DONALD U. WISE

AN OUTRAGEOUS HYPOTHESIS FOR THE TECTONIC PATTERN OF THE NORTH AMERICAN CORDILLERA

Abstract: Cordilleran tectonic trends diverge within the United States to create several distinctive structural provinces. It is proposed that the spreading pattern results from right-lateral distortion of several hundred miles from Paleozoic through modern times across a 300 mile-wide zone from the Colorado Plateau to the Pacific Northwest. Suitable lineaments are indicated on land and sea. Stress-strain patterns within individual structural provinces can be related to this deformation system. The hypothesis is admittedly outrageous and some of its difficulties are pointed out. Nevertheless, it explains enough of the tectonic pattern to merit inclusion among our working hypotheses of causes of Cordilleran spread.

Introduction

The occurrence of an anomaly is always cause for scientific inquiry, particularly if it is so large that people living within it generally overlook it as out of the ordinary. We in the United States live in a strange sprawling portion of the Cordilleran chain which is twice as wide as its Canadian or Mexican counterparts and includes several additional structural provinces (Middle and Southern Rockies, Basin and Range, Columbia and Colorado Plateaus). In the same region some of the tectonic zones suffer abrupt changes of strike. Most obvious is the "Z" shaped pattern (Fig. 1) of the zone of Mesozoic granitic intrusions and of the Mesozoic ultramafic intrusions (Noble and Taylor, 1960). The parallel bars of the "Z" are each about 1000 miles in length and joined by a crossbar of 300 miles in length from northern California to central Idaho. A similar, though less sharply defined, pattern exists in the eastern boundary of the zone of thick Paleozoic and Mesozoic sediment accumulation of the Cordilleran geosyncline (Fig. 1).

This anomalous spreading pattern of the United States Cordillera has three possible explanations. Most common is that some unknown factor, possibly the junction of two island arcs, caused an irregular shape in the Cordilleran geosyncline which has been reflected in the younger tectonic zones and additional structural provinces developed from it. A second explanation is that the spread is merely the reactivation of older Precambrian weakness directions having the same pattern. In effect, this sweeps the problem under a rug of younger sediments, out of sight and mind. A third explanation is that the Cordillera began as a linear belt similar to that of Canada or Mexico but was progressively distorted during its development to produce the present sprawling pattern.

Recent work by Burnham (1959) suggests that the first or traditional explanation of spreading by irregular shape in the Paleozoic-Mesozoic geosyncline is too simple. In investigating metallogenic provinces of southwestern United States and northern Mexico, he found well defined metallogenic belts paralleling the tectonic zones in the same region (Fig. 1). These belts were defined by known ore occurrences and by extensive study of trace-element content of chalcopyrite and sphalerite from 172 localities. The metallogenic belts and the tectonic belts coincide in position and trend but merely overlap in time, the metallogenic belts having existed from earlier Precambrian through Tertiary times. Burnham concludes that the parallelism is the result of some deeper fundamental process rather than being simple cause and effect. If Burnham's rather careful work and cautiously phrased conclusions are accepted, one is driven either to a hypothesis of partial Precambrian control of the tectonic trends or else of younger deformation of Precambrian mineral belts along with the distortion of the Cordilleran trend lines.

A hypothesis involving gross shifting of subcontinental areas would have been completely unacceptable until very recently to most American geologists. With the increasing volume of paleomagnetic data (Cox and Doell, 1960), the discovery of huge displacements of magnetic anomalies along fracture zones in the Pacific (Menard, 1961; Vacquier, Raff, and Warren,

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1961), and the suggested fault opening of the Gulf of California (Hamilton, 1961), a proposal of crustal displacement sufficient to offset the entire Cordillera by several hundred miles now seems only slightly preposterous. William Morris Davis (1926), in discussing the purpose of outrageous geologic hypotheses, noted that their value is not in being correct or incorrect but rather in focusing attention on unsolved problems ultimately leading to their solution. It is in this vein that the explanation by major crustal distortion is considered here.

