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The Cenozoic Era

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Introduction: It has been said that the modern world unfolded during the Cenozoic Era. It is true that every feature of the modern landscape was formed during the Cenozoic Era. The Alps and the Himalaya have literally risen from the ocean floor. The Rocky mountains have been formed, worn away and re-uplifted to their present heights. The Appalachian Mountains that had formed at the close of the Paleozoic and worn away by the end of the Triassic, were uplifted and sculpted into their present form during the Cenozoic. All the other mountains of the world were also elevated and sculpted to their present form during the past 65 million years. In addition to being a time of landscape sculpting, the Cenozoic Era was also a period of crustal unrest. Some of the mountain building events of the Cenozoic are still underway as is evident from the presence of volcanic activity and earthquakes in many parts of the world.

The Cenozoic was also a time when the modern animal and plant world evolved. Life on Earth changed during the Cenozoic in many ways. Many of the animals that had dominated the seas from the marine reptiles to the ammonites had disappeared with their ecological niches being taken over by the modern inhabitants of the sea including bottom-dwelling molluscs, whales, and the teleost fish. On land, the flowering plants became the dominate plants while the mammals took over the spaces once occupied by the dinosaurs.

As the Atlantic Ocean continued to open during the Cenozoic, the western margin of North America was subjected to the massive compressional forces associated with subduction. Early in the era, arc volcanism was resurrected along the west coast and during the latter half of the era, a goodly portion of the western craton was subjected to tensional forces that resulted in the formation of block-fault mountains. Toward the end of the era, a portion of the subduction zone along the western portion of the continent was replaced with a transform movement that gave rise to the most infamous fault in the country, the San Andreas that even today is driving the western margin of the continent from Baja California to northern California northwestward.

Elsewhere in the world, the final breakup of Pangea resulted with the subsequent collision of India with Asia to form the Himalayas and the final separation of Australia, South America and Antarctica took place. While all that was going on, the final closure of the Tethys Sea was underway as Iran and Turkey collided with Asia and the Alps began to rise as Africa converged on Europe. With the separation of Antarctica and the formation of the circum-Antarctic current, the glaciation of Antarctica was initiated.

At the ~~other~~ north pole, major changes were also underway. The Arctic basin had existed during the Cretaceous, but because North America, Greenland, and Eurasia were still united until the beginning of the Paleocene Epoch, it remained separated from the Atlantic. The first connection between the Arctic and Atlantic oceans was made when Greenland rifted from North America. It would be later when Greenland was pulled away from Scandinavia that the broad connection that now exists between the Arctic and the Atlantic was established. Because the Bering Strait between Siberia and Alaska did not exist during most of the Cenozoic Era,; there was no connection between the Arctic and Pacific oceans. The Bering landbridge that connected Asia and North America allowed free exchange of both animal and plants between the two continents.

Epochs of the Cenozoic Era

The Subdivision of the Cenozoic Era The first critical study of Cenozoic rocks was made by the French paleontologist Deshayes in the richly fossiliferous Paris Basin. He was the first to make the observation that uppermost marine beds contained a large percentage of shell-bearing mollusc species that still lived in modern seas. He then observed that as he studied progressively older beds, the percentage of living types contained within the fossil assemblage decreased. It was, however, Sir Charles Lyell, one of the greatest of the early British geologists, who proposed a classification scheme for the Cenozoic that was based on the percentage of living forms contained as fossils in the rocks. Lyell proposed three **series** of rocks, the **Eocene** (Gr. *eos*, dawn + *kainos*, recent), the **Miocene** (Gr. *meios*, less + *kainos*) and the **Pliocene** (Gr. *pleios*, more + *kainos*). Three other series were added later, the **Paleocene** (*palaios*, ancient + *kainos*), the **Oligocene** (Gr. *oligos*, little + *kainos*), and **Pleistocene** (Gr. *pleistos*, most + *kainos*) **(Figure 2)**. Eventually, these terms were used as the subdivisions, or epochs, of the periods that constitute the Cenozoic Era..

