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The North West Geologist

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The North West Geologist

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GeoLancashire

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All three organisations welcome new members.

Visitors and members of other geological societies are welcome to attend meetings.

North West Geologist issues 1 to 20 inclusive will shortly be available to download as printable PDF files from the websites of the three societies.

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Cover image: *Woodocrinus macrodactylus* de Koninck, now in the British Natural History Museum's collection (see article in this journal). It was in Brian Jeffery's garden in Read near Burnley until a chance mention brought it to the attention of Steve Donovan.

Photograph: Steve Donovan

NORTH WEST GEOLOGIST
Issue number 21
2020

Contents

Editorial

Welcome to North West Geologist Number 21. I hope that you will find lots to interest you in the mix of articles. During preparation of this issue the process of digitising past issues has continued. These will be downloadable from the websites of the three geological societies. It is also planned to include a list of articles to make searching easier, so that if your interest is fossils or minerals or the geology of a particular area, you can find relevant articles.

I hope you will investigate this treasure trove. There is a series of articles by Peter Rankilor (Nos 12, 13, 14) about using a digital camera as a polarising microscope or to take stereo images using two cameras.

As I scanned and collated, I read almost all the content of past issues and realised that editor after editor encouraged, cajoled and prodded members of MGA, LGS and GeoLancashire into contributing material for future issues.

In this issue, Stephen Donovan has written an article proposing a strategy for those who might contribute articles. He is especially keen to make sure that contributions can be referenced as in other scientific journals.

I propose that system is adopted – see **Notes for authors**. I hope you will take up the challenge to contribute. As past editors have said, 'This is *your* journal; without you it would not exist'. **Jennifer Rhodes**

Notes for authors

Articles for future issues are invited and should be sent to:

secretary@geolancashire.org.uk

Articles of about 3000 words in length, should be emailed or sent on disk as **Word** files. Coloured images are encouraged. **Please do not embed them in the text.** Indicate where they should be placed in the article and send them as separate high-resolution jpg or tiff files with clear titles/captions so that they can subsequently be inserted into the text.

The journal uses an A5 portrait page layout, so a landscape-format image will be no more than A6 in size although they can be inserted 'sideways' to aid readability. Please pay careful attention to figures and tables, as reduction to A5 format can make them unintelligible. Please send tables and figures as separate Excel spreadsheets or the equivalent to aid the editor in achieving an optimal layout.

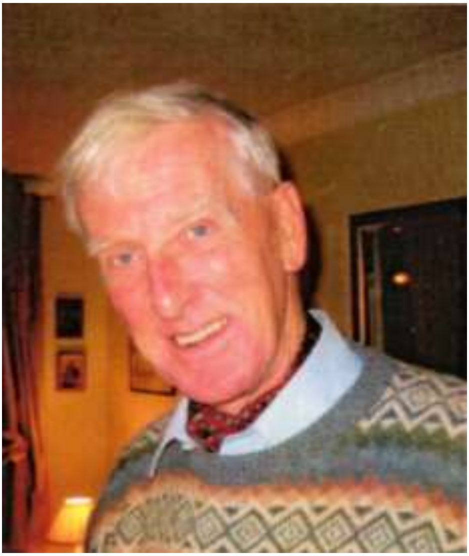
As far as it is possible, I propose that we also use the format suggested in Steve Donovan's article in this issue – see pages 13-18.

If you are willing to include an email address, interested readers might like to make direct contact for further information.

Cover pictures can be photographs or high-resolution digital images and must include the name of the photographer and some information about the image including its location.

Copyright

Obituary



Iain Ashworth Williamson

14 November 1931 - 2 November 2019

Extract from a document provided by Iain's son in law, Mark Witherspoon.

Iain Ashworth Williamson has died after a short illness. He remained very active until recent months and enjoyed walks around Ambleside and Kendal, where he lived in his final months.

Iain was born in Burnley and attended Burnley Grammar School from 1942-1950. He graduated from Nottingham University with a BSc (1958) and MSc (1960) in Geology.

From an early age, Iain had a passion for field geology and enjoyed all aspects of mountaineering, maps and history and he spent many happy hours immersed in books. He travelled to many parts of the globe including some very remote parts of the South Americas, as part of his work and research. Iain was a very accomplished golfer and declined the chance to turn professional in favour of his studies.

Iain was devoted to Pat (nee Holt), his wife of 60 years and was the proud father of Roger and Katie and grandfather to Ross, Bill, Ambrose & Digby. His son Roger followed in his footsteps as a geologist, until his death in 2010.

Iain was elected FGS in 1953, becoming a Senior Fellow. He was also a member of the North-east Lancashire Group of the Geologists' Association (now GeoLancashire) from 1950, YGS from 1950, probably while still at school, MGA from 1951 and the Institution of Mining Engineers from 1965. (*He was also a leading member of the sadly now defunct Wigan and District Geological Society -WDGS*)

He was widely published and wrote papers over the last 50 years including several, often referenced, early papers on Tonsteins* - and was the author of 'Coal Mining Geology', published in 1967.

**Tonsteins occur as distinctive, thin, and laterally extensive layers in coal seams throughout the world. Often used as key beds to correlate the strata in which they are found, the regional persistence of tonsteins indicates that they form by diagenetic alteration of volcanic ash falls in freshwater swamps _Editor*

He was a Senior Lecturer at The Wigan Mining College from 1958–1980 and was a very successful and highly sought-after geological consultant since the early 1970's.

In his own words: 'My most fundamental belief is in there being a God to whom all natural things belong. Please do not grieve - and remember me when the wind blows in your face and when you are walking in a blizzard, enjoying the sensation of nature. I'm now on my next and probably my greatest adventure.'

A personal recollection

I first encountered Iain when I enrolled in his A level geology class at Wigan College, prior to starting an Open University degree course. I still have the lecture notes, taken down at great speed during Iain's excellent lectures. The geology department under Iain's leadership was a treasure trove with its own small but well stocked museum and a library which would have been the envy of larger institutions. It also had all sorts of technical kit so that students could cut rock slices, make thin sections and undertake all manner of geological investigations.

The same speed was his hallmark behind the wheel of his car and on field excursions – you had to work hard to keep up with him. He was very generous with his time and led many field trips. His close links with the coal industry meant access to open cast coal workings. The college ran courses in coal mining technology and generations of NCB employees must have passed through its doors.

It is only now that we realise that we were witnessing the end of an era as the coal mines and quarries are now long gone. He was especially keen to lead groups to investigate the area around Burnley including the Cliviger valley and Pendle. He had an excellent grasp of the history of the area and made sure that the geology was interpreted in the context of the area's history.

FOSSIL HUNTERS: The geologists at Wheatley Lane at the rather wet start to an excellent day's study of Pendle. Photo: Anthony Braithwaite

The image, from the local newspaper in North East Lancashire shows a party of members of what is now GeoLancashire at the start of one of Iain's 'marathons' in the late 1980s. It is typical of him that he had managed to persuade the press photographer to turn out on a very wet morning. Iain is on the far left of the photograph in his characteristic deer-stalker hat.

Iain's links with what was then North West Water, now United Utilities, were instrumental in obtaining permission for a group from the sadly now defunct Wigan & District Geological Society (WDGS) to walk through the six mile Lune-Wyre transfer tunnel between Quernmore in the Lune valley to Abbeystead on the Wyre, before the tunnel was concreted. This of course became the site of the Abbeystead explosion which killed 16 of a group of 44 visitors from St Michael's on Wyre on 23 May 1984. Methane from the Bowland Shales had seeped into the partially empty tunnel, which accumulated at the pumping station before being ignited by an unidentified spark. Iain was retained as an expert witness for the families of those who died.

After his retirement Iain and Pat went to live in Ambleside, where Pat, the senior pharmacist at the Royal Albert Edward Infirmary in Wigan, continued to work as a pharmacist in Barrow in Furness. Iain was able to pursue his love of climbing and fell walking for many years, usually accompanied by Ruadh his beloved dog or one of Ruadh's successors.

Iain was very generous in his help while I was doing my degree, coming to the quarry at Jumbles in 1978 to look at the fossil 'tree' and suggesting ideas for improving my investigation. When it was complete, Iain put me in touch with Michael Eagar who made further encouraging remarks and suggested that I submit the report for publication in Amateur Geologist, the precursor of NWG. To my eternal chagrin I didn't take up this suggestion and the fossil tree was immortalised in print by Ken Riley in the GA Guide to the Manchester area. Potential NWG authors please take note!

I will miss his acerbic wit, pithy comments and characteristic short but apposite messages hand-written on grey Conqueror notepaper.

Jennifer Rhodes

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John Price: an appreciation

From left to right: John Price, Fred Broadhurst and Fred Owen with the display of cobbles at the Knutsford Heritage Centre in March 2006

John Price was a leading light in the MGA for many years and many older members will remember his kindness and sincerity with fondness. Sadly, John has recently passed away, his death hastened by COVID-19. Two members have written appreciations, firstly Fred Owen who worked closely on Council with John and secondly a neighbour and friend Richard Parr.

During John's Presidency I was working on assembling a selection of cobbles for display at Knutsford Heritage Centre to interest the public in their geological origins. John enthusiastically supported the project and MGA Council approved a £750 grant from the Horrocks Fund to cover its full cost. John was always gentle and cheerful and enjoyed communicating his love of geology to others, as is evident in the photo taken after Fred Broadhurst had unveiled the Knutsford display for formal handover to the Heritage Centre, in March 2006. The display is still there (though the poster has been revised) and I tend to it twice a year to keep it clean and respectable. It is a lasting example of the contribution John made, and the MGA continues to make, to bring geology to the public.

I believe it was John who proposed Peter Prydderch as the Association's accounts examiner, a role Peter relinquished at the February 2020 AGM.

John's love for, and contribution to, the MGA is acknowledged and greatly appreciated. **Fred Owen**

John Price was a gentleman, in every sense of the word. He was kind, thoughtful and generous. Before I joined our local U3A, John had organised and led geological visits and holidays that were greatly appreciated, and still remembered today. I know he was a keen walker, who had completed a number of long-distance trails. He was responsible for introducing me to the delights of "Down to Earth", as well as our Manchester Geological Association. He was always delighted to share his enthusiasm and knowledge, but always quietly and modestly. He greatly missed his beloved wife, Enid. We shall miss him, too. **Richard Parr**

Note: A date for your diary

This will be a Zoom meeting. If you wish to join the audience contact info@mangeolassoc.org.uk

Wednesday 14 October 2020 at 7.00pm

The John Price Memorial Lecture

Speaker: **Dr John Nudds** of the University of Manchester

Archaeopteryx and the dinosaur-bird transition

Some notes on writing about geology for publication

Stephen K. Donovan

Donovan, S.K. 2020 (for 2019). Some notes on writing about geology for publication. *The North-West Geologist*, 21.

Abstract: You should be writing about geology for publication. Amateur, student and professional geologists all have contributions to make to the scientific literature. We all make observations and collect specimens that are of general interest to geologists, but only publication will make them available to a broader audience. In the era of the text message and e-mail, we are all writers. Writing geology for publication may be a different discipline, but it uses the same language and similar technology. Like riding a bicycle and cooking a Sunday roast, only practice will improve your scientific writing.

Introduction

This essay starts in your private collection of rocks, minerals and fossils, and in your field notebooks. These are the specimens and observations that you have accumulated over the years. I presume you collected many of the specimens, but there may be those that were gifts or exchanges from like-minded enthusiasts and perhaps some were bought because they were too interesting to leave in a shop window. Thus, your field observations and your collection reflect your interests, ideas and idiosyncrasies, made concrete by an interaction with the geological record.

I want you to focus on one prize specimen in your collection or one set of interesting field notes. All of us collect specimens and make observations that we consider noteworthy for telling a story or asking a question. Even in just reading the last sentence, perhaps your mind flitted off and you thought, for example, “Oh, yes, that strange mineral vein or bedding plane or fossil that I found two years ago.” I would love to see that specimen and hear your ideas and observations about it. But will I? Probably not. And this is where *The North West Geologist* (*NWG*) comes in. If you write an article about your rare specimen or some unusual observation from the field, however brief, it can become known to all the readers of *NWG*. In consequence, it will open a wider geological consciousness.

Excuses

At this juncture there are many possible negative reactions – people habitually have to excuse themselves because they do not consider themselves a writer and (allegedly) they do not have time to write. St. John (2018, pp.10-11) asked many of her friends, all of whom are writers, why they were not writing and has published a list of their answers. They are all excuses. If you want to do something, you do it, using part of the 24 hours each day brings. If you want to cook and eat dinner, you do so. If you want to watch television, then watch it. If you want to write, then you will write. Yet people treat writing as a great mystery, needing more than a simple desire to write. I suggest you treat writing a geological article as a part of life, like breakfast or sleeping.

As I have already stated, there are two negative reactions which I might expect to be the most prevalent at this time: "I am not a writer" and "I just do not have time to write." The second of these is nonsense. In all our lives we find time to do a huge range of things that I need not list – you know what they are and how you juggle them to fit into your life. Writing is a task that needs both time and thought. You can find time to write if you make it a priority, like meals or television, by reallocating time spent on other tasks or forms of relaxation. Let someone else take the dog for a walk, you are writing. No need to go down the pub, you are writing. Additionally, always have a notebook and pencil in your pocket or bag and use odd bits of time to write a sentence or two. So, when you are on the bus, when you are in a long supermarket queue, when you think of a good sentence relevant to your article, write. A sentence per day will give you at least a paragraph per week. After two months you will have 1,500-2,000 words, that is, about as many words as this article. In short, you have as much time in your day as everyone else; how you use it is determined by your desire to write about geology or not.

It is a fact that most of us are already spending more time writing than ever before. Look around that bus. Note the number of people texting and engrossed on their tablet, letting Auntie Nora know the latest about Stan's lumbago or whatever. Their writing is ephemeral, whereas you are aiming for permanence, for publication. This is the only difference between you and everyone else on the bus. Anyone who says that they have no time to write in the age of the text message deserves a horse laugh, nothing more.

Writing for publication

This brings us back to 'I am not a writer' and is deserving of close scrutiny. You are a writer – remember those text messages – but you mean that you are not a writer of scientific research papers, until now. The skill of writing science develops with practice. The transition from text messages to research papers means bridging a gap, but it is narrower than you might think. After all, the same language is used in a text message and a research paper, so you are armed with adequate vocabulary from the start. The best research papers in any field are written in the plainest language available, this reaching the widest audience.

Different journals have different formats and it is a basic truth that the author who follows the correct format is a friend to their editor. Articles for any scientific journal, from *Nature* to *NWG*, have an identifiable style and structure. You can identify the pattern of scientific papers by reading them. Find a paper on a similar subject to the one that you intend to write and, if possible, published in your target journal. Read it and study the structure. Many papers will have a simple style and similar subheadings, thus:

Title
[Name(s) and address(es) of author(s)]
Abstract (comes first, but written last)
Introduction
Materials and methods
Locality and horizon
Description

Results
Discussion
Conclusions [include conclusions if considered necessary, but they say much the same as the abstract]
Acknowledgements
References
Tables and their captions (if any)
Figure captions (if any) [Each figure should be provided separately as jpeg or tiff files.]

I am a systematic palaeontologist and would need most of these headings if I was going to, say, describe a fossil crinoid (such as Donovan and Jeffery, 2020, in this issue of *NWG*). Once your major subheadings are identified, you have determined your structure and will already have started your 'word count'. A blank page is intimidating, so write on it! Write a provisional title, write your name, address and e-mail address. Start to draft an introduction. If, for example, you are describing a distinctive suite of mineral veins in a sandstone cobble collected from a conglomerate, you might start by saying: "Veins and vein minerals are distinctive features of many rock successions, providing clues to the geological history of the host rock between lithification and discovery." Once you have written one sentence, how can you not write the next one? And so on and so on. This is a draft; proof reading, correction, additional content all comes later. Nobody writes the perfect document – not Shakespeare, not Hemingway, nobody. Just write what you write and then massage it to improve it. The way I am writing this article.

When I started writing geology for publication, the choice of tools was a pen/pencil and paper, and, subsequently, a typewriter. I still prefer to write my early draft(s) in pencil (2H or harder for preference), then type, but today a word processor program gives me a flexibility that I never had with a typewriter. I like to type in the main headings, such as listed above, and can then write the different sections in any order. I write what is 'easiest' first. In truth, it is not uncommon for me to start a paper in the middle, such as the 'Locality and horizon' or 'Discussion' sections. If I have a fossil to document, then ‘Description’ is a logical starting point. ‘Abstract’ and ‘Introduction’ are found on the front page of a paper, but may be written late, if not last. I will often write a draft ‘Introduction’ and then write the rest of the paper. I will then return to the ‘Introduction’ to see if it truly introduces the rest of the paper and needs to be changed (it usually does). ‘Conclusions’ are a left-over from the days before most papers were preceded by an abstract – they say much the same thing. This presents us with a writing conundrum – how to finish a paper without too much repetition.

Do not lose sight of your references. Many geologists (and others) write a research paper and only then construct their reference list. This is a recipe for confusion – what paper was I thinking of when I referred to Donovan (2013)? Which Donovan? And did I get the year right? I strongly recommend constructing your reference list as you write, then you will be sure of the year and which Donovan is which.

Format

The thing to bear in mind is format. I just corrected part of a draft of the thesis of one of my students and every one of his references was in a different format, I kid you not. If you are writing an article for publication, then follow the format of your target journal. Many journals make available a document, ‘Instructions for authors’, which is always worth referring to, but dry to read. At least as useful, if not more so, is to have a copy of the journal to hand or at least a paper or two from it. ‘Instructions’ are useful, but actually seeing the layout of the journal, the style of subheadings, references and figure captions is an education for the writer.

Different journals have different styles. Some authors rant against this, but it is a minor foible of academic publishing that I welcome (Donovan, 2013). Different journals look different, the way that diverse newspapers, shoes or cars look different. They ‘sell’ the journal.

So, beware. Speaking as an editor, the first things that I check in a new submission are the reference list – is it an inspiration or a disgrace – and the overall format – does it follow that of my journal or will it take a lot of work to get it right? The first is submitted by a friend, the second is not. Editors like papers from friends which are straightforward to edit; if it is correctly formatted, well written and with good illustrations, all will combine for a happy publishing experience for everyone. The more a paper needs editorial attention, the more work it will involve for everybody.

One final point. I have purposely written this essay without reference to my book on writing (Donovan, 2017), which covers a far larger series of relevant topics than this short essay. The purpose of this essay is to encourage more readers of *NWG* to become contributors. My book is comprehensive, whereas this short essay nonetheless touches on many essentials. I want you to contribute. I firmly believe that writing is fun, but, like riding a bicycle, you will keep falling off if you do not practise regularly. I hope this essay helps your geological writing; my book is there if you need a more in-depth treatment; and you can always contact me if you need further guidance or help. My encouragement does not end at the end of this paragraph.

Dr Stephen K. Donovan
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Geocaching and EarthCaching

Peter Robinson

Being invited to write an article for *The North West Geologist* before ever having seen a copy of it might be likened to putting the cart before the horse, but in a way that might be considered analogous to my introduction to geology as a whole.

My active fascination with things geological, you see, arose essentially from a location-based outdoor activity called *geocaching* and from there became more focused on one aspect of that activity, an *Earth Science*-centred aspect called *EarthCaching*.

What is geocaching?

The most commonly given simple explanation is that it's *using multi-million dollar satellites to hunt for Tupperware® in the woods*, but in some ways those parts of it are incidental to the investment in simple exercise, the enjoyment of nature, the exploration of the great outdoors and, for me and others, the opportunity to learn fascinating things about our planet that had previously been inaccessible or outside the realm of everyday experience.

The website that might be considered the glue which holds the pastime together is *geocaching.com*, which today is a commercial enterprise, but the pastime itself has always been fuelled entirely by a community of willing volunteers hiding geocache containers (and setting up EarthCaches) in the outdoors for other community members to find.

A little bit of history

Most cars built today come with Satellite Navigation (SatNav) built in as standard, reducing our reliance on maps to get from A to B and even guiding drivers to the least congested roads. A common misconception is that there are satellites above our heads tracking our locations. The satellites are up there, but they aren't tracking us. In fact those satellites aren't actually tracking anything. The truth is that each of them consists of little more than a very accurate clock and a radio transmitter.

A constellation of around 24 satellites in geostationary orbits around the Earth constantly broadcast their individual time signals. Down on Earth, portable GPS receivers pick up these signals and, by comparing the time taken by each signal to reach the receiver and then applying some clever mathematics, are able to work out that receiver's geographical location and altitude using the age-old method of *triangulation*.

Today GPS navigation technology is fairly ubiquitous, found in all manner of vehicles and in small, handheld devices including the average smartphone. We can measure our location anywhere in the world to within a few metres and navigate to our target destination with relative ease – which is fuel for the development of location-based recreational activities, like *geocaching*.

The end of selective availability and the birth of geocaching

The *Global Positioning System* (GPS) is owned by the United States Government and operated, these days, thanks to President Trump, by the United States Space Force!

GPS was originally limited for use by the US military, and any potential use by civilians was, at that time, artificially degraded by *selective availability* such that even if said civilians could get their hands on the necessary equipment, their ability to use it to establish their location was frustrated by inaccuracy and instability.

By all accounts though, with a little effort and determination, correcting for this instability was a fairly trivial matter due to the algorithmic mechanism used to introduce it in the first place.

In any case, the US government later chose to remove these limitations and on 2 May 2000, at approximately midnight, eastern savings time, *selective availability* was switched off and the ability to use GPS to accurately measure location became accessible to anyone with the requisite equipment.

Now, said the White House, anyone could ‘precisely pinpoint their location or the location of items (such as a game piece) left behind for later recovery.’ How right they were.

