Paleomagnetism – Tutorial Script

The other tool we use to study plate motion and direction is **paleomagnetism** – or the record of ancient magnetism recorded in the rocks. To understand how, we first have to review how Earth's magnetic field is produced. We first mentioned it in the lecture on Earth formation. It has existed on Earth since earth's layers formed – specifically the liquid iron outer core. What do you remember that layer is doing? It's hot and liquid. So it convects. Because it's a metal, that convection acts very much like a current of electrons moving in a loop, which you'll learn in a basic physics class is one way to produce a magnetic field. Anyone that's ever seen or worked with solenoids can visualize this type of magnetic field. Because of earth's rotation, the convection currents tend to stack up on each other and combine to strengthen the field. The direction of the field is dictated by the right-hand rule. Hold up your right hand. Curl your fingers in the direction of a current of coiled wire, and your thumb will point toward the north pole of the magnet. Hopefully you've played enough with magnets to remember they have two opposite poles, which we call north and south. Try to put the north end of two magnets together and they'll repel. Let one move freely, and it will rotate so its south end is pointed towards the north end of the other. Earth's magnetic field is oriented pretty closely with its rotational north pole, but not perfectly. And that pole wanders around. Why? The currents change. They speed up. They slow down. They change direction. If you sum up all the currents, subtracting those going in the opposite direction, the net sum gives you the strength and direction of Earth's magnetic field. Does the movement of the North Pole happen fast enough to matter? We can see that the movement has been considerable and the direction and speed have varied from one year to the next. If you grew up in these islands and depended on a compass to help you navigate, you'd need to reset it each year to make sure you knew where it was pointing!

As mentioned, the north pole migrates, but so, too, do the poles switch or reverse. How often? Every couple hundred thousand years or so. Can we predict it? Is there a pattern? This image shows the changes in Earth's magnetic field over the past 5 million years. Do you see a pattern? Can we predict a change? Maybe. As these graphs of intensity show, the strength of the magnetic field decreases and then hits zero before either starting up again and increasing in the same direction as before or increasing but in the opposite direction. What happens during a switch in magnetic polarity? We have no evidence from the fossil or rock world that a switch has ever caused an extinction. There are many organisms that seem to use earth's magnetic field to help them navigate. But presumably they also use other clues, including visual clues. And since the field decreases and then disappears before flipping, those organisms must rely on their other senses and clues more and more before they lose the field entirely. After the flip, they can easily connect the new field back to their clues and use it again, even though it's in the opposite direction. They would simply adjust. As would we. The only major concern would be the increase in solar winds that are normally deflected. The ionized particles would collide more with the atmosphere, as they do now over the poles creating spectacular auroras. We might see auroras across the planet at all latitudes, and for a while we might see more intense storms. But evidence also suggests that the absence of a magnetic field wouldn't last long enough to produce any major changes.

So how do we create these lovely graphs that tell us what earth's magnetic field direction has been in the past? And its strength? We get them by studying fossil evidence left behind in volcanic rocks that erupted on land. As this image of a volcano shows, when lavas erupt, they are molten. As crystals begin to form during cooling, they are free to move. Any magnetic minerals that form will rotate to align themselves with earth's magnetic field – and there's one magnetic mineral that is found in all volcanic rocks – it is called, strangely enough, magnetite. So we can go to the piles of lavas that make up volcanoes and starting at the oldest on the bottom, take samples, date them, so we know how old they are, and then measure the direction of their magnetite crystals to see what direction the magnetic field was when they formed. We call that ancient or fossil evidence of earth's past magnetic field, paleomagnetism.

This paleomagnetic record becomes a powerful tool for studying plate tectonics when we apply it to seafloor spreading. During World War II, in the Pacific Ocean, oceanographers conscripted into the navy were combining wartime activities with science and gathering data on seafloor magnetic anomalies. A sensitive magnet towed behind the boat as it criss-crossed the oceans multiple times, was able to pick up the magnetism of the pillow basalts under the sediments at the bottom of the ocean. Where the magnet picked up positive anomalies – they registered magnetic fields that were aligned with the present magnetic field, which we call **normal polarity**, and thus boosted that field making it stronger. Where the magnet picked up negative anomalies, the pillow basalt magnetites were aligned in the opposite direction – **reversed polarity** – and were subtracting from the strength of the current field. By recording these data multiple times as they cross the mid-ocean ridges, they were able to develop maps such as these, which not only show the dramatic mirror symmetry of seafloor spreading, confirming this essential spreading process, but also can be used to measure spreading speed and direction, as we did with hotspots. How? We have to first find the center of symmetry. This is the center of the ridge. Now we start at the center, where we know the rocks to be the youngest, newest rocks, and as we move outwards from the center, we can correlate each anomaly boundary with the known dates for when earth's magnetic field has switched. For example, in this image we see that the most recent flip happened about 700,000 years ago. Before that there was one 900,000 years ago, and another 1.2 million years ago. So back to our anomalies, we can say that rocks along this line must be 700,000 years old, and this one, 900,000 years old, and this one 1.2 million years old, and so on. In fact, we can continue this all the way out to the edges of the oceans and ultimately create an image like this one that shows the age of every rock on the bottom of the seafloor even though only 1% of the ocean floor has ever actually been sampled. What an incredibly powerful tool for making indirect measurements and gathering extremely useful information in a most economical way!

So back to measuring speed and direction. Let's use this normal polarity reading that represents 7 million-year-old rock. Where was this rock when it formed? Here at the spreading center. So what's the direction of plate motion? Away. And how fast on average has it been spreading? If 560 kilometers separates the rock from its origin, then it has travelled 560 kilometers in 7 million years. That's 80 km/my or 8 cm/yr. We call that a half-spreading rate, by the way, because it represents how fast one half of the rift is spreading or how fast the western side is moving away from the center. If we want to know the full spreading rate and how fast both sides are moving away from each other, the distance is doubled, and we get 16 cm/year.

Pause now.

For more information and more detail, continue on to the next video in the series.

<u>**Plate Tectonics Video Series:**</u>
Part I: Earth's Layers and Isostasy
Part II: Plate Tectonics Basics
Part III: Plate Tectonics Global Impacts
Part IV: Plate Tectonics and Calif. Geology
Part V: Hotspots
Part VI: Paleomagnetism
Part VII: Hydrothermal Vents

Paleomagnetism
Produced by Katryn Wiese
City College of San Francisco

All media produced by Katryn Wiese unless indicated below:
**Intro and exit music: used with permission © Alexis Harte*
**Review music: used with permission © Proceed With Caution*
**Geomagnetic Timescale – Late Cenozoic – Public Domain*
**Earth's Magnetic Field as a bar magnet – CC BY-SA 3.0 Attribution: Geek3*
**Earth's magnetic field Dynamo. Image from Smithsonian National Museum of Natural History*
**Solenoid CC BY SA 3.0 Attribution: svjo*
**Reef shark – © Kirk Hargreaves (used with permission)*
**Solar Winds and Magnetosphere – NASA*
**Aurora Borealis – Northern Lights above Bear Lake, Alaska – Public Domain – Attribution: Air Force Staff Sgt. Joshua Strang*
**Volcano cross-section – USGS*

** Magnetic Anomalies on Seafloor Image from Kenneth R. Lang's book The Cambridge Guide to the Solar System, Second Edition 2011.*
**Spreading Center with Anomalies (oblique view across transform) – USGS*
**World Isochron Map – NOAA*
**Magnetic Anomalies Map of Juan de Fuca Ridge – Vine 1968*