Periods of the Cenozoic Era: Most American and some European geologists subdivide the Cenozoic Era into two periods. The older of the two, the **Tertiary Period,** extends from the end of the Cretaceous 65 million years ago to 2 million years ago and consists of five epochs from the Paleocene through the Pliocene Epochs. The younger of the two periods, the **Quaternary Period,** encompasses the time from the start of Northern Hemisphere glaciation 2 million years ago up to the present. Originally, the Quaternary Period consisted of only one epoch, the Pleistocene (refer to Figure 1). Some geologists add a second epoch, the Holocene to encompass the time since the final melting of the Pleistocene ice sheet. The two-fold subdivision was intended to point out the historical significance of the Northern Hemisphere glaciation that occurred during the Pleistocene.

Because of the great disparity in the time intervals and the numbers of epochs represented by the Tertiary and Quaternary periods, another two-fold subdivision of the Cenozoic Era was proposed that was significantly more equable. Most European and some American geologists subdivide the Cenozoic Era into the **Paleogene** and the **Neogene** periods. The Paleogene Period consists of the time interval from 65 million years ago up to 24 million years ago and includes the first three epochs of the era, the Paleocene, Eocene and the Oligocene. The Neogene Period includes the time interval from 24 million years ago to the present and also consists of the Miocene, Pliocene, Pleistocene epochs and, if included, the Holocene. The reason why this classification is more attractive to European geologists is that the transition between the Paleogene and Neogene periods represents the climax of the orogeny that affected the Tethyyan region of southern Europe and the Mediterranean.

The Appearance of Earth's Surface

By the beginning of the Cenozoic Era, the super-continent of Pangea had completely rifted, giving rise to all of the modern continents and ocean basins in their approximate modern sizes, shapes, and locations. the major tectonic events of the Cenozoic involved the making and breaking of connections between continental masses with their subsequent effects on ocean currents, climates, and the world-wide distribution of flora and fauna.

As the era begins, North America was approaching Asia to the west, Europe to the east, and South America to the south but was still independent of all three. During the early Tertiary, however, North America experienced a number of connections and disconnections with Asia and Europe. During the period of time that the three continental masses were temporarily connected, the Arctic Ocean was totally isolated froom both the Atlantic and Pacific oceans. About 60 million years ago, the basin of the North Atlantic began to form as an oceanic ridge began to form between Greenland and Scandinavia, a rifting that continues to this day. About 40 million years ago, a rift formed between Greenland and North Americsa that resulted in the formation of the Laborador Sea. The rifting was relatively short-lived in that Greenland still remains essentially part of the North American continent..

The connection between North and South America occurred about 4 million years ago as the westward moving American plates encountered the eastward-moving Pacific plate. Until the connection between North and South America, there was an open connection between the Atlantic and Pacific ocean basins that allowed the free interrmingling of oceanic life. Today, the life forms on opposite sides of the Panamanian connection between the two continents are quite different. Leter we will see that the land connection between the two continents allowed the placental-dominated mammals of North America to migrate southward and overwhelm the marsupial populations of South America.

Until the Miocene, South America and Antarctica were connected. today, the two continents are separated by the Drake Passage; perhaps the site of some of the roughest seas on Earth. The opening of the Drake Passage combined with the separation of Antarctica and Australia during the Eocene allowed the creation of the very cold Antarctic current that began to sweep around the continent as it moved to its present location over the South Pole. The combination of its polar location and the presence of the circumscribing Antarctic current eventually created the frigid, desert climate of the southernmost continent. It is interesting to note that before its arrival to the South Pole, the climate of Antarctica was sub-tropical.

The Indian Ocean was created as the eastern margin of Gondwana began to rift apart. During the late Triassoc-early Jurassic, the combined masses of Antarctica and Australia rifted from what is now the southeastern margin of Africa. About the same time, the Indian and China plates formed and began their voyage, eventually to collide with and add to the Eurasian plate. Later, in the Oligocene, the formation of the Red Sea Rift resulted in the foermation of the Arabian plate. During middle to late Cenozoic time, these three plates would collide with the Eurasian plate. The collision of the Arabian plate would result in the formation of the Zagros Mountains in southern Iran while the collision of India about 45 million years ago would create Earth's newest and highest mountain range, the Himalaya Mountains. Following the separation of Antarctica and Australia during the Eocene, Antarctica head southward to it present frigid location while Australia moved northward into warmer climes.