By 3 May 2000, Dave Ulmer, a computer consultant and GPS enthusiast had hidden a *navigational target*, a black bucket containing a logbook and pencil and some small prizes including videos, books, software and a slingshot in the woods at Beavercreek, Oregon, near Portland, USA. Then he posted the details on an Internet GPS user’s group, calling the idea the *Great American GPS Stash Hunt*.

Within three days, two different group members read about his stash on the Internet, used their own GPS receivers to find the container, and shared their experiences online. Throughout the next week others, excited by the prospect of hiding and finding stashes, began hiding their own containers and posting coordinates. Like many new and innovative ideas on the Internet, the concept spread quickly.

Within a month the first person to find Ulmer’s stash, Mike Teague, began to collate online bulletin board posts relating to GPS stashes around the world, and their coordinates, and to document them on his personal home page. This in turn led to the creation of an online mailing list and the discussion of a specific name tailored to this rapidly developing recreational activity and thus, the activity came to be known as *geocaching*.

By the time Teague, together with Seattle-based web developer Jeremy Irish had created *geocaching.com* and announced it to the world on 2 September 2000, there were 75 known geocaches in existence.

Today there are more than three million active geocaches worldwide, in 191 different countries on all seven continents (even Antarctica). There are over 361,000 geocache owners throughout the world and geocachers* (or cachers) gather at over 36,000 events annually to share stories and ‘cache together’.

*Non-geocachers are known colloquially as *muggles*.

Geocaches – what do they look like?
All sorts of containers are used for geocaching and many ways of camouflaging and hiding them but the basic geocache typically starts with an inexpensive waterproof container (Figure 1).

The contents of this geocache include the yellow logbook which finders sign as a record of their find – and there's often a writing implement in the geocache for this purpose – although it's commonly accepted in the geocaching community that you're not a proper cacher without a pen.

Figure 1: A typical geocache and its contents

A geocache of adequate size may contain trinkets – known as SWAG. The rule for SWAG items is that if you take something, you replace it with something of equal or greater value – *trade up, trade even or don't trade at all*.

In essence the basic geocache recipe contains the same handful of ingredients today as Dave Ulmer's black bucket back in May 2000.

Finally, in this cache, we see a metal *Travel Bug* – a tag with a unique number which allows it to be tracked as cachers move it from geocache to geocache. Other trackables include custom *geocoins* – although these are increasingly rare in the wild. Trackable owners may set a *mission* for their trackable i.e. to visit specific places or specific geocaches – or even to race against other trackables.

Geocaches – where are they?

As mentioned earlier, geocaches can be found on every continent and in almost every country, from mountain tops to sea beds – and even on the International Space Station. The small map extract (Figure 2) shows a number of geocaches around Hanson Cement's Ribblesdale works, Clitheroe, where members of GeoLancashire hold their regular meetings.

Figure 2: Map showing geocaches in the Clitheroe area

The green icons represent geocaches that I haven't found yet. The grey icon represents a Geocache that's been temporarily disabled by the owner, pending maintenance. The smiley faces are the ones I have found. Every time you find a geocache/complete an EarthCache, its map icon turns into a smiley face.

What are EarthCaches?

EarthCaches are similar to other geocaches in some ways but different in others. EarthCaches represent a partnership between The Geological Society of America (GSA) and geocaching.com's parent company, Groundspeak.

During a GSA meeting in 2003, one member mentioned to the executive the idea of getting involved in geocaching. One stumbling block to this project was the fact that many USA national parks are very much against the idea of people leaving plastic containers behind, considering them trash.

Park managers were much more accepting though of the idea of a type of Geocache which centred not on hiding and finding containers but on educating people about the geology already present on site, and so the EarthCache was born.

The then GSA Director of Education and Outreach, Gary Lewis, geocaching handle *geoaware*, set the first EarthCache with his daughter in New South Wales, Australia. It is still live at http://coord.info/GCHFT2.

In Gary's words:

> "*An EarthCache is a site that you go and visit and undertake an educational task to learn something about the Earth. So the treasure, if you like, is the place that you visit rather than being the container. There's no logbook you sign but by undertaking an educational task related to the Earth Science of the site is how you actually prove that you have been there to log your site*."

Creating an EarthCache

Essentially, anyone with an account on geocaching.com can use it to create an EarthCache, but there are written guidelines and a structured framework and processes in place to ensure each EarthCache published meets certain standards in terms of being educational, technically correct and in accordance with the current scientifically accepted thinking of the day.

An EarthCache must provide an *Earth Science Lesson* (ESL) which is sufficiently complete that the related *Logging Tasks* (questions to be answered) can be completed without any requirement for additional research.

In simple terms, the information on the EarthCache page must be sufficient to allow a person with no previous geological knowledge and a reading age of 14 years, to navigate using a GPS enabled device to a location. They can then understand specific geological feature(s) at that location enabling them to complete the logging tasks i.e. answer the related questions set by the EarthCache owner (ECO).

Each EarthCache 'finder' completes the process by relaying their correct answers back to the ECO, demonstrating that learning has taken place, and then logging their experience online at geocaching.com.

Logs can include text, photographs and hyperlinks and provide both valuable feedback to ECO's and a lasting record of the finder's experience.

Peer review

All geocaches are reviewed by a team of volunteer reviewers, usually with local knowledge, prior to publication. These volunteer reviewers are typically active geocachers themselves, although they have a player account with its own identity separate from their reviewer account.

EarthCaches are reviewed by specialist reviewers, known as '*Geoawares',* equipped with the necessary background knowledge and resources to ensure EarthCaches are published only when they meet the requirements of all the appropriate guidelines, including explicit landowner permission where required as in the case of, for example, nature reserves and Sites of Special Scientific Interest (SSSI).

While many EarthCache owners are enthusiastic amateurs with no academic background in geology, there are also some qualified and experienced geologists, some of whom practise geology in a vocational capacity and some who are professional geoscience educators. The review process helps to ensure that every EarthCache published meets the required standards.

It should be noted that geocache/EarthCache review processes don't actually involve site visits by volunteer reviewers. Review processes are completed remotely, relying on online resources including maps and satellite and street-level location views, and on clear and adequate information from the cache owner.

Finding an EarthCache

By now, you'll no doubt already have a pretty good idea of how to go about 'finding' an EarthCache and what to expect from the related documentation (the Earth Science Lesson on the EarthCache page) but there's other useful information that can be provided on that page which can contribute toward and guide preparation for a safe and pleasant experience.

Every geocache, including the EarthCache type, is rated by its owner for *Difficulty* and *Terrain* in a combination known as the *D/T Rating*. For EarthCaches the D rating is a rough measure of the difficulty of understanding/interpreting the geology through field observation and the use of the ESL provided. For other cache types the D rating relates to the difficulty of, among other things, finding the hidden (often camouflaged) container or solving a puzzle in order to obtain the cache coordinates in the first place.

The T rating on all geocache types relates to the difficulty of getting to the cache location – known as *Ground Zero* in geocaching parlance. Some geocaches are in more difficult to reach places and may involve a long hike over challenging terrain or even require specialist skills or equipment but there are also plenty of more accessible geocaches and EarthCaches – including wheelchair accessible and urban settings.

The cache owner may provide additional waypoints on the cache page in the form of GPS coordinates. These waypoints might help with navigation, pointing out stiles and bridges for example, or the route of a Public Footpath or the best location for parking. The page for a geocache with more than one stage will include additional waypoints for those stages.

Optionally, the cache owner may add up to 12 *attribute* icons to the cache page from a selection of over 70, to provide extra guidance in an easy-to-read format i.e. wheelchair accessible, hike length, special equipment requirements, time restrictions and even the requirement for scuba gear.

Tools of the trade

Getting started with Geocaching/EarthCaching is easy and relatively inexpensive and if you have a GPS enabled smartphone, either iPhone or Android, your essential tech requirements are pretty much covered. After that it's pretty much a case of downloading the appropriate geocaching app and signing up for a free account*.

If you already have a dedicated hand-held GPS receiver and would prefer to use that, sign up for a geocaching account at www.geocaching.com, browse the online maps for the appropriate details for your chosen Geocache/EarthCache target, enter the coordinates on your GPS and you're off.

* Geocaching.com also offers a Premium Member account for a quarterly/annual subscription. This doesn't necessarily provide access to better Geocaches, but does provide better tools for locating those matching specific criteria and for downloading them to your handheld device for offline use.

A few examples

It would seem appropriate, in closing, to include for reference an example of the form and content of a typical EarthCache page. In fact in the strictest sense, there is no such thing!

As long as the page contents, the Earth Science Lesson and the Logging Tasks, meet with official guidelines as enacted by the GeoAwares' review process, the content of the page itself is limited only by the EarthCache owner's imagination, literary and editorial skills.

It should be noted though that meeting those guidelines is no trivial task. The prospective EarthCache owner must assume that the reader has *no prior geological knowledge,* which can and often does lead to some EarthCache pages being rather wordy, mainly in order to ensure that the Earth Science Lesson is substantial enough to support successful completion of the EarthCache by geologists and non-geologists alike.

Finally, I include several captioned examples where the caption includes a short Internet hyperlink to the associated EarthCache page for those interested in further reading and exploration.

Peterloo Memorial, Manchester https://coord.info/GC8C9RY

Liverpool: weathering or erosion?   https://coord.info/GC744T7

Cross Hill Quarry, Clitheroe   https://coord.info/GC5XBNA

Lakeland Lava: Bowder Stone, Borrowdale
https://coord.info/GC1VA2W

King of the castle, Borrowdale https://coord.info/GC4RZGA

Recent borings in glacial erratics (Carboniferous Limestone), Cleveleys, Lancashire

Stephen K. Donovan

Donovan, S.K., 2020. (for 2019). Recent borings in glacial erratics (Carboniferous Limestone), Cleveleys, Lancashire. *The North West Geologist*, 21.

Abstract: Domichnial (dwelling) borings are a common feature of Recent litho- and bioclasts around Britain's coasts. At Cleveleys, Fylde, Lancashire, a rich and varied selection of clasts, dominated by glacial erratics from the Lake District, includes Carboniferous limestones and disarticulated oysters. Common domichnia are *Caulostrepsis* isp. cf. *C. taeniola* Clarke and *Entobia* isp. or ispp.; much rarer is *Gastrochaenolites turbinatus* Kelly and Bromley. The likely producers of these spoor are spionid annelids, clionaid sponges and boring bivalves, respectively. Infestations of *Caulostrepsis* and *Entobia* may be coeval, not boring into each other, but not invariably. This trinity of domichnia – *Caulostrepsis*, *Entobia* and *Gastrochaenolites* – are indicative of the *Trypanites* ichnofacies, but are allochthonous, driven onshore during storms. This trinity is well-known in the fossil record, and in modern assemblages on the coasts of the southern and western North Sea.

Introduction

Modern traces of organic activity are transient and may last only days, hours or less. Consider the structures made on any beach every day. Burrows, footprints and trails are destroyed by wave action and overprinting by other trace-making activity after the producer has moved on or died. Yet, once a burrow or trail enters the rock record, lithification 'freezes' this evidence of activity in its final form. It can now be studied at leisure by the palaeoecologist and ichnologist, having been removed from the ephemeral to the permanent.

Borings are an entirely different proposition. A fossil boring may be well-preserved, but it is rarely so easy to collect as a bored clast on a beach. A modern boring may not be complete, due to degradation of clasts by abrasion and corrosion (= corrasion *sensu* Brett and Baird, 1986, p.214), but it is freely available for study through all possible angles, may preserve the producing organism or post-boring inhabitants (squatters) (for example, Donovan, 2017, figs 2A, B and 3A-H, K, respectively), can be present in large numbers and can be moulded by various means (liquid latex rubber, Plasticine or many alternatives) (Donovan, 2017, figs. 3I, 3J).

The best place to look for modern borings is on the beach and the best substrates are various, but include shells and wood, and clasts of peat (Donovan, 2013), limestone and mudrock. Herein, the Recent borings of a beach site in north-west England are examined with the eye of a palaeontologist in order to glean ichnosystematic and ecological data that may be of relevance to the fossil record.

Figure 1: A view north from high on the beach at Cleveleys, Fylde, Lancashire. The outline of the peaks of the Lake District is plainly visible; it is a sunny, near-windless day in late December and the Irish Sea is particularly calm. The cobbles on the beach are obvious and diverse, a marvellous place for geological beachcombing.

Locality, horizon, material and methods

Cleveleys, north of Blackpool, in Fylde, Lancashire, has a coastline trending north-south and fronting the Irish Sea. The south end of the present study [about NGR SD 312 430] was easily reached by a short walk from the Cleveleys stop of the Blackpool to Fleetwood tram (Donovan, 2021, fig.48.1). Trending north towards Rossall Beach [NGR SD 313 444], the beach, particularly in its upper parts adjacent to the sea wall, has an abundance of cobbles and pebbles of diverse lithologies. At least some of these are erratics reworked out of glacial deposits, particularly the upper till *sensu* Cripps *et al*. (2016, p.7), and derived from the Lake District (Ellis, 1968, p.144), Figure 1.

All the erratics considered herein are limestones and are considered to be Lower Carboniferous (Mississippian). The dome of the Lake District has major outcrops of Mississippian limestones on all sides except to the west (Moseley, 1978, pl.1; Smith, 2010, fig.64; Murphy, 2015). Although there are limestones within the Lower Palaeozoic of the region, these are relatively minor lithologies and are unlikely to be represented in the present collection. Further, the rare identifiable fossils in limestone clasts from Cleveleys are Mississippian colonial corals such as *Syringopora* sp. and lithostrotionids (Donovan, 2021, fig.48.4).

The borings described are distributed between a collection of 39 bored limestone clasts and oyster valves, RGM.1332343 to 1332381. These are registered in the collection of the Naturalis Biodiversity Center, Leiden, the Netherlands (prefix RGM).

With only two exceptions, specimens did not receive any preparation between collection and photography. The exceptions were the two specimens of *Gastrochaenolites*, which were cast using red liquid latex (Feldmann *et al*., 1989). These casts were the only specimens to be whitened for photography. All photography was by a Canon G11 digital camera.

Systematic ichnology

Remarks: Most borings considered herein are in limestone clasts and are illustrated in Figures 2-6. Borings in oyster valves are described separately and shown in Figure 7.

Caulostrepsis Clarke, 1908

Type ichnospecies: *Caulostrepsis taeniola* Clarke, 1908, p.169, by monotypy (Häntzschel, 1975, p.W124).

Diagnosis: See Häntzschel (1975, pp. W124, W126).

Producing organism: Mainly annelids of the family Spionidae (such as *Polydora* spp., common around the coast of the British Isles; Yonge, 1969), but also other polychaete worms (Bromley, 2004, p.460).

Range: Devonian to Recent (Bromley, 2004, p.460).

***Caulostrepsis* isp. cf. *C. taeniola* Clarke, 1908** (Figures 2A-C, E, F; 3B, C, E; 4C, E)

Material: Thirteen limestone clasts, RGM.1332343 to 1332355, also present in certain clasts listed under *Entobia* isp., such as RGM.1332356, 1332359, 1332363 and 1332368. *Caulostrepsis* isp. cf. *C. taeniola* Clarke is numerous in most of these specimens.

Description: Gregarious. Most commonly apparent as small, slot-like boreholes, elliptical to figure-of-eight shaped. Close examination shows that the shaft is divided by a central, longitudinal vane. Where the boring is exposed in longitudinal section, it is U-shaped, Figure 2E.

Remarks: Many, most, perhaps all these borings are likely to be the type species, *Caulostrepsis taeniola* (for diagnosis, see Bromley and d'Alessandro, 1983, p.287). However, almost all specimens are only seen in transverse section (this is probably not the true aperture due to corrasion) which is inadequate for confident identification to ichnospecies. Note that this is a shallow boring and loss of even a short length of anterior boring by corrasion will remove much of the trace.

Careful examination of these specimens demonstrates that these *Caulostrepsis* show site selectivity. The presence of common dense infestations of these borings, Figures 2A, B, E, F; 3B, C, E; 4C, suggests that early settlers secrete a species-specific organic molecule into the water that attracts unsettled larvae, a common feature of many sessile marine borers and encrusters, such as acorn barnacles (see, for example, Buschbaum, 2001, p.132 and references therein).

Caulostrepsis penetrates some *Entobia*, Figure 3B, but not others, Figures 2D; 3C, E; 4B. This suggests that many *Caulostrepsis* – *Entobia* associations were coeval and the producing organisms were living in close association. Where *Caulostrepsis* penetrates *Entobia*, presumably the sponge producing the *Entobia* was dead at the time of infestation by the former. *Caulostrepsis* also shows avoiding behaviour in relation to certain features of the rocks, such as vein calcite, Figure 2F.

***Entobia* Bronn, 1837**

Type ichnospecies: *Entobia cretacea* Portlock, 1843, p.360, by the subsequent designation of Häntzschel (1962, p.W230), from the Campanian(?) of Magilligan, Co. Londonderry, Northern Ireland, UK (Bromley 1970, p.78).

Diagnosis: See Donovan and Portell (in press), slightly modified after Bromley and d’Alessandro (1984, p.238).

Producing organism: Sponges, mainly members of the family Clionaidae (Bromley, 2004, p.459).

Range: Jurassic to Recent (Bromley, 2004, p.459).

***Entobia* isp. or ispp.** (Figures 2D, 3C-F, 4A-D, F, 6)

Material: Sixteen limestone clasts, RGM.1332356 to 1332368 and 1332379 to 1332381, also present in certain other clasts, such as RGM.1332347 (Figure 2D) and 1332371 (Figure 6). *Entobia* isp. is numerous in most of these specimens.

Description: The appearance of *Entobia* isp. is highly variable, partly due to differences in the style of preservation and because of differences in maturity of sponge colonies which can radically change the morphology (Bromley and d'Alessandro, 1984). Surfaces that are essentially uncorraded since infestation are perforated by numerous apertures, Figures 3F, 4D. Corrasion only needs to remove the outer few mm of a clast to reveal the complexities of the 3D structure of the sponge borings (examples include Figures 2D, 3C-E, 4A, B). Most specimens appear to be mature, chambers having grown to be in lateral contact. In maturity, some chambers still appear to be spherical, Figures 2D, 6; they may have coalesced to produce a branching, tubular structure, Figure 4B; and some have reached the stage of a 3D meshwork, Figure 4A. A rare exception is RGM.1332357, Figure 3D, in which chambers are still linked by slender lateral canals, with a more mature colony towards the top of the page.

Remarks: *Caulostrepsis* and *Entobia* are the two most common ichnotaxa in the limestone clasts at Cleveleys. The developmental differences between separate specimens of *Entobia* are difficult to assign to ichnospecific rank. As noted by Donovan and Portell (in press), "These indeterminate specimens combine intense weathering and poor preservation in an ichnogenus with extreme ontogenetic variations between the juvenile and the gerontic, under the direct influence of substrate form", that is, limestone clasts vs oysters.

Gastrochaenolites Leymerie, 1842

Type ichnospecies: *Gastrochaenolites lapidicus* Kelly and Bromley, 1984, p.797, designated therein, from the Basal Spilsby Nodule Bed, Spilsby Sandstone, Middle Volgian (Upper Jurassic) of Nettleton, Lincolnshire, England.

Diagnosis: See Donovan and Ewin (2018, p.106), modified after Kelly and Bromley (1984, p.797).

Producing organism: Mainly endolithic bivalves, but certain gastropods and sipunculan worms produce similar borings (Bromley, 2004, p.462).

Range: Mainly Jurassic to Recent, but extending back to the Ordovician (Bromley, 2004, p.462).

***Gastrochaenolites turbinatus* Kelly and Bromley, 1984** (Figure 5)

Material: Two bored limestone clasts, RGM.1332369, Figures 5A, B and 1332370, Figure 5C.

Diagnosis: See Kelly and Bromley (1984, p.803).

Description: RGM.1332369 is a small clast (*c*.50 mm maximum dimension) preserving the bases of seven *G. turbinatus* on one surface, Figures 5A, B; identifiable borings on the reverse surface are *Caulostrepsis* isp. and a single, shallow base of *G. turbinatus*. All *Gastrochaenolites* in this clast are very incomplete. Borings smooth with well-rounded bases and a chamber tapering gently towards the aperture (not preserved).
RGM.1332370 is a larger clast (*c*.132 mm maximum dimension) strongly infested by *Entobia* and *Caulostrepsis* with a single, moderately well-preserved *G. turbinatus*. The latter is incomplete, but *c*. 20 mm in length and widest (*c*.8 mm) just above the domed base. There is no obvious division between the chamber and the neck; the boring is smooth-sided and tapering gently towards the aperture (not preserved). The slightly 'warty' appearance of the latex mould is presumably an effect of cross-cutting shafts of *Entobia*.

Remarks: *Gastrochaenolites turbinatus* is a rare boring at this site. Whereas *Caulostrepsis* and *Entobia* were both common, and only the best preserved specimens were collected, only two clasts were found with *G. turbinatus*. RGM.1332369 preserves a suite of borings that are all very incomplete; only RGM.1332370 is sufficiently complete that a confident ichnospecific assignment is possible. But comparison of all specimens shows that they are conichnospecific.

Shelly infestations of *Entobia* isp. (Figure 6)

Material: A corraded limestone cobble, RGM.1332371, Figure 6, with shelly invertebrates preserved in depressed chambers.

Description: A limestone cobble (*c*.113 mm maximum dimension) whose corraded surface exposes a mature infestation of *Entobia* isp. which is irregularly exposed (Figure 6A). Chambers are large and in close association, exposed as scalloped channels. These channels preserve evidence of two invertebrate taxa which infested hard substrates. The acorn barnacle, *Balanus* sp., is preserved as gregarious associations of basis plates (Figure 6C). Less common are bryozoan colonies (Figure 6B).

