The Adventures of GEO
Plate Tectonics!

GEO COMICS
Issue #1

[Image of a character on a skateboard surrounded by fire and flames]
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Would you like to know more about plate tectonics and the inner workings of the Earth? Are you interested in printing or downloading a copy of “The Adventures of Geo” of your own? Then check out our website:

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Definitions of key terms (in bold face for their first mention), are found in Geo’s Glossary at the end of the book. Enjoy!

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TWO HUNDRED MILLION YEARS AGO
EARTH WAS VERY DIFFERENT.

IT IS IN THIS TIME WE FIND OUR HERO,
GEO, IN PERILOUS DANGER...

WHAT HAVE I GOTTEN MYSELF INTO NOW?
Somehow I think our experimental time machine has placed us in a less than desirable period.

It appears Earth is going through a dramatic change. If I’m not mistaken we may be witnessing the break-up of Pangea.

I’m not sure where Geo is, but I’m going to be a pile of scrap metal if I don’t get to safety!

Hang on, Rocky! I’ll save you!

That was close! What took you so long?

I ran into some trouble.

What’s happening? It’s like the end of the world.

Actually it’s the beginning of a new age, Geo.

What do you mean, Rocky?

It looks like we’ve transported ourselves back to when the supercontinent Pangea was breaking apart.
About 200 million years ago, all of the continents that we now call North America, South America, Asia, Europe, Africa, Antarctica and Australia, were all part of a much larger continent, called Pangea. Like pieces of a large puzzle, the continents fit together, but it didn’t stay that way. What happened?

The continents, or well, the tectonic plates, began to move as they had done many times before.

That’s right, and tectonic plates differ in thickness and what they are made of depending on where they are.

Yes, each tectonic plate is a piece of the Earth’s lithosphere, the rigid outermost shell of the Earth that includes the crust and upper portions of the mantle.

“THE PACIFIC PLATE IS AN OCEANIC TECTONIC PLATE WHOSE TOP PORTION IS MADE OF OCEANIC CRUST, AND WHILE DENSE IS RELATIVELY THIN AS COMPARED TO CONTINENTAL TECTONIC PLATES, SUCH AS THE NORTH AMERICAN PLATE, WHICH TEND TO BE THICKER BUT LESS DENSE THAN THE OCEANIC TECTONIC PLATES AND THE MANTLE.”

Oceanic crust is the crust under the oceans, whereas continental crust is what the continents are made of.

George! Wake up!

UH OH!
BACK TO REALITY....

GEORGE! WAKE UP! YOU MISSED THE SCHOOL BUS!

OH NO!

I CAN’T BE LATE OR I’LL GET POINTS DEDUCTED. IF I MISS THIS TEST I’LL BE IN BIG TROUBLE!

I GUESS I WAS UP A LITTLE TOO LATE STUDYING.

MY BIG EARTH SCIENCE TEST IS TODAY!

MOM AND DAD MUST HAVE TAKEN OFF FOR WORK EARLY. I KNEW I SHOULD HAVE SET MY ALARM!

GOOD THING I CAN ALWAYS COUNT ON GRANDMA!

I BETTER BRUSH MY TEETH QUICK AND GO. BEING LATE IS NOT AN OPTION TODAY.
COME EAT SOME BREAKFAST, GEORGE. THEN I’LL DRIVE YOU TO SCHOOL.

YOU NEED A GOOD MEAL TO START THE DAY. YOU WERE UP SO LATE STUDYING.

THANKS, GRANDMA! YOU’RE THE BEST! I’LL TAKE SOME TOAST FOR THE ROAD.

I HAVE A BIG TEST I CAN’T BE LATE FOR. AND IT WILL TAKE LONGER TO DRIVE WITH MORNING TRAFFIC.

I CAN MAKE IT THERE QUICKER ON MY SKATEBOARD.

YOU BE CAREFUL ON THAT THING, NOW.

OF COURSE, GRANDMA. I’M ALWAYS CAREFUL.

BESIDES... IT’S MY FAULT I OVERSLEPT.

IF I DOUBLE-TIME IT ON MY BOARD, I CAN MAKE IT TO SCHOOL BEFORE THE BELL AND IN TIME FOR FIRST PERIOD AND MY TEST.

GOOD LUCK, BABY!

BYE, GRANDMA! I LOVE YOU! SEE YOU WHEN I GET HOME!
“Beneath the crust of the earth lies the mantle, the rocky portion of the earth that extends to ~1800 miles (~2900 km) depth. Beneath the mantle is the molten, iron-rich outer core followed by the solid, iron-rich inner core.”

“The earth is very active – its interior is constantly moving.”

