BATH GEOLOGICAL SOCIETY

Journal

No 39, Winter 2021

SOCIETY ACTIVITIES 2021

LECTURE PROGRAMME

January 7th
Prof. Maurice E. Tucker, Fossil Viruses: Viruses are the New Frontier in Earth Sciences.

February 4th
2021 Bath Geological Society AGM followed by
Prof. Tom Blenkinsop, University of Cardiff, Ballistic Impacts in the Cosmos and in Combat.

March 4th
Dr. Hazel Beaumont, University of the West of England, Sediments in Rajasthan, India.

April 8th
Dr. Catherine Klein, formerly of the University of Bath, Snake and lizards through time: what fossils and molecular data can (and cannot) tell us.

May 6th
Prof. Malcolm Hart, Emeritus Professor of the University of Plymouth, A Bug's Life.

June 3rd
Dr. Doug Robinson, University of Bristol, The making of the Mendip Hills.

July 1st
Dr. Haydon W. Bailey, Network Stratigraphic Consulting Ltd. (Retired), Scientific Associate, Natural History Museum, London. The Forensic use of calcareous microfossils, with particular reference to the Soham murder case.

August 5th
Dr. Sam Medworth (Bath Geological Society), Dr Arthur Hutchison - Petroleum Geology from 1929-1949.

September 8th
Matt Williams, Manager of Collections, BRLSI, Strawberry Bank, Bath Royal LSI, and Moore

October 7th
Dr. Chris Spencer, University of the West of England, Extreme Wave Events.

November 4th
Peter Larkin, Director & Owner at Maven Energy Services Ltd, Geoscience and some aspects of the global offshore energy sector .... and a day in the life.

December 7th
Professor John Marshall, School of Ocean & Earth Science, University of Southampton, UV-B radiation was the terrestrial killer at the Devonian-Carboniferous boundary.

December 16th
Zoom Social—quiz and kitchen workshop geology
Leaders: Graham Hickman and Jonathan Slack

FIELD MEETINGS

May 2nd
Portland & Chesil Beach
Leader: Prof. Maurice Tucker, University of Bristol and BGS.

June 9th
Deer Leap and Ebbor Gorge , Wookey Hole area
Leader: Dr. Doug Robinson, University of Bristol.

July 7th
Bath Geological Society Fieldtrip to Murhill, Avoncliff and Winsley
Leader: Prof. Maurice Tucker & Graham Hickman

September 23rd
Vale of Wardour
Leader: Steve Hannath, Wiltshire Geology Group

September 25th
Bath Geological Society Field Trip to Thornbury, South Gloucestershire
Leader: Charles Hiscock

October 16th
Field Trip to Clevedon
Leader: Prof. Maurice Tucker

Other Events

October 17th
WEGA North Yorkshire Coast Field Trip
Leader: Dr. Liam Herringshaw of Hull University and Will Watts, local geologist

November 6th
2021 Reunion of the Geologists' Association

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Cover photo: Cliffs of Moher with O'Brien's Tower. See article on pg. 5

Chairman's Report

2021 has been a bit of a roller coaster year as we have moved through the COVID-19 pandemic. At times it had been hard to keep track of the change in Lock-down rules, the latest Tier system and the spread of new variants! The good news has been the early and efficient rollout of the Covid-19 vaccine. The strong vaccine take -up seems to have reduced the hospitalisation associated with the virus and allowed the country to start getting back to normal.

Despite all the uncertainties the Society has been able to deliver a full programme of lectures, albeit remotely using Zoom and during the second half of the year a significant programme of field meetings. Our membership currently stands at 69 which is a healthy number and reflects the enthusiasm that the committee have shown in putting together the programme. The committee has continued to meet remotely to conduct the business of the Society. In February we held the 2021 AGM over Zoom appointing and welcoming Katie Munday as our new Secretary.

Lectures

Our lecture programme has covered a wide range of geological topics and we hope you have found them stimulating. We have received positive feedback and we are grateful to the speakers who have provided some excellent and interesting presentations. Of particular note was the lecture given in February by Professor Tom Blenkinsop on ''Ballistic Impacts in the Cosmos and in Combat.'' This lecture stimulated discussion on the WWII bomb damage in Bath and prompted Maurice Tucker to undertake several surveys and write three articles for the newsletter.

Another lecture of particular note was the one by Dr Doug Robinson on 'The Making of the Mendip Hills'. The timing of this was particularly well planned as it preceded the field trip Doug led the following week. This model of a lecture ''briefing'' ahead of a field trip allows attendees to get the most out of the information being shared.

Normally the Society doesn't hold lectures in January or August as turnout has been poor due to proximity to holidays. However, the low cost and flexibility of using Zoom has enabled us to add additional lectures to the programme, this included Professor Maurice Tucker's talk on Fossil Viruses in January 2021 and Dr Sam Medworth's talk about his ancestor Dr Arthur Hutchison in August 2021.

As restrictions were gradually lifted in September, we met physically in BRLSI to view the temporary exhibit of the Strawberry Bank Fossils and to hear Matt William's lecture. It was an extraordinary feeling to get back together for the first time for 18 months and to clap together after the lecture. As well as a physical audience, of around 30 people in the lecture room, we were able to broadcast the event over Zoom to a further 11 people online. We are hoping to be able to continue hybrid meetings as we believe it will be popular to some of our more remote or elderly members. Hybrid meetings were held for September, October, November and December. The Society purchased a lapel microphone which made a significant improvement to the sound quality for those listening online

Field Trips

We had planned to run our annual field trip and clean up to Browns Folly on March 6th 2021 however as the UK was in lockdown for much of the Spring and numbers for outdoor meetings limited, we decided not to hold this event. From May 15th 2021 these restrictions were lifted and we added several additional field trips during the second half of the year. I know some people were unable to attend due to the short notice given and I apologise for this. It was felt that it was better to run a trip at short notice than risk cancelling again should the rules and circumstances change.

Fig. 1: Portland Field Trip – May 22nd 2021

Fig. 2: Mendips Field Trip – June 9th 2021

Fig. 3: Murhill & Winsley Field Trip – July 7th 2021

The 2021 Committee

Chairman: Graham Hickman
Treasurer: Phil Burge
Secretary: Katie Munday
Membership Secretary: Polly Sternbauer
Meetings Secretary: Anne Hunt
Journal & Zoom: Mellissa Freeman
Field Trip Secretary: Sue Harvey
Field Trip Safety: Bob Mustow
Webmaster: James McVeigh
Linda Drummond-Harris
Professor Maurice Tucker

I have been very grateful to the hard work and commitment of the Committee during the year. Their efforts have resulted in the delivery of a full programme of lectures and field trips. The circumstances of working remotely have required additional email communications, updating of the website and producing the newsletter/journal. Communicating with new members and keeping track of our finances.

Under normal conditions the committee meets 3 or 4 times per year but under these situations we have met virtually about 6 times. The strength of a Society like ours is measured by those who volunteer their time and I am indebted to those on the committee.

The introduction of a newsletter last year has been a useful tool for communicating upcoming events and news. It also provides an opportunity for members to write and share, please contribute.

If you have any comments or suggestions, we would love to hear from you. On behalf of your committee, thank you again for your support.

Graham P Hickman
chairman@bathgeolsoc.org.uk

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Moher, more and yet more Carboniferous in Ireland

By Charles Hiscock

Ireland, despite its small area, can boast representative rocks and formations from most of the geological periods, from the Precambrian gneiss of south east County Wexford to the Tertiary basalts of County Antrim, overlain in much of the island by post-glacial deposits. However, it is the Carboniferous outcrops that provide about 65% of the land area with the rocks ranging from sandstones, shales to limestone.

Towards the end of the Devonian period, during which Ireland was part of north west Europe, the continent sank and was covered by a warm calcium-rich sea. Great areas of coral reefs were formed which eventually created the Lower Carboniferous Visean limestone (315-325 mya) that outcrops across Ireland, in the Bristol area, Mendip and the rest of the UK. This was followed by extensive deposition of sandstones and shales during the Upper Carboniferous Namurian era (299-315 mya). As the period advanced, so the sea became shallow until eventually swamps and tropical forests provided the organic matter that became the coal deposits of the Coal Measures. During the Triassic period, wide ranging and intense erosion occurred in a desert environment which stripped off most of the coal measures and much of the sandstones and shales. This left Ireland with very small outcrops of Coal Measures, principally in Counties Carlow and Tipperary of central south east Ireland with larger outcrops which were mined in Counties Leitrim, Kilkenny and Cork.

Today, much of the Carboniferous outcrops are covered by bogs which have formed since the last ice age and by soils which have been exploited for agriculture. However, there are some extensive outcrops of limestone, sandstones and shales and it is these which I will be visiting in the following paragraphs. Fig. 1 is a generalised map of the Carboniferous outcrop in the area of Counties Clare and Galway (courtesy of the Burren Centre, Kilfenora, County Clare).

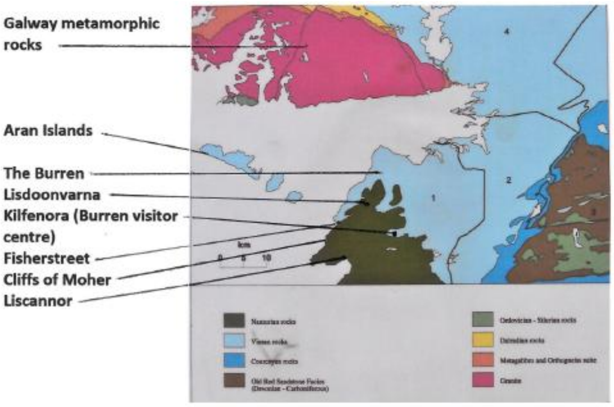

Fig 1: Generalised geology map of Counties Clare and Galway

Cliffs of Moher, County Clare

The Cliffs of Moher on the Atlantic coast of County Clare are famous for being some of the highest sea cliffs in Europe. Rising to 214 metres/702 feet at their highest point, Knockardakin, they stretch for over 8 kilometres from Liscannor to Fisherstreet near Doolin Pier on the southern edge of the Burren. A distinctive feature of the cliffs is that the drop into the Atlantic Ocean is generally vertical, caused by the almost level bedding of the rock layers that make up the cliffs giving the more intrepid (or foolhardy!) the chance to sit on the edges of the almost flat rock platforms, dangling their legs over the edge.

The Cliffs of Moher were laid down during the Namurian era (299-315 mya) of the Upper Carboniferous period with the Cregg Limestone Formation to the south of the visitor centre and the Gull Island Formation to the north at a time when warm seas covered most of the present western European landmass.

The area of the Cliffs was the warm sub-tropical delta of a large river that originated in a plain to the north and west of present-day Ireland. The river supplied much silt, sand and mud, particularly during flood events at times of high rainfall, which blocked the channels of the delta causing the river to flood and develop new channels to the sea. The lowest deposits of sediment became lithified into sandstones and shales forming the foundations of the Cliffs. River erosion, tectonic movements and changing sea levels caused the deltaic sediments to be inundated by the sea and covered by marine sediments. In the Cliffs, five cycles of deposition can be recognised; each cycle commencing with a layer of black shale on the underlying formation followed by beds ranging from a few centimetres to metres in thickness. The lowest shale bands are rich in trace fossils and are superbly displayed in the upright Liscannor flagstones that line the viewing platforms.

Fig. 2: Liscannor flagstone with trace fossils

The flags show the burrows and feeding trails of marine worms, crustaceans or arthropods. The traces meander seemingly at random as the animals fed on or near the surface of the sediment. Closer inspection shows the traces have two lateral furrows along each edge and most show a median ridge or furrow, presumably the imprint of the tail of the animal (Fig. 3).

Fig. 3: Close up showing Scolicia traces

They have been assigned to the ichnogenus *Scolicia* (Hantzschel W. 1989). Many of the large flagstones display fossil ripples on which the trace fossils can be seen while small circular burrows are also present on the flags but difficult to spot (Fig. 3). Just below O'Brien's Tower, built in 1835 for the Victorian tourists, is the sea stack Branaunmore. Once attached to the cliffs but now some distance away, the distinctive cycles that exist in the Cliffs can be seen although binoculars are needed to appreciate the geology (Fig. 4).

Fig. 4: Braunanmore sea stack

The flat even layers of the basal beds have been quarried nearby at Moher and Liscannor quarries since late Victorian times and used for paving and decorative stone facings all over Ireland. The town of Lisdoonvarna not far from the Cliffs has Liscannor flags as paving in the streets and the town square. The flagstone slabs have been used inside the Cliffs of Moher visitor centre along the walkways at the top of the cliffs to keep the public away from the edge. Here they are set vertically with the trace fossils facing the visitors that view the Cliffs, but most do not give the superb trace fossils display a second glance.

Fig. 5: Fossil ripples with trace fossil scolicia

Sadly, it was felt that, apart from the visual presentation in the visitor centre, the geology of the Cliffs was given scant attention at the cliff top and there was no information about the traces or ripples on the flags (Fig. 5).

The Cliffs of Moher are a spectacular natural feature on their own but there is also the huge number of birds that live on them. Large numbers of Puffin, Razorbill, Guillemots, Fulmar, Kittiwake and Shags nest on the Cliffs, some only returning in the early spring to breed. On the sea stack, the white lines marking the bedding planes of rock is the guano that has built up over a long time from the nesting and roosting birds. Less common are Greater Black Backed Gulls and Peregrine Falcons. Flowers such as Ragged Robin, Kidney Vetch, Sea Pink, Sea Campion and many orchids can be found along the cliff top. The natural wonders of the Cliffs of Moher seem timeless, but the fierceness of the Atlantic Ocean is gradually eating away what seems an impregnable fortress of rock, attacking the softer layers so that the harder beds eventually collapse into the sea.

References: 'Cliffs of Moher, County Clare, Ireland Guidebook' & Hantzschel W. 1989 'Treatise on Invertebrate Paleontology, Part W – Miscellanea, Supplement 1 'Trace Fossils and Problematica'

Doolin, County Clare

The Cliffs of Moher stretch north from the visitor centre for about 3 miles to Fisherstreet, all the time gradually losing height until they are only about 100 feet high just south of the village harbour (Fig. 6).

Fig. 6: Cliffs of Moher south of Doolin Pier

The footpath from the visitor centre viewing platform leads along the cliff top, very close to the edge of the cliffs and in one place has fallen into the sea making the walk particularly scary. The harbour for Fisherstrreet is Doolin Pier where, during our walk, the waves were breaking well up the Cliffs at high tide. It is at Fisherstreet that a contrast in the geology becomes evident. Running down through a shallow valley, the River Aille follows the unconformity between the shales and siltstones of the Cliffs of Moher, the Clare Shale Formation, and the limestones of the Burren Formation (of which more later). To the south of the river mouth, the dark level beds of the Upper Carboniferous shales and siltstones of the Gull Island Member exposed in the cliffs are eroded well back compared to the limestone cliffs exposed at Doolin Pier where the level bedding forms low vertical cliffs (Fig. 7).

Fig. 7: Sea cliff, Doolin Pier

The River Aille runs off the hills inland from the Cliffs over the impermeable shales and siltstones, collecting small tributaries as it approaches the sea. As if to confirm the dramatic change in geology with the river very low due to the long dry period, the water could be seen but when it reached the limestones just seawards of Doolin bridge (Fig. 8), it disappeared through swallets leaving a virtually dry riverbed (Fig. 9), not appearing again until the sea was reached.

Fig. 8: River Aille below Doolin Bridge

Fig. 9: River Aille below Doolin Bridge

At about 325 mya, the basin deepened rapidly causing the deposition of limestone to cease. The only sediments that were laid down for 5 million years were the bones and teeth of fish and marine creatures forming thin layers of phosphate material which, at Doolin, was up to 2 metres thick. In the 19th and early 20th centuries, this phosphate was mined for fertiliser, being for a time the richest source of phosphate worldwide. Following this quiet period, the river deposited large amounts of silt and sand to form the deep layers of the Clare Shale Formation.

At Doolin Pier, limestone beds dip west at a very shallow 2-5 degrees and display the typical limestone pavement features of clints and grykes (Fig. 10). At Doolin Pier, the flora that is associated with the microclimate of limestone pavements such as Purple Cranesbill, Bird's Foot Trefoil, Sea Pink, Rock Rose and Tormentil are particularly fine as they exploit the grykes to extract moisture and nutrients from the otherwise dry environment.

Fig. 10: Limestone pavement, Doolin Pier

The Burren National Park, County Clare

The headland of Carboniferous Limestone at Doolin Pier is the most south western tip of the famous area of Ireland known as the Burren (from the Gailteach *Boireann* meaning 'great rock). It covers an area between the villages of Lisdoonvarna, Corofin, Ballyvaghan and Kilfenora where, at the latter, is an excellent visitor centre with displays and videos about the Burren. Exceptionally, there is a full description of the geology of the Burren accompanied by geological survey maps which allow one to put the area into perspective to the rest of the Carboniferous outcrops of Ireland. The Burren is formed mainly of early Carboniferous limestone of Visean age (approx. 325 mya). The Burren Formation itself is subdivided into 7 separate members composed variously of limestone, sandstones and shales. Later, about 318 mya, the Visean rocks were covered by sediments of the Namurian Clare Shale Formation up to a depth of about 1000 feet which protected the underlying limestones for millennia until the onset of the Pleistocene glaciations.

While large areas of Carboniferous limestone are not unusual throughout the British Isles with limestone pavements present in parts of the UK, it is the effect of glaciation that has shaped the Burren (Fig. 11) making it one of the finest glacio-karst landscapes in the world (*glacio* -of ice, *karst* – from the karst region of Slovenia where similar features are present). About 1 million years ago, the Ice Age commenced during which glaciers advanced and retreated many times over Ireland with the last couple extending right across the Burren. Thus, the scenery we see today is the result of the last glaciation of about 10,000 years ago. The effects of the earlier ones have been destroyed. However, since that time the effect of rain, acid solution and the flora has opened the cracks in the limestone to form the characteristic grikes (Fig. 12) in which many plant species, some rare, can retain a foothold. There are no permanent surface rivers in the Burren but underground water has opened up cracks and joints in the limestone forming extensive cave systems.

Fig. 11: Pavement and erratic in the Burren

Fig. 12: Clints and Grykes, the Burren

A legacy of the glaciers is the abundant boulders, glacial erratics, (Fig. 13) that lie on the limestone surface and can be seen over much of the Burren. In addition, the area has been occupied by humans over millennia with many cairns and chamber tombs scattered across the Burren using the abundant glacial erratics, such as the one at Poulnabrone north of Kilfenora. A chamber tomb that is much less obvious, again using a large flattish boulder as the cap stone and situated in a large depression in the limestone, can be seen near the sea at Doolin Pier.

Fig. 13: Glacial erratic boulder, the Burren

Rosses Point and Hill of Knocknarea, County Sligo

Travelling due north up the west side of Ireland from Doolin and giving the metamorphic and igneous areas of Connemara and Galway a miss, one continues to pass over Carboniferous limestone for a distance of about 100 miles. About 4 miles north west of the town of Sligo, at the headland called Rosses Point, the Carboniferous limestone is exposed in the cliffs that form the northern and southern 'bookends' to the sandy beaches. Here however, the thin limestone beds are interleaved with dark shales and frequent bands of blue/black chert. The chert is abundant as beach pebbles and although the surfaces give the impression of fossils, it is not possible to make any identification. Within the limestone there are abundant fossil corals, brachiopods and trace fossils; a high proportion of which are preserved in the black chert and often found as beach pebbles (Fig. 14). At the back of the beach on the north side of Rosses Point is the Lower Carboniferous Dartry Limestone Formation, a medium grained limestone with frequent continuous black chert bands. Immediately under Rosses Point is a similar grey crinoidal limestone with chert bands, the Ballyshannon Limestone.

Fig. 14: Lithostrotion pebble (Rosses Point)

Not far distant from Sligo are two isolated karstic hills, Benbulbin, a few miles to the north, and Knocknarea about 5 miles south west. Both stand up high above the surrounding country with steep, in places vertical, scarp faces which are the result of the last glaciation. Except for the well-equipped mountaineer or rock climber, Benbulbin is inaccessible but not so Knocknarea. The latter rises near the village of Strandhill and can be accessed from a narrow road that climbs over its eastern end where a dedicated car park enables the explorer to start walking. The footpath immediately starts to rise, gently at first, as a rough track with small step-like terraces as each bed of limestone is reached. Alongside the track on both sides are dry stone walls composed of rough, unshaped limestone blocks, a high proportion having abundant fossil corals mainly *Lithostrotion,* and *Syringopora* species and crinoidal remains. As the hill is climbed, so the gradient becomes much steeper and the surface is littered with loose limestone, much of the loose material being fossil corals. Knocknarea can be said to be a large fossil coral reef. However, where the fossils have been replaced by silica the structure of the fossils is etched out of the limestone by erosion. A specimen of *Michelinia* species picked up from the path demonstrates the siliceous preservation and subsequent erosion (Figs. 15 and 16). Like the limestone at Rosses Point, Knocknarea is formed of the Lower Carboniferous Dartry Limestone Formation with abundant bands of blue/black chert formed when the sediments were compacted and lithified.

Fig. 15: Coral Michelinia sp (Knocknarea)

Fig. 16: Detail of Michelinia

The isolation and elevation of Knocknarea appealed to Neolithic people as much as it does now except they used it for ceremonial and religious purposes and about

3400 BC built the great cairn on the top, the legendary grave of Queen Maeve of Connacht who was an Iron Age chieftain about 300AD. Also, there are 8 other cairns, passage tombs, enclosures and monuments built on the hill around the same time. One particular feature of the great cairn is that, as well as limestone, the variety of stones and boulders include many of which are of igneous and metamorphic origin. Maybe the people who used the cairn as a ritual and ceremonial site came from as far afield as Galway, Connemara, and brought offerings in the form of their local often colourful, stone.

Reference – Knocknarea – Westrup R – Sligo – County Geological Site Report & Rosses Point – The Natural History of Sligo and Leitrim.

Whatever the interest of the visitor to Ireland, there are a wealth of attractions matching those of countries across the world and this corner of the Emerald Isle with its attractions can satisfy most requirements. When the attractions have been visited and one leaves the tourist honeypots, it is a peaceful, restful and friendly place.

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WELLS CATHEDRAL SCHOOL

Remote learning at Wells Cathedral School

by David Rowley (Head of Geology at Wells Cathedral School)

Introduction

There are approximately 200 schools and colleges teaching A level geology. The course is broad and scientific emphasising the distinctiveness of geology in its own right as well as its interconnections with the other sciences and geography.

The last two years have proved challenging for society and in this article, I will reflect on the ways in which one school in particular was affected by and coped with the peculiar circumstances of ‘remote learning’.

Wells Cathedral School is where I have taught geology (and geography) for over thirty years. (For those unfamiliar with the terminology it may be worth mentioning that ‘senior school’ begins in Year 7, GCSE year is Y11 and A levels are completed in Y13.) It is a wonderfully busy, thriving school of boys and girls, day pupils and boarders, British and overseas pupils, from 3 years old – 18 years old. Around a quarter of Wells pupils are talented specialist musicians who balance their musical & academic commitments within a ‘conventional’ school of hockey, rugby, cricket, Duke of Edinburgh’s Award, CCF, drama, outdoor education and much else besides.

Introduction of Lockdown

In March 2020 just prior to Government restrictions coming into force, teachers from W.C.S. went to their classrooms, gathered textbooks, folders and other resources and prepared to start teaching from home.

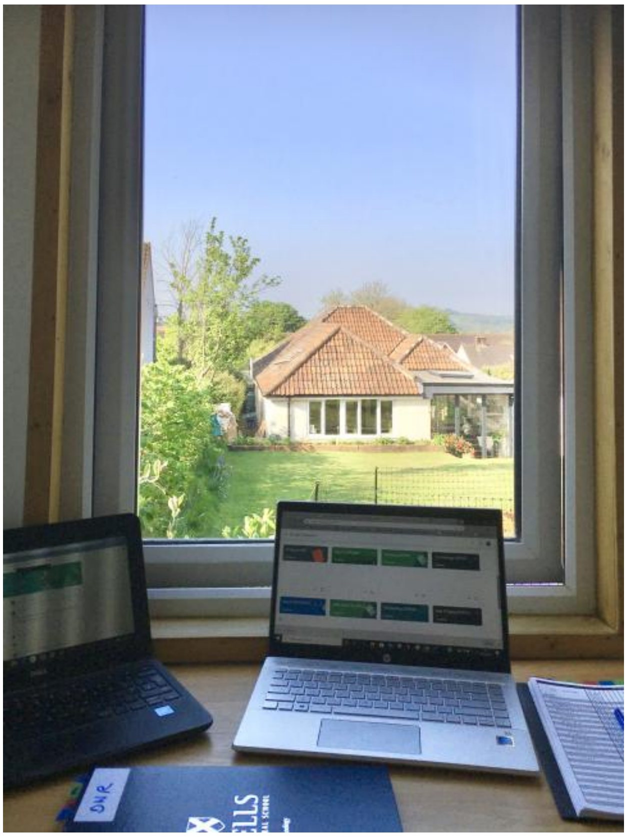

Fig. 1: the classroom

Our school’s ‘bring your own device’ policy (which requires pupils to bring a Chromebook/laptop to all lessons) had been in place for three years and was about to play a crucial part in our ability to engage with pupils remotely and deliver worthwhile & stimulating lessons.

The ‘Google Classroom’ is an application allowing teachers to post worksheets, instructions and resources online for both lessons and homework. Remote learning required us to make full use of the Google Classroom as well as ‘Google Meet’ (the equivalent of Zoom).

We were fortunate that the use of the Google classroom was already part of our usual working practice, and that the skills required for us to use presentations, documents and spreadsheets were well established among (most) pupils and teachers.

So, with all this in place, how did the school adapt, what was the learning experience like, and what were the challenges?

School-wide adaptations

One way systems, year group bubbles, social distancing, hand sanitising & mask wearing became the norm. Meetings and assemblies were livestreamed to tutor groups and classes in their ‘bubbles’. Teachers were not allowed to linger in the staffroom, pigeonholes could be checked but social areas were out of bounds. Teachers retreated to their classrooms for sandwiches at lunchtime while pupils were admitted to and seated in the dining hall strictly by year group. Before long (and quite unexpectedly in some cases) humanities teachers craved the company of mathematicians, while scientists missed spending break time with the English department!

Remote learning

In geography & geology pupils had contact with their teacher (albeit remotely) in almost every lesson. Some classes were inevitably in more of a lecture style with PowerPoint presentations made available to pupils, in others the teacher facilitated the completion of online worksheets or other tasks following a live (or recorded) introduction.

