California Geography

ERA	PERIOD	EPOCH (million years ago)	IMPORTANT GEOLOGIC EVENTS IN CALIFORNIA
CENOZOIC	TERTIARY	Pleistocene	Ice age glaciers carve high areas of the Sierra Nevada and Klamath block. Large lakes flood valleys in Modoc Plateau and Basin and Range. Volcanoes erupt in High Cascades.
		2	
		Pliocene	Sierra Nevada begins to rise; Sutter Buttes volcanoes erupt. Sediments eroded from the Sierra Nevada and Coast Range deposited in Great Valley.
		5	
		Miocene	San Andreas fault lengthens northward as Franciscan trench shortens. Monterey formation accumulates in Coast Range. Flood basalts cover Modoc Plateau. Basin and Range begins to open.
		24	
		Oligocene	Franciscan trench stops jamming oceanic sediments under the Coast Range ophiolite. Cascade volcanoes cover much of Sierra Nevada with ash and lava.
		36	
		Eocene	Streams deposit auriferous gravels in northern Sierra Nevada.
		58	
		Paleocene	
		65	
MESOZOIC	CRETACEOUS		Klamath block separates from Sierra Nevada and moves 60 miles west. Sediments eroded from Sierra Nevada begin to fill Great Valley. Franciscan trench drags sediments under western edge of Coast Range ophiolite, raising first western margin of Great Valley.
		145	
	JURASSIC		Sierran trench jumps 60 miles west to become the Franciscan trench. Oceanic crust of Smartville complex forms about 160 million years ago. Deep continental crust melts into granite magmas that rise into the older rocks of the Sierra Nevada. A chain of volcanoes erupts above the granite batholiths. Sierran trench jams rocks of Calaveras complex onto and under the Shoo Fly complex of eastern Sierra Nevada.
		208	
	TRIASSIC		Ocean floor begins sliding through the Sierran trench, under continental rocks in the Sierra Nevada and Klamath block.
		245	
PALEOZOIC	PERMIAN		Rocks of Calaveras complex deposited on ocean floor and erupted from volcanoes.
		286	
	PENNSYLVANIAN		
		320	
	MISSISSIPPIAN		Antler mountain building event jams older rocks against the margin of the continent, transforming them into tightly folded metamorphic rocks of the Shoo Fly complex.
		360	
	DEVONIAN		
		408	
	SILURIAN		
		438	
	ORDOVICIAN		Oceanic crust of Trinity ophiolite forms and acquires a cover of oceanic sediments.
		505	
	CAMBRIAN		
		570	
PRE-CAMBRIAN	PROTEROZOIC		
		2,500	
	ARCHEAN		Ancient North American continental core formed east of California.

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Introduction

Two hundred million years ago, the western edge of North America was somewhere near the present eastern edge of California. A little more than 200 million years ago, North America began moving west, away from the mid-Atlantic oceanic ridge, where the Atlantic Ocean was beginning to grow. The moving continent collided with the floor of the Pacific Ocean, which sank beneath the continent's oncoming western edge, then disappeared into the hot depths of the earth's mantle. But the sediments and volcanic islands on the oceanic floor were too light to sink. They crumpled in the grinding encounter between continent and ocean floor, to become most of California. And that, briefly told, is the big picture, the basic origin of northern and central California. Now, some details.

PLATE TECTONICS

Like many really powerful scientific theories, plate tectonics is basically simple and easy to understand. It starts with the idea that the earth has a cold and relatively rigid outer rind about 60 miles thick, the lithosphere. The lithosphere consists of segments called plates that cover the earth's surface like the bones in a skull. The earth has about a dozen large plates and an imperfectly known, but small, number of lesser plates. Some plates have only oceanic crust on their surfaces, some have only continental crust, but most have areas of each.

Plates move about the surface of the earth in an apparently random pattern that shows no hint of a grand design. Some pull away from each other, some slide past each other, and some collide with each other, either directly or obliquely.

Roadside Geology of Northern Cal..., Alt & Hyndman (2000)

Oceanic ridges mark the lines where plates pull away from each other. Every ocean has one, a long ridge with a deep rift along its crest that runs the length of the ocean. The opposite sides of the ridge move away from each other at a rate of about 2 inches per year. From time to time, a fissure opens in the rift, and an enormous basalt lava flow erupts from it, forming new oceanic crust. The ocean floor grows flow by flow.

