15 inches, averaging about 3 inches. Chert nodules are present, but are rare and widely scattered.

The upper 150 feet is heavier bedded than that below and is mottled with irregular ovoidal and vermiform markings of darker gray. North of the mouth of Whiterock Canyon, a 10-foot calcareous sandstone bed lies 40 feet below the top of the formation. The sandstone is medium light gray with a medium-granular salt and peppery texture given by an abundance of light-, medium-, and dark-gray chert granules. The medium to fine chert grains are well rounded and set in a calcitic matrix that forms about 35 percent of the rock.

A fossil bed with abundant small *Streptelasma*-like corals is found 175 feet below the top of the formation at Copenhagen Canyon, with other fossil-bearing layers near the top. In this area graptolites have been collected at several horizons in the platy lower and middle parts, especially just below the crest of Martin Ridge on the east side opposite the mouth of Whiterock Canyon (loc. 8).

THICKNESS

A section measured north of the mouth of Whiterock Canyon is 350 feet thick; the total exceeds this figure, for the base is not exposed. At localities along Martin Ridge, estimates of about 300 feet were made in the more broken sections. The dolomitic Hanson Creek at Lone Mountain measured 318 feet, whereas at the type section in the Roberts Mountains it is 560 feet thick.

STRATIGRAPHY

Change from vitreous Eureka quartzite to platy limestone of the Hanson Creek is rather abrupt and of such lithologic contrast as to suggest a disconformity, though no evidence of post-Eureka erosion was detected. In the type Hanson Creek (Merriam, 1940, p. 11), a zone of lime-cemented sandstone separates vitreous Eureka from the lowest Hanson Creek limestone.

Relationship to the overlying Silurian Roberts Mountains formation is one of conformity or gradation, marked by change to a very cherty limestone, which is classified as lowermost Roberts Mountains. Brachiopods of the *Conchidium* type appear in the upper few feet of the cherty zone at Copenhagen Canyon. The siliceous zone is unquestionably an important stratigraphic marker, having been recognized here and there in widely separated areas from the Roberts Mountains to the Inyo Mountains of California. In parts of the southern Great Basin, where the middle Paleozoic is largely dolomite and sparingly fossiliferous, it has not been possible to identify the discontinuous cherty zone, and similar carbonate rocks persist upward from the Hanson Creek (or Ely Springs) interval into beds of paleontologically established Silurian age. In these sections it is not possible to demonstrate that the unit in question or the Ordovician system have lithologically definable tops. The resulting stratigraphic dilemma is perhaps significant in connection with failure thus far to fully resolve some paleontologic questions relating to system assignment of the Richmond interval, which includes the Hanson Creek and equivalents.

Judging from preliminary study of sections in Copenhagen Canyon, a stratigraphic breakdown of the Hanson Creek formation may ultimately be possible. The middle and lower parts are relatively thin bedded, sparingly cherty, and bear diagnostic graptolites, whereas the upper part is somewhat heavier bedded, including a sandstone bed toward the top. The *Streptelasma* coral bed lies not far from the middle of the formation in this area.

AGE AND CORRELATION

Late Ordovician (Richmond) age is established by faunas from Martin Ridge and Wood Cone. These include the graptolite assemblages that characterize the Martin Ridge section and the commoner coral-brachiopod-trilobite faunas as represented in the Wood Cone area, the type Hanson Creek, and many localities in the southern Great Basin. Thus far no comprehensive study of facies and faunas of the Hanson Creek interval has been undertaken.

The Hanson Creek faunas, which introduce abundant rugose corals and new groups of brachiopods and trilobites, differ markedly from those of uppermost Pogonip, and seemingly show no intimate affinity to faunas of the intermediate Copenhagen formation. Abrupt introduction of Richmond-type faunas in carbonate rocks following the Eureka interval of quartzose sand deposition is consistent with profound lithologic change. In fact, this represents one of the great biologic discontinuities of the Great Basin Paleozoic column, its magnitude alone suggesting disconformity.

Graptolites from the middle and lower parts of the Hanson Creek at Martin Ridge (loc. 8) have been identified by Ruedemann as follows:

Climacograptus tridentatus Lapworth var. *maximus* Decker
Orthograptus calcaratus Lapworth var. *trifidus* Gurley
Orthograptus sp.
Dicellograptus complanatus Lapworth var. *ornatus* Lapworth

According to Ruedemann these appear to indicate Late Ordovician of approximately Richmond age.

R. J. Ross, Jr., of the U.S. Geological Survey, has recently made detailed studies of the Hanson Creek graptolite faunas and concludes that they are probably of Ashgillian age in terms of the British succession (written communication, 1956). Ross (written communication, 1956) has prepared the following statement regarding correlation of the Hanson Creek beds at Martin Ridge:

Specifically correlation is with the Polk Creek shale of Oklahoma. However, D. E. Thomas has verified the occurrence of *Climacograptus hastatus* T. S. Hall in these beds; in my opinion these may be identical to *C. tridentatus* var. *maximus* Decker, the types of which I have examined. Similarly the *Dicellograptus* compares favorably with *D. affinis* T. S. Hall, giving the Hanson Creek fauna an Australian flavor. Although there seems to be some disagreement as to precise correlation between Britain and Australia, this would also suggest that the Hanson Creek is highest Ordovician.

The Hanson Creek coral-brachiopod-trilobite facies are characterized by halysitids, *Columnaria*, members of the solitary *Streptelasma* group (Duncan, 1956, p. 226), *Rafinesquina*, *Platystrophia*, *Lepidocyclas*, *Cryptolithus*, and illaenids. Recent studies by Duncan (p. 222) indicate that Late Ordovician halysitids of the region are distinguishable as *Catenipora*.

Collections made north of Wood Cone (loc. 76) consist mainly of undetermined stony bryozoans and brachiopods, among which are *Plaesiomys* n. sp., and *Rhynchotrema* cf. *R. argenturbica* (White). Cystoid plates are numerous. A collection containing the trilobite "*Trinucleus*" from Wood Cone was determined by by Walcott (Hague, 1892, p. 59) as of Trenton age. This form may well be *Cryptolithus*, a common genus in the Hanson Creek type area.

Strata equivalent to the Hanson Creek are assigned to the Ely Springs dolomite in the southern Great Basin. Especially good silicified faunas, comparable to those of the area under consideration, are found in Ely Springs dolomite of the Inyo Mountains of California, where they overlie Eureka quartzite. West of Talc City in the southernmost Inyo Mountains these faunas include the following:

Halysites (*Catenipora*) sp.
Columnaria cf. *C. alveolata* (Goldfuss)
streptelasmid corals, several types
Heterorthis sp.
Glyptorthis cf. *G. insculpta* (Hall)
Thaerodonta sp.
Lepidocycla (at least 2 species)
Platystrophia sp.
Onniella cf. *O. quadrata* Wang
Zygospira n. sp.
Strophomena sp.
Plaesiomys sp.

Correlative Late Ordovician faunas occur in the Fish Haven dolomite of Utah, the Montoya of New Mexico, the Beaverfoot of western Canada (Wilson, 1926), and the Maquoketa of Iowa (Ladd, 1929; Wang, 1949).

WESTERN FACIES ROCKS OF ORDOVICIAN AGE

VININI FORMATION

GENERAL FEATURES

The Vinini formation of Early and Middle Ordovician age was described in the Roberts Mountains (Merriam and Anderson, 1942, p. 1694–1698), where it occurs only as segments of a major thrust sheet. Similarly at Antelope Valley, these rocks form isolated thrust remnants. Near Devils Gate, graptolite-bearing strata of this formation (pl. 1) were at first confused by the Hague Eureka party with lithologically similar Carboniferous rocks, and were accordingly mapped at that time as "Diamond Peak quartzite".

Regional studies indicate that graptolitic strata of Vinini type characterize a western Great Basin subprovince, which contrasts rather sharply in facies with an eastern subprovince in which carbonate deposition prevailed during Ordovician time. An initial aim of these investigations was westward tracing of carbonate subprovince rocks, in the hope that their normal depositional relations to the graptolitic rocks might be determined; this objective has thus far not been achieved, for all occurrences of the typical graptolitic facies so far discovered are clearly thrust over other Paleozoic rocks of the area.

LITHOLOGY AND OCCURRENCE

The Vinini formation includes a wide variety of sedimentary rocks, ranging from fairly coarse sandstone and siltstone to black shale, bedded chert, and limestone. Chloritized lava flows and tuffs are present locally.

Sandstone of the Vinini formation as exposed near the mouth of Yahoo Canyon (pl. 1) weathers brown and is well bedded, poorly sorted, and consists mainly of chert and quartz granules. Limonitic and argillaceous matter is abundant in the interstices. The dark-gray chert fragments that predominate are commonly angular, whereas the quartz grains are generally well-rounded. Interbedded with these sands are dark-gray graptolitic shale beds; the sand contains poorly preserved shreds of probable algal matter, and graptolite fragments. Some large outcrops of Vinini are mainly brown chert-rich sandstone. Light-gray orthoquartzites similar to those of the Eureka quartzite are uncommon in the Vinini, but occur locally in the Charnac Basin area.

Black shales of the Vinini are smooth, very fine textured, and weather in thin plates and flakes. They contain graptolites and much finely divided organic matter. Along Vinini Creek some of these are true oil shale. On weathering, the black shale in some places becomes light bluish gray or white, a feature not observed in Carboniferous black shale of the region. Bedded chert, and more rarely fine-grained limestone, are found in association with the black shale.

Bedded chert in the Vinini is commonly dark gray when fresh, but weathers light gray or, more rarely, green. The beds contain radiolarians, graptolitic debris, and algal matter. They are probably of primary marine origin. Resistant bedded chert makes up a very considerable part of the Vinini throughout its extent, and forms most of the more conspicuous geomorphic features sculptured in this formation.

Vinini thrust outliers in the vicinity of Antelope Valley are distributed from the east side of Devils Gate pass to Charnac Basin. Six groups of Vinini outliers have been mapped or studied; they are situated as follows (pls. 1 and 2): (1) South of the east entrance to Devils Gate, (2) mouth of Yahoo Canyon, (3) lower pediment slopes of Lone Mountain, (4) Twin Spring Hills at the northeast tip of the Monitor Range, (5) narrows of Whiterock Canyon, 5 miles northwest of Martin Ranch, (6) Charnac Basin on the west slope of the Monitor Range.

Small isolated exposures of chert possibly belonging to the Vinini occur in Yahoo Canyon 2 miles south of U.S. Highway 50 (loc. 89) and at localities east of Yahoo Canyon about 3 miles south of Devils Gate. No graptolites were found in these outcrops. Other chert and shale exposures which are suggestive of the Vinini but which have thus far yielded no fossils, are found at the mouth of Ninemile Canyon in the Antelope Range, in fault contact with the Nevada formation (pl. 2, loc. 67).

Eastern limit of the Roberts Mountains thrust, as understood at present, is marked by chert and shale of the Vinini south of the east entrance to Devils Gate. In that area the Vinini lies in low-angle thrust contact with underlying Mississippian sandstone of the Chainman and Diamond Peak sequence. The thrust contact dips east roughly parallel to bedding of both Mississippian sandstone and chert in the Vinini of the upper plate.

Near the mouth of Yahoo Canyon is a large area of Vinini sandstone, chert, and graptolitic shale covered largely by a thin veneer of alluvium. These beds extend southward from U.S. Highway 50 mostly along the east side of the canyon. They reappear north of Highway 50 to crop out in patches along the lower west slopes of Whistler Mountain. Rubble-mantled terraces in that belt are in considerable part underlain by Vinini strata. Westernmost outcrops in the Yahoo Canyon-Whistler Mountain belt are mainly brown sandstone of the Vinini, whereas black graptolite shale and chert compose the outcrops to the east nearer Whistler Mountain. These chert and shale beds illustrate the light-gray to whitish surface weathering.

Small but highly significant outcrops of sandstone, limestone, chert, and graptolite shale of the Vinini occur on the low pediment slopes north, east, and southeast of Lone Mountain. Permian limestone of the Garden Valley formation is intimately associated with the Vinini. In that area the lower plate rocks beneath the overthrust include limestone of the Nevada formation and intensely shattered and silicified dolomite which has the appearance of Lone Mountain dolomite.

Vinini graptolitic shale and chert of the Twin Spring Hills (pl. 1) are in contact with Garden Valley Permian to the north; this relationship appears to be one of unconformity rather than faulting and is in agreement with that at Tyrone Gap. The Twin Spring Hills Vinini is thrust over Pogonip on the south, a relationship found also in Whiterock Canyon. Resistant outliers of chert breccia upon limestone of the Pogonip clearly mark the thrust sole. Discontinuous red coloration of Vinini shale beds in the Twin Spring Hills is not limited to that formation. Leaching of volcanic rocks, which probably overlay the entire area before erosion, may be the explanation (Nolan, T.B., oral communication, 1955).

Vinini strata in Whiterock Canyon narrows mark the southernmost known extent of the major Roberts Mountains overthrust in the Antelope Valley area. The Vinini includes dark-gray graptolitic shale and bedded chert weathering light bluish gray or whitish, as is typical of the formation. Only a small thrust lobe is exposed west of locality 13 beneath the east edge of the Cenozoic volcanic rocks. Upper plate beds of the Vinini revealed here were evidently thrust over a lower plate comprising Antelope Valley limestone and Ninemile formation of the Pogonip group, which in turn override Lower Devonian Rabbit Hill limestone. Such complex structural features suggest an imbricate set of thrust sheets beneath the main Roberts Mountains thrust sole.

Overthrust beds of Vinini crop out west of Charnac Basin on the west side of the Monitor Range, where the Paleozoic rocks are partly surrounded by the Cenozoic volcanic rocks. The thrust relationship of upper plate Vinini to lower plate Antelope Valley limestone of the Pogonip group is well shown 1 mile west of summit 9,033, near the union of Brock Canyon with Charnac Basin. Attention was drawn to these isolated Vinini exposures by J. H. Wiese and G. E. Knowles of the Richfield Oil Co. There are seemingly several thrust slices, for, to the east, Antelope Valley limestone was in turn thrust over limestone beds of Silurian age. Base of the overthrust Vinini is marked by silicified chert breccias like those in the Twin Spring Hills and the Roberts Mountains (Merriam and Anderson, 1942, p. 1703). Associated with upper plate chert and graptolitic shale of the Vinini is light-gray vitreous quartzite resembling the Eureka. West of summit 9,033 this quartzite is overlain by chert and chert breccia.

STRATIGRAPHY

Continuous stratigraphic order in the Vinini formation has not yet been established. Mapping of Vinini outcrops over 2 miles wide south and southwest of Tyrone Gap (fig. 2) reveals definite shale, chert-shale, chert, limestone, and sandstone belts that clearly represent stratigraphic zones. However, uncertainties exist regarding vertical order of these zones, for the rocks are intricately folded and sheared. Small pieces of section, a few hundreds of feet thick, can be measured bed by bed, but eventual arrangement of short segments in stratigraphic sequence can be accomplished only by detailed studies of graptolites in conjunction with detailed mapping and interpretation of structure and stratigraphy.

Preliminary comparison of identified Vinini graptolite assemblages with those of established sequences in eastern North America and the Old World shows that the sandstone belts in the Roberts Mountains area are paleontologically older than the belts which consist mainly of chert and shale. Hence, the prevailingly sandstone interval is designated as the lower part of the

Vinini and the chert and shale part as the upper part of the Vinini. Field evidence of actual superposition of these two divisions is lacking.

A fairly large belt of the sandstone of the Vinini occurs to the west near the mouth of Yahoo Canyon. This belt has not yielded sufficient graptolite evidence to confirm a lower Vinini assignment. Most of the Vinini in the Mahogany Hills and Twin Spring Hills is bedded chert and black shale containing graptolites of the upper division.

Separation of shale and sandstone beds in the Vinini from similar deposits of the Chainman and Diamond Peak sequence is difficult where thrusting brings them into juxtaposition. Discovery of graptolitic shale beds in the northern Mahogany Hills (Merriam, 1940, p. 28) pointed up this problem and occasioned a prolonged stratigraphic study accompanied by gross lithologic comparisons of regional scope between the Vinini and Mississippian strata. In absence of fossils, bedded primary chert in abundance is accepted as evidence of Vinini age. However, small amounts of black bedded chert occur locally in the upper part of the Pilot shale. Other lithologic distinctions are treated under Chainman and Diamond Peak sequence.

Poor exposures and intense deformation obviate measurement of the Vinini formation. Folded Vinini 12 miles north of Devils Gate crops out in a belt more than 2½ miles wide; in this folded belt a stratigraphic thickness of at least 1,000 feet is conceivable.

AGE AND CORRELATION

Previous studies of Vinini graptolite faunas from the Roberts Mountains area (Gurley, 1896; Merriam and Anderson, 1942; Ruedemann, 1947) led to the conclusion that the lower part of the Vinini is of Deepkill age and the upper part of the Vinini of Normanskill age. During this investigation upper Vinini graptolites were collected at the mouth of Yahoo Canyon (locs. 79, 80), northwest of Devils Gate, in the Twin Spring Hills (loc. 84), and on the east pediment of Lone Mountain.

A detailed investigation of Vinini graptolites has been initiated by R. J. Ross, Jr., of the U.S. Geological Survey, who prepared the following age analysis in terms of the British succession, based on published identifications of the Vinini forms:

Lower Vinini graptolites	*British zones*
Dictyonema	
Tetragraptus similis (Hall)	3–5
Tetragraptus quadribrachiatus (Hall)	3–5
Phyllograptus cf. *P. angustifolius* (Hall)	4–5
Didymograptus nitidus (Hall)	4–5
Isograptus gibberulus (Nicholson), *Cardiograptus folium* (Ruedemann) } Yapeenian of Australia	4–5

British zones 3, 4, 5, and 6 represent the Arenig of Britain (Elles and Wood, 1918, v. 2, p. 526).