Hypothesis

One of the many possible systems of younger distortion of Cordilleran lines is right-lateral displacement along a zone striking northwestward through the states of New Mexico and Nevada to Oregon and Washington, generally parallel to and having the same sense of displacement as the San Andreas fault zone (Fig. 2, M). This idea was proposed by Carey (1958) as part of a system of global tectonics. Carey utilized only the San Andreas fault and an assumed strike-slip movement on the Rocky Mountain trench but did not apply the stress environment to structural provinces. The zone of distortion proposed here is 300 miles wide and necessitates 300–400 miles of right-lateral displacement by fracture and flowage if the tectonic belts are assumed to have been an original linear feature. Much of the movement may have occurred in Paleozoic or early Mesozoic times after the laying of foundations leading to eventual emplacement of the Mesozoic batholiths; some movement occurred subsequent to the solidification of the Mesozoic Batholith zone (Fig. 2, E); presumably some continues today in the earthquake activity of the region. Thus, the complete 300-mile displacement need not have taken place in Cretaceous or younger times, nor need the batholith zone show evidence of extreme shearing.

Boundary lines to the proposed zone of distortion are known. Walker lineament (Fig. 2, N) is nicely located along the east side of the Sierra Nevada to form the southwestern boundary of the zone and has the proper right-lateral sense of displacement (Longwell, 1950). On the northeastern side is the Olympic-Wallowa lineament (Fig. 2, G) as described by Raisz (1945) trending from the Straits of Juan de Fuca possibly as far as Craters of the Moon, Idaho. The sense of displacement on this zone is poorly documented and complicated by younger cover. On the basis of position of topographic crests of two ranges, Raisz suggests it may be le lateral.

Possible extensions at sea occur as the Kodia seamount chain and the Columbia fracture zo

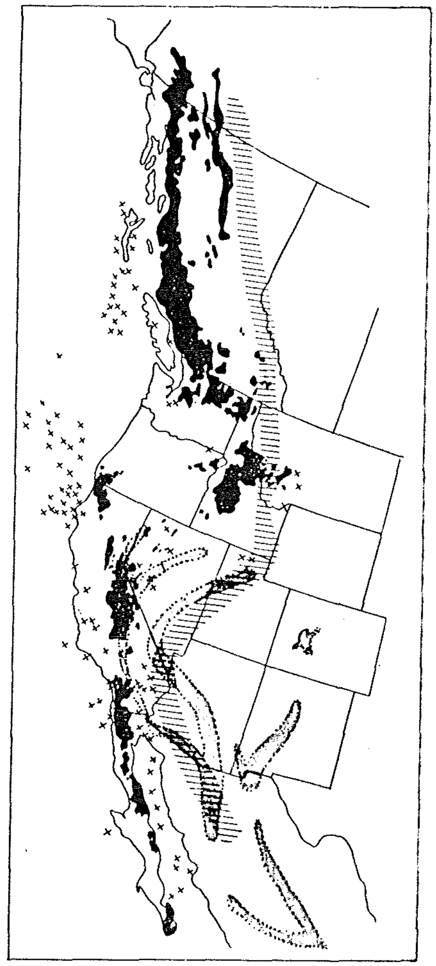

Figure 1. Tectonic belts involved in the sprawl of the North American Cordillera. Black pattern—belt of Mesozoic batholiths; ruled area—eastern border of thick, geosyn clinal deposits; dotted—belts of trace-element concentration reflecting metal logenic provinces (generalized after Burnham, 1959); crosses—earthquake epicenters after Gutenberg and Richter (1954)

(Gibson, 1960) (Fig. 2, B, A). In the intervening areas along these possible marine exten sions, Gutenberg and Richter (1954) show northwest-trending belts of earthquake ep

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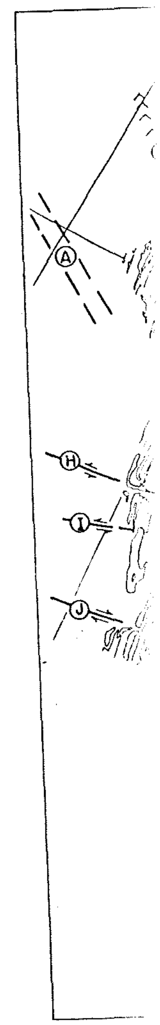