The school looked to manage the inevitable increase in 'screen time' by minimising homework and made other adjustments from time to time to look after the wellbeing of teachers and pupils. For instance, our scheduled lessons on Saturday mornings (for Y9-Y13) were relocated into midweek slots so that pupils had a complete weekend break, lessons were reduced from 60 minutes to 50 minutes to create breathing space and time away from a screen.

From my experience, many pupils seemed to enjoy working hard until 4pm knowing that they had then finished for the day with no homework!

To begin with, a sea of faces greeted the teacher in 'Google Meet' lessons, but increasingly & unsurprisingly over a period of weeks emojis took the place of human faces as pupils turned their cameras off. Compromises were necessary to ensure that video cameras were switched on at important times in lessons and some leeway was given when pupils were 'getting on with work'. Skilful use of the chat function by the teacher and apps for pupils to 'raise a hand' or give a 'thumbs up' kept pupil engagement high. As in most lessons there would be those who are naturally active, some who are engaged (soaking it up) but not regularly contributing their ideas and others who need more encouragement to get involved.

Some hard-working quiet pupils saw remote lessons as a way to get on with their work, achieve good marks and perhaps feel less pressure to interact with the teacher and their peers. One positive was that by March/April 2020 the classes were already in the middle of the school year, good classroom relations had already been established and teachers already knew the pupils well when lockdown began.

Wifi and broadband issues at home created some legitimate reasons for pupils to switch their cameras off and also created the need for many lessons to be recorded for pupils to watch/re-watch at a later date. With a number of our pupils living in other time zones (particularly in Hong Kong), our afternoon lessons were in their late evening so those international pupils weren't required to attend 'live' but could catch up prior to the next lesson by watching the recordings.

Our international pupils would later create challenges for teacher-based assessments further down the Covid line.

Teaching and learning was intense, we roughly kept pace with our schemes of work, but pupils couldn't develop the expected level of practical and fieldwork knowhow. Term ended in summer 2020 with the full expectation that we would be able to catch up in the school year 2020/2021 with things 'back to normal'. However further Covid positive tests meant that some pupils continued to have to isolate into the new school year.

Practical lessons and fieldwork

Though practical lessons and field trips were not possible, creative solutions were employed to try to simulate those essential practical experiences.

Field sketches (https://www.e-rock.co.uk/broadhaven)

Fig. 2, virtual field trips (http://www.see.leeds.ac.uk/virtual-landscapes/demo/) & the 'Instagram challenge' in which pupils found spectacular field locations on Instagram and planned what observations & measurements they would make before comparing locations with a friend.

Figs. 3 & 4: Practical lessons involving hand specimens were also moved outdoors when the weather allowed

By Autumn 2020 some local field trips were again allowed, however restrictions were in place to make them Covid-safe:

- A seating plan was used for both outward and return minibus journeys.
- Masks were to be worn on the vehicle.
- No sharing of equipment was allowed, equipment (such as hand lens, compass & clinometer) was sanitised, individually issued in a Ziplock and sanitised prior to reuse. (Fig. 5).
- Working safely is one of the assessment criteria for A level geology fieldwork and so pupils updated their own risk assessments to include COVID.
- Careful choice of locality to facilitate easy social distancing among the group (Fig. 6).
- Teacher used a laser pointer to guide pupils to maintain social distancing.

Fig. 5: sanitised field equipment

Fig. 6: pupils observing social distancing

Blended learning

Though the number of actual positive Covid tests was thankfully small throughout the Pandemic, overseas pupils, travel restrictions & self-isolation created the need for 'blended learning' in which most pupils were back in the classroom with others joining lessons remotely.

This situation lasted from September 2020 through until Easter 2021, by which time lessons were almost back to normal. When physical lessons were possible, rigid seating plans were in place and pupils were required to sit facing forward rather than clustered around a table to facilitate group work.

Blended learning for geology practical lessons proved particularly difficult to coordinate, photographs or webcam images being a poor substitute for hand specimens. When sufficient hand specimens were available, they were allocated to pupils individually and not passed around.

CAGs and TAGs

In 2020 Centre Assessed Grades (CAGs) were used, these were effectively predictions based upon the work pupils had achieved thus far and rewarded the steady hard workers. This caused a certain amount of alarm for those pupils who tended to leave things to the last minute, as there was no terminal assessment and teachers were asked to use a range of past paper tests, homework and grades accumulated over the course. Based on these data teachers were asked to award a grade based on pupils' likely performance in a summer exam based on and extrapolated from past performance. Pupils were ranked within each letter grade; a government algorithm was then used to modify the results to approximate the performance in previous school years in that subject. Across the country grade inflation was an inevitable consequence of the system, with centres erring on the side of the candidate, yet the system was evidence based with 'umpire's call going in the batsman's favour'. With a cohort of between 8 and 10 pupils, geology doesn't have the numbers to reliably demonstrate a 'normal distribution', in my admittedly small sample the algorithm took our weakest pupil (a solid C grade) and awarded him an E despite evidence to the contrary, seemingly because some previous cohorts had E grade candidates.

By 2021 the system was modified to become 'Teacher Assessed Grades' (TAGs). Summer *externally assessed* exams were cancelled with plenty of warning given to schools, pupils, and parents. The instructions were to use a range of data to inform the grade, which was to be awarded, based solely on performance, not with an eye to 'what they would have got in the summer exam'. Various pieces of evidence were eligible to be used including end of topic tests, mock exams, essays and a series of internal tests held in exam conditions in the summer term (with exam boards providing additional assessment resources.

The administrative process did cause considerable anxiety for teachers, each school/college having its own set of peculiar challenges and there was inevitable variation between centres on how they graded their candidates. Pupils in other parts of the world were being assessed online with little possibility of true exam conditions, and time zone considerations were needed when planning tests.

As geology is a one-person department, I collaborated with a colleague in a similar position at another school to ensure that our assessments were fair and appropriate in the planning stage as well as cross moderating each other's marking. Ultimately the range of assessments used did everything to confirm the ability our opinions of the candidates and as such was fair and reassuring.

CONCLUSIONS

The pupils at Wells were well served during the COVID -19 pandemic and engagement in learning was high in most cases despite the challenges. The cohort missed out on some fieldwork opportunities (not least a trip to Iceland) but good use was made of localities within walking distance and the relaxation of restrictions did enable some trips to take place.

Fig. 7: Colima Volcano, Mexico

The variety of content which is an essential feature of geology helped to maintain interest, it was also great to be able to draw upon former pupils to deliver talks in remote lessons on topics such as the 'Colima Volcano' Fig. 7 and 'Exploration geology in Africa' to help inspire the next generation.

It is good to be able to move forward having developed some new skills, as well as being able to return to the familiarity of classroom teaching & learning.

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Moving Stone: Lewis bolts – their use by the Romans in construction of Aquae Sulis (Bath) and elsewhere

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Have you ever wondered how the Romans moved and lifted the commonly huge blocks of stone used in the construction of their temples, amphitheatres and civic buildings? This short article explores the use and history of the lewis bolt, an ingenious tool devised by the Greeks, used extensively by the Romans, but with continued use through medieval times until the early-20th century (Fig. 1). Lewis bolt holes are documented here from the Roman Baths at *Aquae Sulis*, Bath, and elsewhere, and compared with 18-19th century examples.

Fig. 1: Five lewis bolts from David Pollard's collection from the Box-Corsham mines. The total length of the largest (top left) is 53 cm.

Introduction

The Greeks and Romans constructed many wonderful substantial buildings which in many cases utilised large blocks of natural stone. The Roman Baths and Temple Complex at the World Heritage Site of *Aquae Sulis* in Bath is typical. Those blocks of Middle Jurassic oolitic limestone (Bath Stone), you see around the Great Bath and below present ground-level in the Precinct of the Temple to Minerva, each weighs a tonne or more (a cubic metre of limestone weighs approx. 2.3 metric tonnes). They would have required some real effort and ingenuity to raise them up to heights of several to many metres, let alone extracting the stone from the quarries around Bath in the first place and then transporting them down to the expanding town. To lift or pull the stone blocks the Romans used a particular device known as a *lewis bolt* (Fig. 1) and the evidence for this is seen in the elongate holes chiselled into the stone by the masons. Fig. 2 show examples from Rome (2A) and Mertola, Portugal (2B) and Fig. 3 one on a column at the Roman Baths, Bath.

Fig. 2 A: Two stone blocks near the Forum, Rome, with bolt holes (approx. 10 cm in length).

Fig. 2B: Bolt hole in granite block in wall of Roman fort (later rebuilt), Mertola, Portugal

History of the lewis bolt

Archaeologists have puzzled over the construction of many ancient buildings from the monument of Stonehenge (dated around 3000 BCE), pyramids of Egypt (~2600 BCE), the Parthenon in Athens (447 BCE), the Colosseum and Pantheon in Rome (70 and 126 CE respectively), and Trajan's Column in terms of how and sometimes where the stone was extracted out of the ground then transported and lifted into place. The size of the stones was clearly beyond the capacity of man (or rather several/many men) to move, drag or lift the blocks manually. One of the first accounts of the use of hoisting mechanisms and pulleys in ancient Greece was written around 530 BCE, mainly discussing the construction of the Temple of Artemis at Ephesus (in Turkey). The scientist and inventor Archimedes of Syracuse, living in the 200s BCE, invented many useful devices for civil engineering projects including the compound pulley system and the block and tackle; he also perfected the use of levers. There are several later classical texts describing building techniques, one of the most famous being Marco Vitruvius Pollio's De Architectura: The Ten Books on Architecture. Vitruvius was a Roman engineer living during the time of Julius Caesar and Emperor Augustus. His Book X, written between 27 and 23 BCE, describes various types of crane and the pulley systems that had and were being used in construction projects across ancient Greece and the Roman Empire at that time, as well as the use of treadmills in the lifting process. That Book X also has information on how to build a catapult and siege machines for use in battle! Vitruvius advocated the ideal that all buildings should have three attributes: firmitas, utilitas and venustas, meaning: strength, utility and beauty. These principles were embraced by the Romans in many of their grand buildings. Vitruvius' ten books were even used through to the 15th C in Europe and the Middle East and they had a strong influence on the ideas of medieval architects and building design. Another important scholar, inventor and mathematician was Heron (also known as Hero) of Alexandria who lived in the first century CE and wrote a book called Mechanica. This describes the engineering techniques of Babylonia, ancient Egypt and the Greco-Roman world. Of note is that Heron of Alexandria discussed the use of lewis bolts and noted the risk of injury if they failed; he advocated a good quality of iron as essential. Heron recorded that the nature of the stone itself is an important factor: marble, limestone, travertine and andesite all being suitable for lifting with a lewis bolt, but less good were granite, since it can be brittle, and sandstone, since that is commonly less well cemented. Heron also invented a stream turbine!

One of the earliest cases of the lewis bolt (also called holivela by the Greeks) being used is in the construction of Pergamon, a major city of the Hellenistic period founded around 220 BCE, located in Anatolia, Turkey. The lewis bolt was then a convenient means of pulling and lifting large blocks of stone out from a natural exposure in a quarry or mine and then later for lifting said stones into place at a building site, along with a crane and / or pulley system. The lewis bolt was used extensively by the Romans in the construction of their temples, amphitheatres and walls (etc) across the Empire and it continued to be used in later periods throughout Europe by medieval civil engineers constructing churches and cathedrals. It was used extensively by 18-19th century builders across the world. The use of the lewis bolt waned in the early 20th C as new methods of extracting and lifting stone were devised, notably using compressed air. In England, lewis bolts were widely used to extract Bath Stone, Portland Stone and Beer Stone, indeed, right up until the 1960s, as in Monk's Park Mine, Corsham (as illustrated in Hawkins 2011, p. 188; also see Pollard 2021). These three classic English building stones were used extensively as a freestone and for carving intricate sculptures for temples, churches, cathedrals and civic buildings across the UK and farther afield from Roman times onwards.

The lewis bolt

Although there are several designs of lewis bolt, the most frequent one encountered is the three-legged version (Fig. 1). This consists of three pieces of iron, overall making a dovetail shape that is with two outer triangular / wedge-shaped pieces and a central one, the spacer, which is rectangular. There is a pin or spindle which goes horizontally through a hole in the top of the three iron pieces; a ring or shackle is attached to this bolt. A hole of a dovetail shape is cut by the stonemason with a thin chisel into the stone block and this hole expands into the rock. The two outer wedge-shaped iron pieces are first inserted into the hole, the spacer is placed between them and tapped in. The wedge-shaped end-pieces of the bolt push outward: the greater the weight of the stone, the greater the sideways thrust. The pin and shackle are then attached.

An iron hook with chain or rope is fixed to the shackle and then this is connected to a crane or hoist to be lifted vertically; once tension is applied by beginning to pull or lift the stone, the bolt tightens into the hole. Alternatively, a lewis bolt can be fixed into the side of a stone block so it can be pulled horizontally: by men (or a horse), likely using rollers or a sledge, or in later times, pulled by an engine. In examining stones with lewis bolt holes, a good number have been observed with broken rock around the top of the hole, as if the rock had fractured there.

In terms of how much weight a lewis bolt can take, studies of Roman buildings in the Middle East by Rababeh (2015), as at Gerasa, Jordan, revealed that stones up to 5-6 tons could be lifted with one lewis. The Roman aqueduct at Pont du Gard, France, is made of numerous blocks of limestone, each estimated to be around 6 tons in weight and these were lifted with one lewis. With long pieces of stone (several metres), used in architraves, cornices and friezes, 2 or 3 lewises were commonly used to keep the block balanced while being lifted. In the Temple of Jupiter at Baalbek (Heliopolis), Lebanon, there are several frieze blocks weighing up to 60 tons each which have 8 lewis bolt holes cut into them (Rababeh 2015). The issue with very large, heavy blocks is the tension on the rope or chain and the strength of the lifting crane / hoist. Treadmills were commonly used to pull on the rope and pulleys often used.

Other lifting devices

Two other techniques for lifting blocks of stone used by the Romans should be mentioned. Lifting tongs or grips, are as the name suggests, like giant fireplace tongs: two strong curved pieces of iron (a stretched-out S-shape) fixed together towards one end (like a large pair of scissors and attached to a rope which leads to a hoist / crane. Squarish tapering slots are cut into two opposite sides of the stone towards the top for the ends of the tongs. The holes would be obvious on the side of a block or column, so they were commonly filled in with a cement or the stone was sculpted into a pattern to hide the holes. There is no evidence for lifting tongs being used at the Roman Baths in Bath.

Another method involved leaving a projecting boss on opposite sides of a block or of a drum (part of a column) when it was being prepared above the centre of gravity. A strong rope would then be wrapped around the stone, below these ‘handling bosses’, which then went up to the hoist. Once the stone was in place, the two bosses would have been removed by the stonemason to leave a smooth surface. Apparently, this was the technique used in building the Acropolis in Athens (435 BCE). It has been suggested that handling bosses and lifting tongs were used in the construction of Petra (Jordan) by the Nebataeans (1st century BCE to 1st century CE), since the rock there, a Cambrian red sandstone, is not strong enough to take the lewis bolt (Rababeh et al. 2010).

Lewis bolt holes

The rectangular, dove-tail-shaped holes made for taking a lewis bolt are only occasionally seen at archaeological and other sites. In most cases with a building, the bolt hole would be on the top surface of a stone from when it was hoisted into place and covered by the next stone to form the structure such as a wall or column. Where a bolt hole was left visible it would usually be filled with a cement to make it less obvious or sculpted away.

In the Roman Baths Museum, around the Great Bath especially, and in the stone store, there are many typical lewis bolt holes to be observed (Figs. 3, 4, 5).

Fig. 3: The contrast between Roman (on the left, a column base) and late 19^{th} Century stone (upper right). A bolt hole on the top of the Roman stone is 11 cm in length. Great Bath, Bath.

Fig. 4a & b: Images of lewis bolt holes from Roman stone blocks: surfaces are rather uneven and holes a little crude compared to 18^{th}-19^{th} century holes (e.g., Fig. 6). In the right image there are 2 holes. Roman Baths and stone store, Bath.

Fig. 5: Lewis bolt hole in one end of a Roman column of Bath Stone; length of bolt hole 9 cm. Stone store, Bath.

One has 2 bolt holes (Fig. 4B) and a few extra-large stones have 4 or 5 holes. In some cases, it would appear that the stone has failed around the hole. The most easily observed bolt holes are on the tops of the rectangular Roman column bases located around the Great Bath (Figs. 3 and 4), also on the top of pieces of column, 'drums' (Fig. 5). Although most of these bolt holes are in Roman stone, there are some of these rectangular holes in Georgian and Victorian stone, from the time of redevelopment of the Baths as a tourist destination and health spa in the 18th and 19th centuries (Fig. 6A).

Fig. 6 A: An 18^{th}C bolt hole, length 5.5 cm, from a pediment from the Duke of Kingston's house, built c1750. Note the neat cut of the hole. Stone store, Roman Bath.

Roman lewis bolt holes can be seen farther afield in England: on sandstone blocks forming the abutment for a bridge over the River Tyne at the Roman fort of Chesters, near Corbridge, Northumberland (Morgan 2002), clearly illustrated in Pearson's (2006) book on Quarrying in Roman Britain (plate 18 and Fig. 34). They are also present at the forum of Roman Wroxeter (near Shrewsbury) on the top of column bases (also in Pearson, plate 20). Lewis bolt holes will doubtless be present at many other Roman sites across England where natural stone, especially limestone, was used. Farther afield, lewis bolt holes are recorded across the Roman Empire, especially where limestone and travertine were used (as in Rome itself, Fig. 2A), also Gerasa, Jordan and Baalbek, Lebanon (Tim Lunt pers. comm.). A bolt hole in granite was observed by this author at the Roman port of Myrtilis Iulia, now Mertola, in SE Portugal (Fig. 2B).

Fig. 6B: Bolt hole in a block of Pleistocene limestone at the base of the Royal Naval Clocktower, Bermuda

Elsewhere, a lewis bolt hole has been observed in Bermuda in a block of Pleistocene limestone at the Royal Naval Dockyard Clocktower, constructed 1830 (Fig. 6B). Closer to home, numerous bolt holes are conspicuous on the top of the harbour wall at the Cobb, Lyme Regis, where most have been filled with cement (Fig. 6C). The stone is a variety of Portland Stone known as the Roach, characterised by the presence of fossil bivalves and gastropods (especially Turritella, known as the Portland screw). The harbour wall was constructed in 1825, with the stone being brought from Portland by barge.

Fig. 6C: The Cobb, Lyme Regis composed of blocks of Portland Stone (mostly of the variety Roach), many with bolt holes.

Of particular interest, is a clear lewis bolt hole that occurs in an old quarry in Bath oolite at Brown's Folly, Bathford (Fig. 7; also see Tucker et al. 2020). Bolt holes can also be observed in the walls and roofs of some of the old mines around Bath, as at Murhill for example near Winsley.

Fig.7: Bolt hole in Bath oolite in an old quarry at Brown's Folly, Bathford; dimensions are 10 x 2 cm.

The size of lewis bolts and their bolt holes: a survey

The author has been able to measure the dimensions of 11 actual lewis bolts, that is 7 from the collection of the late David Pollard (5 from Box-Corsham, 2 from Doulting), one each from the Museum of Work at Bath and Combe Down Museum, and 2 from the Beer mines, East Devon. All these bolts are likely to be 19th - early 20th century. The width across at the top of the 3 legs of the bolt below the pin-spindle gives the bolt-hole long dimension (length), and the length of the legs, gives the depth of the hole. From the sizes of the 11 bolts, there are four categories: very small (1 bolt, Combe Down), which would have given a hole length of 4 cm and depth of 8 cm; small (5 bolts), giving a hole length of 5.5 - 8 cm and depth of 12 - 18 cm; medium (4 bolts, hole length 10 - 11 cm, depth 18 - 20 cm) and large (1 bolt, Beer), hole length 14 cm, depth 30 cm.

For bolt-hole size, the author has measured a total of 78: that is 39 at the Roman Baths and stone store, all in Bath Stone, most are Roman with 5 that are 18-19th C. At the Cobb, Lyme Regis, 37 were recorded in Portland Stone (19th C). The Roman stones at Bath can be distinguished from Georgian-Victorian ones by their older-looking, more worn or weathered (darker) appearance, compared with 18th-19th C stones which look cleaner / less weathered (Figs. 3, 4, 6). Some of the latter in the B&NES's stone store come from the Duke of Kingston's house (1750s) which was located near the Roman baths. The bolt holes in the 34 Roman stones from Bath have lengths of 7 to 18 cm, but the majority are around 10 cm in length (see Fig. 8). The widths of Roman bolt holes are generally 2-3 cm, rarely up to 4 cm. Depths of empty holes reach 10-12 cm or more. The five 18th-19th century stones from Bath have hole lengths of 5 to 6 cm and depths to 10 cm. By way of comparison, of the 37 bolt holes measured from the Cobb at Lyme Regis, 31 are 7-9 cm in length. The similar-aged hole from Bermuda is 6.5 cm long. The bolt hole from Brown's Folly has a length of 10 cm (Fig. 5B).

Examining all the data from Bath, the Roman bolt holes encountered were mostly around 10 cm in length with some larger ones, whereas most of the Georgian-Victorian bolt holes are smaller, at 5-6 cm in length (Fig. 8). However, when one looks at the dimensions of the lewis bolts themselves, although only 11 were located, there is quite a range of sizes, from very small to large, such that the holes for these would have ranged from 4 to 14 cm in length; nevertheless, the small (5.5 - 8 cm) and medium (10 - 11 cm) size bolts are the most common (9 out of the 11 bolts measured). Finally, although there appear to be few detailed descriptions of lewis bolt holes from other Roman sites around Europe and the Middle East, they are common at the Baalbek site in Lebanon (Tim Lunt pers. comm.) where limestone was also the material. The size of these bolt holes is closer to 15-18 cm (6 out of 7 measurements). This is also the case with Gerasa in Jordon (Rababeh 2015); most holes are 18 cm across there. However, the size of the stones does appear to be larger in both of these Middle Eastern Roman sites than those at Bath. In part this will be determined by the nature of the limestone beds in the rock formations providing the stone.

Thus, generalising, from the limited dataset that could be assembled from Bath, it does appear that the Roman lewis bolt holes were mostly in the range of 9-11 cm compared to the generally smaller holes of around 6 cm for those of the 18th-19th century. However, it does appear that in both cases, occasionally there was a need for larger bolts, presumably for moving larger blocks of stone. A further consideration is the quality of the cast iron of the bolts themselves, as pointed out by Heron; one can imagine a stronger iron was available in the 18th-19th C such that smaller bolts could be used to lift larger blocks.

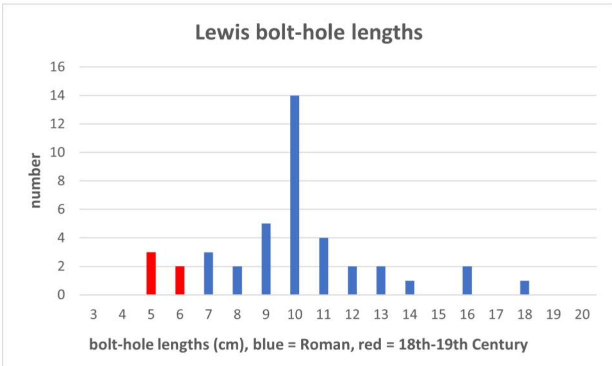

Fig. 8: Histogram showing range of lengths of 34 bolt holes from Roman stone blocks and 5 from 18-19th C stones from the Roman Baths and stone store, Bath

Origin of the term lewis

The origin of the term lewis has been much discussed. It has been suggested it is named after the person who invented it, but more likely it is derived from the Latin levo, levavi or levatum, meaning to lift. It has also been claimed that it was named by a French architect after the King of France at the time (Louis XIV, 1643-1715), with the word later being anglicised by stonemasons. However, the term is actually mentioned in earlier literature (14th C) on building techniques. A lewis bolt does look like a bunch of keys (albeit rather large and heavy!) hence it has been referred to as 'St. Peter's keys' (keys to the Gates of Heaven). Many medieval paintings of St. Peter show him with a set of keys. Interestingly, the word lewis does have a connotation in Freemasonry: the son of a freemason who joins the fraternity. The three-legged lewis bolt itself is one of the freemason symbols, reflecting strength, and a tiny one is available on-line to be worn as a lapel pin.

Acknowledgements

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La Soufrière Volcano, St. Vincent. Eastern Caribbean.

By Graham Hickman

During April 2021 the usually dormant volcano called La Soufrière, on the Caribbean Island of St. Vincent, sprang to life. The explosive eruption made headlines in the world news (Fig. 1). Fortunately, there were no casualties as the 16,000 residence that live near the volcano had been evacuated in plenty of time. The early warnings were the result of good geological monitoring, which had been in-place. Since the 1700s La Soufrière has only erupted 4 times before, the frequency being slightly longer than the average lifespan which, together with the lack of historical record, has meant that the real threat from the volcano gets forgotten.

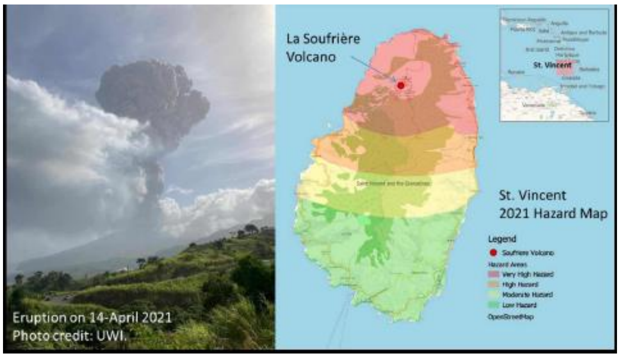

Fig. 1: St. Vincent and La Soufrière Volcano.

The Islands of St. Vincent is located towards the southern end of the Lesser Antilles, a chain of volcanic islands in the Eastern Caribbean. The volcanos are a result of the collision of Caribbean plate and the Atlantic plate. The Caribbean plate is overriding the colder and older Atlantic plate, a process called subduction. As the Atlantic plate sinks it melts and the resultant magma rises to form the volcanic chain of islands from Grenada in the south to Saba in the north.

My 2013 Visit to La Soufrière.

Back in 2013, during my time on assignment with BP Exploration in the nearby island of Trinidad, I had taken a short holiday on St. Vincent and Grenadines. Rather than staying at the popular beach resort to the south of the island, the geologist in me wanted to explore the volcano. I had researched my trip and discovered accommodation close to the volcano and a guide who could take my wife, Kerry, and I to the summit.

The accommodation was at the Richmond Vale Academy. It was more of a youth hostel than a hotel with very cheap rooms and communal meals. The Academy was run by a Danish organisation and pursues educational and environmental projects with the help of volunteers*. We stayed there three nights and they organised our guide, a local man named Franklin, to take us up the volcano.

Fig. 2: – La Soufrière, view from the beach.