Ross has provided the following analysis of the upper Vinini graptolites:

Upper Vinini graptolites	*British zones*
Leptograptus flaccidus (Hall) var. *spinifer* Elles and Wood, mut. *trentonensis* Ruedemann	12–13
Dicranograptus spinifer Lapworth	9–11
Diplograptus angustifolius (Hall)	8–11
Orthograptus calcaratus var. *acutus* Lapworth	9–10
Climacograptus bicornis (Hall)	9–12
Climacograptus modestus Ruedemann	?
Retiograptus geinitzianus (Hall)	9–10

According to Ross "The upper Vinini is Llandeillan and Caradocian, but there is no evidence it is Ashgillian."

Ross observes that the lower part of the Vinini is correlative with part of the Valmy formation of the Mount Lewis area, Nevada, with shales of the Hailey quadrangle, Idaho (Umpleby and others, 1930, p. 17–23), with part of the Glenogle shale of British Columbia, and with beds in the Ledbetter slate of eastern Washington. According to Ross:

> The upper part of the Vinini is correlative with part of the Valmy to the west, Phi Kappa formation of Idaho, graptolite beds in the lower part of the Saturday Mountain formation of Idaho (Ross, 1959), and part of the Glenogle shale of British Columbia.

The problem of correlating the Vinini formation paleontologically with the Pogonip carbonate facies remains unresolved. Factors to be considererd in this connection include occurrence of trilobites of the *Pliomerops* group in the lower part of the Vinini (Merriam and Anderson, 1942, p. 1695), *Didymograptus* in dark silty shale of the Ninemile formation in upper Whiterock Canyon, and *Caryocaris* shale at the base of the Goodwin limestone in Ninemile Canyon.

Graptolites occur sporadically in the eastern or carbonate facies of the Pogonip group. Likewise in the Garden City formation of Utah, Ross (written communication, 1956) recognizes Arenig graptolites at least as high as zone H (fig. 6), which probably correlates with the Ninemile formation. Ross recognizes *Didymograptus artus* Elles and Wood in the basal Swan Peak of Utah and at the top of the Ninemile of Antelope Valley. This form is believed to indicate British zone 6 or highest Arenig. The appraisal by Ross indicates the likelihood that "The lower part of the Vinini is not younger than youngest Ninemile."

Regarding possible equivalence of the problematic *Caryocaris* shale to part of the Vinini on the one hand and to lowermost Goodwin of the Eureka area on the other, Ross states:

> There is a graptolite zone 3 [British] equivalent in the Garden City. Its position is not certain, though I am sure it is some-

where below zone E. I, therefore, see no reason why lower Vinini cannot be equivalent partly to Goodwin as well as Ninemile. So far we have nothing to prevent it from being older than Goodwin at Ninemile Canyon (the base of which is younger than at Goodwin Canyon).

Graptolites occur also in the Copenhagen formation and in the Hanson Creek formation above the Eureka quartzite. Regarding possible correlation of higher shale of the Vinini beds with these units Ross states:

"If the Hanson Creek graptolites are correctly dated as Ashgillian we do not yet have evidence here that any of the Vinini is correlative with it. Some Valmy collections are, however; and Vinini-like rocks in the Tuscarora Mountains, northwest of Carlin, are definitely of Ashgill age. Therefore, although the upper Vinini seems to be equivalent to no more than Antelope Valley, Copenhagen, and Eureka formations, further collecting will probably produce evidence that it also correlates with the Hanson Creek beds on Martin Ridge."

SILURIAN SYSTEM

GENERAL FEATURES

South of the 42d parallel, Silurian rocks of the Far West, as understood at present, occur in two separate provinces, each with its own particular depositional and faunal characteristics. These are (1) the Pacific Border province, represented in the Klamath Mountains of northern California, and (2) the Great Basin province.

The Klamath Silurian comprises siliceous clastic and volcanic rocks and relatively small fossiliferous limestone bodies. It is overlain by beds of probable Early Devonian age. Petrologic and faunal relationships of the Klamath Silurian seem to be with Alaska. As represented in Antelope Valley and adjoining areas, the Great Basin Silurian differs sharply, as it is dolomitic in considerable part and, so far as known, devoid of volcanic rocks. Lateral changes from dolomite to fossiliferous limestone are characteristic.

Study of Silurian history in central Nevada concerns itself largely with strata described by Hague (1892, p. 57) as the "Lone Mountain limestone." Actually, a dolomite in the type section at Lone Mountain, this division originally embraced rocks of Late Ordovician and Silurian age and has been suspected of including Lower Devonian rocks at the top.

In subdividing the original "Lone Mountain limestone" of Hague at Lone Mountain and in the nearby Roberts Mountains, three lithologically distinctive formations were proposed by Merriam (1940, p. 10–14): Hanson Creek formation, Upper Ordovician; Roberts Mountains formation, Silurian; and Lone Mountain dolomite (restricted), Silurian. The name Lone Mountain was restricted to a single, fairly discrete dolomite division, in the hope that it would thus be perpetuated in reference to a useful map unit.

At Antelope Valley, the stratigraphic relations are complicated laterally by disappearance westward of the Lone Mountain dolomite (restricted) and introduction of a higher limestone unit above the Roberts Mountains formation. This higher limestone contains Helderberg (Early Devonian) fossils.

Boundaries separating central Great Basin Silurian rocks from the Ordovician below and Devonian above have been the subject of recent investigations. Acceptance of the Hanson Creek formation with its Richmond faunas as Late Ordovician makes it difficult, if not impossible, to draw a mappable Ordovician-Silurian boundary. Where a cherty zone is present at the base of the Roberts Mountains formation, the bottom of the chert becomes a convenient horizon at which to draw the system boundary. Proponents of the Richmond-as-basal-Silurian controversy find satisfaction in the observation that throughout the Great Basin an impressive lithologic discontinuity separates Eureka quartzite from overlying Richmond-age Hanson Creek limestone, or its equivalent dolomite formations.

The Silurian-Devonian boundary is drawn provisionally at the pre-Oriskany disconformity, which, at Table Mountain (pl. 1), separates Lone Mountain dolomite from basal dolomitic limestone of the Nevada formation containing Oriskany fossils (fig. 7). Absence from this normal western sequence of the Helderberg Early Devonian or Rabbit Hill fauna suggests either no deposition or removal by pre-Oriskany erosion. A third and somewhat less appealing explanation is east-west facies change, whereby the Rabbit Hill limestone changes eastward into uppermost Lone Mountain dolomite, which has yielded no evidence of Silurian age above the *Howellella* zone.

From the standpoint of tectonic history, the pre-Helderberg and pre-Oriskany disconformities at Antelope Valley are of great interest. Unconformities separating Silurian and Devonian rocks have been reported throughout a wide area in the Great Basin, extending from southeastern California to Utah. The crustal unrest so manifested may well have coincided with vulcanism in the Pacific Border province, complete emergence in the Colorado Plateaus province, and with Caledonian deformation in more distant lands.

Paleontologic studies of Great Basin and other Silurian of the Far West have been thus far confined to routine and provisional fossil determinations. Lack of understanding of field relations, stratigraphy, and faunas has resulted in confusion of Silurian and Devonian rocks. These western Silurian strata tend to be dolomitized and, accordingly poor in good fossil material. Nevertheless, well-preserved silicified fossils occur locally, lending themselves well to acid preparation. Furthermore, the restricted limestone facies of the Silurian are sometimes highly fossiliferous.

Corals are especially abundant in the Silurian carbonate rocks of this region (Duncan, 1956). Considerable difficulty has been experienced, however, in attempting to place the rugose forms in appropriate described genera. Some corals are evidently undescribed generically or represent rugose genera not yet adequately diagnosed and figured. Others have previously been recorded only in the Old World.

Silurian faunas under investigation in connection with stratigraphic studies of central Nevada include those of the Roberts Mountains, Antelope Valley, and the Tybo district of Nevada (Ferguson, 1933, p. 20); Gold Hill district (Nolan, 1935, p. 17), and Confusion Range in Utah; Death Valley, Inyo Mountains, and the Klamath Mountains in California.

ROBERTS MOUNTAINS FORMATION

GENERAL FEATURES

The name Roberts Mountains formation has been applied to strata on the west side of Roberts Creek Mountain (Merriam, 1940, p. 11), which rest conformably on limestone beds of the Hanson Creek formation and are overlain concordantly by Lone Mountain dolomite (emended). Type section of the formation lies between the north and south forks of Pete Hanson Creek. In the type area the Roberts Mountains formation, unlike the overlying Lone Mountain, is prevailingly limestone. At other localities this formation, together with subjacent beds of the Hanson Creek, has been subjected to nearly complete dolomitization.

Strata included in the Roberts Mountains formation at Antelope Valley overlie limestone of the Hanson Creek formation conformably and vary from limestone on the west side of the valley to dolomitic limestone and dolomite on the east side. The Roberts Mountains formation is not uniform in its relation to overlying rocks, for on the east it is overlain with apparent concordance by Lone Mountain dolomite, whereas on the west it is apparently overlain depositionally by the Rabbit Hill limestone of Early Devonian age. Absence of Lone Mountain dolomite in the west, either by unconformity or facies change, is further explained below.

AREAL DISTRIBUTION AND LITHOLOGY

The Roberts Mountains formation has been mapped at Copenhagen Canyon and Twin Spring Hills in the Monitor Range and was studied north of Wood Cone in the southern Mahogany Hills.

At Copenhagen Canyon (pl. 2) the Roberts Mountains formation is well exposed at the top of the westward-dipping homoclinal section forming Martin Ridge. To the west, at the union of Whiterock and Copenhagen Canyons, the formation is exposed in two low knobs. In Rabbit Hill (loc. 51), southernmost of the two knobs, Lower Devonian beds are underlain by this formation, which extends northward to form the higher part of the adjacent hill whose lower slopes are composed of Upper Ordovician Hanson Creek. A small isolated exposure of graptolite-bearing beds of the Roberts Mountains occurs on the pediment surface along the northeast side of the Twin Spring Hills (pl. 1). Some of these beds may also represent the Hanson Creek formation.

No exposures of Roberts Mountains formation were found in the northern Antelope Range, where the oldest Silurian rocks exposed at the valley edge are Lone Mountain dolomite. North and northwest of Wood Cone, the formation reappears in a dolomitized condition and extends northwestward along the edge of the Mahogany Hills for 3 miles. It is also exposed at Lone Mountain where it retains its dolomitic character, but changes northward to the normal limestone facies in the Roberts Mountains. Northernmost extent of this formation so far recognized is in the Mount Lewis quadrangle south of Battle Mountain, Nev., where it appears to be lithologically similar to the limestone facies at Copenhagen Canyon.

Northeast of Wood Cone, in the direction of Eureka, the Silurian rocks are entirely dolomitic and highly disturbed. Accordingly, it was not feasible to differentiate the Roberts Mountains formation from the Lone Mountain dolomite.

Silurian limestone beds, probably representing the Roberts Mountains formation, occur on the west side of Charnac Basin and at Ikes Canyon in the Toquima Range, 18 miles southwest of Copenhagen Canyon. West of Charnac Basin the Silurian limestones appear to be in thrust fault contact with limestones of the Pogonip group. At the Ikes Canyon occurrence the beds contain *Monograptus*, *Halysites*, and *Rhizophyllum*.

In Copenhagen Canyon the Roberts Mountains formation comprises dark platy and shaly limestone beds with very cherty limestone at the base. The well-bedded basal cherty member ranges from 110 to about 140 feet in thickness and consists of interbedded dark-gray or slightly bluish gray fine-grained limestone and dark-gray chert that weathers limonite brown. Irregular lenses and beds of chert, one-half to 6 inches thick, make up from one-third to one-half of this member. Above the chert, through the remainder of the formation, the thin-bedded fine-grained gray limestone, though dark gray on fresh fracture, weathers very light gray with brownish patches. A few dark-gray chert nodules are found in the platy limestone member. Subordinate interbeds of coarser textured highly organic partly crinoidal limestone show heavier bedding.

THICKNESS

Sections of the Roberts Mountains formation measured in Copenhagen Canyon at the low hill (loc. 53) just north of Rabbit Hill are about 600 feet thick of which the basal chert member ranged from 110 to 140 feet in thickness. No measurable section was found in the Mahogany Hills, but at Lone Mountain dolomitized beds of the Roberts Mountains are about 740 feet thick. Thickness of the formation increases appreciably northward, to as much as 1,900 feet in the Roberts Mountains.

STRATIGRAPHY

The contact separating Upper Ordovician limestone of the Hanson Creek from the Silurian Roberts Mountains formation is drawn at the base of a very cherty limestone member well shown in Copenhagen Canyon (loc. 53). The cherty member is also present at Lone Mountain and in the Roberts Mountains. Although the change to chert is abrupt, no evidence of discordance has been observed. Similar cherty limestone beds are present at the bottom of the Silurian section as far distant as the northern Inyo Mountains in California. Where the chert marker is absent, it is difficult, if not impossible, to objectively define the Ordovician-Silurian boundary on a lithologic basis. This is especially true where the entire Upper Ordovician and Silurian section above the Eureka quartzite is dolomitic.

At the type section in the Roberts Mountains the upper boundary is conformable, marked by a gradational change from limestone and dolomitic limestone rich in corals to blocky light-gray barren sugary dolomite of the Lone Mountain (emended). Where both formations are dolomitic, as at Lone Mountain and the Mahogany Hills, the boundary is less definite. The Roberts Mountains formation is, in general, less massive or blocky and darker gray than the Lone Mountain dolomite. Fossils are not abundant in either unit where dolomitization has taken place but are more apt to occur in the lower formation than in the Lone Mountain.

The Roberts Mountains formation at Copenhagen Canyon has a thickness less than one-third that in the type section (fig. 7). Lithologically there is fairly close agreement with the lower part of the formation in the Roberts Mountains. In the type section several faunal zones have been recognized, the lower of which is characterized by *Monograptus*, *Heliolites*, and abundant pentameroids of the *Conchidium* type. An upper zone contains diverse coral and associated brachiopod faunas discussed below. The presence of *Monograptus* faunas, relatively small thickness, and absence of the upper coral faunas suggest that the strata in question at Copenhagen Canyon represent only the lower part of the Roberts Mountains formation. The remainder, in fact the greater part of the formation, is absent, presumably because of no deposition or post-Roberts Mountains erosion.

How much of the formation may be represented paleontologically northwest of Wood Cone (pl. 1) cannot be determined until this unit is carefully studied and mapped in the Mahogany Hills along the east side of Antelope Valley.

Progressive thickening of the Roberts Mountains strata to the north, as shown by measured sections at Copenhagen Canyon, Lone Mountain, and Roberts Creek Mountain, suggests that attenuation in Antelope Valley is real, wholly stratigraphic, and not a result of faulting.

AGE AND CORRELATION

The graptolite *Monograptus* is found throughout most of the formation at Copenhagen Canyon. Two species have been determined by Ruedemann: *Monograptus acus* Lapworth and *M. pandus* Lapworth. According to Ruedemann (written communication, 1940) they indicate approximate equivalence with the Gala beds of Great Britain or Clinton and younger Niagaran strata of New York State. In these platy or shaly limestones other fossils are scarce. In the topmost beds of the basal cherty member indeterminate pentameroid brachiopods, more than an inch long, were collected, thus supporting the Silurian age of these beds in Copenhagen Canyon. Northwest of Wood Cone the coral *Halysites* was found in dolomitized Roberts Mountains strata of uncertain horizon. This form occurs at several horizons in the lower part of the formation at Roberts Creek Mountain, but was not recognized in the upper coral beds of the type section. The coral facies that characterizes the uppermost 200 feet of the formation at Roberts Creek Mountain yields the following fossil forms:

Mycophyllum sp. (abundant)
Strombodes sp.
?*Cladopora* (abundant)
?*Australophyllum* sp.
Pycnostylus sp.
Dicoelosia sp.
Homoeospira sp.
Atrypa sp. (abundant)
dasycladacean algae

The upper Roberts Mountains coral zone is of possible Lockport age.

Dasycladacean algae similar to those of the upper coral beds of the Roberts Mountains occur in the higher part of the Laketown dolomite in the Confusion Range, Utah. Comparable dasycladaceans are present also in the Hidden Valley dolomite of the Death Valley region (McAllister, 1952, p. 15) and in the middle part of an unnamed Silurian limestone at Mazourka Canyon in the northern Inyo Mountains of California (Rezak, 1959). *Monograptus*-bearing lower beds of the Roberts Mountains formation are probably equivalent to the lower part of the Laketown, lower part of the Hidden Valley, and lower part of the Silurian limestone at Mazourka Canyon, which last begins with a very cherty limestone similar to the basal chert member of the Roberts Mountains formation. The Trail Creek formation of Idaho includes correlative beds.

LONE MOUNTAIN DOLOMITE

OCCURRENCE AND NAME

The name Lone Mountain limestone was given by Hague (1883, p. 262; 1892, p. 57) to strata between the Eureka quartzite and the Nevada formation at Lone Mountain, 16 miles northwest of Eureka. Except for a small amount of chert, all beds occupying this interval at Lone Mountain are actually dolomite rather than limestone and have yielded few identifiable fossils. In the Roberts Mountains (Merriam, 1940, p. 10–14) the same interval is occupied by three distinctive mappable formations, the lower two of which are mainly limestone. The lower limestone formation, known as the Hanson Creek, is of Late Ordovician age; the overlying or middle limestone is Silurian and has been named the Roberts Mountains formation. Both are fossiliferous. The third or uppermost formation, a medium- to light-gray blocky dolomite, is lithologically almost identical with the upper and thicker part of the original Lone Mountain limestone of Hague at Lone Mountain (fig. 7).

