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 terrane**; 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):

   
   Cretaceous (K)
   Jurassic (J)
   Triassic (T)

T J
2. ** rifing 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 rifing began

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

   b) rifing 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 Æ 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 CO₂
   - 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
  - $O_2$-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 elastic 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
- **metallic 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


• **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

circular structure, \(~180 \text{ km in diameter}\), 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 (CaCO₃) + effects of depressed photosynthesis and wildfires (loss of CO₂ 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)