

PLATE TECTONICS IN OREGON

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While studying Paleozoic strata in the Appalachians of New York, James Hall, in the middle of the 19th century, formulated a theory which for more than 100 years explained to most people's satisfaction the regional relationships of the sedimentary rocks of the Appalachian Mountains. In fact, his theory was thought to explain the origin of the sedimentary rocks occurring in most of the mountain ranges of the world. He hypothesized the development of long linear troughs bordering the continents in the geologic past into which sediments derived from the continents were deposited. The troughs sank in harmony with deposition so that great prisms of rock commonly approaching 8 miles in thickness were produced. Later, according to his theory, the prisms were differentially folded, faulted, intruded, and metamorphosed to give the highly complex suites of rocks characteristic of so many of the mountain belts of the world today.

Although Hall failed to propose a name for his concept, it is generally referred to as the geosynclinal theory. In subsequent years, the theory has undergone a number of revisions and modifications. Among the more significant refinements is the concept that the geosyncline consists of two more or less distinct parts: the miogeosyncline, situated immediately adjacent to the continent, in which relatively well-sorted sediments and limestones accumulated; and the more distant eugeosyncline, into which poorly sorted graywackes and volcanic rocks were dumped from the scattered island arcs growing in the outer parts of the geosyncline. Throughout its evolution the concept of the geosyncline has embodied the concept of deposition in an actual trough (Figure 1).

In recent years the new concepts of sea-floor spreading, or plate tectonics, have superseded many of the tenets of the geosynclinal theory. The plate tectonic model maintains that the earth's crust is divided into slabs or plates which are continually shifting position relative to one another (Figure 3). Continents are rooted in the plates like logs frozen in shifting ice; they are best viewed as incidental by-products of the overall tectonic process. In regions of plate collision, the slabs are believed to override one another, producing regional stresses and tectonic processes which eventually

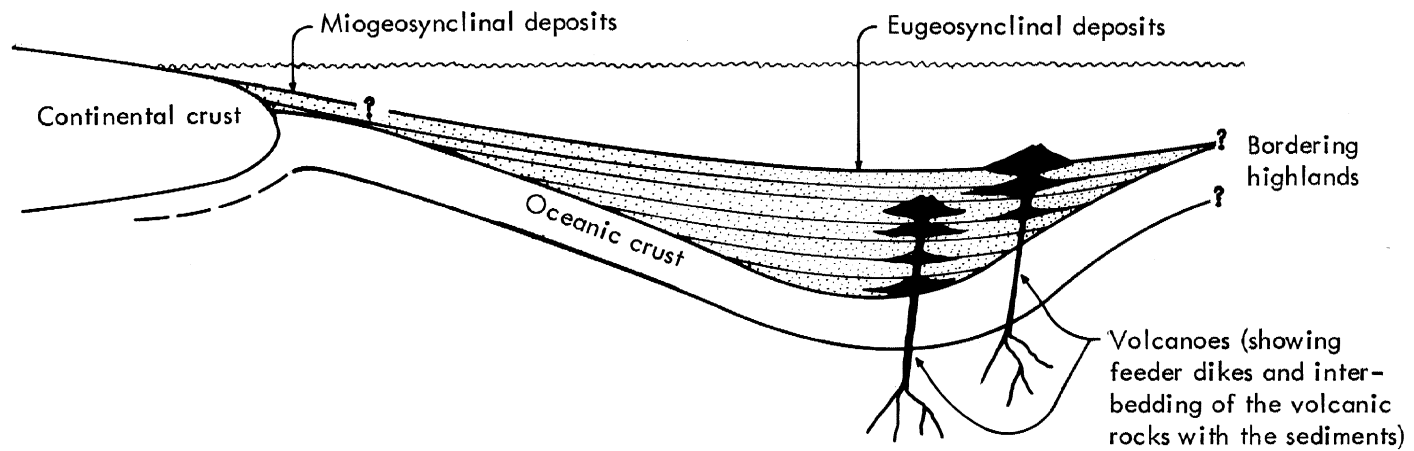


Figure 1. The concept of geosynclines maintained that the marine sedimentary rocks we now see in our mountain belts were deposited in large linear troughs, a cross section of which is shown above. The well-sorted miogeosynclinal sediments were deposited adjacent to the continental interior, whereas the eugeosynclinal deposits were laid down in the outer part of the trough in areas of volcanism.

