INTRODUCTION TO GEOLOGICAL PROCESS IN ILLINOIS

PLATE TECTONICS

INTRODUCTION

The Earth's surface is made of tectonic plates that are constantly in motion. Evidence for this activity is found in the shape of the continents, features of the ocean floor, and the locations of earthquakes and volcanoes. Where plates meet, there are earthquakes, volcanoes, and mountain ranges. Plate tectonics has been shaping the Earth's surface for over four billion years. These movements affect everything on our planet including the rocks, the landscape, the weather, and life. Although far from the edges of the North American Plate, the rocks and landscape of Illinois have been and continue to be impacted by plate tectonics.

PLATE TECTONICS

Plate tectonics is the concept that the surface of the Earth is made of plates that move around and interact with each other. These interactions produce volcanoes, earthquakes, mountains, and ocean basins. In developing the theory of plate tectonics, geologists have discovered that the Earth is a very active planet. The map below shows the Earth's major tectonic plates, labeled with plate names and their directions and rates of movement

http://pubs.usgs.gov/publications/text/slabs.html

Evidence of Plate Tectonics

The search began in the late 1700's with geologists wondering how mountains form. Climbing to the top of the Alps in southern Europe, geologists found limestone and fossils indicating that the rock was formed in a marine environment. What kind of force could push rocks from the bottom of the ocean to the top of a mountain?

By the late 1800's geographers had developed the first accurate maps of the Earth's surface. Several scientists noticed that the west coasts of Africa and Europe have a shape that fits nicely with the east coasts of South America and North America. The landmass created when all of the continents were together is called Pangea.

As with a jigsaw puzzle, when the pieces are fit together, a picture should appear. In this case, the picture is made of rock types, fossil zones, mountain ranges, and prehistoric climate zones. The map below shows the ranges of several fossil organisms that, if the plates had not been together, would have had to cross large oceans.

http://pubs.usgs.gov/publications/text/continents.html

However, for most geologists, this evidence was not enough, so "continental drift" remained a hypothesis.

The story of the development of tectonic theory is covered in greater detail at:
http://pubs.usgs.gov/publications/text/historical.html

New technology developed during World War II and the subsequent Cold War included sonar and magnetometers to scan the oceans and seismic networks to monitor for nuclear explosions. Geologists used this technology to draw detailed maps of the ocean floor, to locate earthquakes around the world, and to study the Earth's interior. The data supported the theory of moving plates.

Geologists discovered that the ocean floor is not shaped like a bath tub but has a long chain of underwater mountain ranges called ocean ridges (see the map below).

http://www.ngdc.noaa.gov/mgg/image/2minrelief.html

Notice that the ocean ridge in the center of the Atlantic Ocean parallels the continental coasts. There are also long, deep trenches all around the edges of the Pacific Ocean and scattered around the other oceans.

Sampling the rocks of the ocean floor, measuring the thickness of the sediments, and using magnetic patterns to correlate rocks of similar age, allowed geologists to produce a map showing the age of the ocean floor.

Age of the Ocean Floor:
http://www.ngdc.noaa.gov/mgg/image/images/WorldCrustalAge.jpg
Detail of section of Ocean Ridge: http://pubs.usgs.gov/publications/text/magnetic.html

Notice that the youngest rocks are found along ocean ridges. The crust gets older as the distance from the ocean ridge increases. The oldest rocks are located along the edges of the continents and near the trenches.

When the locations of earthquakes and volcanoes were plotted on a map, a pattern emerged.

Earthquakes: http://www.iris.edu/seismon
Volcanoes: https://www.volcanodiscovery.com/erupting_volcanoes.html

Notice that most of the earthquakes and volcanoes are located in narrow bands that align with the trenches, ocean ridges, and continental mountain ranges. Most of the Earth's geologic activity is confined to these narrow zones.

Earthquake waves (seismic waves) passing through the Earth have allowed geologists to develop a picture of the Earth's interior.

http://www.iris.washington.edu/gifs/ExplorEarthPoster.jpg

The layers found inside the earth each have unique properties. The core has an average density of 11 g/cm3 and is made of iron and nickel. The inner core is solid while the outer core is liquid. The mantle is primarily a plastic solid (capable of movement) composed of ultramafic rock with an average density of 3.3 g/cm^3. A closer look shows that there are two types of crust.

