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The Nature and Timing of Tectonism in the Western Facies Terrane of Nevada and California—An Outline of Evidence and Interpretations Derived From Geologic Maps of Key Areas

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By Keith B. Ketner

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The Nature and Timing of Tectonism in the Western Facies Terrane of Nevada and California—An Outline of Evidence and Interpretations Derived From Geologic Maps of Key Areas

By Keith B. Ketner

ABSTRACT

Along the outer miogeocline of Nevada and southern California, lower Paleozoic siliceous sediments and basalt flows, known collectively as the western facies rocks or the western assemblage, accumulated in deep water concordantly on a thick substrate of Proterozoic to Upper Cambrian shallow-water to deep-water terrigenous sediments. In the mid-Frasnian of Late Devonian time, the western facies terrane emerged and was deeply eroded. Structural evidence that this event, the Antler orogeny, involved intense folding and thrust faulting is notably scarce. Starting in late Frasnian, siliceous sediments and intercalated basalt flows accumulated disconformably on deeply depressed parts of the western assemblage forming the lower strata of the Havallah and equivalent sequences of the overlap assemblage. In Middle Pennsylvanian the entire stack was moderately deformed, elevated, and again deeply eroded. Starting in later Middle Pennsylvanian, the western assemblage and overlying units subsided and marine sediments accumulated through the Permian over broad areas. Beginning in the Jurassic and ending in the Eocene, the entire region was strongly folded and thrust faulted. Almost all of the intense folding and thrust faulting of Proterozoic to Permian strata dates from the Jurassic to Eocene interval. If this tectonic history is valid, then the genesis of the Antler orogeny is reduced to a question of vertical tectonics. The presence of basaltic flows at all levels in the Paleozoic column suggests a persistently tensional stress regime both before and after the Antler orogeny. Pre-Jurassic contraction involving subduction and collision with island arcs is not indicated or required, but the ultimate origin of Paleozoic tectonism remains unclear.

INTRODUCTION

Detailed geologic maps are one of the most important tools available to geologists for determining tectonic history. This report is essentially a critique of selected maps (fig. 1), most of which have been published since 1958 when currently accepted concepts of the tectonic history of the region were first formulated by R.J. Roberts and others. The purpose of this report is to highlight the most significant stratigraphic and structural relations displayed on these geologic maps, stressing the significance of the maps individually and collectively for the tectonic history of the region.

The age ranges of several stratigraphic units shown on many of the maps are no longer valid, and the maps are unlikely to be revised in the near future. Accumulating paleontological data has led to improved stratigraphic concepts and therefore made possible an improved understanding of the tectonic history. A principal aim of this report is to make the revised ages of stratigraphic units more widely known.

Existing maps represent tremendous physical and mental effort by geologists over the last four or five decades, but unfortunately, the tectonic interpretations in many cases seem to have been driven more by ideology than by the observed structural relations. As a result, interpretations are commonly at variance with the map evidence as noted in the following pages.

This report necessarily demands much from the reader. For maximum benefit from the discussions that follow, the reader should examine the principal geologic maps to which reference is made. Brief summaries of pertinent aspects of stratigraphy and structure are presented, but to duplicate herein parts of the many geologic maps to which reference is made, or to describe in detail the stratigraphy and structure of each map area, would be impractical. Simplified sketches of the maps would be useless; the message is in the details.

Tables 1–3 give locations of some of the more critical exposures.

Acknowledgments. This paper benefitted greatly from reviews by N.J. Silberling and Hugh McLean. My greatest debt is to the paleontologists, mostly of the U.S. Geological Survey, who have provided me with reports on the ages of fossils from critical stratigraphic units in critical areas which, in turn, permitted the correct dating of key strata and improved structural interpretation. I thank especially Reuben J. Ross, Jr., Anita G. Harris, John E. Repetski, Charles A. Sandberg, Bruce R. Wardlaw, W.B.N. Berry, John Huddle (deceased), Benita Murchey, Robert G. Stamm, Mackenzie Gordon, Jr., John Pojeta, Jr., Bruce Runnegar, Norman J. Silberling, and Raymond C. Douglass.

DEFINITIONS OF TERMS

Outer miogeocline. The outer, western part of the Cordilleran miogeocline; also termed outer continental margin (Turner and others, 1989).

Inner miogeocline. The continental shelf and upper part of the continental slope.

Western assemblage, western facies rocks. Siliceous sedimentary rocks and intercalated basaltic strata deposited in relatively deep water along the outer miogeocline; commonly refers to rocks of Ordovician to Devonian age.

Western facies terrane. Area extending from northeastern Nevada southwestward to southern California that is occupied by the western assemblage.

Eastern assemblage, eastern facies rocks. Shallow-water carbonate rocks and lesser quartzite and shale of the Cordilleran inner miogeocline; the term commonly refers to rocks of Cambrian to Devonian age.

Overlap assemblage. Sedimentary and volcanic strata of Late Devonian to Permian age deposited on the western facies assemblage following tectonism. The term commonly refers to Middle Pennsylvanian to Permian units deposited after Middle Pennsylvanian tectonism, but I include in this category also Upper Devonian to Lower Pennsylvanian units deposited after Late Devonian tectonism. The Havallah and Schoonover sequences embrace the entire range of Upper Devonian to Permian units.

Foreland basin assemblage. Upper Devonian to Permian sedimentary strata deposited eastward beyond the eastern limit of the western assemblage. Most of the sediments were derived from uplifted western assemblage rocks. I do not use the term in a genetic sense and do not imply, as some do, that the basin of deposition was formed as a result of tectonic loading of the adjacent area by thrust plates.

Valmy Formation, Vinini Formation, Palmetto Formation. Contemporaneous Ordovician deep-water, dominantly siliceous sedimentary rocks and intercalated basaltic rocks deposited in the outer miogeocline. As used in this report, all three formations span the Ordovician, but the Valmy probably was deposited in deeper water than the Vinini and Palmetto. The temporal equivalence of the Valmy and Vinini has been questioned based on relations in the type area of the Vinini (Emsbo and others, 1993), but as used in most reports, including this one, the two formations are regarded as correlative.

Havallah sequence, Schoonover sequence. Contemporaneous Upper Devonian to Permian, dominantly siliceous sedimentary rocks and intercalated basaltic rocks deposited on the western facies assemblage following tectonism. Each includes a Middle Pennsylvanian stratigraphic break.

Antler orogeny. Late Devonian to Mississippian tectonism during which western facies rocks were elevated and partially eroded, resulting in the accumulation of thick siliceous, detrital deposits in the foreland basin and also on depressed parts of the western assemblage. The date of earliest emergence of marine sediments is here equated with the age of the oldest dated orogenic sediments in the foreland basin—the lower beds of the Pilot Shale. This age is mid-Frasnian, early Late Devonian. As used here, the term Antler orogeny signifies only regional uplift along the outer miogeocline; it does not imply folding and thrust faulting. Ironically, the tectonic event in the vicinity of Antler Peak that is celebrated as the type occurrence of the Late Devonian–Early Mississippian Antler orogeny is probably of Middle Pennsylvanian age.

Sonoma disturbance. A Late Permian or Early Triassic deformational event best represented by unconformable relations between Triassic and Permian rocks at China Mountain, Nevada. The widely used term Sonoma orogeny overstates the importance of this local event.

Thrust fault. A contractional low-angle fault; its contractional nature indicated by older-over-younger superposition, associated strong folding and, most convincingly, by juxtaposition of rocks of contrasting, contemporaneous facies.

Roberts Mountains thrust. Originally, a thrust fault in the Roberts Mountains that juxtaposed contemporaneous western- and eastern-facies rocks. The term has been used in other areas where the same kind of juxtaposition has taken place. Originally this fault in the Roberts Mountains area was regarded as of post-Permian age (Nolan and others, 1956), but currently it is widely regarded as associated with the mid-Paleozoic Antler orogeny following the usage of Roberts and others (1958). However, in many places thrust faults that juxtapose contrasting facies are demonstrably of Mesozoic age or their ages are indeterminate. The term Roberts Mountains thrust should be restricted to the Roberts Mountains area; its depiction on countless maps as a single, continuous line extending from Idaho to California is totally unjustified.

Roberts Mountains allochthon. Deep-water, siliceous, sedimentary and volcanic rocks of early Paleozoic age in the upper plate of the Roberts Mountains thrust. The term should be restricted to the Roberts Mountains area.

Golconda thrust. A thrust fault that carried deep-water, siliceous and volcanic rocks of middle to late Paleozoic age, the Havallah sequence, over partly contemporaneous, relatively shallow water rocks near Golconda Summit on Edna Mountain. Commonly assumed to be linked with the Late Permian or Early Triassic Sonoma disturbance, but that has not been proven; it could be much younger. The term Golconda thrust should be restricted to the type area.

Golconda allochthon. Deep-water, siliceous sedimentary and volcanic mafic rocks in the upper plate of the Golconda thrust. The term should be restricted to the Golconda area.

Greenstone. Altered submarine basaltic flows or shallow sills. Reaction with sea water typically has converted calcic feldspars partially or completely to albite, and pyroxene to sodic amphibole and chlorite. Tabular layers of greenstone intercalated with sedimentary rocks are a common component of both the western and overlap assemblages. The presence of greenstone in rocks of all ages between Proterozoic and Early Pennsylvanian could be interpreted to indicate a generally persistent tensional stress regime.

Unconformity, disconformity. As used here, unconformity implies angular discordance; disconformity implies that beds above and below are parallel even though erosion may have cut down to lower stratigraphic levels in some areas than in others. In some published descriptions the term unconformity has been used where disconformity is more appropriate. The distinction is important because of the different tectonic implications.

