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PALEOZOIC ROCKS OF NORTH-CENTRAL NEVADA[1]

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ABSTRACT

Recent geologic mapping and stratigraphic study in north-central Nevada has increased our knowledge of the Paleozoic stratigraphy and structural history of this complex area. The present paper summarizes the stratigraphy and outlines a suggested synthesis of the Paleozoic geologic history.

Eastern Nevada differs greatly in stratigraphy and structural history from the western part. In eastern Nevada, roughly east of longitudes 116°–117°, the Paleozoic rocks from Middle Cambrian to Upper Mississippian are mostly limestone and dolomite with minor amounts of shale and quartzite. In central and western Nevada the correlative strata are predominantly clastic sedimentary rocks and chert, with intercalated volcanic rocks and pyroclastics. The eastern assemblage is on the order of 15,000 feet thick in most places; the western assemblage is much thicker, probably more than 50,000 feet. The depositional environments of the eastern and western assemblages were clearly different. The eastern assemblage is miogeosynclinal, the western eugeosynclinal. The two have been brought into contact by telescoping along a thrust fault of great magnitude—the Roberts Mountains thrust—which carried the western assemblage relatively eastward or southeastward over the eastern assemblage.

In several places an assemblage that does not belong clearly to either the eastern or western assemblages, but includes elements of both, is recognized as transitional. Rocks of the transitional assemblage occur both in parautochthonous windows beneath the Roberts Mountains thrust plate of western assemblage rocks, and as slivers in the upper plate of the thrust.

The broad geosyncline in which the three assemblages were laid down persisted, with local disturbances beginning in Late Cambrian, until the end of Devonian time. A belt along the 116°–118° meridians—the Antler orogenic belt—was the locus of intense folding and faulting that culminated in the Roberts Mountains thrust fault in Late Devonian or Early Mississippian time. From an

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Besides the field work done in north-central Nevada by the writers, many geologists have furnished data used in this summary. T. B. Nolan, Charles W. Merriam, Ronald Willden, Robert E. Lehner, J. Fred Smith, Olcott Gates, and Keith Ketner of the U. S. Geological Survey have made important contributions. Fossils were identified and age determinations made by A. R. Palmer, R. J. Ross, Jr., Josiah Bridge, Jean Berdan, Helen Duncan, L. G. Henbest, Raymond C. Douglass, James Steele Williams, Mackenzie Gordon, Jr., W. H. Hass, all of the U. S. Geological Survey. Geologists of the University of California at Los Angeles, including C. A. Nelson, E. L. Winterer, Michael Murphy, and Donald Carlisle, made available maps of critical areas and contributed valuable suggestions. Norman J. Silberling, Robert G. Yates, John C. Hazzard, Peter Misch, John H. Wiese, and Philip B. King read the manuscript, and offered many helpful suggestions.

emerged area along this belt coarse clastic rocks were deposited both eastward and westward; these grade laterally into finer sediments and limestone of normal marine facies. In the orogenic belt the sediments that were deposited on the deformed strata of the eastern, transitional, and western assemblages are designated the overlap assemblage. Orogenic movements continued along the belt in Pennsylvanian and Permian time, and throughout the Mesozoic, probably into Cretaceous time, causing further deformation of the previously folded and thrust-faulted rocks and of the sediments of the overlap assemblage as well.

A correlation chart and representative stratigraphic sections of the several stratigraphic assemblages are included.

INTRODUCTION

From the time of the Fortieth Parallel survey, it has been recognized that the Paleozoic stratigraphic and structural history of the eastern part of Nevada differs strikingly from that of the western part (King, 1878, pp. 247, 342, 759; Hague, 1892, pp. 175–82). Many geologists in subsequent years have studied and described these rocks, but Nolan (1928, pp. 150, 153–61) first called attention to the significance of the stratigraphic differences and credited Turner (1902, pp. 265–66) with the first description of western assemblage rocks. Kirk (1933, p. 31) recognized two distinct facies of Ordovician rocks in the Roberts Mountains, noting that the two facies were separated by only a few miles, and suggesting that they had been brought together by thrust faulting. Merriam and Anderson (1942) confirmed Kirk's suggested explanation by discovering and mapping a thrust between the two facies in this area, named the Roberts Mountains thrust fault. Nolan (1943) in his comprehensive summary of the geology of the Great Basin, also emphasized the lithologic differences between the Paleozoic formations of east and west.

Geologic mapping during recent years in north-central Nevada has revealed that the facies contrasts are of regional extent and that the facies are separated by thrust faults. Present understanding of the stratigraphy of this complex area results from the work of many men. Basic data and concepts were developed by Ferguson in papers dealing with central Nevada (1924, 1949) south of the area here considered. Since 1939, Ferguson, Muller, and Roberts have made a geologic reconnaissance of the 1-degree Sonoma Range Quadrangle (Fig. 1), and published the four included 30-minute quadrangles—Mt. Tobin (Muller, Ferguson, and Roberts, 1951), Winnemucca (Ferguson, Muller, and Roberts, 1951a), Golconda (Ferguson, Roberts, and Muller, 1952), and Mt. Moses (Ferguson, Muller, and Roberts, 1951b). The Antler Peak 15-minute Quadrangle, in the southeast part of the Golconda Quadrangle, was mapped by Roberts in 1941–49 and was published in 1951. The Mt. Lewis, Crescent Valley, and Cortez 15-minute quadrangles were mapped by Gilluly and Gates in 1949-55 and the Osgood Mountains Quadrangle by Hotz and Willden in 1951–55, but the results have not yet been published.

Under a cooperative agreement between the Nevada Bureau of Mines and the U. S. Geological Survey, reconnaissance geologic maps of separate counties are in different stages of completion and have already yielded valuable data. In the part of Nevada covered by this paper, field work for reconnaissance surveys

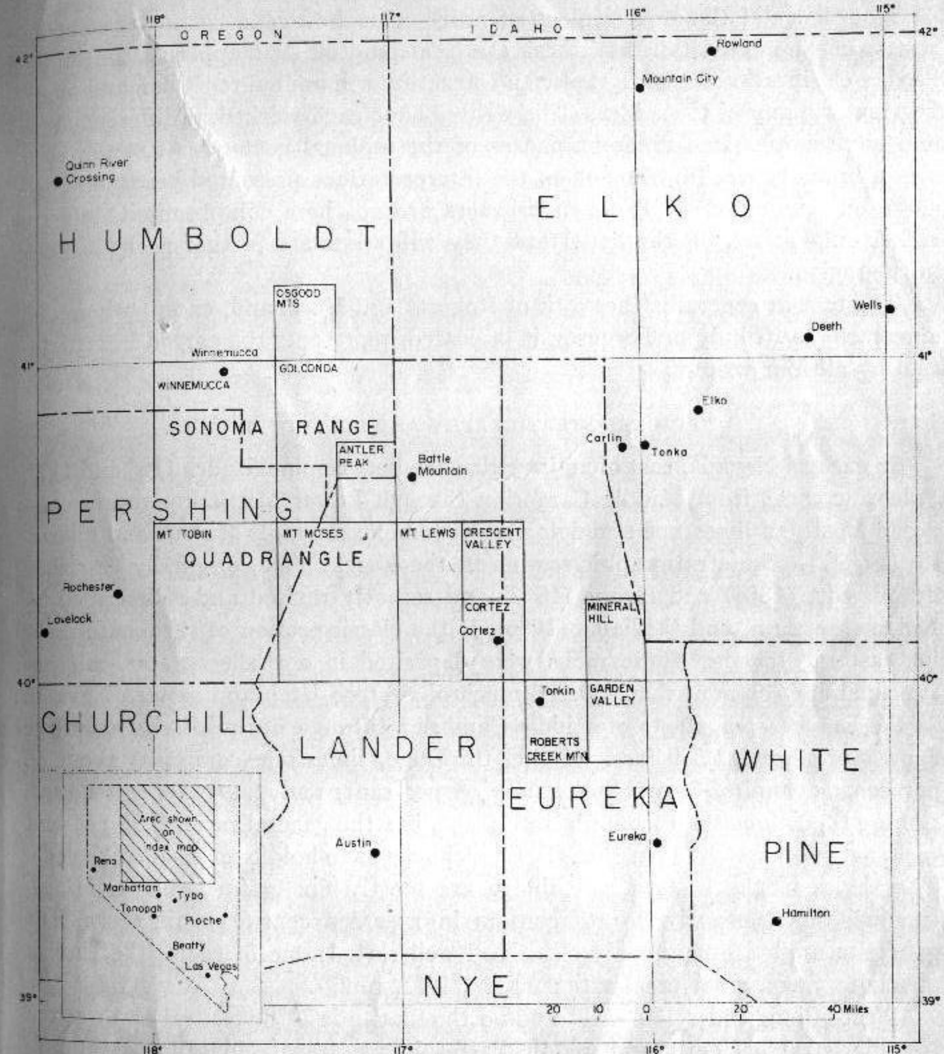


FIG. 1.—Index map of north-central Nevada.

of Elko County by A. E. Granger and Mendell Bell, for Eureka County by R. J. Roberts and Robert Lehner has been completed, and that for Humboldt County by Ronald Willden is in progress.

The recent summary of the stratigraphy of the Eureka district by Nolan, Merriam, and Williams (1956) gives a revision of the standard Paleozoic section for eastern Nevada. The recent paper by Dott (1955), primarily a study of Pennsylvanian stratigraphy of the eastern part of this area, has been drawn on extensively.

Knowledge of the areal geology of north-central Nevada has now reached a stage where a more detailed synthesis can be attempted. As mapping is continued, further clarification of stratigraphy and structure will undoubtedly demand modification of many of these ideas. The writers have each worked in different areas and have emphasized different phases of the regional geology. Although they are in broad general agreement on the interpretations presented here, they disagree on minor points. These divergences are not here compromised, but are rather emphasized, in the hope that they will stimulate further geologic work in the region.

The text in general is the work of Roberts and Hotz, and, except where disagreement by Gilluly or Ferguson is indicated, represents the agreed interpretation by all four writers.

REGIONAL STRATIGRAPHY AND STRUCTURE

In eastern Nevada, east of an irregular line between longitudes 116° and 117°, Paleozoic rocks from Middle Cambrian through Lower Mississippian are composed mostly of limestone and dolomite with minor amounts of shale and quartzite (Fig. 2). The stratigraphic section in the Eureka area, originally described by Walcott (1884) and Hague (1892) and recently revised and redescribed by Nolan, Merriam, and Williams (1956), is the classic section of carbonate rocks for eastern Nevada. These rocks were deposited in a shallow-water, miogeosynclinal environment that covered much of western Utah and eastern Nevada. In the Eureka area, strata of Middle Cambrian through Early Mississippian age aggregate about 14,500 feet. Of this thickness, limestone comprises about 60 per cent; dolomite, 30 per cent; shale, 8 per cent; and quartzite, 2 per cent. These proportions vary from place to place, but the general ratio of 90 per cent carbonate rocks and 10 per cent clastic rocks seems to hold over eastern Nevada. The shales in the eastern assemblage are mostly fine-grained, black, or calcareous; they generally do not contain interbedded coarse clastic rocks. The quartzite units are commonly clean and well sorted; one of them, the Eureka quartzite, has a great areal extent (Kirk, 1933, p. 29).

West of longitudes 116°–117° and north of latitude 39° in central and western Nevada, strata of early and middle Paleozoic age are dominantly clastic sediments and chert, with intercalated volcanic rocks and pyroclastic rocks (Fig. 2). Ferguson (1952, p. 73) pointed out that the western assemblage attains a great thickness in the Sonoma Range area. Subsequent studies there and in adjacent areas indicate that the rocks of Mississippian age or older of this assemblage may aggregate more than 50,000 feet. They were deposited in a eugeosynclinal environment (Stille, 1940, p. 15) west of the shallow shelf seas in western Nevada. Few data on the proportion of rock types in the Nevada segment of the eugeosyncline are available, but it is estimated that shale makes up 20–40 per cent of the section, sandstone, graywacke, and quartzite 10–30 per cent, chert with shale partings as much as 30 per cent, and volcanic rocks and pyroclastics from a few per cent to 30 per cent. The units are characteristically lenticular, and thin or thicken abruptly parallel with and normal to the geosynclinal trend. Limestone, generally shaly or sandy, locally forms thin, discontinuous layers. The shale units are commonly sandy and few are calcareous. The quartzites are generally nearly pure, but the sandstones are either graywackes or feldspathic sandstones. The chert units, partly of volcanic derivation, range from a few inches to several hundred feet thick; individual chert layers are lenticular and range from a fraction of an inch to 3 feet. They are separated by shaly partings which are also lenticular; laterally, chert units grade into siliceous shale units with subordinate chert. The volcanic rocks are largely andesitic or basaltic pillow lavas and pyroclastics that accumulated mainly in a marine environment; most are highly albitic. Siliceous pyroclastic rocks locally form thick sections. The volcanic rocks are highly lenticular, and probably formed around many source centers.

There is generally a sharp distinction between the eastern and western assemblages, but locally a transitional assemblage is recognized (Hotz and Willden, 1955). This belongs neither to the eastern nor western types, but includes elements of both assemblages. These transitional rocks were originally included in the western assemblage, but as further field work was done, and new faunal data accumulated, it was found that correlative units distinctly different lithologically had been placed in the same section. The transitional units are therefore separated from the western units, and treated as a separate assemblage.

The transitional assemblage is characterized by a combination of clastic, volcanic, and carbonate elements. The proportion of carbonate is generally less than 40 per cent; the clastic rocks are mainly shale and sandy shale, in part calcareous. Sandstone and calcareous sandstone beds make up part of the section, but coarse clastic units like those common in the western assemblage are rare. Volcanic material generally consists of fine-grained tuffs or tuffaceous shale but flows are locally present. Chert and chert-shale units are less abundant than in the western assemblage. Individually, some transitional units resemble the eastern assemblage and others the western, but as a whole, the transitional assemblage is recognizable. Boundaries between the assemblages probably oscillated back and forth across central Nevada, and locally deposits of one assemblage may have accumulated in a part of a basin characterized predominantly by another assemblage.