Beneath the upper light-gray dolomite at Lone Mountain lies the thinned, dolomitized, and otherwise modified southern extension of the Roberts Mountains formation, below which is almost unfossiliferous dolomitized Hanson Creek. The original Lone Mountain limestone of Hague at Lone Mountain thus contained strata of at least two geologic systems: Ordovician and Silurian. Lack of fossils in the upper light-gray dolomite leaves open the possibility that the Lone Mountain might conceivably include beds of Early Devonian age; if this were true, Hague's original Lone Mountain limestone would include parts of three systems.

The sections in the Roberts Mountains seem obviously better suited for stratigraphic and paleontologic study than the barren dolomitic strata at Lone Mountain, because they have greater thickness and are preeminently more fossiliferous. Type sections of the Hanson Creek and Roberts Mountains formations were accordingly designated there (Merriam, 1940, p. 10–12).

In coping with the consequent problem of nomenclature at Lone Mountain at least three courses appeared to be open: (1) complete abandonment of "Lone Mountain" as a stratigraphic name; (2) elevation of "Lone Mountain" to group status with three formations, of which only the upper one was represented in its normal or more favorable guise; (3) restriction of the formation name Lone Mountain dolomite to one of the three formational divisions. The last course was elected (Merriam, 1940, p. 13) with the aim of preserving and perpetuating the name Lone Mountain as a useful and objective map term in this region. In so doing, the name Lone Mountain dolomite was applied as emended to the upper light-gray blocky division, the thickest of the three at Lone Mountain and a fairly uniform division well exposed also in the Roberts Mountains.

Had the Hanson Creek and Roberts Mountains formations been represented at Lone Mountain in their normal fossiliferous phases, a reasonable course would have been adoption of the term Lone Mountain group to bracket all three formations occupying the interval of Hague's Lone Mountain limestone. Ideally, a stratigraphic group, whether new or based on subdivision of an earlier defined broad formation, should, if possible, be established where all of its constituent formations exhibit facies considered typical or truly representative. Use of Lone Mountain group, by connotation based on the section at Lone Mountain, would not be especially appropriate in the Roberts Mountains because of lateral facies change and because of probable change in time-rock content. Extended west to the Monitor Range the group name would be even less desirable because of greater lithologic and faunal changes. Introduced westward above the Roberts Mountains formation is the fossiliferous Early Devonian Rabbit Hill limestone facies, a possible time-rock equivalent of uppermost Lone Mountain dolomite as emended. In short, the term Lone Mountain group to be of value in the region here dealt with would have to include units and facies not actually present at Lone Mountain, a usage that would add to the already existing confusion.

AREAL DISTRIBUTION AND LITHOLOGY

Lone Mountain dolomite has been recognized only on the east side of Antelope Valley. This formation does not appear in the Monitor Range and is not known in the Toquima Range or any of the mountain ranges farther west. The Lone Mountain dolomite underlies Nevada formation at the north tip of the Antelope Range; it extends eastward into the Fish Creek Range and northward beneath the Mahogany Hills to the type area at Lone Mountain. From the Mahogany Hills it may be followed eastward into the Eureka mining district. Southeast of Eureka only the upper part is well exposed, but at Oxyoke Canyon (Nolan, Merriam, and Williams, 1956, p. 38) the disconformable relationship with overlying Nevada formation is especially well shown. Sections of Lone Mountain dolomite may be seen to advantage on the west side of Roberts Creek Mountain, in the Sulphur Spring Mountains north of Tyrone Gap (fig. 2) and on the west flank of the Diamond Mountains near the Phillipsburg mine.

Silurian dolomite of comparable lithologic character and stratigraphic situation occurs widely in the Great Basin, extending from the Ruby Mountains on the north (Sharp, 1942, p. 660) eastward into Utah and southward to Death Valley and the Inyo Mountains.

The Lone Mountain dolomite commonly shows rather poorly defined bedding, is massive and blocky-weathering, and has a medium to coarse saccharoidal texture. On the weathered surface it is prevailingly light gray; freshly broken faces are sometimes medium to dark gray.

Sugary dolomites of the Lone Mountain are readily confused with those of the Nevada formation. On the whole, however, bedding is more clearly defined in the Nevada. Moreover, the dolomite of the Nevada commonly includes discrete heavy-bedded sequences in which bands of laterally continuous very dark gray or black uniform carbonaceous dolomite alternate with sharply contrasting light-gray layers.

Organic traces are relatively uncommon in the Lone Mountain dolomite. Near the base of this formation are beds of coarse crinoidal dolomite, and about 500 feet below the top circumscribed or lenticular dark-gray dolomite patches contain fossils. These dark dolomite patches are highly carbonaceous, sometimes fairly well bedded, and occasionally contain silicified fossils and cherty matter.

THICKNESS

Because of faulting no thickness measurement of the entire Lone Mountain dolomite was made at Antelope Valley. In this respect, however, the type section at nearby Lone Mountain, with thickness of 1,570 feet, is probably representative of the area. The section thickens to 2,190 feet at Roberts Creek Mountain, 20 miles to the north (fig. 7).

STRATIGRAPHY

At Lone Mountain and Roberts Creek Mountain, the Lone Mountain dolomite is gradational with the underlying Roberts Mountains formation. Where both units are dolomite, as at Lone Mountain, the line of separation falls within a zone where the color of the rocks changes from predominantly dark gray of the Roberts Mountains interval to prevailingly lighter gray of the higher unit.

The Lone Mountain dolomite in the Mahognay Hills is overlain disconformably by the lower part of the Nevada formation. Good exposures of this contact may be seen on an east-west spur, 2 miles south of the middle of Table Mountain, at altitude 7,900 feet (loc. 75). Topmost Lone Mountain is a light-gray dolomite mud breccia containing angular dolomite fragments and truncated above by a sharply defined erosion surface. The basal Nevada is a medium-gray, faintly laminated dolomitic crinoidal limestone containing large horn corals characteristic of the Early Devonian Oriskany zone. This coral bed is overlain by fossil beds of the Early Devonian "*Spirifer*" *kobehana* zone. No angular discordance was noted.

The pre-Oriskany disconformity at Table Mountain doubtless corresponds to that mapped at Oxyoke Canyon in the Eureka district (Nolan, Merriam, and Williams, 1956, p. 38), where it is overlain by the fine-grained Beacon Peak dolomite member of the lower part of the Nevada, in which no determinable fossils have been found. The disconformity was not recognized at Lone Mountain (Merriam, 1940, p. 14), where the boundary between the Lone Mountain dolomite and the Nevada seems to be gradational. A corresponding unconformity between Silurian Laketown dolomite and the Devonian is reported at Gold Hill, Utah (Nolan, 1935, p. 18) and in the Confusion Range, Utah (R. K. Hose, written communication, 1956).

Earlier in these studies it was theorized that the western sequence Rabbit Hill limestone in the Monitor Range might be a time-stratigraphic equivalent of the Lone Mountain dolomite, both resting upon strata assigned to the Roberts Mountains formation (fig. 7). This theory became at least partially untenable when the diverse Rabbit Hill fauna was demonstrated to be of Early Devonian age, whereas the upper Lone Mountain faunas with *Howellella* proved to be Late Silurian. Thus while fossil evidence rules out correlation of the Rabbit Hill with all Lone Mountain dolomite below the *Howellella* zone, a remote possibility remains that the unfossiliferous uppermost few hundred feet of Lone Mountain dolomite may be as young as the Rabbit Hill strata of Helderberg age.

AGE AND CORRELATION

The Lone Mountain dolomite includes fossil-bearing strata of Late Silurian age. On the whole, however, it is sparsely fossiliferous, unlike the abundantly fossiliferous limestone of the Roberts Mountains that compose the lower part of the system. Most previously reported Lone Mountain fossils, including *Halysites*, evidently came, not from the emended Lone Mountain, but from the lower unit.

Dark-gray lenses of dolomite in the upper part of the Lone Mountain at the type section contain poorly preserved coral debris. Two silicified fossil assemblages have been found in about the same zone, one at a locality 1½ miles north of Wood Cone (pl. 1) and the other in the Fish Creek Range, 9 miles south of Wood Cone. North of Wood Cone the fossil zone lies 500 to 600 feet stratigraphically below the top of the Lone Mountain dolomite. The common fossils are a bushy colonial coral related to *Disphyllum*, the small spiriferoid *Howellella*, and a spiriferoid of the *Lissatrypa* type. A late Silurian age is indicated.

The dark-gray upper lenses of the Lone Mountain dolomite containing silicified fossils appear to have been loci of especially vigorous organic growth, contrasting sharply in this respect with surrounding lighter gray barren dolomite. Abundance of relict carbonaceous matter supports this view. When the fossil-bearing dolomite is dissolved in hydrochloric acid, oily-appearing frothy matter is released. Petroliferous nature of the oily substance was not determined by chemical analysis. It is probable that silicification of the fossils took place at an early stage before dolomitization, thus escaping destruction of shell structure usually attending dolomitic reorganization of the carbonate matter.

A species of *Howellella* similar to that of the upper part of the Lone Mountain occurs near the top of the Silurian Laketown dolomite in the Confusion Range, Utah (R. K. Hose, written communication, 1956; Waite, 1956). These upper Laketown strata are correlative with the Lone Mountain. Fine-textured Sevy dolomite resting unconformably on the Laketown was also correlated by Osmond (1954) with the Lone Mountain dolomite. However, the Sevy is lithologically similar to, and occupies the stratigraphic interval of, the Beacon Peak dolomite member of the lower part of the Nevada formation in the Eureka district.

Hidden Valley dolomite of the Death Valley region (McAllister, 1952, p. 15) is correlative in part with the Lone Mountain but, as delimited by McAllister, includes rocks of early Nevada (Oriskany) age above and Roberts Mountains Early Silurian age below. Hidden Valley Silurian *Disphyllum*-like corals have smaller corallites than those of the upper part of the Lone Mountain. Lower beds of the Hidden Valley contain *Halysites* and dasycladacean algae like those of the Roberts Mountains formation.

Silurian limestone beds at Mazourka Canyon in the Inyo Mountains of California represent undolomitized coral facies of the Hidden Valley; these limestones yield *Disphyllum*-like corals similar to those of the upper Lone Mountain *Howellella* zone. Such corals in the uppermost beds of the Mazourka Canyon sequence show internal features more like those of *Sanidophyllum* Etheridge than *Disphyllum* and may be either Late Silurian or Early Devonian.

Howellella and *Lissatrypa*-like brachiopods in the upper part of the Lone Mountain suggest correlation with the Gazelle formation of the Klamath Mountains in California (Wells and others, 1959), with Upper Silurian of southeast Alaska (Kirk and Amsden, 1952), and with the Read Bay formation of arctic Cornwallis Island (Thorsteinsson, 1958). Similar species of *Howellella* occur in the Polish Silurian (Kozlowski, 1929; 1946). More meaningful long distance correlation of the Lone Mountain dolomite will become possible when the *Howellella* zone faunas from this and other western Silurian formations are more throughly studied.

DEVONIAN SYSTEM

GENERAL FEATURES

Devonian rocks of Antelope Valley are about 4,000 feet thick collectively and range in age from Helderberg Early Devonian to Late Devonian. The entire range in age is not, however, found in a single continuous stratigraphic sequence, for the oldest or Helderberg-age strata compose a geographically restricted unit recognized only in the Monitor Range.

Geologic mapping in the Eureka and Antelope Valley areas (Nolan, Merriam, and Williams, 1956) discloses surprisingly great east-west lithologic and faunal changes as the Devonian strata are traced eastward from the Monitor Range to the Diamond Mountains (fig. 2). Three Devonian stratigraphic sequences are distinguishable: (1) westernmost Helderberg Devonian sequence, (2) normal western Devonian sequence, and (3) eastern Devonian sequence. The westernmost Helderberg-age sequence includes only those Early Devonian strata to which the name Rabbit Hill limestone is here applied. The more inclusive western normal and eastern sequences begin with strata of Oriskany age and continue upward to very late Devonian. Superposed in ascending order, the normal western Devonian sequence includes the Nevada formation, Devils Gate limestone, and the lower part of the Pilot shale.

The normal western sequence Devonian rocks have been mapped southward from Devils Gate to the northern Antelope Range and were followed eastward into the Eureka mining district, where they merge with the eastern sequence. The normal western Devonian sequence is virtually that earlier described at Lone Mountain and Devils Gate (Merriam, 1940, p. 22–29).

The eastern Devonian sequence near Eureka shows the result of great lateral facies change, although comparative thicknesses suggest little difference in time-stratigraphic content relative to the normal western Devonian column at Lone Mountain and Antelope Valley. Occurrence of Helderberg and Oriskany faunas makes the Antelope Valley Devonian column the most nearly complete thus far recorded in western North America.

Because of deformation and erosion, the Early Devonian (Helderberg) Rabbit Hill has no established stratigraphic top in the Monitor Range. Moreover, it has not been shown conclusively that normal western sequence Devonian rocks did not at one time extend westward to the Monitor Range. Their absence may be due to no deposition, erosion, or deformation. Missing normal western sequence units could have been cut out by thrusting that caused Ordovician Pogonip rocks to override Early Devonian Rabbit Hill (pl. 2, fig. 4).

Paleontologic studies were conducted in Lower Devonian rocks of the Sulphur Spring Mountains, where, below the Oriskany zone, occur faunas similar to those of the Monitor Range Helderberg sequence. Detailed geologic mapping is needed in the Sulphur Spring Mountains to further elucidate the relation of these fossil-bearing Lower Devonian beds to the Lone Mountain dolomite and to the lower part of the Nevada formation.

Reviewing the question of base and top of the Devonian system in this region, we are still confronted by uncertainties. Base of the normal western sequence is defined by a pre-Oriskany disconformity that locally separates lower beds of the Nevada from the Lone Mountain dolomite. It is likewise probable that the Monitor Range sequence of Helderberg age rests disconformably upon the lower part of the Roberts Mountains formation of Silurian age, cutting out upper beds of the Roberts Mountains and possibly the Lone Mountain dolomite (fig. 7). The pre-Oriskany disconformity of the normal western sequence may explain absence of the beds of Helderberg age. In spite of this disconformity, the possibility that the Monitor Range beds of Helderberg age may be a limestone facies-equivalent of uppermost Lone Mountain dolomite is not entirely ruled out.

Top of the Devonian system is drawn provisionally at an indefinite horizon within the Pilot shale (fig. 8). Below this horizon the conodonts indicate Late Devonian age for the lower part of the Pilot; the upper part of the Pilot of sections in the Eureka mining district is Early Mississippian.

Hague (1892) originally included the "White Pine shale" in the Devonian system. Later work demonstrates that only the lower part of the Pilot shale, which is the basal part of Hague's division, belongs in the Devonian.

WESTERN HELDERBERG-AGE LIMESTONES OF THE MONITOR RANGE

RABBIT HILL LIMESTONE

GENERAL FEATURES

The Rabbit Hill limestone of Early Devonian age is so named for limestone and calcareous shale that make a small outlying hill at the junction of Whiterock Canyon with Copenhagen Canyon (pl. 2). At this locality (No. 51) is the designated type section of the unit. Although contact relations with underlying lower beds of the Roberts Mountains formation are somewhat obscure, the absence of upper beds of the Roberts Mountains as well as of the Lone Mountain dolomite point to existence of a disconformity. For stratigraphic interpretation the Rabbit Hill occurrence leaves much to be desired; these relatively incompetent strata are deformed beneath the sole of a thrust fault. No strata younger than Rabbit Hill have been found in this area.

AREAL DISTRIBUTION AND STRUCTURE

The Rabbit Hill has been recognized only in the Monitor Range, where its outcrop follows the west side of Copenhagen Canyon for about 5 miles, extending from Ryegrass Canyon northward to disappear beneath the volcanic rocks in the Monitor Range. At the Rabbit Hill type section these beds are about 250 feet thick and dip west about 16°. West of the hill the Lower Devonian beds crop out for more than a mile along Whiterock Canyon. Undulant dips are observed, mainly to the west at rather low angles, and few exceed 40° (fig. 4). Minor drag folds are common; at some places bedding plane slippage has caused complex subsidiary flexing of weaker shaly layers between heavier limestone beds. Structural behavior of these dragged beds is in accord with their position beneath the overriding plate of Antelope Valley limestone. At locality 3 a thrust outlier of the Ordovician limestone appears to rest upon deformed Rabbit Hill. It is probable that minor sympathetic thrusts or reverse faults exist within the Rabbit Hill itself.

LITHOLOGY

The Rabbit Hill limestone comprises dark gray to almost black fine-grained platy and flaggy limestone, calcareous shale, and argillaceous limestone; scattered beds of more coarsely crystalline limestone are as much as 4 feet thick. The heavier beds and lenses are highly organic in many places, consisting in large part of crinoidal, coral, and brachiopod material. In the richly fossiliferous beds much of the material is silicified, showing limonitic staining on the weathered surface. Some of these rocks, especially the argillaceous phases, weather light gray. On the whole the limestone beds are impure, yielding, on solution in hydrochloric acid, a large residue of insoluble clayey and carbonaceous matter together with silicified fossils. Chert is scarce, but there are a few beds of laminated brownish silicified matter, which in thin section has the appearance of medium-grained to very fine silty sand and is composed in large part of comminuted and silicified organic remains, including sponge spicules and crinoidal material.

THICKNESS

Because of the deformation it has not been possible to measure a complete section of the Rabbit Hill limestone. At Rabbit Hill about 250 feet of the formation is exposed. A section measured through the Roberts Mountains Silurian and adjacent rocks, a mile north of Rabbit Hill, shows about 160 feet of the Rabbit Hill limestone, but the exact contact could not be determined. The width of outcrop alone suggests that the Rabbit Hill limestone must considerably exceed the estimate of 250 feet.