SIGNIFICANT FEATURES OF MAPS IN KEY AREAS OF NEVADA AND CALIFORNIA

Following are brief commentaries on maps of key areas of the western facies terrane. In this context, a key area is one that includes clear evidence relating to the timing or nature of tectonism. This report is, as the title states, an outline of work in progress. I hope that it will revive interest and serve as a guide to important localities where additional productive detailed studies can be made. I have examined every locality discussed, some of them many times over a period of 40 years. The interpretations presented in this report are based on a foundation laid by the best work of my predecessors and colleagues, new data not available to the original authors, and a broad background of stratigraphic and structural studies in the region.

ROWLAND AREA

The Rowland area includes exposures in the canyon of Bruneau River, on Bearpaw Mountain, and in the Copper Mountains. Two results of recent mapping are outstanding: (1) the Valmy Formation, commonly regarded as the quintessential component of the Roberts Mountains allochthon, is part of a thick miogeoclinal assemblage and is autochthonous with respect to underlying Proterozoic and Cambrian strata; (2) Mississippian beds are disconformable on Middle Ordovician strata.

The Rowland area was originally mapped by K.O. Bushnell (1967) in 1952–54 as part of the Rowland 15-minute quadrangle. The geologic relations as he interpreted them are shown with few changes on the Elko County (Coats, 1987) and the Nevada State geologic maps (Stewart and Carlson, 1978). Recently part of the area was mapped at a scale of 1:24,000 (Ketner, Repetski, and others, 1995), and the dating of stratigraphic units was much improved by study of 23 conodont collections. The following discussion is based mainly on the map by Ketner, Repetski, and others, partly on that of Bushnell, and partly on unpublished mapping by Ketner.

Pre-Tertiary strata form a well-exposed, steeply dipping sequence that ranges from Proterozoic to Permian in age. The sequence includes Ordovician deep-water deposits generally assigned to the Roberts Mountains allochthon, but in the Rowland area these rocks are not allochthonous. The

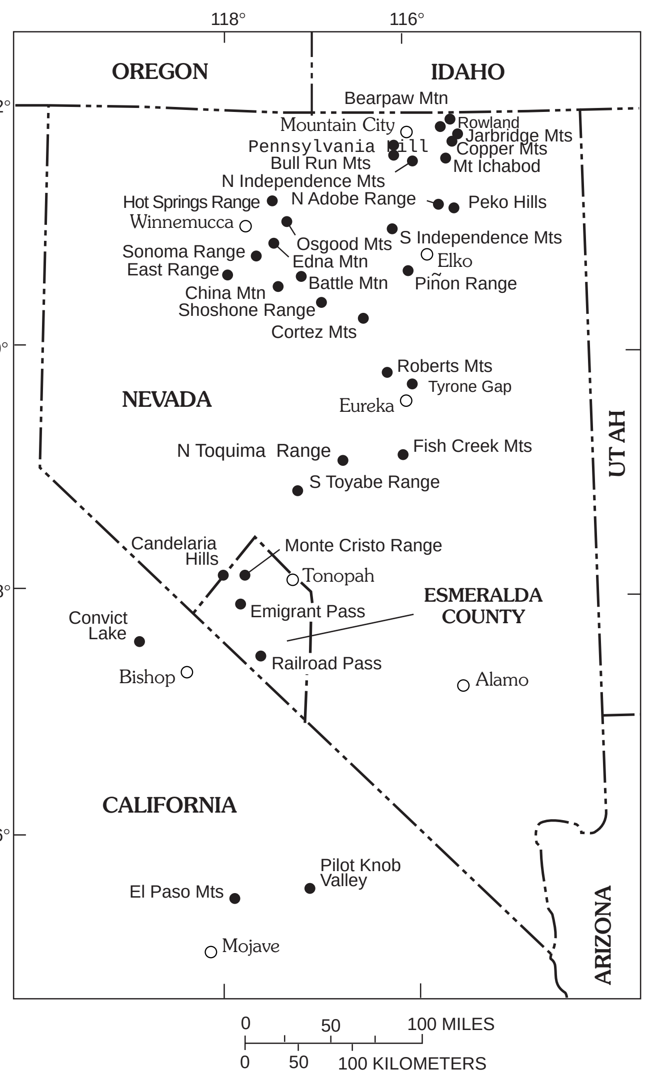

Figure 1. Index map showing localities discussed in text.

Table 1. Locations of exposures showing Ordovician western facies strata conformably overlying thick sequences of miogeoclinal units.

Stratigraphic relations	Location (fig. 1)	UTM East UTM North (meters)	Reference
Valmy Formation on Tennessee Mountain Formation.	Bearpaw Mountain, near Trail Gulch.	612440 4639550	Ketner, Repetski, and others, 1995.
Valmy Formation on Tennessee Mountain Formation.	Rowland, near mouth of Meadow Creek.	609850 4640420	Ketner, Repetski, and others, 1995.
Valmy Formation on Van Duzer Formation (Tennessee Mountain Formation).	Pennsylvania Hill, near head of Lime Creek.	577100 4622090	Ehman, 1985.
Valmy Formation on Ordovician-Cambrian(?) meta-limestone sequence.	East Range, near Rawhide Spring.	427140 4493620	Whitebread, 1994.
Palmetto Formation on Cambrian sequence that includes Prospect Mountain Quartzite.	Southern Toyabe Range, along Summit Creek.	476900 4313900	Ferguson and Cathcart, 1954.
Palmetto Formation on Emigrant Formation	Emigrant Pass, near the “guzzler.”	422200 4200000	Robinson and others, 1976.
Palmetto Formation on Emigrant Formation	Railroad Pass -------------	456430 4157280	Albers and Stewart, 1972.

Table 2. Locations of exposures showing Upper Devonian and Mississippian strata of the overlap assemblage disconformably overlying western facies units.

Stratigraphic relations	Location (fig. 1)	UTM East UTM North (meters)	Reference
Osagean unit on Ordovician Valmy Formation.	Rowland, near Bruneau Mine ---	608840 4642550	Ketner, Repetski, and others, 1995.
Osagean unit on Ordovician Valmy Formation.	Northern Independence Mountains, near Schoonover Creek.	598460 4595645	Miller and others, 1984.
Frasnian and Famennian units on Middle Silurian.	Southern Independence Mountains, near Basco Field.	581070 4550580	Ketner, 1974, and in press.
Middle Frasnian unit on Middle Silurian and Ordovician.	Northern Adobe Range, near Badger Spring.	611070 4561760	Ketner and Ross, 1990.
Osagean beds of the Inskip Formation on Ordovician Valmy Formation.	East Range, Inskip Canyon ------	424600 4496140	Whitebread, 1994.
Kinderhookian Robbers Mountain Formation on Middle Devonian unit.	Pilot Knob Valley, south of Randsburg Road.	486090 3932525	Carr and others, 1992, and in press.

contact between the Valmy Formation and underlying strata is exposed at Trail Gulch and near the confluence of Meadow Creek and Bruneau River. In these two areas the predominantly limestone Tennessee Mountain Formation of Cambrian and Ordovician age grades upward into Ordovician beds of the Valmy Formation over a stratigraphic interval of several hundred feet by upward-increasing proportions of bedded chert, siltstone, and volcanic rock.

Strata of late Early Mississippian age disconformably overlie Middle Ordovician quartzite of the Valmy Formation.

Table 3. Locations of exposures of Middle Pennsylvanian to Permian strata of the overlap assemblage disconformably or unconformably overlying older parts of the overlap assemblage, western facies units, and miogeoclinal strata underlying the western facies assemblage.

Stratigraphic relations	Location (fig. 1)	Reference
Pennsylvanian unconformable on Cambrian dolomite	Bull Run Mountains, at Porter Peak	Ehman, 1985.
Permian unconformable on Ordovician Valmy Formation and underlying Cambrian carbonate.	Northern Independence Mountains, near mouth of North Fork Canyon.	Miller and others, 1984.
Pennsylvanian to Permian disconformable on Late Devonian unit, all within the Schoonover sequence.	Northern Independence Mountains, near Rocky Bluff.	Miller and others, 1984.
Middle to Upper Permian unit unconformable on Ordovician Valmy Formation and Silurian chert.	Mount Ichabod, near Dorsey Canyon	Ketner and others, 1993.
Permian unconformable on Ordovician Valmy Formation and Silurian chert.	Adobe Range, near Garamendi Mine	Ketner and Ross, 1990.
Pennsylvanian unconformable on Cambrian quartzite unit.	Osgood Mountains, near upper Hogshead Canyon.	Hotz and Willden, 1964.
Pennsylvanian unconformable on Ordovician Valmy Formation.	Battle Mountain, near Cottonwood Creek.	Roberts, 1964.
Pennsylvanian disconformable on Ordovician Valmy Formation.	Northern Shoshone Range, near upper Horse Canyon.	Gilluly and Gates, 1965.
Pennsylvanian unconformable on Ordovician Valmy Formation.	Northern Toquima Range, at Wildcat Peak.	McKee, 1976.

This disconformable contact is exposed in the canyon of Bruneau River about 3,000 ft (914 m) southwest of the townsite of Rowland. The Mississippian beds are composed of conglomerate, sandstone, phosphatic siltstone, limestone, and greenstone. Above the Mississippian section, with obscure contact relations, are siliceous and carbonate beds of Pennsylvanian and Permian age. Faults nearly parallel to bedding are probably present in the Pennsylvanian and Permian part of the Paleozoic sequence based on anomalous age relations determined by conodont collections. The disconformable contact between Ordovician and Mississippian units demonstrates that the Antler orogeny of latest Devonian to Early Mississippian age here consisted of uplift of deep-water deposits and exposure to erosion. There is no evidence here of strong folding and intense thrust faulting during the 120-m.y. interval between Middle Ordovician and late Early Mississippian time.

