RELATIVE DATING – Tutorial Script

Wherever rocks are exposed at Earth's surface, they have a story to tell. Each rock layer is like a book in a library telling us the story of the geologic history. The ways in which the rock layers are arranged relative to each other tell us the sequence of events that occurred in a particular location – what happened first in our story and what happened last. A geologic event can be any natural occurrence involving geological materials, including deposition, erosion, tilting, folding, faulting, intrusion of magmas, metamorphism, and others. Sedimentary rocks represent events of deposition. A sandstone records an event of sand deposition, either on a shallow continental shelf, beach, or as sand dunes in the desert. Igneous rocks represent volcanic episodes occurring in an area, which means either subduction zone volcanism, divergent plate boundary volcanism, or hotspot volcanism. Metamorphic rocks record the area being subjected to high temperature and/or pressures, either from a nearby magma chamber, subduction zone, deep burial, or collision of plates. Once we piece together a geologic record of past events or **stratigraphy**, we can tell the story of an area's geologic past.

We determine the order of events through a combination of two different processes: relative dating and numeric dating. **Relative dating** simply describes which events happened before or after another. For example, in an undisturbed pile of sedimentary layers, according to **the Principle of Superposition**, the layers on the bottom will be older than those that deposited on top. A similar process happens with your recycling of newspapers – the oldest newspaper, the one you first threw away, would be on the bottom, the most recent on, on the top. **Numeric dating** applies a variety of techniques to determine a numeric age for a particular rock layer, like 2.3 million years +/- 100,000 years. Numeric ages, as you see, have associated errors and can be determined only for rocks that contain the right ingredients. Turns out, most rocks do not have these right ingredients, and only some of them can have numeric ages associated with them. The most common form of numeric dating is **radiometric dating**, which uses naturally radioactive elements trapped in rocks to calculate the dates of formation. For more information, watch the video tutorial on radiometric dating. Other types of numeric dating processes include lichenometry (studying the time of which it takes for lichen species to grow on a surface of a rock in a particular area) or counting tree rings. For the rest of this video tutorial, we will focus on relative dating.

To read the rocks and their relative order, to piece together the geologic history of an area, we need to gather as much information as possible, which is helped when we can view it in cross section, like viewing a slice of cake edge on. Outcrops at highway excavations, railroad cuts, stream valleys, and cliffs all provide good cross sections of Earth's crust and good libraries filled with information for geologists to interpret.

The process of relative dating begins with determining which rocks or events in an area are the oldest. Then each successive event that occurred after that is placed in sequence relative to the others to build a stratigraphy. **The Principle of Original Horizontality** describes the general tendency for sediments or lava flows to be deposited or erupted in horizontal layers. **The Principle of Superposition**, as already discussed, states that the lowest sedimentary rocks in an undisturbed sequence were deposited first and therefore are oldest. If later we see tilted or folded sedimentary strata or lavas, we know that after the original rocks were deposited, there was a tectonic event that deformed the layers.

The Principle of Cross-Cutting Relationships describes how certain geologic events (such as folding, faulting, magma intrusion, and erosion) are younger than the rocks they alter. For example, igneous intrusions are younger than the crustal rock into which they intrude, and faults are younger than the strata they fracture. It is often possible to determine the relative ages of several mutually cross-cutting intrusions and faults.

Inclusions are pieces of one rock that you find in another rock. Included rocks must be older than the rocks in which they are found. For example, a cliff face of granite will weather. Pieces of the weathered granite will make their way into beach sands. The sandstone that forms from these beach sands must be younger than the granite pieces within.

Let's look more closely at the **contacts** between rock layers. What do they represent? Usually these are **conformable** – meaning that rocks on both sides of the contact formed at about the same time, but in between the environment changed. For example, a mudstone might represent muds depositing in a lagoon, but eventually nearby sand dunes migrate and cover up the lagoon, so sands will deposit on top of the muds through a shift in the environmental conditions. An **unconformity** is a contact between two layers that represents a pause in deposition in an area or when an area has been uplifted and eroded.

How can we tell which kind of contact we're looking at? Conformable or unconformable? When we look carefully at the contact, if we see evidence of erosion, such as an irregular surface, excavation, or inclusions of the rocks below the contact into the rocks above the contact, we know there was erosion at work before the layer above was deposited.

We can further divide unconformities by their type to provide us with more information about the events that took place in a particular area.

Disconformities are unconformities between parallel strata or lava flows. Usually the contact is irregular and pieces of the underlying rock are included in the strata above. These unconformities indicate erosion (or a small period of time with no deposition), but no tectonic transformation and no excavation to deeply buried rocks.

Angular unconformities are unconformities where the parallel sedimentary layers (or lava flows) above the contact are at an angle to the parallel sedimentary layers (or lava flows) below. To see an angular unconformity in an area means the area was subjected to tectonic activity that caused folding or tilting before erosion and renewed deposition.

Nonconformities are unconformities with intrusive igneous rock or metamorphic rock below and parallel sedimentary rock layers (or lava flows) above. The layers on top, which would have formed originally on Earth's surface, sit atop uplifted and eroded igneous or metamorphic rock that formed originally at depth. That means those deep rocks were exposed at one point on the surface. To bring deep rocks to the surface requires significant uplift and erosion and the loss of many layers of rock – many missing books in our geologic history.

The Principle of Original Lateral Continuity describes the tendency for lava flows and sedimentary beds to extend laterally in all directions until they thin to nothing or reach the edge of the depositional basin. In other words, they don't simply disappear. So if we have an unconformity in our local stratigraphy, and one or a number of rock layers have been eroded, we can look around to surrounding areas. If we can correlate the layers above and below the unconformity with those same layers elsewhere – we can use the intervening rocks in the surrounding area to fill in the gaps that might exist in our local story. We call that process **correlation**.

