Relative Time

Part 3 -- Development of the Geologic Time Scale
What to Look For:

- James Hutton (1788) showed that “Primary” rocks can be seen to cross-cut “Secondary” ones, making the idea of a time scale based on rock type a non-starter. This left geology without a way to “tell time” for ~30 years.
- William Smith (1815) (and also Georges Cuvier, who never published) discovered that fossil species (and higher groups) occur in a predictable and invariable superpositional sequence. They called this “faunal succession” but it is now called *fossil succession* because it works for non-animal fossils too.
- Sedgwick and Murchison, in many papers during the 1830’s and 40’s, attempted successfully to use fossil succession to subdivide what we now call early Paleozoic rocks into discrete packages and then correlate them globally. Their “Systems” represent the Periods on the modern time scale.
- Subsequent workers have completely subdivided all of the rock record into Systems and therefore all of geologic time into Periods.
- It has also become clear that this can be done hierarchically – Systems can be lumped into larger units or subdivided into smaller ones. The other way of looking at it is that Periods can be lumped into units of longer duration or subdivided into shorter ones for correlation.
- How precisely we want to “tell time” dictates how precisely we have to be able to identify fossils.
Remember that the first stab at a geologic time scale was based on superposition and was a miserable flop. We will now figure out part of why it was a flop.

<table>
<thead>
<tr>
<th>Period</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>Unlithified loose sediment of streams, lakes, beaches, and glaciers.</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Somewhat lithified sedimentary rocks made of the same material as the Quaternary rocks.</td>
</tr>
<tr>
<td>Secondary</td>
<td>Very well lithified and structurally complex sedimentary rocks. Still obviously made of the same material as the Quaternary rocks.</td>
</tr>
<tr>
<td>Primary</td>
<td>Crystalline (what we now call igneous and metamorphic) rocks. Usually compositionally quite different from Quaternary rocks.</td>
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Even if this had worked it would not have made for a very interesting time scale. With something as complicated as the entire history of a planet you want a little more than when it started and where it stands now. You want intermediate dates too. You want to know what was happening over there when this was happening over here, and how far back toward the beginning was that, anyway?

It’s tempting to say that this “time scale” was better than nothing, but actually, it wasn’t. If your context for thinking about history is wrong then your history will be wrong too, and wrong is not better than ignorant -- unless it’s a step on the road to right, and then only if you intend to follow it.
We’ll be talking a lot about James Hutton. He was the son of a modestly well-to-do Scottish farmer. He went to school in Edinburgh and studied chemistry, then discovered and patented a chemical process that sold like crazy and made him wealthy. He decided to retire and farm his land after his father died.

In the operation of the farm he noticed that erosion annually removed some of his soil and washed it down to sea. Being inherently curious he wondered how long that had been going on, and how much longer it could continue before he wouldn’t have any soil left to farm. We will come back and see what he made of that question in due time, but for now let’s say that he became interested in time and let it go at that.

Hutton reasoned that God would not have created a world on which humans could not live, but he inferred, quite rightly, as he was to demonstrate, that the twin processes of soil formation and its removal by erosion would eventually lower all of Scotland (indeed, all the dry Earth) to below sea level. Obviously at that time farming would no longer be possible and people would starve.
For Hutton the solution was simple. God must have made a way to rejuvenate the land – to raise it up when it gets too low so it would not ever wear completely down.

He therefore set out to do two things:

1) To discover evidence that parts of the Earth have been uplifted in the past, and

2) To identify a natural mechanism for making it happen. (Remember that the late 1700’s was the heyday of the Deists – those who thought that God acts through natural law. Thomas Jefferson is the most famous one, but Hutton was another.)

