HISTORY OF STRATIGRAPHY AND THE AGE OF THE EARTH AT THE END OF 18TH CENTURY AND 19TH CENTURY

The use of the history of geology to teach pupils about geological time

CYNTHIA V. BUREK
Environment Research Group
Chester College of Higher Education

Nobody can fail to be aware of the worldwide celebrations, which accompanied the start of the year 2000. Why did this date generate so much interest? Was it because of the Millennium Bug or was it the number 2000? It seems appropriate to consider 1000 years and how long that really represents in geological terms. Geology is the only science to deal in time as a currency. It is also the science which is least taught in school. So it seems appropriate to examine the history of the geological column - how it was developed, by whom and where and how the perception of the age of the Earth has changed with the centuries. This introduces students to the history of spatial and temporal awareness through history and how scientists have changed their theories with advancing knowledge, travel, fieldwork, and technological ideas. New ideas have arisen and new terminology.

INTRODUCTION.

Geology is one of the few sciences to study the fourth dimension. It is also the science which is least taught in school. Therefore the lecture starts by looking, literally, at how long geological time is i.e. the age of the earth. It is difficult to understand the length of time involved and therefore use is made of everyday analogies. Visual, audio and tactile senses are used to strengthen the awareness of this difficult concept. Secondly, the geological stratigraphic column is used to illustrate the history of how scientists debated the age of the earth and how that relative timescale can be used to put an age on earth materials. This introduces students to two concepts firstly the history of exploring geological time and secondly how human perception of nature's time has changed through history, by highlighting that there is a difference between age and time.

These topics will be further illustrated on the fieldtrip to the volcano Mount Teide.

Geological Time

There are 2 ways of looking at geological time - in a relative way and in an absolute way. Members of the audience will be used to illustrate this.

First interactive part

This will involve the audience.

1. Ask the audience to note on a piece of paper the oldest thing they own. Summarise this verbally.

2. Two people who are obviously different in age, are chosen and then the audience is asked to either write down why one is older or younger than the other and then to discuss with the person next to them or to share this with the whole audience. Ask the people first if they mind being guinea pigs!!

3. Secondly, ask the audience to decide how they would actually put figures to the age of the person. If possible, ask the 2 people how old they are or when they were born. They probably will not know the hour of their birth. So assume 12.00 - noon. Then ask the audience to work out in years, days and then hours how old they are. This brings in the concept of scale and relates directly to the hourglass or the alarm clock ticking.At the end of the lecture, you will ask the audience to add one to the age they have worked out.

Person 1 = age x 365(days in a year) + (difference in date in month born from today's date) x 24 (hours in a day. You may need to add more if it is not noon.) = a

Person 2 = age x 365 (days in a year) + (date in month born) x 24 (hours in a day) = b e.g. David is 25 and born on the 8th of the month. Today is 1st of the month and it is 12.00. So David is 25 x 365 + 7 days old x 24 for the hours = 219,168 hours old. This introduces the students to very large numbers but they feel an ownership as they can relate to it. At the end of the lecture add 1.

During the 19th century, geologists could only reconstruct a relative time scale. The actual age and duration since the Earth's birth in millions remained unknown until the dawn of the 20th century. Table 1 shows the main people involved in the story.

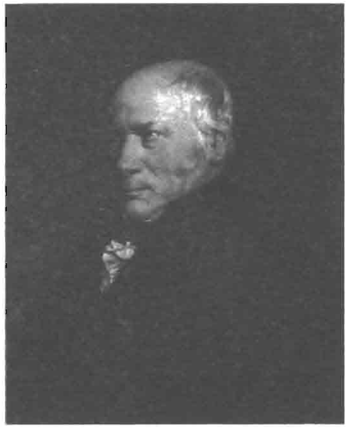
TABLE 1
LIST OF PRINCIPLE PLAYERS ON THE STAGE

