

# Chapter 1 - Introduction to Oceanography

related sciences: physical geography, geology, astronomy, chemistry, meteorology, biology, ecology (marine sciences), navigation & mapping

**Government agencies** involved in oceanography:

- NOAA
- USGS
- FWS
- NPS
- NASA
- DOA
- DOD
- DOE
- EPA
- CDC

**The four principal oceans (71%):**

- Pacific (largest and deepest),
- Atlantic
- Indian
- Arctic
- ("Plus 1") - the "Southern Ocean"

- **Average depth** of oceans about 3688 m (12,100 ft)
- Deepest ocean location: **Mariana Trench** 11,022 m (36,161 ft) - Where?
- Average elevation of continents 840 m (2,756 ft)
- Highest mountain Mt. Everest 8850 m (29,935 ft) - Where?

What is "**Relief**":

- **Topography**:
- **Bathymetry**:

Ancient Explorations: Egyptians, Minoans, Chinese, Mayans, Pacific Islanders

"Historic" Explorations:

- Leif Ericsson
- Christopher Columbus
- Ferdinand Magellan

What is **science**?—systematic knowledge of the physical or material world gained through observation and experimentation

- **goal of science**—"to discover underlying patterns in the natural world."
- **fundamental assumption of science**—"the natural world behaves in a consistent and predictable manner."

The **scientific method** involves:

- **observation**:
- **hypothesis**:
- experiments & testing:
- **research**
- recording results:

The scientific method may lead to:

- establishing **fact**:
- **theory**:
- **scientific law**:

### Essential Chemistry and Physics Concepts for Oceanography

- **atoms**: (nucleus: **protons & neutrons**), outer shells of **electrons**
- **elements**:
- **atomic number**:
- **Periodic Table**:
- **molecules**:
- **chemical compounds**:
- **minerals**:
- **mixtures**:
- **chemical formulas**:

The **most abundant elements** in our physical environment are:

H, C, N, O, Na, Mg, Al, Si, P, S, Cl, K, Ca, Fe

### Molecular bonds:

- **metallic**
- **ionic**
- **covalent**
- **Van der Waals forces** ("friction")

What are **salts**?

- **halite (NaCl)**:
- **gypsum & anhydrite (CaSO<sub>4</sub>)**:

### Metals and metalloid compounds?

- \* **iron minerals**: **pyrite, hematite, limonite** ("rust"), **magnetite**

Two most important **minerals** in oceanography

- \* **Quartz (SiO<sub>2</sub>)**:
- \* **Calcite (CaCO<sub>3</sub>)**:

Many elements have one or more isotopes.

- \* 80 elements in the "natural environment"
- \* **Stable isotopes** (254 in nature):
- \* **Radionuclides** (50): (undergo radioactive decay):

**carbon has 3 isotopes**: **<sup>12</sup>C - <sup>13</sup>C - <sup>14</sup>C** (which are stable isotopes or radionuclides?)

Geiger counter:

### ENERGY:

All physical and chemical reactions involve either the loss or gain of some form of energy

- \* **Electromagnetic spectrum** (rays): cosmic, gamma, ultraviolet (UV), light (ROYGBIV), near infrared (IR), thermal IR, microwave, radio
- \* Different kinds of "Heat":
- \* kinetic vs. potential energy:
- \* Geothermal energy:

## **Gravity, Mass, and Density**

- \* **Gravity** (weak force):
- \* **Mass** (resistance to **acceleration** [atoms]) :
- \* **Density** (**mass/volume = grams/cm<sup>3</sup>** or “cc”):
- \* **Density stratification** (in earth, oceans, air)

## **Rock Cycle** (geologic processes & products, over time)

- \* **Igneous rocks**:
  - **magma & lava**
  - cooling, **crystallization**
  - intrusive (plutonic) & extrusive (volcanic)
- \* **Sediments**:
  - **weathering, erosion, deposition**
- \* **Sedimentary rocks**:
  - **compaction, cementation, lithification**
- \* **Metamorphic rocks**:
  - **metamorphism** involves heat, pressure, fluids

## **Zones of the Earth Climate System**

- \* **Tropical zones**: (Cancer & Capricorn)
- \* **Temperate zones**: (North & South)
- \* **Polar zones**: N & S Frigid Zones

What is the **Ecliptic Plane**?

