Contractional nature of Devonian-Mississippian Antler tectonism along the North American continental margin

Moira T. Smith
Geological Survey Branch, British Columbia Ministry of Energy, Mines, and Petroleum Resources
553 Superior Street, Victoria, British Columbia V8V 1X4, Canada
William R. Dickinson
George E. Gehrels
Department of Geosciences, University of Arizona, Tucson, Arizona 85721

ABSTRACT

Regional tectonic analysis suggests that the entire Cordilleran continental margin, from Nevada to the Yukon, underwent contractional orogeny involving emplacement of deep basinal, submarine-fan, and mafic volcanic strata over autochthonous continental margin strata during Late Devonian to Mississippian time (Antler orogeny). Displaced parautochthonous strata are present from Nevada to east-central British Columbia, and perhaps within the Yukon-Tanana terrane of Yukon and eastern Alaska. Manifestations of the orogenic event in the northern Cordillera are preserved primarily by normal faults and related coarse clastic strata of the Selwyn basin. We propose that these features formed due to flexural extension during foreland deformation, rather than mid-Paleozoic rifting or transtension.

INTRODUCTION

An orogenic event of Devonian to Mississippian age involving emplacement of deep-water sedimentary and volcanic rocks over miogeoclinal strata in Nevada is termed the Antler orogeny (e.g., Silberling and Roberts, 1962). It is interpreted as an episode of contractional deformation involving interaction of an offshore island arc with the continental margin (e.g., Speed and Sleep, 1982; Burchfiel and Royden, 1991). This event terminated early Paleozoic miogeoclinal sedimentation with an influx of coarse clastic foreland basin sediments derived from the overthrust allochthon (Dickinson et al., 1983). Similar relations are apparent in central Idaho (Roberts and Thomasson, 1964) and perhaps in the Kootenay arc, where pre-Mississippian contractional deformation is recognized (Read and Wheeler, 1976). White (1959) inferred a contractional Cariboo orogeny in the Cariboo Mountains on the basis of differing relative degrees of deformation in upper and lower Paleozoic rocks, but Struik (1981) found no evidence for this. Mid-Paleozoic tectonism in the northern Cordillera is recorded by thick accumulations of coarse clastic strata over shelf, basinal, and miogeoclinal strata in the Selwyn basin, Nation River, and Mackenzie Delta areas (Pugh, 1983; Nilsen et al., 1976; Gordey et al., 1987). Formerly thought to be derived from an unknown western source (Gabrielse, 1967), these deposits have more recently been interpreted as extensional basin deposits related to rifting or transtension (Gordey et al., 1987; Turner et al., 1989). Gordey et al. (1987) extended this interpretation to rocks as far south as the Cariboo Mountains, and suggested it as a possible model for deformation in Nevada. Eisbacher (1983) offered the alternative that mid-Paleozoic extension in northern Canada and contraction in Nevada were linked by a sinistral transtensional fault system.

Recognition of widespread extensional structures (including high-angle normal faults) within foreland basins (Houseknecht, 1986; Bradley and Kidd, 1991) suggests by analogy that extensional structures in the northern Cordillera might have formed by flexural extension in the foreland of a contractional orogen. Here we review evidence of mid-Paleozoic tectonism from six areas along the continental margin (see Fig. 1).

CENTRAL NEVADA

In central Nevada the Roberts Mountains allochthon consists of several imbricated thrust wedges of disrupted and locally slightly metamorphosed Middle Cambrian to Upper Devonian quartzo-feldspathic and orthoquartzitic turbidites, chert and argillite, limestone, mafic volcanic rocks, and locally lowermost Mississippian strata (Johnson and Pendergast, 1981) that are in low-angle thrust contact with underlying miogeoclinal strata ranging from latest Precambrian to Late Devonian in age. An overlap assemblage of conglomerate and limestone of Pennsylvanian to Permian age (Silberling and Roberts, 1962) and locally Late Mississippian (Little, 1986) age, unconformably overlies the allochthon. A wedge, thickening and coarsening westward, of foreland basin strata was deposited over miogeoclinal strata in advance of the allochthon (Poole and Sandberg, 1977; Harbaugh and Dickinson, 1981). Deltaic deposits prograded eastward over turbidites. The age range of the foreland basin deposits and the migration of a carbonate-capped flexural forebulge across the foreland region imply allochthon emplacement from Late Devonian (mid-Frasnian) to Early Mississippian (mid-Osagean) time (Johnson and Pendergast, 1981; Goebel, 1991).