What appears to be the same fossil bed containing abundant *Syringaxon* is repeated across the broad outcrop of the Rabbit Hill limestone. Whereas this repetition may be paleontologic recurrence, it seems more probable that the same bed reappears because of sympathetic thrust slicing and drag folding. In this area the rather incompetent and locally much deformed beds of the Rabbit Hill occur in the lower plate of a thrust. In accord with structural repetition, the exaggerated width of outcrop is believed disproportionate to actual stratigraphic thickness of the unit.

STRATIGRAPHY

Although no actual contact surface was observed, the limestone beds of the Rabbit Hill appear to rest depositionally upon the Roberts Mountains formation, 1 mile north of Rabbit Hill. Not only is the Lone Mountain dolomite missing at this boundary, but the Roberts Mountains formation is itself much thinned in comparison with sections at Lone Mountain and Roberts Creek Mountain (fig 7). Barring unrecognized faulting, we may logically reason either that we are dealing with a major unconformity that cuts out the entire Lone Mountain dolomite together with much of the upper part of the Roberts Mountains or that the hiatus is of a lesser magnitude and the Rabbit Hill is a local limestone facies equivalent to a higher part of the Lone Mountain dolomite. Only uppermost Lone Mountain dolomite, about 400 feet thick, need be considered in this connection, for most of this unit up to and including the *Howellella* zone is clearly Silurian and older than the Rabbit Hill limestone.

AGE AND CORRELATION

Large collections of well-preserved silicified fossils from the Rabbit Hill type area (loc. 51) were prepared by the acid technique. All represent virtually a single Helderberg Early Devonian fauna. Many of the Rabbit Hill species are new and undescribed, but a sufficient number are closely related to eastern Helderberg species. Representative Rabbit Hill fossils are listed below:

hexactinellid sponge spicules
Favosites sp.
Cladopora sp.
Striatopora sp. cf. *S. gwenensis* Amsden
Michelinia sp.
Pleurodictyum sp. cf. *P. trifoliatum* Dunbar
Syringaxon acuminatum (Simpson)
Orthostrophia sp. cf. *O. strophomenoides* (Hall)
Dalmanella sp. (small form)
Levenea n. sp. cf. *L. subcarinata* (Hall)
Schizoramma sp.
Leptaena sp. cf. *L. rhomboidalis* (Wilckens)
Schuchertella sp. (large form)
Chonetes sp.
Atrypa sp.
Anoplotheca sp. cf. *A. acutiplicata* (Conrad)
Trematospira sp. cf. *T. equistriata* Hall and Clarke
Meristella sp. (large form)
Kozlowskiellina sp. a
"*Spirifer*" sp. cf. "*S.*" *modestus* Hall
"*Spirifer*" sp. cf. "*S.*" *swallowensis* Foerste
"*Spirifer*" sp. a cf. "*S.*" *cyclopterus* Hall
Tentaculites sp.
Platyceras sp.
Orthoceras sp. (small form)
Leonaspis sp. cf. *L. tuberculatus* (Hall)
Phacops sp.
Dalmanites sp.

Especially distinctive and abundant genera in this fauna are *Levenea*, *Kozlowskiellina*, *Anoplotheca*, *Leonaspis*, and *Syringaxon*. The *Levenea* is closely related to *L. subcarinata* of the Helderberg Birdsong formation in Tennessee (Dunbar, 1918, p. 743), whereas the *Anoplotheca* resembles *A. acutiplicata*, reported in the Onondaga (Kindle, 1912, p. 84) of the Appalachian region. A similar *Anoplotheca* occurs also in the Oriskany fauna near the base of the Death Valley Devonian section. *Leonaspis* cf. *L. tuberculatus* is fairly close to the eastern Helderberg species (Whittington, 1956), whereas *Syringaxon acuminatum* seems to be conspecific with a Brownsport Niagaran species. The new spiriferoid brachiopod, assigned to *Kozlowskiellina* sp. a, resembles a recently described Silurian and Early Devonian genus (Boucot, 1957). Species of *Trematospira*, *Schuchertella*, and "*Spirifer*" sp. a approach Helderberg types.

Of interest is the peculiar *Pleurodictyum*, which closely resembles *P. trifoliatum* of the lower Helderberg Rockhouse shale in Tennessee (Dunbar, 1920, p. 118). In summary, the fossil evidence suggests an earliest Devonian age; only the *Anoplotheca* is not harmonious with this view.

Pre-Oriskany age of the Rabbit Hill is further borne out by comparison of its fauna with faunas recently discovered below the Oriskany in the lower part of the Nevada in the southern Sulphur Spring Mountains (fig. 2). Species of *Levenea*, *Anoplotheca*, and *Syringaxon* resemble closely those of the Rabbit Hill. Higher in the same column of the Sulphur Spring Mountains, the Oriskany zone contains large spirifers of the *arenosa* and *murchisoni* types.

Thus whereas earliest Devonian Rabbit Hill limestone appears to occupy a position wherein Lone Mountain dolomite would logically be expected, it is patently younger than Lone Mountain, except possibly for the uppermost part. The Rabbit Hill limestone probably has a westerly distribution with respect to Lone Mountain dolomite.

NORMAL WESTERN SEQUENCE DEVONIAN ROCKS OF ANTELOPE VALLEY

NEVADA FORMATION

GENERAL FEATURES

The name Nevada as applied to Paleozoic rocks of the Great Basin was first used by King (1876). Distribution ascribed to this unit on his atlas map embraces areas now known to be occupied by rocks of diverse ages, although by implication King probably intended the term solely for Devonian strata ranging from "Chemung to Upper Helderberg." The designation "Nevada" was evidently not used in the "Systematic Geology" by King (1878, p. 206, 210, 235, 248). In this volume the Devonian strata are referred to as part of the inclusive and now untenable "Wahsatch Limestone".

In the Eureka district, Nev., Hague (1883, p. 264–266; 1892, p. 63–68) adopted the term "Nevada limestone" for Devonian rocks that lie between the "Lone Mountain limestone" and the "White Pine shale."

Stratigraphic and paleontologic studies in areas northwest and west of Eureka led Merriam (1940, p. 14–16) to propose redefinition of the division as Nevada formation. The proposed change called for restricting the name to the lower and middle parts of Hague's original "Nevada limestone" and designating the remaining upper part separately as Devils Gate limestone.

On the basis of Walcott's faunal studies, Hague (1883, p. 265) predicted eventual subdivision of the original "Nevada limestone", but considered it provisionally a single major unit with "an upper and lower horizon." Subsequent analysis of the Devonian faunas confirmed the great differences between the lower and upper parts of Hague's original "Nevada limestone", even as implied by Hague himself (1883, p. 264, 266). Merriam's studies do not, however, wholly support Hague's conception of a "mingling of species throughout the beds" as an obstacle to drawing fairly definite stratigraphic boundaries within the original unit. Likewise subject to modification was the view that certain characteristic species like "*Spirifer*" *pinyonensis* and "*Rhynchonella castanea*" ranged from the "lower horizon" to the "upper horizon" of the original "Nevada limestone." This interpretation probably was founded on a broad species concept, and rather loose identification of poor fossil material, coupled with a lack of criteria by which isolated or partial Devonian sections could be correlated among themselves and so arranged in correct order of superposition.

As delimited by Merriam, the Nevada formation comprises limestone, dolomite, shale, and sandstone beds of Early and Middle Devonian age resting upon Lone Mountain dolomite and overlain by Devils Gate limestone.

More recent studies in the Eureka mining district (Nolan, Merriam, and Williams, 1956) elucidate the great sedimentary facies change in the Nevada rocks from Antelope Valley eastward to Newark Valley. Of special interest are changes from limestone to dolomite and from calcareous shale and limestone to quartz sandstone passing eastward.

Hague (1892, p. 65) listed five localities in the vicinity of Eureka where representative sections of the "Nevada limestone" can be examined, without specifically designating one as the type; from these Merriam (1940, p. 15) later selected Modoc Peak (pl. 1), 4 miles west of Eureka, as providing a suitable type section for the redefined Nevada. Because of facies change no individual section of the Nevada formation is wholly satisfactory as a type, but the Modoc Peak column possesses desirable intermediate features of both eastern and western Nevada facies, among which is a western tongue of the Oxyoke Canyon sandstone member.

AREAL DISTRIBUTION

The Nevada formation is found only on the east side of Antelope Valley (pls. 1, 2). It is well exposed at the north end of the Antelope Range, where it makes up a large block in thrust fault contact with Pogonip rocks to the south. Eastward across Fenstermaker Wash it crops out again in the southern Fish Creek

Range. In the Mahogany Hills, the Nevada is exposed from Combs Peak northwestward through Table Mountain; reappearing at Lone Mountain, it constitutes about one-third of the central mountain mass. Throughout the greater part of the Dry Lake arch, the Nevada formation is covered by low-dipping Devils Gate limestone.

To the east, in the Eureka district, the Nevada probably occupies more surface area than any other formation; it reappears on the west side of the Diamond Mountains (fig. 2) near the Phillipsburg mine. Northward the Nevada extends into the Roberts Mountains and beyond in a northwesterly direction to the Cortez district. To the northeast it lies along the Sulphur Spring Mountains through Mineral Hill, and crops out extensively in the southern Ruby Mountains (Sharp, 1942, p. 661).

THICKNESS

No unbroken section of Nevada formation was recognized in Antelope Valley. At Lone Mountain, where the formation is representative of the Antelope Valley depositional belt, measured thickness is 2,448 feet; this figure compares favorably with 2,550 in the eastern facies at Oxyoke Canyon southeast of Eureka. A measured thickness of 2,200 feet on the west side of Table Mountain is unreliable because of frontal faulting.

LITHOLOGY AND STRATIGRAPHY

The Nevada exposures at Lone Mountain and Antelope Valley are collectively unexcelled for completeness of the column and preservation of the fossil record. Lithologically, however, these normal western sequences differ greatly from those in the Diamond Mountains near Eureka, especially with respect to the lower part of the formation (fig. 8). At Lone Mountain (Merriam, 1940, p. 20–24), the formation was for convenience subdivided by means of faunas and lithology into lower, middle and upper parts. These somewhat arbitrary divisions are used at Antelope Valley.

East of Eureka (Nolan, Merriam, and Williams, 1956, p. 40–48) it was lithologically feasible to subdivide the Nevada formation into five members (table 2) of which two, Bay State dolomite and underlying Woodpecker limestone, are traceable as map units to the Antelope Valley area, though somewhat modified lithologically. Bay State dolomite member corresponds virtually to the upper part of the Nevada, whereas the Woodpecker limestone member is roughly equivalent to the upper third of the middle part of the Nevada. The lower three members of the eastern sequence have not been mapped through or correlated precisely with the lower middle and lower parts of the Nevada, as represented in the Lone Mountain-Antelope Valley western sequence.

TABLE 2.—*Comparison of normal western sequence of the Nevada formation with the eastern sequence*

Normal western sequence at Lone Mountain and east side Antelope Valley			Eastern sequence at Oxyoke Canyon, Eureka District	
Stringocephalus zone	Upper part of the Nevada, 670 ft.	Thick-bedded dolomite with layers of limestone.	Bay State dolomite member, 738 ft	*Stringocephalus* zone, *Rensselandia* subzone.
Martinia kirki zone	Middle part of the Nevada, 1,060 ft.	Dolomite and siliceous limestone, well-bedded limestone with crinoidal lenses.	Woodpecker limestone member, 387 ft.	*Martinia kirki* zone with "*Leiorhynchus*" *castanea*.
			Sentinel Mountain dolomite member, 610 ft.	No determinable fossils.
"*Spirifer*" *pinyonensis* zone	Lower part of the Nevada, 718 ft.	Thin-bedded, flaggy and argillaceous limestone underlain by thicker bedded dolomitic sandy limestone.	Oxyoke Canyon sandstone member, 400 ft.	
"*Spirifer*" *kobehana* zone, "*Spirifer*" *arenosa* subzone			Beacon Peak dolomite member, 470 ft.	

The lower part of the Nevada, about 700 feet thick, consists largely of dark-gray thinly bedded to flaggy richly fossiliferous limestone with argillaceous limestone or shaly partings. A basal member of the lower part of the Nevada, ranging in thickness from about 15 feet to more than 40 feet, is thicker bedded dolomitic limestone or dolomite of medium- to dark-gray color, weathering very light gray. Whereas the basal member superficially resembles the underlying Lone Mountain dolomite, it carries Lower Devonian fossils of Oriskany age ("*Spirifer*" *arenosa* and "*S.*" *kobehana*).

Locally, as at Table Mountain, basal Nevada rests disconformably upon sugary Lone Mountain dolomite (figs. 7, 8). From Antelope Valley to Diamond Valley and northward in the Sulphur Spring Mountains, these lowest beds of the Nevada are a distinctive arenaceous limestone or dolomitic limestone with subangular to well-rounded grains of white to cream-colored aphanitic carbonate and subordinate amounts of clear quartz grains. Where strongly dolomitized, as at Table Mountain, the arenaceous character is less obvious because of recrystallization. In all probability these basal are-

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naceous-dolomitic beds of the Nevada correspond to some part of the much thicker Beacon Peak dolomite member, which in the Eureka area is likewise partly arenaceous, containing varying amounts of quartz sand.

The lower part of the Nevada in Antelope Valley and at Lone Mountain is roughly equivalent to combined Beacon Peak dolomite and Oxyoke Canyon sandstone members of the Eureka district. Whereas these two members of the eastern sequence are almost barren of fossils, the lower part of the Nevada at Antelope Valley and Lone Mountain is the most richly fossiliferous part of the Devonian system in the Great Basin. Westerly tongues of Oxyoke Canyon sandstone member within and just above the "*Spirifer*" *pinyonensis* zone at Modoc Peak and Combs Peak (loc. 78) support this correlation. Oxyoke Canyon sandstone was not recognized at Lone Mountain, but appears again in the southern Sulphur Spring Mountains near the top of the "*Spirifer*" *pinyonensis* zone.

The middle part of the Nevada in the Antelope Valley region, about 1,000 feet thick, corresponds approximately to combined Sentinel Mountain dolomite member and overlying Woodpecker limestone member. As shown at Lone Mountain, the middle part of the Nevada consists of fine-grained dark-gray well-bedded limestone with lenses of coarse-grained heavy-bedded crinoidal matter, overlain by rather dense fine-grained well-bedded partly siliceous limestone and dolomitic limestone of medium to dark-gray color. These upper middle siliceous limestone beds of the Nevada, corresponding to the Woodpecker limestone member at Eureka, tend to weather light gray. Limonitic brown mottlings commonly represent silicified organic material. Near Eureka the typical Woodpecker limestone member is somewhat thinner bedded, with argillaceous to silty calcareous shale interbeds sometimes pinkish in color. On the crest of the Antelope Range at the northern tip, the eastern facies Woodpecker limestone member—though somewhat modified—may be distinguished as a lithologic unit, but northward at Table Mountain, intermediate between the Antelope Range and Lone Mountain, these strata of the Woodpecker are greatly changed by dolomitization in a much-faulted area. Similarly at Newark Mountain northeast of Eureka, the Woodpecker member has gone over completely to dolomite and cannot be separated conveniently from the underlying Sentinel Mountain dolomite member.

Upper beds of the Nevada, about 700 feet thick at Lone Mountain and Antelope Valley, correspond to the Bay State dolomite member at Eureka. Largely heavy-bedded or massive, these strata are dolomite of medium-granular to coarse-saccharoidal texture, ranging in color from nearly black or very dark gray to light gray. The darker gray phases predominate. Conspicuous bands are produced by thick alternate light and dark layers. The upper dolomite of the Nevada forms rugged blocky staircaselike slopes with low cliffs. Thick dark-gray beds loaded with "spaghetti coral" (*Cladopora?*) are characteristic, and massive dark and light-gray shell beds contain the large but usually fragmentary and poorly preserved *Stringocephalus*.

FAUNAL ZONES

The viewpoint of the biostratigrapher was adopted in these studies of Antelope Valley Devonian stratigraphy. Accordingly, the Nevada formation was subdivided by fossils into four major faunal zones arranged in stratigraphic order as follows:

4. *Stringocephalus* zone
3. *Martinia kirki* zone
2. "*Spirifer*" *pinyonensis* zone
1. "*Spirifer*" *kobehana* zone

In terms of lithologic divisions earlier discussed the lower part of the Nevada embraces the "*Spirifer*" *kobehana* zone together with the overlying "*Spirifer*" *pinyonensis* zone; the middle part of the Nevada includes the *Martinia kirki* zone, and the upper part of the Nevada or Bay State dolomite member occupies the interval of the *Stringocephalus* zone.

The "*Spirifer*" *kobehana* zone is represented in the northern Antelope Range and at Table Mountain, whence it may be traced southeastward to Combs Peak. Just above the surface of disconformity with the Lone Mountain dolomite (loc. 75), the lowermost beds of this zone are dark-gray dolomite containing the large "Streptelasmoid sp. a" (Merriam, 1940, p. 52). This horn coral is characteristic of the Oriskany Early Devonian *Trematospira* or "*Spirifer*" *arenosa* fauna of the basal Nevada, as represented in the Roberts Mountains and the Sulphur Spring Mountains.

The "*Spirifer*" *pinyonensis* zone, with its large and diverse fauna is well represented in the belt extending from Table Mountain to Combs Peak and at the north end of the Antelope Range. This zone lends itself to further stratigraphic subdivision. For example, a lower subzone in this area is characterized by abundance of *Chonetes macrostriata;* at Lone Mountain this subzone yields corals of the genera *Radiastraea* and *Billingsastraea*.