If new oceanic crust forms at the crests of oceanic ridges, then old oceanic crust must disappear somewhere else. That happens where plates collide. One plate slides beneath the other and on down into the earth's mantle. An oceanic trench appears where the sinking plate bends down as it starts its long slide into the depths. The trench appears as a long trough on maps of the ocean floor. A chain of volcanoes rises above the sinking plate parallel to it and 50 to 200 miles away. Continental crust is too light to sink. It stays on the surface, carrying the rocks that contain the record of the earth's history, the planetary archives.

Plates slide horizontally past each other along transform boundaries. The San Andreas fault, which separates the North American and Pacific plates, is the most famous example of such a boundary. All transform boundaries connect oceanic trenches and ridges in some combination. The San Andreas fault connects the East Pacific ridge with a trench off the coast of northern California, Oregon, and Washington. Transform boundaries define the edges of plates moving away from oceanic ridges and oceanic trenches.

THE OLD CONTINENT

A continent of unknown size, shape, and location existed a billion or more years ago. A continent is a floating raft composed mostly of relatively light igneous and metamorphic rocks, mainly granite, gneiss, and schist. Those are the rocks of the continental crust, the rocks geologists often call basement rocks because they lie beneath all younger rocks.

Our best information about the thickness of continental crust comes from the study of earthquake waves. Seismographic records of earthquakes generally show an echo that follows several seconds after the primary shock wave. This echo appears to reflect off the base of the continental crust. Measurements of the timing of the echoing earthquake waves show that, in most areas, the continental crust is about 25 to 30 miles thick.

TALE OF THREE TRENCHES

The story of northern and central California is mainly a tale of three oceanic trenches. The first of our three trenches appeared during late Devonian and Mississippian time, about 350 million years ago. The old

continent of North America then collided with the ocean floor in what is known as the Antler mountain building event. That collision crushed the oceanic sediments that had accumulated along the coast of North America into the western edge of the continent. The crushing deformed the sediments into tight folds, broke them along faults, and heated them enough to recrystallize them into metamorphic rocks. Those abused rocks, the Shoo Fly complex, now form most of the eastern Sierra Nevada.

Then the Antler collision ended, its trench disappeared, and the rocks of the Shoo Fly complex became the new western fringe of California. A new generation of sediments quietly accumulated to make a new coastal plain along the new coast. The former edge of the old continent is now somewhere near the eastern border of California.

The second trench, the Sierran trench, appeared about the end of Triassic time, about 200 million years ago. That was when the old continent broke along the line of the mid-Atlantic ridge. North America began moving west as the Atlantic Ocean opened behind it, and Eurasia began to move east, also away from the mid-Atlantic ridge. The new North America again collided with oceanic crust along its western edge. This collision first smashed the sediments that had collected along the new coast against the rocks of the Shoo Fly complex, converting them into another mass of horribly deformed and considerably recrystallized rocks, the Calaveras complex. The Calaveras complex is now a long central strip of the Sierra Nevada.

As the collision continued along the line of the Sierran trench, more sedimentary rocks and many volcanic rocks jammed against the Shoo Fly complex. They included such odds and ends as old volcanic islands and sediments that could only have accumulated on the deepest and most remote reaches of the ocean floor. These rocks were thoroughly deformed and recrystallized. Geologists call them the Western Jurassic terrane.

Then, for reasons that remain unknown, the line of collision between continent and ocean floor jumped west about 60 miles. That probably happened during early Cretaceous time, about 130 million years ago. That was when the northern end of the Sierra Nevada detached and moved 60 miles west to become the Klamath Mountains. The gap between the old and new lines of sinking eventually became the Great Valley. We refer to the new line of sinking as the Franciscan trench. It created the Coast Range.

Sediments that were swept into the Franciscan trench were jammed against the western edge of the Klamath Mountains in the north and against the edge of a strip of oceanic crust some 60 miles wide farther south. It would eventually become the bedrock foundation under the Great Valley.

When the Franciscan trench eventually went out of business, between about 30 and 15 million years ago, the sediments stuffed into it rose to become the Franciscan rocks of the western part of the Coast Range. Some of them had been dragged under the edge of the strip of oceanic crust, and they rose too, jacking the edge of that strip up to a steep angle to become the Great Valley sequence along the eastern side of the Coast Range.