Hutton succeeded in his first goal better than he ever imagined. He didn’t do nearly as well on the second, though what he did postulate about the topic pointed later geologists to the solutions of a lot of geological problems. This is what we will explore next. His work was published and popularized in the late 1780’s.
Hutton thought that the internal heat of the Earth would be able to buoy up certain parts of the crust and cause them to rise. With this in mind he went looking for evidence of great internal heat. Because Arduino’s “Primary” rocks looked in some cases like what was known to erupt from volcanoes, Hutton focused on these primary rocks and their origin. At a friend’s summer home in Glen Tilt, Scotland he found what he was looking for. Here the “Primary” rocks could be seen intruding the secondary. This necessarily meant (according to Steno’s logical arguments) that they were liquid when they intruded. They were not sedimentary rocks, as Werner thought, but igneous – crystallized from a molten state!
It wasn’t just the dikes that were igneous. The entire mass of granite was one continuous body, therefore it must all have the same origin. Just as the dikes intruded the beds of the “Secondary”, the stock or batholith below must also have intruded beneath it. Therefore the contact between them is **not** a sedimentary contact (nonconformity), and the principle of superposition does not apply! Probably you have already seen where this leads: if Steno’s principle of superposition doesn’t apply, what does? The answer was right in front of him – Steno’s principle of cross-cutting. Applying this principle reveals that Arduino (and Lehmann and Werner) had it exactly backwards – the “Primary” rocks here are **younger** than the secondary, not older. Their time scale **does not work!**
So, one of the contributions that Hutton made (in 1788) to the study of time was to prove wrong the hypothetical subdivisions of time that Arduino and Lehmann had postulated and that Werner and his students had spread all over the western world.

Some scholars (who had a lot of their lives tied up in work based on the time scale) were understandably not very happy about this, but most serious scholars (including some of those that now had to re-think their life’s work) were glad, at least, not to be working with a bad premise any longer.

Of course knowing how not to tell time is not the same as knowing how to tell it, so it was not clear where to go next, and it would not be clear until 1815.

Hutton further wrecked this time scale in a different way, but we will cover that in the “Deep Time” slide show.
In 1815, after much hardship, William Smith published the map at right. The original now has a prominent place in the displays of the Natural History Museum in London.

All earlier “geologic” maps had really been resource maps, plotting only lithology, and usually only those rocks of particular economic importance to their creators.

Smith’s map was not based on rock type, but rather on the fossil content of the various units. Regardless of lithology, if a rock contained certain groups of species of fossils, it was colored the same as every other rock with those species. For example, the rocks shown in pinkish red (now called Devonian) are limestone in the west and south and reddish sandstone in the midlands and north (Old Red Sandstone). They are correlated on the map because they have the same fossils, not because their lithology matches.

This was the first geologic map on which geology could be seen – specifically, geologic structures.
For example, if we zoom in on the southeastern corner of the map we clearly see the map pattern expected of broad folds – anticlines and synclines. From North to south these are the Weald Syncline, an anticline whose name I do not know, and the Hampshire Basin Syncline.

It is also evident to the north of these that the strata strike north-northeastward (and dip south-southeastward, into the Weald).

Smith’s map was the first ever to reveal such structure.
A current geologic map of Great Britain retains much of the pattern that Smith originally inferred, though it is not an exact match.

The “packages” of fossils that Smith used for his correlations are not the same as the modern ones we use to delineate the various units of geologic time, and, of course, he used different colors for the same strata.

The modern map is also based on quite a lot more detailed observation by many people, and so adds quite a bit of detail.

Still, for a one-person effort over such a huge region, Smith did an admirable job.
Wales (the area enlarged at right) is where Smith’s great discovery was first put to use in making a time scale.

Though the geology is much more complex than the few dips imply, they do catch the general trend. The rocks to the north dip beneath those to the south. They are dominated by hard sandstones or quartzites, shales and even slates, which were called “The Greywacke” by some folks and “The Schistus” by others (though they are not schist). They have been badly deformed and metamorphosed by tectonism (twice).

Adam Sedgwick set out to study the rocks in northern Wales (“Cambria”, as the Romans called it) along with Roderick Murchison, who simultaneously studied those farther south in Roman “Siluria”.
“Sedgewick’s rocks” were the hard sandstones and slates of the highest parts of the Cambrian Mountains, and contain only few fossils. They are hard to extract for study. Given his location, he began calling them the “Cambrian System” of rocks.

“Murchison’s rocks” were the more fossiliferous shales and slates of central Wales, and he had more of fossils to work with. As with Sedgewick, he began calling his rocks the “Silurian System”.

