Geikie's science in the cemetery

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Abstract: Natural stone is an important material used for buildings, walls and monuments. However, when used outdoors, it is subject to damage by the effects of weathering. Inspired by the experiments carried out by Friedrich Pfaff, a German geologist and professor of mineralogy at the University of Erlangen, Germany, in the 1870s, Archibald Geikie became interested in the subject of rock weathering and came up with the idea of using gravestones as a means of monitoring weathering in stone used for building. This work, apparently carried out in cemeteries in Edinburgh as a sideline to his normal fieldwork activities, was described in 1880 in a communication read to the Royal Society of Edinburgh. It represents the first comprehensive scientific study of rock weathering published in English, and the methodology Geikie developed for his study formed the basis for modern studies of rock weathering using gravestones.

It was a simple idea, but a very powerful one. After reading about experiments carried out by the German geologist and professor of mineralogy at the University of Erlangen, Germany, outlined in Pfaff's book *Allgemeine Geologie als Exacte Wissenschaft* (Pfaff 1873, p. 317) in which Pfaff described experiments designed to precisely measure the effects of weathering on samples of a range of rock types, Archibald Geikie became interested in the idea of using gravestones to monitor the effects of weathering on different rock types. Geikie's interest in studying weathering in gravestones may have been influenced by a paper published in 1875 by John George Goodchild, a fellow geologist at the Geological Survey of Scotland. In this paper Goodchild focused on glacial erosion, but also described his use of dated tombstones in Kirkby Stephen Churchyard to measure the rate of weathering in limestones (Goodchild 1875, p. 326).

Natural stone is and remains an important material used for buildings, walls and monuments, and when used outdoors is subject to damage by the effects of weathering. Understanding how a particular stone type will stand up to atmospheric conditions plays an important role in choice of stone, as well as in conservation of stone structures.

In his original experiments, Pfaff had exposed measured and precisely weighed samples of Solnhofen limestone, syenite, rough and polished granite, and bone to the ambient atmosphere for 3 years. At the end of a sampling period, Pfaff examined the samples and reported on features such as cracks, incipient exfoliation, changes in surface texture and the amount of material removed from the sample surface that had appeared during this relatively short sampling interval.

Building on this work, Geikie conceived the idea of using gravestones, rather than prepared samples, to monitor weathering in rocks. This offered a number of advantages. A range of different stone types is commonly used for gravestones, and gravestones are plentiful and easy to access. In addition, gravestones are typically present in a number of different environmental settings. For example, gravestones in urban locations are generally exposed to much higher levels of pollution – including higher levels of CO_2 and carbonic acid – than those in country churchyards. But, on the other hand, gravestones in country churchyards may be more exposed the effects of wind and weather than those in sheltered urban churchyards. Also, and importantly, the death dates commonly included in gravestone inscriptions mean that the information about when the gravestone was first exposed to the atmosphere is literally set in stone. Thus, gravestones provide an ideal set of dated and timed exposure trials for monitoring weathering.

They offer other advantages too. For example, older gravestones provide an opportunity to document the effects of weathering over many tens of years – a much longer period than Pfaff was able to achieve. With gravestones, it is also easy to return to the 'sample site' several times to monitor the results of weathering over various time intervals. By applying these principles, Geikie developed a simple way to estimate and understand the effects of weathering on a range of rock types over time and under different atmospheric conditions.

Geikie first published the results of his gravestone studies in 1880 in a communication to the Royal Society of Edinburgh entitled 'Rock-weathering in Edinburgh churchyards' (Geikie 1880). The same

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text was reproduced in 1881 under the title 'Rock weathering as illustrated in churchyards' in *Popular Science Monthly* (Geikie 1881). Geikie also summarized his gravestone work in a number of his more popular publications, including *The Scenery of Scotland* (Geikie 1897, pp. 36–39) and *A Long Life's Work: An Autobiography* (Geikie 1924, pp. 169–172). In his popular book *Geological Sketches at Home and Abroad* (Geikie 1892, pp. 152–179), the whole of chapter 8, entitled 'Rock-weathering measured by the decay of tombstones', is devoted to a description of his gravestone work. He also refers to his gravestone studies briefly in textbooks including his *Class-Book of Geology*, first published in 1886 (Geikie 1907, p. 15). This book went through four editions and was reprinted many times.