Remarks: This cobble must have lost a few mm of its outer surface to expose the *Entobia* isp. within (Figure 6A); of course, the same is true of all cobbles considered herein (see 'Discussion'). The borings are not deep, but provided sufficient protection for barnacles and bryozoans to preferentially infest them.

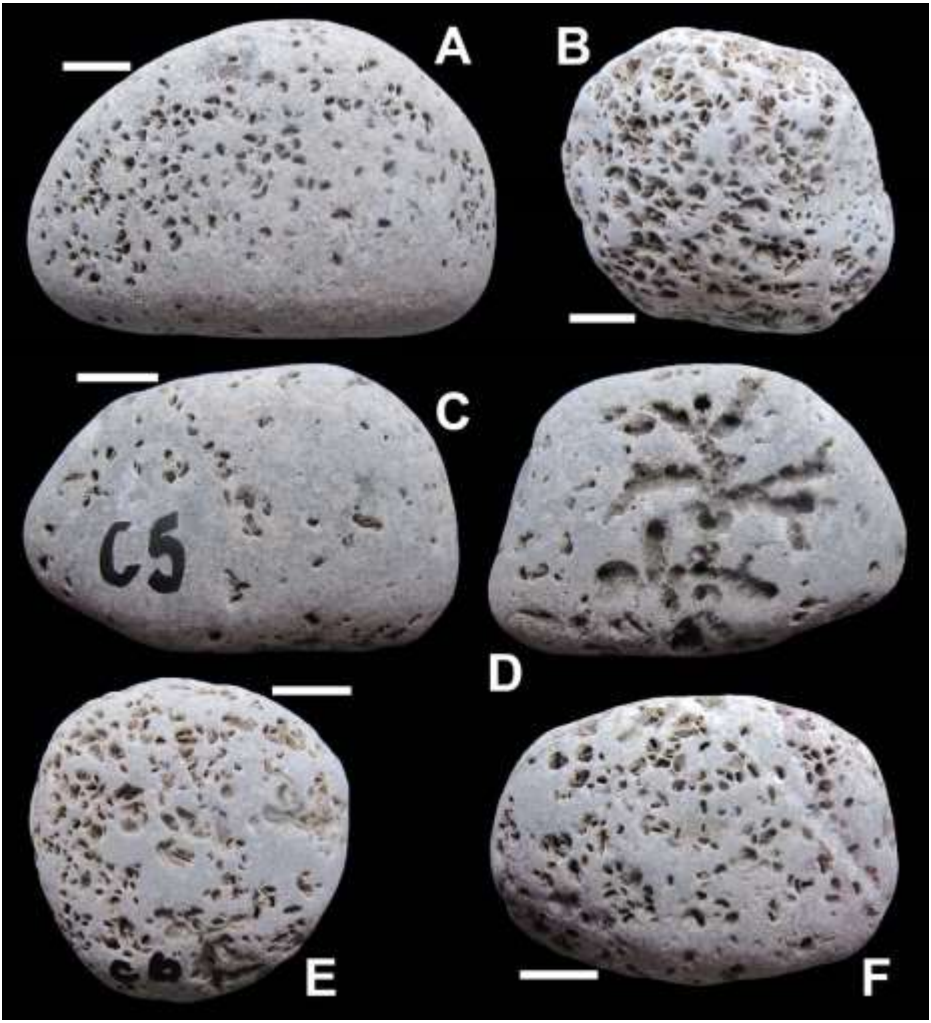

Figure 2: Mainly *Caulostrepsis* isp. cf. *C. taeniola* Clarke, 1908.
(A) RGM.1332343, cobble with common *C. taeniola* seen mainly in cross-section, borings appearing slot-shaped or a figure-of-eight. (B) RGM.1332346, cobble densely infested, but with obvious areas free of borings. (C, D) RGM.1332347, two sides of a cobble, one with sparse *Caulostrepsis* (C) and the other with mainly mature *Entobia* isp. (E) RGM.1332348, several borings are open in longitudinal view, showing parallel borings separated by a central vane and, towards 2 o'clock, the U-shaped termination. (F) RGM.1332351, borings in the limestone, but not in the calcite veins, such as top centre to 4 o'clock. Specimens uncoated. Scale bars represent 10 mm.

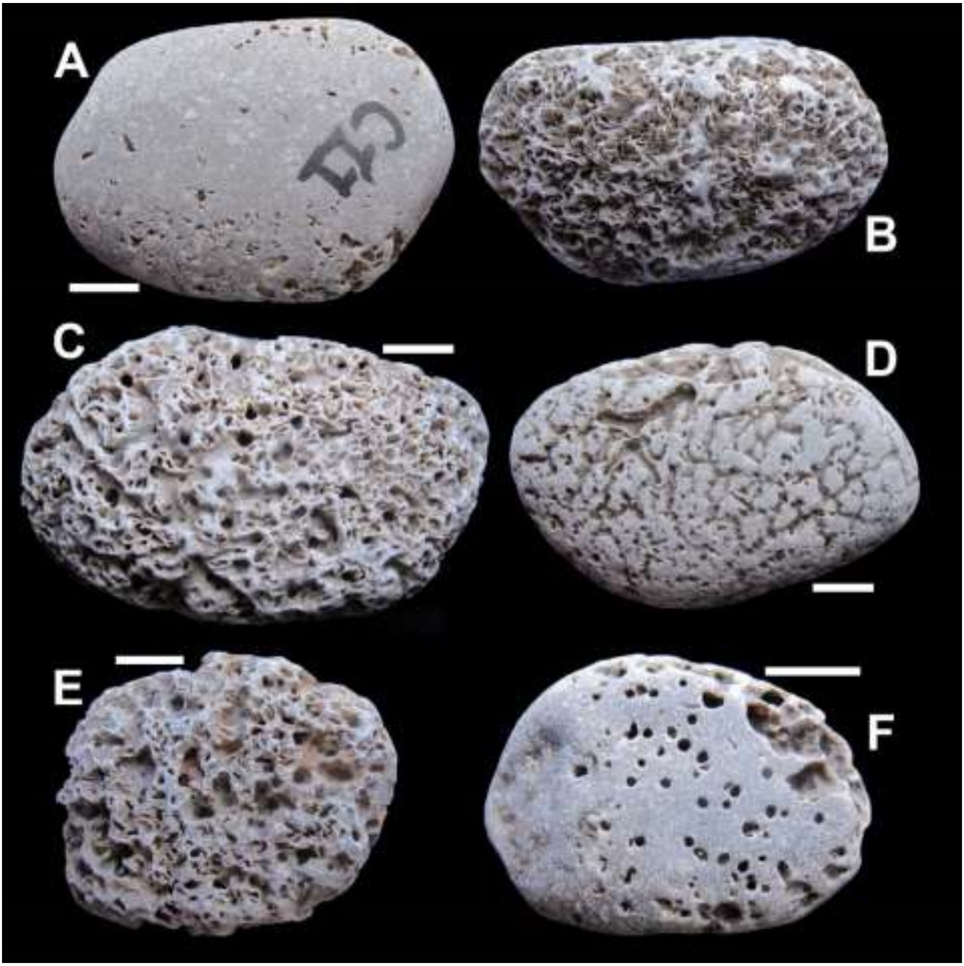

Figure 3: *Caulostrepsis* isp. cf. *C. taeniola* Clarke, 1908 (A-C, E) and *Entobia* isp. (C-F). (A, B) RGM.1332353, two sides of a cobble, sparsely (A) and intensely bored (B). (C, E) RGM.1332356 and 1332359, respectively, numerous *Caulostrepsis* that do not bore into mature *Entobia* isp. (D) RGM.1332357, well-exposed, colonial boring system, the outermost few mm of limestone having been lost through corrasion; more mature borings towards top. (F) RGM.1332360, mainly apertures of sponge colony. Specimens uncoated. Scale bars represent 10 mm.

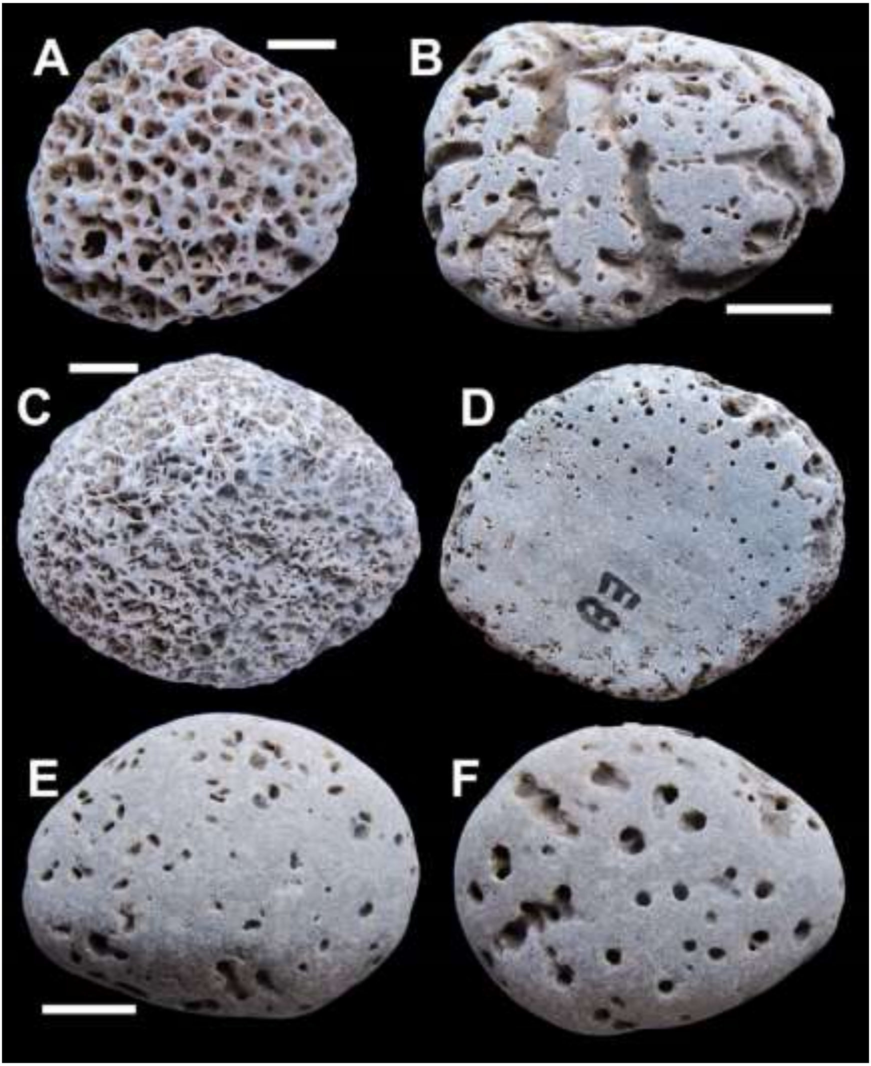

Figure 4: Mainly *Entobia* isp. or ispp. (A) RGM.1332362, densely infested clast in which boring has produced a 3D lattice-like structure. (B) RGM.1332380, mature colony in which chambers have coalesced to form broad channels. (C, D) RGM.1332363, two sides. The more convex surface (C) is densely infested by *Entobia* isp. and *Caulostrepsis* isp. cf. *C. taeniola*, probably coeval. The flatter surface (D) is perforated by apertures of *Entobia*.
(E, F) RGM.1332368, cobble dominated by *Caulostrepsis* on one surface (E) and *Entobia* on the opposite side (F). Specimens uncoated. Scale bars represent 10 mm.

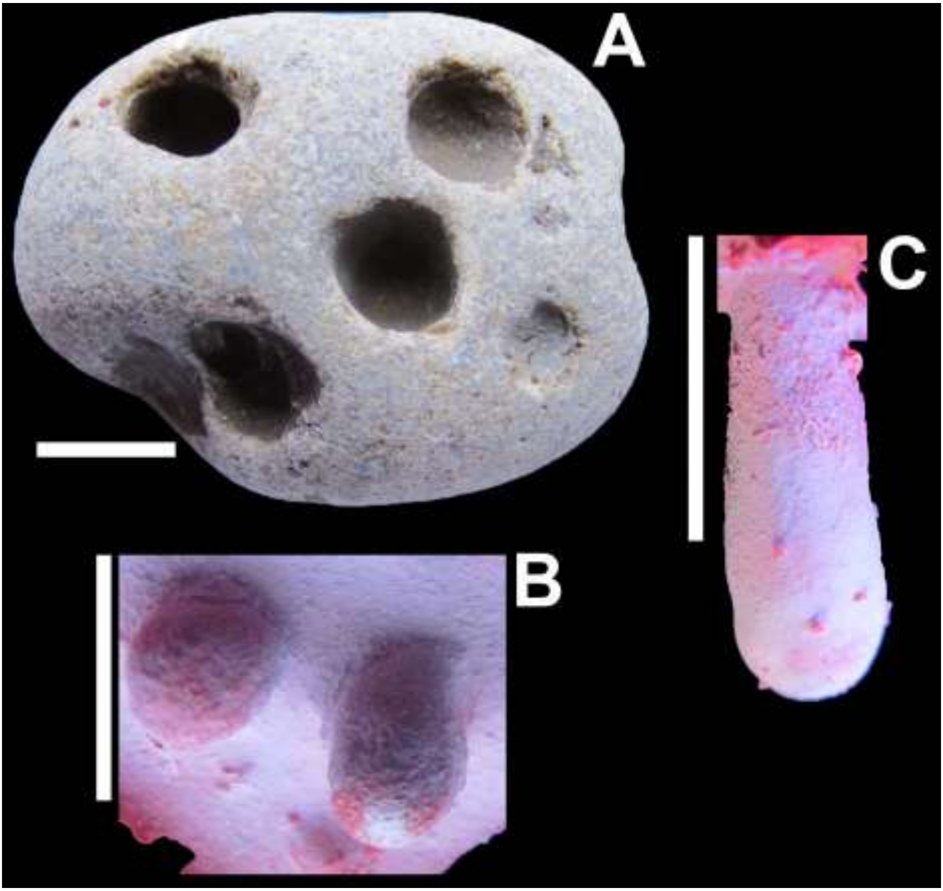

Figure 5: *Gastrochaenolites turbinatus* Kelley and Bromley, 1984.
(A, B) RGM.1332369. (A) Surface with shallow remnants of bivalve borings.
(B) Latex moulds of two of the more complete borings on this surface.
(C) RGM.1332370. Latex mould of the most complete boring of *G. turbinatus*.
Latex moulds coated with ammonium chloride. Scale bars represent 10 mm.

Figure 6: RGM.1332371, corraded limestone clast with remnants of a mature *Entobia* isp. that has provided protected environments for encrusting invertebrates. (A) Surface of clast. Scale bar represents 50 mm. (B) Bryozoan colony encrusting ‘scalloped’ chambers of *Entobia*. (C) Basis plates of *Balanus* sp. encrusting ‘scalloped’ chambers of *Entobia*. Specimen uncoated. Scale bars represent 10 mm unless stated otherwise.

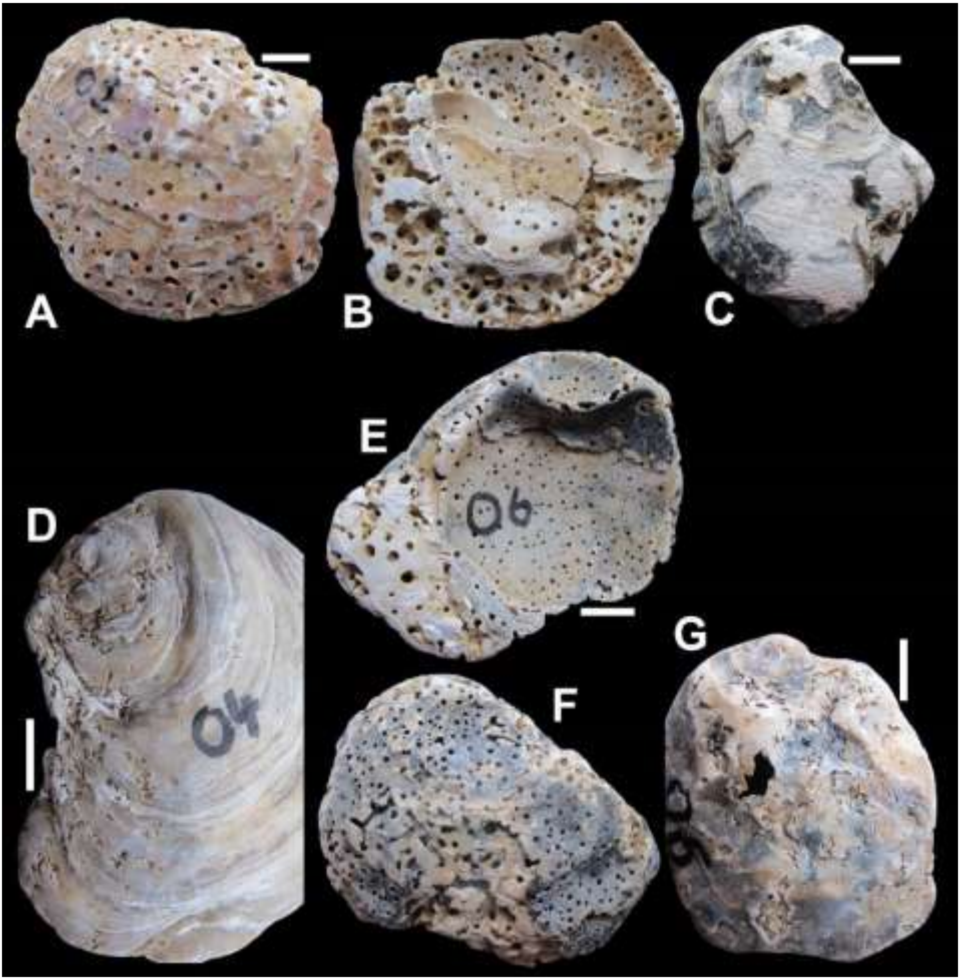

Figure 7: Bored oysters, *Ostrea* sp., all free valves. (A, B) RGM.1332372, outer and inner surfaces, respectively, of a valve densely infested by *Entobia* isp. (C) RGM.1332373, corraded, chalky valve with poorly preserved *Caulostrepsis*? isp. and *Gastrochaenolites*? isp. (D) RGM.1332375, external surface of valve densely infested with *Caulostrepsis* isp. cf. *C. taeniola* Clarke. (E, F) RGM.1332377, inner and outer surfaces, respectively, of a valve densely infested by *Entobia* isp. (G) RGM.1332378, valve with *Caulostrepsis* isp. cf. *C. taeniola* Clarke and bryozoans. The latter are on both the outer shell surface and growing into exposed borings. Specimen uncoated. Scale bars represent 10 mm.

Borings in oyster valves (Figure 7)

Material: Seven bored oyster free valves, *Ostrea* sp., RGM.1332372 to 1332378, Figure 7.

Remarks: On a beach so rich in cobbles and pebbles, disarticulated bivalves are unexpectedly moderately common, most notably cockles, razor shells and oysters. The last are robust enough to be infested by borers after death and disarticulation, particularly by *Entobia* isp., Figure 7A, B, E, F, and *Caulostrepsis* isp. cf. *C. taeniolar*, Figure 7D, G. No *Gastrochaenolites sensu stricto* were noted infesting oysters, although they are known from Recent and fossil oysters elsewhere (such as Donovan *et al*., 2014). However, RGM.1332373, Figure 7C, is slightly different from the other specimens and has slender, elongate, straight borings both through and laterally into the valve. These are assigned, provisionally, to *Gastrochaenolites*? isp. mixed in among *Caulostrepsis*? isp. The boring through the valve in left centre of Figure 7C is lined with calcite.

Discussion

The most important insight into the significance of these borings is provided by comparison with the conclusions of Donovan *et al*. (2018, 2019). The three ichnogenera documented above, namely *Caulostrepsis*, *Entobia* and *Gastrochaenolites* are a common association today on the coasts of the southern and western North Sea, and English Channel (Donovan *et al*., 2018, 2019). Thus, this association is now extended into the Irish Sea. Similarly, they occur together in the fossil record of many areas (such as Farinati, 2007; Santos *et al*. 2010, 2011; Donovan *et al*., 2014). These three ichnogenera have the advantage that they can be easily identified by the novice ichnologist. They form part of the suite of allochthonous ichnotaxa forming the *Trypanites* ichnofacies, indicative of a bioerosional, domichnial assemblage in a rocky setting (Santos *et al*., 2010) and, in this example, transported onshore by wave action. The bored clasts are, of course, mobile and the borings are indicative of environments in the shallow shelf offshore Lancashire. The clasts were washed onshore by during major storms.

What has been missed, if anything? At least some of the surfaces discussed herein are ichnologically somewhat 'busy' (such as Figures 3B, C, E; 4C). It is at least possible that some rare borings have remained undetected in these dense associations, such as the slender tunnels of *Trypanites* Mägdefrau (Häntzschel, 1975, p.W136, fig. 76). The way forward might be to examine clasts by 3D scanning technology, which would also show how borings are differentiated within a chosen cobble. Further, I was surprised to find no shells with small round holes produced by predatory gastropods, *Oichnus* isp., but a big accumulation of disarticulated valves after a major storm would likely yield examples.

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Special thanks to GeoLancashire for their company in the field on Friday, 28th December 2018. In particular both specimens of *G. turbinatus* described herein were collected by their members – thank you all so much!