Name	Dates	Nationality/place of work
LEONARDO DI VINCI	1452-1519	Italian/Apennines, N. Italy
ARCHBISHOP JAMES USSHER	1581-1656	Irish, age of the earth (bible)
ROBERT HOOKE	1635-1703	English/Faunal succession hints
NICHOLAUS (NEILS) STENO	1638-1687	Dane/Italy
G. ARDUINO	1714-1795	Italian/Venice
JAMES HUTTON	1726-1797	Scottish/Scotland
ALEXANDER VON HUMBOLDT	1769-1859	German
GEORGES CUVIER	1769-1832	French/Paris basin
WILLIAM SMITH	1769-1839	English/England
WILLIAM BUCKLAND	1784-1846	English
ADAM SEDGWICK	1785-1873	English/ England & North Wales
RODERICK MURCHISON	1792-1871	English/ South Wales
CHARLES LYELL	1797-1875	Scottish/England
LORD KELVIN (WILLIAM THOMSON)	1824-1907	Scottish
ARCHIBALD GEIKE	1835-1924	Scottish/Scotland
CHARLES LAPWORTH	1842-1920	English/Mid Wales
PIERRE CURIE	1859-1906	French/Paris
(LORD RAYLEIGH) ERNEST RUTHERFORD	1871-1937	English
ARTHUR HOLMES	1890-1965	English
JAMES CROLL	1921-1990	Scottish/Scotland

Relative time

The geological column

The development of the chronostratigraphic scale or the stratigraphic column is seen by some scientists as one of the most significant achievements in geology. Its development started during the age of heroism within geology - end of the 18th century. It fulfills the prime goal in geology by establishing the global standard for a timescale in which to put earth materials. Most of the divisions was developed over a period of 50 years in the first part of the 19th century. Most of the systems were established from the study of the stratigraphic record in Europe and were initially defined on the lithology or rock types alone. An example of this is the Triassic divided into 3 parts by Von Alberti in Germany in 1834. The development of the stratigraphic column was furthered by Murchison who in 1835 defined his Silurian system using fossils as evidence. Perhaps this helped Darwin further clarify his ideas. However it must be remembered that William Smith, the canal surveyor, had already published his geological map of Britain in 1815 and he had adopted a holistic approach based on all observations.



The stratigraphic column is now universally accepted across the world and the names of the individual time units are shown in Table 2.

TABLE 2
STRATIGRAPHIC COLUMN

1970Neogene	Néogène:	Neogeno:	1829 Desnoyers;
Quaternary	Quaternaire	Cuaternario	1833 Reboul (redefined)
Pleistocene	Pleistocéne	Pleisteceno	1833 Charles Lyell
Pliocene	Pliocéne	Plioceno	1833 Charles Lyell
Miocene	Miocéne	Mioceno	1833 Charles Lyell
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1970 Paleogene	Paléogène	Paleogen:	
Oligocene	Oligocéne	Oligoceno	1854 H. Von Beyrich
Eocene	Eocéne	Eoceno	1833 Charles Lyell
Palaeocene	Palaeocéne	Paleoceno	1874 W.P.Schimper
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Cretaceous	Crétacé	Cretàcico	1822 Omalius d'Holloy
Jurassic	Jurassique	Juràsico	1795 Alexander von Humboldt.
Triassic	Trias	Triàsico	1834 F. Von Alberti
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Permian	Permien	Pérmico	1841 Murchison
Carboniferous (Pennsylvanian Mississippian)	Carbonifére	Carbonifero	1822 British consensus 1953 US division
Devonian	Devonien	Devonico	1840 Murchison & Sedgewick
Silurian	Silurien	Silurico	1835 Sedgewick & Murchison 1839 Global recognition Murchison
Ordovician	Ordovicien	Ordovicico	1902 Charles Lapworth
Cambrian	Cambrien	Càmbrico	1835 Sedgewick & Murchison
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Precambrian	Precambrien	Precàmbrico	

The one exception to this is the Carboniferous first named in Britain after the vast coal deposits found. However only the top half of this period contains coal. The bottom part is composed of marine limestones and in recognition of this, the USGS in 1953 further subdivided the system into Mississippian and Pennsylvanian. However this terminology is only widespread in America and not in Europe.

The chronostratigraphic scale is a summation of all stratigraphical knowledge and as such there is no one cliff or quarry section on the Earth at which all units are exposed. It forms the basis of all geological maps and correlation. As it forms such an important part of geological study, the development of the stratigraphic column through the eighteenth and nineteenth centuries follows the thinking and expansion of the geological perspective on the age of the earth.

