Late Paleozoic tectonism in Nevada: Timing, kinematics, and tectonic significance

James H. Trexler, Jr.†
Patricia H. Cashman
Department of Geological Sciences, University of Nevada, Reno, Nevada 89557-0180, USA

Walter S. Snyder
Vladimir I. Davydov
Department of Geology and Geophysics, Boise State University, 1910 University Drive, Boise, Idaho 83725, USA

ABSTRACT

Three late Paleozoic, angular unconformities, each tightly constrained in age by biostratigraphy, are exposed in Carlin Canyon, Nevada. These record deformation as well as erosion. Folding associated with these deformation events is roughly coaxial; all three sets of fold axes trend northeast. Each unconformity represents tectonic disruption of the middle part of the western North American margin between the times of the initiation of the Antler orogeny (Late Devonian–Early Mississippian) and the Permian–Triassic Sonoma orogeny. This paper focuses on one of these unconformities in the Middle Pennsylvanian—the C6 unconformity—and the deformation and age constraints associated with it.

Our data from Carlin Canyon yield detailed glimpses of how the Antler foreland evolved tectonically in Mississippian and Pennsylvanian time. Middle Pennsylvanian (Desmoinesian) northwest-southeast contraction resulted in thin-skinned folding and faulting, uplift, and erosion. These data require reinterpretation of the tectonic setting at the time of the Ancestral Rocky Mountains orogeny and suggest that plate convergence on the west side of the continent played a significant role in late Paleozoic tectonics of the North American continent.

Keywords: tectonics, stratigraphy, structure, Great Basin, Nevada, Pennsylvanian, Ancestral Rocky Mountains.

INTRODUCTION

Although the tectonic evolution of southwestern North America (present-day United States) is generally thought to include only two Paleozoic orogenies, the latest Devonian–Early Mississippian Antler orogeny and the Late Permian–earliest Triassic Sonoma orogeny, many workers have shown that there is considerable evidence for deformation at other times in the late Paleozoic. Mechanisms for this deformation fall into two groups: (1) evolution or continuation of the Antler orogeny, or (2) new orogenic events resulting from a changed tectonic setting.

Both the Antler and Sonoma orogenies are interpreted to have resulted in the tectonic emplacement of deep-marine strata and volcanic rocks eastward onto the continental margin of western North America. However, identifying specific structures (and particularly the original basal thrust fault or suture) unequivocally associated with these events has been difficult. In contrast, the Middle Pennsylvanian and earliest Permian deformations we describe here include folding and thrust faulting that are well constrained in style and timing. This widespread, late Paleozoic contractional deformation appears to require poorly understood (and in some places unrecognized) tectonic activity, thus adding a phase of deformation whose timing is well constrained—but whose nature is poorly known—to the evolution of western North America.

Unusually good exposure and age control in Carlin Canyon, north-central Nevada (Fig. 1), allow us to document the geometry, kinematics, and timing for three episodes of late Paleozoic tectonism in central Nevada: a middle Mississippian event (not discussed in detail in this paper; see Trexler et al., 2003), a Middle Pennsylvanian deformation event, and another in earliest Permian time. Although evidence for late Paleozoic deformation of Antler foreland sedimentary deposits has long been recognized here (e.g., Dott, 1955; Ketner, 1977), it has generally been overlooked in discussions of the tectonic evolution of western North America. Deformation events that cannot be attributed to either a narrowly defined, Late Devonian Antler orogeny or the Permian–Triassic Sonoma orogeny have also been documented elsewhere in Nevada (e.g., Erickson and Marsh, 1974; Silberling et al., 1997; Ketner, 1998; Theodore, 1999, personal commun.). The geologic relationships at Carlin Canyon are significant for two reasons: they record the *geometry* of the contractional deformation, and they narrowly constrain that deformation in *time*. In Carlin Canyon, it is also possible to distinguish between the less intense Mesozoic overprint and the late Paleozoic deformations and to determine the geometry of the Mesozoic deformation.

In this paper, we present evidence for Middle Pennsylvanian and Permian deformation in Nevada, and we then discuss the significance of these events for our understanding of the tectonic evolution of North America. We first summarize (1) the generally accepted Paleozoic history of the Antler foreland, and (2) our approach to reexamining part of this history by using detailed biostratigraphy to recognize and correlate widespread unconformities in the stratigraphic record. Next, we present the structural and stratigraphic results of our detailed studies at Carlin Canyon. We then briefly summarize evidence for late Paleozoic deformation elsewhere in Nevada. We conclude with a short discussion of the im-

---

†E-mail: trexler@mines.unr.edu.

GSA Bulletin; May/June 2004; v. 116; no. 5/6; p. 525–538; doi: 10.1130/B25295.1; 11 figures.

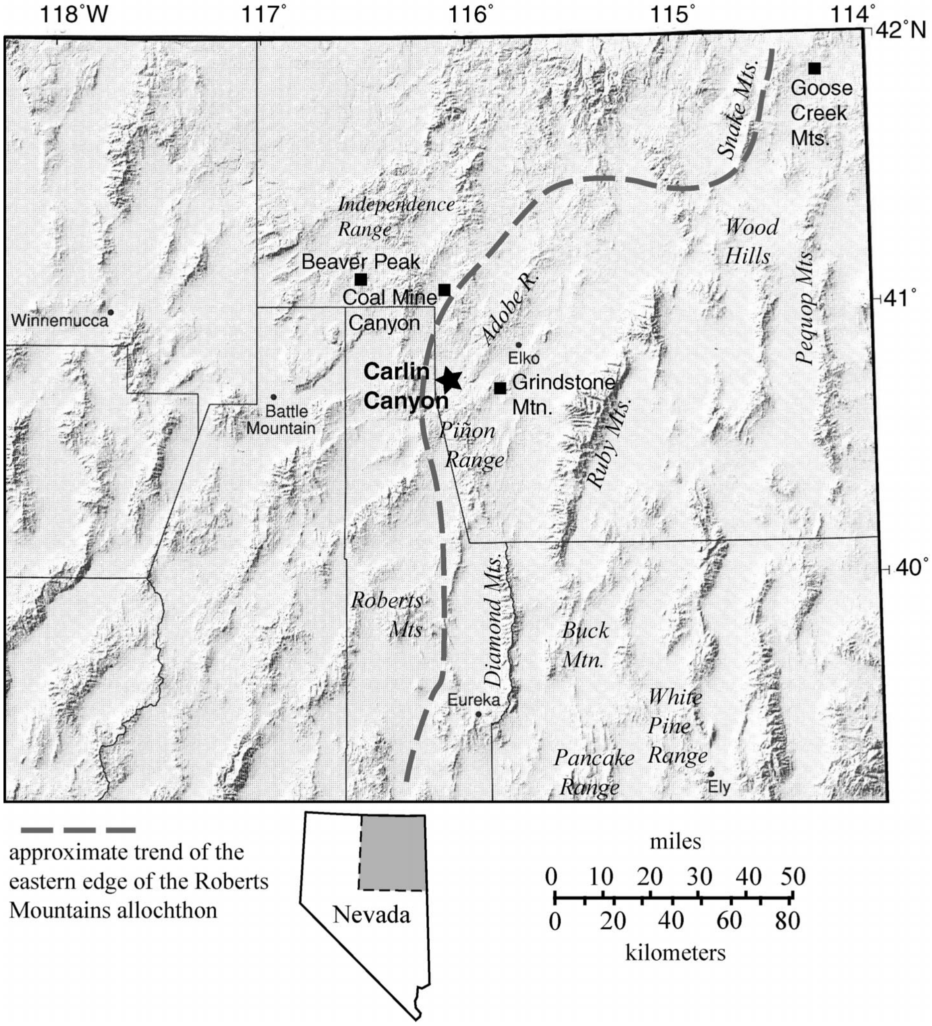

Figure 1. Location map for northeast and north-central Nevada. Squares—sections depicted in Figure 10. Star—Carlin Canyon (geologic map in Fig. 5).

portance of late Paleozoic deformation and some possible implications of this deformation for the tectonic evolution of North America.

BACKGROUND

Paleozoic History of the Antler Foreland

The western edge of Paleozoic North America is thought to have been a passive margin until the Late Devonian–Early Mississippian Antler orogeny (e.g., Roberts et al., 1958; Burchfiel and Davis, 1972, 1975). The Antler orogeny is marked by the formation of a foreland basin in Nevada and by a deep strike-slip basin in Idaho (Link et al., 1996). Most workers think that it also entailed the eastward obduction of the internally deformed Roberts Mountains allochthon onto the continental margin (e.g., Burchfiel and Davis, 1975; Dickinson, 1977; Speed and Sleep, 1982).

Antler tectonism began in latest Devonian to earliest Mississippian time, as recorded by the initiation of a foreland basin with sediments derived from the west (Poole, 1974; Smith and Ketner, 1977; Poole and Sandberg, 1977; Ketner and Smith, 1982; Johnson and Visconti, 1992; Carpenter et al., 1993). In the offshore basin that is now the Roberts Mountains allochthon, deposition continued until Late Devonian (Famennian) to Early Mississippian (Kinderhookian) time (Coles and Snyder, 1985). The rocks of the allochthon are now strongly deformed, and that deformation is widely thought to be ''Antler'' in age. However, attempts to find the oldest overlap units on the allochthon (bracketing the end of deformation) have so far demonstrated only that the internal deformation of the Roberts Mountains allochthon occurred before Middle Pennsylvanian time (e.g., Poole and Sandberg, 1977; Rich, 1977; Dickinson et al., 1983; McFarlane, 1997; McFarlane and Trexler, 1997; Trexler and Giles, 2000). Thus, the Antler orogeny is currently defined by syntectonic sedimentary rocks ranging in age from Late Devonian through Early Pennsylvanian and by deformation that is only known to be pre–Middle Pennsylvanian.

Deformation of the foreland-basin rocks (in contrast to those of the allochthon) as young as middle Mississippian has been attributed to either the Antler orogeny or to an unrecognized younger event. Lower Mississippian rocks in the Piñon Range are deformed, then overlapped by Upper Mississippian strata (for locations of places discussed in text, see Fig. 1) (Silberling et al., 1997; Johnson and Pendergast, 1981; Johnson and Visconti, 1992). Johnson and Pendergast (1981) interpreted this deformation as part of the Antler orogeny in earliest Osagean (middle Early Mississippian) time. Alternatively, where the same relationship occurs in the Diamond Mountains, it was interpreted to *postdate* Antler deformation, because Antler foreland-basin strata are folded beneath the unconformity (Trexler and Nitchman, 1990). Newer models for evolution of foreland systems in which strata of the foreland basin are deformed as contraction propagates inboard (e.g., DeCelles and Giles, 1996) suggest that the Antler orogeny might have lasted longer than previously thought—i.e., Late Devonian through middle Mississippian.

The Antler orogeny created a long-lived contractional foreland basin that filled with syntectonic and posttectonic sedimentary deposits. These strata record most of what we know about the orogeny (citations above, and reviewed in Trexler et al., 2003). In central Nevada, siliciclastic rocks of the foreland consist of conglomerate, sandstone, and shale that were subjected to at least two sedimentary cycles within the Antler foreland system (Fig. 2). Older basin fill is immature, deep-marine, and turbiditic, especially to the west in the foredeep keel. Later sedimentary fill is more mature and was deposited in fluvial, fan-delta, and shallow-marine environments; the common limestone interbeds in most places preserve foraminifera. (Foraminifera [including fusulinids] are ideal for age control. They are rapidly evolving, cosmopolitan, and do not survive recycling.) In some areas, the crustal response was quite different, e.g., strike-slip tectonics in Idaho (Link et al., 1996) and a remnant foredeep in southern Nevada (Trexler et al., 1996).

