PENROSE CONFERENCE REPORT

DAVID BLOOM

The Antler orogeny—Mid-Paleozoic tectonism in western North America

Tor H. Nilsen and John H. Stewart
Conveners

A Penrose Conference on the Antler orogeny was held at Elko, Nevada, September 9-14, 1979. The conference brought together workers engaged in various studies of the Antler orogenic belt to foster understanding of the orogeny and provide a framework for future research. The 51 participants included representatives from the petroleum, mineral, and geothermal industries; professors from Canadian and American universities; workers from the Geological Survey of Canada, U.S. Geological Survey, and several State geological surveys; and three students. The group included a mixture of regional geologists, stratigraphers, sedimentologists, paleontologists, structural geologists, geophysicists, and economic geologists.

The meeting was divided into lecture, discussion, and poster sessions. In addition, two days were spent in the field examining classic aspects of the Antler orogenic belt in north-central Nevada. The first field trip, led by R. J. Roberts and C. T. Wrucke of the U.S. Geological Survey at Menlo Park, California, focused on structural and stratigraphic relations of the Roberts Mountains allochthon in the Battle Mountain area and the Shoshone and Cortez Ranges. The second field trip, led by K. B. Ketner and F. G. Poole of the U.S. Geological Survey at Denver, Colorado, focused on stratigraphic and sedimentological relations of Antler foreland basin deposits in the Carlin area and northern Piñon Range.

The conference was dedicated to Philip B. King and Ralph J. Roberts of the U.S. Geological Survey for their many contributions to the understanding of mid-Paleozoic tectonism in western North America. King's compilations of tectonic and geologic maps, involving the synthesis of vast amounts of stratigraphic and structural data for western North America and detailed work in the Marathon basin and Ouachita Mountains, provide a basis for understanding the scope and character of mid-Paleozoic tectonism. Roberts provided the first clear understanding of mid-Paleozoic tectonic events in north-central Nevada, named the Antler orogeny in 1949, and recognized it to be a major tectonic event affecting western North America.

DEFINITION OF ANTLER OROGENY

At the conference, P. B. King prepared a definition of the Antler orogeny that was generally agreed to by most participants:

> The Antler orogenic belt (*sensu stricto*) is a belt of rocks orogenically deformed in mid-Paleozoic time that extends north-northeastward across central Nevada, southward into the Mojave Desert region of southeastern California, and northward into central Idaho as far as the Salmon River arch. It is bounded on the east by cratonic miogeosynclinal rocks, and on the west by upper Paleozoic rocks of the Golconda allochthon, as well as lower Mesozoic rocks. It is composed of eugeosynclinal (ocean floor?) Devonian and older Paleozoic rocks that were deformed and thrust eastward over the adjacent outer shelf rocks, mainly (possibly not wholly) along the Roberts Mountains thrust. This orogenic event was not accompanied (so far as known) by any plutonism or severe metamorphism, but some sort of deep-seated effect is indicated by the persistence of a positive belt along the orogenic zone through the remainder of Paleozoic time, and even later. A thick sequence of flysch was deposited in a foreland basin to the east of the orogenic belt following uplift of the belt.
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> The Antler orogeny and orogenic belt (*s. l.*) with its rather special features is only one of a series of tectonic features formed at about the same time around the edges of North America—along most of the Pacific side (where they might be called Antler *sensu lato*), along the northern or Arctic side (Ellesmerian orogeny), along the eastern or Atlantic side (Acadian orogeny), and along the southern or Gulf of Mexico side (Ouachita orogeny). The tectonic manifestations of these orogenies differ from those of the Antler belt and involve plutonism, metamorphism, and other features characteristic of orogenic belts in general.