IDAHO

Tectonic elements correlative with the Roberts Mountains allochthon and associated foreland basin deposits in Nevada are also present in the Pioneer Mountains of central Idaho (Nilsen, 1977; Wust and Link, 1988). Deformed Ordovician to Devonian argillite, siltstone, and chert with minor sandstone, dolostone, and limestone that form the upper plate of the Pioneer thrust fault are analogous to the allochthon. Mississippian turbidites of the Copper Basin Formation that lie beneath the Pioneer thrust were deposited in the Antler foreland basin. The Pennsylvanian to Permian Wood River Formation, consisting of sandstone, calcareous siltstone, and lime-

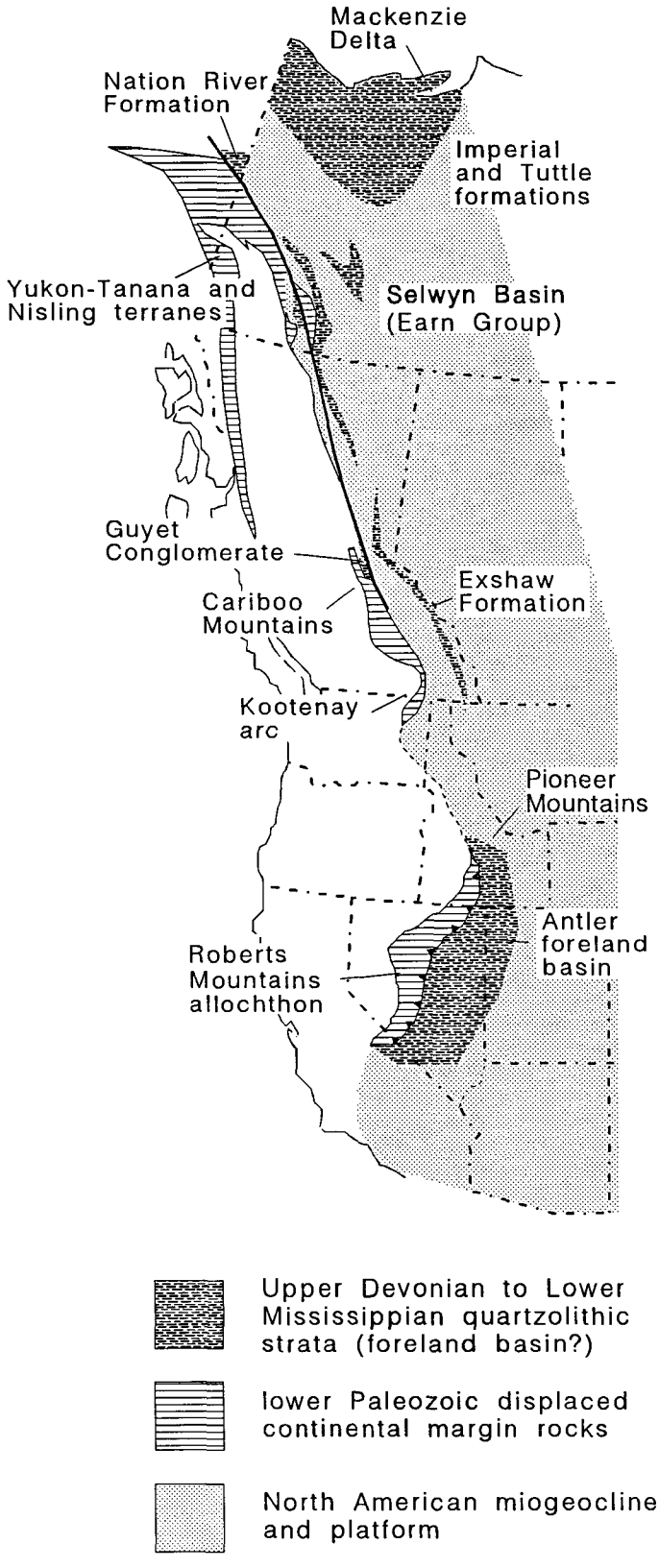

Figure 1. Simplified tectonic map of North American Cordillera, showing locations of important lower and middle Paleozoic stratigraphic, plutonic, and structural elements. Compiled from sources cited in text.

stone with a basal chert-pebble conglomerate, is analogous to the Antler overlap assemblage.

KOOTENAY ARC

In northeastern Washington (Fig. 1) eugeoclinal strata as young as Upper Devonian (e.g., Mills, 1985), including quartzo-feldspathic turbidites, chert, orthoquartzite, shale, limestone, and mafic volcanic rocks, are faulted against Neoproterozoic to Middle Ordovician miogeoclinal strata. In southeastern British Columbia, correlative early Paleozoic eugeoclinal strata of the Lardeau Group are in fault contact (Smith and Gehrels, 1992) with Neoproterozoic to Lower Cambrian miogeoclinal strata. The Lardeau Group is overlain unconformably by the Lower Mississippian Milford Group. Evidence for pre-Milford contractional deformation includes foliated Lardeau Group clasts in the basal Milford conglomerate, and folds, thrust faults, and foliation surfaces that are truncated by or absent in the Milford Group (e.g., Read and Wheeler, 1976; Klepacki, 1985). A Devonian-Mississippian age of deformation may be indicated by the presence of nearby orthogneiss bodies of Late Devonian age (Okulitch