Most of the time it’s hard to tell because the tectonic plates are moving very slowly, about as slowly as fingernails grow!

At other times, it’s easily noticed as sudden movements such as earthquakes.

And when the earth moves, this can cause the landscape to change drastically... cool!
ON HIS WAY TO SCHOOL....

THESE SIDEWALKS ARE SO UNEVEN, I HAVE TO BE CAREFUL NOT TO TRIP ON THEM.

THE CRACKS REMIND ME OF THE FAULTS WE TALKED ABOUT IN CLASS.

“FAULTS ARE FRACTURES OR CRACKS ON THE EARTH’S SURFACE THAT OCCUR BECAUSE OF TECTONIC PLATE MOTION.”

SNAP OUT OF IT, GEORGE! IF I DON’T PAY ATTENTION, THE CRACKS ARE GOING TO SEND ME FLYING!
AND WITH A LITTLE IMAGINATION...

I BETTER TRANSFORM INTO GEO IF I'M GOING TO SURVIVE THIS ONE!

...A BOY AND HIS BACKPACK TRANSFORM...

THAT WAS CLOSE, ROCKY!

WATCH OUT FOR MOVING SIDEWALKS!

...INTO SUPERHEROES!

OR RATHER, MOVING PLATES!

*There are dozens of tectonic plates on Earth, both major and minor. Only ten are labeled here. The arrows indicate the plate motion directions.
But plates don’t move that fast.

They move, on average, up to a few inches each year.

“The tectonic plates move through a process called convection. The hot mantle deep in the Earth moves: hot rock expands, decreasing its density, and begins to rise; while colder, and/or denser rock sinks.”

“This sets up a cycle that moves the rigid tectonic plates on the surface, and cools the deep interior of the planet.”

Convection also happens in the outer core, which also helps to cool the core and generate the Earth’s magnetic field.

But why is it so hot down there?
"Heat in the deep Earth comes from a few sources, primarily radioactive decay and primordial heat."

"Primordial heat is the energy accumulated when the Earth was forming."

"This primordial energy is mostly due to the energy from meteorites that collided together to make the Earth more than 4.5 billion years ago."

Sounds like a violent time!

It was. But the other kind of heating isn’t so dramatic.

Radioactive decay is the process by which an unstable atom becomes stable by releasing energy and often a particle.

"Together, radioactivity and primordial heat provide the energy that makes the Earth’s interior very, very hot."
So it’s heat that causes the motion of the plates?

Yes, and this plate motion results in 3 types of plate boundaries: convergent, divergent and transform.

Tectonic plates move toward each other at convergent boundaries and in doing so, compressional forces are produced.

Large compressional forces can produce mountain ranges such as the Himalayas, Alps and the Rockies.

In the Himalayas, two continental crusts are converging which results in very tall mountains and large earthquakes.

Cool!

How do earthquakes occur?
MOST EARTHQUAKES OCCUR WHERE TWO PLATES MOVE WITH RESPECT TO EACH OTHER.

AS THE PLATES MOVE SLOWLY, SOMETIMES FOR DECADES OR CENTURIES WITHOUT INCIDENT, STRESSES BUILD UP DUE TO FRICTION UNTIL THE PORTION OF THE PLATE WHICH HAD INITIALLY BEEN STUCK SLIPS QUICKLY, ALL AT ONCE!

"THE ENERGY FROM AN EARTHQUAKE IS RELEASED AS SOUND WAVES, CALLED SEISMIC WAVES, WHICH RADIATE FROM WHERE THE EARTHQUAKE RUPTURES, CALLED THE FOCUS. THE EPICENTER IS THE PLACE ON THE SURFACE DIRECTLY ABOVE THE FOCUS."

“Earthquakes can cause damage to buildings and other structures, as well as land formations, which can result in many casualties.”

“Very large earthquakes also occur at convergent boundaries called subduction zones. Subduction occurs when two plates converge.”

“Here the denser oceanic plate sinks beneath the less dense continental plate. Tsunamis are also a possibility...”
SUNAMIS ARE NO JOKE!

AACK! I DON’T WANT TO GET WET!

TIME TO TRANSFORM!
“Tsunamis often occur at subduction zones where the denser oceanic plates sink under the less dense continental plate.”

"Friction between the two plates can cause the plates to "stick," causing the top plate to bulge under the strain."
“IT’S LIKE AN EruptING VOLCANO BURSTING WITH SMOKE AND MOLTEN LAVA.”