Near the summit of the northern Antelope Range (loc. 57), the modified Woodpecker limestone member carries a rich *Martinia kirki* fauna with "*Leiorhynchus*" *castanea* and a large platelike member of the *Receptaculites* group in considerable abundance. At a much lower horizon, fragments of *Receptaculites* occur in the lower Oriskany zone of the Nevada at Lone Mountain. These interesting holdovers from the Ordovician are known also in the Late Devonian of New Mexico (Stainbrook, 1945, p. 3, 11; 1948, p. 786), in the New York Tully (Cooper and Williams, 1935, p. 855), in the Devonian of Australia (Teichert, 1949, p. 11, 33) and in Europe. Coral ledges with *Hexagonaria* are restricted to this part of the column in the Antelope Range. Where the middle and upper parts of the Nevada are dolomitized and badly faulted at Table Mountain, the *Martinia kirki* zone faunas were not found.

Only at Table Mountain was the *Stringocephalus* zone recognized, for in the Antelope Range the Nevada strata above the Woodpecker member appear to have been removed by erosion. Poorly preserved large brachiopods, at least some of which are *Stringocephalus*, range through about 400 feet of massive dolomite at Table Mountain; this is roughly the thickness of the *Stringocephalus* zone in the type Bay State member east of Eureka.

AGE AND CORRELATION

Lowermost and uppermost faunal zones of the Nevada formation are well dated in terms of New York and European standards. A satisfactory tie with the Oriskany Early Devonian of New York is provided by spirifers of the "*S.*" *arenosa* and "*S*" *murchisoni* types found in the basal Nevada, whereas a Givetian late Middle Devonian age is indicated by *Stringocephalus* and *Rensselandia* from the upper part of the Nevada. In the interval between these two well-fixed stages, sound distant correlations are not yet possible on a paleontologic basis, for above the beds with "*Spirifer*" *arenosa* almost no diagnostic lower and middle Nevada species have been reported outside of the Cordilleran belt; in fact, most of the lower Nevada species remain unrecognized beyond the central Great Basin.

Nevada faunas of one horizon or another have in recent years become known at widely scattered localities in the Great Basin, but only in the central part of this region has a full sequence of its faunal zones been recognized. *Stringocephalus* stands as the one zone indicator found at nearly all localities in the Great Basin where rocks of Nevada age have been studied. Future mapping and collecting will no doubt extend the geographic range of other Nevada faunas, but in these undertakings facies change and nondeposition should be considered in connection with problems of Devonian faunal distribution.

North and northeast of the Sulphur Spring Range only the upper middle and upper parts of the Nevada have been identified by fossils. Thus *Martinia kirki* and *Stringocephalus* represent the formation in the southern Ruby Mountains (Sharp, 1942, p. 663–664); on the east at Gold Hill, Utah the Simonson and Guilmette formations (Nolan, 1935, p. 20–21) carry *Martinia* and *Stringocephalus*. But neither at Gold Hill nor in the Ruby Mountains have the "*Spirifer*" *pinyonesis* or older Nevada faunas thus far been recognized. Absence of these assemblages does not necessarily indicate that deposits of early middle and early Nevada age are absent from the areas in question.

Our stratigraphy and mapping between Antelope Valley and the east Eureka belt show eastward disappearance of lower and lower middle Nevada faunas by facies change. The terms eastern facies and western facies are accordingly adopted to express these differences in the study area. In a sense, the results of our reconnaissance studies give these facies terms a broader geographic meaning, for the eastern facies, as seen near Eureka, appear to extend more or less continuously from central Nevada into Utah.

The eastern facies of the lower and middle parts of the Nevada are predominantly dolomite, with subordinate amounts of sandstone or quartzite, and usually are almost devoid of fossils. The western facies, on the other hand, probably representing about the same time-stratigraphic interval, comprises highly fossiliferous platy or flaggy impure argillaceous limestone with a dolomitic limestone member near the base. Lower dolomitic limestone beds of the western facies bear the Early Devonian "*Spirifer*" *kobehana* and "*Spirifer*" *arenosa* faunas. These assemblages have not been found in the eastern facies Beacon Peak dolomite member where they would be expected. The Middle Devonian "*Spirifer*" *pinyonensis* fauna is also unrecognized in eastern facies strata, having been searched for especially in the interval which brackets the upper part of the Beacon Peak and the overlying Oxyoke Canyon sandstone member.

From the Eureka district eastward to Utah, a distance of 125 miles, little is known in detail of the Nevada formation. Presence of *Stringocephalus* near Monte Cristo (fig. 2) shows that the upper part of the Nevada reaches the White Pine district. Late Devonian faunas described and listed from the White Pine and Ely districts (Meek, 1877 p. 25–48; Hall and Whitfield, 1877, p. 246–251; Spencer, 1917, p: 25) actually pertain almost entirely to the Devils Gate limestone rather than the emended Nevada limestone. Dolomite beds that underlie the Devils Gate in these districts have thus far yielded few fossils, and while almost certainly representing eastern facies of the Nevada formation, are of a type readily confused with Silurian Lone Mountain dolomite.

Stringocephalus occurs here and there in dolomite beds at other localities in eastern Nevada, where the lower part of the same dolomite column doubtless includes eastern facies of the middle and lower parts of the Nevada. Although it may be inferred that the eastern facies of the middle and lower parts of the Nevada thins somewhat passing eastward from Eureka through the White Pine and Ely districts, our present sketchy knowledge does not justify the conclusion that these rocks pinch down appreciably or are overlapped eastward by the higher Devonian strata, as was once believed.

Light is shed upon the nature and distribution of eastern sequence dolomite of the Nevada by current studies in the Confusion Range, Utah (R. K. Hose, written communication, 1956), where thick dolomite units underlie a Devils Gate limestone equivalent. Corresponding to the Sevy dolomite, Simonson dolomite, and at least part of the Guilmette at Gold Hill, Utah (Nolan, 1935, p. 18–21), these Lower and Middle Devonian strata of the Confusion Range are approximately equivalent to the eastern sequence of the Nevada formation in the central Great Basin. In fact the fine-grained Sevy dolomite agrees lithologically with eastern sequence Beacon Peak dolomite member at Eureka, which is correspondingly almost barren of fossils. Both Beacon Peak and Sevy rest unconformably on dolomite assigned to the Silurian system. These factors, considered in the light of probable equivalence of barren Beacon Peak and the richly fossiliferous Oriskany age lower part of the Nevada in the western sequence (table 2), seemingly controvert a correlation of the Sevy and Lone Mountain dolomite as suggested by Osmond (1954).

The sparingly fossiliferous Simonson and the lower part of the Guilmette in the Confusion Range seem to be correlative with the middle and upper parts of the Nevada formation.

Our meager knowledge of the geographic extent of lower Nevada faunas suggests that these faunas are distributed southward and southwestward with respect to center of the Great Basin. Considering the lowest faunas, those with spirifers of the "*S.*" *arenosa*, "*S.*" *murchisoni*, and "*S.*" *kobehana* types, we find them to range geographically from the Sulphur Spring Range of central Nevada to the Ubehebe district of Inyo County, Calif. (McAllister, 1952, p. 17), 170 miles southwest of Antelope Valley. Rocks lithologically similar to both eastern and western facies of the Nevada formation occur also in the Yucca Flat-Frenchman Flat area (Johnson and Hibbard, 1957), 175 miles south of Antelope Valley. These strata bear the "*Spirifer*" *pinyonensis* assemblages, but have not yielded Early Devonian indicators of the lowermost Nevada. Absence of the *pinyonensis* faunas above the Early Devonian *kobehana* beds at Ubehebe, 100 miles west of Yucca Flat, is perhaps explainable by facies, for argillaceous limestones of the type normally host for this assemblage, have not been observed in the Ubehebe or Inyo sections.

Absence of the *Martinia kirki* fauna in the southern Great Basin may be explained either by facies or inadequate collecting, but the ubiquitous *Stringocephalus* is well known in that region, having been found north of Las Vegas, at Ubehebe, and in the southern Inyo Mountains of California.

Unlike the older Nevada faunas with respect to geographic distribution, distinctive elements of the upper middle and upper parts of the Nevada occur north and east of the central Great Basin, ranging in fact to arctic Canada. Northern relationships are most evident where faunas of the *Martinia kirki* and *Stringocephalus* zones are concerned.

Medium-sized smooth spiriferoids possessing external features of *Martinia* McCoy and *Martiniopsis* Waagen reached a peak during the medial Middle Devonian in the northern Cordilleran belt and in the Great Basin. Their time of greatest evolutionary differentiation and geographic spread immediately preceded that of the larger *Stringocephalus*. These *Martinia*-like brachiopods require further comparative study and classification based in large part, on internal features, because of the homeomorphy manifested by smooth brachiopods of this kind. Until such studies are made, use of the name *Martinia* in a very loose sense has been adopted (Merriam, 1940, p. 85; George, 1927).

Beginning locally in the upper part of the "*Spirifer*" *pinyonensis* zone with *Martinia undifera*, these forms become abundant in the *Martinia kirki* zone and disappear in the upper part of the Devils Gate limestone with *M. nevadensis*. At Combs Peak *Martinia undifera* occurs just beneath a thin westerly tongue of the Oxyoke Canyon sandstone member (loc. 78, table 2).

Martinia-like brachiopods show a comparable development in western Canada from Great Slave Lake to the Arctic Ocean along the Mackenzie Valley. As reported by Warren (1944, p. 126–128), Warren and Stelck (1949, p. 139–148), and Merriam (1940, p. 77, 85), the Mackenzie Valley *Martinia*-like brachiopods range upward from the pre-*Stringocephalus* Hare Indian River shale and Pine Point limestone through the *Stringocephalus* zone to the Beavertail limestone and the Late Devonian Fort Creek shale. Among the *Martinia*-like brachiopods reported from western Canada are "*Martinia meristoides* Meek" and "*M. richardsoni* (Meek)" in the Hare Indian River beds; "*M. meri-*

stoides," "*M. occidentalis*," "*M. richardsoni*," and "*M. kirki*?" are reported from the Pine Point. "*Martinia meristoides*" occurs in the *Stringocephalus*-bearing Ramparts limestone, "*M.* cf. *occidentalis*" and "*Martinia*? *franklini* Meek" in the Beavertail, and "*M. occidentalis*" in the Fort Creek.

Brachiopods of the "*Leiorhynchus*" *castanea* type locally outnumber the "martinias" in *M. kirki* beds of the Great Basin. This is especially true of exposures east of Eureka. In Canada brachiopods of the same general type are numerous; in fact, Meek's type of the species (Meek, 1867) is reported to have come from Anderson River. There is, however, some uncertainty regarding the horizon from which the type was actually collected. According to Warren and Stelck (1949, p. 144), it may have come from Hare Indian River shale below the *Stringocephalus* zone. Such is the stratigraphic position of our Nevada representatives of this brachiopod group. There are reports of "*castanea*" in the Mackenzie Valley above *Stringocephalus*-bearing Ramparts limestone, as in the Beavertail and Fort Creek (Warren, 1944, p. 107, 112; Warren and Stelck, 1949, p. 142, 143). Thus far we have not recognized brachiopods of this kind in the Great Basin above the *Stringocephalus* zone; that is, in the Devils Gate limestone.

Presence of the compound coral *Hexagonaria* in the Hare Indian River shale of the lower Mackenzie Valley (Warren and Stelck, 1956, pl. 1) agrees stratigraphically with its occurrence at Antelope Valley, where in the *Martinia kirki* zone it forms coral lenses locally.

Of all Devonian faunal zones, in the Great Basin, that marked by the distinctive late Middle Devonian brachiopod *Stringocephalus* has the greatest geographic extent. In the Cordilleran belt this key brachiopod is distributed from the Las Vegas area in southern Nevada and from the Inyo Mountains of California to the Ramparts of the lower Mackenzie Valley in arctic Canada, a meridional distance of 2,500 miles (Kirk, 1927, p. 219–222). Eastward from Antelope Valley, *Stringocephalus* beds extend to the White Pine district and thence to Gold Hill and the Thomas Range, Utah.

Of special interest is discovery of another large terebratuloid *Rensselandia* at the base of the *Stringocephalus* zone in the Alhambra Hills southeast of Eureka, Nevada; its stratigraphic position agrees with that of the same distinctive genus in the Ramparts limestone of the lower Mackenzie Valley (Warren, 1944, p. 116). *Rensselandia* appears to have a very restricted stratigraphic range in western America. Its presence in the Cedar Valley limestone of Iowa (Cooper and Cloud, 1938, p. 446; Cloud, 1942, p. 99; Stainbrook, 1941, p. 43) unaccompanied by *Stringocephalus* supports a late Middle Devonian age for the formation in Iowa.

Province relations of the early Middle Devonian "*Spirifer*" *pinyonensis* faunas are least understood of all in the Great Basin Devonian, in spite of their abundance and great taxonomic diversity. Unlike later Middle Devonian faunas of the Nevada formation, uncertainty exists regarding presence of *pinyonensis* zone faunas in the Cordilleran belt of western Canada. Faunas believed correlative with the *pinyonensis* zone are reported by Warren and Stelck (1950, p. 76–77; 1956, p. 5, pl. 1) in the Hare Indian River shale and referred to the "*Radiastraea arachne* zone." As listed, these faunas seem to include a mixture of species, some to be expected in the upper Nevada *Martinia kirki* zone, others in the lower Nevada *pinyonensis* zone where the typical *Radiastraea arachne* occurs.

Between faunas of the "*Spirifer*" *pinyonensis* zone and those of well-known Middle Devonian formations in eastern North America there is general lack of close similarity. On the other hand it is recognized that coral assemblages of facies comparable to the eastern Onondaga are present in the lower part of the Nevada, at horizons which cannot be far removed in time from that interval. Preliminary comparison of corals in the middle and lower parts of the Nevada with those from eastern Onondaga limestone suggests that the resemblances are more expressive of similar ecologic adaptation and perhaps comparable stage of evolution than close genetic affinity. Provincial relations of "*Spirifer*" *pinyonensis* faunas in the lower part of the Nevada are conceivably to be sought within or adjoining the Pacific province, possibly to the south.

Lowermost Nevada faunas of Early Devonian Oriskany age and the Rabbit Hill faunas of Helderberg age are unreported in western Canada. Possibility of finding Early Devonian fossils in the "Bear Rock formation" below the "*Radiastraea arachne* zone" is, however, considered by Warren and Stelck (1950, p. 77).

DEVILS GATE LIMESTONE

GENERAL FEATURES

Type section of the Devils Gate limestone (Merriam, 1940, p. 16) is at Devils Gate pass, 7½ miles northwest of Eureka. The name "Swallow Canyon" given the gorge in 1858 by its discoverers, the Simpson party, is lost in oblivion. Geological observations and fossil collections made at "Swallow Canyon" (Devils Gate) by the explorers, are the basis for perhaps the earliest published record of far western Devonian rocks. In 1880 fossils were collected here by the Hague party, to whom the locality was known as "The Gate" (Hague, 1892, p. 83). The narrow curving defile, boldly sculptured in gray Devonian limestone, accommodates eastward seasonal drainage from Kobeh Valley to Diamond Valley; since the discovery by Simpson it has been traversed by an important cross-country route, known today as the Lincoln Highway (U.S. Highway 50). So situated, Devils Gate became a popular collecting site for the itinerant fossil hunter; as a result, free-weathering specimens, once abundant, have become scarce.

Overlain by Pilot shale (lower "White Pine shale") and underlain by Nevada formation (emended) the Devils Gate limestone corresponds to only the upper part of Hague's (1883; 1892) "Nevada limestone." When the Devils Gate was proposed as a separate formation by Merriam (1940, p. 25) emphasis was placed on paleontologic criteria. Subsequent work in the Eureka vicinity (Nolan, Merriam, and Williams, 1956, p. 48–52) amplifies the fossil data and, in pointing up rock distinctions, has demonstrated mappability of the Devils Gate-Nevada lithologic boundary.

AREAL DISTRIBUTION

The greater part of the surface in the Mahogany Hills (pl. 1) is formed by Devils Gate limestone, which has been mapped southward from the type area to Table Mountain and Combs Peak, and southeast to Modoc Peak. The Nevada-Devils Gate contact is exposed at few places because of low bedding dip. Relatively small erosion remnants of the overlying Carboniferous strata remain on the flanks of the uparched Mahogany Hills, and scattered outliers of Vinini formation suggest that large areas of present Devils Gate outcrop were probably occupied by the overthrust sheet during earlier stages of geomorphic development.

Devils Gate limestone is absent from the Monitor Range, and its western limit of exposure is in the conspicuous bedrock outlier (loc. 88) northwest of Burlington Canyon.

Devils Gate limestone, together with uppermost Nevada, was apparently stripped by erosion from the Devonian block at the north end of the Antelope Range.

To the north this formation was not previously differentiated from Nevada formation in the Roberts Mountains (fig. 2), though it is represented in that region and in the northern Sulphur Spring Range (Winterer, E. L., 1959, oral communication). It is present also to the northeast in the Ruby Mountains (Sharp, 1942, p. 664).

Strata of the Devils Gate crop out on both east and west sides of the Diamond Mountains. At Newark Mountain on the east, they form the impressive upper sheer cliffy part of the east-facing scarp; on the west, this unit is well exposed near the Phillipsburg mine. At the south end of the Diamond Mountains, Devils Gate limestone beds were mapped separately in the Alhambra Hills, at Silverado Mountain, and at Sentinel Mountain.

