# Abstract

DESPITE their remarkable diversity, the Paleozoic and Mesozoic rocks of northwestern Nevada are related in both their depositional and structural history. In the northern part of the region, lower and middle Paleozoic rocks were greatly deformed during the Antler orogeny, after which shallow-water limestone and clastic rocks of the Antler sequence of Pennsylvanian and Permian age were deposited upon them. The Havallah sequence, an entirely different facies of upper Paleozoic rocks including several thousand feet of fine-grained clastics, chert, and volcanic rocks, is thrust eastward over the Antler sequence and older rocks. Overlying the Havallah are Permian and Triassic volcanic rocks of the Koipato sequence and two different facies of lower Mesozoic sedimentary rocks, the Winnemucca and Augusta sequences. Part of the Augusta sequence of latest Early to Late Triassic age is interpreted as an eastern and more shoreward facies of the Winnemucca sequence, which ranges from Middle Triassic to Early Jurassic in age.

The rocks in the southern part of the region, south of a belt in which there are few pre-Tertiary outcrops, represent the same time span as those farther north, but rock units and structural features differ. Greatly deformed lower Paleozoic rocks along the southeastern and southern margin of the region are unconformably overlain by the Diablo sequence, the lower part of which resembles the Antler sequence and the upper dominantly volcanic part, the Koipato sequence. Overlying the Diablo is the Luning sequence, mainly of calcareous sedimentary rocks ranging from latest Middle Triassic through Early Jurassic in age. The upper part of the Luning sequence was laid down during the initial folding and thrusting of Mesozoic orogeny. Volcanic rocks of the Gillis sequence, tentatively dated as Middle or Late Triassic, are thrust over the Luning sequence from the west.

Three periods of orogeny deformed the Paleozoic and Mesozoic rocks of the area. The Antler orogeny took place during late middle Paleozoic time; this was followed by the Sonoma orogeny during the middle or Late Permian and by folding and thrusting that commenced in the late Early Jurassic and persisted into Cretaceous time. Thrust faulting, represented in some places by faults with great horizontal displacement, characterized all three orogenies. The sequence of thrusts in the northern part of the area, and therefore the paleogeographic interpretation of the upper Paleozoic and Mesozoic rocks, has not been completely resolved. Two interpretations can be made: that the Golconda thrust, bringing the Havallah over the Antler sequence from the west, is one of the youngest of the Mesozoic thrusts and controls the distribution of the Augusta sequence of Triassic rocks; or that the Golconda thrust is older, developed during the Sonoma orogeny, and did not affect the geographic relationships of the Augusta to the Winnemucca sequence.

# Introduction

Rocks of Paleozoic and early Mesozoic age in northwestern Nevada are remarkably diverse. No single set of formational names is applicable to the rocks of all the isolated and widely scattered pre-Tertiary exposures. Some differences in the lithologic succession within and between the various outcrop areas can be explained simply as lateral changes in facies, but abrupt changes result from juxtaposition of different facies by large-scale thrusting. The resulting complicated regional picture invites an attempt to reconstruct the geologic history of these rocks.

Within northwestern Nevada the areas best known geologically are the Sonoma Range and the Hawthorne and Tonopah one-degree quadrangles. Knowledge of these quadrangles is largely the result of studies by H. G. Ferguson and S. W. Muller (Muller and Ferguson, 1939; Ferguson and Muller, 1949; Muller, Ferguson, and Roberts, 1951; Ferguson, Muller, and Roberts, 1951a; 1951b; Ferguson, Roberts, and Muller, 1952). In the present paper the major stratigraphic and structural features recognized in these quadrangles are extended across the intervening areas and to some extent westward and northward. The region considered here consists of six one-degree quadrangles bounded by the 117th and 119th meridians and the 38th and 41st parallels and includes portions of Humboldt, Pershing, Lander, Churchill, Mineral, Nye, and Esmeralda counties (Fig. 1).

Lower Mesozoic rocks in westernmost Nevada, widely scattered in Washoe, Storey, Lyon, and Douglas counties, and in western Pershing County, are not considered in the present summary because they are as yet little known. Reconnaissance mapping by Willden (1956, and in preparation) in northeastern and central Humboldt County has established the presence of upper Paleozoic and lower Mesozoic rocks at several localities; and R. R. Compton, directing the summer field course of Stanford University, has studied in some detail the thick section of lower Mesozoic metasedimentary rocks of the Santa Rosa Range in east-central Humboldt County. These are mainly altered volcanic rocks or thick, monotonous sequences of generally unfossiliferous fine-grained clastic rocks and can be compared only very generally with the correlative rocks farther south.

Roberts and others (1958) presented a broad synthesis of the regional geology of Paleozoic rocks in north-central Nevada. In eastern

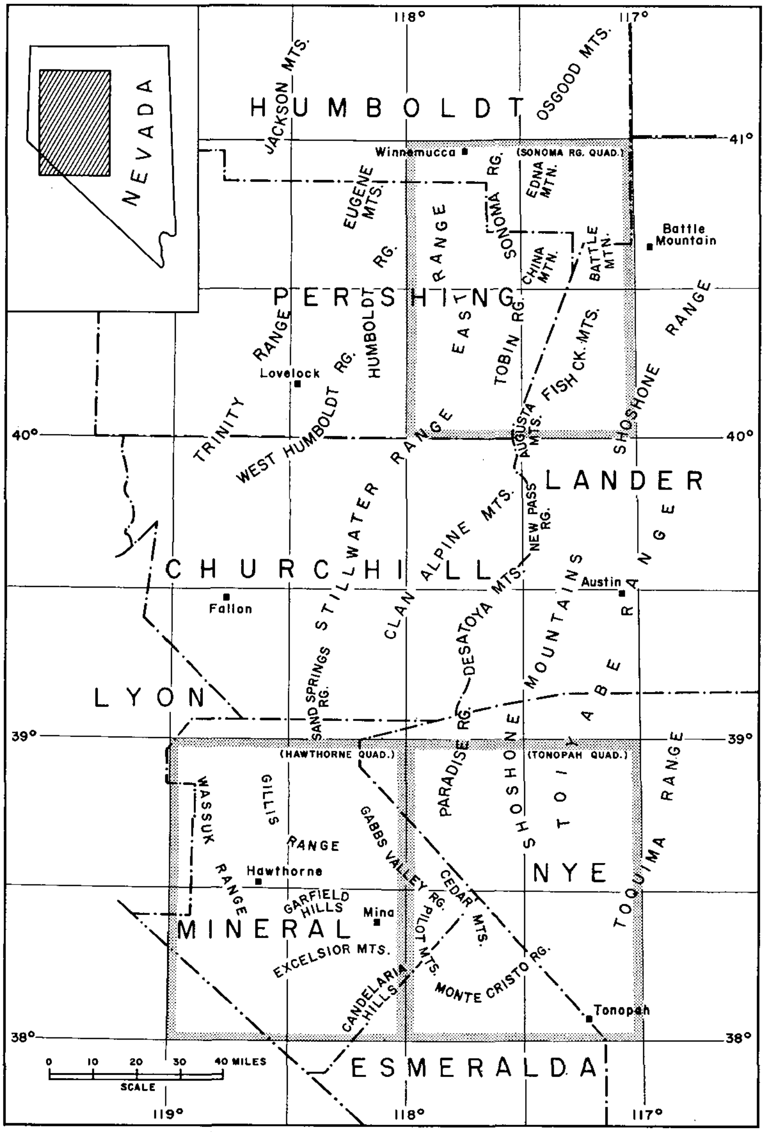



Figure 1. Index map of the portion of northwestern Nevada under consideration

Nevada, generally east of longitudes 116°–117°, Paleozoic rocks from Middle Cambrian to Mississippian age are mostly limestone and dolomite with minor shale and quartzite. In central and western Nevada correlative strata are dominantly clastic sedimentary rocks and chert, with intercalated volcanic rocks. The eastern or carbonate assemblage[1] is generally about 15,000–20,000 feet thick, but the western or detrital-volcanic assemblage is much thicker, perhaps more than 50,000 feet thick. The depositional environment of the two assemblages was clearly different, that of the carbonate assemblage being a marine shelf, and that of the detrital-volcanic assemblage a eugeosynclinal basin. The two have been brought into contact by telescoping along a thrust fault of great magnitude, the Roberts Mountains thrust, which carried the detrital-volcanic assemblage eastward over the carbonate assemblage.

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

The broad subsiding area in which the three assemblages were deposited persisted, with local disturbances, from Late Cambrian until Late Devonian time. During the Late Devonian or Early Mississippian, a belt along the 116th to 118th meridians, the Antler orogenic belt, was intensely folded and faulted, and during Mississippian time the Roberts Mountains thrust sheet was emplaced. From emerged areas along this belt clastic sediments were shed eastward and westward. These graded laterally into finer clastic and carbonate sediments of normal marine facies. In the orogenic belt the sediments deposited upon the deformed lower and middle Paleozoic strata of the carbonate, transitional, and detrital-volcanic assemblages are designated the overlap assemblage.

The Antler orogeny brought to an end the Cordilleran geosyncline

[1]Previously the Paleozoic facies in Nevada have been referred to as "western" and "eastern" (Merriam and Anderson, 1942, p. 1704; Nolan and others, 1956, p. 6, 23, 34; Roberts and others, 1958, p. 2816–17). These terms served adequately in Nevada where the facies boundary originally extended north-northeastward medially through the state. However, as the same facies extend westward and southward into California, and northward into Idaho, these terms are no longer appropriate. It is therefore suggested that lithologic terms be substituted: detrital-volcanic in place of "western," and carbonate in place of "eastern."

in Nevada as it had existed during early and middle Paleozoic time; deposition within the orogenic belt during the remainder of Paleozoic time was in relatively shallow marine straits and embayments. West of this belt, however, eugeosynclinal sedimentation persisted until it was terminated by orogeny in middle or Late Permian time. From Late Permian well into Jurassic time the areas affected by these earlier orogenic movements in northwestern Nevada were free of strong crustal disturbances, and a nearly continuous succession of generally shallow-water marine volcanic and sedimentary rocks was deposited. Marine deposition was finally terminated by orogeny that commenced as early as late Early Jurassic and probably persisted into Cretaceous time. The history of geologic events that followed the Antler orogeny is recorded in the pre-Tertiary rocks of northwestern Nevada.

More than 40 formational names have been applied to the Paleozoic and lower Mesozoic rocks of northwestern Nevada. To discuss their regional stratigraphic and structural relationships it is desirable to combine these formations into larger stratigraphic units. Roberts and others (1958) used the term "assemblage" to designate major groupings of Paleozoic rocks which are representative of a particular sedimentary and tectonic environment in northern Nevada. The term assemblage is used similarly for rocks along the eastern and southern margins of the area considered here.

A different kind of subdivision, however, is required in northwestern Nevada for the upper Paleozoic and lower Mesozoic rocks. The subdivisions adopted are lithologically and geographically discrete units of major rank termed "sequences" that are set apart from underlying or overlying sequences by unconformities. The sequences differ from assemblages in being discrete, vertically delimited rock units, some of which, though lithologically distinct, were deposited under much the same environmental conditions.

In the East Range and adjacent ranges, for example, a generally conformable and continuous sequence of Middle and Upper Triassic rocks rests unconformably on strata of Permian and Early Triassic age which in turn were deposited upon a folded sequence of still older age; hence, this section is readily divisible into three parts, each of which is termed a sequence and is separately named. Where appropriate, other contrasting sections can be subdivided in the same manner by utilizing the unconformities within them that document periods of folding or widespread uplift. The lateral extent of each sequence is determined by the geographic limits of its characteristic component rocks. The term sequence as used here serves the same purpose as the term group in formal rock-stratigraphic nomenclature, but the two terms differ in scope. Some sequences may include more than one established group, and hence the sequences are in effect "supergroups."

The assignment of the upper Paleozoic and lower Mesozoic formations in northwestern Nevada to the different sequences is illustrated in Figure 2, and the distribution and outcrop pattern of the sequences is shown on Figure 3.

# Stratigraphy in Northern Part of Area

## GENERAL STATEMENT

Although Paleozoic and Mesozoic rocks throughout northwestern Nevada reflect a related depositional and structural history, distinctive stratigraphic sections characterize different parts of the area. The relative scarcity of pre-Tertiary outcrops in a belt through the middle of the area separates the Paleozoic and Mesozoic rocks in the northern part from those in the south and makes it convenient to discuss the stratigraphy in the two parts of the area separately.

Pre-Tertiary rocks ranging in age from early Paleozoic to early Mesozoic are exposed in the northern part of the area where they have been considerably disturbed by thrusting. The lower Paleozoic rocks that pre-date the Antler orogeny and are not shown in Figures 2 and 3 are overlain by the late Paleozoic Antler sequence. The Havallah sequence, also of late Paleozoic age, has been thrust over the Antler sequence. The Koipato sequence of Permian and Triassic age rests on the Havallah and is in turn depositionally overlain by two different sequences of Triassic and Jurassic rocks, the Winnemucca and Augusta sequences, which have been telescoped by thrusting.

## LOWER AND MIDDLE PALEOZOIC ROCKS

The rocks deformed during the Antler orogeny represent both the detrital-volcanic and transitional assemblages of Roberts and others (1958) and crop out at Battle Mountain and Edna Mountain, the Osgood Mountains, and the Shoshone, Sonoma, and East ranges. The rocks are part of the Antler orogenic belt which in this area was overlapped during late Paleozoic time by the Antler sequence. A more

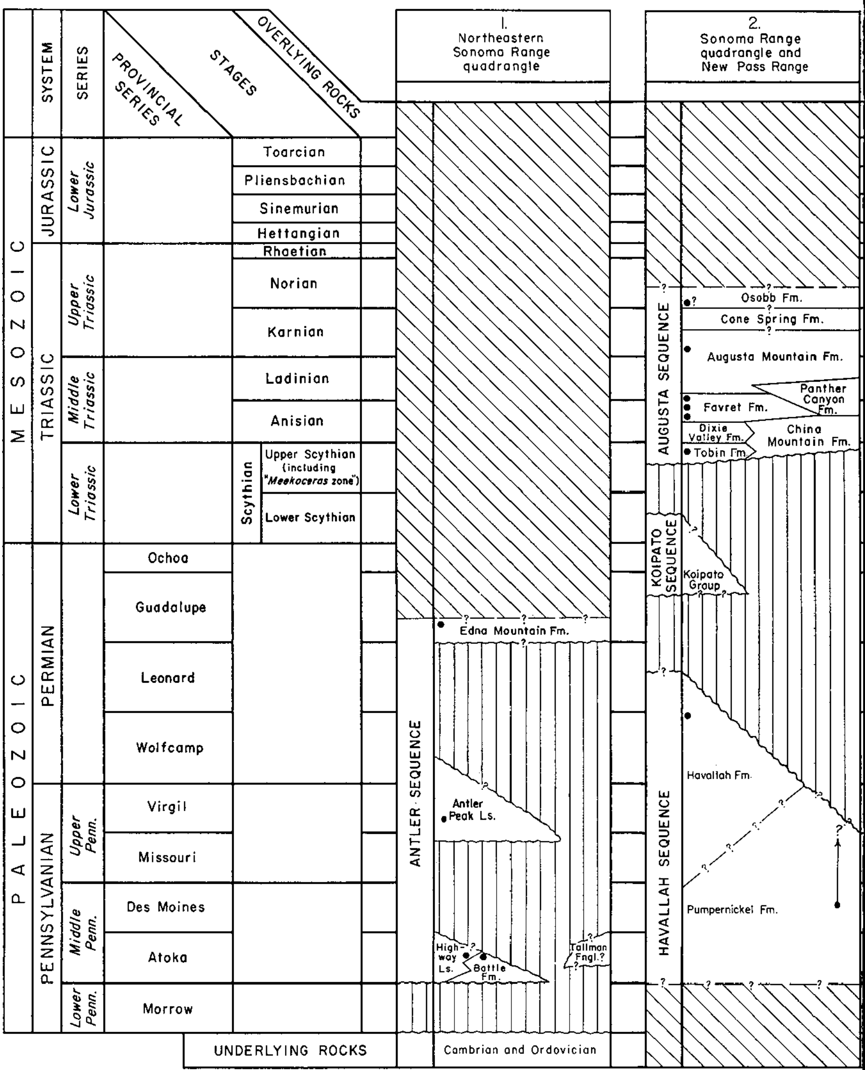



Figure 2. Correlation chart of upper Paleozoic and lower Mesozoic rocks in north-western Nevada. Dots represent occurrence of fossils that provide an age assignment. Stratigraphic hiatus indicated by vertical ruling, lack of data by diagonal ruling.

