MESOZOIC ERA
Triassic Period

1. Sonoma Orogeny*
   latest Permian-Early Triassic

- complete **closure of back-arc basin** between Klamath island arc & N. Amer. craton
  ***accreted terrance**; considerable growth of western margin*
- deepwater deposits thrust eastward over shallow water carbonates
  Golgonda Thrust (Nevada)

change in style of Cordilleran tectonics:

Paleozoic: **"Japan-type" margin**
subduction zone complex - island arc - back-arc basin

Mesozoic-Cenozoic: **"Andean type" margin**
subduction zone complex - forearc basin - magmatic arc - foreland basin

2. **Arid/semi-arid climate** continues in western N. America

- widespread reddish-colored continental deposits
  sandstones & shales; fluvial, alluvial plain, lacustrine, aeolian
- shallow marine deposits restricted to narrow foreland basin

3. **low global sea level** during Triassic

4. **break-up of Pangea** began during Triassic

- **rifting** propagated westward
  first split s. Europe & n. Africa: ***Tethys Sea***
- by Late Triassic, discontinuous **series of grabens** on each side of the future N. Atlantic
- **rift basins: thick sequences of red clastics**, intruded by basalt **dikes & sills**, also extrusive **lava flows**
  alluvial fan, alluvial plain, fluvial, flood plain, lacustrine
- some rift basins hooked-up:
  = **proto-North Atlantic** ocean basin
- others = "**failed rifts**"
  Hartford/Deerfield Basins, Newark Basin
- basins subsided, periodically invaded by Tethys Sea;
  thick salts accumulated in proto-N. Atlantic

MARINE ENVIRONMENTS

"Modern Fauna" replaces "Paleozoic Fauna"

- adaptive radiation of **bivalve molluscs**
  __ecologic replacement__ of brachiopods
  evolution of siphon: __infaunal__ mode of life
  bivalves: __infaunal & epifaunal__, __mobile & attached__
- **scleractinian corals**
  replaced rugose & tabulate corals
- **mobile echinoderms** (echinoids & starfish)
  replaced attached Paleozoic forms (crinoids & blastoids)

Ammonites* rediversified

- nearly wiped-out again at end-Triassic extinction
  1 Family gave rise to incredible Jurassic radiation

*important for **biostratigraphy** throughout the Mesozoic

marine organism diversity remained low during the Triassic

- probably due to low sea level

TERRESTRIAL ENVIRONMENTS

Dinosaurs & **Mammals** evolved in the Late Triassic

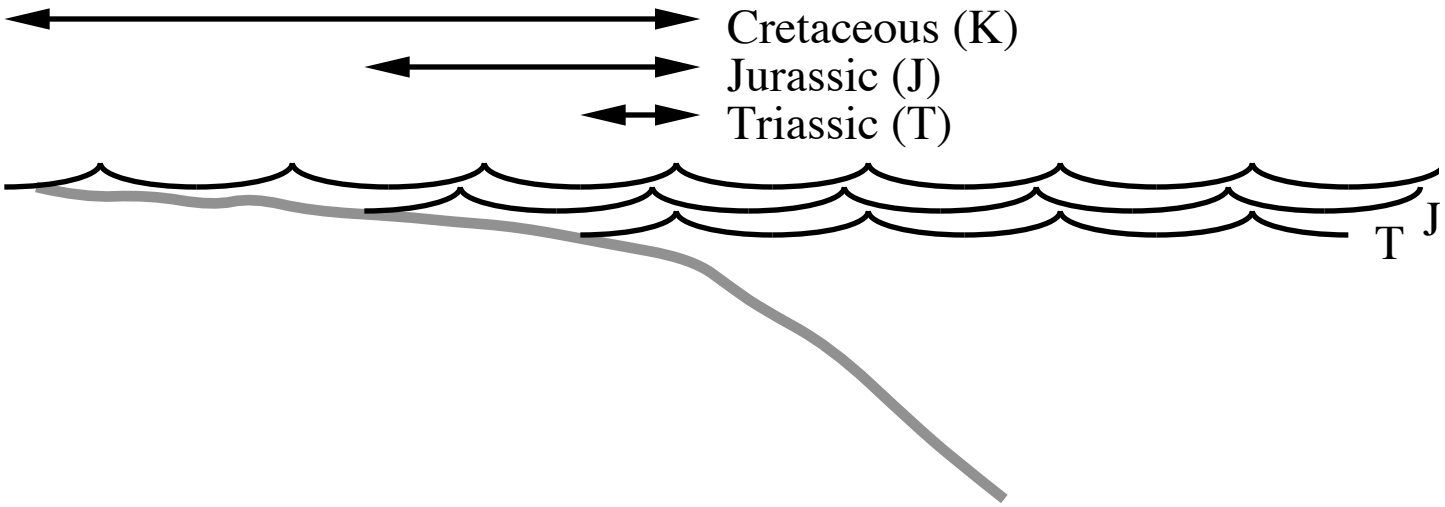
- **dinosaurs** evolved from thecodonts and quickly rose to dominance
  many were small & very agile
- **mammals** remained small & subordinate throughout the Mesozoic

