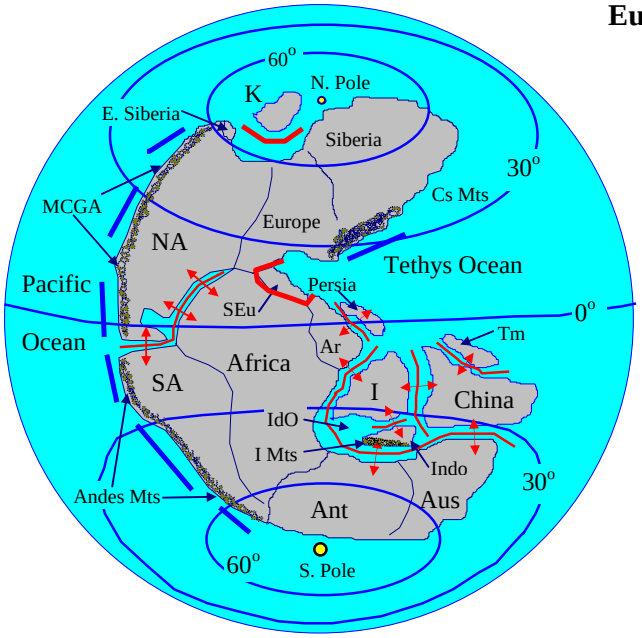
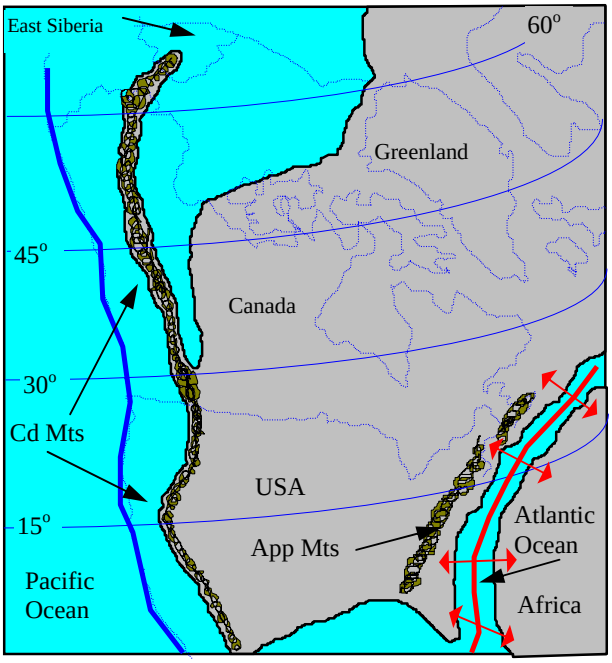
THE MESOZOIC
ABSAROKA
Triassic

Other parts of the world



Triassic World Paleogeography



Europe

Continental Interior

- transgressed by the sea

Continental Margin

- folding in the southeast produced the early **Caucas Mountains** as Gondwanaland rotated counter-clockwise toward southern Asia
- rifting began between Laurasia (North America and Europe) and Gondwanaland

Gondwanaland

- rifting just begins between South America. and Africa
- subduction below west coast of South America generated volcanism and produced the **Andean Mountains**
- Indian Ocean began to form as Australia, India and Antarctica began to rift from Africa
- Southern Europe (also called **Austroalpine-Adriatic Plate** and consists of Italy, Greece and the Balkan area) begins to rift from Africa to become a microcontinent in the Tethys Ocean between Europe and Africa

Indonesia Island Arc

- subduction began in area from Cambodia to Borneo

Climate in the Triassic

- world-wide the Earth was relatively warm and dry
- no evidence for glaciation
- less coal because swamps were probably fewer

North America

- still part of Pangea 2

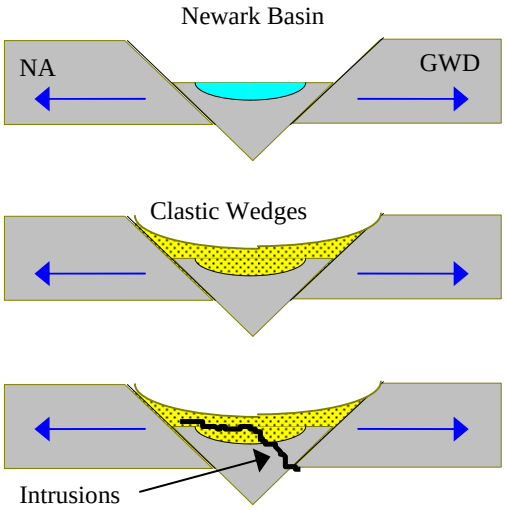
Continental Margins

Atlantic Coast Geocline

Early - Late TRIASSIC

- North America rotated almost to present north-south orientation, but farther south
- Missouri is at 15°S

Late Triassic



- rifting begins to separate N. A. from Gondowanaland
- rift valley forms **Newark Basin** from southeast New York to southeastern Pennsylvania
- graben was initially occupied by lakes, but erosion of the rift valley walls and associated highlands brought over 8000m of sandstone, conglomerate and shale into the rift valley as a series of clastic wedges collective called the **Newark Group**
- intrusion of molten igneous material into these sedimentary layers created the **Pallisades Sill** in New York and New Jersey and now exposed along the Hudson River
- if plot igneous intrusions on a reconstructed map of Pangea 2, they radiate out from the area where the Bahamas are located; this may have been the location of the initial mantle upwelling that lead to the break up of Pangea 2

Gulf Coast Geocline

Triassic

- as Gondwanaland pulled away from N.A., left Florida and the Gulf coast behind with North America.
- rifting produced a basin where evaporation caused deposition of the 600-1300m thick **Louann Salt**

Cordilleran Geosyncline

Early Triassic

- sea again flooded the miogeosyncline
- island arcs were present in the eugeosyncline

Middle Triassic

- uplift and erosion of the miogeosyncline

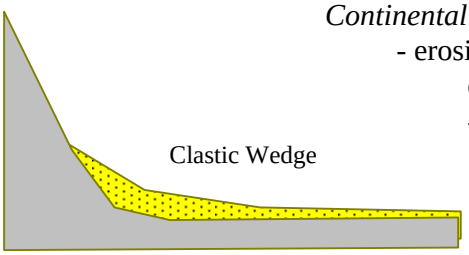
Late Triassic

- massive uplift of **Mesocordilleran Geanticline** developed between the miogeosyncline and eugosyncline from Nevada to Washington state