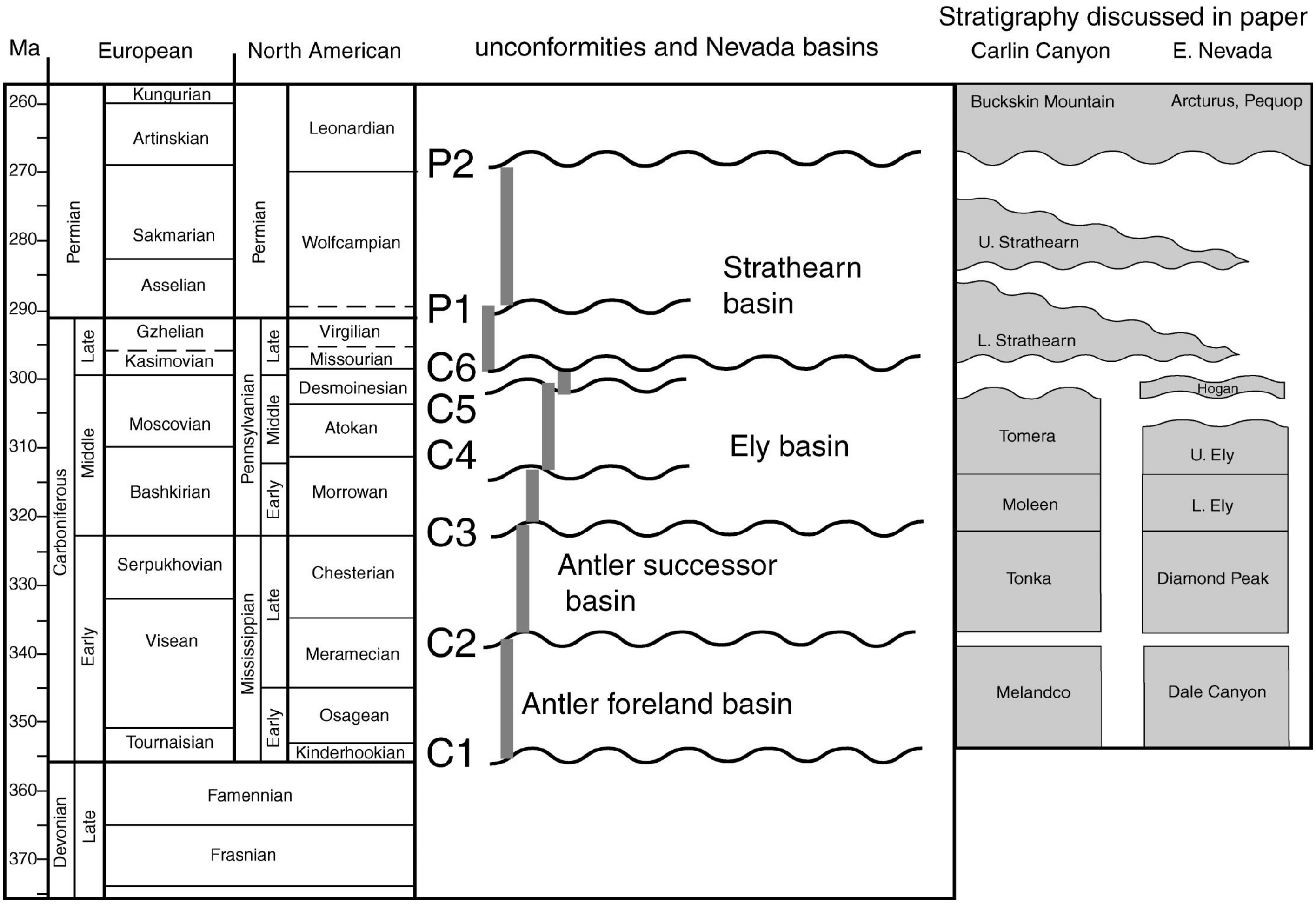

Figure 2. Tectonostratigraphic boundaries, C1 through P2, in the upper Paleozoic section of the Great Basin and correlation of regional stratigraphy discussed in text. The basis for this unconformity-based organization is discussed thoroughly in Trexler et al. (2003).

Intermittent post-Antler (informally defined here as Middle Pennsylvanian through middle Permian time) deformation has been demonstrated in many places, although much of this deformation has been interpreted to be local in extent (e.g., Dott, 1955; Stevens et al., 1997). Some, however, have suggested that it reflects regional phases of tectonism (e.g., Snyder et al., 1991, 1995; Trexler et al., 1991; Ketner, 1977). In the Carlin area, Dott (1955) and Ketner (1977) mapped angular unconformities in the upper Paleozoic section. In central Nevada, Snyder et al. (1991), Gallegos et al. (1991), Perry (1994, 1995), Trexler et al. (1995), and Crosbie (1997) documented Mississippian through Permian unconformities and syntectonic strata. In southwestern Nevada, there are tectonic as well as eustatic controls on sedimentation in the southern Antler foreland basin (Trexler et al., 1996; Trexler and Cashman, 1997; Schiappa et al., 1999). In southeastern California, tectonism included a Desmoinesian (Middle Pennsylvanian) phase of basin formation and two phases of Early Permian folding and thrusting (Stevens et al., 1997). In Utah and Idaho, important aspects of Pennsylvanian and Permian tectonics and sedimentation have been documented by Jordan and Douglas (1980), Geslin (1998), and Mahoney et al. (1991). In summary, there is considerable evidence in the literature for Pennsylvanian and Permian deformation in the region, enough to warrant an examination of whether one or more regional, rather than local, tectonic events are represented.

Unconformities in the Stratigraphic Record—Evidence for Tectonism in the Antler Foreland

Tectonism is recorded by deformation, by syntectonic basin formation, and by unconformities that result from uplift and erosion. Tectonically induced unconformities related to collisional orogenies can be recognized because they are angular where the deformation is greatest (the orogenic belt), and both the angularity and the lacuna typically decrease away from the orogenic belt. We recognize several widespread late Paleozoic unconformities in the Great Basin that separate packages of genetically related sedimentary rocks (Fig. 2). We have adopted a numbering scheme for the unconformities similar to that used for the Mesozoic of the Colorado Plateau (e.g., Pipiringos and O'Sullivan, 1978). They are numbered sequentially from oldest to youngest within each time period (for the late Paleozoic, we use Carboniferous = C and Permian = P) (Snyder et al., 2000).

At Carlin Canyon, three of these late Paleozoic unconformities are particularly easy to recognize because they are angular. With the aid of detailed biostratigraphy, these can be traced laterally into their correlative disconformities. The middle Mississippian (C2) unconformity is an angular unconformity throughout much of the Piñon Range and Diamond Mountains (Figs. 1, 2, and 3) (Trexler

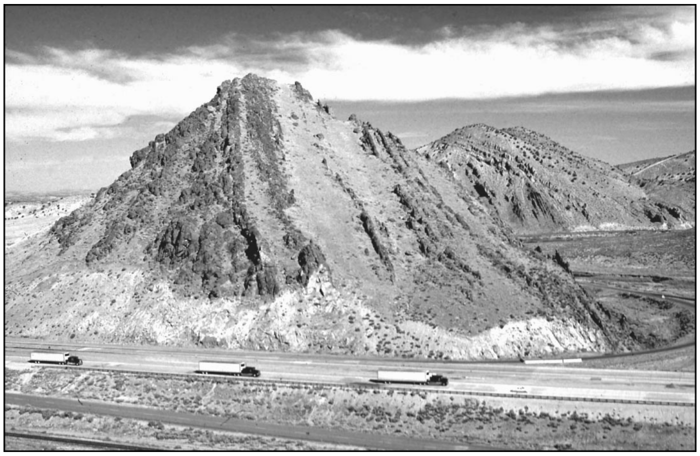

Figure 3. North wall of Carlin Canyon at the west end. Both the C6 and C2 angular unconformities are visible, at right and center, respectively. Here, the C6 unconformity has removed all intervening boundaries.

et al., 2003) and a disconformity in the Spotted Range of southern Nevada (Trexler et al., 1996). The Late Pennsylvanian (C6) unconformity is a dramatic angular unconformity at Carlin Canyon and throughout the Piñon and Adobe Ranges. The earliest Permian (P1) unconformity is a low-angle unconformity at Carlin Canyon, detectable here only through detailed biostratigraphy that shows stratal trimming (down to the east) of the underlying lower Strathearn Formation, which is Missourian. The detailed work necessary to resolve the P1 relationship elsewhere is in progress (W.S. Snyder and J.H. Trexler, Jr., unpublished mapping).

RESULTS

Geologic Relationships at Carlin Canyon—Overview

Carlin Canyon, along the Humboldt River and Interstate 80 in western Elko County, Nevada, exposes the Mississippian through Permian section in the heart of the Antler foreland basin (Figs. 1, 4, and 5). Strata dip steeply throughout the canyon and display both mesoscopic and macroscopic folds and faults. Most workers have assumed that all of the deformation there is Mesozoic or Cenozoic in age (e.g., Ketner and Smith, 1974; Smith and Ketner, 1977; Thorman et al., 1991; Schwarz et al., 1994). This assumption was based on the observation that rocks as young as Triassic are deformed nearby in the northern Adobe Range, rather than on field relationships in or near Carlin Canyon.

The most conspicuous geologic feature in the canyon is the angular contact between Mississippian–Middle Pennsylvanian coarse clastic and carbonate strata (Tonka, Moleen, and Tomera Formations) and overlying Upper Pennsylvanian–Lower Permian limestone (Strathearn Formation) (Fig. 3; see Fig. 4 for stratigraphy). Dott (1955) recognized this relationship as an angular unconformity. Ketner (1977) and Smith and Ketner (1977) attributed it to a Pennsylvanian ''Humboldt orogeny'' and presumed uplift to the west. The concept of the Humboldt orogeny was challenged by Snyder et al. (1991, 1995) and has been abandoned by Ketner, who now favors exclusively Mesozoic deformation in the region (Ketner, 1998). Jansma and Speed (1990) reinterpreted this contact as a Mesozoic omissional fault, a proposition since challenged by Schwarz et al. (1994).

Our new mapping at Carlin Canyon, using detailed biostratigraphic age control, reveals three angular unconformities in the upper Paleozoic section (Fig. 2). The stratigraphically lowest (C2 in Figs. 2 and 4) occurs *within* coarse-grained conglomerates mapped as the Tonka Formation by Dott (1955) and therefore requires a redefinition of the Tonka. We call the rocks below the unconformity Melandco Formation, and those above, Tonka Formation (Trexler et al., 2003). This angular unconformity is Mississippian in age and cuts down section to the west. Although it does not crop out elsewhere in the Carlin area, it is found throughout much of central Nevada (Trexler et al., 2003). The next younger unconformity preserved in Carlin Canyon, C6, separates the Moleen and Tomera Formations (local equivalents of the lower and upper Ely Limestone) from the overlying Strathearn Formation. This unconformity cuts down section toward the west, removing the Tomera and Moleen entirely in the western part of the map area (Fig. 5) and placing Strathearn directly on the upper part of the Tonka. This angular relationship—Strathearn over Tonka—was recognized by Dott (1955) as evidence for Pennsylvanian deformation in the Carlin area. A third angular unconformity (P1) occurs *within* the Strathearn and therefore requires a redefinition of the Strathearn. This surface cuts down section toward the east; in the eastern part of the map area, it has removed all of the lower Strathearn and has placed the upper part of the Strathearn directly on Moleen-Tomera. A fourth unconformity (P2), not obviously angular here, places Buckskin Mountain Formation over Strathearn and cuts down section toward the east in the Carlin Canyon area. This is a major unconformity at a regional scale; it occurs throughout northern Nevada (Snyder et al., 1991; Sweet et al., 2001; Sweet and Snyder, 2002).