On the morning of 24th Feb 2013, we set off from the Richmond Vale Academy to climb the volcano. There were four in our party; Franklin our guide, Kerry and I, plus a friendly Venezuelan called Ricardo. The first part of the hike involved walking along the black volcanic beach (Fig. 2), until we came to a deeply incised gully which a stream had cut through the layers of ash and lava (Fig. 3).

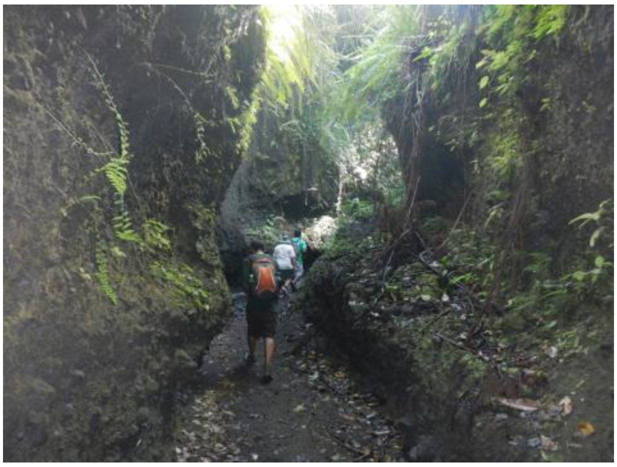

Fig. 3: Walking up the incised gully through layers of lava and ash.

I recorded the route on my GPS. We climbed from sea-level to the crater rim at 934m (3,065ft) then descended 180m (576ft) into the crater (Fig. 4). The first part of the trail had tree cover and good shade. However, the second part of the trail had no shade, exposing us to strong Caribbean sun, 27°C temperatures and high humidity. On approaching the crater edge, we encountered strong winds as we were no longer sheltered on the leeward side of the island but exposed to the full force of the Atlantic Easterlies (Trade Winds).

The view from the crater rim was stunning (Fig. 5). The sides were steep layers of ash and lava from previous eruptions could be clearly seen. A lava dome had grown inside the crater since the last eruption in 1979 but was now covered in vegetation. During the wet season a lake is often formed inside the crater but when we visited it was quite dry although there was still quite a bit of vegetation giving everything a green colour. A fumarole on the southern edge of the lava dome, which had no vegetation, was the only sign of activity. This was our target as we prepared to descend into the crater.

Fig. 4 – GPS track of our route and profile. (11 miles round trip.)

Fig. 5: Panoramic view La Soufrière crater in February 2013.

We descended into the crater using rather old and worn ropes to prevent us from slipping. (Fig. 6). The decent was difficult with loose and unconsolidated ash and lava underfoot. On reaching the crater floor I was exhausted and short of water, but I was also quite exhilarated about being inside the crater of a volcano!

Fig. 6: (left) myself and Ricardo resting on the crater rim. (Right) Our guide Franklin leading the way into the crater, note the fumarole in the distance.

Fig. 7: Inside the crater of La Soufriere heading for the fumerole. Feb 2013.

Once on the crater floor we headed to the area of the fumarole on the southside of the lava dome. (Fig. 7.) Wafts of steam could be seen and there was a stong smell of sulphur. The ground was very hot. I collected a few rock samples and we investigated the fumerole before starting on the return journey. The ascent out of the crater required a lot of crawling on all fours due to the loose material and proved to be easier than I had anticipated. From the crater rim it was then all down hill to the sea.

The 2021 Eruption

As La Soufrière came back to life during December 2020 scientists from the UWI Seismic Research team began monitoring the volcano closely. The photo below (Fig. 8) shows the new lava dome had begun to form to the west of the fumarole, which I had visited in 2013, indicating a new vent had opened up to the west. This new lava dome continued to grow in the early months of 2021.

Fig. 8: La Soufrière crater in January 2021 showing new lava dome. (Photo credit: UWI)

The scientists from the UWI Seismic Research team use a variety of techniques to monitor the volcano; direct observations, gas analysis, seismic detectors, tilt meters and satellite GPS measurements. In December 2020, earthquake swarms referred to as ''Volcano tectonic earthquakes'' were recorded at a depth of 3km and suggested that magma was moving deep inside the volcano stressing the rock and causing it to fracture. This was followed by more earthquakes on April 5th 2021 at a depth of 6km, suggesting even more magma was rising and building pressure within the volcano. Seismic activity is known to occur as a precursor to most large eruptions, so the Island was put on alert. By April 8th alert levels had been raised to ''Red'' and 16,000 people were evacuated from their homes in the northern part of the island. Then on April 9th 2021 an explosive eruption sent clouds of ash 6km into the air, falling like snow on St. Vincent and the neighbouring Caribbean Islands.

Explosive History

I described earlier that La Soufrière was a usually dormant volcano. Prior to colonial times the only clues we have are in the rocks as the indigenous people kept no records. Since the 1700s there have been four recorded eruptive phases; 1718, 1812, 1902, 1979 and now in April 2021 the fifth recorded event in the last 300 years.

An account of the 1718 eruption is recorded by Daniel Defoe, the author of Robinson Crusoe, in the Mist's Journal. Defoe (1718) gave a detailed account of the volcanic explosion of the island of St. Vincent, relying on letters he had received describing the event. He described tephra falling on ships in the region and on several other Caribbean islands. At this time St. Vincent was only populated by the indigenous Caribs and there is no information regarding casualties.

Discovered by the Spanish, St Vincent changed hands several times between the French and the British. It was under British control when the next major eruption occurred on April 30th 1812. The observations were made by Hugh Perry Keane, a barrister and plantation owner. The sketch he made of the eruption was the basis for the dramatic painting made by William Turner (Fig. 9) now in Liverpool Museum and Art Gallery. Few casualties were reported from the 1812 eruption.

Fig. 9: William Turner's painting of the April 30th 1812 eruption.

1902 was the next major eruption occurring on May 7th 1902, accompanying the eruption of Mont Pelée on the neighbouring island of Martinique. This eruption is well documented, Anderson (1902). There were multiple earthquake precursors to the main eruption for about three weeks from mid-April 1902. On the north side of the island numerous earthquakes were felt, causing small landslides and rocks to dislodge and roll down the slopes. On May 6th clouds of steam were observed being emitted from the centre of the old crater along with noises, sounding like canon fire. The climax occurred on May 7th 1902 when a great black cloud swept from the crater to the sea, burning and suffocating those in its path. This event is now recognised and referred to as a nuée ardente, or pyroclastic density flow. It is estimated that 1,500 people died, the death toll being higher on the windward side of the island because their view of the summit had been obscured by clouds. The volcano had eruptions later in May, September and October 1902, with a final explosion in March 1903.

An even more devastating loss of life occurred on the neighbouring island of Martinique where more than 30,000 people were killed by the eruption of Mont Pelée. This was the start of the serious study of volcanos and the modern science of volcanology.

La Soufrière erupted again in 1979. The eruptions were preceded by a strong local earthquake on Apr 12th 1979. 20,000 people were evacuated and major loss of life was avoided. The seismic activity increased throughout the day, leading to continuous harmonic tremors, indicative of magma rising in the vent. Then powerful explosions produced ash clouds and pyroclastic avalanches as the blockage in the vent was opened up.

La Soufrière volcano is a Peléan type volcano, named after the nearby Mont Pelée volcano. It is characterised by having viscous magma that rises but blocks the vent. As gases and magma continue to rise the subsequent eruption is explosive often with nuée ardentes - pyroclastic density flows of super-heated material that kill and destroy anything in their path.

Following such eruptions poor weather conditions also create further hazards, especially in valleys close to the La Soufrière Volcano. Ash can be mobilised as Lahars or mudflows in rainy conditions. Flooding, landslides and heavy accumulation of volcanic ash can result in collapsed roofs of buildings. Vegetation and livestock can be severely impacted. History suggests that the volcanic activity may persist for six months to a year before recovery of the human population can get underway. Meanwhile those affected must rely on friends or the government for help and shelter. The only upside is that the volcanic ash is very fertile and with a warm wet climate vegetation soon gets growing again once the volcanic activity stops.

My visit to La Soufrière in 2013 has certainly left me with a memorable impression and appreciation for the hardships faced by those who live on the volcanic island of St. Vincent.

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Foot Note

*In researching this article I discovered that back in the 1980's the Richmond Vale Academy, where we had stayed, had been accused of embezzlement, financial mismanagement, cult-like behaviour and questionable associations. In addition, Social Services in London had sent a number of young offenders here for rehabilitation in a tropical setting, a world away from their experience. I might have met some of them? Everyone was very pleasant, including the Russian who spoke no English and the Venezuelan who was continually high on marijuana.

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Girls into Geoscience, 28th-29th June 2021, virtual event summary

by Harriet Carlill

Girls into Geoscience (GiG) is an award-winning STEM outreach initiative based around an annual event. Co-founded by Dr Jodie Fisher and Dr Sarah Boulton from the University of Plymouth, the event aims to bring together women working in geoscience and girls interested in the subject in what is a predominantly male-dominated field.

Fig. 1: Girls into Geoscience logo

This year's Girls into Geoscience event, as in 2020, was an online affair. Spanning two days in June, there was a huge range of subjects on offer, both in the virtual field trips on the first day, and the Q&As and subject lectures on the second. There were contributors from all over Britain, as well as from overseas, who had come to talk in the area of expertise to the around 100 girls who attended.

After a short welcome on the first day, I spent the afternoon on two very different virtual field trips. The first - 'Ancient Landscapes and Life! How did the Yorkshire coast change 170 Ma?' with Dr Amanda Owen - explored a sequence of rock on the Yorkshire coast, and how analysing the rock and fossils could determine how they formed. With interactive polls and questions, we were able to work out that over around 26 million years, the area went from a deep marine environment, to a fluvial environment, to a shallow marine/beach environment, and then back to deep marine. Dr Owen then went on to explain why doing this sort of analysis is important. Not only can it show how past environments, animals and plants responded to changing conditions, helping us understand possible changes in the future, but it also helps to find resources based on the environment of deposition (e.g. hydrogen and carbon dioxide storage in geological formations

The second field trip was 'Hidden Glaciers on Earth and Mars' with Dr Katie Miles and Adam Hepburn. Using Google Earth, we were able to fly around the globe and see glaciers from our own screens. After briefly looking at the Perito Moreno glacier in Argentina as an example of a ‘typical’ glacier, we moved to high mountain Asia and the Khumbu glacier - the highest glacier in the world, and more importantly, an example of a hidden glacier (bumpy and covered in debris and depressions).

Fig. 2: Google maps view of Khumbu Glacier

The debris zone of the glacier is also the ablation (melting) zone. Although the glacier is not actually receding (it is still up against the end moraine) it is still melting, but in the middle instead (shown by a dip in the ice). The thickness of debris varies, with a thin layer increasing melt due to the albedo effect, and a thick layer (at the end of the glacier) acting like a blanket and preventing melting. Dr Miles had spent many months out on the glacier studying it, and she talked about some of the work she had done collecting bore holes and using sensors to measure the temperature of the ice. What she had found was that the temperature was worryingly high - around -2°C compared to up to -20°C in the accumulation zone in the western cwm of Mt Everest (where the glacier forms) (Wikipedia, 2021).

Adam Hepburn then took over to talk about how researching hidden glaciers on Earth can help us understand Mars. The planet is covered in canyons and channel networks, with two polar ice caps and active sand dunes.

Fig. 3: view of Mars

Viscous flow features of a similar scale to Khumbu have been found, made up of 90% ice and covered in debris - analogous to the hidden glaciers on Earth. By gaining a better understanding of hidden glaciers on Earth, we can better understand past climates on Mars, and hopefully we will understand more fully how to study Mars in the future (Hargitai, 2014).

Day 2 was a full day of activities and talks. After a brief welcome and introduction from Dr Sarah Boulton, we had four short talks from Dr Natasha Dowey, Dr Marie Cowan, Dr Rehemat Bhatia and Prof Anjali Goswami about their respective careers and how they got into their particular field. Afterwards we were able to ask all of the speakers questions in a Q&A session. After a short break we then had two more Q&A sessions. The first was ‘Dealing with change, challenges and opportunities’ with Lingli Zhou, Jen Brooke, Polly Foster and Jenny Wiggins, and the second was ‘University Life’ with several current undergraduates and recent graduates from all over Britain and Ireland.

After lunch we moved onto the workshops. Prior to the event all participants had been sent a form with a choice of a range of subjects to choose from. The first of the two workshops which I attended was ‘Peruvian glaciers and water resources’ with Prof Caroline Clason and Dr Sally Rangecroft. The workshop began with an introduction to the importance of glaciers as water sources, with ice making up 70% of freshwater globally, despite only covering 10% of the Earth’s surface. Due to low rainfall in South America, especially on the western coast (west of the Andes), around 250,000 Peruvian people are 80 to 100% reliant on glacial meltwater for drinking, sanitation, energy and agriculture. The second part of the workshop used Google Earth to allow us to look at five locations in the Peruvian Andes that are significant in relation to glaciers as water resources. The first stop was the city of Huaraz. At over 3000m high, it is around 15°C all year round, and has both wet and dry seasons. We then moved to a glacier near Huaraz, which flows to the west and has several well-studied melt ponds. This glacier feeds the surface and groundwater towards

Fig. 4: Laguna 69 nr Huaraz

Huaraz, contributing 20% of water annually, and up to 90% in the dry season. Glacial retreat in the region has been around 30%. The next stop was Laguna 69, a glacial lake also near Huaraz. It's a beautiful turquoise colour due to the glacial flour and high turbidity causing the minerals to reflect the light.

Lakes in the region have very different colours depending on what's in them (e.g green = organic matter). The fourth stop was the Rio Negro, or Black River. It's a more red/brown colour than black due to oxidised iron from surrounding iron rich rocks, particularly at the top of the river. Due to this, the water has a very low pH (it's acidic), making it unsuitable for consumption or irrigation, and not a viable water resource in the area. The final location was an area of steep, terraced agricultural land near Ticllos. This was an example of typical farming techniques in the very mountainous area, with the soil terracing creating flat land and reducing soil erosion.

The second workshop which I attended was 'Microfossils as windows to a past climate' with Dr. Tracy Aze. We started off discussing what we can learn from biodiversity. Tropical regions tend to have the most biodiversity, whereas higher latitudes are sparser. This is called the latitudinal diversity gradient. However, it's difficult to prove that this trend is true for all of Earth's history due to an incomplete fossil record

Fig. 5: Planktonic Foraminifera , http://www.microscopy-uk.org.uk

Planktonic Foraminifera can help fill in the gaps in the fossil record and help us understand past climate. Foraminifera are very simple micro-organisms that live in the upper 2km of the water column all over the planet. They can be used to determine past climate as they have been preserved for their entire stratigraphic history (170 million years) and they have clear temperature associations; much higher diversity at high temperatures, and low diversity at low temperatures. They are also much larger at high temperatures than low temperatures. We were then split into smaller groups, and we had to work together to assign latitude zones to five samples of Foraminifera based on size, shape and diversity within the sample, choosing from Tropical, Subtropical, Temperate, Subpolar or Polar.

Our final thing for the day was thank yous and a goodbye from Dr Jodie Fisher, and instructions on how we could access our free membership to the Geological Society after taking part. We took a group photo on the Zoom call to round off the event. It was a really fascinating couple of days, and a great opportunity to hear so many brilliant speakers talking about such a huge range of topics.

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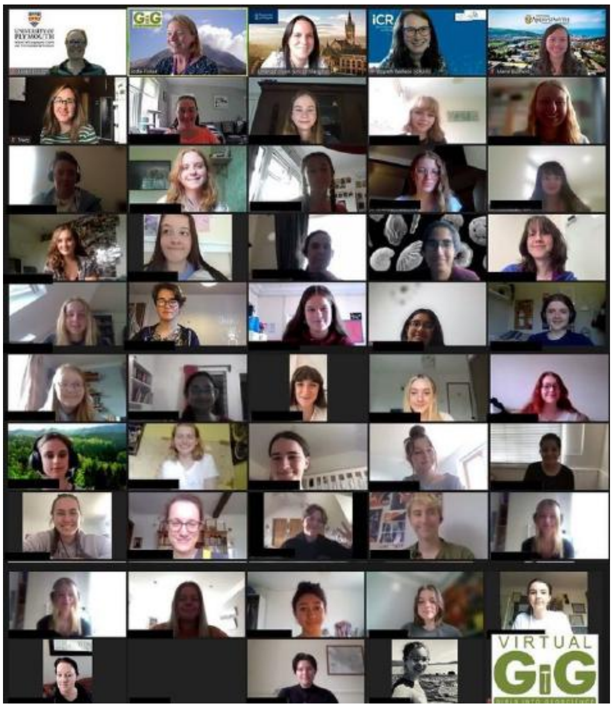

Fig. 6: Group photo from Zoom

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An exciting new project at Somerset Earth Science Centre

by Simon Carpenter

I have recently started volunteering at Somerset Earth Science Centre www.earthsciencecentre.org.uk, to help them repurpose an old geological collection formerly belonging to Kingswood School, Bath. This is an exciting opportunity to examine an important historic collection, containing some exceptional fossils and minerals, many found over a century ago.

Kingswood School, Bath was founded in 1748 by John Wesley, who with his brother Charles, started the Methodist movement in the Church of England.

Sir Arthur Dixon (1867- 1955), an accomplished mathematician and Fellow of the Royal Society as well as a former pupil of the school, donated a substantial geological collection to Kingswood School. His collection, as well as many other fossils and minerals added by former pupils and staff, were used by generations of children studying GCSE and A level geology. With the introduction of the National Curriculum in the late 1980s, a steady decline in the teaching of geology in schools began. These collections, once an important teaching and learning resource, were now no longer needed and often abandoned. Some like the Kingswood School Collection were rescued early on, before serious neglect took hold, but many other teaching collections faced a much bleaker future and were simply discarded.

The Kingswood School Collection is an important, relatively intact, early example of a school fossil and mineral reference collection. It includes many fine examples of invertebrates and some vertebrate fossils. These were collected at a time when there were many more active quarries to collect from, with fewer access restrictions and without the intensity of fossil collecting we see today.

The collection is also associated with a number of prominent and famous geologists including William Jocelyn Arkell (1904 – 1958) who was regarded as the leading authority on the Jurassic Period during the middle part of the 20th century and was friends with Alfred Barrett Sackett (1895 – 1977), the headmaster of Kingswood School between 1928 – 1959. Towards the end of Arkell's short life he had been working on Bathonian ammonites discovered during the excavation of a new hockey pitch on land below Kingswood School.

Somerset Earth Science Centre is rescuing as much of the collection as possible to repurpose it as a reference collection for the Centre, with some of the more interesting and important fossils and minerals put on display for visitors. An immediate priority has been the careful cleaning of fossils, the rescue of specimen labels and tackling conservation issues such as pyrite decay. At the time of writing, only about 20% of the fossil collection has been processed. The Centre have approached the Russell Society to help sort through the minerals.

It has been immensely satisfying to see this old collection rescued and revitalized and a real delight to handle so many fascinating fossils. I hope to bring you updates as the project progresses.

Fig. 1: provided by Adel Avery Adel Avery, Centre Manager and Simon Carpenter with some of the Kingswood School collection

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Life forms in the Torridonian Group of North West Scotland

By Phil Burge

Introduction

As discussed in the first Newsletter of the Society in April 2020, my undergraduate mapping exercise was completed in an area around Diabaig and Upper Diabaig, north of Loch Torridon. I still have the map and write up and, as I still have an interest in the area, the time spent in this area must have had a deep and lasting impact, as I expect each undergraduate geologist experiences. As such, my newsfeed occasionally throws interesting research on the geology of the North West Highlands, one of which described a possible billion year old holozoan with differentiated multicellularity (Strother et al 2021).

The consensus view is that all the Torridonian Group was deposited in fluvial/lacustrine/playa type environments. The finding of multicellular structures in a non-marine environment of this age revises our understanding of the evolution of multicellular life and holozoans.

Torridonian Supergroup Stratigraphy

The North West Highlands have a particular and impressive geography with high hills and mountains of Torridonian age lying uncomformably on Palaeoproterozoic Lewisian gneiss. The Torridonian Supergroup comprises the Stoer, Sleat and Torridon groups (Fig. 1).

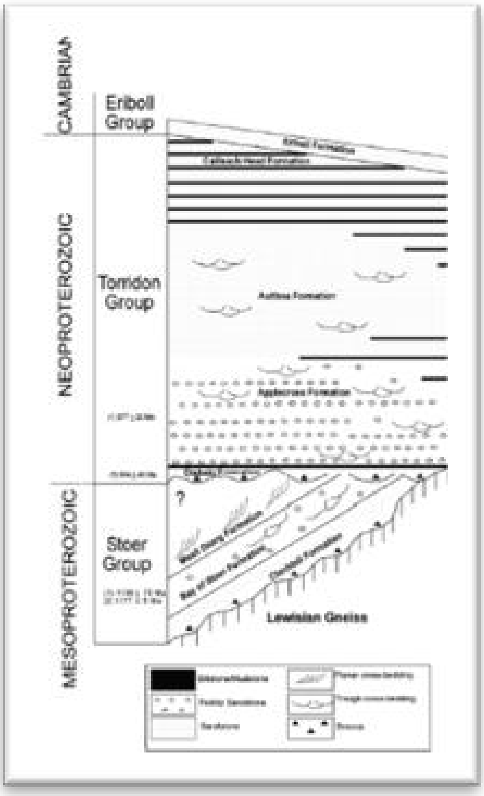

Fig. 1: Generalised Stratigraphy of Torridonian Supergroup (from Callow et al 2011)

The basal Stoer Group comprises the Clachtoll, Bay of Stoer and Meall Dearg Formations of red mudstone, siltstone and sandstone. The Bay of Stoer Formation includes the Stac Fada Member, a possible meteorite injector blanket dated at 1177+/-55Ma (Parnell et al). The Sleat Group found on Skye is believed to be contemporaneous with the Torridon Group. The Torridon Group is made up of mudstone, conglomerate, and sandstone, about 200 million years younger than the Stoer Group. The Group consists of the Diabaig, Applecross, Aultbea and Cailleach Head Formations.

In the area of my mapping exercise and of interest in the debate on life forms in the Torridonian, the Lewisian is unconformably overlain with Torridonian mudstone, sandstone and conglomerate/breccia of the Diabaig and Applecross Formations.

Evidence for Non-Marine Facies

There is some controversy as to the evidence for palaesols and weathered surfaces at the unconformity between the Lewisian and the Torridonian. On the one hand geochemistry such as oxidation of iron in biotite and magnetite, points to a weathered surface where thin layers of hydrothermal dolomite within 1m of the unconformity resulting from retrograde metamorphosis of illite and smectite has been interpreted as pedogenic. The stratigraphy strongly suggests that the Lewisian was sub aerially exposed.

The Clachtoll Formation of the Stoer Group largely composed of Lewisian clasts, was deposited in deep cut valleys. The basal conglomerates grade upwards into interbeds of conglomerate and red sandstone with trough cross bedding interpreted as valley confined alluvial fan deposits. Muddy and desiccated sandstones may have been deposited in a terrestrial mudflat environment.

The Stac Fada Formation has now been interpreted as a single event density current resulting from a meteorite impact.

The Meall Dearg Formation consists of planar cross bedded sandstone interpreted as being deposited as alluvial transverse bar deposits.

The Torridonian Group overlies the Stoer Group uncomformably with a gap of 130 – 200 million years. The lower Diabaig Formation comprises conglomerates with clasts of gneiss, and clasts of sandstone and grey shale deposited in valley-confined alluvial fans. Higher energy shorelines facies outcrop at Shieldaig on the southern shore of Loch Torridon with muddier shoreline facies at Loch Diabaig. Geochemical analysis of the grey shale suggests deposition in a non-marine environment (Stewart et al 1979). Sedimentary structures indicate deposition in shallow water with periodic subaerial exposure e.g., short wavelength symmetrical wave ripples.

The boundary of the Diabaig and Applecross Formations is probably conformable. The depositional environment is terrestrial fluvial to with channel deposits showing trough and ripple crossbedding in sandstones, planar cross bedded gravels and gravel sheets. Commonly seen are soft sediment deformation structures. A neptunian dyke was observed in my mapping area.

Stewart (2002) considered the differences between the Applecross and Aultbea Formations as being “mere facies”, the Aultbea Formation missing pebbles. Microfossils have been reported in a thin grey shale at the base of the Aultbea formation interpreted as non-marine (Zhang 1982).

Emphasis on the Diabaig Formation

The Diabaig Formation has been of special interest in the search for microfossils starting with Peach’s work published in 1907 and continued by many eminent geologists including Selley, Stewart, Brasier and Strother. It is worth looking in more detail at the Diabaig Formation and facies of a few exposed locations.

Shieldaig South – At the base red coarse normally-graded, sandstone and conglomerate of Lewisian gneiss are overlain with medium coarse, cross-laminated red sandstone fining-upwards into fine-grained sandstone and red mudstone. Short wavelength wave ripples and subaerial desiccation cracks are common with synaeresis cracks in some horizons, indicating alternating subaerial and subaqueous conditions. The Shieldaig rocks are courser than other Diabaig Formation localities indicating higher energy in a more proximal deposition. No phosphate nodules or microfossils have been found in this location.

Shieldaig North – Here, fine grained sandstone and siltstone are found with gently dipping bedding planes. Short wavelength wave ripples with multiple generations of desiccation cracks indicate shallow water deposition with periodic exposure. There are abundant phosphate lenses at the top of the section. The facies here is more distal than Shieldaig south, i.e., farther from the sediment source with lower rates of deposition (finer grain size and phosphate).

Diabaig – The Diabaig Formation is clearly seen on the foreshore of Lower Diabaig, first mapped by Peach (1907 and then me in 1975). A succession of fine-grained grey to black mudstone and siltstone alternate at the millimetre scale. Desiccation is very common. These desiccated layers are overlain by thin sandstone beds with short wavelength wave ripples. Authigenic phosphate occurs as nodules, thin laminae and linings of desiccation cracks.

Brasier et al (2016) concluded that it would indeed be controversial to reinterpret the environment of deposition of the Torridon Group as anything other than terrestrial/lacustrine but that doesn't stop some researchers from trying!

Not So Non-Marine

From geochemical analysis the Poll a Mhuilt Member of the Stoer Group has been interpreted as being fluvio-lacustrine deposits, more oxygenated and nutrient-rich than marine environments making them preferable for early eukaryote evolution. Some of the evidence for a lacustrine environment has been contested by researchers (Stewart and Parker 1979 and Stewart 2002). Detailed analysis of the Poll a Mhuilt Member shows the following sequence from oldest to youngest.