Franklin Geocline

Tirassic

- nearly 3000m of sediments deposited in offshore basins



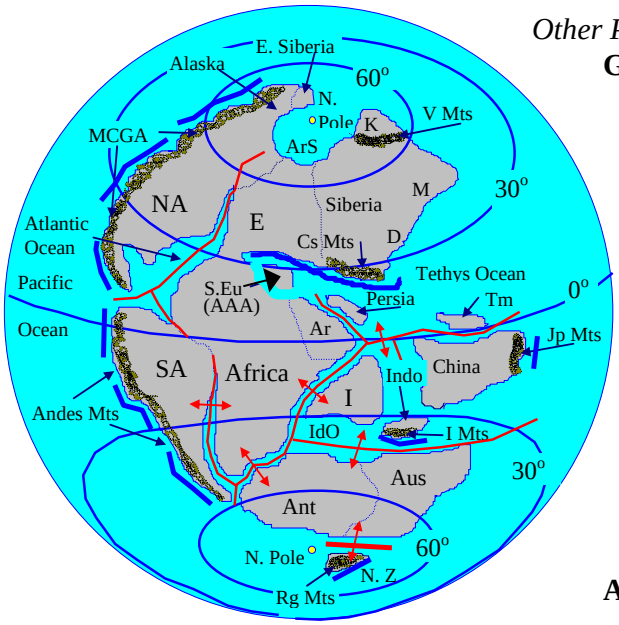
Continental Interior

- erosion of the uplifted Mesocordilleran Geanticline spread clastic wedges onto the miogeosyncline from Dakota to Arizona
  - **Chinle Formation** - red beds deposited as alluvial fans thinning to the east
  - buried trees in Arizona forming the **Petrified Forest**
  - where eroded has produced the **Painted Desert**
- eastern part of U.S. was exposed land subjected to erosion

Life in the Triassic

- corals - re-evolved from a soft-bodied form
  - modern corals not directly related to corals of the Paleozoic
- ammonoids - great diversification (**explosive evolution**)
  - major group for zonation
- reptiles - major land vertebrates
  - **Thecodonts**
    - were bipedal with had long heavy tail for balance
    - initially cold-blooded, but as body size grew became equivalent to warm blooded because body could store heat for long time
    - gave rise to Dinosaurs, Phytosaurs, Birds and Crocodiles
      - **Phytosaurs** - 4-footed thecodont very much like crocodile, but nostrils close to eye, not at end of snout
        -extinct by end of Triassic
  - marine reptiles (not dinosaurs)
    - **Ichthyosaurs**
      - dolphin-like reptiles evolved from Cotylosaurs
      - body stream-lined for swimming and legs replaced with fins
      - could not move on land so evolved to retain egg in body until hatched and gave birth to live young
      - air-breather
    - **Plesiosaurs**
      - long neck, large body, long tail (up to l5m in length)
      - legs evolved into paddle-like fins
      - lived mostly at the surface
- Mammals
  - evolved from the **Therapsids**
  - large brain to body size
  - generally small and rodent-like

ZUNI (Jurassic - Cretaceous)



Jurassic World Paleogeography

Other Parts of the World

Gondwanaland

Late Triassic - Early Jurassic

- expanding grabens developed between Africa, Australia, India, & Antarctica

Middle Jurassic

- sea floor basalt replaced grabens because of widening rift

Late Jurassic

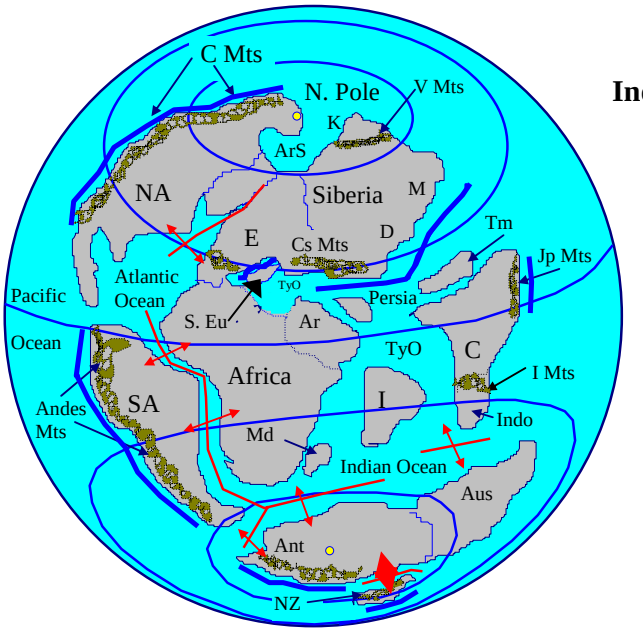
- sea begins to flood gap between South America and Africa and between Antarctica and Africa and South America
- Australia and Antarctica still attached to each other

Australia

- rifting between Australia and New Zealand began and resulted in the **Rangitata Orogeny** because of the subduction beneath New Zealand.

Kolymski

- moved northward and collided with Siberia and produced the the **Verkhoyansk Mountains** in the Cretaceous



Cretaceous World Paleogeography

India, Indonesia, China and **Tarim**

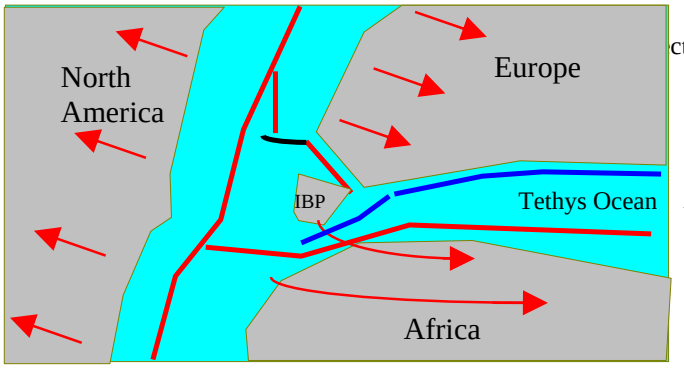
- separate continents and mirco-continents moving northward as the Indian Ocean expands

