BATH GEOLOGICAL SOCIETY

Journal

No 41, Winter 2023

SOCIETY ACTIVITIES 2023

LECTURE PROGRAMME

January 19th
Zoom: Geology of Yemen – an Overview. Speaker: David M. Hall, Bath Geological Society & SulGeology Ltd.

February 2nd
Zoom: The Briksdalsbreen glacier and the Jostedalsbreen ice cap in the past, present, and future. Speaker: Professor Atle Nesje of the University of Bergen, Norway. This was followed by the Society AGM

March 2nd
Zoom: Geological Time and the Anthropocene. Speaker: Ian Fairchild. Emeritus Professor, University of Birmingham and Chair, Herefordshire and Worcestershire Earth Heritage Trust.

April 6th
Hybrid: Extinctions: How Life Survived, Adapted and Evolved. Speaker: Professor Mike Benton. University of Bristol.

May 4th
Hybrid: Short talks from Members. Speakers: Freeman, Hall, Hickman and Hunt. (Sounds like a firm of Solicitors …but we are just four enthusiastic geologists!).

June 1st
Hybrid: Managing Geological Risks in Mineral Extraction. Speaker: Mark P. Howson. Geological Mining Consultant.

July 6th
Hybrid: Devonian Forests. Speaker: Dr Chris Berry, Cardiff University.

Lectures are not normally held in August.

September 7th
Hybrid lecture: The use of Geophysics in Archaeology. Speaker: Tony Roberts, Archeoscan.

October 5th
Hybrid: Geology of the Himalaya made simple. Speaker: Dr. Danny Clark-Lowes. Geological advisor and trip scholar.

November 2nd
Zoom: The Beneath Britain Project. Speaker: Chris Pullan, Director of CP Exploration.

December 7th
Zoom: The NW Highland Controversy. Speaker: Dr Peter Gutteridge, University of Manchester.

FIELD MEETINGS

May 5th
Penarth and Sully, South Wales
Dinosaur footprints and associated Triassic-Jurassic sediments
Leader: Prof. Maurice Tucker, Bath Geological Society

June 10th
Sarsen Geology
Leader: Prof. Peter Worsley

September 3rd
Bristol Naturalists' Society Field Meeting: The Lower Cornbrash (Middle Jurassic) Near Woolverton, Somerset.
Leader: Simon Carpenter

September 17th
The Geology of Cleeve Hill, Gloucestershire
Leader: Dr. Nick Chidlaw

Contents

Cover photo: Group photo from the May 5th field trip to Penarth & Sully, South Wales. led by Professor Maurice Tucker. Photograph taken by Graham Hickman

Chairman's Report for 2023

2023 has been another active year for the Bath Geological Society. Whilst we live with the after effects of the pandemic, one positive outcome has been the general acceptance and ease-of-use of virtual conference technology (Zoom meetings) which has transformed the way we communicate remotely.

During the Winter months (November to February) we decided to hold all our lectures virtually, while during the remainder of the year (March to October) we held hybrid lecture meetings. Hopefully this has encouraged social interactions at the face-to-face meeting while also enabling those who are unable to attend physically to participate online. The feedback we have received from members for holding our lecture programme as hybrid meetings has been very positive and we will continue to do this for the foreseeable future.

During 2023 our membership has increased slightly to 79 compared with 76 in 2022, 69 in 2021 and 54 in 2020. The steady increase is a good sign that the Bath Geological Society is delivering a program of events which are of interest to people and attracting new members. This also provides the Society with a secure financial footing to face increased costs, without the need to increase the membership subscription. I would like to thank all members for their support by renewing their membership of the Bath Geological Society.

Our lecture programme has again covered a wide variety of geological topics. We held eleven lectures during 2023 rather than the usual ten, with the addition of a virtual Zoom lecture in January. The best attended lecture was the April meeting where Professor Michael Benton spoke to us about Extinctions, how life survived, adapted, and evolved. The lecture coincided with the opening of the BRLSI minerals exhibit 'Riches of the Earth' and members were able to browse the exhibit before the lecture. Nibbles and refreshments were served following the lecture. Another lecture of note was that given in February 2023 by Professor Atle Nesje, this was our first overseas lecture given by Professor Nesje, who spoke to us using Zoom from Bergen in Norway. Our October lecture by Dr Danny Clarke-Lowes was also very well attended and his topic of Himalayan geology was particularly relevant to the pupils of Wells Cathedral School who we were very pleased to welcome to this lecture.

Four field meetings were held during 2023, the most memorable and best attended being that to Penarth and Sully, South Wales, to see the newly discovered dinosaur footprints. This trip was led by Professor Maurice Tucker. (See Group Photo on the front cover). Shortly after the group photo had been taken the heavens opened and heavy rain fell for the next 30 minutes or so. The group, exposed on the beach, were soaked through, yet continued an intense discussion about the evidence for and against the interpretation of the depressions as being made by dinosaurs. Fortunately, the sun came out again and after lunch the group continued to Sully Island in search of more dinosaur footprint impressions.
At the 2023 AGM Sue Harvey stood down from her position as Field Trip Secretary and Polly Sternbauer stood down as Membership Secretary. I would like to acknowledge my thanks to both Sue and Polly for their service to the Bath Geological Society. David Hall came onto the committee and Katie Munday has taken on the additional role of Membership Secretary. We are eager to fill the position of Field Trip Secretary, please speak to me if you would like to volunteer for this role.

This is now the fourth year I have served as your chairman; our constitution requires a change of Chairman after three years. This is a healthy requirement as it refreshes the leadership of the organisation and brings new ideas and direction to our society. While I have enjoyed being your chairman, I am hopeful that the responsibilities of chairman will be taken up by someone new in 2024.

The committee has met 5 times during the year using the Zoom virtual conference technology and this continues to work well and assists with communications in programme planning. 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 2023 Committee:

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

If you have any comments or suggestions, I 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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A quick note from the Journal Editor

I really hope you enjoy the articles in this years Journal and I would like to thank everyone who has taken the time to contribute. It has been an absolute pleasure to edit.

Don't forgot we can add anything to future journals; places you have visited, photographs, a book review etc. I am grateful for all.

Thanks again, Mellissa Freeman
journal@bathgeolsoc.org.uk

Obituary

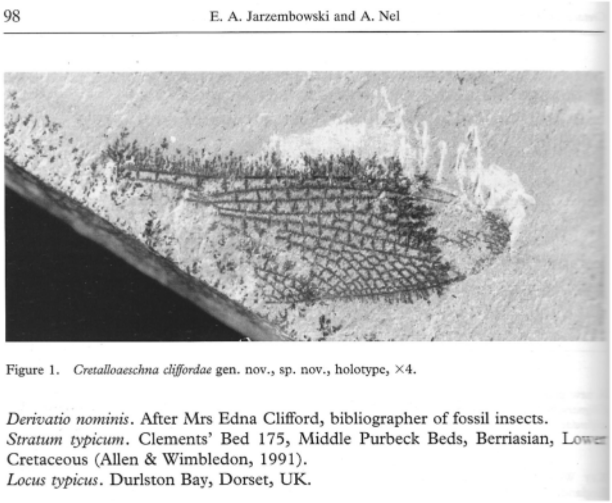
Mrs Edna Clifford (formerly Edna Parmenter) 1915-2021

Edna Clifford passed away in May 2021 at the grand age nearly 106. Edna was a founding member of the Bath Geological Society and served as Chair for two years from 1980 and 1981. Edna was born in Chester in 1915 as Edna Smith. She grew up in Nottingham and in 1937 she married Raymond Parmenter an industrial consultant and they moved around the country with this job. Edna Parmenter worked as a teacher and raised three children. After Ray's death in 1972 she moved to Bath, which is where she became involved with the Bath Geological Society.

She was Chair of the Bath Geological Society when the Journal started in 1981 and was probably instrumental in writing down the origins of the Society. In 1982 she married Arthur "Freddie" Clifford but later moved away to Sussex and when Freddie died in 1998, she moved to Oxford to be near her son.

An article written by Allan Comer in the 1996 Journal of the Bath Geological Society records her continued work with geology after she had moved away from Bath. She sent her greetings after meeting up at the Geologists' Association meeting in November of that year. Allan's article also refers to work she was doing for Dr Edmund Jarzembowski to build up a catalogue of fossil insects using card index files. Edna was rewarded for this task by having a new species of dragonfly *Cretalloaeschna clliffodae* named after her.

Dr Edmund Jarzembowski writes "In 1992, Frank Carpenter's long-awaited Treatise appeared, and Edna volunteered to do a card index of fossil insect genera - and then try to keep it going as volumes like that, though invaluable, get rapidly out of date. Her daughter was the librarian at the Linnean Society, so Edna was undaunted by palaeo-literature and her handwriting was so much better than mine. Naturally, I accepted, although I changed jobs for Kent a few years later...there, Tony Mitchell volunteered to put her work on computer and keep it up to date...and we named the database EDNA after her- it is still there online hosted by Pal Ass!"



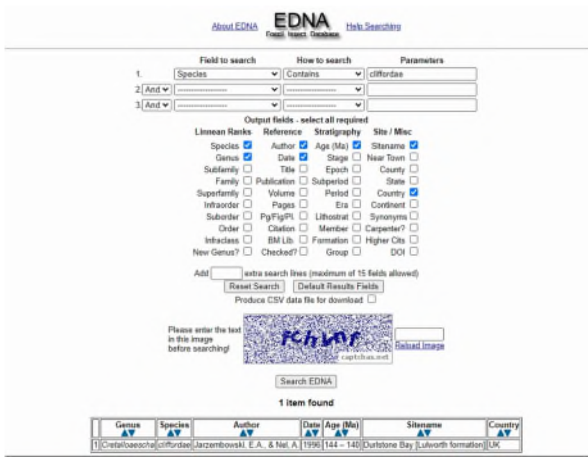
98 E. A. Jarzembowski and A. Nel

Figure 1. *Cretalloaeschna cliffordae* gen. nov., sp. nov., holotype, ×4.

Derivatio nominis. After Mrs Edna Clifford, bibliographer of fossil insects.
Stratum typicum. Clements' Bed 175, Middle Purbeck Beds, Berriasian, Lower Cretaceous (Allen & Wimbledon, 1991).
Locus typicus. Durlston Bay, Dorset, UK.

Charles Hiscock writes "I met her when I was chairman up to 1997. I do remember she greeted me like a long-lost friend, having been chairman in earlier years."

Enda lived a long and full life; she will be missed. She certainly is an inspiration to all of us.



References:

Comer, Allan. 1996. Edna Parmenter, Journal of the Bath Geological Society No.15, 1996, page 1

EDNA Fossil Insect database - fossilinsectdatabase.co.uk

Jarzembowski,E.A, A. Nel, 1996. A new genus and species of hawker dragonfly (Aeshnidae) from the Lower Cretaceous of southern England, Cretaceous Research, Vol.17, Issue 1, 1996, p97-101.

Oxford Mail, 29th July 2017 – One of Oxford's oldest residents Edna Clifford still dancing through Summertown at 102.

‘Picnic at Bushy Grove’

By Charles Hiscock

During the period of lockdown caused by the Coronavirus pandemic in 2020, I reviewed the many photographs and records I had assembled over the years of examining the geology in my area, particularly in the Tortworth Inlier. Much of my work had already been digitised but, apart from the fossils, I had no photographs of the exposures at Bushy Grove, near Berkeley, Gloucestershire. The wood belongs to the Slimbridge Estates and is managed by the Ernest Cook Trust which, in the early 1990’s, were very happy to give me permission to carry out my own investigations at the exposure recorded by Curtis (1968) and Crimes (1975). In June 2020 I gained permission to enter Bushy Grove in order to reacquaint myself with the locality and to take photographs. My return to the wood, accompanied by the Estates Forester was on a blustery day at the end of June. The very wet winter of 2020 was followed by April, May and much of June when there was little rainfall and the warmest sunniest Spring on record! The hope was that the lack of rainfall would make access to the stream bed along the north and west sides of Bushy Grove much easier. In the early 1990’s the water was freely flowing ensuring that any sediment was washed downstream exposing the rock beds but in June 2020 there was no water flowing and the stream bed was covered in a grey sediment, masking much of the soft rocks. In a couple of places, notably where a hard rock band dips approximately 40 degrees north east we were able to examine the bedding and extract some small specimens from the rock and stream bed. Examination of the specimens collected that June produced two small but clear examples of Cruziana, a large smooth oval burrow and a flat slab on which there is what appears to be the impression of a trilobite.

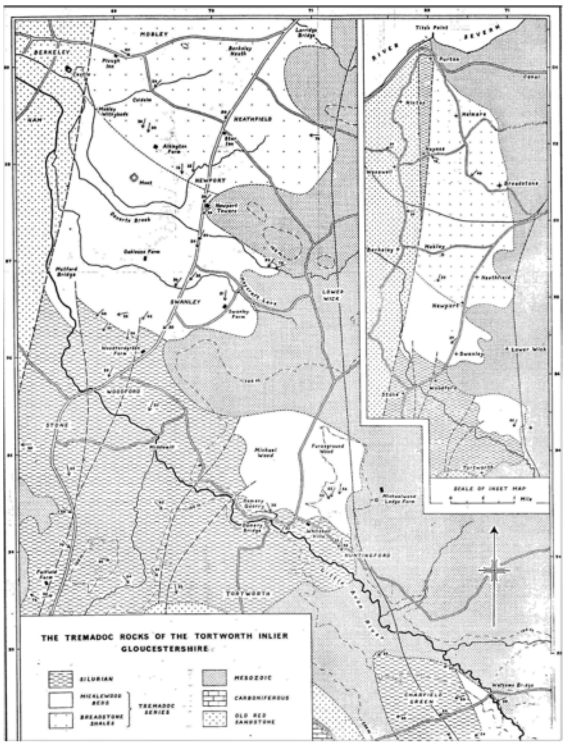


Figure 1: Geological sketch map (Curtis 1968)

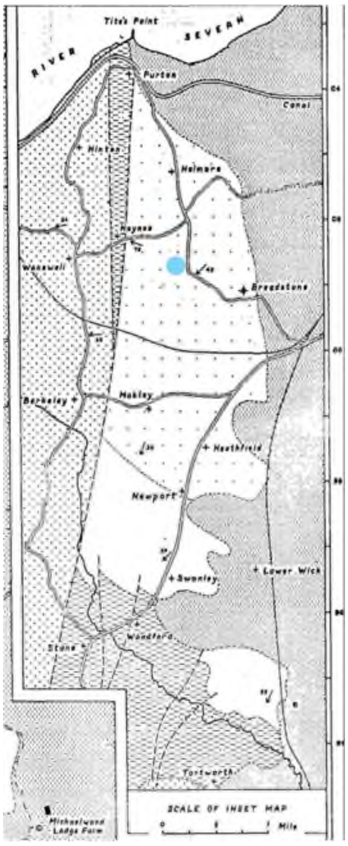


Figure 2: Geological sketch map, Bush Grove marked by blue circle (Curtis 1968)

In 1968 Dr M. L. K. Curtis, for many years in the 1960’s to the 1980’s the Curator of Geology at Bristol Museum, published a paper in the Proceedings of the Geologists’ Association on ‘The Tremadoc Rocks of the Tortworth Inlier’ (Curtis 1968). He referred to trace fossils he had found in a pipe excavation and a small stream in the area north east of Berkeley in the Breadstone Shales. In 1975 T.P.Crimes of Liverpool University published a paper on trilobite traces from the Lower Tremadoc of Tortworth (Crimes 1975) in which he says that Dr Curtis had placed his trace fossils at his disposal and also assisted in the collection of further material from his localities. Crimes records two basic forms of the trace fossils, namely *Cruziana* and *Rusophycus*, both of which are accepted as the traces left by trilobites as they moved and rested respectively in the sediment. The paper describes the locality and assigns species names to the specimens that had been found. Two new *Cruziana* species were named, *Cruziana tortworthi sp. nov.* and *C. breadstoni sp. nov.* while the *Rusophycus* were assigned to the species *R. didymus.*

The Tortworth Inlier is normally taken to be the Silurian succession but north of the Little Avon River in the Damery to Woodford area and extending to Purton on the River Severn are the Micklewood Beds and Breadstone Shales of the Ordovician Lower Tremadoc Series (478 – 485 mya, now included in the Shineton Shales Formation) which are also included in the Inlier. Figure 1 shows the geological sketch map of the Tremadoc Series of the Tortworth Inlier while Figure 2 shows the location of Bushy Grove (Curtis 1968) which lies on the southern edge of the Breadstone Shales. This is an outcrop of mainly mudstones but with sparse and thin siltstones laid down in a medium depth of water on a platform or slope lying to the north of the metamorphic basement of Pretannia which existed from the Pre-Cambrian to the end of the Silurian. Pretannia lay to the south approximately where the south west of the UK and Brittany now lie. (Cope, Ingham & Rawson 1992, Cope & Bassett 1987). This shed sediment into the Tortworth Inlier well into the Silurian and is characterised by greenish siltstone and fine sandstones, often with a micaceous content. Curtis reports that the general dip of the Breadstone Shales is about 40 degrees south west but, due to the paucity of exposures, this has not been confirmed.

Figure 3: Siltstone beds 20 yds S of the field gate, dip 45 deg. NE

During the visit in June 2020, it was noted that the harder siltstone beds that yielded the few trace fossils were dipping at about 45 degrees north east (figure 3). The land underlain by the Breadstone Shales and the Micklewood Beds is gently rolling with only low hills cut by some deep water courses such as the one bordering Bushy Grove. It is a small wood of mainly conifer, edged by deciduous trees and a small stream that runs along the NNW side in a shallow valley. However, the stream bed has cut deeply into the soft shales and mudstones of the Breadstone Shales to produce a narrow gully 6 to 10 feet deep. In the bottom, beds of harder fine siltstone have been scoured and exposed by the running water. On the many occasions I visited the locality in 1993/4 welly boots were needed to stand in the water and rubber gloves to dig in the stream bed. It was a highly successful series of trips as some excellent specimens were found, certainly as good as those illustrated in the paper by Crimes. A few yards away from the stream was a large active badgers' sett and in the mounds of earth dug out by the animals were some small pieces of *Cruziana* and two specimens of the zonal graptolite *Rhabdinopora flabelliforme.* (Curtis and Crimes refer to the graptolite by its earlier name *Dictyonema flabelliforme).*

My explorations in 1990's produced both varieties of the traces and I reproduce photographs of each at the end of this article (figures 4, 5 & 6) plus many others of varying quality. The beds are formed of fine, slightly greenish sandstone much of which is very friable and criss-crossed by the *Cruziana* trails. Scouring of the stream had also loosened some specimens of *Rusophycus,* the resting traces of trilobites.

Figure 4: Cruziana, (Breadstone Shales, Ordovician)

Figure 5: Rusophycus, (Breadstone Shales, Ordovician)

Figure 6: Cruziana (Breadstone Shales, Ordovician)

During the visit of June 2020 a few small specimens were collected of which two are *Cruziana* (figure 7) a large smooth burrow, *Palaeophycus,* (figure 8) and a slab on which can be seen a few faint striations similar to *Cruziana* (figure 9) alongside a faint impression which could be a trilobite body fossil (figure 10).

Figure 7: Cruziana specimins

Figure 8: large burrow (Palaeophycus)

Why my title? When I was considering the subject for this article the lyrics of 'Teddy Bears' Picnic' came to mind (Goodness only knows why but 'trilobites' substitutes very neatly for 'teddy bears' – try it!).

Figure 9: Cruziana with trilobite impression

Figure 10: Trilobite impression enlarged from figure 9

The large number of traces indicate that the trilobite population was dense and, although no body fossils have (or had – depending on the images in figs. 9 & 10) been found in the Bushy Grove exposure they have been recorded by Curtis in other localities in the Breadstone Shales. In the Ordovician Period life was abundant and trilobites were particularly so. However, it was a precarious life and no picnic – indeed, it was more a cannibalistic feast!

<u>In the mud</u>
If you go down and dig in the mud
You will be watched by millions of eyes,
By myriads of crystalline compound eyes.
It will be trilobites here, there will be trilobites there,
There will be trilobites scuttling everywhere,
Out for a picnic, out for a feast,
Out for a morsel or a nice treat,
So, beware of the bite of a trilobite's teeth,
When you go and dig in the mud.

<u>References:</u>

Cope J C W & Bassett M G 1987 Sediment sources and Palaeozoic history of the Bristol Channel area. *Proc. Geol. Ass. 98 Part 4 pp 315-330.*

Cope J C W, Ingham J K & RawsonP F (eds) 1992 *Atlas of Palaeogeography and Lithofacies*. Geological Society, London, Memoir, 13.

Crimes. T.P. 1975 Trilobite traces from the Lower Tremadoc of Tortworth. *Geol. Mag. 112 (1), pp 33-46.*

Blue Bath Stone: the real colour of Bath Oolite (Middle Jurassic, England)

By Maurice Tucker
School of Earth Sciences, University of Bristol, BS8 1RJ
maurice.tucker@bristol.ac.uk

Bath stone (Middle Jurassic oolitic limestone) is a distinctive cream to honey-coloured building stone widely used in the UK for centuries and easily recognised. However, in the shallow subsurface in the underground quarries of Bath, it has a BLUE colour! This article tells the story of how the colour of Bath stone came about, from deposition of a white carbonate sand on a beach to deep burial (500+ metres) and subsequent uplift as a dark ('blue') limestone over 100+ million years to its change to a honey-coloured rock near-surface and at outcrop, as seen today.

The City of Bath is famous for its Georgian-Victorian architecture, the crescents, squares, the Abbey and churches, all made of Bath stone, a Middle Jurassic freestone worked from open and underground quarries since Roman times. The Romans used the stone extensively for the construction of the town, Aquae Sulis, notably for the Temple to Sulis Minerva and the Roman Baths complex, and for sculptures. The use of Bath stone, recognised as a *Global Heritage Stone Resource*, forms part of the designation of Bath as a World Heritage Site.

Bath stone is shallow-water limestone composed largely of ooids with varying amounts of skeletal debris, fragments of bivalves, gastropods, corals and brachiopods, along with rare bryozoans, calcareous algae, foraminifera, echinoid debris and serpulids. This carbonate sand was formed in a warm sea in the subtropics, like the Bahamas today or the Trucial coast (Abu Dhabi) where moderate to high energy conditions move the sediment around to form sand waves and dunes on the shallow seafloor (Tucker 2022). Ooids are precipitated in moderate to high-energy water at depths less than several metres from seawater saturated in $CaCO_3$. Although long considered an abiotic process (wave action, warming and CO_2 degassing), there is now much evidence that microbes are involved: bacteria, EPS (mucus) and viruses. Ooids forming today are mostly composed of aragonite (the metastable form of $CaCO_3$), as they were in the Permian and Triassic, but at other times in the past, ooids were composed of calcite, since seawater chemistry had a different composition (a lower Mg/Ca ratio and higher pCO_2), largely controlled by the rate of seafloor spreading and geotectonics. In the Jurassic, most ooids were composed of calcite. One consequence of this is that they are well-preserved, calcite being more stable than aragonite on contact with freshwater.