The C6 and P1 unconformities truncate mesoscopic and macroscopic structures that record the geometry and kinematics of two deformation events, one occurring in the Middle Pennsylvanian and the other in earliest Permian. The Middle Pennsylvanian (C6) deformation includes thrust faults and macroscopic overturned folds in addition to mesoscopic structures. It records more contraction (at least locally) than the other deformation events exposed in Carlin Canyon. The earliest Permian (P1) deformation is expressed as open, upright macroscopic folds. Both fold sets have gently northeast-plunging axes, but these folds can be distinguished at Carlin Canyon on the basis of details of fold geometry and kinematics (see section on Kinematics of Pennsylvanian and Permian Deformations).

The presence of these late Paleozoic unconformities requires revision of the local stratigraphic nomenclature, in particular, the Tonka and Strathearn Formations. Original mapping in the area (Dott, 1955) designated all Mississippian conglomerate sections as Tonka Formation, defined at Tonka siding in Carlin Canyon. The unconformity within the Mississippian section was not recognized, and the lower section has no known fossil occurrences that would allow biostratigraphic recognition of the older conglomerates. We use the name Melandco Formation for these Lower and middle Mississippian rocks, consistent with unit names nearby to the east (Trexler et al., 2003). The unconformity within the Mississippian conglomerate section is expressed as an angular discordance accompanied by a facies change at the west end of Carlin Canyon, west of the highway and railroad tunnels

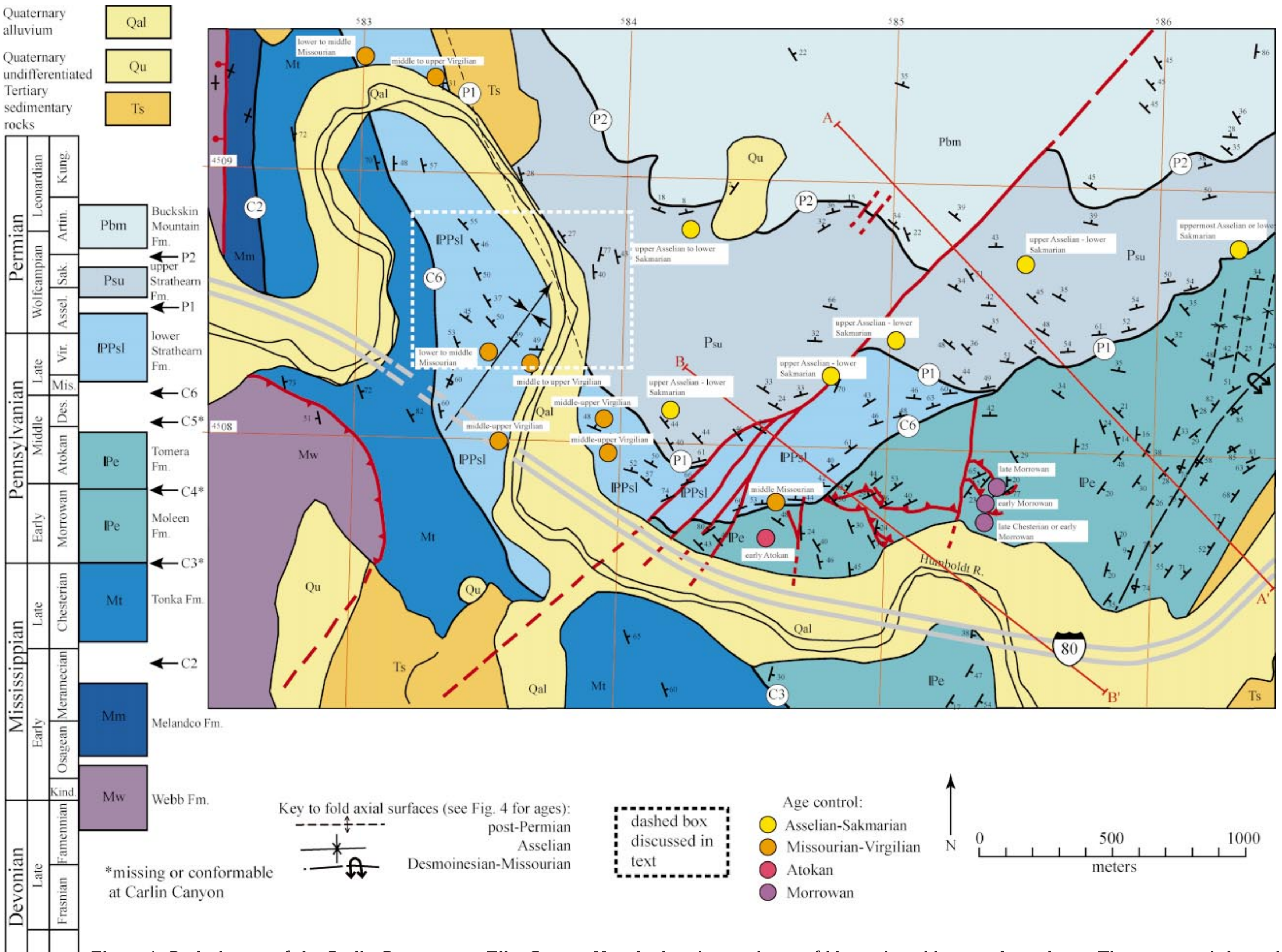

Figure 4. Geologic map of the Carlin Canyon area, Elko County, Nevada; locations and ages of biostratigraphic control are shown. The map area is located at the star in Figure 1. The grid is UTM zone 11. The box outlined by a white, dashed line shows a pre-P1 syncline, truncated by the P1 unconformity (see Fig. 9B for a stereogram of this syncline). Included is Carboniferous and Permian stratigraphy in the Carlin Canyon area; units are color-keyed to map.

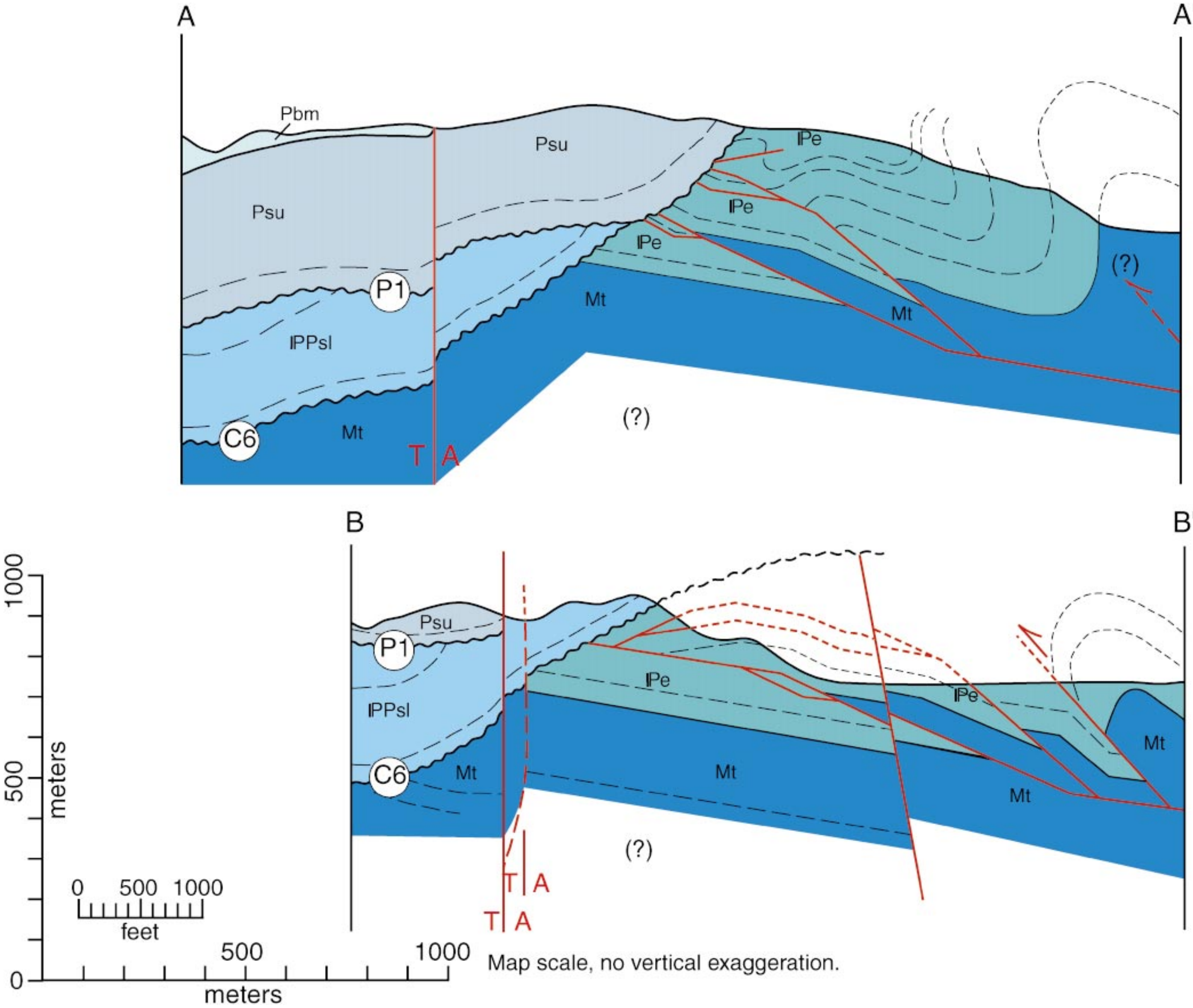

Figure 5. Two cross sections; for locations see Figure 4. Sense of motion on strike-slip faults is shown by T (= toward) and A (= away) from the viewer.

(Figs. 3 and 5). Melandco strata are polymict conglomerate and sandstone that are matrix-rich to matrix-supported and that generally lack sedimentary fabric. The overlying Tonka strata are well bedded; they consist of clean, chert–quartzite–lithic conglomerate and sandstone with interbedded calcareous litharenite.

Our detailed biostratigraphy also documents a hiatus within the Strathearn Formation. In Carlin Canyon, the lower Strathearn Formation was folded and erosionally trimmed prior to deposition of the upper Strathearn. The Strathearn, defined southeast of Carlin Canyon at Grindstone Mountain (Dott, 1955), is lithologically uniform from bottom to top, making recognition and mapping of the two members very difficult where they are conformable. We have not yet renamed these units and have referred to them informally as upper and lower members of the Strathearn Formation.

Evidence for Erosion at the Mapped Unconformity—It Is Not a Fault

Our field work has convinced us that the angular contact at the base of the Strathearn in Carlin Canyon is the regionally important C6 unconformity. Locally, the basal part of the Strathearn Formation is characterized by a rusty-colored, iron oxide–rich regolith zone about 1 m thick. This zone contains clasts derived from the subjacent strata. Where the regolith zone overlies the Tonka, the number and size of Tonka clasts increases downward within the zone, until the rock becomes a recognizable paleosol C-horizon developed on intact Tonka Formation. Vertical, open paleofractures in the Tonka are filled with regolith material. The same regolith zone can be mapped laterally along the base of the Strathearn to where the Strathearn overlies other units such as the Moleen and Tomera Formations. The regolith zone is overlain paraconformably by quartz-arenaceous limestone of the lower and/or upper Strathearn Formation. No recognizable clasts of Strathearn limestone occur in this regolith zone, making it unlikely that the zone is, or contains, a fault-slip breccia. We have not found evidence of organic activity in the regolith zone, although it has extensive iron oxide development suggesting an aridisol.