BULL RUN MOUNTAINS

The Bull Run Mountains display three important geologic relations: (1) a continuous stratigraphic sequence from Proterozoic strata through the Ordovician Valmy Formation including a good exposure of the sedimentary base of the Valmy; (2) exposures of the contact between shallow-water Cambrian strata and overlying Cambrian deep-water strata, (3) a good example of Upper Pennsylvanian strata lying on Cambrian rocks with a moderately angular unconformable contact.

Part of the Bull Run Mountains was mapped originally in the early 1950’s as a Ph. D. dissertation by Robert Decker, and the map was published in Nevada Bureau of Mines Bulletin 60 (Decker, 1962). Kenneth D. Ehman subsequently mapped the northern part of the range as a Ph. D. dissertation and Theodore Clark mapped the southern part as a Master’s thesis (Ehman, 1985; Clark, 1985). Their combined map at a scale of 1:24,000 includes unpublished mapping of Tertiary deposits in the Bull Run Basin by University of California Professor Daniel Axelrod. Stratigraphic and structural concepts were later modified by Ketner, Ehman, and others (1993).

Certain stratigraphic relations in the Bull Run Mountains have been complicated by metamorphism or by faulting, and require clarification. The Aura Formation and Van Duzer Limestone of Decker (1962) and of Ehman (1985) are probably parts of a single stratigraphic sequence equivalent to the Cambrian to Ordovician Tennessee Mountain Formation. Lithic differences between the two parts apparently are due to different degrees of thermal alteration, as suggested by relations of similar units in the Copper Mountains area. There, in correlative rocks, lithic features of the Tennessee Mountain Formation that characterize the Aura are due to contact alteration and they prevail close to large granitic intrusives, whereas features that characterize the Van Duzer in the same stratigraphic unit prevail at a greater distance from the intrusives. The lithic features characteristic of each unit therefore appear to be due to different degrees of contact metamorphism.

The contact between the Cambrian Bull Run Dolomite of Ehman (1985) and the overlying Aura–Van Duzer sequence separates shallow-water deposits below from deep-water deposits above. Ehman originally interpreted the contact as a fault, but our joint examination of the contact in 1992 convinced both of us that it is probably depositional. In the Bluejacket area where exposures are relatively free from colluvium, bedding attitudes in the two units are concordant, and beds of dolomite, similar lithically to the Bull Run Dolomite, are present in the Aura–Van Duzer sequence a few feet up section from the contact. The average dip of beds just above the contact and the average just below the contact as recorded by Ehman (1985) are virtually identical. Recognition of the depositional nature of this contact relates the Aura–Van Duzer sequence to the underlying Cambrian shelf strata. The Cambrian rocks below the contact are shallow-water deposits; the Aura–Van Duzer strata are deep-water deposits. In the Copper Mountains the relations are analogous. There, the Bull Run Dolomite is absent, and shallow-water deposits assignable to the Cambrian Pioche Shale are overlain gradationally by deep-water Cambrian strata of the Tennessee Mountain Formation.

The contact between the Aura–Van Duzer sequence and the Ordovician Valmy Formation is exposed in the Owyhee quadrangle (Coats, 1971) at the northern margin of the Bull Run Mountains. This contact was interpreted without supporting evidence as a thrust fault by Coats. However, along the divide between Van Duzer Creek and Breakneck Creek just north of the peak of Pennsylvania Hill in Section 1, the contact zone is well exposed where it crosses a ridge, and it consists of interbedded limestone, chert, sandstone, and greenstone. Phosphatic beds composed mainly of *Caryocaris* skeletons indicate an Early Ordovician age for the transitional beds. The Aura–Van Duzer sequence clearly grades upward into the Valmy. Thus, the Valmy Formation, here as in the Rowland area, is in its normal stratigraphic position in the Proterozoic-Cambrian-Ordovician stratigraphic sequence of the outer miogeocline. The transition from shallow- to deep-water deposition in the middle part of the Cambrian was probably due to a relative rise in sea level because it took place over a large part of the continental margin.

In a small area of the Bull Run Mountains, at Porter Peak, marine fusulinid-bearing limestone beds of Late Pennsylvanian age overlie Middle Cambrian rocks with a moderately discordant unconformable contact. The unconformity represents erosion of many thousands of feet of deep-water strata, moderate deformation, and resumption of deposition in a shallower marine environment.

MOUNTAIN CITY AREA

The Mountain City area, including the vicinity of the Rio Tinto Mine, and Merritt Mountain, is notable for a display of the disconformable relation between the Middle Ordovician and Mississippian and good exposures of Mississippian volcanic rocks.

The area around Mountain City was mapped by Robert R. Coats and his associates. The following discussion relates to the Owyhee 15-minute quadrangle just west of Mountain City, published at a scale of 1:48,000 (Coats, 1971); the southwest quarter of the Mountain City 15-minute quadrangle, released as an Open-File Report (Coats, 1968) at a scale of 1:20,000; and the southeast quarter of the Mountain City quadrangle, released as an Open-File Report at the same scale (Coats and others, 1984).

Part of the northeast quarter of the Mountain City quadrangle and adjacent areas to the east were mapped by Little (1987). The scale of Little's map varies widely from its average of 1:14,300 (depending on whether latitude or longitude ticks or the bar scale is used to calculate it), and the map was published without topographic contours or other geographic features that could have made it much more useful.

Most of the Owyhee quadrangle is covered by Tertiary deposits, and by older sedimentary rocks too metamorphosed to be identifiable as to formation or age. However, in the southeast corner of the quadrangle, Coats showed the "Van Duzer" Limestone, misdated as "Devonian(?)," overlain by the Ordovician Valmy Formation with a thrust fault contact. In an interpretive diagram in the margin of the map, the thrust fault is labeled Roberts Mountains thrust. The Van Duzer is now known to be stratigraphically equivalent to the Tennessee Mountain Formation and to be Late Cambrian and Early Ordovician in age (Ehman, 1985; Ketner, Ehman, and others, 1993). There is therefore no necessity for a thrust fault along the contact. In fact the contact is concordant and depositional as indicated by relations on nearby Pennsylvania Hill in the Bull Run Mountains.

In the southeastern part of the Owyhee quadrangle and the adjacent southwestern part of the Mountain City quadrangle, Mississippian strata overlie the Ordovician Valmy Formation. The Mississippian sequence was divided into four stratigraphic units by Nolan (1932) and Coats (1969). The type section of the lowest unit, the Grossman Formation, is in the Owyhee quadrangle near the Idaho-Nev mine shaft. The Grossman is undated, but the Banner Formation which overlies the Grossman is Mississippian (Osagean or Meramecian) in age. The Grossman is a coarse conglomerate composed mainly of quartzite boulders derived from the underlying Valmy Formation.

Published statements indicating that the contact between Ordovician and Mississippian units in the Mountain City area is unconformable (implying angular discordance) are not supported by evidence. Coats (1969, p. A22) stated that the Grossman lies unconformably on the Valmy Formation and that, elsewhere, the Banner lies with marked angularity on the Valmy (1969, p. A24; 1987, p. 30). These statements were repeated by Little (1987, p. 5).

No discordant attitudes above and below the contact that might justify such statements are shown on maps by Coats and Little in the Owyhee and Mountain City quadrangles, nor could I find any. In fact, the sparse field evidence in those quadrangles indicates that the strike and dip of strata above and below the Ordovician-Mississippian contact are approximately parallel.

NORTHERN INDEPENDENCE MOUNTAINS

Late Devonian to Early Mississippian deformation in the northern Independence Mountains consisted solely of uplift, whereas Pennsylvanian deformation involved folding or tilting of strata.

Mapping in the northern Independence Mountains by Churkin and Kay (1967) at a scale of 1:62,500 and by Miller and others (1984) at a scale of 1:35,000 describes rocks that the authors assigned to the Roberts Mountains and Golconda allochthons and the overlap assemblage. In this area, the stratigraphic term Schoonover sequence is applied to strata equivalent to the Havallah sequence; the two terms are virtually synonymous.

According to Miller and others (1984), the Schoonover sequence, a highly faulted packet of Devonian to Permian rocks, was emplaced over an autochthon consisting of lower Paleozoic western facies rocks and of Mississippian to Permian rocks assignable to the overlap assemblage.

Stratigraphic relations in three areas are especially significant: (1) Schoonover Creek in the southwestern part of the map area of Miller and others, (2) the mouth of North Fork Canyon in the eastern part of the map area, and (3) Rocky Bluff in the north-central part of the map area.

At Schoonover Creek, basal conglomerate of the Mississippian overlap assemblage depositionally overlies interbedded quartzite and chert of the Ordovician Valmy Formation. This contact was described by Churkin and Kay (1967), without citing evidence, as an angular unconformity and by Miller and others (1984) simply as an unconformity. The contact is well exposed in several outcrops and is concordant in each of them. In some places the conglomerate overlies bedded chert and in others it overlies quartzite, but the concordant relations suggest erosional relief on the surface of the Ordovician rocks rather than angular discordance due to deformation. The concordance of beds above and below the contact indicates again an absence of discernible deformation between Middle Ordovician and Mississippian.

