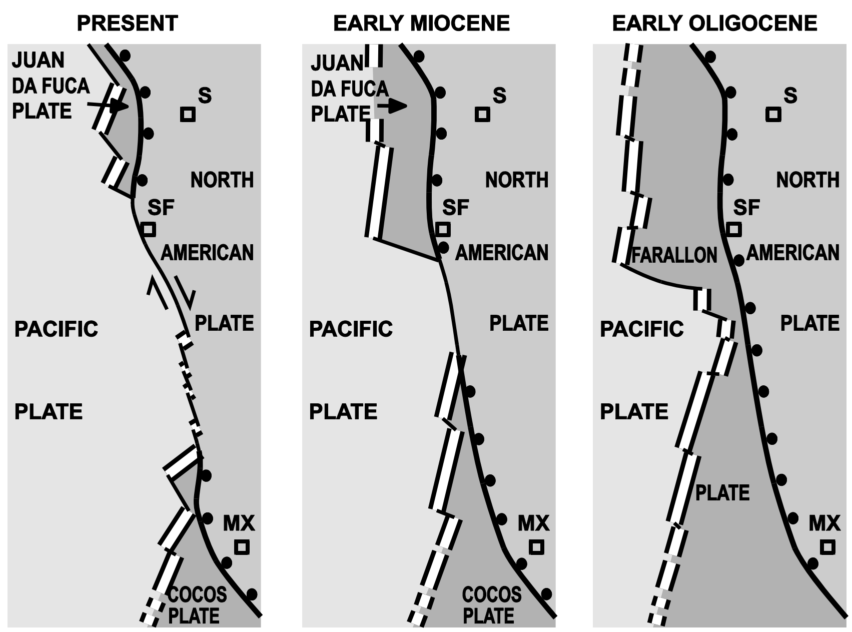
g12 Unraveling the prehistory of Western North America

< 6 cm/yr >

The prize for the first headline use of “plate tectonics” (a 1969 buzz phrase, and used at the time by Dan P. McKenzie and W. Jason Morgan in the text of an article in *Nature*)[1] goes to **Tanya Atwater** who in 1970 published *Implications of plate tectonics for the Cenozoic tectonic evolution of western North America*.[2]

“I [had] learned many things from Bill Menard,[[3]] among them that a new object or phenomenon needs to have a name in order to hold a place in the human mind. ... [For] example, I worked with fellow graduate student John Grow on a paper about the oceanic plate that once lay north of the Pacific plate and that was entirely subducted northward beneath Alaska and the Aleutian island arc” ... Walter Pitman and Dennis Hayes at Lamont had already pointed out the evidence for [this plate], but they had described it and its neighbors as plates I, II, III, and IV, not exactly names that stick in the mind. ... Plates I, III, and IV were, in fact, the Pacific, North American, and Farallon plates. We needed a name for plate II, ... Donna Hawkins, who had done social work with Native American peoples in Alaska, ... dug out her dictionaries and came up with a possible list of names and their definitions. We chose ‘Kula,’ the Athabascan word meaning ‘all gone.’”



Maps *after* Tanya Atwater, 1970, are of western North America. Currently, the differential motion between the Pacific and North America plates is right-lateral at 6 cm/yr. Taking this as a constant, and from the known geology, the other maps show past configurations.

Key: oceanic ridges (double line), transform faults (single line), oceanic trenches (single line with dots (for active volcanoes) on unsubducted plate side of it), S=Seattle, SF=San Francisco, MX=Mexico City

Today

Western North America inland from the coast is mostly at high elevation undergoing erosion. However, several low elevation basins with internal drainage, and some very large with poor drainage, as the Central Valley of California, accumulate great thickness of record-bearing sediments.