Research methods

It is not clear how Geikie became acquainted with Pfaff's experiments on rock weathering. The book was published in German, and does not appear to have been translated into English. Nor is there any obvious evidence that Geikie ever met Pfaff in person to discuss this work. Similarly, it is not known whether Geikie was familiar with Goodchild's use of tombstones in the Kirkby Stephen Churchyard to study the rate of weathering of Lower Carboniferous limestones (Goodchild 1875, p. 326). Nevertheless, Pfaff's and Goodchild's ideas seem to have set off a train of thought, and during the 1870s Geikie seems to have taken the opportunity to examine gravestones as a sideline in the course of his other fieldwork.

Four pages of rather sketchy descriptions of gravestones in Greyfriars Churchyard and Cannongate Churchyard, both in Edinburgh, are recorded in Geikie's field notebook labelled P, which dates from 1874, and a further seven pages containing brief descriptions of gravestones in Greyfriars Churchyard are included in his field notebook labelled Xa, which is undated but, on the basis of information given in Geikie's autobiography (Geikie 1924, p. 170), probably dates from 1879 (Fig. 1).

Occasional sketches of memorials appear in later field notebooks dating from 1878 onwards. For example, in 1878 he records a memorial on the wall of the Church of St Peter in Salzburg (Book R, p. 61), and there are also very occasional and sparse references to interesting tombs in his field notebooks for the years 1880–81 (Book Y) and 1882 (Book EE). Charming watercolours showing gravestones are also preserved among Geikie's archives (Fig. 2). These references, however, appear to refer simply to interesting memorials Geikie came across during his travels, rather than as part of a systematic study of rock weathering.

Rock weathering in Edinburgh churchyards

The brief observations of gravestones in Greyfriars and Cannongate churchyards in Edinburgh recorded in field notebooks P and Xa formed part of the basis of Geikie's main scientific publication on rock weathering – his communication about Edinburgh churchyards published in 1880 in the *Proceedings of the Royal Society of Edinburgh* (Geikie 1880). However, the published paper includes much more information and scientific speculation than appears in these notebooks. Any further more detailed notes Geikie may have recorded on the subject have so far not been found.

In his communication to the Royal Society of Edinburgh, Geikie describes how observations of weathering in gravestones can be used to compare differences in air pollution and temperature differences in towns and country districts. He then goes on to discuss in some detail how weathering affects the three kinds of stone commonly used for gravestones in Edinburgh. These include: calcareous rocks, including marbles and limestones; sandstones and flagstones; and granites. In this work he relies on the death dates recorded on gravestone inscriptions to document how long the stone had been exposed to the atmosphere, and notes the orientation of the gravestone and its situation – whether sheltered by, for example, walls or exposed to the full effects of weather – to allow him to estimate the effects of weathering on different stone types and the rate at which weathering occurs.

Calcareous stones

Marbles, he observed, are particularly susceptible to three processes: superficial solution; the formation of crusts leading to internal disintegration; and curvature and fracture, especially common when upright marble slabs are inserted into a solid framework of a harder stone, such as well-cemented sandstone.

One particularly ironic example of weathering in a marble grave that he cites is the tombstone of the chemist Joseph Black, discoverer of carbonic acid and latent heat, who died in 1799 and was buried in Greyfriars Churchyard. When it was erected, this gravestone consisted of a large upright slab of white marble fastened in a framework of a hard siliceous sandstone, bearing the inscription:

amici,
qui eximiam ejus virtutem et ingenium
colere solebant
locum hunc, corporis receptaculum
dum marmor hocce supersit
sic designatum
voluere.