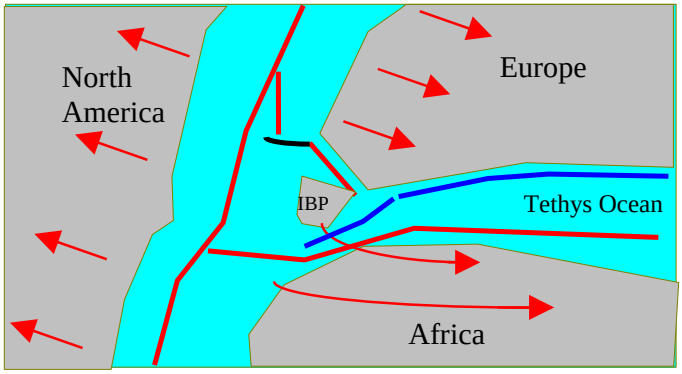
Jurassic

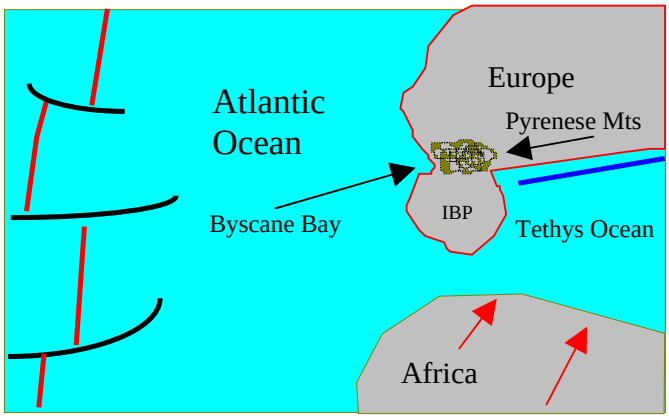
- subduction along the Pacific Ocean side of China produces the Japanese Mountains
- subduction below Indonesia produces the Indonesian Mountains

Cretaceous

- continued subduction of seafloor below China on the east
- collision between Indonesia and China
- new rift (**Mid Indian-Carlsburg Ridge)** system develops which left a small continental fragment, **Seychelles Islands,** stranded in the Indian Ocean







Europe

Iberian Peninsula

- **Iberian Peninsula** was originally located so that present west coast of Spain and Portugal were against the west coast of France
- as Gondwanaland pulled away, Iberian area rifted free of Europe, forming **Biscayne Bay**, rotated counter-clockwise and collided with southern France, creating the **Pyrenese Mountains**
- **Rhine Graben** may be failed arm of this rifting, an aulacogen

- continued uplift of the Caucas Mountains as Africa rotates towards Eurasia and narrows the **Tethys Sea**
- major transgressions occurred during the Jurassic and Cretaceous with a regression between them
- extensive deposition of Cretaceous chalk in Britain and France are exposed now in **White Cliffs of Dover**
- Subduction below Europe led to the formation of the **Alpine Geosyncline** as Gondwanaland moved northward in the Cretaceous

Pacific Ocean Basin

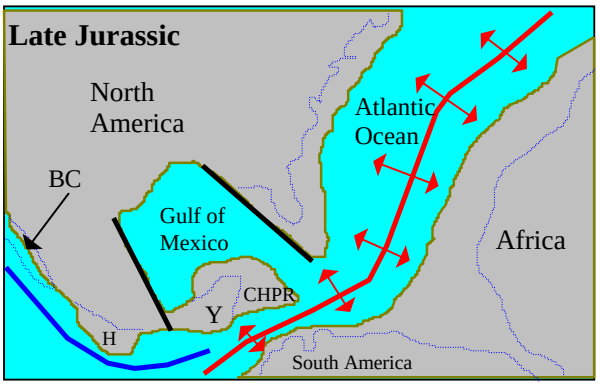
- oldest part of Pacific sea floor is Late Jurassic in age
- older sea floor has been destroyed in the trenches

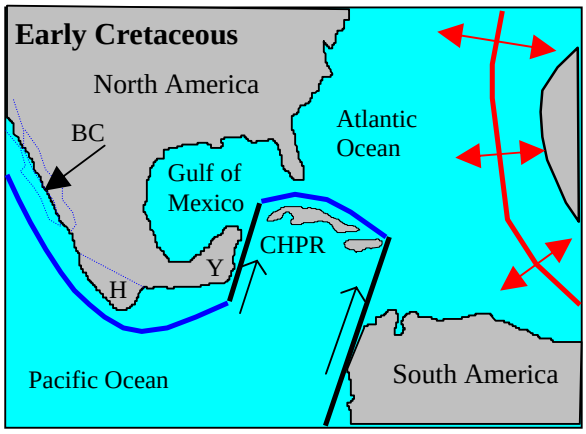
Greater and Lesser Antilles and the Yucatan

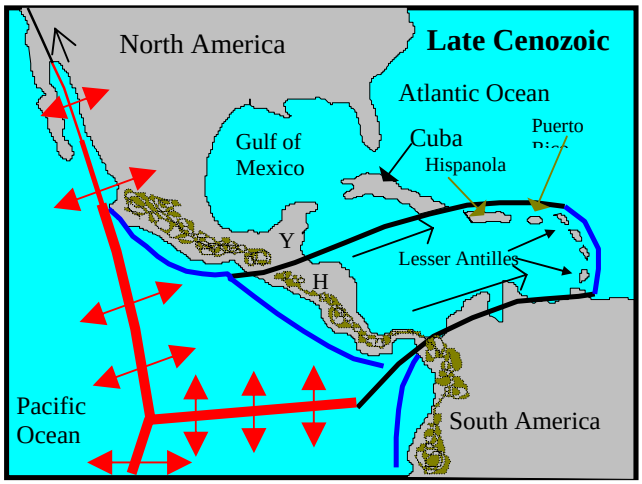
- Greater Antilles = Cuba, Hispanola, Puerto Rico
- Lesser Antilles = chain of volcanic islands
- formed by series of complex plate movements and subductions

Late Triassic

- as Gondwanaland pulls away from N.A. it left Florida and the Gulf Coast behind, but dislodged a large area where Louisiana and eastern Texas are today and moved it south







- this area eventually became the **Yucatan** and the **Greater Antilles** (**Cuba**, **Hispanola** and **Puerto Rico**)

Late Jurassic

- new rift formed which separated this landmass from Gondwanaland and stranded the Yucatan against southern Mexico

Early Cretaceous

- as S.A. rifted from Africa and began to rotate clock-wise, transcurrent faults pushed the Pacific sea floor into area of Caribbean and the faults sheared off Cuba, Hispanola and Puerto Rico from the Yucatan and moved them eastward

Tertiary

- a new patterns of rifting pulled **Hondorus** from the west coast of Mexico and shifted it to its present location south of Mexico
- it also separated Hispanola and Puerto Rice from Cuba and shifted them eastward
- subsequent formation of a trench and subduction lead to the formation of the **Lesser Antilles**, an island arc, and the **Isthmus of Panama**.

