Late Paleozoic extension in the Great Basin, western United States

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ABSTRACT

Geologic mapping in the Toiyabe Range in central Nevada has revealed the existence of normal faults of probable mid-Mississippian to Early Permian age that strike roughly east-west and dip northward. Additional evidence of uplift and erosion followed by mafic volcanism and subsidence suggests that much of the central and southern Toiyabe Range was affected by late Paleozoic extension. Similar patterns of late Paleozoic uplift and subsidence, together with local basaltic volcanism, are widespread in the western United States, suggesting that the continental margin was dominated by extension or transtension in Mississippian to Permian time. This extension was coeval with convergence between North America and South America across the Ouachita and Marathon belts, and the dynamic interaction of these two margins may, by analogy with the Cenozoic tectonics of Asia, have given rise to complex late Paleozoic deformation in the Ancestral Rocky Mountains and adjacent areas of the interior western United States.

INTRODUCTION AND GEOLOGIC SETTING

Upper Paleozoic strata in the Great Basin region of the western United States record a complex pattern of faulting, uplift, and subsidence (Roberts et al., 1965; Ketner, 1977; Stevens, 1977, 1979; Snyder and Spinosa, 1986; Stone and Stevens, 1988; Fig. 1) that Ketner (1977) termed the "Humboldt orogeny" to distinguish it from either the Early Mississippian Antler orogeny or the Late Permian Sonoma orogeny. In many areas, units in the Roberts Mountains allochthon occur in close juxtaposition with autochthonous miogeoclinal units as old as Early Cambrian beneath an Upper Pennsylvanian to Lower Permian unconformity (e.g., Mountain City, Nevada, Little, 1983; Wildcat Peak, Nevada, McKee, 1972; Fig. 1). The possible late Paleozoic structures that caused this juxtaposition are commonly obscured by younger events, and causes of this tectonism are poorly understood. Renewed thrust faulting in the Antler orogenic belt has been proposed as a mechanism for producing the observed tectonism (Roberts et al., 1965; Stevens, 1979; Snyder and Spinosa, 1986), but there is increasing evidence that the deformation may be extensional.

Jordan and Douglas (1980) have described late Paleozoic extensional basin formation in eastern Nevada and western Utah, and Erickson and Marsh (1974) have described a gently dipping fault (the "Iron Point thrust") in the Edna Mountains (EM in Fig. 1) that places steeply tilted Middle Pennsylvanian to Lower Permian conglomerate and limestone on steeply tilted autochthonous Cambrian Preble Formation. This younger-on-older fault is unconformably overlain by the Upper Permian Edna Mountains Formation and is most likely a mid-Permian normal fault. In the Owens Valley region, southeastern California, complex extensional or transtensional basins and uplifts developed in Early to mid-Permian time (Stone and Stevens, 1984, 1988; Stevens and Stone, 1985; Fig. 1). Farther offshore, in the Havallah basin (now part of the Golconda allochthon), local eruption of basalt, influxes of clastic detritus, and depositional breaks within basinal sequences all suggest that active Pennsylvanian to mid-Permian tectonism occurred within the basin and along its eastern margin (E. Miller et al., 1990). High-angle faulting along the basin margin is also suggested by olistostromes of miogeoclinal strata in a thrust slice of Pennsylvanian or younger terrigenous strata beneath the Golconda allochthon in the Toiyabe Range (OW in Fig. 1; Babaie, 1984).

This paper presents geologic mapping from the Toiyabe Range of central Nevada (Figs. 1 and 2) that lends additional support to the proposal that late Paleozoic extension was widespread along the western margin of the continent.