“BESIDES EARTHQUAKES AND TSUNAMIS, CONVERGENT BOUNDARIES CAN ALSO HAVE EXPLOSIVE VOLCANOES. THIS IS DUE, IN PART, TO WATER THAT IS SUBLICTED AT SUBDUCTION ZONES. THE VOLCANOES CAN BE OBSERVED ON THE CONTINENT NEAR THE SUBDUCTION ZONE.”

“...OR AS ISLANDS IN AN ISLAND ARC.”

“OH MY! THANK YOU, YOUNG MAN!”

“FEAR NOT! I’LL SAVE YOU!”

“MY PLEASURE, MA’AM!”
“THE ‘RING OF FIRE’ IS THE BOUNDARY SURROUNDING THE PACIFIC OCEAN WHERE MANY TECTONIC PLATES MEET AND MOVE AGAINST EACH OTHER.”

“The Ring of Fire has areas of subduction at each of the trenches, along with arc volcanism along the boundaries.”

“In fact, nearly all volcanism happens along plate boundaries...”
“Not all volcanism is destructive. At divergent boundaries, where plates move apart, new crust is made. Here, oceanic plates diverge from each other and make the rocks at the bottom of the ocean. This is called seafloor spreading.”

“In fact, most of the volcanism on Earth occurs at these mid-ocean ridges where the seafloor spreads. Where there is active volcanism, heat from deep in the Earth is escaping.”

“Not only does this magma make new rock, the iron-rich minerals in it record the Earth’s magnetic field upon cooling... thereby giving a record of the magnetic field along the ocean floor.”

Hey, kid! Slow down! You can’t ride on this! UH OH!
Some volcanism occurs within the plates. These are hotspots.

Hawaii is one such hotspot where it is suspected that the magma that made these islands originates deep in the mantle.

“As the Pacific tectonic plate moves in a northwest direction, new islands have been formed. The oldest islands are Niihau and Kauai, which stopped erupting 5 million years ago. The youngest and still actively erupting, is the ‘Big Island’ of Hawaii. Given the age of the rocks on each island and the distance between them, one can measure the average speed of the Pacific plate to be approximately 4 inches/year (or 10 cm/year).”
“Uh oh!”

“Ouch! My skateboard just made it in!”

“Finally, tectonic plates can also slide against each other.”

“These strike-slip faults are at transform plate boundaries.”

“Many transforms are along the mid-ocean ridges…”

“…but some are on land.”

“Large earthquakes can happen along these faults as well. The San Andreas fault along the coast of California is a strike slip fault and marks the boundary…”

“…between the North American and Pacific tectonic plates.”

“Click!”

“That was close. Time to get to class!”

“The two plates move past each other, rather than one beneath the other as in subduction zones.”
...you’ll have exactly 45 minutes to finish the test.

Looks like I just made it.

Don’t forget to write your name on all sheets please.

If there are no further questions, you can all get started.

Subduction, I know what that is!

Tsunamis...

Oceanic plates...

Faults...

Mantle...

45 minutes later...

How did you do?

Not sure, but I feel pretty good.
THE NEXT DAY...

I CAN’T WAIT TO SEE WHAT I GOT ON THE SCIENCE EXAM.

I’M STARTING TO FEEL A LITTLE NERVOUS.

OH, BOY.

GREAT JOB, GEORGE!

HUH?

WOW! A PERFECT SCORE!

I GUESS ALL THAT STUDYING PAID OFF.

SURE DID!

THE END!
Asthenosphere: The viscous and mechanically weak region of the Earth’s upper mantle just below the lithosphere.

Basalt: A common magnesium- and iron-rich igneous rock.

Continental Crust: The continental crust is typically ~20-30 miles (~30-50 km) thick and is mostly made of slightly less dense rocks, such as granite, than those of the oceanic crust.

Convection: The transfer of heat by the motion of heated parts. In the Earth’s mantle, density-driven flow moves hot, thermally-expanded and buoyant material upwards, and cool, thermally-contracted material downwards.

Convergent Boundary: An actively deforming region where two (or more) tectonic plates move toward one another and collide. As a result of pressure, friction, and plate material melting in the mantle, earthquakes and volcanoes are common near convergent boundaries. When two plates move towards one another, they form either a subduction zone or a continental collision.

Core: The innermost part of the Earth that is primarily made of an iron-nickel alloy. The outer portion is liquid, while the inner portion is solid. Its outer boundary lies ~1800 miles (~2900 km) beneath the Earth’s surface. The inner core-outer core boundary is located ~3200 miles (~5150 km) beneath the Earth’s surface.

Core-mantle boundary: Lies between the Earth’s mantle and its liquid iron-nickel core at ~1800 miles (~2800 km) depth beneath the Earth’s surface. The boundary is observed via a sharp change in seismic wave velocities at that depth.

