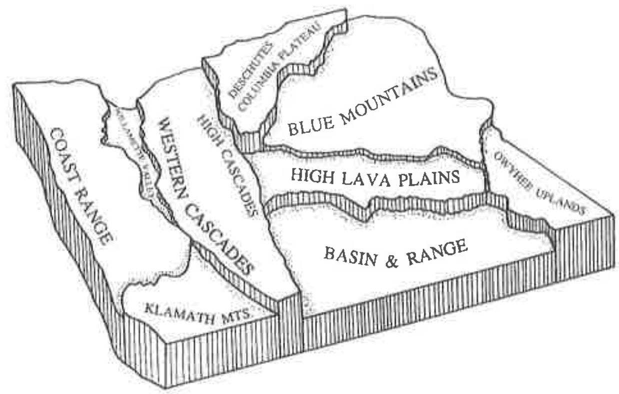
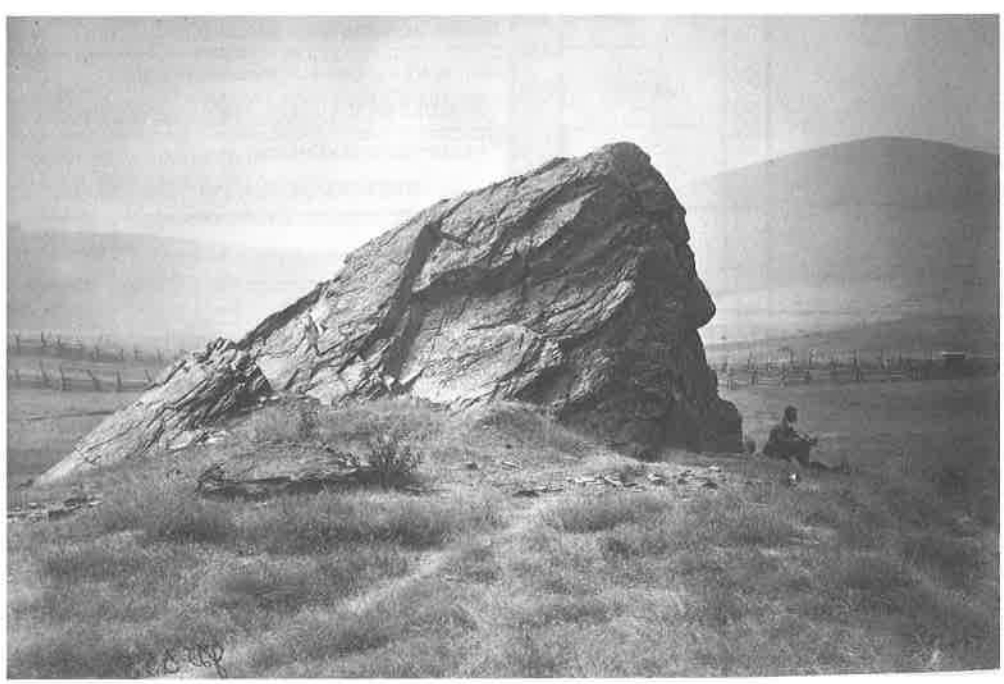
Life on the Edge

Geology is the story of how the earth has evolved through time. Some processes such as volcanism, landslides, or earthquakes are sudden, highly visible, and catastrophic while erosion, deposition, or changing climates and sea levels are more subtle and lengthy. Because of Oregon's position on the leading edge of a moving crustal plate, a striking diversity of geologic events have gone into molding its topography. Before this complex picture could be deciphered, over a century of field work collecting data on stratigraphic relationships, faulting patterns, volcanic episodes, environments, and dates of rocks had to be compiled. Only then could there be an understanding of the tectonic overprint that drives most of the state's geologic episodes.

As the details of Oregon's past emerged, it became apparent that the underlying geology was not completely in concert with the physiographic boundaries. Landforms are more obvious and can readily be drawn, in contrast to the outlines for geologic phenomena, which tend to overlap, be buried, or obscured. In spite of this, the geologic content has been adapted to the individual geographic provinces, defined in 1950 by University of Oregon geographer Samuel Dicken. He imposed them on a base map of the state drawn by Erwin Raisz.