**Seasons: Solstice** (summer & winter) and **Equinox** (spring & fall)

## **Maps: Globe vs. flat maps**

- \* **coordinate systems** (**Mercator**, Lambert, Conical, etc.)
- \* **GIS** (geographic information systems)
- \* **GPS** (global positioning system)
- \* **Latitude**
  - **parallels**:
    - Equator, Arctic & Antarctic Circles:
- \* **Longitude**
  - **meridians**:
    - **Prime Meridian & International Date Line**:

**Geologic time scale**: names of geologic time periods (billions, millions, thousands of years)

- \* Eras in Earth History
  - **Precambrian** (early Earth history - prior to 541 million):
  - **Paleozoic** (ancient multicellular life - 541 to 252 million):
  - **Mesozoic** (middle life - 252 to 66 million):
  - **Cenozoic**: (modern life - 66 million to present):

## **Astronomy Concepts and Evolution of the Earth**

- \* "**Big Bang**"
- \* Size and age of the expanding **Observable Universe**:
- \* **Galaxies** (ex: Milky Way, Andromeda):

## Life cycle of stars:

\* **Nebulas:**

\* **Supernovas:**

## The Solar System:

\* **Age of the Solar System and Earth:**

\* Formation of the Earth-Moon system:

\* Density's role in formation of the Earth and it's layered structure:

— Earth's **crust, mantle, core**

\* Origin of oceans/atmosphere from **stellar gases** and **volcanic outgassing:**

— Early oceans (“organic soup”):

— Early atmosphere (no free oxygen):

\* Planets: (**MVEMJSUNP**)

— “rocky planets”:

— “gas planets”:

— Moon (**age, composition, surface features**)

— Asteroids:

— Comets:

— **Bollides** and **astroblemes:**

— Meteors and **meteorites:**

## Oceans on other planets and moons in the Solar System

\* Venus

\* Mars

\* **Europa**

\* Ganymede

\* **Enseladus**

## Basic Geologic Principles

\* **Uniformitarianism** - "The present is key to the past."

— James Hutton (1726-1797)

\* **Catastrophism:**

\* What are **rock formations**?

\* What are **strata**?

Observable Process	Immediate observable results	Long-term geologic features
river flooding into the ocean	build up of sedimentary deposits along coast	large delta systems many miles thick
earthquakes	observable offset along a fault	uplift of a mountain range
waves and biologic activity in shallow ocean	formation of reef and reef sediments	build up of a great barrier reef

**Geochronology:** Methods for determining the age of Earth materials and features

**Absolute Dating Methods:**

- Decay of radioactive isotopes
- "Half life" concepts

**Radiocarbon Dating:**

- Half-life of  $^{14}\text{C}$ :
- Half-life of Uranium/Lead:

**Relative Dating Methods:**

- \* Law of **Original Horizontality**:
- \* Law of **Superposition**:
- \* Law of **Cross-Cutting Relationships**:
- \* **Inclusions**:

**Unconformities:** Gaps in the "geologic record"

- **nonconformity**:
- **angular unconformity**:
- **disconformity**:
- conformable boundary:

**Chapter 2 - Evolution of Life Through Time**

See **Geologic Time Scale** with highlights in evolution and events in Earth history.

**Carl Linnaeus (1707-1778)**

- **binomial nomenclature**:
- **taxonomy**:
- **classification**:
- **ecology**:

**Charles Darwin** wrote "**Origin of Species**" (1859)

- **Theory of Evolution**

**Gregor Johann Mendel (1865-6)**

- **genetics**:
- **heritable genetic traits**:

**James Watson and Francis Crick (1951)**

- **DNA**

**Human Genome Project** (completed, 2/2001)

- implications for human evolution theory

**Evolutionary Theory**

- \* **natural selection**:
- \* **divergent evolution**:
  - **diversification (diversity)**:
- \* **convergent evolution**

## How Evolution Works

The **life mission** of individuals in any **species**: **eat, survive, and reproduce.**

- What is a **species**?
- What is a **community**?
  
- **competition** (within a population, or with other species).
- **environmental changes**
- **adaptation** (“adapt genetically”)
- **evolve** or **extinction**

What is **extinction**?