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Seismic Lines and the HS2 Railway

Robin Grayson

Thousands of miles of onshore seismic lines criss-cross North-West England. Onshore seismic lines are commonly made along roads. Thumper trucks, Figure 1, transmit vibrational energy into the ground. Some of energy is bounced back by 'reflectors' to the surface and detected by a string of geophones, Figure 2. Each geophone converts ground movement (velocity) into voltage, which is recorded on a Recording Truck. Repeated many times, computers calculate the 2-way travel time akin to 'Hello-*hello*' across a canyon.

Figure 1: Thumper Trucks passing quietly along a rural road. *photo: Mark Abbott*

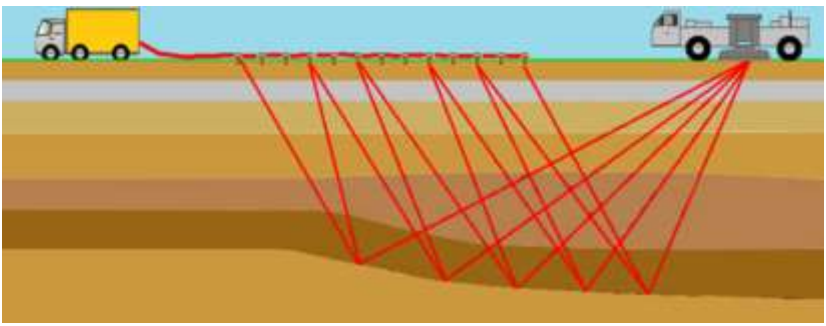

Figure 2: Vibrations from a Thumper Truck are reflected and recorded by geophones.

UK Onshore Geophysical Library (UKOGL); a library with 50,000 miles of onshore seismic lines

UKOGL Seismic Lines are most closely packed in lowland areas, for these hold the greatest potential for discovery of onshore coal, oil, gas and potash resources.

Images copyright of the UK Onshore Geophysical Library UKOGL.

Figure 3: UK Onshore seismic lines (green) *NB: purple lines are administrative boundaries*

A dense network of UKOGL Seismic Lines exists in the Liverpool-Manchester region, Figure 3. This is largely the result of onshore oil exploration in the 1980s.

UKOGL Regional Seismic Lines

Interpreting onshore seismic lines is difficult, even for skilled geophysicists. The good news is that UKOGL includes a selection of seismic lines (green), strung together to make **Regional Seismic Lines** (purple) already interpreted for you, Figure 4. This huge cooperative effort chose ‘picks’ of the best seismic reflectors in boreholes for oil and gas, and mines for coal and potash. One line, Figure 4, threads its way from Whitmoor in the Lancaster Fells across the Fylde to Hesketh, Formby to Croxteth and down to Knutsford in the Cheshire Basin and beyond.

Images strictly copyright of the UK Onshore Geophysical Library UKOGL.

Figure 4: Map of UKOGL Regional Seismic Lines (purple)

Generating each Regional Seismic Line from the best seismic lines linking one deep borehole to the next, the UKOGL team were able to trace ‘picks’ of key reflectors from basin to basin with some confidence. They then assigned a colour to each pick, Figure 5, – a marvellous boon to beginners and experts alike.

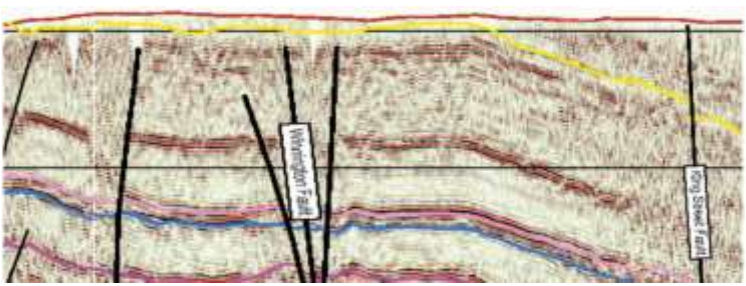

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Figure 5: A Regional Seismic Line, with each pick assigned its own colour

Where are the UKOGL Seismic Lines around Manchester?

Most seismic lines in the local area, Figure 6, are 'vintage', dating from the onshore oil and gas exploration boom in the 1980s, and British Coal efforts to find virgin coal in reach of existing mines. Hundreds of miles of UKOGL Seismic Lines crisscross the HS2 route.

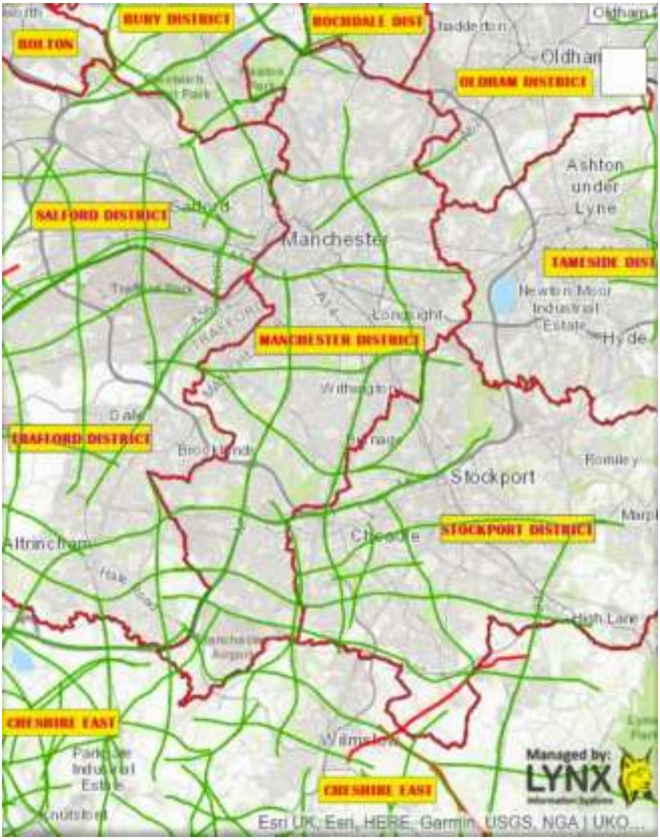

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Figure 6: Map of UKOGL Seismic Lines in and around Manchester

GREEN LINES: UKOGL seismic exploration lines for oil and gas.

RED LINES: UKOGL seismic exploration lines for coal.

UKOGL offers a set of 18 training exercises in the Manchester area to illustrate the value of 'vintage' seismic lines, themed on the final stretch of the HS2 from Rostherne Mere, along the M56, past Manchester Airport to Piccadilly Station, Figure 7.

Figure 7: Brown = UKOGL seismic lines used in training by the author

Key to Figure 7

1 East on M56 - Rostherne to Manchester Airport – AUK87A-135
2 North on M56 - Manchester Airport on Princess Parkway over HS2 Tunnel – SOV88-XL060-G
3 North on Princess Road - Princess Parkway to Mancunian Way/city centre – UK-86-431
4 East on northern perimeter of Manchester Airport – SOV87-X60-05
5 Selecting a pair of rough fault traces – again SOV87-X60-05
6 East on M60 following R Mersey to the Stockport Pyramid – SOV88-XL-060A
7 East on M60 - Stockport Railway Viaduct to central Stockport – SOV88-XL-060A/ BP82-44
8 East on the north side of Mersey from Chorlton to the Stockport Pyramid – UK-86-423
9 East from Stretford - Wilbraham Rd near Fallowfield Loop to Secret Lake, Reddish – UK-86-422
10 Discovery of the Princess Faults cutting the Permo-Triassic rocks – again UK-86-422
11 Selecting 'picks' of strong reflectors in Permo-Triassic rocks – again UK-86-422
12 Deep geothermal energy potential under Fallowfield Campus – again UK-86-422
13 South on Alan Turing Way, via Gorton Park and west to Didsbury Road – UK-86-433
14 East from Salford, under Mancunian Way to Ashton Old Rd nr Tameside – UK-86-421
15 Geothermal energy potential for HS2 Piccadilly Station development – UK-86-421
16 Northeast from city centre - Oldham Road to cross the Oldham border – UK-86-429
17 Shortest HS2 route - Airport to city centre – AUK87A-135, SOV88-XL060-G, UK-86-431
18 Archives show numerous records of methane fires/explosions in coal mines near HS2.

To download the exercises go to https://ukogl.org.uk/regional-and-government-studies/ - this is better done after you have tried the exercise below.

As an example, an exercise is presented below.

Exercise: HS2 following the M56: UKOGL Seismic Line AUK87A-135

1. Go to the UKOGL zoomable map https://ukogl.org.uk/map
2. Type 'Rostherne Mere' in the search box at top right, Figure 8. Enjoy the giddy zoom to Rostherne National Nature Reserve!!
3. Zoom in to see the green UKOGL Seismic Lines
4. Find the green line labelled AUK87A-135; click on it.
5. AUK87A-135 will automatically change from green to turquoise; a pop-up box will appear on the screen (small image in Figure 8).

You can zoom out to see the length of AUK87A-135 from Rostherne to Manchester Airport, which shows that AUK87A follows the M56 (Figure 8). The proposed HS2 route parallels the M56, so by opening AUK87A you reveal the geology under M56 and HS2.

6. Open the pop-up box for AUK87A-135, click on IMAGES (Figure 8 small image).

Figure 8: UKOGL seismic lines used in training by the author

This takes you to another screen, Figure 9, – select Colour seismic and click on View, which opens an image in a new screen.

Figure 9: Image dialog box

7. Copy and paste the image into Powerpoint or Word and crop to remove the lower half of the image, Figure 10.

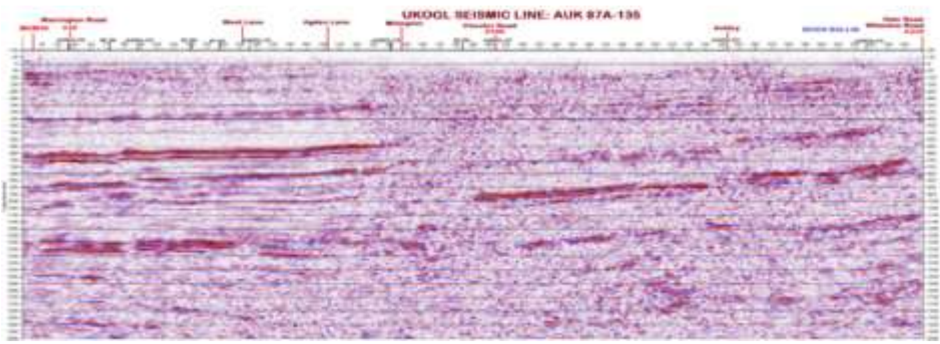

Figure 10: Seismic section.

8. To render your work of art more user-friendly, examine your TURQUOISE Seismic Line AUK87A-135 on the UKOGL map. Notice the tiny black ticks along the line, which are consecutive numbers of the 'shots fired'. Using the tick numbers as your guide, write in your notebook the tick number and the names of a few landmarks on AUK87A-135.

9.Use a suitable program (eg MS Paint) to erase the clutter and to label your chosen landmarks, Figure 11. You are now in a position to interpret the geology.

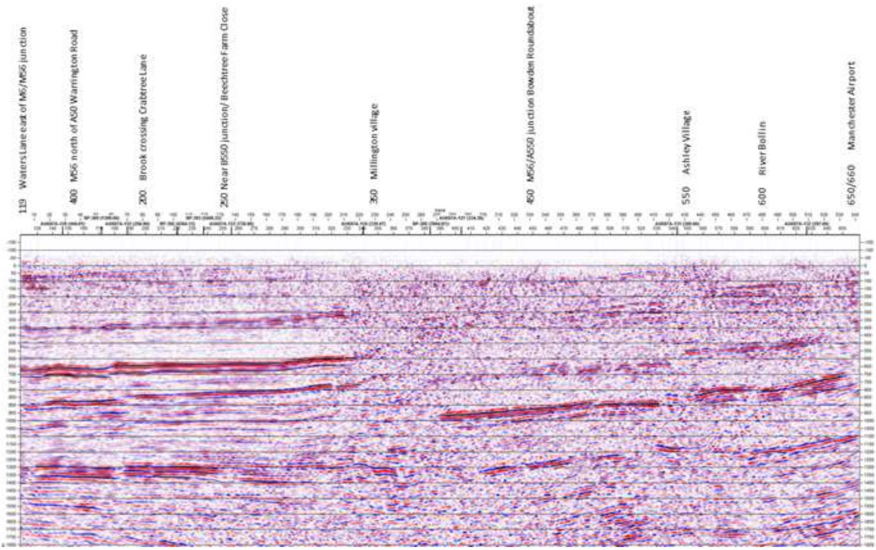

Figure 11: Annotated version of the section

Preliminary interpretation of Seismic Line AUK87A-135

Your Seismic Section, Figure 11, shows strong reflectors clearly broken by a very powerful fault and a fuzzy zone. Because the Lymm and Mobberley saltfields are nearby, the fuzzy zone is probably subsidence due to dissolving of rock salt, which created Rostherne Mere and triggered the general collapse and brecciation of the Bollin Mudstone to form the Bollin Valley. Rock salt is a low density mineral known as halite (NaCl) and famously in September 1947 a gravitational survey by Professor William Bullerwell 1954 using Eötvös' Torsion Balances confirmed the Warburton Fault near Lymm.

Risks to the M56 and HS2 include not only subsidence resulting from dissolution of rock salt, but also include potential upheaval and collapse due to expansion and dissolution of gypsum crystals from sulphate waters. Anhydrite, which is liable to expand and dissolve, may also be present.

The Bollin Breccia has been mapped at Manchester Airport by Grayson *et al.* (1997), and later in much more detail by Albert Wilson, (2003). While the argument to re-route HS2 to avoid salt subsidence areas in central Cheshire, has been made by Chris Eccles and Simon Fearnley (2018), scant attention has been paid to the gypsum hazard spelt out in BGS UK reports (Cooper 1995; Cooper *et al.* 1998, 2011). Gypsum-related subsidence is an active hazard in north Cheshire, as seen in the Bollin Mudstones, Bollin Breccia and Bollin Valley in the vicinity of Manchester International Airport.

For obvious reasons, engineers prefer to put large structures such as runways, motorways, major road bridges, canal locks and high-speed railways on the flattest ground. Too often the route is finalised without the elementary question: *"why is the ground so flat?"* being addressed. As a result, cost overruns and delays occur, and there is increased risk to the construction workforce.

Acknowledgements

The author expresses his gratitude to the UK Onshore Geophysical Library (UKOGL) for permission to publish seismic lines shown in this article. UKOGL was established in 1994 to manage the archive and the official release of onshore UK seismic data. The Library was set up at a time when the data were scattered, deteriorating and in real danger of being lost to the nation. The Library was founded to ensure that this resource was located, recovered, reconciled and saved for the national archive, and it is very effectively run by Lynx Information Services.

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A ‘new’ specimen of *Woodocrinus macrodactylus* de Koninck

Stephen K. Donovan and Brian Jeffery

Donovan, S.K. and Jeffery, B., 2020 (for 2019)**.** A ‘new’ specimen of *Woodocrinus macrodactylus* de Koninck. *North West Geologist*, **21**.

Abstract: Lost sites that formerly produced exceptional fossils may be lamented, but, rarely, specimens re-emerge from obscurity. One such specimen was formerly in the private collection of the junior author, namely the Pendleian (Mississippian; Namurian) cladid crinoid *Woodocrinus macrodactylus* de Koninck. This species is only known from the type locality, now an infilled quarry. The most complete specimen on this slab of limestone does not expose the cup, but the proximal column and, particularly, the arms are well-preserved. A second species is referred to crinoid sp. indet. and is only known from a fragment of the arms. Fragments of arms and stems of *W. macrodactylus* on the bedding plane are suggestive of energetic sedimentation of autotomized (= self-mutilated) components.

Introduction

Lost localities are a fact of geological life. Through the action of natural or man-made phenomena, what was once well-exposed and widely known may be lost to present and future generations. The most ephemeral are temporary exposures associated with engineering works (e.g., Collins, 1962), but even substantial man-made structures such as cuttings on canals, roads and railways, and quarries may be overgrown and filled in. Such sites lack the advantages of natural erosion found on, for example, coastal and river exposures to keep them fresh.

One such lost site is Mr. Wood’s quarry near Richmond, North Yorkshire, which in the 19th Century yielded the type and many other fine specimens of the cladid crinoid *Woodocrinus macrodactylus* de Koninck, 1854. The type material is in the Museum of Comparative Zoology at Harvard University (Wright, 1951, p.49). The type locality is now infilled and lost, and there have been persistent rumours among crinoid specialists of unscrupulous collectors pulling apart dry stone walls in this area in the search for further specimens. It is therefore exciting to record a hitherto unrecognised specimen of *W. macrodactylus* found by ‘accident’, albeit in a collection in Lancashire, not Yorkshire.

Locality, horizon, material and methods

The slab was formerly in the private collection of Brian Jeffery, but has been donated to the national collection of the Natural History Museum, London, registration number (prefix BMNH) EE16661. It is presumed to have come from the type locality of *Woodocrinus macrodactylus*. This was the quarry of Mr Edward Wood, near Richmond, Swaledale, North Riding of Yorkshire (de Koninck, 1854). Wright (1951, p.49) considered the horizon to be “Namurian, E_1 (Red Beds above Main Limestone)”. In more modern terms, this translates to Carboniferous (Late Mississippian; Namurian), Serpukhovian (Pendleian); red beds above Main Limestone, Yoredale Group, North Yorkshire (Ramsbottom *et al*., 1978, fig.9; Ogg *et al*., 2008, fig.8.6; Webster and Webster, 2016, p.2218). Ausich and Kammer (2006, p.105) listed this species only from their locality ‘10RI’ at Richmond [NGR NZ 169 009].

The specimen was cleaned in a dilute solution of domestic bleach to remove mosses and algae. All photography was by a Canon G11 digital camera; the specimen was not whitened for photography. Terminology of the crinoid endoskeleton follows Moore and Jeffords (1968), Moore *et al*. (1968, 1978a), Ubaghs (1978) and Webster (1974). Descriptions are written in the style advocated by Fearnhead (2008).

Systematic palaeontology

Class Crinoidea J.S. Miller, 1821

Subclass Cladida Moore and Laudon, 1943

Order Dendrocrinida Bather, 1899

Incertae familiae

Genus *Woodocrinus* de Koninck, 1854

Type species. *Woodocrinus macrodactylus* de Koninck, 1854, p.210, by monotypy (Wright, 1951, p.47; Moore *et al*., 1978b, p.T651), from near Richmond, Swaledale, North Yorkshire.

Other nominal species. Webster and Webster (2016) accepted nine further nominal species of *Woodocrinus*, but reassigned many more to other genera; only one (further) species in open nomenclature was accepted in their list.

Diagnosis. (After Moore *et al*., 1978b, p.T651.) "Crown widely expanded. Cup low cone shaped; 5 infrabasals upflared but not prominent, tendency toward short sutures between basals, 3 anal plates in normal (primitive) arrangement. Arms typically 20, uniserial, composed of exceptionally wide, very short brachials, first branching on primibrachs *1* in all rays, second branching on about secundibrachs *6-8*, no higher bifurcations, branching variable among specimens and species, including lack of second bifurcation in some rays."

Remarks. The genus was named after Mr. Edward Wood of Richmond, Yorkshire, who owned the quarry from which the type material was collected. We understand that this site has not been exposed for many years; it was not listed by Arkell *et al*. (1954).

Range. Carboniferous, Mississippian, Tournaisian – Namurian, British Isles; Permian of Pakistan (Webster and Webster, 2016, p.2216).

Woodocrinus macrodactylus de Koninck, 1854

Figures 1, 2, 3A, B

Synonymy. See Webster and Webster (2016, p.2218).

Material. BMNH EE16661, a slab of limestone (Figure1) bearing one well-preserved specimen (Figure 2) and several arms (Figure 3A, B) from this or another individual(s).

Locality and horizon. Presumably the type locality: quarry of Mr. Edward Wood, near Richmond, Swaledale, North Riding of Yorkshire;

Carboniferous (Late Mississippian), Serpukovian (Pendlian), red beds above Main Limestone.

Diagnosis. (New, based on Wright, 1951, pp.48-49, and description below.) Attachment by radices in diststele; proximal column N3231323, round in section. Cup dicyclic, resembling a spinning-top in shape; infrabasals low, basals and radials about equal in height; radianal and greater part anal X and right proximal plate of anal tube within cup. Arms commonly 20; IBr_1 and $IIBr_{6-8}$ axillary; tertibrachials 40-70.

Description. (See also Wright, 1951, pp.48-49.) Based solely on BMNH EE16661 (Figs 1, 2, 3A, B). Stem incomplete; attachment structure unknown. About 61 mm of most proximal column preserved. Column circular in section; articulation radial symplectial, marginal(?); broad areola; lumen(?) small, central. Column heteromorphic, regularly N3231323, nodals highest *et seq*., tertinternodals particularly low and largely concealed. Latera unsculptured, convex, except tertinternodals, in which they are planar.

Cup not preserved.

Arms robust, uniserial, pinnulate, branching twice isotomously. Primaxillary close to cup; secundaxillary at *c*.$IIBr_6$. Tertibrachials numerous, low, branches tapering distally. Pinnules close-packed, long, each composed of several long pinnular ossicles.