Oolitic and bioclastic carbonate sediments in modern environments are generally white in colour, although in some places they have a pink tinge, as in Bermuda, from the presence of broken up fragments of the red foraminifera *Homotrema rubrum*, which is an encruster of coral debris in particular. The white sandy beaches of the Bahamas and the Caribbean are legendary, and contrast with those of other shorelines where sand is delivered by rivers, and that is generally composed of siliciclastic grains (quartz, some feldspar), giving a more cream to pale yellow colour. Many beaches in the UK are of this type of sand (sand is a grain-size term referring to particles 62 microns to 2mm in diameter). White sandy beaches are present in a few places in Britain however, where shell-calcareous algal debris is abundant. Such beaches occur in NW Scotland, on the Atlantic coast of Uist, Barra, Harris and Lewis, where the machair grassland forms at the back of the beach on a thin calcareous soil, and in Western Ireland.

Apart from being an excellent freestone (able to be cut in any direction), as a result of its homogeneous composition and lack of fabric, Bath stone is admired for its attractive colour – a subtle white to cream when fresh, developing over time into a light honey colour grading to a beige, even a pale rusty / orange hue in some cases. One can argue about colour of course, depends on one's eye, and of course it does change with the light, sun versus shade and the time of day. But to an extent, it depends on the age of the stone: how long it has been exposed to the elements and its orientation relative to prevailing wind and rain. The colour of a sedimentary rock in general mostly depends on the rock's mineralogy, the content of clay and organic matter, and the state of iron ions present, whether ferrous (Fe^{2+}) or ferric (Fe^{3+}). Bath stone is a limestone ($CaCO_3$) with very little clay (less than 5%). At outcrop, there is little organic matter present, which can give a rock a pale to dark grey colour. The cream to honey to beige colour of Bath stone, and many other Jurassic limestones at the surface (Ham stone, Doulting stone, Cotswold stone, Ancaster-Clipsham stone), is the result of finely disseminated minute particles of iron oxide-hydroxide in the stone, minerals such as goethite (FeO (OH)-limonite ($FeO.nH_2O$). This colour mostly derives from the oxidation of iron pyrite crystals (FeS_2) and any organic matter which are distributed within the sediment. Organic matter buried in sediment, and clay minerals too, usually have adsorbed ions, such as Fe and Mn, which can be released on exposure to the air / oxygen, adding to the development of the pale honey-rust colour. In many places, small cubes of pyrite or even larger, cm-scale nodules of pyrite are visible in Bath stone; in many places these are being oxidised, giving rise to rusty bands of different shades emanating from the pyrite occurrences (see paper by Tucker & Fosbury 2021).

In the underground quarries where Bath stone is being extracted, a rather surprising feature is seen in some deeper areas: the Bath stone is not its usual pale honey colour, but it is BLUE (Figures 1, 2); it may be more grey than blue to some people but it is definitely not honey. The blue colour will be the result of the original organic matter and finely disseminated pyrite still being present within the limestone. The organic matter is within the ooids and shell fragments and will be relics of microbes and the organic tissue of the organisms once present.

Figure 1. Bath stone from an underground quarry in Corsham showing the blue centre to a metre-sized block.

Figure 2. Cut surface of a blue-coloured sample of Bath stone with a sharp boundary to the more typical honey-coloured stone.

When digging in the sand on a beach today, looking for lug worms or building a sandcastle, in England or in the Bahamas, below the normal pale cream-yellow silica or white carbonate sand, the sediment becomes grey after 10-20 cm, then darker grey, and at a depth of 20-30 cm it may become black (and smelly, H_2S and decaying organic matter). Below this a more silvery-grey colour may be seen. This gradual colour change downwards is the organic matter decomposing, extracting O_2 from the porewater, and pyrite beginning to form under the developing reducing – anoxic conditions. There are transitional metastable iron sulphide minerals, mackinawite and greigite, that give rise to the black colour and then in time these transform into pyrite itself which accounts for the deeper silvery-grey colour, some 30-40 cm below the surface.

From this very early burial stage onwards, during continuous burial-subsidence, the sediment will gradually become cemented, generally through the precipitation of calcite if it is a carbonate sand. The Ca^{2+} and HCO_3^- ions for this are present within the marine (subtropical) porewater but they will also be provided through dissolution of the metastable aragonite grains (bivalves and gastropods shells are made of aragonite) in the now slightly more acidic / lower pH conditions. The now developing limestone may continue to be buried into the mesogenetic (deep burial) environment when compaction and pressure dissolution may affect the limestone. Alternatively, there may be phases of uplift / sea-level fall and subaerial exposure shortly after deposition, when meteoric water (fresh, lower pH/neutral than seawater) may affect the sediment; this can also cause dissolution of grains and ooids, as well as further calcite cementation.

In many cases, the limestone will continue to be buried for millions to 10s of millions of years if sedimentation continues in the local basin, until eventually the tectonic regime changes and then uplift and erosion ensues. This may be sufficient enough to bring the original limestone back to the surface. In the case of the Bath oolite, after deposition in the Middle Jurassic (166 million years ago) and short-lived phases of subaerial exposure shortly after, the limestone was buried under Upper Jurassic and Cretaceous sediments to around 500 to 800 metres depth. This was followed by uplift in the Tertiary that brought the limestone back to the surface in the last million years or so (Tucker 2022). Overall this time, the Bath stone will still have been blue/grey, through that disseminated organic matter and pyrite. However, on reaching the near surface, referred to as the telogenetic environment, it will have been affected by groundwater and in most situations this is oxygenated. Thus, the movement of groundwater through the Bath oolite at a depth of several 10s of metres would have then oxidised the organic matter and pyrite to reduce and remove the dark colour and establish the familiar white-cream colour we are used to for this stone. The groundwater would travel first along bedding planes and through fractures-joints, oxidising the adjacent sediment and then gradually seeping farther into the beds to remove eventually all the colour. In large blocks extracted from several 10s of metres below the surface in a mine at Corsham, the blue colour is still preserved within the centre of the blocks and there is a sharp boundary between the oxidised and blue parts of the stone (Figures 1, 2). The blue variety is well seen within the large ammonite found at Corsham (Figure 3).

Figure 3. Large ammonite (20 cm across) with blue sediment within the last chamber and a much smaller earlier one, as well as two small empty chambers with some calcite crystals. Image courtesy of Adrian Boniface.

This phenomenon of limestones at the Earth's surface being very different in colour from their appearance in the subsurface is typical of relatively porous limestones. The Bath stone has a porosity of 20% or more. In the UK, many Jurassic limestones are of this type, including Cotswold stone and Lincolnshire stone, notably Ancaster stone, which is available in a white and a blue variety. By way of contrast, Carboniferous limestones are much tighter, with a much lower porosity (<5%), so that they mostly retain their original quite dark colour at the surface, in spite of deep burial and subsequent uplift.

Two other limestones in the Bath area, where freshly excavated samples are blue and contrast dramatically with surface material with more of an orange to brown colour, are the Forest Marble and the Cornbrash. Recent excavations near Woolverton, 10 km south of Bath, recovered blue varieties of these two limestones at a depth of around 5 metres below the surface (Figures 4, 5). In time, these blue varieties can be expected to lose their dark colour.

Figure 4. Rusty-orange and blue-grey shelly bioclastic limestone from the Forest Marble (Bathonian), Woolverton, Somerset.

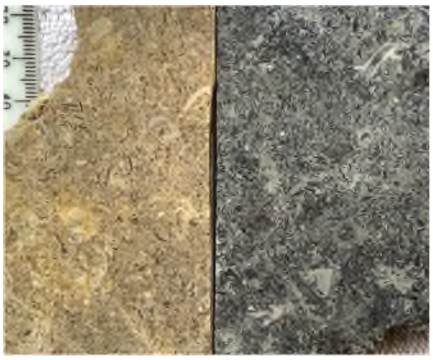


Figure 5. Beige and blue-grey shelly bioclastic limestone from the Cornbrash (Bathonian-Callovian), Woolverton, Somerset.

The Upper Permian Zechstein dolomite and limestone which crops out from near Nottingham to South Shields on the Durham coast is another example of a buff-yellowish carbonate at surface exposures, contrasting with subsurface material which is much darker. Samples of the latter are seen in cores from Yorkshire and the North Sea taken in the search for oil and gas (Figures 6, 7). The Houses of Parliament in London were constructed of honey-coloured Zechstein oolitic dolomite from Anston in South Yorkshire in 1840, following a review by William Smith, Sir Henry de la Beche and others. However, much of the stone was of a poor quality and in the polluted atmosphere of Victorian London, it soon began to crumble, necessitating extensive repairs, some of which are still going on today.

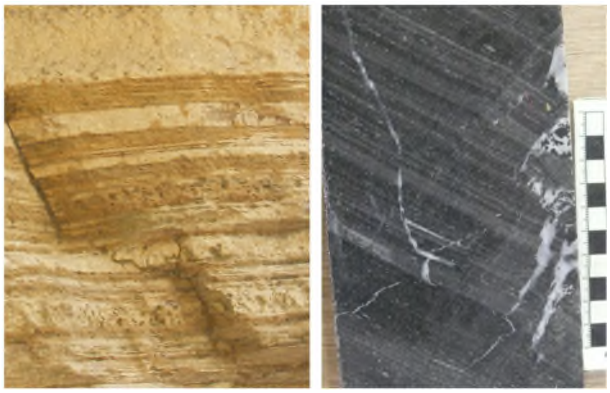


Figure 6. Upper Permian (Zechstein) dolomite from the sea-cliffs at Marsden, Tyne & Wear and from the Lockton borehole, North Yorkshire (depth 1900 metres). Both samples are from the Z2 Roker Formation deeper-water slope facies with thin (cm-thick) calciturbidites and sub-mm-scale lamination between.

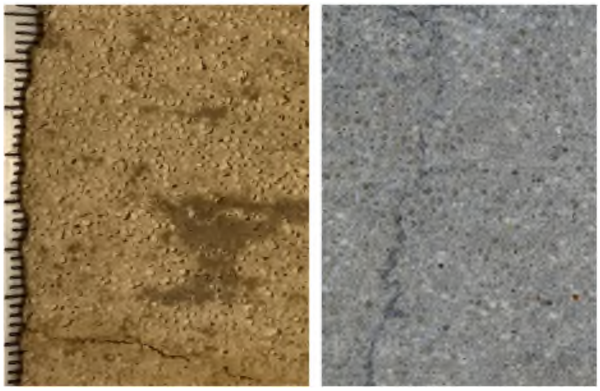


Figure 7. Upper Permian (Zechstein) dolomite from an outcrop at Seaburn, Tyne & Wear and from the Malton borehole (depth 1250 metres), North Yorkshire. Both samples are from the Z2 Roker Formation shallow-water oolite shelf-margin facies.

It is sobering to reflect that if the Bath oolite had been better cemented to give a much lower porosity stone, this would have prevented the circulation of groundwater, and then the City of Bath would have been built of a blue stone!

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Acknowledgements

I am grateful to Adrain Boniface, Simon Hart and Simon Carpenter for facilitation.

A MOOC review: An introduction to geology

by Ayden Sidique

https://www.open.edu/openlearn/science-maths-technology/an-introduction-geology/

I enrolled in the course "An Introduction to Geology" by Open Learn website to go alongside my A level studies. MOOCs are 'Massive Open Online Courses' and are available from many providers at all levels across a wide variety of disciplines.

This course had a duration estimated at total of 12 hours to complete and is designed to be distributed over 4 weeks. Having completed the first year of geology A Level I was able to complete the course in about half the time. Each week has an overarching theme, split up into several articles with each consisting of text accompanied by images and/or videos clips. This layout is very effective because information is given to you gradually which makes the content easy to digest and is more dynamic than a textbook!

The Week 1 course gives a good introduction to some of the basic skills a geologist needs such as being able to identify & date rocks and understand how Earth's processes (such as plate tectonics) create them.

In Week 2 you learn about real world applications of geology, such as 'geology of a smartphone' and looking at how metals are concentrated into ore deposits.

Oil is an essential part of modern society and is the focus of Week 3. Whether as fuel for transport, or for use in plastics and food production. The geology of hydrocarbons and their exploration is a key theme of 20^{th} and 21^{st} century geology.

Appropriately the final 4^{th} Week of study looks at the legacy of our extractive industries, their impact on the environment and the role geology can play in amelioration.

For me, learning about the real-world applications of geology has boosted my interest as it gave purpose to the past year of studying the theory and to my future in Earth Sciences. Additionally, hearing about the ongoing projects to tackle world issues was inspiring because it presented a challenge that was currently unsolvable yet still gave a goal to strive towards.

Meeting the UK's goal of going 'net zero' by 2050 is proving to be formidable, the course provides some geological solutions which have the potential to be effective. All in all, I think the course does tremendously well in highlighting the most engaging and relevant parts of geology and goes into plenty of depth. It compliments the A level geology course and extends it in directions not covered in the current specification.

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Basalt from Fayoum, Egypt

By Graham Hickman

In 1985 during my assignment in Cairo I visited the desert area north of Fayoum. On one of these trips, I collected a piece of basalt stone (Figure 1). The stone was not associated with any ancient building, as far as I could tell, but it had two faces which had been worked and were at right angles as if it had once been part of a larger block. I had read about the basalt quarries of the Egyptian Old Kingdom (2686-2160BC) and assumed this stone had come from them. The perfectly flat faces would have been formed by hand using stone and/or bronze or copper tools, quite a feat and this is what captured my imagination. The Egyptian Old Kingdon was still in the Bronze age and Iron Age tools only reach Egypt much later at around 1300BC.

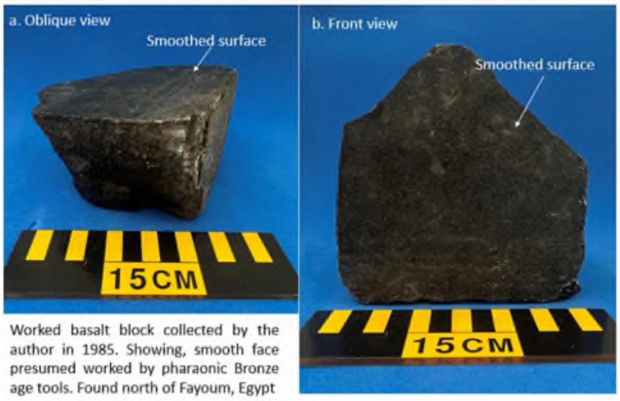

Figure 1- *Worked basalt block collected by the author in 1985. Showing, smooth face presumed worked by pharaonic Bronze age tools. Found north of Fayoum, Egypt*

GEOLOGY

The basalt consists of several lava flows, of Oligocene age (23.5 to 32Ma), believed to have issued from fissures associated with the rifting of the Red Sea. The basalt is a sub-alkali tholeiitic basalt meaning that it contains less sodium than other basalts. It consists of several flows; the composite thickness varies between 2-25m and is exposed for over 40km along the escarpment north of Fayoum.

The more resistant basalt now caps the limestone escarpment. The Widan el-Faras (literarily "Ears of the Mare") refers to the distinctive twin peaks just to the east of the quarry site, this photo was taken during my adventures there in 1985 (Figure 2).

Figure 2 – *Widan el-Faras. Darker colour is the basalt capping to Limestone escarpment*

PHARONIC USE OF BASALT

The use of Basalt in ancient Egypt was limited, probably because of its hardness compared to the more abundant limestone. A small number of basalt vessels, sarcophagi and statues have been found, but the most popular use of basalt was for making floors. Perhaps the best known is the funerary floor in front of the great pyramid (figure 3) but even this was restricted to only a handful of Old Kingdom structures. Five ancient quarries at Widen el-Faras were recognised as the source of the basalt used in the Egyptian Old Kingdom structures. The best descriptions are given by Storemyr (2003) who tried to recommend them for protection as UNESCO world Heritage sites. Unfortunately, modern quarrying in the area has now destroyed many of these ancient quarry sites. Archaeologists have tried to match the five basalt quarries to four Pharaonic building projects where basalt was used. The interpretation being that the quarrying operations seems to have been short lived and only started for specific projects, the material from the fifth quarry having been stacked, but not transported, for whatever reason.

Figure 3: *Darker area is the remains of the basalt floor of the temple at the east foot of the Great pyramid*

THE WORLD’S OLDEST PAVED ROAD

What is also fascinating about these ancient quarries is that the stone was transported south via a paved road, around 11km long and 2m wide, to a dock at the lake. (Figure 4)

Figure 4: *The world’s oldest paved road (~4600 years old, estimated 2500BC)*

Although small sections of this road had been recognised before, it was not until 1994 that the full significance of the road connecting the quarries to the lake was made. Brown and Harrell, American archaeologists, published their observations and claim this to be the world’s oldest paved road (Brown, 1995). The road is made from blocks of basalt, limestone, and pieces of silicified wood. Again, unfortunately this unique piece of history has no protection and has been bulldozed in several places without understanding its significance. The road terminates at an ancient quay where the basalt would have been loaded onto vessels and transported across the Lake, Birket Qarun and onto the Nile. Changes to the North African climate have shrunk the volume of water in the lake such that the quay is now some 8km from the water’s edge.

BRONZE AGE STONE WORKING

It is amazing how smooth the surfaces on the basalt have been made using basic stone and/or bronze or copper hand tools. There is evidence of saw cuts in some of the basalt stones at the great pyramid from samples collected by Flinders Petrie in the 1880s, now in the Petrie Museum of Egyptian Archaeology at UCL (Figure 5).

Figure 5 – *Pharaonic Basalt showing saw cuts. Petrie Museum of Egyptian Archaeology at UCL*

It has been postulated that these were made using some form of rock saw (Moores Jr, 1991), probably using quartz sand as an abrasive. The archaeological evidence of such technology is lacking but the large quality of accurately cut stone must speak to more than just manual chipping and grinding. The destruction of the quarries sites unfortunately removes further evidence that might be gained about their extraction techniques.

Researching this article has certainly given me a greater appreciation for my piece of basalt. It continues to intrigue me how smooth it is - having been crafted 4,600 years ago without the use of iron tools. Remarkably, Stonehenge was also under construction at about the same time as this piece of basalt was being quarried!

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'In search of Dinosaur Footprints' – A field trip to Penarth and Sully in South Wales on Friday 5th May 2023, led by Dr Maurice Tucker

By Charles Hiscock

A group of 26 members and visitors met on a bright but cloudy morning near the pier at Penarth in south Wales where the leader, Dr Maurice Tucker of Bristol University and Bath Geological Society outlined the itinerary for the day. The plan was to walk along the beach south for about a kilometre to examine the controversial dinosaur footprints that are exposed on bedding planes on the beach. The footprints were reported on BBC News in August 2020 and featured in the Channel 5 programme "Behind the Scenes at The Natural History Museum" which was broadcast in 2022. After lunch, we were to drive about 5 miles west to the coast at Bendrick Rock, near Sully, where we would examine the cliffs and search for the dinosaur footprints which have been known for many years.

Before we departed along the beach, Maurice outlined the geology of the Penarth area using an old geological survey map (figure 1) and pointed out the Devonian and Carboniferous foundation rocks in south Wales, with Carboniferous limestone the primary basal formation in the area we were to visit. The map clearly showed that Triassic rocks predominate on the surface in the area of Penarth (locality 1) and Bendrick Rock near Sully (locality 2).

Figure 1: Geological map of the Penarth district (site 1 – footprint locality, site 2 – Bendrick Rock)

In the south Wales and Bristol Channel areas erosion of the Carboniferous mountain range left islands of the limestone around which Triassic sediments were deposited. Figure 2 is a schematic sketch of Triassic marginal lacustrine facies on anticlinal foundation rocks of Carboniferous limestone. Note that 'Keuper Marl' is now called the Mercia Mudstone Formation (Tucker 1978).

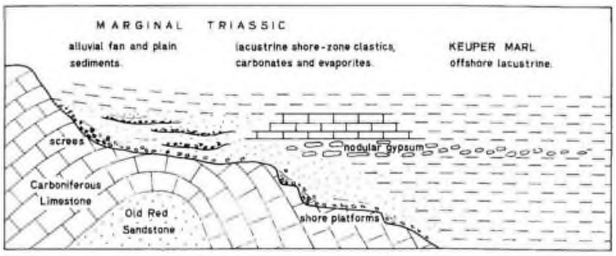

Figure 2. Schematic sketch of Triassic marginal lacustrine facies (Tucker 1978).

The beach and cliffs to the south of Penarth (figure 3) consist of 200 mya Upper Triassic mudrocks of the Rhaetian Stage Blue Anchor Formation and are overlain by Jurassic Lower Lias limestones and mudstones.

Figure 3 View along the beach south of Penarth.

The Triassic was a period of arid desert with very high temperatures when the supercontinent Pangea formed the landmass over a greater part of the earth's surface with Britain near the middle about 15 degrees north of the equator. In the late Upper Triassic, there was a big change across the world when plate tectonics started to split Pangea apart and the sea encroached west along a channel from the Tethys Ocean, producing shallow marine and lagoonal conditions. This induced an increasingly humid climate causing the greenish/ grey of the Blue Anchor Formation at the top of the red Mercia Mudstone Formation. At the end of the Triassic, conditions were fully marine and in the early Jurassic the Atlantic Ocean started to open to the west of the UK.

Body fossils of the late Triassic terrestrial tetrapods in the UK are rare. The three main sources of material are fissure fill deposits mainly in the Carboniferous limestone of the Bristol Channel region, preserved natural moulds in the Lossiemouth Formation of Elgin, Morayshire, Scotland, and a few isolated localities in SW England and Wales. There are several late Triassic sites where small to medium footprints of tetrapods have been recorded – the Lossiemouth Formation near Elgin in Scotland, the Arden Formation of Warwickshire and isolated tracks at Aust, in South Gloucestershire. The most significant trackways are found in the Norian-Rhaetian rocks of the Mercia Mudstone Group of South Wales with the earliest records in 1879 (Sollas, 1879; Thomas, 1879; in Falkingham PL *et al* 2021).

Shortly after moving off to the location of the dinosaur footprints as rain started to fall, we gathered on a groin for a group photograph (figure 4).

Figure 4: Group photograph at Penarth.

Continuing to walk along the beach, the large cobbles and very heavy rain made progress slow with dips and hollows in the beach now swamped with water. We arrived, rather wet, at the locality where Maurice pointed out an irregular line of water-filled hollows in a grey mudstone bed in the Blue Anchor Formation. Figure 5 shows the stratigraphical sequence in the cliff and the dinosaur footprints locality where the level of the trackways is marked by the red star.

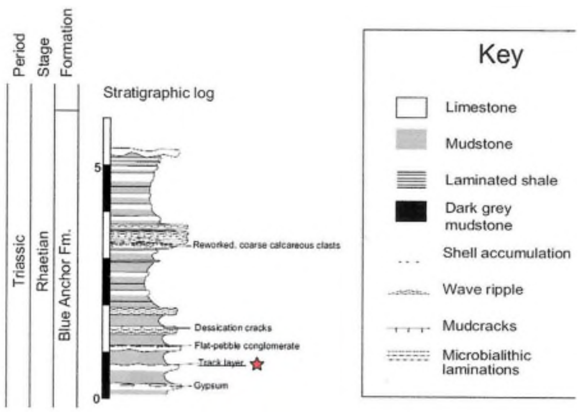

Figure 5: Stratigraphy of the dinosaur footprints locality.