MODOC SEAWAY

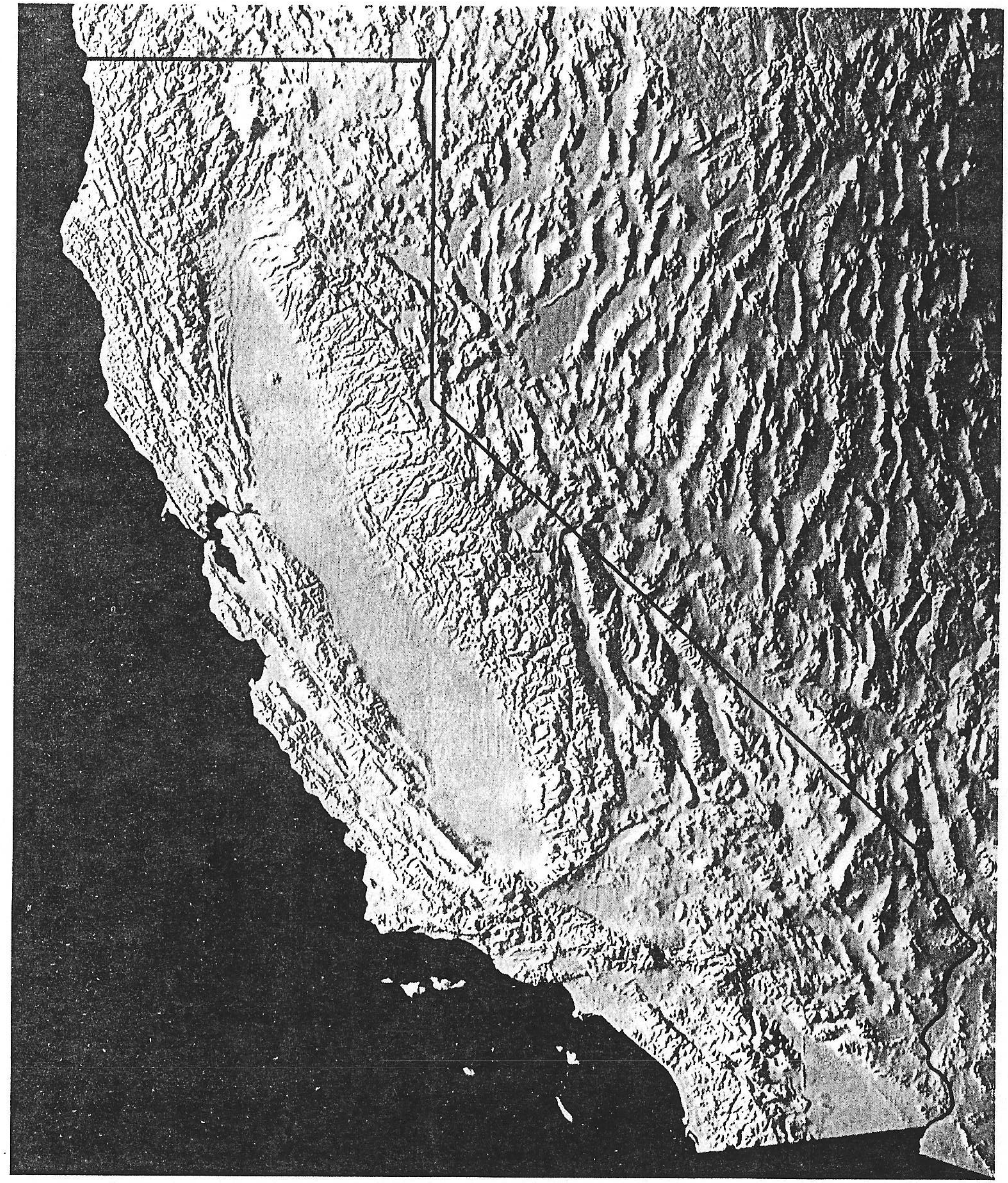
No one seems to understand why or how the Klamath Mountains detached from the north end of the Sierra Nevada, but they did. The rocks show that a seaway opened east of that displaced block as it moved west. The seaway was almost landlocked, so sediment entered from all directions; it was filled within a few tens of millions of years, by the end of Cretaceous time. It was a flat plain then, but volcanic rocks have since covered it, and faults have broken it into mountains and basins.