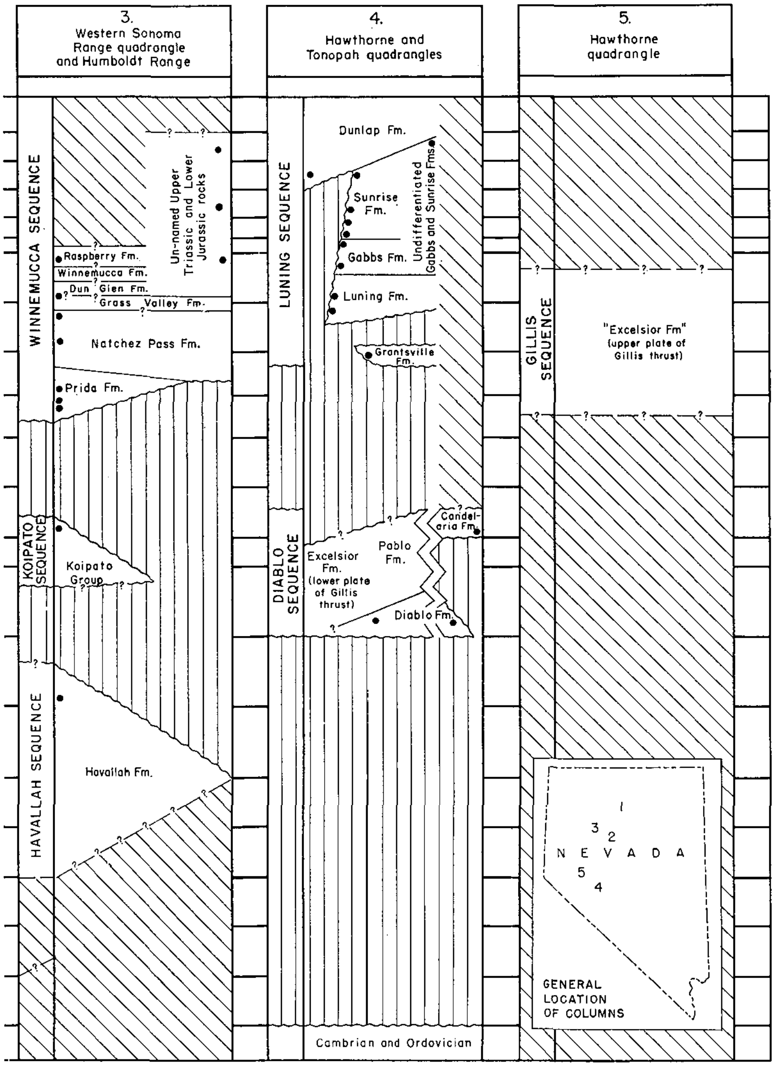
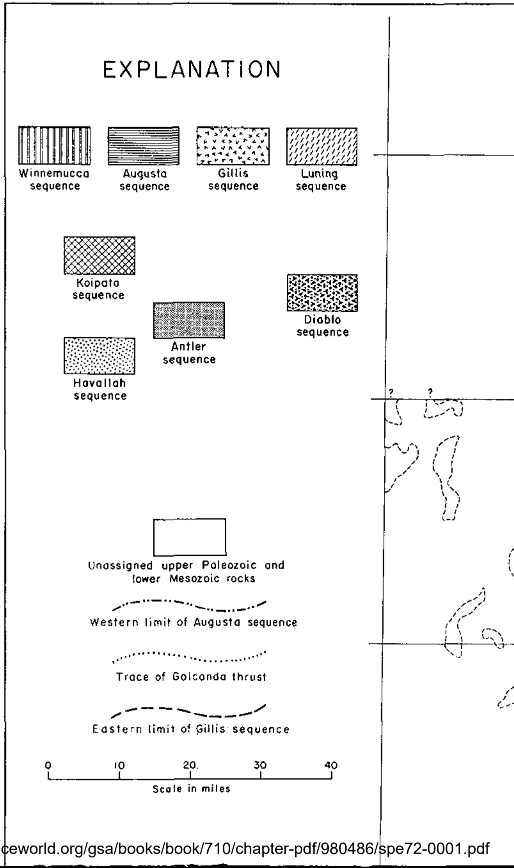
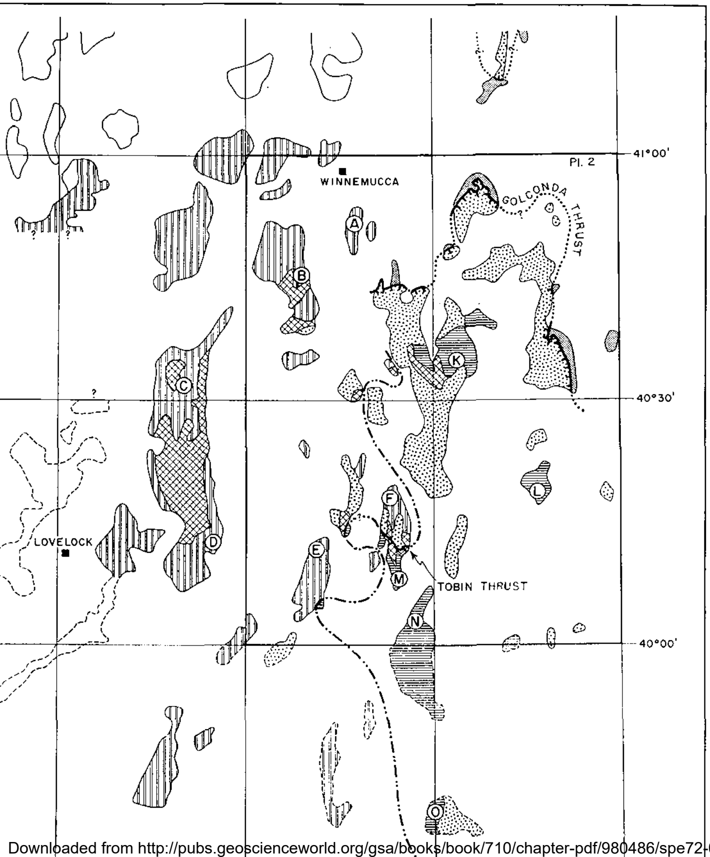



Figure 2 (*Continued*)


EXPLANATION
Winnemucca sequence
Augusta sequence
Gillis sequence
Luning sequence
Koipato sequence
Diablo sequence
Antler sequence
Havallah sequence
Unassigned upper Paleozoic and lower Mesozoic rocks
Western limit of Augusta sequence
Trace of Golconda thrust
Eastern limit of Gillis sequence
0 10 20 30 40
Scale in miles



41°00'
40°30'
40°00'
Pl. 2
WINNEMUCCA
GOLCONDA THRUST
TOBIN THRUST
LOVELOCK
A
B
C
D
E
F
K
L
M
N
O

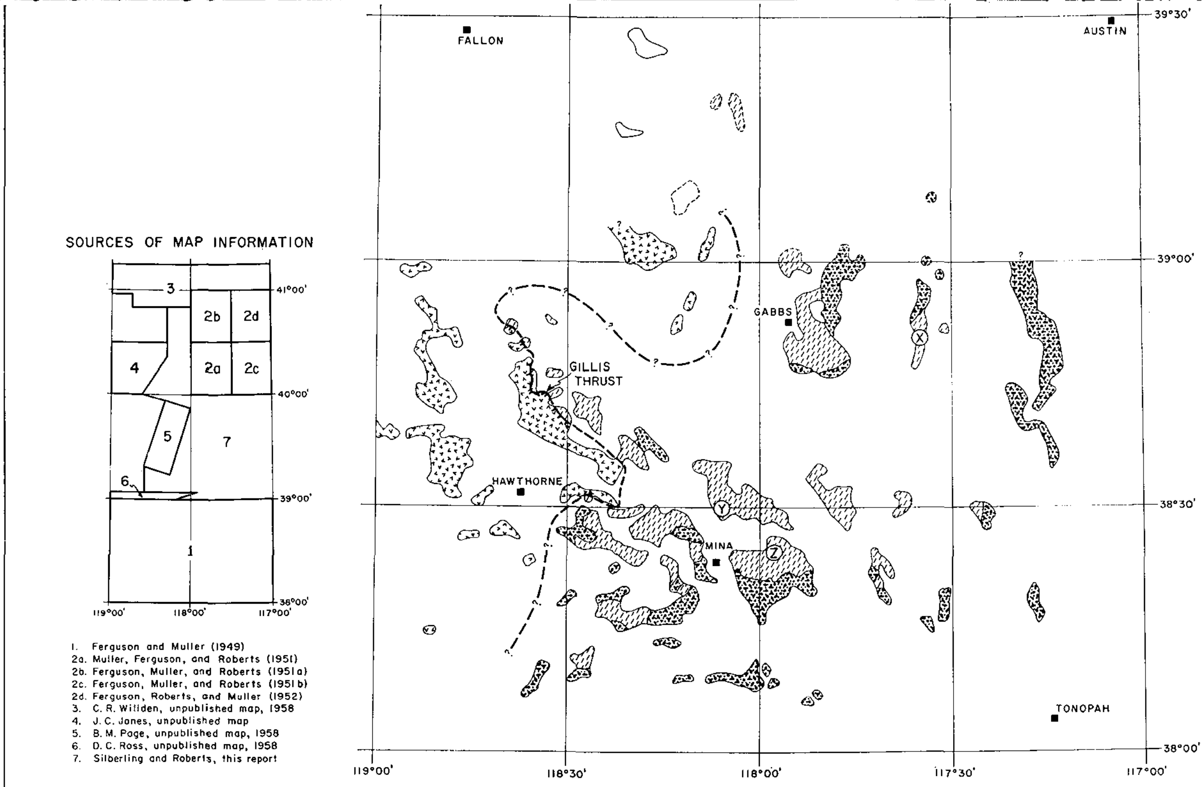



Figure 3. Distribution and outcrop of upper Paleozoic and lower Mesozoic sequences. Contacts considerably generalized and smaller outcrop areas exaggerated in size. Hachures indicate upper plate of thrust contacts. Locations of columnar sections (Fig. 5; Pl. 1) indicated by capital letters

complete description than the following one of the lithologic nature, distribution, and dating of these rocks may be found in Roberts and others (1958).

The detrital-volcanic assemblage is represented, in ascending order, by the Scott Canyon, Valmy, and Sonoma Range formations and the transitional assemblage by the Osgood Mountain Quartzite and the Preble, Harmony, and Comus formations. The Leach and Inskip formations in the East Range also belong to the detrital-volcanic assemblage, but their relationship to other detrital-volcanic assemblage rocks is not definitely known.

The Scott Canyon Formation at Battle Mountain, of early Middle(?) Cambrian age, consists of about 5000 feet of dark chert, thin-bedded shale, and greenstone with a little limestone and quartzite. The Valmy Formation, which has been dated as Early, Middle, and Late Ordovician by graptolites (R. J. Ross, Jr., and W. B. N. Berry, written communication, 1959) in Battle Mountain and the Sonoma and Shoshone ranges, is not in depositional contact with the Scott Canyon, so their relationship is unknown. The Valmy consists of three members: the lower, about 1800 feet thick, is mostly dark radiolarian chert, shale, and greenstone like the Scott Canyon but contains much black, gray, or tan vitreous quartzite; the upper two members are principally interbedded chert and shale with little quartzite and greenstone and are 6000 or more feet thick. The Sonoma Range Formation in the Sonoma Range is thought to be correlative with the upper part of the Valmy.

These formations were deposited in an environment in which chert and shale were the normal sediments. Locally marine volcanism gave rise to interlayered pillow lavas and flows. In places the Scott Canyon Formation contains lenticular limestones composed of algae, sponges, and archaeocyathids suggesting bioherms interlayered with volcanic rocks. The quartzite units are from a few inches to 200 feet thick; the thick units are commonly massive, poorly bedded, and composed almost entirely of quartz grains; they may represent density-current deposits derived from distant source areas. The combination of these rock types suggests deposition mostly below wave base, possibly at bathyal depths from which arose volcanic islands locally surrounded by reefs.

The lower Paleozoic rocks belonging to the transitional assemblage are represented by five units in the Osgood Mountains and adjacent areas. The oldest is the Osgood Mountain Quartzite of Early Cambrian(?) age which is at least 5000 feet thick. The quartzite grades upward into interbedded shale and limestone of the Preble Formation which is of Middle and early Late Cambrian age and is 12,000–15,000 feet thick. Apparently younger formations in the Hot Springs Range are not in contact with the Preble, and their relationship to it is uncertain. These are an unnamed unit of chert, shale, and limestone 300–500 feet thick, which is overlain conformably by the Harmony Formation of coarse feldspathic sandstone and shale, as much as 6000 feet thick. Both units contain trilobites of Late Cambrian age. The youngest formation, the Comus, 3000–4600 feet thick, is nowhere in contact with the Harmony, but is considered to be younger because it contains Lower and Middle Ordovician graptolites.

These transitional units appear to have been deposited in a shallow-water marine environment. The Osgood Mountain Quartzite may be a shore-line facies; the Preble and younger units were probably deposited in an offshore shelf environment. The coarse feldspathic sandstones of the Harmony Formation are graded, suggesting transport by density currents from a distant area of orogenic disturbance.

*Leach and Inskip Formations.* The Leach and Inskip formations underlie much of the central part of the East Range, and the Inskip Formation may form a small outcrop on the west flank of the Sonoma Range. The Leach seems to be older than the Inskip, although their mutual contact is for the most part steeply faulted.

The Leach Formation consists of mafic volcanic rocks with much dark shale, chert, and vitreous quartzite, perhaps as much as 6000 feet thick; the volcanic rocks are mainly in the lower part. No fossils are known from it, but because it evidently underlies the Inskip Formation, presumed to be of Permian age, it was originally assigned by Ferguson and others (1951a) to the Pennsylvanian. The Inskip Formation is dominantly clastic with much impure sandstone and conglomerate, some mafic volcanic material, and subordinate limestone, calcareous shale, and clean quartzose sandstone.

Corals recently collected from limestone in the outcrop belt of the typical Inskip Formation are tentatively assigned to the Mississippian by Helen Duncan (Written communication to H. G. Ferguson, February 25, 1957). The Leach is therefore probably Mississippian or older. The dark vitreous quartzite beds of the Leach are lithologically indistinguishable from the distinctive quartzite of the lower part of the Valmy Formation, and the two formations may be correlative.

Ferguson and others (1951a) thought that the Koipato and Winnemucca sequences of our usage overlie the Leach and Inskip formations in some places and the Havallah Formation in others. However, in 1955–1956 the present authors discovered that the beds depositionally underlying the Koipato sequence, wherever exposed, belong to the Havallah sequence, and that the Leach and Inskip formations in the East Range are in a thrust plate that overrode the rocks of the Koipato and Winnemucca sequences. Figure 4 illustrates the relationships in the central East Range as originally described and the present interpretation wherein the Leach and Inskip formations are not in depositional contact with the adjacent younger rocks.

## PRE-KOIPATO SEQUENCE UPPER PALEOZOIC ROCKS

The upper Paleozoic rocks older than the Koipato sequence in the northeastern part of the region considered here belong to either the Antler or Havallah sequence. Although partially equivalent in age, these are of entirely different facies and have been brought together by thrust faulting of great displacement.

*Antler Sequence.* The Antler sequence is part of the overlap assemblage (Roberts and others, 1958, p. 2841) that includes all the upper Paleozoic rocks deposited within the Antler orogenic belt following folding and thrusting during Late Devonian and Mississippian time. Some rocks of the overlap assemblage are of continental origin, but most contain shallow-water marine faunas. They vary abruptly in lithology, suggesting deposition in local straits and embayments. On the eastern fringe of the orogenic belt, where deposition was continuous, the oldest sediments of the overlap assemblage are Early Mississippian, but within the belt the oldest recognized are Middle Pennsylvanian.

The Antler sequence includes the Battle Formation, Highway Limestone, Antler Peak Limestone, Edna Mountain Formation, and possibly the Tallman Fanglomerate, which crop out in Battle Mountain, Edna Mountain, the Osgood Mountains, and the northern part of the Sonoma Range.

The Battle Formation is chiefly coarse conglomerate with interbedded sandstone, shale, and limestone aggregating about 700 feet thick at the type locality in Battle Mountain. It contains fusulinids of Middle Pennsylvanian (Atoka) age. The Highway Limestone, about 300 feet thick at Edna Mountain and in the Osgood Mountains, contains fusulinids of equivalent age and is a facies of the Battle Formation.