The tracks could be seen on a single bedding plane of grey siltstone where small gypsum nodules can be found near the top although the rain negated any attempt to find them. The tracks are quite deep, up to 10cm and vary in diameter from 20 – 50 cm with the walls damaged by sea erosion and lacking any clear impressions of toes or claws. The depressions show rims which can be related to the displacement of the sediment as the animals walked, consistent with dinosaur trackways at other sites (Falkingham PL *et al* 2021). Due to the conditions, obtaining meaningful photographs was difficult but fig. 6 shows a short sequence of the depressions which have been highlighted.

Figure 6: Line of footprints (highlighted).

We found one print which clearly shows the three-toed formation.

Figure 6.1: 3-toed footprint.

There are two exposures of the trackways on the same bedding plane, the northerly one being about 30 metres long and the southerly track being about 20 metres. A non-contemporaneous fault offsets the two trackways south about 10 metres. The density of prints is very high with more than 40 on the southern exposure and more than 60 on the northern. The depressions lack displacement rims which are a feature of dinosaur prints but their absence could be a function of erosion by the sea (Falkingham PL *et al* 2021). An interesting observation was made to explain this feature – a trackway made by cows in soft mud clearly showed the formation of displacement rims as the cows walked through, which varied in dimension depending on the softness/firmness of the mud. In Fig 6A the two footprint trackways have been photographed from a height and Fig 6B shows digital height-mapped models to demonstrate the deformation of the sediment (Falkingham PL *et al* 2021). At our visit, only one trackway was visible because the other was covered by loose sand and pebbles.

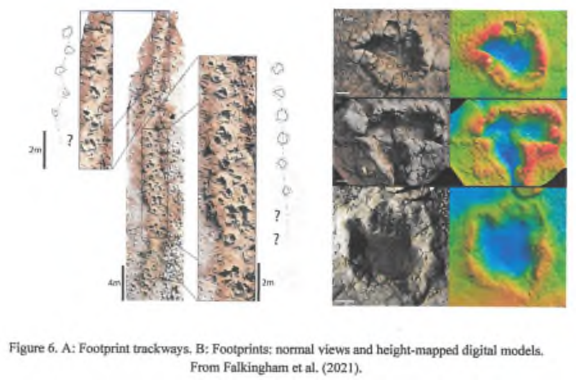

Figure 7: Trackways (6A) and height-mapped models (6B).

Maurice Tucker explained that there have been other explanations suggested for the depressions. The trackways do not show detailed shapes of the makers' feet and the raised rims and sunken floors suggest the possibility of expansion and collapse of sediment caused by gypsum nodules, of which there is a layer beneath the 'footprints' bed (see figure 4). Nodules of gypsum fill and line depressions, become covered by sediment and then are dissolved much later to leave hollows. Alternatively, the gypsum forms within the sediment, displacing it to form the rims. However, it could be expected that even small remnants of gypsum would remain in the depressions after erosion but no evidence has been found of either scenario (Falkingham PL *et al* 2021). Another possible explanation is that the hollows are fish-feeding traces which can be aligned in rows and resemble trackways.

With the rain still pouring down, a very sodden party returned along the beach to Penarth. By the time we reached the promenade, the rain had stopped and a welcome, warm sun shone through. Returning to our cars, we broke off for lunch while the warmth of the sun on the cars dried out all but the most sodden clothing. Our next meeting point was the road at the Barry recycling centre adjacent to the back of Bendrick beach near the village of Sully.

Bendrick Rock and Hayes Point, near Sully, demonstrates playa lake, sheet flood fluvial and pedogenic facies on the margin of a Mercia Mudstone lake. The sediments lie unconformably on crinoidal

Carboniferous limestone and display abundant sedimentary structures, evaporite collapse features and numerous dinosaur footprints near the margin of the lake or playa where the red Mercia Mudstone was deposited.

Figure 8: Bendrick Rock headland

Figure 9 Maurice Tucker describing the geology at Bendrick Rock and standing on a palaeosoil.

Bendrick Rock and Hayes Point, near Sully, demonstrates playa lake, sheet flood fluvial and pedogenic facies on the margin of a Mercia Mudstone lake. The sediments lie unconformably on crinoidal Carboniferous limestone and display abundant sedimentary structures, evaporite collapse features and numerous dinosaur footprints near the margin of the lake or playa where the red Mercia Mudstone was deposited. The dinosaur footprints were originally discovered in 1974 and have been featured recently in 2021when a well-preserved print was found by a 4-year girl. Those who saw her and her father on the BBC News will remember the excitement shown by both – maybe/hopefully, a female geologist now in the making!

The Triassic red beds at Bendrick Rock lie unconformably on Carboniferous limestone, show many sedimentary structures and are slightly older than those at Penarth, being deposited during the Branscombe Formation in the Somerset Basin. Figure 10 shows the stratigraphical sequence at Bendrick Rock and the level of the dinosaur footprints which are located on a sandstone bed (Tucker and Burchette 1977).

The environment was a quiet, shallow lake in arid conditions which favoured sedimentary features such as ripples and salt deposits. Sediments at the lake margin are coarse-grained, indicating possible ephemeral rivers

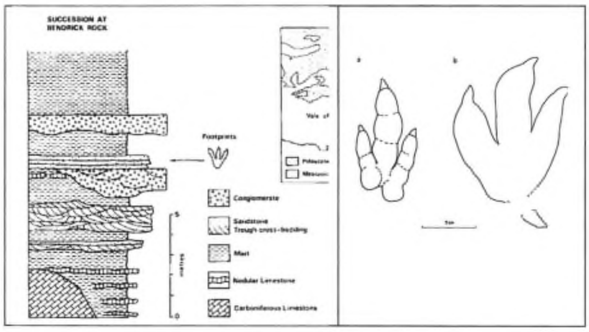

Figure 10: Triassic succession at Bendrick Rock and dinosaur footprints of the Anchisauripus type (Tucker & Burchette1977).

carrying in coarse sediment while within the lake sediments are interbedded fine/coarse with dune structures and ripples (Figure 11).

Figure 11: Interbedded layers of fine and coarse sediment.

There were also sheet flood events that brought in coarse material seen as conglomerates and breccias within the sequence (figure 12).

Figure 12: Coarse channel breccia.Palaeosol

Coarse channel breccia.Palaeosol levels show that, in the arid conditions, the lake dried out occasionally providing conditions for the growth of plants and trees with holes in the bedding possibly attributable to the bases of trees (figure 13).

Figure 13: Possible plant or trees bases.

The environment also favoured the growth of algal mats which, in figure 14, have been broken into fragments.

Figure 14: Fragmentary microbial mat.

The sequence indicates lots of water the level of which is falling due to evaporation in the high temperatures producing evaporites. Small hollow geodes were abundant in the bedding and figure 15 shows a cross-section of a small calcite geode within the sediment.

Figure 15: Small hollow geode in medium to fine sediment.

Geodes are very common in the Mercia Mudstone, known as potato stones because of their similarity to the vegetables (figure 16). In the Bristol area, they can be found filled with crystalline calcite, quartz and chalcedony gaining the name 'Bristol Diamonds' (figure 17).

Figure 16: Potato stones.

Figure 17: 'Bristol Diamonds'.

The basal Triassic rocks at Bendrick lie unconformably on Carboniferous limestone which had not been eroded prior to the Triassic sediment being deposition (figure 18).

Figure 18: The Triassic/Carboniferous unconformity.

The extremes of temperature, from sub-zero nights to 40 °C daytime temperatures, caused 'desert weathering' of the limestone, an exfoliation process that cracks off thin flakes of the limestone which become separated by Triassic mud a feature that was evident on the surface of the limestone and within the Triassic bed above (Figures 19 and 20).

Figure 19: Limestone flakes broken off by desert weathering and separated by mud.

Figure 20: Close-up of the effect of desert weathering.

It is in the marginal sediments at the lakeside that the dinosaur footprints were made. After Maurice had described the geology, he showed us the location where, in 1974, the first dinosaur footprint had been discovered. It was subsequently cut from the rock and is now displayed in the National Museum of Wales in Cardiff (figure. 21).

Figure 21: Dinosaur footprints now in the National Museum of Wales.

There are many prints on the bedding plane, so we went walkabout to discover others for ourselves. Most are just round to oval depressions but a few show imprints of toes and claws (figures 22 and 23).

Figure 22: Trackway with ripples on the bedding plane.

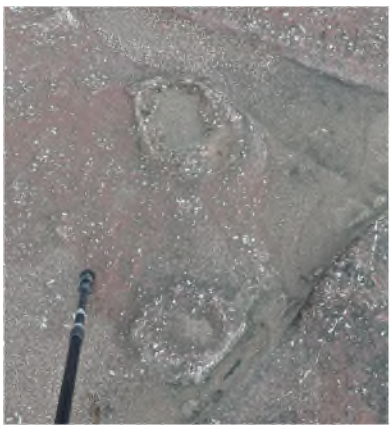

Figure 23: Dinosaur footprints.

One print showed the three-toed form like that seen on the beach south of Penarth on a bed with ripple marks (figure 24).

Figure 24: Three-toed footprint.

Maurice pointed out a bed of fine red mudstone which had a very disturbed surface and suggested that it was probably a palaeosoil. Having read the paper by Falkingham *et al 2021* in which they describe the tracks made by cows in wet mud, the appearance of the disturbed surface of the bed at Bendrick suggests to me it could be a similar trackway made by dinosaurs as they passed through the wet mud at the lake margin (figure 25). Just a thought!

Figure 25: Possible trackways (not made by cows!).

Despite the wet morning, which did not dampen our enthusiasm, we had a very good day with many interesting features, particularly the dinosaur footprints which many of us had not seen before. On our return to the cars Graham Hickman, our chairman, thanked Maurice for leading the field trip.

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Lundy Island

By Jonathan Slack

Lundy is an island in the Bristol Channel. It measures about 5km from north to south, about 1 km from east to west, and lies 19km from the coast of Devon. It is flat-topped and surrounded by steep cliffs (figure 1A, & 1B), with only one landing place at the southern tip. There is a small resident population, and the island is administered by the Landmark Trust, which makes most of its money from visitors. Lundy is popular for its wildlife, including many puffins and seals, but I went to look at the geology.

Lundy is mostly composed of granite and in the past was considered to be an offshore outcrop of the large Cornubian batholith that is visible in Dartmoor, Bodmin moor, and several areas in Cornwall and the surrounding seabed (Dollar, 1941). However, radioactive dating studies from the 1960s onward have shown that it is actually much younger (Dodson and Long, 1962; Miller and Fitch, 1962). The Cornubian batholith has a radiometric age of 298-274 Ma, dating from the Permian, and is associated with the Variscan orogeny and the closure of the Rheic ocean to the south of Britain. By contrast, the age of the Lundy granite is only about 60-58 million years, in the Palaeocene epoch. This means that it must be a part of the British Tertiary Volcanic Province (BTVP) which was formed about that time as the North Atlantic Ocean was opening. The rest of the BTVP lies in western Scotland and Northern Ireland (figure 1C), and it is a part of the North Atlantic Igneous Province, centered on Iceland. Lundy is a remarkable outlier in this system, and it is surprising that there should be a significant magma plume so far from the main action associated with the opening of the North Atlantic.

The MS Oldenberg, an old German steamer which normally serves the island, was out of action when I went, so instead I took a fast inflatable boat from Ilfracombe, which takes about 1 hour (figure 1D). The jetty on Lundy (figure 1E) is quite primitive and requires you to climb up a vertical steel ladder if the tide is low. The landing stage area is geologically quite different from the rest of the island as it consists of Upper Devonian slates (the Morte slate formation). About a mile uphill takes you past the church to the village where there is a shop, pub and hotel. Most of the island is elevated and flat, with delightful granite outcrops along both east and west coasts (figure 2A & 2B). I visited the landing stage area, the principal granite quarries, and also tried to locate some of the many dolerite dykes that dissect the island in a general NW-SE direction.

The granite quarries are to be found a half-mile or so beyond the village on the east side of the island. There are several of them, some with pools of water containing goldfish, and there is plenty of interesting material scattered around on the ground (fortunate as the whole island is a Site of Special Scientific Interest, i.e., no hammering of bedrock is allowed). The granite is light coloured and contains crystals of about 2-20mm in size (figure 2C). In several samples there are obvious discontinuities of crystal size indicating penetration of solidified rock by further molten material. For example, there are many veins of aplite to be found traversing the granite (figure. 2D).

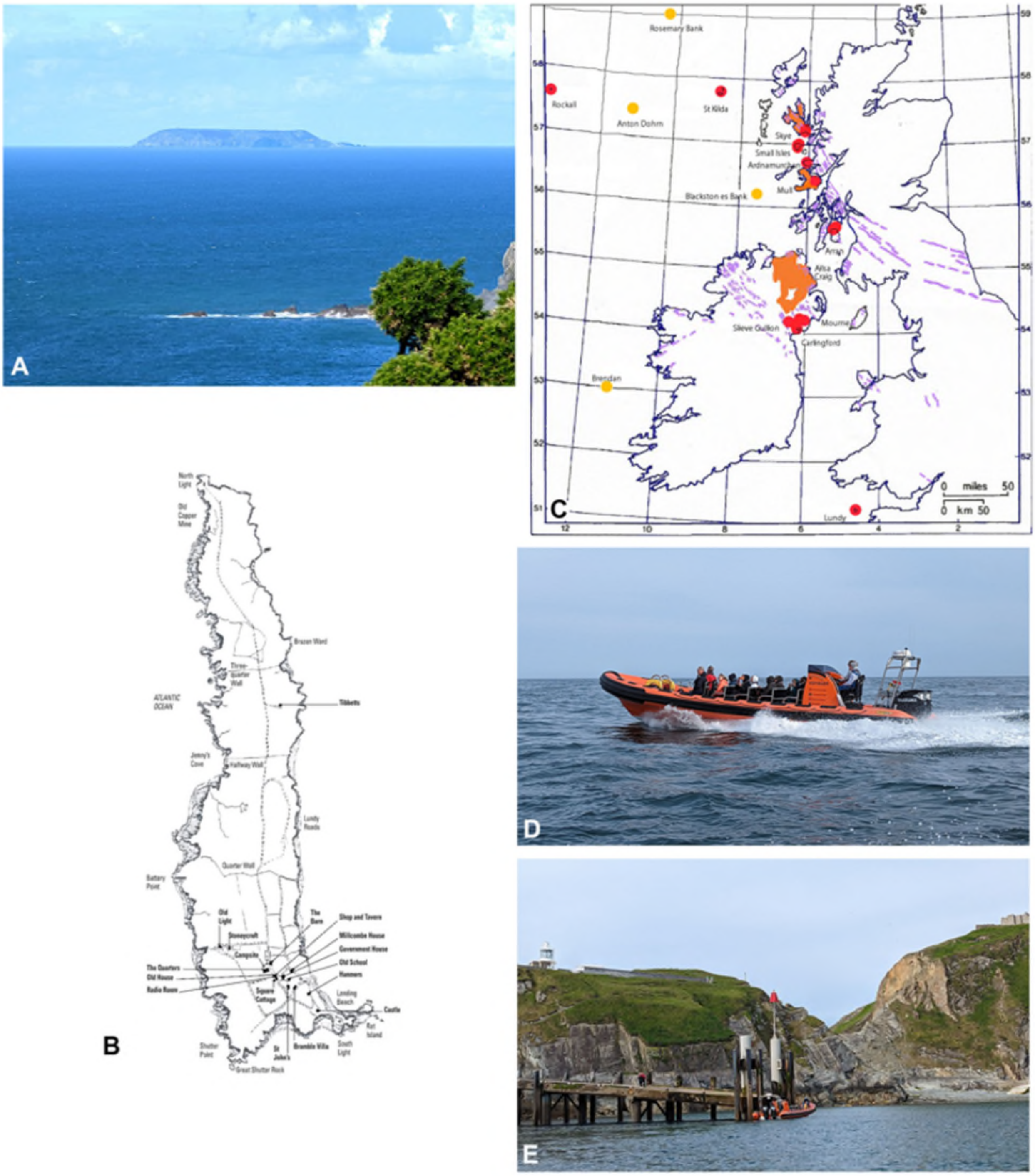
Later, I made thin sections of several granite samples. Figures 2E & 2F shows two magnifications viewed through crossed polars. They show a pretty typical granite containing plenty of quartz, alkali feldspar, plagioclase feldspar and muscovite. Figure 2G shows a junction between the aplite vein shown in figure 2D and the surrounding large crystal granite. There is a sharp junction with no interaction, so presumably the granite was fully formed and cooled before the vein was established and the contents of the vein cooled rapidly. The granite contains relatively little biotite, although the biotite that is present has many inclusions, presumably zircons, surrounded by radioactive halos. These are darkened areas in the surrounding biotite caused by radiation damage from uranium or thorium present in the zircons (figure 2H).

In common with the rest of the BTVP, Lundy has many dykes penetrating the granite, predominantly in a NW-SE direction. However, it is surprisingly hard to find them. This is because they are softer than the surrounding rock and so most of them are only visible as indentations in the steep slopes leading down to the sea. Various dykes have been radiometrically dated and are slightly younger than the main mass of granite (Mussett et al., 1976; Thorpe and Tindle, 1992). I managed to find one respectable dolerite dyke near Battery Point (figure 3A) although I could not reach it to take a sample. Fortunately, there is a nice rhyolite dyke easily accessible near the landing stage (figure 3B). This is embedded in the Devonian slates which make up this south-eastern part of the island (figure 3C, D). There are plenty of debris lying around comprising both dyke material and marginal fragments. A thin section of the junction between this dyke and its surroundings is shown in figure 3E, F. The rhyolite contains quartz and alkali feldspar and the dark area of slate abutting it indicates local baking by the heat of the molten dyke. The fact that there are some acidic (rhyolite) as well as the basic (dolerite) dykes dissecting the granite raises questions about their origin, and this is of course bound up with the nature of the events that led to the formation of Lundy some 60-58 million years ago.

Information about the underground rocks comes from studies of gravity anomalies carried out in the 1950s and 60s. Granite has a lower density than the surrounding slates, while mantle-derived basic rocks such as basalt or gabbro, have a higher density. There is a large positive gravity anomaly centred to the west of the island indicating the presence of a basic intrusion at shallow depth with a maximum thickness of 2.5-4.0 km (figure 4A). Such a body would have a volume of at least 1000 km^3 (Brooks and Thompson, 1973). Within this there is a small negative gravity anomaly over the island itself (figure 4B). This leads to an estimate of the granite mass forming a cylinder of 4.8km diameter and 1.6km height, yielding a volume of about 28.9 km^3 (Bott et al., 1958). So, the overall picture is of a large basic pluton underground, with a small granite laccolith extending to the surface.

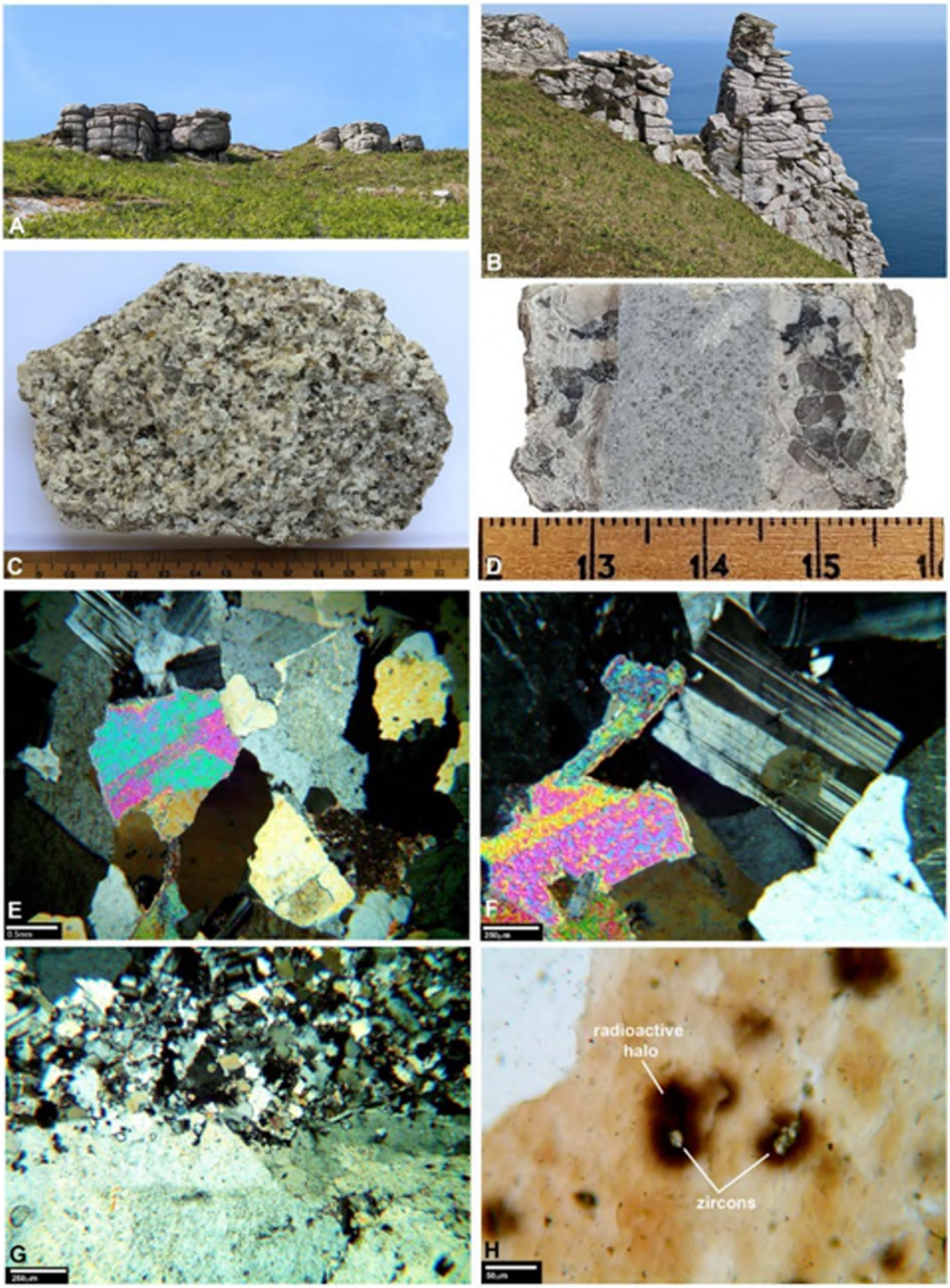
Although the composition of the granite is generally similar to that of the Cornubian batholith, indicating it is formed from melting of similar crustal material, there are divergences in some of the minor components suggesting some admixture from the basic pluton. The dykes are mostly dolerite, providing evidence for the existence of a complex basic-intermediate magma chamber present below Lundy until after solidification of the granite magma. Presumably the fewer rhyolitic and trachytic dykes arose from crustal material.

Taking all this into consideration, Thorpe et al (Thorpe et al., 1990) presented a possible model for the formation of the complex which is shown in figure 4C. According to this, the first step is emplacement of a 1000km^3 pluton of basic magma as a consequence of the tectonic process in the North Atlantic Igneous Province. This caused formation of a dyke and sill complex in the lower crust. The lower crust then melted to form a granitic magma. There was then some mixing of the granite melt with the underlying basaltic magma, accompanied by some fractional crystallisation of both components. In addition, some hydrothermal alteration is indicated by the blue arrows. This model does of course leave unanswered the question of how the basic magma plume arose so far from the main centres of the BTVP and the rest of the North Atlantic Igneous province, so this remains a question for the future.