UNITED STATES (CONTERMINOUS)

After introductory summaries of the historical development of the concept of the Antler orogeny by R. H. Dott, Jr., and R. J. Roberts, the setting of the Antler orogeny in Nevada was described by J. H. Stewart. He outlined a history of one or two episodes of Precambrian rifting that left western North America with an Atlantic-type continental margin characterized by miogeosynclinal shelf deposits of carbonate, shale, and quartzite to the east and deeper marine eugeosynclinal (oceanic?) deposits of chert, argillite, greenstone, and quartzite to the west. This paleogeographic framework persisted without disturbance until Late Devonian time, when it was disrupted by the Antler orogeny. Several participants (G. C. Bond, W. R. Dickinson, K. B. Ketner, J. H. Stewart, and C. A. Suczek) pointed out that quartz-rich sandstone and siltstone in the Harmony, Valmy, and Vinini Formations of the eugeosynclinal belt in Nevada may hold the key to a full understanding of pre-Antler paleogeography. These units, as yet poorly understood, could have been derived from either eastern or western source terranes and thus place constraints on both paleogeographic reconstructions and tectonic models.

As outlined by R. J. Roberts, the major structural expression of the Antler orogeny in north-central Nevada is a large internally complex thrust sheet, the Roberts Mountains allochthon. It consists of Cambrian to Devonian chert, argillite, greenstone, sandstone, and quartzite of the eugeosynclinal belt thrust over uppermost Precambrian to Devonian carbonate, shale, and quartzite of the miogeosynclinal belt. If the eugeosynclinal rocks were originally deposited entirely to the west of the miogeosynclinal rocks, as first proposed by Roberts, the allochthon must have been transported about 140 km eastward to account for the present juxtaposi-

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tion and overlap of facies. K. B. Ketner alternatively suggested that the depositional site of eugeosynclinal rocks advanced progressively eastward with time, so that less tectonic transport is required to account for the juxtaposition of facies.

According to C. T. Wrucke, the Roberts Mountains allochthon in north-central Nevada is generally subhorizontally layered and consists of stacks of thrust plates ranging from metres to kilometres in thickness with locally intermixed blocks of lower-plate rocks scraped off the basal contact. The allochthon contains north-trending folds that are locally overturned to the east.

The sedimentary record of the Antler orogeny in north-central Nevada, as outlined by F. G. Poole, is a sequence of Upper Devonian and Mississippian sedimentary rocks (mainly the Chainman and Diamond Peak Formations) that is locally more than 3,000 m thick. The sequence was deposited in a foreland basin east of the area of emplacement of the Roberts Mountains allochthon. The deposits contain coarse, chert-rich detritus eroded from the uplifted Roberts Mountains allochthon and grade upward from deep-marine turbidites to shallow-marine, deltaic, and fluvial facies.

Deposits of the Antler foreland basin can be traced northward into Idaho from the type region in north-central Nevada. In south-central Idaho, as described by B.A.L. Skipp and T H. Nilsen, thick detrital quartz- and chert-rich deep-sea fan and carbonate-rich basin-plain sequences of Early Mississippian age were deposited in the foreland basin east of the orogenic belt. In this region, however, the Roberts Mountains thrust or its northward continuation has not been recognized in the field and is apparently obscured by younger Sevier-age faulting.

Coarse foreland basin deposits of Mississippian age that were derived from the Antler orogenic belt extend southward from north-central Nevada into west-central and southern Nevada and adjacent parts of California as far as the Mojave Desert region. A major allochthonous terrane south of central Nevada has not been clearly recognized, however, although folding and thrusting of Antler age can be demonstrated locally in the Miller Mountain area of Nevada, where J. S. Oldow has recognized three phases of Antler-age folding. Folds in miogeosynclinal rocks of the Inyo Mountains of easternmost California were attributed by A. B. Sylvester to the Antler orogeny.

Several participants reviewed evidence for Late Devonian tectonism, metamorphism, and igneous activity in the northern Sierra Nevada and Klamath Mountains of California, where volcanic rocks of a Devonian magmatic arc are present. G. A. Davis, G. C. Bond, and R. A. Schweickert emphasized that this Devonian magmatism corresponds temporally with the beginning of the Antler orogeny farther east, and this correspondence suggests a generic relation between the magmatic arc and events to the east. P. J. Coney and R. C. Speed, however, interpreted the Sierra Nevada and Klamath terranes as having been emplaced in their present position much after the Antler orogeny. If so, these terranes are unrelated to events of the Antler orogeny in Nevada, Idaho, and southeastern California.