Remarks. Ausich and Kammer (2006, p.105) listed one other species of *Woodocrinus* from their locality 10RI, *Woodocrinus*? *longidactylus* (de Koninck MS *in* Wright, 1925). Wright (1951, p.59) noted that "There is no sign of a cup in connection with the arms and from the length and structure of the brachials it more probably belongs to another genus, e.g., *Poteriocrinites*." This is confusing as the species was referred to as "? *Poteriocrinites longidactylus* (de Koninck)" on its original publication (Wright, 1925, p.282); why did Wright transfer it to *Woodocrinus* in 1951 if he thought the designation incorrect? Ausich and Kammer (2006, p.105) regarded *W.*? *longidactylus* as a *nomen dubium*

"… because it consists only of a single specimen of a complete ray with long arms." Examination of an image of the only specimen (Wright, 1951, pl.29, fig.2) shows that the arms branch at least four times, *contra W. macrodactylus* and the generic diagnosis of *Woodocrinus* (see above).

Ausich and Kammer (2006, p.105) listed two further species of *Woodocrinus* from their (coeval) locality 10SW (Swaledale, near Richmond; NGR SE 018 986), *Woodocrinus expansus* de Koninck and Wood, 1858, and *Woodocrinus fimbriatus* de Koninck MS. *in* Wright, 1951. The arms of *W. expansus* branch at least four times (Wright, 1951, pl.21, fig.2), unlike those of *W. macrodactylus* and, again, *contra* the generic diagnosis. *Woodocrinus fimbriatus* is based on a solitary, poorly preserved specimen (Wright, 1951, p.58; 1952, pl.36, fig.2). Wright noted its similarities to *W. macrodactylus*, while speculating that it may not be congeneric.

Incerti ordinis
crinoid sp. indet.
Figures 1, 3C

Material. BMNH EE16661, towards the upper left in Figure 1.

Locality and horizon. Uncertain, but presumably the quarry of Mr. Edward Wood, near Richmond, Swaledale, North Riding of Yorkshire; Carboniferous (Late Mississippian), Serpukovian (Pendlian), red beds above Main Limestone.

Description. Brachials slightly wider than high, unsculptured. One or more arms branching isotomously at least twice. Branches slender, comprised of uniserial brachials, apparently apinnulate. Estimated *c*. ten secundibrachials; at least ten tertibrachials, but incomplete.

Remarks. Although very incomplete, enough can be seen of this specimen to say with confidence that it is not *W. macrodactylus*. Ausich and Kammer (2006, table 3) listed five species in four genera from the type locality of *W. macrodactylus*, their site 10 RI (Table 1).

The flexible cladid *Aexitrophocrinus swaledalensis* (Wright, 1954, p.157, pl.42, fig.4), whose occurrence on this site is uncertain (Ausich and Kammer, 2006, p.105), has particularly broad, robust arms quite unlike those in Figure 3C. *Rhabdocrinus swaledalensis* Wright, 1950 (pp.16-17, pl.1, figs.1-3), has particularly well-separated axillaries and its distinctive columnals would be obvious if present on BMNH EE16661 (Donovan and Birtle, 2011). *Ureocrinus bockschii* (Geinitz, 1846) (Wright, 1952, pp.112-116, numerous illustrations, but particularly pl.19, figs.1-4) has unbranched arms. *Woodocrinus*? *longidactylus* and *W. macrodactylus* have both been discussed above. In short, crinoid sp. indet. does not resemble any of the crinoids already described from the type locality of *W. macrodactylus* and is left in open nomenclature until superior specimens are available.

Discussion

The preservation of these specimens poses questions, in particular the pinnulate arm (Figure 3A). This is broken away at or near a major branch of an arm (compare with Figure 3B) and the pinnules are beautifully preserved to the right of the arm. In a modern crinoid, such as the comatulid *Antedon bifida* Pennant, 1777, "… within two days of death, specimens … in completely static sea water had collapsed into a mass of arm and cirrus fragments, even under anaerobic conditions" (Blyth Cain, 1968, p.192). The preservation of such an arm as shown in Figure 3A is likely to have occurred under conditions of high energy, which first broke the arm off, perhaps inducing autotomy (self-mutilation; Wilkie and Emson, 1988), and then led to its rapid burial.

Similarly, the most complete *W. macrodactylus* (Figure 2) lacks the distal stem, including the attachment, and may have autotomized under unfavourable, high energy conditions, after which it was transported and buried alive. Thus, it is probably allochthonous, yet well preserved due to rapid burial. The orientation of this specimen does not seem to relate directly to the preservation of pluricolumnals and disarticulated arms (Figure 1) which have accumulated in two directions at 90° to each other. These suggest current strong enough to roll some specimens while others became oriented parallel to flow.

The large, V-shaped arm fragment (Figure 3B) may indicate a flow from left to right; in contrast, assuming the crown to lie down-current, the more complete specimen (Figure 2) might have been carried from bottom towards the top.

It might be asked, why is this Yorkshire crinoid worthy of being described in *The North West Geologist*? Its provenance was uncertain when B.J. first showed it to S.K.D., but it was formerly thought to come from the Clitheroe quarries. Yet this was unlikely as the preservation of crinoid thecae from these sites rarely retains the arms (Donovan and Sevastopulo, 1986). Indeed, as demonstrated herein, it represented a specimen collected, at latest, in the early 20th Century, and perhaps before; it is a species that is now common only in museum collections; and provides certain lessons in determining provenance and palaeoecology that are of broad interest.

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Table 1: Nominal crinoids known from the type locality of *Woodocrinus macrodactylus* (after Ausich and Kammer, 2006).

Aexitrophocrinus swaledalensis (Wright, 1954)

Rhabdocrinus swaledalensis Wright, 1950

Ureocrinus bockschii (Geinitz, 1846)

Woodocrinus? *longidactylus* (de Koninck *in* Wright, 1925)

Woodocrinus macrodactylus de Koninck, 1854

Figure 1: BMNH EE16661, *Woodocrinus macrodactylus* de Koninck, 1854, and crinoid sp. indet. (towards upper left; compare with Figure 3C). The best preserved specimen of *W. macrodactylus* is right of centre; disarticulated arms are above this and to its left. Specimen uncoated, photographed in natural light. Scale bar represents 50 mm.

Figure 2: BMNH EE16661, *Woodocrinus macrodactylus* de Koninck, 1854. Note the stem is incomplete and the cup is concealed or lost. Specimen uncoated, photographed in natural light. Scale bar represents 10 mm.

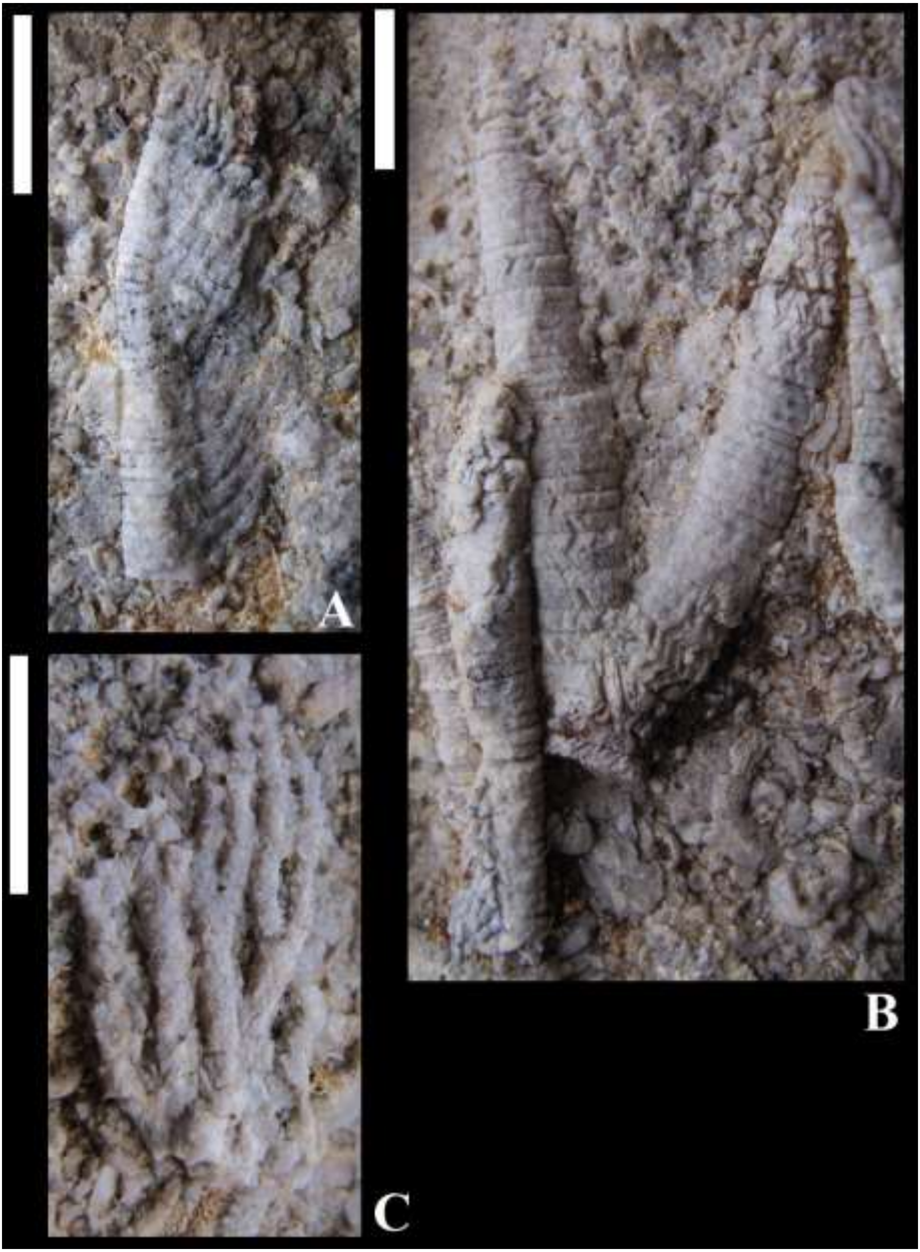

Figure 3: BMNH EE16661. (A, B) *Woodocrinus macrodactylus* de Koninck, 1854. (A) Single arm preserved with pinnules. (B) Branched arm, pinnules not apparent. (C) Crinoid sp. indet., branched arms. Specimen uncoated, photographed in natural light. Scale bars represents 10 mm.

A geological guide to Healey Dell in the valley of the River Spodden near Rochdale

Ron Powell

This is the story of an ancient river delta, ice age torrents and industrial heritage.

Healey Dell lies on the southern limb of the Rossendale Anticline, Figure 1, a low-profile structural arch which rises in the vicinity of Burnley and becomes a broad plateau in the Bacup area before sloping gently south-south-east towards Rochdale. The axis of the anticline runs roughly from Chorley in the west to Todmorden in the east and is in rocks of Carboniferous age (about 320 million years old).

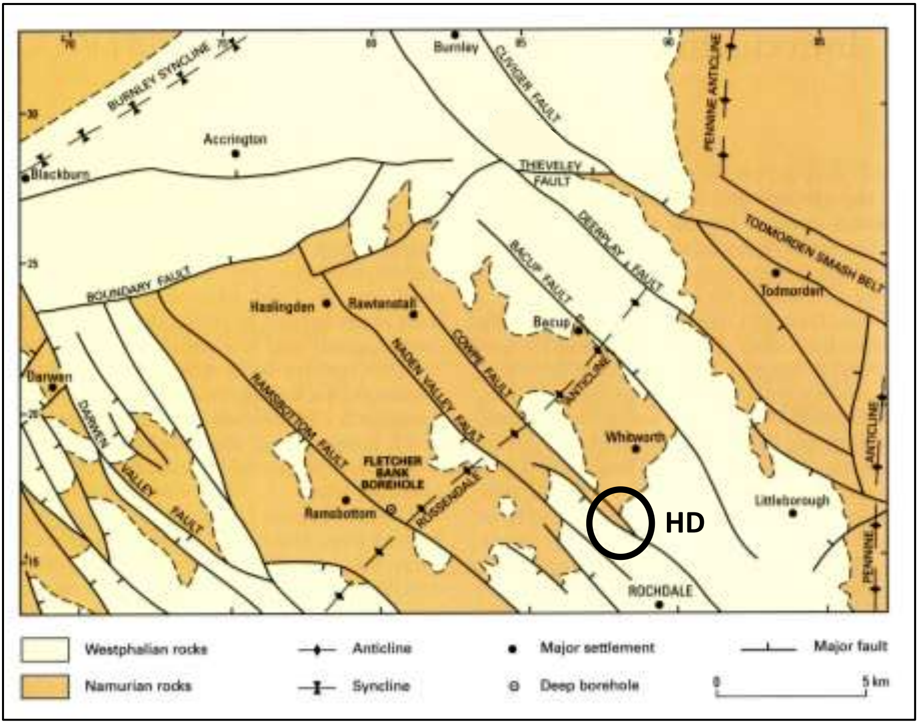

Figure 1: Geological map of the Rochdale district showing Healey Dell's location (HD).

Sketch modified from BGS Rochdale Memoir (1:50,000 Geology Series, Sheet 76)

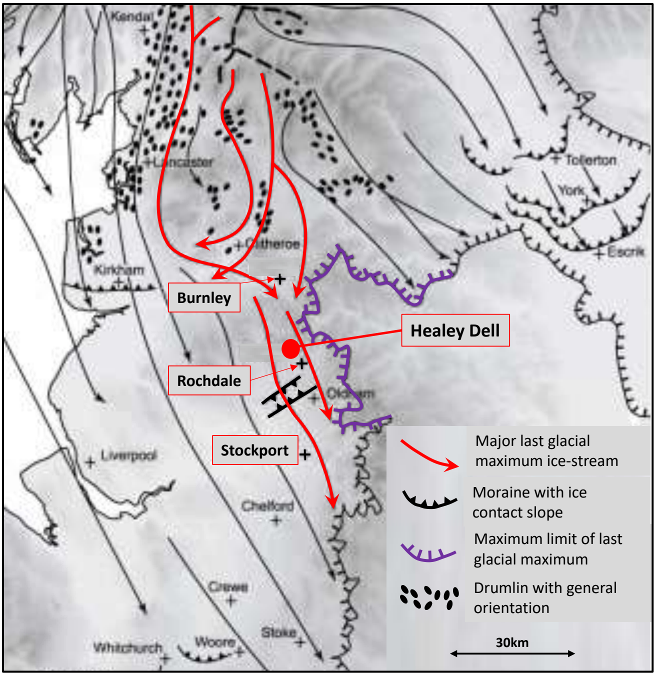

Figure 2: Predominantly NNW-SSE ice sheet flow directions in the vicinity of Healey Dell during the last (Devensian) glaciation, 75 to 15 thousand years ago. [in: Oxford Archaeology North. Aggregates Levy Sustainability Fund (ALSF) Aggregate Extraction in the Lower Ribble Valley. University of Liverpool. Department of Geography, February 2007. *Adapted from Crofts, 2006.*]

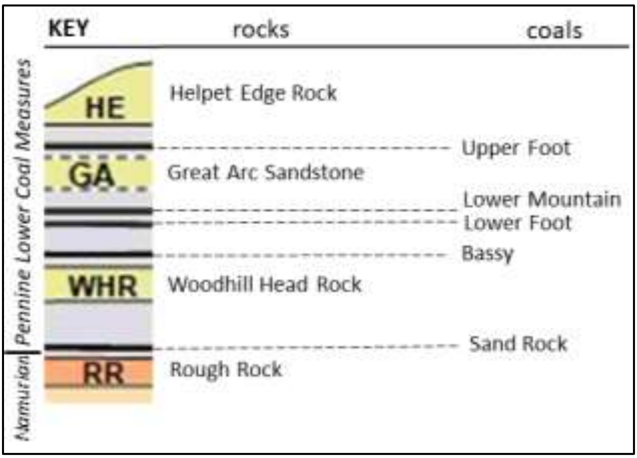

Figure 3: Key to Figure 4.

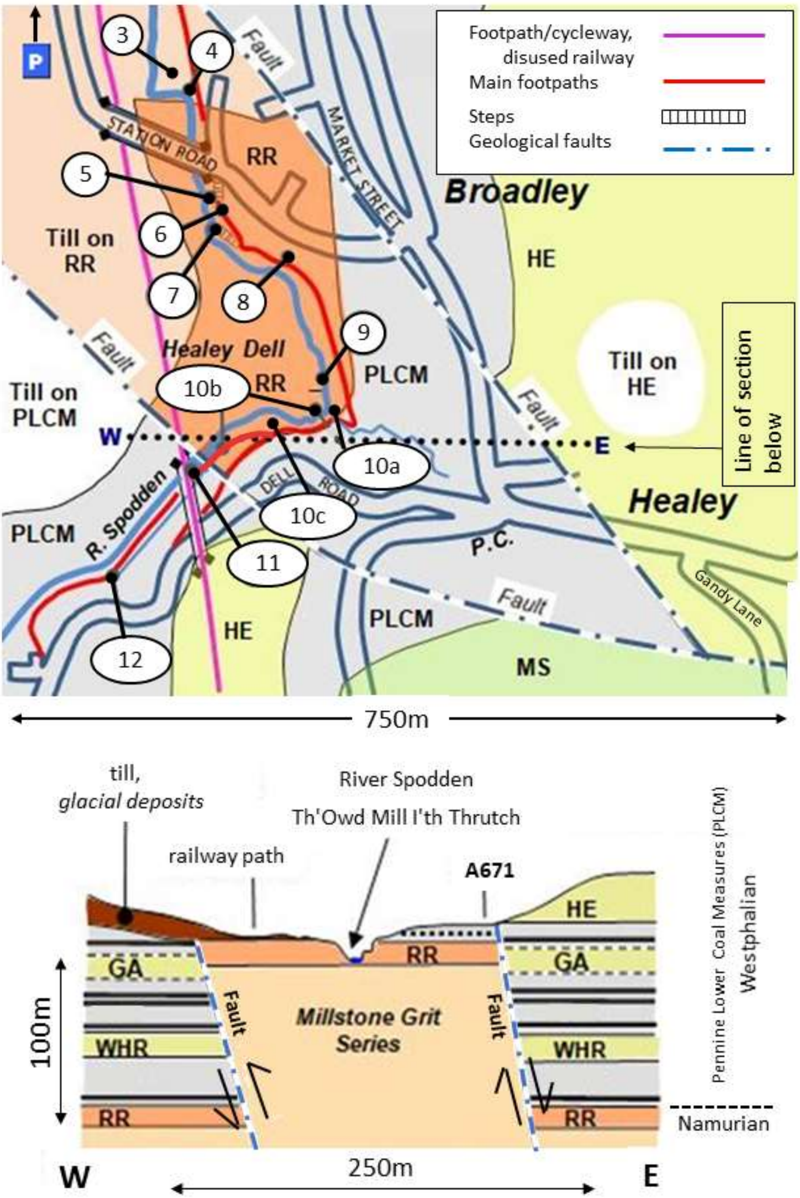

Figure 4: Simplified geological sketch and cross section of the Healey Dell area, showing the trail location numbers in their geological context.
W-E marks the line of the cross section. HE = Helpet Edge Rock (sandstone);
MS = Milnrow Sandstone; PLCM = Pennine Lower Coal Measures (undifferentiated);
RR = Rough Rock (coarse sandstone)

The sediments were deposited in an immense near-equatorial river delta, expanding southwards over millennia with coal-forming forested swamps developing on the delta top. Varying flow rates of river water and lagoons gave rise to sands (higher energy), muds and silts (lower energy) which eventually became rock.

The anticline has been heavily affected by north-west to south-east trending faults and by glacial erosion between 75,000 and 15,000 years ago, which removed most of the younger Coal Measures from the top of the anticline. An overview of the ice-sheets, which were more than a kilometre thick, is shown in Figure 2. As the ice melted, torrential water eroded the valley and fluvio-glacial deposits known as ‘till’ were deposited on higher ground. The Great Flood of 1838, when the River Spodden rose 15ft (4.5m) and destroyed several mills along its banks, pales in comparison.

At Healey Dell melt water created a deep, narrow gorge exposing some of the structure and erosional features in the rocks where the River Spodden cuts down this limb of the anticline and flows on to join the River Roch. The river passes over several faults. Two of the more prominent ones converge beneath Gandy Lane, Healey, Figure 4. The northerly fault crosses the river near Broadley Station, while the southerly one runs from the north side of the old railway viaduct, crossing the river close to Th’Owd Mill i’th’ Thrutch. These two faults bring up a wedge of older rock, including the aptly named Rough Rock at the top of the Namurian, into the Pennine Lower Coal Measures (PLCM). The Rough Rock abuts undifferentiated PLCM, Figure 4. The Woodhead Hill Rock, Helpet Edge Rock and other sandstones are units within the PLCM. Much of the surrounding bedrock in this area, including the northern limb of the fault, is obscured by glacial deposits.

The positions of the two faults are not easily seen but have led to local features in the landscape. Faulting has created a shatter-zone of broken rock and the River Spodden has exploited the weakness to cut the gorge.