1. Lundy Island.

- *A. Lundy from Hartland Quay, North Devon, showing the steep cliffs and plateau.*
- *B. Map of the island form the Landmark Trust.*
- *C. Map of the British Tertiary Volcanic Province (Wikipedia, by Hazel Muzzy). Red: central complex. Orange: lava fields. Yellow: submarine complexes. Lilac: dykes swarms.*
- *D. Our sister ship on the way to the island.*
- *E. The landing area and jetty.*



2. ***The Granite.***

A,B. *Granite tors and pinnacles.*

C. *A sample of Lundy granite.*

D. *An aplite vein, of similar composition but with tiny crystals indicative of rapid cooling.*

E,F. *Thin sections of sample in C, viewed through crossed polars. White-yellow: quartz, grey: alkali feldspar, stripy: plagioclase feldspar, bright colours: muscovite.*

G. *Thin section of the aplite vein shown in D (crossed polars). There is a sharp junction between the two crystal sizes.*

H. *Radioactive halos in biotite.*

3. ***The dykes.***

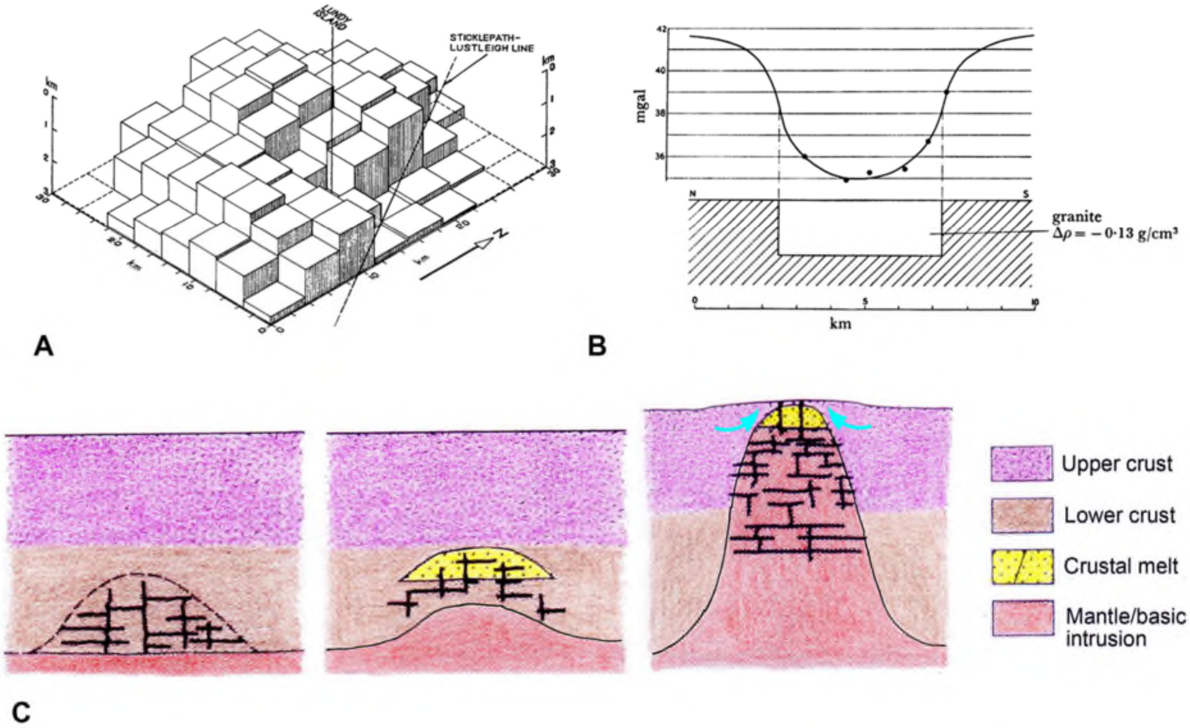
A. Dolerite dyke near Battery Point on the W. side of the island (between red arrows).

B. Rhyolite dyke near the landing stage (red arrows).

C. Devonian slate in the vicinity.

D. Thin section through the slate showing foliation.

E,F. Thin section of junction of slate and rhyolite. E is plane polarised light and F is crossed polars.



4. *Possible structure of the complex.*
   - A. *Model of the basic magma chamber based on gravity measurements (Brooks and Thompson, 1973).*
   - B. *The negative gravity anomaly over the island (Bott et al., 1958).*
   - C. *A possible model of events leading to formation of the complex (Thorpe et al., 1990).*

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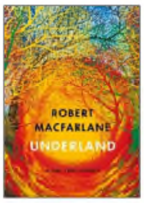
A geologist's world of literature

by David Rowley

From coffee table books & popular science to walking guides & novels with an earthy slant, there is much to entertain and educate on the geological bookshelves. This is a (by no means exhaustive) collection of some enjoyable reading suggested over the years to my students.

Popular science

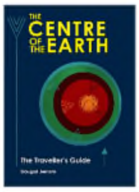


Underland (Robert MacFarlane)

A dazzling journey into the concealed geography & geology of the ground beneath our feet: the hidden regions beneath the visible surfaces of the world. From the vast below-ground networks by which trees communicate, to the ice-blue depths of glacial moulins, and from North Yorkshire to the Lofoten Islands, he traces an uncharted, deep-time voyage.

The Tectonic Plates are moving (Roy Livermore)

The book traces the development of plate tectonics from its beginning to its crucial role in understanding Earth as a system. A detailed account for a cover to cover read, with plenty of interest!



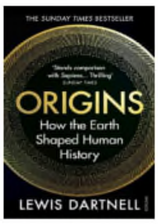
The Centre of the Earth (Dougal Jerram)

This guidebook tells of a trip to the planet's core, with the proposed journey to be made using an ingenious 'Beagle-Pod drilling vehicle'. Starting with your choice of entry into the Earth you'll travel through geological wonders to reach the twin layers of the earth's core and finally the very centre of the Earth.

Adventures in the Anthropocene (Gaia Vince)

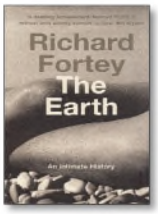
The age of humans; what impact are humans having on the atmosphere, rivers, farmland etc?

Each is succinctly explained and then developed in depth through the author's travels.



Origins (Lewis Dartnell)

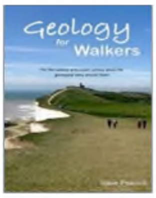
The brilliantly told story of how the evolution of humans is shaped by tectonics, climate, the oceans and landscape. Human evolution in East Africa was driven by geological forces. Ancient Greece developed democracy because of its mountainous terrain. Voting behaviour in the United States today follows the bed of an ancient sea.



The Earth (Richard Fortey)

An account of around the World journey visiting major sites of geological interest. Entertaining and very readable. Could be expensive as it makes you want to travel around the World!

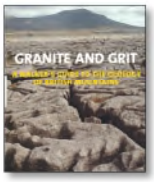
One of several excellent books by the author, including 'The Hidden Landscape', 'Life an Unauthorised Biuography' and 'Dry Storeroom No.1'.



Geology for Walkers (Steve Peacock) *

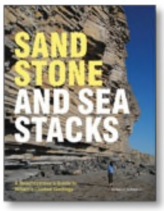
Written by a geologist and walker, this book is for the outdoor enthusiast curious to learn more about, and develop a deeper appreciation for, the story behind the geology around them. Constructed as a 'companion for the scientifically curious' - rather than as a textbook - Geology for Walkers is written in clear language and is packed with bold, colourful illustrations to convey the geological concepts at work.

Coffee Table books



Granite & Grit (Ronald Turnbull)

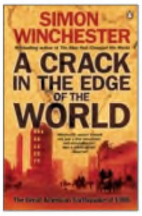
This beautifully illustrated book takes you to the mountain ranges of the British Isles and explains their character and the scenery through a geologist's eyes.



Sandstone & Sea Stacks (Ronald Turnbull)

This beautifully illustrated book takes you to the most beautiful coastal landscapes of the British Isles and explains their character and scenery in this excellent 'coffee table' book.

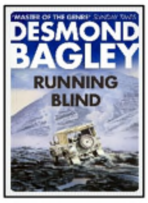
Fiction & fictionalised documentary



A Crack in the edge of the World (Simon Winchester)

Simon Winchester brings his inimitable storytelling abilities—as well as his unique understanding of geology—to this extraordinary event, exploring not only what happened in northern California in 1906 but what we have learned since about the geological underpinnings that caused the earthquake in the first place.

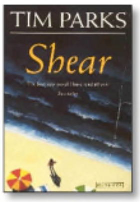
Winchester is also the author of 'The Map that Changed the World' and 'Krakatoa'.



Running Blind (Desmond Bagley)

A rip-roaring (1970's era) spy thriller set in Iceland. The main character is drawn back into the world of espionage. He has a package to deliver on a journey that happens to take him to key places of geological interest.

*Steve Peacock is a member of the Bath Geological Society



Shear (Tim Parks)

A thriller in which an English Geologist working on a Mediterranean island becomes embroiled in a web of deceit, corruption, and tragedy. Some rather cheesy geology puns & not highbrow literature!

Burial Rites (Hannah Kent)

Set in Iceland, the book is based on the true story of Agnes Magnusdottir who was tried for murder in the 19th Century. She lived in Northern Iceland, the novel (is not geological at all!) gives a fascinating account of her life and those she meets and the harsh landscape of the north.

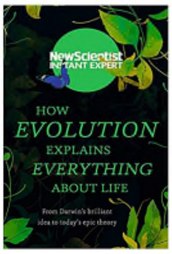
New Scientist Instant Expert

This is Planet Earth (New Scientist)

Explaining how the Earth works and the wonders of the planet. Its long dramatic past and a future shrouded in mystery.

In sections that can be read 'stand-alone'.

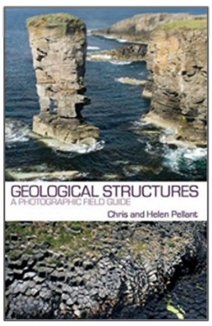
New Scientist Instant Expert books are definitive and accessible entry points to the most important subjects in science; subjects that challenge, attract debate, invite controversy and engage the most enquiring minds.



How Evolution explains everything about Life (New Scientist)

Is life inevitable or a one-off, does evolution have a purpose? Discover how evolution is still an evolving theory.

Photographic field guide



Geological Structures: A photographic Field Guide (Chris & Helen Pellant)

Photos and descriptions of a wide range of geological structures from around the world.

Faults, folds, unconformities as well as Igneous, Metamorphic and Sedimentary features.

EARTH SCIENCE PODCASTS AND BBC RADIO PROGRAMMES by David Rowley		
A Geochemical History of Life on Earth (23 mins)	In the beginning	https://www.bbc.co.uk/sounds/play/w3ct2kyl
	When bacteria ruled the world	https://www.bbc.co.uk/sounds/play/w3ct2kym
	A series of unfortunate events	https://www.bbc.co.uk/sounds/play/w3ct2kyn
	The great chemistry experiment	https://www.bbc.co.uk/sounds/play/w3ct2kyp
	The Anthropocene	https://www.bbc.co.uk/sounds/play/w3ct2x97
The Curious Cases of Rutherford and Fry (30mins)	Jurassic squawk: What sound did dinosaurs make?	https://www.bbc.co.uk/programmes/m0004sdq
	Tiniest dinosaur: Which dinosaur is the smallest and what size can reveal about the life of extinct animals.	https://www.bbc.co.uk/programmes/b09snwmm
Extinct! (30mins)	why almost all of life became extinct 250 million years ago	https://www.bbc.co.uk/sounds/play/b01hjs0s
	Are humans causing the sixth great mass extinction event in Earth's history?	https://www.bbc.co.uk/sounds/play/b01hwcwd
	Adam Rutherford looks at the extinction of humans in the distant past.	https://www.bbc.co.uk/sounds/play/b01j5j2b
Infinite Monkey Cage (30mins)	Are humans still evolving?	https://www.bbc.co.uk/sounds/play/m00026xq
	Dinosaurs	https://www.bbc.co.uk/sounds/play/m0008hkl
	Coral reefs	https://www.bbc.co.uk/sounds/play/m000dpl2
	Science Rocks!	https://www.bbc.co.uk/programmes/b03jz22k
	Volcanoes	https://www.bbc.co.uk/sounds/play/b09r47j1
	Evolution of modern humans	https://www.bbc.co.uk/sounds/play/b08dnkgy
	Climate Change	https://www.bbc.co.uk/sounds/play/b07142ls
	Forensic Science	https://www.bbc.co.uk/sounds/play/b064yglg
	The Origins of life	https://www.bbc.co.uk/sounds/play/b017vsj9
Earthworks (30mins)	When life on land began	https://www.bbc.co.uk/sounds/play/favourites/p033jthv
	Mountains	https://www.bbc.co.uk/programmes/p033jtgn
	Volcanoes	https://www.bbc.co.uk/programmes/p033jtcc
	Earth formation	https://www.bbc.co.uk/programmes/p033jtbz
	When the Earth moves (earthquakes)	https://www.bbc.co.uk/programmes/p033jtk2
	How Life Began	http://www.bbc.co.uk/programmes/p033jtht
	Earthworks homepage	https://www.bbc.co.uk/programmes/p0335nhd/episodes/guide
David Attenborough: Life Stories (10mins)	Quetzalcoatlus: the largest flying animal ever	https://www.bbc.co.uk/sounds/play/b011ckxz
	Charnia	https://www.bbc.co.uk/sounds/play/b00yz55m
	Amber	https://www.bbc.co.uk/sounds/play/b00mydlm
	Fossil tracks	https://www.bbc.co.uk/sounds/play/b00mj16h
	Coelacanth	https://www.bbc.co.uk/sounds/play/b00m74rt
	Faking Fossils	https://www.bbc.co.uk/sounds/play/b00m45d2
	Archaeopteryx	https://www.bbc.co.uk/sounds/play/b00lq99f

In Our Time (55mins)	Doggerland	https://www.bbc.co.uk/sounds/play/m0006707
	Cephalopods	https://www.bbc.co.uk/sounds/play/b09pjgrn
	Feathered dinosaurs	https://www.bbc.co.uk/sounds/play/b099v33p
	PETM	https://www.bbc.co.uk/sounds/play/b08hpmmf
	Extremophiles	https://www.bbc.co.uk/sounds/play/b05zl3v2
	Earth's Core	https://www.bbc.co.uk/sounds/play/b05s3gyv
	Catastrophism	https://www.bbc.co.uk/sounds/play/b03s9tlz
	Ice Ages	https://www.bbc.co.uk/sounds/play/b01qjj99
	Early Geology	http://www.bbc.co.uk/programmes/b01dgh7d
	The Geological Formation of Britain	http://www.bbc.co.uk/programmes/b00n8t48
Science in Action (30mins)	Anak Krakatau	https://www.bbc.co.uk/sounds/play/w3csym2v
	White Island	https://www.bbc.co.uk/sounds/play/w3csym2t
	Detecting earthquakes	https://www.bbc.co.uk/sounds/play/w3cswmqr
	Tailings Dam collapse	https://www.bbc.co.uk/sounds/play/w3cswmqp
	Our geological junk	https://www.bbc.co.uk/sounds/play/w3cswmq9
	Dickinsonia - earliest animal	https://www.bbc.co.uk/sounds/play/w3cswmpy
	Guatemala volcano prediction	https://www.bbc.co.uk/sounds/play/w3cswmpj
	Taal Volcano	https://www.bbc.co.uk/programmes/w3csym2z
	Exciting Geology of Chicxulub Crater	http://www.bbc.co.uk/programmes/p04fshwg

Sculptures in Bath Stone (Middle Jurassic oolite): the MicroArt of Bath Riverside

Maurice Tucker
School of Earth Sciences, University of Bristol, Bristol, BS8 1RJ
maurice.tucker@bristol.ac.uk

The 21st century housing development of Bath Riverside, B&NES, SW England, with its two 'landmark' buildings within the World Heritage City of Bath, capturing the distinctive character of its famous Georgian buildings, is further noteworthy for the large number of pieces of public art distributed across the site. The whole development is constructed from Bath stone (recognised as a *Global Heritage Stone Resource*), as to be expected to be consistent with the majority of the buildings in this historic city. This article draws attention to the 20 quite small pieces of micro-art carved in Bath stone, a Jurassic oolite, and positioned within the walls around the site.

Bath stone is a well-known material for sculpture as well as being a classic building stone used in the UK and abroad. Nearly 2000 years ago, the Romans created many fine carvings for their baths complex and for the Temple to Sulis-Minerva which are on display in the Roman Baths Museum (Tucker et al. 2020). Bath Abbey is another fine example of a building where Bath stone has been used, its impressive fan ceiling in the Nave for example, and the remarkable figures sculpted on the western front of the Abbey in Jacob's Ladder to Heaven. The angels there, along with saints and symbols, were carved around 1500 after the Bishop of Bath (Oliver King) had a dream that he should rebuild the Abbey which was in a state of disrepair. Over the centuries, many of the angels have become badly weathered so that some were replaced in 1900. Wind, rain, frost and pollution can be a problem for Bath stone in exposed positions, in part since it has a quite high porosity (> 20%), a little higher than its rival Portland stone.

Bath stone is a Middle Jurassic limestone within the Chalfield Oolite Formation of the Great Oolite Group. It was deposited on the shallow seafloor of an extensive epeiric sea covering much of NW Europe some 166 million years ago. Similar oolitic sediments are being deposited today in the Bahamas and along the Trucial Coast of Abu Dhabi. Ooids are sub-mm sand grains of $CaCO_3$ precipitated from seawater, likely with the involvement of microbes. After deposition, the oolitic sediment was cemented and buried to a depth of around 500-800 metres by the end of the Cretaceous (65 Ma) and then uplifted towards its present outcrop around Bath from several 10s of million years ago (Tucker 2022). Bath stone was extracted from numerous open-cast and underground quarries from Bath to Bradford on Avon to Box-Corsham in NE Somerset and Wiltshire, especially during the 18th and 19th centuries (Pollard 2021). There are now just two underground quarries operating and one open site, in Combe Down.

John Wood the Elder, architect, and Ralph Allen, postmaster and then owner of the stone quarries in the Combe Down area, together really promoted the use of

Bath stone in the early-mid 1700s with their vision of a classical Bath in Palladian style (Mowl 1988), with the hot springs and associated entertainment as an attraction for the upper classes (as in Bridgerton!). The intricate carving of Bath stone in the pediments of the houses for the first of Wood's building projects, in Queen Square (1728-1735), and then in the Corinthian capitals of the columns and pilasters (there are 648) of the 33 houses comprising the Circus (1754-1769) is eye-catching but especially remarkable are the 525 *metopes*, between the triglyphs, forming the frieze above the Doric columns of the ground floor, above the doors and running around the three terraces of the Circus. These images, carved in moderate to high relief, include musical instruments, tools of the many trades of the time (e.g., stone masonry, Fig. 1), trees and flowers, birds, a dinosaur (?!), measuring devices, windmill, the sun and many others including some which are symbols of freemasonry, one of John Wood's interests. In addition, at the Circus there are 108 large acorns adorning the parapets all around the Circus. The stone masons were clearly kept extremely busy! The acorns could be a reference to Prince, later King, Bladud, the legendary founder of Bath, who arrived here with his herd of pigs in 863 BCE, all suffering from leprosy. They stumbled into the muddy waters of Bath's hot springs and miraculously were all cured. Acorns are a favourite food of pigs. John Wood was also fascinated by the Druids, who lived in the area; they ate acorns (believing they had prophetic qualities) and they kept pigs. Stonehenge and the stone circle at Stanton Drew were inspirations for Wood in designing the Circus; in fact, they are all of a similar diameter, 318 feet! The Colosseum in Rome was also an influence.

Figure 1. A saw for cutting Bath stone. One of the 525 metopes, each separated by a triglyph, in the frieze above the Doric columns at the Circus, Bath, carved in 1765. Width approx. 30 cm.

Are the metopes of the Circus the inspiration for the sculpted stones of the modern housing development at Bath Riverside one may ask? This area is located by the River Avon, downstream from Bath City centre, and was the site of the Stothert & Pitt engineering works, where cranes were made (Fig. 2), the Bath and District Gas works, other factories and railway goods-yards. The disused land was developed by Crest Nicholson Regeneration from about 2005 until 2018. The art consultant for this Crest-B&NES project was Peter Dickinson.

Figure 2. Bath Riverside entrance from the Lower Bristol Road, with a restored rail-mounted, self-propelled steam crane built here in 1904 at the Stothert & Pitt engineering works.

Across the Riverside estate there are 20 pieces of art carved in Bath stone, set within the walls around the site and within the walls of the apartment blocks (see the map for their locations, Fig. 3). They vary in size from 10 to 40 cm across, easy to miss or overlook. The Bath stone here on the Riverside was sourced from the Stoke Hill underground quarry at Limpley Stoke. These pieces of art were carved by students from the Construction Skills Centre, Bath College, and include Tanya Josham and Nigel Bryant (Knight 2021). A course in stonemasonry is available there if anyone is interested! In addition to the carved stone items, the modern metopes as it were, illustrated in this article, there is one other very large piece of art in Bath stone within Elizabeth Park fashioned in the form of 3 chain links creating a bench (Location 10 on the map, Fig. 3). The inspiration behind the bench for local sculptor Sam Flintham (2013) was the industrial heritage of the area, with the strength and integrity of a chain dependent on each and every link, mirroring the connection between the past and the present, the heritage of Bath City and Riverside.

Figure 3. A map of Bath Riverside showing the location of the sculptures in Bath stone. Enlarged version of this map at end of the Journal.

Along with the carved stones, there are also 13 mostly quite small (<10 cm across) pieces of metal art embedded in walls of the Riverside. These include a rosette, a conker, a snake, a Roman centurion's helmet, a train with coaches, Bladud's dreaming wings (of which more later), buttons and keys. Also in metal on Bath Riverside, but on a bigger scale (asterisks on the map, Fig. 3) are two dining chairs in the style of the 1780s, reminding us that William and Caroline Herschel (astronomers who discovered Uranus) lived close by and a two-seater Victorian chair celebrating the life and work of the Rev. Leonard Jenyns (naturalist and friend of Charles Darwin), both sculptures by Patrick Haines, 2014 and 2018, respectively. A pair of large cast-iron architectural decorative scrolls from the bridgeheads of the original Destructor Bridge are displayed in Elizabeth Park. These, and the most recent metal sculpture, the *Maid of the Bridge*, made of cast-iron plates from the original Victoria Bridge by another local artist, Anna Gillespie (2018), celebrate and remind us of the industrial heritage of this area of Bath and the importance of the River Avon in Bath's history.

The wide range of the pieces of art displayed at Bath Riverside reflects the long tradition of using Bath stone for sculpture, as well as for building, and also demonstrates the use of metal and iron in producing bridges and cranes, but also intriguing pieces of micro -art in metal. From starting nearly 2000 years ago with the Romans, the sculptures illustrated here from locations 1 through 21 at the Riverside demonstrate the skill and imagination of today's sculptors, as well as challenging the observer! All this public art enhances the environment and our outdoor space, good for our well-being, and is in keeping with the ethos of Bath City itself and the World Heritage Site as a whole.