et al., 1975) and the Late Devonian age of eugeoclinal strata in the southern Kootenay arc. Middle to Upper Devonian strata locally present to the east in the Purcell Mountains include limestone, dolomite, conglomerate, and volcanic rocks interpreted as foreland basin deposits by K. Root (1992, personal commun.). The Devonian-Mississippian Exshaw Formation in the adjacent Rocky Mountains may represent the eroded distal parts of a foreland basin. It records restricted, anoxic conditions (Savoy, 1988), and contains a ca. 365 Ma (U-Pb) tuff layer (G. Ross, 1992, personal commun.), suggesting the presence of a landmass and orogenic activity to the west.

CARIBOO MOUNTAINS

Lower Paleozoic strata correlative with the Lardeau Group include the upper Snowshoe Group of the Barkerville terrane, composed of quartzo-feldspathic sandstone, orthoquartzite, limestone, shale, siltstone, and basalt (Struik, 1986). This assemblage is overlain with apparent unconformity by the less deformed Permian Sugar Limestone, suggesting "The possibility of . . . pre-Permian metamorphism" (Struik, 1986, p. 1054). The Snowshoe Group and Sugar Limestone are in fault contact to the east with the Cariboo terrane, which consists of parautochthonous, distal miogeoclinal deposits. Upper Devonian to Lower Mississippian strata in this sequence include the Guyet conglomerate, which contains clasts of quartz, quartzite, chert, and lesser limestone, basalt, and pelite, and interbedded volcanic rocks (Sutherland Brown, 1963). The Guyet sequence may be a foreland basin deposit shed off an orogenic highland to the west (Campbell et al., 1973), although Struik (1986) considered it to be fill associated with rift basins. Struik (1986) interpreted the nearby Exshaw Formation in the Rocky Mountains as the distal equivalent of the Guyet conglomerate and part of a graben-edge uplift sequence. Evidence of plutonic activity in the surrounding region includes Late Devonian or Early Mississippian orthogneiss (Mortensen et al., 1987).