The three assemblages were laid down in a broad north-trending geosyncline which persisted in north-central Nevada with local and marginal disturbances until the end of the Devonian, when orogenic movements along a positive area (Nolan, 1928, p. 158 and Fig. 1) resulted in the formation of an emergent area extending north-northeast, medially across the state (Fig. 6). This belt is now known to have been the locus of intense folding and faulting during the Antler orogeny in latest Devonian or Early Mississippian time which culminated in the Roberts Mountains thrust fault. Merriam and Anderson (1942) showed in the Roberts Mountains that this thrust is of great magnitude and brings into juxta-

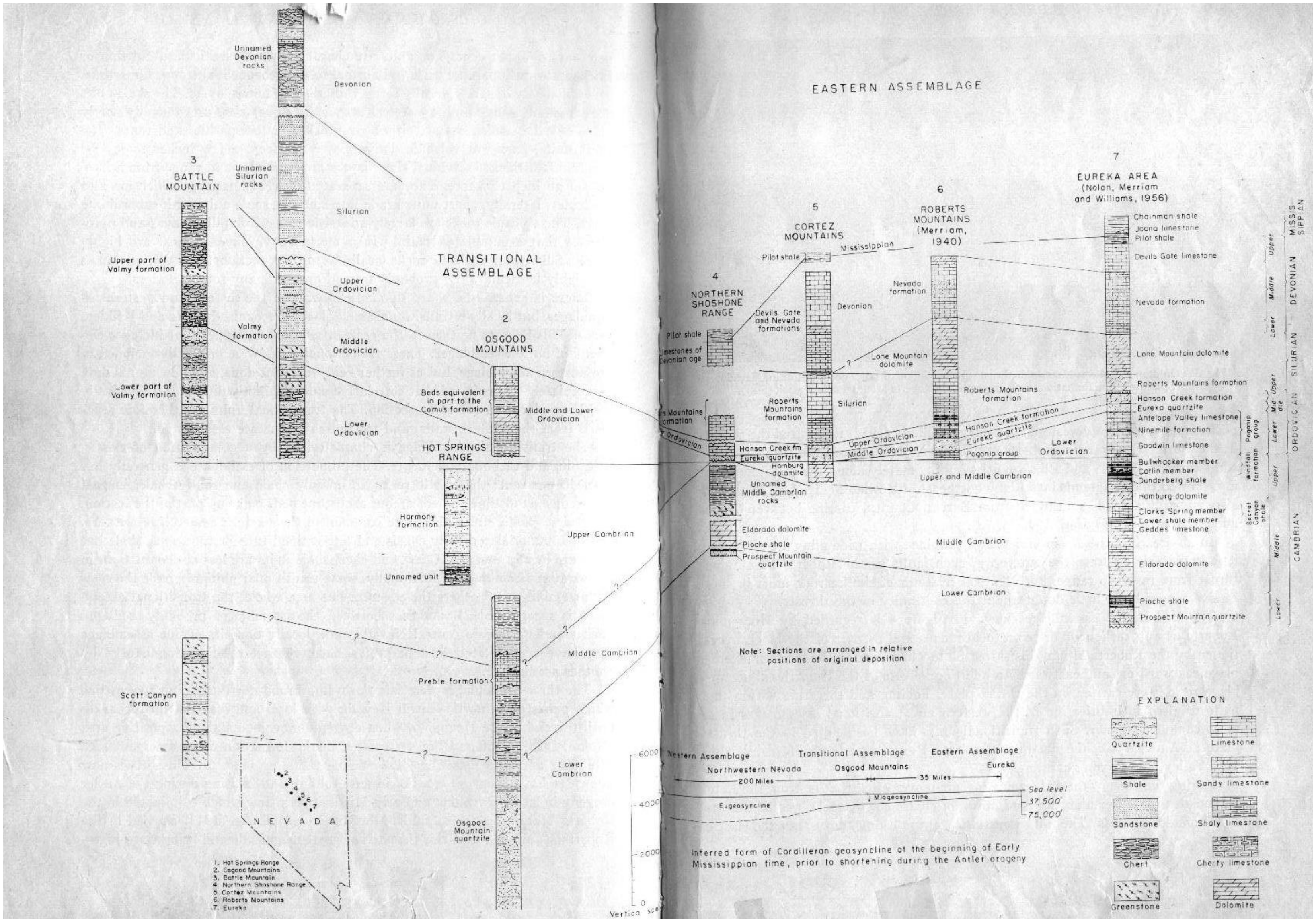


FIG. 2.—Stratigraphic sections of pre-Mississippian rocks in north-central Nevada.

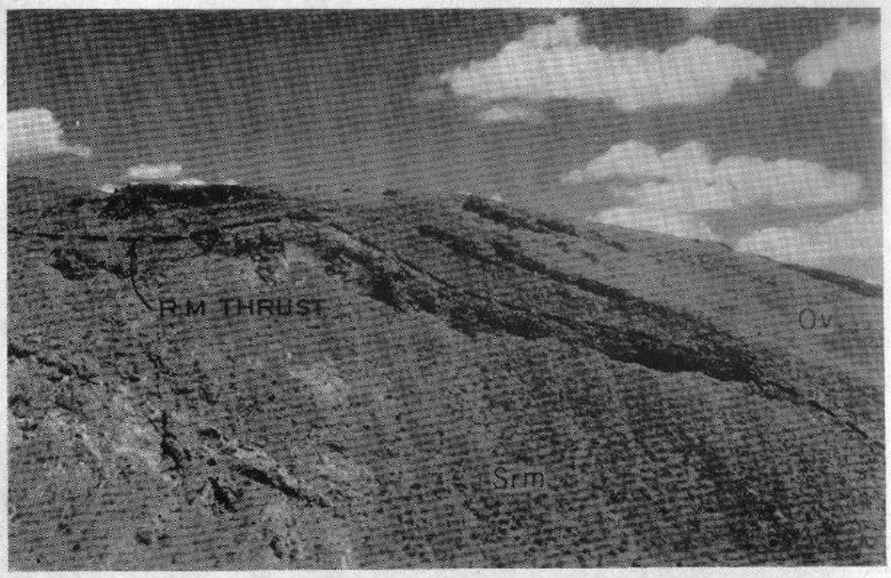


FIG. 3.—Outcrop of Roberts Mountains thrust, Carlin window, 7 miles north of Carlin, Nevada. Upper plate is Vinini formation (Ov); lower plate is Roberts Mountains formation (Srm).

position the eastern and western assemblages. Gilluly (1954) recognized the thrust in the Cortez Quadrangle. Roberts and Lehner (1955) traced the thrust northward through Eureka and Elko counties approximately along the 116° meridian and showed that it extends into Idaho northeast of Rowland (Fig. 3). The thrust also probably extends southward from Eureka County, passing between Tybo and Manhattan (Ferguson, 1942, p. 73).

In an area like the Basin and Range province with wide alluviated valleys, it is impossible to trace the outcrop of such faults as the Roberts Mountains thrust from range to range, but identical relations of similar rock units in successive ranges leave little doubt about the continuity of the thrusts.

The transitional assemblage shown in Figure 4 is regarded by Hotz and Roberts as autochthonous or parautochthonous and as part of the block overridden by the Roberts Mountains thrust plate which carried the western assemblage eastward or southeastward. In addition, slivers of the transitional assemblage rocks were carried on the thrust plate. Folding and thrusting within the plate resulted in imbrication of the western and transitional assemblages in a most complex manner. Such transitional units have been noted in the thrust plate at Antler Peak, the northern Shoshone Range, and in the Mineral Hill, Pine Valley, and Carlin quadrangles.

During the time of the Paleozoic orogenic movements, that is, from the Late Devonian to late Permian, a broad apron of coarse clastic rocks was laid down over much of Nevada. The full extent of the apron is not known, but the clastic rocks probably extended as far south as Beatty, as far southeast as Pioche, and as far north as Mountain City. Coarse clastics were also shed westward from the highland into basins in western Nevada although some of these also could well have been derived from farther west. Away from the orogenic belt (Fig. 6, inset map) the clastics grade into finer sediments that intertongue with the normal marine section; in the orogenic belt the clastics and associated lenticular limestones, ranging in age from Mississippian to late Permian, overlap folded and faulted eastern, transitional, and western assemblage strata that had been involved in the orogeny. These rocks were named the overlap assemblage (Roberts and Lehner, 1955, p. 1661). (Fig. 6.)

Pre-Orogenic Stratigraphy

The Paleozoic rocks of north-central Nevada are here described system by system, and respectively assigned to eastern, transitional, and western assemblages that can be conveniently compared (Fig. 2, 5.)

CAMBRIAN

The oldest Cambrian rocks over large areas of eastern and southern Nevada are generally termed the Prospect Mountain quartzite. The lowest Cambrian unit in north-central Nevada is the lithologically similar Osgood Mountain quartzite which is at least 5,000 feet and may be as much as 10,000 feet thick. Both are thick, massively bedded quartzites that differ markedly from overlying units.

Cambrian rocks of the eastern assemblage are exposed in the north-trending ranges in southern Eureka County and in windows at Cortez, the Lynn district, and in the Goat Ridge window of the northern Shoshone Range. Rocks of equivalent age, but lithologically different, assigned to the transitional assemblage, are exposed at Battle Mountain, the northern Shoshone Range, in the northern Sonoma Range, the Edna Mountains, the Osgood Mountains, and Hot Springs Range.

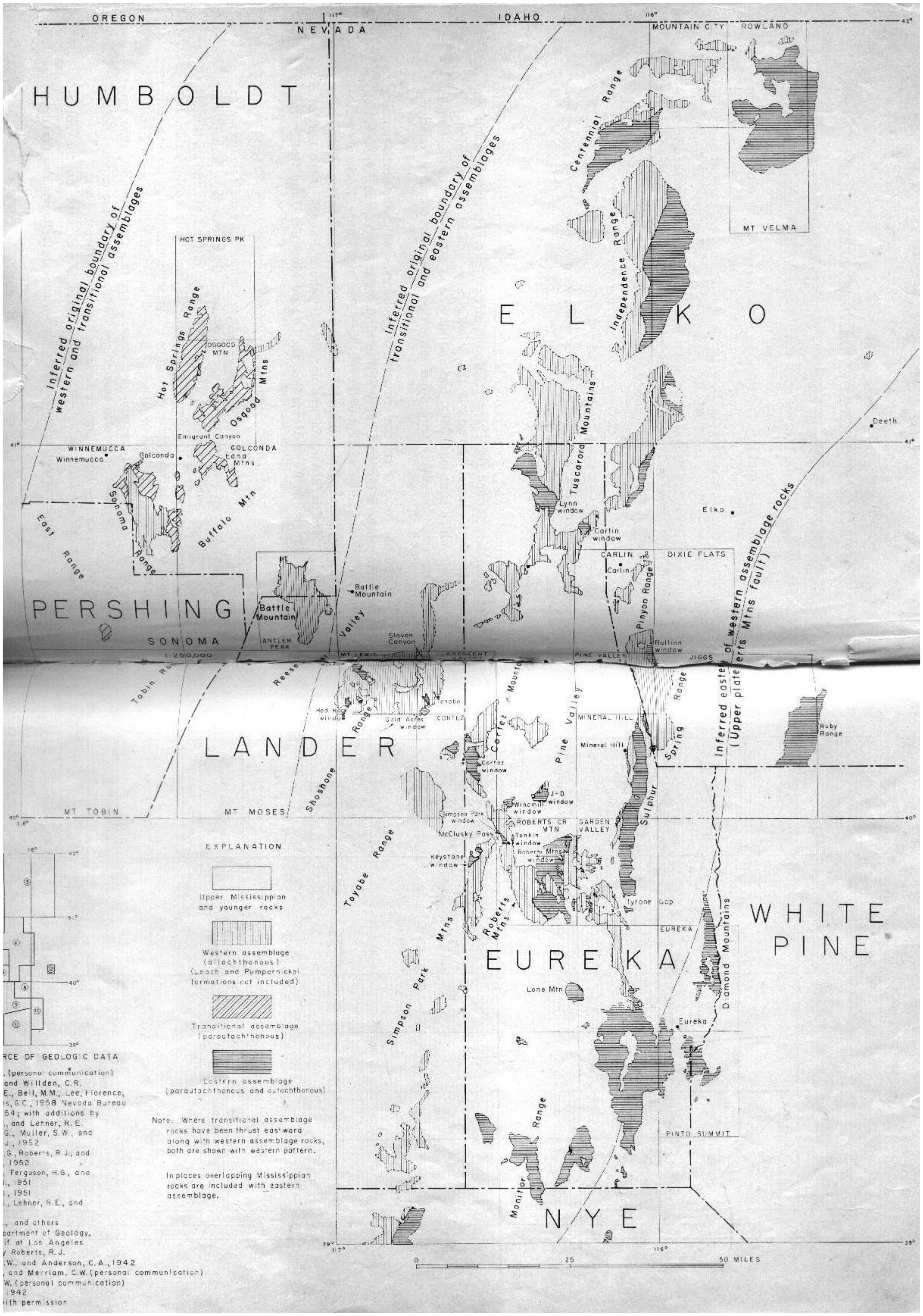
EASTERN ASSEMBLAGE

Cambrian units of the eastern assemblage are remarkably uniform over wide areas and, though local variations are recognized, they are minor; formational units can be followed as far south as the southern tip of the state and southwestward into southern California. The sequence is essentially conformable, but toward the west, unconformities and gaps in the section gradually become more pronounced. The Cambrian sequence at Eureka, summarized in Figures 2 and 5, is typical of the eastern assemblage (Nolan, Merriam, and Williams, 1956, pp. 5–23). Other sections of eastern assemblage Cambrian rocks are exposed northwest of Eureka in windows[3] in the Roberts Mountains thrust sheet.

Roberts Mountains window.—Cambrian rocks are exposed on the north-

[3] The term window as used in this paper refers only to windows in the Roberts Mountains thrust sheet.

LOC.