The Cenozoic History of ~~Eastern~~ North America

The ~~Atlantic Coast~~ [Changing History of Eastern N.A.]: The Cenozoic tectonic history of eastern and western North America are quite different due to the fact that eastern North America represents a ***passive continental margin*** adjoining an opening ocean while the margin of western North America is an ***active margin*** as the North American and Pacific plates collide. As a result east portion of North America experienced little tectonic activity during the entire Cenozoic Era. By the beginning of the Paleogene, [except for a few erosional remnants such as the crest of the Great Smokies & the summit of White Mountains] the entire Appalachian region had been reduced to a low, relatively featureless plain not far above sealevel by the combined efforts of weathering, mass wasting, and erosion. The sedimentary debris created by weathering and erosion was transported to the eastern margin of the newly-formed North American continent where it accumulated to form a geocline along the continental margin. Beginning in the Early Paleogene, the entire eastern portion of the continent was uplifted into an northeast-southwest trending arch that extended from the continental interior to the Atlantic Ocean. The maximum amount of uplift, about 6,000 feet above sealevel, was located along what is now the eastern edge of the Appalachian Plateaus.

Streams, rejuvenated by the uplift, sculpted a new topography for the region controlled largely by the structures that had formed during the Alleghenian Orogeny at the close of the Paleozoic and by the differences in rock lithologies. As they do today, the more resistant sandstones hold up northeast-southwest trending ridges while the softer, less resistant shales and limestones occupying the intervening valleys.

The uplift of the eastern portion of the continent resulted in a seaward tilting of the coastal plain and its seaward extension, the continental shelf . Sediments generated from the interior were carried to the east coast by major river systems such as the Susquehanna, Potomac, Hudson, and Delaware and were deposited both on the coastal plain and carried out onto the continental shelf, adding to the growing geocline. The Cenozoic sediments within the geocline along the Atlantic coast thicken seaward to more that 1200 feet with the rocks becoming less clastic in the offshore direction (**Figure XX**: Fig. 14-2 in Levin). From Canada to the southernmost extent of the Appalachians, the sediments accumulating offshore are dominated by clastics. Eventually, sources for clastic sediments decrease and southward in the vicinity of Florida, carbonate sediments begin to dominate. In the region of Florida, more than 7500 feet of carbonates have accumulated in association with coralline platforms similar to those that now support the Bahamas (**Figure XX**: Fig. 14-3 in Levin). During the Late Paleocene, the region was uplifted above sealevel to create the peninsula of Florida.

The Gulf Coast: The best record of Cenozoic marine sedimentation is along the northern margin of the Gulf of Mexico where the Mississippi River has deposited it load of sediments into a rapidly subsiding basin. Within the Mississippi delta complex, more than 25,000 feet of sediments have accumulated. (**Figure XX**: Fig.14-4 in Levin). The sediments of the Gulf record at least eight marine transgressions in the region with at least one driving the Mississippi River Valley into southern Illinois. It was the intricate inter-fingering of sands and shales during these multiple episodes of transgression/regression that provided the reservoirs for the prolific petroleum deposits for which the Gulf region is known.

The Cenozoic History of Western North America

The Rocky mountains and the High Plains: At the very end of the Cretaceous Period and continuing into the Middle Eocene, the western portion of North America experienced a sequence of orogenic events. The first of these was the Sevier Orogeny that affected the western portion of north America from southwestern Utah and northward into Canada. Following the Sevioer Orogeny, the most profound orogeny since the pre-Cambrian in the form of the **Laramide Orogeny** in Eocene. Nearly all the major structures of the Rocky Mountains were formed during the Laramide Orogeny.