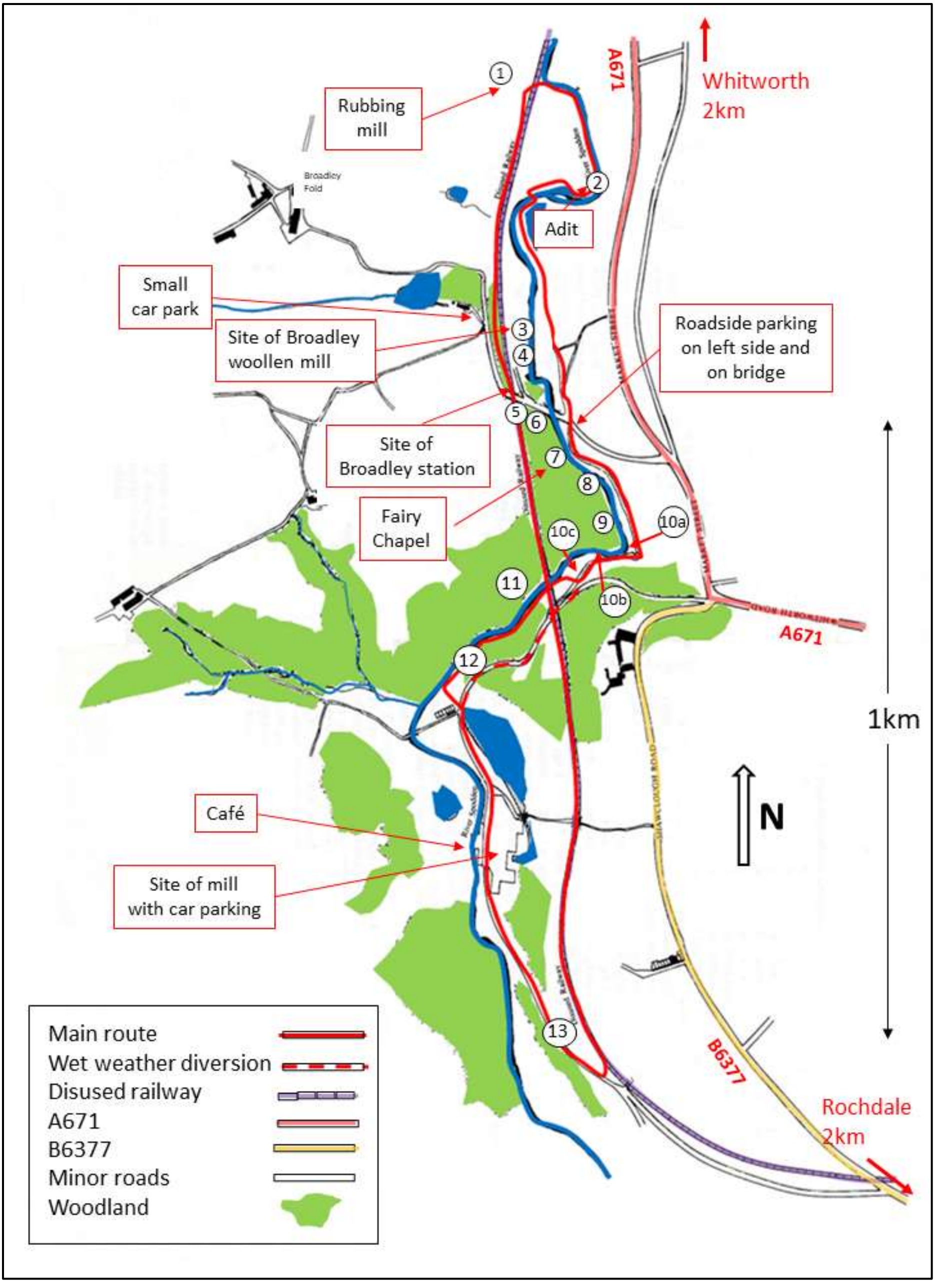

Figure 5: Trail route map (based on map in Marshall, 1976).

Geology on the Trail

Much of the route of this trail is in an area designated an LGS, a Local Geodiversity Site (previously described as RIGS, Regionally Important Geological/Geomorphological Site). LGSs are the most important places for geology and geomorphology outside statutorily protected areas such as Sites of Special Scientific Interest (SSSI). They are important as an educational, historical and recreational resource. The designation of LGS is a way of recognising and protecting important Earth Science and landscape features for future generations to enjoy.

The trail focuses on geology but some key aspects of industrial heritage are indicated. Several explanation boards can be found along the route. All location numbers are marked on the maps, Figures 4 and 5. In severe wet weather some locations on the trail may be unsafe and no attempt should be made to visit them.

There is no need to visit the locations in numerical order. The description for each location stands alone.

Location 1: This is the site of a rubbing mill, used for making the top face of flagstones flat. There is an explanation board at the side of the railway.

Location 2: Although there was coal mining in the valley, the adit on the far side of the river was probably associated with a siderite mine. Siderite, iron carbonate ($FeCO_3$), was the ore used for the production of iron in a late mediaeval bloomery which was located nearby. No signs of it remain.

Location 3: The site of the 18th Century Broadley woollen and cotton mill and most likely a 15th Century corn mill. Water power and coal were heavily exploited locally throughout the industrial revolution.

Location 4: East of the remains of Broadley station the river crosses the Cowpe fault system (Figure 1), the more northerly of the two converging faults, and cuts a gorge through the older Rough Rock. From the footpath to the east of the station, you can see that the River Spodden makes an abrupt turn under rock bluffs as if following a line of weakness in the Rough Rock, Figure 6. The lines show the direction of river flow and the relative movements of the rock in at least one fault.

Figure 6: Sharp bends in the River Spodden against an outcrop of Rough Rock (RR). The curved arrows mark the direction of river flow. 'F1' marks the approximate direction of one fault, with half arrows indicating the relative movement. ‘F2’ is the presumed position of a second fault controlling the bend in the river. The bank of the river to the right is disturbed ground (the site of an old mill) on glacial till.

Figure 7: Water-worn rock in the bed of the river.

Location 5: Cross Station Road and descend the stone steps. Except when in flood, the river runs on both sides of a prominent water-worn slab of bedrock, Figure 7.

Location 6: From a little further down the wide path, you can look over to the opposite side of the gorge and see the sheer sides. This is a clear indication of rapid down-cutting by the river, into a weak rock joint system, caused by prolonged torrents of melt water during the waning of the last ice age, from about 20,000 years to 10,000 years ago by which time the ice sheet had retreated far to the north.

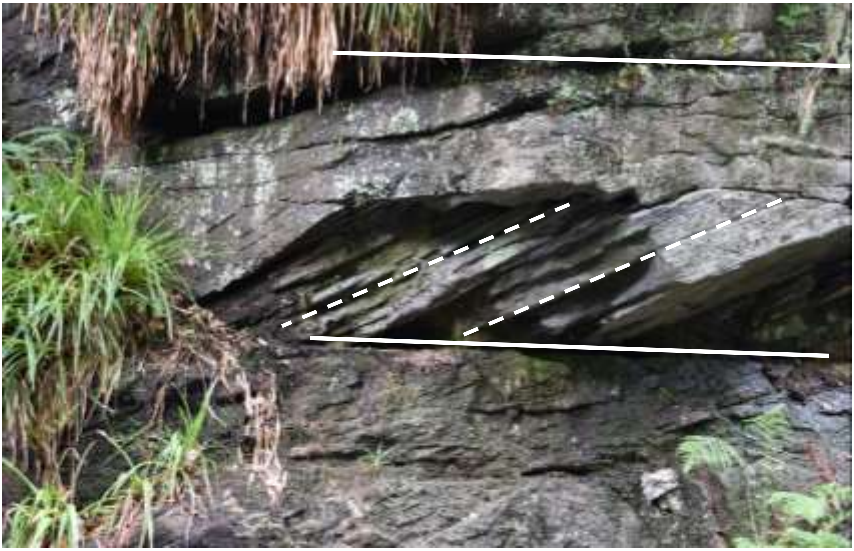

Figure 8: Cross-bedding, on the far side of the stream at Fairy Chapel. The solid white lines mark the bedding planes and the dotted lines mark the cross-beds.

Location 7: If it is safe to do so, descend the steep, uneven steps to the 'Fairy Chapel' (also known as Fairies Chapel). From this platform there are spectacular views of waterfalls and chutes. On the other side of the river is a good example of cross-bedding, Figure 8. You will see further examples close up in the path-side cliffs at Location 8. Cross-bedding is the result of underwater dunes moving downstream in a river bed or in an advancing delta front. The dunes move down-current in the same way that desert dunes move downwind. It is best to look at them in three dimensions; they may be shaped like troughs, in which case they are described as trough cross-bedding. The orientation of ripples and the troughs between them will change with the currents prevalent at the time of deposition and there may be ripples on surfaces of the cross-beds. All these phenomena are only preserved when the sediments were being deposited faster than they were eroding, implying subsidence which, over an extended period, must have been considerable for the deposition of shallow-water sediments hundreds of metres thick.

Location 8: Climb back to the main path and continue down to the long rock face on the left. There are good examples of cross-bedding here too. Under some overhangs you can see casts of ripples on the under-surface. You might spot a fossil imprint of a very small piece of a coal-forest tree in a rock above head height.

Figure 9: Weir

Location 9: Towards the bottom of the long face, viewed over the rail and down into the gorge, a stone built weir stands on a prominent water-worn bed of rock, Figure 9. This weir used to feed water via a wooden laund and a masonry leat to 'Th'Owd Mill i'th' Thrutch' around the next bend in the river. Just below the weir are numerous potholes or 'eddy mills', which are created by pebbles lodging into crevices and then being driven round and round by the force of the water, wearing these deep circular depressions, Figure 10.

Figure 10: Potholes below the weir (Figure 9)

Location 10a: At the abrupt bend in the river, look at the waterfalls back up the gorge, Figure 11. Further waterfalls can be seen downstream of the weir, the final and largest forming the acute bend. Perhaps the line of the lower valley was already set against the wedge of Rough Rock by a 'shatter zone' around the fault when the ice age torrents came through.

Location 10b: There is also a prominent stream descending steeply from Healey Corner, high up on the right. When there are no leaves on the trees, you can see an unusual laminated spherical concretion set into a cleft high on a bluff opposite (binoculars are useful here), Figure 12. This is thought to be a relict piece of cross-bedded sediment, which, if in situ, has been left when poorly cemented sediment around it has weathered away.

Location 10c: The path now rises toward Dell Road, where there is a mill between the path and the river, with an explanation board at the side of the path. The waterwheel pit, treatment tanks, sulphur ovens and a single arch (of the original 2) across the narrowest, deepest stretch of the river ('The Thrutch') are all that now remains. The arches, Figure 13, once supported a mill building.

Figure 11: Gorge with waterfalls. An arrow marks the location of Figure 12.

Location 11: If conditions allow, the nimble can make a steep, winding descent to the concrete weir at the riverside on the upstream side of the disused railway viaduct (which will be the route back to the start of the trail). A much safer route to locations 11 and 12 is to follow the road and take a path to the right just before the cottages and come back to locations 11 and 12 up the leat path. This narrow path follows the leat and in places there is a steep drop down to the river.

In July 2020 this route was unsafe. A board walk above a steep bank alongside the leat had partially collapsed. The route along the leat should not be attempted, in either direction, unless the board walk has been replaced.

By the base of the viaduct is the sluice-gate which controlled the supply of water via the leat to the mill pond. In the far river bank by the last arch of the viaduct the southern limb of the fault system is exposed, showing older solid Rough Rock above and younger shales below, Figure 14. The bedding of the shales steepens towards the fault as the softer shales deformed against the robust Rough Rock during movement along the fault. The down-throw on both faults is roughly 100 metres. A short distance, (20m) downstream, i.e. south, above the leat, the bedding of these shales is almost horizontal. The viaduct and most local buildings are believed to have been built with local stone, brought from the Rossendale quarries along the now disused railway line.

Figure 12: Cross-bedding in a concretion; for location see Figure 11.


Figure 13: Arch over the Thrutch. Two arches once supported a building (see 10c).

Location 12: About 100m south along the leat path, the water enters a tunnel, where you can also see the shales, Figure 15. If you scrape off some algae you can see that they are made of very fine sand in wavy beds with lenses of mud in the troughs. This is 'laminar lenticular shale' and is unusual. It can be formed by alternating currents in shallow and slack water, tidal flats, floodplains, subtidal etc.

Location 13. Opposite the Café are the ruins of a munitions works which produced around 136 million 20lb bombs and an unspecified number of 25lb shells during WW2. Walk south past the café and follow the road until you reach the path on the left which turns sharply back to the north and leads to the disused railway, along which you return to the start. About 100m before the path, shales are exposed in a steep slope at the road side. You may see siderite nodules here. They are rusty brown in colour and if you are able to pick one up you will notice immediately that it is surprisingly heavy, being very dense. Pure siderite contains almost 50% iron (see Location 2).

Figure 14: Fault near the abutment of the railway bridge. RR = Rough Rock;
F = location of fault plane; B = line following planes of bedding in the shales.

Figure 15: Water flowing from the leat on the left into the tunnel on the right.
Inset bottom right: shales – see Location 12

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Dedicated to the memory of Marjorie Mosley, a member of Council of the MGA (Manchester Geological Association) and chair of Greater Manchester RIGS Group (GMRIGS Group), whose enthusiasm and dedication led to the creation of this geological guide. The logo is her design.

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The building stones of the Peterloo Memorial, Manchester

Jennifer Rhodes

The memorial, designed by artist Jeremy Deller and architects Caruso St John, was built by local stonemasons Mather and Ellis. It stands at the junction of Lower Mosley Street and Windmill Street, just metres from the heart of the former St Peter's Field where the Peterloo massacre took place, Figure 1.

A short history of the Peterloo Massacre

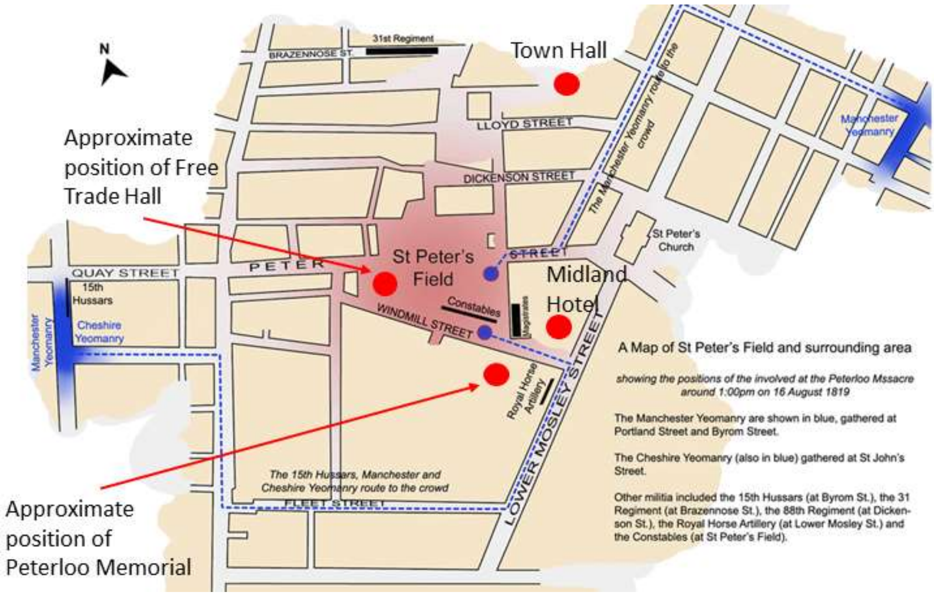

Figure 1: the location of the Peterloo Massacre and the Memorial
Based on work in Reid, Robert (1989) The Peterloo Massacre, William Heinemann Ltd ISBN: 0434629014.

The massacre took place on Monday 16 August 1819, when cavalry charged into a crowd of 60,000-80,000 people who had gathered to demand the reform of parliamentary representation.

After the Napoleonic Wars in 1815, famine and chronic unemployment created social unrest, exacerbated by the introduction of the Corn Laws, which put even a loaf of bread beyond the reach of many families. In 1819, political radicalism was rising in popularity because of poor economic conditions, made worse by the relative lack of suffrage in Northern England. The Manchester Patriotic Union, agitating for parliamentary reform, organised a demonstration to be addressed by well-known radical orator Henry Hunt.

Figure 2: A caricature by George Cruikshank depicting the charge upon the rally; text reads: "Down with 'em! Chop ‘em down my brave boys: give them no quarter they want to take our Beef & Pudding from us! — & remember the more you kill the less poor rates you'll have to pay so go at it Lads show your courage & your Loyalty!"

Shortly after the meeting began, local magistrates called on the Manchester and Salford Yeomanry to arrest Hunt and several others on the stage with him. The Yeomanry charged into the crowd, knocking down a woman and killing a child, and finally apprehended Hunt. Cheshire Magistrates' chairman William Hulton then summoned the 15th Hussars to disperse the crowd (Figure 2). They charged with sabres drawn; 18 people were killed and 400-700 were injured in the ensuing confusion.

Historian Robert Poole has called the Peterloo Massacre one of the defining moments of its age. The London and national papers shared the horror felt in the Manchester region, but Peterloo's immediate effect was to cause the government to pass the Six Acts, which were aimed at suppressing any meetings for the purpose of radical reform. It also led directly to the foundation of the *Manchester Guardian*, but had little other effect on the pace of reform.

Why Parliamentary reform was needed
In 1819, Lancashire was represented by two members of parliament (MPs). Voting was restricted to the adult male owners of freehold land and votes could only be cast at the county town of Lancaster, by a publicly spoken declaration at the hustings.

Constituency boundaries were out of date, and the so-called rotten boroughs had a hugely disproportionate influence on the membership of the Parliament of the United Kingdom compared to the size of their populations: Old Sarum in Wiltshire, with one voter, elected two MPs, as did Dunwich in Suffolk, which by the early 19th century had almost completely disappeared into the sea. The major urban centres of the Manchester area, with a combined population of almost one million, plus other centres of population in the county, were represented by the two county MPs for Lancashire.

More than half of MPs were returned by just 154 owners of rotten or closed boroughs. In 1816, it was claimed that of the 515 MPs for England and Wales 351 had the patronage of 177 individuals and a further 16 by the direct patronage of the government: all 45 Scottish MPs owed their seats to patronage. These inequalities led to calls for reform.

Where people came from, how they were organised, what happened
The crowd that gathered in St Peter's Field arrived in disciplined and organised contingents. Each village or chapelry was given a time and a meeting place, from where its members went on to assembly points in the larger towns and from there to Manchester. Contingents came from all parts of the region, the largest and "best dressed" of which was a group of 10,000 from Oldham, Royton (including many women), Crompton, Lees, Saddleworth and Mossley. Others marched from

Middleton, Rochdale and Stockport (Figure 3). Reports of the size of the crowd at the meeting vary: modern estimates are 60,000-80,000.

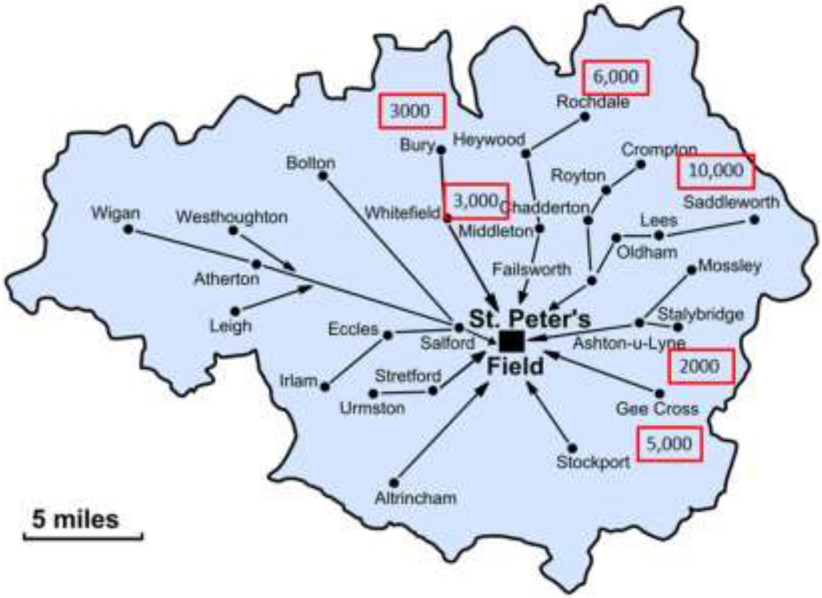

Figure 3: Some of the locations people came from to Peterloo

The assembly was intended by organisers and participants to be a peaceful meeting; Henry Hunt had exhorted everyone attending to come "armed with no other weapon but that of a self-approving conscience", and many were wearing their "Sunday best" clothes.

Banners with texts like "No Corn Laws", "Annual Parliaments", "Universal suffrage" and "Vote by Ballot" were carried. Women, dressed in white, from the Manchester Female Reform Society, accompanied Hunt to the platform. President Mary Fildes carried its flag and rode in Hunt's carriage. The only banner known to have survived was carried by Thomas Redford, who was injured by a yeomanry sabre. It is of green silk embossed with gold lettering, one side of the banner inscribed "Liberty and Fraternity" the other "Unity and Strength" and is in Middleton Public Library’s collection. William Hulton, chairman of the magistrates, saw the enthusiastic reception Hunt received on his arrival at the assembly. Hulton issued an arrest warrant for Hunt, Joseph Johnson, John Knight, and James Moorhouse. The Constable, Jonathan Andrews, said that the crowd would make military assistance necessary. Hulton then summoned the Manchester and Salford Yeomanry Cavalry and the overall military commander in Manchester, Lieutenant Colonel Guy L'Estrange.

The Manchester and Salford Yeomanry were stationed in Portland Street, drew swords and galloped towards St Peter's Field. One trooper knocked down Ann Fildes in Cooper Street, causing the death of her son who was thrown from her arms; two-year-old William Fildes was the first casualty of Peterloo.

As the horses were thrust into the crowd they reared and plunged as people tried to escape. The cavalry pushed towards the speakers' stand and becoming stuck in the crowd, started to hack with their sabres. Hunt, Johnson and others were arrested. The yeomanry then began destroying banners and flags, "cutting indiscriminately to right and left to get at them". Only then did people retaliate. This was seen as an assault on the yeomanry, and when the hussars arrived they were ordered to disperse the crowd. They charged into the crowd as the Cheshire Yeomanry charged from the southern edge. The crowd had some difficulty in dispersing, as the main exit route into Peter Street was blocked by the 88th Regiment of Foot, standing with bayonets fixed.