Location 1: A happy sun, that's nice; it cheers one up ….

Location 2: Part of an ammonite – but which one? It looks realistic, as if the sculptor was copying a real one from the Jurassic. Ammonites are very rare in the Bath oolite but there is a large nautilus (20 cm diameter) in a stone of the south side wall of the Theatre Royal (4 metres up) in Saw Close, Bath.

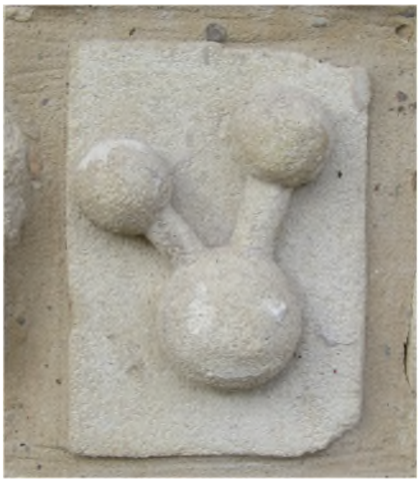
Location 3: You cannot turn your nose up at this one. Unusual subject – I like it.

Location 4: Now this one is a puzzle – any ideas? Could it be part of a wing? I am thinking of Bladud's dreaming wings? There is a small (10 cm) metal sculpture of this close-by on the eastern side of the south abutment of Victoria Bridge. The story is that King Bladud, the founder of Bath (863 BCE), made himself a pair of wings with which he attempted to fly. Another possibility is that it refers to the carving of a gorgon, to the left of Medusa's head, on the pediment of the Temple of Sulis-Minerva in the Roman Baths. But to me, it looks like part of a trilobite (e.g., Calymene, Silurian) with the lower right part of the sculpture being the centre of the thorax (rachis), the upper left part being the pleurae, and the area top right with the cephalon and left eye (with the pimples).

Location 5: A stonemason's mallet; used with chisels, originally made of wood but these days of plastic or nylon

Location 6: Handout. This is for you. Crystal in hand. But what type of crystal? It looks cubic, so could it be salt - halite? Salt may originally have been made close-by at Saltford in Roman-Saxon times; before any weirs were constructed on the River Avon the water was salty there. Alternatively, could it be a sugar cube? Sugar is a mineraloid so does not form a real crystal, but cubes of sugar are readily available of course. Is it an offering (salt or sugar) or a reference to the slave trade?

Location 7: A hot-air balloon – plenty of these taking off from Royal Victoria Park on a quiet summer's evening. But it also looks like a hand-grenade! And the right size too.



Location 8: This is a clever one … is it water, H_2O?

Location 9: The tree of life, but there are no roots?! It is supposed to connect Heaven and Earth and commonly symbolizes a connection to the afterlife, ancestral roots and divinity. In Chinese mythology the tree of life produces a peach every three thousand years, giving immortality to the person who eats it. The Tree of Life is ultimately about the forces of nature combining to create balance and harmony, a timeless symbol of our connections to everything around us.

Location 10: The Chain Link Bench. The black metal wall behind is to reduce light pollution from the Park to the River Avon, which is over the wall, to prevent disturbance to the bats that have a flight corridor here.

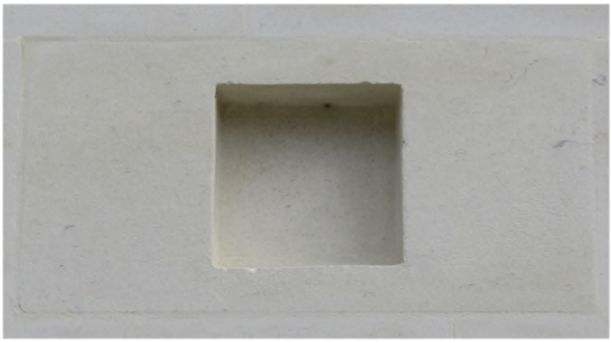
Location 11: Victoria Bridge: built in 1836 by Motley & Dredge, pioneering a double cantilever method of bridge design, initially for James Dredge to transport barrels of beer from his brewery nearby, over the river, to save using a ferry or having to detour via the city.

Location 12: My favourite – a Roman chariot. There has been much speculation as to whether there was an amphitheatre in Bath. There is one on the reconstruction of Aquae Sulis in the Roman Baths Museum. Bath was a recreation and pleasure centre for the Romans so there must have been some entertainment laid on.

Location 13: Fingers crossed. The symbolism here dates to a pre-Christianity belief in Western Europe in the powerful symbolism of a cross. The intersection was thought to mark a concentration of good spirits and served to anchor a wish until it could come true.

Location 14: A quite plain-looking bridge with 3 arches over a river. The only stone bridge across the River Avon in Bath with 3 arches is Pulteney Bridge (built 1774, designed by Robert Adam), but that has buildings above. The Churchill Bridge (built 1965), near the bus station, is single span, and the bridges there before, St Lawrence's Bridge (from 1220) and then the Old Bridge (from 1754), both had 5 arches. New Bridge in Twerton, built by Ralph Allen in 1727 to facilitate transport of Bath stone to Bristol by river, originally had 3 arches, but this was changed to single span later that century, as it is now.

Location 15: This looks like a salmon, from its concave tail, but it could be a roach or a bream, which are the most common fish in the River Avon at Bath.



Location 16: Watch this space, or is it Empty space? Is this Bath Riverside's equivalent of Trafalgar Square's fourth plinth?

Location 17: Any ideas? Could it be another bridge (there are hints of the old Destructor Bridge, which was close by), or is it just a random pattern?

Location 18: There is an old Irish saying: "Any man can lose his hat in a fairy-wind." A fairy wind is a sudden gust of wind or a whirlwind that was thought to have been caused by the fairies

Location 19: A train ticket for a journey from Green Park Station to Bitton (6 miles), a bargain at 2/- (that is 2 shillings to the younger generation, now 10 'new' pence). Green Park station with its vaulted glass roof in a single-span, wrought-iron arch structure was constructed in 1870. It was the start of the Midland Line from Bath to the north of England as well as the Somerset & Dorset line to Bournemouth. The station closed in 1966.

Location 20: Train emerging from a tunnel. The engine looks like a Somerset & Dorset Railway 2-8-0 7F class built in 1914 in Derby. The tunnel appears to be the western portal of the Box Tunnel on the GWR London to Bristol railway, completed in 1841 by Brunel. It was then the longest tunnel in the world at 2.8 km. During the tunnel's excavation a section through good quality Great Oolite resulted in Bath stone being extracted in extensive underground quarries for the next 100+ years.

Location 21: A steam-powered Fairbairn Crane built by Stothert & Pitt from the 1870s. The crane's innovation was in the use of a curved jib, made of riveted wrought-iron platework to form a square-section box girder. The curved jib could reach farther into the hold of a ship, clear of the deep gunwales alongside the quay.

Acknowledgements
I am grateful to several chums for comments on various sculptures.

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Rare Fossils found by BGS members

By Graham Hickman

During September 2023, Simon Carpenter led an excellent field meeting to examine the Lower Cornbrash (Middle Jurassic) near Woolverton in Somerset. Bath Geological Society Members Dr. Sam Medworth and Graham Hickman attended along with members of the Bristol Naturalists' Society Geology Section.

The site consists of a recently excavated lake which exposes the Lower Cornbrash and the very top of the Forest Marble Formation. The excavated rocks have been left as a series of spoil heaps which are rich in Lower Cornbrash fossils. The Cornbrash Formation in north Somerset and Wiltshire is only a few meters thick and varies rapidly over short distances. An Upper and Lower division to the Cornbrash Formation has been recognised with the non-sequence between them approximating to the Bathonian–Callovian stage boundary; this represents a minor marine regression. The absence of diagnostic Upper Cornbrash fossils at the Woolverton site suggests that only the Lower Cornbrash is present. At other sites the Lower Cornbrash has a bored top and an overlying pebble bed, suggesting that a significant break in deposition occurred at this time.

The most abundant fossils at this site were invertebrates; bivalves, brachiopods, serpulids and echinoids. Many are incomplete or damaged by predation which indicates periodic reworking and erosion of sediments. However, the occurrence of rare ammonite, fish and shark fossils indicates that water depths were sufficient at times to support these pelagic predators.

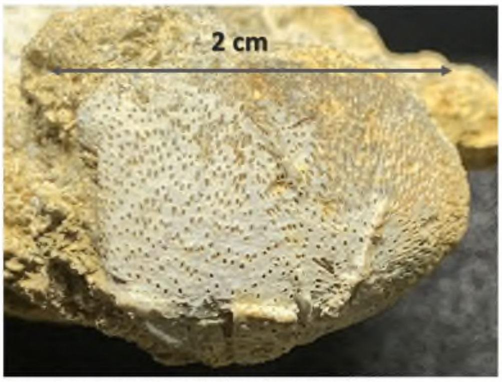
Within the Bathonian strata of the Bath area, ammonites are generally sparse due to the turbulent, shallow water conditions which reworked the sediments. As such when a nearly complete ammonite was found by Graham Hickman, Simon was delighted to arrange for it to be identified, cleaned, and donated to Bristol City Museum. Ammonites are of particular interest as they are used by Stratigraphers as ‘index fossils’ to correlate marine strata across large distances using an ammonite-based chrono-stratigraphical framework.

Alan Bentley identified the ammonite as Delecticeras delictum, a Clydoniceras microconch, mature. The rare ammonite in question is shown in figure 1. The small black and white image (Pl IV) is an illustration of this same ammonite species from the memoir (Arkell, 1951). Alan commented on its rarity saying ‘It can now join the other half dozen complete specimens known in the UK!’

Delecticeras delectum (a Clydoniceras microconch , mature)

Figure 1. Photo curtesy of Bristol City Museum, Copyright Bristol Culture

A similarly unique fossil was found and donated by Dr. Sam Medworth. Sam found a Bryozoan encrusting a bivalve. Identified by Dr. Paul D Taylor of the NHM he describes the specimen as ‘a bryozoan encruster of the form-genus ‘Berenicea’ which encompasses half a dozen or so genera, differing in the morphology of the gonozooids used for larval brooding. Unfortunately, like so many such colonies, the Cornbrash specimen lacks gonozooids and cannot be assigned to a genus. That said, the somewhat irregular arrangement of the apertures leads one to think that it is more likely to be a species of Reptomultisparsa than any other genus.’



Bryozoan: genus – Berenicea, probable species - reptomultisparsa

Figure 2. Photo curtesy of Bristol City Museum, Copyright Bristol Culture

Bryozoa are sometimes described as ‘moss animals’ - they are aquatic colonial invertebrates adapted to filter feeding. Most of the bryozoa in the Cornbrash are of the encrusting type and can be found cemented to many of the bivalves and brachiopods.

Simon has done a systematic analysis (type/abundance) of the fossils found at this site and will be publishing his findings into the biostratigraphy and palaeoecology of the Lower Cornbrash.

Acknowledgement:

Many thanks to Simon Carpenter for leading this field trip and enabling the identification and donation of these specimens to Bristol Museum. Photos curtesy of Bristol City Museum, **Copyright Bristol Culture**

References:

Arkell, W.J., 1951. A Monograph of English Bathonian Ammonites

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Dr Sam Medworth has also provided some photographs from this trip. A selection of these are below.

Photo 1: Avicula echinata

Photo 2: Clydoniceras discus

Photo 3: Epithyrus

Photo 4: infilled burrow *Photo 5: Nucleoites*

Photo 6: Pleuromya

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The Cliff at Blue Anchor Point: Anatomy of A Buttress Anticline

By David M. Hall

Introduction:

The faulted contact between the Late Triassic brick-red (foot wall) and grey (hanging wall) sediments at Blue Anchor Point is a well known local landmark on the West Somerset Coast. What is less appreciated is that the cliff outcrop provides an opportunity to observe some of the key processes involved in rifting, basin inversion and generation of fluid overpressure. The hanging wall, which is characterised by a gentle anticline containing a complex array of gypsum veins, is of particular interest. This structure has been interpreted as a "buttress anticline" formed by compressional forces that were superimposed on the rift faults during basin inversion. During basin inversion, the migration of gypsum-rich fluids also played a significant role in the fracture-forming process.

Blue Anchor is the starting point of a Site of Special Scientific Interest (SSSI) that extends about 18km eastwards to Lilstock which, among its many other geological attributes, is recognised internationally as an excellent location to study the geometries of rock fractures.

This article contains a description of the structures that can be seen in the cliff at Blue Anchor Point and concludes with a short interpretation of the geological processes that are involved. The six main diagrams are shown in full page format (referred to as "plates") with the intention that these can also be used a field guide. Other supporting figures are interbedded with the text.

Description:

Maps (Plate 1): The geological map of the Blue-Anchor Lilstock SSSI (Plate 1a) is segmented by a series of WNW to NW trending faults which, as shown in Fig 1 (below) are part of a system of regional NW-SE strike-slip faults that extend from the English Channel to the northern margin of the Bristol Channel Basin. These basement lineaments have had a long history; during the Carboniferous they compartmentalised the Variscan thrust-fold belt and then, from the Permian to Cenozoic, influenced basin geometry during successive phases of reactivation. The Blue Anchor Fault is part of this system and may be linked to the Watchet – Cothelstone fault which controls the SW boundary of the Quantock Hills.

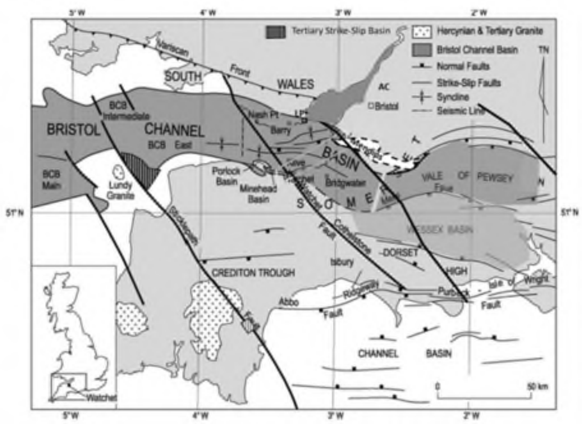


Figure 1: Regional Structure and Location of Bristol Channel basin (after Glen et al 2005 & Dart et al 1995).

The trend of the Blue Anchor Fault across the foreshore at Blue Anchor Point is clearly visible in the aerial LIDAR image shown in Plate 1b. The trend of the hanging wall fold axis can also be tentatively recognised although this needs to be confirmed by closer inspection of the foreshore outcrop. The southern limb of the anticline is cut by the smaller fault F2 which can only be clearly identified with confidence in the cliff section (Plates 2 and 4). Slightly further north on the foreshore (i.e., seawards) a tightly folded and fragmented hanging wall syncline and foot wall anticline can be identified either side of yet another NW trending fault (F3) with cross-cutting shears. Similar complex fault-fold patterns can be be seen along the entire length of the SSSI and are typical of fault systems that have been reactivated by compression and strike-slip movement.

Lastly, the LIDAR image shows that the upper part of the cliff has been eroded by a series of overlapping landslide detachments.

Blue Anchor Point (Plate 2): This photo shows the relationship between the Blue Anchor Fault (F1), fault F2 and the hanging wall anticline.

Plate 1a: Blue Anchor – Lilstock SSSI : Solid Geology

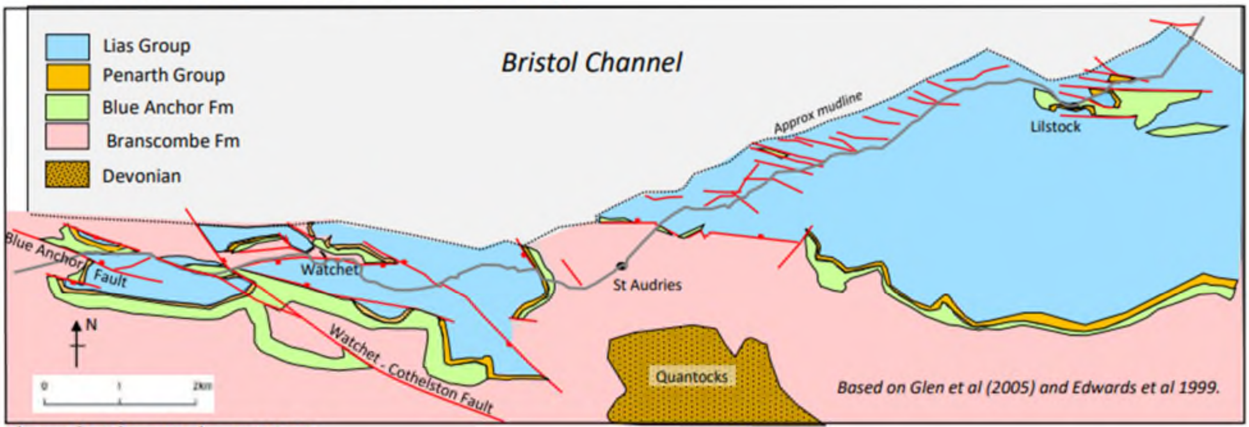


Plate 1b: Blue Anchor : LIDAR

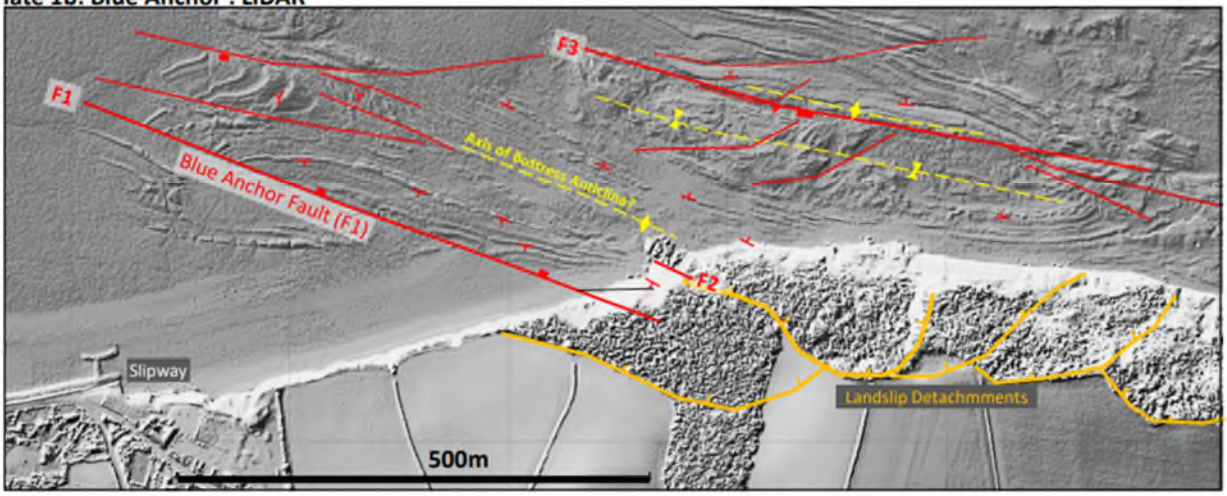


Plate 2: Blue Anchor Point Cliff.

System	Stage	Grp	Fm	Abbr
Jurassic	Hettangian	Lias	Blue Lias	BLi
Trias	Rhaetic	Penarth	Lilstock	LF
			Westbury	WF
	Rhaetic to Norian	Mercia Mudstone	Blue Anchor	BAF
			Branscombe	BF

F1 F2	Fault Displacements: Blue Anchor Fault (F1) > 50m (i.e. must be greater than thickness of BAF to basal BLi), F2 : < 5m (minor intraformational displacement)
	Joint Planes (largely responsible for the stepped erosional profile of the cliff)
D	Landslip Detachment (approximate position.)

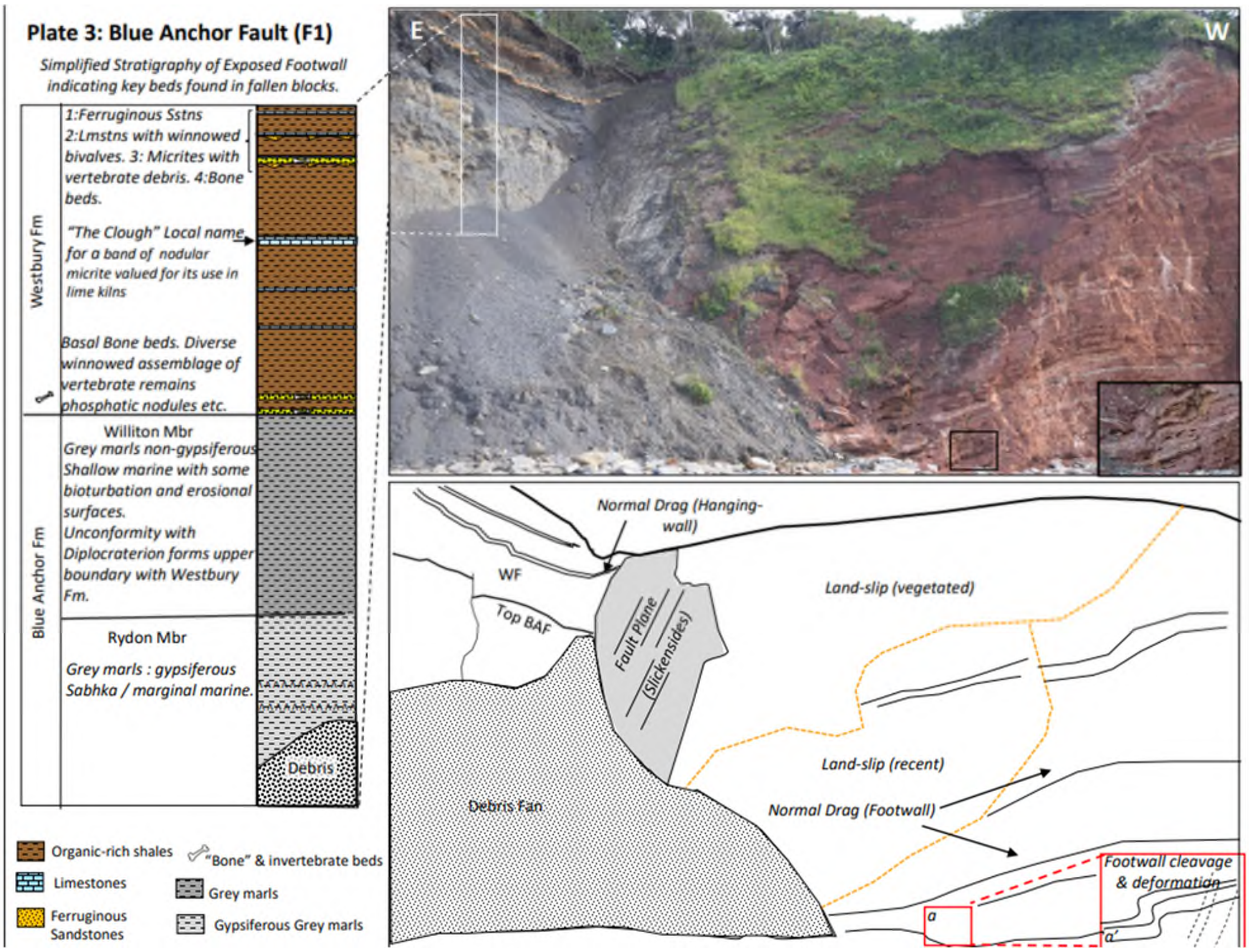


Plate 3: Blue Anchor Fault (F1)
Simplified Stratigraphy of Exposed Footwall indicating key beds found in fallen blocks.
1:Ferruginous Sstns 2:Lmstns with winnowed bivalves. 3: Micrites with vertebrate debris. 4:Bone beds.
"The Clough" Local name for a band of nodular micrite valued for its use in lime kilns
Basal Bone beds. Diverse winnowed assemblage of vertebrate remains phosphatic nodules etc.
Westbury Fm
Williton Mbr
Grey marls non-gypsiferous Shallow marine with some bioturbation and erosional surfaces. Unconformity with Diplocraterion forms upper boundary with Westbury Fm.
Rydon Mbr
Grey marls : gypsiferous Sabhka / marginal marine.
Blue Anchor Fm
Debris
Organic-rich shales
"Bone" & invertebrate beds
Limestones
Grey marls
Ferruginous Sandstones
Gypsiferous Grey marls
E
W
Normal Drag (Hanging-wall)
WF
Top BAF
Fault Plane
(Slickensides)
Land-slip (vegetated)
Land-slip (recent)
Debris Fan
Normal Drag (Footwall)
Footwall cleavage & deformation
a
a'