OREGON
IDAHO
NEVADA
117°
116°
42°
41°
40°
39°
HUMBOLDT
ELKO
PERSHING
LANDER
EUREKA
WHITE PINE
NYE
MOUNTAIN CITY
ROWLAND
MT VELMA
HOT SPRINGS PK
WINNEMUCCA
GOLCONDA
SONOMA
1:250,000
ANTLER PEAK
MT LEWIS
CRESCENT
PINE VALLEY
JIGGS
CARLIN
DIXIE FLATS
CORTEZ
MINERAL HILL
MT TOBIN
MT MOSES
ROBERTS CR MTN
GARDEN VALLEY
EUREKA
PINTO SUMMIT
Inferred original boundary of western and transitional assemblages
Inferred original boundary of transitional and eastern assemblages
Inferred eastern edge of western assemblage rocks (Upper plate of Roberts Mtns fault)
Centennial Range
Independence Range
Hot Springs Range
Osgood Mtns
OSGOOD MTN
Emigrant Canyon
Edna Mtns
Winnemucca
Golconda
Sonoma Range
East Range
Buffalo Mtn
Tuscarora Mountains
Lynn window
Carlin window
Carlin
Pinyon Range
Elko
Deeth
Battle Mountain
Valley
Slaven Canyon
Bullion window
Tobin Range
Reese River
Red Hill window
Gold Acres window
Tenabo
Cortez Mountains
Pine Valley
Mineral Hill
Spring
Sulphur
Ruby Range
Cortez window
J-D window
Windmill window
Simpson Park window
McClusky Pass
Tonkin window
Roberts Mtns window
Keystone window
Shoshone Range
Toyabe Range
Roberts Mtns
Tyrone Gap
Diamond Mountains
Lone Mtn
Eureka
Simpson Park Mtns
Monitor Range
0
25
50 MILES
EXPLANATION
Upper Mississippian and younger rocks
Western assemblage (allochthonous) (Leach and Pumpernickel formations not included)
Transitional assemblage (parautochthonous)
Eastern assemblage (parautochthonous and autochthonous)
Note: Where transitional assemblage rocks have been thrust eastward along with western assemblage rocks, both are shown with western pattern.
In places overlapping Mississippian rocks are included with eastern assemblage.
RCE OF GEOLOGIC DATA
. (personal communication)
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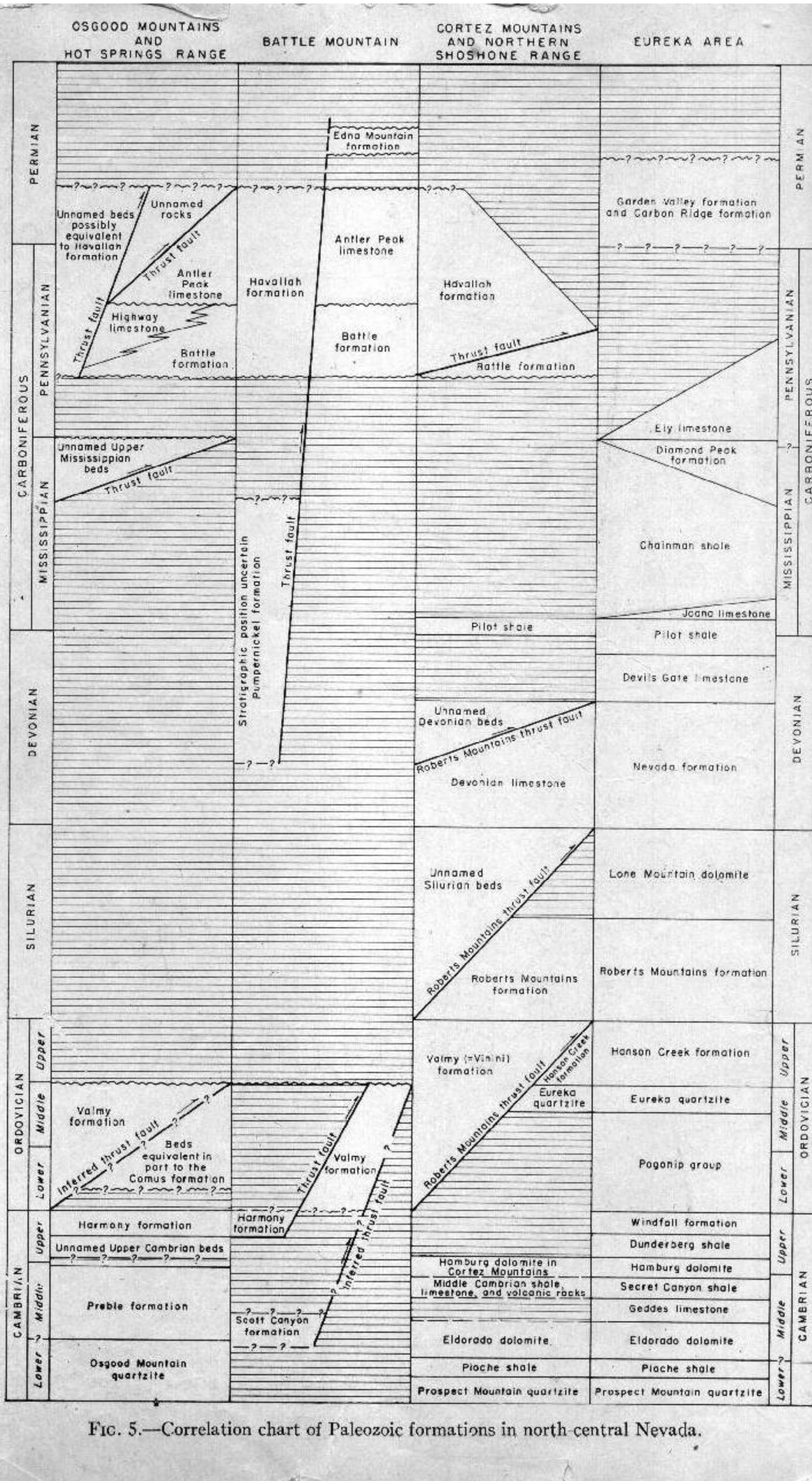

Fig. 5.—Correlation chart of Paleozoic formations in north-central Nevada.

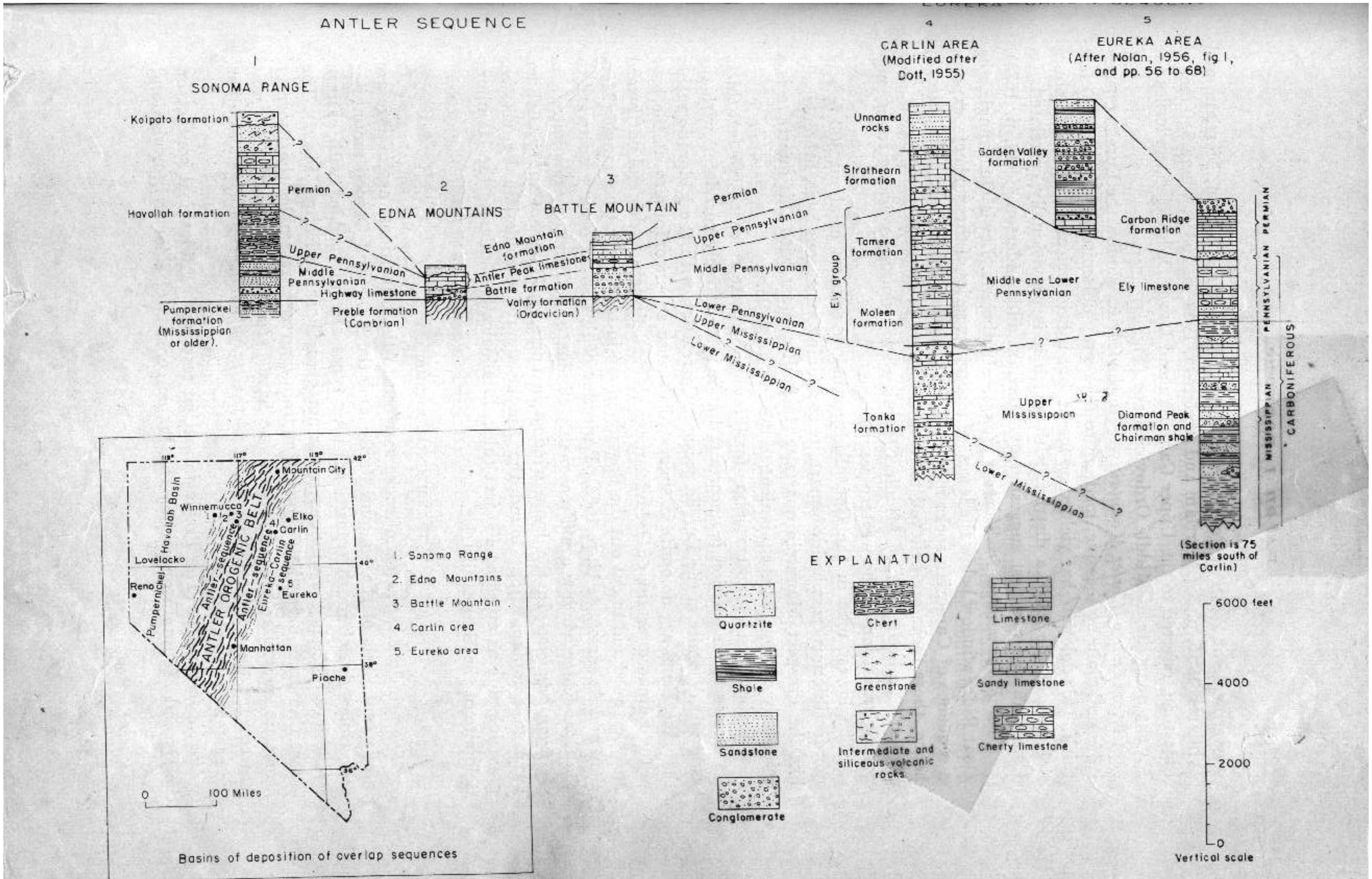

FIG. 6.—Stratigraphic sections of overlap assemblage in north-central Nevada.

western side of Western Peak in the Roberts Mountains (Nolan, Merriam, and Williams, 1956, p. 25; Merriam and Anderson, 1942, p. 1683), where 350 feet of limestone, referred to the Upper Cambrian and Lower Ordovician, underlies the Eureka quartzite of Middle Ordovician age (Fig. 4).

Cortez window (Cortez Mountains).—In the Cortez window the Eureka quartzite is underlain by massive, medium to dark gray dolomite more than 800 feet thick. This dolomite has yielded no fossils, but is lithologically like the Hamburg dolomite of the Eureka district, with which it is provisionally correlated. Its Cambrian age was first suggested by Merriam and Anderson (1942, p. 1684).

Goat Ridge window in Shoshone Range.—In the Mt. Lewis Quadrangle, the Goat Ridge window below the lowest of a complex series of thrust sheets, exposes a sequence of Cambrian rocks like the known eastern assemblage near Eureka; hence, these rocks are believed to be autochthonous or parautochthonous. The highest Cambrian unit, of Middle Cambrian age, contains volcanic rocks, suggesting transition to the western assemblage.

The lowest unit in the Goat Ridge window consists of about 300 feet of non-fossiliferous cross-bedded quartzite containing micaceous beds, lithologically like the Prospect Mountain quartzite. In fault contact with this quartzite is a thin shaly unit, perhaps equivalent to the Pioche shale.

Also bounded by faults is a non-fossiliferous dolomite at least 1,000 feet thick. Its stratigraphic position is uncertain, but it is tentatively correlated with the Eldorado dolomite of the Eureka section. Correlation with the Eldorado rather than the Hamburg dolomite is suggested because an unconformity at the base of the Eureka quartzite of Ordovician age seems definitely to descend northward and westward and to cut out the Pogonip group in the Cortez Quadrangle (Merriam and Anderson, 1942, p. 1684). Projection of this unconformity westward to the Goat Ridge window could reasonably eliminate the Hamburg dolomite.

Lynn window.—In the Lynn window in northern Eureka County, Lehner (written communication) found the Eureka quartzite underlain by massive gray dolomite as much as 400 feet thick, lithologically similar to the Hamburg dolomite of the Eureka district.

TRANSITIONAL ASSEMBLAGE

The principal exposures of rocks assigned to the transitional assemblage are in adjacent parts of the Sonoma Range and the Edna and Osgood mountains near Golconda, although transitional rock types are interbedded with eastern assemblage rocks in the windows in the northern Shoshone Range (Fig. 2). The lowest Cambrian unit, the Osgood Mountain quartzite, resembles the Prospect Mountain quartzite; hence it appears to have been part of a widespread unit that covered the shelf, and forms part of the transitional assemblage as well as the eastern assemblage.

Preble formation.—The Preble formation rests with gradational contact on the Osgood Mountain quartzite. The Preble consists of a lower brownish and greenish micaceous shale member, an intermediate limestone and shale member, and an upper shale member. Fossil collections range from early Middle Cambrian to early Late Cambrian, according to A. R. Palmer (written communication). It is estimated that there are probably between 5,000 and 10,000 feet of beds in the Osgood Mountains, and between 12,000 and 15,000 feet in the Emigrant Canyon section on the south (Ferguson, Roberts, and Muller, 1952; Ferguson, 1952). The lower part of the Preble may be approximately contemporaneous with part of the Scott Canyon formation of the western assemblage in the Antler Peak Quadrangle. The Preble formation contains perhaps up to 30 per cent carbonates and shows closer affinities with the eastern assemblage than the western. This is regarded by Roberts and Hotz as suggesting that the boundary between transitional and eastern assemblage rocks may have locally extended west of Golconda during Middle Cambrian time.

Upper Cambrian rocks.—Two Upper Cambrian units, an unnamed unit and the Harmony formation, are conformable in the Hot Springs Range west of the Osgood Mountains in the northwest part of the Osgood Mountains Quadrangle. The Harmony formation is also found in thrust plates in the Sonoma Range and in Battle Mountain where it was carried with western assemblage rocks on the upper plate of the Roberts Mountains thrust and on Mesozoic thrusts. The relation of the Upper Cambrian units to the Preble formation is not definitely known, as they are nowhere in depositional contact. This part of the section is therefore shown in Figure 2 slightly offset from the remainder of the section of the transitional assemblage.

The unnamed unit underlying the Harmony formation, found only in the Hot Springs Range, contains a trilobite fauna which, according to A. R. Palmer, indicates age equivalence with the Dunderberg shale of Late Cambrian age of the Eureka section. It consists of gray, brown, and black bedded chert, a little siliceous shale, and some very thin lenticular beds of fine-grained bioclastic limestone. Chert and siliceous shale predominate over limestone in a ratio of perhaps 5:1. No volcanic rocks have been recognized. The full thickness is not known because the base is not exposed; the exposed thickness is 300–500 feet. The association of abundant chert with thin discontinuous limestone beds suggests that this formation was deposited in a marine environment different from that in which the eastern, dominantly carbonate, assemblage was laid down. It more closely resembles the western or eugeosynclinal assemblage, but in the absence of interbedded greenstone or basic tuff it and the overlying Harmony formation are tentatively considered to belong to the transitional assemblage.

The Harmony formation, previously regarded as Mississippian (?) (Ferguson, Muller, and Roberts, 1951a; Roberts, 1951; Ferguson, Roberts, and Muller, 1952; Ferguson, 1952), is now known to be of latest Cambrian age, because of trilobites found in the Hot Springs Range and Osgood Mountains (A. R. Palmer, written communication). The formation is lithologically distinct from all the other formations with which it is in contact, for it is dominantly feldspathic sandstone, arkose, and grit with minor amounts of shale, some limestone, and chert. The coarse feldspathic sandstone, arkose, and grit are composed of nearly fresh feldspars, unaltered biotite and muscovite, and quartz, and have clearly been derived from a granitic source near the basin of deposition. Determination of the age of detrital zircon from the Harmony gave 680 million years, and it is therefore probable that the source rock was upper Precambrian, though no Precambrian rocks have yet been recognized in north-central Nevada.