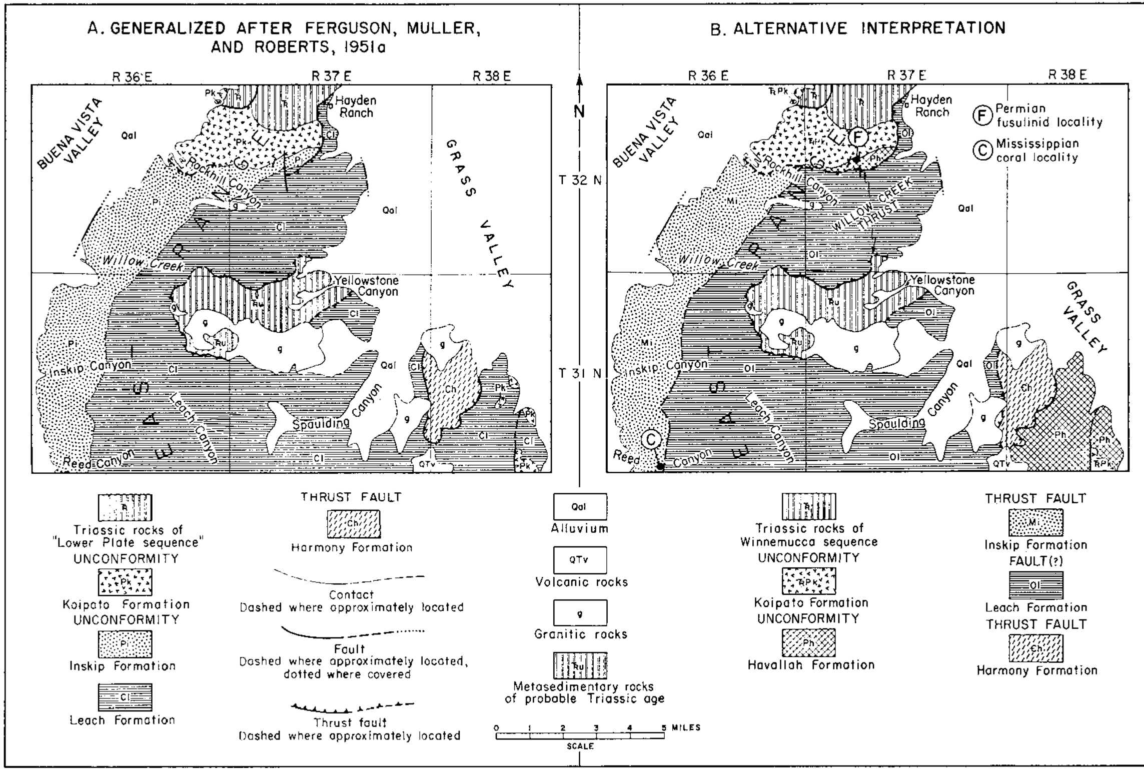



Figure 4. Generalized geologic map of part of East Range illustrating structural and stratigraphic interpretations of Paleozoic and Mesozoic rocks originally made by Ferguson and others (1951a) and alternative interpretation by present authors

The Battle Formation and Highway Limestone are overlain disconformably by the Antler Peak Limestone, which thickens from 625 feet at the type locality to nearly 1000 feet northeast of the Osgood Mountains. The Antler Peak contains a diversified fauna of Late Pennsylvanian to Early Permian age.

The Edna Mountain Formation of Permian age is mainly sandstone, calcareous shale, and limestone and contains a fauna correlative with that of the Phosphoria and Gerster formations (Williams, 1959, p. 40). At the type locality in Edna Mountain it is about 400 feet thick; elsewhere it ranges from less than 100 to 300 feet thick. In parts of Edna Mountain erosion has removed the underlying Battle, Highway, and Antler Peak formations, so that the Edna Mountain Formation rests directly on the Preble Formation of Cambrian age.

The unfossiliferous Tallman Fanglomerate crops out in a single small area of the northwestern Sonoma Range where it overlies folded strata assigned here to the Sonoma Range Formation in the upper plate of the Thomas thrust. The Tallman is formed mainly of coarse detritus from the Sonoma Range Formation, but it includes fragments of the Harmony Formation and may be a local post-orogenic deposit of the overlap assemblage analogous to the Battle Formation at Battle Mountain. Ferguson and others (1951a) originally mapped the Tallman as overlain depositionally by the Koipato, but the contact between the Tallman and Koipato may be a fault (Fig. 6).

*Havallah Sequence.* In continuous sections that contain the Koipato and Winnemucca sequences or the Koipato and Augusta sequences, the oldest rocks recognized are assigned to the Havallah sequence which includes the Havallah and Pumpernickel formations. These formations, at their type locality in the Tobin Range and China Mountain, as well as in the Sonoma Range, Augusta Mountains, and New Pass Range, occur in the same sections as Triassic rocks of the Augusta sequence. In the East Range and part of the Tobin Range, however, the Havallah sequence is in sections characterized by the Winnemucca sequence of Triassic rocks. Although thrusting has foreshortened the gradation between the Augusta and Winnemucca sequences so that they differ abruptly where juxtaposed, the Havallah beneath each of them is generally of similar lithology and age.

The Havallah sequence is mainly confined to the Sonoma Range quadrangle but extends as far north as the Osgood Mountains and as far south as the New Pass Range. West of the outcrops of the Havallah sequence in the East and Stillwater ranges, the oldest rocks exposed are the Koipato and Winnemucca sequences. The base of the Havallah sequence is unknown; where mapped, its lower contact is a thrust fault.

The Pumpernickel Formation is dark bedded chert and siliceous argillite with some intercalated mafic volcanic rocks, whereas the overlying Havallah Formation is dominantly quartzose sandstone, bedded chert, and argillite or slate, with subordinate sandy limestone and pebbly sandstone. Each formation is at least several thousand feet thick; they differ in the greater proportion of dark vitreous chert and mafic volcanic rock in the Pumpernickel and the prevalence of sandstone and limestone in the Havallah. The Havallah Formation of the East Range—the westernmost outcrop area—contains some mafic volcanic rocks; otherwise its composition is like that farther east.

The association of bedded chert, volcanic rocks, and shale in the Pumpernickel Formation suggests continuation of eugeosynclinal conditions in western Nevada from early to late Paleozoic time. Most chert beds are composed of fine-grained quartz (0.01–0.08 mm), a little feldspar, sparse radiolaria, and clay minerals, cemented by chalcedony. The beds are finely laminated and are separated by shaly partings, suggesting deposition below wave base in an offshore environment.

The Havallah Formation in Battle Mountain, the only outcrop area studied extensively, consists of three members: a lower one of sandstone, pebbly sandstone, and fine-grained conglomerate with some calcareous sandstone beds; a middle one of dark chert, and shale; and an upper one of sandy limestone, quartzite, shale, and chert (Roberts, 1951; Roberts, and others, 1958, p. 2848). The lower member contains graded bedding that suggests sediment transport by density currents; the chert and shale of the middle member suggest deposition in an offshore environment like that of the Pumpernickel; interbedding of limestone, quartzite, shale, and chert in the upper member suggests shallowing water and change to an environment similar to that in which the Antler sequence accumulated.

Fusulinids of late Wolfcamp or early Leonard age have been collected from numerous localities at Battle Mountain in the upper member of the Havallah and from one locality in the upper part of the lower member. Two collections from the lower part of the lower member, however, contain fusulinids of Middle Pennsylvanian (Atoka) age according to R. C. Douglass (Written communications, Dec. 7, 1953; Nov. 4, 1960). Douglass points out that the fusulinids of Atoka age occur as rounded detrital grains, possibly indicating redeposition from older beds, and he suggests that all three members of the Havallah might be Permian.

Fusulinids of "early middle, or possibly late Early Permian" (early Leonard, or possibly late Wolfcamp) age (L. G. Henbest, written communication, Aug. 19, 1958) were collected by the writers from a sandy limestone in the Havallah Formation at the crest of the East Range about 2 miles southwest of the Hayden Ranch (Fig. 4). The rocks from which these fossils were obtained were originally included in the Inskip Formation by Ferguson and others (1951a).

The age of the Pumpernickel Formation has never been satisfactorily established. As the Havallah may rest disconformably on the Pumpernickel, and fusulinids of Atoka age were found in the lower part of the Havallah, the Pumpernickel was tentatively assigned a Mississippian or older age by Roberts and others (1958, p. 2848). Recently, from the upper part of the Pumpernickel at Battle Mountain, Roberts has collected conodonts considered to be late Middle Pennsylvanian (Des Moines) or younger by W. H. Hass (Written communications, Aug. 18, 1958; Feb. 6, 1959). The age of the oldest fossils found in the Havallah Formation thus conflicts with the upper age limit of the Pumpernickel; in view of the conflict the age boundary between the two formations has been left indefinite on Figure 2.

During the summer of 1960, Roberts visited localities of Pennsylvanian and Permian rocks near Mountain City, Nevada, and Ketchum, Idaho, and at both places found rocks similar in lithology to the Havallah Formation. The Havallah-like rocks near Ketchum have been assigned to the Wood River Formation (Umpleby and others, 1930, p. 29–34).

### KOIPATO SEQUENCE

The Koipato sequence includes the rocks generally assigned to the Koipato Group or Formation that rests with marked angular unconformity on the Havallah sequence. Like the Havallah, the Koipato underlies Triassic rocks of both the Winnemucca and Augusta sequences. Between the Koipato and these younger rocks is a minor angular unconformity.

At its type area in the Humboldt Range where it underlies the Winnemucca sequence, the Koipato may be more than 10,000 feet thick, and the base is not exposed. Here, the lower part is dominantly altered andesitic flows and tuff and the upper part is mainly rhyolitic tuff and clastic rocks with some flows. Several subdivisions of this section have been formally named by Knopf (1924) and Jenney (1935). Farther east in the East Range where both the top and bottom of the Koipato are exposed, the Koipato is thinner; in the Tobin Range it is locally absent. In both ranges, and in the Stillwater and Sonoma ranges, the Koipato underlies the Winnemucca sequence, and in all of them rhyolitic and andesitic pyroclastic and flow rocks dominate, although well-stratified water-laid tuffaceous clastic rocks occur in places.

A thick section of Koipato, mainly dark rhyolitic volcanic rocks, underlies the Augusta sequence in the southern Tobin Range. At China Mountain and in the Augusta Mountains, however, the Koipato is much thinner or is locally absent between the Augusta and Havallah sequences. Reconnaissance indicates that the Koipato is also missing beneath the Augusta sequence of the New Pass Range.

Fossils have been found in the Koipato only in the Humboldt Range. The dental spiral of an edestid fish, reportedly from a locality representing a stratigraphic position several thousand feet below the top of the Koipato, has been ascribed by Wheeler (1939) to the genus *Helicoprion*. D. H. Dunkle (Written communication, Nov. 15, 1957) considers this specimen more closely allied to *Lissoprion* according to the classification used by Nielsen (1952). According to Dunkle, forms with generic characters that Nielsen attributes to *Lissoprion* range through most of the Permian but are not known to occur above Permian rocks. As the Koipato in the adjacent East Range unconformably overlies strata containing fusulinids of probable Leonard age, a late Permian age is likely for the rocks at the locality where the edestid was found in the Humboldt Range.

Impressions of ammonites are locally abundant in tuffaceous beds interstratified with the rhyolitic rocks near the top of the Koipato in the Humboldt Range. Although poorly preserved, some of these ammonites can be identified as noritacids; they are definitely of Early Triassic age and probably of early Early Triassic age.

### POST-KOIPATO SEQUENCE LOWER MESOZOIC ROCKS

Lower Mesozoic rocks above the Koipato sequence in the northern part of the area belong to either the Winnemucca or Augusta sequences. Exposures of the Augusta sequence lie generally east of those of the

Winnemucca sequence, but at least locally the two sequences have been brought together by thrust faulting.

The Winnemucca sequence includes Triassic rocks in the Sonoma Range quadrangle that have been referred to the "lower plate facies" with respect to the Tobin thrust (Muller, 1949; Muller and others, 1951; Ferguson and others, 1951a); the Augusta sequence includes the Triassic rocks formerly referred to as the "upper plate facies."

*Winnemucca Sequence.* The Triassic formations that typify the Winnemucca sequence underlie parts of the Humboldt Range and the western part of the Sonoma Range quadrangle, where they crop out in the northern Stillwater Range, East Range, Tobin Range, Sonoma Range, and in the hills northwest of Winnemucca. At these localities the Winnemucca sequence is divisible into six formations, in ascending order: the Prida, Natchez Pass, Grass Valley, Dun Glen, Winnemucca, and Raspberry formations.

The unconformity between these Middle and Upper Triassic rocks and the underlying Koipato sequence has only minor angular discordance, but the hiatus represents most of Early Triassic and early Middle Triassic time. In places, as in the Tobin Range, the Koipato was removed by erosion before deposition of the Winnemucca sequence, so that the latter rests directly on the Havallah sequence.

The Prida and Natchez Pass formations are largely carbonate rocks that thicken westward to a maximum of about 3000 feet. Overlying formations, with the exception of the Dun Glen, are for the most part fine-grained terrigenous clastic rocks.

The Prida is impure, silty and marly limestone, generally with some basal clastic rocks and impure dolomite. The Natchez Pass Formation is chiefly massive and relatively pure limestone and dolomite, but mafic volcanic rocks are interbedded at various levels in the middle. In the southwesternmost exposures of the formation in the Humboldt Range, andesitic breccia, flow rocks, and tuff thicken to about 1000 feet and form nearly half the total thickness.

Above the dominantly calcareous rocks that form the base of the Winnemucca sequence are the Upper Triassic Grass Valley, Winnemucca, and Raspberry formations which aggregate more than 8000 feet in thickness and are mainly shale, mudstone, siltstone, and sandstone with little carbonate rock. The only exception is the Dun Glen Formation of massive dolomite and limestone that separates the Grass Valley and Winnemucca formations and is more than 1000 feet thick in the Sonoma Range. Generally shallow-water marine deposition of the fine-grained terrigenous clastic sediments of the Winnemucca and Raspberry formations is indicated by the prevalence of interstitial calcareous cement, by sandstones ripple marked by wave action, and by rare coralline or stromatolitic limestone interbeds.

In the Sonoma Range quadrangle the strata from the Prida to the Winnemucca Formation are continuous and conformable, but the Winnemucca and the younger Raspberry formations are not in depositional contact. Willden (1956) believes that a unit he has mapped in the hills northwest of Winnemucca occupies a stratigraphic position between the Winnemucca and Raspberry formations and is faulted out of the section in the Sonoma Range quadrangle.

The Prida, Natchez Pass, and Grass Valley formations form nearly all the Winnemucca sequence preserved in the Humboldt Range. The Star Peak Group as originally defined in the Humboldt Range by King (1878, p. 269) and revised by Cameron (1939, p. 581–582) is equivalent to the first two of these formations, and the "argillaceous slates" at the north end of the Range that King (1878, p. 295) erroneously considered to be Jurassic are the lower part of the Grass Valley Formation. In the Pershing district at the southern tip of the Humboldt Range and in the West Humboldt Range are younger Triassic and Lower Jurassic rocks which are partly equivalent to the Dun Glen, Winnemucca, and Raspberry formations, but will require a partly or wholly new formational nomenclature.

Uppermost Triassic and Lower Jurassic clastic sedimentary rocks lithologically similar to those in the West Humboldt Range crop out to the southeast in the Stillwater and Clan Alpine ranges and to the north and northeast in the Eugene Mountains, southern Jackson Range, and the hills northwest of Winnemucca. These dominantly fine-grained rocks are considered to be the upper part of the Winnemucca sequence, and they border the better known lower part of the sequence on the north, west, and south. Owing to their lithologic homogeneity, general lack of fossils, and complex structure, these rocks cannot yet be assigned to discrete formations. Nevertheless, their structural complexity is in itself an argument for placing them in the Winnemucca sequence rather than in the contiguous Augusta sequence which is distinguished by its slight structural deformation (Muller, 1949).

Lateral variations of paleogeographic significance are conspicuous in the lower part of the Winnemucca sequence. A southward and eastward transgression of the sequence is shown by overlap of the basal units of the Prida Formation which can be accurately dated by ammonite faunas. The dominantly calcareous lower part of the Winnemucca sequence thins consistently from the northern Humboldt Range northeastward to the East Range and Sonoma Range, and from the southern Humboldt Range eastward to the northern Stillwater Range and Tobin Range (Pl. 1). Pinching out of units such as the Prida Formation suggests a shore line to the east and southeast. The upper part of the Prida in the northern Humboldt Range is about 1000 feet of thinly laminated, sparsely fossiliferous, dark cherty limestone indicative of deposition below wave base in an environment unfavorable for bottom-dwelling animals. Compared with the massive organic detrital limestones in the correlative part of the section to the east, these rocks are relatively offshore and deep-water deposits.

