

# Chapter 4 Study Guide and Case Studies: Continental Drift and Plate Tectonics

## Key Concepts

- initial observations that support continental drift: continents fit together like pieces in a jigsaw puzzle. Fossils, geological units, mountain belts, coal and glacial deposits are found on both sides of an ocean. Apparent polar wander curves are different on different continents.
- Supercontinent Pangaea formed between 300 and 250 million years ago and broke up shortly after that.
- Earth's magnetic field is maintained by fluid flow in the metallic outer core (geodynamo). The field is nearly dipolar but changes with time, and even reverses. The field at a certain location is defined by the inclination, the declination and the intensity. Iron-bearing rocks can "record" the ambient magnetic field through remnant magnetization.
- Apparent polar wander curves on continents allows the reconstruction of relative movements between continents.
- initial observations that support seafloor spreading: ocean basins are dissected by mid-ocean ridges (MORs). The seafloor deepens away from MORs, rocks become older, surface heat flux decreases, sediment cover increases. No oceanic rock is older than 200 million years.
- The symmetric recording of reversals of the magnetic field across mid-ocean ridges provides evidence for seafloor spreading.
- Oceanic lithosphere is consumed in subduction zones that are characterized by deep seafloor trenches. Accretionary prisms form behind the trench. Oceanic lithosphere becomes denser and thicker with age until subduction eventually starts. Only oceanic lithosphere subducts. Continental lithosphere is not dense enough to subduct.
- Slab pull, ridge push and asthenosphere drag are the driving forces of mantle convection where slab pull is the dominant force.
- Plate tectonics is the grand unifying theory of geosciences. It explains why continents drift, how new lithosphere forms and how old oceanic lithosphere is consumed. It also explains why and where earthquakes, volcanoes and mountain building occur.
- The lithosphere is broken into 12 major plates, 4 smaller plates and many microplates. The plates move about at a rate of a few cm per year.
- The three types of plate boundary are: divergent plate boundaries (MORs and continental rifts), convergent plate boundaries (subduction zones and continental

- collision), transform boundaries (that connect one type of boundary to another). Three plates (and plate boundaries) join at triple junctions.
- Earthquakes occur along all plate boundaries but deep ones occur only along subduction zones. The Wadati-Benioff zone is a down-dipping band of seismicity that traces the subducting slab. Some of the largest, most devastating earthquakes occur along subduction zones.
  - Volcanoes and volcanism occur along divergent and convergent plate boundaries. No volcanism occurs at zones of continental collision and along transform boundaries.
  - Some intra-plate hotspot volcanism is fed by mantle plumes. Age-progressive hotspot tracks form when the overriding plate moves over the mantle plume. In the oceans, the hotspot tracks are chains of seamounts. The age progression points in the direction of plate motion.

## Key Terms

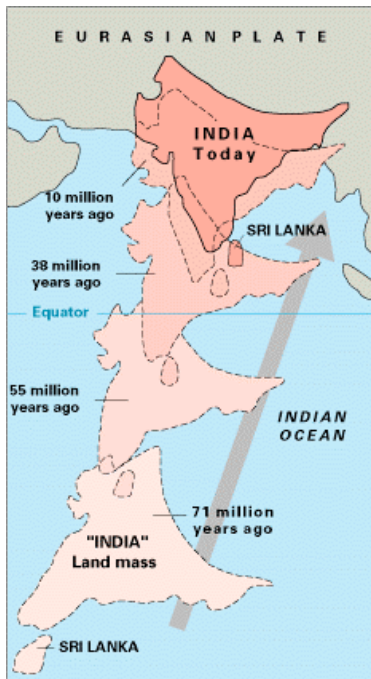
- continental drift
- Pangaea
- plate tectonics
- Earth's magnetic dipole and geodynamo
- magnetic inclination and declination
- Curie temperature
- remnant magnetization
- stratigraphic profile
- apparent polar wander curves
- magnetic stripes
- seafloor spreading
- spreading rate
- mid-ocean ridges
- subduction zones
- the Wadati-Benioff zone
- accretionary prism
- ridge push
- slab pull
- asthenosphere drag
- mantle convection
- viscosity
- plate boundaries
- triple junctions
- mantle plumes
- age-progressive hotspot volcanism
- hotspot tracks
- seamounts