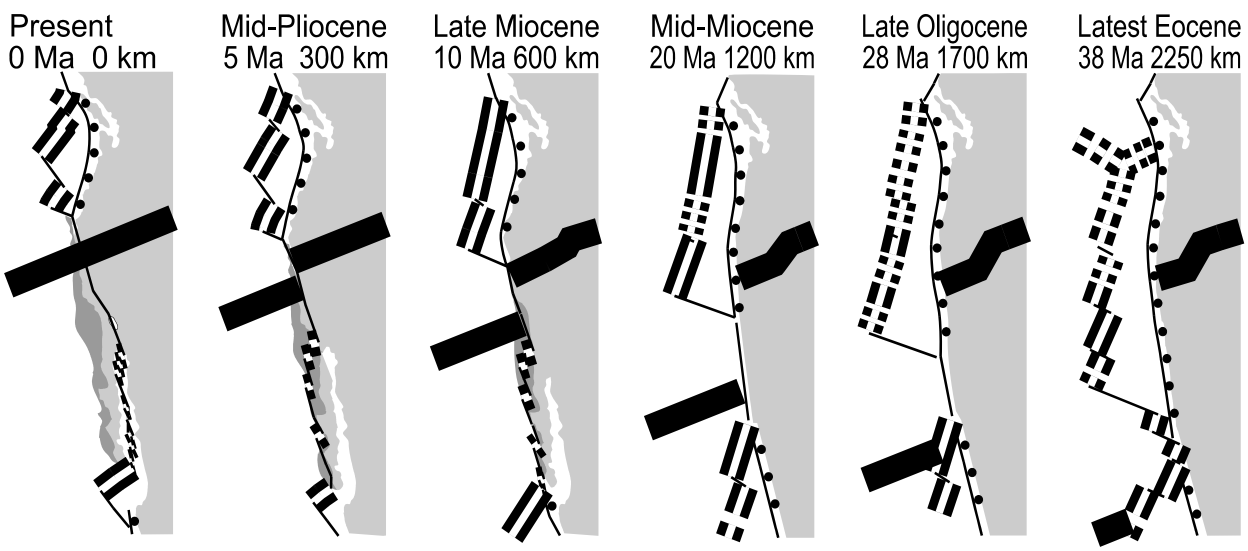
Cascade Mountain volcanism is related to the subduction of Juan da Fuca plate beneath the North American plate. An associated trench (sediment covered) parallels the coast south from just north of Vancouver Island to the Mendocino triple junction (the point, seaward, north of San Francisco, where the Juan da Fuca, North American, and Pacific plates conjoin).

South of the Mendocino triple junction, the Mendocino fault zone (the southern margin of the Juan da Fuca plate) continues inland as a system of transform faults. The most prominent of these is the

San Andreas Fault that joins to the ridge in the Gulf of California (Sea of Cortez). This ridge is the northern end of the East Pacific Rise ridge which is the divergent margin between the North American and the Pacific plates. Seafloor spreading opens the Gulf. The crack runs north to the Salton Sea geothermal field.[4] The western side of the Gulf is the east coast of a large block of the North American continent that is part of the Pacific plate. This block is bounded north of the Gulf on its eastern side by the San Andreas Fault. The San Andreas Fault is a transform-fault boundary between the North American plate and the Pacific plate. Thus, unlike the Juan da Fuca and the Cocos plates, the Pacific plate is not subducting beneath the North American plate. Corroborating this is that between San Francisco and Guaymas, the Cascade subduction-related strato-volcanoes are extinct.

The present absolute motions of the North American and Pacific plates are known to be counterclockwise. The North American plate is rotating about a pole within it and the motion of the Pacific plate moves its eastern margin north-northwest. Consequently, the shear displacement between them and which is partly accommodated by the San Andreas Fault system, is right-lateral strike-slip.[5]

The maps below are of western North America. A reference line (wide black), is drawn though San Francisco at right angles to the present NNW movement of the Pacific and North America plates. Currently, the differential motion between these plates is right-lateral strike-slip at 6 cm/yr. Taking this as a constant, and from the known geology, the other maps show past configurations. *After* Atwater (1970). *Key*: oceanic ridges (double line), transform faults (single line), oceanic trenches (single line with dots for active volcanoes on the unsubducted-plate side of it), emergent land (pale gray), submerged continental margin (gray), water (white). Ma = million years ago.