Within this history of geology lecture this will be explored in 2 ways.

Firstly, in a relative way by exploring the idea of comparative time using the 5 main principles employed within stratigraphy.

- ✓ Principle of Superposition
- ✓ Principle of Uniformitarianism
- ✓ Principle of Faunal succession
- ✓ Principle of Cross cutting relationships
- ✓ Principle of Inclusions.

Second to explore the history of the use of absolute time within geology

The second area of study will be achieved using firstly the debate about the age of the earth using Archbishop Ussher's calculation and the bible and secondly Lord Kelvin, the discovery of radioactivity and its application to the above debate by Ernest Rutherford. From here the use and limitations of half lives in radioactive elements will be explored.

The Principles.

The principles of stratigraphy are discussed using the main scientists involved.

✓ Principle of superposition.

Look at the work of Steno (1638–1687)

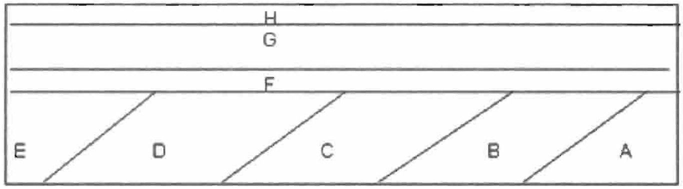
Steno was born in Copenhagen as Neils Steensen. He studied medicine and anatomy there and in Paris. He traveled widely and eventually became the court physician to Grand Duke Ferdinand II in Florence.

His observations were based on a comparison of modern and fossil shark's teeth. He worked in the hills around Tuscany and was able to appreciate that the sediments had been deposited in a primeval ocean.

He described his ideas on the relationships between strata in *De solido intra solidum naturaliter contento dissertationis prodromus (1669).*

> «At what time there was formed any bed, the matter incumbent on it was all fluid and by consequence, when the lowest Bed was laid, none of the upper Beds was extant.
>
> When any Bed was formed, its inferior surface, and that of its sides, did answer to the surfaces of the interior Body and of the Bodies lateral. [...] Beds, either perpendicular to the Horizontal, or inclined to it, have been at another time parallel to the same».

From these observations, we have the **Principle of Superposition**, basically *what lies on top is the youngest.*



What is the youngest deposit in this diagram?

✓ **Principle of uniformitarianism.**

The work of James Hutton (1726 - 1797)

James Hutton was born in Edinburgh in Scotland where he studied law and then chemistry and medicine at university, first in Edinburgh but later in Paris and Leiden. He completed his studies in 1749. James Hutton never practiced medicine but instead studied improved mixed farming techniques in Norfolk in England. Here new scientific ideas on farming were developing following enclosure of the fields. First-hand experience of crop rotation and improved road transport allowed Hutton to take his ideas back to Berwickshire in Scotland and apply them to land he had inherited. It was from his time in Norfolk that we can trace Hutton's interest in rocks and minerals. His ideas on geology developed and mushroomed after he moved to Edinburgh but this time spent in Norfolk and Berwickshire is important in his developing and observing geological structures and sections. He realised that the marine erosion he saw at work on the coasts of England and Scotland and the intrusion of granite into other rocks demanded an explanation and that the time taken for these processes to occur must be longer than the 6000 years accepted at that time as the age of the Earth. Hutton believed in observation and then theory and explanation. His observations on Isle of Arran in 1787and at Siccar Point in 1788, are known worldwide. He gave us the axiom:*The present is the key to the past.*

From these observations he developed the idea of unconformities (as shown in Fig. 3) which represented a vast amount of time. The processes involved in their formation i.e. deposition, subsequent uplift, folding and then erosion, subsidence and further deposition, must take time and Hutton's observations showed him that 6000 years was just not long enough for this to happen.

As he himself says:

«The purpose of this dissertation is to form some estimate with regard to the time the globe of this Earth has existed, as a world maintaining plants and animals [...]. The solid parts of the present land appear , in general, to have been composed of the productions of the sea...Hence we find reason to conclude [...] secondly. that , before the present land was made, there had subsisted a world composed of sea and land, in which were tides and currents, with such operations at the bottom of the sea as now take place. [...] And lastly that, while the present land was forming at the bottom of the ocean, the former land maintained plants and animals, at least, the sea was the inhabited by animals, in similar manner as it is at present».