The folding and faulting generated by these orogenic events on a colossal scale created the a majestic range of mountains that stretched from Alaska to Central America; the portion of the range within North America being the Rocky Mountains. From north to south along the Rockies, the geology undergoes a profound change. To the north, a belt of enormous thrust faults can be traced along the mountain front from Alberta, Canada, southward across Montana, eastern Idaho and western Wyoming into north-central Utah and then southwestward across eastern Nevada. The displacements of many of the thrust faults within this belt were great enough to carry pre-Cambrian rocks up over Cretaceous rocks. An excellent example is the Lewis Thrust which drove a thick plate of pre-Cambrian Beltian rocks a distance of more than 15 miles and deposited them on top of Cretaceous rocks of the western Great Plains. The fault and the mass of pre-Cambrian rocks can be seen today in Glacier National Park in northwester Montana as Chief Mountain. The eastern front of the Absaroka Mountains east of Yellowstone Park in northwestern Wyoming is similarly defined by the Heart Mountain Thrust that moved rocks nearly 30 miles eastward along a 125 miles mountain front. All of the spectacular mountain scenery one observes from central Wyoming to Canada is the result of the presence of these stacked thrust sheets.

In contrast to the thrust fault dominated northern Rockies, the geology of the southern Rockies is dominated by broad anticlinal and synclinal folds. the difference in tectonic style is interpreted as being due to a change in the angle at which the Pacific plate subducted below the North American plate. Compared to the relatively steep angle at which the Pacific plate subducts along the northern margin of the continent, to the south, the angle is significantly more gentle. The result is that rather than relieving the compressional forces by faulting, the thin overlying continental; plate responded by plastic deformation and folded. From central Wyoming southward, the topography of the Rockies becomes more subdued reflecting the underlying folded structures.

The Colorado Plateau and the Great Basin:

The **Colorado Plateau** is perhaps one of the best examples of pure uplift in North America. The rocks within the plateau are essentially horizontal indicating that the entire rock section was totally unaffected by any of the Mesozoic orogenies. The entire region was uplifted from near sealevel to elevations of about 10,000 feet during the Pliocene with no deformation except for normal faulting and monoclinal folding around its perimeter. The faulting around the perimeter of the uplift served as conduits for magmas rising to the surface. For example, the San Francisco mountains near Flagstaff, Arizona are a group of volcanoes and cinder cones formed as lava erupted to the surface. The cause of uplift is still much argued and there is no consensus of opinion as to the source of energy that resulted in the uplift of such a vast portion of Earth's crust. The explanation most often offered is that a buildup of heat under the crust resulted in the expansion of the rocks at depth with the subsequent decrease in density resulting in a degree of bouancy that caused the uplift. The spectacular scenery of the region is the result of the rejuvenation of the major streams of the region during the uplift, the most impressive of which is the Grand Canyon. since the beginning of uplift about 10 million years ago, the Colorado River has carved its channel downward more than 7,000 feet through the entire Paleozoic sequence of rocks, exposing the pre-Cambrian basement. Other impressive features resulting from the rejuvenation of the Colorado River and its tributaries include the Canyonlands, Arches National monument, and Monument Valley.

The **Great Basin** refers to the region between the Sierra Nevada and the western margin of the Colorado Plateau. During the Oligocene, rocks of the Great Basin were subjected to tensional forces and broken by many parallel, north-south trending normal faults. In some cases, the faults dip in the same direction resulting in the rotation of the fault blocks while in other cases, the faults alternately dip in opposite directions forming a sequence of parallel up-thrown blocks called **horsts** and down-thrown blocks called **grabens**. It is believed that the tensional forces were the result of relaxation following the earlier Sevier and Laramide orogenies. A question that might be asked is why were the rocks of the Great Basin broken as a result of being subjected to tensional forces while the rocks of the Colorado Plateau immediately to the east were not? The explanation most often given is that the rock section underlying the Colorado

Plateau were thick enough to resist the tensional forces while those underlying the Great Basin were not.

The faulting and subsequent erosion has resulted in the formation of the parallel mountain ridges and intermontane valleys. The unique geology led to the entire region being designated as the Basin and Range Physiographic Province. The best examples of the Basin and Range topography are found throughout Nevada. The rugged topography desert conditions that prevail throughout the region served as a very effective barrier to the original attempts of the settlers make their way to California. Eventually, the settlers had to skirt around the region either by taking a southern route across New Mexico and Ariozona into southern California, a route that became old Route 66, or by skirting the basin to north by way of a trail from Salt Lake City, Utah to Elko, Nevada to Reno, Nevada then across the high Sierra through Donner Pass.

