Weathering processes on headstones and monuments

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Weathering is defined as the breakdown of rock in situ, that is without being moved. Weathering processes depend upon the presence of water, the temperature, the mineral composition of the rock and its chemical composition. Headstones are subjected to weathering simply by standing in a graveyard or cemetery.

Hepworth churchyard, near Holmfirth
The headstones are made of different rocks so they will all weather differently.

Weathering is often confused with erosion, but the word erosion implies that the rock has been subjected to transport processes which has worn it down. Rocks are transported by water in rivers or by waves. They can be moved by glaciers or rock falls or landslides. Small particles of rock can be blown by wind. All of these transport processes make rocks smaller, but only weathering will break down rock which stays in one place.

Bank Edge Quarry, Rake Bank, Halifax, showing that rock can break down in situ, particularly when water can get into joints and weaknesses.

HOW DOES WEATHERING OCCUR?

Weathering falls into three types of processes - Physical, Chemical and Biological. Students and pupils at GCSE level and above will be able to appreciate the processes which occur in each type of weathering. However, for those younger and for adults who have no background in chemistry, it will be necessary to simplify the explanations.

PHYSICAL WEATHERING

Physical Processes are easier to understand and there are two main types:

Expansion-contraction weathering (also called exfoliation or onion-skin weathering) depends upon expansion and contraction caused by heating of the rock in the sun. The outer rock surface expands during high day-time temperatures and then cools rapidly at night, setting up stresses in the rock surface which then cracks open. This process is far more likely to occur in hot and arid climates so is probably very unusual in the UK.

Mudstone scree slope on Mount Road, Marsden

Freeze -thaw weathering (sometimes known as frost-shattering) depends upon the expansion of water when it freezes into ice. This affects rocks in climates where temperatures fluctuate around freezing-point. Most people have experience of this process. Any water in pore spaces, joints or cracks in rocks, will expand on freezing and push blocks of rock apart. This results in broken rocks which then fall under gravity, often forming scree slopes in hilly areas.
Sandstones break into individual sand grains or into blocks along joints or bedding planes, while mudstones break into small angular fragments, as shown in the photo. Crystalline rocks, such as limestone and the igneous rocks, break into blocks, the shape of which is controlled by joint patterns.

Rock fall in Worlow Quarry, Marsden, in January 2006

CHEMICAL WEATHERING

Chemical weathering is more complicated to understand because it is difficult to visualise the chemical reactions which take place on the surface of a rock.

Chemical reactions cause the minerals in a rock to decompose in various ways. There are several different types:

Oxidation Iron in the minerals which make up some rocks or which cements rock particles together, will oxidise (or rust) if water and air are present. Iron is usually orange, yellow or brown when it has oxidised and many rocks have a brown or yellow outer skin. This accounts for the brown skin on many sandstones which have iron cement.

Hydrolysis Rain water, which is slightly acidic because it picks up carbon dioxide in the atmosphere, reacts with some minerals, causing them to decompose to other weaker minerals. One example is the feldspar minerals in granites which decompose readily to clay minerals, which can then be washed away by rainfall. Granites weather along their joints where water can attack the minerals, even though they seem to be tough, crystalline rocks.

Carbonation This process is a form of hydrolysis, which occurs when rain water reacts with any minerals containing carbonate. It particularly affects limestone, chalk and marble rocks. Rain water gets into joints or weaknesses and widens the gaps, often causing blocks to fall off. The surface of limestone or marble recedes gradually, because the calcium carbonate is being removed by rainwater.

The surface of this marble headstone has receded by **carbonation**, leaving the lead lettering standing proud of the rock surface. It is possible for students to measure the amount of recession by counting how many sheets of paper can be inserted between the stone surface and the lead letters. The date of the headstone can be estimated from the dates of deaths and a rate of recession can be calculated. It is necessary to take at least 10 measurements on each headstone, at different positions. Weathering sometimes takes place faster at the top or base of a headstone, depending on the amount of water available at that site.

A graph relating age of headstone and amount of recession can be drawn. The relationship is not necessarily linear, but that leads to interesting discussion.

The crystals in the granite are being decomposed by **hydrolysis**. Feldspar crystals are white and will break down faster than the quartz crystals which are greyer. The process is beginning to take place on the top surface of this granite headstone, where a black weathering layer is developing..

Oxidation is shown on the edge of the surface skin, where iron in the rock is turned orange. Another reason for the outer skin being dark is because of the soot deposited by domestic and industrial coal burning before the Clean Air Acts which were passed in the 1950s.

The amount of **spalling** on a sandstone headstone can be assessed in various ways. The student who did this study made a standard sized cut-out, as shown in the photo, and then assessed the percentage of spalled surface within this area. It is necessary to select the area randomly and look at the front and back of each headstone, if that is appropriate.

BIOLOGICAL WEATHERING

Lichens and mosses attach themselves to rock surfaces with rhizoids and take moisture and nutrients from the air, as well as from the rocks.