SELWYN BASIN

In the Selwyn basin (Fig. 1) lower Paleozoic basinal strata, including the Ordovician to Silurian Road River Group (chert, argillite, and volcanic rocks) and the Devonian-Mississippian Earn Group, conformably overlie miogeoclinal strata and grade eastward into shelf facies (Gordey et al., 1987). The Earn Group consists of chert-rich sandstone and conglomerate, alkalic volcanic rocks, chert, shale, and stratiform barite. Coarse clastic strata were originally interpreted, on the basis of paleocurrent indicators, to have been derived from an unknown western landmass (Gabrielse, 1967).

Gordey et al. (1987) later interpreted the strata to represent fill in extensional basins caused by rifting or transtensional faulting. This argument was based on (1) lack of contractional structures, (2) presence of syndepositional normal faults controlling sedimentation, (3) volcanic rocks with a chemistry consistent with rift origin, (4) stratiform barite deposits interpreted to be related to rifting, and (5) inferred derivation of recycled sedimentary detritus from an uplifted outer segment of the miogeoclinal prism.

NATION RIVER AND MACKENZIE DELTA

Coarse clastic strata of the Devonian and Mississippian Nation River, Imperial, and Tuttle formations overlie Neoproterozoic to Middle Devonian platform, basinal, and miogeoclinal strata over a large area of northwestern Yukon, the District of Mackenzie, and east-central Alaska. The Upper Devonian Nation River Formation consists of submarine fan turbidites, including shale, siltstone, chert-quartz arenite, and rare conglomerate (Nilsen et al., 1976). Paleocurrent data indicate derivation from the west (in present-day coordinates) (Howell and Wiley, 1987). The time-transgressive Imperial Formation is a coarser, proximal-fan equivalent that ranges in age from mid-Famennian in the north to Early Mississippian in the south, and is overlain by fluviodeltaic(?) coarse clastic strata of the Lower Mississippian Tuttle Formation (Pugh, 1983). These units form a succession typical of foreland basin sedimentation, although Howell and Wiley (1987) related their present position to Mesozoic tectonic rotation of the Brooks Range.

DISCUSSION

Relations described above in Nevada, Idaho, the Kootenay arc, and the Nation River and Mackenzie delta areas are consistent with a model of contractional deformation of Devonian-Mississippian age. The intervening Cariboo Mountains and Selwyn basin areas were originally interpreted as areas of or related to contractional orogeny, then reinterpreted as sites of extension related to rifting or transtension. Without discounting evidence for localized extension in either area, we suggest that strata of Devonian-Mississippian age in both areas can be regarded as foreland basin deposits, and that the generally accepted contractional model of deformation for the Antler orogeny may be applicable to the entire Cordilleran margin.

In the Cariboo Mountains the Guyet conglomerate may represent a proximal foreland basin assemblage, as originally proposed by Campbell et al. (1973). A local post-Devonian, pre-Permian unconformity, nearby Late Devonian age orthogneiss, and evidence for pre–mid-Mississippian contraction in the nearby Kootenay arc all suggest that Devonian-Mississippian tectonism in the Cariboo Mountains may have been contractional. In our view, the Snowshoe Group may be part of the thrust allochthon, the Sugar Limestone is probably the overlap sequence, and the Guyet Conglomerate and Exshaw Formation are proximal and distal foreland deposits.

In the Selwyn basin, high-angle syndepositional normal faults, stratiform barite and polymetallic sulfides, alkalic volcanic rocks, absence of contractional structures, and the interpretation of local derivation of sediments are inferred to support a rift hypothesis. Recent emphasis on the presence of syndepositional, orogen-parallel normal faults in foreland basins (e.g., Houseknecht, 1986; Bradley and Kidd, 1991) indicates, however, that extensional features related to flexural deformation are locally common in foreland regions. In the Arkoma foreland of the Ouachita orogen, for example, abrupt facies changes and nearly 2000 m of cumulative syndepositional throw on numerous high-angle normal faults are observed (Houseknecht, 1986). Mississippi Valley–type barite-Pb-Zn deposits may be related to expulsion of deep basinal brines along these faults during formation of the Ouachita fold belt (Leach and Rowan, 1986).