The Grass Valley Formation provides the most paleogeographic data of all the units in the Winnemucca sequence. In its southeasternmost exposure in the Tobin Range it is almost entirely clean arkosic sandstone with sweeping cross beds suggestive of strand-line deposition. To the west in the Humboldt Range and northern East Range it thickens and changes to noncalcareous shale or mudstone with subordinate intercalations of regularly bedded fine-grained impure sandstone and lenticular bodies of clean, generally featureless sandstone. The impure sandstones contain many wood fragments and commonly form sets of thin beds which have drag and impact casts on their soles and linguloid current ripples on their tops. These markings indicate current directions, but they have not been adequately sampled; observations made thus far show consistent northwestern current directions in the northern East Range and the north and south ends of the Humboldt Range. The Grass Valley Formation is now believed to be a deltaic deposit. In the argillaceous sections to the west the discontinuous bodies of clean sandstone may be bar or channel deposits, and the impure sandstone beds may have been deposited by sheet floods running northwesterly across the subaerial or intertidal surface of the delta toward the sea.

Age assignments for rocks of the Winnemucca sequence (Fig. 2; Pl. 1) incorporate the results of recent work and differ in part from those made previously (Muller and others, 1951; Ferguson and others, 1951a; Silberling, *in* Reeside, 1957). An ammonite fauna characterized by *Paraceratites*, *Gymnotoceras*, and *Nevadites* occurs at or near the base of the Prida Formation and establishes a late Anisian (middle Middle Triassic) age for the lower part of the Winnemucca sequence. Only in the northern Humboldt Range is an older Anisian ammonite fauna containing *Acrochordiceras* and *Cuccoceras* found in the Prida about 100 feet below the *Paraceratites* beds. The ammonite *Trachyceras s. s.*, indicative of the basal Upper Triassic (lower Karnian), has been found in the middle part of the Natchez Pass Formation in both the East Range and the Humboldt Range; hence the upper part of this unit is somewhat younger than was previously thought. Tropitid ammonites, *Spirogmoceras shastense* (Smith), and species of *Halobia* indicate a late Karnian age for the uppermost part of the Natchez Pass in the northern Humboldt Range. The brachiopod and pelecypod fauna, characterized by *Plectoconcha aequiplicata*, in the uppermost part of the Grass Valley and in the Dun Glen Formation is provisionally regarded as early Norian in age. Elements of this fauna are associated with lower or middle Norian ammonites in the Pershing district at the south end of the Humboldt Range in beds that may correspond to the uppermost Grass Valley Formation.

*Augusta Sequence.* The Augusta sequence is broadly similar to the Winnemucca sequence, but none of the formations in one sequence can be recognized in the other.

The most complete section of the Augusta sequence is in the Augusta Mountains in the southern part of the Sonoma Range quadrangle, where six formations, the Tobin, Dixie Valley, Favret, Augusta Mountain, Cane Spring, and Osobb, form an unbroken succession of late Early Triassic to middle Late Triassic age (Muller and others, 1951). Aside from a locally conspicuous basal conglomerate, the Tobin Formation is mainly fine-grained, commonly calcareous, terrigenous clastic rock with some limestone interbeds. Marine mollusks from the Tobin Formation are of late Early Triassic age (equivalent to the *Prohungarites similis* zone). Coarse clastic sediments characterize the overlying unfossiferous Dixie Valley Formation which is conglomerate and conglomeratic, dolomitic sandstone interbedded with shaly or sandy dolomite and limestone. These dominantly clastic rocks are overlain by carbonate rocks as much as 5000 feet thick belonging to the Favret, Augusta Mountain, and Cane Spring formations. The basal Favret Formation is middle Anisian (early Middle Triassic) in age and, on the basis of lithic correlations with sections at China Mountain and New Pass Range where the lower Karnian *Trachyceras* zone is recognized (Silberling, 1956), the Middle Triassic-Upper Triassic boundary is within the Augusta Mountain Formation. The Osobb Formation, of clean sandstone with subordinate shaly and calcareous beds, is the highest part of the Augusta sequence preserved. A *Plectoconcha aequiplicata* fauna, like that in the basal Dun Glen Formation of the Winnemucca sequence, occurs in the upper part of the Osobb, and, in the absence of more reliable fossils, the Osobb is considered to be of early Norian (middle Late Triassic) age.

About 35 miles north of the Augusta Mountains at China Mountain, the conglomeratic China Mountain Formation supplants the Tobin and Dixie Valley formations. Here, as well as in the Fish Creek Mountains (McCoy District) about 25 miles northeast of the Augusta Mountains, terrigenous clastic rocks assigned to the Panther Canyon Formation intervene between the Favret and Augusta Mountain formations. The China Mountain and Panther Canyon formations generally contain less carbonate and more coarse clastic material, which suggests greater proximity to a shore line than the equivalent parts of the section in the Augusta Mountains. This is indicated further by the marked thinning of the calcareous Augusta Mountain and Cane Spring formations from Augusta Mountain to China Mountain and the Fish Creek Mountains. In the New Pass Range, about 20 miles south of the Augusta Mountains, a thick clastic unit resembling the China Mountain Formation forms the base of the Augusta sequence. The Favret and Augusta Mountain formations overlying this clastic unit are as thick as the corresponding part of the section in the Augusta Mountains, but conglomeratic and sandy interbeds in the lower part of the Augusta Mountain Formation may be a tongue of the Panther Canyon Formation that is lacking in the Augusta Mountains. The lateral variations within the Augusta sequence suggest that a land area lay to the north and east during Middle and Late Triassic time.

Some representative sections of the Augusta sequence are illustrated on Plate 1.

Muller (1949) considered the Augusta sequence (his "upper plate facies" of the Triassic with respect to the Tobin thrust) to have been formed in a more offshore marine environment than the Winnemucca sequence ("lower plate facies") because clastic rocks with shallow-water or lagoonal sedimentary structures and organic remains are prevalent in the Winnemucca sequence whereas carbonate rocks predominate in the Augusta sequence. These differences, however, are not apparent between correlative parts of the two sequences. The massive carbonate rocks in the lower part of the Augusta Mountain Formation and the coarse clastics of the Panther Canyon Formation are equivalent to the upper part of the Prida Formation in the more western exposures of the Winnemucca sequence and were formed in shallower water and nearer shore. The Osobb Formation is of about the same age as the Grass Valley Formation but resembles only its southeastern exposures which seem to be less seaward deposits than the argillaceous parts of the Grass Valley farther west. In general, the Middle and Upper Triassic rocks of the Augusta sequence are most like the eastern outcrops of the Winnemucca sequence and can be considered grossly as a near-shore facies of the correlative part of the Winnemucca sequence.

# Stratigraphy in Southern Part of Area

## GENERAL STATEMENT

Pre-Tertiary rocks exposed in the southern part of the area, principally the Hawthorne and Tonopah one-degree quadrangles, represent the same time span as those to the north. Greatly deformed lower and middle Paleozoic rocks crop out around the southeastern and southern margin of the area and are unconformably overlain by clastic and volcanic rocks of middle Permian to earliest Triassic age assigned to the Diablo sequence. The lower part of the Diablo sequence has affinities with the Antler sequence to the north, whereas the upper part is more closely related to the Koipato sequence. Overlying the Diablo sequence unconformably, but generally with minor angular discordance, is the Luning sequence of shallow-water marine sedimentary rocks of late Middle Triassic through Early Jurassic age. The dominantly volcanic Gillis sequence, of probable Middle or Late Triassic age, is thrust over the Luning and Diablo sequences from the west.

## LOWER AND MIDDLE PALEOZOIC ROCKS

Lower Paleozoic rocks crop out to the east and south of the principal exposures of the Diablo and Luning sequences and roughly delimit the original area of deposition of these sequences. Rocks of Cambrian and Ordovician age are exposed in the Candelaria Hills, Monte Cristo Range, near Tonopah, in the Toquima Range, the Toiyabe Range, and the Shoshone Mountains. They are generally similar at all these places and are mainly slate and chert with locally conspicuous carbonate and quartzite units; on the whole they resemble transitional assemblage rocks farther north. Where the sections are most complete, both Cambrian and Ordovician strata are several thousand feet thick. Middle Paleozoic rocks are known only at one locality a short distance north of Tonopah, where several hundred feet of limestone containing Mississippian corals (Helen Duncan, written communication, 1954) rests on the Ordovician rocks. These limestones were formerly assigned to the Devonian (Ferguson and Muller, 1949, p. 51).

### DIABLO SEQUENCE

The Diablo, Pablo, and Candelaria formations, and the Excelsior Formation in the lower plate of the Gillis thrust are here considered to be genetically related, possibly intergrading, parts of a single lithic unit, the Diablo sequence. Although this assumption is reasonable, it is based on two unproved inferences: that the typical Excelsior Formation in the lower plate of the Gillis thrust is equivalent to the Pablo Formation which is partly of Late Permian age, and that the Candelaria Formation of Early Triassic age is a lateral facies of the upper parts of these formations.

The Diablo sequence overlies Cambrian and Ordovician rocks with pronounced angular unconformity along an arcuate belt that more or less borders the Luning sequence on the south and east. Not only are the older Paleozoic rocks beneath the unconformity in the Toiyabe Range more intensely folded, but they are of a distinctly higher metamorphic grade than those of the overlying Diablo sequence.

In its eastern and northeastern exposures the Diablo sequence includes the Diablo and Pablo formations. The Diablo Formation in the Toiyabe Range includes more than 3000 feet of dominantly conglomeratic rocks, near the base of which is a *Punctospirifer pulcher* fauna probably correlative with the fauna of Edna Mountain Formation in the Antler sequence (Ferguson and Cathcart, 1954). Several thousand feet of andesitic volcanic and clastic sedimentary rocks of the Pablo Formation gradationally overlie the Diablo Formation. The Pablo Formation also occurs farther west in the Shoshone Mountains and Paradise Range where it disconformably underlies the Luning sequence. Marine fossils from the Shoshone Mountains suggest that part of the Pablo is Permian (Silberling, 1959, p. 9).

In the Garfield Hills, Pilot Mountains, and the northwestern Gabbs

Valley Range, the Luning sequence lies unconformably on volcanic and fine-grained clastic rocks of the Excelsior Formation. These rocks, as well as the typical Excelsior Formation in the Excelsior Mountains, are in the lower plate of the Gillis thrust, a structural feature that apparently extends the length of the Gillis Range and has been projected by Ferguson and Muller (1949, p. 24) to the northwest Garfield Hills Diagnostic fossils have not been found in the Excelsior that depositionally underlies the Luning sequence beneath the Gillis thrust. In the northeast part of the Candelaria Hills, greenstone agglomerate and tuffaceous sandstone, believed by Ferguson and Muller (1949, p. 46) to be the basal Excelsior Formation, rest with marked angular unconformity on Ordovician rocks.

As the rocks that form the upper plate of the Gillis thrust are dominantly volcanic, they were also assigned to the Excelsior Formation by Muller and Ferguson (1939). Middle Triassic fossils were found in the upper plate of the Gillis thrust at one locality in the Gillis Range, so Muller and Ferguson (1939) and Ferguson and Muller (1949, p. 5) provisionally assigned all the Excelsior Formation of their usage, both above and below the Gillis thrust, to the Middle Triassic.

The present writers believe that the Excelsior beneath the Gillis thrust is equivalent to the Pablo Formation and therefore is Permian or earliest Triassic in age. The dominantly volcanic rocks that form the upper plate of the Gillis thrust are excluded from the Excelsior Formation and are treated as a distinct sequence, the Gillis, because (1) the Excelsior in the lower plate of the Gillis thrust, like the Pablo Formation, is depositionally overlain by the Luning sequence; (2) the Luning sequence is absent in the upper plate of the thrust; and (3) there may be a lithologic distinction between the rocks originally assigned to the Excelsior Formation above and below the Gillis thrust. Concerning this last statement, D. C. Ross (1961, p. 20–21) points out that the Excelsior Formation at its type area in the Excelsior Mountains, and in the Garfield Hills and Pilot Mountains, is dominantly fine-grained clastic and tuffaceous sedimentary rock with subordinate primary volcanic material and virtually no limestone, whereas the so-called Excelsior above the Gillis thrust in the Gillis Range and in the Wassuk and southern Sand Springs Range is chiefly volcanic flows and tuff with subordinate tuffaceous sedimentary rock and minor, but locally conspicuous, limestone.

If the typical Excelsior Formation is partly Early Triassic in age, it is a lateral equivalent of the Candelaria Formation, which has a lower Lower Triassic ammonoid fauna near its base (Muller and Ferguson, 1939, p. 1584). The Candelaria, which is dominantly shale and sandstone, crops out only in the Candelaria Hills. It disconformably overlies the dominantly sandy Diablo Formation that here, as in the Toiyabe Range, contains a *Punctospirifer pulcher* fauna, and rests with marked angular discordance on Ordovician rocks. According to Ferguson and Muller (1949, p. 48) the Ordovician overlain by the Diablo and Candelaria formations in the Candelaria Hills has been brought into juxtaposition by the Monte Cristo thrust with the Ordovician overlain by the Excelsior Formation. The correlation of the Candelaria and Excelsior is substantiated by the prevalence of sandy volcanic debris in the upper part of the Candelaria Formation.

The Diablo sequence is thus a thick and areally extensive unit of Permian and Triassic age that underlies the Luning sequence and is composed of dominantly volcanic and tuffaceous clastic rocks that were at least partly deposited in a marine environment. These volcanic rocks are currently assigned to either the Excelsior or the Pablo Formation, but future studies may demonstrate that the name Pablo should be suppressed as a synonym of Excelsior. The shaly and sandy Candelaria Formation of Early Triassic age is probably a marginal facies brought into juxtaposition with this volcanic unit by thrusting from the south or southeast. The nonvolcanic, sandy and conglomeratic Diablo Formation, which contains a *Punctospirifer pulcher* ("Phosphoria") fauna, forms the base of the sequence in its eastern and southern exposures and rests with pronounced unconformity on lower Paleozoic strata.

### POST-DIABLO SEQUENCE LOWER MESOZOIC ROCKS

*Luning Sequence.* The Luning sequence, one of two distinct sequences of lower Mesozoic rocks in the southern part of the area, comprises in ascending order the Grantsville, Luning, Gabbs, Sunrise, and Dunlap formations, of Middle Triassic to Middle Jurassic age. Sections representative of the Triassic part of the sequence are illustrated in Figure 5 for comparison with the Triassic rocks of the Winnemucca and Augusta sequences to the north, that formed under generally similar depositional conditions.

The Luning sequence is bordered on the east and south by the arcuate outcrop belt of the Diablo sequence; on the west it is in thrust contact with the Gillis sequence. The northern limit of the Luning se-

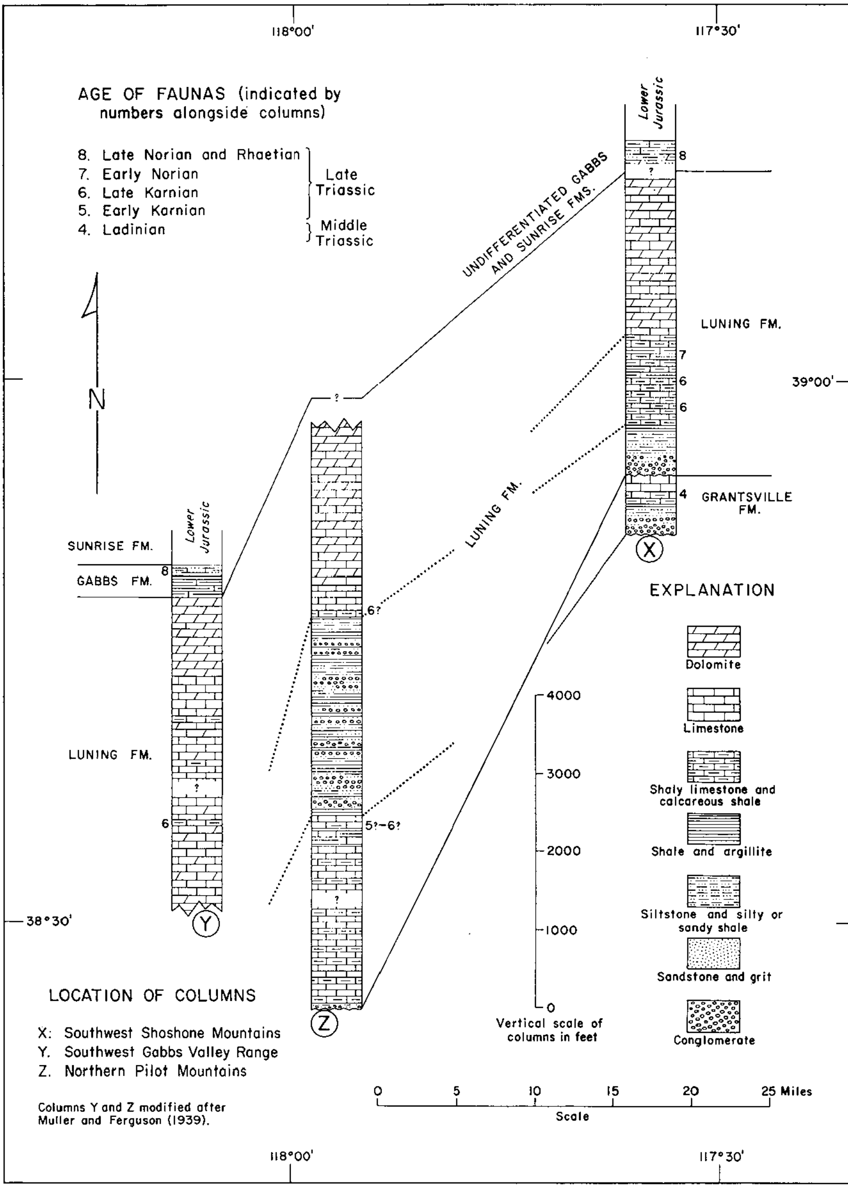



Figure 5. Reconstructed columnar sections of Triassic rocks of Luning sequence. Sections based in part on estimates from geologic mapping; hence lithology is generalized, and some thicknesses are approximations. Lines connecting columns indicate lithic correlations. Locations of columns in relation to general distribution of sequences shown in Figure 3.

quence and its relationship to the Winnemucca and Augusta sequences is indefinite owing to the scarcity of pre-Tertiary exposures between lats. 39°00′ and 39°30′ N. The Lower Jurassic rocks at Westgate at the southern end of the Clan Alpine Range are tentatively placed in the Luning sequence; if correctly assigned, they represent its northernmost known exposure.