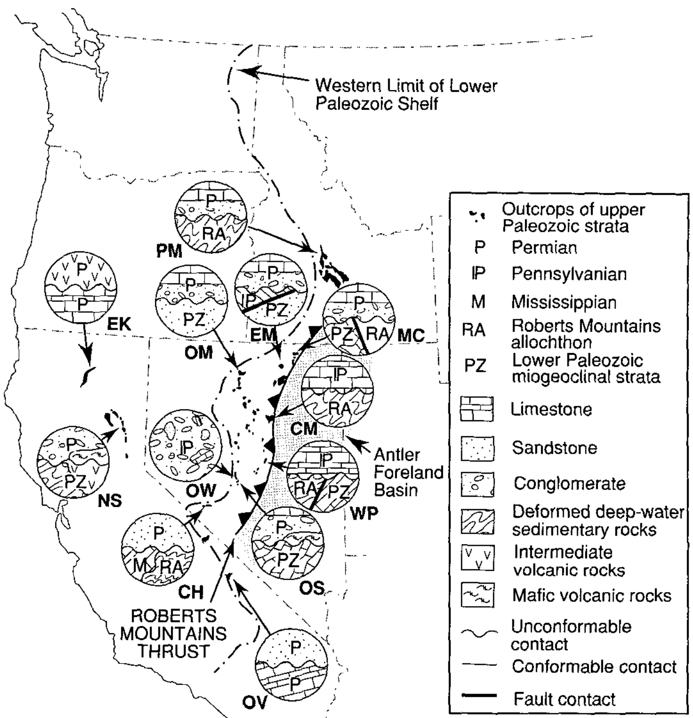

Figure 1. Summary map of late Paleozoic geologic relations in Nevada and California. Circles show conformable, unconformable, or fault relations among units that are representative of area. Letters below circles denote area of exposures. CH = Candelaria Hills; CM = Cortez Mountains; EK = Eastern Klamaths; EM = Edna Mountains; MC = Mountain City; NS = Northern Sierra; OM = Osgood Mountains; OS = Ophir to Summit Creek, Toiyabe Range; OV = Owens Valley; OW = Ophir Wash, Toiyabe Range; PM = Pioneer Mountain; WP = Wildcat Peak, Toquima Range. After E. Miller et al. (1990); data from Babaie (1984), Bushnell (1967), Coash (1967), Erickson and Marsh (1974), Hotz and Wilden (1964), Little (1983, 1987), Stone and Stevens (1988), Harwood (1988), M. Miller (1987), McKee (1972), and this study.

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LATE PALEOZOIC EVENTS IN THE TOIYABE RANGE

Birch Creek Area

In the Birch Creek area (Fig. 2A), both the Roberts Mountains allochthon and Paleozoic miogeoclinal strata are cut by 10°–15° north-dipping faults (McKee, 1976; this study). These faults have top-to-the-north, younger-on-older senses of offset. Hanging-wall and footwall strata are tilted an average of 40° to 60° to the south. Bedding near faults is folded and locally overturned. On the west side of the range, these gently dipping faults cut and offset a subvertical fault zone between the Roberts Mountains allochthon and the autochthonous shelf-facies Roberts Mountains Formation (Fig. 2A). Duplexlike imbrication of both units within this fault zone suggests that it is the Early Mississippian Roberts Mountains