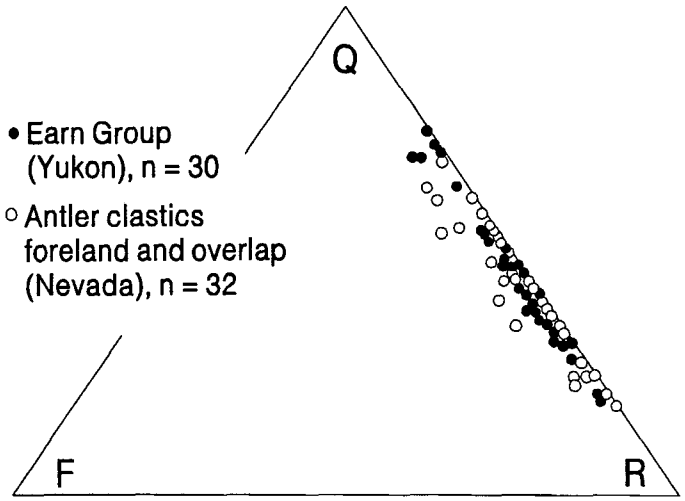

Figure 2. Comparative QFR framework modes of Devonian-Mississippian quartzolithic sandstone (litharenite) from northern and southern Cordillera. Solid circles are Earn Group, Pelly Mountains, Selwyn basin, Yukon (Gordey, 1981); open circles are combined Antler foreland succession and overlap sequence, Nevada (Dickinson et al., 1983). Q = quartz grains; F = feldspar grains; R = total lithic fragments (including chert).

In the Selwyn basin, one of the largest stratiform Zn-Pb-barite deposits, the Silurian Howards Pass deposit, is not clearly related to any extensional episode, and the source of mineralizing fluids, as well as that for many Devonian-Mississippian deposits in the area, is inferred to be the underlying "Hadrynian grit" unit (e.g., Goodfellow and Jonasson, 1986).

Compositionally, Earn Group litharenites of the Selwyn basin match closely Antler foreland sandstones in Nevada (Fig. 2). Both suites are composed dominantly of quartz, chert, and argillite grains. Gordey et al. (1987) inferred sources in miogeoclinal strata uplifted locally by rift tectonism. In Nevada, however, the petrology of foreland basin sandstones is accounted for by the abundance of quartzose turbidites and associated chert-argillite successions in the Roberts Mountains allochthon source. In a global view, moreover, voluminous quartzolithic sandstone suites are most characteristic of foreland basins receiving recycled detritus from thrust belts (Dickinson and Suczek, 1979).

It has been implied (e.g., Gordey et al., 1987) that no obvious candidate for a western mid-Paleozoic allochthon is known within the northern Cordillera, and thus that the foreland basin model is untestable. However, rocks of the same approximate age and composition as the Roberts Mountains allochthon and Kootenay terrane compose much of the Yukon-Tanana terrane, which lay adjacent to and west of the Selwyn basin prior to Tintina fault movement. The Yukon-Tanana terrane contains abundant lower Paleozoic continental margin strata, as well as Devonian to Mississippian felsic orthogneiss and metavolcanic rocks interpreted to represent a continental magmatic arc (Mortensen, 1992). Rubin et al. (1991) suggested that this mid-Paleozoic arc system extended the length of the Cordilleran margin. Although the Paleozoic geographic position of the Yukon-Tanana terrane is suspect, detrital zircon and inheritance ages (e.g., Mortensen, 1992) are consistent with a northern North American source. Thus we propose that the Yukon-Tanana and related terranes may represent the "missing" allochthon and source for the Earn Group.

In summary, we propose that the contractional Antler orogeny may be valid as a model for Devonian-Mississippian tectonism from Nevada to the Yukon and east-central Alaska, and we suggest that

the Earn Group and related strata in the northern Cordillera are deposits of a foreland basin affected by flexural extension. This hypothesis allows a single (contractional) model of Antler deformation to apply to the entire length of the Cordillera.

ACKNOWLEDGMENTS

Supported by National Science Foundation grant EAR-8715773 to Gehrels, and by the Geological Society of America, Sigma Xi, and the Washington Division of Geology and Earth Resources. We thank Meghan Miller and David Howell for constructive reviews.

