Written Assignment – Evolution of North America

Write a one page summary of the tectonic evolution of the region of the North American continent in which you live. Refer to your assigned reading.

Discussion – Future Accretion

Where are today's exotic terranes? What is their fate? Once East Africa has rifted from the African Plate, is it destined to become an accreted terrane? Will it become a new continent? Discuss these issues, based on this week's reading.

Chapter 2 – Reading

2.1 From Continental Drift to Plate Tectonics Summarize the view that most geologists held prior to the 1960s regarding the geographic positions of the ocean basins and continents. Prior to the late 1960s most geologists held the view that the ocean basins and continents had fixed geographic positions and were of great antiquity.

Scientists came to realize that Earth's continents are not static; instead, they gradually migrate across the globe. These movements cause blocks of continental material to collide, deforming the intervening crust and thereby creating Earth's great mountain chains (Figure 2.1).

Furthermore, landmasses occasionally split apart. As continental blocks separate, a new ocean basin emerges between them. Meanwhile, other portions of the seafloor plunge into the mantle. In short, a dramatically different model of Earth's tectonic processes emerged. Tectonic processes def

This profound reversal in scientific thought has been appropriately called a scientific revolution. The revolution began early in the twentieth century as a relatively straightforward proposal termed continental drift. For more than 50 years, the scientific community categorically rejected the idea that continents are capable of

Figure 2.1

The Himalayan mountains where created when the subcontinent of India collided with southeastern Asia. (Photo by Hartmut Postges/Robert Harding) movement. North American geologists in particular had difficulty accepting continental drift, perhaps because much of the supporting evidence had been gathered from Africa, South America, and Australia, continents with which most North American geologists were unfamiliar.

After World War II, modern instruments replaced rock hammers as the tools of choice for many researchers. Armed with more advanced tools, geologists and a new breed of researchers, including geophysicists and geochemists, made several surprising discoveries that rekindled interest in the drift hypothesis. By 1968 these developments had led to the unfolding of a far more encompassing explanation known as the theory of plate tectonics.

In this chapter, we will examine the events that led to this dramatic reversal of scientific opinion. We will also briefly trace the development of the continental drift hypothesis, examine why it was initially rejected, and consider the evidence that finally led to the acceptance of its direct descendant—the theory of plate tectonics.

2.1 Concept Checks Briefly describe the view held by most geologists regarding the ocean basins and continents prior to the 1960s. What group of geologists were the least receptive to the continental drift hypothesis? Why?

2.2 Continental Drift: An Idea Before Its Time

List and explain the evidence Wegener presented to support his continental drift hypothesis.

The idea that continents, particularly South America and Africa, fit together like pieces of a jigsaw puzzle came about during the 1600s, as better world maps became available. However, little significance was given to this notion until 1915, when Alfred Wegener (1880–1930), a German meteorologist and geophysicist, wrote The Origin of Continents and Oceans. This book outlined Wegener's hypothesis called continental drift, which dared to challenge the long-held assumption that the continents and ocean basins had fixed geographic positions.

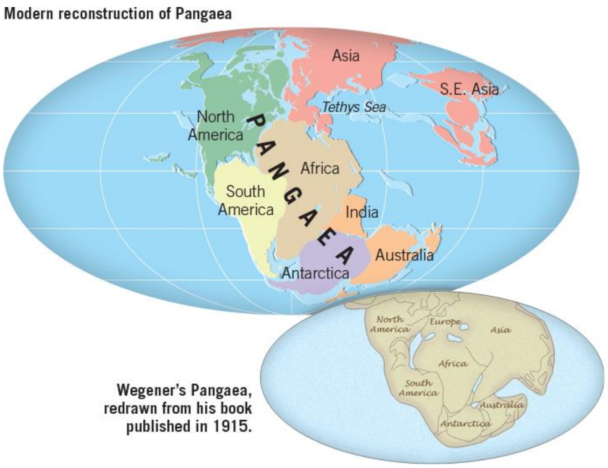
Wegener suggested that a single supercontinent consisting of all Earth's landmasses once existed.* He named this giant landmass Pangaea (pronounced "Pan-jee-ah," meaning "all lands") (Figure 2.2). Wegener further hypothesized that about 200 million years ago, during the early part of the Mesozoic era, this supercontinent began to fragment into smaller landmasses. These continental blocks then "drifted" to their present positions over a span of millions of years.