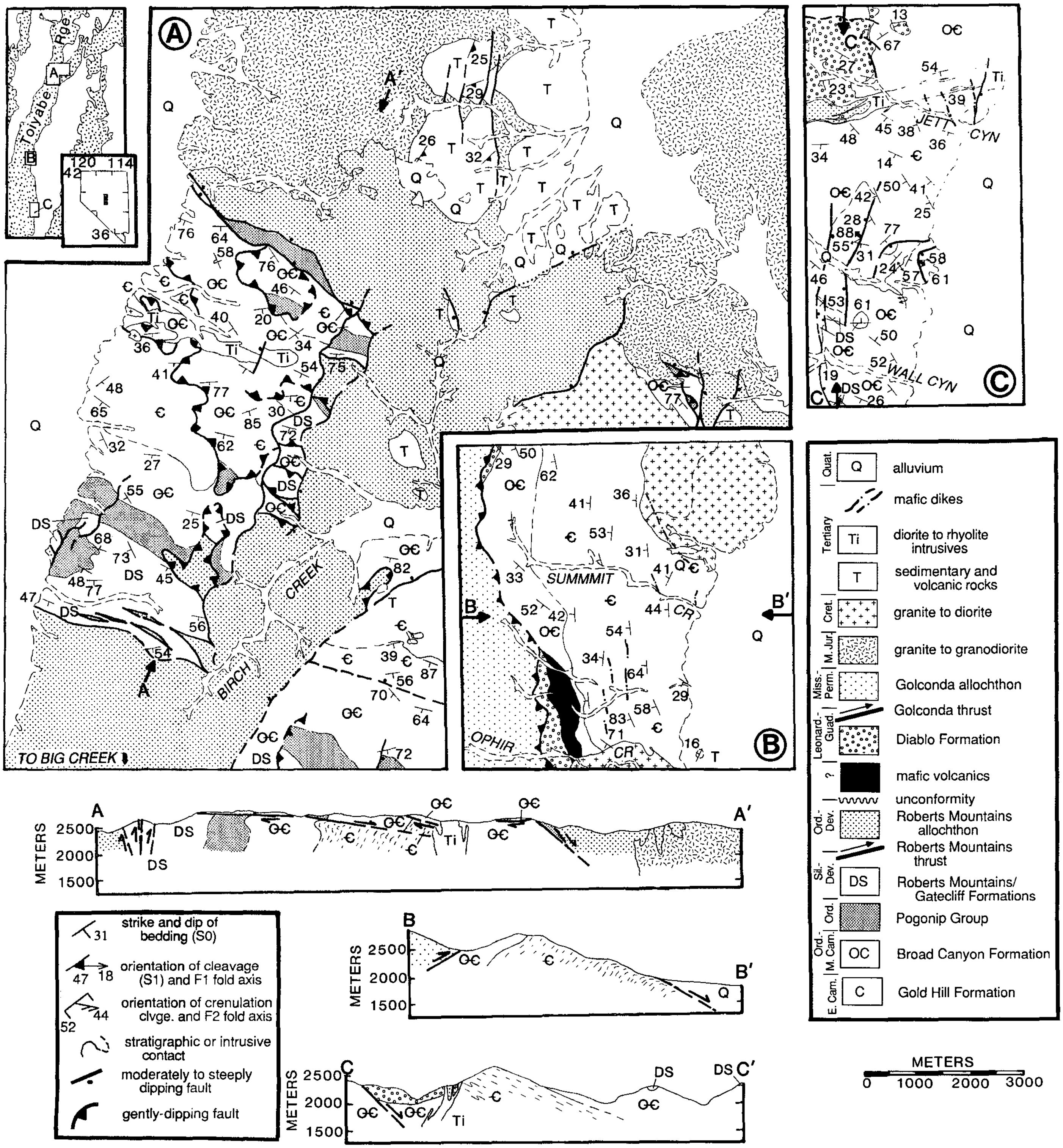

Figure 2. Geologic maps and cross sections of areas of detailed study in Toiyabe Range, Nevada. A: Birch Creek area. B: Ophir–Summit Creek area. C: Jett Canyon (Cyn) and Wall Canyon area.

thrust. Ubiquitous younger-on-older offsets, large bedding-to-fault angles, and the steep dip of the originally subhorizontal Roberts Mountains thrust suggest that the gently dipping faults in this area formed as steeply north dipping normal faults that rotated to gentler dips during extension. If Paleozoic strata were subhorizontal prior to faulting, these faults could have produced more than 200% localized extension.

On the east side of the range, these gently dipping faults are cut and intruded by the Middle Jurassic Austin pluton (161 ±5 Ma; Krueger and Schilling, 1971), indicating that normal faulting was pre–Middle Jurassic in age. On the west side of the range, these faults are cut by folds, cleavage, and isograds developed in the contact aureole of the Austin pluton (Smith, 1989), confirming their pre–Middle Jurassic age.

The age of faulting is better defined by exposures about 5 km to the south of the area shown in Figure 2A, on the south side of Big Creek (McKee, 1976). There, rocks of the Roberts Mountains allochthon are tilted steeply south and are overlain by a sequence of poorly exposed conglomerate and limestone that dips gently east. These strata were originally mapped as Tertiary conglomerate (Washburn, 1966), but have been reinterpreted as in situ Pennsylvanian strata on the basis of fossil corals in the limestone beds (McKee, 1976). The strong southward tilting of the underlying allochthonous rocks is very similar to the tilting of the allochthon documented in Figure 2A. Southward tilting of a large area is not an expected result of east-directed Antler-age shortening, and thus we infer that the allochthonous strata near Big Creek were tilted by the same episode of normal faulting seen in the area of Figure 2A. If so, the age of the faulting is more tightly defined as Late Mississippian to Pennsylvanian.

Ophir Canyon to Summit Canyon

In this area (Fig. 2B), conglomerate and sandstone of the Diablo Formation (Babaie, 1984; Speed et al., 1977) unconformably overlie the Ordovician Broad Canyon Formation (Means, 1962). These Ordovician strata and similar rocks in the area of Jett Canyon to Wall Canyon (see below) have been inferred to be part of the Roberts Mountains allochthon (Ferguson and Cathcart, 1954; Speed et al., 1977). First-generation folds in these units are now known to be Mesozoic in age, not Paleozoic (Smith, 1989), and the units are better interpreted as miogeoclinal strata. This reinterpretation implies that the Roberts Mountains allochthon and part of the miogeocline were removed prior to Diablo deposition. Near Ophir Creek an unusual section of mafic lava flows overlies the Broad Canyon Formation with an angular unconformity of 5°–10° and is in turn overlain nearly conformably by the Diablo Formation. The Diablo Formation is undated in the Ophir-Summit area, but is known to be mid-Permian 25 km to the south (Speed et al., 1977), suggesting that uplift, erosion, and eruption of basalts all occurred in Late Mississippian to Early Permian time. No faults of that age have been identified, but the sequence of uplift and erosion followed by deposition of chert-bearing clastic strata is similar to the events recorded in the Birch Creek area.