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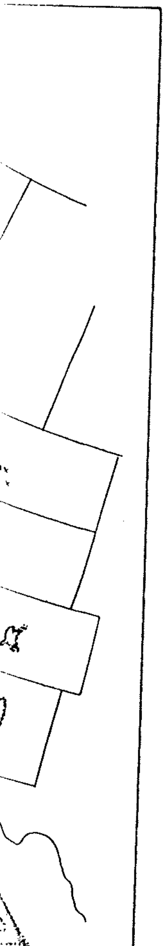

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nters (Fig. 1). These boundaries mark the ra between the confines of the massive Meso- ic batholith zones. On the outer edge of these nes, lineaments and/or strike-slip movements ould also be predicted at the present position of the San Andreas fault and Rocky Mountain trench. At sea the magnetic pattern (Raff and Mason, 1961) has a 45-degree difference in strike from continental tectonic trends with the discontinuity occurring on the approximate

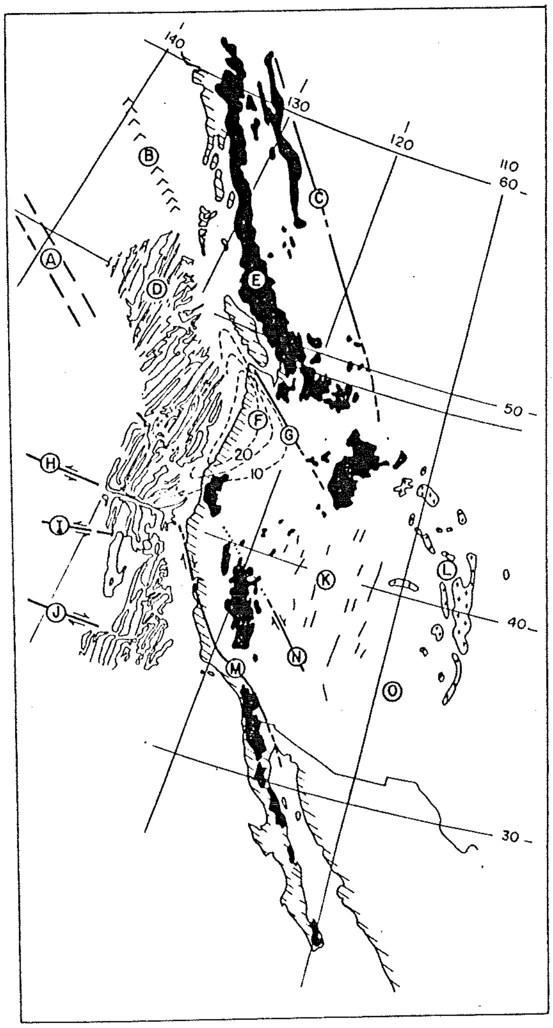

Figure 2. Possible tectonic elements in a hypothesis of right-lateral distortion of the North American Cordillera. (A) Columbia fracture zone; (B) Kodiak seamount chain; (C) Rocky Mountain trench; (D) Magnetic pattern of the sea floor; (E) Mesozoic batholith zone; (F) Isopachs (in thousands of feet) of thickness of Tertiary sediments; (G) Olympic-Wallowa lineament; (H) Mendicino fracture zone; (I) Pioneer fracture zone; (J) Murray fracture zone; (K) Basin and Range faulting; (L) Middle and Southern Rockies Basement uplifts; (M) San Andreas fault; (N) Walker lineament; (O) Colorado Plateau

projection of the Olympic-Wallowa lineament. The magnetic pattern off the coast of Oregon has a number of apparent fault displacements, including one aligned with the projection of the Walker lineament and having approximately 60 miles of right-lateral displacement. A submarine fault zone with at least 1500 feet relief extends along this same line for at least 250 miles (H. W. Menard, personal communication). Raff and Mason (1961) note that, "Most of the area on the (magnetic) map from 41° N. Lat. to 49° N. Lat. looks like angular pieces of the earth's crust that have slipped and rotated with respect to neighboring pieces." These latitudes are on the direct projection of the proposed zone of distortion (*see* Fig. 2). The 20-degree change in strike of magnetic trend lines toward the northeast in this region is consistent with clockwise rotations expected from right-lateral shearing (*see* Fig. 3, upper left).