MESOZOIC ERA
Jurassic Period

1. slowly rising global sea level
   related to the break-up of Pangea

generalized Mesozoic sea level trends

relative area of shallow marine waters (epicontinental seas):



2. **rifting of Pangea** continued, but **Gondwana** remained intact until Cretaceous time

a) N. Amer. began to **drift** away from NW Africa in early Middle Jurassic
~30 m.y. after rifting began

- **passive margins** developed on both sides of N. Atlantic
- **carbonate platforms** border Tethys Sea
  Late Jurassic

b) rifting of proto-**Gulf of Mexico**
Middle & Late Jurassic

c) **Tethys Sea**: circum-tropical seaway
Pacific → N. Atlantic → Indian ocean basins

3. Cordilleran Orogeny

- 3 pulses:
  Nevadan *- Late Jurassic*
  Sevier *- Cretaceous*
  Laramide *- Early Tertiary*
- driving force:
  subduction *of oceanic crust beneath N. Amer.*
  (& opening of N. Atlantic)

CROSS-SECTION OF NEVADAN OROGENY:

California:

1. Franciscan Formation

- subduction zone complex
  accretionary wedge *(melange)*
  low T/high P metamorphism

2. Great Valley Sequence

- fore-arc basin
  *thick sequence of turbidites (**submarine fans**)*

3. Sierra Nevada

- magmatic arc
  granitic plutons *now exposed*

Western Interior

- foreland basin
  *Lower Jurassic terrestrial facies overlain by series of 4 **marine transgressions** ("Sundance Sea")*

- Morrison Formation
  *widespread blanket of **molasse facies** (AZ Canada)*
  "dinosaur graveyard"

MARINE LIFE

*radiation of marine organisms related to **rising sea level** & **expansion of shallow seas***

- great diversification of **ammonites**
- great diversification of **oceanic plankton**
  siliceous protists → deep-sea chert
  calcareous protists → deep-sea calcareous ooze & chalk, limestone

TERRESTRIAL LIFE

- radiation of **dinosaurs**

2 major groups:
  "bird-hipped"
  "lizard-hipped" - includes very large sauropods

- **pterosaurs** - flying reptiles
- **first birds** by Late Jurassic (*Archaeopteryx*)
- **ichthyosaurs** & **plesiosaurs** - large aquatic/marine reptiles
- **mammals** - small, subordinate to dinosaurs
- gymnosperms, especially **cycads**, dominated terrestrial flora
  "Age of Cycads"

MESOZOIC ERA
Cretaceous Period

1. Active Tectonics

- Gondwanaland began to split-up (rift drift)
  - increased length of **spreading centers**
- major intra-plate **hot spot volcanism**:
  flood basalts: "**Large Igneous Provinces**"
  e.g., mid-Cretaceous of Pacific
- increased rates of **seafloor spreading**
  - increased rates of subduction, increased **volcanism**
  mid- to Late Cretaceous

Predict the consequences of this active tectonism

2. High global sea level & widespread epicontinental seas
   → decreased albedo
   mid- to Late Cretaceous

3. "Greenhouse world" of elevated CO_2
   → warm, equable climate
   ice-free poles

4. Distinctive marine sediments

- widespread **chalk seas**
  Kreide: "K" or Cretaceous
- widespread deposition of **organic carbon-rich sediments**:
  "**black shales**" of deep-sea & epicont. seas
  ~60% of hydrocarbons are mid- to Late Cretaceous age

Beginnings of an important transition in **paleogeography**

Early Cretaceous

- **east-west Tethys Sea**
  circum-tropical seaway
- poor deep-sea circulation in Atlantic

Late Cretaceous

- opening of South Atlantic
  beginnings of ***north-south Atlantic***
- improved oceanic circulation

Later:

- *progressive closure of Tethys Sea*
- *opening of northern North Atlantic*
- *isolation of Antarctica*

green & black deep-sea sediments
O2-poor, reducing environments

red & brown deep-sea sediments
better oxygenation

MARINE LIFE

- adaptive radiation of **marine plankton**
  *calcareous & siliceous **algae** & **protists***
- **ammonites** were abundant & very diverse
- **rudist bivalves** = dominant reef frame-builders
  mid- to Late Cretaceous
- radiation of **shell-penetrating predators**
  teleost fish, crabs, carnivorous gastropods

TERRESTRIAL LIFE

- **dinosaurs** = dominant land animals
- **conifers** (**gymnosperms**) replaced cycads as dominant flora
  Early Cretaceous
- evolution & diversification of **flowering plants** (**angiosperms**)
  more efficient reproduction (enclosed seed) than gymnosperms (naked seed); mid- to Late Cretaceous