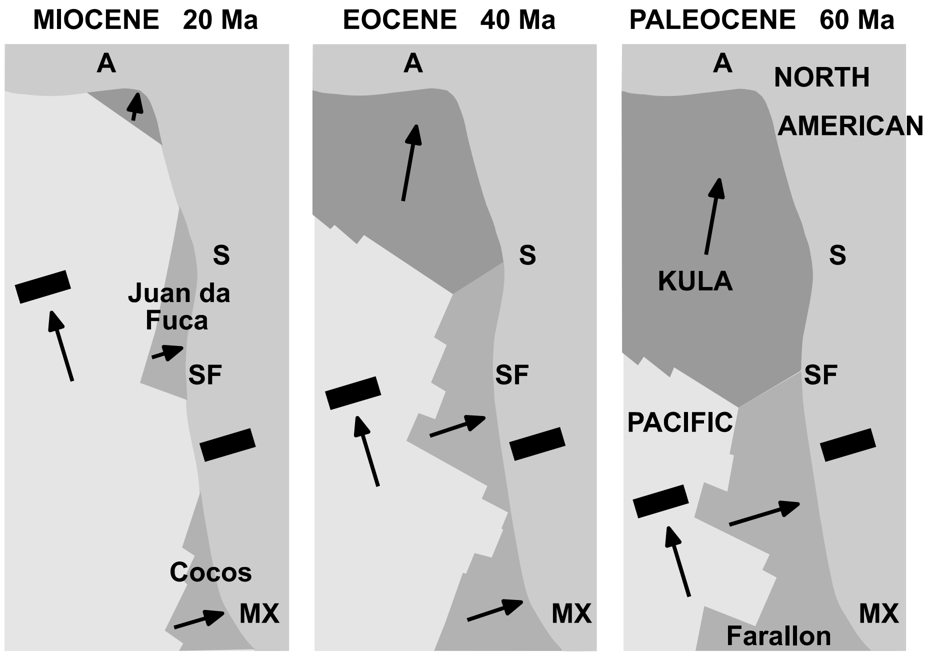
Pliocene

The Sea of Cortez began to open its true deep seafloor during the Pliocene. Its present narrowness is consistent with this. Linked to its opening was the inception of the present San Andreas Fault system that, from a study of related details of local sedimentary accumulations and deformations, has been active for some 5 million years. Offset by this fault system are batholithic granites and metamorphic rocks that would otherwise be a southern on-strike continuation of the Sierra Nevada. The measured right-lateral strike-slip for these is 315 kilometers. That accords with the present 6 centimeters a year displacement across the San Andreas fault, being the average rate since the Mid-Pliocene (5 Ma). The thin continental crust and horst-and-graben faulting of the Basin and Range province could be due to either, both, or neither of:

1) Differential motion between the Pacific and North American plates that causes clockwise distortion and east-west tensional strain of the region,

2) A ramifying, incipient, oceanic-ridge boundary between the Pacific and North American plates.

Plates and their directions of motion (arrows) with the absolute NNW offset of the Pacific plate with respect to the America plate indicated by a reference bar (wide black) on each. *After* Atwater (1970). *Key*: A=Anchorage, S=Seattle, SF=San Francisco, MX=Mexico City.



Miocene

In the Late Miocene, there is no evidence of the present San Andreas fault, but the offshore continental margin was complexly faulted, folded, and sedimented. This indicates that the transform-fault system, which connects between the Juan da Fuca and Cocos plates, was then located along the edge of the North American continent.

Eocene

During the Eocene (***Figure g12.1***), south of where Seattle is today, a continuous trench, as is recorded inland by arc-related volcanics, was parallel the coast. By contrast, north along the coast subduction facies of the same age are not in evidence. Reversing today's known absolute plate motion by 40 My, pulls back out from beneath Alaska a vanished plate called the *Kula* plate. Atwater has proposed that far out to sea, west of where Seattle is today an oceanic-ridge triple-junction would have existed between the Kula, Juan da Fuca, and Pacific plates.