P. B. King discussed the sedimentary and tectonic history of the Ouachita geosyncline and particularly its west end, the Marathon basin of Texas. This mobile belt trends southwestward into Mexico, contains turbidites composed of both carbonate and chert detritus, and was terminated by northward thrusting of the turbidite sequences over the continental edge in Pennsylvanian time.

C. A. Sandberg outlined the use of conodonts for defining the history of the Antler orogeny in the western United States, analyzing sedimentation rates, conodont zones, regional unconformities, and transgressive-regressive cycles. He documented the beginning of the Antler orogeny in Nevada and Idaho as coincident with a major eastward transgression onto the continent 16 m.y. before the end of the Devonian. He also dated thrusting as beginning 2 m.y. before the end of the Devonian and the first deposition in the foreland basin 6 to 9 m.y. after the end of the Devonian. B. C. Burchfiel, on the basis of this work, concluded that the Roberts Mountains allochthon was emplaced in about 8 m.y., a rate of about 1 cm/yr if the estimated amount of tectonic transport of the allochthon is corrected for Cenozoic extension in the Basin and Range province. This rate is compatible with convergence rates of many modern lithospheric plates, although subduction rates are commonly somewhat faster.

CANADA

Evidence for mid-Paleozoic orogeny in the western Canadian Cordillera, as outlined by H. Gabrielse, consists of Devonian quartz monzonite plutons in southeastern British Columbia and the northern Yukon Territory and discontinuous belts of mainly Upper Devonian chert-pebble conglomerate and arenite that extend from British Columbia to the Yukon and Northwest Territories. The original evidence of the Caribooan orogeny in the Cariboo Mountains is no longer valid, and this name is no longer used for mid-Paleozoic events in Canada.

In southeastern British Columbia, A. V. Okulitch described lower Paleozoic rocks that were metamorphosed, recumbently folded, and foliated before deposition of the unconformably overlying mid-Mississippian conglomeratic Milford Formation. Okulitch indicated difficulties in dating this pre-mid-Mississippian tectonic activity, but suggested an Ordovician age, which has been inferred for tectonism and metamorphism elsewhere in British Columbia. Upper Devonian or possibly Lower Mississippian quartz monzonite intrusive rocks in British Columbia, however, indicate the likelihood of Antler-age tectonic activity, an idea supported by the presence of Mississippian conglomerates in the Milford and Guyet Formations. These units are thin and not similar to the thick foreland basin deposits of the western United States. Clasts are locally derived, and chert debris is present only in the northern part of southeastern British Columbia.

In both northern British Columbia and the Yukon Territory, no compressional tectonic structures of mid-Paleozoic age have been recognized. However, Upper Devonian and Lower Mississippian clastic rocks containing chert detritus are widespread in much of the Cordillera. Clastic debris is thought by W. J. Roberts and S. P. Gordey to have been derived from local western sources that developed as a result of block faulting and vertical uplift rather than east-directed thrusting. Much of the coarse debris, derived from erosion of lower Paleozoic cherts on the uplifted blocks, was deposited as deep-sea fans.

H. P. Trettin summarized the sedimentary, metamorphic, and plutonic history of the Franklinian geosyncline in the Canadian Arctic Islands area. The Late Devonian to Pennsylvanian Ellesmerian orogeny terminated a long history of early Paleozoic deposition of turbidites in the axial part of the geosyncline and shelf carbonates and quartzites along the southeast margin of the geosyncline adjacent to the North American craton. A clastic wedge as thick as 5,000 m advanced southwestward across the geosyncline during Devonian time; it consists chiefly of fluvial, coastal plain, and shelf deposits. Derived chiefly from the Pearya Mountains of northeastern Ellesmere Island and the Precambrian Greenland shield and Caledonian Mountains of northeastern Greenland, this clastic wedge is composed predominantly of chert, quartz, and quartzitic detritus similar to that of the Antler flysch rather than the arkosic Old Red Sandstone fluvial deposits of the Caledonian and Acadian belts. L. V. Hills emphasized that the oldest Devonian clastic debris is present on Ellesmere Island, with the base of the clastic wedge becoming progressively younger southwestward into the Yukon Territory.