In the lower North Fork Canyon area, Permian conglomerate overlies a Cambrian and Lower Ordovician carbonate sequence with a sedimentary contact that ranges from concordant to very discordant. The concordant relation between Mississippian strata of the overlap assemblage and the Ordovician strata of the Roberts Mountains allochthon at Schoonover Creek on the west side of the range contrasts with discordant relations between Cambrian and Permian strata in North Fork Canyon on the east side of the range. The deformation of the Cambrian strata prior to Permian therefore must be younger than Late Mississippian and is likely of Middle Pennsylvanian age as in areas described in the present report and elsewhere (Ketner, 1977). There is a corresponding discontinuity within the Schoonover sequence; Middle Pennsylvanian to Permian strata lie disconformably on Upper Mississippian and older beds.

The northern Independence Mountains and nearby areas supply significant information on the times of internal faulting and of tectonic emplacement of the Schoonover sequence. At Rocky Bluff and over a large area to the northwest of Rocky Bluff, volcanic rocks of Eocene age (Ehman, 1985) unconformably overlie the Schoonover sequence with angular discordance. Structure contouring of the base of the Eocene strata, as it was mapped by Miller and others (1984), indicates that the base slopes gently to the northwest at about 5°, whereas beds and bedding-parallel faults in the Schoonover sequence dip to the northwest at an average of about 50°. The relations at Rocky Bluff indicate strong deformation within the allochthon in earliest Eocene or prior to Eocene. They do not necessarily cap the age of *emplacement* of the allochthon because the Eocene rocks are not known to overlap the contact between the Schoonover and the autochthon.

Miller and others (1984) cited the presence of Jurassic plutons in the nearby Bull Run Mountains to support a pre-Jurassic age for the emplacement of the Schoonover sequence in the northern Independence Mountains, but according to Ehman (1985), those intrusives do not pin the allochthon and their presence is irrelevant to the age of its emplacement. In the Mount Ichabod area, 15 miles east of the Independence Mountains, an allochthon composed of rocks identical to much of the Schoonover sequence overlies rocks of Early Triassic age with a low-angle fault contact (Ketner, Murchey, and others, 1993, 1995). All that can be said presently concerning the emplacement of the Schoonover allochthon is that it took place later than Early Triassic based on relations at Mount Ichabod.

The question has been raised as to whether the Schoonover sequence was emplaced in an extensional regime (Ehman, 1985, p. 150). Structural relations near the mouth of North Fork Canyon and in the Mount Ichabod area just east of the Independence Mountains supply pertinent evidence. In both areas, partially correlative upper Paleozoic strata of contrasting facies have been juxtaposed by low-angle faulting. This juxtaposition must be the result of contractional faulting, but superposed extensional faulting cannot be ruled out.

SOUTHERN INDEPENDENCE MOUNTAINS

The southern Independence Mountains display some unfaulted segments of stratigraphy typical of the western assemblage and good evidence that the basal beds of the overlap assemblage are as old as mid-Frasnian.

Parts of the Blue Basin and Singletree Creek quadrangles were mapped at a scale of about 1:21,400 by Lovejoy (1959) as a Ph. D. dissertation, and the entire Blue Basin quadrangle was subsequently mapped at 1:24,000 by Ketner (1974). Maps of the entire area have been revised and ages of stratigraphic units improved by a large number of graptolite and conodont collections (Ketner, in press). Lower, Middle, and Upper Ordovician and Lower and Middle Silurian strata of the western assemblage are present as are Upper Devonian units of the overlap assemblage. The unit designated as Oc in the Blue Basin quadrangle (Ketner, 1974) was originally thought to be solely of Ordovician age. However, upper parts of that unit are probably of Early Silurian age. No Lower Silurian fossils were found in the southern Independence Mountains, but uppermost Ordovician and Lower Silurian graptolites are present in similar beds of the neighboring Adobe Range.

An important stratigraphic discontinuity separates the upper Frasnian and Famennian strata from the underlying Middle Silurian beds in the southern Independence Mountains. The presence of this discontinuity representing the Antler orogeny is based on the absence of Upper Silurian to lower Frasnian beds and also on the lithic and faunal content of the Upper Devonian strata. These beds are composed of conglomerate, sandstone, bedded chert, bedded barite, limestone, and greenstone. The Famennian beds contain clasts lithically identical to certain distinctive beds in the Lower Ordovician western assemblage rocks. Some of those clasts are composed of *Nuia*, an alga restricted to the Cambrian and Early Ordovician. The Famennian strata also contain reworked conodonts of earliest Ordovician age (C.A. Sandberg, oral commun., 1976).

Frasnian beds of the southern Independence Mountains are among the oldest known strata of the overlap assemblage, and together with the Frasnian age of the oldest known foreland basin deposits, indicate a very short interval between the earliest elevation of the western assemblage and subsequent depression of part of this assemblage below sea level.

MOUNT ICHABOD AREA

The Mount Ichabod area displays good evidence that rocks commonly assigned to the Roberts Mountains and Golconda allochthons were tectonically emplaced after Early Triassic time and most likely in a contractional environment.

The Mount Ichabod area was originally mapped in 1952–53 as part of the Mount Velma 15-minute quadrangle by J.R. Coash (1967), and his stratigraphic and structural interpretations were incorporated with little change into the geologic maps of Elko County (Coats, 1987) and Nevada (Stewart and Carlson, 1978). Unfortunately, owing to lack of paleontological data, Paleozoic and Triassic rocks are not correctly distinguished on any of these maps. Interpretations herein are based on new mapping at a scale of 1:24,000 (Ketner, Murchey, and others, 1993, 1996). The Paleozoic rocks were dated by means of conodonts. The Triassic rocks were dated by use of conodonts and also through lithic resemblance to strata in the northern Adobe Range containing Triassic conodonts and ammonites (Ketner and Ross, 1990; C.A. Sandberg, oral commun., 1996).

The Mount Ichabod area displays two major structural features: a low-angle fault that emplaced Paleozoic rocks above Lower Triassic strata, and a pair of high-angle normal faults bounding Mount Ichabod. Mount Ichabod is a horst that brings into view the Paleozoic strata underlying the Lower Triassic sequence.

Rocks structurally overlying the Triassic sequence comprise Ordovician and Silurian western assemblage strata, Mississippian to Permian rocks comprising the Havallah, or Schoonover sequence, and conglomeratic Pennsylvanian and Permian rocks of the overlap assemblage.

The Mount Ichabod horst is composed of western assemblage Ordovician rocks and unconformably overlying Permian strata of the overlap assemblage. The presence of Ordovician western facies rocks and strata of the overlap assemblage lying both above and below the Triassic sequence indicates tectonic thickening and repetition of strata and therefore a compressional, rather than a tensional, stress regime.

The time and manner of emplacement of the Havallah sequence at Mount Ichabod are pertinent to the time and manner of emplacement of its equivalent, the Schoonover Formation, in the Independence Mountains only 15 miles (24 km) distant to the west.

NORTHERN ADOBE RANGE AND PEKO HILLS

These areas afford evidence that western assemblage rocks commonly assigned to the Roberts Mountains allochthon were emplaced after Early Triassic time by southeast-directed compressional stress. Stratigraphic relations in the Adobe Range indicate that the Antler orogeny involved uplift and erosion but provide no support for strong folding or thrust faulting of Antler age.

The northern Adobe Range (Ketner and Ross, 1990) and Peko Hills (Ketner and Evans, 1988) were mapped at intervals between 1967 and 1988 at a scale of 1:24,000, and the stratigraphic units were well dated by more than 125 fossil collections, mainly of conodonts and graptolites. There were no earlier maps of these areas. Subsurface stratigraphy near the northern Adobe Range was revealed by an exploratory well (Diamond Shamrock Kimbark Fed. 1-28, T. 37 N.; R. 56 E.) that reached shelf and upper slope strata as old as Ordovician.

In the northern Adobe Range, relatively autochthonous strata of Mississippian and older ages were overridden by Paleozoic and Triassic rocks, and then the entire stack was deformed into southeast-verging folds and overridden by thrust plates composed of strata ranging in age from Ordovician to Triassic.

Ordovician and Silurian strata in the allochthonous plates are western facies rocks conventionally assignable to the Roberts Mountains allochthon, and the thrust faults on which they rode conventionally could, collectively, be termed the Roberts Mountains thrust because they stacked rocks of shelf and basin facies.

Siliceous, deep-water, allochthonous rocks of Devonian age are commonly assigned to the western assemblage. However, such rocks in the Adobe Range should be assigned to the overlap assemblage because they overlie Ordovician and Silurian beds disconformably. In the central part of the map area, 10 conodont collections from Devonian beds indicate unequivocally a Frasnian age. Five collections indicate a Middle Devonian age, but of those five, two contain conodonts of diverse ages, indicating that some or all of the specimens were reworked. The most thoroughly studied area is the east bank of Badger Creek from 500 to 1,500 feet (152–457 m) north of Badger Spring. Here each of six conodont collections from limestone beds yielded a Frasnian age. Radiolarians from chert beds associated with the six limestone beds indicated a Late Devonian age. The Frasnian beds lie directly on thin remnants of Middle Silurian siltstone and on Ordovician beds. Pending further detailed collecting, I conclude that the Devonian beds are all of Frasnian age but that some contain reworked conodonts of earlier ages.

Paleozoic and Triassic rocks of the northern Adobe Range were warped on a vertical axis to form an orocline and then capped by Eocene sedimentary and volcanic rocks. Finally, part of the area was domed resulting in dips of Eocene strata as much as 45°.

The Peko Hills lie about 15 miles (19.2 km) southeast of the northern Adobe Range. Formations ranging from Late Devonian to Triassic in age were folded to form a tight southeast-verging syncline that was overridden by thrust plates of Mississippian to Permian rocks.