The Harmony formation has been found in two kinds of structural settings: as parts of a folded block comprising the Hot Springs Range and northern part of the Sonoma Range; and in thrust sheets of Paleozoic and Mesozoic age in the East Range, Sonoma Range, Osgood Mountains, Battle Mountain, and Shoshone Range.

The Upper Cambrian rocks in the Hot Springs Range and northern part of the Sonoma Range may be either autochthonous or allochthonous, for relationships are concealed by valley alluvium and younger rocks. There is, however, no direct evidence that they have been carried in on a thrust, and folds in the Hot Springs Range are generally accordant with folds in the Osgood Mountain and Preble formations in the Osgood Mountains. Furthermore, the rocks in the Hot Springs Range lie on the west flank of an anticline that involves the Osgood Mountain and Preble formations in the Osgood Mountains, which would be a normal position for the higher beds. They are not present on the east flank of the anticline, but their absence may be explained by faulting that drops younger rocks down along the east flank of the fold. In the northern part of the Sonoma Range, Ordovician rocks of the western assemblage are thrust over the Harmony formation as well as over the Preble and Osgood Mountain formations, which are regarded as autochthonous. Roberts and Hotz believe, in the absence of direct evidence to the contrary, that the blocks of Harmony formation in the Hot Springs Range and in the northern Sonoma Range are autochthonous or parautochthonous, and, because of associations with other rocks of early Paleozoic age of the transitional assemblage, consider that the formation was deposited within or near the transitional zone. As no similar rocks are known on the east, south, or west, it is suggested that the source area was north or northwest of Winnemucca.

In the other localities, the Harmony formation rests on thrust plates whose structures are sharply discordant with the structures of adjacent plates. In Battle Mountain the Harmony formation is on the upper plate of a thrust of pre-early Middle Pennsylvanian age (Roberts, 1951); in the East Range and western Sonoma Range it is in thrust contact with rocks of Paleozoic and Triassic age. On the west side of the Osgood Mountains a sliver of Harmony formation is in a thrust zone of post-Pennsylvanian age.

In order to account for the present distribution of the Harmony formation in so many structural settings it is postulated by Roberts and Hotz that slivers of Harmony were stripped off the underlying units by growth of a contemporaneous subsidiary thrust beneath the Adelaide-Roberts Mountains thrust plate and that these slivers broke through and overrode the eugeosynclinal rocks. In Figure 2 these slivers are included with the eugeosynclinal rock pattern. Subsequent thrust faulting during the Mesozoic has caused further imbrication of the Harmony with Triassic rocks and with other rocks of Paleozoic age.

An alternative explanation favored by Gilluly and Ferguson is that the Harmony formation was deposited farther west, and was carried eastward during both Paleozoic and Mesozoic thrusting. They do not regard the Adelaide and Roberts Mountains thrusts as the same. Such an interpretation implies that all the Harmony in the area is allochthonous.

Goat Ridge window in Shoshone Range.—The highest Cambrian unit in this window is a sequence of shaly limestones, calcareous shales, and volcanic rocks—some pillow-lavas, others green phyllites thought to be pyroclastic—at least 1,200 feet and perhaps 2,000 feet thick. A sparse fauna in the limestones is considered nearly equivalent to the Secret Canyon shale of the Eureka section by A. R. Palmer (written communication). Actual interbedding of limestone and volcanic rocks is somewhat questionable because of faulting and isoclinal folding, but their association is so close and persistent that the two rock types are probably interbedded. It is impossible to be sure that the rocks are autochthonous, because of their greatly disturbed attitudes, but this is suggested by their association with the Prospect Mountain quartzite and Eldorado dolomite. The association of volcanic rocks, with limestone suggests that this formation belongs to the transitional assemblage. Perhaps the volcanic intercalations are merely local, as equivalent rocks farther west are shaly limestones and shales that resemble the eastern assemblage more than the western.[4]

WESTERN ASSEMBLAGE

Scott Canyon formation.—The only formation of Cambrian age thus far recognized as clearly belonging to the western assemblage is the Scott Canyon formation. It is exposed in the Antler Peak Quadrangle and consists of about 5,000 feet of dark, thin-bedded chert, shale, and greenstone with a little limestone and quartzite. As the Scott Canyon formation is overthrust by the Harmony formation, its relations to younger formations of the western assemblage such as the Valmy, are not known. The Valmy and Scott Canyon are similar lithologically except that the Scott Canyon has only a few thin layers of quartzite. Lenticular limestone units, apparently in the middle part of the Scott Canyon, contain an association of archaeocyathids and algae. According to Helen Duncan (written communication) archaeocyathids are described only from Lower Cambrian rocks elsewhere in the Cordilleran region, but these organisms continue into Middle Cambrian rocks in Asia and the Mediterranean regions and are recorded in the

[4] Because of the great transport demonstrable on many of the thrusts of the area, measured in tens of miles, the writers regard position as irrelevant to the classification of a formation with respect to assemblage.

lower Middle Cambrian of Alaska. Some of the archaeocyathids and algae in the Scott Canyon are forms that are said to be restricted to the Middle Cambrian in Asia.

ORDOVICIAN

Ordovician rocks of the eastern assemblage are found in southern Eureka County and in the Roberts Mountains window, the Cortez window, the Lynn window, and two of the Shoshone Range windows. Ordovician rocks of the transitional assemblage have been recognized only in the Edna and Osgood mountains. Ordovician rocks of the western assemblage are widespread, and apparently make up most of the upper plate of the Roberts Mountains thrust. Probably none of the masses now known is autochthonous.

EASTERN ASSEMBLAGE

Roberts Mountains window.—Ordovician rocks of the eastern assemblage are exposed on Western Peak in the Roberts Mountains in central Eureka County. Here the Early Ordovician is represented by the lower part of the Pogonip group which is estimated to be about 350 feet thick, and consists largely of thin-bedded limestone (Nolan, Merriam, and Williams, 1956, p. 25). It is disconformably overlain by the Eureka quartzite, a vitreous, white, rather pure quartzite about 500 feet thick, and over this by the Hanson Creek formation, which consists mainly of dark gray dolomite as much as 560 feet thick.

Cortez window.—The Pogonip group is absent in the Cortez window on the western side of Eureka County and the Eureka quartzite rests directly on the Hamburg(?) dolomite. The Eureka quartzite is about 350 feet thick and is overlain by dark gray dolomite of the Hanson Creek formation which ranges from 250 to 300 feet in thickness.

Lynn window.—In the Lynn window, northern Eureka County, the Eureka quartzite also rests on dolomite tentatively assigned to the Hamburg dolomite. The section of Eureka quartzite here has not been measured, but is about 300 feet thick. The overlying Hanson Creek formation is massively bedded at the base but grades upward into thinner-bedded layers; its thickness is about 300 feet.

Shoshone Range (Goat Ridge and Red Rock windows).—The Goat Ridge window contains about 120 feet of Eureka quartzite whose base is faulted out. The quartzite is overlain by approximately 500 feet of dolomite of the Hanson Creek formation. The Red Rock window contains a faulted section of dolomite and limestone of the Hanson Creek formation. The Eureka is not represented in the Red Rock window. Twenty miles southeast at Cortez, the Eureka rests on supposedly Upper Cambrian rocks; 4 miles north at Goat Ridge the obscure relations suggest that the Eureka was originally deposited on Middle Cambrian beds.

Though faulting in both the Shoshone Range windows makes the matter uncertain, the simplest interpretation of these facts is that uplift along an axis transverse to the general Cordilleran trend occurred in early Middle Ordovician time. Erosion removed the strata of Early Ordovician and Late Cambrian age from this axis. The essential identity in composition and age of the Eureka with some of the quartzites of the Valmy and Vinini suggests that all could have been supplied from the same source. Thus, clastics of western derivation transgressed the Middle Ordovician ridge in later Middle Ordovician time. The upper part of the Eureka quartzite at Cortez may be of Late Ordovician age (Duncan, 1956, p. 217). In areas represented by the Ruby Mountains (Sharp, 1942, p. 659) and, much farther east, the Gold Hill area of Utah (Nolan, 1935, p. 16) the Eureka apparently did not cover the uplift. During Late Ordovician time the Hanson Creek formation and its equivalents were deposited throughout the area of distribution of the eastern assemblage.

TRANSITIONAL ASSEMBLAGE

The Comus formation was first defined in the Edna Mountains where it is composed mainly of interbedded shale and chert, with minor limestone and dolomite (Ferguson, Roberts, and Muller, 1952). Graptolites of Early Ordovician age (Josiah Bridge, written communications) were found in a few of the shaly beds. In the Osgood Mountains, 12 miles north of the Edna Mountains, approximately 3,000–4,600 feet of beds which are roughly on strike with the Comus but separated by an alluvium-covered valley, are predominantly dolomite, limestone, and shale with subordinate amounts of chert, siltstone, and silicic tuffaceous material. The ratio of carbonate to fine-grained clastics and chert ranges from about 1:2 to 2:1. The proportion of calcareous rocks is apparently higher here than at the type locality of the Comus. Graptolites from these beds are of Early and Middle Ordovician age.

Relations of the Comus formation and strata in the Osgood Mountains to the Upper Cambrian rocks are not known. The Comus formation was mapped in the Golconda Quadrangle (Ferguson, Roberts, and Muller, 1952) as in normal contact with the Preble formation of Middle or Late Cambrian age, but restudy of the relationships at the type locality has shown that the contact is a high-angle fault. Upper Cambrian rocks that may have been present between the Preble and Comus have been cut out along the fault. In the Osgood Mountains, the contact of the beds which are equivalent in part to the Comus with the Preble formation is covered with alluvium and deep soil, but at one place mining has exposed a brecciated zone along the inferred position of the contact.

The Comus formation and partly equivalent strata in the Osgood Mountains indicate a transition from the eastern to the western assemblage. The dating of these units is well substantiated, according to the late Josiah Bridge, as they contain graptolite faunas nearly identical with those of the Valmy and Vinini formations, which are in turn roughly equivalent in age to the Pogonip group and the Eureka quartzite. The lithologic characters of the three assemblages are so different, however, as to suggest deposition in distinctly different environments.

The chert and shale unit of the northwest side of Battle Mountain, originally assigned to the Comus formation (Ferguson, Roberts, and Muller, 1952; Roberts, 1951), is now referred to the upper part of the Valmy formation of Middle and Late Ordovician age in this area because it contains no carbonate beds.

WESTERN ASSEMBLAGE

Rocks of Ordovician age that belong to the western assemblage are widely exposed throughout north-central Nevada. They underlie large areas in the Sulphur Spring Range, Roberts Mountains, Tuscarora Mountains, Cortez Mountains, northern Shoshone Range, Toyabe Range, Battle Mountain, and the Sonoma Range. So far as known they are allochthonous.

Vinini formation.—Merriam and Anderson (1942, p. 1694) used the name Vinini formation for rocks of Ordovician age of the western assemblage in the Roberts Mountains. They divided the formation into two units. The lower part of the Vinini, Early Ordovician in age, consists of quartzite, limestone, and calcareous sandstone, and silty and shaly sediments with minor amounts of andesitic lava flows and tuffs; perhaps the relatively abundant limestone here suggests an approach to the transitional assemblage. The upper part of the Vinini, of Middle Ordovician age, is composed of bedded chert and black organic shale, clearly of normal western lithologic type. Strata lithologically and faunally similar to these two units make up much of the Simpson Park Range, the Cortez Mountains, and the Tuscarora Mountains. Where they contain fossils of Ordovician age they were assigned to the Vinini formation by Roberts and Lehner during the reconnaissance mapping of Eureka County.

The most complete stratigraphic section of the Vinini formation thus far seen is in the Tuscarora Mountains, northern Eureka County, about 5 miles north of U. S. Highway 40. Strata of Early, Middle, and probably Late Ordovician age are present; no detailed measurements were made, but it is estimated that the section is a least 7,000 feet thick.

Valmy formation.—In the Shoshone Range, Battle Mountain, and Sonoma Range the proportion of massive quartzite, chert, and volcanic material in the Ordovician rocks of the western assemblage is larger than in the Vinini formation. These rocks were named the Valmy formation in Battle Mountain (Roberts, 1949, 1951) where they have been subdivided into two members. The lower part of the Valmy consists mainly of rather pure, generally light-colored quartzite, dark gray and greenish chert, some gray to black siliceous shale, and a significant amount of greenstone. The upper member consists principally of dark thin-bedded chert interbedded with dark shale and a little greenstone. The base of the Valmy is concealed but at least 4,000 feet is present. The upper beds of the Valmy are highly contorted, but are estimated to be 3,000 or more feet thick. The lower part of the Valmy formation contains graptolites of Early and Middle Ordovician age and is correlative in part with beds assigned to the lower part of the Vinini formation in the Roberts Mountains (Merriam and Anderson, 1942, p. 1694). The upper part of the Valmy is probably equivalent to the upper part of the Vinini of these authors. The quartzite beds of the lower part of the Valmy are generally not so pure as the Eureka quartzite of the eastern assemblage, but they are similar, and probably represent partly contemporaneous deposition as as they contain fossils of equivalent age (Fig. 2).

In general, there seems to be a gradation eastward from thick quartzite beds in the Valmy to thinner and finer-grained rocks in the Vinini. The Ordovician rocks of the western assemblage in the Tuscarora Mountains do not include significant amounts of quartzite, and appear to have been deposited in a part of the eugeosyncline farther from the source of the quartz.

The Valmy formation of the northern Shoshone Range resembles the formation at the type locality, although the lower part contains a higher proportion of calcareous, silty, and sandy beds. Some thick quartzites are essentially all quartz, like the Eureka. Thin greenstone units are present low in the section and thick ones high in the section. The aggregate thickness of these clastic, chert, and volcanic rocks is estimated to be at least 15,000 feet, and may exceed 25,000 feet. In separate fault plates a single section of 6,500 feet and several others each exceeding 4,000 feet show no lithologic parallels—they are considered to be in sequence rather than laterally equivalent.

Similar rocks of Ordovician(?) age, the Sonoma Range formation, underlie the central part of the Sonoma Range (Ferguson, Muller, and Roberts, 1951a), and are probably equivalent to part of the Valmy as mapped in the Shoshone Range and in Battle Mountain.

Remnants of the Valmy formation, downfaulted against the Harmony formation, occur in two small areas on the east side of the Hot Springs Range. A small area of the Valmy formation is exposed on the northeast flank of the Osgood Mountains where it overlies metamorphosed Comus formation of the same age but lithologically different, probably in thrust contact.