- \* **Paleontology**:
- \* **Paleoecology**:
- **fossils**:
- **fossilization**:
- **trace fossils**:
- \* What is the "**Fossil Record**":

**Sedimentary Sequences**:

- impact of **transgressions**:
- impact of **regressions**:
- \* Sequences exposed in the **Grand Canyon**
- \* What is the "**Great Unconformity**"?

## Early Earth history and cell theory:

### Precambrian Era

- \* ~4.5 billion: formation of Solar System
- \* ~4 billion - early **life**
- **prokaryotes**:
- **eukaryotes**:
- \* ~3 billion - **photosynthesis**
- **photosynthetic bacteria**
- \* 3.0-1.8 billion - **Banded-iron formations (BIFs)**:
- role of BIFs in oceans/atmosphere?
- formation of the Ozone Layer
  
- \* 1.8 billion - Sex!
- **endosymbiosis** (origin of **organelles**):
- **viruses**:
- **stromatolites** appear:
- life migrates into shallow oceans
- first “carbonate algal reefs”
  
- \* 1.0 billion - **metazoans** first appear:
- Ediacaran fauna (635 to 541 million years)

## **Paleozoic Era (541-252 million years):**

**Cambrian Period** (541-485 million years):

— "**Cambrian Explosion**" - **chitinous** and **calcareous shells** and **exoskeletons** first appear in the "fossil record."

**bioturbation (trace fossils):**

all major **phyla** appear:

common fossils: **trilobites, brachiopods, crinoids, bryozoans, sponges, and gastropods**

all are **invertebrates**:

"**Great Unconformity**" (Grand Canyon)

**Sauk Sequence** - first sedimentary deposits containing abundant fossils in North America

**Ordovician Period (485-444 million years):**

Abundant fossils of the Cincinnati Arch:

"**Age of Invertebrates**"

brachiopods, crinoids, bryozoans, sponges, corals and gastropods are common fossils

giant shelled **cephalopods**:

first **fish** (rare, tiny, jawless) appear:

first primitive **land plants**:

first **mass extinction**:

**Silurian Period** (444-419 million years)

First "**forests**" (primitive)

Fish (**chordates**) flourish

**Insects, scorpions, sea scorpions**

**Devonian Period** (419 to 359 million years):

ray-finned & lobe-finned **bony fish, sharks**:

**plants with true leaves & roots, seeds** appear:

**coal beds** (ferns, cycads):

**black shale**: (target of "fracking"):

**second mass extinction**:

**Mississippian/Pennsylvanian Periods (Carboniferous Period)** (359 to 299 million years):

**Appalachian Mountains** form:

**Limestone** (shallow seas):

**Coal measures**:

"**Age of Amphibians**"

**Permian Period** (299 to 252 million years):

**Tetrapods**:

**Great reefs**:

**Greatest mass extinction**:

**Mesozoic Era (252-65 million years)**

"**Age of Reptiles**"

Differences of **reptiles & dinosaurs**:

**Triassic Period** (252 to 201 million years):

"**Petrified Forest**"

"red beds"

**Triassic mass extinction:**

**Jurassic Period** (201 to 145 million years):

"Breakup of Pangaea"

**Atlantic Ocean basin:**

"Zuni" desert:

first **birds, mammals** appear:

**marine reptiles:** (ichthyosaurs, plesiosaurs):

**Cretaceous Period** (145 to 66 million years):

**Western Interior Seaway:**

**Rocky Mountains:**

"chalk":

**mosasaurs:**

**ammonites:**

**flowering plants:**

**K/T Boundary extinction:**

**Cenozoic Era** (66 million to Present):

"Age of Mammals"

**Tertiary Period** (66-2.6 million)

– **Paleogene** Period (66-23 million)

– **Neogene** Period (23-2.6 million)

– **Quaternary** Period (2.6 million - present)

What survived the **K/T extinction**?

– "niches" (Paleogene diversification)

– **coniferous** and **deciduous forests:**

– "great lakes" replace:

– "Great Plains" replace:

– "Coastal California" evolves:

Neogene changes:

**Himalayas** begin to form:

Destruction of the **Tethys:**

**Isthmus of Panama:**

"grasses replace sedges":

**Ice ages** begin:

**Quaternary Period (Pleistocene and Holocene Epochs):**

Pleistocene **continental glaciations:**

Sea level changes:

**Hominids** evolved in Africa:

Modern humans appear (~200,000 ya):

**Holocene Epoch:**

End of "**Wisconsinian**" **glaciation:**

Current mass extinction begins:

Human civilizations appear:

## Chapter 3 - Structure of the Earth

How have the Earth's internal structure (rock), oceans (water), and atmosphere (air) changed over geologic time?