Roots of plants are able to penetrate small spaces and prise sand grains and bedding planes apart. They can even get into cracks between crystals in tough igneous rocks. Thus biological weathering can have a physical effect. Both rhizoids and plant roots secrete acids, which promote chemical breakdown of minerals such as feldspars.

Ivy has suckers which attach themselves to the stone. Ivy leaves arrange themselves into a blanket so that each receives maximum light and water, so rock surfaces under ivy are often dry. This means that the chemical weathering processes do not operate, so ivy acts as a protection in some instances.

Moss and ivy growing over headstones will result in both physical and chemical weathering. Tree or shrub roots will push sections of gravestones apart and can cause them to topple over.

HOW TO STUDY HEADSTONES

For younger pupils who are studying weathering, close attention to individual headstones works well. Several different headstones, preferably of different rock types, can be studied in detail. Drawings or photos of areas of a headstone, which show signs of the main weathering processes, can be labelled to point out the differences between freeze-thaw, chemical and biological weathering.

This sandstone grave shows many types of weathering. The poor quality stone on the side panels is spalling under the cover of ivy and green algae. The better quality sandstone on the top is becoming pitted.

A SCIENTIFIC STUDY OF GRAVESTONES

This is appropriate for older pupils who are developing their understanding of the scientific method. Here is a structure which can be used:

1. Teach weathering processes - as appropriate for age group
2. Discuss variables which affect weathering in the chosen area. Variables are complex, largely because of the variety of weathering types, geology of headstones and the site chosen.
3. Set up a hypothesis - older students could design their own bivariate hypothesis, after considering variables and their chosen site. The age of a headstone is clearly the important factor to consider and most hypotheses relate age of headstone to another variable, while keeping all the other variables constant.

A good discussion of which variables to keep constant is needed. If a local graveyard has many sandstone headstones, then that is a variable which can be constant, so that other variables, like shading under trees and exposure to weather, can be assessed against age.

4. Sampling techniques - depending on the measurement system, at least 10 samples would be required in order to take an average or use a statistical test or draw a graph.
5. Measuring techniques - to be devised by the student or teacher as appropriate for the site
6. Analysis of data collection - by drawing graphs or using a statistical test
7. Interpretation of results - usually there is no simple answer, but the discussion is the interesting bit.
8. Evaluation of the methods used, their effectiveness and accuracy.

VARIABLES

Age is the most important factor influencing the amount of weathering to which a headstone has been subjected. The point of using headstones for studies like this is that there are dates on the stones. However, there are great difficulties in deciding which dates to use.

Headstones are generally erected within a year or so of the death of an individual. This works well if the headstone records a single person. However, many headstones record more than one person and have multiple dates of death. Headstones are often erected retrospectively, perhaps by a younger relative, who can better afford a good headstone and whose intention is to be commemorated on the same stone. Young children are often recorded when one of their parents dies, rather than on a headstone of their own. Stonemasons can engrave headstones in situ, so that inscriptions can be added later, although it is usually possible to see from the nature of the engraving if this has happened.

The best system in dealing with headstones with multiple dates seems to be to take the earliest date of death on the monument, particularly if this is a prominent person,often a husband or wife. However, this is not always the case, so studying the wording of the inscription can sometimes give a clue as to when the stone was erected. If in doubt, then do not use that headstone. If possible, use only headstones with single inscriptions if there are enough available for study.

This headstone commemorates the seven children of John and Martha Smith. They died between 1848 and 1865. As the inscriptions are in the same style, the stone was probably erected shortly after 1865.

This headstone commemorates many members of the Turner family. The first inscription is to Mary Elizabeth Turner, who died in 1907. The inscriptions below have been added later, as you can see from the varied lettering and the amount of gold retained in the letters.

Climate is clearly significant on a global scale but does not seem to affect results in this area of Yorkshire. However, students who study graveyards in other countries, as sometimes happens if coursework is set during school holidays, can compare effects of weathering on the same rock type in different climate zones.

Altitude is probably significant on a global scale for many climatic reasons. While rainfall and temperature varies greatly between the Pennine areas and lower-lying ground, we have never found this to be a significant factor, even with a height difference of 200m or so.

Exposure to weather is significant on a local scale. Headstones which are exposed to sun and drying wind show less weathering in general. However, they may be more susceptible to freeze-thaw weathering as temperatures fall faster in the open air than under trees.

Aspect is the compass direction in which the headstones face. In many graveyards, the headstones are aligned with the engraved side facing to the east. Therefore, in West Yorkshire, the back of the headstone faces the prevailing winds, so should be more weathered. However, this has never been satisfactorily shown in studies, probably because it is difficult to compare east and west facing headstones.

Shade under trees seems to be important, but not in the way expected. Most students think that trees will stop rain reaching the headstones. In fact, the environment under trees is usually very moist, so that chemical and biological weathering takes place faster.