The Poll A Mhuilt Member consists largely of red beds showing channels and trough cross bedding, desiccation cracks and flat laminated to ripple cross bedding all indicative and consistent with a fluvial-lacustrine environment. Within this Member can be found thin beds (>50cm) of fine to medium sandstone and calcareous grey shale showing wave ripples, herring bone cross-lamination, flaser and lenticular bedding, reactivation surfaces and evaporite pseudomorphs after gypsum. The features within this 3-30m thick layer show evidence of marine tidal flats. Geochemical analysis shows $^{87}Sr/^{86}Sr$ ratios indicative of marine environments (Steuken et al 2017).

The significance of this reinterpretation is with regard to the origin of eukaryotes within the lower Torridonian sequence. This we now discuss.

Proterozoic Terrestrial Lifeforms

The widespread evolution of life on land occurred in the Late Cambrian to Ordovician, although actinobacteria and cyanobacteria could have emerged on land as much as 3 billion years ago. Some cyanobacteria are only known from freshwater environments.

Archean microbialites (formed through mats of prokaryotic cyanobacteria) are found in sediments 1.5 billion years older than the Stoer/Diabaig formations. That Torridonian lakes and land surfaces were colonized by microbial mats should not be surprising. Stromatolites have been reported from the Stoer Group, though possibly of an abiotic genesis. Some sedimentary structures indicative of windswept sediments forming ripples, were locally bound by microbial mats (Prave 2002).

Microbial mats (biofilms) can be identified from wrinkle structures, pustules, sand chip, shrinkage cracks and lineations, otherwise known as microbially induced sedimentary structures (MISS). Structures like this have been reported in the Torridonian since Peach in 1907 and variously interpreted as abiogenic. Since 2002 these structures have been related to the effects of microbial mats (Fig. 2-4).

Fig. 2: Reticulate structures forming on planar bedding surfaces and ripple horizons. Scale bar 5 cm (from Callow et al 2011)

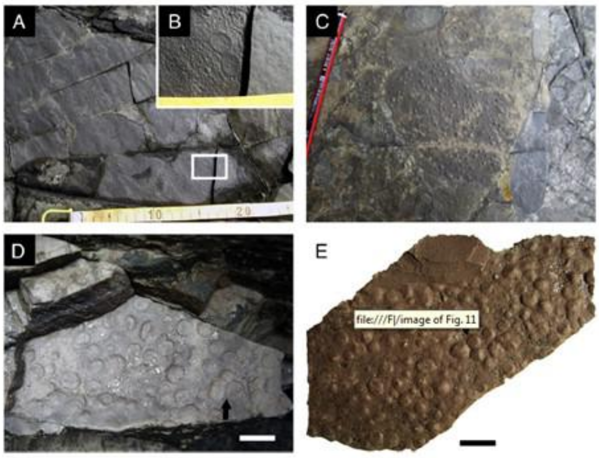

Fig. 3: Discoidal features from bedding planes (A, B) comparable with Aspidella terranovica. C,D, E pimple structures due to gas domes during decomposition of microbial mat (from Callow et al 2011)

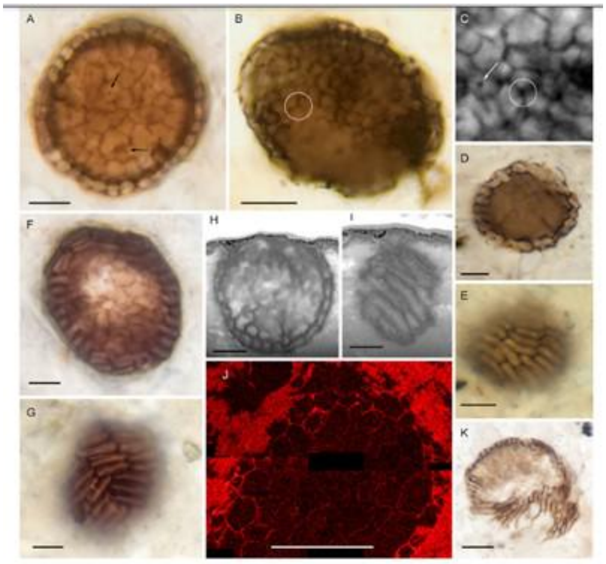

Fig. 4: Bicellum brasieri from thin sections of Diabaig Formation, Lower Diabaig location. Scale bar A-J 5 micron, otherwise 10 micron (from Strother et al 2021)

Studies beginning in the early 1980's found evidence of a range microfossils including: single celled sphaeromorphs and other eukaryotic forms, multi-walled and colonial forms, organisms with complex morphologies. Examples include *Leisphaeridia* and *Lophosphaeridium*, the latter showing cysts encased in thin-walled vesicles interpreted as original vegetative cell walls – evidence of eukaryotic organisms living in these Torridonian lakes.

The best preservation of these microfossils occurs in phosphatic nodules within the Diabaig Group. Cell membranes and cell contents are well preserved. Explanations of phosphogenesis include a biotic origin within microbial mats for instance, the result of seasonal anoxic conditions in the deeper lake environment or the breakdown of seasonal microbial blooms. The phosphates in the Diabaig Group are found in green sands and mud suggesting a reducing environment.

This brings us back to the first paper cited in the introduction to this article. A new organism *Bicellus brasieri* has been identified within Diabaig phosphate nodules (Fig. 4). Bicellus consist of a solid, spherical ball of tightly packed roughly spherical shaped cells surrounded by elongate cells. Some examples appear to show the development from a spheroidal cluster to one showing the elongate outer cells. There is an absence of cell walls suggesting that these cells did not originate from algae but are more consistent with a holozoan origin. The simple cell differentiation and morphogenic processes are similar to those of present-day metazoans. It is then concluded that *Bicellum* shows that differentiation and morphogenesis occurred in freshwater protists as much as a billion years ago.

Summary

The evidence is clear that the Torridonian Group formations were laid down in terrestrial, freshwater lacustrine environments. Microbial mats and microfossils showing eukaryotic characteristics are found in facies ranging in depth and exposure above the water line. The further examination of these, perhaps unique Torridonian rocks may suggest a revised view on the evolution of eukaryotes on land.

Built from the oldest metamorphic and sedimentary rocks in Britain, the North West Highlands are among the most scenic and well worth a staycation. While the resources available to a mid 1970's undergraduate geologists undertaking a mapping exercise were somewhat limited in comparison to today's generation of geology students and not capable of coming close to consider or identify holozoan genesis within the studied rocks, the experience lingers and still engages. The advantage of newsfeeds ensures a continuing source of new material to entertain and enlarge upon these youthful experiences. I am also pleased to record that it was due to suggestions by my sedminentology lecturer and field trip leader Sandy Stewart and my tutor Roland Goldring at Reading University that the work on Torridonian microfossils began.

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Machair – a gaze across deep time

by Charles Hiscock

In 1788, the eminent pioneering Scots geologist James Hutton made one of the most profound statements in the history of geology. He wrote "we see no vestige of a beginning, no prospect of an end". He had visited the localities in Scotland that are now famous sites, Hutton's Unconformity on Arran, at Jedbergh and elsewhere, culminating in his visit to Siccar Point in 1788. From his observations he recognised the huge passage of time in the formation of the earth, "deep time" as he called it. He is justly called the "Father of Geology".

I was standing on the sand dunes looking out over the beach and sea at Seilebost on the west coast of the Isle of Harris. In front of me, the beach was a very pale creamy colour, bright and glistening in the sunshine while the sea was a brilliant turquoise blue, graduating at the shallows from a pale hue to a deep, intense blue away from the shore (Fig. 1). Gentle wavelets broke over the sand while the brisk breeze scattered dry sand grains along the beach. I walked along the sand with the wind in my back and the dunes rising up from the back of the beach, capped by abundant marram grass.

Fig. 1: Seilebost beach

My walk took me along the firm sand until I came upon an extensive area where it seemed more consolidated, cemented into a flat, slightly raised platform. At the same time, I noted that the dunes, which had up to that point been steep gradients rising at the back of the beach, were fronted by low cliffs showing patterns of lower, older dunes and with large numbers of bare marram grass roots just hanging in the air. I remembered that the north of Scotland, in particular the Outer Isles, had experienced severe storms during the previous winter. Clearly, the storms had eroded large quantities of the dunes in this area, exposing the grass roots and the platform of cemented sand fronting the dune cliffs. Close examination of the cemented sand showed it to be composed of comminuted minute shell fragments with some larger pieces and almost complete molluscs. What I was standing on was a modern day 'hard ground' in the making; the lime content of the shells being leached out by the action of percolating water through the dunes to form the hard, crusty surface which had been exposed as the storms removed the dunes (Figs. 2 and 3).

Fig. 2: Calcified sand surface, Seilebost

Fig. 3: Dunes showing old dune formation

Behind the dunes the land was mainly flat and fertile with abundant flowers in the grassy sward. Nesting oyster catchers and redshank called in alarm as I walked across this wildflower extravaganza while, in the distance, a few cows and sheep grazed on the lush grass. However, not much further inland the mountains of Harris rose steeply up, virtually devoid of vegetation. Across the deep blue sea, other mountains provided a hazy backdrop to the scene (Fig. 4).

Fig. 4: The machair at Seilebost and Lewisian gneiss mountains

I was walking across the machair, the fertile land which has been cultivated by the crofters of the Outer Hebrides, the west coast of Ireland and some Scottish mainland coasts. Composed of the shell material washed and blown in by the Atlantic winds and seas, it has provided a precarious living for the farmers over many centuries as well as being the habitat for rare flowers and birds like the corncrake. Standing on the grassy bank, looking out over the platform of exposed cemented sand, my mind dwelt on the interminability of the earth and the processes that have formed it. Here I was considering a newly forming hardground with, to my back and in the distance in front of me, rocks of the Lewisian gneiss that were 1.7 to 3.0 billion years old. I admit that I did not think of the words that Hutton used in 1788 but, nevertheless, the same sentiments passed through my mind. I remembered that I had seen ‘hardgrounds’ and fossil assemblages over the years in the rocks and specimens that I had collected, all from different periods of geology; Jurassic of the Cotswolds at North Nibley quarry, Silurian Wenlock limestone and Llandovery sandstone beds of the Tortworth inlier, Carboniferous limestone of the Forest of Dean, a modern one on the beach of red Mercia Mudstone at Sidmouth bored by piddock shells. Here, on this deserted white shell beach in the far north west of the United Kingdom was a fossil assemblage in the making.

The machair, which is Scots Gaelic for 'fertile plain', is the recognised name for the land which lies behind the dune systems on the western coasts of the Outer Hebrides, the west coast of Ireland and some of the coast of the Scottish mainland. In the Outer Hebrides the largest development of machair is on the southern islands of the Uists, Benbecula and Barra, but nevertheless on Harris and to a lesser extent on Lewis, there are some fine machair. It is a precarious and rare habitat subject to the harsh winds and storms which regularly blow in from the Atlantic, particularly in latter years as global warming has intensified the severity of the storms. It is this combination of wind and tide that provides the continual feed of shell fragments onto the western shores and the development of the dune systems. Behind the dunes the land is well drained and becomes covered in grass and abundant flowers such as Sea Pink, Bird's Foot Trefoil, Daisy, Scabious, Milk Wort (ranging from deep blue to white), and during June, carpets of Buttercups giving the machair a glorious yellowness. Also abundant are orchids - tall spikes of purple Northern Marsh Orchid, pale pink Early Marsh Orchid, Early Purple Orchid and Spotted Orchids (Figs. 5 to 7). At Seilebost on the edge of the machair bordering the dunes was a rare Frog Orchid. At the same beach a small river, water the colour of strong black tea from the peat, enters the sea behind the machair which gradually evolves into a salt marsh on which oyster catchers, lapwing and redshank nest. Meadow pipits were everywhere while skylarks rose into the sky with their distinctive song.

Fig. 5: Frog Orchid (Seilebost, West Harris) 20.6.19

Fig. 6: Early Marsh Orchid (Taobh Tuath) 20.6.19

Fig. 7: Machair flowers

Farming, or more correctly, crofting on the machair has been a way of life for centuries. In Lewis, evidence of Bronze age dwellers can be seen on the headlands, Pictish brochs such as Carloway, the Norse mill and kiln at Shawbost and medieval cultivation strips provide evidence of the long association humans have had with this harsh environment. The fertile land provides rich grassland for the small herds of dairy and beef cattle that range freely across the machair, often accompanied by flocks of sheep. It is this combination of fertile grassland and gentle cropping by the animals that provides the ideal habitats for the nesting birds. At Seilebost and Carbost lines of cultivation strips show where the islanders were forced to retreat during the infamous Clearances in the late 18th and 19th centuries. The sea eroded dunes at Seilebost and the cemented hard ground in the foreground are a stark illustration of the precarious and vulnerable nature of the machair. Photographs of the mollusc shells, sea urchin test and crab's leg are typical of the elements that are broken down to produce the lime sand of the beaches, dunes and machair (Figs. 8 to 10).

Fig. 8: Assorted shells

Fig 9: Shell sand (x10)

Fig. 10: Sea urchin test

In the photographs that accompany this article we see the machair at Seilebost (Fig 4), and in the shadow of Chaipaval (365m), at Taobh Tuath (Fig. 11).

Fig. 11: Machair, near Chaipaval

Since the early 20th century geological research, techniques and investigation has advanced our science to a stage that Hutton could only dream about to the extent that we now know the age of the planet Earth to be 4567 billion years old. We even have an inkling of how long the Earth will exist and how it may meet its end. But there, on that windy beautiful spot of 'God's creation', Hutton's words seem wholly appropriate – 3.0 billion year old rocks around me and new rock being formed in front of me. It felt and was timeless!

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IMPACT MARKS ON BATH STONE (JURASSIC OOLITE): WW2 BOMB AND BULLET DAMAGE ON BUILDINGS IN BATH

By Maurice Tucker
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Impact structures observed in geological strata record a range of completely different processes, operating on vastly different scales: from the potential devastating consequences of a meteorite strike with shatter cones in the country rock at the impact site, the imprints of rain on a muddy shoreline, the landing of volcanic bombs and the dropping of stones from melting icebergs on to the deep seafloor disturbing the strata. Marks from pebbles and fossils bouncing across the seafloor carried by a turbidity current and the footprints of dinosaurs impressed into soft sediment are other types of impact mark. Following Cardiff University's Professor Tom Blenkinsop's fascinating talk to the Bath Geological Society on 4th February 2021 on impacts from meteorites and comparisons with ballistic damage from bullets and shrapnel in conflict zones, I visited the former Labour Exchange building in Bath (Fig. 1). This is a Grade II listed building preserving the damage from the German air-raids during WW2 on 25th to 27th April 1942. There are some really interesting features of detail to be seen there, from a geological-geotechnical point of view, which may be relevant to other impacts in the rock record. Further to this, during the 2021 lockdown, the author has been wandering the streets of Bath looking for more Bath Blitz damage and in so doing has found further examples and some other intriguing marks on the Bath Stone walls (Middle Jurassic oolite) of many buildings.

Fig. 1: The former Labour Exchange building, built 1938, repaired 2017, James Street West, Bath, with shrapnel damage in the lower few metres.

The Bath Blitz, April 1942

On those two fateful nights in 1942, 100s of bombs and 1000s of incendiaries were dropped on Bath by the Luftwaffe, destroying many buildings, killing 417 people and injuring 1000s. This was one of the so-called Baedeker raids, allegedly inspired by the German tourist guidebook to Britain. Targets were chosen for their historical and cultural value rather than any strategic or military purpose following the RAF's bombing and destruction of the German city of Lübeck in March 1942. Bath is described in Baedeker's 1910 (7th) edition (page 116) as: "… a handsome place, beautifully situated in the valley of the Avon, perhaps unrivalled among provincial English towns for its archaeological, historic, scenic, and social interest". There follows one further pertinent compliment: "… built of a fine limestone (oolite)…" (my favourite rock-type!). There were three waves of attack over the 2 nights of the Bath Blitz. 80 planes arrived before 11 on the night of the 25/26 April and bombed the city for 2 hours; they then returned to northern France, refuelled, re-armed and returned at 4.30 am, mainly dropping incendiaries and using their machine guns. The third wave after midnight on 26/27th was a smaller number of planes but with heavier bombs, now being dropped on a city still ablaze. Over those two nights of terror, 19,000 buildings in Bath were affected, with 1100 seriously damaged or destroyed, including 218 of architectural or historic interest. It was many decades before the city was completely rebuilt. There is now little evidence of those air-raids, except for the presence of new buildings where others were destroyed, but one building with extensive shrapnel damage has been preserved, the Labour Exchange (former Weights and Measures Office), built in 1938, in James Street West, by Milk Street.

Fig. 22 at the end of this paper is a map showing the bomb sites of Bath city-centre (from Wainwright 1992). For the location of all sites, from Bathampton to Twerton, Lansdown to Combe Down, see the Bath Blitz website: www.BathBlitz.org.

The Labour Exchange building

In the very early morning of 26th April, the Labour Exchange was hit by shrapnel from a 250 kg bomb that landed in James Street West and badly damaged the nearby Holy Trinity Church (later demolished). The next night, another bomb landed across the road, opposite Kingsmead North, and created further blast damage. The building also caught fire and the top floor was gutted. Repairs were made, a temporary roof erected, and the building continued to serve its purpose, providing essential support for those Bathonians bombed out of their homes and ensuring that the war effort had sufficient manpower. The Labour Exchange also found suitable jobs for unmarried women who were required to contribute to the war effort under emergency legislation. After the war, the building was used for storage, became a furniture shop and then Grade II listed in 2002. The building was finally fully renovated in 2017 with the pock-marked façade thoughtfully retained. It is now a shop selling kitchen-catering equipment (Nisbets) with student flats above.

The building is constructed of Bath Stone, as to be expected, which is a well-sorted uniform oolitic grainstone with few bedding or sedimentary features – a good freestone in other words, possibly from Box-Corsham. The hundreds of impact craters on two sides of the building reach up to 20 cm across and 8 cm deep but there are numerous smaller ones a few cm across (Fig. 2).

Fig. 2: The Labour Exchange, Milk Street side, with bomb damage and pink stone upper right from the effects of fire on higher floors.

They are mostly near-circular, some more asymmetric. There are some radiating fractures related to the impacts, and in places there are hints of concentric fractures. The stone would seem to have broken off in shards and flakes and been comminuted or pulverised. Some craters are quite smooth in fact, as if the stone at the point of impact was finely broken up and recemented or recrystallised from the shock (Figs. 3, 4).

Fig. 3: Labour Exchange impacts marks, variable size. Size of stone blocks 30 cm high.

Fig. 4: Labour Exchange impact craters close-up with smooth interior compared with weathered stone.

Where an impact struck towards the margin or corner of a stone block and in some cases the crater stopped at the edge of a block, the generally circular shape of the crater did not develop. Rather, the crater has one or two straight sides (Fig. 5). Clearly here the shock was not able to propagate across the boundary between blocks, where there is some mortar, but not always.

Fig. 5: Labour Exchange impact crater shape affected by stone block boundaries.

However, in other cases where the crater has developed across two blocks, the boundary itself between the blocks is not visible (Fig. 6). Presumably, this is the result of the shock pulverising the rock and causing its recrystallisation or recementation so that the boundary and mortar disappear. One interesting observation from those witnessing the Blitz is the significant amounts of dust that Bath Stone produced from these ballistic impacts. In fact, not only did carbonate dust cause respiratory problems for people breathing in the pulverised stone, but it also led to infections of open wounds.

Fig. 6: Labour Exchange impact crater across 2 blocks where the boundary has been lost. Note the granular nature of the weathered surface of the limestone, contrasting with the finer-grained nature of the stone within the crater.

Of further interest there is a lead damp course running across the building's wall at two levels: 40 cm and 1 m above the ground. Where an impact struck near the lead sheet, it has curled up and been deformed (Fig. 7). Indeed, it may possibly have even melted since in some places it seems to have thickened up or even disappeared, vaporised (?) (Fig. 6). This would indicate significant heat generated by the impact as shock metamorphism.

Fig. 7: Labour Exchange impact crater with deformation of the lead damp course

Fig. 7 continued: Black discolouration here and in other figures is likely recent organic-microbial staining.

Other shrapnel impact marks

Shrapnel marks are not that common around Bath, but they are there once you get your eyes focused. The best place to look is a little higher up on buildings (1-4 m) in a location where bombs are recorded to have landed nearby (see Fig. 22). For example, around Queen Square, also to the north of Julian Road (Northampton Street) near where St Andrew's Church was destroyed and St Mary's Church badly damaged. There is a memorial on the wall of the latter church where the names of all those killed are listed. There are maps on the Bath Blitz website which show the locations of many of the bomb sites. Around 240 bombs were dropped (approx. 130 tons), across the whole of the city. There is also damage where some incendiaries hit.

In some places around the city, shrapnel craters on buildings have been filled with a cement to hide them. However, this has met with varying degrees of success depending on how much effort was put into matching the colour and grain-size of the cement to the stone itself. Many filled impact marks can be seen in the curved wall outside the main entrance to Bath Spa railway station (4 bombs landed very close by) and on the north side of Queen Square, where a 500 kg bomb landed in the SE corner destroying 4 houses that were part of the Francis Hotel. Another example can be seen in Third Avenue, Oldfield Park, with an unfilled crater higher up (Fig. 8).

Fig. 8: Four cement-filled impact craters and one empty one higher up on the wall of a house in Third Avenue, Oldfield Park, in the immediate vicinity of a bomb site.

Machine-gun bullet marks

Apart from the obvious shrapnel marks, resulting from flying debris from the exploding bomb itself, along with chunks of stone etc. generated by the explosion, the German planes also raked the streets with machine-gun fire during and after dropping their bombs. There are vivid accounts of this on the Bath Blitz website and many people were killed this way. Some planes came as low as 50 feet (15 m), such that the pilot could be seen. Thus, there should also be bullet holes on buildings. These might be expected in more open areas, where people might have been congregating, putting out fires and rescuing trapped people. German machine-gun bullets were 7.92 mm and 13.1 mm in diameter and could fire up to 25 per second or 1500 per minute. Bullet-damage on stone might be expected to be directed downwards with an elongate shape from glancing impact. Most shrapnel damage on the Labour Exchange and elsewhere is roughly circular / symmetrical, rather than elongate. Presumably, the shrapnel would have travelled out horizontally and at a low angle from the bomb-impact sites such that the hits were direct rather than glancing.

On the walls of some buildings there are 'gouge' marks that are somewhat elongate. In some places, several occur close together and they can have a similar orientation, commonly directed downwards or at an angle (see Figs. 9, 10). They tend to be 10-20 cm in length and 2-5 cm across, 1-2 cm deep. These would appear not to be formed in the same way as the more circular, deeper, shrapnel impact marks, formed by exploding bomb fragments and debris flying out from the impact site, bits of building, road, pavement etc. The shrapnel impact marks tend to occur in the lower parts of building walls, and they get smaller higher up the wall as at the Labour Exchange; the elongate marks tend to be higher up at 1st-2nd floor level. It is suggested then that these elongate features were produced by the machine-gun bullets being fired from the German planes. They can be seen in Queen Square, east side and top of Barton Street close to where a bomb landed, near where a large part of the Francis Hotel was destroyed, and elsewhere, Jane Austen's house and Miles's Buildings.

Fig. 9: Elongate marks possibly from machine-gun bullets, on a wall of Miles's Buildings.

Fig. 10: Likely bullet gouge marks on Jane Austen's house, Gay Street.

Fire damage

Thousands of incendiary devices were dropped in the first and third air-raids designed to set fire to buildings and create havoc. Two houses in the Royal Crescent were hit by incendiaries; numbers 2 and 17 (Isaac Pitman's house) were burnt out. A bomb landing on the grass in front of no. 21 created a large hole but seems to have only caused minor shrapnel damage to a few houses. Most bombs likely intended for the Royal Crescent landed behind (northwards) in the Julian Road area.

The effect of fire on Bath Stone is to turn it a pinkish-red colour. This will be the heat causing oxidation of iron minerals like pyrite (a ferrous iron, Fe^{2+}), turning it into a ferric oxide (Fe^{3+}, like hematite). After the war, historic buildings were repaired where possible but stone that had been involved in a fire was generally not re-used for buildings except locally in the construction of walls. Such pink-red stones can be seen in walls along the north side of Julian Road (Fig. 11), opposite the site of St Andrew's Church. Pink stones can also be seen on the front wall of the historic Abbey Church House (Westgate Buildings), the only domestic survival from the 16thC in Bath. It was near-destroyed, but then rebuilt in 1953 to be more Elizabethan than it was before the war, replacing Georgian sash-windows with lattice casements! The higher part of the Labour Exchange wall in Milk Street has many pink stones resulting from the fire that destroyed the upper floors (Fig. 2).

Fig. 11: Blocks of pink Bath Stone in a wall by Julian Road, likely coming from a nearby building which suffered fire damage.

Curious small impact marks

On quite a few buildings around Bath, easily seen in Queen Square (north and east sides) and in The Paragon on two houses (not far from where a 250 kg bomb landed and destroyed house numbers 28, 29 and 30), there are some intriguing structures that look very much like small impact marks (Fig. 12). They are mostly in the range of 10-20 mm in diameter. Some are clearly impact marks, like miniature shrapnel marks, where stone has flaked off to create a small crater. Some appear to be asymmetric, as if they formed from an object coming at an angle. In many cases these mini-crater-like structures, have a central hole of ~5 mm in diameter, and there may be a fragment of metal within the hole. The other notable feature is that these holes tend to occur in clusters, several or many 100s in the same area, covering a square metre to several m^2. They mostly seem to occur on walls up to 1-3 metres above pavement level and between ground-floor windows, but they do also occur higher up, on first-second floor walls. These clusters are not particularly common across the city, although the more you look the more you find!

Fig. 12: The Paragon, a classic Georgian street in Bath, with an area of small impact holes, here many with a central hole, in some cases occupied by metal. Stone blocks 30 cm high.

These small impact marks are also clearly visible on two houses in Walcot Parade, and a few buildings in Queen Square (notably in the SE corner, but also on the north side, east end) (Fig. 13). They can also be seen on some houses in the Royal Crescent and good examples are present in Bathwick Street (Fig. 14). They are present at first-floor level on the front wall of Magdalen Hospital (rebuilt 1761), in Holloway, near Beechen Cliff. Seven bombs landed around here, causing much damage, and 2 soldiers were killed by machine-gun fire. Somewhat similar ballistic impact marks are illustrated in Mol & Gomez-Heras (2017) from the School of Medicine of the Complutense University, Madrid, a site of action during the Spanish Civil War (1936-39).

Fig. 13: A wall in Queen Square with some new stone but numerous small impact marks on older stone, with a range of features.

Fig. 14: A wall in Bathwick Street peppered with small impact marks, some with a central hole (+/- metal), others just a crater.

