Klamath–Blue Mountain lineament, Oregon

Robin Riddihough*
College of Oceanography, Oregon State University, Corvallis, Oregon 97331
Carol Finn
U.S. Geological Survey, MS 964, Denver Federal Center, Denver, Colorado 80225
Richard Couch
College of Oceanography, Oregon State University, Corvallis, Oregon 97331

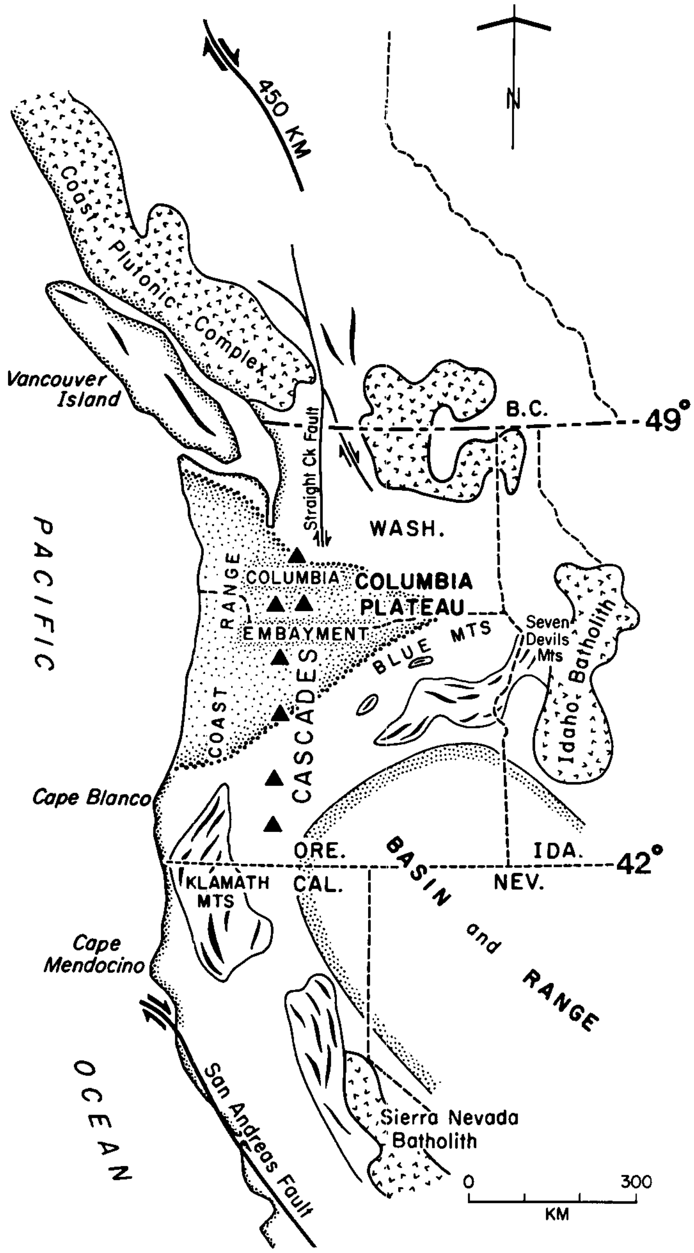

Figure 1. Location and tectonic map of Pacific Northwest (modified from Wilson and Cox, 1980). Tectonic grain marked by trend lines in Klamath Mountains and elsewhere.

ABSTRACT

Regional gravity data clearly show a zone of southwest-northeast lineations across Oregon that defines a major crustal lineament. Its existence is supported by geologic and geophysical data. Its correlation with the northwestern boundaries of the Klamath and Blue Mountain provinces suggests that these are continuous beneath the Cascade volcanic arc. The lineament may represent a pre-Tertiary strike-slip continental margin which, from paleomagnetic evidence, later rotated clockwise into its present position.

