Miocene tectonics and climate

Jarðsaga 2
- Saga Lífs og Lands -
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The Miocene (~24-53 MY) was first recognized and defined by Charles Lyell in the early 19th century. While examining rocks in the Paris Basin, he noted that different strata contained varying percentages of living mollusc species. The Miocene consisted of layers in which 18% of the fossils were represented among living mollusc species.
Miocene tectonics
Middle Miocene continental configuration
The Miocene saw a change in global circulation patterns due to slight position changes of the continents and globally warmer climates. Conditions on each continent changed somewhat because of these positional changes, however it was an overall increase in aridity through mountain building that favored the expansion of grasslands.
North American Miocene tectonics and climate

In N America, the Cascades and Sierra Nevada Mountain ranges formed, causing a non-seasonal and drier mid-continent climate. The increasing occurrences of drought and an overall decrease in absolute rainfall promoted drier climates. Grasslands spread, leading to evolutionary radiation of open habitat herbivores and carnivores.

The first of the major periods of immigration via the Bering land bridge between Siberia and Alaska occurred in the middle of the Miocene, and by the end of the Miocene the Panama isthmus had begun to form between Central and South America.
The Cascades

About 35 million years ago a volcanic arc grew across a complex mosaic of old terranes. Volcanoes erupted to cover the older rocks with lava and ash. Large masses of molten rock invaded the older rocks from below. The volcanic arc is still active today, decorating the skyline with the cones of Mount Baker and Glacier Peak.
The eruptive history of Mount St. Helens began about 40 ka ago with dacitic volcanism, which continued intermittently until about 2.5 ka ago. This activity included numerous explosive eruptions over periods of hundreds to thousands of yrs, which were separated by dormant intervals ranging in length from a few hundred to about 15 ka. The range of rock types erupted by the volcano changed about 2.5 ka ago, and since then, Mount St. Helens repeatedly has produced lava flows of andesite, and on at least two occasions, basalt.
The youngest of the active Cascades volcanoes
Cascade tectonics
Cascade Range Volcanoes - Interactive Imagemap

The Columbia River Basalts

The Columbia River Flood Basalt Province (Miocene, 17-13 MY), forms a plateau of 164,000 km². In all, >300 individual large (average volume 580 km²) lava flows cover parts of the states of Idaho, Washington, and Oregon. At some locations, the lava is >3,500 m thick. The total volume of the volcanic province is 175,000 km³
A stack of basalts...

The volume of the Columbia River Flood Basalts is 1/10th the volume of other large igneous provinces such as The Deccan and Siberian Traps.

Photos: Thor Thordarson
The Sierra Nevada mountain range

Sierra Nevada is ca. 640 km long and 60–130 km wide mountain range in eastern California. It rises to 4,418 m in Mt. Whitney, the highest peak in the United States outside Alaska.
About 30 MY ago, volcanism began in the Sierra Nevada region. The northern part was covered by thick layers of volcanic ash and volcanic rock (andesite and rhyolite). About 10 MY ago, the Sierra began uplifting. Parallel faults formed along the eastern edge of the range. The area to the west rose, and to the east dropped. While today the mountains rise about >3000 m above the surroundings, the total uplift was >6000 m!
Sierra Nevada, an enormous tilted block

It has long been recognized that the Sierra Nevada is a tilted block of the Earth's crust. A major fault zone bounds the block on the east, and it was along this that the great mass that became the Sierra Nevada was uplifted and tilted westward. This explains the asymmetry of the range. As the block was uplifted the abrupt, east-facing escarpment was cut into by the erosive action of wind, rain, temperature change, frost, and ice, and a series of steep-gradient canyons developed. Though the massive uplift began in Miocene, it has continued through the Quaternary Period. The present-day relief of >3500 m along the eastern slopes in the southern Sierra Nevada attests to the tremendous uplift.
Geology of the Sierra Nevadas
Sierra Nevada Geology

- Geologic history of last 25-30 millions years dominated by expansion and thinning of crust
- Large scale block faulting associated with expansion produces high relief of parallel mountain and valley sequences
- Faulting and erosion exposes billion year-old rocks in mountains several million years old
- Thinning of crust produces volcanic activity.
  - Long Valley caldera produced by massive eruption about 700,000 years ago
  - Mammoth Mountain area shows evidence of ongoing volcanic activity
Geologic history of last 25 million years dominated by expansion and thinning of crust.

Geophysical studies have shown that the uplift of the Colorado Plateau and the formation of the Basin and Range landscape is related to swelling of the Earth’s mantle causing elevation of broad areas of the American west.
The faulting exposes old (1.5-1 BY) bedrock
The eastern fault scarp
The San Andreas Fault originates in Miocene, some 15 MY ago. Geological features cut by the fault suggest that the total movement since then is ~315 km.
Uplift causes the formation of the Grand Canyon...

