Instructional Segment 3 Teacher Background and Instructional Suggestions:
In the early 1900's, Alfred Wegener, a German meteorologist, proposed that all of Earth's continents had been connected together millions of years ago and subsequently moved to their current locations. His theory, known as "Continental Drift," was based on substantial evidence.

Fossil Evidence of Continental Drift

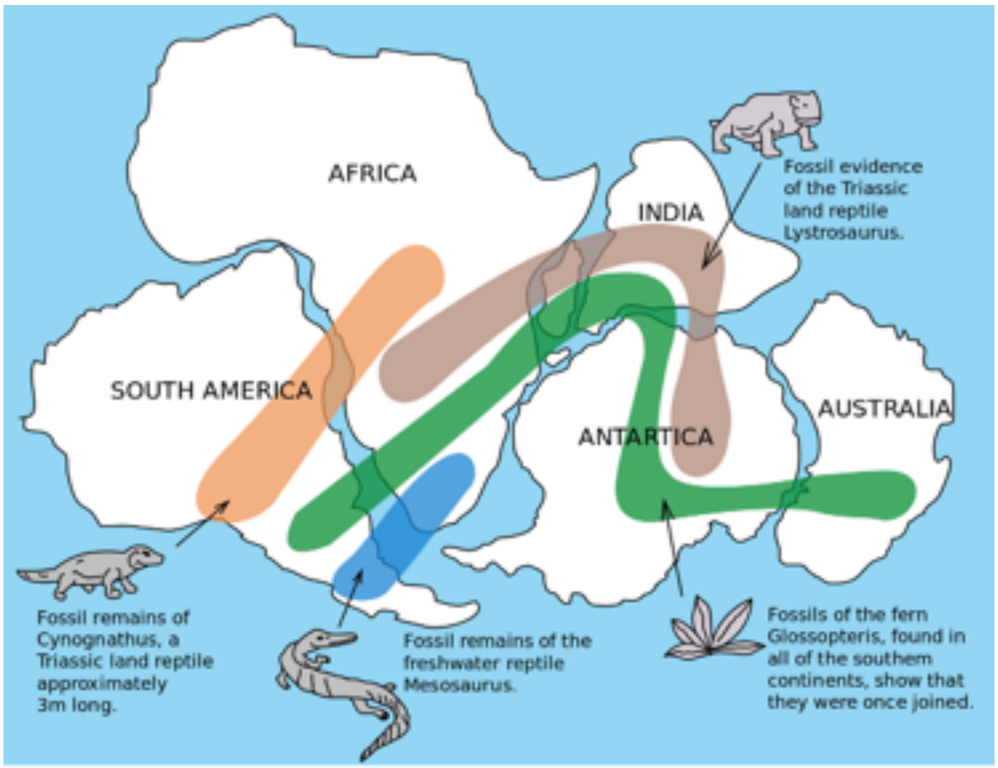

Figure 13: A summary of Wegener's fossil evidence that Southern Hemisphere continents were once joined together. (Wikibooks 2015)

Some of this evidence came from using maps to show how well the continents fit together, especially including the submerged continental shelves in aligning the continents, and most obviously with South America and Africa (Figure 13). Fossils and rocks provided even more persuasive evidence. Using source information such as Figure 13, students can make jig-saw type **models** that include coding of different fossil locations, and then challenge each other to assemble a map that shows how the continents were connected in a large land mass before they moved apart. They can then **explain** using evidence that the overlap of fossil locations help indicate not only that these continents were joined together, but also specifically that the connection points match those predicted by matching the outlines of the continents. Their **explanation** should include that there is no other plausible mechanism to account for the existence of these same fossil types in such widely separated locations.

Wegener also traced the past positions and motions of ancient glaciers based on grooves cut by those glaciers in rocks, and also by rock deposits that the glaciers left on different continents. His evidence indicated that if the continents had been in their current locations, the glaciers would have formed very close to the equator, an extremely unlikely situation. If the continents moved as he hypothesized, those glaciers would have formed much closer to the South Pole.