Our field observations do not support a fault interpretation (Jansma and Speed, 1990) for the sub-Strathearn contact. Although there appears to have been local slip on the contact during subsequent folding, throughgoing, well-developed slip surfaces are absent, and there is no evidence for measurable offset along the base of the Strathearn. We were unable to find any kinematic features consistent with fault-zone deformation along or near the contact. Instead, the base of the Strathearn is a mappable regolith zone. We conclude that any slip along this contact is insignificant.

Age Control on Pennsylvanian and Permian Deformations

The strata that most tightly bracket the C6 unconformity in Carlin Canyon are the subjacent Middle Pennsylvanian Tomera Formation (sensu Dott, 1955), and the superjacent, Upper Pennsylvanian–Lower Permian Strathearn Formation (Fig. 4). Below the unconformity, the youngest sub-C6 strata in Carlin Canyon are Atokan (Fig. 4), and angular trimming of the section suggests that younger strata may be preserved nearby. On a regional scale, we have shown that sub-C6 strata are as young as medial to possibly late Desmoinesian (Bissel, 1964; our unpublished work). The oldest Strathearn rocks overlying C6 in Carlin Canyon are lower to middle Missourian (Fig. 4). Therefore, the C6 hiatus in Carlin Canyon (and the tectonic event it records) is bracketed to be 5 m.y. or less in duration, depending on the time scale used for the extrapolation of numerical ages from biostratigraphic ages.

All Mississippian–Pennsylvanian strata in Carlin Canyon were folded again in the earliest Permian, during an event bracketed by the lower Strathearn Formation, below, and the upper Strathearn Formation, above. The resulting angular unconformity is the P1 boundary. Fusulinids from the upper Strathearn are upper Asselian to lower Sakmarian in age (Fig. 4). Therefore, in Carlin Canyon, the P1 hiatus is 5 to 7 m.y. in duration.

Still higher in the section at Carlin Canyon, the P2 boundary is defined at the base of the Buckskin Mountain Formation, where it overlies the upper Strathearn Formation. The old-

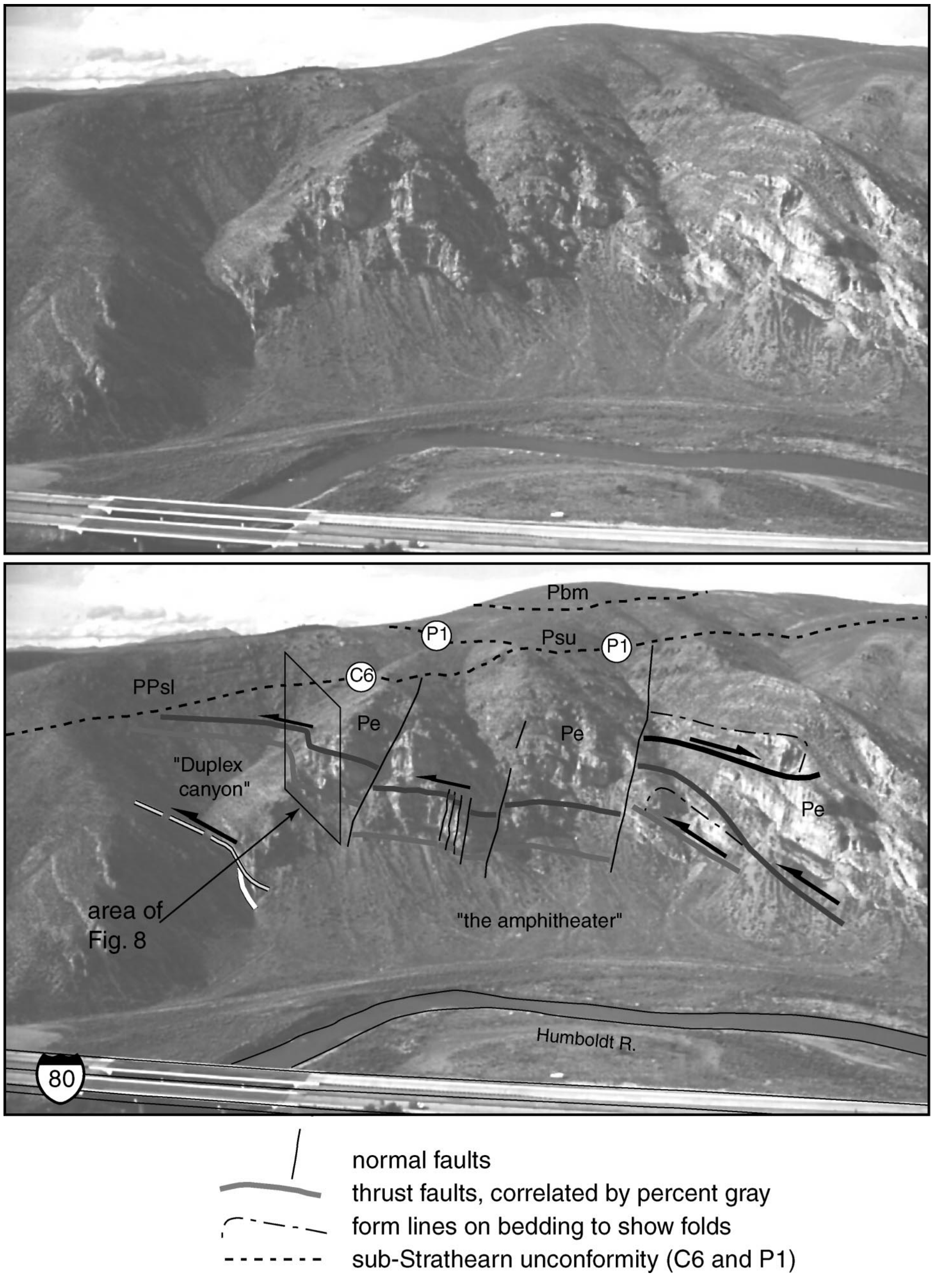

Figure 6. Panoramic photograph looking at the north wall of east-central Carlin Canyon (“the amphitheater”). “Duplex Canyon” is the southwest-trending gulch on the left (west) end of the amphitheater. Mesoscopic folds are asymmetric to overturned and have amplitudes of meters to tens of meters and northeast-plunging axes (see Fig. 9A for a stereogram of this folding). Vergence is toward the northwest for some structures and southeast for others (see Fig. 5). For example, the lowest of the three closely spaced thrust faults near the center of Figure 6 cuts upsection to the northwest and has a northwest-vergent hanging-wall anticline. The middle thrust cuts upsection to the northwest in the footwall here and cuts upsection to the northwest in the hanging wall in “Duplex Canyon” (see the hanging-wall ramp in the upper thrust in Fig. 8). The upper thrust has a southeast-vergent hanging-wall anticline and cuts upsection to the southeast. Stratigraphic throw on these thrust faults is tens to hundreds of meters; faulting duplicates the Lower Pennsylvanian section at least hundreds of meters. Horizontal displacement is unknown, but may be large.

est Buckskin Mountain strata are early Artinskian in age. The P2 unconformity trims the section down to rocks as old as Sakmarian at Carlin Canyon, but regionally (e.g., Secret Canyon, in the Fish Creek Range) the erosional surface cuts as far down as Chesterian rocks (Schwarz, 1987; Snyder et al., 1991). Where the P2 hiatus is the most tightly constrained, it is possibly as short as 5 m.y.

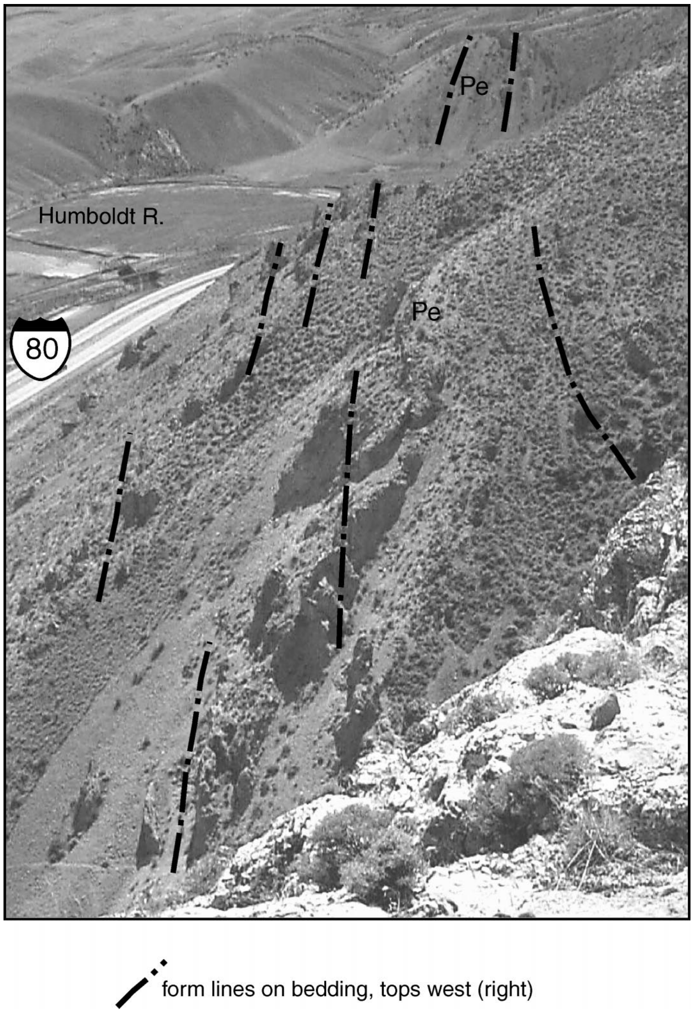

Figure 7. View toward the south, showing deformation in the Moleen and Tomera (= Ely Limestone) Formations at the east end of Carlin Canyon. Vertical bedding occurs in the foreground and across the Humboldt River on the south canyon wall in the distance. Stratigraphic ''tops'' are toward the northwest, indicating that this large fold is northwest-vergent. This macroscopic fold is coaxial with the thrust-related folds (see Figs. 6 and 9A); all are consistent with a single northwest-southeast shortening event.

Kinematics of Pennsylvanian and Permian Deformations

Deformation, expressed as angular discordance, folding, or imbricate thrusting, can be documented below the unconformities in the upper Paleozoic section at Carlin Canyon (Fig. 6). Wherever fold axis orientations can be determined, they trend northeast, making it difficult to distinguish between the folding events on the basis of their general orientation. However, there are consistent differences in both fold style and precise axis orientation that make it possible to distinguish these deformations, even where good age control is absent. In the following paragraphs we document the geometry and kinematics of each deformation event, named—for simplicity—after the unconformity that represents it (Fig. 2). The events are discussed in chronologic order, from oldest to youngest.

C2 Event

The pre–late Late Mississippian (Chesterian) C2 unconformity is marked by Melandco (lower Tonka) below and (upper) Tonka above. Deformation below the C2 unconformity in Carlin Canyon is expressed only as an angular truncation (Fig. 3). After the steep tilt of the overlying Tonka is removed, the bedding in the Melandco dips east, and the unconformity cuts down section to the west. The contact between the Melandco and Tonka is not exposed over a wide enough area in Carlin Canyon to determine the geometry of the pre-Chesterian deformation. However, this deformation event is regional in extent (Trexler et al., 2003) and has also been mapped in the northern Piñon Range ~30 km to the south where there is middle Mississippian folding and thrusting (Silberling et al., 1997; R.M. Tosdal's mapping in Trexler et al., 2003) and in the Diamond Mountains 120 km to the south where an angular truncation exists below the C2 unconformity (Trexler and Nitchman, 1990).