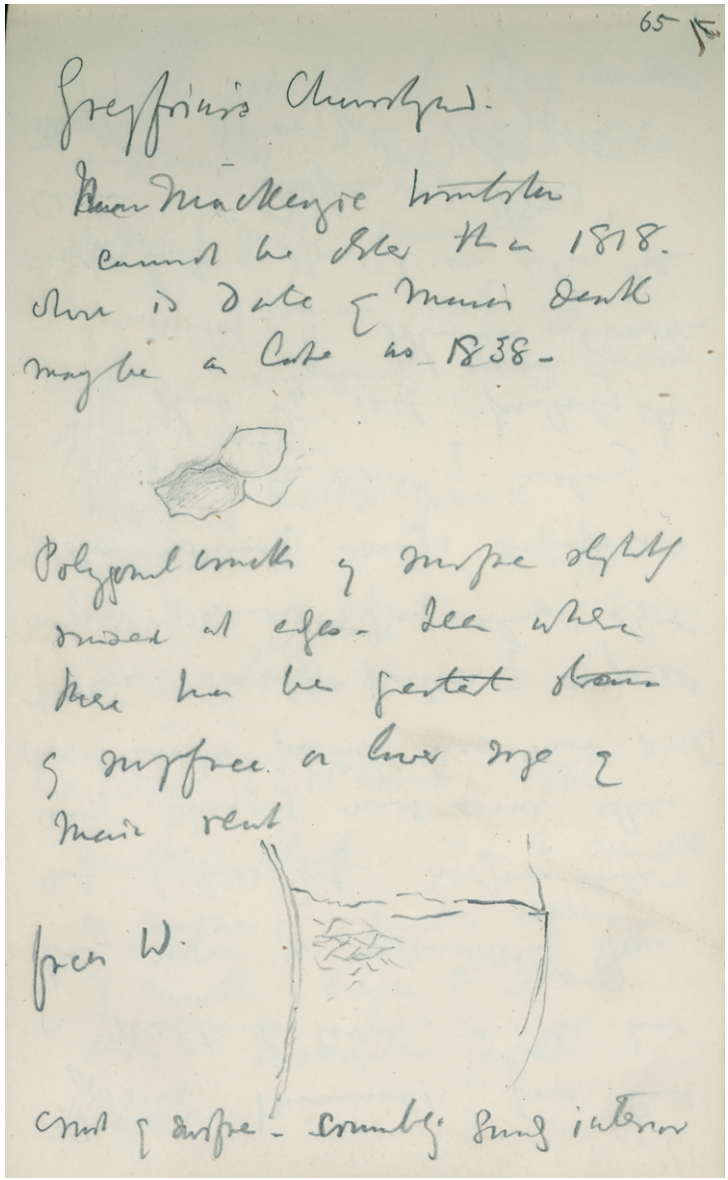

Fig. 1. Page 65 of Geikie's field notebook Xa, probably dating from 1879, describing tombstones in Greyfriars Churchyard, Edinburgh. (Photograph Geikie Archive LD.04.21 courtesy of Haslemere Educational Museum, Haslemere, Surrey, UK.)

[The friends who were accustomed to revere his exceptional virtue and intellect wished this place, the receptacle of his body while this marble survives, to be marked like this.]

When Geikie visited this grave in 1879, less than 80 years since it was first erected, weathering was already very apparent. The inscription, he reported, was already becoming difficult to read and the marble tablet, illustrated in a sketch, had already blistered and cracked (Fig. 3). These and other observations of marble on tombstones exposed to the air in Greyfriars Churchyard led Geikie to conclude that acid rain – essentially carbonic acid (H_2CO_3) formed when carbon dioxide (CO_2) emitted from the burning of coal was dissolved in rainwater – was a major culprit.

