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Early Cenozoic Geology of Central Washington State: II. Implications for Plate Tectonics and Alternatives for the Origin of the Chiwaukum Graben

Abstract

Reconstruction of tectonic events of central Washington prior to about 50 mybp is tenuous. The early Eocene Swauk Formation may have been deposited after a period of tectonic quiescence. Folding of Swauk on E-W axes between 51-47 mybp cannot be readily correlated with presumed plate motions. Coeval emplacement (at 47-48 mybp) of two tensional dike swarms (Teanaway and Corballey Canyon), of contrasting lithologies and extensional directions, presents a tectonic paradox that is not easily solved. The paradox may be resolved by assuming sufficient right-lateral strike-slip motion on the east-bounding fault of the Chiwaukum graben (the Entiat fault) so that the counterpart of the Teanaway dikes lies somewhere southeast below the Columbia Plateau. Two models for development of the Chiwaukum graben from about 46 to 40 mybp by strike-slip motion are possible. The first requires a wedge-shaped graben; this is the "ball-bearing" model that reconciles the Chiwaukum graben with documented clockwise rotation of Eocene rocks that lie to the west. A preferred model for the graben is as a rhombochasm ("pull-apart" structure), such as has been proposed for Tertiary basins of California. By this model, a primary kink in a strike-slip fault opens into a diamond-shaped depression during active movement. The exposed Chiwaukum graben is thus interpreted as the northern end of a rhombochasm that projects beneath the Columbia Plateau. Cessation of graben activity at about 40 mybp agrees with the end of Laramide deformation over western North America, and it is correlated with global reorganization of plate motions. A period of tectonic and magmatic quiescence from 40-34 mybp correlates with development of a major erosion surface over western North America during plate reorganization. Deformation of the Wenatchee Formation during 34-29 mybp marks the onset of renewed techonism and magmatism as subduction was initiated in the Pacific Northwest. Deformation of the southern part of the Chiwaukum graben by right-lateral shearing and associated emplacement of the Horse Lake Mountain complex may be related to the initiation of strike-slip motion elsewhere along the Pacific margin as the spreading center between the Farallon and Pacific plates encountered a subduction zone at the continental margin. Erosional stripping of the Wenatchee Formation in the region now occupied by the Cascade Range occurred before deposition of the Columbia River Basalt Group in Miocene time and may mark the beginning of the ancestral Cascades.

Introduction

Carlson (1976) correlated Cenozoic plate motions with the geology of the continental margin of the Pacific Northwest (Coast Range and Puget-Willamette Lowland) and the Cascade Range of Washington-Oregon. The summary of geologic history presented in Part I (Gresens 1982) supplements the correlation of plate motion with the geology of the central Cascade Range of Washington.

Plate Tectonic Implications

Early Eocene

The lateritic paleosol present at the base of the Swauk Formation and the probable widespread occurrence of the unit suggest that it may have been deposited on an erosion surface developed during a time of tectonic and magmatic quiescence. It is difficult to attempt correlation with plate motions because the age of the presumed erosion surface is not well documented, lying between 88 my (age of the Mt. Stuart granodiorite; Engels and Crowder 1971) and somewhat less than the 51 my age of upper Swauk Formation (Tabor and Frizzell 1977). Erickson (1976) used fission-track apparent ages and annealing temperatures of apatite to suggest that the Mt. Stuart batholith was uplifted and unroofed at 55 ± 6 mybp. This date could reflect the onset of renewed tectonism after a period of crustal stability, but considerable uncertainty remains.

East-west fold axes, suggestive of N-S compression, pre-date Teanaway Basalt and therefore were formed in the interval of about 51-47 mybp (Gresens 1979, Ewing 1980). This compressive direction does not fit well into a plate tectonic model. During the Cretaceous and into the early Tertiary, the Kula plate was moving northward with respect to the Pacific plate (Hayes and Pitman 1970) as the Pacific plate itself was moving northward relative to a presumably fixed "hot-spot" (Clague and Jarrard 1973). Interaction of either plate with North America could produce N-S compression and E-W fold axes. However, North America, moving relatively westward, was presumably interacting with the Farallon plate moving relatively eastward (Atwater 1979, Hayes and Pitman 1979); these movements should have produced N-S fold axes. It is possible that this area was involved in crustal rotation, as observed for Eocene rocks to the west and southwest (Simpson and Cox 1977, Beck 1976), so that they no longer reflect the true direction of tectonic stresses during early Eocene folding.

Armstrong (1978), Vance (1979), and Ewing (1980) suggested that a broad NW-SE subduction-related magmatic arc, the Challis arc, was active in early and middle Eocene time in British Columbia, Washington, central Oregon, Idaho, Montana, and Wyoming. Much of the igneous activity of the Chiwaukum graben area, including the Teanaway Basalt and the Corbaley Canyon dike swarm, would be included in Challis volcanism. Definition of the magmatic arc is based on regional plots of occurrences of plutonic or volcanic rocks and their ages. Failure to examine the tectonic setting and the tectonic implications of the petrology of individual occurrences leads to over-simplification in broad overviews of this type. For example, the Corbaley Canyon tensional bimodal dike swarm is better explained by deep crustal rifting than by a subduction mechanism.