Despite the evidence that he compiled, Wegener's theory was not accepted and was generally forgotten. While Wegener was using traditional Science Practices of **analyzing data and constructing explanations** based on evidence, the other geologists were viewing his claims through the lens of the crosscutting concept of ***cause and effect: mechanism and explanation***." Wegener could not propose any possible mechanism that would cause continents to plow through the ocean over great distances. In the absence of a mechanism to cause the proposed movements of continents, the geologists of his time rejected Wegener's claims.

Technological developments approximately 50 years later resulted in new information that supported Wegener's claims and also provided the missing mechanism. Results from submarine explorations revealed that the largest mountain ranges actually exist below the ocean. For example, the Mid-Atlantic Ridge rises about 3 km in height above the ocean floor and has a length of about 10,000 km running from a few degrees south of the North Pole to an island at a latitude of 54^0S. Even more profound was the discovery that the ocean floor is actually spreading from these mid-ocean ridges causing the ocean to grow in size. The spreading sea floor and increasing ocean size made it easier to understand a cause and effect mechanism that resulted in continents moving away from each other.

Two Perspectives of Earth's Layers

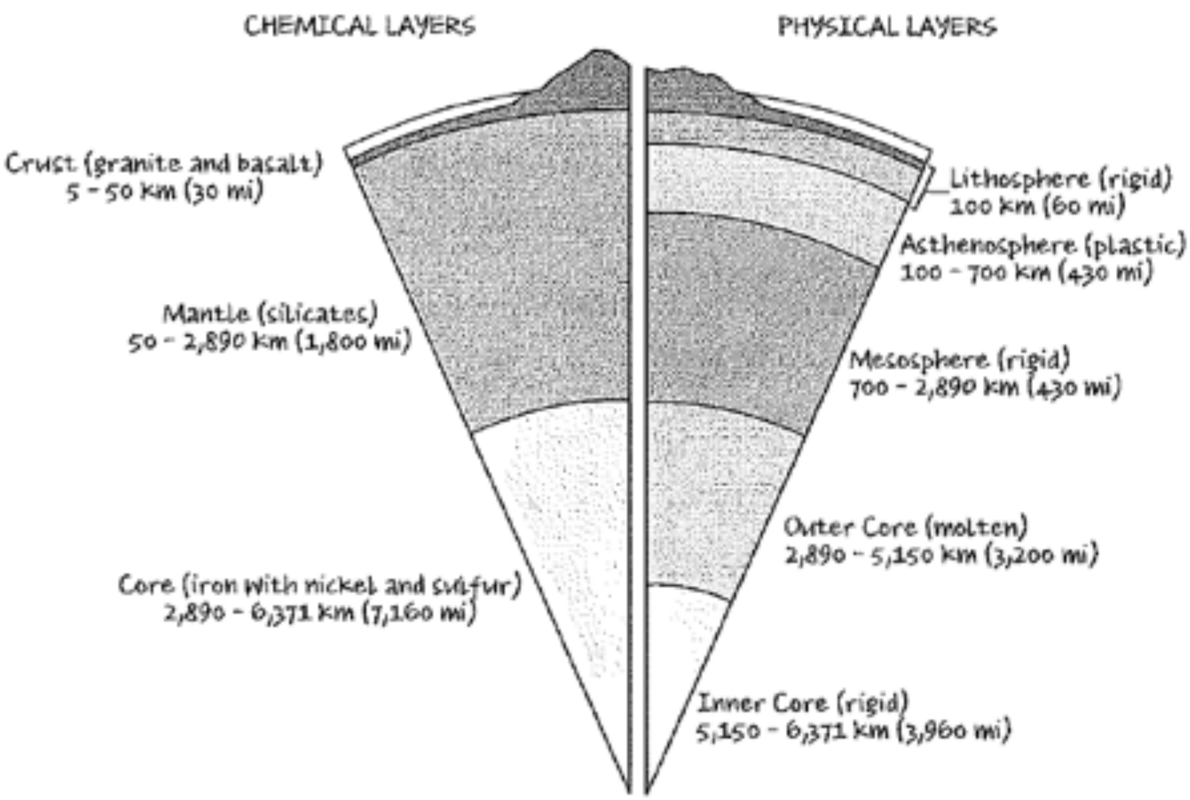

Figure 14: Two complementary models of Earth's layers juxtaposed next to each other. (Illustration from Making Sense of Science *Earth Systems* course, courtesy of WestEd)

These and other discoveries provided critical evidence leading to today's well-accepted theory of plate tectonics. Wegener's continental drift theory can be viewed as a precursor to plate tectonics, which is a much more complete and robust explanation. Plate tectonics is best viewed in conjunction with a description of our planet's layered structure. As shown in Figure 14, geoscientists describe Earth's layers from two perspectives. The more familiar perspective of Earth having three main layers (crust, mantle and core) is based on chemical composition. The crust and mantle are both mostly silicate rock, but the mantle rock has more magnesium and iron. In contrast, the core is made mostly of iron and some nickel.