The Adobe Range and Peko Hills illustrate the contractional history of the area exceptionally well: thrust faulting and large-scale, southeast-verging folding followed by overthrusting with telescoping of contrasting facies. The two areas also illustrate the post-Paleozoic age of principal contractional structures in the region.

ELKO HILLS

The Elko Hills reveal evidence that primarily Mesozoic contractional deformation persisted at least locally into the Eocene.

The Elko Hills were mapped intermittently between 1968 and 1988, and the map was published at a scale of 1:24,000 (Ketner, 1990). Information from Solomon and others (1979) and Solomon and Moore (1982) was incorporated in the published map.

On the north and northeastern flanks of Elko Mountain, klippen of Mississippian and Pennsylvanian rocks lie on folded Eocene and older strata with low-angle fault contacts. In nearby areas the folded Eocene strata are overlain unconformably by undeformed upper Eocene strata (Ketner and Alpha, 1988). The map scale folds in the Eocene strata and the distinctly older-on-younger relation are interpreted to indicate compressional stress.

PIÑON RANGE

The stratigraphy and structure of the Piñon Range are uncommonly complex and are a source of ongoing controversy. However, the stratigraphic and structural relations in the Carlin Canyon area are unequivocal: the area was subject to deformation in Pennsylvanian and again after mid-Permian time.

A geologic map of the core of the Piñon Range by Ketner and Smith (1963) was published at a scale of 1:12,000, and later a map of the entire range and part of the Sulphur Spring Range by Smith and Ketner (1978) was published at a scale of 1:62,500. The adjacent Elko Hills were mapped at 1:24,000 by Ketner (1990). Although most of the formations in the Piñon Range are fairly well dated and the exposures moderately good, stratigraphic relations in the critical Devonian to Mississippian interval were not clearly understood at first and they remain unclear. Upper Devonian siliceous strata and some Mississippian strata probably should be assigned to the overlap assemblage rather than, respectively, to the western and foreland basin assemblages. The probable presence of Jurassic to Eocene contractional faults and Tertiary extensional faults was not adequately recognized during the original mapping or in subsequent studies.

Evidence for Middle Pennsylvanian tectonism is displayed widely in the Piñon Range and especially in the Carlin Canyon area, where the Upper Pennsylvanian and Lower Permian Strathearn Formation lies with angular discordance on deformed Mississippian and Lower Pennsylvanian strata. The discordant contact has been interpreted as a fault (Jansma and Speed, 1990). Faults, both large and small, are ubiquitous in the region, and the contact therefore may indeed be faulted in places. However, exposures of Middle Pennsylvanian to Permian strata are common in the region, and the sedimentary nature of their lower contacts has been widely observed (Dott, 1955; Smith and Ketner, 1978; and Ketner, 1977).

Johnson and Pendergast (1981) argued that in the Piñon Range the Roberts Mountains allochthon normally lies on the Mississippian Chainman Shale and is overlapped by the Mississippian and Pennsylvanian Diamond Peak Formation. Carpenter and others (1993, 1994) presented a detailed account of stratigraphic and structural features of the Piñon Range in which the Ordovician to Devonian deep-water siliceous rocks and the Lower Mississippian Webb Formation are lumped together and included in the Roberts Mountains allochthon. Otherwise, their model is similar to that of Johnson and Pendergast. Jansma and Speed (1993) offered the hypothesis that the Mississippian Chainman Shale had been thrust over older foreland basin strata including the Kinderhookian Webb Formation by the encroaching Roberts Mountains allochthon. Their figure 2 of an area only 0.4 mi^2 (1 km^2) in extent depicts the principal field evidence on which they based their hypothesis.

All of the above-named authors would adjust the emplacement of rocks assigned to the Roberts Mountains allochthon from earliest Mississippian to mid-Mississippian. This is a step in the right direction but more steps are called for. The Piñon Range could hardly have escaped the tectonism that affected nearby ranges. Most of the structure is probably of Jurassic to Eocene age with a probable overprint of extensional faults.

I believe that in the original mapping, and subsequent studies, certain basic assumptions were made that, in retrospect, are probably erroneous. First, it was assumed that upper, Famennian, beds of the Woodruff Formation are part of the western assemblage, and second, that all Mississippian strata are part of the foreland basin assemblage. It now seems more in accord with the regional picture to assign the Famennian beds and some of the Mississippian beds to the overlap assemblage. In particular, this applies to the Devonian and Mississippian units between Trout and Willow Creeks. They, and the underlying Ordovician rocks of the western assemblage, are probably equally allochthonous.

The Piñon Range should be remapped at 1:24,000 scale; the Devonian and Mississippian strata should be more finely subdivided and accurately dated. Stratigraphy and structure of the range should be interpreted with due regard to that of the neighboring Cortez Mountains, Adobe Range, and Elko Hills where profound Jurassic to Eocene contractional structures are more clearly evident.

CORTEZ MOUNTAINS

The northern Cortez Mountains display good evidence of strong deformation in the Jurassic to Early Cretaceous interval.

The Cortez 15-minute quadrangle mapped by Gilluly and Masursky (1965) reveals much about the style and intensity of deformation in the range but little about the age of deformation. However, the nearby Frenchie Creek 15-minute quadrangle (Muffler, 1964) and mapping by Smith and Ketner (1978) in the adjacent Pine Valley quadrangle supply reliable evidence for the principal time of deformation.

In the Frenchie Creek quadrangle, the Upper(?) Jurassic sedimentary beds of the Big Pole Formation in its main exposure and type locality strike northeast and dip steeply northwestward. The northeast-trending strike of the Big Pole Formation was unaffected by the discordant intrusion of a large granitic stock of Cretaceous age, except directly adjacent to the contact, indicating that the steep dips of strata in the Big Pole probably were not caused by igneous intrusion. The Cortez Mountains are part of a tilted Basin and Range fault block. If the 10°–20° east tilt of the range, determined from the dips of Cretaceous, Miocene, and younger beds, were to be restored to horizontal, the dip of bedding in the Big Pole Formation would become steeper, generally approaching vertical, and in places would be overturned (Ketner and Alpha, 1992). The Lower and Upper Cretaceous Newark Canyon Formation in the vicinity of the Big Pole Formation is nearly undeformed (Smith and Ketner, 1978), and its beds would be horizontal if Tertiary tilt were to be subtracted.

Regional structural trends suggest that the Big Pole is enclosed in the post-Early Triassic Adobe Range syncline—a notably contractional feature (Ketner and Smith, 1974). In any event, the evidence clearly indicates strong deformation of Late Jurassic to Early Cretaceous age.

NORTHERN SHOSHONE RANGE

The northern Shoshone Range is important because of its well-displayed evidence for Pennsylvanian and Mesozoic deformation and, considering its location in the heartland of the Roberts Mountains allochthon, a remarkable absence of evidence for Antler-age deformation.

The Mount Lewis and Crescent Valley quadrangles, located principally in the northern Shoshone Range, were mapped by Gilluly and Gates (1965) and their numerous assistants, including myself, at intervals between 1950 and 1959. The map was published at a scale of 1:48,000. The range, composed mainly of lower Paleozoic, siliceous, deep-water deposits of the western assemblage, is extremely complex structurally. The tremendous effort that went into mapping this extensive, rugged area resulted in greatly improved understanding of the stratigraphy and style of deformation of the western facies rocks and could have resulted in an understanding of the true age of deformation if the evidence had been more logically interpreted.

Gilluly and Gates divided structures in the northern Shoshone Range into two packages separated by the Whisky Canyon fault—a west-dipping low-angle fault on the west slope of Mount Lewis. Structures below the Whisky Canyon fault were arbitrarily attributed to the Antler orogeny of Late Devonian to Early Mississippian age; those above the fault were arbitrarily attributed to an event termed the Lewis orogeny. The Lewis orogeny was considered to be of Mesozoic age because strata assigned to the Triassic China Mountain Formation were involved. Those strata are still undated by fossils, but the Pennsylvanian and Permian Antler Peak Limestone is present and is highly deformed. The following quotation (p. 98) reveals the weakness of the reasoning by which the tectonism was divided into two distinct orogenies instead of a single orogeny of Mesozoic age.

> Although it seems more than likely that all the structures have been somewhat modified by the post-China Mountain(?) Lewis orogeny, *we consider* the structures below the Whisky Canyon fault to be mainly products of the Antler orogeny; they are treated as wholly of this epoch. The structures associated with the Whisky Canyon fault and those at higher tectonic levels *are described under the heading* "The Lewis orogeny."

The two phrases that I have italicized are especially significant because they indicate that the assignment of the structures to two distinct orogenic events was based on inference rather than on hard evidence. The following quotation (p. 125) indicates Gilluly's assessment of the intensity of deformation that the authors assigned to the Lewis orogeny.

> A glance at the map of plate 1 shows how much broken by faulting is the rock mass above the Whisky Canyon fault. Along its eastern side the mass is a jumble of much faulted blocks of Battle Conglomerate, Antler Peak Limestone, Havallah and China Mountain(?) Formations. These are still further confused by a whole series of fault slices grouped***as the Pipe Canyon fault group.

The style and intensity of deformation above and below the Whisky Canyon fault are identical, as the map patterns indicate, and the distinction between Antler-age structures below and Mesozoic structures above has no basis in evidence or reason. If the intensity of post-Permian deformation above the Whisky Canyon fault is subtracted from that below the fault, little is left that can be ascribed to the mid-Paleozoic Antler orogeny.