Fig. 2. Watercolour of Old Cross Kirkconnel, Springkell, unknown date (FP.3.27). (Photograph courtesy of Haslemere Educational Museum, Haslemere, Surrey, UK.)

In his autobiography, Geikie describes re-visiting Black's grave in 1899, 20 years after his first visit, and notes with satisfaction that the decaying marble slab had been replaced by a plaque made of 'far more durable sandstone' (Geikie 1924, p. 171).

This and other observations of decaying marble gravestones led Geikie to caution against the use of marble for monuments in outdoor settings. In a letter to *The Times* newspaper (Geikie 1919), he argued against the use of marble for war memorials, writing:

> On no account should white statuary marble be employed in any structure in the open air. Even the purest air of the country contains carbonic acid, which, dissolved in falling rain, acts on the stone as a solvent.

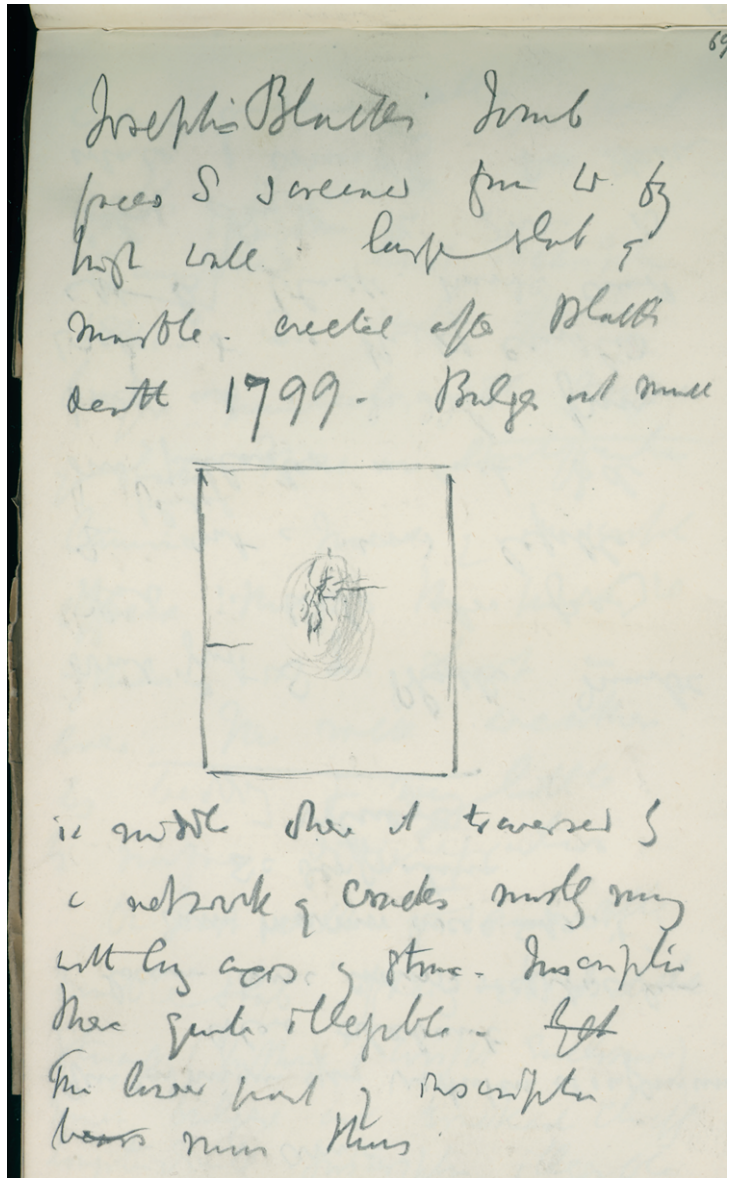

Fig. 3. Page 69 of Geikie's field notebook Xa, describing weathering on Joseph Black's grave. (Photograph Geikie Archive LD.04.21 courtesy of Haslemere Educational Museum, Haslemere, Surrey, UK.)