Parts of the **Atmosphere**

- **troposphere:**
- **stratosphere:**
- **mesosphere:**
- **thermosphere:**

What is **solar wind**?

**Corona ejections** cause solar storms:

- **Aurora Borealis:**
- **Auroa Autralis:**

**Hydrosphere:**

97% seawater:

**Cryosphere:**

Describe the **Hydrologic Cycle**:

"**Biosphere**":

### **Subdivisions of the Structure of the "Solid" Earth**

The Earth consist of several layers: a **core**, a **mantle**, and a **crust** (also **hydrospheres** and **atmospheres**).

- What do other planets and moons have?

#### **Crust**

- silicates-rich rocks:
- 3 km at the oceanic ridges
- oceanic crust (3.0 gm/cc)
- 70 km in some mountain belts
- continental crust (2.7 gm/cc)

#### **Mantle**

- differentiated in composition by density
- highly viscous layer between the crust and the outer core
- heavier silicates rich in iron and magnesium
- depth of about 2900 km
- partial melting?

#### **Core**

- magnetic iron-nickel rich sphere (meteoric metals)
- outer core: 1400 mile thick: dense molten material
- inner core: 758 mile thick: solid and very dense

**Important relationship between the "crust" and "mantle"**

## **lithosphere**

- (the cooler, more rigid uppermost part of the mantle and overlying crust).
- averages about 100 km in thickness, but may be 250 km
- "brittle" (cool)
- large-scale observable surface features: ocean basins, continents, and mountain ranges

## **asthenosphere**

- semi-fluid layer beneath the lithosphere (within the upper mantle)
- 40 to 80 miles (100-600 km) below lithosphere
- "plastic" (hot)
- flows vertically and horizontally - "independently" of the lithosphere
- "isostasy" - involves uplifts and subsidence

## **Geophysical Method used to study the interior of the Earth**

- **Magnetic measurements**
- what causes **magnetism**?
- **magnetometers**

**Gravity measurements** from the surface or from precise measurements from satellites orbiting a planet or moon

- **gravimeters** and **satellites**

## **Seismology**

- **Seismic waves** from **earthquakes** or **large explosions**
- **seismographs**

**Radiation measurement** (many varieties)

- **geiger counters** and radiation detectors

**Magnetism** measurements reveals the **Earth's metallic core**

- Earth's magnetic field: convection in the liquid metallic outer core?
- magnetic compass (China - since 2nd century BC)
- Geographic North Pole: offset from the Magnetic North Pole by about 11.5 degrees
- **"polar wandering"**:
- **magnetic reversals**:
- **paleomagnetism**:

**Gravity measurements** reveal denser material deeper in the Earth

gravitational attraction exists between objects on the surface and objects orbiting the planet.

- **Newton's Law of Universal Gravitational Attraction**

$$\text{Gravitational Attraction} = g \cdot (m_1 \cdot m_2)/r \cdot r$$

g = the gravitational constant

m1 = mass of the first body

m2 = mass of the second body

r = radius between the two bodies

**gravimeters** (on orbiting satellites):

- Gravity show differences in the **density of the crust**:
- High gravity regions?
- Low gravity regions?

### **Seismic Waves**

- Seismology is the study of earthquake shock waves as they pass through the earth.
- Seismology is the science that helped resolve many questions about the internal structure of the earth.

### **Terms used to describe earthquakes**

- **earthquake** (sudden movement on a **fault** or by **volcanic** disturbance).
- **fault** (fracture or crack along which two blocks of rock slide past one another)
- **focus**:
- **epicenter**:

### **Types of faults:**

- **strike-slip fault**
- **normal fault**
- **reverse fault**
- **thrust fault**

- "rupture zone":

**Seismic waves** (low-frequency **acoustic** energy - 2 types)

- **surface waves** travel on the surface
- **body waves** travel through the earth.

**Two types of body waves:** P waves and S waves

**P (primary) waves** are **compressional** (move parallel to wave movement)

- P waves travel through denser and more compact elastic materials (solid, liquids, gases) faster than S waves.