INTRODUCTION

One of the major tectonic elements of the Pacific Northwest is the "Columbia embayment" (Fig. 1). First proposed in the "orocline" concept of Carey (1958), it was developed further by Hamilton and Myers (1966), who suggested that northwestern Oregon and southwestern Washington were built upon post-Mesozoic ocean crust. The boundaries of the embayment thus represented preexisting continental margins. Hamilton and Myers considered that preliminary paleomagnetic evidence for rotations (Irving, 1964; Watkins, 1965) supported Carey's concept. Hamilton (1969) further proposed that the arcuate shape was produced by a westward bend of the previously continuous continental margin as the result of Basin and Range extension. The bending process required extension between the Blue Mountain, Klamath, and Sierra Nevada blocks. The concept of the embayment has subsequently been supported by several lines of evidence and is now widely accepted (e.g., Dickinson, 1976; Davis et al., 1978).

Geologically, the nature of the southeastern flank of the embayment is dependent upon continuity between the pre-Tertiary and Mesozoic accreted rocks of the Klamath and Blue Mountain regions. Peck et al. (1964) considered that these rocks were continuous beneath the younger Cascade volcanics and identified northeast-trending structures in the Eocene rocks which reflected this structural grain.

Skeehan (1965) and Taubeneck (1966, 1967) identified the Blue Mountain Front as a line of contrast between oceanic crustal basement (to the northwest) and continental crustal basement (to the southeast). Close correlation between the late Paleozoic and Mesozoic rocks of the Klamath and Blue mountains is now accepted (e.g., Davis et al., 1978; Heitanen, 1981), although detailed interpretation of their accretionary history is actively debated (e.g., Saleeby, 1983; Davis et al., 1978; Beck, 1980; Frei et al., 1984). The continuity of these rocks beneath the southern Cascades and part of the Columbia Plateau basalts remains unproven. As noted above, the reconstruction of Hamilton (1969) requires that they are rifted apart and not connected.

The northeastern margin of the embayment (coinciding with the Olympic-Wallowa geomorphic lineament of Raisz, 1945) is neither a striking regional gravity nor magnetic feature. By contrast, the southeastern flank coincides with a zone of gravity lineations (Fig. 2) which we

*Present address: Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, Ontario, Canada K1A 0Y3.