It is difficult to underestimate the task these two had set for themselves. William Smith had shown that he could use fossils to subdivide the rocks above a certain layer, called the “Carboniferous” because it was the coal-bearing strata of Britain (and the mainland, and, as it turns out, eastern North America).

The Carboniferous was easy to recognize because of the coal and the abundance of fossils of land plants and animals associated with it. Beneath it lay another “formation” called the “Old Red Sandstone” (because it was the lower of two distinctively hematite-rich sandstones.) The Old Red had few fossils in it, and these only fragmentary fish bones. The scarce fish and other evidence such as ripple marks like those seen in streams indicated that it was a terrestrial and not a marine deposit.

The Old Red also occurs in Wales, and is, in fact, the most distinctive and easiest to map rock in the entire country. What Sedgewick and Murchison set out to do was to work out the correct sequence of rocks beneath the Old Red Sandstone, which Smith had not seen. (They do not occur in England proper and Smith did not work in Scotland, where they do occur). They also, of course, wanted to see if they could establish a sensible set of subdivisions that would encompass all the rocks of Britain and that would correlate to other parts of the world as well – to test, if you will, the idea that the organisms had lived during particular discrete periods of time. If so, they would form the perfect basis for a real time scale to replace the one Hutton had forced them to discard.
After the first field season it was clear that Murchison could easily define a package of rocks (what we would now call an **assemblage zone**) based on “his” abundant fossils, but it was not clear at all that Sedgwick could. Furthermore, it looked as though there would be some overlap, making that problem even worse. Several more field seasons with the two working together failed to make any noticeable progress. This diagram (with letters representing individual fossil species and lines representing the collections from individual localities) illustrates the problem.

(Notice that species D and E are under debate — both men claim that they are part of their assemblage.)
The issues the two were working on might never have been settled had not a separate issue arisen. Many (including Murchison) had postulated that no coal should ever appear below the Carboniferous. This hypothesis badly needed testing because it would focus the search for additional coal deposits in places where they should occur rather than those where they should not. To this end the British Government had agreed to appoint and pay a geologist (Henry de la Beche) to map around the Old Red Sandstone in southernmost Wales and see if he could find any lower coal measures.

After a very short time he reported finding some minor coal deposits “in the greywacke”. Murchison doubted this very much, and he and Sedgewick went to the region to see what light they could shed on the matter. They came away convinced that de la Beche had misinterpreted a tightly folded syncline as an anticline and that his “greywacke” was just a badly deformed Carboniferous rock.

They both set their positions in stone and would not budge – Murchison claiming that there were no pre-Carboniferous coals, de la Beche that there was at least one “greywacke-aged” coal. For several years they carried on an increasingly bitter feud, until two things happened to show the way to the correct resolution of the problem.
First, a very good paleontologist named Phillips found some unusually good fossils in the rocks under debate and concluded that they were not really Carboniferous species and also not really Silurian species either. (By this time Murchison’s Silurian was beginning to be adopted as a valid package, though the Cambrian was not). Instead, Philips proposed that they were somehow intermediate between the two systems. He suggested that there might be an additional system of rocks and that the combatants should test his hypothesis.

Second, Murchison and Sedgewick realized that more mapping in the highly complex rocks of Wales was never going to solve the argument, and so they sought and got permission from the German government to study the pre-Carboniferous rocks in the region of the German coal fields. The structural complexity there is much less problematic than in Britain.

In the first field season it became clear (to Murchison – Sedgewick stayed in Britain) that there was a recognizable “Silurian” fauna there, but he still considered it to go right up to the Carboniferous. It was on a second visit, with both men present, that they finally realized that there was, in fact, another distinctive assemblage of fossils between the Silurian and Carboniferous. These rocks, they also realized, had the same terrestrial fossils in them as Phillips’s locality and the same fish as in the Old Red Sandstone, and the same marine fossils as some as yet poorly studied rocks in the Devon peninsula that Smith had correlated with the Old Red based solely on superposition.
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These rocks, they realized, had the same terrestrial fossils in them as Phillips’s locality and the same fish as in the Old Red sandstone, and the same marine fossils as some as yet poorly studied rocks in the peninsula south of Wales (which includes the county of Devonshire) Smith had correlated these with the Old Red Sandstone based solely on superposition).