ALASKA

Evidence for Antler-age tectonism in Alaska, as outlined by M. Churkin, Jr., consists of mid-Paleozoic clastic wedge deposition and Devonian plutonism, volcanism, and metamorphism in the southern and northeastern Brooks Range.

T. H. Nilsen summarized the three major belts of mid-Paleozoic clastic rocks in Alaska: (1) local Upper Silurian and Lower Devonian fluvial deposits in southeastern Alaska, (2) the Upper Devonian Nation River Formation of east-central Alaska, and (3) Upper Devonian and Lower Mississippian fluvial deposits in the Brooks Range. The clastic rocks in southeast Alaska are in terranes that may have been sutured to North America long after the Antler orogeny and, if so, are unrelated to the geology of North America. The Nation River Formation of east-central Alaska was clearly deposited along the western margin of North America and consists of a large deep-sea fan, composed primarily of chert, quartz, and quartzite debris. Paleocurrents from this fan indicate westward transport of sediment. However, its paleogeographic relation to turbidite sequences in the Yukon and British Columbia remains unclear. The Upper Devonian Kanayut Conglomerate was deposited as a thick fluvial-dominated delta that prograded westward across the area of the Brooks Range, derived from a source terrane rich in chert, quartzite, and quartz.

The Brooks Range, in addition to Upper Devonian and Lower Mississippian clastic deposits, is characterized by Devonian plutonism, volcanism, and metamorphism, as described by J. T. Dillon. J. T. Dutro, Jr., and T. H. Nilsen emphasized that the lower Paleozoic geology of the Brooks Range is more similar to that of the Canadian Arctic Islands and Caledonian geosyncline than to that of western North America; this relationship suggests that the Brooks Range may be allochthonous relative to North America.

MEXICO

T. H. Anderson noted that there is no clear evidence of mid-Paleozoic orogeny in Mexico or Central America. Preliminary geochronologic and geologic studies indicate that rocks of Mesozoic age are most common along the western margin of Mexico. However, widespread areas where the geology is little known could contain fragments of the Antler belt that have been truncated and displaced southward.

MID-PALEOZOIC TECTONISM

Discussions at the conference indicated that some geologic features suggest a simi-

TABLE 1. SUMMARY OF ANTLER OR MID-PALEOZOIC OROGENY BY REGION

	Major allochthon	Folding	Volcanism	Plutonism	Regional metamorphism	Clastic wedge	Age of folding and/or thrusting	Age of clastic wedge	Source of clastic wedge
Nevada	Yes	Yes	Sparse	No	No	Yes	L. Dev. and E. Miss.	Miss.	West
California	No?	Yes	No	No	No	Yes	L. Dev. and E. Miss.	Miss.	West
Idaho	?/yes	Yes	No	No	No	Yes	L. Dev. and E. Miss.	E. Miss. (L. Miss?)	West
Northern Sierra Nevada, California	Melange	Yes	Yes	Minor	No?	No	Pre-Dev.	. .	. .
Klamath Mountains, California	Probable	Yes	Yes	Minor	Yes	Maybe	Dev.	Miss.	?
Southern British Columbia	No	No?	?	Yes	No?	Yes	Ord. to Miss.	L. Miss.	Local
Northern British Columbia and southern Yukon[*]	No	No	Yes	No?	No	Yes	. .	L. Dev. and E. Miss.	West
Northern Yukon	No	No	No	Yes	No	Yes	. .	L. Dev. and E. Miss.	East, west, and north
Canadian Arctic Islands	No	Yes	?	Yes	Yes	Yes	M. Dev., L. Dev., and E. Miss.	M. Dev. and L. Dev.	North, minor east
Brooks Range, Alaska	No?	Yes	Yes	Yes	?	Yes	Post-M. Dev. and pre-L. Miss.	L. Dev. and E. Miss.	East
Central Alaska[†]	?	No	No	No	No	Yes, with ultramafic clasts	. .	L. Dev.	East and south (?)