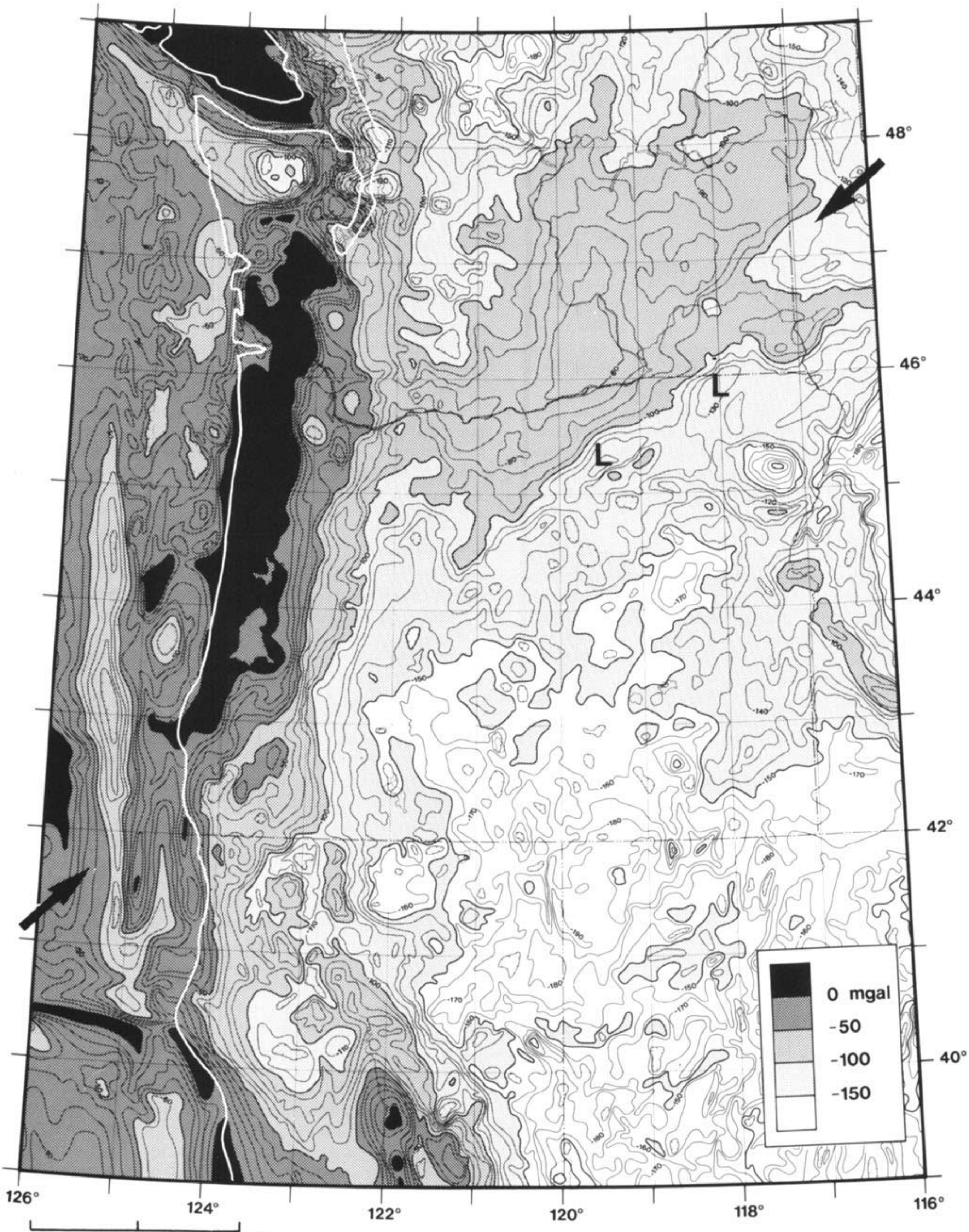

Figure 2. Bouguer gravity anomaly map of Pacific Northwest. Data from Finn et al. (1984) and Riddihough (1982). Arrows indicate KB (Klamath-Blue Mountain lineament); L marks local anomalies referred to in text.

believe marks a fundamental crustal lineament. We refer to this lineament as the Klamath–Blue Mountain lineament (KB). Geographically, it coincides with the northwestern margins of both the Klamath and Blue Mountain structural and geologic provinces.

GRAVITY EXPRESSION

A major feature of the Bouguer gravity anomaly field of the Pacific Northwest (Fig. 2) is the north-south "high" that corresponds to the Oregon-Washington Coast Range (Bromery and Snavely, 1964; Dehlinger et al., 1968; Riddihough, 1979). Eastward, a north-south "low" coincides with the Cascade Mountains (Couch et al., 1982; Finn and Williams, 1983; Finn et al., 1984). East of this "low," the two principal regional features are a broad gravity "high" occupying the center of the Columbia Plateau basalt province and a series of deep "lows" in southeastern Oregon corresponding to the northern part of the Basin and Range province (Eaton et al., 1978). Forming a boundary for all the features except the "low" associated with the Cascade Mountains is a 700-km-long, northeast-trending zone of discontinuity (about 50 km wide) that we interpret as marking the KB (see arrows, Fig. 2).

For much of its length, the zone is a linear gravity gradient of 40–60 mgal down to the southeast. It provides a striking termination to the south end of the Coast Range gravity "high" and extends at least 50 km onto the continental shelf south of Cape Blanco. Although the north-south Cascade Mountain "low" is continuous across the gradient, there are indications that the gradient itself is continuous across the "low," and this suggests the superposition of two separate features.

The gravity expression of part of the KB was first noted by Blank (1966), who felt that data in southwestern Oregon supported the contention of Peck et al. (1964) that the Klamath "upwarp" continued northeastward into central Oregon. Thiruvathukal (1968) noted a series of northeast-trending gravity features and concurred. However, Thiruvathukal et al. (1970) concluded that "no obvious regional gravity trends connect the two [Klamath and Blue Mountain] provinces."