These mini-crater-like structures certainly look like small ballistic impact marks, like someone has been firing a gun with lead-shot at the wall. These holes are too small to be from German machine-gun bullets, 7 or 13 mm in diameter, interpreted to account for the structures in Figs. 9 and 10. One type of missile which would have made small holes like these is a *flechette* or aerial dart, several cm (1 inch) to 10 cm (4”) long (Fig. 15). They were used by the Germans in WW1, dropped in their 1000s from planes on to soldiers below, notably over the trenches of northern France, and by the US Air Force in the Vietnam war (so-called ‘beehive bombs’); however, I cannot find reference to their use by the Luftwaffe in WW2.

Fig. 15: Flechettes – aerial darts dropped by planes, are the correct size for the small impact marks with central holes. Scale inches. Image: Wikimedia Commons.

One further possibility (Ollie & Oscar, email comms) is that these small impact marks relate to anti-aircraft gunfire. AA guns fired a range of shells in an attempt to bring down enemy planes, but one particularly relevant type here is a shrapnel shell full of 1000s of ball-bearings (see HMSO 1936). AA-gun emplacements were located on high ground at Lansdown Park (1 km north), Southstoke and Claverton Down; if the shells missed their targets, they could well have fallen back down on to the city. However, these AA sites were set up after the Bath raids (Penny 1997), actually the next day! It does seem that Bath was totally unprepared for these Luftwaffe air-raids, but after that April 1942 Blitz there were no further attacks on the city.

Fig. 16: Ballistic impact marks (scale in mm) in Bath Stone from an air-rifle using .177 calibre Webley VMX pellets from a distance of 2 metres. These mini-craters are similar to some of those on buildings in Bath.

As an experiment, and thanks to Graham Hickman’s son’s air-rifle, a few rounds of VMX pellets were fired at some slabs of Bath Stone (Fig. 16). The ballistic impact marks produced are not very different from many of the small ones on the buildings in Bath. Since the gun was firing aero-dome head pellets rather than pointed pellets/bullets, there is no central indentation there. More elaborate experiments and measurements to determine the effects of bullets on stone have been reported by Mol et al. (2017) and Gilbert et al. (2019) using an AK47 on sandstone.

Alternative explanation for small impact marks

However, could it be that these small holes have nothing to do with WW2 at all and are formed through a completely different process? One explanation could be that these holes (or some of them) derive from the impact of masonry nails being hammered into stone to hold up trellis work or to fix clematis, vines or wisteria (as in *Bridgerton*, partly filmed in Bath!) to the wall (Fig. 17); of course, some creepers like ivy and Virginia creeper have their own mechanisms for attaching to a wall but if this is the origin of the holes, then the effect on the stone has been really detrimental, permanently scarring the

Fig. 17: Vegetation growing against/on the front walls of buildings, magnolia in the Royal Crescent with small impact holes behind and Virginia creeper in Queen Square.

stone. It would almost be a type of self-inflicted vandalism to produce so many holes on the front wall of one’s house – although of course you would not see the holes until the creeper was removed! Interestingly, there are relatively few 18th–19th C houses in the city with creeper growing on their front walls today, as noted by examining old photos of some classic streets, such as the Royal Crescent. Is that because the damage related to creepers is now appreciated or is it just fashion?

If the small impact marks are related to holding up a creeper, one might expect the holes to be better ‘organised’, occurring in a line or more regularly spaced out (perhaps to take a wire), rather than in their apparent random, scattered arrangement. However, hammering a masonry nail into Bath Stone does produce a hole very similar to some of those on Bath house walls (Fig. 18), and if a nail broke off or rusted away, there could be a bit of metal left in there.

Interesting, the effect of knocking a nail into the stone is to produce a powder which forms a coating inside the hole. And fragments of Bath Stone flake off during the hammering.

Finally, in terms of man-made holes in Bath Stone, the front walls of a few heritage buildings in Bath are patterned with ridges and hollows, or pitted by circular chiselled or drilled holes of various sizes. These kinds of decoration are referred to as ***vermiculation*** (since reminisent of worm burrows) and can be seen on the front of the Guildhall, built 1778, and the former bank at the top of Milsom Street (Devon et al. 2001). But there is one building where the front wall at ground floor level is covered in small pits of a similar size to those small impact marks that are a puzzle: The Hospital of St John the Baptist, built in 1727 by John Wood, the Elder (Fig. 19**);** in fact this was his first project, followed by the classical palladian-revival style of Queen Square (built 1728-36).

Fig. 18: Hole created from the impact of hammering a nail into a block of Bath Stone. Scale mm.

Fig. 19: Vermiculation on the wall of The Hospital of St John the Baptist.

What other possible origins could there be for these holes? Are there any likely natural explanations? Some of these structures could be cross-sections through burrows. Bath Stone is an oolitic grainstone, a lime sand composed of ooids deposited in a shallow, moderate-energy sea, like the margins of the Bahama platform today, Joulters Cay for example (Tucker et al. 2020). In such a location there would have been animals living within the sediment, annelids (worms), but especially crustaceans (like *Callianassa*), and there are definitely some burrows in the stone. Some of these burrows are lined, with slightly better cemented sand, and less well-cemented sand within the burrows themselves. On weathering of the burrows, holes are formed in the oolite, as in Fig. 20. Although a few of the holes could be burrows, this cannot be the explanation for all of them.

What about stone or masonry bees? Perhaps not …. although in a few places there are concentrations of holes in the mortar between the stone blocks (Fig. 21), so maybe some. Thus, in summary here, these small impact marks are a conundrum. Perhaps, like many features in geology, they are the result of several different processes rather than just one.

Fig. 20: Holes on a wall in Duke Street, likely to be the burrows of Jurassic crustaceans (or worms), i.e., bioturbation.

Fig. 21: Holes which could be from the activities of masonry bees. Or more nails for the clematis (or both)?

Concluding remarks

This article has attempted to show that there are many features of interest which can be observed on the walls of heritage buildings in Bath: some are related to the WW2 Blitz of April 1942, but other marks on the stone are the result of other processes, natural and anthropogenic. Close observations of the walls of the former Labour Exchange reveal how the Jurassic oolite building stone reacted to severe ballistic impacts from shrapnel. The fracturing and comminution-recementation of limestone reported here have also been described from the relatively small Meteor Crater (Arizona, 1 km across). Permian carbonates at that impact site were recrystallised and twinning of course calcite crystals was induced by the shock deformation (Burt et al. 2005). A petrographic study of the Bath oolite around shrapnel impact craters would provide useful detail on the degree of limestone deformation. Heritage and cultural buildings are at risk from conflict damage in many parts of the world and Bath provides one example of a city where most of the evidence of the extensive WW2 damage has been removed with just one clear example of a building with shrapnel damage tastefully preserved as a memorial to those dark days of April 1942.

Acknowledgements

For comments and suggestions, thanks to Tom Blenkinsop, Ollie Campbell, Oscar Gilbert, Lisa Mol, Mark Lewcun, Jim Warren, Stuart Burroughs, Tim Lunt, Vince Baughan, Graham Hickman (and for use of air-rifle), Phil Burge and two stone masons I bumped into at Bath Riverside. I am grateful to Martin Wainwright for permission to use his map (Fig. 22).

I dedicate this article to my dear sadly-departed brother Eric, who collected over 200 Baedeker guidebooks and gave talks on the Baedeker Raids.

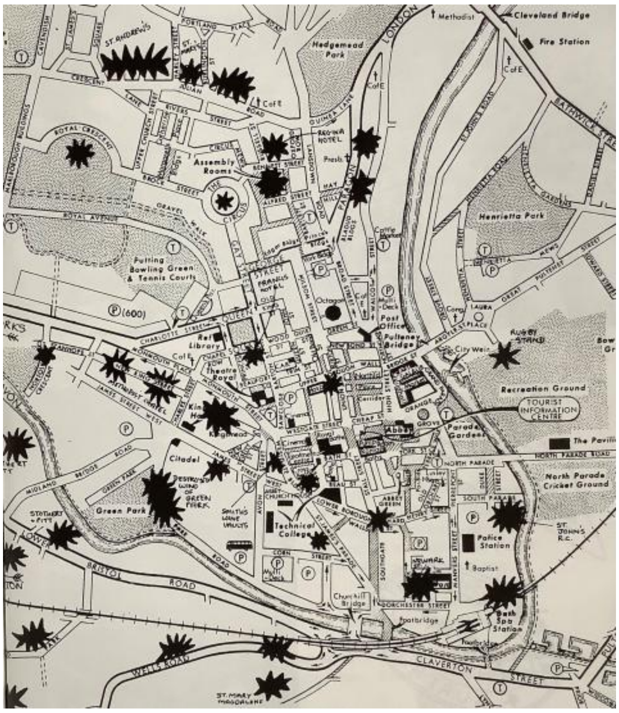

Fig. 22: Map of the bomb-sites in central Bath (from Wainwright 1992, with permission).

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Bath Geological Society Journal Issue #1 – A Review

By Phil Burge

The Bath Geological Society was inaugurated on the 25th September 1970 with the first AGM held on 13th May 1971. It was not until 1981 that the first issue of the Journal of the Society was published. Before a review of the articles in this first issue a few interesting other items can be found. At the AGM in May 1971 the Society had funds of £209.49 and had 41 members. Including within the Journal was a note from the editors

"In presenting the first issue of the Bath Geological Society's Journal, we hope that readers will be inspired to contribute notes to future issues. In addition to reports of lectures and field excursions, it is hoped to publish notes on sites of particular interest and other contributions by members".

And an extract from the Proceedings of the Bath Natural History and Antiquarian Field Club, Secretary's Report 1886 – 1887

"The weekly walks have been kept up, but the secretary has not received any Notes respecting them, and concludes that bodily exercise, unaccompanied with any particular strain upon the mind by way of observation, was the chief object. As he is not always able to join these walks himself, he wishes members would from time to time send him some result of their meetings".

It would seem that encouragement to submit field trip reports was as necessary then as it is now! However, the depth and range of articles in the Journal (and Covid inspired Newsletter) since the Society's first issue shows a great degree of enthusiasm and engagement with the

Journal. Our thanks to all contributors to the Journal in this 51st anniversary year and to the editors who put the whole thing together. It doubtless fills the editor with anxiety until the articles arrive in time for the publication deadline!

Here follows a summary of the articles that appeared in the 1981 issue of the Journal.

Dr D Parkin of Bath University provided the opening short article entitled “Cosmic Spherules”. These are the minute dust particles that are found in red clays on the ocean floor. Their composition is the same as the meteorites namely nickel, iron, olivine and pyroxene.

“Bath and Geology in the 18th Century” by Dr H.S.Torrens describes the burst in interest in fossils and fossil collecting arising from the quarrying of Bath Stone by those such as Ralph Allen in the early to mid18th century. Collections of plants, fossils and minerals were common and discussed at meetings of various “philosophical societies”. John Walcott of Bath (father and son) were avid fossil collectors. John Walcott (son) published his “Descriptions and Figures of Petrifactions Found in Quarries and Gravel Pits near Bath” in 1779 and priced as 2s 6d. His attempts at classification failed as the concept of extinction was not yet appreciated. Other notable members of philosophical societies and fossil collectors included Edmund Rack, William Herschel and Joseph Priestly. Economics in the form of coal extraction encouraged interest in stratigraphy including a geological map of the coal seams near High Littleton. Of course, William Smith played a huge role in the development of our subject and no more will be said as his story is well known except for the following quote from 1869 written by W.S. Mitchell. “Bath can claim that the first collection of fossils stratigraphically arranged was made by Smith whilst at Cottage Crescent. The first table of the strata was dictated by Smith at Putlteney Street. The first geological map known is his map of the district around Bath. The first geological map of Britain was coloured by him whilst living near Bath. The first announcement of the publication of a geological map was his prospectus dated from Midford. The first introduction of his discovery to the public was through friends he made in Bath”.

Mr D Anthony wrote an article entitled “The Winning and Working of Fullers Earth”. This article describes a Fullers Earth mine at Combe Hay at a depth of 18 to 25 metres below the surface and capped by a thin limestone band below the Great Oolite. This deposit was worked by the Romans for cleansing cloth. The mine was active until 1981.

“Groundwaters, Ancient and Modern” by Dr J Andrews, Bath University began by describing the potential for geothermal energy for heating and electricity supply. Dr Andrews raised the possibility of obtaining heat from deep wells by circulating water between two wells. The author then describes the use of isotopes of tritium H3, carbon 14, helium 4, and uranium to date water. Using carbon dating places the age of the Bath hot spring water at 8 – 10,000 years old, suggesting that the water flowing today originated as melt water form the last ice age.

C.P. Horstmann wrote about “Mineral Micromounts” which described a method of mineral identification that does not require thin sections, which are as the author suggests of no use in the field and collections of large crystals becomes problematic for the amateur collector. Micormounting refers to the mounting of small mineral crystals in a specific sized and prepared small box. Examination of the specimens can be done at a magnification of x10.

Further afield now to Hawaii and the “Geology of the Kilauea Volcano” b Dr C Wood of the Avon Wildlife Trust. The author explains that the sea mounts making up the Hawaiian group are made of basalt arising from mantle plumes and that the plate overriding the plume is moving in a south easterly direction. The author describes the various types of lava flow including Pahoehoe and Aa. Of particular interest is the description of cave systems not unlike those in limestones that had only recently been discovered.

“The Chesil Bank - An Account of a Lecture and Field Excursion led by Mr G.C. Poole” followed. The article opened with the statement that “the formation of the Chesil Bank has puzzled scientists for a very long time”. It would appear that this is still the case as judged by the discussion on the Bank during our recent field trip in June 2021! Without going into too much detail, Mr Poole’s thesis as to the origin of the Bank depends on the land geometry between Lyme Regis to Portland, a coastline of much faulting in hard and soft rocks but little folding; the accumulation of debris from melt water following the glacial and interglacial periods which were then submerged when the Straits of Dover were cut; and the effects of wind and wave power specifically the very long fetch from the Atlantic Ocean up the channel where the first resistance encountered is Portland Bill.

Mr C Copp, Bristol City Museum gave a lecture on the “Evolution of the Molluscs”. Tracing the ancestry of molluscs to 570 million years ago, the evolution from a basic body plan of head, foot, gills and a feeding organ and the origin of molluscs from work like creatures was described. The original explosion of mollusc species in the Cambrian gave way to extinction of many in the Silurian. The three groups of molluscs, the Bivalves, Gastropods and Cephalopods are distinguished by their degree of mobility from sedentary to free living, fast swimmers. Mention is made of the living fossil Trigonia first found in Australian waters in 1820. A description of the evolution of the Cephalopods from the straight from Orthoceras, then the coiled Nautiloids, Goniaitites, Ceratites and Ammonites. The worldwide nature of the free-swimming ammonites makes them invaluable as zone as zone index fossils.

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Deer Leap and Ebor Gorge. Mendips Field Trip Report for the Bath Geological Society, 9th June 2021

By Graham Hickman

As a pre-view to the trip Dr Doug Robison had given a Zoom lecture entitled 'The Making of the Mendip Hills' to the Bath Geological Society only a few days before. This proved to be the prefect introduction to what was an extremely interesting field trip. This trip was led by Dr Doug Robinson together with his friend and neighbour David Scarth. Both Doug and David live in Wookey Hole Village and part of this field trip was across land owned by David Scarth.

We met at the Deer Leap car park (ST 5190 4928) and the group enjoyed the pleasant views from the Mendips across to the Bristol channel. Being only the second field trip to be held in 2021, members were delighted to be out in the field together, after an abeyance of 15 months when all meetings had to be cancelled because of the Covid-19 pandemic. Doug introduced the geology and described how the Mendip Hills are interpreted as a foreland fold and thrust belt which has undergone shorting by some 20km. In the area around Deer Leap the thrust belts are E-W trending. (Fig. 1).

Fig. 1: Doug Introduces the Geology using the local map.

The group then proceeded to walk west across to several small outcrops of the Clifton Down Limestone and the Oxwich Head (Hotwells) limestone. Dips were measured, confirming the 60 degrees to the SW, shown on the published geological maps (Fig. 2). The coarser nature of the Oxwich Head limestone was also noted. Several of the outcrops showed a karstic weathering while others did not. It was suggested that the lack of karstic features on some outcrops were due to quarrying activities rather than dolomitization, distinct depressions next to them showed where stone had been won. The ancient Deer Leap Standing stones further up the hill confirm this area has been occupied and exploited by man for millennia.

Further down the hill, younger rocks of the Millstone Grit were encountered as we walked ''up the stratigraphy''. Its appearance was as a fine-grained quartz arenite. Doug pointed out how the difference in lithology, which affects how rocks weather, can also be seen as slight breaks in slope. The largest of these being at the boundary with the softer Coal Measures which are composed mainly of shales. To the west a depression marks the location of a palaeo-valley or Wadi infilled during the Permian with the dolomitic conglomerate group.

Fig. 2: Doug demonstrating the SW dip of the bedding

This area of the southern Mendips is unique in that the Ebbor thrust overrides a thin unit of Coal Measures (CM), which are preserved in a tight syncline underlying the thrust (Fig. 3). Finding the Ebbor thrust was our next task.

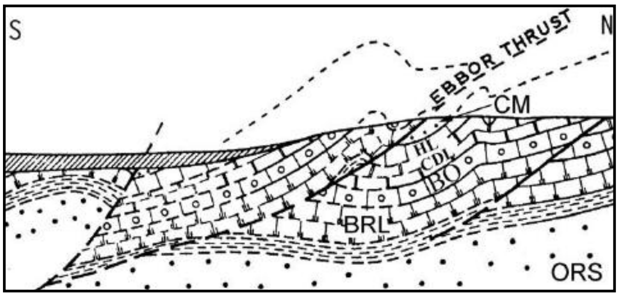

Fig. 3: Modified images from 1965. Geology of the country around Wells and Cheddar. Memoir of the British Geological Survey).

On crossing the road and entering the land owned by David Scarth we made our way down to an old overgrown quarry (shown as an adit on an 1871 published map). Here the Ebbor thrust is clearly exposed. The strike of the thrust was measured as 120/300 degrees, with a dip of about 45 degrees. Limestones occur to the south (in the hanging wall) and coal measure sandstones to the north (in the footwall). (Fig. 4) The limestones immediately adjacent to the thrust have undergone low-grade alteration and a thin band known as Ebbor Marble can be found.

Fig. 4: Doug demonstration the position of the Ebbor Thrust

Then we walked back to the Deer Leap carpark through the fields on the east side of the road. Working our way up to older rocks ''down through the stratigraphy'', we noted the outcrop of sandstone, now attributed to the coal measures and the area of boggy ground where a small stream flows over the coal measure shales. Finally reaching the higher ground of the Carboniferous limestone. A pleasant picnic lunch was eaten on the benches near the car park.

After lunch we drove a little way down the road to the NT Ebbor gorge car park and made our way into the woods, then following the stream, to the location of an abandoned mineshaft. Doug explained how in 1871 the shaft was sunk to 36m in depth in the search for coal. It may be presumed that the reddish sandstone we had seen earlier, had been mis-identified as Triassic in age or the presence of carbonaceous shales had misled the investors. A contemporary account by the geologists' Bristow and Woodward describes the folly of the event *''The sinking of this shaft under such manifestly hopeless conditions shows a want of knowledge of the elements of geology and coal-mining that could scarcely be supposed to exist at the present day on the part of persons likely to embark in a search for coal within five miles of a Cathedral City"* (Geological Magazine, V8 November 1871, pp. 500-505)

We then drove into Wookey Hole and made our way to the garden of David Scarth. His house is set in an old quarry and the Triassic Sandstone quarry walls form the boundary of his garden. This was the perfect place for a group photo (Fig. 5).

Fig. 5: Group Photo, Bath Geological Society participants.

The sandstones have a slight westerly dip, they are very thick bedded and laterally persistent. They probably represent stream flood deposits during the Triassic. Some thinner bedded units were recognised as more nodular and probably represent a palaeo-soils. Of special interest is a small normal fault in the east side of the quarry, this has a strike of 030/210 degrees and a throw of about 1m down to the west. It is called 'Doug's Fault' as it goes under Doug's house! Fortunately, there has been no recent movement on it.

During the final part of trip, we walked east across the fields following the Triassic, past its onlap point, until we came again onto the Carboniferous limestone where there is a large disused quarry and lime kiln. The Carboniferous limestone here is the Burrington Oolite Formation. The massive nature of the limestone means that bedding planes are quite difficult to identify, and the group spent some time identifying candidate bedding surfaces. There are also a number of mineral bands, about 30cm wide, with symmetric banding, the veins have grown in thickness by opening and closing along the vein fracture and progressive depositing minerals on the growth surface (Fig. 7).

Fig 6: Doug demonstrates the throw on 'Doug's Fault'

Fig, 7: Symmetric banding within a mineral vein

The group returned to Wookey Hole, having enjoyed wonderful weather and a great day learning about the rocks of the Mendips. We thanked Doug and David for a very informative and enjoyable field trip.

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Making thin sections at home

by Jonathan Slack

Last year I wrote an article for this journal entitled "Fun with thin sections". As all readers of this journal will know, thin sections of rocks enable identification of the constituent minerals and are often also very beautiful. At that time they were made for me by Robert Gill of Geosec. I did not believe that it would be possible for an amateur to make them at home because of the complex equipment I thought would be required. However, as a result of the Covid pandemic, Robert Gill was unable to continue processing customers' own specimens. This meant that if I wanted any more sections, I should have to grasp the nettle and have a go myself.

Setting up to do this kept me busy for much of Autumn 2020 and involved a lot of trial and error. In the end I can make fairly good thin sections although I suspect not quite of professional quality. I shall only describe the process I have ended up with, and not all the failures on the way. Some of the details are covered in the Appendix.

The procedure in 9 steps:

1.	Collect the samples.
2.	Cut suitable size blocks.
3.	Grind and polish one face to complete smoothness.
4.	Dry thoroughly, then glue this face to a glass slide.
5.	Slice off the rest of the block leaving about 1mm thickness stuck to the slide.
6.	Grind this down to 50-100µm thickness.
7.	Grind further by hand keeping a careful eye, and finish when the section is 30µm thick.
8.	Wash, dry, and apply some Canada Balsam and a coverslip.
9.	Allow the balsam to set and label the slide.

The great thing about making your own sections is that you can make as many as you like since they are no longer rationed by cost. Also, for each sample, you can make more than one block and keep for future reference any that are not immediately used. The specimens can be anything, depending on your interests. The prettiest results come from plutonic rocks because of the crystals they contain, but most kinds of rock can yield something of interest. I prefer samples actually taken from the bedrock, as you can then be sure of what you have got. As hammering bedrock is not allowed in some places, it may be necessary to take pieces that are lying around which look as though they have been eroded off the neighbouring bedrock. The ideal size for a sample is about the size of a fist. Pieces that are not too thick are easier to cut up with a tile cutter, but many samples do not come in the ideal shape and so it is necessary to break them up further. This is better done by cutting a deep groove and then breaking as gently as possible with a chisel, rather than hammering, so as not to introduce unwanted cracks which can cause the blocks to fall apart.

When I collect each sample, I put it in a plastic bag with a note of when and where it was found. As soon as possible I photograph it and give it a name (e.g., NQ7 is the seventh rock collected on a trip to the Newquay area). I also record a tentative identification based on hand lens inspection.

I cut out the blocks using an ordinary tile cutter (Fig.1a). I keep separate diamond edge wheels for cutting the blocks and for trimming them after they have been glued to the slide. Ideally a block should be about 2x2.5 cm in area and thick enough to handle easily (Fig. 1b), although I have used many smaller than this and many with somewhat irregular shapes. The blocks are labelled in felt tip with the name of the sample.

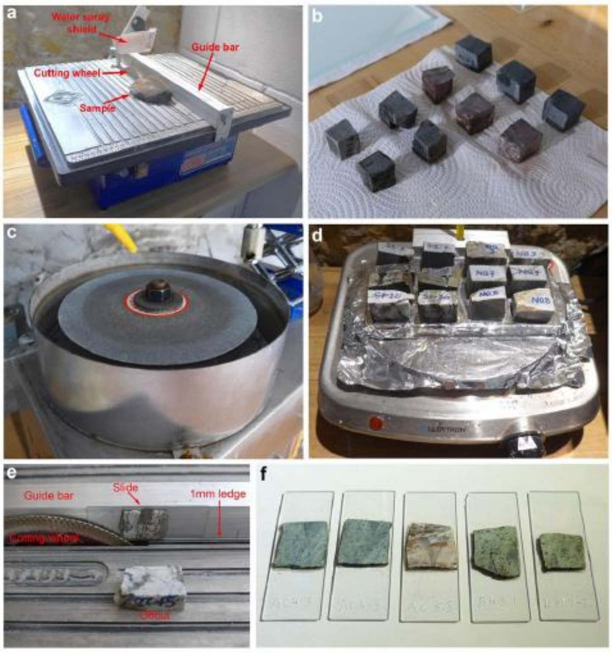

Fig. 1: (a) Tile cutter used for making small rectangular blocks. (b) Some blocks prepared. (c) Flat lap wheel for creating a smooth surface on the block. (d) Drying the blocks preparatory to mounting on slides. (e) Trimming the blocks to about 1mm thickness. (f) Slides bearing trimmed samples, ready for grinding.

Then one face of the block needs to be made absolutely flat. This is done by grinding on a flat lap machine, which has a horizontally mounted diamond-coated wheel (Fig. 1c). I hold the block by hand and use a 120 grit (coarse) wheel to get a flat surface, followed by manually grinding with 600 (medium) grit silicon carbide powder, with some water on a glass plate, to make it even flatter and to remove the grooves made by the wheel. Final polishing is done by rubbing for a minute or two with aluminium oxide powder (1200 grit) and water. The opposite face just needs to be ground fairly flat, and approximately parallel, so that it can rest on this surface when the slide is applied to the polished surface. I then put the blocks on a hotplate at about 100°C and dry them for several hours (Fig. 1d). This is to remove any water from deep cracks and crevices that might erupt and generate bubbles at a later stage.

I use 7.5x2.5cm glass slides. Petrographic sections are often made on smaller format slides, but I am wedded to the 7.5x2.5cm size which is used in biology. I use a thickness of about 1.4mm, which is quite thick and chosen to reduce the risk of the slides cracking as the epoxy resin sets. The epoxy resin I use is heat-activated and can be mixed in advance and stored indefinitely at -20°C. I allow the container to warm up before opening to avoid condensation. The blocks are placed polished side up on the hotplate at a surface temperature about 150°C. One drop of epoxy is spread over the surface of a block then a slide applied carefully so as to avoid bubble formation. A pre-heated weight is placed on top and the epoxy is allowed to gel for a few minutes. Then the weight is removed and the slide is turned over and placed on the hotplate to achieve a hard set over about 30 minutes.

Once the blocks have been attached to their slides, the slides themselves are labelled with a diamond pen. The blocks are cut down to a thickness of about 1mm using the same tile cutter with a thinner blade. The guide bar I made for this step has attached to the base a thin steel plate to act as a ledge allowing the slide to be slid smoothly past the cutting wheel (Fig. 1e, f).