Crust: The outermost solid shell of a rocky planet, which is chemically distinct from the underlying mantle.

Density: Mass per unit volume. The density of a material varies with temperature and pressure. Increasing the pressure on an object decreases the volume of the object and therefore increases its density. Increasing the temperature of a substance generally decreases its density by increasing the volume of that substance.

Divergent Boundary: A boundary between two tectonic plates moving away from each other. Most active divergent plate boundaries occur between oceanic plates and exist as mid-ocean ridges. Over millions of years, tectonic plates move many hundreds of kilometers away from both sides of a divergent plate boundary. Because of this, rocks closest to a boundary are younger than rocks further away on the same plate.

Earthquake: An earthquake occurs when two tectonic plates slip past each other resulting in a sudden release of energy that creates seismic waves. Earthquakes are measured using observations from seismometers. All else being equal, the shallower an earthquake, the more damage to structures it causes.

Elasticity: A measure of how a material reversibly deforms under stress.

Epicenter: The point on the surface of Earth directly above the point where an earthquake originates (focus) or where the fault begins to rupture. Usually this is also the area of greatest damage.

Fault: A planar fracture in a rock, across which there has been significant movement. Large faults within the Earth’s crust result from the action of plate tectonic forces. Energy release associated with rapid movement on active faults is the cause of most earthquakes.

Focus: Where an earthquake originates.

Granite: A common type of igneous rock consisting mainly of quartz and feldspar minerals. Granite is usually found in continental crust.
**Hotspots:** Volcanic regions thought to be fed by underlying mantle that is anomalously hot compared with the mantle elsewhere. They may be on, near to, or far from tectonic plate boundaries. Well-known examples include Hawai’i or Yellowstone.

**Igneous:** Igneous rock is formed through the cooling and solidification of magma or lava. The magma is derived from melting of rocks in either the mantle or crust. Typically, one or more processes cause melting: an increase in temperature, a decrease in pressure, or a change in composition.

**Inner Core:** The innermost, hottest part of the Earth and as detected by seismological studies, is primarily solid and about 760 miles (~1220 km) in radius. It is believed to be made of an iron-nickel alloy.

**Island Arc:** A chain of volcanic islands, whose alignment is arc-shaped, and situated parallel and close to the boundary between two, converging tectonic plates.

**Lava:** Refers both to molten rock erupted by a volcano and the resulting rock after solidification and cooling.

**Lithosphere:** The rigid outermost shell of a rocky planet. On Earth, it comprises the crust and the portion of the upper mantle that behaves elastically on time scales of thousands of years or greater.

**Magma:** Molten or semi-molten rocks found beneath the surface of the Earth. Besides molten rock, magma may also contain suspended crystals, dissolved gas and sometimes gas bubbles. Magma often collects in magma chambers that feed a volcano or turn into a pluton. Magma is capable of intrusion into adjacent rocks, extrusion onto the surface as lava, and as explosive ejecta.

**Magnetic Field:** The Earth’s magnetic field extends from the Earth’s core outward. It is approximately the field of a magnetic dipole (like a bar magnet at the center of the Earth) tilted at an angle of 11 degrees with respect to the rotational axis. However, unlike the field of a bar magnet which doesn’t change with time, Earth’s field changes over time because it is generated by the motion of fluid iron alloys in the Earth’s outer core, called the geodynamo. At random intervals (averaging several hundred thousand years) the Earth’s magnetic field reverses (the north and south magnetic poles change places with each other). These reversals leave a record in rocks that allow geologists to calculate past motions of continents and ocean floors as a result of plate tectonics.

**Magnetic Stripes:** The past record of geomagnetic field reversals was observed by the magnetic “stripe” anomalies on the ocean floor. Minerals in the “stripes” record the prevailing geomagnetic field direction at the time of their formation. The “stripes” on one side of the mid-ocean ridge are the mirror image of those on the other side and the magnetic variation in successive bands of ocean floor parallel with mid-ocean ridges is important evidence supporting the theory of seafloor spreading, central to plate tectonics.

**Mantle:** Earth’s mantle is a rocky shell about 1800 mi (~2900 km) thick and constitutes about 84% of Earth’s volume. It is predominantly solid although past episodes of melting and volcanism at the shallow depths produced a thin crust.

**Mantle Plume:** A hypothetical thermal upwelling of abnormally hot rock that starts at the core-mantle boundary and rises through the Earth’s mantle. Some of these volcanoes lie far from tectonic plate boundaries (e.g., Hawai’i), whereas others represent unusually large-volume volcanism on plate boundaries (e.g., Iceland). The currently active volcanic centers are known as hot spots.