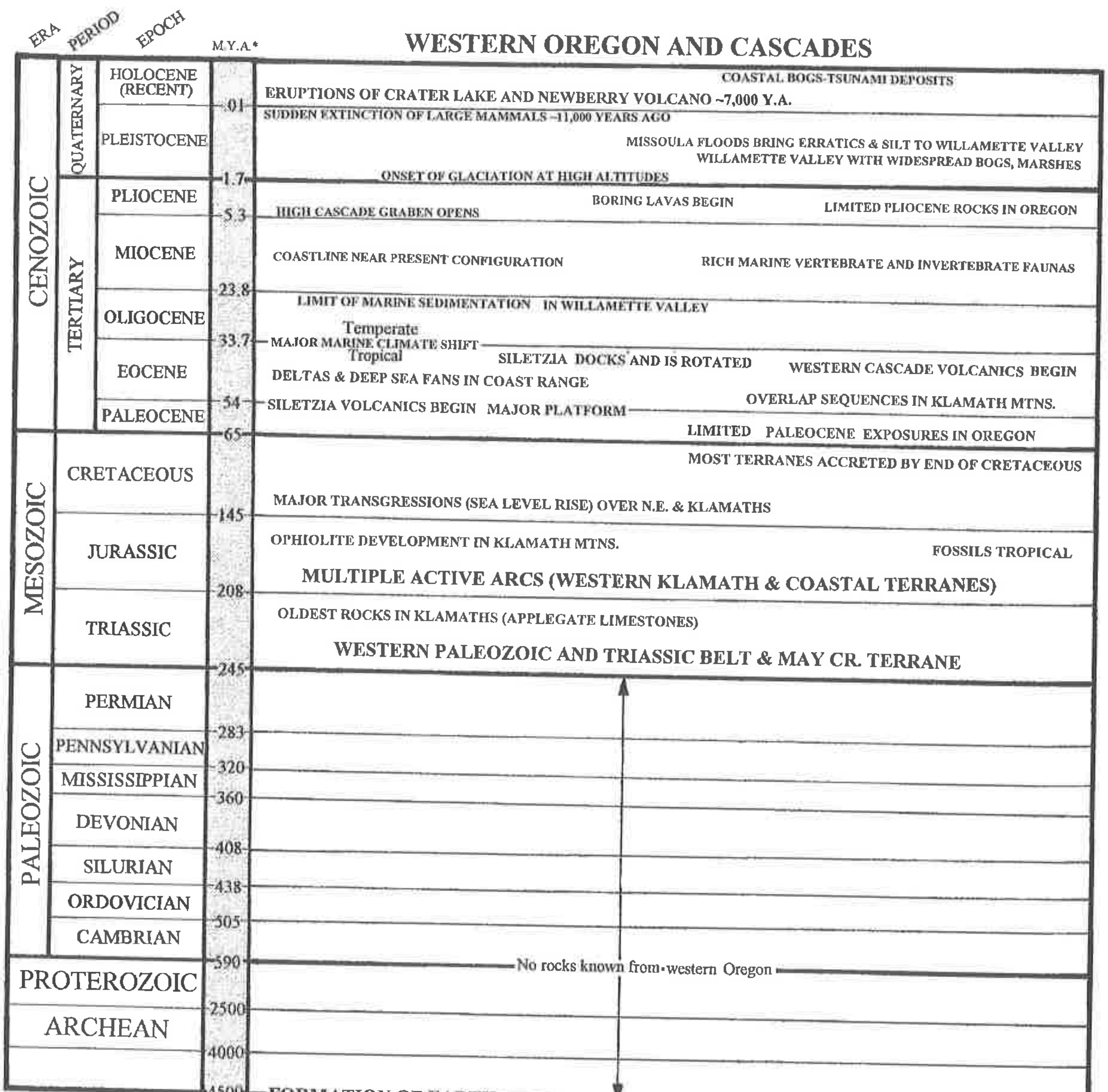
Geologists such as Thomas Condon, Joseph Diller, Israel Russell, and Howel Williams took the first steps at interpreting Oregon's geologic terrain. (In this unusual 1898 photo, Diller is sitting beneath a large schist outcrop of Otter Point Formation near Winston, Oregon; courtesy Douglas County Museum, Roseburg)

Drifting tectonic plates

The premise of moving continents or plate tectonics is central to all aspects of Oregon's geology. The notion that continents move was first published in 1915 by its chief advocate Alfred Wegener when he reconstructed the supercontinent Pangaea by matching the shapes of continental margins. Continental drift as a workable theory soon came up short in light of what was known at the time about the structure of the earth's crust. The theory stalled for almost 50 years until marine geologists recognized evidence from ocean floors to support the hypothesis that deep-seated plates, with continents imbedded on their surfaces, are in motion. The new idea of global plate tectonics emerged after studies of rock magnetics and the realization that the plates are not drifting but are spreading along mid-ocean ridges. The adoption of this idea ushered in an entirely new way of looking at the prehistory of the earth as well as at the beginnings of the Pacific Northwest.