Late K Geography

- much flooding of the continents
- numerous ocean basins, but well connected by **circumglobal tropical seaway** consisting of the **Tethys Seaway** and the gap between North and South America
- continents isolated from .each other

Climate in the Jurassic

- warm, not as dry as the Triassic
- no major glaciation

Climate in the Cretaceous

- warm and dry
- no major glaciation

North America

Continental Margins

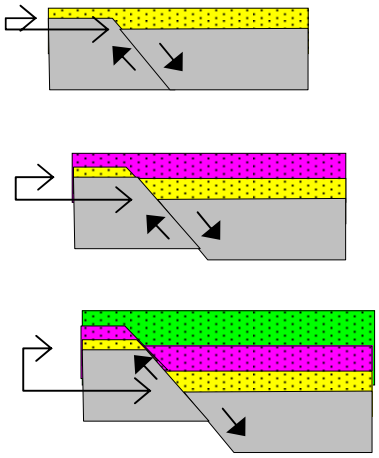
Atlantic Coast Geocline

Jurassic

- continued separation of North America from Europe, but rift passed to the west of Greenland and Greenland is part of **European Plate**
- sea began to flood the widening gap between Europe, N.A. and Gondwanaland
  - during initial flooding, **Argo Salts** deposited in the narrow seaway from Florida to Newfoundland in Early Jurassic
  - by Late Jurassic, the seaway was wider and limestones, chalk and shale were deposited in proto-Atlantic

Cretaceous

- rifting between N.A. and Greenland ceased and a new ridge developed between Greenland and Europe
- left Greenland as an island partially attached to N.A.
- **Atlantic Coast Geocline** (**East Coast Geocline**) accumulated several 1000m of sediment on shelf, slope and rise



Gulf Coast Geocline

- igneous intrusions developed in Ouachita Mountains in Arkansas
- intrusions include the ultramafic rock **Kimberlite** which contains diamonds
- accumulated over l0,000m of sedeiment
- coastal plains extended outward as series of deltaic wedgesonto shelf and sediments were mostly clays, silts and sands
- in areas of rapid deposition **Growth Faults** developed
  - normal faults with the down thrown side toward the Gulf
  - ground surface remained level because of deposition, but subsidence allowed more deposition on the downthrown side than the upthrown
  - displacement of beds increases with depth and over time

Cordilleran Geosyncline

- well developed miogeosyncline and eugeosyncline

Early Jurassic

- desert dunal sands occurred throughout much of miogeosyncline in the southeast

Middle - Late Jurassic

- sea flooded miogeosyncline and deposited the **Navajo Sandstone**, as well as limestone and shale

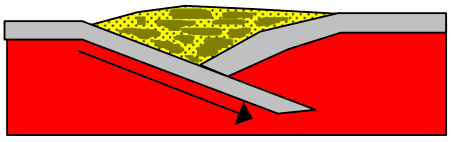
Late Jurassic

- **Cordilleran, Rocky Mountain** or **Columbian Orogeny** affected western N.A.
- Part I **Sever Orogeny**
  - major thrusting and folding of the miogeosyncline created uplift that eroded and shed clastics into the **Zuni Sea** as **Morrison Clastic Wedge**
  - affected Arizona into northern Canada
- Part II **Nevadian Orogeny**
  - **Mesocordilleran Geanticline** broadened into mountain chain from **Mesoamerica** to Alaska in length and from California to Utah in width.
  - erosion shed over 5000m of shale, cherts and volcanics which were deposited into the offshore trench as the **Belt Series** in California
  - emplacement of Mafic dikes in **Brooks Range** and **Sverdrup Basin** in Alaska

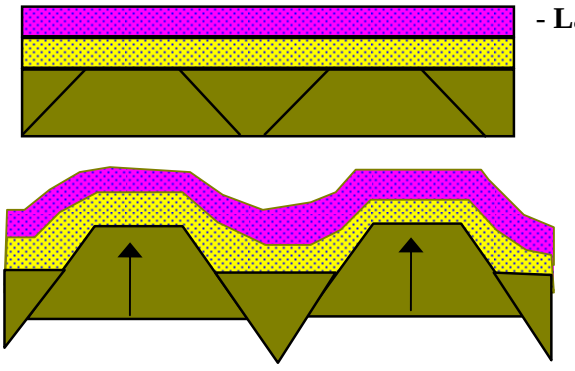
Late Jurassic - Early Tertiary

- massive accumulations of sediments were deposited along the west coast near California, including :

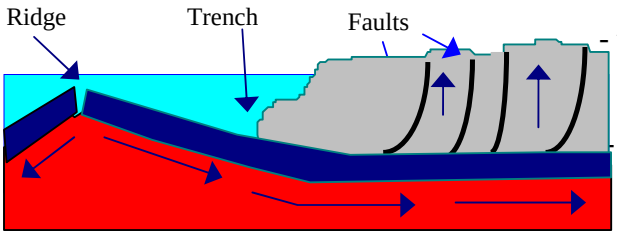
1. **Great Valley Formation** - 8 - 16000m of sandstone and shale
   - extensively folded in Middle to Late Cretaceous.
2. **Fransciscan Formation** - a **melarge** (May-lawn-jay)
   - deep water sediments that filled the trench and was intensely deformed and churned as the seafloor below it was subducted
   - became a chaotic jumble of blocks, some over a kilometer in diameter, in a shaly to slaty matrix and was plastered onto the west coast



Cretaceous



- **Laramide Orogeny** (Late Cretaceous - Early Paleocene)
  - series of uplifts from southwest Texas to Montana developed when deeply buried Pre-Cambrian faults were reactivated
  - sediments above faults were deformed into anticlines
  - reactivation may have occurred because N.A. was so close to the Pacific Ocean spreading ridge that the sea floor was no able to plunge down into the mantle because of the upwelling
  - subducted plate flattened out and scraped along the underside of North American Plate



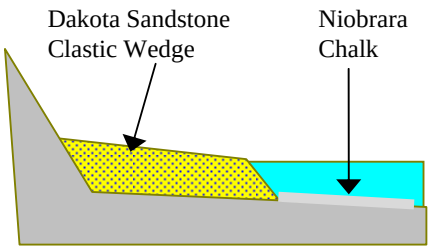
- this subducted plate did not melt as is normal at a zone of subduction and this was reflected by the sudden lack of volcanism in the region
- emplacement of numerous batholithic intrusions in the west from Mexico to Alaska
  - intrusions tend to be rich in metals

Continental Interior

Middle Jurassic

- **Zuni sea** transgressed from north toward south across the western interior, but did not reach Gulf of Mexico
  - deposited the **Sundance Shale**