The other perspective of Earth's layers is based on physical properties. The outermost layer, called the lithosphere, consists of the crust and the topmost portion of the mantle. Its physical characteristics are that it is hard and rigid, and somewhat elastic but brittle. Movements of the lithosphere often result in fractures or faults. Earth's lithosphere is divided into huge chunks, and each of those chunks is a tectonic plate. Plates can include both oceans and continents, or more specifically oceanic crust (denser) and continental crust (less dense). Continents are the uppermost parts of plates, so if a plate is moving, then the continent simply moves along with the plate as a whole and does not have to plow through the oceans.

Directly below the rigid lithosphere, the asthenosphere is the semi-plastic, bendable and "flowable" layer of the mantle. Its plasticity helps cause the plate movements. The other three physical layers (the lower rigid part of the mantle, the liquid outer core and the solid inner core) do not play such direct causal roles in plate tectonics.
At their boundaries, plates bang into, dive under, split further apart, or slide along each other (like the San Andreas Fault in California). The highest continental mountain range, the Himalayas, results from the collision of two continental plates. All these movements can ***cause*** earthquakes, and as a result, plate boundaries have the most earthquakes and volcanoes.

Volcanoes emit lava and build mountains at locations where plates diverge, such as the mid-ocean ridges, and also where the less dense oceanic plate subducts (dives under) other crust, usually continental. The South American Andes and the North American west coast Cascades are continental examples of a volcanic mountain range resulting from an oceanic plate subducting under a continental plate (Figure 15).