The northern Shoshone Range provides evidence that contractional structures and the juxtaposition of contrasting facies customarily assigned to the Antler orogeny are actually much younger than that event. Just how much younger depends on the age assigned to the youngest deformed strata. The youngest well-dated formation involved in the thrust faulting is the Upper Pennsylvanian and Lower Permian Antler Peak Limestone. If the China Mountain(?) Formation was correctly identified, then the deformation in the Shoshone Range is younger than Early Triassic, and in any case it is younger than mid-Permian.

EDNA MOUNTAIN

Edna Mountain is the type area of the Golconda thrust, defined as the thrust that regionally emplaced deep-water facies of upper Paleozoic rocks over contemporaneous shallow-water facies. The traditionally assumed link between the Golconda thrust and the latest Permian or Early Triassic Sonoma disturbance, while theoretically possible, is not supported by any evidence here or elsewhere. The Golconda thrust could be much younger than the Sonoma disturbance.

The Edna Mountain area was first mapped by Ferguson and others (1952) and later by Erickson and Marsh (1974a, b). The Golconda allochthon, here consisting of Pennsylvanian and Permian deep-water, siliceous components, overlies correlative overlap assemblage strata of shallower water facies on the Golconda thrust. The structure is clear from the field relations but the timing of the thrust is not. The youngest beds in both the upper and lower plates are mid-Permian in age. The oldest units overlapping the thrust are Tertiary deposits. Based on the local evidence, the thrust could be as old as Late Permian or as young as early Tertiary.

OSGOOD MOUNTAINS AND HOT SPRINGS RANGE

The Osgood Mountains and the Hot Springs Range are more notable for stratigraphic and structural puzzles than for solutions to problems. However, one stratigraphic relation is certain: shallow-water to subaerial Lower Cambrian quartzitic strata are in gradational sedimentary contact with overlying Middle to Upper Cambrian and Ordovician deep-water carbonate deposits (Hotz and Willden, 1964). This important observation confirms the interpretation of corresponding but less clearly exposed stratigraphic relations in the Bull Run Mountains and contributes to an understanding of lower Paleozoic stratigraphy of the East Range.

The Osgood Mountains also clearly display Middle Pennsylvanian conglomerate lying with a sedimentary contact on Lower Cambrian quartzite where rocks of the western assemblage have been eroded away completely.

The Osgood Mountains and part of the adjacent Hot Springs Range were mapped by Hotz and Willden (1964) at a scale of 1:62,500. The utility of the map for tectonic interpretation is limited by uncertainty over the ages of the Paradise Valley Chert and the overlying very thick arkosic Harmony Formation. Stratigraphic units bearing those names are confined to the Osgood Mountains and ranges within 50 miles (80 km) of the Osgood Mountains.

Both the Paradise Valley and Harmony were assigned an age of Late Cambrian based on trilobites from limestone lenses at several locations. All of the trilobite-bearing limestone bodies appear to me to be debris flows. They lack the lateral continuity normally exhibited by marine limestone strata and are typically composed of large, rounded to angular loosely cemented fragments. If the limestone bodies are correctly interpreted to be debris flows, the contained trilobites may or may not correctly date the two formations in which the debris flows occur. The history of dating of the

Scott Canyon Formation in the Battle Mountain area is pertinent: it was dated as Cambrian on the basis of trilobites from debris flows until Devonian radiolarians were discovered in the chert beds.

Arkosic boulders apparently derived from the Harmony Formation are present in Mississippian units at widely separated localities: the northern Independence Mountains (Miller and others, 1984), the Adobe Range (Ketner and Ross, 1990), the Piñon Range (unpublished data), The East Range (unpublished data), and the Fish Creek Mountains (unpublished data). Therefore neither the Paradise Valley Chert nor the Harmony Formation can be younger than Early Mississippian. The trilobites preclude an age older than Late Cambrian. Within the Cambrian-Mississippian interval they are quite possibly of Silurian age based on their lithic composition. Commonly, Lower Silurian chert at several localities in Nevada is red or green, and some unusually thick beds are pure white (Ketner, 1991a, b). In its type locality, the Paradise Valley Chert exhibits these features. Middle Silurian strata in several localities in northern Nevada are composed of somewhat arkosic sandstone or siltstone that is conspicuously rich in flakes of muscovite, suggesting possible correlation with the arkosic Harmony Formation.

The tectonic interpretation of stratigraphic and tectonic relations in the Osgood Mounains and Hot Springs Range must await a resolution of the problem of the ages of the Paradise Valley Chert and Harmony Formation, but the gradational contact linking the Lower Cambrian shelf quartzite to overlying Cambrian and Ordovician deep-water carbonate units is a secure relation of regional significance.

BATTLE MOUNTAIN

Structural relations in the Battle Mountain area remain uncertain owing mainly to uncertainties in the ages of the Harmony and Scott Canyon Formations. However, the area contains a good example of an angular unconformity below Middle Pennsylvanian strata.

Two versions of the Antler Peak 15-minute quadrangle, mapped by R.J. Roberts, were published at a scale of 1:62,500 (Roberts, 1951, 1964). Parts of the same area, published at 1:24,000 scale by J.L. Doebrich (1992, 1994) and by T.G. Theodore (1991a, b), show greater detail and revised formation ages but do not significantly change original structural interpretations outlined by Roberts. Some formations in the area have been difficult to date, and consequently, their stated ages have changed drastically and are still undergoing revision. The Harmony Formation has evolved from Mississippian(?) (Roberts, 1951) to Cambrian (Roberts, 1964). The Scott Canyon Formation has evolved from Mississippian(?) (Roberts, 1951) to Cambrian (Roberts, 1964) to at least partly Devonian (Doebrich, 1994).

As mapped by both Roberts and Doebrich, the Harmony Formation is separated from the Valmy Formation by the Dewitt thrust fault. Along most of its length, the contact is covered, but on hill 6835 it is fairly well exposed and could be interpreted as sedimentary. Whatever the nature of the contact between the Valmy and the Harmony, it is overlapped unconformably by the Middle Pennsylvanian Battle Conglomerate. The angular unconformity testifies to tectonism between Ordovician and Middle Pennsylvanian, but the nature and exact time of the tectonic event within that interval are indeterminate from local evidence. The deformation could be the same age as the Late Devonian to Early Mississippian Antler orogeny or, more likely, an expression of widespread Middle Pennsylvanian tectonism documented in this report and elsewhere (references in Ketner, 1977). It is ironic that the type area of the Antler orogeny displays no clear evidence of Late Devonian to Mississippian tectonism.

SONOMA RANGE

The basal conglomeratic beds and substrate of the Havallah sequence are exposed in Clearwater Canyon and Grand Trunk Canyon (Ferguson and others, 1951; Silberling, 1975). Silberling's map and report are very informative as to the lithic composition and locations of map units, but paleontological data are notably scarce. According to Silberling's mapping, the Havallah is a continuous, concordant sequence composed of three stratigraphic units—a lower bedded chert unit underlain by a thrust fault, a middle clastic unit, and an upper greenstone unit, all indicated to be of Permian age.

In my view the bedded chert unit, which consists of black and distinctive white chert, correlates lithically with a similar chert sequence in northeastern Nevada that was dated as Late Ordovician and Early Silurian by stratigraphic position and by contained graptolites (Ketner and Ross, 1990; Ketner, 1991b). Based on conodonts from samples of limestone that I collected near Clear Creek, the lower part of the clastic unit is of Famennian age and the upper part is Meramecian (B.R. Wardlaw, written commun., 1978). I interpret the greenstone unit to be of Mississippian age because it is intercalated with, and is overlain by, sedimentary rocks similar to the upper part of the clastic unit. If my interpretation of the stratigraphy is correct, the area was broadly elevated, probably in Late Devonian, was eroded down to the Lower Silurian, and then was submerged in latest Devonian. The disconformity below the Famennian beds represents the Antler orogeny and indicates that that event, here as elsewhere, consisted of uplift and erosion without strong deformation.

EAST RANGE

The East Range is one of the most important sources of tectonic information in Nevada. It supplies unequivocal evidence that, for 120 million years between Middle Ordovician and late Early Mississippian, (1) the area was unaffected by folding and (2) almost all the large-scale folding now evident in the area is younger than Triassic. It also supplies evidence on the sedimentary substrate of the Havallah sequence.

The East Range was first mapped by Ferguson and others (1951). Although the geologic map of the Dun Glen 15-minute quadrangle by D.H. Whitebread was released in 1978 as a U.S. Geological Survey Open-File Report, it remained unnoticed and the tectonic information that can be derived from it has had no effect on widely accepted tectonic concepts. This map now is published in full color as Miscellaneous Investigations Map I–2409 at a scale of 1:48,000 (Whitebread, 1994). It is the product of tremendous effort and attention to detail, but new information requires revision of the ages of certain units and therefore revision of the structure as it was perceived by Whitebread.

In the Willow Creek area a thick unnamed sequence of metamorphosed limestone, siltstone, and greenstone is overlain with a gradational, concordant contact by the Ordovician Valmy Formation. For whatever now-unknown reason, the lower part of this sequence was originally thought to be of Mesozoic age, and since the Valmy Formation overlies it, the contact between them had to be regarded as a thrust fault, and was originally mapped as such by Ferguson and others (1951), and also by Whitebread (1978). On the basis of lithic correlation with dated units in other ranges and a conodont collection from the Rawhide Canyon area, the upper part of the sequence underlying the Valmy Formation can now be quite certainly dated as of Late Cambrian(?) and Early Ordovician age. The base of this sequence is not exposed in the East Range, but the base of the equivalent sequence in the Osgood Mountains is well exposed. There, the lower part of the sequence is in sedimentary contact with Lower Cambrian quartzitic rocks of the miogeocline.