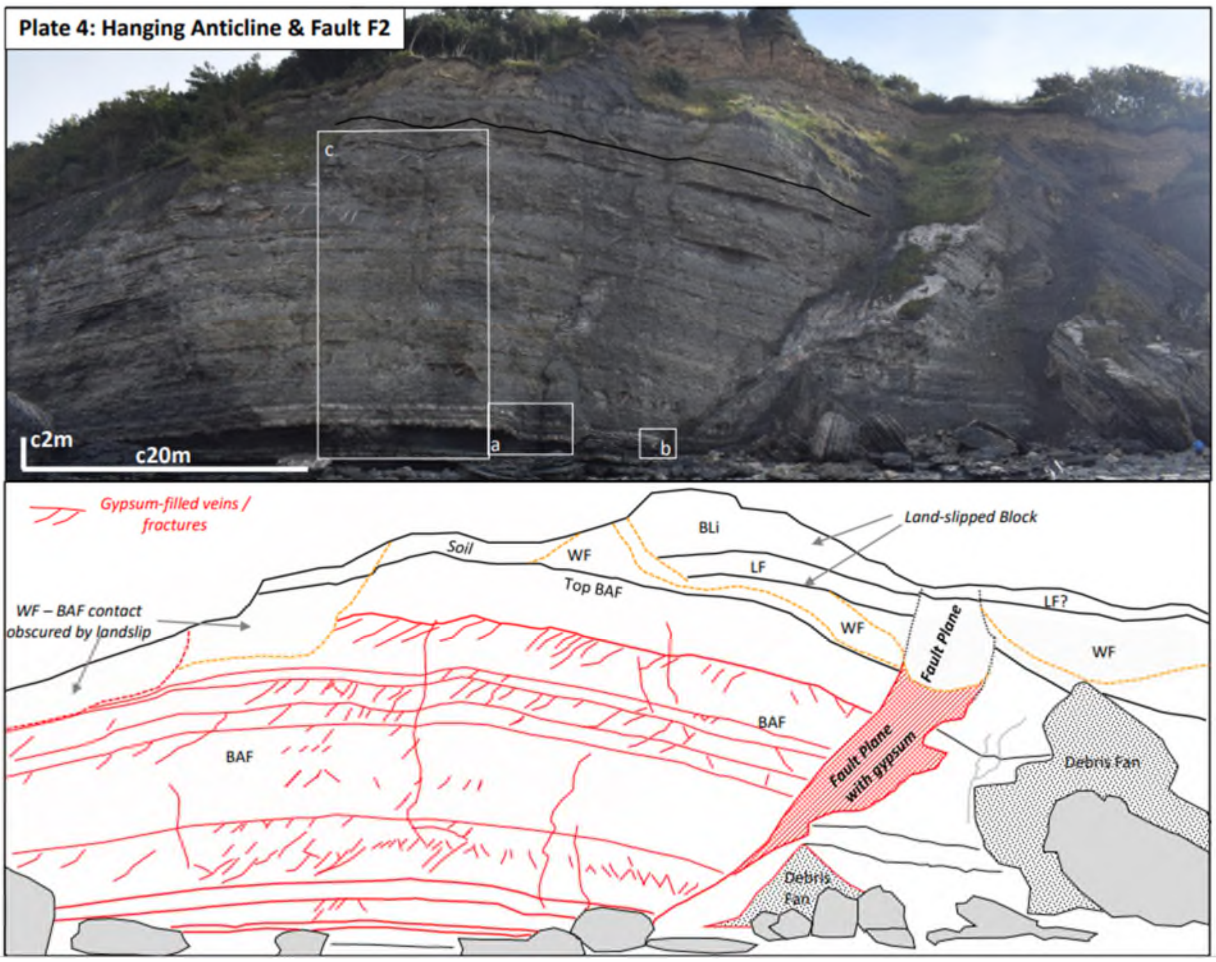


Plate 4: Hanging Anticline & Fault F2
c
a
b
c2m
c20m
Gypsum-filled veins / fractures
Soil
WF
BLi
Land-slipped Block
LF
Top BAF
LF?
WF – BAF contact obscured by landslip
WF
Fault Plane
WF
BAF
BAF
Fault Plane with gypsum
Debris Fan
Debris Fan

Plate 5: Gypsum Mobilisation Fabrics

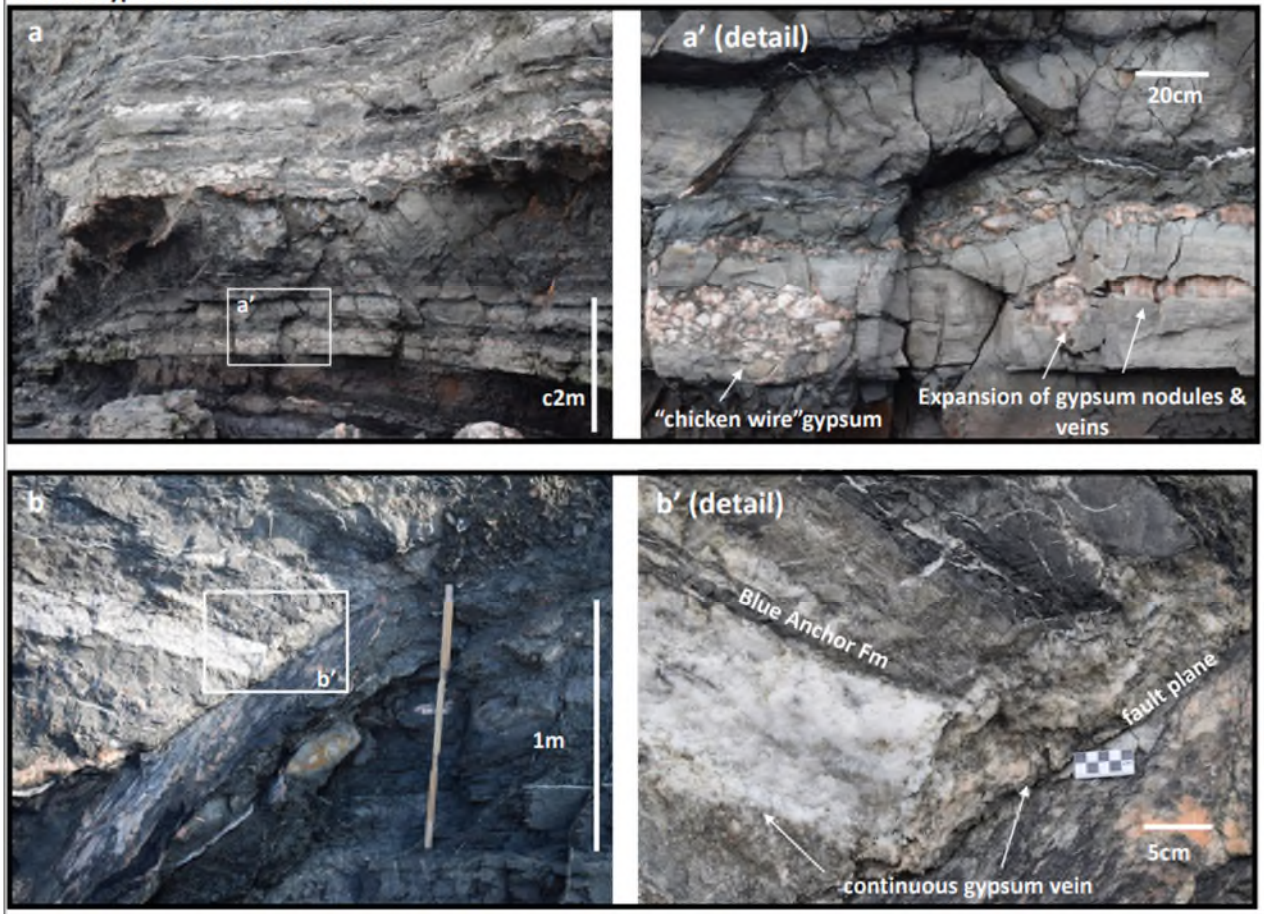
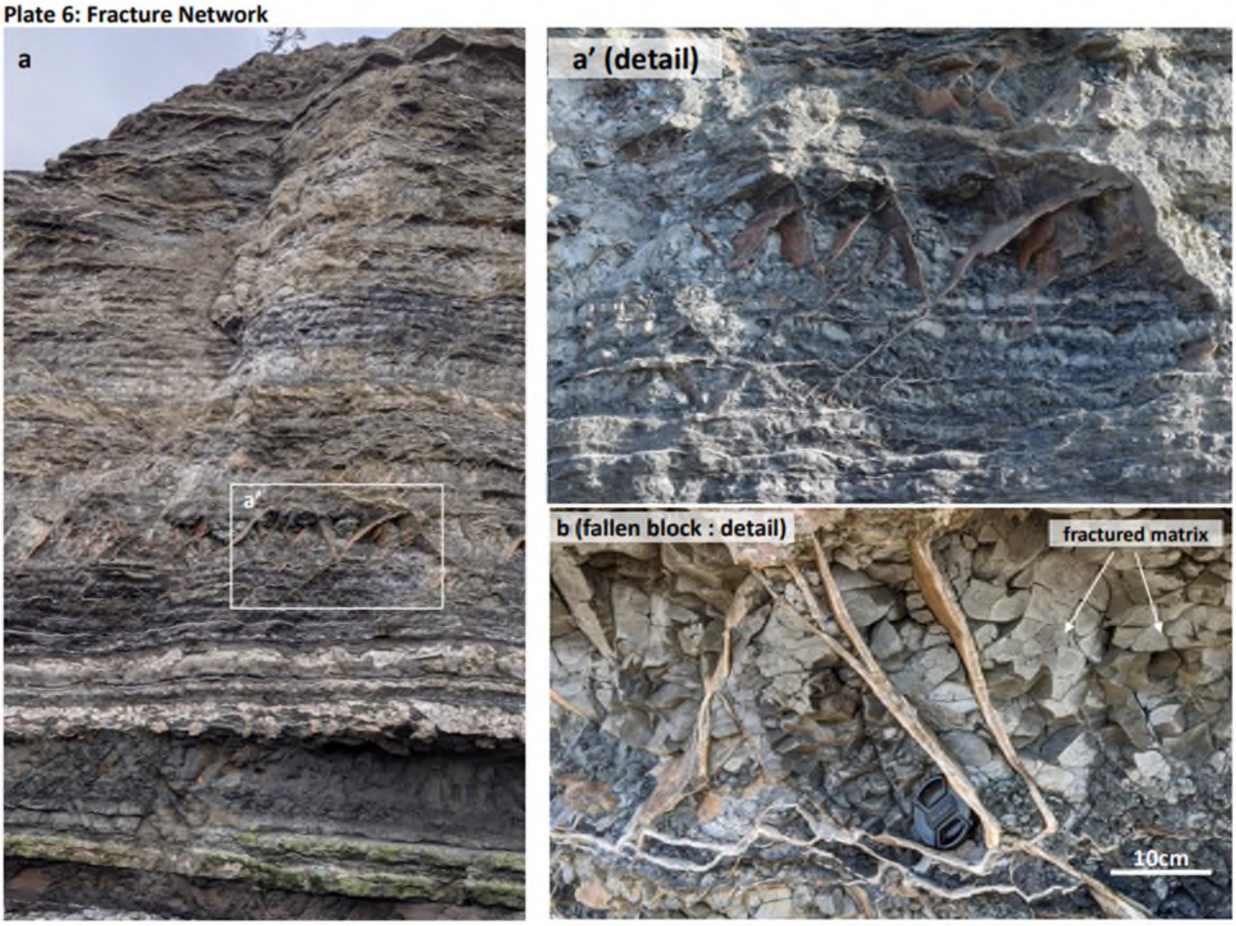


Plate 6: Fracture Network



Blue Anchor Point (Plate 2): This photo shows the relationship between the Blue Anchor Fault (F1), fault F2 and the hanging wall anticline.

The Blue Anchor Fault has a displacement of at least 50m based on the measured thickness of the Blue Anchor to basal Lias section that is juxtaposed against the red siltstones of the Branscombe Formation. Depending on the missing thickness of the red beds (Branscombe Formation) at the top of the cliff the true fault throw may be 100+m. In contrast the throw of fault F2 is poorly controlled as the displacement across the fault is within the Blue Anchor Formation. A rough estimate based on current observation is that the fault does not appear to have a normal displacement of more than 5m although this estimate can no doubt be improved by more detailed study.

The Blue Anchor Formation also contains a number of joint planes (i.e., linear fractures with no observable displacement) that have acted as failure planes for the large rock falls that have spalled off the lower cliff face. Between the Blue Anchor Fault and fault F2 the joints are inclined in the same sense as the bounding faults whereas the joint planes in core of the anticline to the east of fault F2 are approximately vertical and off-set from one another.

As noted in Plate 1 the upper part of cliff face has been eroded by a series of overlapping landslides which sole out within the dark grey and ductile shales of the Westbury Formation. The Lilstock Formation and Blue Lias section at at the top of the cliff may be part of one of these landslips as the section appears to be unconformable with the underlying Westbury Formation. In contrast the Westbury Formation to Lias sequence appears to be conformable in a photo taken in 1911 (Fig 2) suggesting that the landslip has occurred within the last 100 years.

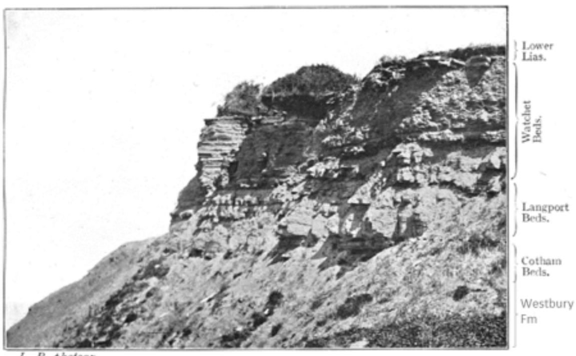


Figure 2: Cliff top at Blue Anchor Point in 1911 displaying a conformable Westbury Fm sequence (Richardson 1911). Compare with the contemporary cliff rofile in Plate 2.

Blue Anchor Fault (Plate 3): The up-turned drag of the parallel beds within the hanging wall of the Blue Anchor Fault is clearly visible which together with the presence of clay smear, slickensides, and down-turned drag (convex up) drag in the foot wall indicates that fault movement was normal (extensional) and also post-depositional. The presence of steeply dipping cleavage and other deformation fabrics in the soft red beds proximal to the fault plane indicates that the foot wall has been compressed. However, there is no evidence the fault itself has been reactivated by strike-slip or reverse movement.

The exposed foot wall stratigraphy comprises the Westbury Formation and upper Blue Anchor Formation, the lower part being mostly hidden by debris from the disintegration of the overlying Westbury Formation shales. The clastic and carbonate lithologies interbedded within the soft shales can be examined in the fallen blocks at the cliff base. Although a detailed description is beyond the scope of this article these beds are generally interpreted as storm ("tempestite") and transgressive lag deposits which interrupted the anoxic low-energy environment during deposition of the shales. The possibility that some of these beds were deposited by tsunamis generated by regional seismicity during the initial break-up of Pangea should also be considered.

Hanging wall Anticline and Fault F2 (Plates 4 to 6): Plates 4 to 6 illustrate the character of Fault F2 and the fracture network within the hanging wall anticline:

The western limb of the hanging wall anticline is cut by fault F2 which displays the following notable differences with the Blue Anchor Fault:

- The dip of the F2 fault plane is about 20 degrees less (i.e., "flatter") than the Blue Anchor Fault.
- The throw of the fault F2 is clearly significantly less than the Blue Anchor Fault. Note also that there does not appear to be any discernible fault displacement at the top of the cliff (Lilstock and Blue Lias Formations) although this may be because the fault plane has been truncated by a horizontal landslide detachment.
- As shown in Plate 1, fault F2 cannot be recognised in the foreshore outcrop with any degree of certainty and therefore appears to be of limited lateral extent.
- Lastly, but certainly by no means least, the F2 fault plane is mineralised with a continuous layer of gypsum whereas the Blue Anchor Fault is unmineralised.

Part of the fault plane gypsum seems to have been sourced from the Blue Anchor Formation near the base of the cliff. In Plate 5 photographs a - a' it can be seen that these beds contain a "chicken wire" fabric of closely packed gypsum nodules, plus larger nodules and veins that have fractured the encasing claystone lithologies. In Plate 5 photographs b-b' gypsum mobilisation has developed further and resulted in a band of solid gypsum over 10cm thick that is continuous with the gypsum layer in fault plane. This feature was exposed after heavy rainfall in 2023 and it may be the first time it has been described as the lower part of the fault plane has previously been covered by a debris fan and is likely to be covered up again after the next landslip.

Fracture Network: A significant part of the fracture network has been veined by finely crystalline "satin spar" gypsum making it visually distinctive. This type of gypsum is a common occurrence in high permeability fractures that have been circulated by CaSo4-rich fluids derived from nearby evaporite beds. Referring again to Plate 4 it can be seen that the gypsum veins in the cliff face nearly all occur to the east of Fault F2 within distinct layers that are more or less concordant with the curvature of the anticline. The top of each interval is defined by prominent bedding surface veins that can be traced into the F2 fault plane. The top-most interval of gypsum veins occurs a few meters below the top of the Blue Anchor Formation. Significant fracturing is absent within the overlying Westbury Formation which is to be expected in a sequence dominated by ductile organic-rich claystones.

Within each layer inclined veins propagate downwards from the thicker bedding plane veins that define the upper surface. The dominant inclination is in the same sense (synthetic") as the Blue Anchor Fault and fault F2. A sub-dominant set of veins inclined in the opposite direction to the Blue Anchor Fault and fault F2 ("antithetic") are best developed in the lower axial part of the anticline where the intersection of the two fracture sets forms "V" and "X" cross-cutting geometries. The inclined fractures commonly sole out downwards into a wispy "micro-veins" that are approximately parallel with bedding.

Close-up examination reveals that fractures within the Blue Anchor Formation are more extensive than indicated by the presence of gypsum veins. This is clearly illustrated by the fallen blocks (Plate 4, Photo C) which show that pervasive, and unmineralised fractures are present in rock matrix between the gypsum veins.

Interpretation

The structural history and related processes based on current observations can be summarised as follows:

Rift Phase: it is likely that the Blue Anchor Fault originated as a Variscan lineament that was reactivated intermittently from the Permian to Late Jurassic during the rifting and subsidence of the Bristol Channel Basin. It is possible that fault F2 was a minor splay of the Blue Anchor Fault although there is no clear evidence of this.

Burial Phase. Based on the thermal maturation of the basal Lias shales, the section at Blue Anchor was buried to depths exceeding 2km during the Jurassic subsidence. As a result, gypsum ($CaSO_4.2H_2O$) in the late Trias evaporite deposits will have been dehydrated to anhydrite ($CaSO_4$). The water released by the transformation will have been added to the formation water already in the matrix of the sediments. These fluids are likely to have been trapped beneath the regional pressure seal formed by the ductile shales of the Westbury Formation. The trapped fluids will have generated overpressure within the late Triassic sediments to increase as burial increased. As noted below the subsequent release of this overpressure during uplift (inversion) had a major impact on the development of the fracture network.

Inversion Phase. Inverted basins are former extensional depocenters that have been subjected to subsequent compression and uplift (exhumation). It is generally accepted that the Bristol Channel Basin has been subjected to two main periods of inversion: i) regional uplift during the Lower Cretaceous which may have been due to underplating and ii) north – south compression related to the Alpine orogeny during the early Tertiary which also caused the reactivation of the regional NW-SE lineaments and localised reactivation of the fault- network within the Bristol Channel Basin.

Due to their localised fault-related nature the structures at Blue Anchor Point are interpreted to have developed during the second (early Tertiary) phase of inversion. Two stages are recognised:

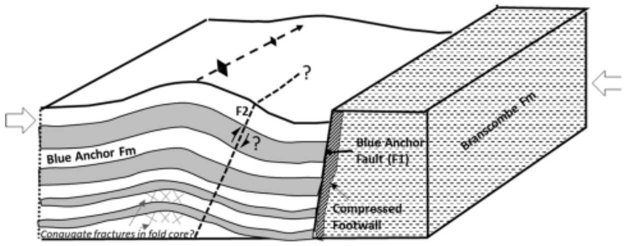


Figure 3. Blue Anchor hanging wall anticline: Stage 1:

Stage 1: Compression orthogonal to the Blue Anchor Fault resulted in a hanging wall fold axis that is parallel with the fault plane. There was no reverse reactivation of the Blue Anchor Fault due to the steep dip of the fault plane and as a result the foot wall acted as a buttress against which the hanging wall anticline developed – hence the term "buttress anticline". This model also explains the compressional deformation seen in the Branscombe red beds near the fault plane. Fault F2 may have either at this stage as a minor thrust on the flank of the fold or as the reactivation of a pre-existing normal fault.

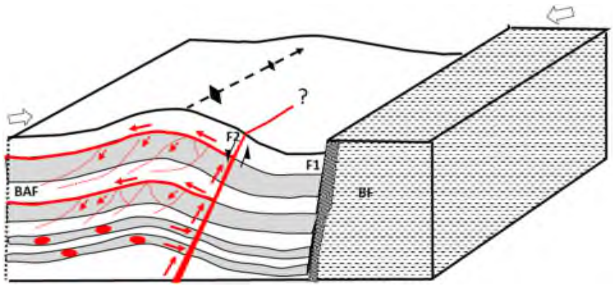


Figure 4: Blue Anchor hanging wall anticline: Stage 2:

Stage 2: Relaxation of the compressional forces combined with the release of fluid overpressure resulted in the generation of extensional fractures and the dilation of fault F2. The geometries of the inclined fractures sets are similar to those of "riedal shears" which commonly form during strike-slip movement. This in may indicate that the tectonic stresses have changed from compression to trans-extension. The reason for the layered fracture sets is because the fractures will be preferentially concentrated in in the more brittle lithologies. This can be referred to as "mechanical stratigraphy."

The rehydration of anhydrite to gypsum during uplift caused localised overpressure and fracturing of the adjacent beds.