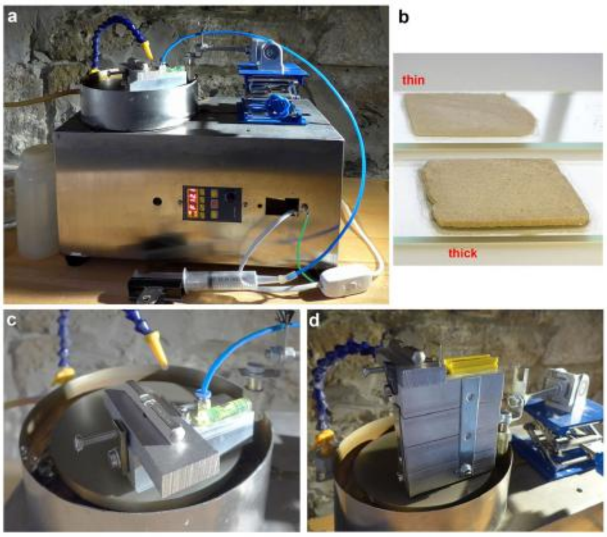

Fig. 2: (a) Slide grinding apparatus. (b) Reduction of sample thickness. (c) Close up of slide holder. (d) Heavy slide holder.

Now each sample is on its own labelled slide and is about 1µm (=1000mm) thick. This needs to be reduced to 30µm which is the standard thickness for petrographic sections. The reduction of thickness is mostly carried out using the flat lap machine (Fig. 2a, b). The slide holder used for this stage (Fig. 2c) is my own design and consists of a rectangular block of aluminium carrying two small spirit levels for levelling. It has a hole through the centre bearing a vacuum line attached to a syringe, the modest vacuum from this being enough to retain the slide in place. Between the aluminium body and the slide is a sheet of silicone rubber, with some silicone grease on the metal side, or sometimes both sides, to achieve a vacuum-tight seal. The slide holder is held by a ball and socket joint which can be raised and lowered with a lab jack to level it, as shown in Fig. 2a. The grinding regime depends on the hardness of the rock. I usually start with a coarse, 120 grit, wheel and steady the slide holder by hand until a flat level surface has been produced. Grinding is continued using a finer wheel, usually about 240 grit. A soft rock requires only minutes to reduce while a hard one may need hours, especially if the wheel is getting old. For hard rocks I may use an alternative slide holder which weighs 900 gm rather than 300 gm and therefore exerts more pressure on the sample (Fig. 2d). Careful timing and regular inspection is required to avoid grinding the sample away completely or allowing it to become less than perfectly level in both axes. Fig. 2b shows "before" and "after" views of the thickness reduction process.

When reduction has proceeded to something under 100µm the slide is removed and finished by hand. Now I hold it with a simple sucker and syringe device and grind it on a glass plate using water and silicon carbide powder, usually 400 grit (Fig. 3a, b). Hand grinding allows careful monitoring of the uniformity of the thickness, and regular examination under the microscope usually enables a final thickness of 30µm to be obtained.

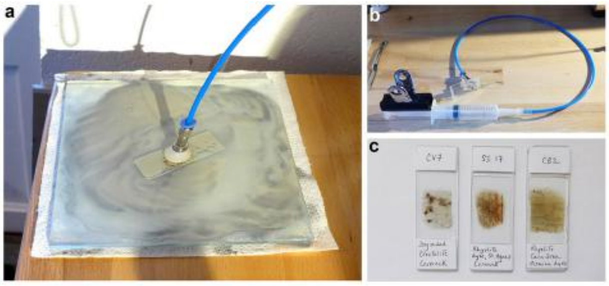

Fig. 3: Manual finishing. (a) Grinding on a glass plate with silicon carbide grit. (b) the slide holder. (c) the finished product.

How do you know when you have got to 30µm? The easiest way is to have some quartz or plagioclase feldspar in the section. Quartz has a very uniform composition and at 30µm should give a maximum white birefringence (see below for explanation of birefringence). If the quartz shows a maximum orange-yellow colour, then the section is about 50µm thick, if shows a maximum of light blue then it is about 75µm thick. Plagioclase is easy to recognise as it often has a stripy appearance (lamellar twinning) and at 30µm these stripes should be alternating black and white rather than the colours shown by thicker sections. If the specimens contains neither of these minerals, then it is more difficult to assess the thickness. Sometimes I make a small hole in the middle with a diamond pen and can then focus up and down through the section and note the thickness from the number of fine adjustment gradations traversed.

When I am satisfied with the thickness, the slide is washed in reverse osmosis water and dried on a 70°C hotplate. The coverslip is cleaned with xylene and meths, a streak of Canada Balsam is applied to the section and the coverslip carefully laid on top, avoiding bubble formation. It is then left overnight on the hotplate to set the balsam, and finally labelled (Fig. 3c). Although Canada Balsam is a very old-fashioned mounting medium, I use it instead of epoxy because, if there is a problem, it is easy to dissolve it off with xylene and to apply the coverslip again. Since I don't have a fume cupboard at home, I handle xylene and other noxious solvents outdoors.

Once the slide is ready, I look at it with my old Zeiss microscope, which has a rotating stage and a polarising attachment. I now use an AmScope MU300 camera in preference to the Canon used a year ago. These are remarkably cheap, have good resolution (3MPx), a flat field, and the software enables live streaming and image capture with colour temperature correction. You can even make videos of the image as you rotate the stage. I keep images of typical or attractive views and allow myself to adjust the sharpness, brightness, contrast, colour balance and intensity using Photoshop. However, my scientific background inhibits me from making any non-linear adjustments to the images, as this would be unethical and is forbidden in publications!

As I indicated in last year's article, it is fairly easy to become familiar with the main minerals found in sedimentary and igneous rocks, but the minerals of metamorphic rocks can be very tricky. Here I will just illustrate what can be done by showing a few specimens sectioned during the last year which present some point or other of interest.

Some results

First, a brief recap on optical terminology. The slides are usually viewed in plane polarised light (PPL) or in crossed polarised light (XPL). PPL gives a similar view to unpolarised transmitted light except that some minerals show *pleochroism*, meaning that they change colour when the stage is rotated. XPL shows the *birefringence* of mineral crystals. This is a colour caused by the interference of light rays taking different routes through a crystal. For the standard section thickness of 30µm, each mineral will show a characteristic maximum degree of birefringence when it is oriented in the correct way. Since crystals in any specimen are normally oriented at random, only some of them will show the maximum birefringence. Birefringence manifests itself as one of a sequence of colours, starting with grey, then white, then yellow, orange, pink, blue and green, then approximate repeats of the same sequence. The whole repeating series of colours is known as Newton's scale, and it is shown in all books on optical petrology. Some minerals, such as metallic oxides and sulphides, are opaque even at 30µm and these are best viewed in reflected light (RFL), for which I use a fibre optic light guide shining obliquely onto the slide.

The average refractive index of a mineral crystal determines its *relief*, or how it appears in transmitted light or PPL when immersed in Canada Balsam. The balsam has a refractive index of 1.516 and minerals close to this, such as quartz, appear almost invisible, and said to have a low relief. Minerals whose index deviates below, or, more usually, above this value show up more clearly and are said to have a medium or high relief depending on how great the deviation is.

The *cleavage* of a mineral crystal denotes cracks parallel to one or two of the main crystal planes. Their appearance, and the angle between them if there is more than one cleavage, is characteristic of the mineral. When viewing birefringence in XPL, as the stage is rotated, the colour will come to maximum intensity and fade to zero four times in each complete rotation. The point of zero transmission, or *extinction*, may be parallel to a principal cleavage plane, or may be at a characteristic maximum angle. This again is characteristic of the mineral.

Hopefully most minerals crystals can be identified by looking at the morphology, the relief, the pleochroism, if any, the maximum birefringence, and the maximum extinction angle. The nature of the rock will, of course, be defined by its mineral composition.

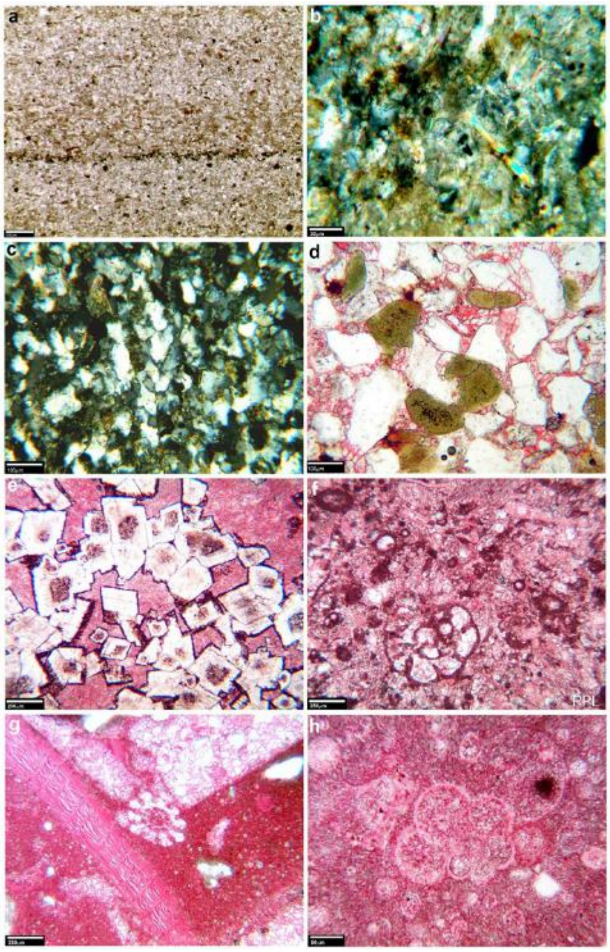

Fig. 4: (a) A Silurian shale from Shropshire, viewed in transmitted light. (b) High power view of the same shale. (c) May Hill sandstone (XPL). (d) Upper Greensand, viewed in PPL with alizarin stain of the calcite cement. (e-h) Limestones. (e) A Devonian limestone with many crystals of dolomite. Alizarin stain. (f) A Carboniferous limestone. Alizarin stain. (g) Great oolite from my garden in Bradford on Avon, . Alizarin stain. (f) A chalk from Bratton, Wiltshire. Alizarin stain.

<u>Sections of a few sedimentary rocks</u>

I must confess to have spent much more time on igneous than on sedimentary rocks. But I have collected a few sedimentary samples. Fig. 4a, b shows a randomly selected example of a shale from the Silurian of Shropshire (Edenhope Hill). It is composed of fine particles of clay minerals with a little quartz. The horizontal lamination, whose presence makes it a shale rather than a mudstone, is apparent. The high-power view shows the birefringence of the clay minerals.

Fig. 4c and d are sandstones. By definition, sandstones consist largely of quartz particles, and Fig. 4c is May Hill sandstone of the Silurian period, collected from the Malvern Hills. The majority mineral is quartz, visible as white and grey crystals, but there is also 5-10% of feldspar and some clay mineral particles. A less typical type of sandstone is the Greensand, found in the Lower Cretaceous. This gives attractive thin sections because it contains the bright green mineral glauconite, in between the quartz particles. The example shown in Fig. 4d is Upper Greensand from near Potterne, Wiltshire. It contains a calcite cement, presumably derived from the huge amount of overlying chalk, which binds the particles of quartz and glauconite together. The cement is here stained with alizarin which makes it pink and gives a pleasing three-colour effect, with white quartz crystals, green glauconite and pink calcite.

Carbonate rocks are quite varied in thin section appearance. They have various different microstructures and often contain abundant microfossils. The principal mineral, calcite, has an exceptionally strong birefringence. In fact, it is so strong that in a 30µm section it is often not visible at all, although it can show a characteristic cross-hatched appearance (apparent in Fig. 9f below). Because calcite often shows up poorly in XPL, I usually stain limestone sections with alizarin which colours calcite pink. Fig. 4e-h shows some specimens stained in this way. The first is a Devonian limestone from Black Head, Torquay. This contains crystals of dolomite, which does not take up alizarin, against a pink matrix of calcite, which does. The second is a Carboniferous limestone from Goblin Combe, near Bristol Airport. This is very rich in microfossils which I confess I have not attempted to identify. The third is a sample of limestone from my garden in Bradford on Avon, which is perched on a steep slope of the Jurassic Great Oolite above the River Avon. The fourth is a Cretaceous chalk from Bratton, Wiltshire. Both of these are also rich in microfossils.

Sections of a few igneous rocks

For much of the last year travel has been restricted so I was unable to go out to collect any new samples. This meant that I had to rake through my collection to see if there was anything that might be worth sectioning and was also large enough to be able to preserve a portion. One sample came from a long-ago expedition to Mount Kilimanjaro (Fig. 5a). Kilimanjaro lies near the equator in the north of Tanzania and is a dormant volcano with just a few fumaroles indicating its former activity. Because of its altitude of 5895m, it is cold enough at the summit to have an ice cap. Fig. 5b shows me standing on the summit of Kilimanjaro in 1969 along with a very tall Dutchman and our guide. Although bemused by oxygen starvation I did pick up a piece of what I thought at the time was obsidian (Fig. 5c), but on later examination proved to be too brittle to really be obsidian. In 2021 a thin section and a little research on the geology of the mountain revealed that it was a phonolite lava. Fig. 5d-f show some crystals of anorthoclase feldspar and another of crystals of (probably) olivine and apatite, all surrounded by a dark brown matrix.

In 2003 my family went to Tenerife, where there is another dormant volcano, Mount Teide (Fig. 6a). At my insistence we took the cable car up to near the summit and I collected a black and a red sample of the local lava (Fig. 6b). These lay in a drawer until 2021 when I processed the black lava sample and made a thin section. Although there is phonolite on Mt Teide, this particular lava sample is very different from that from Kilimanjaro. The section revealed that it is an andesite containing nice crystals of plagioclase feldspar, hornblende and clinopyroxene in a matrix of feldspar laths (Fig. 6c-e).

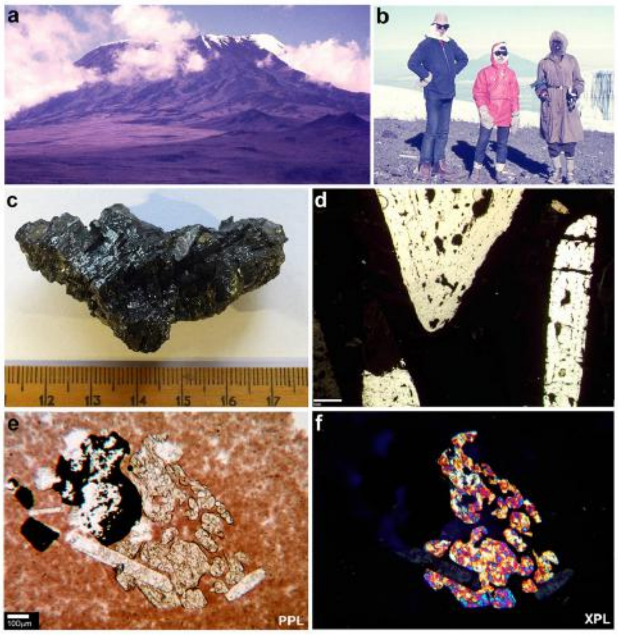

Fig.5. Kilimanjaro. (a) Kibo summit. (b) Summit party at Uhuru Point. I am in the middle flanked by a tall Dutchman and our guide. (c) A sample of the black lava from the crater rim. (d) Phenocrysts of anorthoclase feldspar. (e,f) PPL and XPL views of olivine and apatite in a brown matrix.

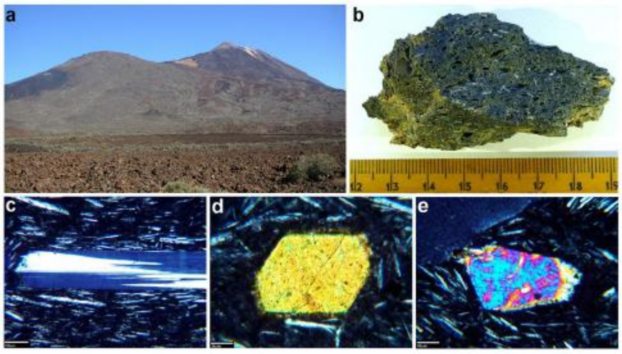

Fig. 6: Mt. Teide, Tenerife. (a) The mountain. (b) Sample of black lava. (c) Plagioclase feldspar. (d) Hornblende. (e) Clinopyroxene. (c,d,e are all XPL views).

An unlikely source of igneous, indeed somewhat metamorphosed, material is Portishead, just south of Bristol on the Somerset coast. I was able to go there on a day trip in between lockdowns in the summer of 2020. The bedrock is mostly limestone and Pennant sandstone, both of Carboniferous age, along with some conglomerate from the Triassic. It is not at all an igneous location as on the beach by the Royal Hotel there are some pieces of gneiss (Fig. 7a, b). These are mentioned by Williams and Hancock in Chapter 3 of *Geological Excursions in the Bristol District*, University of Bristol 1977. They may be fragments from a glacial erratic or are perhaps just part of a ship's ballast that was dumped in the area. Anyway, they are still there and they make nice sections showing a largely granitic composition. There is abundant microcline, the triclinic form of potassium feldspar, which is characterised by a tartan-like black and white birefringence (Fig. 7c). There is plenty of quartz and biotite, the latter being brown with strong pleochroism (Fig. 7d, e). There are also some garnets (Fig. 7f, g), which are indicative of some metamorphism. Because garnet belongs to the cubic crystal system it is optically the same in all directions and shows no birefringence. This means it appears black in XPL at all angles of rotation

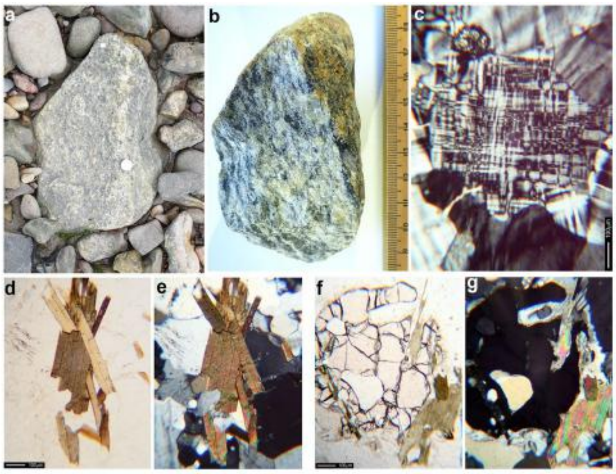

Fig. 7: Definitely in the wrong place. (a) A piece of granitic gneiss on the beach at Portishead. The coin is 10p. (b) A different sample under better illumination shows clear foliation. (c) It contains abundant microcline. (d, e) Biotite and quartz. PPL and XPL views. (f, g) A garnet with some more biotite. PPL and XPL views.

When regulations loosened enough to go for overnight trips to the South West coast path, I was able to collect some new material as an adjunct to the main business of walking. Fig. 8 shows a few of the products, with a focus on mineralised granite. Although Cornwall is legendary for its minerals, I find it difficult to find examples of the principal ores of tin and copper, respectively cassiterite (SnO_2) and chalcopyrite ($CuFeS_2$). I suspect that collectors have already removed all the surface specimens, and that the spoil tips of the old mines have all been well searched. Carn Brea is a classic mining area adjacent to Redruth, but the granite from the summit is quite ordinary without noticeable mineralisation (Fig. 8a, b). Fig. 8c shows a famous quarry at Cligga Point, which displays a "sheeted vein complex" with parallel bands of granite and of greisen, which is granite mineralised by hydrothermal fluids. The greisen bands here appear dark. They contain a few probable crystals of cassiterite (Fig. 8d) and a lot of pyrite (FeS), which is opaque in thin section but appears a silvery-yellow colour in reflected light (Fig. 8e). Iron oxides and hydroxides usually appear as opaque clumps but can sometimes be more picturesque and the delicate tendrils in Fig. 8e are fine enough to appear a translucent brown in transmitted light. Tourmaline is a ring silicate containing boron and fluorine, and is very abundant in mineralised granites. Fig. 8 (f) shows a crystal with zones showing blue-green and brown pleochroism as the plane of polarisation is rotated.

Another of our walking haunts is Offa's Dyke which runs the length of Wales approximately along the England-Wales border. Once you get north of Hay on Wye, some igneous sites come into range. Just off the dyke, west of Kington, is Stanner Hill. This is the northerly of three hills which are Neoproterozoic igneous intrusions. Stanner Hill provides both mafic (Mg and Fe rich) and felsic (SiO_2 and Al rich) rocks for the collector. The mafic region is displayed in a gabbro quarry at the south end of the hill and a felsic dyke cuts across the summit (Fig. 9a, b). This gabbro contains plenty of clinopyroxene, with cleavages exaggerated by the presence of iron ore (known as a "diallage" structure) (Fig. 9c, d).

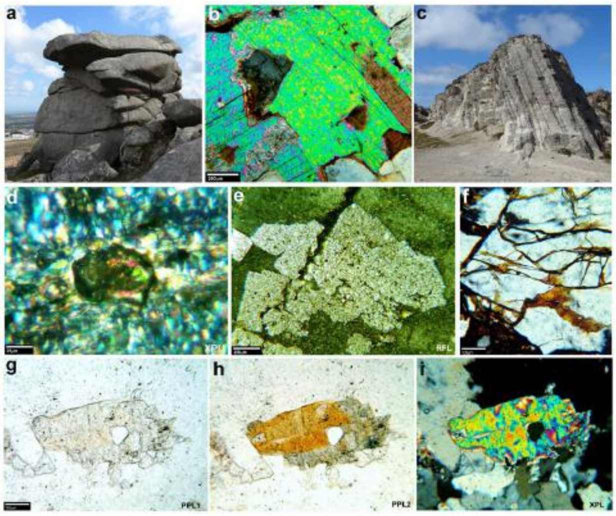

Fig. 8: (a) Granite tor on Carn Brea, Redruth. (b) Muscovite in granite from Carn Brea. (c) Quarry at Cligga Point, Cornwall, showing dark greisen veins. (d) Probable crystal of cassiterite in a mica-rich vein within the greisen. (e) Pyrite crystals viewed in reflected light. (e) Iron mineralisation in a sample from Botallack mine, XPL. (g-i) Tourmaline in greisen. Note the high pleochroism in PPL2 and the birefringence in XPL.

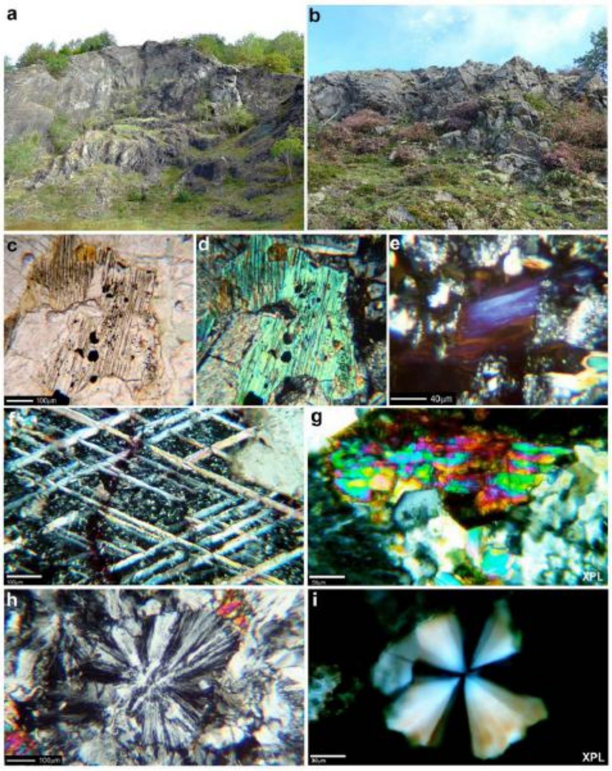

Fig. 9: (a) Stanner Rocks, gabbro quarry. (b) Stanner rocks. Felsic dyke. (c,d) Gabbro: diallage, PPL and XPL views. (e) Chlorite, XPL. (f) Calcite in vein, XPL. (g) Epidote (upper centre), XPL. (h) Spherulite in the felsic rock, XPL. (i) Spherulite from microgabbro of Corndon Hill, XPL.

It has taken me some time to get used to the fact that the appearance of igneous rocks, particularly the older ones, can diverge a lot from the textbook norm because of "alteration"; a slow change of the constituent minerals due to chemical reactions, especially with water. This is particularly true for mafic rocks, and the Stanner Hill gabbro is no exception. There is plenty of alteration visible, with the presence of abundant chlorite. Chlorite is a variable group of minerals with a sheet type of molecular structure comparable to the micas. Despite its name it does not contain chlorine. It is a common alteration product of mafic rocks and is notable for showing birefringence colours outside the normal Newton's series. These are a Prussian Blue and a deep brown, both evident in Fig. 9e. This gabbro also contains some calcite veins showing a typical "cross hatched" appearance in XPL (Fig. 9f).

The felsic dyke at the summit of the hill is very different. It consists of quartz and feldspar with some crystals of epidote (Fig. 9g). Epidote is a chain silicate with a characteristic high relief and an attractive "stained glass" appearance in XPL. It is an alteration product that arises in felsic rocks from metamorphism or hydrothermal processes. The feldspar in the dyke displays abundant spherulitic structures, which are radial masses of thin birefringent fibres (Fig. 9h). They apparently develop when volcanic glasses devitrify and crystallise in a radial manner. I later found some even more spectacular spherulites further up Offa's Dyke at Corndon Hill, near Church Stoke. In this case they are present in a microgabbro (Fig. 9i). As the slide is rotated the "Maltese Cross" moves round the spherulite, because the birefringence is coming from a full 360° of radial fibres.

Conclusions

The aim of my activities has been to find out if making thin sections at home was feasible and to generate some elegant and attractive specimens. I have not attempted to analyse any particular rock type or locality in detail. I have found that it is indeed possible to make thin sections of reasonable quality and at moderate expense. It does not require a lot of engineering skill or geological knowledge, although some general lab experience and the ability to take care is undoubtably helpful.

As an amateur, I still have a lot of trouble identifying minerals down the microscope! Any society member who would be willing to assist me looking at some slides for an hour or two will be very welcome. I can be contacted at: j.m.w.slack@bath.ac.uk.

Appendix on equipment and supplies

A set of equipment and starter set of consumables can be acquired for about £800. This Appendix gives some more detail about the equipment, the procedures, the problems and the sources of materials.