The lower part of the Valmy formation in Battle Mountain contains graptolites of Early and Middle Ordovician age; the upper member contains Middle and Late Ordovician graptolite faunas (Josiah Bridge, written communication). Graptolites of Early, Middle, and Late Ordovician age have also been collected from the same formation in the northern Shoshone Range (R. J. Ross, Jr., personal communication). No fossils have been found in the remnants in the Hot Springs Range, but exposures on the northeast side of the Osgood Mountains yielded trilobites of Early Ordovician age and some poorly preserved graptolite remains (R. J. Ross, Jr., written communication).

SILURIAN

Silurian rocks of the eastern assemblage have been mapped locally in Eureka County and in windows in the Simpson Park, Cortez, and Tuscarora mountains, and Shoshone Range. Only one unit of transitional Silurian rocks has been discovered in the Shoshone Range. Western assemblage rocks of Silurian age have thus far been recognized at only a few places.

EASTERN ASSEMBLAGE

Two formations of Silurian age, the Roberts Mountains and Lone Mountain, crop out in many ranges in Eureka County. The Roberts Mountains formation is composed of a thin-bedded platy limestone 740–1,900 feet thick (Merriam and Anderson, 1942, pp. 1686–87). The formation is 500–650 feet thick in the Sulphur Spring Range (Donald Carlisle and C. A. Nelson, oral communication). The Lone Mountain dolomite is a light to medium gray, fine-grained to saccharoidal dolomite and dolomitic limestone that weathers light yellowish gray. At the type locality on Lone Mountain it is 2,200 feet thick. In the Sulphur Spring Range it is as much as 3,200 feet (Carlisle and Nelson, oral communication).

Winterer and Murphy (1958, p. 51) report that the Lone Mountain dolomite and Roberts Mountains formation are largely lateral equivalents in the Roberts Mountains. The Lone Mountain is considered to be a reef-and-bank complex whose original features were largely obliterated by dolomitization, and the Roberts Mountains formation is a deeper-water reef-flank, off-reef, and basin deposit. The Silurian in a north-trending band through the Roberts Mountains is as much as 4,500 feet thick, about four times the regional average.

Windmill window.—The Windmill window at the northern end of the Simpson Park Mountains, west-central Eureka County, discloses a thick section of the Roberts Mountains formation, possibly 3,000 feet, at the range front facing Pine Valley. The lower beds are thin-bedded, typical of the formation, and grade upward into thick-bedded limestone. The highest beds exposed contain a fauna of Early Devonian (Helderberg) age (C. W. Merriam, written communication). The Lone Mountain dolomite is apparently missing in this area; possibly part of the thick-bedded limestone below the beds containing the Helderberg fauna are of Late Silurian age, and represent a limestone facies of the Lone Mountain.

Cortez window.—The only Silurian unit in the Cortez window, central-western Eureka County, is the Roberts Mountains formation which is more than 1,200 feet thick.

Windows of Shoshone Range.—The Roberts Mountains formation is also exposed in windows in the Shoshone Range. At Gold Acres are several hundred feet of dark, platy, and carbonaceous limestone. In the Goat Ridge window the beds are highly contorted, and 500–1,000 feet of platy and carbonaceous limestone appear to be present.

Windows of Tuscarora Mountains.—The Roberts Mountains formation is exposed in the Carlin window and the Lynn window in the Tuscarora Mountains, northern Eureka County. Neither window has a complete section, but much more than 1,000 feet of beds are present. The lower beds are platy, sandy, and silty limestones, containing graptolites suggesting Late Silurian age according to R. J. Ross, Jr. (written communication); these are overlain by thick-bedded limestones, presumably also of Late Silurian age and partly equivalent in age to the Lone Mountain dolomite.

TRANSITIONAL ASSEMBLAGE

Silurian beds that have a transitional aspect have been mapped by Gilluly in the southern part of the Mt. Lewis Quadrangle; these beds are a few hundred feet thick in the window south of Mill Creek and about 2,000 feet thick in the Red Rock window, where they are chiefly calcareous fine-grained sandstone and platy shaly limestone. The approximate contemporaneity of this unit with the Roberts Mountains formation is indicated by the presence of *Monograptus*, and the fine platy parting strongly resembles that of the Roberts Mountains formation. The formation contains dominantly yellowish sandstone that weathers reddish brown.

WESTERN ASSEMBLAGE

Silurian rocks of the western assemblage appear to be widespread, but because they resemble the Ordovician units, they have not everywhere been differentiated in mapping.

On the east side of Pine Valley about 8 miles south of Carlin, unnamed black shale and tawny to buff tuffaceous shale and calcareous shale have yielded *Monograptus* determined by R. J. Ross, Jr. (oral communication) to be of Silurian age. The thickness of these beds is not known.

Black shale containing *Monograptus* is reported by C. W. Merriam (oral communication) from the vicinity of McClusky Pass in the northern part of the Simpson Park Mountains. C. A. Nelson (oral communication) also reports *Monograptus* in shale on the east side of Pine Valley near Mineral Hill. On the west side of the Tuscarora Mountains in the valley of Mary's Creek, graptolites that according to R. J. Ross, Jr., have affinities with Silurian forms were collected by Roberts in 1954. Silurian strata (R. J. Ross, Jr.), including about 4,000 feet of sandstone, arkose, shale, and a little chert, form part of the overriding plate of the Roberts Mountains thrust in the northern Shoshone Range and in the Cortez Mountains.

The beds containing graptolites of Silurian age are on the whole less cherty, and contain more calcareous shale and limestone layers than the Vinini and Valmy formations. On the other hand, the Silurian beds of the western assemblage appear much less calcareous than the Silurian of the transitional assemblage. The western rocks contain some siliceous pyroclastics, which have not been recognized in the other assemblages.

DEVONIAN

Devonian rocks of the eastern assemblage crop out widely in southern and eastern Eureka County, and also occur in the Keystone, Cortez, Gold Acres, and Lynn windows. Devonian rocks of the transitional assemblage have not so far been identified in north-central Nevada, but calcareous shales of that age suggesting transitional rock types are closely associated with western assemblage rocks in the upper plate of the Roberts Mountains thrust fault. As the facies boundaries probably varied in position from time to time there is nothing surprising about such an association. Devonian rocks of the western assemblage have been recognized in the Shoshone and Sulphur Spring ranges and south of Carlin on the east side of Pine Valley.

EASTERN ASSEMBLAGE

Devonian strata of the eastern assemblage include an unnamed unit of Helderberg (Early Devonian) age (Merriam, 1954, p. 1284), the Nevada formation, the Devils Gate limestone, and lower part of the Pilot shale. The unit of Helderberg age consists of medium gray, coarsely crystalline limestone in the Monitor Range. The lower part of the Nevada formation, of late Early Devonian age, consists mainly of light to medium gray limestone and some dolomite with lenticular interbeds of sandstone and quartzite. In the Roberts Mountains it is about 2,400 feet thick. The Devils Gate limestone of Middle and Late Devonian age consists of blue-gray fine-grained limestone with beds of dolomite and dolomitic limestone aggregating about 2,065 feet thick (Merriam and Anderson, 1942, p. 1690). The Pilot shale of Devonian and Mississippian age ranges from 315 to 425 feet thick in the Eureka area (Nolan, Merriam, and Williams, 1956, p. 52). It consists mostly of dun-colored to black calcareous shale and shaly limestone.

Devonian rocks of the Sulphur Spring and Pinyon ranges have been recently described by Carlisle and others (1957, pp. 2175-90), who showed that northward from the Roberts Mountains the Nevada-Devils Gate sequence thickens, becomes more dolomitic, and less fossiliferous. The sequence contains vitreous quartzite units as much as 400 feet thick that grade into carbonate quartz arenites and thus resembles the Devonian section near Eureka more than the section at Lone Mountain.

Windows of Simpson Park Mountains.—Devonian strata make up the major part of the Keystone and other windows in the north end of the Simpson Park Mountains. In the Keystone window it is estimated by Roberts that there are more than 800 feet of strata belonging to the upper part of the Nevada formation. Devonian rocks also form the two small windows north of McClusky Pass; and in the northeast corner of the range in the J-D window, there is a fairly complete section of Devonian rocks. The unit containing the fauna referred to the Helderberg rests on the Roberts Mountains formation in the Windmill window. As the upper beds are partly covered by Tertiary volcanic rocks, the total thickness of the Devonian sequence is not known, but more than 2,000 feet of beds may be present.

Cortez window.—Devonian rocks of the Cortez window aggregate about 4,000 feet thick. Limestones equivalent to both the Nevada and Devils Gate formations may be represented (C. A. Nelson, oral communication, 1949) but have not been mapped separately.

Gold Acres window.—At Gold Acres a window about ½ mile in diameter has been eroded through the Roberts Mountains thrust exposing shaly limestone and calcareous shale of the Pilot shale and underlying limestone which contain fossils of Devonian age (C. W. Merriam, oral communication).

WESTERN ASSEMBLAGE

Devonian rocks of the western assemblage appear to be widespread throughout north-central Nevada, but are most abundant from the Shoshone Range eastward. These lack the basic volcanic flows and pyroclastics characteristic of Cambrian and Ordovician rocks of the western assemblage, but locally contain silicic pyroclastics, much chert and shale, and a little calcareous shale.

In Slaven Canyon in the Shoshone Range and elsewhere in the Mt. Lewis Quadrangle, there are at least 4,000 feet of strata composed dominantly of dark gray to black chert with some dark shale, a little sandstone, and very small amounts of limestone. These have yielded ostracods and conodonts of Middle Devonian age (Berdan, 1953, p. 1394). Similar rocks on and south of Bald Mountain, in the northern Toyabe Range southwest of Cortez, are probably correlative.

The Devonian rocks of the upper plate of the Roberts Mountains thrust in the Mineral Hill region, Sulphur Spring Range, consist of two units that are tentatively assigned to the western assemblage. The lower is composed of limestone conglomerate, chert, black shale, and quartzite; the upper of chert conglomerate, clastic limestone, and quartzite (Carlisle and Nelson, 1955, pp. 1645–46). These are reported to be of local extent and to grade laterally into chert-black shale facies. The predominance of coarse clastics in these units indicates early orogenic activity in the basin on the west in which these sediments accumulated (Fig. 10, B). Conodonts in the upper unit were studied by W. H. Hass (written communications) who considers them to be Middle to early Late Devonian age.

Tuffaceous shale and calcareous shale on the east side of Pine Valley about 8 miles south of Carlin have also yielded conodonts of Devonian age (W. H. Hass, written communication). These rocks are associated with Silurian and Ordovician rocks in the upper plate of the Roberts Mountains thrust.

CARBONIFEROUS

LOWER MISSISSIPPIAN

Lower Mississippian strata of the eastern assemblage occur in southern Eureka County and in the Diamond Mountains. In the Carlin area equivalent rocks are largely clastics, indicating the onset of orogeny at an earlier date north of Lat. 39°30'. . to

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EASTERN ASSEMBLAGE

Lower Mississippian rocks of the eastern assemblage in north-central Missis- near Eureka are represented by the upper part of the Pilot shale and by the unit limestone. The upper part of the Pilot consists of black shale and c and have , p. 2268) shale, with thin limestone interbeds. It is overlain by the Joana limestone, coarse-grained and clastic, about 84–135 feet thick (Nolan, Merriam, and Williams, 1956, p. 55), that contains a fauna similar to that of the Madison limestone. The Joana limestone thins and pinches out a short distance north and west of Eureka; at Devils Gate, about 10 miles west of Eureka, interbedded shale and sandstone assigned to the undifferentiated Chainman and Diamond Peak formations are separated by an alaskite sill from silty shale and shaly limestone 50–75 feet thick. The shale and limestone contain a fauna partly equivalent to the fauna of the Pilot shale, and rest directly on the Devils Gate limestone (C. W. Merriam, oral communication).

Orogenic and Post-Orogenic Stratigraphy

At the close of the Devonian, fundamental changes took place along the western part of the area of predominantly carbonate deposition (eastern assemblage). The carbonate rocks were folded and overridden by the Roberts Mountains thrust plate that brought clastic and volcanic rocks of equivalent age but different facies from the west or northwest. Clastic rocks eroded from the rising upland in the west heralded the end of the broad geosyncline in north-central Nevada as it had existed earlier, and marked a change to narrow straits and embayments in the orogenic belt during the remainder of the Paleozoic. These clastic rocks do not belong to the assemblages laid down in the geosyncline during early and middle Paleozoic, but overlap all of them (Roberts and Lehner, 1955, p. 1661). (Figs. 6, 10.) On the west, overlapping rocks rest with angular unconformity on rocks of the western and transitional assemblages; in the Carlin area, west of Elko, the unconformity is much less marked; and on the east, the discordance fades out and the overlapping rocks interfinger with the eastern assemblage rocks and grade eastward into the carbonate section of late Paleozoic age of eastern Nevada and western Utah.

OVERLAP ASSEMBLAGE

Coarse clastics were shed eastward and westward from the Antler orogenic belt, overlapping pre-orogenic rocks of the eastern, transitional, and western assemblages (Fig. 6). The lithologic character of the overlap assemblage is variable from place to place, and different names have been applied to correlative beds. In the east, the Eureka-Carlin sequence includes the Chainman shale, Diamond Peak formation, Ely limestone, Carbon Ridge, and Garden Valley formations of the Eureka area, and correlative formations in the Carlin area. In the west, the Antler sequence includes the Battle formation, Highway limestone, [An]tler Peak limestone, and Edna Mountain formation. Because of local variations in source areas, in conditions of deposition, and subsequent history of these [rocks], it is impossible to make precise correlations of the units in the different [sequenc]es. Regional lithologic similarities indicate, however, that similar en[vironmen]tal conditions prevailed over broad areas. The Havallah formation of the Sonoma and East ranges was probably laid down 50–100 miles west of the orogenic belt and was thrust eastward into juxtaposition with the Antler sequence during Mesozoic orogeny. It therefore has had a somewhat different history and is not strictly comparable with the approximately contemporaneous Eureka-Carlin and Antler sequences.

The basal sediments of the overlap assemblage differ in age throughout north-central Nevada. In the Eureka area the intertonguing Chainman shale and Diamond Peak formation of Late Mississippian age are the earliest orogenic sediments recognized. In the Carlin area the Tonka formation of Dott (1955, pp. 2222–33) and correlative units farther southeast in Pine Valley mapped by J. Fred Smith and Keith Ketner included Lower Mississippian clastic beds that overlap the upper plate of the Roberts Mountains thrust fault, indicating that the thrust reached the Carlin area during Late Devonian or Early Mississippian time.