Jett Canyon to Wall Canyon

In the area of Figure 2C, miogeoclinal strata (Lowell, 1958) are overlain by Leonardian to Guadalupian clastic strata of the Diablo Formation (Speed et al., 1977) with an angular unconformity of as much as 70°–90° (Fig. 2). This unconformity cuts upsection to the south. It is developed on the Ordovician Broad Canyon Formation in Jett Canyon and above the Silurian Gatecliff Formation in Wall Canyon, suggesting that the rocks in this area were tilted southward prior to mid-Permian time.

In Jett Canyon, radiolarian chert and phyllite of the Roberts Mountains allochthon are downdropped in a small east-west–trending graben between autochthonous Ordovician strata to the north and Cambrian strata to the south. These contacts must once have been faults but have since been intruded by branches of a large Tertiary dike (John, 1987; Fig. 2C). The Diablo Formation is deposited on both the allochthon and the autochthonous phyllites, indicating that some amount of extension and graben formation occurred in Late Mississippian to Early Permian time. The Diablo is absent immediately to the south of the dike and was either not deposited at all or was uplifted and eroded following deposition, perhaps by additional syn- or post-Diablo offset on this fault system.

SUMMARY AND DISCUSSION

Cambrian to Early Mississippian strata and structures in central Nevada were cut and tilted by north-dipping normal faults and then beveled and overlain by Pennsylvanian to Early Permian sedimentary sequences. These sequences generally fine upward, suggesting subsidence or sea-level rise during deposition, and are locally associated with mafic lava flows. In light of the evidence for Mississippian to Permian normal faulting in the Toiyabe Range and the similar evidence of late Paleozoic extension or transtension outlined above from a number of areas in Nevada and California, it is likely that extensional or transtensional tectonics affected most of the continental margin of the western United States in Late Mississippian to Early Permian time.

Within the same interval, high-angle faults formed a series of mountain ranges and basins across much of the craton of the western United States (Fig. 3). These ranges are known as the Ancestral Rocky Mountains (Kluth, 1986, and references therein). Many of the bounding faults have been overprinted by younger deformation, and normal, reverse, and strike-slip faulting may all have played a role in producing the documented