Note that a similar effect can be achieved by pushing a piece of paper against the steeply inclined palm of a hand. The paper should buckle but not move up the dip of the hand which is analogous to the *formation of a buttress anticline. However, if the inclination of the hand is decreased the paper will move up the palm which is analogous to a thrust fold.*

These fractures propagated outwards from the expanding gypsum nodules and also formed veins that forced bedding surfaces apart (similar to calcite "beef"in calcareous rocks). This process was amplified by movement of fluids from the overpressured rock matrix resulting in the injection of gypsum-rich fluids into evolving fracture system via the dilated F2 fault plane. Some of the gypsum has a pinkish colour indicating that the fault has acted as the conduit for gypsum-rich fluids mixed with red sediment from deeper levels in the Branscombe Formation.

Fault F2 is therefore good example of the dilation (opening) of fault planes by hydraulic and tectonic forces and appears to have been a major conduit for fluid movement. The dilation may have been coincident with normal fault movement as there would have been minimal frictional stress along the fault plane.

The bedding plane gypsum veins provide an indication of the magnitude of the fluid pressures involved as these must have be greater than the weight of the overlying rock to open the fracture. Furthermore, the fluid pressure must have been maintained long enough for the fibrous gypsum crystals to grow into the opened fractures.

As illustrated in Plate 6 (photo b) the rock matrix also contains pervasive network of unmineralised fractures. These are likely to be the result of continued uplift and release of confining pressure that post-dates the circulation of gypsum-rich brines.

Comments

This outcrop presents a superb example of the combined role of tectonic forces and fluid overpressure in rock deformation. As noted above the cliff is continually being eroded by the double "whammy" of landslips and spalling of rock pillars and slabs along joint planes that then fall onto the beach. The upside of this erosion is that new features appear regularly although the downside is that interesting exposures can disappear just as quickly.

The descriptions and interpretation presented here are based on beach level interpretation. A more detailed study, for example using LIDAR images of the cliff face, will improve understanding of the structural model (this could make a neat post-graduate project).

The aesthetic "geo-art" qualities of the red and white gypsum fracture and nodule fabrics which can be seen close-up in the fallen blocks attracts significant interest from general visitors. Given the level of interest it would be highly appropriate to have an information board with a geological explanation at the entrance to the beach slipway. This could also provide the opportunity to highlight key safety messages of which the two most important are: 1) do not try to walk towards Wales at low tide as getting stuck in the mud is a very real risk; incidents occur every year. 2) Do not get too close to the cliff face unless wearing a hard hat and even then, exercise extreme caution; rock falls occur at all times of the year.

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Note. *The full bibliography of published papers on the structural geology of the West Somerset Coast is extensive and too long to list here.*

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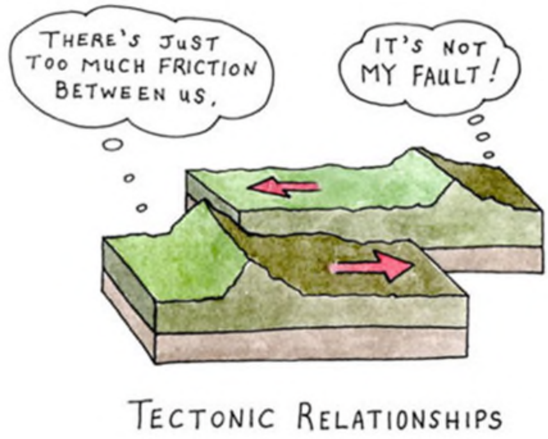
A note from Jon Mortin, Bristol Regional Environmental Records Centre , Bristol:

Just to let you know "Geological Sites of the Bristol Region" is back in print and available to order from @bristolmuseum https://shop.bristolmuseums.org.uk/collections/books/products/geological-sites-of-the-bristol-region?variant=8667449589811

This is a revised edition.



Quiz
by Kerry Hickman

1. In which American state would you be able to hike over this?

2. What are these called and exactly where can they be found?

3. What are these?

4. Can you name this formation?

5. Which famous British Fossil bed is this?

6. Who is this?

7. What was this man famous for?

8. What was the name of William Smith's wife?

9. Who is Kathy Sullivan?

10. Where was Mary Anning born and what is her exact date of birth?

** Answers provided at the end of the Journal **

Holiday rocking in Scotland's Northwest Highlands

By Charles Hiscock

In 2010 Gill and I spent a holiday in the Assynt area of Scotland and visited many of the important geological sites in the Northwest Highlands Geopark, which had been set up in 2004. We used the booklet 'Exploring the landscape of Assynt' published by the British Geological Survey in 2007, to guide us around the Geopark. The publication is in two parts. The first introducing the geology, plate tectonics, how rocks form and information and illustrations on each of the rocks that outcrop in the park. A sequence of ten walks is described, each detailing the features that can be examined in the field. The second part is a simplified geological map showing the formations, structures and particularly details of the Moine and other thrusts in the park with the ten walks marked on the map.

Using the guide, we explored different parts of the area. Our first walk started at Clachtoll, about 6 miles north west of Lochinver, and continued to the Bay of Stoer in the Stoer peninsula. The booklet describes the geology which is characterised by the Stoer Group (1200 mya), the oldest part of the Torridonian Sandstone group. The rock sequence in Assynt and the Bay of Stoer can be summarised as shown in table 1.

Mya	Period	Formation
417	Silurian	Igneous intrusion, dykes etc. (Metamorphosis of Durness Limestone producing Ledmore Marble)
443	Ordovi-cian	Durness Limestone
495	Cambrian	Salterella Grit Fucoid Beds Pipe Rock Basal Quartzite
550	Proterozo-ic	
1000		Torridon Sandstone
1200		Stoer Group (Stac Fada Formation)
1200-2500		Moine Schists/psammite
2500-3100		Lewisian Gneiss

The walk gives good views of the 'Split Rock' (the 'split' was an arch which has since collapsed) on the south end of Clachtoll beach (Clachtoll - gaelic for Split Rock, figure 01) where the beds of the Stoer Group dip about 40 degrees south-west with the higher ground of the Lewisian Gneiss just inland (figure 02). The walk also enables a visit to the well restored Pictish broch at the back of the beach. In 2010 the Ranger's Hut in the car park at Clachtoll displayed a small presentation about a possible meteorite strike that had occurred in the area, possibly in The Minch, the sea between the mainland and the Outer Hebrides, and described the evidence that could be found on the beach and in the small headland called Stac Fada that juts into the sea at the western end of the Bay of Stoer. However, the Geopark booklet describes the headland as composed of a thick layer of sandstone covered in black lichen which can be seen to contain 'reddish sand grains mixed with angular shards of green volcanic material, pink pebbles of older gneiss and blocks of mudstone and sandstone', describing it as a volcanic mudflow formed at a time when a volcano was erupting nearby, spewing out fragments of volcanic ash and rock mixed with sand.

Figure 1: Split Rock

Figure 2: Clachtoll Bay

In 2021 we made a return visit to the northwest Highlands and stayed on a caravan site just behind the beach at Clachtoll where we spent a very windy, cold four days. (One night the gale blowing in from the Atlantic peaked at gusts of 40+ mph and the van bucked about as though we were at sea!). However, the purpose of our stay was to re-visit the Bay of Stoer, a walk of one mile along the coast from Clachtoll. The sandstones of the Stoer Group outcrop in a narrow belt that extends for about 32 miles along the north west coast of Scotland from Poolewe in the south to Cnoc Breac on the north side of the Stoer Peninsula.

The rocks are composed of conglomerates and breccias which have been divided into three sub-groups, the Clachtoll, Bay of Stoer and Meall Dearg Formations. The Bay of Stoer Formation is also sub-divided into three, a lower un-named member, the Stac Fada Member and the Poll a Mhuilt Member. The Stoer Group of sandstones are exposed at a few locations along the west coast within the 32 miles of the outcrop, notably at Enard Bay on the north side of the Rubha Colgeach Peninsula. However, the Stac Fada headland is the clearest exposure where the unusual deposit described in the booklet can be found.

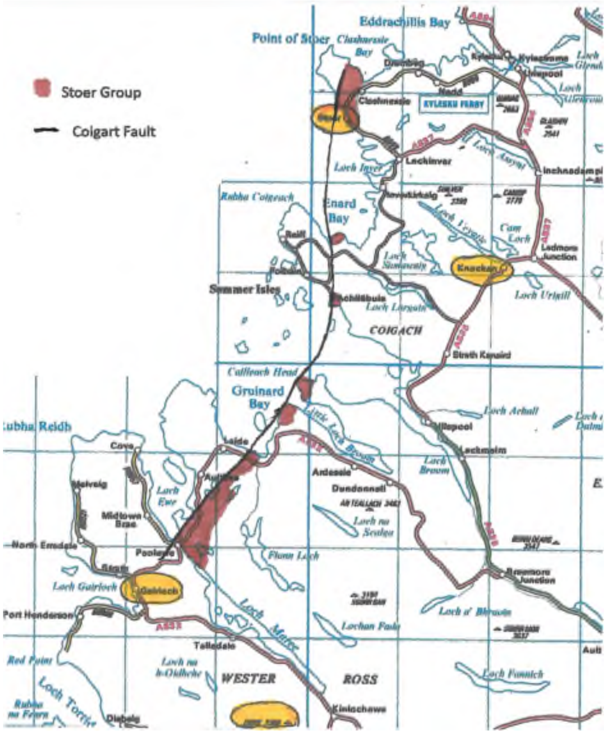


Figure 3: Map of locations and outcrops of the Stoer Group.

Even before the publication of the Assynt booklet and map in 2007, several geologists had expressed strong doubts about the origins of the unusual features of the beds in the Stac Fada promontory. Since our visit in 2010, there has been much information published on a meteorite strike in the area and the effect that it had on the geology (Simms J. 2015). The meteorite is stated to have landed near Lairg, a small town about 30 (50km) miles east of Stoer where an anomalous dip in the gravity readings, in a roughly circular 40 km formation, has been detected. The Stac Fada Member represents an ejecta deposit consistent with a meteorite impact. Measurements of directional data of the intrusions consistently indicate an easterly direction along the sedimentary bedding planes beneath and above the Stac Fada Member. A Gravity Anomaly is the difference between a locally observed gravity reading and the calculated theoretical gravity value. The difference reflects the local variation in the density of underlying rocks. In the case of the Lairg anomaly, the impact compressed the rocks significantly causing a decrease in the density, hence a lower gravity value. At Lairg, there is an excellent display in the Heritage Visitor Centre with 6 boards, based on the paper in PGA, giving the history and interpretation of the discovery.

I went to the Stac Fada headland (figure 4) on two occasions, both in windy conditions and at fairly high tides both conditions constraining my ability to examine the outcrop closely but enough to determine the main features. Immediately below the bottom ejecta bed are the flat, almost parallel beds of the Clachtoll Sandstone Formation supplying a ‘datum’ level for the succeeding beds (figure 5).

Figure 4: Stac Fada, Bay of Stoer

Figure 5: Stac Fada Member, sandstone beds outlined in blue

I was able to see the ejecta deposit beds above and below distorted sedimentary beds and the distortion of the sandstone between the ejecta beds (figure 6). The ejecta beds below and above the distorted sandstone are rich in small dark green to grey clasts, a large proportion being surrounded by pinkish vitreous margins, with the beach being littered with pebbles and boulders displaying the same features (figure 7), a sure sign that the hot ejecta had melted the sandstone as it entered the matrix (figure 8).

Figure 6: Distorted sandstone beds between the ejecta deposits

Figure 7: Boulder with greenish inclusions

Figure 8: Vitreous margins in sandstone

Our journey continued via Kinlochewe in the Torridon area, staying on a site with a view of Beinn Eighe from our campervan window looking as though it was liberally sprinkled in icing sugar as it glistened in the sunlight. Most of the summit of Beinn Eighe (figure 9) is composed of Cambrian Pipe Rock (540 mya), a quartzite with *Skolithos*, vertical worm burrows (figure 10) and Cambrian Basal Quartzite (540 mya), which looks like icing sugar, on a basement of Torridon Sandstone. Both quartzites outcrops very widely in the north west Highlands and are a major component of the Assynt complex.

Figure 9: Beinn Eighe, Cambrian Pipe Rock & Basal Quartzite

Figure 10: Pipe Rock, top part of Cambrian Quartzite

The final stop of our highland tour was at Gairloch, a small village at the head of a sea loch of the same name approximately 25 miles south west of Ullapool (figure 11). In the distant west across the flat calm sea, we could see the hazy blue outlines of the mountains of the Isle of Skye. On the first morning our walk took us past the Gairloch Heritage Museum which, fortunately, was open during the pandemic restrictions. The museum, which had recently been converted from a World War 2 anti-aircraft radar station, is run by volunteers from the village and focuses on the life and archaeology of Gairloch. However, there is also an excellent small geology exhibition with specimens of the rocks to be found in the area. In the bookshop I found a booklet, costing £2.99, 'Rocks of Wester Ross' which gave illustrations, descriptions, and localities of all the rocks in the exhibition and was an excellent investment for our stay in Gairloch.

Figure 11: Gairloch village and beach

The beach at Gairloch is a combination of sandy areas with interspersing shingle, larger pebbles, and boulders. At the western end the underlying Torridon Sandstone rock is exposed, the almost flat and level surface well eroded by the sea. From the sea wall some structures on the rock surface were visible which looked like large trace fossils. However, the age of the sandstones, about 1000 mya, meant that the structures could not be trace fossils, certainly not of this size! Close examination showed them to be fine sand or mud infill of cracks and joints of tectonic origin in the coarser sandstone (figure 12), a conclusion confirmed during the visit to the museum where the feature was described in detail.

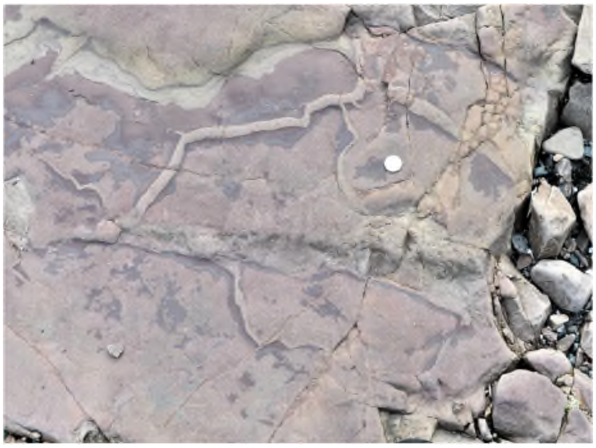


Figure 12: Mud infill in Torridonian sandstone

At the east end of the village is a steep sided mountain rising to about 500 feet, its western face marking the significant Flowerdale fault. The mountain is composed of amphibolite of the Loch Maree Group. Originally, this had been basalt 2000 mya but during the assembling of the terranes that made up the northwest Highlands 1600 mya, was folded into the gneiss and metamorphosed into foliated meta-basalt, a mafic rock with the main mineral being hornblende. It is usually grey but does show some rusty patches and is the predominant rock of the Loch Maree Group (figures 13a & 13b). At one point, a large boulder of Torridon Sandstone is perched precariously on the edge of the cliff, a relic of the ice age glaciers (figure 14).

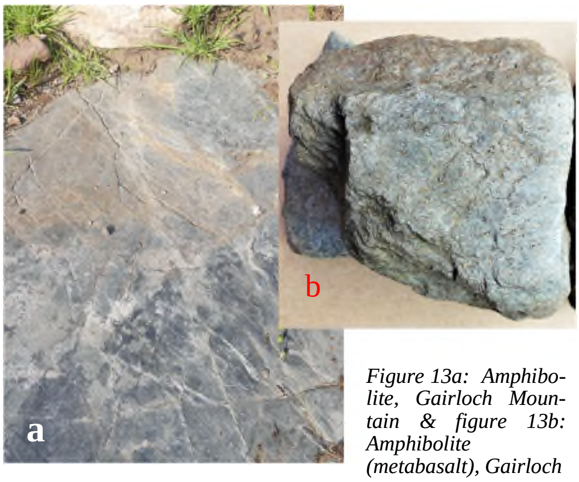


Figure 13a: Amphibolite, Gairloch Mountain & figure 13b: Amphibolite (metabasalt), Gairloch

Figure 14: Torridon sandstone erratic on amphibolite, Gairloch

Road access to the far western reaches of the Highlands even in the recent past was always difficult and slow but some years ago the main road west from Kinlochewe was greatly improved with most of its length being made into two lanes. The work cut through huge lengths of rock outcrop giving excellent access to the different rock types. As the coast is approached the road turns north north west to Charlestown harbour, with the picturesque valley of Flowerdale rising gently inland. The road continues along the coast and then cuts inland and rises as the next bay at Gairloch is approached. At the highest point on a sharpish bend the rock has been excavated back to provide a wide verge on both sides. In the space of about 50 yards four rock types of the Loch Maree Group are exposed. From the east the first is Semipelite which was deposited as greywacke, a muddy sandstone, in an accretionary prism on the ocean floor about 3100 mya (figures 15 & 15.1). This was metamorphosed to Mica Schist at the same time as the next outcrop of basalt was metamorphosed to amphibolite. The Semipelite is grey with a flat fracture and a nearly vertical dip and displays rust patches due to the high iron content. It is soft and easily erodes, a feature that I saw on the following day in Flowerdale.

Figure 15: Semipelite (mica schist) Gairloch

Figure 15.1: Semipelite (mica schist) Gairloch

Walking along the road through the rock section, a couple of metres on from the Mica Schist is a narrow outcrop of Amphibolite, the main component of the hills east of Gairloch (figure 16 16.1). Directly across the road on the seaward side a low cliff of Torridon Sandstone stretches for about 90 metres, displaying the breccia of the Slattadale Member formed around 1000 mya (figure 17). It is the lowermost layer in the Loch Maree Group of the Torridon Sandstone, above the Stoer Group and contains debris from a mountain range which was west of the present Outer Hebrides and is now the Appalachian Mountains of America. Large rivers deposited the material in a desert on top of the Lewisian Gneiss within a sinking rift valley, incorporating scree from the underlying gneiss and amphibolite. This juxtaposition of three rock types and ages underlines the complexity of the geology of the Highlands so I was most grateful to the museum for being open so that I could buy the little booklet.

The next day of our visit I followed the prompts in the

Figure 16 & 16.1: Amphibolite (metabasalt) Loch Maree Group

Figure 17: Torridon Sandstone, (Slattadale Mbr) breccia, Gairloch

'Rocks of Wester Ross' and walked up the narrow valley of Flowerdale that ascends from Charlestown harbour. It has been an important area of farmland for centuries in an otherwise mountainous and harsh landscape. The landowner has laid out good paths in the lower parts of the dale so that walking is easy but my intention was to explore higher up where the paths become very rugged and steep. For the first mile or so after the farmland the track passes through the semipelite obvious by the smooth, flat fracturing and the extensive rust development showing in the track side. The bedding is almost vertical making climbing the rough path a tricky operation (figure 18). The semipelite is much softer than the amphibolite and the river, which had been flowing gently in the lower reaches, then tumbles over three waterfalls in the amphibolite which also forms the mountains on both sides of Flowerdale. Then, almost unexpectedly, the wooded valley opens onto a wide u-shaped valley with typical mountain vegetation and a small loch which, in the dry conditions Scotland had latterly experienced, was empty. More in hope than expectation, I scanned the mountains on both sides for golden eagles but was disappointed.

Figure 18: Semipelite (Biotite Schist) Flowerdale

The main components of the Loch Maree Group around Gairloch, below the Torridon Sandstone, are –

	Torridon Sandstone
2000	Banded Iron Formation, marble and sulphide deposits
	Amphibolite (metabasalt)
2000-3100	Semipelite (mica schist)
2850-3100	Scourie Dykes
2800-3100	Lewisian Gneiss

Despite the good description in the guide, I was unable to locate the Banded Iron Formation (BIF) that outcrops in Flowerdale. Certainly, it is described as difficult to find and, as the rock is magnetic, a compass is needed.

BIF are found in most ancient basement rocks around the world and the deposit, one of the Loch Maree Group metasediments in the Flowerdale vicinity, is the only place in Great Britain where the Banded Iron Formation (2000 mya) can be found.

Maybe another visit to Gairloch and Flowerdale is called for?

Return to Gairloch, June 2022.

In 2022, we returned to Gairloch so exactly 12 months later we drove onto the same caravan site with the intention of finding Banded Iron Formation in the field. During the intervening 12 months I had done my research to discover the best locations of the elusive deposits and had also updated my compass, an essential tool to discovering the magnetic outcrops. The Loch Maree Group contains two principal types of original rocks, basalt and sandstone, which were laid down 2 billion years ago under an ocean. Subduction and metamorphosis followed during which they were incorporated into the unique type of Lewisian Gneiss of the Loch Maree Group north of the loch and around Gairloch. As subduction of the basalt occurred an accretionary prism of sediments accumulated in the ocean trench. Folding and refolding followed when the basalt was metamorphosed into amphibolite and the sediments into semipelite. The sedimentary rocks show evidence of early life in the impure limestone metamorphosed to marble in Flowerdale, while in nearby Kerrysdale are small deposits of graphitic schist, mixtures of sulphide minerals, copper, iron, zinc and minute traces of gold and silver originating from hot springs along the trench. Also, in Kerrysdale there are deposits of Banded Iron Formation, seen as alternating bands of black magnetite and silica which were laid down in a shallow sea where iron from ‘black smokers’ was abundant. Free oxygen was not available so it was supplied by algal and bacterial decomposition. The deposit of BIF in Kerrysdale is unique to Britain but extensive deposits exist in other areas of the world, notably in Australia where huge deposits have been mined for a very long time.

Our next venture was to discover the banded iron formation (BIF) which we knew from 2021 was difficult to find, a compass or magnet being essential kit. The locality is well described in the guide (Fenton 2019) as being just north of the A832 along the ‘Old Road’ which ran from Flowerdale to Kerrysdale. It is an area of old quarry and surface workings from which sulphide deposits, marble and the BIF were extracted. The 18 miles of A832 from Kinlochewe to Gairloch was widened into a two-lane carriageway in the 1980’s except for the last few miles as it approaches Gairloch. Here the road alternates between two and single lanes with passing places hemmed in by high rock buttresses on the north side and the river Kerry on the south. To our bitter disappointment, the narrow sections were being widened with temporary traffic lights, roadside barriers, heavy earth moving plant and, crucially, the entry to the old road blocked by the huge excavations. So, our attempt to find the only outcrop of BIF in the UK was thwarted. You might say we were really ‘BIFfed’ off about it!

All was not entirely lost. Although I had not been able to collect my own specimen in the field the Gairloch Community Museum had a small geological display of most of the rocks which can be found in the area. All the specimens are available to handle so it was easy to photograph the BIF (figure 19).

Figure 19: Banded Iron Fmn (Gairloch Mus.)

Although the weather did not come up to the standard of 2021, I have to admit that the Gairloch district has a particular charm. On the last page of Fenton’s ‘Guide’, there is a short poem which I quote –

A warning to visitors.

If this is your first visit, then beware:
make sure your eyes and ears and mind stay closed,
or else you risk enchantment while you’re here.

Ignore the glories of the hills and lochs,
the peaceful woods, the sea, the craggy coast,
avoid the heather moors and ancient rocks.