Tile cutter

I use a Vitrex 750 tile cutter. This is a simple one-speed device with quite a large working area. It has a water reservoir to cool the wheel. This reduces the risk of breathing in rock dust but does create a substantial muddy spray, meaning that the device is best used outdoors. The device comes with an adjustable guide bar, called a rip fence, to steady the tile. Because this is not entirely satisfactory for cutting up rocks, I have made two new rip fences from aluminium bar. One is used for cutting rocks up into the small blocks and is rather heavier and higher than the original (shown in Fig. 1a). The other, which is lighter, is used to trim the blocks to 1mm after they are glued to the slide (shown in Fig. 1e). To enable the slide to be slid smoothly along this guide bar, I attached a metal strip to its base with superglue. This projects about 1mm clear of the guide bar which is about enough to support the slide without fouling the cutting wheel (red arrow, Fig. 1e). For the cutting, I use an ordinary diamond-edge wheel to cut rock specimens down to blocks, and a thinner porcelain cutting wheel for trimming down the blocks once they are glued to the slides. The cutting wheels get dulled by a lot of cutting through rock and so they do need changing every so often.

Hotplate

My hotplate is just an electric cooking plate (Fig. 1d). As this is quite crude, I am currently considering replacement with a proper stirrer/hotplate which would have more reliable temperature control. I place a number of 1cm thick aluminium blocks on top to spread the heat. One of these contains a boring for a thermometer which I take as measuring the surface temperature.

Lapping device

My lapping wheel is described as a gem-faceting machine ("Vevor" brand from Amazon). It was made in China and the original electrics were of very poor quality. I have replaced the control box, all the wiring, the switch, removed the other peripherals and earthed the casing. After all this it seems to work fairly reliably. The advantage of this model is that it has a steel case which allows for mounting of a lab jack from which to suspend the slide holder. The actual slide holder took some time to perfect. My final version is an aluminium block held horizontal with a ball joint. Between the block and the slide is a thin silicone sheet, anchored with silicone grease, to act as a vacuum seal. The block has a vertical hole into which a vacuum line is attached. The actual vacuum does not need to be very strong and is generated simply with a syringe held open with a bulldog clip, as shown in Fig. 2a. On the surface of the aluminium block are two spirit levels at right angles (Fig. 2c). One, glued along the long axis, enables levelling by adjustment of the lab jack. The other is held on a 1cm aluminium block mounted crossways. If there is a deviation from level this block can be slid to one side or the other to provide a slight extra weight to that side. The ball and socket joint is quick-release enabling the whole slide holder to be removed easily to inspect the state of the slide underneath. The whole weighs 300 grams, enough to impart a modest pressure to the slide.

Hard rocks containing a lot of quartz can take a long time to grind down, so I have also made a heavier slide holder, shown in Fig. 2d. This weighs 900 grams and the extra weight does increase the grinding speed somewhat. The arrangement is similar to that of the small slide holder except that no vacuum is necessary. Because of the extra weight the slide seems to stay put if a little silicone grease is applied both to it and to the silicone sheet.

The diamond lap wheels do not last long, and to get the most value out of them I have found it best to use the coarsest grade that is compatible with a smooth action, that is avoiding hunting movements. This is 180 or 240 grit. I try to use as much of the surface as possible by occasionally moving sideways the arm holding the attachment socket. When the diamond coating is worn out, some additional life can be obtained by reversing the direction of the wheel.

Manual finishing

This requires only a smooth glass plate, I use one 20cm x 20cm x 6mm thick (Fig. 3a). I use a suction pad connected to a syringe to hold the slide, although if it needs preferential grinding on one side this is best done just holding by finger or thumb. Mostly I use 400 grit silicon carbide plus some water for manual grinding. On the rare occasions when more than about 50µm needs removing I may use 120 grit to speed things up, although the finer grade is needed later to remove score marks.

Alizarin stain

Alizarin is useful for staining calcium carbonate (calcite and aragonite, but not dolomite). It is used as 0.2% Alizarin Red S in 1.5% v/v hydrochloric acid, which is more or less a saturated solution. The acid etches the section slightly and so the timing of treatment with the stain is important. I normally use one minute and then wash off the stain in tap water, which is slightly alkaline and stops the reaction.

Reverse osmosis water

To generate RO water for making up solutions (and for our steam iron) I use an aquarium system from Water Filterman. This produces about 4 litres per hour when connected to a mains pressure tap.

Sources of materials

For construction:
Aluminium bars: Metals 4U.
Ball and socket joints: Springfix linkages.
Feeler strip (Starretts), silicone sheet: Amazon
Suction caps, vacuum fittings, pivot joint, threaded rods: RS Components

Consumables:
Alizarin Red S: APC Pure.
Canada Balsam: discdi_9558, Bulgaria (Ebay)
Methylated spirit, hydrochloric acid: Local hardware store.
Petrographic Epoxy Resin: Electron Microscopy Sciences, Hatfield, PA, USA.
Silicon carbide grit: Craft and Design UK.
Silicone grease: RS Components.
Slides and coverslips: Galvoptics
Tile cutter blades, diamond lapping wheels, xylene, acetone: Amazon

Trouble Shooter

Problem	Solution
Cutting wheel dulling	Replace wheel
Bubbles under epoxy	If the rock contains cracks or holes, coat with epoxy first, allowing to gel on a piece of aluminium foil. Then peel off the foil and mount as usual.
Slide cracking	Don't use too much epoxy. Be careful not to stress the slide when trimming the block. Avoid vibration when trimming.
Lapping wheel dulling	Clean after each use with a nylon brush. Reverse sense of rotation. Replace wheel.
Keeping specimen absolutely level	Pay careful attention to the spirit levels while reducing thickness and adjust as necessary. Manual grinding can be done preferentially on part of the section if necessary.
Edge thinning relative to centre	Make sure the epoxy layer is as thin as possible so the section is not raised up from the slide. Grind as thin as possible on the lap before commencing manual grinding.
Controlling thickness	While finishing, check under the polarising microscope regularly. Continue until the quartz maximum birefringence is white, or the plagioclase is black and white. If these minerals are absent, make a small hole in the centre and focus up and down through the section thickness, noting the position of the fine adjustment knob.

Safety

Hazard	Risk	Remedy
Breathing in rock dust	Silicosis and other respiratory diseases	Always use water to lubricate cutting and grinding wheels, and to remove dust. Wear mask if necessary.
Inhaling solvents	Poisoning	Handle hazardous solvents outdoors.
Corrosive materials	Damage to hands	Wear gloves when handling epoxy, Canada Balsam, acids and solvents.
Hot items	Burns	Show warning notice when hotplate is on. Handle hot items with forceps.
Cutting and grinding wheels	Grazes	Use guard on tile cutter. Keep fingers clear!
	Spatter	Wear face shield to protect face and eyes.

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Iron Minerals in Bath Stone (Great Oolite, Middle Jurassic, UK): Pyrite, Goethite and Glauconite, their Spectra and Origins

By

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Bath Stone, so familiar to all who live in or visit Bath, is an oolitic limestone (in the Great Oolite Group) deposited in a shallow sea like that in the Bahamas now, around 167 million years ago in Middle Jurassic time. Bath Stone has been extracted from open and underground quarries around the city for nearly 2000 years, since the Romans arrived here and started building Aquae Sulis and their baths about 45 CE. Although Bath Stone is a very pure limestone, composed of just calcite and a little clay, there are iron minerals present in the rock. We describe the presence of pyrite (now replaced by goethite) but also report the surprising and rare occurrences of glauconite, a mineral common in the Cretaceous greensands, identified by visible-IR reflectance. We discuss the formation of these minerals within the oolitic sediment and note the potential value of a high-fidelity spectral bio-marker from the Middle Jurassic.

Pyrite

Pyrite is a common mineral in sedimentary rocks, especially in organic-rich mudrocks, and it is commonly dispersed in limestones. Within the Bath Stone, there are dark, mm-size, metallic looking crystals scattered in the rock but they do also occur in discrete areas (Fig. 1a). These crystals are referred to as 'shot' by the stonemasons. In some cases, there are larger rusty-brown nodules, several cm in diameter (Fig. 1b). Although these crystals and nodules are likely to have been composed of pyrite (iron sulphide, FeS2), they are now composed of goethite (FeO(OH), see below). On close inspection the individual crystals can be seen to have a cubic shape or in some cases more of a spheroidal, framboidal shape. Fossils are not very common in the Bath Stone, apart from ubiquitous sand-sized fragments (bioclasts), but rarely pyrite is observed closely associated with bivalve or coral fossils, as in Fig. 2, where the crystals are concentrated immediately below a large shell. The more elongate patches-nodules of goethite/pyrite may relate to burrows, which were created in the sediment by crustaceans particularly.

In many places in the Bath Stone there are patches of a dull orange to reddish-brown discolouration in the vicinity of pyrite-goethite (Fig. 3). These stains in the mostly cream-coloured stone are the result of oxidation of the pyrite crystals when exposed to the atmosphere. Effectively, the pyrite, composed of the reduced form of iron (Fe2+), is 'rusting' to limonite, the hydrated form of ferric oxide-hydroxide: i.e., FeO.nH2O.

Fig. 1a: Scattered pyrite crystals. Field of view 8 cm.

Fig. 1b: An elongate nodule of pyrite crystals, likely formed within a burrow. Field of view 6 cm. Bath Stone, Bath Riverside.

Fig. 2: A bivalve shell with pyrite crystals developed just beneath the shell. At 10-15 mm below the pyrite there are scattered green grains at a similar level, interpreted as glauconite. Field of view 10 cm across.

Fig. 3: Orange-brown stain emanating from rusting pyrite crystals and spreading out into the oolitic limestone. Field of view 15 cm across.

Glauconite

Glauconite is another iron mineral found in sedimentary rocks, but it is a silicate, related to the clay minerals (phyllosilicates); it also contains potassium and magnesium. It has a complicated formula KMg(FeAl)(SiO3)6. 3H2O and the iron here is present in both the ferric (Fe3+, also written as Fe (III)) and ferrous (Fe2+, Fe (II)) valence states. Glauconite is especially common in the greensands of the Cretaceous, well exposed in road cuttings at Potterne, just south of Devizes for example, at Cley Hill near Warminster and in the Vale of Wardour near Dinton. Greensand has been used locally as a building stone, as in Mere and villages around Shaftesbury. It is known as Hurdcott Stone and is still quarried near Tisbury (see Geddes 2011).

Glauconite has a distinctive green colour in thin-section (Fig. 4); it is usually pleochroic, with an aggregate polarisation pattern. In many cases the sand-sized grains are ovoid-shaped and these are often interpreted as glauconite-impregnated faecal pellets. In some cases, glauconite occurs within microfossils, such as foraminifera.

Fig. 4: Photomicrograph of glauconite grains along with quartz grains in Greensand, Dorset. Plane polarised light. Field of view 8 mm across.

Millimetre-size grains of glauconite have been found (with the aid of a hand-lens) in the Bath Stone of several buildings and walls around the city: at Bath Riverside, in York Street and in Denmark Road East Twerton for instance. These grains are mostly spheroidal to ellipsoidal in shape, 0.5 to 1 mm in diameter (Fig. 5), but a thin flaky clay-like variety is also present (Fig. 6). The grains appear to be scattered within the oolitic sediment, rather than concentrated in laminae or lenses. In one particular occurrence at Bath Riverside, these green grains are located in the oolitic sand along a level of about 10-15 mm below the convex-upward bivalve shell which is forming an 'umbrella structure' in the limestone where pyrite is present immediately below the shell itself (Fig. 2). Green grains have also been observed in the Fuller's Earth Rock, the limestone 10 m below the Bath Stone, from Winsley. In addition, Sellwood et al. (1985) recorded glauconite in the Great Oolite Humbly Grove reservoir in Sussex.

Fig. 5: Close-up of glauconite grains in Bath oolite. Field of view 8 mm across.

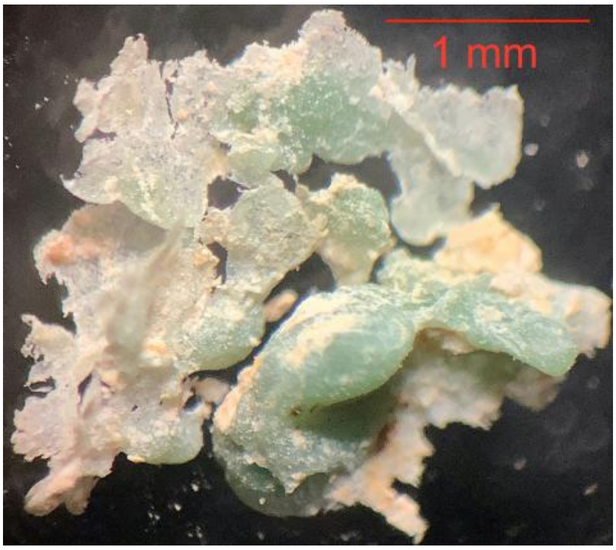

Fig. 6: Green and flaky grains extracted from Bath oolite interpreted as glauconite. Our experiments focused on the largest grain at the bottom right of this image.

Identifying the green grains as glauconite just from their colour and shape is clearly not conclusive, although there are no other obviously green, sand-size minerals that might occur in sedimentary rocks. Mafic minerals like olivine and pyroxene which might be green are very unlikely to occur in the Bath oolite, since there are no igneous rocks as a source in the region and such mafic minerals anyway are extremely rare as reworked grains. Other green minerals such as the clay chlorite are typically flakes; another green mineral is celadonite, also flaky, but that is derived from alteration of basalt.

Unfortunately, we do not have sufficient material to prepare a thin-section for petrographic studies. However, there are two non-destructive techniques that can be applied to grains with a view to determining their mineralogy: X-Ray Diffraction and Visible-IR Spectroscopy. We did try XRD, but the peaks obtained did not confirm the mineral. This could be a consequence of just using the few grains we had (rather than grinding them into a powder) or the mineral itself being poorly crystallised. Visible-near-IR Spectroscopy is a technique used on individual minerals as well as in remote sensing surveys from a distance, as from a satellite, and this has been successfully applied to surveys of Mars for example (e.g., Horgan et al. 2020). In our case the use of spectroscopy confirmed glauconite but also provided some extra intriguing detail, described here.

Visible-IR Spectroscopy and mineral identification

The non-destructive use of reflection or transmission spectroscopy of translucent samples can reveal diagnostic electronic (UV and visible) or vibrational (infrared) transitions in atoms or molecules within many materials. The spectra obtained from the dark metallic crystals (shot) we interpret as pyrite actually reveal that they are composed of goethite (brown line Fig. 7). As noted earlier, this mineral will have formed by oxidation of the pyrite.

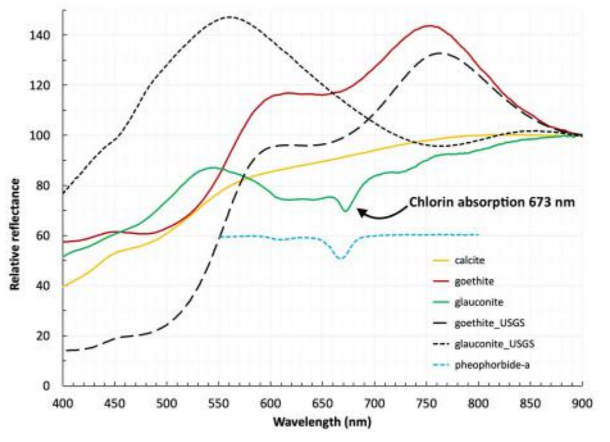

Fig. 7: Visible reflectance spectra. The unbroken coloured lines show the relative reflectance spectra, normalised at 900 nm, of the three minerals: yellow — Bath oolite (calcite); brown— goethite (after oxidised pyrite), and green — the largest grain of the green material glauconite). The prominent absorption line at 673 nm, identified as a chlorophyll derivative, is marked with an arrow. The spectra shown for comparison are samples of: goethite (long-dashed black) and glauconite (short-dashed black), both from the US Geological Survey spectral database, and in dashed blue, a transmission spectrum of the chlorophyll derivative, pheophorbide-a in ethanol, with a concentration and sample depth adjusted to provide a similar strength absorption close to 670 nm from a biological chlorin.

For a translucent sample like the Bath green grains, the reflectance signal is dominated by light that has entered the material and emerged after single or multiple scattering within it. In practice, there is little difference between the signal in reflected or transmitted light. To examine the small green grains in the Bath Stone, we used reflectance spectroscopy covering the range from 400 to 2500 nm. Given their small size, we generated a small, 0.2 mm diameter, high-intensity spot on the stage of a microscope. Light from an Ocean Insight HL-2000 halogen visible/near-IR lamp, fed with a collimated fibre, illuminated the back of a low-power microscope objective. The sample was then placed precisely within the spot using the microscope x-y stage and focus controls. Scattered light was collected from the illuminated fragment with a second collimated fibre aimed at the sample using a micro-manipulator. This setup allowed the collection of high-quality visible spectra from the grains using an Ocean Insight Maya2000Pro (200–1100 nm) spectrometer with a resolution (FWHM) of 2 nm. For the IR spectrum, an Ocean Insight NirQuest (900–2500 nm) spectrometer with IR-transmitting fibres and collimator was used. For this wavelength range the microscope optics could not be used so we were unable to achieve such a high signal-to-noise ratio. The same HL-2000 lamp was employed for both ranges. The resolution of the IR data is a factor of 4 or more lower than for the visible range. To calibrate the reflectance, an Ocean Insight WS-1 diffuse reflectance standard was used over the entire wavelength range. Given the different modes of illumination and sample structures, our reflectances are reported as relative rather than absolute values (i.e., the plots can be arbitrarily scaled vertically).

In Figure 7, the broad reflectance peak (green line) from the sample centred around 540 nm is typical of glauconite and is predominantly the result of a gap between the strong broad absorptions of Fe^{3+} increasing the absorbance at longer and shorter wavelengths. The narrow absorption feature at 673 nm is not generally seen in glauconite samples and this led us to an intensive search for possible identifications of this prominent signature. The only narrow absorption feature found in rock samples that appears remotely feasible comes from chromium in the form of Cr^{3+}, present for example in chrome diopside. Although chromium-rich glauconite is known (Bitschene et al. 1992), this identification is not convincing since the wavelength is a poor match and the Cr^{3+} absorption line (seen in a range of chromium-coloured gemstones including emerald, kyanite and zoisite), commonly appears with an asymmetric profile arising from a Fano resonance (https://en.wikipedia.org/wiki/Fano_resonance) that influences the absorption profile to make it asymmetric.

A more promising identification of the 673 nm absorption is with a chlorin associated with the transformation of plant material/organic matter. In the Treibs's scheme for chlorophyll degradation to petroporphyrins (Milgrom 1997), the final stage before the chlorophyll-porphyrin transition exhibits an olive-green colour and a chlorin-type absorption that is very close to our wavelength of interest. The dashed blue line in Figure 7 shows a typical absorption spectrum of a chlorophyll derivative, pheophorbide-a, but there are other chlorin candidates that differ little in wavelength.

The typical near-IR spectrum of glauconite shows prominent absorption bands near 1900 and 2300 nm and these are both seen in the sample of Cretaceous Greensand from Cley Hill in Wiltshire (dashed red line). Figure 8 shows the combined visible and near-IR spectrum of the largest green grain along with the Cley Hill comparison.

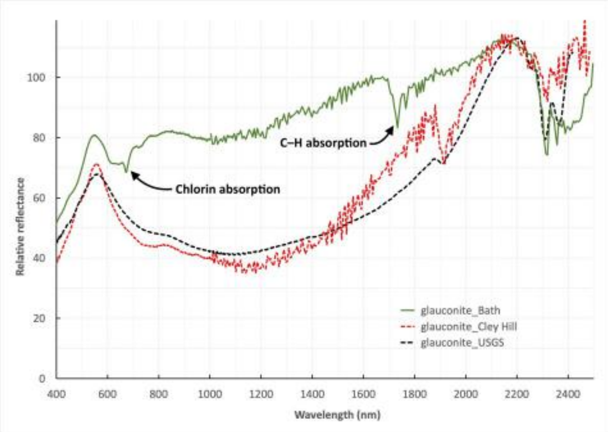

Fig. 8: Visible to near-IR reflectance spectra. The solid green line is the combination of the visible and the near-IR spectra of the largest Bath Stone green grain. The comparison spectra (dashed lines) are (black) the same USGS sample of glauconite as shown in Figure 7 and (red) the reflectance of greensand grains from Cley Hill, Wiltshire (material separated from quartz sand using a strong rare-earth magnet). The spectra of the Bath glauconite exhibit the organic absorption features at 673 nm and ~1750 nm which are both absent in typical glauconite.

In their account of the visible and near-IR remote sensing spectra of phyllosilicates, Bishop et al. (2008) ascribed the 2300 nm feature to individual OH stretching and bending modes as a function of variable octahedral cation composition. While the absorption complex around 2300 nm is present in both the Bath sample and typical glauconites, the weaker 1900 nm absorption seen in some glauconites is undetected in our Bath sample. There is instead a band between 1700 and 1800 nm that is normally identified as an overtone of the fundamental C-H vibrational stretching mode in organic materials.

By examining material that had been exposed to weathering for several years after cutting, we clearly had to ensure that our measurements were not affected by contamination from recent surface growth of organic material such as algae and/or lichens. To do this, we carefully examined the measured samples with a microscope using both visible and ultraviolet light, the latter being a sensitive test of algal chlorophyll fluorescence. Since chlorophyll itself absorbs around 670–680 nm, any presence of this must be eliminated from our measurement.

To be certain of this, we examined a second stone sample from the same mine that showed clear signs of organic surface growth. This revealed no significant red fluorescence signal but did show an absorption band at 675 nm. This band was however significantly broader and had a longer wavelength than the absorption in our green grains. In addition, the difference in absorption strength between the thick (granular) and thin (flaky) samples we measured strongly suggests that the prominent narrow absorption line at 673 nm is from the bulk green material and not from surface contamination. It should also be remarked that, while the examined material was selected by examination of the cut and subsequently exposed stone surface, most of the green material had been buried beneath the surface. We used ooid grains prised from the surface in the same way as the green grains for the calcite measurement shown in Figure 7 which shows no sign of chlorophyll contamination.

We have only found two other references to the ~670 nm chlorin absorption in sedimentary formations. These both refer to sediments in the Antarctic dry valleys. Bishop et al. (2013), in their analyses of Antarctic sediments as Mars analogue materials, recorded a sample of a dry lake sediment (H3 JB207) with an absorption feature identified as a chlorophyll-like signature. Hawes & Schwarz (2000) described the transmission characteristics of benthic microbial mats from 10 m water-depth in Lake Hoare, an ice-covered lake in the McMurdo Dry Valleys area of Southern Victoria Land, Antarctica, which show a very similar spectral structure to our BGG around 670 nm. Both of these references however refer to samples that are considerably younger than Bath Stone.

In summary, our Bath green grains show spectroscopic similarities to typical glauconite, especially the green reflectance peak near 550 nm and the IR absorption at 2300 nm. Unusually, however, they show two clear organic signatures in the form of a narrow absorption at 673 nm, most likely from a chlorophyll-derived chlorin typical of Treibs's porphyrin transformation scheme, and a C–H overtone band near 1750 nm.

Formation of pyrite and glauconite in Bath oolite

With iron precipitation, the redox of the water, i.e., the Eh, whether the water is oxidising (positive Eh) or reducing (negative Eh), is a major control on the mineralogy (Tucker 2000). In oxic water, iron is present in the insoluble ferric form, as oxide or hydroxide, commonly attached to clay minerals; the iron is only released when the water turns anoxic, and then it is ferrous iron. One of the main factors affecting the Eh of natural aqueous environments is the amount of organic matter present, since its decomposition, mainly brought about by bacteria, consumes oxygen and creates reducing conditions. Normal seawater has a positive Eh (it is oxic), as is the pore water in most surficial sediments on the seafloor. However, organic matter deposited in the sediments soon decomposes with depth so that a reducing environment is formed some 10s of cm below the sediment-water interface. Thus, an oxic seafloor and near-surface sediment pore-water passes down through a suboxic zone into an anoxic diagenetic zone. This trend is sometimes seen when digging down into beach sand near low tide, as in making a sandcastle or burying grandad, or digging for lugworms. The near-surface sand is the normal cream to pale yellow colour, but then 10-20 cm down the colour turns grey (suboxic) and then a little deeper (20-30 cm) to black (anoxic); there may also be a smell of H2S (bad eggs). This colour change is the result of microbial decomposition of organic matter in the sand and the precipitation of pyrite in the black zone where the reduced form of iron (Fe2+) is developing under the anoxic conditions, and sulphate (SO4 2-) in the pore-water is reduced to sulphide (S-).

The organic matter present within the Bath oolitic sediment will be derived from the seawater and from decomposing organisms, such as bivalves, brachiopods, etc., buried within the oolitic sediment. There may also be organic matter derived from thin biofilms growing on the seafloor, from organic matter within burrows, or from within the ooids themselves which in recent years have been interpreted as bacterial-microbial in origin, rather than being purely abiotic. The random, scattered occurrence of pyrite crystals in Bath Stone reflects the original disseminated nature of organic matter in the sediment and its decomposition to create reducing conditions which liberated iron from clays deposited with the ooids. The preferential occurrence of pyrite concentrated just beneath the shell in Figure 2, and within burrows, suggests that there was an abundance of organic matter decomposing there to generate the reducing, anoxic micro-environment wherein the pyrite precipitated.

Glauconite is a potassium-iron aluminosilicate containing both Fe (III) and Fe (II), usually with a high ferric/ferrous ratio. Glauconite is being formed on many modern continental shelves at water depths from a few 10s to 100s of m, but it is invariably a poorly-ordered phase. Glauconite forms in the sediment by the transformation of degraded clay minerals and by the authigenic growth of crystallites in the pores of substrates, be they clay minerals, skeletal grains or faecal pellets. Glauconite is commonly associated with localized occurrences of organic matter, which create local reducing conditions, but within an overall oxic environment. The occurrence of the glauconite at a level 10-15 mm below the pyrite (Fig. 4) could be a reflection of changing pore-fluid away from the anoxic conditions of the decomposing bivalve organism where the pyrite was being precipitated to more suboxic-oxic water below, allowing glauconite to form.

Oxidation of pyrite and the development of the orange-rust stains in Bath Stone

After the precipitation of the pyrite and glauconite, just below the Jurassic seafloor within the oolitic sediment, the Bath Stone was cemented and gradually buried. It would appear that the Middle Jurassic limestones in the Bath region were buried to around 500-700 metres during the Upper Jurassic, through the Cretaceous and into the Eocene. Soon after this, the area was uplifted, as a consequence of tilting towards the southeast and the effects of larger-scale plate-tectonic movements in southern Europe as a result of the closure of Tethys, the collision between Africa and Europe, and the formation of the Alpine Mountain chain. On uplift over the last 20 million years or so, the Bath oolite would have come into contact with oxic groundwaters and then the atmosphere when at the surface, such that the pyrite would become unstable and the ferrous iron sulphide would then decompose into ferric oxide-hydroxide, goethite-limonite, and give the orange-brown stains we see on the stone today.