EUREKA-CARLIN SEQUENCE

The overlap assemblage to the east in Eureka County is represented by at least five formations which range from Mississippian to Permian in age, and are here included in the Eureka-Carlin sequence. In the Eureka section these are the Chainman shale, Diamond Peak formation, Ely limestone, and Carbon Ridge and Garden Valley formations (Nolan, Merriam, and Williams, 1956, pp. 56–68). Dott (1955) has named approximately correlative formations in the Carlin area the Tonka, Moleen and Tomera, and Strathearn formations.

The oldest unit of the overlap assemblage in the Eureka area is the Chainman shale of Late Mississippian age. According to Nolan, Merriam, and Williams (1956, p. 58) the Chainman appears to rest with erosional unconformity on the Pilot shale north of Eureka. The Chainman consists largely of black shale with thin sandstone interbeds; in the Eureka area it reaches an apparent thickness of 5,000 feet, but here it may be thickened by folding or faulting. The Chainman shale grades upward and laterally into the Diamond Peak formation which consists mainly of conglomerate with interbeds of sandstone, quartzite, and black shale. In the Diamond Mountains the two units have not been differentiated in mapping. The conglomerate beds are made up chiefly of coarse to fine fragments of chert and quartzite derived from western assemblage rocks. The Diamond Peak formation was assigned to the Late Mississippian by Nolan, Merriam, and Williams (1956, pp. 60–61) on the basis of cephalopod faunas collected from zones 1,000–1,500 feet below the top and near the top. These faunas were studied by Mackenzie Gordon, Jr., who considers them to be equivalent to faunas of Chester age. Locally, the uppermost part of the Diamond Peak contains faunas usually found in Pennsylvanian rocks, suggesting that the Mississippian-Pennsylvanian boundary should be placed below the top of the unit (Fig. 6). Easton and others (1953, p. 147) have gone much further, and have placed the Diamond Peak in the Lower Pennsylvanian. Dott (1955, p. 2268)

FIG. 7.—Post-orogenic conglomerate of Early Mississippian age resting on western assemblage siliceous shale of Silurian age, 8 miles south of Carlin, Nevada.

considered the Diamond Peak to be principally Upper Mississippian, but included basal Pennsylvanian strata in the upper part.

The Tonka formation of Dott (1955, p. 2222) consists mainly of conglomerate with sandstone and siltstone interbeds. The type section is directly southeast of Tonka, but lower conglomeratic strata, exposed ½ mile west, were also included in the formation. The basal contact of the Tonka was traced southward about 10 miles to the vicinity of Cole Canyon by Roberts and Lehner in 1954 where it was found to rest on western assemblage siliceous shale of Silurian age. The type section contains faunas of Late Mississippian and Early Pennsylvanian age according to Dott (1955, pp. 2232–33) and confirmed by Mackenzie Gordon, Jr. (oral communication). The lower conglomerate beds contain a much older fauna according to Mackenzie Gordon, Jr. (oral communication), with fossils of Early Mississippian (Kinderhook and Osage) age. The Tonka therefore contains older beds than the partly equivalent Diamond Peak formation, indicating that orogenic sediments derived from the rising lands on the west reached the Carlin area considerably earlier than they reached the Eureka area.

The Ely limestone of Early and Middle Pennsylvanian age conformably overlies the Diamond Peak formation. In the Eureka district it is about 1,500 feet thick, but elsewhere the thickness is highly variable because of pre-Permian erosion. Toward the east the Ely thickens; toward the north in the Carlin area where Dott (1955, p. 2235) divided his Ely group into two formations, the Moleen and Tomera, it intertongues with conglomerates that are probably equivalent to the Battle formation of the Antler sequence.

In the Eureka area the Carbon Ridge formation, a sequence of interbedded conglomerate, limestone, shale, and sandstone beds 1,500–1,750 feet thick, rests unconformably on the Ely limestone and the Diamond Peak formation (Nolan, Merriam, and Williams, 1956, pp. 64–67). Fusulinid faunas in the lower part indicate early Permian (Wolfcamp) age; in the upper part, probable Leonard age. The Garden Valley formation in the Sulphur Spring Range contains a higher proportion of clastic rocks and is considered to be a westward equivalent of the Carbon Ridge. The Strathearn formation of Dott (1955, p. 2255) east of Carlin is probably roughly equivalent to the Carbon Ridge and Garden Valley formations, but may include older beds in some places.

Dott's Tonka formation and his Ely group in the Carlin area were folded and eroded during late DesMoines or early Missouri time (Dott, 1955, p. 2255) and his Strathearn formation was deposited unconformably upon them. The subsequent marine invasion during latest Pennsylvanian and earliest Permian time was widespread, extending southward to Eureka, westward beyond Winnemucca, and northward to Mountain City. However, as the Antler Peak limestone was brought into the northern Shoshone Range area by later thrusting, the sea may not have covered either the present Cortez or northern Shoshone ranges during Permian time, as some areas thereabouts must have furnished the coarse gravels of the Carbon Ridge and Garden Valley formations.

In the Cortez Mountains unnamed limestone and conglomerate about 800 feet thick are probably westward equivalents of the Ely limestone. Throughout most of the area of outcrop the basal beds rest unconformably on western assemblage rocks, but locally the basal beds are brecciated and in thrust contact with the underlying beds. The lower beds are mainly limestone and dolomite which in places grade into conglomerate, sandstone, and limestone. Poorly preserved fossils indicate that the lower limestones are Pennsylvanian.

K. P. Bushnell (oral communication) reports conglomerate about 1,900 feet thick near Mountain City and Rowland overlain by pebbly limestone containing fusulinids interpreted to be of Late Pennsylvanian and early Permian age. This section is similar to the Antler and Carlin sequences.

ANTLER SEQUENCE

Rocks of the overlap assemblage here assigned to the Antler sequence, ranging in age from Middle Pennsylvanian to Permian, underlie parts of Battle Mountain, the Edna and Osgood mountains, and the Sonoma Range. Their abrupt lateral variations in lithologic character and thickness from place to place indicate widely differing conditions of deposition over a relatively small area. The Antler sequence includes the Battle and Highway formations of Middle Pennsylvanian age, the Antler Peak limestone of Late Pennsylvanian and Permian age, and the Edna Mountain formation of Permian age.

Battle and Highway formations.—The Battle formation (Fig. 8) is mainly a coarse red to brown conglomerate with minor amounts of interbedded sandstone, shale, and limestone. It rests unconformably on Cambrian and Ordovician rocks

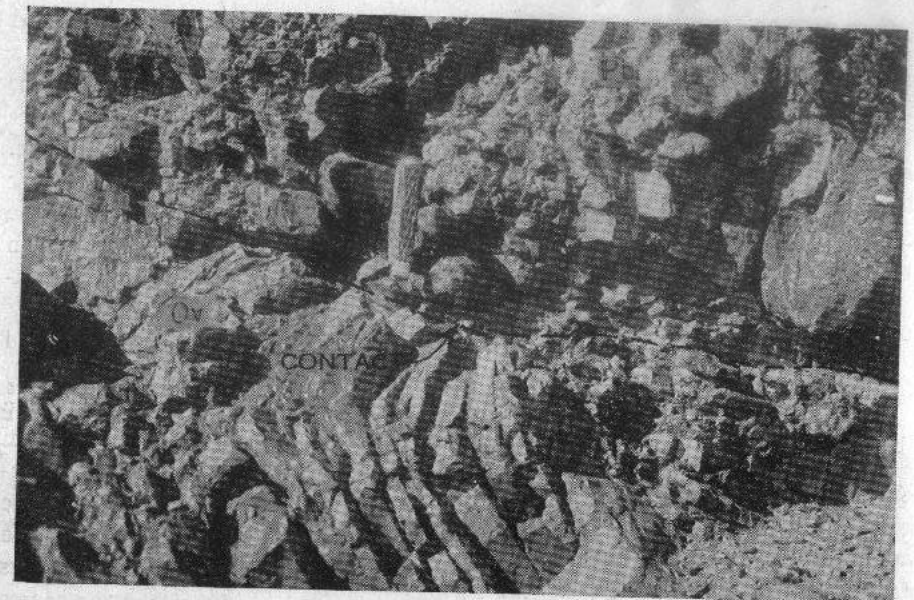


FIG. 8.—Basal conglomerate of Battle formation (IPb) resting with angular unconformity on deformed chert of Valmy formation (Ov), Antler Peak Quadrangle.

of the western and transitional assemblages, and consists of fragments of locally derived rocks of the older formations. The Battle varies widely in thickness; it is about 700 feet at its type locality in the Antler Peak Quadrangle (Roberts, 1951); at most places in the Osgood Mountains it is not much more than 100 feet, and is absent in the Sonoma Range where the Antler Peak limestone overlies the Harmony formation. Limestone lenses in the upper part of the Battle formation contain an early Middle Pennsylvanian fusulinid fauna. Lawson (1913, p. 328) considered the Battle formation to be a fanglomerate. The lower beds contain plant fragments and may have been deposited under terrestrial conditions, but the upper beds are clearly marine.

The Highway limestone, about 200 feet thick, in the Osgood and Edna mountains in the northwest corner of the Golconda Quadrangle, is a facies of the Battle formation composed of limestone and some interbedded conglomerate and calcareous clastics. According to L. G. Henbest its fusulinids are comparable with those that occur in the middle and upper parts of the Battle formation. The correlative of the Battle and Highway formations in eastern Nevada is the Ely limestone.

Between Battle Mountain and the Diamond Mountains, in the Tuscarora, Cortez, and Simpson Park Mountains, and Shoshone, Sulphur Spring, and Carlin ranges scattered remnants of conglomerate units of Pennsylvanian and Permian age rest on the cherts and shales of earlier Paleozoic age of the western assemblage. In the Shoshone Range and the western part of the Cortez Mountains

FIG. 9.—Antler Peak viewed from east. Lower 250 feet of the Antler Peak limestone (P IPap) underlie peak; the cliffs on left are downfaulted higher beds. Smooth slopes in foreground are sandstone and conglomerate of Battle formation (IPb).

these conglomerates are locally thrust over the western assemblage, but generally the contacts are angular unconformities.

Antler Peak limestone.—The Antler Peak limestone (Fig. 9) is now found as remnants of a formerly extensive formation, scattered from the southern Shoshone Range to a point near Quinn River Crossing in central Humboldt County. At the type locality in the Antler Peak Quadrangle, the formation rests disconformably on the Battle formation. In other places the Antler Peak rests directly on the older rocks of the western or transitional assemblage. At the type locality, the formation is 625 feet thick; northeast of the Osgood Mountains nearly 1,000 feet is exposed.

The Antler Peak is predominantly limestone consisting of medium- to thick-bedded units of light to dark gray or black limestone, locally cherty, that weathers medium gray. Some shale and shaly limestone and some sandy limestone are interbedded. The upper part includes shaly limestone, shale, and some dolomite. The formation contains a diversified fauna including fusulinids, which range from Late Pennsylvanian to early Permian in age (L. G. Henbest, written communication.

Edna Mountain formation.—The Edna Mountain formation crops out in the Edna Mountains in the northwest corner of the Golconda Quadrangle, in the southeastern part of the Winnemucca Quadrangle, and in the Antler Peak Quadrangle. It has not been positively identified in the Osgood Mountains, though some thin remnants of lithologically similar rocks occur there. The Edna Mountain formation is composed dominantly of clastic sedimentary rocks, fine-grained brown sandstone and dolomitic sandstone, calcareous shale, some thin beds of fine conglomerate, and some interbedded limestone. The maximum thickness is 400 feet in the Edna Mountains; no more than about 200 feet are exposed at Battle Mountain; and 300 feet in the Sonoma Range.

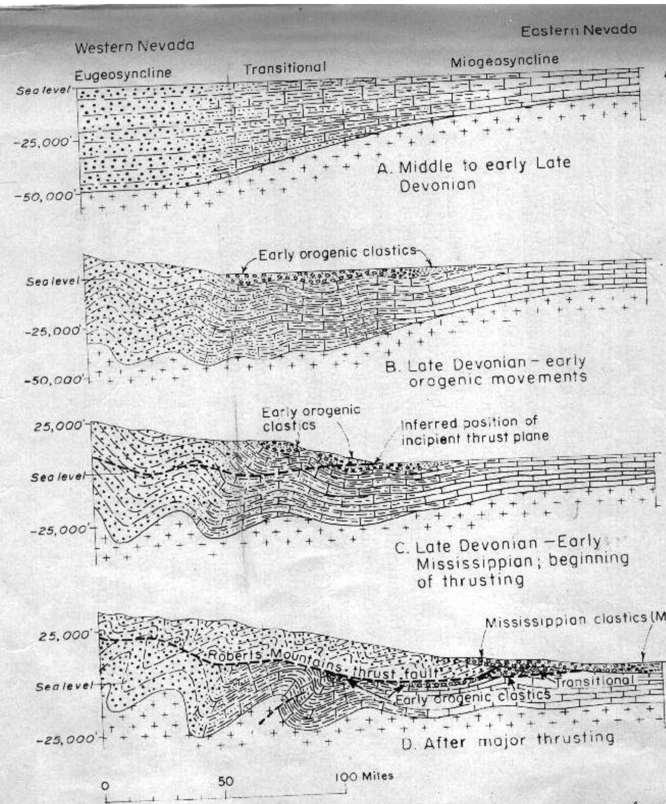
The Edna Mountain formation rests on the Antler Peak limestone with an erosional unconformity. The interval between the deposition of the Edna Mountain and Antler Peak formations represents a break during which there was local warping, uplift, and erosion. In the Edna Mountains, post-Antler Peak erosion has locally entirely removed the Battle, Highway, and Antler Peak formations, and the Edna Mountain formation rests directly on the Preble formation of Cambrian age. Fossils indicate that the Edna Mountain formation is considerably younger than the Antler Peak limestone, possibly of Word (late Permian) age (James Steele Williams, written communication). It is probably equivalent to the Gerster formation farther east at Gold Hill (Nolan, 1935, pp. 39–41). According to Williams (1956, p. 2859), "fossils from the Gerster and Edna Mountain formations suggest Phosphoria age."

DEPOSITION OF OVERLAP ASSEMBLAGE

Basal beds in the overlap assemblage near the orogenic belt, especially in Mississippian and Early Pennsylvanian, are usually coarse conglomerates (Figs. 8, 9, and 10,D) which grade laterally into finer conglomerates and sands, then into silt, clays, and limestone. These clastic beds may be terrestrial locally within the belt, but they are mainly marine adjacent to it. The belt may have been largely submerged at times, for widespread marine limestone units interfinger with the clastics. The lenticularity of the overlap sediments as a whole suggests deposition in several separate basins, possibly in a series of straits separated by peninsulas and islands. The presence of coarse clastics throughout much of the Pennsylvanian indicates continued orogenic activity from time to time, perhaps continuing into the Permian.