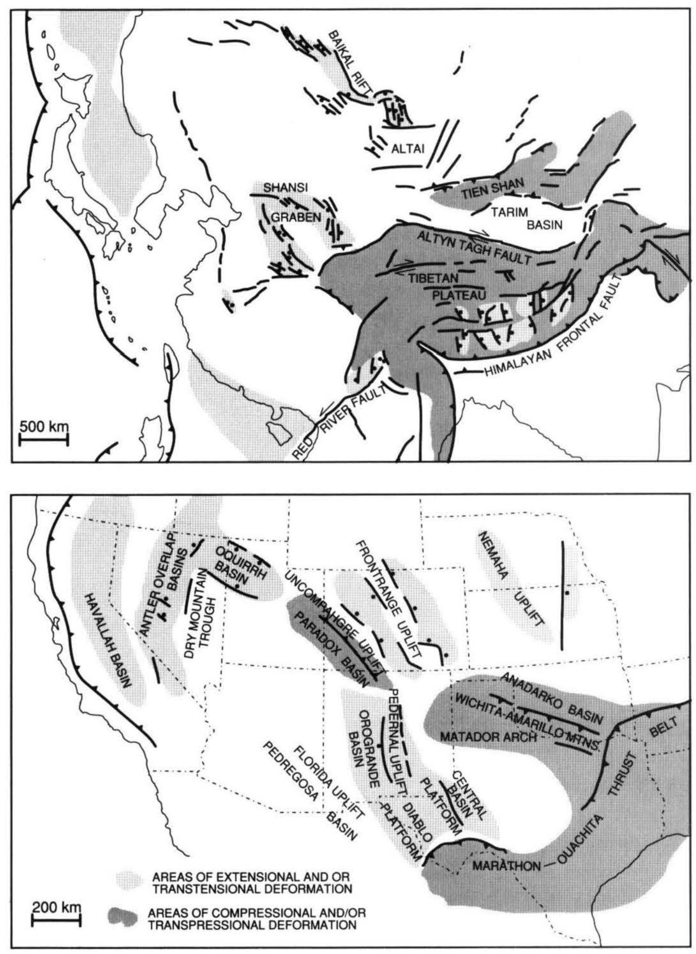

Figure 3. Comparison of late Paleozoic paleogeography of western United States with Cenozoic paleogeography of Asia. Note that scales are different and that map of Asia has been inverted and rotated so tectonic geometry will match that of western United States. Havallah basin is marginal basin of unknown width.

uplifts and basins (Kluth, 1986; Jordan and Douglas, 1980; Stevenson and Baars, 1986; Handschy and Dyer, 1987). Kluth and Coney (1981) and Kluth (1986) have inferred that formation of the Ancestral Rockies was driven by convergence of North and South America across the Marathon and Ouachita fold-and-thrust belts in Pennsylvanian and Permian time and was localized by preexisting weaknesses in the craton. Kluth (1986) has also suggested that the Ancestral Rockies may be analogous to the Cenozoic tectonics of Asia, which are a function of both collision along the Himalayas and extensional tectonics along the southeast Asian margin (Tapponnier et al., 1982). As shown in Figure 3, the distribution of structures is similar, but the western United States is about two and a half times smaller.

In the western United States, the western extensional margin and the southern compressional margin were approximately the same length and were approximately equidistant from the Ancestral Rockies. According to the continuum model of England and Houseman (1988), the deformation related to each margin should decrease exponentially away from the margin and be negligible at a distance approximately equal to the length of the margin. Although extension on the eastern margin of Asia has little effect on the Tibetan Plateau because of the large distances involved (England and Houseman, 1988), the heterogeneous structures developed across the much smaller Ancestral Rockies and adjacent Cordilleran shelf may well reflect the overlapping influences of both the extensional and compressional margins.

REFERENCES CITED

Babaie, H.A., 1984, Structure and tectonic history of the Golconda allochthon, Toiyabe Range, Nevada: Evanston, Illinois, Northwestern University, 263 p.

Bushnell, K., 1967, Geology of the Rowland quadrangle, Elko County, Nevada: Nevada Bureau of Mines Bulletin 67, 38 p.

Coash, J.R., 1967, Geology of the Mount Velma quadrangle, Elko County, Nevada: Nevada Bureau of Mines Bulletin 68, 20 p.

England, P., and Houseman, G., 1988, The mechanics of the Tibetan Plateau: Royal Society of London Philosophical Transactions, ser. A, v. 326, p. 301–320.

Erickson, R.L., and Marsh, S.P., 1974, Paleozoic tectonics in the Edna Mountain quadrangle, Nevada: U.S. Geological Survey Journal of Research, v. 2, p. 331–337.

Ferguson, H.G., and Cathcart, S.T., 1954, Geology of the Round Mountain quadrangle, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-40, scale 1:125,000.

Handschy, J.W., and Dyer, R., 1987, Polyphase deformation in Sierro del Cuervo, Chihuahua, Mexico: Evidence for Ancestral Rocky Mountain tectonics in the Ouachita foreland of northern Mexico: Geological Society of America Bulletin, v. 99, p. 618–632.

Harwood, D.S., 1988, Tectonism and metamorphism in the northern Sierra terrane, northern California, *in* Ernst, W.G., ed., Metamorphism and crustal evolution, western coterminous United States: Englewood Cliffs, New Jersey, Prentice-Hall, p. 764–788.

Hotz, P.E., and Wilden, R., 1964, Geology and mineral deposits of the Osgood Mountains quadrangle, Humboldt County, Nevada: U.S. Geological Survey Professional Paper 431, 128 p.

John, D.A., 1987, Map showing the distribution and characteristics of plutonic rocks in the Tonopah 1° by 2° quadrangle, central Nevada: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1877J, scale 1:250,000.

Jordan, T.E., and Douglas, R.C., 1980, Paleogeography and structural development of the Late Pennsylvanian to Permian Oquirrh Basin, northeastern Nevada, *in* Fouch, T.D., and Magathan, E.R., eds., Paleozoic paleogeography of the west-central United States: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists Paleogeography Symposium 1, 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: Pacific Section, Society of Economic Paleontologists and Mineralogists Pacific Coast Paleogeography Symposium 1, p. 363–369.