This sequence rests unconformably on the Diablo sequence, either with small angular discordance as in the Shoshone Mountains, or with moderate discordance as in the Pilot Mountains. Local folding and even thrust faulting began during late Early Jurassic time, so that at some localities upper Lower or Middle Jurassic coarse clastics of the Dunlap Formation lie unconformably on older parts of the Luning sequence or even on the Diablo sequence where the Luning was completely eroded. Nevertheless, these orogenic and commonly nonmarine strata are included with the Luning sequence because Lower Jurassic deformation was localized and in some places deposition of the Dunlap Formation apparently was not preceded by an interruption in sedimentation.

The Luning Formation commonly makes up the greater part of the sequence and most of its exposures. At its type locality in the Pilot Mountains, and in the nearby Gabbs Valley Range and Garfield Hills, it is at the base of the sequence and occurs in several thrust plates (Muller and Ferguson, 1939; Ferguson and Muller, 1949). It varies considerably, but is mostly either carbonate rock or chert conglomerate interbedded with argillaceous rocks. Most of the carbonate rocks are pure and massive, except those at the base in the Pilot Mountains, which are thin-bedded and include coral reefs. Conglomerate and slate occur in the Pilot Mountains and Garfield Hills, the conglomerate being most abundant in the southernmost and lowest thrust plates, suggesting a shore line to the south. Because of the complex structure a complete section of the Luning Formation is not preserved, but it is at least several thousand feet thick. The greatest exposed thickness, 8000 feet, is in the Pilot Mountains where the top is missing.

Rocks in the northern and northeastern exposures of the Luning Formation are like those at its type locality; massive limestone and dolomite dominate, but the various rock types have somewhat different proportions and succession. According to Ferguson and Muller (1949, p. 41) two different facies of the Luning have been brought together in the Shoshone Mountains by a major thrust fault. The Luning in the lower plate of this postulated thrust includes conglomerate, argillaceous rocks, and impure limestone, whereas massive dolomite and limestone make up the entire upper plate. A different interpretation is favored by Silberling (1959, p. 14), who regards these supposed thrust plates as parts of a continuous sequence, the massive carbonate rocks being the upper part of the Luning Formation of the same lithology and age as the upper part of the type section. The supposed facies differences between the Luning Formation above and below the Paradise thrust in the Paradise Range (Muller and Ferguson, 1939, p. 1597) are likewise suspect, although details of the formation are inadequately known here.

The Luning Formation probably did not extend far east or south of its present outcrops, as conglomerate is prominent in its southernmost outcrops, and as it is not preserved over the older rocks to the south and east. Deposition took place in "a local easterly bight in the margin of a broad Upper Triassic seaway whose general eastern boundary followed a northerly course" and which was named the Luning Embayment by Ferguson and Muller (1949, p. 5).

The fossiliferous lower and middle parts of the typical Luning Formation in the Pilot Mountains were considered to be Karnian (early Late Triassic) in age by Muller and Ferguson (1939, p. 1598). This is broadly corroborated in the nearby Gabbs Valley and Gillis ranges by the occurrence of upper Karnian ammonites apparently well above the base of the formation. In the Shoshone Mountains to the northeast, uppermost Karnian ammonites occur near the base of the unit, so that its deposition apparently began here somewhat later than in the type area. However, the Luning here is separated from the Diablo sequence by the Grantsville Formation. The Grantsville resembles the Luning lithologically, but recent fossil collections indicate that it is of latest Middle Triassic and perhaps earliest Late Triassic age. It is either a single remnant of a marine Triassic transgression into the Luning Embayment before the invasion of the Luning sea, or is a marine tongue of a basinward, older part of the Luning itself.

The upper part of the Luning Formation, including more than 2000 feet of massive carbonate rocks, is of Norian (late Late Triassic) age in the Shoshone Mountains, according to Silberling (1959, p. 23–24), who suggests that the Luning elsewhere may also extend well into the Norian.

The Gabbs and Sunrise formations, consisting of various proportions of calcareous silty shale, argillaceous silty limestone, silty limestone, and calcareous siltstone, overlie with sharp contact the relatively pure massive carbonate rocks of the Luning Formation. The type Gabbs Formation in the Gabbs Valley Range was correlated by Muller and Ferguson (1939, p. 1606, Table 3) with the entire Norian and Rhaetian stages of the Upper Triassic, but the lower and perhaps even the middle part of the Norian may occur in the underlying Luning Formation. The boundary between the Gabbs and Sunrise formations at their mutual type locality was originally established by Muller and Ferguson at the Triassic-Jurassic systemic boundary. However, this contact in the type area is marked by only a subtle change in lithology, and at other localities the two formations probably cannot be separated solely on lithologic grounds.

The upper part of the Sunrise Formation in the Gabbs Valley Range is Pliensbachian (late Early Jurassic) in age (Muller and Ferguson, 1939, p. 1621), whereas in the Shoshone Mountains the Sunrise extends into the Toarcian, the highest stage of the Lower Jurassic. In both areas the Sunrise is overlain with apparent conformity by the Dunlap Formation. At some other places, however, particularly along the southern margin of the Luning Embayment, nonmarine(?) sandstone, conglomerate, fanglomerate, and volcanic rocks of the Dunlap rest with angular unconformity on older parts of the Luning sequence or on the Diablo sequence, indicating that some of the Dunlap was deposited concurrently with folding and thrusting and destruction of the marine depositional basin (Muller and Ferguson, 1939, p. 1619).

*Gillis Sequence.* The Gillis sequence, the other distinct lower Mesozoic sequence in the southern part of the area, is a catch-all for rocks in the northwest part of the Hawthorne quadrangle that resemble one another and that, according to the present interpretation, do not belong to the contiguous Diablo and Luning sequences. It has been carried eastward over the Luning sequence by the Gillis thrust.

The dominantly volcanic Gillis sequence has no known counterpart in the area farther north. However, the increasing amount of volcanic rock in the westernmost exposures of the Natchez Pass Formation of the Winnemucca sequence suggests that some of the uppermost Triassic and Lower Jurassic rocks cropping out west of the Winnemucca sequence may surmount a dominantly volcanic sequence like the Gillis.

The rocks of the Gillis sequence are in the upper plate of the Gillis thrust in the Gillis Range and in the northwest Garfield Hills; lithologically similar rocks occur in the Wassuk Range and southern Sand Springs Range. These dominantly volcanic rocks were originally assigned by Muller and Ferguson (1939) and Ferguson and Muller (1949) to the Excelsior Formation, but this unit is here restricted to the lower plate of the Gillis thrust.

Fossils have been found at two localities in the Gillis sequence. Muller and Ferguson (1939, p. 1589) reported a pelecypod and brachiopod fauna of possible early Middle Triassic age in lenticular limestones interbedded with lavas and volcanic breccias above the Gillis thrust in the Gillis Range, and based the age of the Excelsior Formation as a whole on this fauna. D. C. Ross collected abundant large club-shaped echinoid spines and spongiomorphid hydrozoans from a thick limestone body included in volcanic rocks at the south end of the Sand Springs Range. These kinds of fossils are common in Middle and Upper Triassic rocks in California and Nevada and have not been observed in older rocks; hence they are suggestive of a post-Early Triassic age. Although incomplete, the faunal evidence suggests that the volcanic rocks in the Gillis sequence are younger than the Diablo sequence, as interpreted here, and are either older than, or correlative with, the nonvolcanic lower part of the Luning sequence.

# Structural and Depositional History

## INTRODUCTORY REMARKS

During the mapping of the Hawthorne and Tonopah quadrangles by Ferguson and Muller and the Sonoma Range quadrangle by Ferguson, Muller, and Roberts, it was recognized that thrust faults separate many of the structural blocks, and that thrusts are an important influence on the distribution of the Paleozoic and Mesozoic rocks in the region.

Some thrust faults mapped in western and central Nevada extend for many miles along the strike and have displacements measured in tens of miles (Roberts and others, 1958). Generally, the actual plane of a thrust can be traced for only a few miles before it is covered by younger rocks, but identical relationships of similar rock sequences in successive ranges indicate the continuity of some major thrusts.

Three periods of orogeny, during which thrust faults were developed, are documented by the rocks of northwestern Nevada. The Antler orogeny took place from Late Devonian to Middle Pennsylvanian time (Roberts, 1949; Roberts and others, 1958). This was followed during middle or Late Permian time by the Sonoma orogeny, the effects of which are most evident in the rocks beneath the Winnemucca and Augusta sequences. Finally, folding and thrust faulting were resumed in late Early Jurassic time (Ferguson and Muller, 1949, p. 13) and apparently persisted into Cretaceous time (Willden, 1958). This last orogenic period is here termed the Jurassic and Cretaceous orogeny.

The most difficult problem in interpreting the tectonic history of the area is to place the major thrust faults in their proper orogenic epoch. At first the thrusting was considered by Ferguson and Muller to be mainly post-early Mesozoic, but the discovery of Paleozoic thrusts in north-central Nevada (Roberts, 1949) requires reconsideration of the dating and sequence of thrusting and of the paleogeographic history. In some places where one thrust plate overlaps another their sequence can be established, but indirect evidence must be used where different structural units are not in contact or where their relationships are obscured by complex structures.

## PALEOZOIC HISTORY

The oldest orogeny recognized in northern Nevada is the Antler orogeny which involved rocks exposed only along the eastern and southern margins of northwestern Nevada.

One of the principal structural features of the Antler orogeny in north-central Nevada is the Roberts Mountains thrust fault which brought allochthonous eugeosynclinal rocks of the detrital-volcanic assemblage into juxtaposition with the autochthonous transitional assemblage and the shelf rocks of the carbonate assemblage. The Roberts Mountains thrust is exposed as far west as the Shoshone Range near Battle Mountain; westward it probably passes under Battle Mountain. Roberts and Hotz (*in* Roberts and others, 1958, p. 2851) believe that the Adelaide thrust in the Sonoma Range may be the westward extension of the Roberts Mountains thrust.

Before the Antler orogeny the Cordilleran geosyncline extended without interruption across Nevada. Eastern Nevada, east of the 117th meridian, was generally a shallow marine shelf throughout early and middle Paleozoic time. Westward the geosyncline changed to a deeper, or at least more rapidly subsiding, eugeosynclinal trough or complex of troughs between volcanic archipeligos. During the Antler orogeny a north-northeasterly trending emergent belt developed within this broad composite geosyncline, and marine sedimentation in north-central Nevada temporarily ended. Clastic sediments were shed eastward from the orogenic belt into eastern Nevada where shallow-water marine deposition continued throughout the remainder of the Paleozoic. Orogenic sediments were also shed westward into the Pumpernickel-Havallah basin.

Following the Antler orogeny, sedimentation within the orogenic belt was resumed: in northwestern Nevada, the Antler sequence was deposited beginning in Middle Pennsylvanian time; in west-central Nevada, the Diablo sequence was deposited beginning in Permian time. Both of these sequences rest with pronounced angular unconformity on lower and middle Paleozoic rocks and overlap structures developed during the Antler orogeny. Thus they are part of the overlap assemblage of Roberts and others (1958, p. 2838–2846). These sequences apparently have remained more or less autochthonous.

Sporadic occurrence of sand and fine-grained conglomerate in the Antler Peak Limestone suggests local emergent areas near the Antler depositional area, but most of north-central Nevada was probably submerged during Late Pennsylvanian and Early Permian time. Regional upwarping during the Permian is shown by local erosion of the Antler Peak and Battle formations before deposition of the Edna Mountain Formation of middle(?) Permian age. Except for this upwarping, the Antler belt was relatively stable during deposition of the Antler sequence.

Eugeosynclinal deposition west of the orogenic belt during late Paleozoic time is recorded by the Havallah sequence which was probably originally deposited west of its present exposures and thrust to the site of the Sonoma Range quadrangle. The Havallah is partly equivalent in age to the Antler sequence but is of such different facies that the two could not have been deposited in the same area; the most reasonable explanation is that they were brought together by thrust faulting of great magnitude. No lithologic equivalents of the Havallah sequence occur in the correlative upper Paleozoic rocks in eastern or southern Nevada; as the Antler sequence is considered autochthonous, the Havallah was presumably thrust from a westerly direction.

As pointed out by Roberts and others (1958, p. 2849), the rocks of the Garlock series in the El Paso Mountains near Mojave, California (Dibblee, 1952, p. 15–19), are lithologically like the Havallah sequence.

The lower 11,000 feet of the Garlock is mainly chert, greenstone, shale, and quartzite; the upper 24,000 feet is sandstone, shale, limestone, and chert with some andesite and has yielded a Lower Permian fauna at the base. The lower unit is therefore lithologically like the Pumpernickel Formation, and the upper unit like the Havallah Formation; moreover, the upper unit contains a fusulinid fauna of the same age as the upper part of the Havallah at Battle Mountain. The Havallah sequence could not have been derived by thrusting from an area so far away as the El Paso Mountains, but the Garlock series of Dibblee (1952) may well have accumulated in the southern part of the same basin in which the Havallah was deposited.

Wherever exposed, the lower contact of the Havallah sequence is the Golconda thrust (Pl. 2), which carried this sequence over the Antler sequence and underlying rocks at Battle Mountain, Edna Mountain, the Osgood Mountains, and the Sonoma Range. As the Winnemucca and Augusta sequences, along with the Koipato, rest depositionally upon the Havallah sequence, the age of the Golconda thrust has an important bearing on how the paleogeography of the lower Mesozoic rocks is interpreted.

*Sonoma Orogeny.* Evidence for orogeny during Permian time is best illustrated in the China Mountain area of the Golconda quadrangle (Ferguson and others, 1952) where the Havallah Formation of Pennsylvanian and Permian age has been tightly folded and thrust-faulted and is overlain unconformably by the Koipato Formation, the base of which is probably no older than Late Permian, followed by the Augusta sequence. An unconformity of similar magnitude between the Koipato and the Havallah sequence also occurs beneath the Winnemucca sequence, suggesting that Permian orogeny affected a large part of western Nevada. This period of folding and thrusting is here named the Sonoma orogeny.

## MESOZOIC HISTORY

Following the Sonoma orogeny in western Nevada, vulcanism was resumed in Late Permian time and persisted into the early part of the Early Triassic resulting in the accumulation of the Koipato sequence over the tightly folded rocks of the Havallah sequence and the accumulation of the Diablo sequence over the Antler orogenic belt farther south. Physical criteria and sporadic marine fossils indicate that both the Diablo and Koipato sequences are mainly marine deposits. As part of the time during which these sequences were deposited is represented by a hiatus in eastern Nevada and western Utah, this marine incursion was evidently from the west.

Emergence and nondeposition followed, after which the Triassic seas advanced eastward and southeastward across western Nevada. Throughout Middle and Late Triassic time and probably during the Early Jurassic as well, the Antler orogenic belt was intermittently a local source of clastic debris for the flanking areas. Nevertheless, the major portion of the fine-grained terrigenous sediment deposited in the lower Mesozoic seas of western Nevada must have been transported across the beveled orogenic belt from the continental area farther east and southeast.