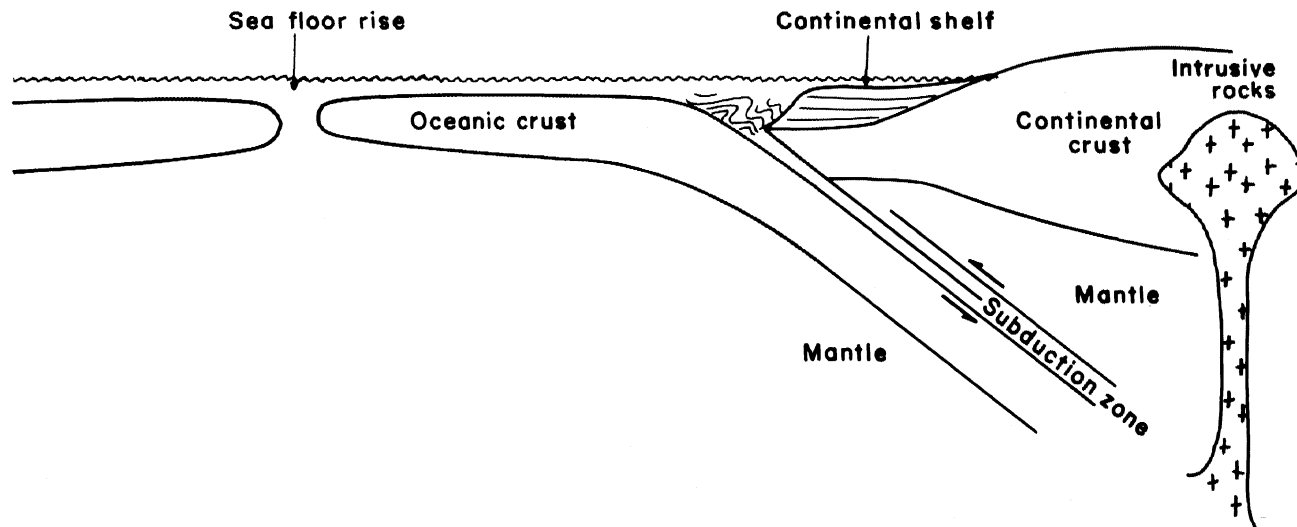


Figure 2. In the plate tectonic model sediments of the continental shelf represent the so-called miogeosyncline. The eugeosyncline is made up largely of the highly deformed rocks of the oceanic crust (mainly basalts and deep-sea sediments).

produce mountain ranges. In regions of divergence, hot material wells up from the mantle to fill the void and new crust is formed.

Regions of plate convergence often have associated with them at depth a dipping plane of seismic activity where one plate scrapes over the other (Figure 2). In currently active areas these are termed Benioff or subduction zones. In the rock record, they are more commonly referred to as subduction zones. Areas of plate divergence are characterized by rifting and are commonly represented by sea-floor rises. A classic example is the mid-Atlantic Ridge, along the axis of which new sea floor is being produced at the present time. In many areas plates glide past one another along lateral faults termed transform faults. Displacement along some of these faults (e.g. San Andreas Fault) is measured in terms of hundreds of miles.

Actually, the plate tectonic model in no real way alters the basic geometry of the rock distributions as described by Hall. Well-sorted sediments are restricted to the edge of the continent, and eugeosynclinal deposits are laid down in more distant areas. However, the original pattern of distribution or deposition is greatly modified. Most notably, deposition is not thought to occur in a trough (Figure 2).

Briefly, the miogeosynclinal rocks represent wedges of sediment laid down on the continental shelf; they thicken away from the continent and terminate abruptly at the continental slope (Dietz and Holden, 1966). The eugeosynclinal rocks are thought to represent deep ocean-floor crustal material that has been rafted against the continent into juxtaposition with the wedge deposits of the continental shelf (Dietz, 1972).

Because no trough as such is proposed by the plate tectonic model one of the major difficulties of the geosynclinal model is avoided. That is, nowhere in the world are eugeosynclinal and miogeosynclinal deposits seen being deposited side by side in the manner required by the geosynclinal theory. Failure to find such a depositional pattern is easily explained in terms of the plate tectonic model.