Eaton et al. (1978; see their Fig. 3-1) considered that the gravity lineation marked part of the northwestern boundary of the Basin and Range province. They noted that it separated areas of markedly different average elevation and that it coincided with the crustal boundary of Hamilton and Myers (1966). Recent filtered Bouguer gravity anomaly maps (Hildenbrand et al., 1982) clearly show the lineation for wavelengths greater than 250 km, and it is also traceable on the residual maps for wavelengths less than 250 and 1000 km. The feature is also evident on the isostatic gravity maps of Simpson et al. (1983).

GEOPHYSICAL INTERPRETATIONS

Thiruvathukal (1968) interpreted the Bouguer gravity anomaly gradient that coincides with the KB east of the Cascades as representing an increase in crustal thickness from 35–40 km in the northwest to 40–45 km in the southeast. Cady (1980) and Cady and Fox (1984) modeled a north-south section across the KB and noted that, depending upon the density assumed for the Columbia Plateau Basalt Group, the gravity gradient could be entirely explained by either a north-south change of mantle depths from 27 to 35 km or from 31 to 35 km. However, Thiruvathukal et al. (1970), Eaton et al. (1978), and Veen (1982) concluded that the lower Bouguer gravity anomaly values of southeastern Oregon could also be explained either by thin crust underlain by mantle of reduced density or a regional compositional contrast related to Basin and Range magmatic invasion and metamorphism. Eaton et al. (1978) computed maximum depths to the causative bodies of the gravity gradient and concluded that they lay within the crust (14 ±5 km). Features along the KB such as L in Figure 2 are indeed probably of shallow origin; Thiruvathukal (1968) suggested that they were due to depressions in the pre-Tertiary basement containing low-density sediments beneath the surface Eocene volcanics.

West of the Cascades, crustal thicknesses have been estimated from gravity data as around 20 km beneath the Coast Range north of the KB (Dehlinger et al., 1968; Couch and Braman, 1979; Riddihough, 1979) and 32–35 km beneath the Klamath Mountains (Griscom, 1980; Couch, 1980).

The electrical sounding and resistivity interpretations of Cantwell and Orange (1965) indicated a region between northern Washington and southern Oregon where the lack of resistive basement might be explicable by underlying basaltic oceanic crust. A marked change in seismic P_n arrival times was observed by Hill (1972) at the northern edge of the Blue Mountains and interpreted as either a contrast in crustal thickness or composition. The profile of Leaver et al. (1984) along the axis of the Oregon Cascades and across the KB showed a fairly uniform seismic velocity structure with deepening depth to mantle (40–48 km) to the south. Recent seismic refraction data (Catchings et al., 1984) has been interpreted as showing crustal velocities at depths of as much as 40 km beneath the Columbia Plateau. This may imply either a reduced contrast in crustal thickness across the KB or the existence of anomalous upper mantle beneath the plateau.

Gravity, seismic, and other geophysical interpretations, where they have been applied, all seem to confirm that the KB represents a zone of change, either of crustal thickness or composition or both. It may also mark a discontinuity in the underlying mantle.

IMPLICATIONS

The implications of the existence of the KB for the tectonics of the Pacific Northwest are considerable. It could, of course, be an accidental alignment of unrelated elements. However, if it represents some form of boundary to the pre-Tertiary rocks of the Klamath and Blue mountains, a number of questions arise: Why is it straight? What is the significance of its orientation? Can it be reconciled with the recent reconstructions of the region based on multiple block rotation (e.g., Magill and Cox, 1981; Frei et al., 1984)?

The straightness of the lineament over a length of at least 700 km is suggestive of a zone of major strike-slip faulting. Recent concepts of Cordilleran assembly (e.g., Beck, 1980; Coney et al., 1980; Monger and Irving, 1980; Jones et al., 1982) involve considerable strike-slip motion. Several major fault systems of similar length have been identified in the Cordillera (Davis et al., 1978), generally with a north through northwest orientation.