*Wegener was not the first to conceive of a long-vanished supercontinent. Edward Suess (1831–1914), a distinguished nineteenth-century geologist, pieced together evidence for a giant landmass comprising South America, Africa, India, and Australia.

Wegener and others who advocated the continental drift hypothesis collected substantial evidence to support their point of view. The fit of South America and Africa and the geographic distribution of fossils and ancient climates all seemed to buttress the idea that these now separate landmasses were once joined. Let us examine some of this evidence.

Evidence: The Continental Jigsaw Puzzle

Like a few others before him, Wegener suspected that the continents might once have been joined when he



SmartFigure 2.2 Reconstructions of Pangaea
The supercontinent of Pangaea, as it is thought to have formed in the late Paleozoic and early Mesozoic eras, more than 200 million years ago.
(https://goo.gl/eOttu9)

Figure 2.3 Two of the puzzle pieces
The best fit of South America and Africa along the continental slope at a depth of 500 fathoms (about 900 meters [3000 feet]). (Based on A. G. Smith, "Continental Drift," in Understanding the Earth, edited by I. G. Gass, Artemis Press.)

noticed the remarkable similarity between the coastlines on opposite sides of the Atlantic Ocean. However, other Earth scientists challenged Wegener's use of present-day shorelines to "fit" these continents together. These opponents correctly argued that wave erosion and depositional processes continually modify shorelines. Even if continental displacement had taken place, a good fit today would be unlikely. Because Wegener's original jigsaw fit of the continents was crude, it is assumed that he was aware of this problem (see Figure 2.2).

Scientists later determined that a much better approximation of the outer boundary of a continent is the seaward edge of its continental shelf, which lies submerged a few hundred meters below sea level. In the early 1960s, Sir Edward Bullard and two associates constructed a map that pieced together the edges of the continental shelves of South America and Africa at a depth of about 900 meters (3000 feet) (Figure 2.3). The remarkable fit obtained was more precise than even these researchers had expected.

Evidence: Fossils Matching Across the Seas

Although the seed for Wegener's hypothesis came from the striking similarities of the continental margins on opposite sides of the Atlantic, it was when he learned that identical fossil organisms had been discovered in rocks from both South America and Africa that his pursuit of continental drift became more focused. Wegener learned that most paleontologists (scientists who study the fossilized remains of ancient organisms) agreed that some type of land connection was needed to explain the existence of similar Mesozoic age life-forms on widely separated landmasses. Just as modern life-forms native to North America are not the same as those of Africa and Australia, during the Mesozoic era, organisms on widely separated continents should have been distinctly different.

Mesosaurus

To add credibility to his argument, Wegener documented cases of several fossil organisms found on different landmasses, even though their living forms were unlikely to have crossed the vast ocean presently separating them (Figure 2.4). A classic example is Mesosaurus, a small aquatic freshwater reptile whose fossil remains are limited to black shales of the Permian period (about 260 million years ago) in eastern South America and southwestern Africa. If Mesosaurus had been able to make the long journey across the South Atlantic, its remains should be more widely distributed. As this is not the case, Wegener asserted that South America and Africa must have been joined during that period of Earth history.

How did opponents of continental drift explain the existence of identical fossil organisms in places separated by thousands of kilometers of open ocean? Rafting, transoceanic land bridges (isthmian links), and island stepping stones were the most widely invoked explanations for these migrations (Figure 2.5). We know, for example, that during the Ice Age that ended about 8000 years ago, the lowering of sea level allowed mammals (including humans) to cross the narrow Bering Strait that separates Russia and Alaska. Was it possible that land bridges once

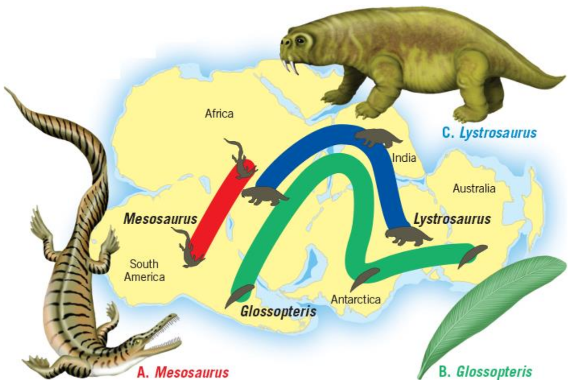


Figure 2.4 Fossil evidence supporting continental drift

Fossils of identical organisms have been discovered in rocks of similar age in Australia, Africa, South America, Antarctica, and India—continents that are currently widely separated by ocean barriers. Wegener accounted for these occurrences by placing these continents in their pre-drift locations.

connected Africa and South America but later subsided below sea level? Modern maps of the seafloor substantiate Wegener's contention that if land bridges of this magnitude existed, their remnants would still lie below sea level.