No longer, then, are continents viewed as quiescent fixtures rooted since antiquity in immobile crust and mantle. Continents are now seen as dynamic and complex structures imbedded in shifting lithosphere plates. In areas of plate collision the continents grow in size as more sea-floor material is rafted into them and also through volcanism and plutonism. Elsewhere, as in the Red Sea area today, continents are literally torn apart as the lithosphere plates beneath them diverge in response to deeper seated activity in the earth's mantle.

Paleozoic Tectonics

Paleozoic rocks in Oregon are limited to a few small exposures in the southwestern and northeastern corners of the state. In the southern Klamath Mountains quartz-mica schists, termed the Abrams Schist, and hornblende-epidote-albite schists, termed the Salmon Hornblende Schist, are thought

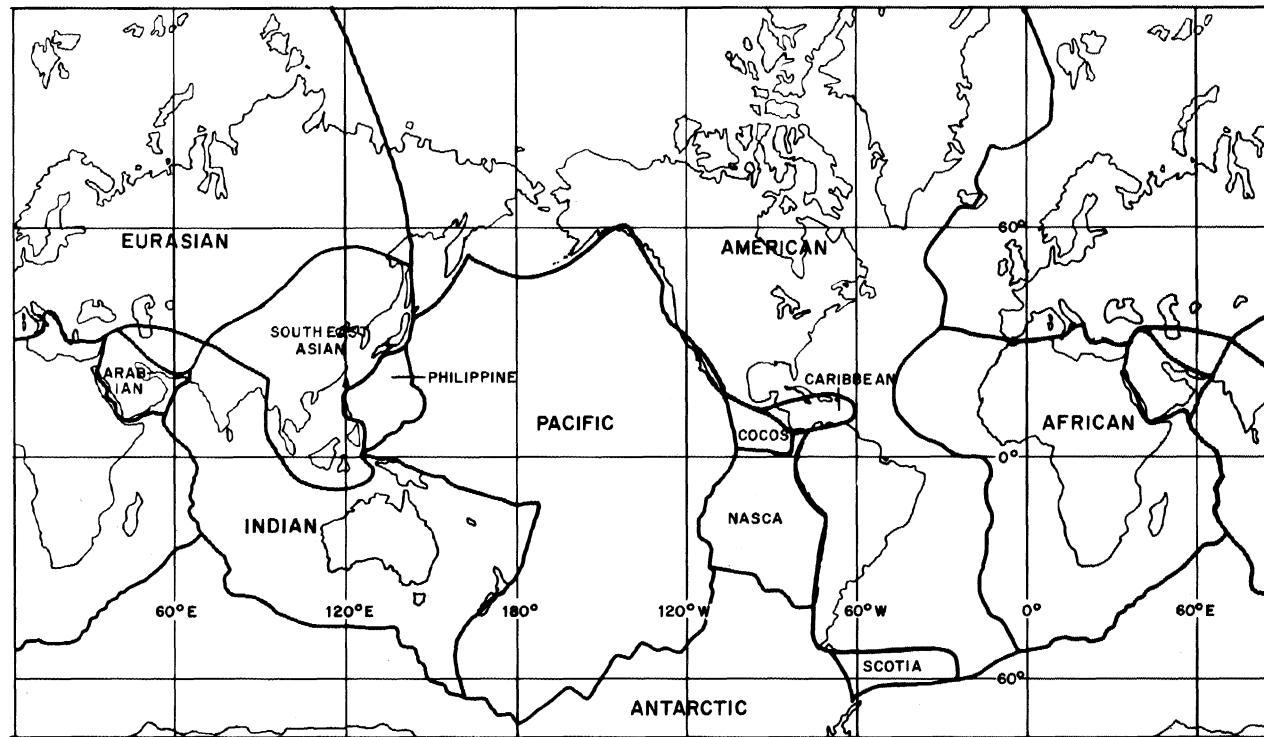


Figure 3. Projection of the lithospheric plates. According to the plate tectonic model, the outer 50 to 200 kilometers of the earth (the lithosphere) is divided into numerous plates which are in motion relative to each other. Zones of divergence are termed rises or ridges; zones of convergence are typified by trenches. In places, long transform faults separate the plates.

to represent metamorphosed mafic volcanic rocks and associated sedimentary rocks. On the basis of strontium isotopic data Lanphere and others (1968) conclude that a Devonian age of metamorphism is most likely for the strata. According to the plate tectonic model, the gross composition of the schists suggests that they may represent early Paleozoic sea floor that was metamorphosed in a subduction zone as one plate overrode another in Devonian times. Although not specifically stated in the literature, such interpretation is alluded to in a diagram by Burchfield and Davis (1972), who show a Devonian subduction zone in the vicinity of the Klamath Mountains.