Abstract of a Dissertation, 1785.

«This earth, like the body of an animal is wasted at the same time that it is repaired. It has a state of growth and augmentation; it has another state, which is that of diminution and decay [...]. We find no vestige of a beginning – no prospect of an end»

Theory of the Earth, 1795.

Hutton's ideas were being published at a time of political unrest and controversies were feared. He also has a difficult writing style. His "Theory of the Earth" ran to 1204 pages. 6 additional chapters were found a century later. Both these facts led to his initial ideas being dismissed by many. As Humphrey Davy (1805) states "Dr. Hutton is obscure and perplexed from the multitude of facts which crowded on his mind." However, his long term friend, John Playfair translated his ideas into readable English in 1802 as "Illustrations of the Huttonian Theory" five years after his death.

To summarise, Hutton's geology rests on the concept of continuous natural processes working over periods of time that are infinitely long compared with a human life span. Decay and erosion of the land produce the sediments and running water moves it to the sea. The internal heat of the earth converts them from sediments to rocks.

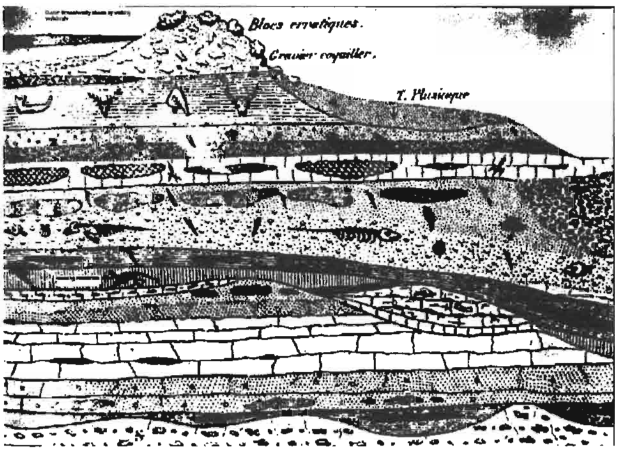
✓ **Principle of Faunal succession.**

The work of Cuvier (1769–1832) & William Smith (1769–1839).

Baron Georges Cuvier was born in Montbeliard in 1769 in what was at that time the Duchy of Wurttemberg to become Germany in the following century. However following the French Revolution Montbeliard was annexed by the French and Cuvier became French. He attended school in Stuttgart where he had a broad education and became fluent in German. This was to stand him in good stead later when he moved to Paris as few of his colleagues could speak both French and German. At that time French was the premier language as English is today. This allowed him to be exposed to the scientific literature of both those central European cultures.

Cuvier had always had an interest in natural history from a boy and eventually after tutoring in Normandie, he managed to secure a job after the Terror of the French Revolution, at the Museum National d'Histoire Naturalle as a junior assistant. This was to become his scientific and domestic home for the rest of his life. Many publications on comparative anatomy of marine invertebrates and then mammals followed. His work on the 3 species of elephants and the fact that mammoths were related to none of them and were extinct caused a stir. He emphasized the importance of comparative anatomy as a tool for establishing the theory of the Earth.

His empirical work on the alternation between freshwater and marine fossils and sediments with Brongniart on the Paris basin and his rigorous and painstaking analysis of these fossil shells led to his advocacy of catastrophic events to explain geological phenomena. His assertion that he had discovered whole fauna of extinct mammals which were distinct from living ones was his primary concern. The physical cause of the processes, which led to this, were only of secondary importance to him. Cuvier regarded catastrophies as part of the order of nature and they had repeatedly occurred in the course of Earth's history. Hence we had a faunal succession.