Ewing (1980) attempted to explain E-W fold axes in the Swauk Formation and the NE trend of the tensional Teanaway dikes by a single stress regime having a principal stress direction oriented slightly east of north. The change from north-south compression to WNW-ESE extension was presumed to reflect an exchange of the intermediate and least principal stresses at about 47 mybp. But such an exchange should produce NNW dextral or NNE sinistral strike-slip faults, not the extensional rifting indicated by the Teanaway dikes. Clearly, much work remains before a definitive correlation between early Eocene plate motions and igneous and tectonic events is possible for this region.

Middle Eocene

The Chiwaukum graben became active immediately after or during the close of the early Eocene events. Geologists familiar with the Pacific Northwest have long speculated informally on the possibility of strike-slip motion on the Entiat fault, and the suggestion was recently formalized (Gresens 1979, Ewing 1980). There is no evidence that the fault existed prior to about 46 mybp. Features suggestive of strike-slip movement include (1) the linearity of the fault, (2) the failure of the Jurassic ultramafic rocks to appear east of the Chiwaukum graben, and (3) the failure of the NE-trending Teanaway dike swarm to appear east of the Chiwaukum graben. Ewing (1980) considered the Entiat to be part of a network of strike-slip faults that were active in the Eocene.

The new radiometric dates obtained during this investigation emphasize another geologic incompatibility across the Entiat fault. The Teanaway and Corbaley Canyon dike swarms are essentially coeval. Yet they represent markedly different compositions and crustal extension in directions nearly 90° apart, even though they are geographically only 50 km apart. These observations present a fundamental tectonic problem if they are in their original positions with respect to each other. Two possibilities for the origin of the graben, each calling for strike-slip motion on the Entiat fault, are presented.

Model One—Rotation and Strike-slip Movement

Figure 1a shows the outline of the graben. There is a basic wedge shape, although the irregular Leavenworth fault zone must be given a "best fit." Figure 1c shows the schematic development of the graben by a combination of strike-slip motion and clockwise rotation. Although the wedge shape could be explained by rotation alone, restoration of the rotation would make the Teanaway-Corbaley paradox an even greater tectonic problem (Fig. 1b).

Clockwise rotation of crustal rocks of Eocene age along the Oregon and Washington coasts is well documented by paleomagnetic data (Beck 1976, Simpson and Cox 1977, Globeman 1979, Beck and Burr 1979). It could be argued that there must be a transition, either gradually over a broad zone or abruptly over a narrow zone, from the marginal part of the continent that is strongly affected by rotation into the stable continental interior that has not been rotated. The Entiat fault zone and the Chiwaukum graben could be an abrupt transitional area. This model follows the "ball-bearing" model for combined right-lateral strike-slip motion and clockwise rotation as proposed by Beck (1976).

Model Two—Rhombochasm

The geometry of the Chiwaukum graben also lends itself to interpretation as a rhombochasm (Carey 1958), with the southern half covered by the Columbia River Basalt Group (Fig. 1d). This model does not require a rotational component, but merely strike-slip motion along a fault having an original "kink." This is, for example, a plausible model for the origin of late Cenozoic basins of California (Crowell 1974). The Chiwaukum graben has the correct geometry for this type of "pull-apart basin" as defined by Crowell. The side bounded by strike-slip movement is straight (Entiat fault), whereas the tensionally rifted "kink" boundary is irregular (Leavenworth fault).

Either of these models would explain the mismatch of geology across the Chiwaukum graben and would alleviate the tectonic paradox posed by the coeval Teanaway and Corbaley dike swarms; sufficient separation by restoration of strike-slip movement might make separate stress regimes plausible. Either model would allow the gradual opening of a depression that could ultimately accommodate 5800 m of Chumstick sediment. The author prefers the second model, but either is possible. The models differ in terms of the possibility of differential rotation across the graben, but this may be tested by