Interaction of plates

The advent of plate tectonics was a milestone in geologic thinking. Moving slabs of crust and upper mantle may separate, collide, or grind past one another. Where plates rift and divide, new crust forms. Currently, lengthy continuous chains of undersea volcanic mountains can be found at rifting zones



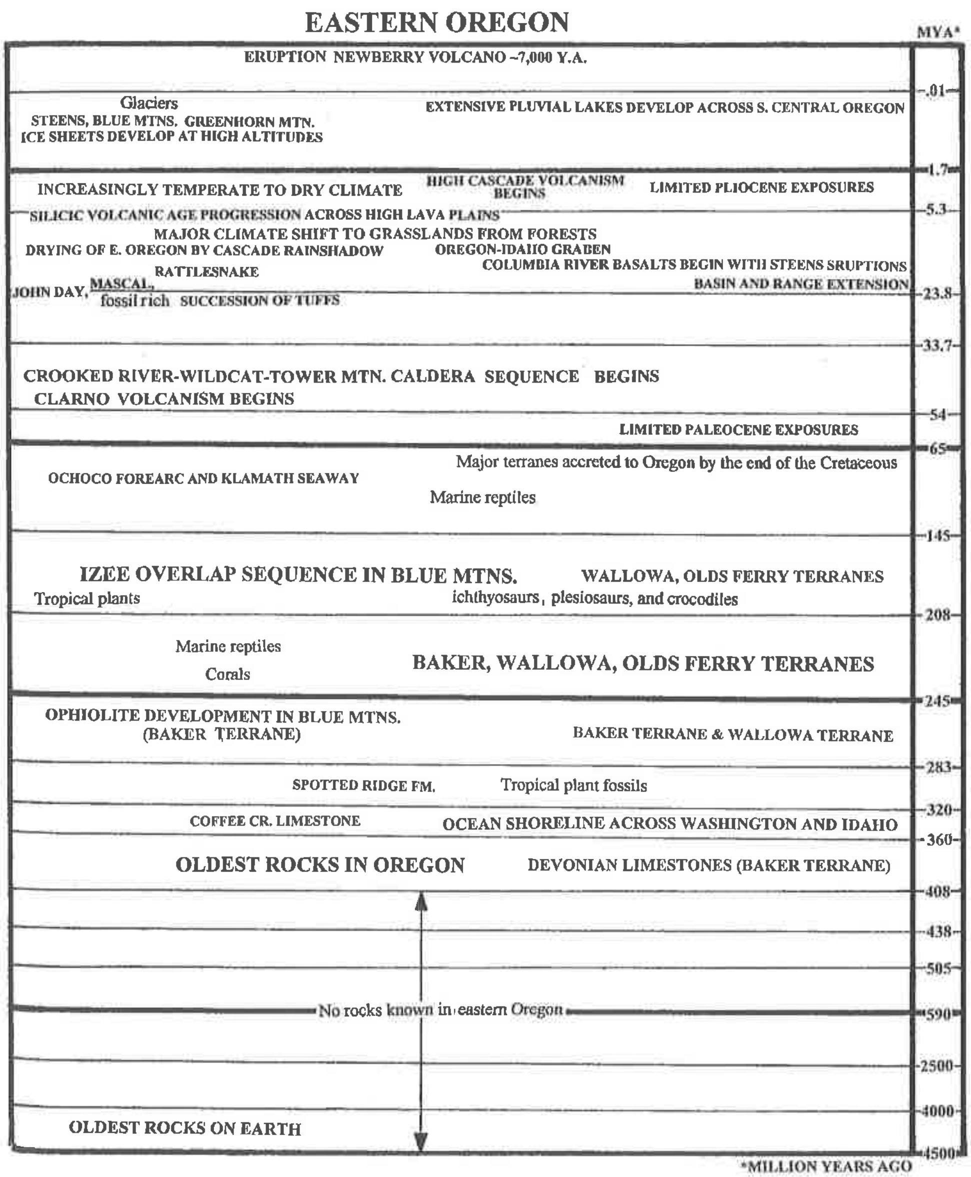
*Million years ago

along the floors of every major ocean. Subduction takes place when two plates collide, and one descends beneath another. Once ocean crust ages and cools, its density increases, and the older, heavier crust is thrust below or subducted by the overriding slab. Where plates slide past each other, transform faults of epic size and length develop at the boundary between the two, accompanied by destructive earthquakes.