Note: E, Early; M, Middle; L, Late; Ord., Ordovician; Dev., Devonian; Miss., Mississippian.

[*] Block faulting inferred.

[†] Preliminary data indicate volcanic arc collision.

larity between the various mid-Paleozoic tectonic events in western North America, whereas other features emphasize the diversity of these events (Table 1). Some of the variability results from the diverse tectonic settings of terranes in which mid-Paleozoic events have been recognized. P. J. Coney, in particular, emphasized that a large part of the western Cordillera may have been accreted to North America in post-Devonian time and thus probably has little relevance to the Antler orogeny. Such terranes, which Coney called "suspect" because of their unknown original relation to North America, will cause confusion in understanding the orogeny if they are considered to have always been in their present position. Coney concluded that suspect terranes in western North America include most of Alaska except a small part of east-central Alaska between the Tintina and Kaltag faults, most of Canada west of the Rocky Mountain trench and its southward continuation into fault zones in the Fraser River area, all of Washington, Oregon, central and western California, and large parts of Mexico and Central America. R. A. Schweickert and G. C. Bond, however, argued that Paleozoic rocks in the Sierra Nevada and Klamath Mountains of California have always been close to their present position relative to the main part of North America.

A unifying feature of mid-Paleozoic tectonism in nonsuspect North American terranes is the presence of synorogenic or postorogenic clastic-wedge deposits rich in chert detritus. In many regions, these clastic-wedge deposits are the first westerly derived Paleozoic clastic sedimentary rocks, and they record the end of a long period of stable shelf deposition along the North American continental margin. The clastic-wedge deposits extend from the Mojave Desert in California to the Canadian Arctic Islands and range from thick sequences (3,000 to 5,000 m) deposited inland from orogenic belts (Nevada, Idaho, and Canadian Arctic Islands) to thin sequences (250 m) deposited in regions not clearly related to orogenic belts (southeast British Columbia). Prominent clastic sequences composed of chert-rich detritus are also present in some suspect terranes (Klamath Mountains, Brooks Range).

The nonsuspect North American terranes were characterized by brief spans of tectonic activity that generally extended from Late Devonian to Early Mississippian time. Although lacking ophiolite assemblages, these terranes contain small masses of widely spaced Alpine-type serpentinites within the Antler orogenic belt in Nevada and ultramafic debris in clastic-wedge deposits in east-central Alaska.

Features of mid-Paleozoic tectonism in western North America that are highly variable in character and duration include the amount of folding, thrusting, plutonism, volcanism, and regional metamorphism. A major allochthon related to mid-Paleozoic tectonism has been recognized only in central and northern Nevada. Mid-Paleozoic plutonism has been recognized in some suspect terranes as well as in nonsuspect terranes of southern British Columbia, the northern Yukon, and the Canadian Arctic Islands. Volcanism is widespread in suspect terranes, minor in nonsuspect terranes of northern British Columbia and the southern Yukon, and sparse in nonsuspect terranes in Nevada. Regional metamorphism is clearly recognized only in the suspect terranes and the Canadian Arctic Islands.

TECTONIC MODELS

As summarized by J. H. Stewart and W. R. Dickinson, ten possible models (Fig. 1) for the origin of the Antler orogeny have been proposed: (1) the geotectonic cycle, (2) an eastward-expanding uplift, (3) gravity sliding off a highland to the west, (4) flake tectonics, (5) continent-continent collision, (6) continent-arc collision, (7) back-arc thrusting, (8) a flipping subduction zone, (9) incipient subduction, and (10) block faulting. No general agreement existed as to which model, if any, is appropriate. P. J. Coney noted that most of the models had been proposed by the early 1970s and that little progress had been made since in focusing on a definitive model. R. C. Speed advocated the continent-arc collision model, citing modern Barbados and the accretionary wedge forming above its west-dipping subduction zone as characteristic of the Roberts Mountains allochthon; he noted that the Barbados wedge would be thrust over the continental edge of Africa when and if it collides with the Barbados Ridge. Speed suggested that the volcanic arc would subside when subduction ceased following collision; this subsidence would have developed a late Paleozoic ocean basin west of the collision zone. R. A. Schweickert, on the other hand, argued that the late Paleozoic ocean basin may have formed by westward rifting of the arc after collison.