The continental crust is 25 to 35 kilometers (15 to 20 miles) thick, has a felsic to intermediate igneous composition, and a density of 2.7 to 2.9 g/cm^3. The ocean crust is five kilometers (three miles) thick, has a mafic composition, and a density of 2.9 to 3.0 g/cm^3. The geologists also found that a rigid portion of the mantle approximately 200 kilometers (120 miles) thick was stuck to the bottom of the crust. This combination of crust and mantle is called lithosphere. The rigid lithosphere floats on the higher density mantle.

The theory of sea floor spreading combines all of this evidence to show that the oceans are pulling apart along the ocean ridges. The ocean ridges are a chain of active volcanoes that form as the crust separates and hot igneous rock rises up from below. As the rock cools, its density increases and the crust sinks and, ultimately, returns to the mantle when it disappears down a trench. Ocean basins form when continents pull apart, which explains why the oldest ocean crust is near the continents. New ocean crust is forming at the ridges and moves away as the ocean continues to widen and add newer material in the middle. Ocean crust is lost when it is forced under other sections of crust (this process is called subduction) with ocean trenches marking the locations where the crust goes down. Volcanoes form behind the trench as the ocean crust and upper mantle melt. The diagrams below show the movement of the plates and the creation and loss of ocean crust.

http://www.odsn.de/odsn/services/paleomap/animation.html
http://pubs.usgs.gov/publications/text/Vigil.html
http://vulcan.wr.usgs.gov/Glossary/PlateTectonics/Maps/map_juan_de_fuca_subduction.html

The final piece of evidence supporting plate tectonics has been provided by modern positioning technology using lasers and satellite-guided global positioning systems. The movement of the plates can now be measured with rates from two to ten centimeters (one to four inches) per year. This information is used to create maps showing the direction and rate of plate motion.

The biggest question that remains in plate tectonics is what makes the plates move? There are several models that involve hot mantle material rising, cooling near the base of the lithosphere, and sinking (a process called convection). Different convection models involve small plumes or large cells of rising mantle and can include all of the mantle or just the upper part. Other models show that the ocean crust could also move under the force of gravity as the crust slides downhill from the ocean ridge into the trench. Improved images of the mantle and lithosphere using detailed computer modeling of seismic data are helping to answer this question.

Effects of Plate Tectonics

The effects of plate tectonics are found primarily at the plate boundaries; however, geologists have discovered that the boundaries between plates can change location over time. By understanding the rocks and structures forming at active boundaries, geologists can identify ancient plate boundaries and interpret the history of plate tectonics. The map below shows the Earth with the major tectonic plates, the directions they are moving, and rates of their movement.

http://sideshow.jpl.nasa.gov/mbh/series.html

The Web site below includes a series of helpful illustrations.

http://pubs.usgs.gov/publications/text/understanding.html

Divergent boundaries occur where two plates pull apart in a process called rifting. Three things happen when plates pull apart: the crust on the sides of the rift caves in, molten rock rises from below, and water fills the rift.

The initial rifting of a continent creates a rift valley with faults on either side and down-dropped blocks of crust in the middle. The thinner crust reduces pressure on the mantle and allows the hot mantle rock to melt. The composition of the mantle is ultramafic, but as the molten rock rises to the surface, it begins to cool and its mineral composition changes. The volcanoes in the rifted zone have lava with a mafic composition. This process is now splitting open East Africa, creating the Great Rift Valley and volcanoes such as Mount Kilimanjaro.

Sometimes when continents pull apart, portions of the initial rift will stop spreading and become dormant. These "failed rifts" are heavily faulted weak zones in the continental crust that can be reactivated by the pressures of distant plate collisions and by the addition of weight from sediment that washes in to fill the rift valley.

As the process continues, the gap widens until the down-dropped blocks of continental crust can no longer fill the gap and it becomes filled with a thin layer of dense, mafic igneous rock. This rock floats lower in the mantle and the low rift fills with sea water. This process is slowly widening the Red Sea, pulling Africa farther from the Arabian Peninsula.