Adding to the complexity of the area are the reported Asian and east European affinities of the early Paleozoic brachiopods and trilobites recovered in parts of the Siskiyou Mountains to the south. It is possible that the early Paleozoic rocks were originally part of Asia, that they were rafted eastward away from Asia, and that they subsequently collided with the North American continent (Sedden, oral communication, 1970). More recently Beck and Noson (1971) have postulated a similar idea that various Cretaceous granitic bodies in northern Washington originally were not a part of the North American continent and that they were rafted against the continent later in Tertiary times.

In northeastern Oregon, more extensive Paleozoic units consist of Permian exposures of greenstone, argillite, chert and limestone pods assigned to the Clover Creek Greenstone, the Burnt River Schist, and the Elkhorn Ridge Argillite. Unfortunately, structural and metamorphic patterns are complex and fossils are scarce. Gross lithology, however, is consistent with the concept that the units represent ancient sea floor; possibly the various units represent slabs of oceanic crust that were rafted against the continent and metamorphosed in a late Paleozoic subduction zone.

Triassic-Jurassic Subduction

On the basis of a wide variety of evidence accumulated from around the world it is widely agreed that at the beginning of Mesozoic times all the continents of the world were closely clustered to form one super-continent (Figure 4). In the literature this continent is referred to as Pangaea. Although the exact paleogeography and specific position of the super-continent is debated, the super-continent concept is fairly well accepted. Beginning in Triassic times, rifting of the lithosphere beneath Pangaea initiated the progressive splitting of the super-continent into a series of fragments. By the close of Mesozoic times, the separate continents of North and South America, Europe, Asia, Africa, Antarctica, Australia, and the subcontinent of India were fairly well established.

Synchronous with Mesozoic rifting in the eastern United States, a variety of collision features were produced in the west as the North American Plate was rafted westward to impinge upon the ancestral oceanic East Pacific Plate. The andesitic breccias of the Late Triassic Applegate

Formation and Late Jurassic Rogue Formation in the Klamath Mountains and the meta-andesites of the Late Triassic Clover Creek Greenstone in the Blue Mountains conform favorably on a lithologic basis to the types of rocks that are produced over active subduction zones in oceanic areas. Moreover, the siltstones and thin turbidite sandstone of the Late Jurassic Galice Formation overlying the Rogue Formation may represent the distal edges of an abyssal fan spreading westward from the former continental slope.

The Nevadan (Late Jurassic) intrusive and metamorphic features of the Klamath Mountains may record deformation and fusion arising from active subduction. In this connection also, the older high-grade blueschist slabs of the Colbrooke Schist, supposedly derived from the Galice Formation (Coleman, in press), acquire added significance. Blueschist pods are indicative of high-pressure low-temperature conditions and are generally interpreted to be signposts of previous zones of plate subduction.

Postdating the Nevadan orogeny are the massive sandstones of the Dothan Formation and the more westerly, more tectonically deformed, and highly sheared sandstone, greenstone, blueschist, serpentine, chert, and limestone exposures of the Otter Point Formation. Possibly the Dothan represents the near-shore facies of an abyssal fan and the Otter Point represents the distal edges of the fan as it spread westerly to mingle with other deep-sea-floor deposits. The sheared disordered appearance of the Otter Point Formation and the presence of tectonic blocks within it suggest tectonic deformation immediately following deposition. Possibly the unit was partially engulfed in a subduction zone prior to lithification as the North American Plate continued to ride westward over the ancestral oceanic East-Pacific Plate. A similar process is hypothesized for the contemporaneous Franciscan Formation of California (Hamilton, 1969) with which the Dothan and Otter Point Formations are commonly equated.

Masses of peridotite and other ultramafic rock occur as large sheets (Medaris and Dott, 1970) throughout much of the Mesozoic terrain of the Klamath Mountains Province and closely resemble ultramafics recovered from ocean ridges today. Lacking in chrysotile, a relatively high-pressure mineral of the serpentine group (Medaris, 1972), they are quite different mineralogically from the peridotites formed in subduction zone tectonic settings. It is postulated that the ultramafic bodies represent slabs of upper-mantle material which were brought up from depth along ancestral sea-floor rises in the Pacific Ocean (Medaris and Dott, 1970). They were subsequently rafted eastward against the continent. According to Coleman (1971), the mobile serpentine derived from hydration of the peridotites may have functioned as lubricating layers that permitted great blocks to slide over one another during periods of late Mesozoic thrust faulting.