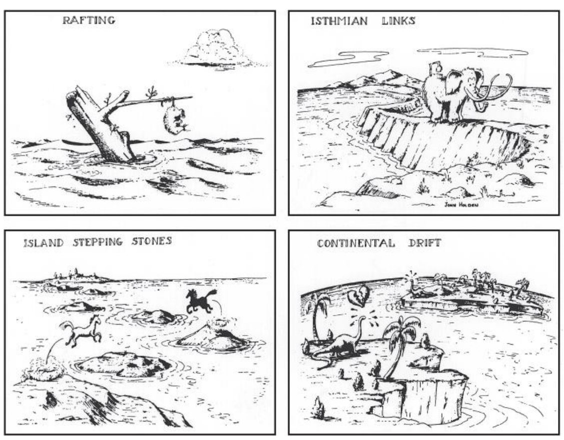


Figure 2.5 How do land animals cross vast oceans?
These sketches illustrate various proposals to explain the occurrence of similar species on landmasses now separated by vast oceans.
(Used by permission of John C. Holden)

Glossopteris

Wegener also cited the distribution of the fossil "seed fern" Glossopteris as evidence for Pangaea's existence (see Figure 2.4). With tongue-shaped leaves and seeds too large to be carried by the wind, this plant was known to be widely dispersed among Africa, Australia, India, and South America. Later, fossil remains of Glossopteris were also discovered in Antarctica.* Wegener also learned that these seed ferns and associated flora grew only in cool climates—similar to central Alaska. Therefore, he concluded that when these landmasses were joined, they were located much closer to the South Pole.

* In 1912 Captain Robert Scott and two companions froze to death lying beside 35 pounds (16 kilograms) of rock on their return from a failed attempt to be the first to reach the South Pole. These samples, collected on Beardmore Glacier, contained fossil remains of Glossopteris.

Evidence: Rock Types and Geologic Features

You know that successfully completing a jigsaw puzzle requires fitting the pieces together while maintaining the continuity of the picture. The “picture” that must match in the “continental drift puzzle” is one of rock types and geologic features such as mountain belts. If the continents were once together, the rocks found in a particular region on one continent should closely match in age and type those found in adjacent positions on the adjoining continent. Wegener found evidence of highly deformed igneous rocks in Brazil that closely resembled similar rocks in Africa.

Similar evidence can be found in mountain belts that terminate at one coastline and reappear on landmasses across the ocean. For instance, the mountain belt that includes the Appalachians trends northeastward through the eastern United States and disappears off the coast of Newfoundland (Figure 2.6A). Mountains of comparable age and structure are found in the British Isles and Scandinavia. When these landmasses are positioned as they were about 200 million years ago, as shown in Figure 2.6B, the mountain chains form a nearly continuous belt.