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

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

Krueger, H.W., and Schilling, J.H., 1971, Geochron/Nevada Bureau of Mines K-Ar age determinations: List 1: Isochron/West, v. 71, p. 9–14.

Little, T.A., 1983, Structure and metamorphism of upper Paleozoic rocks in the Mountain City quadrangle, Elko County, Nevada: Stanford, California, Stanford University, 392 p.

—— 1987, Stratigraphy and structure of metamorphosed upper Paleozoic rocks near Mountain City, Nevada: Geological Society of America Bulletin, v. 98, p. 1–17.

Lowell, J.D., 1958, Lower and Middle Ordovician stratigraphy in eastern and central Nevada: New York, Columbia University, 117 p.

Means, W.D., 1962, Structure and stratigraphy in the central Toiyabe Range, Nevada: University of California Publications in the Geological Sciences, v. 42, p. 71–110.

McKee, E.H., 1972, Preliminary geologic map of the Wildcat Peak quadrangle and the western part of the Diana's Punch Bowl quadrangle, Nevada: U.S. Geological Survey, Miscellaneous Field Studies Map MF-337, scale 1:62,500.

—— 1976, Geologic map of the Austin quadrangle, Lander County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1307, scale 1:62,500.

Miller, E.L., Miller, M.M., Stevens, C.H., Wright, J.E., and Madrid, R., 1990, Late Paleozoic paleogeographic and tectonic evolution of the western U.S. Cordillera, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., eds., The Cordilleran orogen: Conterminous United States: Boulder, Colorado, Geological Society of America, The Geology of North America, v. G-3 (in press).

Miller, M.M., 1987, Dispersed remnants of a northeast Pacific fringing arc: Upper Paleozoic terranes of Permian McCloud faunal affinity, western U.S.: Tectonics, v. 6, p. 807–830.

Roberts, R.J., Crittenden, M.D., Jr., Tooker, E.W., Morris, H.T., Hose, R.K., and Cheney, T.M., 1965, Pennsylvanian and Permian basins in northwestern Utah, northeastern Nevada, and south-central Idaho: American Association of Petroleum Geologists Bulletin, v. 49, p. 1926–1956.

Smith, D.L., 1989, Structural geology and tectonic development of the Toiyabe Range, Lander and Nye counties, Nevada: Stanford, California, Stanford University, 169 p.

Snyder, W.S., and Spinosa, C., 1986, The Lower Permian Dry Mountain trough, eastern Nevada: Possible flexural response to a reactivated Antler orogenic belt: Geological Society of America Abstracts with Programs, v. 18, p. 414–415.

Speed, R.C., MacMillan, J.R., Poole, F.G., and Kleinhampl, F.J., 1977, Diablo Formation, west-central Nevada, *in* Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States: Pacific Section, Society of Economic Paleontologists and Mineralogists Pacific Coast Paleogeography Symposium 1, p. 301–314.

Stevens, C.H., 1977, Permian depositional provinces and tectonics, western United States, *in* Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States: Pacific Section, Society of Economic Paleontologists and Mineralogists Pacific Coast Paleogeography Symposium 1, p. 113–135.

—— 1979, Lower Permian of the central Cordilleran miogeosyncline: Summary: Geological Society of America Bulletin, v. 90, part I, p. 140–142.

Stevens, C.H., and Stone, P., 1985, Early Permian thrust faulting in eastern California: Geological Society of America Abstracts with Programs, v. 17, p. 410.

Stevenson, G.M., and Baars, D.L., 1986, The Paradox: A pull-apart basin of Pennsylvanian age, *in* Peterson, J.A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 353–369.

Stone, P., and Stevens, C.H., 1984, Stratigraphy and depositional history of Pennsylvanian and Permian rocks in the Owens Valley–Death Valley region, eastern California, *in* Lintz, J., Jr., ed., Western geological excursions: Reno, University of Nevada, Mackay School of Mines, v. 4, p. 94–119.

—— 1988, An angular unconformity in the Permian section of east-central California: Geological Society of America Bulletin, v. 100, p. 547–551.

Tapponnier, P., Peltzer, G., Le Dain, A.Y., Armijo, R., and Cobbold, P., 1982, Propagating extrusion tectonics in Asia: New insights from simple experiments with plasticine: Geology, v. 10, p. 611–616.

Washburn, R.H., 1966, Structure and Paleozoic stratigraphy of the Toiyabe Range, southern Lander County, Nevada: New York, Columbia University, 79 p.

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