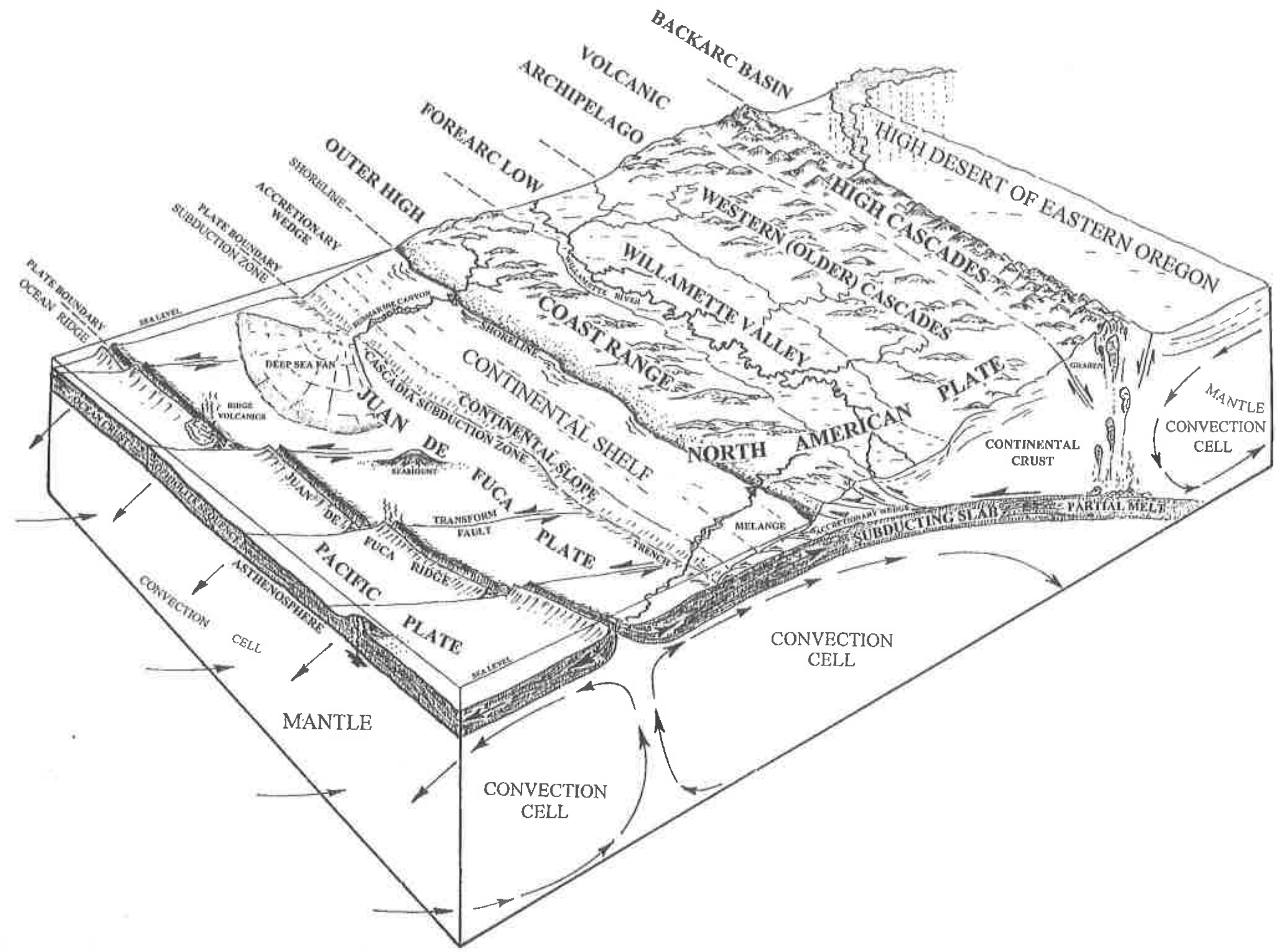
Among the most visible by-products of plate collision and subduction are the build-up of an accretionary wedge, the emplacement of volcanic archipelagos (arcs), and the formation of sedimentary basins. During the subduction process, sediments atop the descending slab are peeled off to accumulate as a jumbled prism or mélange at the outer margin of the upper plate. Associated with this, magma, rising from the lower descending plate, penetrates the upper slab to emerge at the surface as a volcanic chain. Between the accretionary prism and the volcanic archipelago, a forearc basin or depression may develop with a similar backarc basin between the arc and the larger continental mass (craton). Over time, erosion of the volcanic highlands sheds copious amounts of sediment into both basins.

