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Penrose Conference report

# Sonoma orogeny and Permian to Triassic tectonism in western North America

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Four days of discussion, a field trip to the Antler Peak area, Nevada, and an optional postmeeting trip to the Bilk Creek Mountains, Nevada, constituted the Penrose Conference on the Sonoma orogeny of Nevada and related Permian to Triassic tectonism in western North America. The conference took place in Winnemucca, Nevada, September 8–13, 1982.

## SONOMA OROGENY IN NEVADA

The Sonoma orogeny was defined by Silberling and Roberts (1962) as the event in northern Nevada in which deep-water chert-argillite-limestone-greenstone sequences (Pumpernickel and Havallah Formations, or the Havallah sequence of Silberling and Roberts, 1962) were folded and faulted prior to the deposition of unconformably overlying and relatively undeformed rocks of the Koipato Formation. The Havallah sequence is as young as late Early Permian or possibly early Late Permian, and the Koipato is as old as late Early Triassic, indicating a Late Permian or Early Triassic age for the Sonoma orogeny as defined by Silberling and Roberts (1962).

The Havallah sequence occurs in a major thrust sheet (Golconda allochthon) that moved eastward along the Golconda thrust for as much as 70 km over autochthonous shallow-water upper Paleozoic terrigenous detrital and carbonate rocks. The age of emplacement of the Golconda allochthon was a subject of considerable debate at the conference. The emplacement can be viewed either as a part of the Sonoma orogeny and thus of pre-late Early Triassic age or, as emphasized by K. B. Ketner, it may be unrelated to the Sonoma orogeny, and of Jurassic or Cretaceous age. The latter idea means that the relatively undeformed Triassic rocks that rest on the Golconda allochthon were brought in "piggyback" on the Golconda allochthon. If this is so, the pre-late Early Triassic deformation (Sonoma orogeny) may have taken place far from the area where the rocks are now exposed.

Dating of the emplacement time of the Golconda allochthon is difficult because Triassic rocks are not known to overlap the leading edge of the allochthon, and, in fact, the Triassic rocks in north-central Nevada are confined to positions on top of the allochthon. Raul Madrid described outcrops in the Shoshone Range, Nevada, where sedimentary rocks of possible Triassic age contain debris derived from the Golconda allochthon as well as from the autochthon, suggesting emplacement of the allochthon prior to sometime in the Triassic. John MacMillan described folds in the New Pass Range, Nevada, related to emplacement of the Golconda allochthon that are lacking in superjacent Triassic rocks, suggesting emplacement before late Early Triassic time. R. C. Speed proclaimed an Early Triassic age of emplacement in the Candelaria area of west-central Nevada, where Lower Triassic hemipelagic sediments are overlain in turn by a prograding volcanigenic fan and a serpentinite melange and are capped by the Golconda allochthon—relations compatible with Early Triassic emplacement. N. J. Silberling proposed that Upper Triassic deltaic rocks in northern Nevada (lower part of the Auld Lang Syne Group), which are part of the Triassic rocks that lie above the Golconda allochthon, may have had a source from fluvial Upper Triassic systems of the Colorado Plateaus region of the western United States and thus record sediment transport across the in-place Golconda allochthon. In support of a Jurassic or later emplacement of the Golconda allochthon, K. B. Ketner cited observations from two areas in northern Nevada. In the Adobe Range, Lower Triassic basinal sediments deposited east of the Golconda allochthon include no westerly derived orogenic sediments that could be attributed to the Sonoma orogeny. In the Bilk Creek Mountains west of the Golconda allochthon, a Permian to Upper Triassic sequence displays no sedimentary or structural evidence of orogeny; the sequence may, however, comprise an exotic terrane that was not in its present position until after the Sonoma orogeny. All evidence on the age of the Golconda thrust, however, is equivocal, and the issue is unresolved.