FLOOD BASALT FLOWS

A little more than 17 million years ago, an enormous center of volcanic activity appeared in the southeastern corner of Oregon. Its edges probably lapped into southwestern Idaho and northern Nevada. We think it developed in the crater that opened where an asteroid struck the earth and exploded. Many other geologists argue that a huge mass of especially hot rock rose through the mantle and partly melted to form basalt magma. Whatever the cause, something drastic certainly happened about 17 million years ago that seems to have started a great many other events. The coming of the flood basalts coincided with the establishment of most of the San Andreas fault, the rise of the Coast Range, and the beginning of crustal stretching in the Basin and Range.

That great volcanic center in southeastern Oregon was one of those that erupt flood basalt flows—lava flows so overwhelming that they add an entirely new dimension to our ordinary notions of volcanic catastrophe. They may contain more than 100 cubic miles of lava, hundreds of times more than the volumes of ordinary basalt flows. These basalt flows flooded all the low areas around the great volcano, which was not a mountain but a volcanic plateau.

Some of those floods of molten lava poured southwest across the sediments that filled the Modoc seaway. They covered it with enormous sheets of basalt, making it the southern end of the great Pacific Northwest flood basalt province. The big flood basalt eruptions ended about 15.5 million years ago. The earth has not seen their like since.



California as seen from space.
—G. P. Thelin and R. J. Pike, U.S. Geological Survey

BASIN AND RANGE

The Basin and Range is a vast province of isolated mountain ranges set between broad desert basins. It stretches from eastern Oregon south into Mexico, and from the eastern front of the Sierra Nevada to the Wasatch Front in Utah. The part that embraces most of Nevada and western Utah is the Great Basin. It includes the part of California east of the Sierra Nevada crest and east of the Warner Mountains, in the northeastern corner of the state.

Since middle Miocene time, during the past 16 million or so years, the continental crust in the Basin and Range has stretched from east to west and has greatly thinned. No one knows exactly how far the region has stretched, but most geologists estimate that it is now at least twice as wide as it was.

SAN ANDREAS FAULT

The ocean floor that sank through the Franciscan trench belonged to the Farallon plate, which was growing from an oceanic ridge to the west. New oceanic crust formed at the ridge, then sank beneath the oncoming western edge of North America. As North America moved west, it finally reached the ridge where the Farallon plate was forming. The last of the plate disappeared as the ridge met the trench. The ridge and trench annihilated each other in an act of mutually assured destruction. As the last of the Farallon plate vanished into the earth's mantle, the western edge of North America met the Pacific plate. That new plate boundary is the San Andreas fault, actually a swarm of parallel faults.

All the rocks west of the San Andreas fault belong to the Pacific plate, those east of it to the North American plate. The Pacific plate is moving north at a rate of approximately 2 inches per year and has so far carried the part of California west of the fault at least 350 miles north.

HIGH CASCADES

Volcanoes had been erupting in the Western Cascades before the eruptions of flood basalts. That volcanic chain died when the flood basalt eruptions began. The new chain of volcanoes is the modern High Cascades, parallel to what remains of the Franciscan trench. Shasta and Lassen are the best-known volcanoes of this range in California.

WHITHER CALIFORNIA?

Someone once described history as just "one damned thing after another." That seems equally true of geologic history. The geologic development of California seemed firmly set on a predictable course until the flood basalts, Basin and Range, and extinction of the Western Cascades volcanoes changed the agenda about 17 million years ago. Now the situation again seems fairly stable and the future fairly predictable.

If present trends continue, the slice of California west of the San Andreas fault will continue to move north and will part company with the rest of California sometime around 15 million years from now. It should eventually arrive in Alaska. Other members of the San Andreas system of faults will continue to slice the Coast Range into long slivers. Meanwhile, new faults in the western edge of the Basin and Range will take great slices off the eastern Sierra Nevada, creating new ranges like the White Mountains and new valleys like the Owens Valley.

All that will happen right on schedule if no unpredictable happening again changes the course of events. Given the great length of geologic time and the number of unpredictable events that could happen, one will happen, eventually.