Arrival of terranes

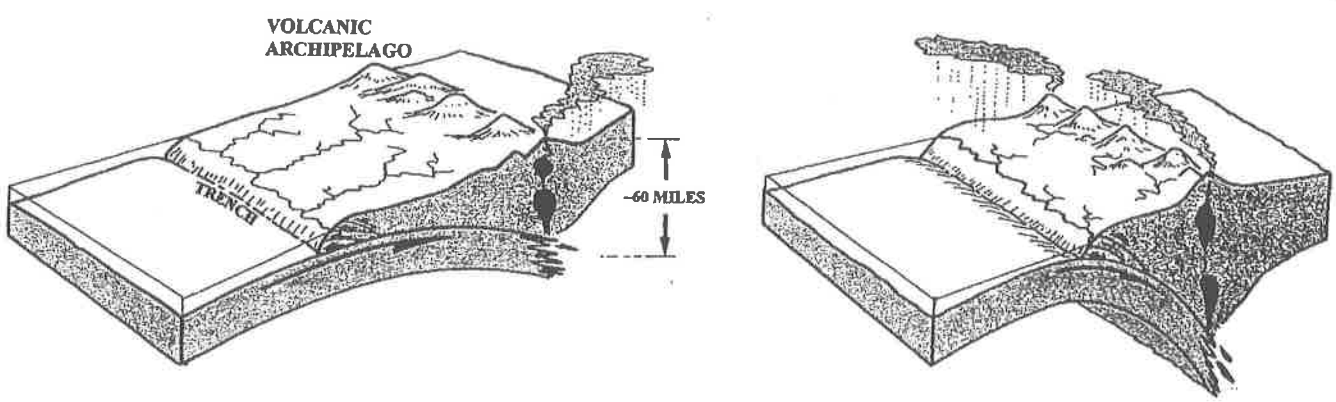
Almost a half billion years in the past, the oldest rocks that would make up Oregon were being



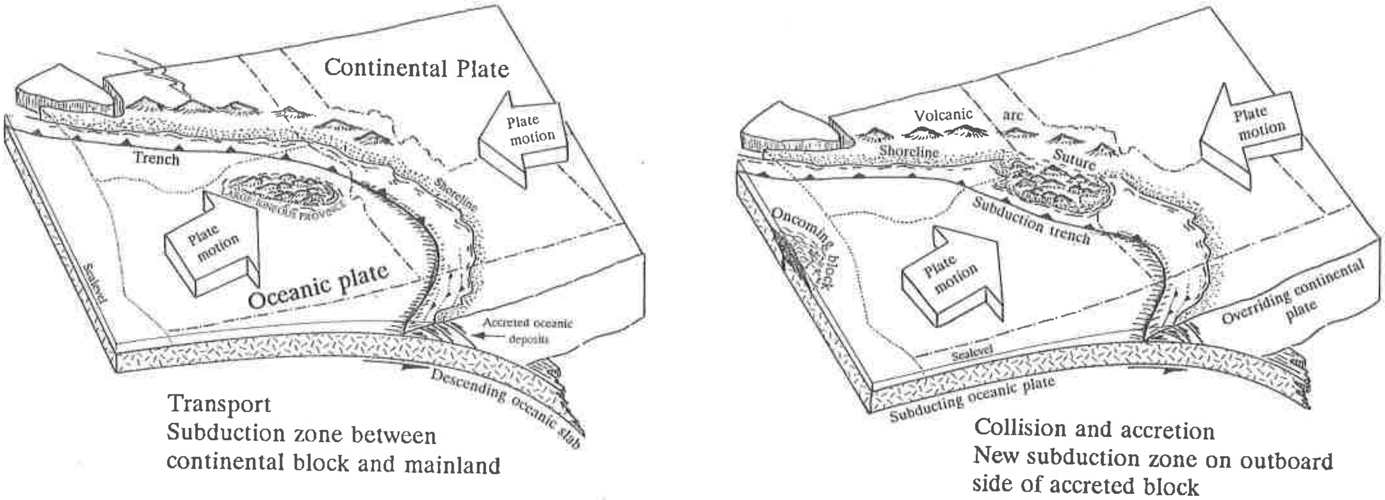
Going back 400 million years, Oregon has had a fascinating history of piecemeal construction, volcanism, and sedimentation even as it was populated by an array of plants and animals.



The configuration of the Pacific Northwest adapts easily to global models that address the interaction between tectonic plates. Composed of multiple strips, the continental margin and outer high of the Coast Range, the Willamette Valley forearc low, the Cascade volcanic arc, and the high desert backarc basin fit together to make the parcel that is Oregon.



The geographic distance between the subduction trench and volcanic archipelago is a function of the relative age of the crust being subducted and the rate of plate movement. Young, warm crust is buoyant and assumes a low angle of subduction with considerable distance between the arc and trench. Older cooler crust is more dense and droops at a pronounced angle upon subduction, bringing the arc close to the trench.



When tectonic plates collide, seamounts, crustal fragments, and island archipelagos are scraped off and accreted to the larger overriding continental block. Following accretion of particularly large tracts, a new subduction zone develops on the outboard side of the oceanic slab.

deposited elsewhere in the Pacific basin or even in distant Asia. Atop subducting plates, assemblages of rocks or terranes, imbedded within the crust, are borne along to be annexed to a larger landmass. The terranes might be volcanic island chains or larger pieces of crust. Defined as recognizable suites of rocks that have a similar geologic origin, terranes are bordered by faults, share a history of sedimentation and displacement, and are distinct from the surrounding strata. After attachment (accretion) to the continent, the terranes are altered and deformed by the heat and pressure of metamorphism as they are being rotated into position. Arriving one after the other, the displaced terranes gradually converged to construct the Pacific Northwest.