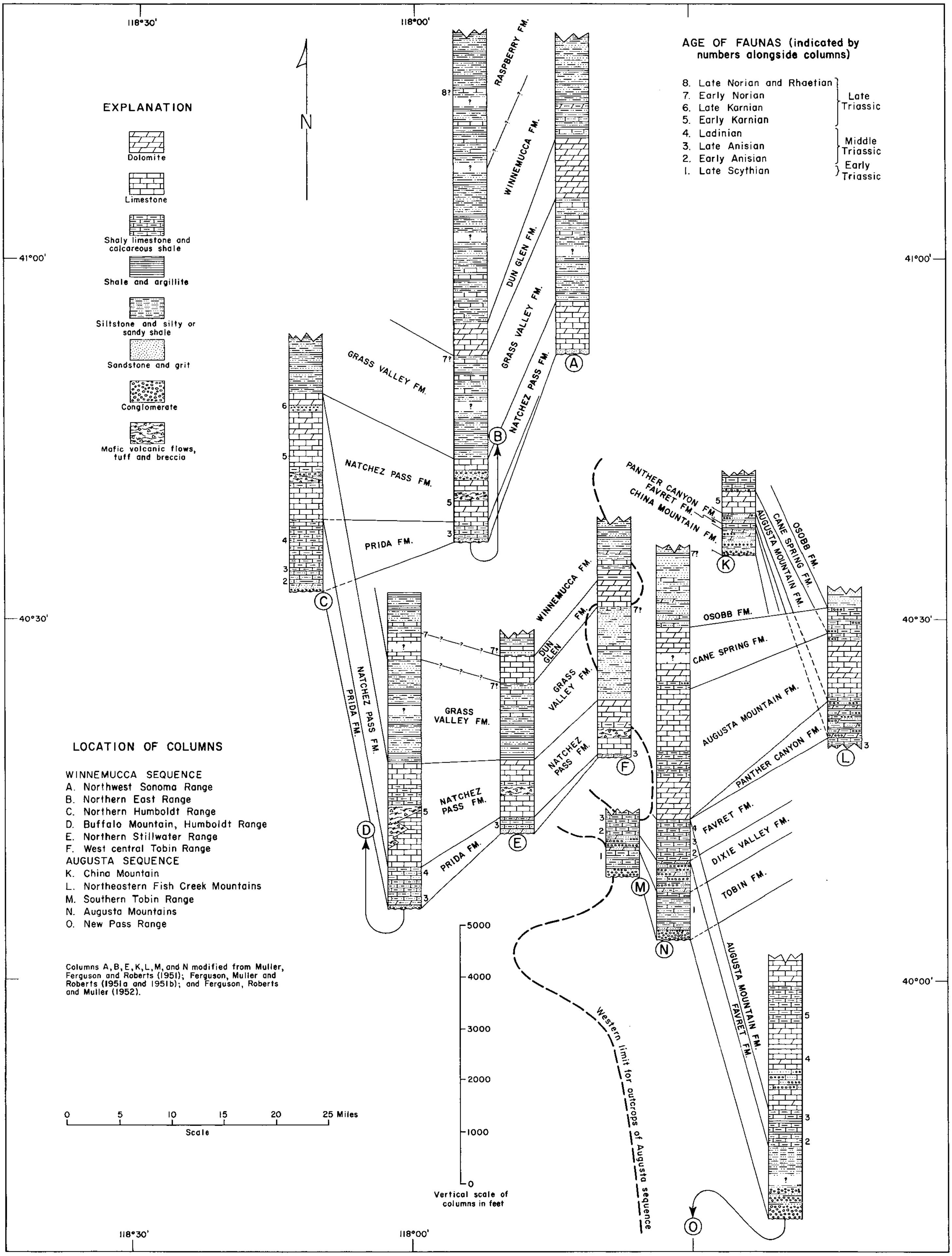
The lower Mesozoic rocks that crop out in the Sonoma Range quadrangle and vicinity belong either to the Winnemucca or the Augusta sequence, both of which are mainly of shallow-water marine origin. Starting with the Middle Triassic, these rocks apparently accumulated on a shelf area marginal to an early Mesozoic geosyncline to the west. Relationships in both sequences indicate an eastward shore line during Middle and Late Triassic time, and the Augusta sequence apparently was the more shoreward of the two. This is the reverse of the paleogeographic interpretation made by Muller (1949), who considered the Augusta sequence a relatively offshore facies of the Winnemucca sequence, and by postulating thrusting of the Augusta sequence into its present position from the east, implied the persistence of a marine basin in northeastern Nevada throughout the Triassic. The present writers disagree with this view because, in addition to the evidence for offshore conditions to the west, there is no record of marine Middle and Upper Triassic rocks in the Great Basin east of central Nevada; on the contrary, continental Upper Triassic has been reported in southeastern Elko County, Nevada (Wheeler and others, 1949).

It seems probable, therefore, that the Middle and Upper Triassic rocks of the Augusta sequence were deposited near the eastern margin of a sea which transgressed over the area from the west. However, the marine Lower Triassic rocks of the Tobin Formation at the base of the Augusta sequence must have formed under different conditions, as the Tobin has no counterpart in the Winnemucca sequence to the west. The Tobin Formation—dominantly calcareous siltstone and shale—resembles the partly correlative marine Lower Triassic rocks cropping out in the eastern part of the Great Basin and may be genetically related to them. Strata representing the middle part of the Lower Triassic are absent throughout northwestern Nevada, northern California, and Oregon suggesting that much of this region was emergent while an epicontinental sea occupied the eastern Great Basin. During latest Early Triassic time this sea may have transgressed westward to the depositional site of the Tobin Formation; by Middle Triassic time, when the seas invaded northwestern Nevada from the west, nonmarine conditions evidently prevailed in the region to the east. Thus, although the area of the two inundations may have overlapped at the depositional site of the Augusta sequence, neither seaway was continuous across northern Nevada. The suggestion by Clark (1957, p. 2214–2217, Fig. 3) that Lower Triassic seas were continuous across northern Nevada, as evidenced by "cratonal rocks" in north-central Utah, "miogeosynclinal rocks" in northwestern Utah and northeastern Nevada, and "eugeosynclinal rocks" in western Nevada, seems oversimplified. "Eugeosynclinal" strata correlative with the "miogeosynclinal" and "cratonal" Lower Triassic rocks discussed by Clark are unknown in northwestern Nevada.

The Luning sequence, like the Winnemucca and Augusta sequences, comprises mainly marine shallow-water sedimentary rocks which again indicate the existence of a shore line to the east, as well as to the south, during Middle and Late Triassic time. As the Luning sequence and the underlying Diablo sequence overlap the Antler orogenic belt, they were apparently autochthonous with respect to large-scale thrusting during Mesozoic time.

The dominantly volcanic Gillis sequence, as interpreted here, contrasts abruptly with the contiguous Luning sequence in which correlative rocks are either absent or of an entirely different and nonvolcanic facies. Hence, if the Luning sequence is autochthonous, the Gillis sequence must be allochthonous and must have been greatly displaced. The volcanic nature of the Gillis sequence indicates a derivation generally from the west, but until its composition and age are better known, its original stratigraphic relationships to the lower Mesozoic rocks exposed to the north cannot be inferred.

*Jurassic and Cretaceous Orogeny.* Ferguson and Muller (1949, p. 13) have shown that, in the Hawthorne and Tonopah quadrangles, the youngest lower Mesozoic rocks were deposited concomitantly with the initial folding and thrusting in the area. Orogenic movements began in Early Jurassic time and were apparently prolonged. Similar orogenic movements in north-central Nevada may also have taken place in




RECONSTRUCTED COLUMNAR SECTIONS OF TRIASSIC ROCKS OF WINNEMUCCA AND AUGUSTA SEQUENCES OF NORTHWESTERN NEVADA

Lithology generalized, and many thicknesses are only approximations. Lines connecting columns indicate lithic correlations. Location of the columns in relation to the distribution of the different sequences is shown in Figure 3.

SILBERLING AND ROBERTS, PLATE 1

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Jurassic time, but Willden (1958) has shown that some thrust faulting there continued into Cretaceous time. As there is presently no means of assigning the various structural features in northwestern Nevada to different pulses of orogeny during Jurassic and Cretaceous time, the term "Jurassic and Cretaceous orogeny" is appropriate.

The only thrust that requires great horizontal displacement—perhaps as much as several tens of miles—and that was unquestionably developed during the Jurassic and Cretaceous orogeny is the Gillis thrust which brings the Gillis sequence and the Luning and Diablo sequences together in the southwestern part of the area. It is tempting to visualize a northern extension of the Gillis thrust, possibly through the Sand Springs or Stillwater ranges and west of the Humboldt and West Humboldt ranges, but documentation for such a thrust is lacking.

Aside from the Gillis thrust, thrust faulting in the Hawthorne and Tonopah quadrangles, although complex, is mainly local, and displacements of a few miles or less involve rocks of the same sequence or depositionally contiguous sequences. The Monte Cristo thrust in the eastern Candelaria Hills and southwestern Monte Cristo Range deserves special attention, as it brings together different facies of the Diablo sequence. On it the Diablo and Candelaria formations were carried over the Excelsior Formation, presumably from the south or southeast. Ferguson and others (1953) relate the folding in the Excelsior beneath the Luning formation to this thrusting and postulate a Triassic age for the Monte Cristo thrust; nevertheless, a younger age is possible.

### THRUST FAULTING IN THE SONOMA RANGE QUADRANGLE

In contrast to thrusting in the southern part of the area, that in the Sonoma Range quadrangle involves movements of several large plates which bring together depositionally unrelated sequences by displacements of as much as several tens of miles. Some of these thrusts involve lower Mesozoic rocks and are obviously the result of Jurassic and Cretaceous orogeny; others can be assigned to either the Sonoma or Antler orogenies. However, the ages of some are uncertain. As the interpretation of this thrust faulting is important for the understanding of the structural and paleogeographic history of the pre-Tertiary rocks throughout northwestern and north-central Nevada, special emphasis is given here to the thrust sequence and the direction of movement of plates in the Sonoma Range quadrangle.

Seven of the major thrust faults in the Sonoma Range quadrangle were named by Ferguson and others (1951a; Muller, Ferguson, and Roberts, 1951; and Roberts, 1951). These are the Tobin, Golconda, Dewitt, Adelaide, Clear Creek, Sonoma, and Thomas thrusts (Pl. 2). Several additional thrust names are introduced here.

As originally described, the Clear Creek and Sonoma thrusts in the northern Sonoma Range complexly intersect one another and other thrusts (Fig. 6). Using the original mapping, one can assign or connect the different segments of these two thrusts in several ways and arrive at different interpretations of their age and sequence. These interpretations bear in turn on the age of the Golconda thrust and on the structural and depositional history of the area in general. To avoid using the names Sonoma thrust and Clear Creek thrust for unlike concepts, depending upon which interpretation is adopted, these names are restricted to the typical segments of the thrusts, and new names, the Mullen Canyon, Water Canyon, and Elbow Canyon thrusts, are proposed for the other segments. New names are also introduced for two other thrust faults: Hoffman Canyon for the thrust within the Havallah sequence which is overlapped by the Koipato at China Mountain, and Willow Creek for the thrust in the East Range that carried the Leach and Inskip formations over the Winnemucca sequence.

As the relative age and importance of the various thrusts is a matter of interpretation, the following descriptions are arbitrarily arranged geographically from east to west across the Sonoma Range quadrangle.

*Dewitt Thrust.* The Dewitt thrust (Pl. 2) carried Harmony Formation of the transitional assemblage of lower Paleozoic rocks over the Scott Canyon and Valmy formations of the detrital-volcanic assemblage at Battle Mountain (Roberts, 1951). As the thrust is overlapped by the Battle Formation at the base of the Antler sequence, it was clearly emplaced during the Antler orogeny and can be considered as a branch of the Roberts Mountain thrust, which underlies the detrital-volcanic assemblage rocks in this part of Nevada.

*Golconda Thrust.* The Golconda thrust was first interpreted by Muller and others (1951, Fig. 1) as having an arcuate trace extending from Battle Mountain through Edna Mountain to the west side of the Sonoma Range (Pl. 2). Wherever exposed, the thrust carried the Havallah sequence over deformed lower Paleozoic rocks and locally over the Antler sequence, which rests unconformably upon lower Paleozoic rocks. The similarity of relationships between the disconnected exposures of the thrust in the Sonoma Range and at Edna Mountain with those at Battle Mountain leaves little doubt as to its continuity. Muller and others (1951) originally suggested that the Golconda thrust may be the same as the Tobin thrust and used the names interchangeably. The thrusts are treated separately here, because, whereas the Tobin thrust displaces Mesozoic rocks, the Golconda thrust cuts only Paleozoic rocks and its age is subject to interpretation. Also, generally eastward movement of the Havallah sequence on the Golconda thrust seems mandatory, yet the facies relationships between the Triassic rocks above and below the Tobin thrust indicate a westward displacement of the Tobin plate.

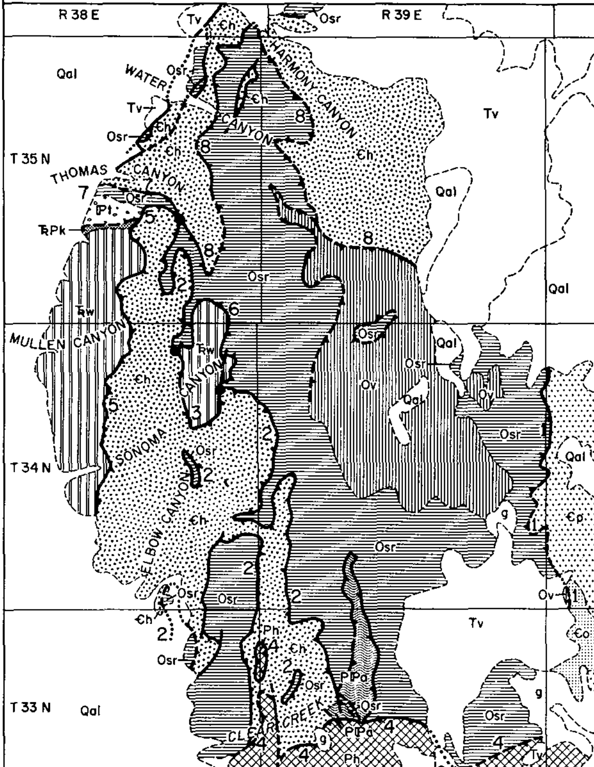
*Hoffman Canyon Thrust.* The name Hoffman Canyon is proposed here for the thrust described by Ferguson and others (1952) at the south end of China Mountain (Pl. 2) that carried the Pumpernickel Formation eastward over the Havallah Formation and is overlapped by the Koipato and Augusta sequences. Displacement on this thrust within the Havallah sequence may be relatively minor, yet it indicates strong deformation during the Sonoma orogeny before deposition of the Koipato.

*Tobin Thrust.* Typical exposures of the Tobin thrust are at the south end of the Tobin Range where it carried the Augusta sequence and a thick mass of Koipato over the Winnemucca sequence. The isolated patches of Augusta sequence in the eastern Stillwater and East ranges are provisionally included in the upper plate of the Tobin thrust (Pl. 2). The thrust perhaps extends south of the Sonoma Range quadrangle for several tens of miles (Fig. 3) where, though covered by Cenozoic deposits, it may separate the homoclinally dipping Augusta sequence in the New Pass Range from rocks of the Winnemucca sequence in the Clan Alpine Range which are isoclinally folded and overturned toward the southwest.