## Questions for Review

1. What are the pieces of evidence supporting continental drift?
2. Which process maintains Earth's magnetic field? What is the shape of Earth's magnetic field? Which parameters define this field?
3. How are apparent polar wander curves constructed?
4. Which initial seafloor observations support the idea of seafloor spreading?
5. Why is the oldest oceanic lithosphere only 200 million years old, while the oldest continental lithosphere is 4 billion years old?
6. Explain the concept and observation of magnetic stripes on the seafloor across mid-ocean ridges.
7. Describe the life cycle of oceanic lithosphere.
8. What is the Wadati-Benioff zone?
9. Why do earthquakes occur to a maximum depth of about 700 km but not deeper?
10. What are the three types of plate boundary? On which do earthquakes occur? On which does volcanism occur? Which types of plate boundary have no earthquakes and/or no volcanism?
11. Subduction zones form on which types of plate boundary?
12. Which forces drive mantle convection?
13. Describe the viscosity of a material.
14. What are hotspots? What is a mantle plume?
15. Describe how age-progressive seamount chains form.
16. In which direction, relative to plate motion, does the age of seamounts progress?

## Case Studies

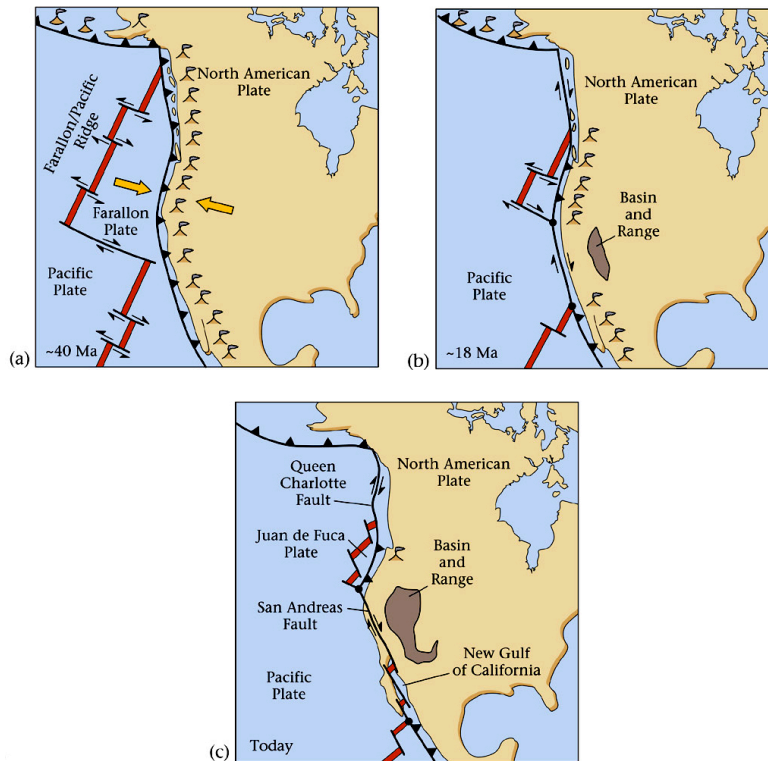
### Case Study 1: The Indian Plate and the Himalayas



**Figure C4.1** The Indian plate split from Gondwanaland and Madagascar about 90 million years ago. Due to continental drift, it moved toward Eurasia and collided with that continent about 35 to 55 million years ago. This collision resulted in the formation of the Himalayas. (source: Wikipedia/USGS)

In the late Cretaceous Period about 90 millions years ago, the Indian plate formed when India broke away from a larger supercontinent called Gondwanaland. The Indian plate moved northward to collide with the Eurasian continent some 35 – 55 million years later. If the earlier estimate of 55 million years was correct, then the Indian plate would have been the fastest-moving known plate, traveling at 20 cm per year (Fig. 4.27). There is now evidence from seismic imaging that the Indian plate had a sliver of oceanic lithosphere attached to it, so subduction occurred for some time before the two pieces of continental lithosphere collided to form the Himalayan mountains, the tallest mountain belt on Earth. No subduction occurs at present along the current continent-continent convergent plate boundary. But many plate-boundary maps such as the ones in Figs. 4.19 and 4.22 mark the ancient subduction zones. The reason for this is that some slab remnants still remain in the upper mantle, as revealed by seismic imaging. Some intermediate-depth earthquakes may also still occur (Fig. 4.21) which indicates than some last remnants are still relatively close to the surface.