Because the Ordovician Valmy Formation is in normal stratigraphic sequence above the unnamed Cambrian(?) and Ordovician sequence in the East Range, there is no structural requirement for an important thrust fault separating the two formations. Moreover, a sector of the contact where it crosses a ridge northwest of Rawhide Spring appears to be concordant and gradational. This is not to say that the contact is unfaulted along its entire length. Bedding attitudes suggest the presence of a fault of some kind in one segment of the contact, but the concept of the contact as a major thrust fault is no longer valid.

The Valmy Formation is composed of a lower interval of greenstone, argillite, siltstone, chert, and minor limestone, and an upper member consisting mainly of quartzite. The lower interval is dated by means of conodonts as Early Ordovician. The quartzite member, based on its stratigraphic position and conodont dating elsewhere, is Middle Ordovician.

The quartzite member of the Valmy Formation is overlain by the Inskip Formation, a sequence of arkosic sandstone, conglomerate, siltstone, limestone, and volcanic rock at least 9,000 ft (2,743 m) thick. The contact with the Valmy Formation is a disconformity, as indicated by concordance of bedding attitudes on both sides and the presence in the Inskip of conglomerate composed of pebbles derived from the Valmy. It was mapped as a disconformity by Ferguson and others (1951) and by Whitebread. Silberling and Roberts showed the contact as a fault on an interpretive sketch map (1962, fig. 4) but described it in the text as "***for the most part steeply faulted," implying that they regarded part of the contact as sedimentary.

The contact between the Valmy and Inskip Formations is remarkably concordant. The strike of beds above and below the contact is essentially parallel along the 12-mile-long (19.2 km) contact within and to the south of the Dun Glen quadrangle. The average dip of the quartzite member of the Valmy based on nearly 100 measurements is within 3° of the average dip of the Inskip, based on more than 200 measurements. Although the Inskip is partially mylonized, the mylonite foliation is clearly parallel to original strata that were relatively unaffected by shearing. These include basaltic flows, limestone beds, and conglomerate deposits.

At Hot Spring Canyon, 5 miles (8 km) south of the Dun Glen quadrangle (Muller and others, 1951), the basal conglomerate beds of the Inskip are composed in part of large cobbles of quartzite apparently derived from quartzite beds of the concordantly underlying Valmy Formation. Here also, the Valmy Formation lies concordantly on a limestone sequence. The limestone sequence was originally designated as Triassic, but based on lithic correlation with dated rocks in the Dun Glen quadrangle, it is more likely to be Late Cambrian or Early Ordovician in age.

The age of lower beds in the Inskip Formation was originally thought to be Devonian(?) and Mississippian(?) on the basis of a coral collection and preliminary evaluation of conodont collections from thin limestone bodies in the lower part of the formation (Whitebread, 1978). The coral collection is now regarded as early Late Mississippian by W.J. Sando (1993) and reevaluation of the conodont collections by Anita Harris (revised unpub. report, 1980) indicates a late Early Mississippian age. The corals appear to be redeposited and the conodonts certainly may have been redeposited, so the age of the lower, but not lowest, part of the Inskip must be regarded as mid-Mississippian or possibly younger. Conodonts collected from the uppermost exposed beds in conformable sequence with the Mississippian part of the formation are Morrowan, Lower Pennsylvanian (B.R. Wardlaw, oral commun., 1997).

North of Rockhill Canyon in the northern part of the Dun Glen quadrangle and separated from the Inskip by a fault, Whitebread showed Triassic rocks in normal contact with rocks he designated as the Havallah sequence. Conodonts collected by Whitebread and fusulinids reported by Silberling and Roberts (1962) indicate a Permian age for this exposure of the Havallah. The collections contain fragmentary conodonts apparently reworked from older units. There is no apparent reason other than its age for separating this exposure from the Inskip, and in my opinion, it should be regarded as the uppermost segment of that formation. If that interpretation is valid, then the age range of the Inskip is essentially the same as that of the Havallah sequence, and the two units logically should bear the same name.

The disconformable contact between the Middle Ordovician Valmy and mid-Mississippian beds of the Inskip records little if any deformation between Middle Ordovician and mid-Mississippian—an interval of at least 120 million years. This hiatus represents (1) regional uplift probably in Late Devonian, (2) erosion of Devonian, Silurian, and Upper Ordovician strata assumed to have been present, then (3) submergence in mid-Mississippian and accumulation of more than 9,000 ft (2,743 m) of sedimentary and volcanic strata in a deep marine environment.

At the map scale, the Triassic rocks in the East Range are no less deformed than the lower and middle Paleozoic units. If the degree of large-scale deformation of the Triassic rocks is subtracted from that of the Paleozoic rocks, little or none is left to ascribe to older tectonic events. The concept that the Antler orogeny of middle Paleozoic age involved strong folding and thrust faulting is supported by neither stratigraphic relations nor map-scale structural relations in the East Range.

SOUTHERN TOYABE RANGE

The east slope of the southern Toyabe Range is important for several good exposures of shallow-water shelf strata of Early Cambrian age overlain with a sedimentary concordant contact by deep-water western facies rocks of Late Cambrian to Ordovician age.

Reconnaissance mapping by Ferguson and Cathcart (1954) at a scale of 1:125,000 is still the only published source of critical stratigraphic and structural data. The grand exposures in the Summit Creek and Wisconsin Creek area show a sequence of Lower Cambrian rocks, mainly of coarse- to medium-grained, crossbedded quartzite, grading upward into fine-grained siltstone, shale, chert, limestone, and greenstone. The fine-grained strata resemble the Upper Cambrian to Ordovician Emigrant Pass and Palmetto Formations of Esmeralda County. Cambrian conodonts were extracted from limestone beds in the upper part of the sequence along Summit Creek, and Early and Middle Ordovician graptolites at unspecified locations in the range were reported by Ferguson and Cathcart.

A belt of coarsely detrital rocks of the Mississippian and (or) Permian Diablo Formation overlies the lower Paleozoic sequence. The base of the Diablo is shown as a normal fault and the original nature of the contact is unknown. However, the parallel orientation of outcrop belts and the generally similar attitude of beds in the entire sequence as mapped by Ferguson and Cathcart provide no support for the concept of intense tectonism in the middle Paleozoic.

Here, as in parts of northern and southwestern Nevada, Ordovician western facies rocks are autochthonous with respect to underlying Cambrian shallow-water deposits. Deposition of sediments of the western assemblage in relatively deep water reflects sea-level change or vertical tectonics, and their occurrence in sequence with older, shallow-water deposits does not require eastward tectonic transport. The frequent depiction of the Roberts Mountains thrust at this latitude is unsupportable by stratigraphic or structural evidence.

EMIGRANT PASS AND RAILROAD PASS

Geologic relations at Emigrant Pass and Railroad Pass in Esmeralda County are significant because they provide clear evidence that the Palmetto Formation, lithically similar and temporally equivalent to the Ordovician Valmy Formation of northern and central Nevada, is autochthonous with respect to the underlying miogeoclinal sequence.

The Cambrian Emigrant Formation, which gradationally underlies the Palmetto, is part of a concordant sequence of Proterozoic and Cambrian formations assignable to the Cordilleran miogeocline. The Emigrant is a deep-water deposit, but it is underlain by strata that include distinctly shallow water units containing an abundant shelly fauna.

The geologic map of Esmeralda County (Albers and Stewart, 1972) and the Rhyolite Ridge quadrangle (Robinson and others, 1976), in which Emigrant Pass is located, show the contact between the Palmetto Formation and the Emigrant Formation as a thrust fault. Moreover, the index maps of countless publications on aspects of Nevada geology show the Roberts Mountains thrust extending through Esmeralda County. Apparently this reflects the assumption that Ordovician western facies rocks, by whatever name and wherever found, must be allochthonous. Actually, the contact between the Emigrant Pass and the Palmetto is concordant and gradational in several good exposures near Emigrant Pass, Railroad Pass, and elsewhere in the county. This was recognized by John H. Stewart (1980), who stated (p. 40) in reference to the Esmeralda County area: "***the Palmetto is apparently in conformable contact with the underlying Cambrian Emigrant Formation." A sample collected from the transitional beds between the two formations at Emigrant Pass yielded basal Ordovician conodonts (J.R. Repetski, oral commun., 1997).

Recently, microfossils collected at Railroad Pass from lower levels of the transition zone between the Emigrant and Palmetto include proconodonts and euconodonts that suggest latest Cambrian ages, whereas slightly higher collections indicate an Early Ordovician age (John Repetski, written commun., 1993). The lithic similarity of the upper part of the Emigrant and the lower part of the Palmetto, the concordance of bedding above and below the contact, and the position of the Cambrian-Ordovician contact determined by conodonts within a lithically homogeneous sequence together confirm that the Palmetto Formation is autochthonous with respect to underlying Proterozoic and Cambrian units.

MONTE CRISTO RANGE AND CANDELARIA HILLS

At a locality in the Monte Cristo Range, 5 miles (8 km) north of Coaldale, the contact between a Mississippian dolomite and conglomerate unit and the underlying Ordovician Palmetto Formation is definitely an angular unconformity and therefore constitutes an exception to one of the main themes of the present report.

The Monte Cristo Range was mapped in reconnaissance by Ferguson and others (1953). Their map, published at a scale of 1:125,000, remains the principal source of geologic relations in that area. Ferguson and others assigned the dolomite and conglomerate interval to the Permian Diablo Formation. The formation is now known to be Mississippian, based on corals collected there by F.G. Poole and identified by Sando (1993). The distinctly unconformable contact between Mississippian rocks and underlying Palmetto Formation constitutes evidence of local tectonism between Ordovician and Early Mississippian. The area deserves detailed study to determine the nature and exact age of this exceptional occurrence of pre-Mississippian tectonism.