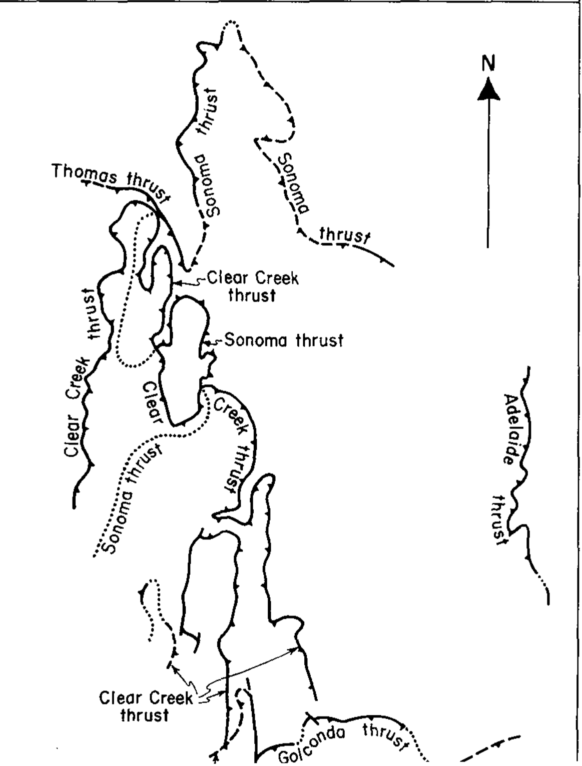
Westward thrusting of the Augusta sequence—presumably on the Tobin thrust—on the "order of several tens of miles" was first proposed by Muller (1949). Although the paleogeographic interpretation of the Augusta and Winnemucca sequences made here differs from his, this direction of displacement still seems the most likely. Nevertheless, a large displacement is not mandatory in view of the general similarity of the Winnemucca and Augusta sequences, which represent shallow-water deposits in which rapid lateral variations are to be expected. As the trace of the Tobin thrust is nearly parallel to the inferred trend of the Middle and Upper Triassic shore line, the thrust might have

A

Thrust nomenclature of this report; numbers refer to list below



B
Thrust nomenclature of Ferguson, Muller, and Roberts (1951)



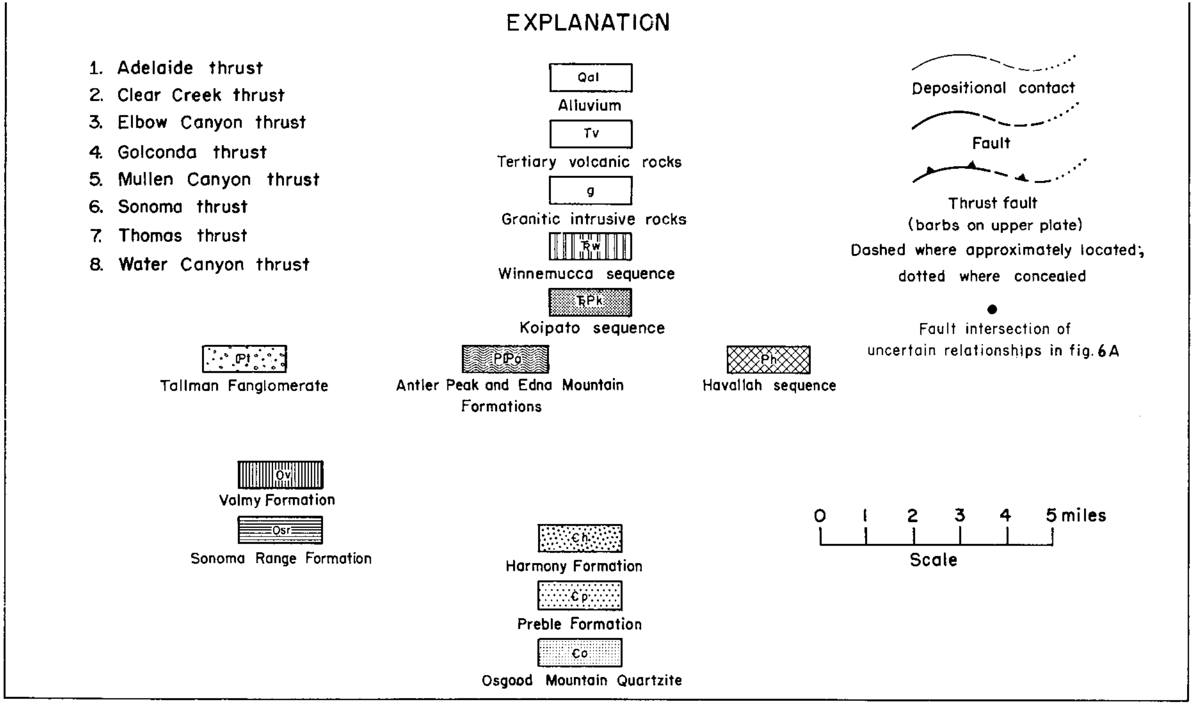



Figure 6. Geologic map of northern part of Sonoma Range generalized and somewhat modified from Ferguson and others (1951a). A illustrates thrust fault nomenclature adopted in this report; B shows thrust faults named by Ferguson and others and original nomenclature. On A, fault intersections where relationships are uncertain are indicated by dots.

telescoped the Triassic rocks along a major change in facies. Only a few miles of displacement would then be required in the typical area of the thrust, and other exposures of the Augusta sequence might have been unaffected by it.

*Adelaide Thrust.* The Adelaide thrust (Muller and others, 1951) (Fig. 6; Pl. 2) is exposed along the east flank of the northern Sonoma Range. It cuts only lower Paleozoic rocks; the upper plate comprises the Sonoma Range and Valmy formations of the detrital-volcanic assemblage which overrode the Harmony, Preble, and Osgood Mountain formations of the transitional assemblage.

*Clear Creek Thrust.* The Clear Creek thrust in the northern Sonoma Range is restricted here to the eastern part of the trace originally assigned to it by Muller and others (1951) and to the exposures of the thrust that bound several windows of lower Paleozoic rocks in the southern part of its upper plate (Fig. 6). It extends generally southward from its mutual intersection with the Thomas, Mullen Canyon, and Water Canyon thrusts to its intersection with the Golconda thrust which truncates it. In Sonoma Canyon the trace of the thrust is interrupted by a window of Triassic rocks bounded by the Elbow Canyon and Sonoma thrusts. As redefined, the thrust carried the Harmony Formation over detrital-volcanic assemblage lower Paleozoic rocks of the Sonoma Range Formation. As mapped by Ferguson and others (1951a), a small patch of the Antler sequence rests depositionally on folded Harmony Formation at the southeast corner of the Clear Creek plate, and apparently overlaps the Clear Creek thrust as well. This relationship and the fact that the Clear Creek thrust is structurally involved with the same kinds of rock as the Dewitt thrust, strongly suggests kinship of these two thrusts.

*Mullen Canyon Thrust.* The name Mullen Canyon is proposed here for the thrust in the northern Sonoma Range originally interpreted by Ferguson and others (1951a) as the westernmost segment of the Clear Creek thrust (Fig. 6). The Mullen Canyon thrust is exposed from its intersection with the Clear Creek thrust, as restricted here, and the Thomas and Water Canyon thrusts southward to the west front of the range. Above the thrust are lower Paleozoic rocks of the Harmony Formation; the lower plate is mainly Triassic rocks of the Winnemucca sequence, but toward its north end it includes rocks of the Koipato sequence, Tallman Fanglomerate, and Sonoma Range Formation. The nature of the contact between the Koipato and Tallman is uncertain, but may be a fault as shown on Figure 6A.

*Sonoma Thrust.* The Sonoma thrust is restricted here only to that segment of the thrust as originally described by Ferguson and others (1951a) which borders the north end of the window of Triassic rocks in Sonoma Canyon (Fig. 6). It extends from its intersection with the Clear Creek and Elbow Canyon thrusts on the east side of the window around the north end of the window to its intersection with these same thrusts on the west side. Above the thrust is the detrital-volcanic assemblage Sonoma Range Formation, and below it are Triassic rocks of the Winnemucca sequence.

*Elbow Canyon Thrust.* The thrust bounding the southern part of the Triassic window in Sonoma Canyon is here called the Elbow Canyon (Fig. 6). Ferguson and others (1951a) originally connected this thrust with the Clear Creek thrust, but it is uncertain whether it joins the Clear Creek or the Sonoma thrust, so it is named separately here. The rocks above the thrust are the Harmony Formation, and those below are the Winnemucca sequence.

*Water Canyon Thrust.* The name Water Canyon thrust (Fig. 6) is used here for what was considered by Ferguson and others (1951a) to be the northern segment of the Sonoma thrust. From its intersection with the Thomas, Mullen Canyon, and Clear Creek thrusts, the trace of the Water Canyon thrust extends southeasterly, then turns abruptly northward and continues to the northwest flank of the range, whereupon it turns southeast again and crosses to the east side of the Sonoma Range where it is covered by Cenozoic rocks. The upper plate includes the Sonoma Range and Valmy formations of the lower Paleozoic detrital-volcanic assemblage, and the lower plate is Harmony Formation of the transitional assemblage.

*Thomas Thrust.* The Thomas thrust as described by Ferguson and others (1951a) is exposed along the south wall of Thomas Canyon in the northwestern Sonoma Range from the range front to its intersection with the Water Canyon, Mullen Canyon, and Clear Creek thrusts (Fig. 6). The rocks below the thrust are the Harmony Formation, and those immediately above, although originally regarded as part of the Leach Formation, are here assigned to the Sonoma Range Formation.

The Tallman Fanglomerate overlies the Sonoma Range Formation in the upper plate of the Thomas thrust but is not cut by the thrust itself. The Koipato and Winnemucca sequences were also included in the upper plate by Ferguson and others (1951a), but these may be normally faulted against the Thomas plate (Fig. 6A) and distinct from it.

*Willow Creek Thrust.* The thrust beneath the Leach and Inskip formations in the East Range (Fig. 4; Pl. 2) is here named the Willow Creek thrust. The Leach, mainly greenstone, chert, shale, and quartzite, is generally similar to the Valmy Formation and may be partly correlative with it. The Inskip is largely sandstone and conglomerate, with some limestone and greenstone, and has no lithologic equivalent elsewhere in the Sonoma Range quadrangle, although it is similar in age and composition to an unnamed formation in the Osgood Mountains (P. E. Hotz, unpub. ms.). The small patch of Harmony Formation shown in thrust contact with the Leach (Fig. 4) may also be part of the Willow Creek plate. The Willow Creek plate is thus composed of lower and middle Paleozoic rocks of the detrital-volcanic assemblage and possibly also of the transitional assemblage. Presumably it moved into the area from the east as it overrode the Winnemucca sequence which extends with apparent continuity for many miles to the west. In addition, the Winnemucca sequence is overturned toward the northwest beneath the north end of the Willow Creek plate, suggesting generally westward movement of the plate.

The Willow Creek thrust is tentatively projected southward beneath Tertiary volcanic rocks to the southeastern East Range where the Havallah and Koipato sequences form its lower plate (Pl. 2). However, it is not known whether the Havallah and Koipato beneath the thrust in the southeastern East Range were originally overlain by the Winnemucca or by the Augusta sequence of Triassic rocks. On Plate 2 they are assumed to have been overlain by the Winnemucca sequence.

*Relationships between Thrusts in the Northern Sonoma Range.* Eight of the thrusts described heretofore are in the northern part of the Sonoma Range, and each, except the Adelaide thrust, either joins or is truncated by another. The northern Sonoma Range thus provides a unique opportunity for establishing the sequence and relative age of the various thrusts. Some of these thrusts are undoubtedly equivalent, but they can be combined in different ways to create diverse interpretations of the structural history.

In the original interpretation of the area by Ferguson and others (1951a), all the thrusts in the northern Sonoma Range were believed to be post-Triassic. The oldest was the Thomas thrust, on which the Koipato and Winnemucca sequences were introduced. The Thomas thrust was then overlapped by a plate of the detrital-volcanic assemblage along the Sonoma, Water Canyon, and Adelaide thrusts of present terminology. This plate was overridden in turn by a plate of Harmony Formation riding along the Clear Creek, Elbow Canyon, and Mullen Canyon thrusts. Finally, the Havallah sequence and overlying Augusta sequence were introduced on the Golconda thrust, which truncates the Clear Creek thrust (Fig. 7A).

A modification of this scheme, suggested by Roberts and Hotz (*in* Roberts and others, 1958, p. 2951), is that the Adelaide thrust is the westward extension of the Roberts Mountains thrust and formed during the Antler orogeny. The Adelaide in turn might be equivalent to the Water Canyon and Thomas thrusts, forming a plate of Valmy and Sonoma Range formations of the detrital-volcanic assemblage that overrode the Harmony, Preble, and Osgood Mountain formations of the transitional assemblage. This would then be the lowest thrust in the Sonoma Range, and as it involves only lower Paleozoic rocks, it might have formed during the Antler orogeny (Fig. 7B). However, this requires two alterations of the original structural interpretation of the area. First, a connection for the Sonoma thrust must be found—most likely a fault between the Koipato and Tallman formations beneath the Mullen Canyon thrust (Fig. 7A). Second, a thrust (Fig. 7B, labelled 3a) that is nowhere exposed would have to underlie the Winnemucca sequence. This is required because transport of the Havallah sequence from the west is mandatory, and according to this scheme, the Golconda thrust, which carried the Havallah sequence that underlies the Augusta sequence, is the youngest of the Mesozoic thrusts. As the Winnemucca sequence would be in the lower plate of the Golconda thrust and yet depositionally overlies rocks of the Havallah sequence, it must also have been derived from a westerly direction on a thrust pre-dating the Golconda thrust.

A third and more novel structural interpretation of the northern Sonoma Range can be made if the Clear Creek, Thomas, and Adelaide thrusts are ascribed to the Antler orogeny (Fig. 7C). The Thomas and Adelaide thrusts may then be segments of the Roberts Mountains thrust on which the detrital-volcanic-assemblage lower Paleozoic was introduced into north-central Nevada during the Antler orogeny. During or closely following this initial thrusting, further deformation created the Clear Creek thrust which carried the Harmony Formation over the detrital-volcanic assemblage. The Clear Creek would thus be analogous to the Dewitt thrust at Battle Mountain; both would have carried the Harmony Formation over lower Paleozoic rocks of the

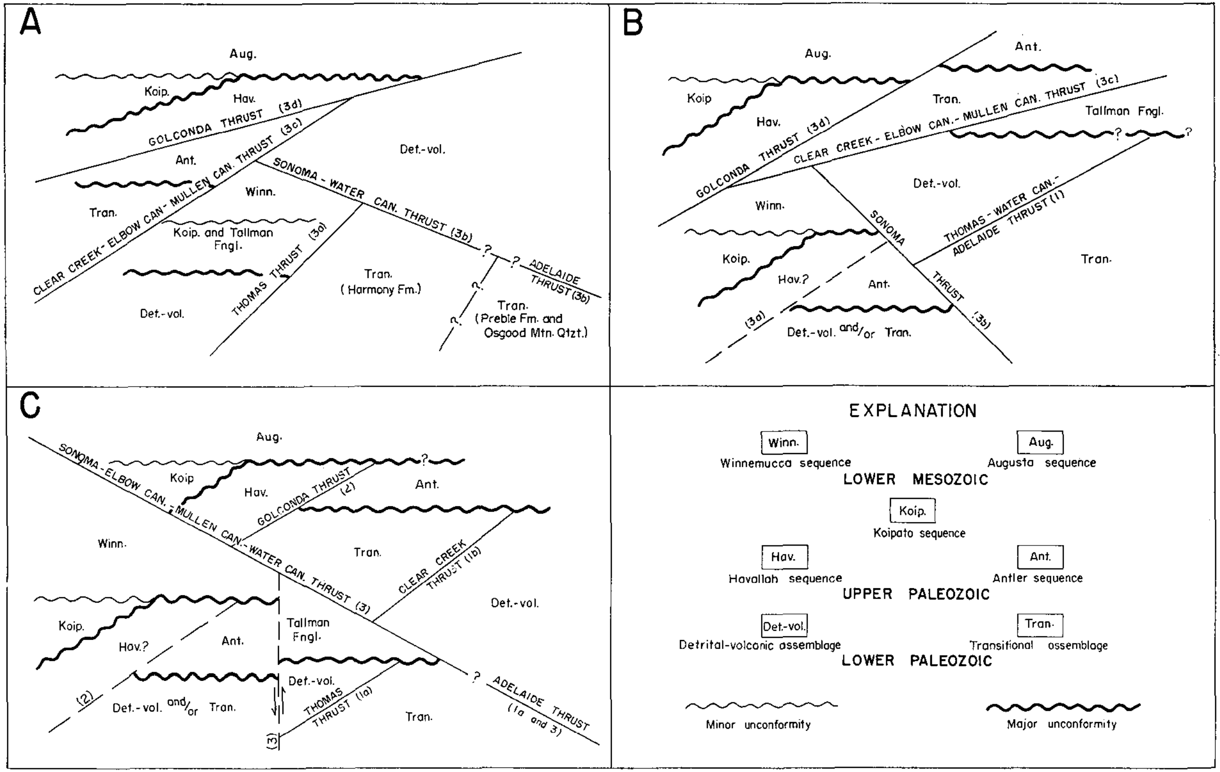



Figure 7. Three diagrammatic interpretations of sequence and relationships between various thrusts in northern Sonoma Range. Relative ages assigned to thrusts indicated by number and letter symbols (1a, 1b, 2, *etc.*): 1 designates thrusts thought to have been developed during Antler orogeny, 2, those developed during Sonoma orogeny, 3, those developed during Jurassic and Cretaceous orogeny. Slope of thrusts has no significance. A is modified from Ferguson and others (1951a); B and C represent alternative interpretations discussed in text.

detrital-volcanic assemblage, and both may be overlapped by the Antler sequence. The Golconda thrust, which truncates the Clear Creek thrust, is then of indefinite age and might have been formed during the Sonoma orogeny (Fig. 7C). The remaining thrusts in the northern Sonoma Range, the Sonoma, Elbow Canyon, Mullen Canyon, and Water Canyon thrusts, would then be parts of one dislocation that carried a structurally complex plate of lower Paleozoic over Triassic rocks of the Winnemucca sequence. The trace of the Mullen Canyon and Water Canyon thrusts would mark the western and northern limits of this plate, through which appears a window of the Winnemucca sequence bounded by the Sonoma and Elbow Canyon thrusts. A relationship between this thrust plate and that of the Willow Creek thrust in the northern East Range is suggested by their similarity in composition and the fact that both overrode the Winnemucca sequence and underlying rocks. Displacement of the Sonoma-Elbow Canyon-Mullen Canyon-Water Canyon thrust would be post-Triassic, but on the northern part where it carried the detrital-volcanic assemblage of lower Paleozoic rocks over the Harmony Formation, it might have been a renewal of movement on the Paleozoic Adelaide thrust (Fig. 7C).