So far as the orientation of the KB is concerned, paleomagnetic data from both the Klamath Mountains (Schultz and Levi, 1983; Fagin and Gose, 1983) and the Blue Mountains–Seven Devils areas (Wilson and Cox, 1980; Hillhouse et al., 1982) suggest that since Late Jurassic–Early Cretaceous time, neither of these two provinces has moved latitudinally by large amounts (less than 10° lat), but both have been rotated clockwise by at least 60°. It may thus be possible to propose that at the beginning of the Cretaceous, the KB was oriented closer to north-south. The Jurassic accretion and suturing of the arc rocks of the Klamaths and the Blue Mountains (Brooks, 1979) might therefore have taken place along an essentially north-south continental margin, as envisaged by Hamilton (1969).

Irving et al. (1980, 1985) and Beck et al. (1981) have interpreted paleomagnetic data from sites in British Columbia and Washington as showing that some Mesozoic plutons (including the Coast Plutonic Complex) and the terranes with which they are associated (Wrangellia, Stikinia) moved northward "outboard" of the Klamath–Blue Mountains region during the Cretaceous. It thus seems possible that at least for this period, the KB may have formed a dextral strike-slip or obliquely convergent margin to the North American plate, much as the Queen Charlotte–San Andreas fault system does today.

REFERENCES CITED

Beck, M.E., 1980, Paleomagnetic record of plate margin tectonic processes along the western edge of North America: Journal of Geophysical Research, v. 85, p. 7115–7131.

Beck, M.E., Burmeester, R.F., Engebretson, D.C., and Schoonover, R., 1981, Northward translation of Mesozoic batholiths, western North America: Paleomagnetic evidence and tectonic significance: Geofisica International, v. 20-3, p. 143–162.

Blank, H.R., 1966, Geological features of the Bouguer field in southwestern Oregon: U.S. Geological Survey Professional Paper 550, p. C113–C119.

Bromery, R.W., and Snavely, P.D., 1964, Geologic interpretation of reconnaissance gravity and aeromagnetic surveys in northwestern Oregon: U.S. Geological Survey Bulletin 1181-N, p. N1–N13.

Brooks, H.C., 1979, Plate tectonics and the geologic history of the Blue Mountains: Oregon Geology, v. 41, p. 71–80.

Cady, J.W., 1980, Gravity highs and crustal structure, Omineca crystalline belt, northeastern Washington and southeastern British Columbia: Geology, v. 8, p. 328–332.

Cady, J.W., and Fox, K.F., 1984, Geophysical interpretation of the gneiss terrane of northern Washington and southern British Columbia, and its implications for uranium exploration: U.S. Geological Survey Professional Paper 1260, p. 1–29.

Cantwell, T., and Orange, A., 1965, Further resistivity measurements in the Pacific Northwest: Journal of Geophysical Research, v. 70, p. 4068–4072.

Carey, S.W., 1958, A tectonic approach to continental drift, *in* Carey, S.W., convener, Continental drift: A symposium: Hobart, University of Tasmania, Geological Department, p. 177–355.

Catchings, R.D., Mooney, W.D., and Holbrook, W.S., 1984, Crustal structure of southeastern Washington from seismic refraction [abs.]: EOS (American Geophysical Union Transactions), v. 65, p. 988.

Coney, P.J., Jones, D.L., and Monger, J.W.H., 1980, Cordilleran suspect terranes: Nature, v. 288, p. 329–333.

Couch, R.W., 1980, Seismicity and crustal structure near the north end of the San Andreas fault system, *in* Streitz, R., and Sherborne, R., eds., Studies of the San Andreas fault zone in northern California: California Division of Mines and Geology Special Report 140, p. 139–151.

Couch, R.W., and Braman, D., 1979, Geology of the continental margin near Florence, Oregon: Oregon Geology, v. 41, p. 171–179.

