Dating the Earth – before the discovery of radioactivity

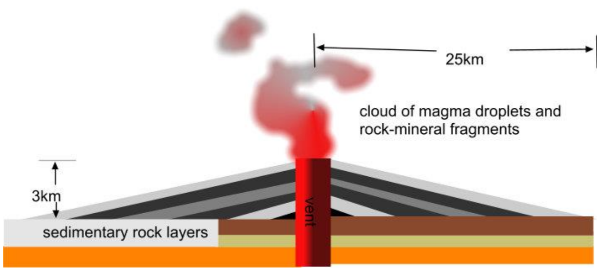
Charles Lyell and Mount Etna, 1828

Since the early years of the 20th Century, we have been able to date the Earth using radioactive minerals, and we are used to thinking in terms of up to thousands of millions of years. Before this, however, estimates of the ages of geological events were very variable and nobody was able to find out how long ago they were. Most people thought that geological processes happened very quickly, to explain how things could happen in just a few thousand years (when the Earth was thought to be only a few thousand years old).
The Scottish geologist, Charles Lyell, was sure that past processes had worked at the same rate as modern ones and so most of Earth's features had taken a very long time to form, but how could he prove it?
A visit to Mount Etna, in Sicily, gave him an idea which would enable him to estimate how many years it had taken for Etna to grow from nothing to a large volcano. Although by no means giving the age of the Earth, he would at least be able to show how long it had taken for a relatively tiny part of it to form, which would begin to stretch the time scale in people's thinking.

Mount Etna in 2007,

Lyell knew the approximate size of Mount Etna, from the lowest lava flow, which was resting on some fossiliferous limestones, to its summit. He also knew that it erupted fairly regularly and that most of its eruptions since Roman times had been recorded. So, if the volume of lava from each eruption could be measured, he could calculate how long it had taken for the whole mountain to be formed.
Point out to students that the calculations which follow have been simplified and are very approximate, but that they show how Lyell was thinking. Ask students to show all their working.

Etna is approximately 3km high, and roughly circular in plan, with a radius of about 25 km.



Sketch cross-section of Mount Etna (*Peter Williams*)

- Calculate the volume of Etna, using the formula for the volume of a cone: $V = 1/3\ \pi r^2 h$, where V is the volume of the cone in km^3; r is the radius in km; and h is the height in km. Take π as 3.2
  (*Volume = 0.333 x 3.2 x 25 x 25 x 3 = 2000 km^3 approx).*

On average Lyell found that each lava flow measured 10km long by 1km wide by 2m deep (0.002km).

- Calculate the average volume of lava in one flow.
  (*10 x 1 x 0.002 = 0.02km^3).*

He also found that, on average, there had been 5 eruptions per century (100 years) since records were first made.

- Calculate the average volume of lava produced in a century. (*5 x 0.02 = 0.1km^3*).
- Calculate what volume of lava has been erupted since Roman times, 2000 years (20 centuries) ago. (*20 x 0.1 = 2km^3*).

Lyell realised that the total amount of lava erupted in the last 2000 years is still tiny compared with the volume of lava making up the whole mountain.

- Calculate how long it would have taken for all the lava to have built up the whole of Etna.

(*2000km^3 / 0.1km^3 per century = 20,000 centuries = 2,000,000 years*).

Next, Lyell searched for and found fossil shells in the limestones beneath the lowest lava flows of Etna. Geologists had already built up the stratigraphical column, where strata were divided up by the types of fossils which each contained, although no dates in years could be given to the different events in the column. The shells belonged very near the top of the column, in the geological Period in which we ourselves are living. This is called the Quaternary Period.
When Lyell compared the fossils to the modern shellfish living in the nearby Mediterranean, he found that they were very nearly the same species. In other words, if there were so few changes in the last 2 million years, the Earth must be many, many times older than this to allow enough time for all the well-known changes in fossilised life to have taken place.

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The back up

Title: Dating the Earth – before the discovery of radioactivity

Subtitle: Charles Lyell and Mount Etna, 1828

Topic: Using simplified calculations to demonstrate the immense age of the Earth, before the discovery of radioactivity.

Age range of pupils: 14-16 years

Time needed to complete activity: 20 minutes

Pupil learning outcomes: Pupils can:
- make simple calculations from given data;
- show how an estimate of the age of a relatively recent part of the geological record may be obtained;
- put themselves in the position of a scientist struggling to find the age of the Earth, from geological evidence alone, without any knowledge of radioactive dating methods.

Context:
The activity provides an opportunity to use simple mathematics in solving a long-standing geological problem. Students should be made aware that the figures are extremely approximate, and that the activity is designed to show the principle behind Lyell's approach, rather than providing an accurate value. Answers are shown *in italics.*

Following up the activity:
Use the Earthlearningidea activities named below to build up a wider picture of the ways in which geologists thought 200 years or so ago, to appreciate how Lyell was ahead of his time. Use Bob White's paper listed below to open up discussion (carefully!) about current diversity of views about the age of the Earth. Study a geological column to see what a small part of geological time is represented by the Quaternary Period.

Underlying principles:
A number of different and innovative ways have been used to calculate the age of the Earth since the first scientific estimation in 1779.
Calculations of the age of the Earth from radiometric dating have given the most reliable figures, and in recent years have all clustered around 4.6 billion years, more easily remembered as near 4567 million years.

Thinking skill development:
Although the calculations are basically simple, some students may experience cognitive conflict as they work through them. Relating the exercise to the real world of volcanoes and geological time requires bridging skills.

Resource list:
- a worksheet, (or on-screen version) showing the data to be calculated; pocket calculators or calculators on mobile devices.

Useful links: The following Earthlearningideas will help to put Lyell's work in perspective with that of other geologists of the late 18th and early 19th Centuries:
- Working out the age of the Earth – moving backwards as time moved forwards: Link up your own timeline of how scientists worked out the age of the Earth, http://www.earthlearningidea.com/PDF/141_Age_Earth.pdf
- James Hutton – or 'Mr. Rock Cycle'? **-** Thinking towards the rock cycle, the Hutton way**,** http://www.earthlearningidea.com/PDF/93_James_Hutton.pdf

Able pupils will find Bob White's description of the debate about the Age of the Earth useful. It can be found in Faraday Paper No. 8 at: http://www.st-edmunds.cam.ac.uk/faraday/resources/Faraday%20Papers/Faraday%20Paper%208%20White_EN.pdf

Source: The most recent version of this activity is "Blasts from the past 9: The length of geological time – Charles Lyell and Mount Etna", *Teaching Earth Sciences* (2017) Vol 42.1. The original approach was described by Peter Whitehead in *Geology Teaching* (1982) Vol 7.3, pp. 100-101. The original data on which this exercise is based were published by Wadge, G., Walker, G. and Guest, J. (1975) "The output of the Etna volcano". *Nature* 255, pp. 385-387.