Murchison quickly wrote a paper proposing the Devonian System, defined by the marine fossils of Devon and the terrestrial ones of Wales and the Old Red.

Within a matter of weeks the debate was considered settled by almost everyone, including the two parties most involved in the argument.

It should be pointed out that both sides had to give up some of their cherished beliefs in this compromise. de la Beche had to admit that he had misunderstood the fold that led him to consider the rocks “greywacke” and Murchison had to admit that there are, in fact, pre-Carboniferous coals in the world, in rocks that look like greywacke.
Sedgewick and Murchison now returned to their original project. Murchison strutted around with the cockiness that went with demonstrating that “his” Silurian System could be applied on the mainland as well as in Britain.

Simply because “his” rocks had more fossils, Murchison almost completely subsumed Sedgwick’s Cambrian into his Silurian, which, of course, would have defeated the purpose of a time scale that aspired to subdividing time. The two began to fight as earnestly as Murchison and de la Beche had done. (As you might have guessed by now, Murchison was a rather hot-headed bully!)

Eventually, tiring of the continued debate, the Geological Society commissioned Lapworth to re-map the area and settle the matter.
Lapworth worked back through all of the areas Sedgwick and Murchison had mapped, but his approach was somewhat different. Instead of simply recording which species *assemblages* occurred at which places, he paid attention to the positions of each species in those places. In other words he looked at *simple zones* instead. Then using a comparatively small subset of the fossils he could get a much better picture than his predecessors about how the fossils were distributed in time as well as space. He looked for places within the section where there were an unusually large number of LADs and/or FADs. See if you can spot any likely boundaries.
What he found was that there is not one big “Silurian” assemblage, but a sensible way of subdividing the fossils. Furthermore, there is not one clear natural break (between the Cambrian and Silurian, as Sedgewick and Murchison were trying to find), but two! This means there are not two, but rather three identifiable systems in Wales. Lapworth proposed recognition of Sedgewick’s Cambrian System at the base, Murchison’s Silurian System at the top, and his own Ordovician System between. (The Romans called the Celtic tribe that had lived in the relevant part of Wales the “Ordovici”). This solution was adopted by the Geological Society.
I can’t help pointing out two ironies in Lapworth’s solution. The first is that all of the Ordovician rocks were carved out of “Murchison’s” system, and there was nothing he could say about it.

To add insult to injury, Lapworth’s fossils demonstrated that the remaining Silurian was not one continuous package of strata. Reverse faults had cut it twice, producing three repeated sections of the same rocks stacked one atop the other. Once it was known where to look, the faults were obvious. The diagram shows the idea. (Shales are notoriously prone to faulting and it is still very hard to find the faults in shale.)

The result was that Murchison’s Silurian ended up being the smallest of the three packages – poetic justice for having been so grabby, maybe!
Most of the rest of the time scale was assembled outside Great Britain.
Because Smith had not characterized the entire faunas of the post-Carboniferous rocks in Britain, but had only identified a few “index” fossils, people finished out the systems from nicely fossiliferous rocks on the continent, as shown on the diagram.

1) As we've seen, the earliest part of the modern time scale was assembled in western Britain.

2) Perm Basin of eastern Russia

3) The Trias of Germany

4) Jura Mountains of France and Switzerland


Underlie
So let’s make sure we understand the structure of the time scale to this point.

First, it is not a true time scale (or geochronologic scale) because there is no actual or absolute time associated with it. It was assumed by the people who assembled it that each successive fauna lived during a specific time and then disappeared, to be replaced by the next fauna. As you can imagine, how this happened was of considerable interest.

Instead it is a chronostratigraphic or “time-rock” scale. The units (Cambrian and so on) are rock units that record the time that their faunas lived, but are not time themselves. They are called “systems” of rock.

The order in which they occur on the scale is superpositional, but it is not rocks that are superposed (as in Arduino’s scale) but fossil faunas – the fossils characteristic of the Ordovician are always beneath those of the Cambrian in a section of rocks that contains both, for example.