The Candelaria Hills, a short distance northwest of the Monte Cristo locality, were mapped originally by Ferguson and others (1953, 1954), who included undated Mississippian dolomite and limestone in the Permian Diablo Formation. Page (1959), in a detailed map of the Candelaria mining district, included the Mississippian strata, still undated, in the Ordovician Palmetto Formation. The correct, Mississippian, age of the dolomite and limestone unit was determined between 1972 and 1976 by Sando (1993) based on corals collected by F.G. Poole. Most of the deformation in the area appears to be post-Mississippian and pre-Permian, but without detailed mapping done in the light of the new paleontological data, the relations among the Permian, Mississippian, and Ordovician strata remain unclear.

CONVICT LAKE

The geologic map of the Convict Lake area in the Mount Morrison 15-minute quadrangle (Rinehart and Ross, 1964) together with new conodont-based dates of stratigraphic units reveals a west-facing Cambrian to Devonian stratigraphic sequence similar in some respects to the lower Paleozoic sequence in adjacent parts of Nevada.

The Buzztail Spring Formation and the overlying Mount Aggie Formation constitute a thick sequence of thin- to thick-bedded metamorphosed limestone, sandstone, shale, chert, and greenstone. The presence of bedded chert and greenstone and the lack of shelly fauna suggest a relatively deep water environment of deposition, and these units are therefore assignable to the western or transitional assemblage.

A collection of conodonts from the middle part of the Mount Aggie Formation on the northwest side of Convict Lake indicates a stratigraphic position of these beds near the Cambrian-Ordovician boundary (J.E. Repetski, oral commun., 1994); therefore most of the Buzztail Spring–Mount Aggie sequence below the conodont collection is of Cambrian age and possibly older. Overlying the Mount Aggie Formation with a gradational contact is the Convict Lake Formation of Ordovician age as determined by a well-preserved graptolite fauna (Rinehart and Ross, 1964; C.H. Stevens, written commun., 1995). Disconformably above the Convict Lake Formation is a series of quartzitic beds originally assigned by Rinehart and Ross to the Mount Morrison Formation and Sevehah Cliffs sequence. This quartzitic sequence is now known to be of Devonian age, based on conodont fragments from the upper beds identified by A.G. Harris and J.E. Repetski (oral commun., 1994) and correlations by Stevens and Greene (1994, 1995).

The Devonian beds are overlain in the Convict Lake area and in other pendants of the Sierras, by the Bright Dot Formation, a sequence of chert, argillite, and sandstone containing Mississippian conodonts (C.H. Stevens, written commun., 1995). The contact between the two units is generally concordant according to Stevens. The stratigraphic relations indicate two intervals of erosion—one between Ordovician and Devonian and another between Devonian and Mississippian—but do not indicate any significant folding between Ordovician and Mississippian.

The Buzztail Spring Formation and lower part of the Mount Aggie Formation are lithically similar to, and correlative with, the Emigrant Formation of Esmeralda County, Nevada. The upper part of the Mount Aggie Formation and the Convict Lake Formation are similar to, and correlative with, the Palmetto Formation. None of the strata near Convict Lake has been dated as Silurian, and beds of that age are presumed to have been eroded prior to deposition of the Devonian quartzitic strata.

The Convict Lake area displays good evidence of continuous deposition through the Upper Cambrian–Lower Ordovician interval and for periods of erosion or nondeposition. It displays no evidence for intense mid-Paleozoic deformation.

PILOT KNOB VALLEY AND EL PASO MOUNTAINS

Pilot Knob Valley and the El Paso Mountains are important because they provide exposures of Lower Mississippian strata lying disconformably on western facies, deep-water, siliceous deposits correlative with western facies deposits in Nevada.

Parts of Pilot Knob Valley (Carr and others, 1992, pl. 1) and the northern El Paso Mountains (Carr and others, in press) were mapped at a scale of 1:24,000.

In Pilot Knob Valley the lower Lower Mississippian Robbers Mountain Formation, composed of a basal conglomerate and overlying meta-argillite, disconformably overlies sandy marble and quartzite of Middle Devonian age according to Carr and others (1992). They described the contact of the Robbers Mountain Formation with underlying units in general as "***either a slight angular unconformity or a major disconformity regionally having significant erosional relief, because the formation rests on different Devonian units in the El Paso Mountains than it does in Pilot Knob Valley" (p. 14).

In the El Paso Mountains, near Iron Canyon, a sandstone, shale, and conglomerate sequence of undated Mississippian(?) and dated Pennsylvanian ages overlies a western facies map unit of Cambrian and Ordovician age along a normal fault contact about 4 miles (6.4 km) long according to Carr and others (in press). Attitudes and outcrop patterns do not seem to require the contact to be a fault along its entire length. Near the Apache Mine, beds above and below the contact are parallel, and some beds above the contact contain clasts apparently derived from the underlying unit. I interpret the contact near the Apache Mine to be a probable disconformity although it may be faulted elsewhere.

The slightly angular or disconformable contact separating Devonian and Ordovician strata from overlying Mississippian strata in Pilot Knob Valley and the El Paso Mountains supplies evidence for a period of erosion prior to deposition of the Mississippian strata but no support for the concept of strong deformation in the Devonian-Mississippian interval.

CONCLUSIONS

Verifiable stratigraphic and structural relations and reasonable interpretations based on those relations cited in this report lead to the following general conclusions.

1. Lower Paleozoic sediments of the western assemblage were deposited along the continental margin, not directly on oceanic crust but concordantly on a thick substrate of terrigenous sediments. The substrate includes Proterozoic sandstones, Lower Cambrian shallow-water quartzite and shale, and Middle to Upper Cambrian detrital limy turbidites.

2. In mid-Frasnian time the deep-water deposits of the western assemblage emerged and were eroded as deeply as the Lower Ordovician. The Frasnian age of emergence is determined by the age of the oldest siliceous detrital sediments derived from the western assemblage—the lower beds of the Pilot Shale in the foreland basin. Structural evidence that this tectonic event, the Antler orogeny, involved intense folding and thrust faulting is notably scarce.

3. Immediately after uplift, part of the elevated western assemblage terrane began to subside below sea level and became the site of deposition of the overlap assemblage. The oldest deposits, identified in the southern Independence Mountains and the Adobe Range, are of Frasnian age. These were deposited concordantly on Silurian and Ordovician strata. Elsewhere, deposits of Famennian and Mississippian ages lie generally concordantly on eroded remnants of the western assemblage. Such deposits comprise the lower parts of the Havallah and Schoonover sequences and the Inskip Formation. Sediments composing the overlap assemblage, and foreland basin deposits, were derived from areas of the western assemblage that remained elevated. Basaltic greenstone is a significant component of the overlap assemblage at all stratigraphic levels.

4. In Middle Pennsylvanian time the western facies terrane and overlying Upper Devonian to Lower Pennsylvanian strata of the overlap assemblage were elevated, moderately deformed, and deeply eroded. Whether the deformation involved folding or tilting is uncertain in most areas, and there is no evidence of thrust faulting. Subsequent subsidence resulted in detrital deposits of Middle Pennsylvanian to Permian age lying directly on Frasnian to Lower Pennsylvanian sequences of the overlap assemblage, Ordovician to Devonian sequences of the western assemblage, and the Cambrian substrate of the western assemblage. Middle Pennsylvanian tectonism in Nevada was a small part of continental-scale tectonism, including the Ouachita orogeny and formation of the ancestral Rocky Mountains. Middle Pennsylvanian to Permian deposits of the western facies terrane are a small part of the regional blanket that covers much of Nevada and includes sequences such as the Oquirrh of Utah and the Wood River of Idaho.

5. Beginning in the Jurassic and ending in the Eocene, the entire region was strongly folded and thrust faulted. With the exceptions of moderate folding or tilting in the Middle Pennsylvanian, and Tertiary extension, deformation in almost all areas of the western assemblage dates from the Jurassic to Eocene interval—a conclusion reached also by Dover (1980) with respect to the western facies terrane of Idaho and by Ketner (1986; and with Noll, 1987) with respect to the western facies terrane in northern Mexico.

If the above conclusions are valid, then the genesis of the Antler orogeny is reduced to a question of vertical tectonics. And if the abundance of basaltic greenstone intercalated with sediments throughout the Proterozoic to Pennsylvanian interval indicates tensional stress, then the Antler orogeny and Pennsylvanian deformation must have taken place under generally extensional conditions. Subduction and collision with island arcs are not indicated or required, but the problem of origin remains. Any hypothesis of origin of the Antler orogeny must deal with a remarkable coincidence in time and space: the Alamo megabreccia said to have been caused by a meteor impact in or near western Nevada (Warme and Sandberg, 1996) was formed in mid-Frasnian time at about the same time as the onset of the Antler orogeny. Similar megabreccias were formed at the same time in Alberta (Cook and others, 1972). Were the Alamo and other megabreccias effects of the Antler orogeny and not the result of impact? If there actually was a meteor impact in the mid-Frasnian, did it trigger the Antler orogeny? In any event, the old model for the tectonic development of the western facies terrane is outdated and should be replaced by a new model that accords with field relations—Late Devonian to Early Pennsylvanian uplifts and depressions without contraction; middle Pennsylvanian deformation and uplift followed by regional depression; intense Jurassic to Eocene folding and thrusting; Tertiary and Quaternary extension.

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