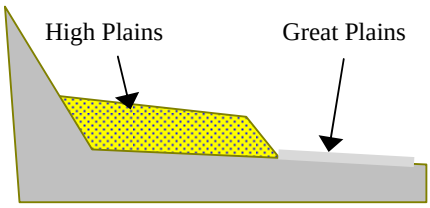
Late Jurassic



- seas withdrew as clastic wedge spread eastward from **Mesocordilleran Uplift**
- deposition of **Morrison Formation** which is important for dinosaurs fossils

Cretaceous

- transgression expanded across western N.A. and eventually created a seaway that extended from Gulf of Mexico to Arctic
- deposited the **Dakota Sandstone**, a major aquifer in the western U.S. and the **Niobrara Chalk** which is important for its preservation of fossils and extends from South Dakota to Texas
- in Late Cretaceous the sea withdrew and left behind an 800km wide alluvial plain (called the **High Plains**)



Life in the Jurassic

- **ammonoids** - increased diversification; major index fossils
- amphibians - continued decline because of competition with reptiles
  - first modern frogs appear
- **reptiles**
  - **Dinosaurs**- major land vertebrates = thunder lizards
    - two major types:
      1. **Saurischians** - lizard- or reptile-hip dinosaurs
         - **pubis bone** is directed forward and downward
         -two subdivisions:
           A. **Theropods**
           - carnivorous
           - appear in Late Triassic
           - bipedal with strong hind legs and small reduced forelimbs

- **Tyranosaurus Rex**

B. **Sauropods** -
- evolved from the **Theropods** in Early Jurassic
- reverted to **quadripedal** stance
- herbivores
- includes the largest reptiles with long tails and necks
- **Brontosaurus** = **Apatosaurus**;
  - 15m long, 30-40 tons, each foot print covers meter square
  - generally had weak jaw and peg-like teeth

2.**Ornithischians** - bird-hip
- pubis bone is forward and up and continues downward to the rear where where it is against the **ischium**
- mostly herbivorous with horny beak or bill-like structure
- no front teeth, but crowded back teeth for grinding
- bipedal and quadrepedal forms
- include heavily armored forms with spines, spikes horns an club-like tails

Pterosaurs (flying reptiles)
- evolved from the Thecodonts
- initially could only glide, but by Middle Jurassic probably could fly
- wing consisted of wide membrane attached to body and elongated 4th finger (similar to bat)
- bones were thin and hollow
- flight allowed exploitation of flying insects as food source
- Jurassic forms about size of robin

Birds
- warm-blooded and covered with **feathers**
- feather evolved from-scale
- **Archaeopteryx** - first bird; had teeth
- evolved backward facing toe that allows bird to grasp
- earliest forms probably just gliders
- evolved independently from thecodonts or from an ornithischians reptile, but not pterosaur

Plants
- evolution of the **Angiosperms**, flowering plants

Life in the Cretaceous

- protozoa - evolution of pelagic foraminifera (imp for chalk formation)
- clams - giant forms over lm in length
- ammonoids - very abundant and diverse; major index fossil
- **belemnoids** - evolved from the cephalopods
    - had internal shell and squid-like fleshy of body
- amphibians - continue to decline
    - evolution of salamanders
- reptiles - still major land vertebrates
    - evolution of the **ceratopsis** group
        - had plate-like bony extension over skull and back of neck for camouflage and thermal regulation, not defense
        - had one or more spike-like projections for defense
    - evolution of snakes from lizards
    - evolution of the turtles
    - evolution of the **Mosasaurs**
        - up to 9m long
        - doubly jointed jaw
    - evolution of giant pterosaurs with wing span of 15m

Extinctions at the end of the Mesozoic

Groups that became extinct:

Dinosaurs, pleisosaurs, ichthyosaurs, mosasaurs, pterosaurs, ammonoids, many marine algae, some foraminifera, giant clams and some plants

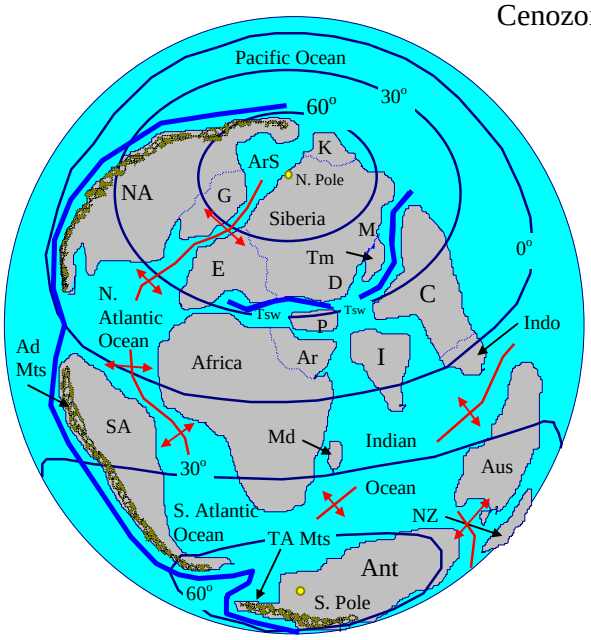
Possible reasons for extinctions:

1. change in climate
2. change in vegetation to angiosperms
3. regression of sea and elimination of marine habitats
4. reduction of swamps and shallow waterways
5. collision of Asteroid with Earth and generation of dense volcanic dust cloud and fire storm

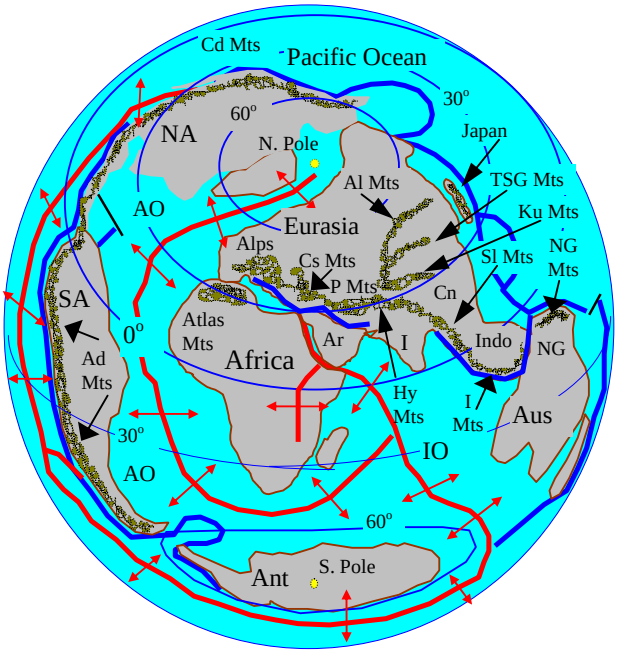
CENOZOIC = TEJAS SEQUENCE

Cenozoic Era is divided into two periods and several epochs:

Period	*Epoch*
	Holocene (Recent)
Quarternary	**Pleistocene**
	Pliocene
	Miocene
	Oligocene
	Eocene
Tertiary	**Paleocene**



Early Cenozoic World Paleogeography



Middle Cenozoic World Paleogeography

Europe

- collision of Europe with Southern Europe (Austro-Alpine-Adriatic Plate) raised the **Alps** in the **Alpine Orogeny** and fused the two into a single continent

Asia

- collision of India and Asia occurred in the Late Cenozoic and raised the **Himalayas** in the **Himalayan Orogeny**

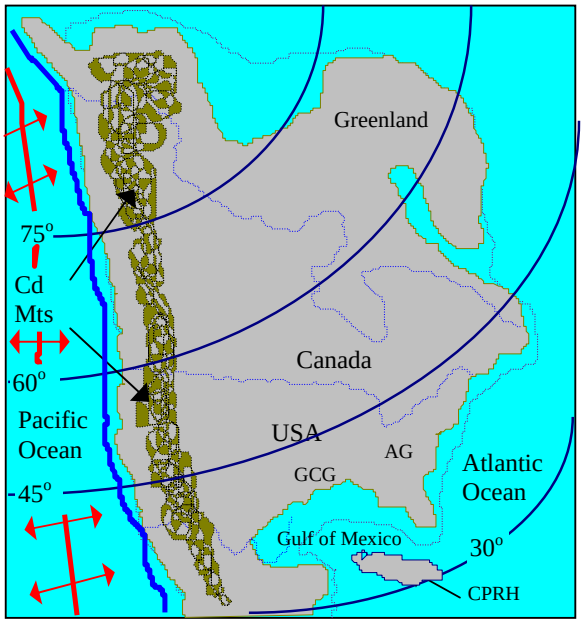
South America

- continued uplift of the Andes and volcanic eruptions as Pacific sea floor is subducted
- *Eocene-Oligocene* - **Andean Orogeny** produces the **Andes Mountains**
- *Pliocene* - Andes Mountains are largely eroded
- *Post-Pliocene* - renewed uplift and volcanism
- *Miocene* - **Amazon River** began to deposit its submarine fan in the Atlantic
  - it is now 14km thick

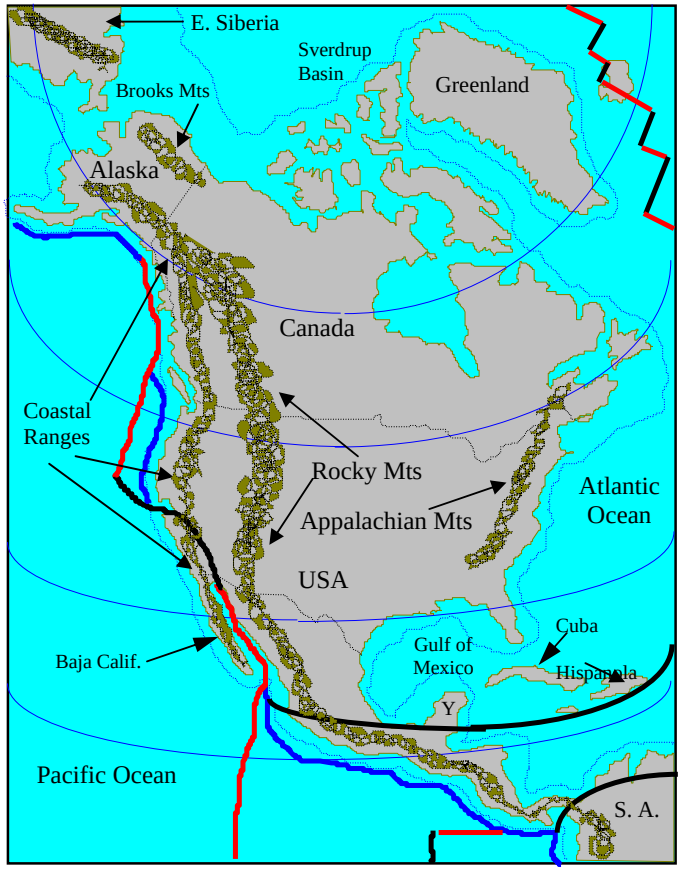
North America

Cordilleran

- at the end of the Mesozoic the **Pacific Spreading Ridge** was just west of North America and a trench was off the coast of the continent
- in the Cenozoic, Mexico and California collided with the ridge, over rode it and



Early Cenozoic North American Paleogeography



the by the Oligocene subduction along the west coast ceased
- spreading motion was changed into **transform motion**, creating the **San Andreas Fault** in the Eocene
- fault pulled **Baja California** away from Mexico and a new rift developed in the **Gulf of California**
- changed direction of Pacific Plate motion from northward to northwestward
- evidence for this is seen in the **Emperor Seamounts** and the **Hawaiian Island Chain**
- part of **East Pacific Plate** (**Farallon Plate**) is still being subducted below N.A. in the region of the Northern California to Canada
- this creates the volcanoes of the **Cascades** in Oregon and Washington including **Mt. Rainier**, **Mt. St. Helens** and **Crater Lake**
- also have continued subduction of **Juan De Fuca Microplate** in Washington
- **Pasadena** or **Coastal Range Orogeny**
  - period of folding and faulting of Mesozoic and Cenozoic strata, producing the **Coastal Ranges** of California
- much of the coastal areas of Northern California to Canada are composed of material transported great distances scraped off the subducted plate and plastered against the continent
  - material referred to as **exotic teraines**

Ocean Basins

Atlantic and Indian oceans expand as the Pacific Ocean Basin is reduced

Pacific Ocean - sea floor motion changed from North to Northwest
- **Galapagos Ridge** developed in Pliocene and the older **Chilean Ridge** ceased activity.