**S (shear or secondary ) waves** have a shear effect (shake-perpendicular to the waves movement).

- S waves **do not travel through** liquids or gas and are **40% slower** than P waves.

**Seismographs** measure P and S waves:

- **minimum of 3** seismographs: Why?

**earthquake magnitude (M)**

- **Richter scale**—a numerical (logarithmic) scale
- **moment magnitude scale (MMS)** — (important for seismic measures throughout a rupture zone)

## Earthquake intensity (I)

- **Modified Mercalli Intensity (MMI) scale** — (seismic impact on humans and their structures)

How do seismic wave data revealed the internal structure of the Earth?

- "Earth's **Shadow Zones**"
- "**Moho**" (**Mohorovicic discontinuity**):
- **core-mantle boundary (CMB)**:
- **Lehmann Discontinuity**:

Earthquake map of the world shows:

- **fault systems**:
- **lithospheric plate boundaries**:
- **deep vs. shallow earthquakes**:
- changes over time (**old faults**):

## Mantle convection:

- **gravitational heat convection** and density:
- crustal "extension":
- crustal "compression":
- crustal **deformation: folding vs. faulting**:
  - asthenosphere behavior:
  - lithosphere behavior:

**Ocean crust** (under oceans, denser)

- "**mafic**" (**basalt** and **gabbro**)

**Continental crust** (land masses, less dense)

- "**felsic**" (**granite** or "**granitic**")

**Isostasy** (applied to lithosphere/asthenosphere)

- **Isostatic equilibrium** (eg. wood blocks, continents)
- "**rebound**"
  - impact of melting continental glaciers
  - impact of eroding mountain ranges
  - heating and cooling of crust

Origin of **Continental Shields** (impact of uplift and erosion through time)

Discoveries leading up to modern **Plate Tectonics Theory**

- **Abraham Ortelius** (Flemish cartographer) in 1596 first suggested continents had "drifted apart."
- Geologic observations in the 1600-1700-1800's (global exploration)
- Maps of world's volcanoes (maps) and lead to the recognition of the "**Ring of Fire**"

**Continental Drift Hypothesis** proposed by Alfred Wegener (1880-1930)

- geologic and fossil trends on separated continents
- "**Pangaea**" (supercontinent broke up starting ~200 million years ago)
- **Mesosaurus**
- **Glossopteris**
- **Observable impacts on evolution**:

- "divergent evolution"
- "modern distribution of plants & animals"

### **The "Atlantic-Pacific Paradox"**

- Appalachians-Atlas Mountains

Why was "Continental Drift" rejected?

### **Discoveries in the 20th Century**

- **SONAR** (WW1 submarine warfare):
  - **Mid-Atlantic Ridge**

**Seismology:** (1930's: Kiyoo Wadati and Hugo Benioff)

- "Ring of Fire" earthquake data

### **Paleomagnetism**

- **magnetometers** (WWII warfare)
- **thermoremanent magnetization**
- "Curie Point"
- "magnetic reversals"
  - relationship to **mid-ocean ridges (MORs)**
  - "seafloor spreading"

**Relative & Absolute age dating** (post WWII)

- **radiometric age dating** of mineral **crystals**
- **relative age dating** using "microfossils"

**"Geologic Paradox: differing ages of oceanic and continental rocks"**

- **Age of continental rocks:**
  - continental **shield** regions:
  - world **mountain belts:**
- **Age of seafloor rocks (see map!):**
  - along **MORs:**
  - along **ocean margins:**

## **Chapter 4 - Plate Tectonics**

"This Dynamic Planet" (USGS)

"This Dynamic Earth" (USGS)

**Plate Tectonics Theory** - a "unifying" theory about how the "Earth works"

- involves "**seafloor spreading**"
- distribution of **MORs**
- rate of opening of the **Atlantic Ocean Basin:**
- geometry of ocean **trenches** relative to coastlines
- location of "**Ring of Fire**" **volcanoes**
- distribution of world's **earthquakes**
- **lithospheric plate boundaries**
- **subduction zones**
- role of "**isostasy**"
- **lithosphere** (where is it floating or sinking?)