REFERENCES CITED

Bradley, D.C., and Kidd, W.S.F., 1991, Flexural extension of the upper continental crust in collisional foredeeps: Geological Society of America Bulletin, v. 103, p. 1416–1438.

Burchfiel, B.C., and Royden, L.H., 1991, Antler orogeny, a Mediterranean-type orogeny: Geology, v. 19, p. 66–69.

Campbell, R.B., Mountjoy, E.W., and Young, F.G., 1973, Geology of the McBride map area, British Columbia: Geological Survey of Canada Paper 72-35, 104 p.

Dickinson, W.R., and Suczek, C.A., 1979, Plate tectonics and sandstone compositions: American Association of Petroleum Geologists Bulletin, v. 63, p. 2164–2182.

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

Eisbacher, G.H., 1983, Devonian-Mississippian sinistral transcurrent faulting along the cratonic margin of western North America: A hypothesis: Geology, v. 11, p. 7–10.

Gabrielse, H., 1967, Tectonic evolution of the northern Canadian Cordillera: Canadian Journal of Earth Sciences, v. 4, p. 271–298.

Goebel, K.A., 1991, Paleogeographic setting of Late Devonian to Early Mississippian transition from passive to collisional margin, Antler foreland, eastern Nevada and western Utah, *in* Cooper, J.D., and Stevens, C.H., eds., Paleozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 401–418.

Goodfellow, W.D., and Jonasson, I.R., 1986, Environment of formation of the Howards pass (XY) Zn-Pb deposit, Selwyn basin, Yukon, *in* Morin, J., ed., Mineral deposits of the northern Cordillera: Canadian Institute of Mining and Metallurgy Special Volume 37, p. 19–50.

Gordey, S.P., 1981, Stratigraphy, structure, and tectonic evolution of the southern Pelly Mountains in the Indigo Lake area, Yukon Territory: Geological Survey of Canada Bulletin 318, 44 p.

Gordey, S.P., Abbott, J.G., Tempelman-Kluit, D.J., and Gabrielse, H., 1987, "Antler" clastics in the Canadian Cordillera: Geology, v. 15, p. 103–107.

Harbaugh, D.W., and Dickinson, W.R., 1981, Depositional facies of Mississippian clastics, Antler foreland basin, central Diamond Mountains, Nevada: Journal of Sedimentary Petrology, v. 51, p. 1223–1234.

Houseknecht, D.W., 1986, Evolution from passive margin to foreland basin: The Atoka Formation of the Arkoma basin, south-central U.S.A., *in* Allen, P.A., and Homewood, P., eds., Foreland basins: International Association of Sedimentologists Special Publication 8, p. 327–345.

Howell, D.G., and Wiley, T.J., 1987, Crustal evolution of northern Alaska inferred from sedimentology and structural relations of the Kandik area: Tectonics, v. 6, p. 619–631.

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.

Klepacki, D.W., 1985, Stratigraphy and structural geology of the Goat Range area, southeastern British Columbia [Ph.D. thesis]: Cambridge, Massachusetts Institute of Technology, 268 p.

Leach, D.L., and Rowan, E.L., 1986, Genetic link between Ouachita fold-belt tectonism and the Mississippi Valley–type lead-zinc deposits of the Ozarks: Geology, v. 14, p. 931–935.

Little, T.A., 1986, Stratigraphy and structure of metamorphosed upper Paleozoic rocks near Mountain City, Nevada: Geological Society of America Bulletin, v. 98, p. 1–17.

Mills, J.W., 1985, Geology of the Kettle Falls, Marcus, Colville, and Echo Valley quadrangles, northeast Washington: Washington Division of Geology and Earth Resources Open-File Report 85-4, 9 p.

Mortensen, J.K., 1992, Pre–mid-Mesozoic tectonic evolution of the Yukon-Tanana terrane, Yukon and Alaska: Tectonics.

Mortensen, J.K., Montgomery, J.R., and Fillipone, J., 1987, U-Pb zircon, monazite, and sphene ages for granitic orthogneiss of the Barkerville terrane, east-central British Columbia: Canadian Journal of Earth Sciences, v. 24, p. 1261–1269.