C3, C4, and C5 Events

At Carlin Canyon, the Late Mississippian and Early Pennsylvanian C3, C4, and C5 boundaries are conformable contacts, are contained within other unconformities, or are otherwise not preserved. Each is expressed elsewhere, however, and is a stratigraphic boundary that is of potential tectonic significance. These unconformities, not preserved at Carlin Canyon, are not described in detail here.

C6 Event

The post–early Middle Pennsylvanian (middle Desmoinesian), pre–late Late Pennsylvanian (middle Missourian) C6 event has juxtaposed the Tonka, Moleen, and Tomera Formations below and Strathearn Formation above. The deformation involves overturned folding and imbricate thrusting within the Tonka, Moleen, and Tomera Formations at Carlin Canyon. Faulting and folding are developed at both the macroscopic (Fig. 7) and mesoscopic (Figs. 6 and 8) scales and are dominantly northwest vergent. Mesoscopic folds visible on the north side of I-80 (Fig. 6) have northeast-trending axes and verge both northwest and southeast; some are fault-propagation folds preserved in the hanging walls of mesoscopic thrusts. Imbricate thrusting in ''Duplex Canyon'' is the best evidence that the deformation was dominantly northwest-directed. Here, individual thrusts step up-section to the northwest, and folds associated with hanging-wall ramps, which oc-

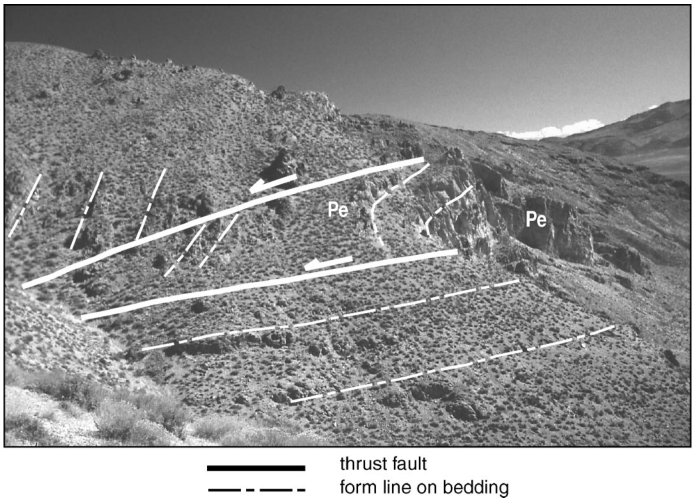

Figure 8. "Duplex Canyon" in the north wall of Carlin Canyon; see Figure 6 for location. View is toward the east. Although the thrust faults now dip gently toward the northwest, the truncation of hanging-wall bedding into the thrusts represents hanging-wall ramps and documents northwest-directed thrusting.

cur in several of the imbricate sheets, all verge northwest.

Macroscopic folding also records northwest vergence. A macroscopic anticline-syncline pair that is coaxial with the mesoscopic folding is well exposed along I-80 east of the tunnels. It crops out adjacent to the hoodoos of Tertiary Humboldt Formation on the north side of the highway and continues along strike south of the highway (Fig. 7). The subvertical limb of this fold has stratigraphic ''tops'' to the northwest, indicating northwest vergence.

The overlying Strathearn Formation is not preserved immediately above many of these structures, so the later deformation cannot be removed with confidence. In their *present* orientation, however, fold axes characteristic of this deformation are subhorizontal and trend 040°–065° (usually 060°–065°) (Fig. 9A).

P1 Event

The post–late Late Pennsylvanian (middle–upper Virgilian), pre–middle Early Permian (late Asselian) P1 event is expressed as an unconformity separating lower Strathearn below and upper Strathearn above. The deformation within the lower Strathearn is expressed as upright, open folding. After the tilt of the overlying upper Strathearn has been removed, the fold axes plunge gently toward 030°–035° (Fig. 9B). This folding is easily visible in the eastern half of the big meander loop of the Humboldt River at the I-80 tunnels. Here, interbedded conglomerate and limestone of the lower Strathearn are folded into a broad synform on the west side of the Humboldt River, and this synform terminates against the homoclinal upper Strathearn on the east side of the river (see box on map, Fig. 4). Note that the Mesozoic ''Adobe syncline'' has been mapped through this area (Ketner and Ross, 1990), and bedding orientations within the highest preserved part of the section (Permian) are consistent with a large syncline. This syncline is a different, and later, structure than the erosionally truncated syncline below the P1 unconformity. The overlying unconformity cuts down section to the east, removing the entire lower Strathearn 1.5 km east of the east portals of the I-80 tunnels and suggesting that deformation-related uplift might have been greater farther to the east.

High-angle normal faults of late Paleozoic age are locally developed in Carlin Canyon and have meters to hundreds of meters of displacement (Fig. 6). Brecciation is typical along these faults, and drag folding occurs locally. A normal sense of motion is shown both by the offset of marker units across the faults and by steeply plunging oblique-slip striae along the fault surfaces. The high-angle faults cut thrust-related structures, but they are older than the sub–upper Strathearn (P1) unconformity. At least one of these high-angle faults has been reactivated by post-Pennsylvanian deformation. Although this fault can be mapped across the unconformity into the base of the upper Strathearn Formation (Fig. 5), displacement of the Strathearn is an order of magnitude smaller than displacement of the underlying Moleen Formation (lower Ely Limestone).

P2 Event

The post–early Early Permian (late Asselian–early Sakmarian), pre–late Early Permian (early Artinskian) P2 unconformity separates upper Strathearn Formation below from Buckskin Mountain Formation above. The deformation features in the upper Strathearn are not as well developed as those of the preceding two deformations in the Carlin Canyon area. The unconformity below the Buckskin Mountain Formation cuts down section toward the east in Carlin Canyon. We have not yet collected enough structural data along this contact to determine the geometry of the deformation below the unconformity. Although not dramatic in the Carlin Canyon area, the P2 is a major unconformity at a regional scale; it occurs throughout northern Nevada (Snyder et al., 1991; Sweet et al., 2001; Sweet and Snyder, 2002).

Post–Late Early Permian (Late Artinskian) Events

In the Carlin Canyon area, the Permian section is deformed. The immediately overlying Tertiary Humboldt Formation remains undeformed. Therefore, the timing of the open, upright folding exhibited in the younger Permian section is not well constrained—it postdates all of the Permian units present in this area (upper Strathearn, Buckskin Mountain, Beacon Flat, and Carlin Canyon Formations) and predates the Tertiary Humboldt Formation. In their present orientation, the folds are open and upright, and fold axes plunge gently (25°) toward the north-northeast (020°) (Fig. 9C). These folds are commonly meters to tens of meters in amplitude. A set of open, upright folds in the Moleen and Tomera Formations is also attributed to the post–Early Permian deformation event on the basis of their fold style and orientation; the axes are subhorizontal or plunging gently toward 025° (Fig. 9C).

Open, upright folding is demonstrably post-Triassic elsewhere in the region, but this age control is not available in the Carlin Canyon area. In the northern Adobe Range, the Adobe syncline involves rocks as young as Triassic (Ketner and Smith, 1974; Smith and Ketner, 1977; Thorman et al., 1991). Broad folding in the Carlin Canyon area has been correlated with the Adobe syncline, but the youngest rocks involved are Early Permian in age. Folding cannot be directly connected between the northern Adobe Range and Carlin Canyon; therefore, we can only constrain the latest folding seen at Carlin Canyon to be late Early Permian or younger in age.

Evidence for Pennsylvanian and Permian Deformations Elsewhere in Nevada

The relationships we document at Carlin Canyon are also found both west and east of Carlin Canyon (Figs. 1, 10). Map relationships document unequivocal Pennsylvanian or Permian tectonism and indicate that late Paleozoic deformation is widespread. In some cases, the deformation is in rocks of the Antler foreland basin—so it either postdates the Antler orogeny or represents propagation of Antler contraction into the foreland basin. In other cases, deformation is in rocks of the Antler allochthon and would probably be attributed to the narrowly defined Antler orogeny (i.e., Late Devonian–Early Mississippian) except that rocks of Carboniferous age are involved in the deformation. In both cases, it is the presence of Pennsylvanian or Permian sedimentary rocks unconformably overlying the deformation that demonstrates the late Paleozoic age. These ''overlap assemblage'' rocks are absent in most places, so interpretation of the age of deformation has often been based on inference: Antler deformation for rocks of the allochthon and Mesozoic deformation for rocks of the Antler foreland basin.

At Beaver Peak west of Carlin Canyon, both members of the Strathearn Formation have been identified and mapped (Figs. 1, 10) (Berger et al., 2001). There they are both conglomeratic, and conodont ages there confirm our fusulinid dates for both units. The lower member of the Strathearn, along with lower Paleozoic rocks of the Roberts Mountains allochthon, is involved in thrusting on a fault that is unconformably overlapped by the upper Strathearn, tightly bracketing the age of thrusting as middle to late Asselian (Early Permian), equivalent to the deformation at Carlin Canyon below the P1 boundary.

The age of the folding and thrusting can be constrained only to pre-Permian at Coal Mine Canyon, in the northern Adobe Range (Fig. 1). There, Mississippian shale of the Antler foreland basin is in the footwall of a thrust fault (Ketner and Ross, 1990) that clearly postdates the Antler foreland basin. Mesoscopic northeast-trending folds in the upper plate and in the thrust itself are erosionally trimmed and overlain by silicified sandy carbonates dated only as ''Permian'' on the basis of macrofossils (Ketner and Ross, 1990). Our attempts to refine this age by using small foraminifera or fusulinids were unsuccessful because of poor fossil preservation in these silicified, coarse-grained rocks.