Stress Patterns in Structural Provinces

If the proposed pattern of regional distortion has any validity, it should accord with stress-strain distribution within the distinctive structural provinces of the United States Cordillera. Within the broad right-lateral shear zone, a strain ellipsoid would be oriented with its long axis east-west (Fig. 3, center), the precise orientation depending on the value of the compressive stress normal to the zone. With this orientation of the ellipsoid, extension features such as normal faults should trend north-south; lower elevations should result from a thinner elongated crust; and volcanism might be expected to accompany the extension. The reader will recognize these as the essence of Tertiary tectonics of the Basin and Range Province.

Northwestward along the zone in western Washington and Oregon the same stress-strain pattern (Fig. 3, northwest corner) would be expected with the original crustal material of the area as oceanic floor or continental shelf. Accordingly, lower original elevation, thick sedimentary fill, and lack of basement exposure is to be expected. Isopachs of thickness of Tertiary deposits in the area (Fig. 2, F, after Eardley, 1951) reflect the younger filling of this region. Some of the Tertiary structural trends are compatible with the proposed orientation of the strain ellipsoid. The conjugate strike-slip fault system in basalt flows of Oregon as described by Donath (1962) is perfectly oriented for maximum compression north-south and has stronger development of the northwest-trending set of right-lateral strike-slip faults. The known dike swarms and feeders of the Columbia River lavas, presumably extension features, trend north-south plus or minus 15 degrees (Waters, 1961). In addition, the younger fold axes of south-central Washington trend west-northwest to east-west (Waters, 1955) in accord with strain-ellipsoid predictions.

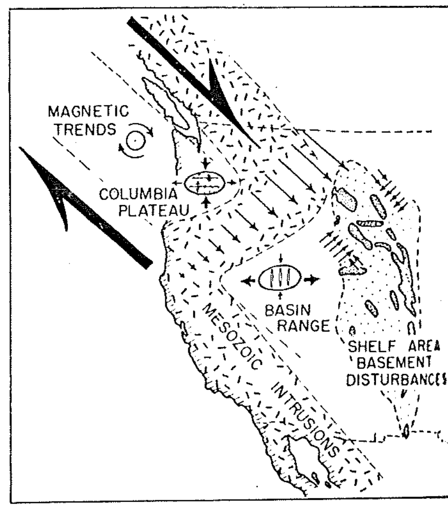

Figure 3. Hypothetical stress distribution in the Cordilleran region. California and Mexico batholith zone on the south, Canadian batholith zone on the north. Strain-ellipsoid orientation for Basin and Range province and for Pacific Northwest indicated. Rotational sense of marine magnetic pattern indicated at northwest. Small arrows in Wyoming indicate combined compression and shear to produce parallelogram pattern.

If the Cascade volcanic line is regarded as an independent Pacific borderline process, agreement of hypothesis and most major tectonic features of the province is good.

In the brittle shelf areas on the east and southeast projection of the zone of offset are the massive basement structures of the Middle and Central Rockies. Along with these the author would include the basement-related monoclines, uplifts and basins of Laramide age within the Colorado plateau as structures of dimension, trend, and style analogous to the Wyoming Rockies, the differences merely reflecting relative levels of erosion and superposition of younger uplift structures. These regions of intense basement deformation far east of the main geosyncline are localized on a surprisingly direct projection of the offset zone and of the batholithic zone of Canada (Fig. 2). From a mechanical viewpoint this otherwise anomalous distribution of block ranges is a logical consequence of the dissipation and transition of shearing effect in the more plastic, western geosynclinal region into the more brittle basement of the shelf areas to the southeast. The frontal ranges of Colorado would be the easternmost rolled edge of the disturbed shelf area. As these frontal ranges project southward toward a merger with the Mexican Cordillera, only a fraction of the total width of the shear zone is involved, requiring a lesser total displacement to be absorbed and a corresponding disappearance of the ranges southward.