5. Margins of North America

Passive (divergent) margins

- Atlantic margin
  dominated by ***clastic sediments***
- Gulf of Mexico
  dominated by shallow water ***carbonates*** *(rudist reefs)*

Active (convergent) margin

- Pacific (Calif.)
  continued accretionary wedge & fore-arc basin
- Pacific (Canada & Alaska)
  accretion of "exotic terranes"

6. Sevier Orogeny
part of Cordilleran O.

- **magmatic arc**: Baja Alaska
- large **granite plutons** emplaced in Sierra Nevada
- **metalic ores** (e.g., gold) emplaced by hydrothermal fluids associated with magmatic arc
- abundant **volcanic** activity
- large **foreland basin**:
  "**Western Interior Sea**"
  UT MN
  Gulf of Mexico Arctic Ocean
  where present-day Rocky Mtns. are

END-CRETACEOUS MASS EXTINCTION

Cretaceous/Tertiary Boundary (K/T boundary)

Losses:

- ~30% marine invertebrate families went extinct
- all ammonites
- all rudist bivalve molluscs
- ~90% calcareous plankton
- all dinosaurs
- all flying reptiles

Survivors:

- nautiloids
- mammals
- reptiles (turtles, crocodiles, lizards)
- birds

DEVELOPMENT OF THE IMPACT HYPOTHESIS

- extinctions long thought to be due to volcanism, falling sea level, changing climate, or even disease

- classic paper of discovery & controversy:
  Luis W. Alvarez, Walter Alvarez, Frank Asaro, and Helen Michel, *Science*, 208:1095-1108.

- **Ir anomaly** at K/T boundary
  Ir is v. rare in Earth's crust (~0.03 ppb)
  *clay layer at K/T boundary in **Gubbio Italy** ~9.1 ppb = 30X increase above background levels in limestone above & below boundary = "**Iridium anomaly**"*
  found Ir anomaly at other sites

- Alvarez et al. concluded that it must be an **asteroid impact**
  estimated 10+/-4 km diameter, 10 km/sec, crater ~150 km diameter

Likely Cause?

Catastrophic environmental changes related to a **bolide impact** (northern Yucatan Peninsula)

"Smoking gun" (**impact crater**) not discovered until 1989/1990

Hildebrand et al., 1991, *Geology*, 19:867-871

circular structure, **~180 km in diameter**, seen only in gravity and magnetic anomaly surveys

90 m-thick ejecta breccia found close to edge of crater

tektites (glass spherules = melted target rock) found in Haiti, Mexico, off eastern Florida

Evidence of impact?

- **iridium** found globally in clay layer*
  "aerosol fallout"
  by 1990, 100 scientists in 21 labs in 13 countries found Ir anomalies in 95 sites world-wide
- **shocked quartz**
  found at many sites globally
- **tektites** (melt droplets - glass spherules)*
  "ballistic fallout" limited to Western Hemisphere
  geochemical fingerprinting of glass matches Yucatan target rocks [limestones and evaporite (gypsum) deposits]
- **tsunami deposits** around Gulf of Mexico
- **catastrophic slope failure**: Gulf of Mexico, Caribbean, western N. Atlantic
  shock of a magnitude 13 earthquake!
- **fern-spore spike** at base of Tertiary in N. Amer.
- **soot** found in basal Tertiary deposits

**impact ejecta:*

- ***two macroscopic layers*** *in N. America*
- ***single layer*** *in Europe, n. Africa, New Zealand, S. Atlantic, and Pacific*

lower layer = ballistically emplaced ejecta curtain
upper layer = vapor-rich plume (aerosol) carried globally

Some environmental consequences:

- **darkness** (dust & smoke) shuts down photosynthesis
  organisms at base of food webs; therefore most organisms affected, some to extinction
- **wildfires**, especially in N. Amer.
  ejecta would have ignited wildfires on several continents*

modeling of impact trajectories and comparison with ejecta debris (Kring and Durda, 2002, JGR, 107-E8) suggests that debris is concentrated near Chicxulub and at an antipode (India and Indian Ocean 65 myr) and slightly smeared longitudinally due to Earth's rotation (Coriolis effect)

- brief **cooling** followed by **warming?**
  darkness + stratospheric sulfuric acid aerosols (cooling) followed increased greenhouse gases (warming) due to vaporization of target rock ($CaCO_3$) + effects of depressed photosynthesis and wildfires (loss of CO_2 sinks)
- **acidic aerosols** & **acid rain**
  vaporization of target rock = shallow water limestones & evaporites (gypsum) creates sulfuric acid rain
  shock-heating of atmosphere creates nitrous oxide acid rain

Other longer-term environmental changes at time of K/T:

- **falling global sea level**
  shallow marine niches
  global albedo & climate
  seasonality on land
- **changing vegetation** on land
  rise of angiosperms
- eruption of **Deccan Traps** (India)
  flood basalt (LIP)