The modern scale has some differences from the one of the early 19th century. The Arduinian terms “Tertiary” is not used “Quaternary” is only used by some people in a sense different from its original. The Precambrian is not a formal part of the scale (though it is still used informally – we will look into the proper divisions of it later in the term), and the proper international terms for Carboniferous are now Mississippian and Pennsylvanian.
As people back-correlated the Continental European systems (from Permian on) back to Smith’s original English subdivisions, and as the systems were used successfully to correlate North American rocks to the European ones, and as it became clearer and clearer that this was truly a way to establish subdivisions of geologic time on a global scale people became more comfortable using it.

Bright people who comfortable with an idea are likely to play with it – to devise new ways of testing or of applying it, and late 19th century geologists were no exception. It soon became apparent that the same idea could be applied at different scales – that systems could be lumped and subdivided by paying closer attention to what general types (on the one hand) or which more specific types (on the other) of fossils are present.

For example, several of the lower systems (above the Precambrian) have a kind of fossil called a “trilobite” in them. Each system has its own kinds of trilobites, but they all have some. This ends with the Permian. Above that level not a scrap of a trilobite was to be found, and still has not, despite many man-centuries of looking.
Contains fossils of things very similar to, and in many cases identical with, living organisms – it has, in other words, a “perfect” or “complete” set of animals (and plants, and so on).

Contains many familiar-looking organisms but also some oddities like abundant ** ammonoid cephalopods ** or ** rudistid clams **. It is a mixture of “modern” and “primitive” forms, in other words.

Contains very few or no familiar organisms. The most noticeable are truly strange – ** trilobites **, for example. There is no close living relative of a trilobite (though larval horseshoe crabs are pretty similar). Even things that look somewhat familiar (like ferns and some of their relatives) are odd in some way, for example, their size. Ferns are routinely tree-sized in the upper Paleozoic systems.

As originally defined this system had no fossils – it was in other words “pre-life”. That is not literally true, but the fossils are of little to no help in subdividing this huge stack of rocks.
The systems with the familiar or “completely modern” fossils are the “perfect” (*kainos* or *ceano*) “animals” (*zoos*). (These are Greek roots).

The rocks with the mix of modern and odd organisms are the “middle” (*meso*) animals (*zoos*) rocks.

Because they are superpositionally the lowest organisms these are necessarily the oldest or most ancient (*palaios*) animals (*zoos*).

To repeat, this was thought to be “pre-life”.

<table>
<thead>
<tr>
<th>Paleozoic</th>
<th>Neogene (Ng)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Paleogene (Pg)</td>
</tr>
<tr>
<td></td>
<td>Cretaceous (K)</td>
</tr>
<tr>
<td></td>
<td>Jurassic (J)</td>
</tr>
<tr>
<td></td>
<td>Triassic (T&lt;sub&gt;k&lt;/sub&gt;)</td>
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<tr>
<td></td>
<td>Permian (P)</td>
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<tr>
<td></td>
<td>Pennsylvanian (P&lt;sub&gt;i&lt;/sub&gt;)</td>
</tr>
<tr>
<td></td>
<td>Mississippian (M)</td>
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<tr>
<td></td>
<td>Devonian (D)</td>
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<tr>
<td></td>
<td>Silurian (S)</td>
</tr>
<tr>
<td></td>
<td>Ordovician (O)</td>
</tr>
<tr>
<td></td>
<td>Cambrian (C)</td>
</tr>
<tr>
<td></td>
<td>“Precambrian” (pC)</td>
</tr>
</tbody>
</table>
As we will see, the observation that life becomes progressively more odd as you proceed down this stack (toward older rocks) was important even early in the process of assembling the time scale. (We should rightly view it as life becoming more familiar as you proceed up the stack, since that is the direction time actually runs.)

Murchison, for example, argued that land plants only arose in the Carboniferous and therefore coal (modified plant remains) could not exist in rocks below that level. (It turns out there were land plants in the Devonian as well, and perhaps very small, primitive ones in the Silurian). J.B. Lamarck, in France, even proposed an evolutionary explanation for it.