Rocks of the Golconda allochthon are composed of numerous tectonic slices bounded by thrust faults. J. H. Stewart, B. Murchey, and D. L. Jones illustrated this style in the Tobin Range, where a 2,000-m-thick homoclinal sequence is composed of Upper Mississippian to Lower Permian strata that have been repeated at least six times and may originally have been no more than 700 m thick. Similar repetitions of strata by imbricate thrusting were described in the Antler Peak area by W. S. Snyder, B. Murchey, and E. L. Miller and in the Independence Mountains by E. L. Miller.

In addition to major imbricate thrust faults, the Golconda allochthon contains mesoscopic folds, shears, lenticular bedding (or boudins), and bedding-parallel cleavage. The folds are asymmetrical and generally east vergent. E. L. Miller suggested that most of the folds and faults were produced by folding and east-directed thrust faulting during a progressive deformational event. W. S. Snyder and H. K. Brueckner, on the other hand, suggested that the structural fabric indicates several generations of folds and shears resulting from a prolonged evolution rather than a single episode of thrusting.

Inland effects of the Sonoma orogeny in Nevada appear to be minor. In contrast to thick foreland basin deposits that developed following the mid-Paleozoic Antler orogeny that had a similar structural style and setting to the Sonoma orogeny, no foreland basin deposits related to the Sonoma orogeny are known in northern Nevada. In western Nevada, R. C. Speed related the Lower Triassic Candelaria Formation to deposition in a foreland basin that was inboard of and partly overridden by the Golconda allochthon.

Away from the Golconda allochthon in Nevada and in adjacent parts of California and Arizona, local basal Lower Triassic conglomerates lie on an erosional surface that bevels and truncates underlying units. These relations suggest local upland areas near the margin of the North American continent, possibly related to the Sonoma or similar tectonic events along the continental margin. J. D. Walker reported volcanic debris, presumably related to continental margin volcanism, in Lower Triassic strata in easternmost California.

## WESTERN CONTERMINOUS UNITED STATES, EXCLUSIVE OF NEVADA

Known or possible Permian and Triassic events were described from several areas in the western United States outside of Nevada. The types of events were variable from area to area.

C. H. Stevens and Paul Stone outlined two tectonic events of Permian age in the Inyo-Argus Ranges of easternmost California. First, at least one deep southeast-trending turbidite basin, perhaps related to extensional or strike-slip faulting, was developed during the earliest Permian above shelf rocks of older Paleozoic age. This event was followed in the latest Wolfcampian by emplacement of an allochthonous block of basinal rocks which juxtaposed two unlike facies of lowermost Permian rocks. A Late Permian or Early Triassic orogenic event (the Sonoma orogeny) is not recorded in the Inyo-Argus Ranges.

M. D. Carr and F. G. Poole described Permian tectonism of a considerably different style in the El Paso Mountains of the Mojave Desert of California. There, Permian rocks exhibit a transition from marine sedimentary rocks to arc-related andesitic volcanic rocks. The sequence was penetratively deformed with the development of west-vergent folds, and the deformed rocks were intruded by Late Permian or Early Triassic plutonic rocks. E. L. Miller discussed similar Permian or Triassic deformation and plutonism in the southwestern part of the Mojave Desert region.

R. A. Schweickert, Warren Sharp, and Jason Saleeby described the Sierra Nevada region of California, which contains Lower and middle Permian arc-related volcanic rocks in its northern part, depositional hiatuses ranging from Late Permian to Middle Triassic age in its northern and eastern parts, and possible Permian and Triassic deformation and metamorphism of the Shoo Fly Complex and Calaveras Formation in the central part of the range. The hiatuses span the age of the Sonoma orogeny, but the exact relations of the rocks and deformational structures of the Sierra Nevada to the Sonoma event are not clear.