Cuvier's example of an unconformity and faunal succession

William Smith was styled by Sedgwick "The father of English Geology". William Smith was born in Churchill, Oxfordshire into exactly the opposite type of family on the other side of the English Channel but in the same year as Cuvier. He was the son of a village blacksmith who died when he was a young boy. He had to support himself from an early age and was trained as a surveyor. At this time canal, building was important in Britain and Smith was employed by companies in this pursuit. He was a keen observer and realized that set faunas followed one another in strict sequence. Eventually he became confident enough to predict rock types based on their fossil content. He traveled widely with his work covering as much as 16,000km a year, a huge distance in those days, mostly on horseback. Eventually he produced the first geological "map of England and Wales with part of Scotland", in 1815. In 1819, he published part of a work entitled *Strata identified by organized fossils.* However William Smith never felt confident about his writing and never joined a scientific society. His greatest contribution was his field observations and his synthesis into a geological map.

These three principles apply to sedimentary strata. However 2 other principles are also used. They are the principles of cross cutting relationships and principle of inclusions.

The Stratigraphic Column

The first stratigraphic period to be recognised was the Tertiary in 1760 by Arduino, a mining expert working in the Venetian Republic. He distinguished 4 separate stages or orders one above the other. These were Primary, Secondary, Tertiary and Quaternary, the Atesine Alps, the Alpine foothills, the sub-Alpine foothills and the plains of the river Po respectively. The second, the Jurassic, a well-recognised name nowadays, was named by Von Humboldt in 1795, the same year that James Hutton published his "Theory of the Earth" in Scotland. This was based on the work done in the Jura Mountains of France. While social revolution surpressed new stratigraphic idea development in Europe, no new systems were acknowledged. Following the Treaty of Versailles in 1815, relative time was debated again. In 1822 the Carboniferous was recognised in Northern England by Conybeare and Phillips and at the same time the Cretaceous in France by d'Halloy. The majority of period names were then devised. The last section of the stratigraphic column to be recognised was the Ordovician in 1879 following the lengthy debate or indeed argument between Sedgwick and Murchison in Wales. Once the stratigraphic column was complete, type sections could be agreed and debated.

Absolute time.

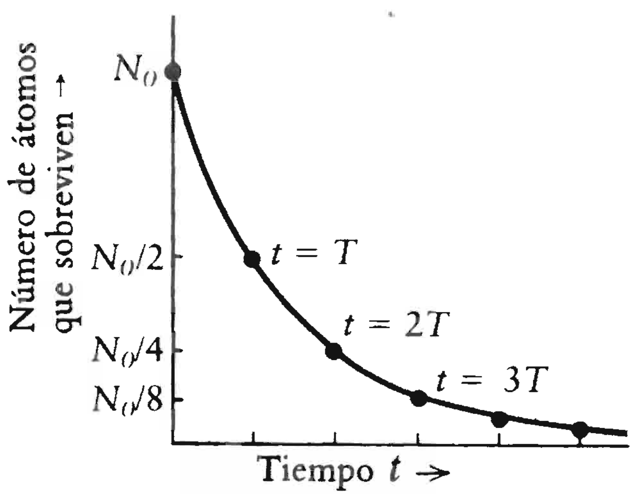
Introduction.

Absolute time had to await the discovery of radioactivity in 1896 by Antoine-Henri Becquerel and later the recognition that radium radiates heat continuously by the Curies and Laborde in 1903. The suggestion by Lord Rutherford in 1903 that radioactive elements could be used to date rocks was revolutionary and Strutt demonstrated that radioactive elements were widespread in minerals throughout rocks. In 1907, Bertram Borden Boltwood suggested that the rate of disintegration of uranium into lead could be used to actually date rocks Thus the higher the percentage of lead in an ore the older the rock.

With the new radiometric dating methods, geologists could calibrate the relative scale of geological time thereby creating an absolute one. Arthur Holmes was the first geologist to construct a time scale (1927), based on radiometric dating and many time scales have been constructed since for the Cambrian upwards (Phanerozoic Gk. Plainly evident life). It is being refined even to this day as more isotopic data become available.