In Eureka County near Eureka (Nolan, Merriam, and Williams, 1956, pp. 57–60), coarse conglomerates were deposited during Late Mississippian time. By early Middle Pennsylvanian time limestone was being formed there while conglomerate was laid down to the west near Battle Mountain. The seas apparently transgressed westward, as in Late Pennsylvanian and early Permian time limestone was being deposited in the Battle Mountain area.

Another possible interpretation is that orogenic uplift took place between Cortez and the Sonoma Range in Mississippian time, shedding coarse conglomerate eastward to the area now occupied by the Sulphur Spring Range and Diamond Mountains. By early Middle Pennsylvanian time the land had been lowered so that the sea encroached on it from the east. Though still yielding conglomerate locally—the Battle formation—in the Battle Mountain and Edna Mountains area, the sea encroached farther westward, forming the Highway



A. Near the end of the Devonian the Cordilleran geosyncline covered most o Nevada. Clastic and volcanic rocks predominated in western Nevada; carbonate rocks in central and eastern Nevada; and transitional rock types in western and west-central Nevada.

B. Orogenic movements in early Late Devonian time caused uplift, folding, and erosion in western Nevada; clastics derived from the uplift were deposited in central Nevada

C. Folding continued into Late Devonian and Early Mississippian, along with continued uplift

D. The Roberts Mountains thrust plate, including slivers of transitio and clastic rocks, moved eastward overriding part of the early orogenic clastics and the shelf rocks. After major thrusting, coarse clastics (M) eroded from the emer orogenic belt were shed into eastern Nevada and deposited partl continental and partly in marine environments, overlapping the plate and shelf.

FIG. 10.—Diagram showing inferred sequence of events during Antler orogeny in north-central Nevada.

limestone and calcareous parts of the Battle formation. In the Edna Mountains, indeed, the conglomerate is present only in discontinuous lenses and the Highway limestone directly overlies the unconformity at the base of the overlap series. Thus an unconformity whose time gap was very brief at Eureka and Carlin becomes greater 70 miles farther westward in the Edna Mountains. From evidence of a thrust sliver of eugeosynclinal Upper Mississippian rocks in the Osgood Mountains, another depositional basin lay west of the orogenic zone.

The full extent of the clastic apron derived from the orogenic belt is not yet known. Dott (1955) shows that Mississippian, Pennsylvanian, and Permian clastics extend into the Elko and the northern Diamond mountains. Ball (1907, pp. 120–21) reports sandstone and pebbly sandstone 800–1,000 feet thick in the Belted Range about 35 miles northeast of Beatty. Westgate and Knopf (1932, p. 21) described the Scotty Wash quartzite about 1,000 feet thick near Pioche. Sharp (1942, pp. 669–70) records chert-pebble conglomerate 4,000–10,000 feet thick in the southern Ruby Mountains. K. P. Bushnell (oral communication) reports thick clastics of Pennsylvanian age at Gold Creek near Mountain City. In the Ely area sandstone of the Permian Arcturus formation probably represents a marine phase deposited far from the source. These occurrences indicate that the clastic apron covered much of eastern Nevada. Less is known of the stratigraphy of the rocks younger than the Late Mississippian of western Nevada, although sedimentary rocks were probably being deposited with some interruptions through Pennsylvanian and Permian time.

WESTERN SEQUENCES OF UPPER PALEOZOIC ROCKS

Seven formations of late Paleozoic age, an unnamed formation in the Osgood Mountains, and the Leach, Inskip, Pumpernickel, Havallah, Tallman, and Koipato formations in the Sonoma Range Quadrangle are predominantly clastic and volcanic and are therefore assigned to a completely different assemblage. These formations were carried into the area by thrusts of considerable displacement during Mesozoic time. Their stratigraphy and structural history are significantly different from the formations of equivalent age deposited in central Nevada, but they warrant discussion because they give a partial record of events in the geosyncline in western Nevada. As far as known, these formations include rocks ranging from Mississippian to Permian, but may also include older and younger beds. Their lithologic character is unlike the coarse clastic formations of the overlap assemblage deposited farther east, and signifies that eugeosynclinal conditions were present in western Nevada throughout late Paleozoic as well as during early and middle Paleozoic time.

Unnamed formation of Late Mississippian age.—A formation consisting of andesitic flows and pyroclastics, thick lenses of coarse-grained clastic limestone, chert, and some calcareous shale is exposed in a thrust slice in the Osgood Mountains and in the northern part of the Hot Springs Range. Fossils indicate that the formation is probably of early Late Mississippian age (Mackenzie Gordon, Jr., and Helen Duncan, written communication). The unit is in thrust contact with Cambrian and Upper Pennsylvanian rocks, so its relation to other western assemblage rocks are not known. It may be, in part, correlative with the Inskip formation (Helen Duncan, written communication).

Leach and Inskip formations.—The Leach and Inskip formations underlie much of the central part of East Range. Throughout most of their outcrop area they are in fault contact and their stratigraphic relations are not definitely known, but the Leach appears to underlie the Inskip.

The Leach formation is characterized by an abundance of altered basic volcanic rocks (greenstone) and pyroclastics, with much dark chert, siliceous shale, and vitreous quartzite. In addition, it contains interbedded sandstone, limestone, and conglomerate similar to the overlying Inskip formation. The thickness may exceed 6,000 feet. No fossil evidence for dating the Leach formation has been found. Lithologic similarity of the distinctive vitreous quartzites in the Leach with quartzites in the Valmy formation strongly suggests that they are in part equivalent. Ferguson, however, considers the lithologic similarities are not sufficient to infer this correlation. For the present, the Leach can only be considered as Mississippian or older.

The overlying Inskip formation is dominantly clastic, with a large proportion of graywacke and conglomerate and also some chert and greenstone in its lower part. The upper half contains some thin-bedded limestone interbedded with siliceous and calcareous shale and quartzite. The total thickness may exceed 9,000 feet.

The only fossils so far obtained were found in a small lens of shaly limestone in the lower part of the Inskip. These consist of rather poorly preserved corals, regarded by Helen Duncan (written communication, 1957) as probably Mississippian, and correlation with the unnamed formation of Late Mississippian age in the Osgood Mountains is suggested.

Pumpernickel and Havallah formations.—Like the Leach and Inskip, the Pumpernickel and Havallah formations constitute a pair of which the lower dominantly volcanic unit is overlain by an upper sedimentary formation. On this basis, correlation between the two pairs was originally assumed, but the recent assignment of the Inskip to probable Mississippian, in contrast to the Pennsylvanian and Permian age of the Havallah, eliminates this interpretation. An unconformity at the base of the Havallah, however, leaves open the possibility that the lower volcanic units, the Leach and Pumpernickel formations, may be correlative.

The Pumpernickel and Havallah formations are essentially co-extensive and crop out over a wide area in the eastern part of the Sonoma Range Quadrangle, below a westward-dipping thrust carrying the Leach and Inskip formations on its upper plate.

The Pumpernickel formation is composed mainly of shale, chert, sandy shale, and subordinate amounts of sandstone with large amounts of greenstone and greenstone breccia; its lithologic character is similar to the Upper Ordovician part of the Valmy formation and to part of the Scott Canyon formation of Cambrian age as well as to the Leach formation. In the Antler Peak Quadrangle greenstones and associated pyroclastic rocks are present only near the top of the Pumpernickel. In the Sonoma and Tobin ranges volcanic rocks make up a much larger proportion of the formation. Folding, presumably related to the thrusting, makes measurement of detailed sections extremely difficult, although in places the general sequence of beds is known and rough estimates of thickness can be made; in the Antler Peak Quadrangle strata assigned to the Pumpernickel are about 5,000 feet thick.

The age of the Pumpernickel formation is not yet certain. Because of its stratigraphic position beneath the Havallah, which was originally considered to be of Permian age, the Pumpernickel was believed to be Carboniferous, probably Pennsylvanian. Roberts, however, has subsequently shown that there is probably an unconformity between the Havallah and Pumpernickel formations and has recently collected early Middle Pennsylvanian (Atoka) fusulinids from the lowermost Havallah beds. The Pumpernickel formation must therefore be older than Middle Pennsylvanian, and is probably Mississippian or older. There is no way of estimating the interval of time represented by the basal unconformity.

The Havallah formation contains abundant sandstone and quartzite plus some limestone and calcareous shale, as well as chert and shale. At the type locality in the Tobin Range (Muller, Ferguson, and Roberts, 1951) the Havallah probably is more than 10,000 feet thick. In the Antler Peak Quadrangle more than 4,600 feet of beds are exposed, and in this area it has been possible to subdivide the Havallah formation into three members. The lower member is mainly sandstone, pebbly sandstone, and fine conglomerate with some calcareous sandstone beds; the middle member is mainly dark chert and shale; and the upper member is composed of limestone, quartzite, shale, and chert.

Fusulinid faunas determined to be of early Middle Pennsylvanian (Atoka) age (Raymond Douglass, written communication) were collected from beds in the lower member, which is therefore in part of the same age as the Battle formation; the middle member has not yet yielded fossils; and the upper member contains a fusulinid fauna determined to be of Leonard age (L. G. Henbest and Raymond Douglass, written communication).

The Havallah formation is essentially co-extensive with the underlying Pumpernickel formation. In the Antler Peak Quadrangle there is a pebbly sandstone at the base of the Havallah, that suggests a significant unconformity between the units. Moreover, the sharp lithologic contrast between the Pumpernickel and Havallah formations is indicative of a marked change in conditions of deposition. The increase in amount of clastic material furnished to the Havallah sea testifies to renewal of orogenic movements in the source areas. In Havallah time basic volcanism within the basin was lacking, though the dark chert and shale, characteristic of the middle member of the formation, may have been formed from pyroclastic material.

The basin in which the Pumpernickel and Havallah formations accumulated may have originated at the southwest near the present California-Nevada border (Fig. 6). The Pumpernickel and Havallah formations have temporal, but not lithologic correlatives in the sequences to the east, south, and north. The only lithologic correlatives known are in the Garlock series, El Paso Mountains, southeastern California, which contains Lower Permian fusulinids in the upper part (Dibblee, 1952, pp. 15-19); it is unlikely that the Pumpernickel and Havallah have been thrust from that area, but the seaway in which they accumulated may have extended northward into western Nevada in the area indicated in the inset map on Figure 6.

Tallman fanglomerate.—The only outcrop of the Tallman fanglomerate (Ferguson, Muller, and Roberts, 1951a) is in the northern Sonoma Range. The formation consists of coarse angular fragments of chert, quartzite, slate, and arkosic sandstone. No determinable fossils have been found. The stratigraphic relations in the area of outcrop are complicated by shearing associated with thrusts during Mesozoic time, but apparently the Tallman unconformably overlies a volcanic formation, possibly the Leach or Sonoma Range formation, and is overlain by the Koipato formation.

Koipato formation.—The Koipato formation is in thrust contact with the Inskip formation in the northern part of the East Range, but rests with marked angular unconformity on the Havallah in the southern part of the East Range and Tobin Range. In the Sonoma and Tobin ranges, the Koipato is composed dominantly of silicic lavas and pyroclastics; also included are less abundant clastic sedimentary rocks, mainly conglomerate, sandstone, tuffaceous shale, and a little limestone. In the East Range rhyolitic, keratophyric, andesitic, and trachytic lavas predominate over pyroclastics.

The Koipato is 14,000 feet thick in the West Humboldt Range a few miles west of the Winnemucca Quadrangle (Knopf, 1924; Wheeler, 1939); in the East Range the thickness may be about 4,500 feet. In the southern Sonoma and Tobin ranges, it has a maximum estimated thickness of 2,000 feet, thinning out completely at the northern end of the range (Ferguson, Roberts, and Muller, 1952). Thus, the Koipato thickens westward, and pinches out eastward.

The fossil fish, ***Helicoprion***, first found in the Koipato in the Rochester district about 60 miles southwest of Winnemucca in the Humboldt Range (Wheeler, 1939), has been regarded as establishing the age of the Koipato as Permian. Recently, however, Norman J. Silberling (written communication) discovered an ammonite fauna of possible Early Triassic age in clastic lenses interbedded with rhyolite tuffs and flows at the type locality. This, if confirmed, may indicate that the Koipato overlaps the Permian-Triassic time boundary. Other Triassic rocks, ranging from Lower to Middle Triassic (Scythian to Anisian of the European stages according to Muller) overlap the Koipato with marked erosional unconformity (Ferguson, Muller, and Roberts, 1951a), but angular unconformity, noted only in a few places, does not exceed a few degrees at most, in sharp contrast to that at the base of the Koipato. Relations with the underlying formations indicate that an episode of folding, accompanied by thrusting, and followed by uplift and erosion, preceded volcanism during Koipato time in an area an unknown distance toward the west.

ANTLER OROGENY

In north-central Nevada sedimentation continued without noteworthy orogenic breaks during early and middle Paleozoic time (Fig. 10, A.) Locally, disconformities in the section indicate broad regional uplift and erosion, or nondeposition, possibly reflecting marginal disturbances or orogeny in other parts of the geosyncline. It is the intention here to emphasize only the major orogeny—the Antler orogeny—of latest Devonian to Early Pennsylvanian age, whose effects can be studied directly in this area. In many places the beveled folds and thrust faults formed during the orogeny can be observed, and, in addition, the coarse detritus derived from the folded belt can be studied both within the belt, and on the fringe areas. Although Hague (1892, pp. 165, 177, 203) suggested that conglomerate of the Upper Coal Measures in the Eureka area indicated uplift and erosion on the west, late Paleozoic orogeny was first recognized in central Nevada by Ferguson (1924, p. 37), Ferguson and Cathcart (1924, pp. 376–79, and cited in Nolan, 1928, p. 158), who found Permian rocks overlapping folded and eroded strata of Ordovician age in the Toquima and Toyabe ranges and Candelaria Hills. From these and other data Nolan (1928, Fig. 1 and p. 159; 1943, Fig. 12 and p. 171) postulated that a geanticline formed in Nevada during late Paleozoic time, extending north-northeasterly, medially through the state. Eardley (1947) later named the upwarped area the Manhattan geanticline. Since then, additional evidence for late Paleozoic orogeny in Nevada has been found in many places (Roberts, 1949a, 1949b, 1951; Roberts and Arnold, 1952; Dott, 1955). At first, the orogeny could be dated no closer than post-Ordovician to pre-Permian. It is now known that strata of the eastern, transitional, and western assemblages as young as Late Devonian were involved in the orogenic movements and thrusting, and that these deformed rocks are unconformably overlain by beds of Early Mississippian and early Middle Pennsylvanian age. This dates the orogeny as Late Devonian or Early Mississippian to Early Pennsylvanian, and is strongly supported by the widespread coarse clastics of equivalent age in central Nevada. The orogeny probably comprised several distinct pulses, taking place at different times throughout the region.