You must not linger by refreshing streams,
nor wander on the quiet wave-lapped sand,
do not let nature’s beauty spoil your dreams.

Resolve to shun the wildlife from the start,
and scorn the views (head down and phone in hand),
or Wester Ross’s charms will win your heart.

Acknowledgments

I am pleased to acknowledge the significant assistance gained from using the three publications by Jeremy Fenton, without which these articles would not be possible. They contain a wealth of information on walking and rocking in the north west Highlands. Also, hands-on access to the geological specimens in the Gairloch Community Museum was most welcome.

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THE BIGGEST BURROWS - EXCAVATED BY EXTINCT PLEISTOCENE GIANT GROUND SLOTHS, SOUTH AMERICA

By Maurice Tucker
School of Earth Sciences, University of Bristol, BS8 1RJ
maurice.tucker@bristol.ac.uk

INTRODUCTION TO BURROWS

Fossil burrows are common in sedimentary rocks of all sorts, from mudrocks to sandstones to limestones, and right back to the latest Precambrian. They can form in many different environments: from terrestrial to marine and shallow- to deep- water. Burrows are a type of trace fossil excavated within sediments; other common trace fossils form on a sediment surface, features such as tracks and trails, including footprints of course. The study of trace fossils is *ichnology* and ichnofossils are described and named in the same way as body fossils with Latin genus and species names.

There are several different types of burrow: some are dwelling structures; others are where organisms have been feeding, working their way through the sediment, often systematically, seeking out food, worms, insects etc, and extracting nutrients and organic matter from the sediment. Burrows come in many forms, shapes and sizes: from simple unlined tunnels and passageways with no particular features (e.g., *Planolites* sp.), to ones that branch in a free or regular manner. They can be empty or filled with sediment, in some cases finer or coarser than the host sediment. They may be simple dwelling burrows, like the vertical tubes of *Skolithos* or *Monocraterion*. U-shaped dwelling burrows are common, vertical to subvertical (*Arenicolites*, *Diplocraterion*) or horizontal (*Rhizocorallium*). Burrows may be lined by mud or pelleted mud (e.g., *Ophiomorpha* or *Thalassinoides*), to maintain them from collapsing in loose sandy sediment. Complex feeding burrow systems include *Chondrites*, *Zoophycos* and *Spirorhaphe*. In some instances, burrows resemble the roots of plants, and vice versa, making interpretation uncertain.

Many different types of animal can create burrows and burrow systems; in the marine environment, these include crustaceans, annelids and bivalves, along with echinoids and sea anemones. In the terrestrial realm, many vertebrates produce burrows of course: badgers, rabbits, moles, along with many smaller creatures, including worms and insects. It is often difficult to be certain about the organism that created a burrow; in general, the animal itself or its shell are rarely preserved within the structure.

HUGE FOSSIL BURROWS IN SOUTH AMERICA

Over the last 20 years or so, many remarkable and extremely large fossil burrows (ginormous one could say), up to 2 metres in diameter, 100s of metres long, have been discovered in South America. To me these are such amazing structures, so mind-blowing, that I felt compelled to write this article for your delectation and to spread the word. Dr Amilcar Adamy from the Brazilian Geological survey (CPRM) discovered such burrows in Rondônia state in the Amazonia region of NW Brazil (Adamy 2015) and Prof Heinrich Frank from the University of Rio Grande do Sol, Porto Alegre, in southern Brazil, has recorded around 1500 of these tunnel structures, notably in road-cuts in the region of Porto Allegre in SE Brazil, and in the state of Santa Catarina just to the north (Frank et al. 2023). I am extremely grateful to Amilcar Adamy and Heinrich Frank for their permissions to include several of their images in this article, based on their work.

These burrows have a height of 1 to 2 metres and are up to many 10s of metres long, with the longest tunnel recorded as being 650 metres! In cross-section, they are near-circular to oval with a flat base (Figures 1, 2, 3, 4). Some tunnels are simply straight, going into a small cliff / escarpment or hill-slope. Others are more complicated and show branching with tunnels off tunnels (Figure 4). They may have more than one entrance and they do rise and fall along their length. Some tunnels open up into much larger chambers. Many of the burrows are open, empty tunnels, suggesting they are not excessively old, whereas others are filled with sediment, mostly a red coloured clay-silt (Figure 5).

Figure 1. Burrow system excavated in a red silty palaeosoil with vertical to irregular white nodular features, probably pedogenic and calcareous. Ponto do Abunã, Rondônia state, Amazon region, NW Brazil. Image courtesy of Amilcar Adamy.

Figure 2. Burrow system excavated in red silty palaeosoil. Rondônia state, NW Brazil. Image courtesy of Amilcar Adamy.

Figure 3. Several empty burrows excavated in a red silty sandstone. Morro Grande, Santa Catarina, SE Brazil. Image courtesy of Heinrich Frank

Figure 4. Large chamber, excavated by giant sloths in the aeolian Botucatu Sandstone, with fallen rocks and debris and deep scratches on the roof. Boqueirão do Leão, Rio Grande do Sol. Image from Lopes et al. (2017), courtesy of Heinrich Frank.

Figure 5. Cross-sections through several large burrow structures filled with a deep red-brown silty clay. Ivoti, Rio Grande do Sol, Southern Brazil. Image from Frank et al. (2023) with permission from Heinrich Frank.

One feature of many of these tunnels which confirms an animal origin is the presence of scratch marks on the sides and roof; these indicate an animal with very large claws made the burrows (Figures 6, 7) (Frank et al. 2023). It does seem unlikely that an individual animal would have made such a long burrow; rather, they must have been created by many working together or more likely over several generations. The extensive tunnel systems would have necessitated the removal of huge amounts of soil / sediment; 4000 metric tons have been calculated for a long burrow. This would have required a huge concerted effort, almost a team effort (!), if a tunnel was several 100 m long. In some cases, there is evidence that a burrow was used for human habitation, from marks on the walls and ‘cave’ art, but a human origin is ruled out by all the similar scratch marks on the walls (Figure 7).

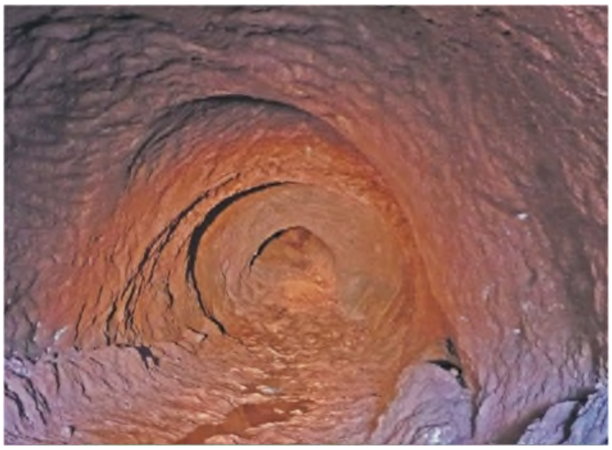

Figure 6. Sloth burrow with scratch marks on the walls. Novo Hamburgo, Rio Grande do Sol state, Southern Brazil. Image from Frank et al. (2023), courtesy of Heinrich Frank.

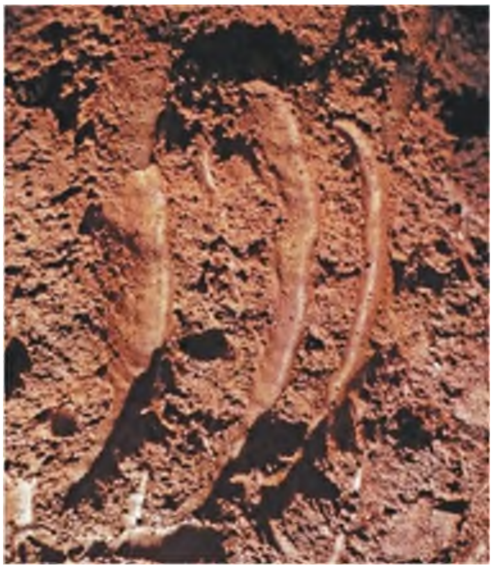

Figure 7. Scratch marks (25 cm long) on the side of a burrow. Novo Hamburgo, Rio Grande do Sol state. Image from Frank et al. (2023), courtesy of Heinrich Frank.

Although many of these burrows have been discovered in Brazil in recent years, and some in Argentina too, they will have been known to local farmers and villagers. But it is only recently that they have been appreciated for what they are: the burrows of the Plio-Pleistocene megafauna that dominated the region until about 8-10,000 years ago. Previous interpretations have included them being man-made or somehow produced by ground water; they are of course quite different from typical caves produced by dissolution of limestone (or gypsum).

THE CULPRITS

The most likely animals responsible for these tunnels are considered to be the extinct giant ground sloths (Figures 8, 9) (Frank et al. 2023). From their fossil bones and claws, relatively common in South and Central America and southern North America, these animals appear to have been adapted for digging, judging by the size of their claws (30 cm long). Modern sloths in South and Central America are completely different, living most of their lives in trees (Figure 10) and being notable for their extremely slow movements. It has also been suggested that armadillos may have created some burrows. Modern armadillos do live in burrows and some extinct ones were much larger than those living today, although smaller than the giant ground sloths. These extra-large burrow structures have been given the ichnogenus name of *Megaichnus*, for obvious reasons.

Figure 8. A skeleton of a giant fossil ground sloth (Megatherium) from South America, of the type found by Charles Darwin in 1832 in Argentina. When standing up on its hind legs it was 3.5 metres (12 feet) tall. Not an animal to meet on a dark night! Natural History Museum, London. From Wikimedia Commons.

Figure 9. Reconstruction of the extinct giant sloth Megatherium and two armadillos from the Pleistocene megafauna of South America. From Westell, W.P. (1910) The Book of the Animal Kingdom (Plate XV111). From Wikimedia Commons.

Figure 10. Two-toed tree sloth (Choloepus hoffmanni), with a baby. Tortuguero, Costa Rica. MET Dec 2023.

One question that is still being discussed for these huge burrow systems is why they were so long and complex. They appear to be much longer than necessary to escape or hide from predators, or to shelter from the rain.

One difficulty with the burrows is knowing the timing of their construction. The sediments in which the burrows were excavated vary from relatively recent river sediments and soils right back to highly-weathered Precambrian igneous rocks. The burrows occur in a whole range of rock-types and lithologies, but mostly in those that are consolidated by not highly indurated. Thus, they have been found in weathered granites and basaltic rocks, sandstones, such as Jurassic-Cretaceous fluvial-aeolian deposits which are quite widespread in southern South America, and in much younger Plio-Pleistocene fluvial-colluvial sediments and soils.

THE WIDER CONTEXT

As noted, the animals that created the burrows are likely to have been the giant ground sloths and armadillos; these became extinct around 8,000-10,000 years ago in the '*Great Pleistocene extinction event*', along with woolly mammoths, mastodons and sabre-tooth tigers, which were common across the latitudes, especially in more northern areas. There has been a lot of speculation as to the cause of this extinction event: with climate change and habitat loss, and the influence of man being the most likely explanations. Coming out of the last ice age, with rising temperatures, changes in precipitation and vegetation, at the same time that human occupation was expanding into South America, would have put a lot of pressure on the large animals that were roaming the countryside at this time. In South America, during the ice age, the temperature was around 10^{o}C lower than it is now. However, the latest research using genomic data suggests that man's ancestors were largely responsible for the extinction of the large animals and decline of many others in the late Pleistocene-early Holocene (Bergman et al. 2023).

The South American Pleistocene megafauna has been well documented. The first fossil of a giant sloth was found in Argentina in 1788 and given the name *Megatherium*. It was as big as an African elephant, 6 metres long, and weighing 2-3 tons. The famous French naturalist Georges Cuvier (1769-1832) suggested that these large animals used their long claws to climb trees, but with their huge size, he later decided it more likely that they stood up on their hind legs (giving a reach of 4 metres) to rip branches and leaves off trees, and that the claws were also used for burrowing. Although regarded as a herbivore, like its modern tree-living counterparts, this giant ground sloth may also have been an opportunistic carnivore. On his travels in Argentina, Charles Darwin collected four *Megatherium* specimens in 1832, with their huge bones attracting his attention. One of these skeletons is on display in the Natural History Museum in London (Figure 8).

Megatherium and other elements of the Pleistocene megafauna evolved there in South America over several 10s of million years, from when South America was isolated and separated from North America in the late Cretaceous. With the formation of the Central America (Panama) isthmus around 3 million years ago, as a result of an extensive and extended period of volcanic activity in the region of present-day Panama and Costa Rica, a land connection was established between the two mega-continents. As a result, *Megatherium*, along with other South American animals, including armadillo, anteater and possum, were able to migrate north. Giant sloth relatives evolved there, including *Megalonyx*. Some North American animals, including bear, cat, dog, pig, horse and elephant, headed south. This episode is referred to as the *Great American Biotic Interchange* (GABI).

Although the bones of giant sloths and armadillos have been found in North America, no large fossil burrows have been found there. This could be a genuine absence related to soil-type and climate; perhaps soils and sediments were too hard to burrow into, or they have not yet been discovered or recognised. However, of interest here is that there is evidence from fossil footprints preserved in lacustrine sediments in New Mexico, dated at 13-15,000 years ago, that humans were around at the same time as the ground sloths in this late Pleistocene time. From the footprints it has been suggested that the humans were stalking and hunting the sloths (Bustos et al. 2018); this is another example of a remarkable story recorded in trace fossils.

These ginormous burrows, attributed to the extinct giant ground sloths, are amazing for their size and are a wonder of ancient animal behaviour. And it just goes to show that there are remarkable features out there still to be discovered about our world and its ancestors.

Postscript: The study of these burrows must have been an exciting field project but spare a thought for the hazards faced by the geologists, described by Frank et al. (2023) as “a painful learning experience”. Hazards included: lack of oxygen in the inner unventilated parts of the burrows, collapse of the entrances and roofs within, dust causing dermatitis, poisonous spiders and snakes, issues with bats and their viruses, and lime ticks.

Acknowledgements

I am really grateful to Amilcar Adamy and Heinrich Frank for giving permission to use some images from their papers and studies.

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In addition, there are short articles on this topic in online science magazines.

And finally… Rock Faces

By Mellissa Freeman

On a nice blustery autumn day following a visit to the pub at Avebury, some friends and I decided to go for a walk around the stones. While on my walk and talking about the stones I started to ponder the fact that when observing I often see a face in the rocks and wondered if anyone else also did this? Of course, the friends I was with thought I was a little bonkers and had consumed too much wine with lunch!

Once home, I started to look through my photos from past geology trips to see what I could find and thought I would share them as a light-hearted end to our Journal. Some are obvious, some not so and will definitely require the eye of faith. I will leave it to you to let me know if you agree. I would also be interested if other have similar photos.

1. Avebury: This is one of the large sarsen stones making up the stone circle at Avebury; These stones are incredibly hard sandstone or silcretes, the result of localised patchy cementation of Tertiary sands which originally covered the chalk.

2. Andalusia: there are several examples of the karstic limestone formations at El Torcal de Antequera. Formed ~ 175MA.

The area was uplifted during the Miocene exposing the rocks over time to the elements leaving what we see today.

Also in Andalusia we find a face on a far larger scale. This is Peña de los Enamorados or Lover's rock. Legend has it that two Young Moorish lovers from rival clams were chased by the girl's father and his men. Upon realising they couldn't escape they threw themselves from one of the ledges at the top. A sad story. The nearby town is Antequera.

3. Next we have some photos from the El Teide National Park near the base of Mount Teide. Called the "Roques de Garcia" or Rocks of Garcia they were also created by erosional processes and quite spectacular.

Also from Tenerife, this one may need the "eye of faith" but I can clearly see the side profile of a face surrounded by flower petals – it's quite a surreal picture. This is called "The Rose" it is columnar basalt that cooled in a concentric pattern from the outside in creating what looks like rose petals.

4. Moving on to the USA this photo was taken from a helicopter at the Grand Canyon close to the top. It is clearly sandstone, and probably in the Toroweap Formation going by the colour and elevation.

5. Still in the USA.. This is one of the Cottonwood basin fumeroles in the Verde Valley, Arizona. Known locally as the Tee Pee rocks. The Cottonwood Basin fumaroles are the result of volcanic ash falling on what was once a freshwater lake that covered the Verde Valley. The steam mixed from the lake's calcium carbonate-rich water deposited calcite into the ash, forming a cement-like shell around the vents that were exposed when surrounding lake sediments dried up and eroded. Wind erosion has caused the strange holes and shapes by rattling around small stones and pebbles in small cavities carving out larger cavities and these strange shapes.

6. This is Tête d'Indien or Indian head rock and is located in Saint-Georges de Malbaie, halfway between Percé and Gaspé, Quebec. Here we have another legend which tells the story of a young man who waits for the return of his beloved who was kidnapped by white men. He sits with his back turned to the sea until the sea brings his love back to him.

7. I found this tiny face while on a trip to the in West coast of Ireland in 2018 :-)

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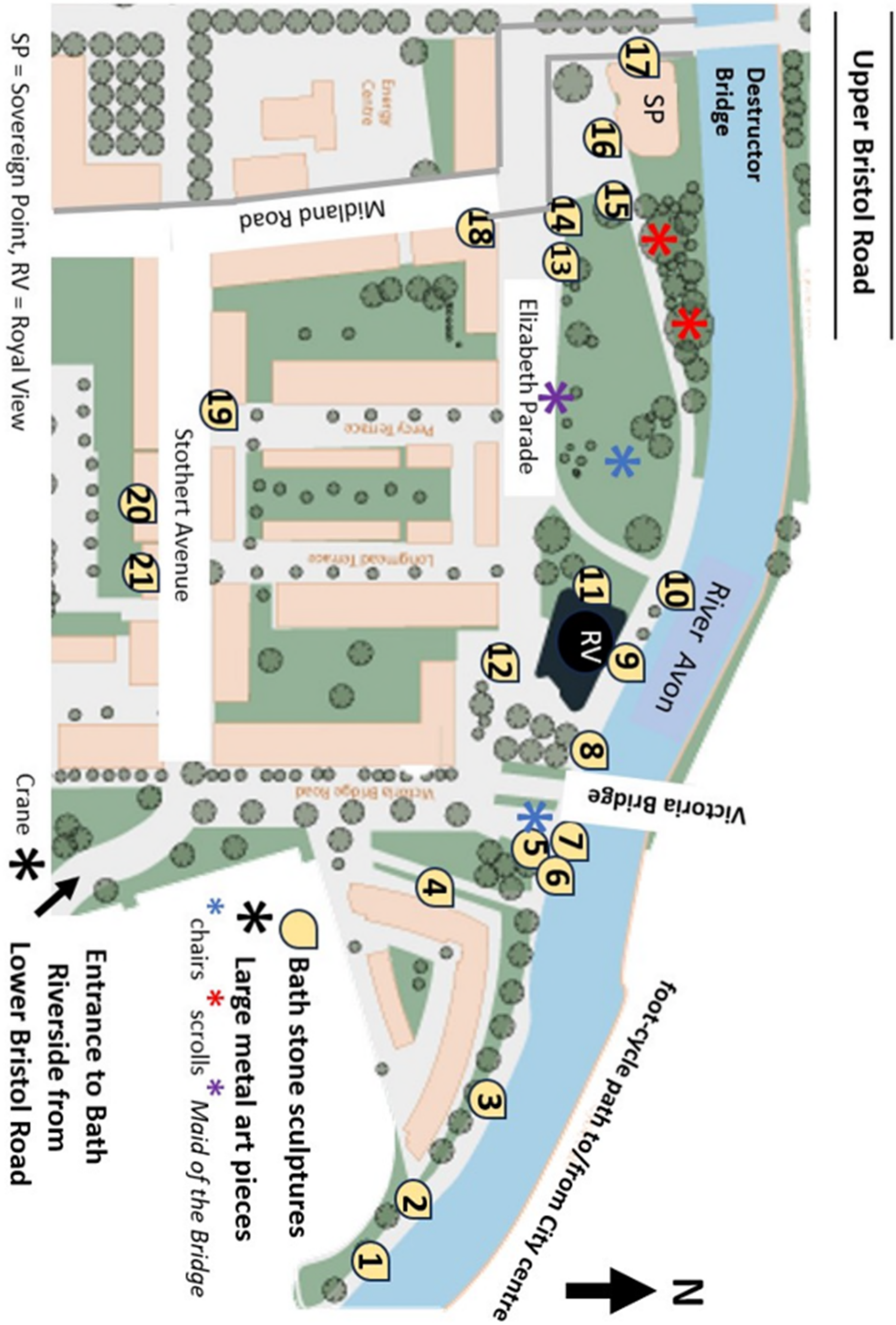
Full scale copy of the location map from the Bath stone sculptures article on page 27



Quiz answers
provided by Kerry Hickman

1. The Vermillion Cliffs wave formation. Arizona

2. Rainbow mountains, Zhangye Danxia, China

3. The Pinnacles,(Limestone) Namburg National Park, Western Australia.

4. Folding Rocks Agia Pavlos, Greece.

5. Herne Bay, Kent.

6. Niels Steensen (Danish: Niels Steensen; Latinized to Nicolas Steno or Nicolaus Stenonius[Geology and stratigraphy. January 1638 – 25 November 1686.

7. Alfred Lothar Wegener 1 November 1880 – November 1930) was a German climatologist, geologist, geophysicist, meteorologist, and polar researcher. Best known for his Continental Drift Theory.

8. Mary Ann

9. Kathryn Sullivan, PhD, is a geologist, former NASA astronaut, and oceanographer who was the first American woman to walk in space, the first woman to dive to the Challenger Deep in the Mariana Trench (the deepest part of the Earth's oceans), and is the first and only person to do both.

10. Mary Anning was born 21 May 1799 in Lyme Regis, Dorset.

Additional notes on Niels Steens—Stratigraphy (6)

The law of superposition: "At the time when a given stratum was being formed, there was beneath it another substance which prevented the further descent of the comminuted matter and so at the time when the lowest stratum was being formed either another solid substance was beneath it, or if some fluid existed there, then it was not only of a different character from the upper fluid, but also heavier than the solid sediment of the upper fluid."

The principle of original horizontality: "At the time when one of the upper strata was being formed, the lower stratum had already gained the consistency of a solid."

The principle of lateral continuity: "At the time when any given stratum was being formed it was either encompassed on its sides by another solid substance, or it covered the entire spherical surface of the earth. Hence it follows that in whatever place the bared sides of the strata are seen, either a continuation of the same strata must be sought, or another solid substance must be found which kept the matter of the strata from dispersion."

The principle of cross-cutting relationships: "If a body or discontinuity cuts across a stratum, it must have formed after that stratum."[35]

Additional notes on Continental Drift Theory (7)

Alfred Wegener first thought of this idea by noticing that the different large landmasses of the Earth almost fit together like a jigsaw puzzle. The continental shelf of the Americas fits closely to Africa and Europe. Antarctica, Australia, India and Madagascar fit next to the tip of Southern Africa. But Wegener only published his idea after reading a paper in 1911 which criticised the prevalent hypothesis, that a bridge of land once connected Europe and America, on the grounds that this contradicts isostasy.[18] Wegener's main interest was meteorology

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Please note the final submissions for the 2024 journal need to be with the Journal Editor by the 30th November. Any articles received after this date will be added to the following years journal.

The Bath Geological Society Disclaimer

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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