Example of Subduction

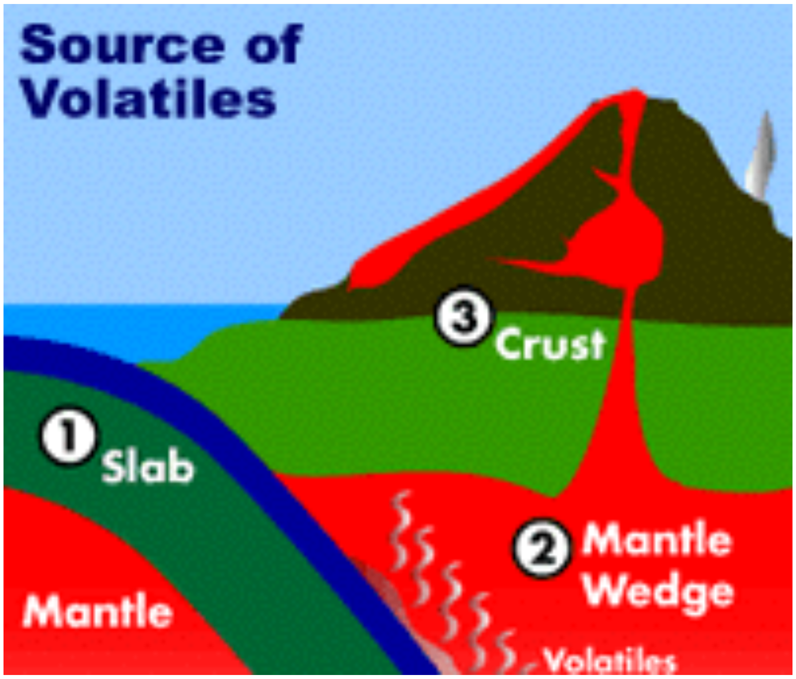

Figure 15: Subduction of an oceanic plate under a continental plate can result in volcanic coastal mountains such as the Cascade mountain range. (Illustration from *"Volcano Expedition" website of Scripps Institute of Oceanography at* http://ucsdnews.ucsd.edu/archive/newsrel/science/Hilton%20Science%20Volcano.htm

Students can create a digital or physical **model** of an oceanic plate subducting under a continental plate, and resulting in a volcanic mountain. In Figure 15 the darker green represents a slab of subducting marine crust (labeled number 1). This marine crust slab includes sediments (dark blue) that have lots of water and carbonates. Chemical reactions break down the carbonates and release carbon dioxide. These sediments are particularly volatile, and they release steam and carbon dioxide as they contact the very hot mantle that is wedged between the subducting marine crust and the more dense oceanic crust (lighter green). This mantle wedge itself also releases volatiles (labeled number 2). The rising melted rock can also create more steam and carbon dioxide to form in the oceanic crust (labeled number 3). The result can be an explosive or slow release of lava, either building a mountain or blowing its top off. Some of the same processes happen when marine crust subducts in ocean trenches, such as the famous Mariana Trench.

In high school Earth science, students delve deeper into the evidence and mechanisms of plate tectonics. The middle school introduction to plate tectonics provides background that helps **explain** many of Earth's landscape features. The forces of weathering and erosion would make Earth very flat, and it is plate tectonics that ***results*** in the continuing creation and existence of beautiful mountains that play important roles in biology, climate and human cultures.

Plate tectonics is also one of the geoscience processes that play an important role in the uneven distribution of Earth's natural resources (performance expectation MS-ESS3-1). This performance expectation very broadly addresses Earth's mineral, energy and groundwater resources. Each of those three categories (minerals, energy, groundwater) can provide multiple examples. From an instructional perspective, each category provides opportunities for students to engage with the science and engineering practices to pose questions, gather information, develop and use models, analyze and interpret data, use mathematical and computational thinking, construct explanations, argue from evidence, and communicate information.

With respect to energy resources, plate tectonics is most directly involved with geothermal sources. The thermal energy at plate boundaries can be used to generate electricity and as a source of energy for heating buildings and commercial purposes. Volcanic and uplift processes can bring important minerals on or near the surface where they can be profitably mined. For example, most copper mines are located near plate boundaries. The prospector's shout that "there's gold in them thar hills" directly connects gold distribution with the plate tectonics that created them thar hills.

Fossil fuel distribution is one the most politically important uneven distributions of natural resources. The Middle East has about 2/3 of the world's proven reserves of crude oil. Petroleum and natural gas are generally associated with sedimentary rocks. These fuels formed from soft-bodied sea organisms whose remains sank to the ocean floor, decomposed in the relative absence of air, and were further transformed by heat and pressure deep underground.
Coal, the most abundant fossil fuel, was created 300 to 400 million years ago during the Carboniferous period that had a generally warm and humid climate. Tropical swamp forests of Europe and North America provided much of the organic material that was

buried and compressed in sediments to form coal. Locations, such as today's Appalachian Mountain region, that supported these Carboniferous swamp forests have more of the unevenly distributed coal.