K. B. Ketner argued for an eastward-migrating uplift that would have shed debris to the east through time into an eastward-migrating "eugeosynclinal" trough, thus proposing a western source for the quartzose sandstones of the Harmony, Valmy, and Vinini Formations in northern Nevada. The Roberts Mountains allochthon, according to this hypothesis, was gradually constructed of small plates of eugeosynclinal rocks that slid eastward down the face of the advancing uplift and

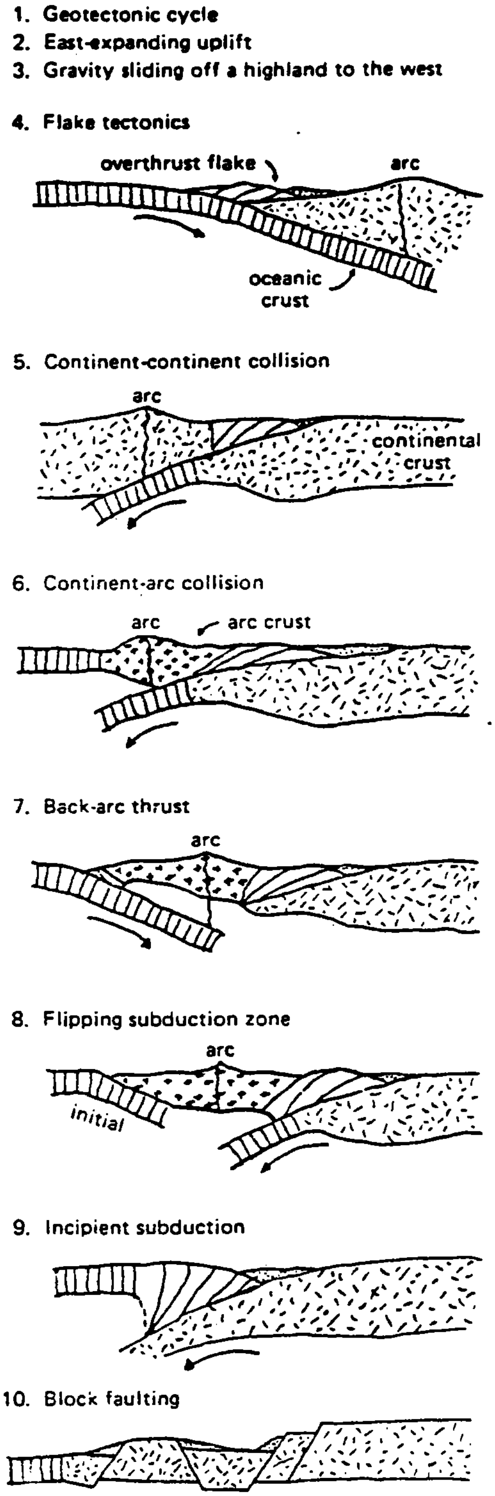
1. Geotectonic cycle
2. East-expanding uplift
3. Gravity sliding off a highland to the west
4. Flake tectonics
5. Continent-continent collision
6. Continent-arc collision
7. Back-arc thrust
8. Flipping subduction zone
9. Incipient subduction
10. Block faulting

Figure 1. Possible tectonic models of Antler and equivalent mid-Paleozoic orogenies.

were nudged along by its advance into the east-retreating depositional trough.

H. Gabrielse concluded that models based on the geology of Nevada did not explain very well the Antler events in western Canada, where compressional or thrusting features are not evident. He presented for western Canada the rifted fault-block model developed by D. J. Tempelman-Kluit to explain features such as alkalic volcanic rocks in Mississippian strata, ore mineralization related to faulting, and local derivation of chert-pebble conglomerate.