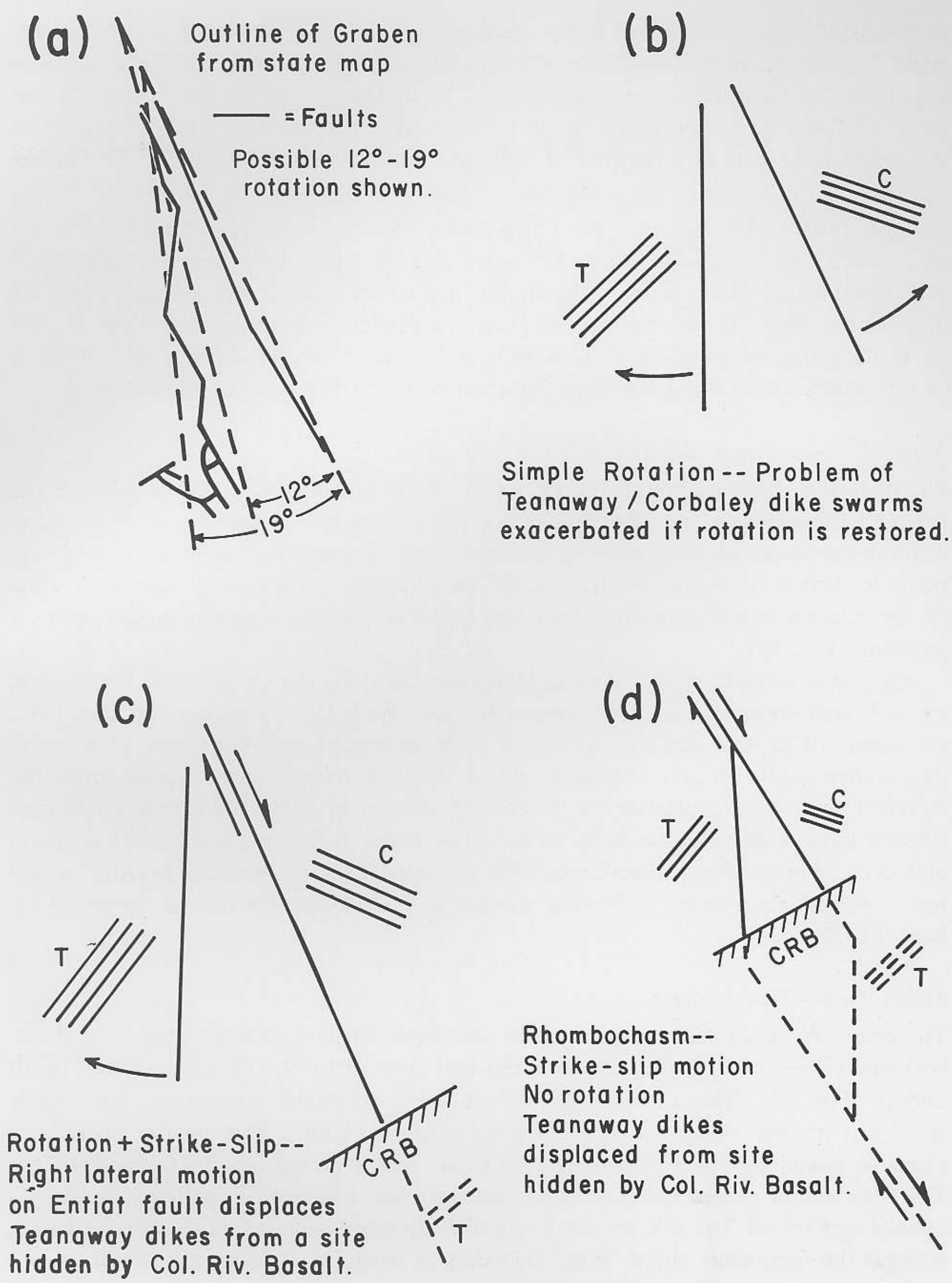

Figure 1. Possible origins for the Chiwaukum graben. "T" and "C" on the diagrams indicate the Teanaway and Corbaley Canyon dike swarms, respectively. "CRB" refers to Columbia River Basalt group, which covers the southern projection of the Chiwaukum graben. Further explanation in the text.

paleomagnetic work on the Teanaway Basalt and Corbaley Canyon rocks. The required paleomagnetic work is now in progress (M. Beck, pers. comm., 1979, 1980).

Late Eocene-Early Oligocene

The Chiwaukum graben became inactive at about 40 mybp, and a period of tectonic quiescence ensued. This period coincides with the end of Laramide deformation over the entire western Cordillera, which is in turn correlated with changes in motion of the North American and Pacific plates (Coney 1971, 1972; Epis and Chapin 1975; Gresens 1978, 1980) and probably with a global reorganization of plate motion during the Eocene (Rona and Richardson 1978; Gresens, in press).

Late Oligocene

Post-34 mybp compression of the region must correlate with renewed tectonism and magmatism over much of the western Cordillera at about 35 mybp (Epis and Chapin 1975) and, more specifically, with the renewal of subduction in the Pacific Northwest (Vance 1979). Compressive stress was transmitted to the continental interior.

The spreading center between the Pacific plate and the Farallon plate encountered a subduction zone at the western margin of North America at about 29 mybp (Atwater 1979), and this initiated right-lateral strike-slip deformation at the continental margin near San Francisco. The passive emplacement of the 29 my Horse Lake Mountain complex is associated with right-lateral strike-slip motion, and it is suggested that this may be a more northerly expression of renewed strike-slip motion on the North American continent (Gresens 1980). Central Washington is admittedly rather far from San Francisco, but the timing and sense of motion coincide.

Concluding Remarks

The part of the North American continental margin now represented by the state of Washington has a long history of right-lateral strike-slip faulting, including the late Createaceous (Davis *et al.* 1978) as well as the middle Eocene and late Oligocene events described above. These apparently are interspersed with "conventional" continental margin subduction and related igneous activity and with at least one period of tectonic quiescence. The writer appreciates that correlations may be revised as new data become available. However, any regional tectonic synthesis must take into account the factual chronology of geologic events presented in Part I of this paper.

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