- **asthenosphere** (role of "mantle convection")
  - changes in **ocean crust density** (new vs. old)
  - density of "new" continental crust and mountain ranges

### Three Types of Lithospheric Plate Boundaries

- A. Divergent boundary**
- B. Convergent boundary**
- C. Transform boundary**

#### A. Divergent Plate Boundaries

- 2 to 17 cm/year
- zones of "tensional" forces
- **MORs** and "spreading centers"
- features on **Iceland**
- geometry of **faults**
- **composition and location of volcanoes**
- **basalt and gabbro (mafic and ultramafic rocks):**
  - significance of "ultramafic rocks"
- changes in **thickness and age of oceanic sediments**
- **formation of ocean crust** from rising mantle materials:

Difference between a "ridge" and a "rise"

- **ridges:**
  - **Mid-Atlantic Ridge:**
- **rises:**
  - **East Pacific Rise:**

#### Continental Rifting

- involves **continental crust (CC)**
  - "rift zones"
    - **African Rift Zones**
    - **Red Sea**
    - **Rio Grande Rift**
    - **Breakup of Pangaea:**

#### Crustal Extension and Continental Rifting

- **Gulf of California** and **Salton Sea**
- **Great Basin**

#### B. Convergent Plate Boundaries

- zones of "compressional" forces
- all are "active margins":
  - where **trenches occur:**
    - **subduction zones**
      - how they work (revealed by earthquakes):
      - **volcanic arcs**
      - "andesite" (explosive) volcanoes:
        - why they form:
        - "destruction" of ocean crust (what happens?):
        - relationship to **tsunamis:**

## Three types of Convergent Plate Boundaries: OC/CC, OC/OC, & CC/CC

### 1. Subduction of OC beneath CC:

- Andes
- **Pacific Northwest (Cascades)**
- Mount St. Helens, Mt. Shasta, Mt. Rainier
- Sierra Nevada and Peninsular Ranges
- life-cycles of **andesitic/granitic volcanoes**

### 2. Subduction of OC beneath OC.

- "warm, young" meets "old, cold"
- volcanic arcs (not as "explosive")
- less "mixing" with continental rocks (mostly basaltic)
- **Aleutian Islands (Alaska), Japan, Tonga Islands**

### 3. Continental Collisions: CC colliding with CC

- no subduction
- little volcanism
- isostasy and earthquakes:
- **Himalayas**
- **Alps**
- **Appalachians**

## C. Transform boundaries

- "**shearing**" lithospheric plate boundaries
- faulting dominates (shallow earthquakes), some volcanism
- Can occur in any crustal type (**OC and/or CC**)
- Crust is neither produced or destroyed
  
- **San Andreas Fault (SAF)** average 2-5 cm/yr
- "**bends**" result in local uplift (compression) or subsidence (tension)
- **Turkey**
- **India & Pakistan**
- **Jordan River Valley-Dead Sea:**
- Continental Transform Faults:
- Oceanic Transform Faults:

**Important! Continental margins may or may not be plate boundaries!**

## Hotspots and Mantle Plumes

- **Hotspot:** extremely hot magma from the lower mantle (a **mantle plume**) upwells to melt through the crust usually in the interior of a tectonic plate to form a volcanic feature.
- found on both **OC** and **CC**
- Mostly **mafic or ultramafic (basaltic)** in oceans, both **basalt & rhyolite** on continents
- long-lived geologic features
- **seamount chains**
- massive **calderas**
- **Hawaii** (and **Emperor Seamount Chain**)
- **Yellowstone** (and older caldera on Snake River Plain)
- **Valles Caldera, NM**

**Relationship of Hotspots to Astroblemes?**

- **“Flood basalts”**
- **Columbia River Plateau**
- **Deccan Traps**
- **Siberian Traps**

**Forces that drive plate motion:**

- **Slab-pull** - the slow pull of mantle material where it moves from a rising location to a sinking location.
- **Slab-suction** - The high density of cold ocean crust sinking into the mantle pulls crust with it.
- **Ridge-push** - new ocean crust is warm and tends to rise above the ocean floor, pushing older cooler crust away

**Continental Accretion:** how continents grow

- **"pot of soup" analogy**
- addition of **"terranes"** to **active continental margins**
- **igneous refining**: converting ocean crust into continental crust
- roles of **sediments** and **seawater** in formation of **“granitic magma”**
- formation of **cratons** and **shields** (ancient **terranes**)

**Stages in the formation and breakup of Pangaea**

**Stages in the formation of "California"**