Rocky Mountain Basins and the High Plains

While the Seiver and Laramide orogenies were responsible for most of the structural features of the Rocky Mountains, it was uplift that began during the Miocene that is resoinsible for the present topography of the Rockies and the creation of a number of intermontane basins throughout the region. With the exception of a very brief incursion of marine conditions into what is now western North Dakota, all of the Cenozoic sedimentation is of terrestrial origin with the highlands serving as the source of the sediments and the adjoining basins the depositional sites. Some of the more well-known basins are located in the Wyoming-Utah-Colorado region including the Powder River Basin , Wind River Basin, and the Green River Basin of Wyoming, the Uinta Basin of Utah, and the Piceance Basin of Colorado. Perhaps the most well known of these is the Green River Basin of western Wyoming where over 1800 feet of Paleocene and

Eocene fresh water limestones and fine-grained, thinly laminated shales entrapped the remains of fish, insects, and leaves. In addition, to their spectacular fossil assemblages, many of the shales within these basins are rich in a waxy, solid hydrocarbons that, upon being subjected to pyrolysis, can produce an estimated 200 liters of oil per ton, giving rise to their being referred to as "oil shales", even though they no not contain oil. . It is for that reaso

During the Oligocene, explosive volcanic activity to the west covered many of these areas with volcanic ash and dust that fell into lakes that occupied the basins, settled to the bottom entrapping both plant remains and animals. A well-known example of such a lake accumulation is located near Florissant, Colorado, that became the resting place of many perfectly preserved remains of fish, leaves, spores, pollen, and even upon occasion birds.

What caused the formation of these fold structures so far to the east of the previous tectonic activity? The theory is that the subducting plate within this central region assumed a near-horizontal angle in response to an increase in the westward motion of North America. As the subducting plate passed under the overlying continental crust, compressional forces were applied over a wider segment of the overlying continental crust which resulted in the folded the basement and overlying rocks rather than thrusting. Even though the uplift was significant, erosion apparently kept pace with the uplift and, as a result, the topographic relief of the region remained low. In time, the basins between the uplifted regions were filled with debris shed from the Cryptozoic and Paleozoic rocks exposed in the adjacent highlands. Allivial fans formed along the margins of the basins that eventually spread across and filled the basins, in many cases, to depths of 10,000 feet. Some of the basins were occupied by swamps accumulated peat that eventually were to form coal beds hundreds of feet thick. An excellent example is the Powder

River Basin of Wyoming, where two beds of coal totaling 100 feet of coal separated by as 10 foot parting lie beneath about 20 feet overburden. The coal is now being mined in an open pit that is one of the largest surface mines in the country.

As the intermontane basins filled with debris during the Oligocene Epoch, another phase of uplift occurred that sent a sheet of sediment called the **White River Clastic Wedge**, eastward beyond the Rockies out onto the western margin of the High Plains of Colorado, wyoming, Nebraska, and south Dakota where countless animals were trapped by flooding streams and encapsulated in the sediments to form the most complete remains of mammals anywhere in the world. Included in the fossil record of the White River beds are 150 species of animals, some of which are still aloive while others are now extinct. The Wind River Formation are now exposed in the Badlands of South Dakota.

In addition to the widespread layers of Miocene volcanic ash and interlayered lava flows found encorporated into the sediemnts of the southern Rockies, at Cripple Creek, Colorado, gold has been mined from veins that are associated with a Miocene volcano. By the end of the Oligocene, most of the topography of the original Rocky mountains had been worn down nearly to sealevel. The Miocene was also the beginning of regional uplift that elevated the Rockies nearly 10,000 feet to their present elevations. With uplift and subsequent erosion of the rising highlands, sediment was also spread eastward as far as the Mississippi River, creating the Great Plains.

The Columbia Plateau ~~and the Cascade Mountains~~: During the late Paleogene and into the Neogene, long fissures opened throughout central and eastern Washington and Oregon above what has been interpreted as a hot spot. Enormous volumes of basaltic lavas were extruded from the fissures that spread out over an area of about 200,000 square miles and literally buried the topography under more than 5,000 feet of successive lava flows. Being basaltic in composition, the lava was very fluid with individual flows flowing up to 100 miles from the point of origin. The region is now the site of the Columbia Plateau through which the Columbia and Snake rivers have carved impressive canyons **(Figure XX)**.