Nilsen, T.H., 1977, Paleogeography of Mississippian turbidites in south-central Idaho, *in* Stewart, J.H., et al., eds., Paleozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 1, p. 275–300.

Nilsen, T.H., Brabb, E.E., and Simoni, T.R., Jr., 1976, Stratigraphy and sedimentology of the Nation River Formation, a Devonian deep-sea fan deposit in east-central Alaska, *in* Miller, T.P., ed., Recent and ancient sedimentary environments in Alaska: Anchorage, Alaska Geological Society, p. E1–E20.

Okulitch, A.V., Wanless, R.K., and Loveridge, W.D., 1975, Devonian plutonism in south-central British Columbia: Canadian Journal of Earth Sciences, v. 12, p. 1760–1769.

Poole, F.G., and Sandberg, C.A., 1977, Mississippian paleogeography and tectonics of the western United States, *in* Stewart, J.H., et al., eds., Paleozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 1, p. 67–86.

Pugh, D.C., 1983, Pre-Mesozoic geology in the subsurface of the Peel River map area, Yukon Territory and District of Mackenzie: Geological Survey of Canada Memoir 401, 62 p.

Read, P.B., and Wheeler, J.O., 1976, Geology, Lardeau west half, British Columbia: Geological Survey of Canada Open-File Map 432, scale 1:125,000.

Roberts, R.J., and Thomasson, M.R., 1964, Comparison of late Paleozoic depositional history of northern Nevada and central Idaho: U.S. Geological Survey Professional Paper 475-D, p. D1–D6.

Rubin, C.M., Miller, M.M., and Smith, G.M., 1991, Tectonic development of Cordilleran middle Paleozoic volcano-plutonic complexes: Evidence for convergent margin tectonism, *in* Harwood, D.S., and Miller, M.M., eds., Paleozoic and early Mesozoic paleogeographic relations of the Sierra Nevada, Klamath Mountains, and related terranes: Geological Society of America Special Paper 255, p. 1–16.

Savoy, L.E., 1988, Stratigraphy of Devono-Mississippian oxic-anoxic facies transitions, Cordilleran fold and thrust belt, southeastern British Columbia and adjacent Montana: Geological Society of America Abstracts with Programs, v. 20, no. 7, p. 122.

Silberling, N.J., and Roberts, R.J., 1962, Pre-Tertiary stratigraphy and structure of northwestern Nevada: Geological Society of America Special Paper 72, 53 p.

Smith, M.T., and Gehrels, G.E., 1992, Structural geology of the Lardeau Group near Trout Lake, southeastern British Columbia: Canadian Journal of Earth Sciences, v. 29.

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

Struik, L.C., 1981, A reexamination of the type area of the Devono-Mississippian Cariboo orogeny, central British Columbia: Canadian Journal of Earth Sciences, v. 18, p. 1767–1775.

Struik, L.C., 1986, Imbricated terranes of the Cariboo gold belt with correlations and implications for tectonics in southeastern British Columbia: Canadian Journal of Earth Sciences, v. 23, p. 1047–1061.

Sutherland Brown, A., 1963, Geology of the Cariboo River area, British Columbia: British Columbia Department of Mines and Petroleum Resources Bulletin 47, 60 p.

Turner, R.J.W., Madrid, R.J., and Miller, E.L., 1989, Roberts Mountains allochthon: Stratigraphic comparison with lower Paleozoic outer continental margin strata of the northern Canadian Cordillera: Geology, v. 17, p. 341–344.

White, W.H., 1959, Cordilleran tectonics in British Columbia: American Association of Petroleum Geologists Bulletin, v. 43, p. 60–100.

Wust, S.L., and Link, P.K., 1988, Geology of the Pioneer Mountains core complex, south-central Idaho: Northwest Geology, v. 16, p. 85–94.

Manuscript received April 13, 1992
Revised manuscript received September 29, 1992
Manuscript accepted October 13, 1992