Sandstones and flagstones

On the other hand, he observed that tombstones made of well-cemented siliceous sandstones often fared better, in some cases with inscriptions and tool marks remaining sharp after 200 years of exposure to the elements. However, not all sandstones, he noted, survived so well.

Resistance to weathering, he hypothesized, depended on factors such as the type of matrix in which the sand grains are embedded. By far the most resistant sandstones, so far as weathering is concerned, are those consisting of a nearly pure siliceous sand, with little or no iron or lime and without a trace of bedding structure. Where a sandstone contained a matrix that was soluble – for example, a

Fig. 4. The grave of Geikie's wife and son at Brookwood Cemetery in Surrey. (Photograph courtesy of Nina Morgan.)

matrix made of calcium carbonate or clay – he observed that it tended to weather more quickly. Sandstone gravestones which contained peroxides of iron, he noted, were particularly susceptible to weathering. For example, he describes a sandstone monument in Greyfriars Churchyard on which the

Fig. 5. Geikie's grave in Derby Road Cemetery, Haslemere, Surrey. (Photograph courtesy of Nina Morgan.)

inscription had weathered away after just 16 years. He also noted how quickly layers eroded off the surface of monuments made using face-bedded sandstones (stones in which the sedimentary bedding is orientated vertically, rather than horizontally) and thinly-bedded flagstones. Concretions – areas of the

stone of a different composition or texture – he observed, also weathered at different rates; often leading to 'irregular and often exceedingly fantastic shapes' in gravestones (Geikie 1880, p. 530). He also pointed out that where the concretions contain the mineral pyrite (FeS_2 or iron sulphide), which gives off sulphuric acid as it decomposes, the sandstones degrade very quickly, and cautioned that such stones should never be used for building.

Granites

The technology for working and polishing granites for use as gravestones did not become widely available until the mid–late nineteenth century (Morgan & Powell 2015, p. vii), so when Geikie was writing his 1880 paper on rock weathering in Edinburgh churchyards he notes that 'granite has been employed for too short a time as a monumental stone in our cemeteries to afford any ready means of measuring even approximately its rate of weathering'. Although he cites Pfaff's experiments on syenite and granite, which indicated that a polished surface of granite will weather more rapidly than a rough surface, Geikie was unable to confirm these results in his own study of gravestones.

While admitting that hard evidence for comparison does not yet exist, Geikie goes on to speculate that 'even the most durable granite will probably be far surpassed in permanence by the best of our siliceous sandstones' (Geikie 1880, p. 531).

Geikie family graves

It seems that Geikie did not take his own advice when it came to choosing durable stone for gravestones for his own family. Rather than choosing a siliceous sandstone, he seems to have preferred granite. The gravestone commemorating his wife, Alice Gabrielle Pignatel, and his son, Roderick Geikie, which is located in Brookwood Cemetery in Surrey, is made of smoothed but unpolished granite, possibly from Scotland (Fig. 4). The inscription in white lettering, still clearly visible reads:

TO THE MEMORY OF A BELOVED SON
RODERICK GEIKIE
WHO DIED 6 DECEMBER 1910, AGED 36
THE CARE OF HIM IS WITH THE MOST HIGH
AND
TO HIS MOTHER
ALICE GABRIELLE
PIGNATEL
WIFE OF ARCHIBALD
GEIKIE OM KCB
BORN 13 SEPT 1852
DIED 21 JAN 1916

Fig. 6. The experimental site at Wytham Woods near Oxford. (Photograph courtesy of the Oxford Rock Breakdown Laboratory (OxRBL).)

Although it is not known whether he chose the stone for his own tombstone, Geikie's own grave in the Derby Road Cemetery in Haslemere in Surrey, UK, is also made of granite with a smooth, but unpolished, surface (Fig. 5). The slightly pink or orange tinge to the stone suggests that the feldspar in this granite may be a potassium-rich variety, and may have come from the granite quarry at Peterhead in Aberdeenshire, Scotland.