It became even more important in the latter half of the 19th century after a young Turk named Darwin watched the Devonian controversy unfold at the Geological Society meetings in the 1830’s.
Those coarser subdivisions of time (or, more properly, agglomerations of systems) are called “Erathems”. The root of the “Era” part of the name should be obvious – these are the rocks presumably deposited during some Era. The “them” ending simply reminds us that we are talking about rocks and not time itself.

Finally, different as the fossils are in all the Erathems they are all still fossils, which were originally thought to be absent from the “Precambrian”. Thus it seemed reasonable to go through one more lumping process and create the Phanerozoic Eonathem (rocks of that Eon) and (originally) the Precambrian Eonathem. (We will examine the modern treatment of the Precambrian later in the term).

Incidently the “Phanero” root is the same as for a phaneritic rock – visible or obvious fossils in this case.
Even though this scale is, in the way we are using it right now, a chronostratigraphic scale, it is only a matter of a simple tweak to make it a true time (geochronologic) scale once you can add numerical ages.

Indeed, the people who originally assembled it were thinking about it as a time scale even as they created it. The Devonian System of rocks, for example, was all that rock deposited during a specific interval of time, when the typical fossils were alive. This they called a “Period”, specifically the Devonian Period.

Similarly, an Era was that time interval during which a specific Erathem of rocks was formed, and an Eon when an Eonathem formed. The same idea applies as we proceed in the other direction.
The same idea was taken in the opposite direction as well. Smith’s original packages of rock turned out to be smaller subdivisions of the Permian to Paleogene Systems, correlative with subdivisions on the continent – in the Jura, for example. Soon all the Systems had been subdivided into several “Series” each. The ones you are responsible for knowing are included here, but be aware that the rest of the chronostratigraphic scale has them as well. A Series was deposited during an Epoch.

Further work recognized even finer subdivisions that were called “Stages” (deposited during an “Age”), and even these can generally be subdivided into “zones”, though the correlations of those finest divisions are not usually applicable on a global scale and they are not technically part of the chronostratigraphic scale. No stage or zone names are given on the diagram, but you should know that they do exist.
There is therefore a hierarchy of nested chronostratigraphic units and an identical hierarchy of the time units that correspond to them. We keep them separate because one (the rocks) is the evidence for the other (the time units) – one is tangible and the other must be inferred. The farther down this scale you go the more precisely you are “telling time”.

Eonathem ----------- (deposited during) ----------- Eon

Erathem ------------------------ Era

System ------------------------ Period

Series ------------------------ Epoch

Stage ------------------------ Age

[Zone ------------------------ Range]

(not really part of the hierarchy)
I want to leave this topic with one last observation. There is another hierarchical natural structure that we will soon encounter, and this is the hierarchical classification of living organisms.

Though there is not a one-to-one correspondence between the two things there is a close relationship. The Eons (big chunks of time) we have examined were initially differentiated by whether there was evidence for life or not. Zones are invariably recognized by individual species of fossils. In between, in general, the time resolution you can achieve is directly tied to how precisely you can identify the fossils you see.

You will soon learn to recognize a few Phyla and Classes and an Order or two, and these will allow you to determine from which Erathem those fossils were collected. In a couple of cases I’ll show you how going one step further would let you determine the System. If you wanted to do Series or Stages you’d have to learn the fossils to Family or better, and we will not go there in this class. **BUT WE COULD** and I want to be sure you realize that. I almost always work with species because 1) I have the time to learn them, and 2) I need to resolve time as tightly as I can – hundreds of thousands of years or better. You will have to be satisfied with hundreds of millions (Erathems worth).
Short Version:

• James Hutton (1788) showed that “Primary” rocks can be seen to cross-cut “Secondary” ones, making the idea of a time scale based on rock type a non-starter. This left geology without a way to “tell time” for ~30 years.

• William Smith (1815) (and also Georges Cuvier, who never published) discovered that fossil species (and higher groups) occur in a predictable and invariable superpositional sequence. They called this “faunal succession” but it is now called fossil succession because it works for non-animal fossils too.

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