J. E. Wright related a magmatic arc of Permian and Triassic age in the eastern Klamath Mountains to an east-dipping subduction zone in the so-called western Paleozoic and Triassic belt of the Klamath Mountains. D. L. Jones, however, noted that the youngest rocks in the western Paleozoic and Triassic belt are Late Triassic, thus documenting subduction only as far back as this. Regardless of the age of subduction, E. L. Miller and J. E. Wright suggested that the Permian and Triassic magmatic arc in the eastern Klamath Mountains may have been originally continuous with Permian and Triassic arc rocks in the Sierra Nevada of California and southward to the Mojave Desert region of California, where they intrude North American Precambrian crusts.

R. I. Coward summarized information on Permian and Triassic arc-related volcanic rocks of eastern Oregon and western Idaho, considered by D. L. Jones and W. J. Silberling to be a part of the highly disrupted Wrangellia terrane.

## CANADA

The Canadian Cordillera east of the allochthonous terranes, accreted to western North America during the Mesozoic and presumably underlain by cratonal crust, contains little if any evidence of Late Permian to Early Triassic tectonism. Permian and Triassic strata are essentially paraconformable, and foreland basin deposits are absent. Indeed, a much more conspicuous event in the eastern Cordillera is marked by the widespread unconformity at the base of Permian rocks.

Within the allochthonous terranes, tectonic relationships between Permian and Triassic rocks are variable. J.W.H. Monger discussed a well-exposed contact in the northeastern part of the Stikine terrane in British Columbia where volcanic sandstone, tuff, and argillite of Late Triassic (late Karnian) age disconformably overlie Lower Permian basic tuff and chert. Near the northern part of the Stikine terrane a profound structural discordance occurs between Permian limestone, chert, and phyllite and Middle Triassic (Anisian) phyllitic argillite, tuff, and chloritic phyllitic rocks. In this same area, the pre-Triassic strata generally record two distinct, nearly orthogonal structural trends, whereas the Triassic rocks have been significantly deformed along one, generally westerly, trend.

Allochthonous, far-traveled oceanic terranes in northern British Columbia and the Yukon Territory, such as the Sylvester allochthon, include rocks ranging from Mississippian to Upper Triassic, commonly with internal imbrication. They closely resemble the Havallah sequence and related rocks in Nevada. In the Canadian Cordillera, however, the allochthons were emplaced in post-Triassic time.

L. Struik noted that in the Cariboo Mountains area, east-central British Columbia, two allochthonous terranes composed in part of deep-water chert and pillow lavas of late Paleozoic age and similar to rocks of the Golconda allochthon are emplaced over strata along the western margin of ancestral North America. The emplacement of these allochthons can be dated no more closely than Late Permian to Jurassic, an age span that includes the time of the Sonoma event in Nevada.

D. Klepacki described the stratigraphic relationships in southeastern British Columbia in an area containing the easternmost occurrences in the Canadian Cordillera of upper Paleozoic and (or) lower Mesozoic volcanic rocks. There, Upper Triassic phyllite and limestone with a basal conglomerate overlie pillow lava and associated volcanic sediments of post–Late Mississippian age. This locality is important because it is possible that the Upper Triassic strata can be linked to those on the craton.

A. Okulitch presented evidence for Permian to Triassic tectonism in south-central British Columbia. Several critical localities may exhibit structural discordance between Upper Triassic and underlying rocks.

In the Wrangellia terrane along the western margin of the Cordillera little structural discordance occurs between Permian and Triassic rocks, although a significant disconformity is widespread.

In the Taku-Skolai terrane along the Alaska-Yukon boundary, Middle Triassic (Ladinian) phyllite and minor limestone disconformably overlie Lower Permian limestone and mafic volcanic rocks.

## ALASKA

In the complex collage of terranes in Alaska discussed by D. L. Jones, P. J. Coney, and N. J. Silberling, only the Chulitna terrane of south-central Alaska, a few tens of kilometres in extent, contains a record of Triassic deformation. No important structural breaks are recorded in Permian and Triassic rocks in other terranes, although the abundance of Upper Triassic basalt in many terranes indicates rifting events.