Attitude means whether the stones are vertical or laid horizontally on the ground or table grave. Horizontal stones are susceptible to erosion by feet, if they are used as a path, though this is hard to measure. They also seem to hold water in puddles for longer than vertical stones, which shed rainfall. It has proved difficult to assess whether the attitude of the stone is significant, so it is best to suggest that this is a variable which should be kept constant. However, if a student is looking at individual stones to see what weathering is taking place, horizontal stones are worth studying.

Rock type is a very significant variable.
Sandstones are the local rock type in most areas of West Yorkshire and make up the majority of headstones. Local sandstone is made of about 90% quartz grains and 10% feldspar grains, cemented together with a mixture of quartz, which is very resistant to chemical weathering, and iron, which gives the yellow colour. If the cement between the grains is distributed evenly so that all the grains are bound together, then the sandstone will be very resistant to physical weathering. If the grains are large or badly cemented or there is a higher proportion of weaker feldspar, then the sandstone is of much poorer quality.

Water has got behind the outer weathered skin of this sandstone headstone. When it expanded on freezing, the dark outer surface peeled off (spalled).

It is possible to measure the quality of sandstone by assessing grain size, using a standard grain size card available from geological suppliers. Studies relating grain size to a measure of weathering give good results when carried out carefully.

Horizontal sandstone gravestones laid as a path outside Bradford Cathedral

The main weaknesses in sandstone headstones are bedding planes, which will be parallel to the face of the headstone. Rain can get behind the surfaces, which will begin to **spall** if freeze-thaw weathering occurs. Water will also percolate between sand grains in a badly-cemented sandstone so that individual grains are forced off by ice during freeze-thaw weathering. This leads to **pitting**, which is sometimes seen on sandstones. The percentage of pitting in a given area can be measured and related to other variables, such as grain size.

Crystalline rocks (usually igneous rocks) with stable mineral composition (in other words they consist predominately of quartz), weather very slowly. Polished igneous rocks have only been used since railway transport enabled rocks to be brought from other areas in the last 100-150 years. Such rocks usually show limited signs of weathering. If there is any weathering, the weakest minerals (feldspars - white/pink/yellow) weather by hydrolysis. This can sometimes be observed in coarse-grained rocks such as granites, which begin to form pits in the surface which may feel rough under the fingers. The degree of pitting is difficult to measure in igneous rocks.

Granite headstones

Marbles are weathered by carbonation which acts very rapidly under rainwater (pH 5.5). The surface recedes and engraved letters lose their sharpness and disappear after 70/80 years, as shown in the photo to the left. This is easy to assess with Rahn's Index, but can be observed in any marble carvings on old headstones.
To counteract this effect, stone masons have traditionally used lead letters instead of engraving the stone. Lead letters have small pins at the back which are affixed to the marble. As the marble surface recedes the lead letters are left proud of the surface. If the surface recedes further, then the lead letters will fall out completely. The amount of surface recession can be measured as described earlier.
Tyre gauges can also be used, but the basic paper method seems to work very well.

METHODS OF ASSESSING WEATHERING
Using the date at which you think the headstone was erected and an index of weathering it is possible to assess the rate of weathering. This website gives useful information and references on how weathering indices have been devised.
http://www.envf.port.ac.uk/geo/inkpenr/graveweb/methods.htm
Useful teaching plans and lesson preparation notes are given in the websites below:
http://www.gravegarden.org/pdfs/LessonPlan2.pdf
http://www.evergreen.ca/en/lg/lessons/gravestone.html

A useful assessment of the sharpness of engraved letters called **Rahn's Index** is given below. It allows the observer to feel or to look at the quality of the lettering. This system seems to produce very good results when related to age of headstones, though good students will realise that it is entirely subjective. It has the advantage of being quick and easy to carry out. Results should be substantiated by labelled photographs.

Rahn's Index - Visual Weathering Class

1 Lettering sharp and distinct. No evidence of change.
2 Lettering slightly rounded showing evidence of some removal of grains. Still legible and clear though.
3 Lettering rounded. Edges clearly being removed and some original edges removed completely. Still legible and clear.
4 Lettering rounded. All or most original edges removed, but lettering still legible, but increasingly becoming indistinct from the surface of gravestone.
5 Lettering disintegrating. Lettering still just about legible, but now almost indistin-guishable from the surface of the gravestone.
6 What lettering? Lettering virtually disappeared. Need to be able to make out date to be able to date period over which lettering has disappeared.

Index 1 No evidence of change

Index 3 Edges be-ing re-moved but still clear and legible

Index 2 Lettering becoming round-ed but still legible and clear

Index 4 Letter-ing becoming indistinct from the surface of the stone.

Index 5 Lettering just about legible

Headstones with lead lettering cannot be assessed using Rahn's Index, so the method of meas-uring the gap due to surface recession is used. It is described earlier. It seems to work very well and is useful in cemeteries or graveyards that contain a lot of marble or limestone headstones.