G. A. Davis and B. C. Burchfiel proposed a new model, developed during the meeting, in which limited subduction along a shallow westward-dipping subduction zone in the western United States changed to a steep eastward-dipping subduction zone in Canada, where the strontium-isotope–determined western edge of North America protrudes westward. By their model, the early Paleozoic arc of southwestern Canada that caused volcanism, plutonism, and metamorphism was subsequently rifted away and collided with Nevada during the Triassic to produce the Sonoma orogeny.

W. R. Dickinson, in a discussion of possible modern analogues to the Antler orogeny, noted the requirements of tectonic transport of a thrust sheet onto the continent and deposition of a clastic wedge transported eastward onto the continent. Six analogous modern examples were cited: the Apennines, Timor, Taiwan, north coast of New Guinea, Indo-Burman ranges, and the Mediterranean ridge.

FUTURE STUDIES

Several major problems concerning the Antler orogeny were outlined for future research: (1) the origin of the lower and middle Paleozoic "eugeosynclinal" cherts and quartz-rich clastic rocks of Nevada—if they are deep-marine deposits, a more complex mechanism of tectonic emplacement of the allochthon from the ocean basin to the shelf may be required; (2) an explanation for the deposition of nonmarine, shallow-marine, and deep-marine chert-pebble conglomerate throughout all parts of western North America affected by mid-Paleozoic deformation, despite the fact that the deformation clearly involved different plate-tectonics settings; (3) the sources and reasons for deposition of carbonate turbidites in various parts of the Antler foreland basin; (4) the relation between patterns of mid-Paleozoic subsidence and uplift on the miogeosyncline and western part of the craton to the Antler orogeny; (5) the timing of orogeny and clastic-wedge sedimentation, which appears at present to indicate a clearly defined southward younging of Antler events; (6) determination of the southern and northern margins or extensions of the Antler orogeny—whether Antler events extend into Mexico, the Ouachita geosyncline, and the Canadian Arctic Islands to the Caledonian or Uralian geosynclines; (7) the nature of Ordovician deformation needs to be clarified—whether events of this age in the Klamath Mountains, southern Canada, and the Brooks Range indicate the influence of the Taconic orogeny in western North America; (8) the geochemistry and petrogenesis of the plutons characteristic of mid-Paleozoic orogeny in the Canadian Arctic Islands, northern Yukon, Brooks Range, and southern Canada, need to be defined; (9) the geology of Alaska and the origin of the Canada basin need to be better resolved to understand evolution and spatial relations of the northern part of the Antler belt; (10) the proposed modern analogues, particularly their structural and sedimentary evolution, need to be better understood before they can be accepted as analogues for the Antler orogeny.

Participants in the Penrose Conference

T. H. Anderson
A. K. Armstrong
G. C. Bond
E. R. Brooks
B. C. Burchfiel
M. P. Cecile
C. K. Chamberlain
M. Churkin, Jr.
R. R. Coats
P. J. Coney
G. A. Davis
W. R. Dickinson
J. T. Dillon
R. H. Dott, Jr.
J. T. Dutro, Jr.
H. Gabrielse
S. P. Gordey
J. L. Hannah
L. V. Hills
L. F. Hintze
R. K. Hose
K. B. Ketner
P. B. King
S. W. Laule
E. L. Miller
T. H. Nilsen
A. V. Okulitch
J. S. Oldow
A. H. Pekarek
F. G. Poole
J. Riva
R. J. Roberts
W. J. Roberts
A. Saller
C. A. Sandberg
R. A. Schweickert
B.A.L. Skipp
J. F. Smith, Jr.
W. S. Snyder
R. C. Speed
L. A. Standlee
C. H. Stevens
J. H. Stewart
C. A. Suczek
A. G. Sylvester
J. Tingley
H. P. Trettin
R. J. Varga
M. J. Welland
D. H. Whitebread
C. T. Wrucke