In the Chulitna terrane, Upper Triassic strata containing well-rounded clasts of gabbro, diabase, serpentinite, basalt, tuffaceous chert, fossiliferous (Permian?) limestone, and Late Devonian red radiolarian chert rest unconformably on upper Paleozoic and Lower Triassic rocks. The unconformable relation and the abundance and variety of conglomeratic debris clearly indicates a major post–Early Triassic and pre–Late Triassic tectonic event in the Chulitna terrane. The remarkable similarity of Upper Triassic faunas of the Chulitna terrane to those in Nevada and California and the dissimilarity to those in Canada and elsewhere in Alaska suggest that the Chulitna terrane may be far traveled from its original position.

## ACCRETED AND DISPLACED TERRANES

P. J. Coney, D. L. Jones, and J.W.H. Monger emphasized that the North American Cordillera outboard of the craton is a mosaic of terranes of uncertain Paleozoic and Mesozoic paleogeographic setting with respect to North America. Many terranes are far traveled and were accreted to North America primarily in Jurassic to early Cenozoic time. Large-scale transcurrent and post-accretionary horizontal translations also have disrupted paleogeographic relations. Paleomagnetic studies, summarized by M. E. Beck, Jr., and paleontological studies described by C. A. Ross, N. J. Silberling, and C. H. Stevens provide much of the evidence that the western Cordillera is allochthonous. Their criteria indicate large northerly displacements of most Mesozoic allochthonous terranes. Paleogeographic reconstructions for Permian and Triassic time in the western Cordillera are severely hampered by our not clearly knowing the relative position of the various terranes.

## ABSOLUTE PLATE MOTION

Allan Cox indicated that absolute plate motions can be derived from the changing position of the magnetic pole through time as viewed from the moving plate. He noted that plates do not change direction much once they are moving, that changes in direction are generally related to the development of a new trench system, and that plates not attached to downgoing slabs move slowly, whereas those that are attached move fast. Cox's studies indicate that the absolute plate motion of North America was at a much higher rate in the Late Permian and Triassic than in Carboniferous, Early Permian, or Early Jurassic time. This relation may indicate a changing plate-tectonic system for North America in Late Permian and Triassic time. The paleomagnetic data are consistent with, but do not require, a downgoing slab attached to North America during the Late Permian and Triassic. Tectonism, such as the Sonoma orogeny, and the abundance of arc-related volcanic rocks of Permian and Triassic age in the Cordillera may be related to this interval of rapid plate motion.

## TECTONIC MODELS

Two competing tectonic models drew most of the attention at the conference. The first, championed by R. C. Speed, W. S. Snyder, and others relates the Sonoma orogeny to the collision of an island-arc terrane with a stable North America. A westward-dipping subduction zone below the arc led to the consumption of oceanic crust and the relative approach of the continent to the arc. An accretionary wedge of ocean-floor strata accumulated in front of the arc and was emplaced as the Golconda allochthon on North America by underslipping of the continent.

The second tectonic model, championed by E. L. Miller and J. E. Wright, relates the Sonoma orogeny and the emplacement of the Golconda allochthon to the closing of a back-arc basin lying between an offshore island-arc system and stable North America. The arc was underlain by an east-dipping subduction zone, and convergence of the arc system toward North America caused compression of the back-arc basin and emplacement of the Golconda allochthon on North America. The Permian arc system of the northern Sierra Nevada and eastern Klamath Mountains of California is considered in this scheme to represent the offshore arc system related to the Sonoma orogeny, whereas along-strike magmatism and deformation in southern California occurred in an Andean arc setting.

## REFERENCE CITED

Silberling, N. J., and Roberts, R. J., 1962, Pre-Tertiary stratigraphy and structure of northwestern Nevada: Geological Society of America Special Paper 72, 58 p.