The gravestone, a Celtic cross with rope decoration, bears an inscription in slightly raised lead lettering that reads:

TO THE DEAR MEMORY OF
ARCHIBALD GEIKIE OM KCB
BORN IN EDINBURGH 28 DEC 1835
DIED AT HASLEMERE 10 NOV 1924
WISDOM IS A TREASURE THAT
NEVER FAILETH WHICH THEY THAT
USE BECOME THE FRIENDS OF GOD

A metal plaque attached on one side of the plinth commemorates his three daughters:

Lucy Isabell A. Webb 22.7.1872–11.6.1953
Elsie Geikie 14.7.1877–23.11.1915
Gabrielle Jeanne Behrens 20.9.1880–21.4.1958

Following on

The study of weathering in gravestones continues to play an important role in studies of rock weathering and in conservation of stone. Among the earliest studies were those undertaken by John George Goodchild (Goodchild 1875, 1890), who documented rock weathering on the basis of his observations of weathering in gravestones in the churchyard at Kirkby Stephen.

More recently, gravestones have been used by researchers to study the effects and rates of weathering in stone. Examples include studies by Robert Inkpen of the Department of Geography at the University of Portsmouth, UK, which examined weathering rates in urban and rural areas in southern Britain (e.g. see Inkpen & Jackson 2000), and research by M. J. Thornbush of the University of Birmingham, UK, and S. E. Thornbush of the University of Edinburgh on the application of a limestone weathering index in churchyards in central Oxford (Thornbush & Thornbush 2013). More recently, gravestones in two cemeteries located on the Isle of Portland, Dorset, UK have been studied to provide data on surface hardness as a proxy for weathering behaviour of limestone (Wilhelm *et al.* 2016).

In addition, old or unused gravestones made of an Upper Jurassic limestone, known as Portland Stone, and sourced from the Commonwealth Graves Commission were used in a Leverhulme-funded project which began in 2007. As part of the research, experimental sites located at Wytham Woods near Oxford, UK and at Wakeham, UK on the Isle of Portland in Dorset were set up in 2009. As well as gravestones, the sites also included automatic weather stations and soil water probes (Fig. 6). A major the aim of the project was to assess the impact of predicted climate change on the deterioration of limestone monoliths (Eklund *et al.* 2017). The project concluded in 2011, and results have yet to be published. However, the Wytham Woods site still stands and is now being used for other research (Eklund pers. comm.).

The results of these and other studies using gravestones to study rock weathering are already being applied by conservation organizations including Historic Scotland (Maxwell *et al.* 2001).

Beyond the graves

Gravestones are now also playing an important role in the teaching of geology and in science outreach aimed at the general public. The use of gravestones for these purposes was championed by Dr Eric Robinson, now retired from the Department of Geology at University College London (UCL). In the 1980s and beyond, Robinson regularly led amateur groups around cemeteries to examine the different types of stone used for gravestones and the geological features which could be seen in them. As a result, he did much to promote interest in geology among the public at large, as well as to inspire other geologists to take advantage of stone in the urban environment as tools for teaching and science outreach. The excellent geological walks devised and published by Dr Ruth Siddall (Siddall 2014) and gravestone-based teaching materials created by Professor Wendy Kirk (Kirk 1999–2017), both colleagues of Robinson at UCL, are just two examples. Robinson's recognition of the teaching and outreach potential of gravestones has also encouraged the preparation of a number of geological walk leaflets highlighting the geology that can be observed in gravestones (e.g. see Cheshire RIGS undated), and was the inspiration behind a recent book highlighting the geology of gravestones in Oxford (Morgan & Powell 2015).

Given Geikie's great interest in science communication and talent for popular writing about geology, he would surely be pleased with this outcome.

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