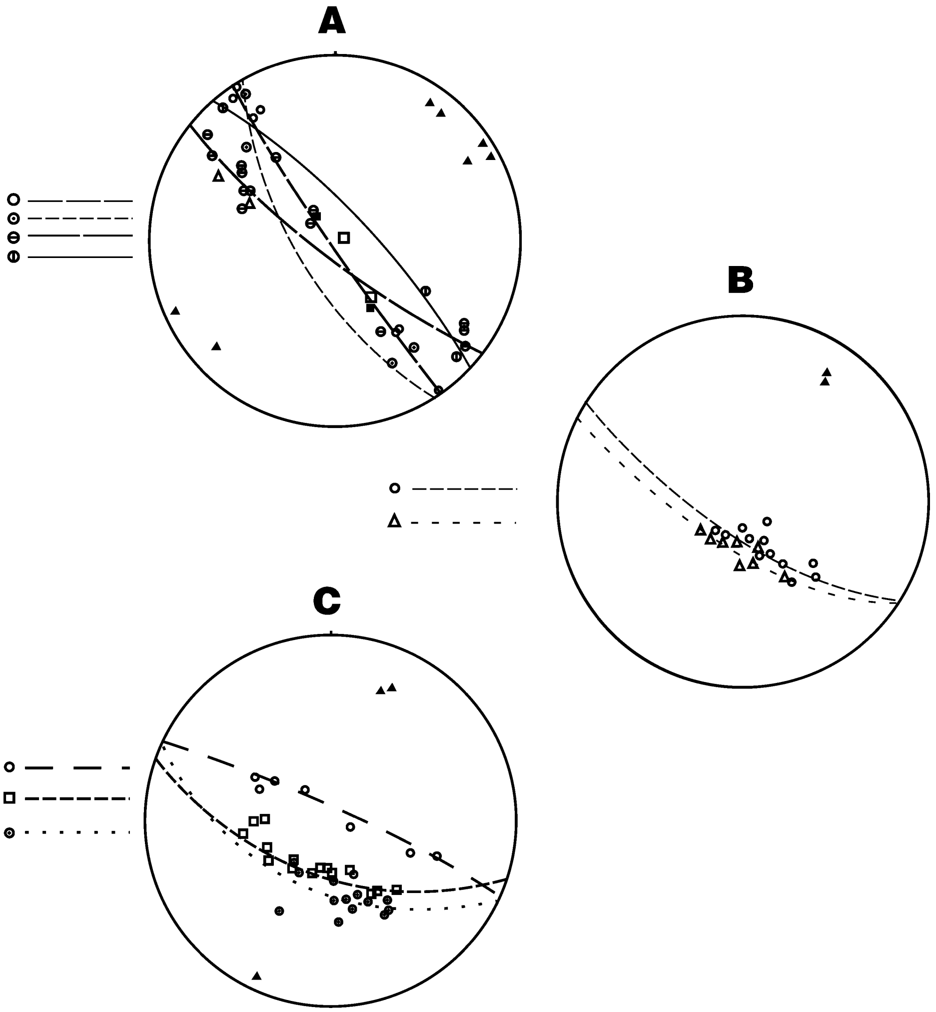

Figure 9. Stereograms of the three different fold sets in the Carlin Canyon map area. All are lower-hemisphere, equal-area plots; poles to bedding are shown as circles, squares, or open triangles. Different symbols represent individual mesoscopic or macroscopic folds. Fold axes for individual folds are shown as filled triangles. (A) Pennsylvanian (C6) deformation, characterized by asymmetric to overturned folding and northwest-directed thrust faulting. Stereogram shows poles to bedding in macroscopic, mesoscopic, and hanging-wall folds; also plotted are individual fold axes. Fold axes most commonly trend east-northeast (050°–065°). Note: The subsequent deformation has not been rotated out for most of these folds, because the overlying Strathearn Formation is not preserved. However, the three folds where subsequent tilt has been removed do not differ systematically from the other folds on this stereogram, indicating that subsequent rotation is not significant here. (Fold axis orientations, presented as plunge/trend: 11/037, 08/039, 04/056, 04/063, 18/059, 02/246, 12/228.) (B) Lower Permian (P1) deformation, characterized by open, upright folds (see also box, Fig. 5). The tilt of the overlying upper Strathearn has been removed, and the P1 fold axes plunge gently toward 030°–032°. (Fold axis orientations, presented as plunge/trend: 16/032, 13/030.) (C) Post-Permian deformation, characterized by open, upright folds. The tilt of the overlying upper Strathearn has been removed, and the P1 fold axes plunge gently toward 020°–026°. (Fold axis orientations, presented as plunge/trend: 21/026, 25/020, 05/205.)

Erickson and Marsh (1974) documented Paleozoic deformation in the rocks of the Roberts Mountains allochthon and recognized that this orogenic event could not be attributed to either the Antler or Sonoma orogenies as then conceived. Lower Pennsylvanian to Lower Permian rocks that overlap pre-Pennsylvanian (Antler age?) deformation in the Edna Mountain quadrangle, in Humboldt County, Nevada, are asymmetrically folded and thrust fault-

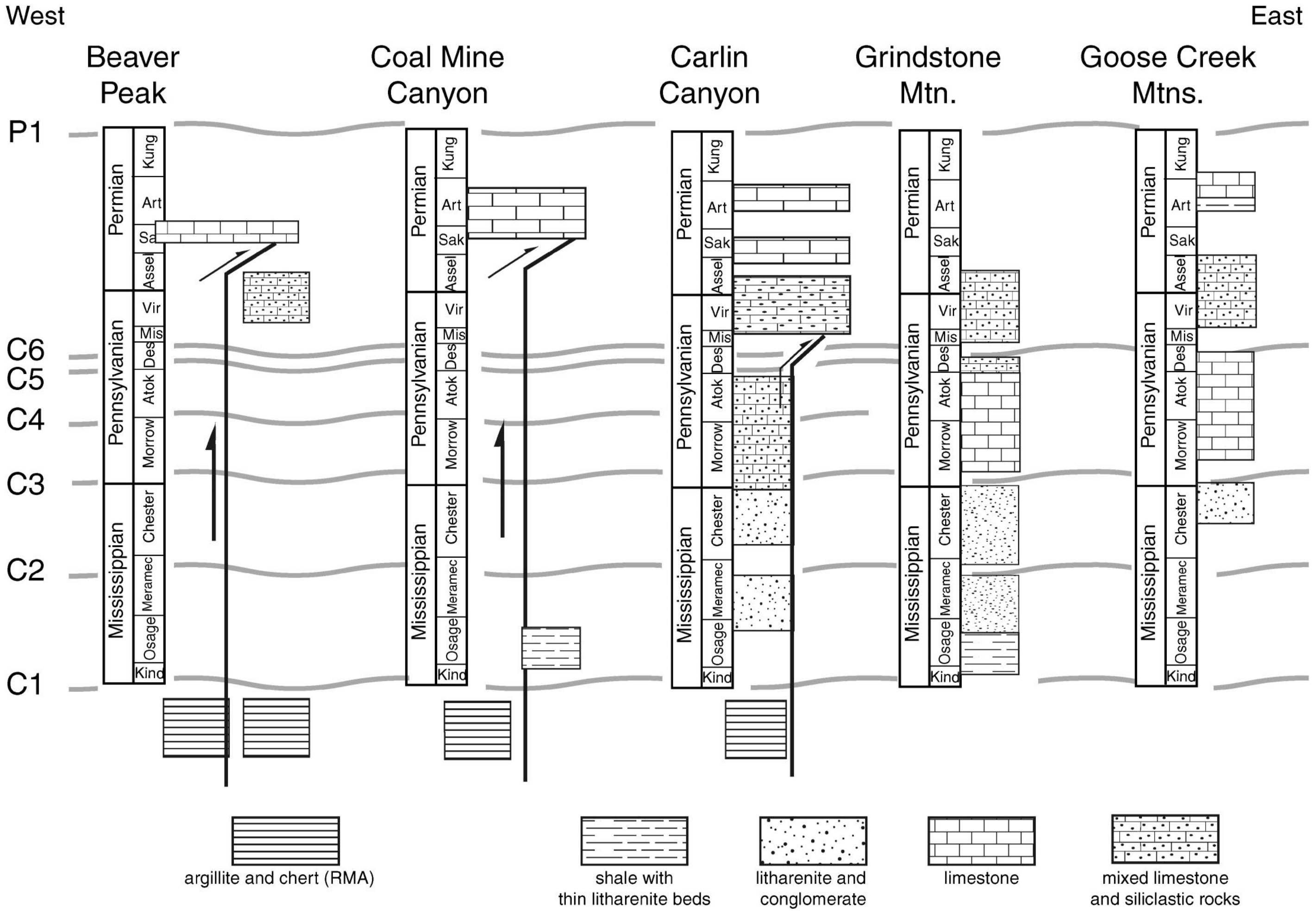

Figure 10. Measured sections in upper Paleozoic strata of central and northeast Nevada discussed in the text. Locations of measured sections are shown in Figure 1. Data for Beaver Peak are from Berger et al. (2001). All other sections are from our unpublished work. Note that unconformities generally span less time in eastern sections than they do in western ones. RMA—Roberts Mountains allochthon.

ed and are themselves unconformably overlain by Upper Permian rocks. Erickson and Marsh (1974) emphasized that ‘‘orogenic movements which do not conveniently relate to either the Antler or Sonoma orogeny deserve more attention and must be accounted for in the geologic history of the southern Cordillera’’ (p. 336).

In northeastern Nevada, the C5 and C6 boundaries have been documented independently by Sweet et al. (2001) and Sweet and Snyder (2002) in the Pequop Mountains (Fig. 1) and by McFarlane (1997) and McFarlane and Trexler (1997, 2000) in the Snake Mountains. In the southern Pequop Mountains, the Ely Limestone is folded and faulted, erosionally truncated, and overlain by the Hogan Formation (C5). In the Snake Mountains north of Wells, Nevada, an imbricate stack of thrust sheets containing rocks of both the continental-shelf autochthon and the Roberts Mountains allochthon is erosionally truncated and overlain by Missourian Strathearn Formation (along the C6 unconformity).

DISCUSSION

The fortuitous combination of exposure, preservation, and datable rocks is the reason that several late Paleozoic deformation events can be unequivocally documented in Carlin Canyon, although they have not yet been widely recognized elsewhere. Paleozoic rocks are exposed discontinuously and poorly throughout central and western Nevada because of widespread Tertiary volcanic cover in the ranges and Tertiary and Quaternary sedimentary cover in the basins. Furthermore, clear preservation of a complex deformational record is unlikely because of the very nature of the late Paleozoic deformations; the accompanying uplift and erosion remove or obscure the evidence of earlier deformations. Finally, many of the upper Paleozoic sedimentary rocks, and particularly the syntectonic sedimentary rocks, are clastic rocks that are unlikely to contain or preserve age-diagnostic fossils. However, all of the necessary conditions are met in the Carlin Canyon area, and earlier workers correctly interpreted the upper Paleozoic rocks there to record deformation in Pennsylvanian and/or Permian time (e.g., Dott, 1955; Ketner, 1977).

Even within the Carlin Canyon area, the evidence for some of the late Paleozoic deformation is cut out laterally by higher unconformities. For example, the P1 unconformity cuts down section toward the east, eventually placing the upper Strathearn Formation directly on the Moleen and Tomera Formations, completely removing the lower Strathearn Formation and with it, all evidence of the C6 unconformity (Fig. 4). On the basis of the distribution of unconformities in Carlin Canyon, even with 100% exposure one would not expect to find the C6 unconformity east of the map area or the C3 unconformity west of the map area. The problem is not unique to Carlin Canyon—Sweet et al. (2001) and Sweet and Snyder (2002) described similar relationships in the Pequop Range. There, a higher unconformity (C6) cuts deeply enough that it locally removes all record of an older unconformity (C5) that is preserved elsewhere in the range. This repeated erosional trimming (due to uplift during later tectonic events) is probably the reason that the late Paleozoic deformation events have not been widely recognized, in spite of the accurate interpretations by early workers in the area (e.g., Dott, 1955; Ketner, 1977).

Structures we have mapped in Carlin Canyon may (understandably) have been seen but misinterpreted as to age elsewhere in Nevada, especially where age control is limited. In Carlin Canyon, three fold sets (two unequivocally late Paleozoic and the third probably Mesozoic) all have generally northeast-plunging axes. It would be hard to distinguish them in the absence of datable Pennsylvanian and Permian rocks that occur in overlap relationships.

We suggest that much of the deformation attributed to the Antler orogeny in Nevada may in fact be Pennsylvanian or Permian in age (see also Trexler et al., 1999; Snyder et al., 2000). This possibility may be particularly true within the Antler allochthon, where Ordovician to Devonian chert, argillite, and volcanic rocks are folded, but usually there is no sedimentary overlap assemblage to constrain the time of folding. Our interpretation requires significant revision to the conventional understanding of the Antler orogenic event, extending the activity of this orogen well into the Pennsylvanian.