**Mid-ocean ridges:** An underwater mountain system that consists of various mountain ranges (chains), typically having a valley known as a rift running along its spine, formed by plate tectonics. This type of oceanic ridge is responsible for seafloor spreading and the growth of new oceanic crust. A mid-ocean ridge marks the boundary between two tectonic plates, and is a divergent plate boundary.

**Oceanic Crust:** The oceanic crust is ~3-6 miles (~5-10 km) thick and is made of dense rocks such as basalt.

**Outer Core:** The outer core of the Earth is a liquid layer about 1400 miles (~2200 km) thick primarily made of an iron-nickel alloy which lies above the Earth’s solid inner core and below its mantle. Its outer boundary lies ~1800 miles (~2900 km) beneath Earth’s surface.

**Pangea:** A supercontinent that formed ~300 million years ago and began to rift ~200 million years ago, before the component continents were separated into their current configurations.
Plate Tectonics: A scientific theory that describes the large-scale motions of Earth's lithosphere. The theory builds on the concepts of continental drift, developed during the first decades of the 20th century. The geoscientific community accepted it after the concepts of seafloor spreading were developed in the late 1950s and early 1960s.

Pluton: A body of intrusive igneous rock that crystallized from magma slowly cooling within the crust.

Primordial Heat: The heat or energy that resulted from the formation of the Earth.

Radioactive decay: The process by which the nucleus of an unstable atom loses energy by emitting ionizing particles. A decay, or loss of energy, results when an atom with one type of nucleus, called the parent radionuclide, transforms to an atom with a nucleus in a different state, or to a different nucleus containing different numbers of nucleons, called the daughter radionuclide.

Ring of Fire: An area where a large number of earthquakes and volcanic eruptions occur surrounding the Pacific Ocean. In an ~25,000 mile (~40,000 km) horseshoe shape, it is associated with a nearly continuous series of trenches, Island arcs, and volcanism. The Ring of Fire is home to more than 75% of the world's active and dormant volcanoes.

Seafloor Spreading: Process that occurs at mid-ocean ridges, where new oceanic crust is formed through volcanic activity and then gradually moves away from the ridge.

Seismic waves: Waves of energy that travel through the Earth, and are a result of an earthquake, explosion, or a volcano. The speed of the waves depends on density and elasticity of the rock it travels through.

Seismometer: Instruments that measure ground motion generated by earthquakes, volcanic eruptions, and other seismic sources. Records of seismic waves allow seismologists to map the interior of the Earth, and locate and measure the size of the earthquakes.

Strike-slip fault: A usually nearly vertical fault that moves either left or right or laterally with very little vertical motion. A special class of strike-slip faults is the transform fault, which form plate boundaries.

Subduction: Process that takes place at convergent boundaries by which one tectonic plate sinks under another tectonic plate, as the plates converge. Rates of subduction are typically measured in centimeters per year, with the average rate of convergence being approximately 2 to 8 centimeters per year (about the rate fingernails grow).

Subduction zone: Where two tectonic plates move towards one another and one sinks under the other.

Supercontinent: A landmass composed of more than one continents or cratons.

Tectonic plate: Pieces of the Earth’s crust and uppermost mantle, together referred to as the lithosphere. The plates range in thickness and composition. Tectonic plates made of oceanic crust are ~3-6 miles (~5-10 km) thick and of basaltic composition, whereas tectonic plates made of continental crust are ~18-28 miles (~30-45 km) thick and less dense in composition.

Transform Boundary: Also known as a conservative plate boundary, as these boundaries neither create nor destroy lithosphere. Transform boundaries end abruptly and are connected on both ends to other faults, ridges, or subduction zones. While most transform boundaries are hidden in the deep oceans where they form a series of short zig-zags accommodating seafloor spreading, they can also be found on land at the margins of tectonic plates.

Trench: Created by the tectonic plate motion at subduction zones. An example is the Mariana Trench, which is deep ~6 miles (~10 km), linear and formed by subduction.

Tsunami: A series of water waves caused by the displacement of a large volume of water, caused by disturbances such as earthquakes, volcanic eruptions, underwater explosions, landslides, glacier calvings and meteorite impacts. Tsunami waves do not resemble normal sea waves, because their wavelength is far longer. Wave heights of tens of meters can be generated by large events.

Volcano: An opening in a planet's crust, which allows hot magma, volcanic ash and gases to escape from below the surface. Volcanoes are generally found at divergent or convergent boundaries. Volcanism away from plate boundaries has also been explained as mantle plumes, often called "hotspots", such as Hawai'i.