Constructing Oregon

Because the foundation bedrock of the state has been assembled piece-by-piece, it is a collage of displaced terranes which originated elsewhere around the Pacific basin. On opposite sides of Oregon, terrane rocks of the Blue Mountains and the Klamath Mountains are the oldest and most accessible, offering the best areas to decipher the state's accretionary history. During the Mesozoic era, successive waves of volcanic island chains traveled eastward and merged with western North America to construct these two provinces. Originating in tropical settings, the crustal pieces brought with them a striking array of fossil fish, large marine reptiles, and fern-like terrestrial plants in association with limestones and reefs.

By the end of Cretaceous time, 65 million years ago, the last of the older terranes had arrived and been accreted. Only the Coast Range block (Siletzia) remained to be emplaced during the early Eocene. With the acquisition of Siletzia, the contours of Oregon were beginning to appear.

Volcanoes, extension, and tectonics

Volcanism and sedimentation, the predominant geologic processes throughout Oregon's Cenozoic interval, are direct by-products of plate tectonic activity. Eocene to Oligocene volcanism coincided with collision of the Farallon and North American plates. While the Farallon slab was being subducted, partial melting at depths up to 75 miles produced low density magma that rose through the overriding North American plate to erupt thick layers of ash and lava over the area that is now the Western Cascades.

Well into the Miocene Epoch, the landscape was reshaped by the construction of vast basalt plateaus in northeast and southeast Oregon and by the spread of incandescent, fast-moving ash flows in the central region. Episodes of volcanism rarely matched worldwide began with immense outpourings of Columbia River flood basalts from a shield volcano in the vicinity of Steens Mountain. The basalt platform would ultimately cover half of

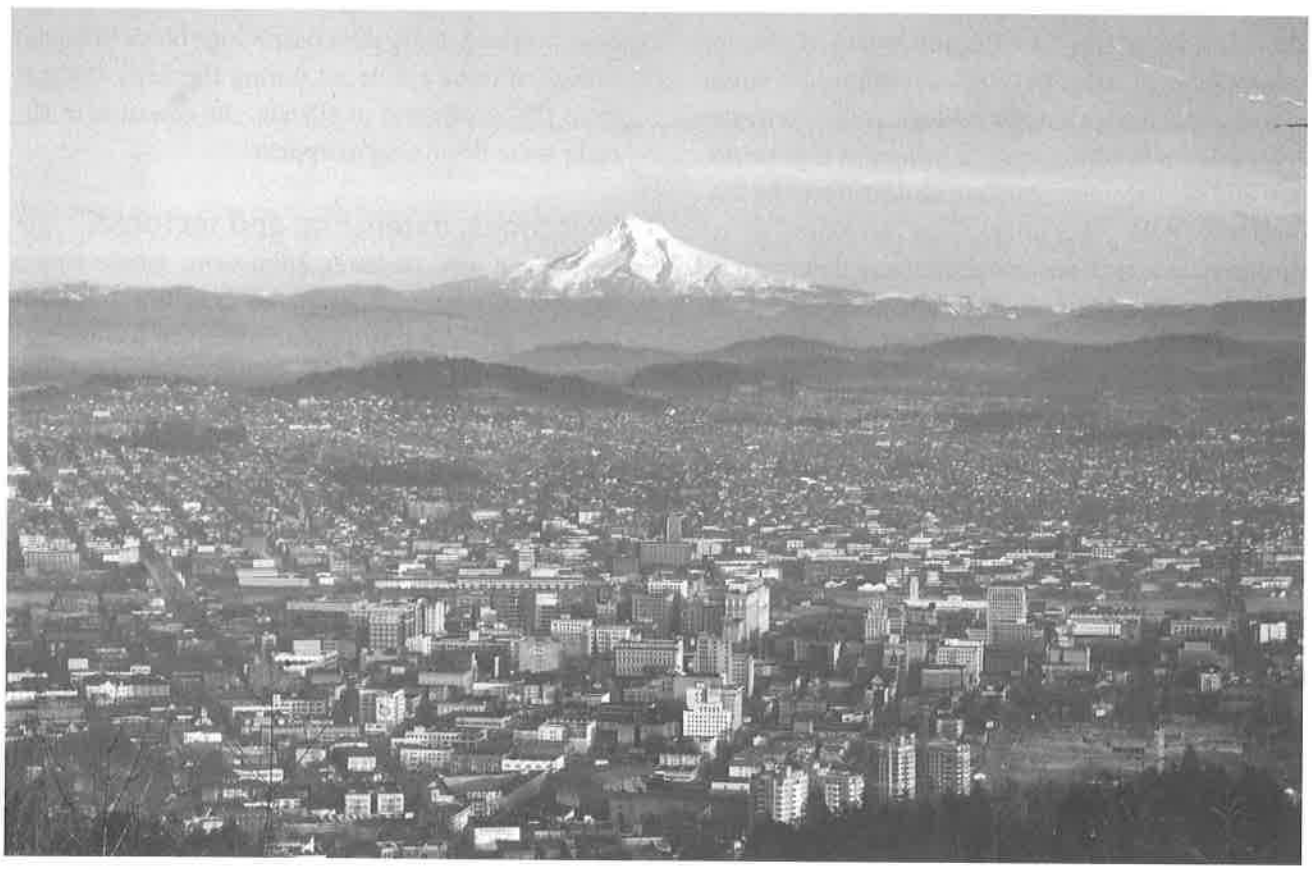
Oregon and large portions of Washington and Idaho. Because they were so voluminous and rapid, tongues of the flows raced across the landscape to the Pacific Ocean where they penetrated the soft coastal sediments.