Couch, R.W., Pitts, G.S., Gemperle, M., Braman, D.E., and Veen, C.A., 1982, Gravity anomalies in the Cascade Range in Oregon: Structural and thermal implications: Oregon Department of Geology and Mineral Industries Open-File Report 0-82-9, 66 p.

Davis, G.A., Monger, J.W.H., and Burchfiel, B.C., 1978, Mesozoic construction of the Cordilleran "collage," central British Columbia to central California, *in* Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Coast Section, Pacific Coast Paleography Symposium 2, p. 1–32.

Dehlinger, P., Couch, R.W., and Gemperle, M., 1968, Continental and oceanic structure from the Oregon coast westward across the Juan de Fuca Ridge: Canadian Journal of Earth Sciences, v. 5, p. 1079–1090.

Dickinson, W.R., 1976, Sedimentary basins developed during the evolution of Mesozoic-Cenozoic arc-trench system in western North America: Canadian Journal of Earth Sciences, v. 13, p. 1268–1287.

Eaton, G.F.P., Wahl, R.R., Pvostka, H.J., Mabey, R.D., and Kleinkopf, M.D., 1978, Regional gravity and tectonic patterns: Their relation to late Cenozoic epeirogeny and lateral spreading in the western Cordillera, *in* Smith, R.B., and Eaton, G.P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 51–92.

Fagin, S.W., and Gose, W.A., 1983, Paleomagnetic data from the Redding section of the eastern Klamath Belt, northern California: Geology, v. 11, p. 505–508.

Finn, Carol, and Williams, D., 1983, Gravity studies in the Cascade Range: Geothermal Resource Council Transactions, v. 7, p. 247–251.

Finn, Carol, Williams, D.L., Couch, R.W., Danes, Z.F., Pitts, G.S., and Phillips, W.M., 1984, Gravity anomaly maps of the Cascade Range, California, the Pacific Northwest, Oregon, Washington and British Columbia: U.S. Geological Survey Geophysical Map Series GP-972, scale 1:2,500,000.

Frei, L.S., Magill, J.R., and Cox, A., 1984, Paleomagnetic results from the central Sierra Nevada: Constraints on reconstructions of the western United States: Tectonics, v. 3, p. 157–177.

Griscom, A., 1980, Klamath Mountains province, *in* Oliver, H.W., ed., Interpretation of the gravity map of California and its continental margin: California Division of Mines and Geology Bulletin 205, p. 34–36.

Hamilton, W., 1969, Mesozoic California and the underflow of Pacific mantle: Geological Society of America Bulletin, v. 80, p. 2409–2430.

Hamilton, W., and Myers, W.B., 1966, Cenozoic tectonics of the western United States: Reviews of Geophysics and Space Physics, v. 4, p. 509–549.

Heitanen, A., 1981, Extension of Sierra Nevada–Klamath suture system into eastern Oregon and western Idaho: U.S. Geological Survey Professional Paper 1116-C, 11 p.

Hildenbrand, T.G., Simpson, R.W., Godson, R.H., and Kane, M.F., 1982, Digital colored residual and regional Bouguer gravity maps of the conterminous United States with cut-off wavelengths of 250 km and 1000 km: U.S. Geological Survey Geophysical Investigations Map GP-953-A, scale 1:1,000,000.

Hill, D.P., 1972, Crustal and upper mantle structure of the Columbia Plateau from long-range seismic refraction measurements: Geological Society of America Bulletin, v. 83, p. 1639–1648.

Hillhouse, J.W., Gromme, C.S., and Vallier, T.L., 1982, Paleomagnetism and Mesozoic tectonics of the Seven Devils volcanic arc in northeastern Oregon: Journal of Geophysical Research, v. 87, p. 3777–3794.

Irving, E., 1964, Paleomagnetism: New York, Wiley.

Irving, E., Monger, J.W.H., and Yole, R.W., 1980, New paleomagnetic evidence for displaced terranes in British Columbia, *in* Strangway, D.W., ed., The continental crust and its mineral deposits: Geological Association of Canada Special Paper 20, p. 441–456.