Atlantic - **Iceland** formed in Miocene

Indian - **90 degree ridge** active from Jurassic to Oligocene separated Australia from India

Seas

Red Sea - first opened in Oligocene, but motion ceased and then restarted in the Pleistocene

Gulf of California - opened in the Miocene because of San Andreas
- rifting began in Pliocene

Mediterranean Sea
- part of the Tethys Seaway in Early Tertiary
- in the Oligocene the Austro-Alpine-Adriatic plate collided with Europe and form Alps
- in the Miocene the Red Sea opened and Arabia collided with Asia, closing the east end of the seaway and creating the Mediterranean Sea
- in the Oligocene to Late Miocene Africa and Spain came together and closed the western end of the sea, converting it into a great giant evaporite basin
  - over 1 million cubic km. of salt was deposited as the sea completely evaporated and formed a basin 3000m below sea level
- in Late Tertiary the ocean eroded through at the **Straits of Gibralta** and produced a waterfall 1000 times size of Niagara Falls and the sea refilled the basin

Climate in the Cenozoic

Paleocene and Eocene
- tropical conditions were widespread with palm trees in Germany and corals as far as 50^{o} degrees north and south of equator
- arid regions of the Rockies were much more humid and several large lakes filled western basins including:
  - **Green River Lake** in Wyo., Co, and Utah.
    - accumulated the **Green River Shale**, a deposit **of oil shale** which contains enough **kerogen** to produce 180 million barrels of oil
    - as climate became drier, lake evaporated

Oligocene - world became cooled

Miocene-Pliocene - cooler and drier

Pleistocene - major cooling and glaciation.

Glaciation

Eocene - Glaciers isolated to mountain tops and locally in Antarctica
Pliocene - Widespread glaciation in Antarctica
Pleistocene - widespread glaciation in N.A. and Europe; = **Ice Age**
- about 1.8 million to 8,000 years ago.
- glaciers covered about 44 million square km. and in some places the ice was over 4000m thick.
- at maximum extent covered a third of N.A. and extended as far south as Kansas and covered much of Europe down to the river **Thames** in England, all of Germany and much of European Russia
- Asia mostly too dry for glaciers, but very cold
- glaciers removed a removed large volume of water from the sea and lowered sea level about 197m (644 ft.)
- loading of ice on the continents would have depressed the crust, causing outflow of mantle, pushing the seafloor upward, resulting in a rise in sea level
- sea level probably only dropped 133m (431 ft.)
- if all remaining glaciers melted, sea level would rise 65m (210 ft.)
- multiple glaciations
- Pleistocene was not just one major period of glaciation, but a period when glaciers repeatedly expanded and melted back
- Pleistocene divided into:
A. **Glacial Age** - time during which glaciers advanced
Glacial Stage - sedimentary layers of **till** deposited during the glacial age and named for the southernmost state glacier entered
B. **Interglacial Age** - time of glacial meltback (retreat)
Interglacial Stage - named for soil that developed between the glacial ages
- North American glacial and interglacial stages (oldest to youngest)
- **Nebraskan Glacial Stage** (2 major advances)
Aftonian Interglacial Stage
- **Kansan Glacial Stage** (3 advances)
Yarmouthian Interglacial Stage
- **Illinoian Glacial Stage** (3 advances)
Sangamonian Interglacial Stage
- **Wisconsin Glacial Stage** (4 or 5 advances)
End of Glaciation and Pleistocene

Effects of Glaciation
1. Changes sea level
- exposed most coral reefs
- created numerous new islands
- exposed vast areas of continental shelf

- created numerous land bridges between isolated areas
- greatly increased gradient of streams resulting in more erosion
- caused deposition of much sediment on ocean floor

2. Altered distribution of wet and dry climates
   - surges of cold air brought cooler climates farther southward and more rain into the midlatitudes.
   - areas that are today very dry were wet during the Pleistocene
     - **Sahara** and **Gobi Deserts** were grass lands with large lakes
     - in western U.S. 2 major pluvial bodies formed:
       Lake Lahontan in northwest Nevada
       Lake Bonneville
         - covered 50,000 square km.
         - 340m at its deepest
         - overflowed basin through rivers
         - **Great Salt Lake** is what remains today

3. Erosion of areas by glaciers and melt waters
   - **Finger Lakes** in New York were gouged out by glaciers
   - **Great Lakes** basins were eroded by glaciers and area depressed by the weight of the ice
   - Canadian Shield was mostly stripped bare of sediment and sedimentary rock cover as glaciers flowed across
   - streams carrying melt water eroded large valleys which today areoccupied by much smaller (**underfit**) streams
     - Mississippi River
   - glaciers sometimes blocked valleys and dammed streams forming huge lakes (**proglacial lakes**) behind the ice dams
     - when dams broke, the flood of water eroded deep valleys
     - **Lake Missoula**, which contained over 2000 cubic km. of water, drained across Washington State in a few hours after the ice dam broke and eroded the **Channeled Scablands** and the **Grand Coulees**

4. Depressed Crust
   - great weight of the ice caused the crust to warp downward and the mantle to flow outward
   - crust subsided about 1m for every 3.6m of ice that accumulated
   - as ice melted, land slowly rebounded (rose)
     - in Norway it continues to rise about 30cm/l00yrs.

5. Deposition of Sediment
   - much sediment was dumped by the glaciers at their termini and this was reworked by the melt waters into **outwash plains**

- cold, dense air formed on top of the glaciers and flowed down the front of the glaciers as strong, erosive winds which blew away the dust size sediment of the outwash plain and deposited it as thick layers of **Loess** which blanketed large areas and formed rich soil

Causes of Glaciation

- there has been a general decline in temperature since the end of the Cretaceous, but any explanation must also explain the glacial-interglacial cycle.
- possible causes for decline in temperature since the end of the Cretaceous:
  1. Uplift of the continents
     - water stores heat better than land. With more land exposed, less heat stored. Sea also transports heat poleward and helps moderate the polar climate.
     - more land exposed means more erosion, more dust generated and dust would block out the sunlight and cause less heating.
  2. Increased Volcanism
     - increase in volcanism would increase the amount of dust in the atmosphere, thereby reflecting the sunlight and causing cooling. In 1883 when Krakatoa erupted the temperature of the earth was lowered for the next 3 yrs.
  3. Meteoric Impact
     - would increase the amount of dust and lower the temperature
  4. Plate Tectonics
     - for ice to collect need an isolated environment that can become very cold, such as a continent at the pole, as in Antacrtica or a nearly landlocked sea, as in the Arctic Sea.
     - Arctic Sea became increasingly isolated in the Cenozoic
  5. Closing of the Tropical Seaway
     - warm currents had mainly circled the globe at the equator
     - when the Tethys Seaway and gap between N.A. and S.A. existed
     - when this closed, warm currents were forced to flow to north and south bringing much moisture to these regions and increasing precipitation

Growth of the Great Ice Sheets (**Continental Glaciers**)