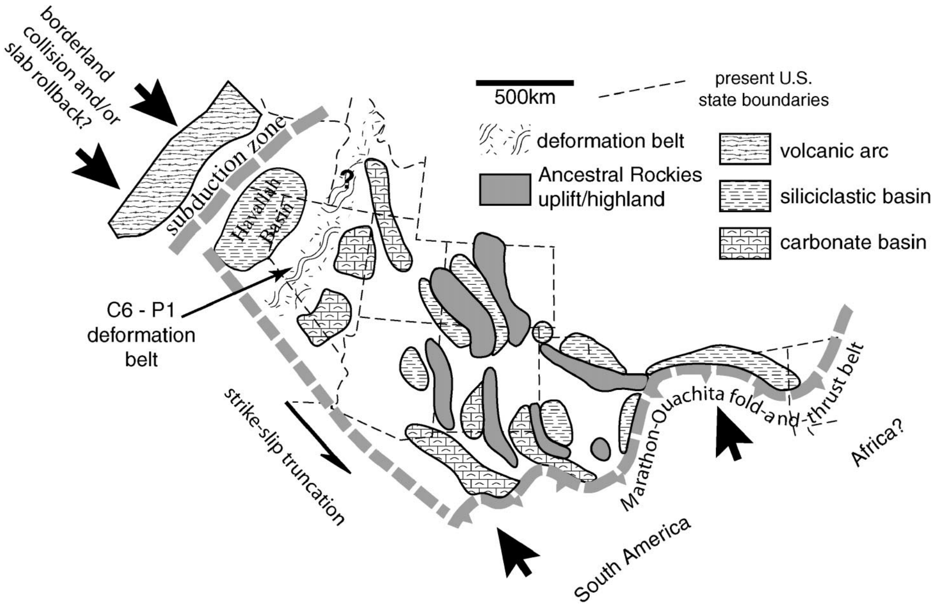

Figure 11. Tectonic setting for North America during the Pennsylvanian Ancestral Rocky Mountains orogeny. Many workers have contributed to the ideas present in this conceptual map (see Discussion in the text).

Although the Pennsylvanian (C6) deformation in Nevada is synchronous with the Ancestral Rocky Mountains orogeny, the style, intensity, and orientation of deformation suggest that, unlike the Ancestral Rocky Mountains, it could not be a far-field effect of collision with Gondwana along the southeastern continental margin (Kluth, 1986). The deformation style we describe here is thin-skinned contraction, similar to the Rocky Mountain fold-and-thrust belt of late Mesozoic age. We do not yet know whether the scale approaches that of the Sevier thrust belt; that determination will require detailed work to define the ages of potentially correlative structures throughout the Great Basin. In contrast to the thin-skinned deformation in Carlin Canyon, Ancestral Rocky Mountains structures generally comprise steep thrust faults involving basement and very thick sedimentary sections documenting rapid and deep subsidence (e.g., Paradox basin). In addition, Ancestral Rocky Mountains–related structures are generally oriented northwest-southeast, orthogonal to the folds and thrusts in Carlin Canyon.

Several plate boundaries may have influenced the tectonic development of western North America in Pennsylvanian time (Fig. 11). On the south and east, the Marathon-Ouachita orogenic belt is a complex and well-documented record of the collision of North America with Africa and South America (e.g., Kluth and Coney, 1981; Ross, 1991). To the south or southwest, Ye et al. (1996) have suggested a Pennsylvanian low-angle, northeast-dipping subduction zone (not shown in Fig. 11), although subsequent work has failed to corroborate this hypothesis. To the southwest and west, Stone and Stevens (1988) and Stevens et al. (1998) have proposed a left-lateral truncation of the continental margin in Pennsylvanian time. Dickinson and Lawton (2001) also invoke a sinistral transform fault along the western edge of North America, and suggest that the major displacement along the transform occurred from Early Permian to Middle Triassic time. Walker (1988) suggests that this transform margin was initiated as early as Pennsylvanian time. Convergence along the western margin is a consistent theme among many workers, and has recently been refined by Dickinson (2000), who suggests a northeast-southwest trend.

The recurrent and well-dated deformation events at Carlin Canyon appear to require an active orogenic belt to the west of North America at the latitude of the Great Basin in Carboniferous and Permian time. Continued shortening during the late Paleozoic may have reactivated older structures in the Antler foreland and orogenic belt as well as producing overprinted folding, thrusting, and erosion such as that at Carlin Canyon. Although traditional ‘‘Antler age’’ (Late Devonian) structures may have been reactivated during this shortening, we prefer the interpretation that most, or all, of the structures originated in late Paleozoic time. The contrasting deformation style in Nevada relative to coeval deformation in Utah and Colorado may result from the marked difference in crust: old, thinned, passive continental margin and accreted terranes to the west and thick, homogeneous, largely crystalline continental crust to the east. Also, note that the Oquirrh basin of western Utah, usually thought to be the westernmost expression of the Ancestral Rocky Mountains, is also among the thickest of the Ancestral Rocky Mountains basins (Erskine, 1997). This, like the northwest-southeast shortening at Carlin Canyon, is an unexplained anomaly if formation of the Oquirrh basin resulted solely from plate convergence along the southern margin of the continent (Geslin, 1998), but is consistent with convergence along the western margin of North America.

In conclusion, we think that late Paleozoic deformation in the Great Basin is much more widespread and important than has been recognized. This contractional deformation occurred repeatedly between the times generally accepted for the Antler and Sonoma orogenies. Continent-continent collision along the Marathon-Ouachita orogenic belt, widely cited as the driving force for the Ancestral Rocky Mountains orogeny, cannot alone explain concurrent deformation in the Great Basin. We conclude that plate convergence along the western margin of the continent must have played a significant role deformation and sedimentation in western North America during the late Paleozoic.

ACKNOWLEDGMENTS

National Science Foundation grants to Trexler, Cashman, and Snyder (EAR-9304972, EAR-9305097, EAR-9903006) funded much of the research that led to this paper. Our attention was drawn to this area by the spectacular exposure, but the thorough and prescient work by Bob Dott made it possible to begin to understand it; his mapping was our starting point to unravel the stratigraphy and structure. We thank Scott Ritter and Dave Schwarz for their help in the field early in the project. Mapping and paleontology by graduate students at both Boise State University and the University of Nevada, Reno, played a role in sorting out this complex locality. The manuscript was much improved by reviews from Tim Lawton, Paul Link, and Joan Fryxell.

REFERENCES CITED

Berger, V.I., Singer, D.A., and Theodore, T.G., 2001, Sedimentology of the Pennsylvanian and Permian Strathearn Formation, northern Carlin trend, Nevada: U.S. Geological Survey Open-File Report 01–402, 99 p.

Bissel, H.J., 1964, Ely, Arcturus, and Park City Groups (Pennsylvanian–Permian) in eastern Nevada and western Utah: American Association of Petroleum Geologists Bulletin, v. 48, p. 565–636.

Burchfiel, B.C., and Davis, G.A., 1972, Structural framework and evolution of the southern part of the Cordilleran orogen, western United States: American Journal of Science, v. 272, p. 97–118.

Burchfiel, B.C., and Davis, G.A., 1975, Nature and controls of Cordilleran orogenesis, western United States: Extensions of an earlier synthesis: American Journal of Science, v. 275-A, p. 363–396.

Carpenter, D.G., Carpenter, J.A., Dobbs, S.W., and Stuart, C.K., 1993, Regional structural synthesis of the Eureka fold and thrust belt, east-central Nevada, *in* Gillespie, C.W., ed., Structural and stratigraphic relationships of Devonian reservoir rocks, east-central Nevada: Reno, Nevada Petroleum Society, p. 59–72.

Coles, K.S., and Snyder, W.S., 1985, Significance of lower and middle Paleozoic phosphatic chert in the Toquima Range, central Nevada: Geology, v. 13, p. 573–576.

Crosbie, R.A., 1997, Sequence architecture of Mississippian strata in the White Pine Mountains, White Pine County, Nevada [M.S. thesis]: Reno, University of Nevada, 257 p.

DeCelles, P.G., and Giles, K.A., 1996, Foreland basin systems: Basin Research, v. 8, p. 105–123.

Dickinson, W.R., 1977, Paleozoic plate tectonics and the evolution of the Cordilleran continental margin, *in* Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States, Volume 1: Los Angeles, Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 137–156.

Dickinson, W.R., 2000, Geodynamic interpretation of Paleozoic tectonic trends oriented oblique to the Mesozoic Klamath-Sierran continental margin: Geological Society of America Special Paper 347, p. 209–245.

Dickinson, W.R., Harbaugh, D.W., Saller, A.H., and Snyder, W.S., 1983, Detrital modes of upper Paleozoic sandstones from Antler orogen in Nevada: Implications for nature of the Antler orogeny: American Journal of Science, v. 283, p. 481–509.

Dickinson, W.R., and Lawton, T.F., 2001, Carboniferous to Cretaceous assembly and fragmentation of Mexico: Geological Society of America Bulletin, v. 113, p. 1142–1160.

Dott, R.H., 1955, Pennsylvanian stratigraphy of the Elko and northern Diamond Ranges, northeast Nevada: American Association of Petroleum Geologists Bulletin, v. 39, p. 2211–2305.

Erickson, R.L., and Marsh, P., 1974, Paleozoic tectonics in the Edna Mountain Quadrangle, Nevada: U.S. Geological Survey Journal of Research, v. 2, no. 3, p. 331–337.

Erskine, M.C., 1997, The Oquirrh basin revisited: American Association of Petroleum Geologists Bulletin, v. 81, p. 624–636.

Gallegos, D.M., Snyder, W.S., and Spinosa, C., 1991, Tectonic implications of facies patterns, Lower Permian Dry Mountain trough, east-central Nevada, *in* Cooper, J.D., and Stevens, C.H., eds., Paleozoic paleogeography of the western United States, Volume II: Los Angeles, Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 343–356.

Geslin, J.K., 1998, Distal Ancestral Rocky Mountain tectonism: Evolution of the Pennsylvanian–Permian Oquirrh–Wood River basin, southern Idaho: Geological Society of America Bulletin, v. 110, p. 644–663.

Jansma, P.E., and Speed, R.C., 1990, Omissional faulting during Mesozoic regional contraction at Carlin Canyon, Nevada: Geological Society of America Bulletin, v. 102, p. 417–427.

Johnson, J.G., and Pendergast, A., 1981, Timing and mode of emplacement of the Roberts Mountains allochthon, Antler orogeny: Geological Society of America Bulletin, v. 92, p. 648–658.

Johnson, J.G., and Visconti, R., 1992, Roberts Mountains thrust relationships in a critical area, northern Sulphur Springs Range, Nevada: Geological Society of America Bulletin, v. 104, p. 1208–1220.

Jordan, T.E., and Douglas, R.C., 1980, Paleogeography and structural development of the Late Pennsylvanian to Early Permian Oquirrh basin, northwestern Utah, *in* Fouch, T.D., and Magathan, E.R., eds., Paleozoic paleogeography of the west-central United States: Rocky Mountain Paleogeography Symposium, Volume I: Denver, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 217–238.

Ketner, K.B., 1977, Late Paleozoic orogeny and sedimentation, southern California, Nevada, Idaho, and Montana, *in* Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States, Volume 1: Los Angeles, Pacific Section, Society of Economic Paleontologists and Mineralogists, p 363–369.

Ketner, K.B., 1998, 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: U.S. Geological Survey Professional Paper 1592, 19 p.

Ketner, K.B., and Ross, R.J., 1990, Geologic map of the northern Adobe Range, Elko County, Nevada: U.S. Geological Survey Map I-2081, scale 1:24,000.