The distribution of groundwater is most directly related to the amount of precipitation and to the permeability of the soil and rocks. Groundwater is not like an underground lake or river. Instead groundwater is simply the water under the surface that can fully saturate pores or cracks in soils and rocks. Sedimentary rocks such as sandstone tend to hold more water. Groundwater needs to be replenished since it can be depleted by plants, evaporation and human uses. The uneven distribution of groundwater strongly correlates with the regional latitude and geographic conditions that determine the amount of precipitation.

Water and other natural resources provide a strong link with the Instructional Segment 3 life science ecosystem performance expectations and disciplinary core ideas. MS-LS2-3, one of the central Instructional Segment 3 performance expectations, states, "**Develop a model** to describe the ***cycling of matter and flow of energy*** among living and nonliving parts of an ecosystem." Student teams have been gathering **information** about cycles of matter and flows of energy from the perspectives of organisms and of ecosystems. Using environment diagrams, they have shared their ideas and evidence, and are now primed to create more complex models that address this performance expectation.

Figure 16 illustrates some of the instructional issues that arise in this modeling. The model needs to identify forms of matter that are biomass. The biomass molecules have the complex carbon molecules that organisms can use as building blocks to manufacture, replace, and repair their internal structures. The biomass molecules also have significant stored chemical potential energy that organisms can use in their biological activities and processes. In the Figure 16 model, a black arrow with a reddish interior signifies the coupling of biologically useable matter and energy in the form of biomass, and the transfer of that coupled matter and energy through the eating of food. Simple black arrows represent transfers of matter that are not biomass, and that cannot provide calories to organisms. Examples are water, carbon dioxide, and the simple minerals that decomposers such as microorganisms release to the soil. Note that this model uses these simple black arrows to represent the respiration flows of carbon dioxide out of plants and animals back into the local environment. These black arrows help to emphasize the recycling of carbon atoms.