Cretaceous Folding and Thrusting

The Cretaceous strata of the Klamath Mountains Province consist of well-washed sandstones, chert-pebble conglomerates, and siltstones.

Evidence of contemporaneous volcanic activity is completely lacking; overall, the Cretaceous section differs markedly from the eugeosynclinal piles of earlier Mesozoic times. The strata represent deposition on the continental shelf rather than on the continental slope and the deep-sea floor and are most appropriately referred to as miogeosynclinal. In a plate-tectonic sense they record deposition during the later stages of development of the basement rocks of the Klamath Mountains area.

The Cretaceous was not a time of tectonic inactivity, however. Compression continued, and regional folds, faults, and large-scale thrusts developed. According to Coleman (1972) the Colebrooke Schist is involved in imbricate thrust pattern with the Myrtle Group, indicating post Early Cretaceous thrusting. Thrust faults in the lower member of the Umpqua Formation and isoclinal folding (Baldwin, 1964) indicate that compressional deformation may have continued intermittently well into the Eocene (Baldwin and Lent, 1972).

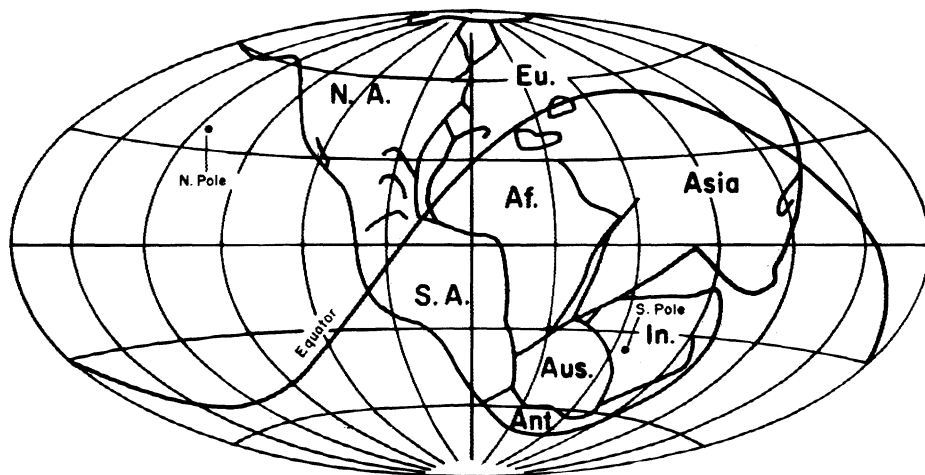


Figure 4. A generalized representation of the Permian supercontinent of Pangaea. By the end of Mesozoic times crustal rifting had fragmented the protocontinent to give the seven more or less autonomous continents we recognize today (adapted from Clark, 1971).

Eocene Rifting

The Eocene epoch is represented by the Clarno Formation in north-central Oregon, the Colestin Formation in southwestern Oregon, and a variety of subaerial and submarine volcanic and marine sedimentary rocks in northwestern and west-central Oregon including the Umpqua Formation, Siletz River Volcanics, Tyee Formation, Nestucca Formation, Elkton Siltstone, Yamhill Formation, Goble Volcanics, and others. The extent of Eocene strata in the subsurface of southeastern Oregon is unknown. The andesitic composition of the Clarno and Colestin Formations may suggest possible subduction in Eocene times.

Attention has been focused recently on the more mafic volcanic units that make up much of the Coast Range. According to McWilliams (1972), the pattern of distribution of the various volcanic and sedimentary rock units is such that progressively older Eocene strata form the basement northward in Washington and southward in Oregon. Paleocene ages have been assigned to parts of the lower Umpqua in southwestern Oregon (Baldwin, 1964), whereas rocks no older than late and possibly middle Eocene (Nestucca Formation, Goble Volcanics, Keasey Formation, and the Tillamook Volcanics) are known in northwestern Oregon. McWilliams (1972) infers an easterly trending zone of rifting in northwestern Oregon throughout Eocene times and postulates that the volcanic rocks were generated along a sea-floor rise. It is noteworthy that Atwater (1970) independently postulates an east-trending sea-floor rise in the vicinity of Oregon in Eocene times on the basis of paleomagnetic data.