Devils Gate limestone crops out with characteristic prominence in the White Pine (Hamilton) and Ely mining districts, where it has not been differentiated from "Nevada limestone" in the sense in which this term was earlier used. Limestones of Devils Gate age, and to some extent Devils Gate rock type, are recognized in the southern Shell Creek Range (Merriam, 1940, p. 39), and more distantly at Yucca Flat in southern Nevada (Johnson and Hibbard, 1957). Other remote occurrences are treated below under "Age and correlation."

LITHOLOGY

The Devils Gate is largely medium-dark- to dark-gray well-bedded limestone and ranges from thin and flaggy to heavy bedded. In general, thick-bedded massive-weathering phases predominate, thicker beds ranging from 2½ feet to about 5 feet. Formation of cliffs is more characteristic of the Devils Gate than other formations of the region, with exception of the Ordovician Antelope Valley limestone. Marked by incipient caves and solution hollows, the Devils Gate cliffs provide a notable geomorphic contrast with the less precipitous slopes and ragged staircase effect produced by erosion of underlying dolomite of the Nevada. Viewed from a distance, the cliff-forming members seem massive and homogeneous; this appearance may be deceptive, for at close range the sheer faces sometimes exhibit distinctly platy or flaggy bedding lines.

Argillaceous limestone beds recur through the Devils Gate section. They have thin clayey partings or interbeds and argillaceous mottlings. Where the limestone is more than ordinarily argillaceous, parting or bedding tends to be thinner. Pinkish coloration is characteristic of the argillaceous matter and may also pervade the contiguous purer limestones.

Variation in gray color of the nonargillaceous limestone is doubtless a function of carbon content. Weathering sometimes produces light-gray surface coloration with a suggestion of blue.

The predominant dark-gray limestone beds are fairly pure, have a medium-grained to fine-grained or aphanitic texture, and are brittle. Dark-gray chert nodules are scattered in the upper 250 feet of the formation but are rarely found below.

The Devils Gate is normally, but not always, limestone; this usually serves to distinguish it from the Nevada formation, which is ordinarily dolomite in its upper part and may be almost entirely dolomite. The lower part of the Devils Gate is the most susceptible to magnesian alteration. Near its base, magnesian limestone or primary dolomite beds sometimes alternate with limestone. Higher in the section, dolomite occurs in patches and more rarely as rather extensive irregular bodies that are readily confused with dolomite of the higher part of the Nevada formation. In some places these local bodies of dolomite are probably a result of relatively late hydrothermal activity, the magnesian solutions having moved upward along faults.

Depositional features, both mechanical and organic, serve to distinguish carbonate rocks of the Devils Gate from those of otherwise similar formations. Especially distinctive are the coarse mud breccia or intraformational limestone conglomerate. These are widespread in the Mahogany Hills and were recognized as far east as Newark Mountain in the Diamond Mountains. Limestone pieces, ranging in length from less than 1 inch to 8 inches, are imbedded in a matrix of virtually the same sediment, but usually having a different shade of gray. More than half of the fragments are angular, others show some rounding. Commonly the fragments include fossils not found in the matrix, but there is no indication of long transportation. The mud breccia is not made up of flat pieces that are rather closely spaced like some so-called edgewise conglomerate. Although slump bedding and evidence of flowage were not noted, these deposits are probably a result of oversteepening and undermining by wave and current action along banks of partly consolidated sediments.

Mud breccia of this type is easily confused with cataclastic breccia of later origin, especially where the rocks are badly deformed; this is true in the outlying pediment outcrops of Devils Gate northwest of Burlington Canyon (loc. 88), where mud breccia and associated limestone beds of the Devils Gate are strongly disturbed, possibly in the lower plate of a thrust.

Whereas no suggestion of coral reef structure has been detected in the Devils Gate limestone, corals, stromatoporoids, and other important lime-building organisms are locally abundant. There exist scattered centers of concentrated rugose coral growth, but no moundlike biohermal masses of corals and associated lime builders were observed. That these may eventually be found in this area is not improbable. It may also be significant that the mud breccia is commonly in limestone that contains much colonial and solitary coral material.

Nearest approach to biohermal or patch-reef development is in thick-bedded stromatoporoid and "spaghetti coral" facies of the middle and lower parts of the Devils Gate. These bedded deposits are locally made up largely of slender digitate favositids and stromatoporoids that include both nodular growths and branching forms of the *Amphipora* type. No suggestion of steeply inclined flank beds or the moundlike shape of coral-stromatoporoid limestone bodies was detected. The finer organic structure is commonly so poorly preserved in these limestones that material of surficial stromatoporoid appearance may be partly algal and best classified as "stromatolitic".

Fossil material is frequently silicified in the upper part of the Devils Gate limestone, the shells of corals and brachiopods weathering limonitic brown. The fossil silification pervades the rock and probably took place relatively early, perhaps as a result of diagenetic activity.

Where fossils in the upper part of the Devils Gate are unsilicified, as in the *Spirifer argentarius* zone, they are characteristically preserved as soft white pearly-shell material that contrasts sharply in color with the enclosing dark-gray limestone. Owing to hardness and brittleness of the rock, these soft fossils, though excellently preserved, are removed with the greatest of difficulty. Hence, most of the fossils from these beds available for study are weathered and peeled, lacking surface ornamentation.

STRATIGRAPHY AND FAUNAS

The Devils Gate limestone lies between the Nevada formation and the lower part of the Pilot shale of Late Devonian age. The type section is faulted, intruded by igneous rocks and lacks an exposed stratigraphic base. Southward older beds of Devils Gate limestone are exposed and the formation rests conformably upon the Nevada north of Modoc Peak (pl. 1). Recent work at Newark Mountain (Nolan, Merriam, and Williams, 1956, p. 48–52) shows the Devils Gate section to be unbroken from bottom to top (fig. 8). Therefore, in describing Upper Devonian strata of the region it is advantageous to consider both sections jointly. Whereas faunal differences are evident in the formation between Devils Gate and Newark Mountain, the lithology is far more uniform passing laterally from west to east than is that of the subjacent Nevada formation.

A transition zone, ranging from 30 feet to about 75 feet in thickness, usually marks the Nevada-Devils Gate boundary. This boundary zone is well shown at Newark Mountain and on the west side of Table Mountain in the Mahogany Hills. Within the transition interval, dolomite and limestone beds sometimes alternate. Light-gray dolomitic beds and irregular dolomite bodies occur sporadically above the transition zone in the lower third of the formation.

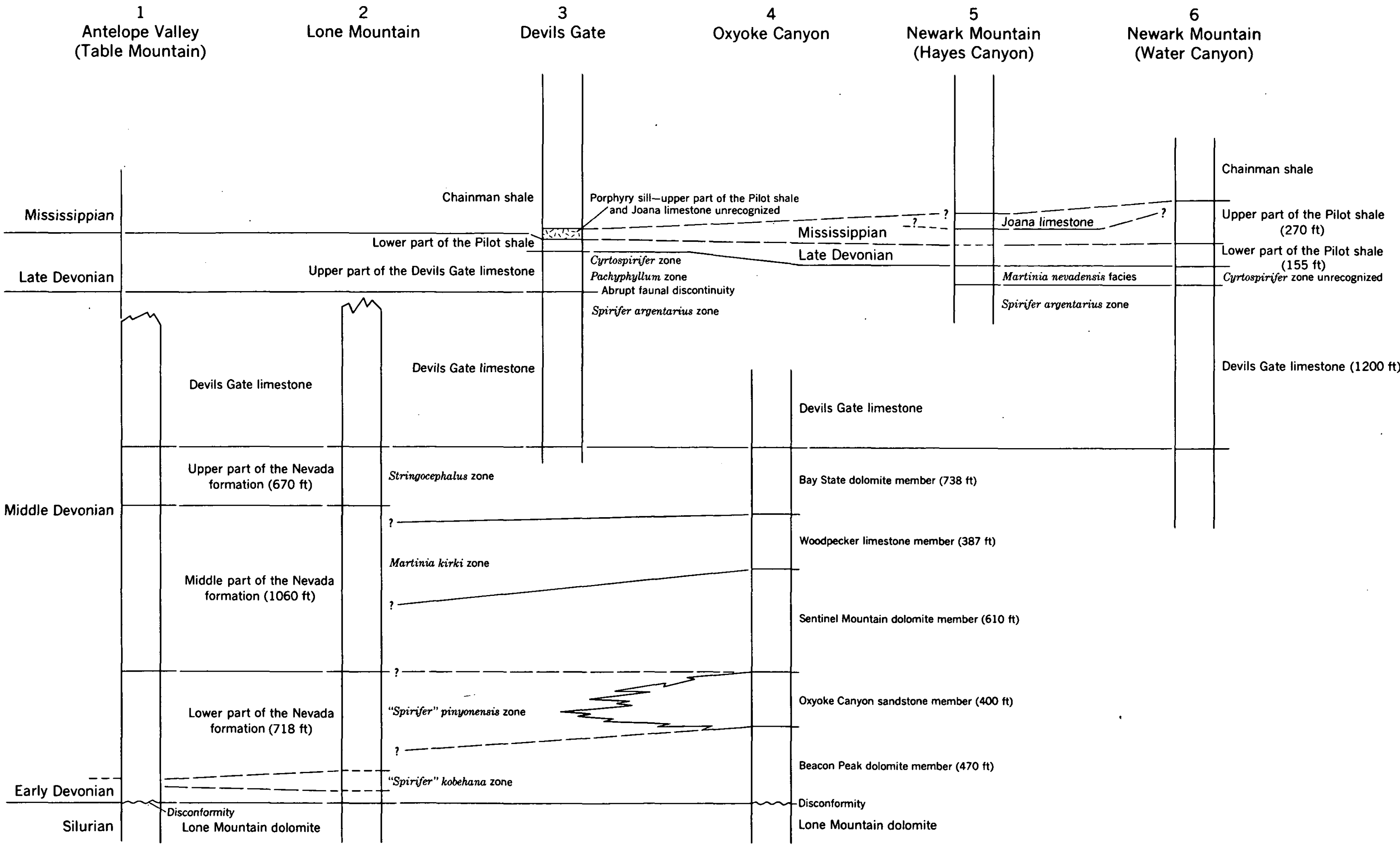

Figure 8.—Correlation diagram showing probable age relationships of Devonian strata in the Antelope Valley and Eureka areas, Nevada.

Topmost Devils Gate limestone grades upward into the basal Pilot shale. At the east entrance to Devils Gate pass, the formational boundary is well shown north of U.S. Highway 50, about 65 feet stratigraphically below the lower porphyry sill. This contact may also be seen in Toll House Canyon (Hayes Canyon) at Newark Mountain. Uppermost layers of the Devils Gate limestone contain an increasing amount of silt and fine siliceous sand introductory to the pinkish, shaly, and arenaceous conodont-bearing limestone beds of the lower part of the Pilot.

The Devils Gate formation is on the whole rather monotonous lithologically, and unlike the Nevada formation does not lend itself particularly well to convenient lithologic subdivision. Two members have been defined locally in the Diamond Mountains (Nolan, Merriam, and Williams, 1956, p. 49), where a separation could be made by mapping a thin bed of oolitic limestone. In the type area and the Mahogany Hills, where the oolitic marker was not recognized, it is possible to distinguish an upper interval about 300 feet thick, in which brachiopods and rugose corals are abundant and diverse and wherein occur the mud breccias and sporadic dark-gray chert nodules. Pinkish-mottled argillaceous limestone interbeds with lumpy bedding surfaces and nodular weathering are characteristic. Below the upper interval, the lithology and faunas are less diverse, and the most abundant fossils are stromatoporoids and *Cladopora.*

In the Mahogany Hills the Devils Gate limestone lends itself to a fourfold paleontologic zonation as follows in stratigraphic order:

4. *Cyrtospirifer* zone
3. *Pachyphyllum* zone
2. *Spirifer argentarius* zone
1. stromatoporoid zone

The two upper faunal zones occupy the upper 300-foot lithologic division, and the *Spirifer argentarius* zone extends upward from the lower monotonous and thicker lithologic division into the upper division.

Thick beds of stromatoporoids and slender branching favositids of the *Cladopora* type characterize the stromatoporoid zone. The "spaghetti limestone" formed largely by favositids includes also the branching stromatoporoid *Amphipora.* Nests of *Atrypa* are fairly abundant, but other brachiopods are sparsely represented. In the southern Diamond Mountains, corals of the genera *Temnophyllum*, *Disphyllum*, and *Thamnopora* were collected in the lower 200 feet of this zone.

Faunas of the *Spirifer argentarius* zone range through about 500 feet of the middle part of the Devils Gate. Fossils are numerically abundant in some beds, although the number of species is small. Most common are *Spirifer argentarius*, *Atrypa montanensis*, and *A. devoniana;* less common is *Tenticospirifer utahensis. Hypothyridina* appears low in the zone with the small *Hypothyridina* sp. a. Among the corals only the genus *Mictophyllum* has been identified.

Large spirifers with the external features of *S. argentarius* occur locally in the middle part of the Devils Gate. *Spirifer argentarius* is ordinarily a small form. The larger spirifers also resemble *S. raymondi* Haynes and may be confused with the much older "*S.*" *pinyonensis* of the Nevada formation.

Within the lower range of *Spirifer argentarius* are localized molluscan facies with abundant *Orecopia mccoyi* (Walcott), a distinctive gastropod (Knight, 1945). In this association is the small *Spirifer engelmanni*, differing at least subspecifically from *S. argentarius* in its high cardinal area and narrower shell. In the Newark Mountain and Alhambra Hills areas, there occurs in abundance below beds with *S. argentarius* a small crytinoid brachiopod with external appearance of the genus *Tylothyris* North, or *Eosyringothyris* Stainbrook (1943, p. 431, 438). Provisionally called *Tylothyris* sp. a this distinctive form probably occurs in the lower range of *S. argentarius.*

A significant faunal discontinuity separates the *Pachyphyllum* zone from the underlying *Spirifer argentarius* zone. In the *Pachyphyllum* zone, rugose corals are abundant and diverse; such forms are scarce below and are virtually absent in the overlying *Cyrtospirifer* zone. Characteristic are species of *Pachyphyllum* and *Phillipsastraea*, the large solitary *Chonophyllum infundibulum* (Meek), and *Macgeea.* Common also is *Syringopora.* In contrast, brachiopods are scarce in the *Pachyphyllum* zone of this particular area, though the important key fossil *Hypothyridina emmonsi* (Hall and Whitfield) occurs with *Pachyphyllum* northeast of Modoc Peak.

An incomplete ammonoid from the upper part of the Devils Gate was identified as *Manticoceras* cf. *M. sinuosum* (Hall) by N. J. Silberling of the U.S. Geological Survey. It occurred as float below the *Pachyphyllum* zone north of Devils Gate and may have come either from that zone or from the *Cyrtospirifer* zone above. *Manticoceras sinuosum* is an Upper Devonian species in New York State (Miller, 1938, p. 115), where it is reported in the Genesee, Naples, Chemung, and Canadaway formations.

Faunas of the *Cyrtospirifer* zone are fairly large, diverse, and manifest a complete change from those of the underlying zones. Corals are commonly lacking, the fauna consisting mainly of brachiopods. Absence of *Atrypa* is significant, especially when its abundance in the middle and lower parts of the Devils Gate is considered. Characteristic fossils are: *Cyrtospirifer portae* Merriam, *Nudirostra walcotti* (Merriam), *Athyris angelicoides* Merriam, *Schizophoria simpsoni* Merriam, and *Productella.*

FACIES LOCALIZATION OF FAUNAS

A comparison of Devils Gate faunas and stratigraphy of the Mahogany Hills with those of the Diamond Mountains and more distant areas reveals a geographic spottiness of faunal occurrence (fig. 8). The discontinuity suggests control by local environmental conditions. A case in point is seeming absence of the *Cyrtospirifer* faunas from the Newark Mountain section, which otherwise appears to be complete depositionally. Physical evidence of nondeposition or erosion of upper beds normally including this zone was not observed. Similarly the *Cyrtospirifer* faunas seem to be undeveloped in the White Pine district, where the Devils Gate formation is otherwise well represented.

Approximate position of the *Pachyphyllum* zone at Newark Mountain is indicated by a single float specimen of this coral collected in 1938. Evidently the colonial rugose corals are extremely scarce in the Newark Mountain-Alhambra Hills belt, where the interval in question is occupied by a predominantly brachiopod facies characterized by *Martinia nevadensis* (Walcott). Use of the generic name *Martinia* should be qualified by saying that, like earlier members of this form group in the Nevada formation, the Devils Gate species is probably neither true *Martinia* or *Martiniopsis.* Further comparison may show that *nevadensis* is correctly placed in *Warrenella* (Crickmay, 1953, p. 596). Associated with *M. nevadensis* are species of *Schizophoria. Dalmanella*, *Pugnoides*, *Atrypa* of the *A. devoniana* Webster type, and scattered corals assigned to *Macgeea*, *Tabulophyllum*, *Disphyllum*, and *Thamnopora.* Locally *Schizophoria* is the most abundant fossil.

Conversely, *Martinia nevadensis* was not found during this study in the *Pachyphyllum* zone of the Devils Gate type area. However, the type specimen is reported by Walcott to have been collected 4½ miles south of Devils Gate.

At Newark Mountain (fig. 8) beds of the *Martinia nevadensis* facies, or probable *Pachyhyllum* zone equivalent, are overlain by the limy, arenaceous conodont beds of the lower part of the Pilot shale. At Devils Gate equivalent conodont beds rest upon strata of the *Cyrtospirifer* zone.

Fossil collecting in Upper Devonian beds of the central Great Basin reveals five separate loci where the *Pachyphyllum* and *Phillipsastraea* coral facies is well developed. These are: (1) Devils Gate vicinity; (2) Mahogany Hills, 2 miles south of Hay Ranch (loc. 81); (3) Belmont Mill in McEllen Canyon, White Pine district; (4) Treasure Peak, White Pine district; and (5) the northern part of an unnamed range, 3½ miles southwest of Monte Cristo (Green Springs quadrangle), Nev. (See fig. 2.)