<table>
<thead>
<tr>
<th>Geological Era</th>
<th>Age Range (My)</th>
<th>Rock Type</th>
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<tbody>
<tr>
<td>Precambrian</td>
<td>3.5B-2.5B</td>
<td>Granite, basalt</td>
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<tr>
<td>Paleozoic</td>
<td>545-252Ma</td>
<td>Sandstone, limestone</td>
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<tr>
<td>Mesozoic</td>
<td>248-66Ma</td>
<td>Coal, limestone, sandstone</td>
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<tr>
<td>Cenozoic</td>
<td>66-0Ma</td>
<td>Volcanic rock, sedimentary rocks</td>
</tr>
</tbody>
</table>

*My* stands for millions of years ago.
...and the Basin and Range physiography

Figure 33. The alternating basins and ranges that characterize the topography of the area were formed during the past 17 million years by the gradual movement along faults. A, horst and graben blocks of the Earth’s crust. B, tilting of blocks of the Earth’s crust. The arrows indicate the relative direction of movement of rocks on either side of the faults.
Basin and Range = Graben and Horst
Basin and Range landscape
Death Valley floor at sea level
Fault near Furnace Creek
Uplift causes erosion of former lake bed sediments
Long Valley caldera produced by massive eruption about 760,000 years ago.
Long Valley Caldera was created about 760,000 years ago by an enormous explosive eruption. Scientists estimate that about 600 km$^3$ of magma was erupted, mainly as hot pyroclastic flows; this eruption ejected at least 50 times more magma than the 1991 eruption of Mount Pinatubo in the Philippines. The ejection of so much molten rock partially evacuated the magma reservoir, which caused the ground to collapse into the reservoir. The result was an enormous depression between 17 and 32 km in diameter!

Long Valley Caldera

Since the enormous explosive eruption formed the caldera about 760,00 years ago, hundreds of smaller eruptions have partially filled the initially deep depression.
Long Valley Caldera Eruptives

Columnar basalt in andesite

Caldera pyroclastic deposits
Glass Mountain obsidian lava dome. Glass mountain is a part of the Long Valley Caldera system.
Thinning of the crust causes volcanic activity

Ubehebe Crater in Death Valley

Crater Mtn and lava flows in Owens Valley
The Andes continue rising during the Neogene.

Plate tectonics also led to the Tertiary rise of the Andes Mountains in South America. The most active phase was 15-6 MY ago. This led to the formation of a rain shadow effect in the southeastern part of the continent. The movement of the plates also facilitated trends favoring non-desert and highland environments.
The Andes - still in the making

- The Andes Mountains are the longest chain of mountains, stretching along the entire west coast of South America from Cape Horn to Panama and Venezuela for a distance of 7,200 km. This second highest Mountain Range in the World has many peaks rising over 7,000 m feet. The chain is about 645 km wide across its widest part.

- The tectonic processes that created the Andes have continued to the present day. The system — part of the larger Circum-Pacific volcanic chain that often is called the Ring of Fire — remains volcanically active and is subject to devastating earthquakes.
Some Andean dimensions

The mountain system exhibits an extraordinary vertical difference of \(>13,000\) m between the bottom of the Peru-Chile Trench off the Pacific coast and the peaks of the high mountains within a horizontal distance of \(<300\) km.
The Andean structure
Rain shadows on both E and W side of the Andes
Tectonic developments in Europe

• During the Miocene, Eurasia underwent some significant tectonic rearrangements. The Tethys Sea connection between the Mediterranean and Indian Ocean was severed in the Mid-Miocene causing increased in aridity in Southern Europe.

• Africa collided with Eurasia during the Miocene, closing off the warm shallow Tethys Sea. Leaving the modern, enclosed Mediterranean. Dropping sea levels isolated and dried the Mediterranean Sea, leaving salt (evaporite) deposits on the former sea floor.
The red regions represent material of the African plate: 1) African foreland; 2) deformed African continental margin complex; 3) Austro-alpine nappes. The blue regions represent material of the European plate: 4) European foreland; 5) deformed European continental margin complex. The black regions (6) indicate areas with oceanic remnants; 7) Yellow, metamorphosed Alpine and pre-Alpine complexes.
Miocene tectonic developments in Africa

Africa was affected by rifting in East Africa and the union of the African-Arabian plate with Eurasia.

- A major uplift in East Africa created a rain shadow effect between the wet Central-West Africa and dry East Africa.

- The union of the continents of Africa and Eurasia caused interruption and contraction of the Tethys Sea, thereby depleting the primary source of atmospheric moisture in that area. Thus rainfall was significantly reduced, as were the moderating effects of sea temperature on the neighboring land climates.
Formation of Red Sea

Tension on the Triple Junction at Afar began in the Oligocene was dominant in the Miocene. This formed the Red Sea and the Gulf of Aden, which eventually were flooded by a rise in sea level.
The Tell Atlas originally arose out of a basin filled with sediment, which was dominated to the north by a marginal rim, of which the massifs of Tizi Ouzou, Collo, and Edough are the remnants. Its elevation took place during a lengthy Tertiary mountain-building process in connection with the collision between the African and Eurasian plate.
Atlas Mountains keep Sahara dry

The fertile Tell Atlas Mountains are the heartland of Algeria, containing most of its cities and population. Made up of hills and plains of the narrow coastal region, the several Tell Atlas mountain ranges and the intermediate valleys and basins form the basis for agriculture in the country. Sahara is in a rain shadow of the Atlas Mountains.
The Miocene - a phase of rapid Himalayan uplift
In Australia, the Miocene climate saw an overall increase in aridity as it continued to drift northwards. The number of rainforests began to decrease, to be replaced by dry forests and woodlands. The vegetation began to shift from closed broad-leaved forests to more open, drier forests as well as grasslands and deserts.
Throughout the Miocene, there is abundant evidence for the existence of a large ice sheet on Antarctica. The Miocene ice sheet was at times larger than today’s ice sheet. In the middle Miocene, both the East and West Antarctic ice sheets advanced onto the continental shelf, cutting deep glacial erosion surfaces and leaving a deposit of till all around Antarctica. The Antarctic glaciation caused global cooling and lowering of sea level.
The climate during the Miocene was warmer than today - but on a cooling trend. Well-defined climatic belts stretched from Pole to Equator, however, there were palm trees and alligators in England and Northern Europe. Australia was less arid than it is now.
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