Previously, Snavely and others (1968) noted the close petrographic similarity between the Siletz River Volcanics and the floor of the present-day Pacific Ocean. Also, Thiruvathukal and others (1970) and Johnson and Couch (1970) demonstrate rather conclusively on the basis of geophysical evidence that no appreciable root underlies the Coast Range.

If the Eocene volcanic rocks of the Oregon Coast Range do indeed represent volcanic activity closely related to the rifting floor of the Eocene Pacific Ocean as suggested by the above data, it follows that the concept of an Eocene trough as proposed by the geosynclinal model is no longer valid (McWilliams, 1972). We may have to begin thinking in terms of Eocene sea floor generated along a rift zone which progressively displaced the older rocks to the north and the south. There may be no rocks older than late Eocene in the subsurface of parts of northwestern Oregon.

According to the rift model, the Eocene volcanics and associated sediments of present-day western Oregon became incorporated into the North American continent in early Tertiary times through progressive deformation, overriding, and uplift brought about by the continuing westward migration of the North American Plate. Reconstructing the Eocene paleogeography, the various turbidite units including the Umpqua Formation and Tyee Formation may represent abyssal fans spreading over the crumpling sea floor. The

numerous scattered unconformities throughout the Eocene may record periods of especially intense collision. It is noteworthy that the lower member of the Umpqua Formation is characterized by thrusting and isoclinal folding, features which are strongly suggestive of plate collision.

Oligocene Subduction

Explosive volcanism of andesitic composition characterized much of Oregon in Oligocene times and is recorded in a variety of marine and non-marine units throughout the state. The John Day Formation consists of several thousands of feet of ash blown from scattered vents and deposited throughout north-central Oregon. Although Oligocene beds in southern Oregon are poorly exposed, the Pike Creek beds on the southeast flank of Steens Mountain and the "Cedarville Series" of south-central Oregon suggest that volcanism analogous to that of the John Day was extensive throughout eastern Oregon in middle Tertiary times.

To the west the andesitic breccias, flows, and ash-flows of the Little Butte Volcanic Series (Peck and others, 1964) constitute the bulk of the Western Cascades. Farther to the west in the Coast Range, scattered intrusive rocks of Oligocene age indicate additional tectonic activity in that area. Moreover, virtually all the marine deposits of Oligocene age in western Oregon (including the Tunnel Point Formation, siltstone at Alsea, the Eugene Formation and other Oligocene marine units) are notably tuffaceous in composition.

On the basis of widespread explosive andesitic volcanism similar to that associated with active Benioff zones of today, active subduction beneath what is now the state of Oregon is inferred for Oligocene times. Recently Lipman and others (1971) defined two east-dipping subduction zones underlying western North America on the basis of plotted variations of K_2O/SiO_2 ratios in carefully collected igneous rocks. Conceivably one of these subduction zones was active in the Oligocene. Also, heat-flow patterns plotted by Blackwell (1971) are consistent with the concept of plunging lithosphere plate beneath Oregon in the geologic past. More recently, MacKenzie and Julian (1971) have defined on the basis of seismic evidence a subducted plate plunging eastward beneath the state of Washington.

Miocene Rifting

Oligocene explosive andesitic volcanism was succeeded in middle to late Miocene times by a tremendous outpouring of flood basalts over much of the northwestern United States on a scale that has been equalled only rarely in all of geologic time. The flows contrast markedly with the earlier eruptions and consist primarily of tholeiitic (little or no olivine) and high alumina basalt. They are assigned to the Columbia River Group in

southern Washington and northern Oregon, to the Owyhee Basalt in eastern Oregon, to the Steens Basalt and the unnamed igneous complex (Kittelman and others, 1965) in southeastern Oregon, and to a variety of unnamed Miocene volcanic rock units in south-central Oregon. In Idaho the slightly younger Snake River Basalts are analogous to the Miocene outpourings in many respects.

The great volume and markedly different composition of the Miocene basalts signal a profound and fundamental change in tectonic style in the northwestern part of the United States in middle Miocene times. The rocks are not the kind commonly associated with subduction zones and regions of plate collision. Rather they are characteristic of rifting and plate divergence. Swarms of dikes which fed the flows have been identified in parts of eastern Oregon and central Washington and are suggested in the subsurface in the Pasco Basin by geophysical evidence (Hill, 1972). The dikes and regional patterns of late Miocene and Pliocene block faulting are suggestive of tensional processes. Clearly, the whole tectonic character of the northwestern United States shifted abruptly from one of compression to one of rifting in middle Miocene times.