Finally, an ocean basin develops with a volcanic ocean ridge near the center. A close view of the ocean ridge shows the rift with blocks of ocean crust dropping to fill the gap. This process is occurring in the middle of the Atlantic Ocean. In Iceland, the crest of the ocean ridge is above sea level, and the rift runs through the center of the island, pulling it slowly apart and creating earthquakes and volcanoes.

The structure of the ocean crust is unique with intrusive ultramafic igneous rock on the bottom, intrusive mafic igneous rock in the middle, and extrusive mafic igneous rock on top. When this sequence is found on a continent it is called an ophiolite and is interpreted as former ocean crust that was pushed onto land.

Convergent boundaries occur where two plates push into each other. The collision results in the folding and faulting of crust and the formation of mountains in a process called orogenesis. When ocean crust is involved, it is usually pushed down into the mantle in a process called subduction.

Where the ocean crust is subducted, a trench forms along the ocean floor. Earthquakes occur along the subducted crust as it is forced down into the mantle; the earthquakes get deeper as the distance from the trench increases, showing geologists the location of the subducted crust. The subducted crust contains a large quantity of water which lowers the melting point of some of the minerals in the mantle and crust. This causes partial melting of the mantle and crust rock and produces molten rock of felsic to intermediate composition. The molten rock rises to the surface creating a chain of volcanoes known as a volcanic arc. At the same time, the compression where the two plates meet causes folding and faulting, the formation of metamorphic rock, and pushes the rocks up into mountains. Anything sticking up from the subducted crust will be scraped off and added to the side of the overriding crust in the process of continental accretion. The combination of volcanic activity and continental accretion has, over time, created the large continents that exist today. Subduction zones are found all around the Pacific Ocean and include the west coasts of North and South America, the Aleutian Islands, Japan, the Philippines, and New Zealand.

When an ocean basin closes and two continents collide, subduction ends as the last of the ocean crust is destroyed or pushed up into the mountains. Continental crust is too thick and the density is too low for one of the plates to be pushed down into the mantle. Instead, large mountain ranges are pushed up and many damaging earthquakes occur as the continents are slowly forced into each other. The Himalayas and Alps are actively pushing up mountain ranges of this type that began forming over75 million years ago. The Appalachian Mountains were created this way several hundred million years ago.

Click here to see an animation of subduction and continental collision.
http://www.pbs.org/wgbh/nova/everest/earth/shock.html

Transform boundaries occur where two plates slide past each other. There is no igneous activity since nothing happens that would cause molten rock to form. A long crack may be found where the boundary is straight, and small mountains are pushed up where the boundary curves. There can be damaging earthquakes all along the boundary. This type of boundary can be found in California (see map below) and Turkey.

http://pubs.usgs.gov/gip/earthq3/where.html

Away from the plate boundaries, not all is quiet. Active volcanoes can form above "hot spots" of rising mantle material. As the plate moves over the hot spot, a chain of volcanoes forms. Each volcano is active for a short time and then dies as the plate moves it away from the hot spot. The Hawaiian Islands formed in this manner, as did the volcano that underlies Yellowstone National Park.

PLATE TECTONICS & ILLINOIS

Illinois is located thousands of miles from the nearest plate boundary (in California) yet plate tectonics still affects the state. The deepest rocks of Illinois are igneous and metamorphic rocks that formed along a subduction zone and subsequent collision between two small continents over 1 billion years ago. This continental accretion was part of the process that resulted in the formation of North America. Between 1 billion and 600 million years ago, a rift began to form just south of the southern tip of Illinois. This would have placed the state at the edge of a deep ocean; however, the rifting stopped and the failed rift was subsequently covered with sediment.

Over the last 600 hundred million years, the moving North American plate has taken Illinois from near the equator to its present, much colder, latitude. When North America collided with Africa approximately 300 million years ago, the sediments washing off of the new mountain range covered Illinois. When North America pulled away from Africa, the old failed rift south of the state started to spread, but again stopped and was again buried.

ILLINOIS STATE PARKS AND NATURAL AREAS OF NOTE FOR THEIR STRUCTURAL FEATURES

Beall Woods (Wabash Valley Faults)

Dixon Springs (Faults exposed in roadcuts along IL 146 east and west of the intersection with IL 145.)

Castle Rock (Sandwich Fault passes through area)

Mattheissen (Steeply dipping rocks along the west limb of the LaSalle Anticline fold can be observed along the Vermillion River.)