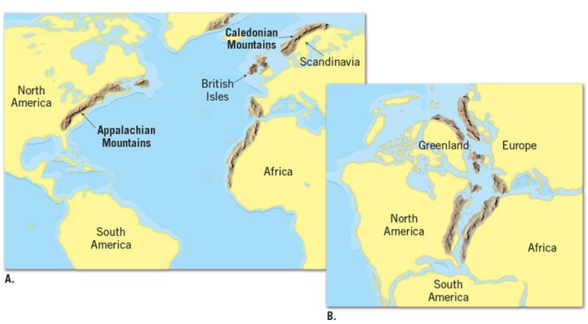


Figure 2.6 Matching mountain ranges across the North Atlantic

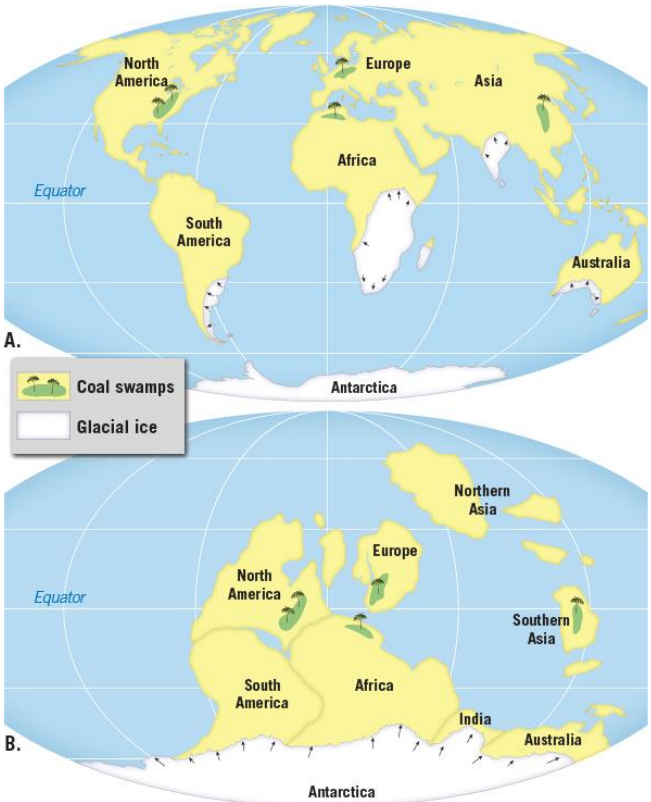


Figure 2.7 Paleoclimatic evidence for continental drift

A. About 300 million years ago, ice sheets covered extensive areas of the Southern Hemisphere and India. Arrows show the direction of ice movement that can be inferred from the pattern of glacial scratches and grooves found in the bedrock. B. The continents restored to their pre-drift positions account for tropical coal swamps that existed in areas presently located in temperate climates.

Wegener described how the similarities in geologic features on both sides of the Atlantic linked these landmasses: “It is just as if we were to refit the torn pieces of a newspaper by matching their edges and then check whether the lines of print run smoothly across. If they do, there is nothing left but to conclude that the pieces were in fact joined in this way.”†

†Alfred Wegener, The Origin of Continents and Oceans, translated from the 4th revised German ed. of 1929 by J. Birman (London: Methuen, 1966).

Evidence: Ancient Climates

Because Alfred Wegener was a student of world climates, he suspected that paleoclimatic (paleo = ancient, climatic = climate) data might also support the idea of mobile continents. His assertion was bolstered by evidence that a glacial period dating to the late Paleozoic had been discovered in southern Africa, South America, Australia, and India. This meant that about 300 million years ago, vast ice sheets covered extensive portions of the Southern Hemisphere as well as India (Figure 2.7A). Much of the land area that contains evidence of this Paleozoic glaciation presently lies within 30 degrees of the equator in subtropical or tropical climates.

How could extensive ice sheets form near the equator? One proposal suggested that our planet experienced a period of extreme global cooling. Wegener rejected this explanation because during the same span of geologic time, large tropical swamps existed in several locations in the Northern Hemisphere. The lush vegetation in these swamps was eventually buried and converted to coal (Figure 2.7B). Today these deposits comprise major coal fields in the eastern United States and Northern Europe. Many of the fossils found in these coal-bearing rocks were produced by tree ferns with large fronds—a fact consistent with warm, moist climates.** The existence of these large tropical swamps, Wegener argued, was inconsistent with the proposal that extreme global cooling caused glaciers to form in areas that are currently tropical.

** It is important to note that coal can form in a variety of climates, provided that large quantities of plant life are buried.

Wegener suggested a more plausible explanation for the late Paleozoic glaciation: the supercontinent of Pangaea. The southern continents being joined together and located near the South Pole would account for the polar conditions necessary to generate extensive expanses of glacial ice over much of these landmasses (Figure 2.7B). At the same time, this geography places today's northern continents nearer the equator and accounts for the tropical swamps that generated the vast coal deposits.

How does a glacier develop in hot, arid central Australia? How do land animals migrate across wide expanses of the ocean? As compelling as this evidence may have been, 50 years passed before most of the scientific community accepted the concept of continental drift and the logical conclusions to which it led.

2.2 Concept Checks

What was the first line of evidence that led early investigators to suspect that the continents were once connected?

Explain why the discovery of the fossil remains of Mesosaurus in both South America and Africa, but nowhere else, supports the continental drift hypothesis.

Early in the twentieth century, what was the prevailing view of how land animals migrated across vast expanses of open ocean?

How did Wegener account for evidence of glaciers in the southern landmasses at a time when areas in North America, Europe, and Asia supported lush tropical swamps?