The boundary between the Kula plate and the North American plate was, as trench facies are absent, a transform fault. Its existence at the time, and for long before, is evidenced by discordant blocks (terrane fragments) of the North American plate margin that are transcurrent-fault displaced great distances north from correlatives in the south (***Figure g12.2***).

Paleocene

During the Paleocene, south along the coast from where San Francisco is today and recorded inland by arc-related volcanism, was an oceanic trench. By contrast, north along the coast there is no evidence of subduction during this time.

Reversing today's absolute plate motion by 60 My moves the triple junction between the Kula, Juan da Fuca, and Pacific plates, south and seaward of where San Francisco is today. Likely, the Juan da Fuca and the Cocos plates were then one. That plate has been named the *Farallon* plate.

Block uplift, shedding of sediments, and magmatism record the particular style of the Laramide orogeny in the Paleogene. Its effects were local to the Central and Southern Rocky Mountains. This focus suggests a straight-on collision. Related magmatism far inland from the coast, records shallow subduction of the Farallon plate under the North American plate.

Late Cretaceous

Eastward migration of the focus of the Laramide orogeny records a shallowing of the causing Farallon-plate subduction that began in the Late Cretaceous.

Jurassic

In western North America, orogenies continuing into the Early Cretaceous that began during the Jurassic are collectively called the *Nevadan* orogeny. Throughout that time, normal subduction is recorded by island arc facies along the entire length of the Cordilleras. Details are in the erosionally exposed granitic batholiths and associated metamorphic rocks, and in the compression-folded and thrust-faulted strata. Arrivals of terranes occasioned major compressional events.[6] Associated are thrust faults and thin-skinned tectonics that give special character to the geology of the Northern Rockies and the Canadian Cordillera. ❑

Figure g12.1 [7] (below) The ongoing absolute-displacements of the continents can be judged from this map that shows the continents in their present positions (dark gray superimposed on where their areas were (black) in the Eocene. (In this Lambert Equal Area map projection, Earth's far side is in the pale gray area.)

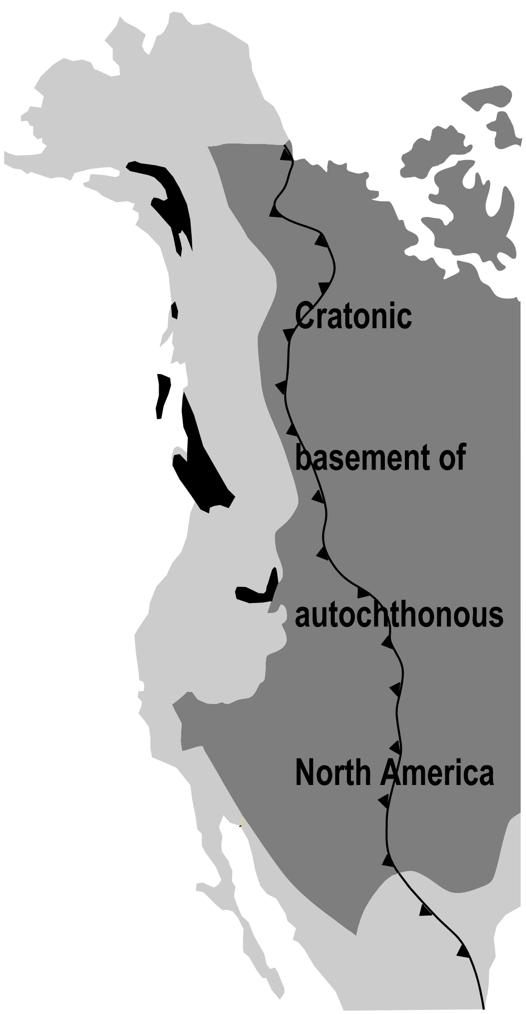


Figure g12.2 [8] (left) Wrangellia terrane fragments (black areas). The barbed line marks the eastern limit of Cordilleran Cenozoic and Mesozoic orogenic deformations.