Ketner, K.B., and Smith, J.F., Jr., 1974, Folds and overthrusts of Late Jurassic or Early Cretaceous age in northern Nevada: U.S. Geological Survey Journal of Research, v. 2, p. 417–419.

Ketner, K.B., and Smith, J.F., 1982, Mid-Paleozoic age of the Roberts Mountains thrust unsettled by new data from northern Nevada: Geology, v. 10, p. 298–303.

Kluth, C.F., 1986, The plate tectonics of the Ancestral Rocky Mountains, *in* Peterson, J.A., ed., Paleotectonics and sedimentation in the Rocky Mountain region: Tulsa, American Association of Petroleum Geologists Memoir 41, p. 353–369.

Kluth, C.J., and Coney, P.J., 1981, Plate tectonics of the Ancestral Rocky Mountains: Geology, v. 9, p. 10–15.

Link, P.K., Warren, I., Preacher, J.M., and Skipp, B., 1996, Stratigraphic analysis and interpretation of the Mississippian Copper Basin Group, McGowan Creek Formation, and White Knob Limestone, south-central Idaho, *in* Longman, M.W., and Sonnenfeld, M.D., eds., Paleozoic systems of the Rocky Mountain region: Tulsa, Rocky Mountain Section, SEPM (Society for Sedimentary Geology), p. 117–114.

Mahoney, J.B., Link, P.K., Burton, B.R., Geslin, J.K., and O'Brien, J.P., 1991, Pennsylvanian and Permian Sun Valley Group, Wood River basin, south-central Idaho, *in* Cooper, J.D., and Stevens, C.H., eds., Paleozoic paleogeography of the western United States, Volume II: Los Angeles, Pacific Section, SEPM (Society for Sedimentary Geology), p. 551–579.

McFarlane, M.J., 1997, The Roberts Mountains thrust in the northern Snake Mountains, Elko County, Nevada, *in* Perry, A.J., and Abbott, E.W., eds., The Roberts Mountains thrust, Elko and Eureka Counties, Nevada: Nevada Petroleum Society Field Trip Guidebook: Reno, Nevada Petroleum Society, p. 17–34.

McFarlane, M., and Trexler, J.H., Jr., 1997, Antler tectonism in the northern Snake Mountains, Elko County, Nevada: Geological Society of America Abstracts with Programs, v. 29, no. 6, 233 p.

McFarlane, M., and Trexler, J.H., Jr., 2000, Extension or contraction in earliest Antler tectonism?: Geological Society of America Abstracts with Programs, v. 32, no. 7, p. A-383.

Perry, A.J., 1994, Stratigraphic and sedimentologic analysis of the (Upper Mississippian) lower Newark Valley sequence, Diamond Range, Eureka and White Pine Counties, Nevada [M.S. thesis]: Reno, University of Nevada, 243 p.

Perry, A.J., 1995, Depositional setting of the Upper Mississippian to Lower Pennsylvanian Newark Valley sequence, Diamond Range, Nevada, *in* Hansen, M.W., Walker, J.P., and Trexler, J.H., Jr., eds., Mississippian source rocks in the Antler basin of Nevada and associated structural and stratigraphic traps: Reno, Nevada, Nevada Petroleum Society, p. 97–114.

Pipiringos, G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, Western Interior United States—A preliminary survey: U.S. Geological Survey Professional Paper 1035-A, p. A1–A29.

Poole, F.G., 1974, Flysch deposits of the Antler foreland basin, western United States, *in* Dickinson, W.R., ed., Tectonics and sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 22, p. 58–82.

Poole, F.G., and Sandberg, C.A., 1977, Mississippian paleogeography and tectonics of the western United States, *in* Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States, Volume 1: Los Angeles, Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 67–85.

Rich, M., 1977, Pennsylvanian Paleozoic patterns in the western United States, *in* Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States, Volume 1: Los Angeles, Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 87–111.

Roberts, R.J., Hotz, P.E., Gilluly, J., and Ferguson, H.G., 1958, Paleozoic rocks of north-central Nevada: American Association of Petroleum Geologists Bulletin, v. 42, p. 2813–2857.

Ross, C.A., 1991, Pennsylvanian paleogeography of the western United States, *in* Cooper, J.D., and Stevens, C.H., eds., Paleozoic paleogeography of the western United States, Volume II: Los Angeles, Pacific Section SEPM (Society for Sedimentary Geology), p. 137–148.

Schiappa, T.A., Snyder, W.S., and Trexler, J.H., Jr., 1999, Tectonic signatures within the Pennsylvanian–Early Permian Tippipah Limestone, Nevada Test Site: Geological Society of America Abstracts with Programs, v. 31, no. 4, p. A-54.

Schwarz, D.L., 1987, Geology of the Lower Permian Dry Mountain trough, Buch Mountain, Limestone Peak, and Secret Canyon areas, east-central Nevada [M.S. thesis]: Boise, Boise State University, 149 p.

Schwarz, D.L., Carpenter, J.A., and Snyder, W.S., 1994, Reexamination of critical geological relations in the Carlin Canyon area, Elko County, Nevada, *in* Dobbs, S.W., and Taylor, W.J., ed., Structural and stratigraphic investigations and petroleum potential of Nevada, with special emphasis south of the Railroad Valley producing trend, Volume II): Reno, Nevada Petroleum Society, p. 255–272.

Silberling, N.J., Nichols, K.M., Trexler, J.H., Jr., Jewell, P.W., and Crosbie, R.A., 1997, Overview of Mississippian depositional and paleotectonic history of the Antler foreland, eastern Nevada and western Utah, *in* Link, P.K., and Kowalis, B.J., ed., Geological Society of America Fieldtrip Guidebook: Provo, Brigham Young University Geology Studies, v. 42, no. 1, p. 161–196.

Smith, J.F., Jr., and Ketner, K.B., 1977, Tectonic events since early Paleozoic in the Carlin–Pinon Range area, Nevada: U.S. Geological Survey Professional Paper 876C, 18 p.

Snyder, W.S., Spinosa, C., and Gallegos, D.M., 1991, Pennsylvanian–Permian tectonism along the western United States continental margin: Recognition of a new event, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, Symposium Proceedings: Reno, Geological Society of Nevada, p. 5–20.

Snyder, W.S., Schwarz, D.L., Spinosa, C., and Torrealday, H., 1995, Pennsylvanian–Permian tectonic sequence stratigraphy: Implications for the structure and stratigraphy of eastern Nevada, *in* Hansen, M., ed., Mississippian source rocks in the Antler foreland basin of Nevada and associated structural and stratigraphic traps: Reno, Nevada Petroleum Society, p. 125–134.

Snyder, W.S., Trexler, J.H., Jr., Cashman, P.H., and Davydov, V.I., 2000, Tectonostratigraphic framework of the upper Paleozoic continental margin of Nevada and southeastern California: Reno, Geological Society of Nevada Program with Abstracts, p. 76–77.

Speed, R.C., and Sleep, N., 1982, Antler orogeny and foreland basin: A model: Geological Society of America Bulletin, v. 93, p. 815–828.

Stevens, C.H., Stone, P., Dunne, G.C., Greene, D.C., Walker, J.D., and Swanson, B.J., 1997, Paleozoic and Mesozoic evolution of east-central California: International Geology Review, v. 39, p. 788–829.

Stevens, C.H., Stone, P., Dunne, G.C., Greene, D.C., Walker, J.D., and Swanson, B.J., 1998, Paleozoic and Mesozoic evolution of east-central California, *in* Ernst, W.G., and Nelson, C.A., eds., Integrated Earth and Environmental Evolution of the Southwestern United States: Columbia, Maryland, Bellwether Publishing. p. 119–160.

Stone, P., and Stevens, C.H., 1988, Pennsylvanian and Early Permian paleogeography of east-central California: Implications for the shape of the continental margin and the timing of continental truncation: Geology, v. 16, p. 330–333.

Sweet, D., and Snyder, W.S., 2002, Middle Pennsylvanian through Early Permian tectonically controlled basins: Evidence from the central Pequop Mountains, northeast Nevada: Late Paleozoic tectonics and hydrocarbon systems of western North America—The greater Ancestral Rocky Mountains: Tulsa, AAPG Hedberg Research Conference, p. 74–77.

Sweet, D., Snyder, W.S., Davydov, V.I., Trexler, J.H., Jr., and Groves, J.R., 2001, Upper Paleozoic Tectonic unconformities in the central Pequop Mountains, Nevada: Geological Society of America Abstracts with Programs, v. 33, no. 5, p. 47.

Thorman, C.H., Ketner, K.B., Brooks, W.E., Snee, L.W., and Zimmermann, R.A., 1991, Late Mesozoic–Cenozoic tectonics in northeastern Nevada, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin, Symposium Proceedings: Reno, Geological Society of Nevada, p. 25–45.

Trexler, J.H., Jr., and Cashman, P.H., 1997, A southern Antler foredeep submarine fan: The Mississippian Eleana Formation, Nevada Test Site: Journal of Sedimentary Research, v. 67, p. 1044–1059.

Trexler, J.H., Jr., and Giles, K., 2000, The Antler orogeny in the Great Basin: A review of the data: Geological Society of America Abstracts with Programs, v. 32, no. 7, p. A-382.

Trexler, J.H., Jr., and Nitchman, S.P., 1990, Sequence stratigraphy and evolution of the Antler foreland basin, east-central Nevada: Geology, v. 18, p. 422–425.

Trexler, J.H., Jr., Snyder, W.S., Cashman, P.H., Gallegos, D.M., and Spinosa, C., 1991, Mississippian through Permian orogenesis in eastern Nevada: Post-Antler, pre-Sonoma tectonics of the western Cordillera, *in* Cooper, J.D., and Stevens, C.H., eds., Paleozoic paleogeography of the western United States, Volume II: Los Angeles, Pacific Section, SEPM (Society for Sedimentary Geology), p. 317–330.

Trexler, J.H., Jr., Snyder, W.S., Schwarz, D., Kurka, M.T., and Crosbie, R.A., 1995, An overview of the Mississippian Chainman Shale, *in* Hansen, M.W., Walker, J.P., and Trexler, J.H., Jr., eds., Mississippian source rocks in the Antler basin of Nevada and associated structural traps: Reno, Nevada Petroleum Society, p. 45–60.

Trexler, J.H., Jr., Cole, J.C., and Cashman, P.H., 1996, Middle Devonian–Mississippian stratigraphy on and near the Nevada Test Site: Implications for hydrocarbon potential: American Association of Petroleum Geologists Bulletin, v. 80, p. 1736–1762.

Trexler, J.H., Jr., Snyder, W.S., and Cashman, P.H., 1999, Pennsylvanian deformation right under our noses all this time!: Geological Society of America Abstracts with Programs, v. 31, no. 4, p. A-59.

Trexler, J.H., Jr., Cashman, P.H., Cole, J.C., Snyder, W.S., Tosdal, R.M., Davydov, V.I., 2003, Widespread effects of middle Mississippian deformation in the Great Basin of western North America: Geological Society of America Bulletin, v. 115, p. 1278–1288.

Walker, J.D., 1988, Permian, and Triassic rocks of the Mojave Desert and their implications for timing and mechanisms of continental truncation: Tectonics, v. 7, p. 685–709.

Ye, H., Royden, L., Burchfiel, B.C., and Schuepbach, M., 1996, Late Paleozoic deformation of interior North America: American Association of Petroleum Geologists Bulletin, v. 80, p. 1397–1432.

MANUSCRIPT RECEIVED BY THE SOCIETY 14 NOVEMBER 2002
REVISED MANUSCRIPT RECEIVED 3 JUNE 2003
MANUSCRIPT ACCEPTED 14 AUGUST 2003

Printed in the USA