Regional geophysical evidence also favors the concept of rifting in middle and late Miocene times. As in present-day areas of rifting, the parts of Oregon underlain by flood basalts are characterized by high heat flow (Blackwell, 1971), shallow crust (Hill, 1972; Hamilton and Myers, 1966), and anomalous mantle (Gilluly, 1970). Hamilton and Myers (1966) and Gilluly (1970) have rigorously analyzed the geometry of the block faulting of the Basin and Range Province and conclude that significant crustal extension in an east-west direction has occurred since the Miocene. Finally, the uplifted structural pattern of the entire Basin and Range Province is similar to that observed in areas overlying inferred crustal rifting elsewhere in the world.

From a variety of regional plate tectonic and topical studies involving the western part of North America, the Pacific Basin, and the San Andreas Fault a picture is emerging in which the North American continent is seen to override the deep-sea floor of the ancestral east Pacific Ocean in early Tertiary times and to meet the actual sea-floor rise system of the Pacific Ocean in the mid-Tertiary (Atwater, 1970). At this time the compressional processes resulting from subduction were superseded by tensional processes the nature of which is not clearly understood.

Until recently it was postulated that the East Pacific Rise was overridden by the North American Plate and that tensional phenomena in late Tertiary times were an indirect result of continued rifting deep within the mantle. According to Atwater (1970), however, present concepts relating to plate mechanics and the precise nature of the boundaries between plates no longer permit such an interpretation; lithospheric slabs cannot override sea-floor rises.

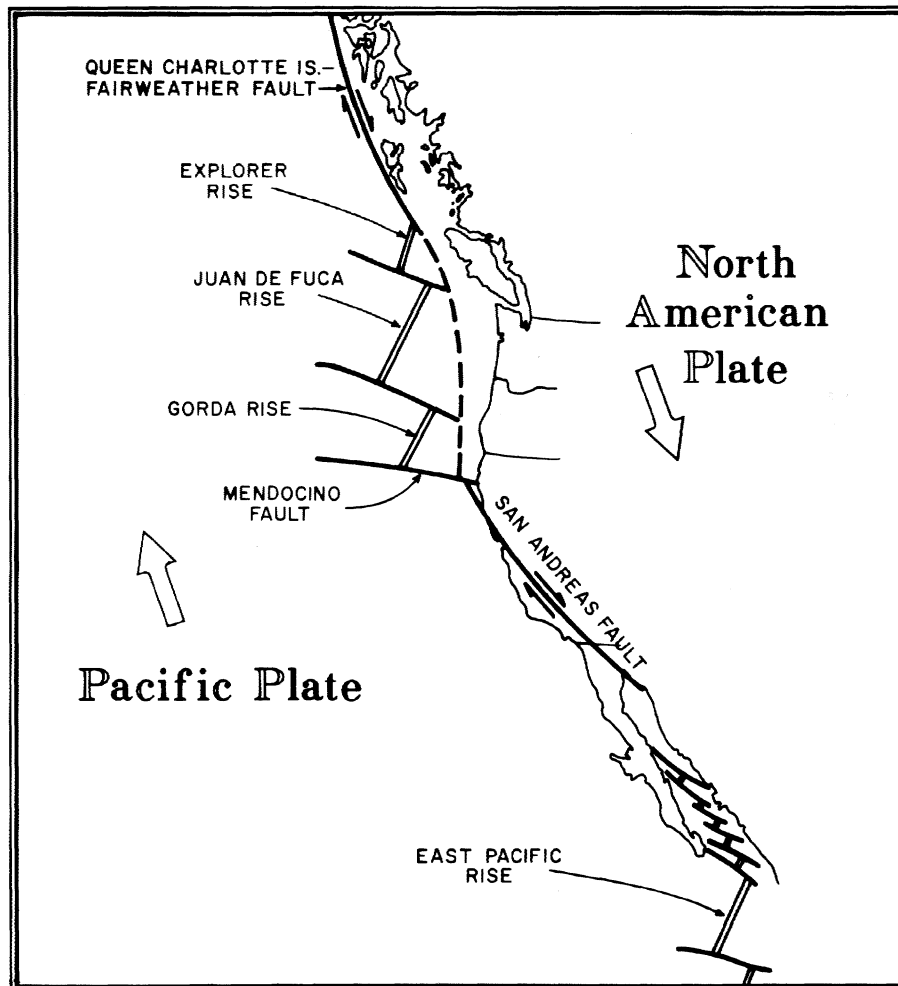


Figure 5. Index map of western North America showing the various faults and rift systems which make up the boundary between the North American Plate and the East Pacific Plate. At present the East Pacific Plate is moving northwest relative to the North American Plate. In the opinion of Atwater (1970) much of the late Tertiary deformation of the Western United States can be explained in terms of a broad zone of shearing between the more rigid central portions of the two plates.