Snow line

- altitude above which more snow accumulates each year than melts
- presently about 5 - 6000m above sea level at the equator and is the at the surface in polar regions
- in the Pleistocene the snow line was only 3000m high at the equator and so the tops of the **Laurentide Plateau** of the Canadian Shield was above the snow line

- this formed the growth center of the glaciers in North America

Glacier Growth

- as snows collected on the plateau, the white surface reflected sunlight and decreased heating, causing the region to become cooler allowing more snow to survive the summer
- as the area of permanent snow grew, the region became even cooler causing greater snow accumulation
- as the snow thickened, lower layers recrystallized into ice
  - when ice reached a thickness of 60m, it became plastic and flowed outward becoming a glacier
    - as long as the ice is thicker than 60m it will flow
- cold air blowing outward from the glacier caused more precipitation and increased the amount of snow fall
- eventually the mass of ice became so high and large that the glacier began producing its own **orthographic effect**
  - forcing winds upward where the air cooled and lost its moisture as snow
- glacial advance (flow) is slow, only about l00m/yr., but can briefly move in **glacial surges** of 40-50m/day

Cause of Multiple Glaciations

1. Astronomical Controls
   a. **declination** (tilt) of the Earth toward sun varies from 21.5^{o} to 24.5^{o} in a 40,000 yr. cycle
      - greater the inclination, cooler the winter and warmer the summer.
   b. Earth's orbit varies from nearly circular to oval in a 92,000 year cycle
      - oval orbit produces cooler seasons when Earth at **apogee** (greatest distance from sun)
   c. **precession of equinoxes** - Earth spins as a top with the axis pointing in one direction then the other in a 21,000 cycle.

- Combine all of these cycles together and will have a 40,000 year cycle of cold and warmth which coincides well with the glacial-interglacial cycle observed.

2. Ocean Control
   - began with Arctic Sea ice free, oceans deeper than today and the Arctic warmed by currents entering between Alaska and Siberia
   - winds blowing from the Arctic Ocean onto the land carries abundant moisture which fell as snow on the continents
   - snow accumulated on the land, reflected sunlight, lowered the temperature, causing more snow to accumulate
   - as some of the snow melted, cold water flowed out into the ocean and began to lower the ocean temperature in the Arctic Ocean

- more ice accumulated and glaciers formed, but sea level began to drop because of the removal of water from the sea
- eventually the warm currents could no longer enter the Arctic
- the Arctic Ocean began to cool rapidly and eventually froze over
- the ice cover prevented the evaporation of water and the cold winds blowing towards the land were dry
- gradually the source of snow was eliminated
- glaciers continued to flow outward because of the accumulated ice
- as the glaciers melted back (interglacial), sea level began to rise, warm currents again flowed into the Arctic and the sea ice melted
- the open surface again provided moisture and the cycle repeated

Life in the Cenozoic

- foraminifera - several "giant" forms develop with shells about the size of quarters
- **Teleost** (bony) fish - dominate ocean, but sharks (**cartilagenous**) are the largest (up to 23m long with 15cm, 6in, teeth).
- amphibians - represented by frog, toad, salamanders
- reptiles - represented by snake, turtles, lizards and crocodiles
- birds
  - underwent major diversification at the start of the Cenozoic
  - showed initial trend toward **giantism** during the early Tertiary
    - as body size increased, up to 2 m tall they became flightless
    - in Eocene were the major carnivore
    - ostriches are the only giant flightless birds extant
- mammal
  - **Pantotheres** - gave rise to:
    Marsupials - born immature and finish development within an external **pouch** in the mother
    Placentals - full development in **uterus**
    - Placentals rapidly replaced marsupials as dominant form in Europe, Asia, Africa and North America, but not in Australia and South America because these land masses were isolated before the evolution of the advanced placentals
      - Marsupials dominated in South America until the Late Tertiary when a land bridge connected it with North America
      - Marsupials dominated in Australia until Late Quarternary when man began to introduce placentals.
    - Paleocene- mammals were small to medium size
    - Eocene - trend toward giantism because more metabolically efficient - develop with a larger brain size

- Hoofed mammals
  - Odd toed - large central toe which bears most of weight
    - allows animal to be very fast
    - includes horse, rhino and many extinct forms
      - Eocene horse was dog size with 4 toes in front and three in rear
      - Miocene - diet changed to grazing
      - Pliocene - single toed horse
  - Even Toed - includes camels, pigs, **probosideans** (elephants), deer and cattle
    - camels - evolved in Eocene in N. A.
      - initially was small but as size increased, number of toes decreased
      - migrated to Asia, Africa and South America
    - Pigs - evolve in Eocene in Asia
      - some became gigantic in the Oligocene with skulls over a meter long
    - Probosideans (elephants)
      - evolved in Africa and Asia from small, short-tusked forms
      - Migrated to North America in the Miocene
      - Pliocene forms developed with tusk in upper law
      - Pleistocene extinction in North America
    - deer and cattle -evolve in Asia in Oligocene
      - migrated to N. A. in Pleistocene
- **Primates**
  - evolved from **insectivores** in Late Cretaceous-Early. Paleocene
  - developed opposable thumb, **stereoscopic vision**, complex brain
  - includes hominids, apes, monkeys, lemurs, tree shrews, tarsiers

- Plants - evolution of the **grasses** in the Miocene

Mammalian Faunas

- strongly influenced by plate tectonics
- when initially evolved, continents were close together and this allowed migration of the mammals to all of the land masses
- in Late Cretaceous - continents were far enough apart that faunal migration was difficult and each landmass became a separate province
- in Late Tertiary, Australia became completely isolated and dominated by **monotremes** (egg laying mammals) and marsupials
- also in Late Tertiary N. and S. America became separated
  - South America developed its own fauna of marsupials and primitive placentals
  - **homeomorphic** (look alike) forms develop between marsupials and placentals

- during Pliocene the isthmus of Panama reunited N. and S. America resulting in the mixing of the faunas and loss of most of the marsupials, except the armadillo, porcupine and for a while the **giant ground sloth**

- in the Late Tertiary, Asia, Africa Europe, North America and South America came sufficiently close together that faunas mixed and resulted in competition of forms and much extinction
- in Pleistocene strong distinction between cold and warn faunas and flora developed because of the glaciation
  - faunas show major migrations as climates change between glacial and interglacial.

- end of Pleistocene (5 - l0000yrs ago)
  - most giant forms became extinct including:
    Wooly Mammoth
    Mastadon
    Irish elk
    Giant ground sloth
    Saber-tooth cats
  - also saw the extinction of horses, camels and elephants in North America