The basalt eruptions were triggered by movement of the North American plate over a hot spot or mantle plume that is located today beneath Yellowstone, Wyoming. If an area of concentrated heat in the mantle rises, the plume melts the overlying crust and emerges as a volcanic hot spot. As the continent passed over the stationary plume, the balloon-like head flattened and spread out west and northwestward, sending lavas to the Blue Mountains and across the High Lava Plains and Basin and Range.

On the Owyhee plateau, Miocene volcanic centers were concurrent with eruptive phases of the Columbia River basalts. Explosive activity in the McDermitt and Owyhee fields some 17 million years ago was generated by crustal stretching and the proximity of the Yellowstone hot spot. The violent episodes and subsequent collapse of the vents created immense calderas, that are several times larger than those at Crater Lake and Newberry Caldera.

The geologic signature of the Basin and Range and High Lava Plains is the consequence of crustal thinning and volcanism imposed by the interaction between the North American continental and the offshore Pacific plates. As the crust stretched, it eventually broke into a landscape of north-south faulted hills and valleys, characterizing the region today. Volcanism, initiated 10 million years ago, continued into the Recent. The eruptive surges were both age progressive and bimodal. That is, they became younger in age from east to west, beginning at Harney Basin and ending near Newberry Crater. In conjunction with the age progressive phenomenon, the bimodal composition varied from older rhyolitic to younger basaltic lavas.

With waning cycles of the Columbia River basalts, eruptions in the Cascades had shifted as in



Around 50,000 years ago, what is now the Portland-Vancouver metropolitan area saw extensive volcanic activity from the Boring lava field. Looking eastward across Portland toward Mount Hood, just a few of the 80 small volcanoes and cones that compose the Boring field can be seen. (Photo courtesy Oregon State Highway Department) a wave eastward to construct the High Cascade shield and stratocones during the late Miocene and into the Quaternary Period. Composed of both basalt and andesitic lavas, the High Cascade peaks stand in sharp contrast to those of the eroded older Western range. While most of the High Cascade eruptions in Oregon had diminished or ceased by 30,000 years ago, there have been a number of episodes since that time. Mount Mazama's spectacular explosion, dated at 7,700 years, is the most notable, but Mount Hood and numerous domes in the central chain have been active historically. The 1980 eruption of Mount St. Helens in Washington was the most visible and largest in recent times.

Marine and terrestrial basins

Thick sedimentary layers that cover large areas of Oregon are critical to interpreting the state's geologic past. Changing marine and terrestrial environments are reflected in the stratigraphy and fossils, which have been especially useful for interpreting depositional settings and climate variations.

As part of a worldwide trend during the late Mesozoic, rising seas covered much of Oregon. Some 60 million years ago, only the Blue and Klamath Mountains projected above the surrounding oceans, with a shoreline that ran diagonally from the Klamath Mountains into eastern Washington. Following repositioning of the Farallon, Kula, and North America plates, a lengthy forearc basin connected these two provinces with the Great Valley of California. A thick covering of Cretaceous sediments, which spread across the basins in the Ochoco and Klamath mountains, entombs some of the state's first autochthonous (home-grown) rocks and fossils. This was the high water mark before regional uplift forced the waters to retreat.