Within 10 minutes the crowd had been dispersed, at the cost of 11 dead and more than 600 injured. Only the wounded, their helpers, and the dead were left behind. For some time afterwards there was rioting in the streets, most seriously at New Cross, where troops fired on a crowd attacking a shop. Peace was not restored in Manchester until the next morning, and in Stockport and Macclesfield rioting continued the next day. There was a riot in Oldham that day, where one person was shot and wounded. The exact number of those killed and injured at Peterloo has never been established with certainty.

Female reform societies had been formed in North West England during June and July 1819, the first in Britain. Many of the women were dressed distinctively in white, and some formed all-female contingents, carrying their own flags. Of the 654 recorded casualties, at least 168 were women, four of whom died either at St Peter's Field or later from their wounds. It appears that less than 12 per cent of the crowd was female, but they were three times as likely to be injured. Eleven of the deaths occurred on St Peter's Field. Others died later of their wounds, and some were killed in riots following the crowd's dispersal.

The Stones of the Peterloo Memorial

The monument is conceived as a landscaped 'hill' made of concentric steps. It is designed to be a gathering place and platform for oratory and references the march of people from surrounding towns and villages to demand recognition of their rights. These place names and the names of the 18 men, women and children who died, are engraved on the vertical faces of the steps around the memorial in positions that accurately depict their compass location.

Figure 4: Burlington slate surface with arrows indicating other violently disrupted peaceful protests around the world including Tiananmen Square.

The horizontal surfaces of the steps have inlaid decoration, imagery associated with Peterloo. The design of the top of the memorial references events similar to Peterloo around the world, where peaceful protests were violently broken up by the state. The design of the top five layers has been repeated in a smaller circle adjoining the larger one, enabling the viewer to read the information on the flat slate top of the monument.

Figure 5: The memorial on a wet day, showing up the stones' colours (Photo: SJ Rhodes)

Jeremy Deller's aim was to use stone, including granites, sandstones and slates from various parts of the UK. The bright range of colours, seen especially well in the rain (Figure 5), together with the names, emblems and texts incised into the surface of the stones, makes reference to the bold graphics of banners calling for social reform, which were carried by protesters.

The base of the Peterloo Memorial is a semi-circle of Portland Stone, which serves to level the site of the memorial to make it possible for wheelchair users to get close. Portland Stone is a limestone of late Jurassic age, about 150 million years (Ma) old. The rock is described as oolitic, consisting of tiny spheroidal pellets of precipitated limestone (ooliths) with the fossilised remains of marine organisms including bivalves related to today's scallops and oysters. Examination of the nearby Cenotaph, made from the same stone, will show that it has been weathered in Manchester's acid rain, resulting in some of the fossils standing proud of the matrix, Figure 6. One wonders how the Memorial stone will be affected both by acid rain and by being walked over – Editor.

Figure 6: Portland Stone in the Manchester Cenotaph, St Peter's Square, showing ooliths and weathered-out fossils of bivalves

A bronze plaque gives a summary of the events of 16 August 1819.
https://www.stonespecialist.com/news/stones-quarries/great-british-stone-portland-limestone

Above the base are 11 circles of decreasing diameter, numbered in this account, from the base.

1. Corrennie pink granite, from Tillyfourie, Aberdeenshire, Figure 7
https://www.stonecontact.com/corrennie-granite/sl2314
The Corrennie intrusion is a granite, of Silurian age (419-444 Ma)
https://canmore.org.uk/site/139486/corrennie-quarry

This granite, from a quarry about 20km west of Aberdeen, was selected because of its deep pink coloration. The pink crystals are orthoclase feldspar, which together with mica and quartz give the stone its speckled appearance. This is an igneous rock, its interlocking crystals indicating its molten origin in a plutonic silica-rich magma, cooled at depth to form a small batholith.

Figure 7: Corrennie pink granite

2. Whitworth stone, Bury (Upper Haslingden Flags)
This is a blue variant of Upper Haslingden Flags of Carboniferous age (~320 Ma) and is a well compacted, very hard, fine-grained, cross-bedded sandstone from the Millstone Grit series, Figure 8. (The best quality of this rock, almost a quartzite, was locally called Lonkey and was widely used for paving flags and for setts.) The stone shows ripples and is obviously water-lain. The ripples are polished flat on top, but they show in the cross-sections on the side and are possibly climbing ripples. The top surface features hearts cut from red sandstone.

Figure 8: Upper Haslingden Flags from Rossendale

The riser of this step is inscribed with the names of those who were killed: Arthur O'Neill, Mary Heyes, Sarah Jones, William Bradshaw, Margaret Downes, Samuel Hall, William Evans, William Fildes, Thomas Ashworth, Martha Partington, John Ashton, Thomas Buckley, James Crompton, Joseph Whitworth, Edmund Dawson, John Lees, the unborn child of Elizabeth Gaunt, John Rhodes.

3. Fletcher Bank Grit, locally sourced in Lancashire, Figure 9.
Fletcher Bank Grit is a sandstone of the Namurian (Millstone Grit) series of Carboniferous age (322- 320Ma) and lower in the succession than the Upper Haslingden Flags seen previously. This is another sedimentary rock laid down in the huge deltas of rivers flowing from mountains to the north. The photograph shows well-marked Liesegang rings, caused by the percolation of iron salts through the sediment during the diagenetic (rock forming) process.

Note: This stone, but in this case taken from Brinscall quarry near Chorley, is being used to complete the Basilica de la Familia Sagrada in Barcelona. It was chosen because it is varied in colour as was the original stone taken from Mont Juic quarries in Barcelona.

Figure 9: Fletcher Bank Grit from Rossendale

The top surface is decorated with items referencing the textile trade; bobbins of St Bees sandstone and shuttles with cores of Burlington slate. These emblems are repeated in level 7

The riser of this step is inscribed with the names of places from which people came to the Peterloo meeting: Burslem, Macclesfield, London, Huddersfield, Leeds, Ripponden, Burnley, Lancaster, Warrington and Northwich.

4. St Bees Sandstone (Sherwood Sandstone) from Salton Bay near St Bees, West Cumberland, Figures 10 and 11.
https://cumbrianstone.co.uk/featuredhome/st-bees-sandstone/

Figure 10: St Bees Sandstone

Figure 11: Design of scales inset into St Bees sandstone

St Bees Sandstone is a dark red, fine grained stone of early Triassic age (252-247Ma). St Bees quarry is on the west coast of Cumbria, where stone has been quarried and processed for hundreds of years. It is fine grained with cross-bedding and is a water-lain sediment. It was used for the interior of John Rylands University of Manchester Library.

The upper surface of this level is inlaid using stone used on other tiers depicting weighing scales, Figure 12.

Inscriptions on the riser indicate the compass directions of other places, from which people came to the meeting: Saddleworth, Rochdale, Tottington, Bolton, Tyldesley.

5. Whinstone (Dolerite) from West Lothian, Scotland

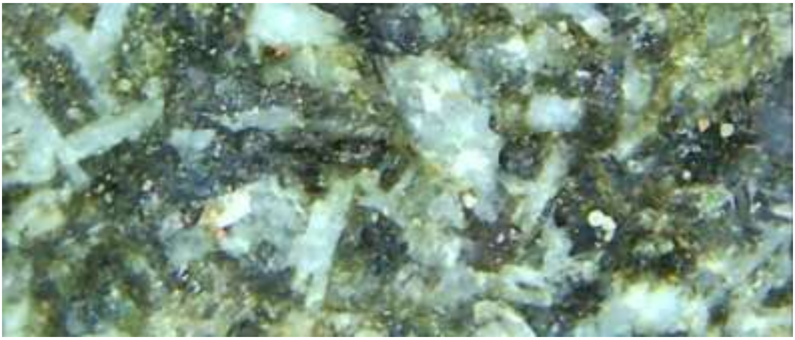

Figure 12: Dolerite

This is an igneous rock of basaltic composition, Figure 12. When cooled slowly as in the Black Cuillin of Skye it is called gabbro. This rock frequently forms as sills and dykes, as for example in the Whin Sill. Plagioclase feldspar crystals can be seen in the enlarged image above.

The riser bears inscriptions of Lees and Crompton, whence people also came.

6. Cop Crag Sandstone from Byrness Quarry, near Otterburn, Northumberland

https://www.dunhouse.co.uk/stonefinder/cop-crag/

This sandstone, Figure 13, of Carboniferous age, 329-319Ma, is from the Tyne Formation. It was deposited in an environment of swamps, estuaries and deltas. Cop Crag is varied in colour with Liesegang rings in rusty buff, shades of brown and burnt orange with deep pink banding.

Figure13: Cop Crag Sandstone from Northumberland

The images on this tier are nine crossed swords with liberty caps (Bonnets de la Liberté), a reference to the French Revolution.

On the riser are the names of more towns from which people came: Chadkirk, Stalybridge, Oldham, Royton, Bury, Irlam.

7. De Lank Granite from Bodmin Moor, Cornwall

https://en.wikipedia.org/wiki/De Lank Quarries

Figure 14: De Lank granite

This granite, Figure 14, is part of the south-west England plutonic mass, emplaced during Carboniferous/Permian Periods (331-272Ma) and characterised by large white orthoclase feldspars. The surface features bobbins and shuttles, referencing Manchester's importance as a textile town.

The riser bears names of towns whose people came to the meeting, Hyde, Dukinfield, Ashton-under-Lyne, Hopwood, Worsley, Flixton.

8. Whitworth Blue sandstone (Upper Haslingden Flags).

This is the same stone as that used in level 2, but here the surface has been inlaid with handshake symbols, Figure 15.

The names on this level are Heaton Norris, Stockport, Chadderton

9. Cove (Red) Sandstone from Kirkpatrick Fleming in SW Scotland.

https://blockstone.com/stone-types/cove-red-sandstone/

Cove Red Sandstone, Figure 15, is of Triassic age, 200-250 Ma old. It is a fine-grained, warm terracotta-red coloured sandstone, often with distinct bed markings, deposited in an environment of river channels and terraces. This stone was used for the base of the Statue of Liberty, Lord Leverhulme's Bolton School and Thornton Manor, Wirral.

Inscriptions refer to Hollinwood, Middleton, Whitefield, Barton-upon-Irwell.

Figure 15: Cove Red Sandstone, left and Whitworth Blue, right

10. Peak Moor Sandstone (Ashover Grit), Stanton Moor, Matlock, Derbyshire.

This is another sandstone of the Millstone Grit series of the Carboniferous (322-320Ma), deposited in an environment dominated by swamps, estuaries and deltas. Peak Moor is a fine- to medium-grained water-lain sandstone, predominantly buff in colour with occasional pink markings and/or brown iron staining, Figure 16.
The stone has been used as a background for inlaid laurel wreaths, cut from two different types of slate. The darkest parts of the leaves are cut from Cwt-y-Bugail Welsh slate, of Ordovician age, 488-443 Ma old, from a quarry east of Blaenau Ffestiniog in Wales, connected to the Ffestiniog Railway at Duffws Station via the Rhiwbach Tramway.

The lighter stone is Westmorland Green Slate from Broughton Moor in Cumbria. This is stone of Ordovician age, formed by accumulation on the seafloor of volcanic ash, later metamorphosed during deep burial. The green colouration is due to the mineral chlorite, formed during metamorphism.

Inscriptions refer to Droylsden, Failsworth, Prestwich, Pendlebury, Eccles, Stretford.

Figure 16: Peak Moor Sandstone inset with Cwt-y-Butail and Westmorland Green Slates to form laurel leaves

11. Burlington Slate, Broughton Moor near Kirkby in Furness, Cumbria. Burlington slate, Figure 4, is one of the quarry products produced by the Holker Group. This stone was used as roofing material on many of Manchester's Victorian buildings, including the Town Hall in 1877 and again when the roof was renewed in 1977. It forms cladding on John Dalton House, John Dalton Street, an unusual eye-level application.

Acknowledgements

I would like to thank Eric Bignell, editor of the Natural Stone Specialist.

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Active tufa deposits in Shotwick Dale and Dibbinsdale: a description and analysis of Wirral tufa sites

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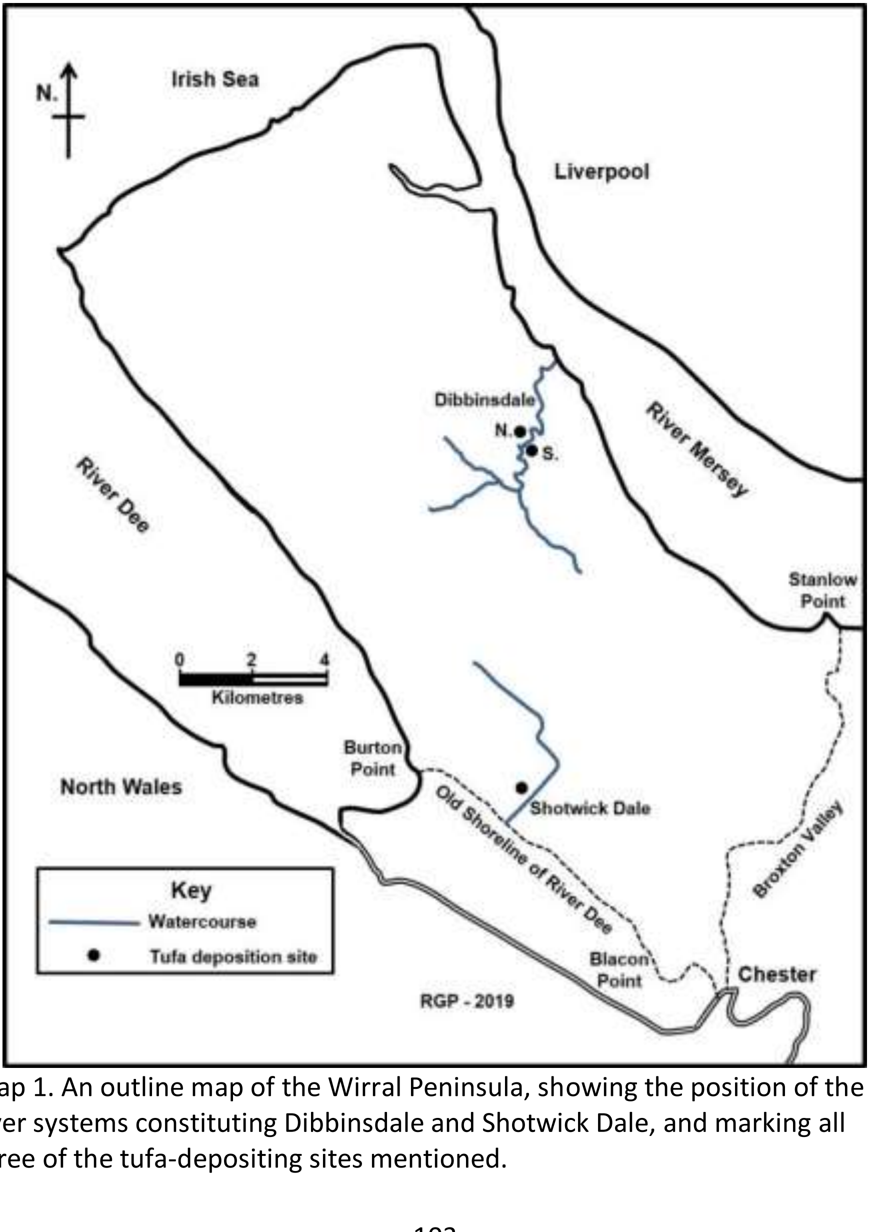


Map 1. An outline map of the Wirral Peninsula, showing the position of the river systems constituting Dibbinsdale and Shotwick Dale, and marking all three of the tufa-depositing sites mentioned.

The presence of a 'petrifying' spring in the Wirral township of Bromborough has been known since the 18th Century. Water derived from this spring deposits a calcareous layer upon any material it lies in contact with, these deposits being a form of freshwater limestone known as tufa. Such a phenomenon is unusual in this area and the Bromborough site has been described as the only occurrence in Wirral. However, fieldwork by the author has led to the discovery of two new sites, seemingly hitherto unknown. One of these is also in Bromborough, but the other is in a quite different part of the peninsula, Map 1. This article aims to describe that new spring in the township of Shotwick, compare it to the sites at Bromborough, and will analyse the deposits in an investigation of their geological background.

1. The geological background to tufa formation

Tufa is deposited by spring waters which are saturated with calcium bicarbonate, $Ca(HCO_3)_2$. Having emerged from the ground and been exposed to the atmosphere, these saturated waters emit carbon dioxide (CO_2), thus forcing the precipitation of excess calcium carbonate ($CaCO_3$), which is rapidly deposited on nearby surfaces leading to tufa formation. Tufa may also be formed by photosynthesising plants removing carbon dioxide from the water and inducing the precipitation of excess carbonate. Similarly, the metabolic processes of bacteria can contribute to the formation of tufa, although for any tufa deposit only a very small proportion of the total seems to be formed in this manner. Thus various processes act towards tufa formation and it is difficult to determine the contribution of each (Ford, 1989; Ford & Pedley, 1996).

Spring water capable of depositing tufa must have dissolved calcium carbonate to the point of saturation. Logically therefore, active tufa sites tend to be associated with certain rock types, from which carbonate can be dissolved. Tufa deposits are distributed on the basis of local geology, being most commonly associated with limestone areas (Pentecost, 2005). Tufa sites in Britain may also be found in association with other geological conditions, but not so commonly as where the local rock is a form of calcium carbonate (Pentecost, 1993).

The local rock at both Bromborough and Shotwick is Triassic sandstone of the Sherwood Sandstone Group, overlain by glacial till. Arguably the most intriguing question regarding the deposit at Bromborough has always been the source of the dissolved and re-deposited calcium carbonate. This interesting geological question is equally applicable to the newly discovered site at Shotwick, and it will be considered with respect to both sites later in this article.

2.1 A review of the Bromborough spring

The spring was first attested in 1762, when it was said that – ‘In the township of Bromborough there is a well, whose waters petrify moss, leaves &c. after lying in it some time, in a beautiful manner’ (Ingenuus, 1762). This well was next written of in 1801, when it was said to ‘possess an incrusting quality’ (Britton & Brayley, 1801). In the first half of the 20th Century, there appears to have been a renewed local interest in the spring. This led to the publication of several papers on the subject, all of which examined different aspects of the site.

The first of these papers by Hancox (1933) examined the geological implications of the spring. Some details of Hancox’s work were included in a book on Cheshire (Coward, 1932). McMillan (1947) focussed on the ecology of the spring, specifically its molluscan fauna, along with a note on a species of moss found there. There was also a red sandstone structure of unknown age at the site, which had previously captured the petrifying waters into a basin. This was first mentioned by Hancox (1933). The history and archæology of the structure were later discussed in more depth by Connah (1955). More recently the spring was included in a review of 159 sites nationwide where tufa is present (Pentecost, 1993). It was the only site listed in Merseyside and no sites were covered in Cheshire, Bromborough’s historic county.

The tufa-depositing spring at Bromborough occurs in the deep, wooded valley of the River Dibbin at grid reference SJ 341 825, some 3.7km upstream of the point where this river empties into the River Mersey. The spring lies in Patrick’s Wood, a private Cheshire Wildlife

Trust nature reserve, which itself is situated within Dibbinsdale Local Nature Reserve. The valley of the Dibbin has been carved through glacial deposits, largely till, covering much of the peninsula, which overlies Triassic rock of the Wilmslow Sandstone Formation. The till is sometimes exposed, where trees on the wooded slope have fallen. Within the till there are interbedded layers of glacial sand which are also exposed at various points along the slope. The petrifying water does not emanate from a single point but wells up in a straight line for approximately 100 metres along a steep, wooded bank above the river.

Figure 1: A sample of tufa-coated material collected from the tufa-depositing spring at Bromborough South, including twigs, bark and moss (scale: 5p coin).

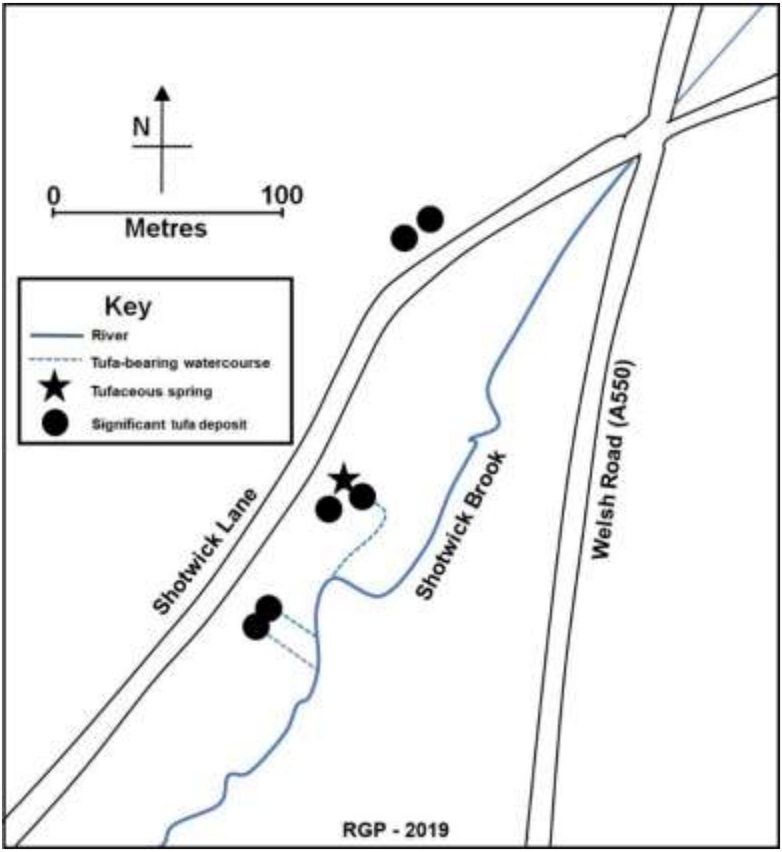
At various points along the slope there is a noticeable flow of water, although this is very slight. Other sections of the slope are simply waterlogged, with no evidence of visible flow. The flow of water can occasionally be traced back to the glacial sand beds, a point which will be returned to in section 5.2. Tufaceous deposits may be found across the slope in both the flowing and non-flowing areas, Figure 1. The first evidence of tufa is slightly below the point where the spring water initially rises, a point noted by McMillan (1947). After the first appearance of tufa it is widespread and may generally be noted as organic material with a fairly light calcareous coating occurring on the slope in small pools and damp patches, almost all the way down to the Dibbin. Hancox (1933) and McMillan (1947) both described terraces, which ran step-like down the slope. These had been formed from tufa-encrusted moss and could be 30 cm in height. These terraces are not so obvious today, nor is there any sign of the sandstone structure, which must have become completely buried by organic debris and awaits re-discovery.