Atwater (1970) postulates, rather, that a wide zone of deformation separates the North American Plate and the Pacific Plate (Figure 5). The geometry of relative movement allows for considerable tension as the two plates grind past one another. Although this may be the mechanism by which late Tertiary block faulting and tholeiitic volcanism has developed in Oregon, many advocates of sea-floor spreading do not find it very appealing. If plate movement and plate interaction is to explain tectonism, we cannot relegate tens of thousands of square miles of anomalous terrain to poorly defined "mush zones" between plates. Clearly, much remains to be done in the field of plate tectonics.

Conclusions

The plate tectonic history of Oregon is but one piece of a worldwide jigsaw puzzle encompassing much of geologic time. With the splitting of Pangaea in Mesozoic times, Oregon has occupied the leading edge of the North American Plate as it has impinged upon the ancestral oceanic East Pacific Plate. In the process Oregon has undergone profound subduction type tectonism. In addition, it may have acquired much lithospheric material from other plates, possibly some of the Paleozoic rocks of the Klamaths from Asia, ultramafic rocks and volcanic rocks from the Triassic oceanic crust, and the Siletz River Volcanics from the Eocene deep-sea floor.

In middle Tertiary times, Oregon, along with the rest of western North America, actually caught up with the East Pacific Rise, an event which profoundly altered the pattern of tectonic behavior within the state. Flood basalts and block faulting replaced andesitic volcanism and thrust faulting as the dominant mode of tectonism. The pattern of deformation in late Tertiary times is extremely complex and a plate tectonic model consistent with all the data has yet to be formulated.

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ORE BIN SUBSCRIPTION FOR 1973

\$2.00

January 1 through December 31

FORMER COUNTY COMMISSIONER ON GOVERNING BOARD

Governor Tom McCall has announced the appointment of Donald G. McGregor of Grants Pass to the Governing Board of the Department of Geology and Mineral Industries. McGregor succeeds Fayette I. Bristol of Rogue River, who served two terms.

McGregor, who will serve on the Board until March 15, 1976, was a Grants Pass retailer for 25 years, served six years on the Josephine County Board of Commissioners, and was Josephine County "Man of the Year" in 1945. He has served as State Parks Advisory Board representative to the Governor's Livable Oregon Committee and is a member of the Citizens Advisory Council to Southern Oregon College.

McGregor was born in Lincoln, Nebraska, graduating from the University of Nebraska School of Business Administration in 1924. He and his wife, Lucille, live at 924 N.E. Savage Street in Grants Pass. They have two sons and two daughters.

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GEOLOGICAL HIGHWAY MAP SERIES IN PROGRESS

A series of full-color, regional geological highway maps are being issued by the American Association of Petroleum Geologists (in cooperation with the U.S. Geological Survey) for the benefit of tourists, amateur geologists, and the general public. The colored maps show the age and distribution of the various rock types and explain the origin of the land forms. Up-to-date state and federal highway maps are used as the base. Maps published so far cover the following regions:

- Map 1. Mid-Continent (Kan., Mo., Okla., Ark.)
- Map 2. Southern Rockies (Ariz., Colo., New Mex., Utah)
- Map 3. Pacific Southwest (Calif., Nev.)
- Map 4. Mid-Atlantic (Ky., W.Va., Va., Md., Del., Tenn., N. Car., S. Car.)
- Map 5. Northern Rockies (Ida., Mont., Wyo.)

A regional map that will include Oregon and Washington will be available within the next year, it is reported.

Each map is 28 by 36 inches at a scale of 1 inch = 30 miles. The maps may be ordered from AAPG, P.O. Box 979, Tulsa, Oklahoma 74101. The price per map is \$1.50 folded, or \$1.75 rolled, plus 50 cents for handling charges.

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