The writers have so far only suggested the widely different structural interpretations that can be based on the original mapping of the northern Sonoma Range. Clearly, a long-term project of detaield mapping of this critical area is desirable, but even this may not provide a completely objective solution to the sequence of thrusting because of the shearing and poor exposures in critical areas. The structural interpretation of the Sonoma Range will probably always depend at least in part on the inferred regional relationships of the rocks involved.

## STRUCTURAL INTERPRETATION OF THE SONOMA RANGE QUADRANGLE

Two different general interpretations can be made of the structural history of the Sonoma Range quadrangle; these result in different Mesozoic paleogeographic histories. The crux of the problem is the age of the Golconda thrust, as the dissimilarity of the upper Paleozoic rocks in its upper and lower plates requires great horizontal displacement. If the Golconda thrust is a major displacement of Jurassic and Cretaceous age, it controls the present location of the Triassic rocks of the Augusta sequence. On the other hand, if the thrust formed during the Sonoma orogeny, the distributions of the Augusta and Winnemucca sequences were not affected by it.

*Golconda Thrust Related to Jurassic and Cretaceous Orogeny.* A structural history of the Sonoma Range quadrangle that favors development of the Golconda thrust during the Jurassic and Cretaceous orogeny fits the original interpretation of the area by Ferguson, Muller, and Roberts. This requires deposition of the Augusta sequence and underlying Koipato some distance west of their present exposures and transport of both of them and the Havallah sequence into the site of the Sonoma Range quadrangle on the Golconda thrust. It is supported by: (1) the apparent confinement to the upper plate of the Golconda thrust of rocks that can be assigned without question to the Augusta sequence; and (2) the feasibility of ascribing a post-Triassic age to the Golconda thrust in the northern Sonoma Range by connecting the Clear Creek thrust, which is truncated by the Golconda, with the Elbow Canyon and Mullen Canyon thrusts, which cut Triassic rocks.

However, the Middle and Upper Triassic part of the Augusta sequence is a more easterly and nearer-shore facies of the equivalent part of the Winnemucca sequence. If the Golconda thrust were the youngest of the Mesozoic thrusts in the northern Sonoma Range, the overlapping relationships of these thrusts would require emplacement of the Augusta sequence as part of the Golconda plate after introduction of the Winnemucca sequence on a structurally lower plate. As the Winnemucca sequence now extends far to the north and west of the Augusta sequence and is apparently a relatively offshore facies, the rocks of the Augusta sequence could not have been derived by thrusting from these directions. Thrusting of the Augusta sequence into the area from the southwest is possible, but the distribution of the evidently autochthonous and strikingly different Luning sequence (Fig. 3) does not leave room for deposition of the Augusta sequence at any point nearer than 100 miles to the southwest. Even with this great horizontal displacement, the presence of marine Lower Triassic rocks at the base of the Augusta sequence could not be explained, as they have no equivalents in the other lower Mesozoic sequences of northwestern Nevada.

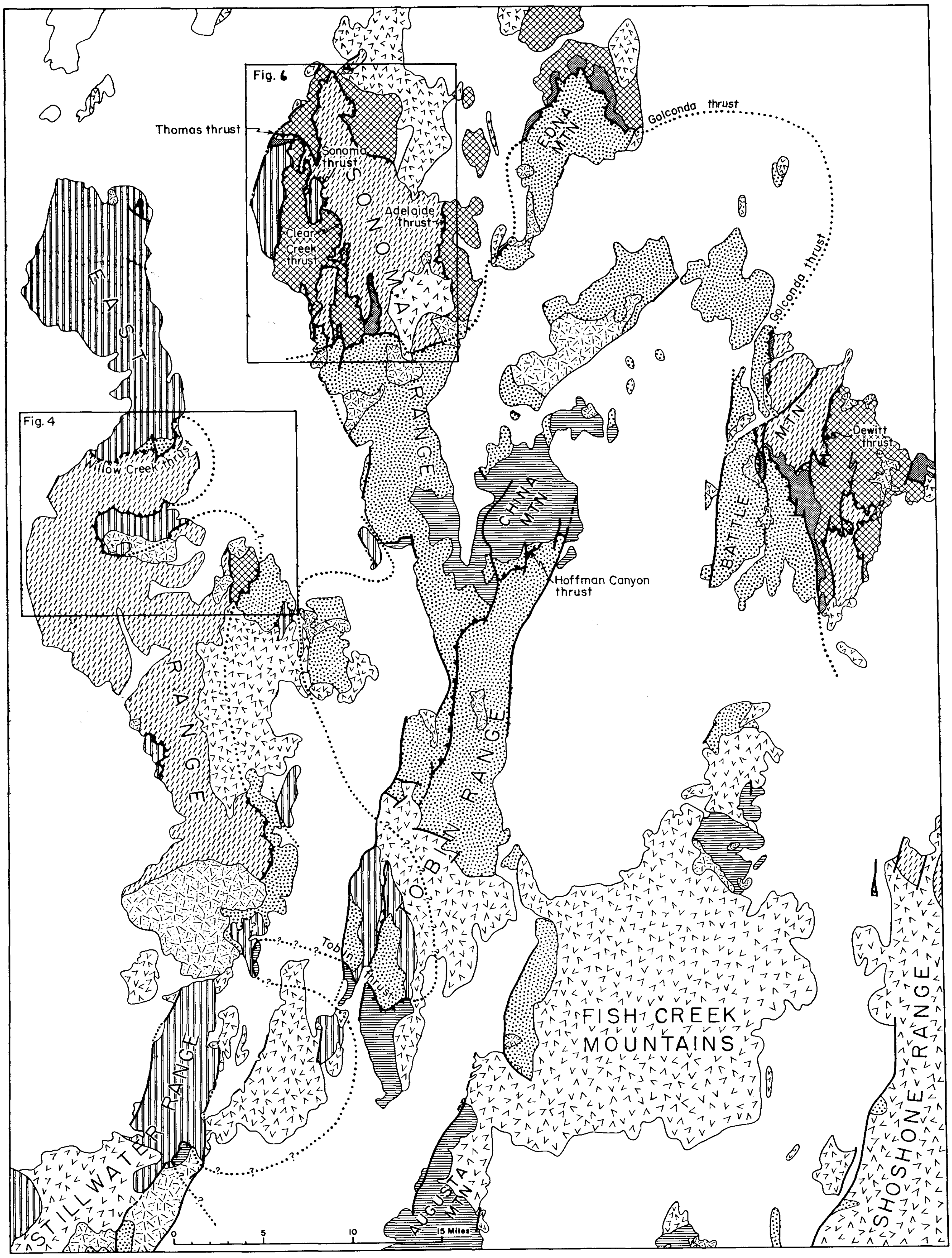
The paleogeographic requirements of the Triassic rocks could be accommodated by assuming that both the Winnemucca and Augusta sequences were introduced during late Mesozoic time on the Golconda thrust in their present east-west geographic relationship. The thrust that carried the Havallah, Koipato, and Augusta sequences in the Sonoma Range (Pl. 2) would then not be part of the Golconda thrust, but would be younger and analogous to the Tobin thrust that telescoped rocks in the upper plate of the Golconda thrust. However, similarity of the upper and lower plates of the so-called Golconda thrust in the Sonoma Range to those of the Golconda thrust at Edna Mountain and Battle Mountain and apparent continuity of the trace of the thrust between the three areas seems to oppose such an assumption.

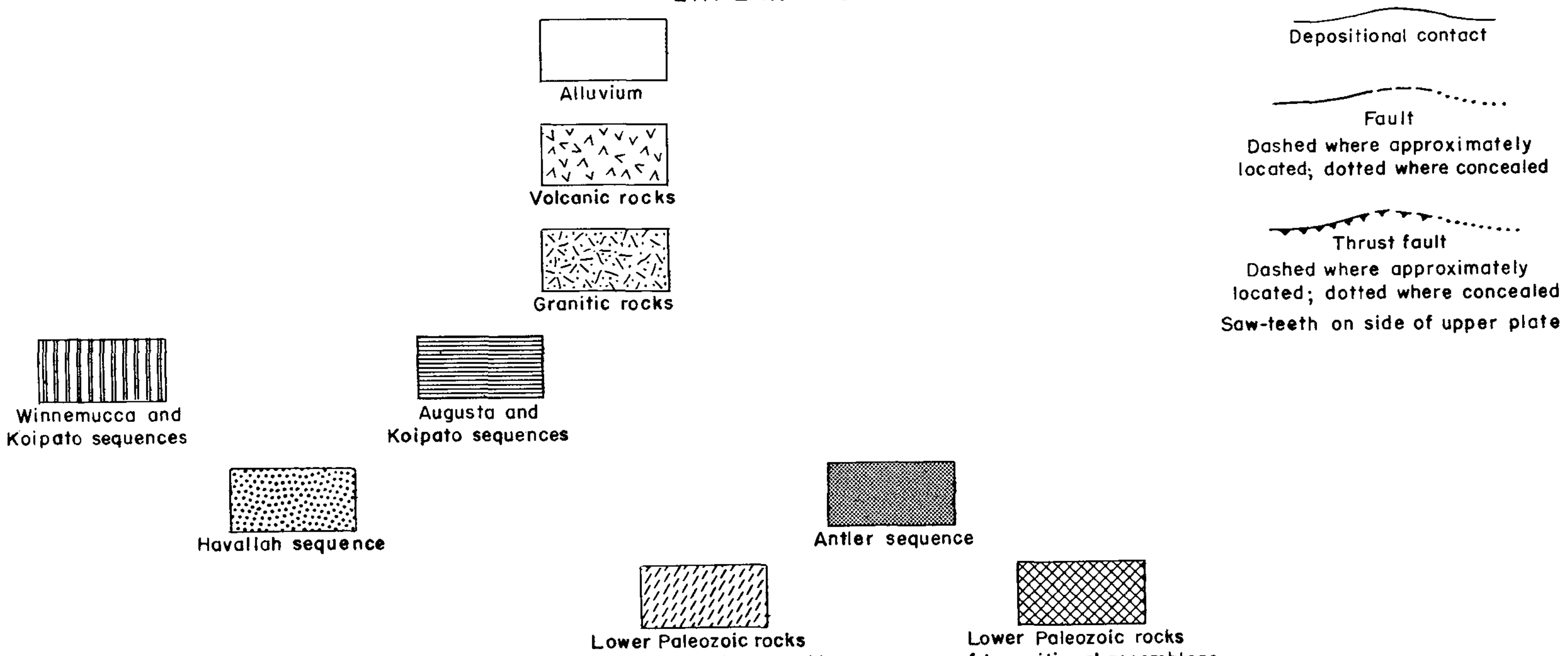
*Golconda Thrust Related to Sonoma Orogeny.* The alternative structural interpretation of the Sonoma Range quadrangle assigns the Golconda thrust to the Sonoma orogeny. The Havallah sequence would then have been thrust into the area before deposition of the Koipato and lower Mesozoic sequences. The Augusta and Winnemucca sequences would have been deposited more or less where they are now exposed with only minor telescoping by westward dislocation of the Augusta sequence on the Tobin thrust and on the Sonoma-Elbow Canyon-Mullen Canyon-Water Canyon thrust. The following considerations support this interpretation: (1) The facies relationships between the Winnemucca and Augusta sequences indicate that they were originally deposited in their present east-west geographic relationship. (2) The presence of marine Lower Triassic rocks in the Augusta sequence and the absence of correlative strata in the other lower Mesozoic sequences in northwestern Nevada may be explained by considering the Tobin Formation at the base of the Augusta sequence as the westernmost deposit of the epicontinental Early Triassic sea that occupied the eastern Great Basin. This explanation is more reasonable if the Augusta sequence was originally deposited at least as far east as its present location. (3) The present eastern extent of the Koipato sequence corresponds with that of the correlative volcanic rocks of the Pablo and Excelsior formations farther south (Fig. 3) where they are evidently autochthonous with respect to large-scale thrusting during Jurassic and Cretaceous time. (4) The Augusta sequence, wherever exposed, has been little deformed and lacks any internal structures indicative of great transport by thrusting. (5) The Clear Creek thrust in the northern Sonoma Range may be reinterpreted as having been formed during the Antler orogeny rather than during Jurassic and Cretaceous orogeny, and the Golconda thrust, which truncates the Clear Creek thrust, may then be as old as Permian. (6) If the Thomas-Adelaide and Clear

Creek thrusts belong to the Antler orogeny and the Golconda thrust to the Sonoma orogeny (Fig. 7C), displacements on the Mesozoic thrusts in the Sonoma Range quadrangle, *i.e.*, the Tobin, Willow Creek, and Sonoma-Elbow Canyon-Mullen Canyon-Water Canyon thrusts, are uniformly to the west and not necessarily of great magnitude. This contrasts with the original view (Fig. 7A) wherein a criss-cross of plates in the northern Sonoma Range is required, some of which moved eastward and some westward during the Jurassic and Cretaceous orogeny. (7) Evidence for strong deformation during the Sonoma orogeny is provided by the Hoffman Canyon thrust and by the tight folding of the Havallah sequence wherever it is exposed beneath the Koipato or the Winnemucca and Augusta sequences. If the Golconda thrust formed during the Sonoma orogeny, it must be younger than the Edna Mountain Formation at the top of the Antler sequence and older than the Koipato sequence. As the fauna of the Edna Mountain Formation is probably equivalent to that at the base of the Diablo Formation in the Toiyabe Range, and as the Koipato is equivalent to the Pablo Formation, the thick section of coarse conglomerate in the upper part of the Diablo Formation in the Toiyabe Range may have formed during the Sonoma orogeny. Similarly, the disconformity between the Candelaria Formation and the relatively thin section of the Diablo in the Candelaria Hills may be related to orogeny that took place to the north.

Conglomerates forming part of the Garden Valley Formation at Tyrone Gap, 18 miles north-northwest of Eureka, Nevada, conformably overlie fusulinid-bearing rocks assigned an early Guadalupian age by Steele (1960, p. 112). These coarse clastic rocks may represent debris shed eastward from areas uplifted during the Sonoma orogeny.

The validity of assigning the Golconda thrust to the Sonoma orogeny depends on dating the rocks that would bracket the thrust in age—the Koipato sequence and the Edna Mountain Formation at the top of the Antler sequence. The published ages for these units suggest that the time interval between them, if one exists at all, is not great enough to accommodate a period of major thrust faulting, but neither unit is firmly dated. The Edna Mountain Formation is dated by its correlation with the Phosphoria Formation, the age of which is probably no younger than Kungurian, considered by some Russian geologists as late Early Permian (Williams, 1959, p. 40). The Koipato sequence contains Lower Triassic ammonites in its upper part, but the age of its lower part is indefinite. The edestid fish fossil described by Wheeler (1939) from the Koipato is of doubtful age within the Permian, and the Artinskian or Uralian age suggested by Wheeler for the lower part of the Koipato is almost certainly too old, as the Koipato rests with pronounced angular unconformity on the Havallah sequence, part of which is as young as Leonard. Until more reliable information is available, the ages of the Koipato sequence and the Edna Mountain Formation do not preclude development of the Golconda thrust during the Sonoma orogeny.




GENERALIZED GEOLOGIC MAP OF THE SONOMA RANGE QUADRANGLE, NORTHWESTERN NEVADA

Modified from Muller and others (1951); Ferguson and others (1951a; 1951b); and Ferguson and others (1952)

SILBERLING AND ROBERTS, PLATE 2
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