Let's practice these principles by building a stratigraphy for a cross-section through the Grand Canyon. If you were to hike down into the Grand Canyon, here's the top where you would start, and here's the base where the Colorado River runs. Where is the oldest rock? The ones that appear closest to the bottom are O, a schist, and N, a Granite. We know that granites intrude into existing rocks, so unless that granite has signs of being exposed at the surface and eroding, the schist likely happened first. Also, schists form during high grade metamorphism. And if the granite had been inside the schist before or as it was metamorphosing, the granite would have also turned into a schist. So all those clues plus the shape of the intruding granite tell us that the schist was there first and is thus the oldest, followed by intrusion of the granite. We now have the first two events at the base of our stratigraphy determined.

What next? We see a contact that looks irregular between the schist and granite and the Bass Limestone (M), which sits above. Based on the irregularity of the surface and the fact that granites and schist form deep underground while limestones form on the surface, we can label this contact as a nonconformity, meaning many layers existed above the schist and granite when they formed, but they've since been removed through erosion. Therefore, we have erosion happening potentially over many millions of years and then after the erosion stops (likely because the area has been eroded flat), deposition resumes, and M is laid down followed by L, K, and J. The contact between J and the rocks above, I, is also irregular, indicating erosion. Furthermore, the rocks below the contact are an angle to the ones above. Here is when we see evidence of a tectonic event that tilted the rocks, after which, the area was eroded flat, and deposition began again with I. So between J and I, we have an angular unconformity. After I was laid down, H was laid down, followed by G, then between G and F, we see an irregular eroded surface, which is a disconformity, as there's no tilting happening prior to erosion, and the rocks immediately below the surface aren't deep metamorphic or plutonic igneous rocks. After the erosional event, F is laid down and then again a disconformity appears. That means we don't know how many other rocks had been laid down after G and before F or after F and before the rock above. These are gaps in our story. After the erosion to F, deposition resumes and we see bed E laid down, followed by D, C, B, and A. We don't know how many more rocks were laid down after A, because the area is currently experiencing erosion by the Colorado River, and the top of A is an eroded surface. This vertical timeline with oldest on the bottom and youngest on the top is our complete stratigraphy. Gaps in our story exist everywhere there's an unconformity. How much of a gap? To determine that, we could try to correlate with surrounding geology, which it turns out is possible with the nearby Bryce Canyon and Zion National Parks. We could also conduct numeric dating on the rocks above and below if they contained the right ingredients for radiometric dating. Or we can use fossils.

Fossils are direct or indirect evidence that a particular organism lived in an area at the time a rock was formed. Direct evidence would be shells, bones, fossilized dung (known as coprolites), whole organisms trapped in amber or tar, or molds or casts of the organism. Sometimes organisms like leaves will leave a carbon film on the surface of rocks after they've been buried and broken down. Sometimes the original buried shells will be replaced by minerals. In all these cases, the evidence we find is some part or all of the organism's body. Indirect fossil evidence includes footprints, burrows, teeth marks, nests, and stomach rocks (known as gastroliths), evidence that an organism was in the area, but very little about its structural shape. To form any of these fossils, we first have to rapidly bury the dead organism or its indirect mark and thus preserve it in rock layers at depth.

Paleontologists study the evolution of Earth's life through the study of fossils. They have collectively created the Geologic Time Scale, which breaks Earth history into particular eons, eras, and periods, each given its own name based on rocks studied from that period somewhere on the planet. According to this time scale, the first 4 billion years of Earth's history is collectively known as the Precambrian. Why that date for the boundary? The oldest fossil evidence we have of organisms that have hard parts. After hard parts were developed by living organisms, it was easier to preserve them as fossils when they died, therefore, much more fossil evidence available to differentiate different events and environments in Earth history, especially extinction events. Paleozoic (old), Mesozoic (middle), and Cenozoic (recent) are each separated by major extinction events on the planet – the largest of which happened at the end of the Paleozoic, 252 million years ago – known as the Permian extinction. What caused this extinction? Likely the eruption of a new hotspot and the pouring out of the Siberian Traps flood basalts. The end of the Mesozoic is 65 Ma, also known as the Cretaceous Tertiary boundary (or K-T boundary). It corresponds to another major extinction event, this one involving the extinction of all Dinosaur species. The cause of that extinction was likely the eruption of the Deccan Traps flood basalt province combined with a large asteroid hit.

The principle of faunal succession describes how flora and fauna succeed each other in a reliable order based on evolution and extinction. We can use fossils of these organisms, therefore, to assist with relative dating, and in particular to help us determine the extent of gaps for unconformities. Fossils of organisms that lived for very short periods of time across a wide habitat geographically are called index fossils. We can use them to better narrow the possible ages of a rock and to correlate rocks from one part of the world with those of another. The genus *Olenellus* is a great example of an index fossil as these marine organisms lived across the world ocean between 510 and 522 million years ago. Stromatolites, on the other hand, are marine organisms that have existed on planet Earth for the last 3.5 billion years. What do we know if we find a fossil stromatolite in a rock? That its age is between today and 3.5 billion years old. Not so useful in terms of relative dating. However, fossils also help us identify past environments and climate. Finding stromatolite fossils in a rock tells us that the environment where the rock was produced was warm and dry and in a salty coastal ocean. Foraminifera shell fossils in ocean sediments can be used to determine the temperatures of oceans as different species are adapted to different temperatures. Fossils in a sandstone can help us differentiate between sand dunes found behind a beach and those found in a desert.

For more information on Earth history and the evolution of life on Earth, continue on to the Earth Formation series of video tutorials.

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