The orientation and fabric of the Laramide block ranges can be fitted nicely into the regional stress system. Throughout the Wyoming and Colorado Rockies and the Colorado Plateau is a very pronounced northwest-trending grain of intermediate-sized folds, faults, and uplifts which are remarkably parallel to the trend of the Canadian and Mexican Cordillera (Fig. 2). A number of larger uplifts including the Wind River and Bighorn ranges of Wyoming parallel the same trend. Thrusting and folding associated with these structures would make them comparatively easy to interpret as the result of regional compression perpendicular to the general trend of the Cordillera. Unfortunately, other major structures have differing trends to form large uplifts and basins transverse to the northwest grain. Examples include the north-south Front Range of Colorado and the east-west Owl Creek Range of Wyoming, both of which are composed of northwest-trending en echelon segments. In Wyoming the transverse structures tie together the ends of major northwest-trending uplifts to form parallelogram-shaped basins such as the Wind River and Bighorn basins, with local thrusting along their edges. This intersecting jumble of uplifts was long regarded as the reactivation of Precambrian basement trends modified by Laramide compressions. Considerable attention to the older basement structures of Wyoming during the last decade has revealed little correlation between Precambrian and Laramide structural trends. Accordingly, a more complex Laramide stress system is needed. If to the overall compression perpendicular to the Cordillera is added the northwest-trending right-lateral regional shear, the result would be formation of crossbar uplifts linking the ends of the major ranges and leaving the intervening areas as parallelogram-shaped basins. Continuation of this system of compression and superimposed shear would result in the observed local thrusting and folding in ranges along the edges of the parallelograms.

Difficulties and Tests

If this regional stress distribution should have some basis in truth, there would be innumerable local areas for which additional refinements and *ad hoc* hypotheses would be necessary. It would be futile to propose a large number of these local explanations in a paper of this type even if such explanations were available. Nevertheless, a few of the largest problems and possible objections should be listed.

(1) The great fracture zones of the Pacific (Fig. 2, H, I, J) do not have any obvious relation to the proposed scheme. However, our present tectonic theories cannot satisfactorily relate these oceanic displacements to the immediately adjacent and nonhypothetical San Andreas fault.
(2) The late Tertiary rise of the Colorado plateau region must be an independent feature, possibly a continuation of the East Pacific rise.
(3) The Puget Sound and Cascade trends bear little or no relation to the scheme and would have to be considered younger Pacific borderline structures.
(4) The Snake River downwarp remains as an anomalous transverse structure.
(5) There is minimal evidence of displacement sense on the Olympic-Wallowa lineament, but that available suggests the wrong direction.
(6) The structure by which the proposed distortion was accomplished is largely unrecognized.

These are some of the many difficulties which make the hypothesis seem outrageous, but many of them reflect omissions in our general tectonic knowledge as much as difficulty for this particular hypothesis.

Tests of the hypothesis might come from a number of fields. Paleomagnetic data could be used to this advantage; comparison with the offset batholith zone of Chile might be helpful; evaluation of sedimentary thicknesses, facies changes, and source areas within the disturbed zone are most important; the structures by which the proposed displacement was accomplished should be recognized somewhere within the region. Above all, the tectonic scheme must be capable of explaining time and space relations within individual structural provinces. For the Middle Rockies, the area with which the author is most familiar, the hypothesis is as reasonable as any of several others which might be proposed. However, the most critical areas for detailed testing are those in the proposed zone of distortion, particularly in the states of Utah, Nevada, Oregon, and Washington.

Conclusions

A fundamental question of the tectonics of North America is the cause of the spreading pattern of the United States Cordillera. Many of the largest tectonic, geophysical, and geochemical trends of continent and nearby ocean can be fitted into a system involving several hundred miles of right-lateral distortion across a 300-mile-wide northwest-trending zone transecting the Cordillera. Many of the major tectonic features of individual structural provinces can be fitted into the stress system. One of the strongest arguments for considering the idea is that the immediately adjacent crustal region of the San Andreas fault zone has similar orientation, similar sense of displacement, time of movement, and possible magnitude of movement. It is immaterial whether this particular hypothesis, an elaboration of Carey's (1958) idea, is *the* explanation of Cordilleran sprawl, but serious consideration of the basic problem of cause of tectonic spreading is long overdue.

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Dept. Earth Sciences, University of California, La Jolla, Calif. (Present Address: Dept. Geology, Franklin and Marshall College, Lancaster, Pa.)

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DUNCAN McCONNELL

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