In the Eureka area continued deposition of carbonate rocks until the middle part of the Mississippian indicates that major orogenic movements did not begin there until later. At Devils Gate, about 10 miles west of Eureka, beds assigned to the undifferentiated Chainman and Diamond Peak formations by C. W. Merriam (oral communication) have been overriden by the upper plate of the Roberts Mountains thrust suggesting that the thrusting continued locally into Late Mississippian time.

As the term "geanticline" does not adequately describe the complex structure of this area, Roberts (1949a, p. 95) has proposed that it be replaced by the term "Antler orogenic belt," after Antler Peak in Battle Mountain, where some structural features of this belt are especially well shown. The area affected by the Antler orogeny covers a belt 80 miles or more wide extending north-northeasterly through central Nevada (Fig. 6, inset map). Folding related to the orogeny extends as far east as a line through Mountain City, Carlin, and Eureka, and the Roberts Mountains thrust fault carried rocks of the western and transitional assemblages eastward over those of the miogeosynclinal suite.

The recognition of the transitional assemblage makes necessary a major reinterpretation of the structure of north-central Nevada. The pre-orogenic rocks were deposited in a broad basin in which the miogeosynclinal carbonate rocks graded westward through a transitional assemblage into eugeosynclinal rocks. During the folding and telescoping on the Roberts Mountains thrust, the western assemblage rocks were moved as far eastward as a line extending between Elko and Eureka (Figs. 4, 10). In the eastern part of the Antler orogenic belt the upper plate rests on carbonate rocks of the eastern assemblage. In the western part the upper plate rests on rocks of the transitional assemblage. There are as yet many unsolved questions concerning the details of structural relationships and the mechanism of the thrusting.

One of the interesting structural questions is whether the upper plate moved on a single plane or on two or more planes. Roberts and Hotz suggest that the Adelaide thrust in the Sonoma Range which carries western assemblage over transitional assemblage rocks is the western extension of the Roberts Mountains thrust and that the upper plate rides on a single plane. The basis for this interpretation is that the Adelaide thrust is the lowest thrust in the Sonoma Range; in the upper plate the western assemblage rocks are lithologically identical with those in Battle Mountain and the Shoshone Range on the east. The lower plate rocks are lithologically different from these farther east in the Shoshone Range, but are considered to represent a normal westward facies change in the miogeosyncline from carbonate rocks to carbonate-fine clastic rocks. In accordance with this interpretation, the source area for the Adelaide-Roberts Mountains sole thrust lies west of Winnemucca, and the width of the belt over which the western assemblage has been thrust is about 90 miles.

Gilluly, though agreeing to extensive thrusting farther west, does not feel that the Roberts Mountains thrust can be recognized west of the Reese River Valley. The basis for this is that the most westerly windows of eastern assemblage rocks are in the Shoshone Range. The Adelaide thrust, though assumed to be contemporaneous with the Roberts Mountains thrust, is considered to be structurally higher.

Ferguson agrees with Gilluly, though not as to the possible contemporaneity of the Adelaide and Roberts Mountains thrusts. A tentative correlation of the Adelaide and Sonoma thrusts was made on the basis of field mapping on the Winnemucca Quadrangle (Ferguson, Muller, and Roberts, 1951a, Fig. 2, and sections

CC′ and DD′). If valid, this excludes the correlation of the Adelaide and Roberts Mountains thrusts, for field mapping indicated that the Sonoma thrust overrides the lower plate facies of Triassic age. However, there is a 3-mile gap between the outcrops of the Sonoma and Adelaide thrusts. The lower plate formations are different, the Harmony formation lying beneath the Sonoma thrust, and the Osgood Mountain quartzite and Preble formation underlying the Adelaide thrust. Although the Harmony formation is not in contact with these formations in the Osgood Mountains Quadrangle, it is considered reasonable to assume that a fault overridden by the Sonoma-Adelaide thrust of Mesozoic age separates them in the concealed area.

Inasmuch as no basement rocks have as yet been found in western Nevada there is no reason to regard the Roberts Mountains thrust as having roots. Gilluly suggests, therefore, that the thrust is possibly an écoulement structure; he considers that the imbrication and folding of both the main thrust and many subordinate ones are more readily explicable by gravitative sliding than by compression of the whole crust. Possibly the "fluid pressure" mechanism suggested by Hubbert and Rubey (1957, pp. 1748–49) may have played a part in reducing shear stress as the Roberts Mountains thrust fault moved eastward.

Merriam and Anderson (1942, p. 1706) suggested that the Roberts Mountains thrust may have taken place in Late Cretaceous or early Tertiary time, and correlated it with Laramide orogeny; Nolan, Merriam, and Williams (1956, p. 68) suggest that major movement along the thrust was of post-Permian age. On the other hand, Kay (1952, p. 1270) reported that in the Toquima Range and Carlin Canyon the "principal thrusting and folding seems to have preceded Pennsylvanian deposition." Dott (1955, pp. 2274, 2288 and Fig. 11) postulates a similar history. The Antler orogeny is dated on regional geologic evidence and local structural relations. Regional evidence is the widespread extent of the coarse conglomerates of Mississippian and Pennsylvanian age that were shed from the orogenic belt both eastward and westward. The conglomerates contain chert and quartzite pebbles, clearly derived from western assemblage rocks of Cambrian to Devonian age that were thrust into juxtaposition with transitional and eastern assemblage rocks. Local structural relations show that major thrusting took place prior to the deposition of Lower Mississippian rocks and that orogenic movements continued into the Permian. Five areas which give specific evidence about the age of the thrusting and related orogeny are the following.

1. At Antler Peak the Battle formation of early Middle Pennsylvanian age overlaps formations of the western and transitional assemblages, the Scott Canyon and Harmony of Cambrian age, and the Valmy of Ordovician age (Fig. 11) (Roberts, 1951). The underlying units had been complexly folded and broken prior to Middle Pennsylvanian time, and the orogeny culminated in large-scale telescoping of the western and transitional assemblages on major thrust faults. The overlapping Battle formation is predominantly conglomeratic, deposited partly in a terrestrial and partly in a marine environment.

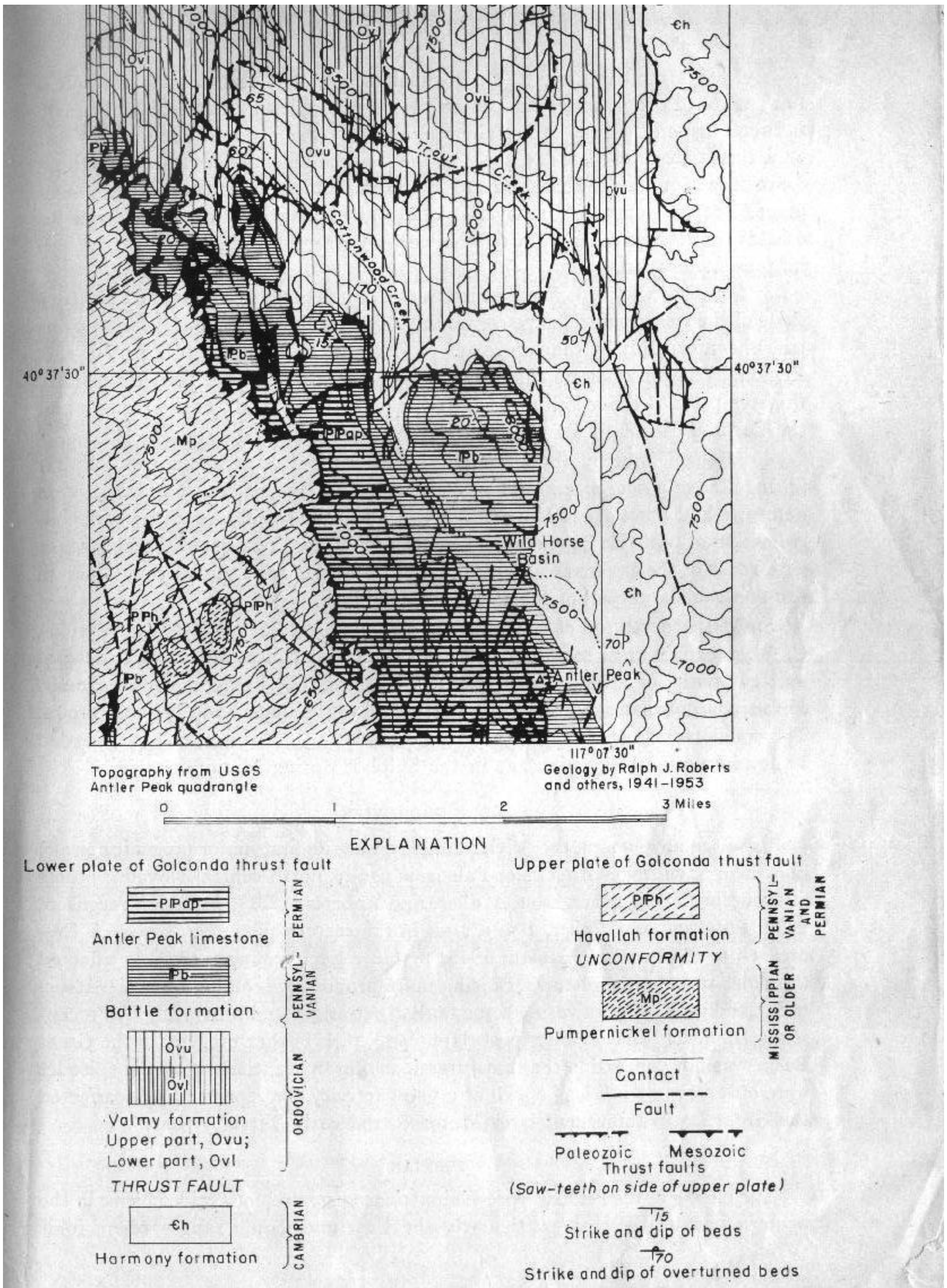


FIG. 11.—Generalized geologic map of part of Antler Peak Quadrangle, showing overlap of Paleozoic thrust plates by Pennsylvanian rocks.

2. Near Mountain City, K. O. Bushnell and J. R. Coash (oral communication) mapped conglomerate and limestone of Pennsylvanian and possibly early Permian age on Cornwall Mountain where these rocks of late Paleozoic age rest on a thrust sliver of chert and shale of the western assemblage; a mile north on Tennessee Mountain the basal unit rests on shaly limestone of the eastern assemblage. The conglomerate thus overlaps both assemblages, and field evidence indicates that it was deposited after the western assemblage had been thrust into its present location.

3. South of Carlin, J. Fred Smith and Keith Ketner have mapped siliceous shale of the western assemblage containing Silurian and Devonian(?) fossils overlain unconformably by conglomerates of Early Mississippian and Permian age. Regional relations indicate that the siliceous shale must have been thrust into the area prior to the deposition of the conglomerates; this dates the thrusting in the Carlin area as Late Devonian or Early Mississippian.

4. Michael Murphy (oral communication) reported that in the Sulphur Spring Range a conglomerate of probable Permian age rests unconformably on quartzite and limestone of Devonian age. This is the second locality where conglomerate of probable Permian age has been found in direct depositional contact with rocks of the eastern assemblage. A short distance west similar conglomerate rests on shale and chert of the western assemblage.

5. At the north end of the Monitor Range about 25 miles west of Eureka, C. W. Merriam (oral communication) has mapped conglomerate with a basal unit composed of limestone pebbles and boulders. The boulders contain fossils of Early Ordovician age, apparently derived from the underlying Pogonip group. The conglomerate has been tentatively correlated by Merriam with the Garden Valley formation of Permian age in the Sulphur Spring Mountains.

LATER OROGENIES

As far as now known, the Antler orogeny was the first major orogenic episode known to have involved rocks of Paleozoic age in north-central Nevada; others followed in Permian (Ferguson, Muller, and Roberts, 1951), Jurassic (Ferguson, 1952; Ferguson and Muller, 1949), and, in the eastern part of the area, in Cretaceous or Eocene time (Nolan, 1943, p. 173). Each younger orogeny affected the older rocks and structures, causing more pronounced folding of earlier structures, and perhaps reactivating some faults that originated previously. All recent study confirms Nolan's earlier postulate (1943, p. 177) that orogeny in the Great Basin was not confined to the late Jurassic or Laramide; these orogenic episodes were only "events in a long epoch of crustal activity that spasmodically affected the Great Basin throughout later Mesozoic and early Tertiary time."

PERMIAN

The effects of the Permian (pre-Koipato) orogeny are noticeable chiefly in the western part of the area, particularly the East and Tobin ranges where folds and thrusts involving the Inskip and Havallah formations are overlapped by the Koipato formation. The rocks involved in this orogeny are thought to have been transported to this area by large-scale post-Triassic thrusting, and the autochthonous formations belonging to the overlap assemblage were not greatly affected.

JURASSIC TO TERTIARY

Another period of intense orogeny involves rocks as young as Late Triassic. The episode can not be definitely dated in this area but may be tentatively correlated with the Jurassic orogeny studied in the Hawthorne and Tonopah quadrangles at the south, where at least the beginning of thrusting has been closely dated as late Early Jurassic (Ferguson and Muller, 1949, p. 13). Elsewhere within the eastern part of the area some orogenic events may be still younger. Nolan (1943, pp. 173–78) has summarized published accounts of these events. Willden (1958) has recently discussed Cretaceous orogeny in the Jackson Mountains, northwestern Nevada.

East of the Sonoma and Tobin ranges thrust faults of post-Permian age were also of great magnitude. Nolan, Merriam, and Williams (1956, p. 68) infer that the Carbon Ridge formation in the Diamond Mountains and the Garden Valley formation in the Sulphur Spring Range, both of Permian age, are probably correlative formations of different facies, and postulate that they are separated by a thrust fault of the magnitude of the Roberts Mountains thrust. Dott (1958, p. 3) suggests that the facies changes are minor, and sees no necessity for such large-scale thrusting.

The final phase of the structural history of the area was the period of block faulting, which began at least as early as middle Tertiary, and has continued intermittently to the present (Nolan, 1943, pp. 178–85).

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