Irving, E., Woodsworth, G.J., Wynne, P.J., and Morrison, A., 1985, Paleomagnetic evidence for displacement to the north of the Coast Plutonic Complex, British Columbia: Canadian Journal of Earth Sciences, v. 22, p. 584–598.

Jones, D.L., Cox, A., Coney, P., and Beck, M., 1982, The growth of western North America: Scientific American, v. 247, no. 5, p. 70–84.

Leaver, D.S., Mooney, W.P., and Kohler, W.M., 1984, A seismic refraction study of the Oregon Cascades: Journal of Geophysical Research, v. 89, p. 3121–3134.

Magill, J., and Cox, A., 1981, Post-Oligocene tectonic rotation of the Oregon western Cascade Range and the Klamath Mountains: Geology, v. 9, p. 127–131.

Monger, J.W.H., and Irving, E., 1980, Northward displacement of north-central British Columbia: Nature, v. 285, p. 289–294.

Peck, D.L., Griggs, A.B., Schlicker, H.G., Wells, F.G., and Dole, H.M., 1964, Geology of the central and northern parts of the western Cascade Range in Oregon: U.S. Geological Survey Professional Paper 449, p. 1–56.

Raisz, E., 1945, The Olympic-Wallowa lineament: American Journal of Science, v. 243-A, p. 479–485.

Riddihough, R.P., 1979, Gravity and structure of an active margin—British Columbia and Washington: Canadian Journal of Earth Sciences, v. 16, p. 350–363.

——1982, Juan de Fuca plate map: Gravity anomalies: Ottawa, Canada Department of Energy, Mines and Resources, Earth Physics Branch, scale 1:1,000,000.

Saleeby, J.S., 1983, Accretionary tectonics of the North American Cordillera: Annual Reviews of Earth and Planetary Science, v. 11, p. 45–73.

Schultz, K.L., and Levi, S., 1983, Paleomagnetism of Middle Jurassic plutons of the north-central Klamath Mountains: Geological Society of America Abstracts with Programs, v. 15, p. 427.

Simpson, R.W., Saltus, R.W., Jachens, R.C., and Godson, R.H., 1983, Description of colored isostatic gravity maps and a topographic map of the conterminous United States: U.S. Geological Survey Open-File Report 83-884, 16 p.

Skeehan, J.W., 1965, A continental-oceanic crustal boundary in the Pacific Northwest: Air Force Cambridge Research Laboratories Report AFCRL-65-904, 52 p.

Taubeneck, W.H., 1966, An evaluation of tectonic rotation in the Pacific Northwest: Journal of Geophysical Research, v. 71, p. 2113–2120.

——1967, Reply *to* Comments *on* "An evaluation of tectonic rotation in the Pacific Northwest": Journal of Geophysical Research, v. 72, p. 1415–1421.

Thiruvathukal, J.V., 1968, Regional gravity of Oregon [Ph.D. thesis]: Corvallis, Oregon State University, 92 p.

Thiruvathukal, J.V., Berg, J.R., and Heinrichs, D.F., 1970, Regional gravity of Oregon: Geological Society of America Bulletin, v. 81, p. 725–738.

Veen, C.A., 1982, Gravity anomalies and their structural implications for the southern Oregon Cascade Mountains and adjoining Basin and Range province [Ph.D. thesis]: Corvallis, Oregon State University, 86 p.

Watkins, N.D., 1965, Paleomagnetism of the Columbia Plateau: Journal of Geophysical Research, v. 70, p. 1379–1406.

Wilson, D., and Cox, A., 1980, Paleomagnetic evidence for tectonic rotation of Jurassic plutons in Blue Mountains, eastern Oregon: Journal of Geophysical Research, v. 85, p. 3681–3689.

Manuscript received August 19, 1985
Revised manuscript received February 19, 1986
Manuscript accepted March 12, 1986