The gastropod facies with abundant *Orecopia* is very much localized and is usually limited to relatively pure clean limestone. In this facies the beds are sometimes loaded with *Orecopia* accompanied by very few other forms. Locally these *Orecopia* beds have been dolomitized, as in outlying hills at the east foot of Newark Mountain.

THICKNESS

Where the base is unexposed at Devils Gate, the Devils Gate limestone is about 1,100 feet thick. An estimate of 1,800 feet made earlier at Modoc Peak, where the Devils Gate rests on the Nevada, proves unreliable because of faulting. At Newark Mountain the relatively unbroken Devils Gate section is about 1,200 feet thick, agreeing with Sharp's (1942, p. 664) measurement of 1,200 feet in the southern Ruby Mountains.

AGE AND CORRELATION

The Devils Gate limestone includes deposits of Late Devonian and probable late Middle Devonian age. It rests with gradational boundary on upper dolomite of the Nevada bearing *Stringocephalus*, an indicator of the Givetian stage, late Middle Devonian in Europe. The stromatoporoid zone in the lower beds of the Devils Gate, though yielding no distinctive Middle Devonian indicators, seems to lack fossils that would place them conclusively in the Late Devonian. The coral *Temnophyllum* in the lower 200 feet suggests Middle Devonian.

Merriam (1940, p. 9) initially regarded the *Spirifer argentarius* zone as of late Middle Devonian age; however, in recent years these beds have come to be classed by most Devonian authorities as Frasnian Late Devonian. It is nonetheless recognized in the central Great Basin that an abrupt faunal discontinuity exists between beds of the *S. argentarius* zone and those of the *Pachyphyllum* zone. Above this discontinuity appear genera of acknowledged Frasnian Late Dovonian age, among which are *Pachyphyllum* and the ammonoid *Manticoceras. Hypothyridina emmonsi* of the *Pachyphyllum* zone may also relate these beds to the Independence shale of Iowa (Stainbrook, 1945, p. 3, 42–43) and to the Frasnian of Europe. This distinctive brachiopod also resembles *H. venustula* of the New York Tully limestone, but associated faunas provide little support for close alinement, as those of the Tully are seemingly older, if not actually Middle Devonian.

The *Cyrtospirifer* zone with *Cyrtospirifer* and *Athyris angelicoides* is clearly of Late Devonian age, in the range from Frasnian to Famennian of Europe (Merriam, 1940, p. 59–61; Cooper and others, 1942, p. 1756).

Since the initial Devils Gate studies, much information has accumulated on distribution and correlation of its faunas within the Great Basin. Upper Devils Gate faunas have been recognized at scattered localities as far east as the Thomas Range, Utah, and south to Yucca Flat, Nev., and west to the Death Valley-Inyo region of California. Detailed stratigraphic studies of Devils Gate equivalents have been made for the U.S. Geological Survey by M. H. Staatz in the Thomas Range and by R. K. Hose in the Confusion Range in Utah; by Johnson and Hibbard (1957) in the Yucca Flat area of southern Nevada; and by McAllister (1952) and Merriam in the Ubehebe and Inyo areas of southeastern California.

In the Thomas Range *Pachyphyllum* beds persist through a remarkably great thickness of limestone and are overlain by beds with *Cyrtospirifer*. In the Confusion Range, as demonstrated by Hose, beds of middle Devils Gate age are characterized by *Tenticospirifer utahensis* seemingly unaccompanied by *Spirifer argentarius*. At a lower horizon *Tylothyris* sp. a is abundant in a zone that seems to agree stratigraphically with occurrence of this form at Newark Mountain. The upper Lost Burro formation (McAllister, 1952, p. 19) of the Ubehebe and Inyo Mountains in California carries *Cyrtospirifer* and gastropods questionably referred to *Orecopia mccoyi*. Lower beds of the Lost Burro yield *Stringocephalus* and are of Middle Devonian age.

With most of the Great Basin occurrences the *Cyrtospirifer* zone is distinguishable from the *Spirifer argentarius* zone. In the lower range of *S. argentarius* the gastropod *Orecopia mccoyi* (Walcott) is an especially useful indicator (Knight, 1945, p. 586), having been found at widely separated localities in the upper Guilmette of Gold Hill, Utah (Nolan, 1935, p. 21), the Valentine member of the Sultan limestone at Goodsprings, Nev. (Hewett, 1931, p. 16), and the Devils Gate equivalent at Yucca Flat, Nev. (Johnson and Hibbard, 1957).

Beyond the Great Basin, but within the Cordilleran belt, are many recorded occurrences of Late Devonian stata equivalent in age to some part of the higher Devils Gate limestone. To the north some of these less distant strata are classed as Three Forks formation and to the south as Martin limestone (Merriam, 1940; Cooper and others, 1942). In Arizona the Martin carries *Cyrtospirifer* faunas and *Pachyphyllum*; the so-called "Jerome formation" bears *Pachyphyllum* (Stoyanow, 1936, p. 498). The Sly Gap formation of New Mexico yields *Cyrtospirifer*, *Pachyphyllum*, *Macgeea*, and *Hypothyridina* cf. *H. emmonsi* (Stevenson, 1945, p. 239; Stainbrook, 1948, p. 765–790).

Largely under impulse of petroleum exploration, significant advances have recently been made in knowledge of Late Devonian rocks from Montana north to the Mackenzie Valley of Canada. Although faunal similarities to Great Basin Late Devonian have long been recognized, only recently has it become possible to evaluate these objectively, as the northern Cordilleran fossils become more fully described.

Cyrtospirifer and related brachiopods show an exceptional degree of morphologic and phylogenetic differentiation in western Canada (Crickmay, 1952, p. 585–609) comparable to that in the southern Shell Creek Range, Nev. (Merriam, 1940, p. 39–40). As shown by McLaren (1954, p. 159–181), rhynchonellids of the genera *Nudirostra* and *Pugnoides* are diverse in Canada, and have detailed zonal value. These genera appear abruptly and abundantly above the *Spirifer argentarius* zone in the Great Basin. Of the Great Basin species *Nudirostra walcotti*, of the upper part of the Devils Gate, is cited by McLaren as characterizing the Alexo formation, where it occurs with *Cyrtospirifer*. *Cyrtospirifer* persists through the overlying Palliser beds.

Strata of the *Pachyphyllum* or *Martinia nevadensis* zone are identifiable in western Canada (Warren, 1942, p. 133). In the Canadian Rockies (McLaren, 1954, p. 160) these are represented by the Perdrix with *Martinia* cf. *M. nevadensis* and the overlying Mount Hawk with *Hypothyridina* cf. *H. emmonsi*.

The *Spirifer argentarius* fauna is reported from several localities in the region extending northward from Montana (Laird, 1947, p. 453–459) to Canada. Representative is the Flume formation of the Canadian Rockies, with *Spirifer jasperensis* and *Spirifer* cf. *S. engelmanni*. Though detailed comparison is needed, it seems likely that *jasperensis* is a synonym of *argentarius*.

Spirifer engelmanni, or similar forms, have been identified in other northern areas of Montana (Laird, 1947, p. 453) and western Canada (Warren, 1942, p. 130; McLaren, 1954, p. 160), where *Tenticospirifer utahensis* of the *argentarius* zone is also represented.

Late Devonian beds assigned to the Waterways and Hay River formations, in the territory stretching from Great Slave Lake along the upper Mackenzie Valley, are correlative with the Devils Gate of the Great Basin (Warren, 1944, p. 106–107; Warren and Stelck, 1949, p. 146–147; McLaren, 1954, p. 169). The Hay River limestone contains *Cyrtospirifer* and *Nudirostra walcotti*, whereas the Hay River shale beds (Warren, 1944,

p. 112–113) have yielded *Hypothyridina* cf. *H. emmonsi.*

Corals from the upper Mackenzie basin (Smith, 1945) show obvious relationship to upper Devils Gate species. Among these are members of the *Pachyphyllum*, *Phillipsastraea*, *Tabulophyllum*, and *Macgeea* groups.

STRATA OF LATE DEVONIAN AND EARLY MISSISSIPPIAN AGE

PILOT SHALE

Lowest beds of the "White Pine shale" defined by Hague (1892, p. 68) are seemingly equivalent to the Pilot shale of the Ely area, Nevada (Spencer, 1917, p. 26). In the Diamond Mountains northeast of Eureka (Nolan, Merriam, and Williams, 1956, p. 52–53) more than 300 feet of Pilot is represented. The lower part of these shale beds contains Late Devonian conodonts. The upper part, which has yielded no fossils in the Eureka area, is probably of Early Mississippian age on the basis of fossil evidence from other districts. Accordingly, the Pilot is classed as Late Devonian and Early Mississippian. Only the lower part of the Pilot of Devonian age was identified in the Antelope Valley area.

LOWER PART OF THE PILOT SHALE

GENERAL FEATURES

Of Late Devonian age, the lower part of the Pilot shale rests conformably on Devils Gate limestone at Devils Gate. These relations are well shown on the north side of U.S. Highway 50, at the east entrance to the pass; here the lower part of the Pilot, about 75 feet thick, is gradational with *Cyrtospirifer*-bearing Devils Gate and is separated from stratigraphically higher black shale by an alaskite porphyry sill. The lower part of the Pilot consists of fine silty to sandy calcareous shale and platy arenaceous limestone. Medium to dark gray in color when fresh, these rocks weather light gray with pinkish surface stain. Silt-size quartz granules are numerous, together with dark-brown phosphatic particles, many of which are fragmentary conodonts. These strata are similar lithologically to the lower part of Pilot of the more continuous exposures at Newark Mountain (Nolan, Merriam, and Williams, 1956, p. 53). Higher black shale beds above the porphyry sill remain undated paleontologically but are provisionally regarded as Chainman shale rather than the upper part of the Pilot on the basis of lithology.

AGE AND CORRELATION

In the Eureka district the conodont-bearing Pilot shale (Nolan, Merriam, and Williams, 1956, p. 53) may bridge the gap between latest Devonian and earliest Mississippian. The late W. H. Hass of the U.S. Geological Survey examined conodonts from the Devils Gate locality and lists the following genera:

Hindeodella sp.
Icriodus sp.
Palmatolepis spp. (common)
Polygnathus spp.
numerous fragments of bladelike, barlike, and platelike conodonts

Hass reported as follows concerning age of this faunule:

> It is my opinion that this collection comes from beds of Late Devonian age because of its stratigraphic position and because it contains specimens of *Icriodus* and *Palmatolepis*. I believe that the stratigraphic range of these two genera is Middle to Upper Devonian; however, some stratigraphers are of the opinion that these two genera range naturally into the lower part of the Mississippian.

No detailed comparison has yet been made with the better preserved and doubtless equivalent lower Pilot conodont assemblages from Newark Mountain. Collections from Newark Mountain also studied by Hass likewise are from pinkish platy arenaceous limestone. In addition to genera listed above from the occurrence at Devils Gate, the Newark Mountain assemblages include *Ancyrodella* cf. *A. curvata* Branson and Mehl, *Bryantodus*, *Hibbardella*, *Ligonodina*, and *Prioniodus*. The upper part of the Pilot shale has not yielded fossils at Newark Mountain, but the discontinuous Joana limestone, which here and there overlies it, is of Early Mississippian (Madison) age.

UPPER PALEOZOIC ROCKS

GENERAL FEATURES

Mississippian and Permian rocks are present in the vicinity of Antelope Valley, but the two systems are not superposed and occupy widely separated outcrop belts. No Pennsylvanian strata were recognized. To the east in the neighboring Diamond Mountains and Eureka district, the higher Paleozoic section is more nearly complete, with Mississippian, Pennsylvanian, and Permian rocks in continuous depositional order.

Siliceous clastic rocks of Mississippian age resembling closely those of the Diamond Mountains occur in the northern Mahogany Hills; these strata were not found in the Monitor Range on the west side of Antelope Valley. The Mississippian clastic rocks in the Mahogany Hills are the youngest Paleozoic strata exposed and are overridden directly by the upper plate Ordovician Vinini formation. There is no indication that Pennsylvanian or younger strata of the Diamond Mountains were deposited in that area.

Although knowledge of areal geology is not adequate in these latitudes, the Mahogany Hills belt may approximate the western limit of Carboniferous deposition in the Great Basin. To the west, only Permian strata are known with assurance in the upper Paleozoic column. Black shale beds intruded by granitoid rocks near Austin, Nev., in the Toiyabe Range have previously been assigned to the Carboniferous (Emmons, 1870). Lithologically these shale beds are more suggestive of Ordovician Vinini than Carboniferous, but only fossil evidence will eliminate possibility of Carboniferous age. Emergence and erosion were taking place during Pennsylvanian time in the Eureka district, as shown by lateral discontinuity and local absence of the Pennsylvanian Ely limestone. Whether nondeposition and erosion were responsible for complete absence of Carboniferous from the Mahogany Hills westward cannot at present be fully demonstrated.

Rocks of the Permian system occur in the west, where Carboniferous strata are lacking. They are exposed on the flanks of Lone Mountain, in the northern Monitor Range, and at scattered localities farther west in the Great Basin. Permian rocks of Antelope Valley and the western Great Basin are usually associated with graptolite-bearing Ordovician deposits.

MISSISSIPIAN ROCKS

In the Mahogany Hills and at Devils Gate the rocks of Mississippian age agree rather closely with the middle and upper parts of this system, as exposed in the Diamond Mountains and in the vicinity of Eureka; in those areas the Mississippian includes the following formations in stratigraphic order: Diamond Peak formation, Chainman shale, Joana limestone, and upper part of the Pilot shale. However, in the area under consideration the lower units, Joana limestone and the upper part of the Pilot shale, were not recognized. Moreover, separation of Chainman from Diamond Peak was not practicable through the Mahogany Hills. Use of these terms follows revision of Carboniferous stratigraphy in the Eureka district (Nolan, Merriam, and Williams, 1956, p. 52–63), where Pilot, Joana, Chainman, and Diamond Peak are regarded as separate formations, and the controversial name "White Pine shale" is avoided (Merriam, 1940, p. 45).

CHAINMAN SHALE AND DIAMOND PEAK FORMATION, UNDIFFERENTIATED

AREAL DISTRIBUTION

The Chainman and Diamond Peak formations, undifferentiated, are well exposed at Devils Gate and southward along the east side of Yahoo Canyon for 4 miles. Small erosion-remnant outcrops occur on the lower north and west flanks of the Mahogany Hills. Just south of Devils Gate pass, the eastward-dipping shale and sandstone of this section rest on the lower part of the Pilot shale of Late Devonian age and are overthrust on the east by Ordovician chert and shale of the Vinini formation. North of U.S. Highway 50, near the east entrance to Devils Gate pass, the lower black shale beds may be observed to advantage between two alaskite porphyry sills. A lower sill separates these beds from the conodont-bearing upper Devonian beds of the Pilot. The upper part of the Pilot and the Joana limestone of Early Mississippian (Madison) age are not present, but would normally be expected at about the position of the lower sill. Alaskite sills and dikes of this type, as much as 50 feet thick, are common in the Chainman and Diamond Peak sequence south of Devils Gate.

LITHOLOGY AND STRATIGRAPHY

In the Devils Gate area, the lower part of the Chainman and Diamond Peak section is largely black carbonaceous shale, whereas the upper part is prevailingly gritty sandstone with shale intercalations and scattered beds of fine conglomerate. No limestone beds were recognized. In general, the character and vertical distribution of these strata are in agreement with the combined Chainman shale and Diamond Peak formation of the Diamond Mountains and Eureka district.

As seen on the north side of Devils Gate pass, the lower beds of this sequence are black noncalcareous somewhat silty clay shale. They are fairly smooth, with pencil structure in some places, and lack black interbeds of chert like those of the upper part of the Pilot shale in the Diamond Mountains. Although the upper part of the Pilot would be expected at this stratigraphic position, the shale beds in question resemble normal Chainman more closely. Lack of bedded chert also distinguishes the black shale from the Vinini, which tends to weather light gray or white and breaks down to thin flat plates and flakes. Pencil structure is generally not a feature of the Vinini nor is white weathering a characteristic of the Mississippian black shale.

Poorly sorted sandstone that weathers brown, and fine conglomerate of the Chainman and Diamond Peak sequence consist mainly of chert fragments, many of which are angular. Well-rounded quartz granules are present in smaller amounts. The chert varies in color from light gray to black, and some is greenish. Darker gray fragments of chert predominate and limonitic matter is fairly abundant in cavities and interstices. These dark-colored gritty clastic rocks contrast sharply with the clean well-sorted light-gray quartz sand and orthoquartzite that characterize the normal eastern sequence of Ordovician, Silurian, and Devonian formations in this region. The dark Mississippian chert-rich clastic rocks are, however, distinguished with considerable difficulty from those of the overthrust Vinini Ordovician. In fact, both were mapped together as "Diamond Peak quartzite by the Hague party. Like the brown Mississippian sandstones, some of those in the Vinini contain abundant angular gray chert fragments. Whereas the Mississippian sandstone beds commonly show a somewhat greater proportion of very dark chert and less argillaceous matter than those of the Vinini, it is doubtful that the two can be distinguished readily by gross lithologic features. Furthermore, both contain poorly preserved plant and plantlike matter. With the Vinini this material is probably in part algal and in part graptolitic.

Significant problems of stratigraphy in this area pertain to apparent absence of the lowermost Mississippian units and to means of distinguishing Mississippian clastic rocks from similar rocks of the Ordovician Vinini formation.