## Case Study 2: The Ancient Farallon Plate and Current Plate Boundaries in Western North America



**Figure C4.2** Much of the western margin of North America changed from a convergent plate boundary into a transform boundary (the San Andreas Fault) when the Farallon-Pacific Ridge encountered the North American continent. (a) Convergence along the North American margin and subduction of the Farallon plate 40 million years ago. (b) Transition into a transform boundary. Concurrent shearing of the North American continent formed the Basin and Range area. After subduction stopped, volcanism above what is now the Sierra Nevada stopped as well. Volcanoes were eroded, thereby exposing the batholiths below. (c) Current plate arrangement after the Gulf of California opened. Parts of California and the Baja Peninsula jumped plates and are now located on the Pacific plate. (source: ME)

40 million years ago, the plate boundary system along the west coast of North America looked very different from today, as shown schematically in Fig. 4.28. An oceanic plate, the now gone Farallon plate, subducted beneath North America. During the subduction, volcanism occurred on the overriding plate along the entire length of North America, including where the Sierra Nevada stands tall today. Since the subducting slab pulled the rest of the Farallon plate behind it, the Farallon/Pacific mid-ocean ridge moved closer and closer to the continent.

By the time the mid-ocean ridge reached the continent (about 30 million years ago), subduction stopped because MORs are too buoyant to subduct. Continued plate movement to the north and south forced the plate boundary along California's coast to transition into a transform boundary, the San Andreas Fault. Volcanism ceased at the location of today's Sierra Nevada. Over time, the volcanoes eroded and the batholiths that fed these volcanoes are now exposed as the Sierra Nevada. Batholiths are essentially huge blobs of magma that intrude into the crust from below. Shearing of the North American plate during the transition from subduction to a transform regime caused thinning and the breakup of crust in the Basin and Range area. Subduction also transitioned into a transform boundary regime along the coast of Canada.

Subduction of a small plate remnant, now the Juan de Fuca and Gorda plates, continues today to the north of the Mendocino Triple junction, along the Cascadia subduction zone (Fig. 4.23). The Cascade volcanoes are currently the most active volcanoes in the lower 48 states and some are capable of violent eruptions, as the 18 May 1980 eruption of Mt. St. Helens, WA dramatically demonstrated. There are no records of recent very large earthquakes. But research in the last decade has identified the Cascadia subduction zone as being capable of very large, magnitude-9 earthquakes. In 2005, U.S. Geological Survey geologist Brian Atwater connected the dots. Japanese records report an "orphan tsunami" in late January of 1700 for which a local Japanese earthquake was never found. Aware of reports of ground shaking in old Native American legends, Atwater found evidence for great sudden subsidence along some stretches of the Cascadia coast that can only be explained by a large earthquake. Atwater could date the subsidence rather accurately and determined that this earthquake was responsible for the orphan tsunami on the other side of the Pacific Ocean. If such an earthquake struck today, damages and economic losses would likely reach many 10s of billions of dollars.

About 17 million years ago, the Gulf of California opened in the south. Sea floor spreading now occurs along several spreading centers. This new mid-ocean ridge system leads south into a triple junction with another mid-ocean ridge system and the subduction zone of the Rivera microplate (the unmarked sliver in Fig. 4.28c that is south of the Gulf of California). As the San Andreas Fault formed and the Gulf of California opened, parts of California and the Baja Peninsula jumped plates and are now located on the Pacific plate. At the same time, much of the San Andreas Fault moved ashore and deformed. It is nearly parallel to the coast in central California but then swings into the Big Bend north and east of Los Angeles (Fig. 4.23). It continues southward along the eastern shore of the Salton Sea but the continuation beyond that is currently debated. Some postulate that it connects to the Imperial Fault but others argue that it stops or fans out into many smaller faults. The Pacific plate moves northward relative to the North American plate. The San Andreas is therefore a right-lateral fault.