Radiometric dating

Radiometric dating techniques were developed at the beginning of the 20th century and use the regular rate of decay of unstable, radioactive elements such as U-235, K-40, Rb-87 and C-14 to their daughter products either in a single step or through a series of steps. These elements resemble virtual "clocks" within the earth's rocks and form the geologists' timekeepers. This decay is accompanied by the emission of radiation or particles (alpha, beta or gamma rays) from the nucleus, by nuclear capture or by ejection of orbital electrons. Thus heat is given off and this was an important point in the 1903 lecture by Ernest Rutherford when debating the age of the Earth in the company of Lord Kelvin at the Geological Society of London. If a daughter product is stable, it accumulates until the parent isotope has completely decayed. If a daughter isotope is also radioactive, equilibrium is reached when the daughter decays as fast as it formed.



Curva de vida media de una desintegración. Tras cada intervalo de tiempo, T, la mitad de los átomos remanentes se han desintegrado.

The radioactivity of an element is described in terms of half-life, the time the element takes to lose 50% of its activity by decay.

This can cover a large scale of time from billions of years to microseconds. At the end of the period constituting one half-life, half of what was left is halved again, leaving one quarter of the original quantity and so on. Every radioactive element has its own half-life e.g. C-14 is 5730 years.

Limitations

There are however some limitations in the use of radiometric dating.

- ✓ The minerals making up the rocks must contain suitable radioactive elements within their crystal lattices
- ✓ The rocks must be the correct age to start with for the half-life available.

Thus it is useless trying to date a shell 1 million years old with C-14 as there will be no C-14 left. Similarly, it is no good trying to date pure sandstone composed only of Quartz, SiO_2, using the U-235 method, as Quartz does not normally contain uranium.

CONCLUSION

Perhaps one of the best known scientists in the world is Charles Darwin. What is less well known is that he trained as a geologist. You will hear about a little of his work from John Cartwright. The understanding of the development of man's perception of time, both relative and absolute and the age of the earth have helped us understand the context of our place on the planet on which we live.

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Workshop.

The workshops will involve

- ✓ A loud ticking clock and a timer set for one hour
- ✓ Perhaps a sand hour glass if available
- ✓ A piece of string measured at various intervals to show prominent earth events,
- ✓ 2 members of the audience (if not already done in the lecture)
- ✓ A cartoon geological cross section

This has then introduced the audience to the 2 ways of looking at geological time.

The last two principles will hopefully be illustrated in the field at Mount Teide and in the workshop exercise.

- ✓ Principle of cross cutting relationships
- ✓ Principle of inclusions.

It will be possible to illustrate at least one of these on the field excursion. It will be shown how these can be illustrated in an urban environment using windows and doorways in a building.

➜ Activity 1

Length of string exercise

The string and significant dates can be varied depending on the country in which this exercise is being done (e.g. Black Death). Obviously, the events on the string could vary between Britain and for example Spain or Greece. Use a scale of 1 cm per 1000 years. This is significant as it will be the year 2001.

Event	Years Ago
Today	0
Birth of Jesus Christ	2,000
Age of the Earth according Archbishop Ussher	6000
End of Ice age in Northern Europe,	10,000
Evidence of first *Homo sapiens* in Europe	500,000
Tenerife	8,500,000
Gran Canaria 1	3,500,000
Extinction of dinosaurs	65,000,000
Age of the earth according to Lord Kelvin (1846)	100,000,000
Age of the earth according to Lord Kelvin (1866)	20-400,000,000
First appearance in fossil record of multicellular algae	2,100,000,000
Oldest rock on earth	3,800,000,000
Birth of Earth	~ 4,600,000,000

➜ Activity 2.

Bible exercise.

Natural scientists were interested throughout the 16th, 17th centuries to know the age of the earth and many calculations were produced. However in 1658 Archbishop Ussher came up with a date which the whole of the Christian world seemed to initially accept. How did Archbishop Ussher of Armagh come up with 09.00 26th October 4004BC in 1658?

An analysis of the first book of the Old Testament seems the obvious place to start. The beginning of Genesis details the creation and then goes on to list in detail Adam and his decendants. Students will try to calculate how many years are accounted for in the Old Testament of the Bible.

A discussion will then take place as to why there might be a discrepancy both between student group addition! And Archbishop Ussher's calculation. What else could scientists of that time be concerned about and where do the errors arise.

➜ **Activity 3.**

<u>Cartoon cross section exercise. What happened first?</u>

Work out the geological sequence of the section and decide which principles could have been used at the following dates
1000AD
1500AD
1832AD