The early Tertiary saw the arrival and rotation of the large Coast Range block of Siletzia, the final terrane to be annexed. Situated along the edge of North America and west of the emerging Cascade volcanic arc, Siletzia subsided into a narrow trough even as it was being accreted. Throughout the Eocene Epoch, erosion from both the interior of the continent and the Klamath Mountains shed copious quantities of debris into the basin, which today underlies the continental shelf and Coast Range, Willamette Valley, and Western Cascades. Elevation of the coastal margin and depression of the Willamette Valley brought a shallowing of ocean waters and a reduction of sedimentation during the latest Oligocene.

The subduction of Siletzia beneath the Cascades and eastward toward Idaho generated the Clarno and Challis volcanic eruptions. Lava and ash of the Clarno Formation blanketed large portions of eastern Oregon, overwhelming lakes and streams. Clarno sediments and mudflows, along with those of the successively younger John Day, Mascall, and Rattlesnake formations, preserve remarkable fossil plant and animal remains, which provide a continuous environmental picture from the Eocene through the Miocene.

Climate change

Oregon's geologic record reveals extraordinary shifts in climate, from the tropical humid conditions of the Paleocene and Eocene to glaciation during the Pliocene and Pleistocene. Many of these were global trends and not restricted to the Pacific Northwest.

Often regional climates are a consequence of tectonic activity. Moving from one latitude to another, crustal plates experience profoundly divergent conditions enroute. Ash from explosive volcanism, triggered by plate collision, can obscure the sunlight and cause a rapid drop in temperatures. Alternately, the same episodes may foster a rise in temperatures with the release of greenhouse gasses. Because of its proximity to the Pacific Ocean and the direction of prevailing winds, much of western Oregon's climate is additionally governed by variations in the marine offshore realm.

Worldwide, the Eocene to Oligocene boundary marks a global transition from tropical and semi-tropical climates to those of a more temperate nature. Cooling ocean water and falling air temperatures generated clear floral and faunal modifications, sometimes even leading to extinctions. In western Oregon, changes in the subtropical terrestrial plants and marine invertebrates in the Keasey, Cowlitz, and Eugene formations are particularly notable. In eastern Oregon, the tropical humid environment was transformed with the steady elevation of the Cascade volcanic barrier. By cutting off the moist air

An indirect effect of the cold Pleistocene was cataclysmic flooding as continental ice masses advanced into Washington from Canada. Ice dams, which impounded glacial Lake Missoula, failed periodically, releasing as many as 100 huge floods that scoured eastern Washington and the Columbia River channel on the way to the Pacific Ocean. The volumes of water backed up as temporary Lake Allison in the Willamette Valley, leaving thick layers of silt across the floor. (In the photo, the individual shorelines of Lake Missoula in Montana are visible on the hillsides; courtesy U.S. Geological Survey)

masses from the Pacific, it dramatically altered conditions by the late Oligocene and into the Miocene, resulting in the high desert of today.

Beginning a little less than 2 million years ago, the Ice Ages or Pleistocene Epoch was time of cold temperatures, heavy rainfall, and the rapid build-up of continental ice masses. Worldwide, lower temperatures fostered polar ice caps and lowered sea levels. Throughout this interval, ocean waters rose and fell during cycles of cooler and warmer periods, and glacial erosion deeply etched the land. These trends peaked around 18,000 years ago, after which the earth entered its present-day warm interglacial phase.

While no continental glaciers reached Oregon, thick ice caps covered the mountain ridges, and increased precipitation filled pluvial lakes in the broad fault-bounded depressions of the Basin and Range. These ephemeral lakes, some of which covered hundreds of square miles, provided habitats for herds of mammals, migratory birds, and varieties of fish. Today all of these shallow basins have diminished or dried up completely.

The geologic future of Oregon

The geology perspective means examining the past as well as anticipating the future. To do so, it is necessary to take the long view of modifications to the earth's surface and atmosphere, which are extremely complicated and invariably cyclic. Certainly, this applies to the current public focus on global warming. Glaciologists calculate that, at present, the earth is approaching the end of a 10,000-year interglacial period and should be entering a glacial phase within the next 23,000 years. During these larger episodes, average global temperatures fluctuate frequently, and the last 10,000 years (Holocene) has been anything but stable. If, in the future, glacial conditions prevail and vast ice sheets take up and store ocean water, the Oregon coast will see a substantial drop in sea level. But, on the other hand, with warmer conditions and melting ice, the oceans will rise to invade the land. These are long-term developments that come about over thousands of years.

Caught between converging crustal plates, the Pacific Northwest faces a future of massive earthquakes and tsunamis. Only in the last 20 years has the public become aware of the potential for high magnitude quakes associated with the Cascadia subduction zone. Since then, there has been an ongoing push to compile and analyze data on seismicity. Efforts to explain the current low incidence of Cascadian subduction activity include a number of theories, but to date they fail to explain all possibilities satisfactorily.