Late Devonian conodont-bearing strata of the lower part of the Pilot are present here, but the upper part of the Pilot and Joana limestone are unrecognized, suggesting local disconformity beneath the Chainman and Diamond Peak sequence. However, no physical evidence of stratigraphic break was observed, and marine deposition appears to have continued through the Devils Gate limestone interval into that of black shale assigned to the Chainman and Diamond Peak succession. Evidence of disconformity is more convincing on the west side of the Mahogany Hills (pl. 1), where coarse chert-rich brown sandstone like that of the Diamond Peak rests directly upon the Devonian Devils Gate limestone. The basal sandstone contains reworked angular blocks of Devils Gate limestone. Fossil evidence is insufficient to determine whether or not the sandstone actually represents the upper or Diamond Peak part of the Mississippian column.

Relationship of lower plate Mississippian to upper plate Vinini Ordovician is especially confusing where brown sandstone of the one is either in contact with or in close proximity to that of the other. Such relationships are noted along Yahoo Canyon. Less difficulty was experienced in mapping the thrust boundary just south of the east entrance to Devils Gate pass, where overthrust Vinini is in considerable part bedded chert. The same eastern thrust segment continues north beyond Devils Gate pass and may be observed at Anchor Peak, where lower plate standstones of the Chainman and Diamond Peak contain land plants.

Fossils, other than fragmentary plant remains, are extremely scarce in the Chainman and Diamond Peak of the Mahogany Hills. Limestone interbeds, which elsewhere yield marine fossils in this part of the section, were not discovered in the area under consideration. Only unidentifiable brachiopod impressions were found in the coarse basal sand on the west side of the Mahogany Hills, and conodont impressions occur in the lower black shale at Devils Gate pass.

PERMIAN SYSTEM

GARDEN VALLEY FORMATION

OCCURRENCE AND NAME

The Garden Valley formation of Permian age underlies the northern half of the Twin Spring Hills (pl. 1), a northeast terminal salient of the Monitor Range. These Permian strata are lithologically and faunally similar to the Garden Valley formation of the type area (Nolan, Merriam, and Williams, 1956, p. 67), 25 miles northeast of the Twin Spring Hills. Beds of the Garden Valley have not been recognized elsewhere in the area under consideration, but are exposed on pediment slopes of Lone Mountain, halfway between the Twin Spring Hills and the type Garden Valley outcrop.

On the south the Garden Valley strata of the Twin Spring Hills (loc. 82) are in contact with and probably rest unconformably upon Ordovician graptolitic deposits of the Vinini formation. On the north they are overlain unconformably by sandstone and shale assigned to the Newark Canyon formation of Cretaceous age (loc. 91).

The Garden Valley Permian rocks, everywhere associated with the graptolitic beds of the Vinini are provisionally regarded as a western facies introduced by thrust movement, together with the Vinini.

LITHOLOGY AND STRATIGRAPHY

In the Twin Spring Hills, the Garden Valley strata consist of arenaceous and pebbly limestone, siltstone, sandstone, chert pebble conglomerate, and limestone cobble conglomerate. Limestone cobble conglomerate and arenaceous limestone are the most abundant.

Mapping of the Garden Valley-Vinini contact in the Twin Spring Hills suggests that it is probably an unconformity. Such a relationship has been demonstrated at Tyrone Gap (fig. 2) in the type area of the formation, where angular chert fragments of the Vinini were reworked depositionally in basal beds of the Permian unit. Reworked Vinini fragments were not observed in lower beds of this Permian sequence in the Twin Spring Hills.

Coarse, gritty brown and reddish-brown sandstone beds rest upon the limestone cobble conglomerate at the north end of the Twin Spring Hills. With these are silty shale and fine-grained sandstones that weather olive tan to dusky yellow. The coarse-grained sandstone consists largely of gray chert grains, many of which are angular. Distribution of these beds suggests that they overlap unconformably upon the limestone cobble conglomerate, though no angular discordance was recognized. Absence of fossils in the upper sand unit prevents determination of age, but these beds resemble the Lower Cretaceous Newark Canyon formation of the Diamond Mountains and the Eureka mining district (Nolan, Merriam, and Williams, 1956, p. 68).

Two principal stratigraphic subdivisions are definable in the Garden Valley formation of the Twin Spring Hills: a lower unit, about 500 feet thick, composed largely of medium-gray rather thick-bedded sandy to pebbly limestone, and an upper unit, approximately 4,500 feet thick, composed of limestone cobble conglomerate. Between these two major divisions there occurs a thin reddish and buff sandstone, siltstone, and shale unit. The lower 500-foot limestone unit is clearly of marine origin, whereas the overlying reddish unit suggests emergent conditions that may well have persisted into the interval of limestone cobble conglomerate, which yielded only reworked fossils.

The lower part of the lower 500-foot carbonate unit includes buff and pink platy-weathering fine-grained silty beds of limestone. Like contiguous red-stained shale of the Vinini, these Permian beds may have received their pinkish coloration by leaching of ferruginous matter from lavas which, prior to erosion, probably covered this area. Most of the lower 500-foot unit is thick-bedded; crossbedding is well shown where siliceous sand grains weather in relief. Bands of limestone with very coarse sand grains and lenses of chert pebble conglomerate are also present. This chert was probably derived from the underlying Vinini.

Silicified fossils occur in the lower platy pinkish limestone, whereas just above this zone lies a coral bed containing numerous large colonial corals. Fine-grained fairly-pure limestone beds of medium-gray color near the middle of the lower 500-foot unit contain productids, and have yielded a fauna of small silicified brachiopods.

Limestone conglomerate makes up nine-tenths of the Garden Valley formation as exposed in this area. It is composed of subrounded to angular fragments of light-gray and medium-gray limestone ranging in diameter from less than 1 inch to 10 inches. Cement is calcareous matter mixed with fine sand of light gray to pinkish color. Scattered angular fragments of gray and greenish-gray chert are present and were possibly derived from Ordovician bedded chert of the Vinini. The conglomerate tends on the whole to weather fairly light gray with patches of pinkish, yellowish, and buff color.

THICKNESS

The Garden Valley formation is estimated to be more than 5,000 feet thick in the Twin Spring Hills. Of this succession, the lower marine Lower Permian division is about 500 feet thick, the overlying limestone conglomerate about 4,500 feet thick.

AGE AND CORRELATION

Only the lower 500-foot arenaceous limestone is dated paleontologically, the upper limestone conglomerate having yielded no contemporaneous fossils. Early Permian (Wolfcamp) fossils are common in the lower 250 feet of the formation near the Garden Valley-Vinini contact. Three fossil zones are recognized: A lower brachiopod zone with a silicified brachiopod assemblage; a middle colonial coral bed; and an upper zone with productids. Protracted search for fusulinids in Garden Valley strata of the Twin Spring Hills was unsuccessful. Fusulinids are present in the type Garden Valley and in this formation at Lone Mountain. In the type Garden Valley, the lower sandy limestone unit contains *Schwagerina* near the base, with *Pseudoschwagerina* and *Parafusulina* higher in this division. At Lone Mountain only *Schwagerina* has been identified.

In the Twin Spring Hills the lower brachiopod fauna includes the following:

Crenispirifer n. sp.
Hustedia cf. *H. mormoni* (Marcou)
Dielasma sp.
?*Crurithyris* sp.

The common form in the coral bed is a large bushy colonial tetracoral provisionally assigned to *Pseudozaphrentoides*, associated with which is a *Syringopora* possessing unusually thick tubes.

The upper or productid zone, which lies near the middle of the 500-foot arenaceous limestone unit, is characterized by a medium-sized *Buxtonia*, small rhynchonellids, and other small silicified brachiopods.

Detailed comparisons with faunas of the type Garden Valley and the Carbon Ridge formation at Eureka (Nolan, Merriam, and Williams, 1956, p. 64–68) have not yet been made. The bushy colonial coral *Pseudozaphrentoides* is similar to that occurring in the upper part of the Carbon Ridge formation near the mouth of Secret Canyon in the Eureka district. Comparable species of *Dielasma* and ?*Crurithyris* occur in the lower brachiopod fauna of the Twin Spring Hills and in the basal Garden Valley of the type area. Spiriferinids occur in both; the Twin Spring Hills forms are assigned to *Crenispirifer* Stehli (1954, p. 347), whereas those of the type Garden Valley appear more closely related to *Spiriferellina newelli* Stehli.

Lithologic comparison of the Permian section in the Twin Spring Hills with the type Garden Valley reveals significant resemblances as well as some differences. Thus both columns have a lower fossil-bearing arenaceous limestone division, about 500 feet thick, each overlain by thick unfossiliferous conglomerate. In the type area a disconformity separates the lower arenaceous limestone from the overlying conglomerate. Whereas this unconformity was not recognized in the Twin Spring Hills, its position may be indicated by the reddish intermediate sand and shale member. The two columns differ in that limestone conglomerate predominates in the Twin Spring Hills, whereas siliceous conglomerate prevails in the typical Garden Valley, with limestone conglomerate appearing only in the upper part of this division. In places, the Twin Spring Hills conglomerate beds contain large amounts of angular chert fragments, although the cement is calcareous.

Derivation of the limestone cobbles is of interest, for many contain Pogonip Ordovician fossils. Among these is the large gastropod *Palliseria*, a characteristic fossil of the Antelope Valley limestone. Certain of the light gray limestone cobbles have the character of Goodwin limestone of Early Ordovician age. It is assumed that such materials did not undergo prolonged transportation by water.

Lack of contemporaneous fossil evidence in the thick upper limestone conglomerate of the Twin Spring Hills suggests that possibly all beds above the intermediate reddish sandstone may be post-Paleozoic and possibly nonmarine. The limestone conglomerate is evidently post-Wolfcamp Permian and almost certainly pre-Cretaceous. Accordingly, it may be Late Permian or as young as Jurassic. Cobbles, some containing fossils, were derived from Ordovician limestones of the Pogonip like those of the normal Antelope Valley sequence. This evidence may be interpreted as conflicting with the theory of thrust introduction of younger rocks, as part of a western sequence. It is conceivable that the post-Wolfcamp conglomerates, if locally derived, may be considerably younger than the thrusting. If, however, they have been introduced by thrusting, it is possible that rocks of the normal Antelope Valley Ordovician carbonate sequence may extend farther west than heretofore suspected.

Geologic mapping in the Toquima and Toiyabe Ranges (fig. 2) may yield information on the western extension of Garden Valley rocks and elucidate their origin. Emmons (1870, p. 323, 335) and Hill (1915, p. 116) report fusulinids and the coral *Syringopora* at Santa Fe Canyon in the northern Toiyabe Range (fig. 2). Slates and shales of Vinini Ordovician type occurring in that vicinity recall the widespread association of Garden Valley Permian with the Vinini graptolitic deposits. Carbonate rocks of possible Garden Valley age are likewise associated with graptolite-bearing Ordovician rocks in the Toquima Range (Marshall Kay, oral communication, 1959).

LOCALITY REGISTER

Fossil localities and exposures revealing significant stratigraphic and structural features in the Paleozoic rocks of Antelope Valley are given below. Locality numbers are plotted on the geologic reconnaissance maps (pls. 1 and 2).

Southern half Antelope Valley area (pl. 2)

1. Monitor Range on west side of Copenhagen Canyon, 5½ miles north of Martin Ranch: Antelope Valley limestone with *Maclurites* and *Girvanella* in upper plate of thrust.
2. Monitor Range in saddle on Martin Ridge, 3¼ miles north of Martin Ranch: Copenhagen formation, abundant fossils.
3. Monitor Range on west side of Copenhagen Canyon and on north side of Whiterock Canyon: Outlier of Pogonip group on Lower Devonian Rabbit Hill limestone.
8. Monitor Range on east of summit 7702 Martin Ridge, 4¾ miles north of Martin Ranch: Hanson Creek formation with graptolites.
9. Monitor Range on top of Martin Ridge, 2 miles southeast of Martin Ranch: Hanson Creek formation with graptolites.
10. Monitor Range in Copenhagen Canyon on west side of Martin Ridge, 2 miles north of Martin Ranch and 1 mile southeast of junction Ryegrass Canyon and Copenhagen Canyon: Copenhagen formation with abundant fossils.
13. Monitor Range in narrows of Whiterock Canyon, 1½ miles northwest of Rabbit Hill: Ninemile formation and Antelope Valley limestone with abundant fossils, especially in *Orthidiella* zone. *Didymograptus* in shales of the Ninemile. Overthrust Vinini graptolitic shale and chert across canyon west of locality 13.
27. Monitor Range at east foot of Martin Ridge near north end: Antelope Valley limestone with abundant *Palliseria*.
49. Monitor Range at northern tip of Martin Ridge: Goodwin limestone with *Kainella*.
51. Monitor Range at Rabbit Hill: Type section of Rabbit Hill limestone, with abundant silicified fossils.
52. Monitor Range, 1¼ miles north of Rabbit Hill: Abundant fossils in Rabbit Hill limestone.

Southern half Antelope Valley area (pl. 2)—Continued

53. Monitor Range in hill 1 mile north-northeast of Rabbit Hill: Limestone of the Hanson Creek formation overlain by platy limestone of the Roberts Mountains formation with *Monograptus*.
55. Antelope Range on east side of Ninemile Canyon near mouth: *Caryocaris* shale.
56. Antelope Range on east side of Ninemile Canyon in saddle on northwest spur of range at measured section: Type section of Ninemile formation with abundant fossils.
57. Antelope Range on crest of northern tip at altitude 7,500 feet: Nevada formation, *Martinia kirki* beds with *Receptaculites*.
58. Antelope Range on west side of Ninemile Canyon: Shaly Ninemile formation with *Kirkella;* near base overlying Antelope Valley limestone.
59. Antelope Range, 2½ miles north-northeast of Blair Ranch ("Segura Ranch"): Copenhagen formation with abundant fossils.
60. Antelope Range, 2 miles north-northeast of Blair Ranch ("Segura Ranch"): Copenhagen formation with fossils.
61. Antelope Range, 2¼ miles northeast of Blair Ranch ("Segura Ranch"): Hanson Creek formation with graptolites.
63. Antelope Range, 4 miles north-northeast of Blair Ranch ("Segura Ranch"): Beds of Hanson Creek formation with graptolites resting on Eureka quartzite.
64. Antelope Range, 4 miles northeast of Blair Ranch ("Segura Ranch"): Ninemile formation with fossils.
65. Antelope Range, 5½ miles north-northeast of Blair Ranch ("Segura Ranch"): Ninemile formation with fossils.
66. Antelope Range near west base, 5 miles north-northeast of Blair Ranch ("Segura Ranch"): Dark-bluish-gray calcareous shale, possible *Caryocaris* shale.
67. Antelope Range, north of mouth Ninemile Canyon at range front: Cherty shale and sandstone probably represents Ordovician Vinini formation outlier; no graptolites found. Fossils in limestone of the Nevada formation to east.

Northern half Antelope Valley area (pl. 1)

71. Mahogany Hills on west side north of Table Mountain: Small erosion remnant of Cretaceous Newark Canyon formation resting on Devils Gate limestone. Plant fragments.
72. Mahogany Hills on west side north of Table Mountain: Upper part of the Nevada formation with *Stringocephalus*.
73. Mahogany Hills on west side north of Table Mountain: Upper part of the Nevada formation with *Stringocephalus*.
74. South end of Mahogany Hills, 1½ miles north of Wood Cone: Upper part of the Lone Mountain dolomite with silicified fossils in dark-gray carbonaceous dolomite.
75. Mahogany Hills, south of Table Mountain: Disconformity between Lone Mountain dolomite and fossiliferous Nevada formation.
76. South end of Mahogany Hills, north of Wood Cone near road: Hanson Creek formation with fossils. *Halysites* found northwest of locality 76 may be in either Hanson Creek or overlying dolomitic limestones of the Roberts Mountains formation.

Northern half Antelope Valley area (pl. 1)—Continued

77. West side of Mahogany Hills, southwest of Table Mountain: Lower part of the Nevada formation with "*Spirifer*" *kobehana*.
78. South end of Mahogany Hills, on south spur of Combs Peak: Lower and middle parts of the Nevada formation with abundant fossils.
79. East side of Yahoo Canyon near mouth, west of Devils Gate just south of Lincoln Highway: Ordovician shale and chert of the Vinini formation with graptolites.
80. East side Yahoo Canyon, three-quarters mile south of Lincoln Highway and one-half mile south of locality 79: Ordovician shale and chert of the Vinini formation with graptolites.
81. North end of Mahogany Hills, 2 miles south of Hay Ranch: Devils Gate limestone with *Pachyphyllum*.
82. North end of Monitor Range, on east side of Twin Spring Hills:Permian Garden Valley formation near base, with corals and brachiopods.
83. North end of Monitor Range, in Twin Spring Hills: About same horizon as locality 82.
84. North end of Monitor Range, in Twin Spring Hills: Shale of the Vinini formation with graptolites.
85. North end of Monitor Range, in Twin Spring Hills: Pogonip group, Antelope Valley limestone with *Palliseria*.
86. North end of Monitor Range, in Twin Spring Hills: Pogonip group with fossils.
87. North end of Monitor Range, in Twin Spring Hills: Pogonip group with fossils.
88. East side of Antelope Valley on road 3 miles south of Lincoln Highway: Pediment outlier of limestone breccia-conglomerate. Exposure mainly depositional limestone breccia-conglomerate of Devils Gate subjected to strong deformation.
89. Yahoo Canyon, 2¼ miles south of Lincoln Highway: Outcrop of dark gray bedded chert; possible Vinini formation outlier.
90. East side of Twin Spring Hills: Small pediment exposure Silurian platy limestone of the Roberts Mountains formation with *Monograptus;* may also include limestone of the Hanson Creek formation.
91. North end of Twin Spring Hills: Sandstone of probable Cretaceous Newark Canyon formation.

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