To the west, the Cascade Mountains are subdivided into two parallel north-south trending zones referred to as the Western Cascades and the High Cascades. The Western Cascades averages about 50 miles in width from the western base of the High Cascades to the eastern margin of the Willamet Valley and consist of more than 13,000 feet of volcanic rocks ranging in age from Late Eocene to Late Miocene. The volcanic activity in the Western Cascades involved fissure eruptions of a variety of magma types ranging from granitic to basaltic. The eruption of the granitic magmas generated enormous volumes of pyroclastic materials that accumulated in thick layers ranging from coarse agglomerates to fine tuffs. The result of the fissure eruptions is that the Western Cascades developed as a plateau rather than more mountainous terrane that is characteristic of vent-type eruptions. The High Cascades formed in an entirely different way. The High Cascades consist of large cones constructed around central vents. Although most of the cones in the High Cascades are shield volcanoes constructed of basaltic lavas, several andesitic strato- or composite volcanoes more typical of subduction zones were constructed during the Pleistocene. Perhaps the best known of the composite volcanoes of the High Cascades was Mount Mazama that erupted violently about 7,000 years ago and gave rise to a cwater-filled caldera known erroneously as Crater Lake (Figure XX). During the Pleistocene, massive outpourings of basaltic lava issued from fissures near the base of the high Cascades and traveled both westward across portions of the West Cascades as well as eastward where they can now be seen in the valley of the Deschutes River. At the same time, many small basaltic cinder cones were created, one such cone, Pilot butte, is located within the city limits of Bend, Oregon. Volcanic activity has been especially intense during the past 1,000 years with more activity occurring around Bend than at any other portion of the Cascades. Within the past few thousand t=years, the most intense level of activity in the Cascades has occurred about 25 miles west-northwest of Bend in the vicinity of the Three Sisters., the most recent eruption being responsible for a sheet of obsidian that covers Rock Mesa and a chain of obsidian domes.

The recent eruption of Mt. St. Helens indicate that the Cascade chain is still an active volcanic site and as the Juan de Fuca plate continues to subduct beneath the North American plate, they will continue to be active.

The Sierra Nevada: The granitic rocks now seen in the Sierra Nevada were implaced during the Nevadan Orogeny in the Cretaceous. By the beginning of the Tertiary, the chain of continental arc volcanoes that once lay over the granitic intrusions was removed by erosion, exposing the granitic core. During Pliocene time and continuing into the Pleistocene, the entire Sierra Nevadan block was tilted along normal faults along its eastern margin and tilted westward. The eastern front was lifted more than 12,000 feet while the western portion of the block forms the base of the California Valley. It is postulated that the uplift and rotation of the Sierra Nevada block was the result of isostatic adjustments that were being made between the continental crust and the denser underlying rocks. During the Miocene, the region west of the Sierra Nevada underwenst a change from a zone of subduction to one of strike-slip motion. We will discuss the results of this change in the next section.

West Coast Tectonics: For most of the Cenozoic, the western margin of North America was the site of an eastwrad-dipping zone of subduction. It was the compressional forces resulting from the convergence of the Pacific **Farallon Plate** and the **North American Plate** that resulted in the implacement of batholiths, volcanism, rock deformation and metamorphism that were associated with the Mesozoic and Early Tertiary orogenies. .During the Cenozoic, the Farallon Plate was being consumed at the subduction zone faster than new plate material was being created at the oceanic ridge. About 30 million years ago, parts of the Farallon Plate and East Pacific Oceanic Ridge were consumed by the subduction zone. Today, only the small Juan de Fuca Plate off the coast of Oregon and Washington remains of the once extensive Farallon Plate. The result of the consumption of the Farallon Plate was that the south-westward moving North American Plate was brought into contact with the northeast moving Pacific Plate. Once the Pacific and North American plates came into contact, the Andean-type margin no longer existed and the Pacific plate began to move parallel to what had been the zone of subduction. It was this lateral movement that eventually resulted in the ripping of Baja California from the Mexican mainland and the formation of the San Andreas Fault that is responsible for most of the earthquake energy released in the lower forty eight states.