Ecosystem Cycles of Matter and Flows of Energy

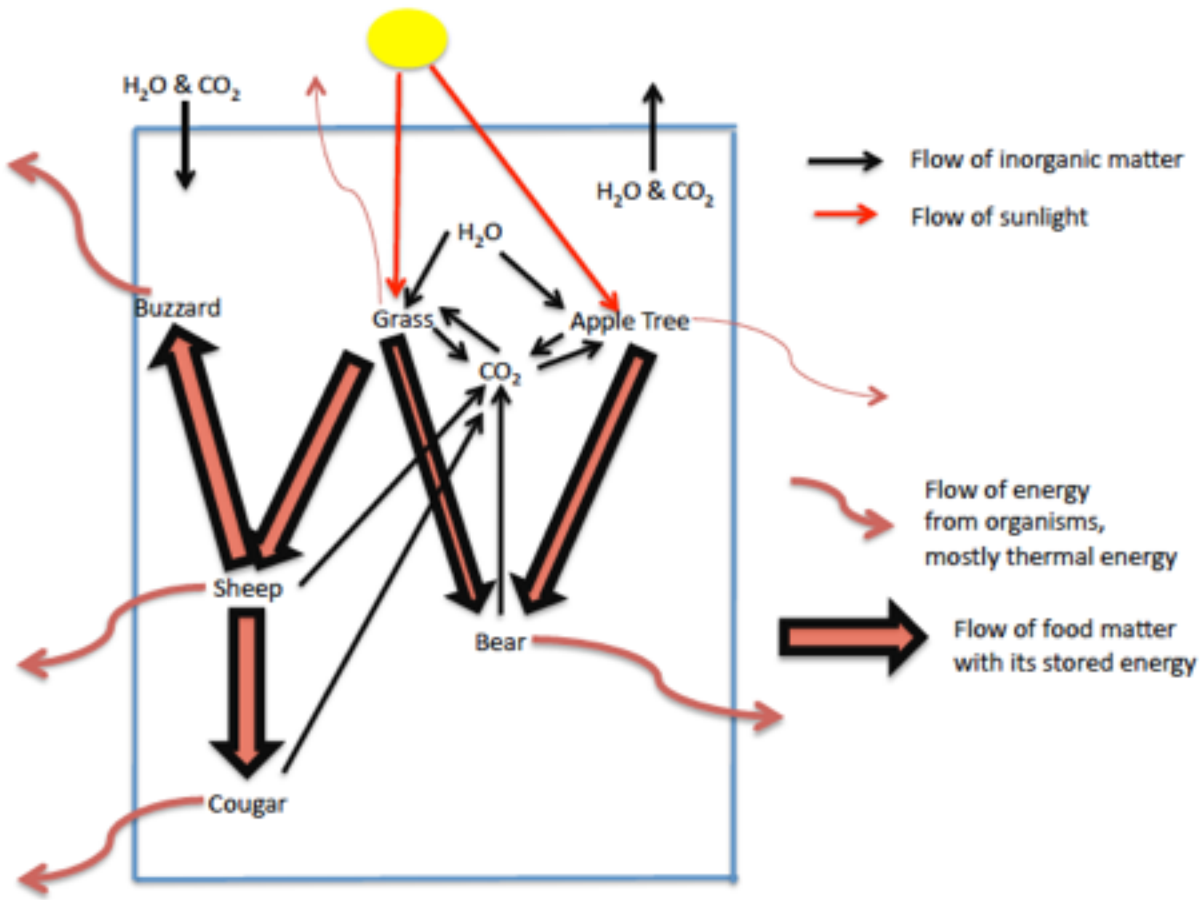

Figure 16: A model of the flows of energy and matter into, within and out of a simplified ecosystem. The wider arrows represent transfers of matter and energy coupled together in biomass. (Illustration from Dr. Art Sussman, courtesy of WestEd)

Similarly, the model needs to distinguish between different ***flows of energy***. The straight red arrows represent the input of sunlight energy via photosynthesis. Producers transform the input energy and matter into biomass (food). This biomass is then available to the producers themselves and all the consumers, and they release and obtain that energy via respiration. The pinkish interior of the food arrows represents the transfer of the biomass chemical potential energy.

The wavy red arrows represent the dissipation of much of the biomass energy that inevitably transfers to “waste heat” that escapes and leaves the system. Everything that an organism does dissipates some form of energy out of the system. The plants have the most food energy available to build their bodies. The herbivores have significantly less food energy available to them, and the carnivores have much less than the herbivores. One important result of this dissipation is the “energy pyramid,” a common graphic representation that the amount of biomass decreases markedly at each step going from producers to primary consumers to higher-level consumers and to decomposers.

A model such as Figure 16 can become much more complex if the developer of the model chooses to increase the kinds of ***flows of matter and energy*** and/or the number and types of organisms that are included. This complexity can pose a problem, but it can also provide great learning opportunities in situations where productive academic discourse flourishes.

Students should be **asking** themselves and their peers about which features are important to display in the model and why? The crosscutting concept of ***system models*** teaches that, “Models are limited in that they only represent certain aspects of the system under study.” The students get to choose what features to include, but they need to provide **evidence-based explanations** for why they have included those features. A necessary part of gaining proficiency in the science and engineering practice of **developing and using models** involves learning to wisely choose and omit features in order to hit the sweet spot of detail complexity.

One criterion for evaluating a **model** representing “ecosystem cycles of matter and flows of energy” is whether it helps distinguish why we use that phrase instead of “cycles of energy and flows of matter.” Figure 16 clearly has many more energy arrows going into and out of the system (flowing) compared with the preponderance of matter arrows that remain within the system (cycle). This particular model includes two black arrows to indicate that no ecosystem is a closed system for matter. There are flows of matter, such as carbon dioxide and water in the air, that move into and out of ecosystems. Was that too much detail or still within the sweet spot of complexity? It depends on the goals of the modeler and on the nature of the audience.