Summary

Close observation of Bath oolite reveals the common presence of iron pyrite and the rare occurrence of glauconite. These iron minerals were precipitated within the oolitic sediment soon after deposition at a depth of several to 10s of cm below the seafloor where the appropriate micro-environments were established as a result of decomposing organic matter: anoxic conditions in the case of pyrite, and oxic-suboxic conditions in the case of glauconite. On recent uplift and contact with oxic groundwater and then subaerial exposure, the pyrite was oxidised to goethite, and weathered to give the orange-brown stains on the stone due to limonite ('rust'). Visible-IR reflectance was able to confirm the presence of goethite and glauconite although intriguingly with the latter an unexpected absorption peak was detected which could indicate the presence of degraded chlorophyll within the mineral. The presence of an additional organic spectral signature in the IR spectrum attributed to an overtone C–H vibrational absorption band is not inconsistent with this conclusion.

Acknowledgements

We are grateful to Janice Bishop (SETI Institute, California), Ian Jarvis (Kingston University, London), and others for their comments on the spectral data and to Natalie Pridmore and Hazel Sparkes (Chemistry School, Bristol) for XRD analysis.

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The Saline Water Well at Culver Close, Bradford on Avon Bowls Club

By Simon Kay

In late April 2021, I was approached by a member of the Bradford on Avon (BoA) Bowls Club concerning a water well they had just drilled. The club used mains water for their green and the neighbouring cricket pitch. Water bills were sufficiently high that installing their own well would save money. The BoA Bowls Club initiated the project, assembled the funding package and project managed it. The project was a partnership between the Bowls Club, BoA Cricket Club and the landowners BoA Town Council. Funding came from the Landfill Tax credits fund of the Hills Group via Community First of Devizes, The BoA Area Board and the three partners.

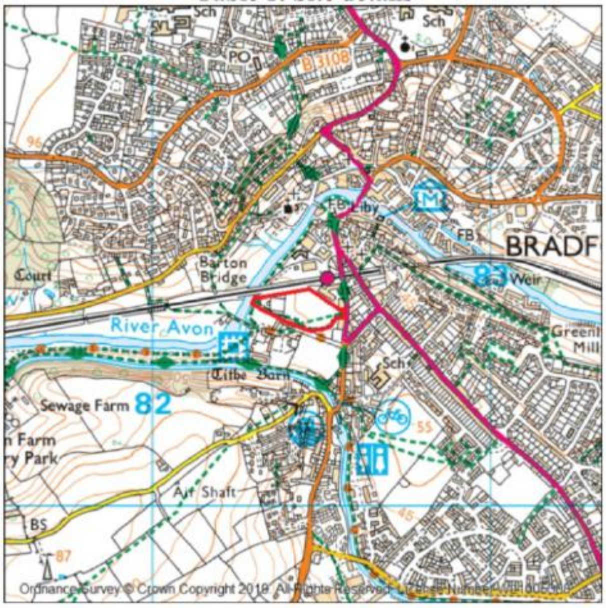


Fig. 1: Borehole location highlighted in red

Unexpectedly, the well encountered brackish water. The club hoped the water would be all right for watering the grass, but it was not potable. This troubled the club and intrigued me. The town water supply comes from groundwater of the Chalfield Oolite and there are also several local springs that are perfectly drinkable. Why is the Bowls Club well water different?

Before drilling, the Bowls Club commissioned a detailed study from B.A. Hydro Solutions of Royston, Herts. They assembled an excellent report with good geological detail. The well location is in the bottom of the Bristol Avon river valley. Their recommendation was to drill through the near-surface Fuller's Earth Formation to target the underlying Inferior Oolite and Bridport Sand aquifers. This makes hydrogeological sense as the overlying Fuller's Earth would be likely to have poor productivity. I would have recommended the same. I've included a diagram of their planned well here alongside what was actually drilled. The well was drilled by Ilminster-based contractor Matthew B Downing Farm Water and Geotechnical Drilling Services. As you can see from the diagram, the well was only drilled to a depth of 37.2 metres below ground level (mBGL). Water was present from 4.05 mBGL onward. At 34 mBGL very salty water was encountered which apparently also was quite gassy but odourless. The deeper water flowed at a higher rate (up to 8 cu m/hr compared to 2.5 cu m/hr for the shallower water). This very salty water was not sampled and the deeper interval was plugged off with bentonite. The Inferior Oolite was reportedly not reached but could have been close, judging from the well plan. The higher flow rate for the deeper water is more consistent with fractured Inferior Oolite and/or Bridport Sand. The Fuller's Earth is described by the driller from the well cuttings as clay and mudstone but was probably mudstone and muddy limestone. The hard pale grey mudstones as described are probably the limestone intervals, which would be naturally fractured and capable of flowing water.

Water Quality

The well was pumped for 3 days to clean up the water, and a sample was taken for analysis by Somerset Scientific Services (part of Somerset County Council). Key results (drinking water limits in parentheses) were:

Total dissolved solids	1171 mg/L
Ammonia as NH_4	1.06 mg/L (0.5)
Chloride	288 mg/L (250)
Sulphate	252 mg/L (250)
Calcium	131 mg/L
Sodium	229.7 mg/L (200)
Iron	340 ug/L (200)

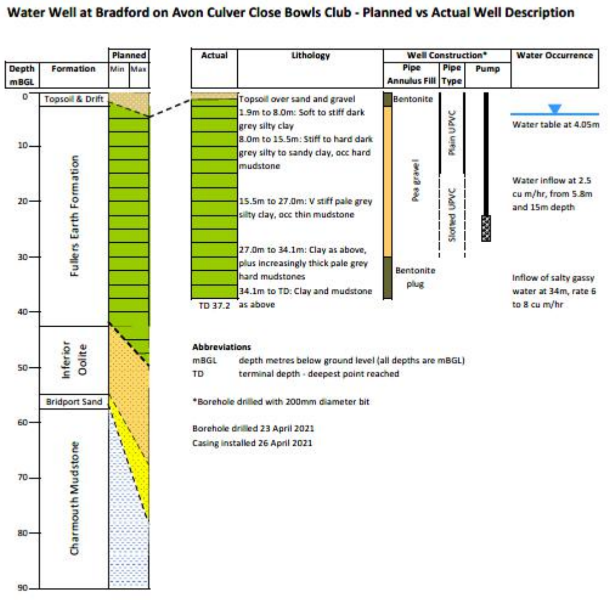
Brackish water may be defined as total dissolved solids (TDS) >600 mg/L, while 1000 mg/L is considered the upper limit of human potability (livestock can tolerate higher levels). The dissolved components listed above all exceed limits for drinking water quality in a private supply. For comparison, note that seawater TDS is typically 35,000 mg/L, with chloride 19,000 mg/L, so our water is much fresher. Of course, the water quality may change through time, and follow-up testing is advisable. The elevated ammonia level made me think of groundwater contamination by sewage, but I would expect appreciable levels of nitrate and phosphate in that case, and these were undetectable. A map in Buss *et al*., 2020, indicates that similarly brackish water has occasionally been encountered from boreholes in the area, but brackish groundwater is unusual in southern England except in shallow aquifers around estuaries.

Water Source

The source of the brackish water may be a deeper aquifer connected to Triassic evaporites. This is often the case in northern England where halite deposits are more widespread (Buss *et al*., 2020). Perhaps there is communication via faults/fracture zones. The Bath hot spring water is a good example of a local deep groundwater source. Looking at the water composition for the Bath hot springs as sampled from the Stall Street borehole (Edmunds *et al*., 2014), sodium and chloride levels are similar, although calcium and sulphate levels are much higher:

TDS	2290 mg/L
Chloride	344 mg/L
Sulphate	1080 mg/L
Calcium	385 mg/L
Sodium	218 mg/L

Another nearby example is at Melksham. In 1770 a shaft was sunk looking for coal. Instead, saline water was encountered flowing from the Forest Marble Formation at around 100 mBGL. It wasn't until 1813 that it was realised the water could have "curative" properties and a spa was constructed by local speculators. Two wells were sunk to supply Melksham Spa, in 1814 and 1815. The spa was briefly fashionable but fell out of use by 1822 and could not compete with Bath Spa or with the changing fashion in favour of sea bathing. Published water analyses (Whitaker and Edmunds, 1925) give a concentration of 552 grains per gallon of "saline matter", chiefly sodium chloride. This equates to 7,868 mg/L TDS which is saltier than the Bath or Bradford on Avon waters.



It's a pity that the deeper more saline water was not sampled in the Bradford on Avon well, or that a water temperature was not taken. Who knows – Bradford on Avon may be sitting on its own spa or thermal water source!

Both BoA Bowls Club and BoA Cricket Club are very happy with their new water supply. The total project cost was £15,000 and the club estimate that the saving is £2,000 per year. The untreated, chlorine-free water is better for the grass than mains water. Moreover, it is much greener and less wasteful to use a local water source; rather than using mains water that has been treated to drinking water standards at a high energy cost, and then just poured away onto the ground!

The Club will be closely monitoring the effects on the bowling green and the water quality over the next few seasons.

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Should anyone wish to know more about this project contact Derrick Hunt, Honorary Secretary. Bradford on Avon Bowls Club via the website:

http://www.westwilts-communityweb.com/site/Bradford-on-Avon-Bowls-Club/

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Book Review
Digging Bath Stone – A Quarry and Transport History
by David Pollard
Published by Lightmoor Press, Lydney, Glos.,UK
ISBN 9781911038 86 3. Cost £50, 512 pages.

Reviewed by Maurice Tucker
maurice.tucker@bristol.ac.uk

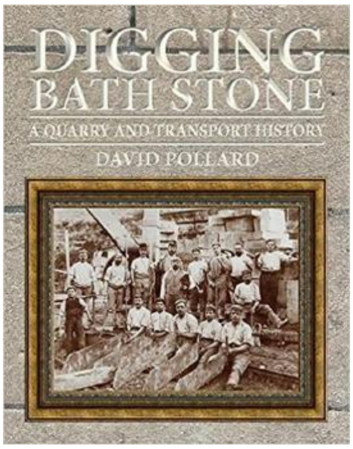
Anybody with an interest in English building stones, in Bath stone and the industrial history of the Bath area or who is just inquisitive about stone, old quarries and mines in general, will love this book. The use of Bath stone as a building material is well documented: first used by the Romans for their town *Aquae Sulis* here in Bath, then again during medieval times for churches and mansions, including Malmesbury Abbey (7th-12thC), Bath Abbey (7th-16thC) and Longleat House (1568). It was also then the stone of choice for John Wood the Elder and architects after him in the construction of Georgian Bath with its impressive crescents and public buildings. This book is a comprehensive account of Bath stone contained within 512 pages of text and 100s of images; many of the latter are historic B&W photographs – all fascinating to ponder over: seeing the masons at work, their various roles, their tools and devices. David Pollard began his career as a boiler maker and engineer at Swindon railway works building locomotives in the 1960s. In the early 1980s he was an industrial archaeologist with Avon County Council and his deep interest in the stone industry eventually resulted in him buying his own underground quarry at Hartham, Corsham, which is still operating today. He collected tools, old machinery, stone samples etc. etc. with the intention of setting up a museum. I was lucky enough to join a BACAS (Bath & Counties Archaeological Society) fieldtrip in July 2016 led by David to visit his underground quarry and see his collection of artefacts. Sadly, David passed away in 2017 before his book was published. I was privileged to be able to re-visit his collection in 2019 to measure the size of his lewis bolts.

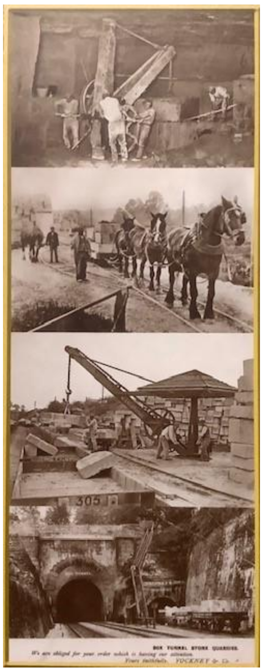
Reading David's acknowledgements in the book one appreciates the huge efforts and lengths he went to in his quest for information and detail on his Bath stone passion; he was clearly in contact with numerous people, mostly in the local area and in the stone industry, but also farther afield and in many organisations. He probably visited all the sites mentioned in the book. He also used documents from stone companies, record offices and archives, and online databases to search for information on people and relevant newspaper items. The detail in this book is staggering; he brings the topic alive with accounts of the quarrymen and their families, the incidents and hazards, the subtle differences in the stone, quarry to quarry, and the development of techniques.

David began collecting information for his book around 40 years ago when he became interested in quarry tramways and then in the quarries themselves, the methods of extraction and the people working the stone and running the companies. The book begins with some geology, explaining the origin of the stone back in the Middle Jurassic, some 167 million years ago, as mostly oolitic sediment (made of ooids) accumulating on a shallow seafloor in the subtropics, just like the Bahama Banks or the Trucial Coast of the Arabian-Persian Gulf in Abu Dhabi today. The book moves on to the people involved in the industry, following on from Ralph Allen in the mid-18th C to the quite small number of families who ran the operations in our area, with many amalgamating in 1887 to create the Bath Stone Firms Ltd which later became the Bath & Portland Stone Group. Another chapter describes how the quarries operated, with gangers and their team of quarrymen, the pickers, quarry boys and the foremen. Next follows a section on the actual digging out of the stone: the techniques of picking, jading, wedging, shaking and sawing the stone. Next comes the removal of the stone from its bed: heaving, lifting, pulling, using rollers, lewis bolts, cranes, hoists, horses, engines, and eventually the use of cutting machines, but that was mostly after 1945, although sawing machines were being invented in the late 1800s. Now stone is removed using a hydrobag: an inflatable bag made of thin gauge, mild steel sheet which is inserted into a saw cut and inflated with water under pressure causing it to expand and break the stone.

The longest chapter (8) of nearly 200 pages deals with all the quarries in the region, that is between Bath in the west, Corsham in the east and Bradford on Avon in the south; there were more than a 100. Today there are just 3 working underground quarries (Stoke Hill, Hartham and Park Lane) and one open quarry (Upper Lawns, Comb Down). Another long chapter (9) is the one dealing with haulage and transport, discussing the different methods of moving-carrying stone, by road, river, canal, sea, tramways, early railways, and then rail, followed by detailed accounts of specific 19thC tramways constructed to take the stone from quarries to canal and rail wharfs for onward transport. The construction of the Kennet and Avon canal in 1810 and then the coming of the railways in 1840 allowed much easier transport and distribution of Bath stone. Thence, it could be taken to London and other cities and be in direct competition with Portland stone which had the monopoly previously since it could be transported by sea directly from the quarries near Weymouth-Swanage. Bath stone is now recognised as an international treasure through its designation as a Global Heritage Stone Resource (a GHSR) by the International Union of Geological Sciences (IUGS). This designation "requires a stone to have been in use for at least 50 years and to be commonly recognised as a cultural icon".

This is a book to read as well as to dip into for reference, to find specific sites or aspects of the industry; it is also a book to pick up and flick through, like a coffee-table book, to marvel at the old photos of past-times and past-activities. We should be grateful to David for his lifetime of research into the winning of Bath stone and to the editor/publisher (Neil Parkhouse) and David's wife (and others) for seeing David's project through to completion.





Front and back cover "Digging Bath Stone. A Quarry and Transport History

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Obituaries

Written by Graham Hickman

Lothar Respondek Remembered

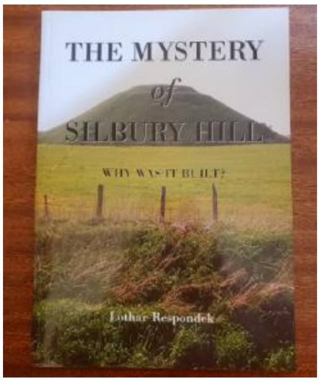
It is with sadness that we have to report the death of one of our longstanding members. Lothar Respondek who died earlier this year aged 95. Lothar, originally from Germany, was a member of the Bath Geological Society from at least 1981 through to 2015.

The photo taken on the BGS 25th anniversary walk in 1995 shows Lothar Respondek (left) with Bob Whitaker (right).

Between 1992 and 1995 Lothar Respondek was the Secretary of our Society, working alongside Charles Hiscock (chairman) and Sonia Chant (treasurer). Charles remembers ''He was a very efficient secretary and I enjoyed working with him. One thing which struck me was his politeness, always shaking hands when we met. He was a good geologist and his interests extended into archaeology.''

Lothar made a significant contribution to our Journal submitting many articles between 1997 and 2006. Some of these have been digitized and are available on our website. For instance, his article on the Chalk and Flints of Wiltshire: https://bathgeolsoc.org.uk/journal/articles/2001/2001_Chalk_Flints.pdf

His longest article (12 pages) on Silbury Hill, Water and Geology has yet to be added to our website. Lothar wrote this article for our Journal in 2002 and later went on to publish a book entitled the Mystery of Silsbury Hill in 2005. The Wiltshire Gazette and Herald interviewed Lothar and asked him about his book. https://www.gazetteandherald.co.uk/news/7268302.geologist-believes-hill-was-an-accident/ Lothar's theory tied the creation of the hill to trenches dug to reach a sunken water table during a climatic warming 3,000 BC. Perhaps one of our members has a copy you can read?
We are grateful to Lothar for his long support of the Bath Geological Society, he will be missed.

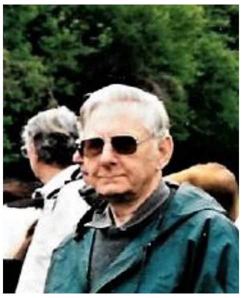


About his Book…
Silsbury Hill is an enigma. For centuries people have wondered why such a hill in the bottom of a waterlogged hollow was built. In spite of many investigations the largest man-made hill in Europe remains a mystery. The author has tried to redress the imbalance by researching climate, the landscape and the natural environment of the Neolithic people some 4500 years ago. The results of his study are rather surprising.

Lothar Respondek lives in Wiltshire and is a well-travelled amateur geologist. He has thoroughly researched the origin of the Sarsen stones on the Marlborough Downs and their use in the construction of Stonehenge and Avebury monuments. His work also embraced the effect of springs, rivers and streams on the local chalk scenery and the formation of coombes and asymmetrical valleys. His other geological main interest are volcanism and plate tectonics

Lt. Cmdr. A.T.F Comer Remembered

We were saddened by the news that Allan Comer had died on 27th February 2021 at the age of 97.



Allan Comer . Photo from 1995

Allan was a Founder and Honorary member of the Bath Geological Society. He served as the Treasurer for six years from 1978-1983. Continuing to serve on the committee from 1984-6 and then took on the role of Deputy Chairman in 1988 and Chairman in 1989.

Allan Theo Frank Comer (A.T.F for short) was born in July 1923 in West Ham.

Allan joined the Royal Navy and rose through the ranks initially as a commissioned Electrical Officer but quickly reaching the rank of Engineering Lieutenant Commander. In June 1975 Allan was awarded the MBE.

In 2005 he was granted Honorary Membership in recognition for his long service. His son John Comer writes ''Although he wasn't able to participate in the Society affairs during the last few years, he did have a framed certificate hanging in his home acknowledging his Honorary Membership, which the Society granted in April 2005. My father had a deep and abiding interest in geology and his membership of the society meant a lot to him.''

His other son Tony Comer writes ''While I'm sure he would have liked to have been remembered for his enthusiasm and organisational skills in the world of geology and as a founder member of the Bath Geological Society, perhaps he should also be remembered as a rebel! He derived so much satisfaction lampooning conventional geological axioms and presenting alternative explanations. His chosen victims included ice-age and glaciation modelling, tectonic theory and climate change. He would write at great lengths on these subjects, not because he was qualified to do so, but because he wasn't. His contributions to the science he would say, were not written to gain a certificate but were to present well-conceived alternatives to accepted theory based on sound scientific and engineering principles, and, of course, to get people thinking!''

Allan was a prolific writer for the Bath Geological Society Journal and between 1983 and 2004 he wrote around twenty articles. Some of his longer pieces were on Montserrat and the geology of Crete. These older journals are being scanned and will be made available on our website soon.

Allan will be sadly missed, but hopefully his writing will continue to get people thinking. The Bath Geological Society is truly grateful to his commitment and organisational skills in the early years of our Society.

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Field Trip Review – Winsley and Avoncliff 7th July 2021

By Phil Burge

The morning of Wednesday 7th July dawned with the possibility of favourable weather for this our second mid-week field trip of the year. While a mid-week date is not suitable for everyone it was felt that, given the Covid implied difficulties that we have had since March 2020 it was necessary to provide members with field trips wherever possible. But, back to the weather – would it hold off?

A very detailed set of field trip notes were provided by Graham Hickman and our guides for the day were Graham and Maurice who had arranged a trip with 11 locations around Winsley and Avoncliff for us. Twelve members (Fig. 1) met opposite Quarry Lane in Winsley and the trip started with a review of the palaeogeography of the mid to lower Jurassic of the area. In summary warm shallow seas creating the Great Oolite (specifically the Corsham Limestone) and Inferior Oolite as well as deeper seas creating the clays of the Fullers Earth and lower in the sequence the Lias.

Fig. 1: Team photo

Walking down Quarry Lane we stopped at the top of the tramway which allowed quarried rock to be transported down the hill to a wharf alongside the canal. A brief examination of "spoil" revealed some interesting fossils including bryozoans (Fig. 2). Walking further down the tramway takes you to firstly the Murhill mine (Fig. 3) and lower down the Murhill Quarry.

Fig. 2: Bryozoans

Fig. 3: Murhill mine

The Murhill mine is significant now as a SSSI because of the hibernating Greater Horseshoe Bat. The Murhill quarry was worked from 1803 until the mid-1870's. Measured sections from 1832 and 1893 show a complete section thickness of 10-13 metres with workable freestone of 2-3 metres. It is clear looking at the imposing walls of the quarry that the job of a quarry man was fraught with danger as revealed by the extensive jointing of the limestone due to a mass movement known as cambering.

The Limestone overlays the Fullers Earth clay. During periglacial periods drainage from the limestone coupled with the plasticity of the clay causes extensional joint movement in the limestone and extensive cracking, known as gulls. Identifying gulls from other jointing due to water flow is by looking at how the two sides of the gull match up as shown in Fig. 4. The Murhill Gull has been surveyed to a length of 287 metres with a further 30 metres not yet surveyed.

Fig. 4: Cambering in Murhill Quarry

The walk so far and down to the Wharf alongside the canal has more than geology to offer! Industrial archaeology! The steep tramway was originally built in 1803 using wooden rails. A new track made of cast iron was laid in 1826 and remnants of the rail can be seen (Fig. 5). The rails are of I section, fish belly type with the ends of the adjoining rails overlapping. The track gauge is 48-49 inches.

Fig. 5: Cast iron tram way lines

The lower Murhill Quarry was known as the Engine Quarry on account of the steam powered stone cutting saw installed in 1835. At the base of the quarry two adits are found, lined with freestone which tapped springs for water for the steam engine (Fig. 6). The springs emerge, as they do throughout the area at the base of the Great Ooilte and top of the Fullers Earth. The steam saw was housed in an engine shed, no longer visible, adjacent to the water collection pond.

Fig. 6: remains of adits and water pond

At the end of the tram way and alongside the canal is the wharf which is scheduled as an Ancient Monument (Fig. 7).

The group walked along the canal towards the Avoncliff Aqueduct. An outcrop of Inferior Oolite outcrops on the north side of the canal. It cannot be described as overwhelming! However, of more interest is the story of the troglodyte, Charles Norris who lived in a cave within the Inferior Oolite for 8 years in the late 1890's.

Before we return to geology there are two more industrial archaeology sites of interest to be seen. We saw them in the wet as it began to rain heavily. The first is the line of pill boxes built in 1940 along the south side of the canal as part of the GHQ defensive line.

Fig. 7: Loading wharf on Avon canal

A short walk further on takes you across the Avoncliff aqueduct. Not only is this a fine piece of Georgian engineering it has an interesting geotechnical story. The aqueduct was built by John Rennie and chief engineer John Thomas between 1797 and 1801. It has three arches and spans 100 metres. The central elliptical arch has an 18-metre span and the two semi-circular side arches are each 10 metres across. The use of cheap local stone resulted in frost splitting and the collapse of buttresses. The rebuild used Bathstone from Bathampton Down. The aqueduct and canal were lined with concrete in 1980 to make them watertight.

Before our lunch break at the Cross Guns, we stopped to look at an impressive Tufa spring. The spring is near the boundary of the Inferior Oolite and the Midford Sands. Professor Tucker explained that calcium carbonate can be deposited either abiogenically or biogenically. In the former deposition is the result of degassing of the spring water. The biogenic source of precipitation are viruses that inhabit the microbial mats around the spring. These act as nucleation points for the precipitation of calcium carbonate (Fig. 8).

After lunch, it rained a bit, we walked up the hill towards Winsley. The sun shone and rain wear put back in rucksacks. We passed by the Turleigh Trows (troughs) which are a series of interconnected basins cut from stone along which water passes from a spring. This spring emerges from the base of the Great Oolite and the Fullers Earth. Until mains water was supplied around 1930 these trows provided the village with clean drinking water.

Our final two stops included the sponge rock arch at Midway House on Green Lane, so named because they look like sponges. Very popular with the Victorians as an ornamental building stone used for archways and grottos, these sponge rocks are the result of crustacean burrows within firm ground (Fig. 9). Our last stop was to look at three ammonites embedded within a garden wall and identified as the genus Coroniceras.

Fig. 8: Tufa spring at Avoncliff

Fig. 9: Sponge rock

Finally, we arrived back at our vehicles, thanked Graham and Maurice for a great field trip, wonderfully organised, with an extensive field trip guide, got in our vehicles and the heavens opened! Perfect!

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A note from the Journal Editor

I would like to say a huge thank you to everyone who as contributed to this years Journal. I wouldn't be able to put together without your efforts.

Here are a couple of photos from me. The first one was taken from our really good Zoom social on the 16th. It was a really good night with some brilliant discussions/ quizzes/opinions on kitchen work surfaces and cake. Absolutely fantastic. The second photo is a taste of what is to come next year.. I hope you enjoy it! Mell

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The Bath Geological Society
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The Purpose of the Journal is to record the activities of the Bath Geological Society. It may include, but is not limited to the following; Chairman's report for the year, record of the meetings held, list of members including committee, officers of the Society and obituaries. Illustrated articles of geological interest written by members.

The Editor of the Journal will be appointed by the committee and report to the committee on issues and costs relating to the production of the journal. The Editor has the final say on inclusion of articles in the journal, their inclusion in part or whole. The Editor can request help from members of the Society or elsewhere in proof reading, verifying or correcting articles.

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