McMillan (1947) reported the tufa-associated moss *Palustriella commutata* at this site. Samples collected by the author and examined by Dr Allan Pentecost contained the algae *Phormidium incrustatum* and *Gongrosira incrustans*, both of which are common species on tufa (Pentecost, 2003).

2.2 A second spring in Dibbinsdale

The spring just described (hereafter Bromborough S.) is on the southern bank of the Dibbin. On the basis of the sandstone structure which once existed there, this must be the spring mentioned in historical accounts. However, the wooded valley of Dibbinsdale is also the site of a second spring (hereafter Bromborough N.). Just 200 metres to the north, this was found during the author's fieldwork. This second spring must arise for the same reasons as the first, but it is clearly distinct since it lies on the north bank of the Dibbin. A spring on that side of the river has never previously been recorded.

A path runs south from the end of Vanderbyl Avenue, Spital, and travels down the bank of the Dibbin to enter Dibbinsdale Local Nature Reserve. The River Dibbin runs parallel and to the east of this path, at the bottom of a steep, wooded, river bank. The spring wells up several times across 50 metres of the valley side and is associated with a number of tufa deposits at SJ 341 827. In character this spring is much like that on the other side of the river. There are multiple points along the slope where the ground is waterlogged and material with a calcareous coating lies upon the damp ground and a couple of places where the spring water can be seen flowing down the slope. It is generally hard to trace the flow of water to a specific point, the exception being the most easterly deposit on the slope. That is associated with a very obvious flow of water, which emanates from the base of an exposed section of till. Most of these deposits lie on the east side of the path and continue right up to the path itself. If the line along which the water wells up is inspected to the west side of the path there is also one occurrence of tufa there, immediately adjacent to the path.



Map 2. A detailed map of Shotwick Dale showing the location of the principal tufa-depositing spring and the major tufa deposits discovered in this valley.

3. A description of the Shotwick spring

More remarkable than this second spring at Bromborough is the newly-found spring at Shotwick. The Shotwick spring lies in Shotwick Dale, a steep-sided valley associated with Shotwick Brook. Shotwick Brook is the only stream of any significance in Wirral flowing into the River Dee, for virtually all the peninsula's streams and rivers eventually drain into the River Mersey. As with the Dibbin valley at Bromborough, Shotwick Dale is cut through till overlying Triassic Sandstone, which is here part of the Chester Formation. As at Bromborough, calcareous spring waters may be found along a 100-metre section of steep, wooded stream bank. Whereas at Bromborough the spring water wells up in numerous small channels and damp patches of ground, the calcareous water at Shotwick rises at several specific locations, Map 2. Shotwick Lane, the dead-end road to Shotwick village, runs through the dale. The river is on the southern side of the road and this is where most of the tufa is to be found. However, the wooded slope of the valley continues above the road to the north, and a small amount of calcareous material has been found there.

Figure 2: The tufaceous spring marked on Map 2 has a noticeable flow emanating from a crevice in the till. The channel below the spring contains much tufa, and across the channel small but substantial tufa dams have developed (scale: 50p coin).

Starting to the south of the road and moving downstream, the first deposits are associated with a tiny stream of water. This is the only place where there is an obvious flow, for the water here can distinctly be seen to emerge from a crevice in the till and flow down the bank of Shotwick Dale in a small channel. This flow of water contains a large amount of $Ca(HCO_3)_2$ and tiny tufa dams have formed where calcareous material has built up across the channel, Figure 2.

Figure 3: A large mound of tufaceous shingle in Shotwick Dale, consisting mainly of small pieces of organic material, covered by a very thick tufa coating (scale: 50p coin).

Moving down the valley, the next site is reached very shortly. Here there is no obvious flow of water, but the slope suddenly becomes covered by a large mound of tufa, which is damp and clearly has calcareous water passing through it, just not visibly so. This mound is composed of twigs, bark, mollusc shells, leaves, mosses etc. all of which have been coated by a very thick deposit of tufa, Figures 3, 4, 5, 6, 7. This material forms a dense carpet of tufaceous shingle on the valley side, many of the constituent pieces being coated so heavily that it is not clear what is inside them. A little way below this mound is a small ditch which drains directly into Shotwick Brook, Figure 8. This seems to contain water which has passed through the mound plus water from the flowing channel just upstream. Precipitation within this ditch is not nearly so substantial as at the source of the springs. That is because most of the tufa has been deposited when the spring water emerges from the ground. Carbon dioxide is rapidly evolved on change of atmosphere, thus leading to the immediate precipitation of calcium carbonate.

Figure 4: Detail of the tufaceous shingle which forms part of a large mound, lying on the bank of Shotwick Dale. It evidently has tufa-depositing water passing through it, although not visibly so (scale: 50p coin).

Figure 5: Detail of substantial tufa deposits at Shotwick, lying on waterlogged ground, and including sticks, a mollusc shell and bark (scale: £1 coin).

Figure 6: Tufaceous material at Shotwick, bearing a substantial calcareous coating. The size of this material ranges from a few millimetres, to heavily coated twigs with a 4 mm thick coating (scale: £1 coin).

Figure 7: A representative sample of tufa-coated material collected at Shotwick, consisting of twigs, acorn cups, mollusc shells, bark and moss (scale: 5p coin).

Figure 8: The water from the main tufa-bearing spring at Shotwick runs in a channel down the valley-side, before turning sharply south west. It then runs until it meets Shotwick Brook, the junction being shown in this photograph.

Continuing some distance downstream, no calcareous material may be seen until two tiny gullies are reached, within a few metres of each other. The sides of these channels show them to be cut through the till. Both contain some good specimens of tufa, Figure 9, but no more tufa-bearing sites have been found anywhere downstream from here. It may be noted that directly above those gullies a depression in the side of the valley contains some standing water, but no tufa deposition. Further tufa has been found on the north side of Shotwick Lane, upstream and to the east of the sites previously noted. Along this lane runs a large ditch containing some stagnant water, which may have drained from higher up the slope. At two points along the ditch, tufa was observed in the standing water. However, no tufa was seen at any other places in the ditch, and none is to be seen anywhere on the valley side above the ditch. This tufa is more lightly coated than that seen on the south side of Shotwick Lane.

Figure 9: A large piece of bark, ~ 15 cm in length, entirely covered by a heavy coating of tufa. This specimen was recovered from the most southerly channel in Shotwick Dale where tufa is deposited.

4. Analysis of Wirral tufa sites

Samples of tufa collected at Bromborough and Shotwick were analysed for comparison. The results of these analyses are reported below. Section 4.1 is a purely visual comparison between samples collected at all three sites. Sections 4.2 and 4.3 are the results of analytical testing carried out on both the tufa itself, and on the spring water from which it is derived. At Bromborough, analysis was carried out only on samples from the well-known spring Bromborough S., no testing being conducted on the new spring Bromborough N.

The data presented here is considered in more detail in the next section, which studies the geological background to these Wirral tufa deposits. The results may also usefully be compared to equivalent data reported for tufa deposits at Malham (Pentecost, 1981). The tufa sites at Malham lie in the Yorkshire Dales and are classic examples of tufa deposited in a limestone area. Another interesting comparison involves examining the composition of Wirral's tufas and associated water alongside mean values calculated for tufa deposits across the UK (Pentecost, 1993 & 2003).

4.1 Visual Comparison

Visually speaking, recent samples of tufa collected at the three spring sites show distinct differences:-

> Tufa collected at Bromborough S. is generally friable, being porous and easily crumbled. The calcareous coating on twigs for example tends to be very thin, too thin to easily measure its thickness, and it flakes off easily.
>
> Tufa collected at Shotwick is much more substantial, being less porous and very densely consolidated. Continuing with the example of a twig, a 2 mm twig may have developed a 2 mm thick coating of tufa, thus the diameter of the calcareous item is triple the size of the twig. Larger twigs might easily have a 4 mm thick coating, and it was not uncommon to find organic material with an even thicker coating.
>
> Tufa collected from Bromborough N. has generally attained a thicker coating than that at Bromborough S. The tufa coating twigs was found to be up to 3 mm in thickness. This tufa is better consolidated and considerably less porous than material from Bromborough S., but less substantial than the tufa from Shotwick. Comparing the cross-section of tufa specimens collected at Bromborough N. and Shotwick, the Shotwick tufa is clearly of higher density.

Possibly the difference between the three sites is related to the rate at which tufa is deposited, the current deposition rate potentially being significantly faster at Shotwick than at Bromborough S. The deposition rate at Bromborough N. would then be intermediate between the other two sites.

4.2 Tufa Chemical Composition

A composition analysis was carried out on samples of tufa collected at Bromborough S. and Shotwick, testing for the proportion of calcium, magnesium, strontium and iron. This analysis was kindly carried out by the Natural History Museum in London using inductively coupled plasma atomic emission spectroscopy (ICP-AES).

The percentages of calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) are reported in Table 1. These were calculated on the assumption that all calcium and magnesium are present as carbonates. Trace amounts of strontium and iron in the samples are reported in parts per million.

The Wirral tufas are largely composed of calcium carbonate. The newly discovered deposit at Shotwick has a $CaCO_3$ content 3.5% higher than the Bromborough tufa, the material being 92.9% $CaCO_3$ overall. The mean proportion of $CaCO_3$ for the Wirral tufas is similar to the mean for tufa collected at six sites in the Malham area of North Yorkshire (Pentecost, 1981). The proportion of $MgCO_3$ was similar at both Wirral sites, being 1.79% on average. This $MgCO_3$ percentage is nearly eight times higher than for tufas recorded at Malham. The magnesium present in the tufa is due to the substitution of calcium by magnesium in the calcite lattice.

Site	$CaCO_3$ (%)	$MgCO_3$ (%)	Sr (PPM)	Fe (PPM)
Bromborough	89.4	1.83	230	117
Shotwick	92.9	1.75	199	342
Wirral mean	91.2	1.79	214.5	229.5
Malham mean	91.8	0.23	-	450
UK mean	94.2	0.38	465	1140

Table 1: The chemical composition of Wirral tufa deposits, shown alongside mean values from Malham and across the UK.

The UK mean value in Table 1 is the mean composition of tufa samples analysed from ten active sites where tufa is deposited (Pentecost, 1993). The percentage of $MgCO_3$ for the Wirral sites can be seen to be significantly larger than the UK mean, almost five times higher. On the other hand, the traces of strontium and iron present in Wirral's tufas are lower than the UK mean. When considered worldwide, calcite-based tufas containing more than 3.5% $MgCO_3$ are rare (Pentecost, 2005). Wirral's tufas contain around half this percentage.

4.3 Spring Water Analysis

Samples of tufa-yielding spring water were collected at both Bromborough S. and Shotwick. These samples were obtained as close as possible to the point where the springs emerge from the ground. The water collected was tested to determine the concentration of calcium and magnesium ions present. Additionally, the pH at each site was measured in the field, at multiple points along the valleys and average values were calculated from the results.

Table 2 shows the data obtained for the water chemistry. The concentration of calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}) within the spring water is reported in millimoles per litre (mmol/L). The concentration of calcium in the water is fairly typical for tufa-bearing spring waters, although the Wirral spring waters have a mean calcium concentration 0.5 mmol/L higher than the UK mean. This UK mean for the calcium and magnesium concentrations of tufa forming spring waters was taken across ten sites nationwide (Pentecost, 2003). The mean calcium concentration for the Wirral springs is also 1.54 mmol/L higher than spring waters sampled near Malham. Considering the Malham springs flow through limestone country, it is surprising to find Wirral's tufa-depositing springs have the higher concentration of calcium. Indeed, the mean concentration of the Wirral springs is almost exactly twice that of the Malham springs.

It will be seen that the concentration of magnesium in Wirral's spring waters is extremely high in both instances. Magnesium concentrations of this magnitude are highly unusual. Indeed, the magnesium concentration present in Wirral's springs is fifty times higher than is present at Malham and nine times higher than the UK mean. Even more remarkably, the magnesium concentration of tufa depositing waters rarely exceeds 2 mmol/L, when considered worldwide. Water from both springs exceeds this value, and at 2.78 mmol/L that from Shotwick exceeds it significantly. Worldwide, the ratio of Mg^{2+}/Ca^{2+} for tufaceous spring waters is rarely above 0.25 (Pentecost, 2005). The ratios in Table 2 for Wirral's springs are therefore noteworthy as being uncommon, the mean Mg^{2+}/Ca^{2+} ratio for Wirral being 0.77.

When considering the source of the dissolved carbonate, magnesium concentrations this high strongly imply the dissolution of the mineral dolomite ($CaMg(CO_3)_2$) by the spring water. It appears from these analysis results that Wirral's spring waters must dissolve a mixture of dolomite and calcite, thus leading to a slight excess of calcium in the water. The high magnesium concentration of the water also clearly leads to the relatively high percentage of $MgCO_3$ in the tufa itself.

Site	Ca^{2+} (mmol/L)	Mg^{2+} (mmol/L)	Mg^{2+}/Ca^{2+} ratio	pH
Bromborough	2.87	2.04	0.71	7.86
Shotwick	3.37	2.78	0.82	7.95
Wirral mean	3.12	2.41	0.77	7.91
Malham mean	1.58	0.048	0.03	7.50
UK mean	2.62	0.27	0.10	8.11

Table 2: Analysis of spring waters in Wirral which yield tufa, shown alongside mean values from Malham, and across the UK.

5. The Geology of Wirral Tufa Deposits

Wirral's tufa deposits are fascinating, especially to the geologist for whom they hold a special interest. Despite its geological interest, the long-recorded tufa deposit at Bromborough has not been studied in a sufficiently thorough manner, whilst that at Shotwick has never been examined before. The final part of this article will attempt to consider the reasons why these deposits occur. There are two possible sources for the dissolved carbonate which is later precipitated as tufa. The source of the Bromborough tufa has never been satisfactorily explained. It is difficult to conclusively prove the carbonate source for these tufa deposits, but notwithstanding that obstacle, this article aims to discuss the geological background to Wirral's petrifying springs more thoroughly than any previous account.

As previously noted, all these springs rise in valleys carved through till and are underlain by Triassic sandstone of the Sherwood Sandstone Group. The valleys largely pass through till, but towards the bottom of both valleys there are places where the sandstone bedrock may be seen exposed (Hewitt, 1922). Hancox (1933) was the first to question what the carbonate source could be at Bromborough. He suggested the likely origin to be boulders of limestone within the till. Certainly, there are erratic pebbles of Carboniferous limestone within the till and possibly the till itself contains some ground limestone, thus making it slightly calcareous. However, it is not known what concentration and distribution of limestone erratics would be required, to saturate spring water with calcium bicarbonate and lead to tufa formation.

The only other publication to consider why tufa forms at Bromborough is 'British travertines: a review' (Pentecost, 1993). This lists the carbonate source to be a Triassic formation, the Keuper Marl (now the Mercia Mudstone Group). Thus, of the two published sources, one suggests a glacial source the other a Triassic source. Greenwood & Travis (1915) analysed material from the Mercia Mudstone Group in Wirral and found it to be highly calcareous in all instances. These rock formations in Wirral have even been found to contain nodules of calcite (Schofield, 1940; Caspell, 1940). However, these Triassic beds are largely restricted to an area of north Wirral 8 km or more to the north of Bromborough, and even further from Shotwick. Triassic deposits of the Mercia Mudstone Group are found neither in Dibbinsdale, nor in Shotwick Dale, therefore this formation is not likely to be the carbonate source of these tufas.

5.1 A Triassic Carbonate Source?

The absence of material from the Mercia Mudstone Group does not necessarily preclude a Triassic origin for the dissolved carbonate. Sandstones of Triassic age are occasionally associated with tufa deposits due to interbedded limestones or beds of calcrete. No evidence has been discovered of such beds existing in Wirral's Triassic sandstones. However, Travis & Greenwood (1911) and Greenwood & Travis (1915) in 'The Mineralogical and Chemical Constitution of the Triassic Rocks of Wirral', considered that calcite and dolomite were the primary cementing agent present in Wirral's Triassic sandstones. Therefore, it is possible that the carbonate source, if Triassic, could be minerals dissolved out of the sandstone itself. The presence of dolomitic cements is interesting considering the water analysis in section 4.3, which suggests the dissolution of dolomite by spring waters at both Shotwick and Bromborough.

It is also known that the Triassic sandstone of Wirral contains intercalated beds of mudstone, shale and clay (Greenwood &Travis, 1915; Jeffs, 1889). Such beds could feasibly be calcareous in nature and could therefore present another source of calcium carbonate. However, it is perhaps less likely that intercalated beds of this kind would be dolomitic. An important consideration when studying these petrifying springs, is to consider the conditions which allow for the existence of springs in general. For a spring to exist in the Triassic rocks of these stream valleys, permeable and impermeable strata are required. The spring water would pass downwards through a permeable bed until it hit an impermeable layer, at which point its only route outwards would be to escape from the bedding plane where exposed on the valley-side. The permeable nature of sandstone does not lend itself to the frequent existence of springs. However, bands of clay or mudstone of the type described in the sandstone, could constitute an impermeable bed of the type which would allow for a spring to exist (Hewitt, 1922).

Tufa deposits associated with Triassic rocks are often iron-rich, due to dissolution by the spring water of some of the iron which is commonly associated with the Triassic beds. The red colour of much of Wirral's sandstone is due to the presence of iron oxide as a cementing agent, hence if these tufas are associated with a Triassic source, this could be a relevant factor. However, the composition analysis shown in Table 1 shows that neither the tufa at Shotwick or Bromborough is rich in iron.

Indeed, the Wirral tufas are low in iron. They have a lower iron content than tufas associated with the carboniferous limestones of Malham, and the trace of iron they contain is five times lower than the UK mean.

The highest percentage of dolomite found by Travis & Greenwood (1911) in a sandstone sample was 18%, a significant quantity. In general however such high concentrations were rare, only 4% of the samples tested having a carbonate content above 14%. The quantity of carbonates within the Triassic rock increases with depth. This is due to the soluble nature of these components, which have been dissolved by rainwater from surface exposures, often leaving but a few percent present. Travis & Greenwood (1911) found there to be around 2.5% carbonates in a boring at Heswall at a depth of 20 metres, but percolation of rainwater had dissolved the carbonates above this level. Double (1935b) on analysing the mineralogical content of a well core from Spital, found carbonates to be absent from the sandstone above a depth of 170 metres. The fact that carbonate-based cements generally only reach high concentrations at depth, may mitigate against these as a likely source.

5.2 A Glacial Carbonate Source?

Returning to the possibility of a carbonate source derived from the glacial deposits, tufa arising from calcareous glacial till has been recorded. In terms of till, this is a known source. Indeed, Pentecost (1993) suggests that as many as 1.1% of British tufa sites where the carbonate source is known, could be associated with springs issuing from till. Springs can arise on till due to glaciofluvial deposits, these being interbedded sands and gravels. Such beds form a permeable layer within the till, through which spring waters can flow. The till covering Wirral is known to contain substantial beds of glacial sand (Wedd *et al.*, 1923; Morton, 1891), and springs can emerge from the till where a layer of sand is exposed near the surface (Hewitt, 1922).

Patches of glacial sand are exposed at the surface on the wooded banks of the Dibbin, where Bromborough's original petrifying spring rises. Hancox (1933) noted that the spring water at Bromborough appeared to flow from one of these exposed beds of sand. This valuable observation seems to suggest how this petrifying spring forms, although we cannot say with any certainty where exactly the water has flowed before emerging from the sand. A thorough investigation of the site Bromborough S. revealed a bank of glacial sand, from the very base of which spring water does indeed seep. No sand was found at the site Bromborough N., but at one point the spring can be seen welling up from a crack in the till. Since glaciofluvial deposits are present on the other side of the valley, we can be almost certain they also exist here even if not exposed. Sands and gravels of glacial origin were discovered in the till in borings further down the Dibbin valley (Owen, 1947).

Detailed mapping of superficial deposits indicates that there are also glaciofluvial deposits of sand and gravel in Shotwick Dale, at the point where those petrifying spring waters emerge. No exposed deposits of sand have been found during field study, but the fact these deposits exist suggests that the Shotwick spring emerges from a sand bed within the till, as for the spring at Bromborough S. At the main location in Shotwick Dale where the spring waters can be observed flowing from the ground, the water clearly emanates from a large crevice in the till. In addition, at the point the Shotwick spring emerges, the till is exposed in the stream bed of Shotwick Brook at the bottom of the valley. This suggests that the spring is likely to have only passed through glacial deposits, although Owen (1947) noted exposed rock in Shotwick Dale and suggested that ‘it is apparent that the boulder clay [till] covering is thin’.

In terms of glacial carbonate sources, the till covering Wirral does contain Carboniferous limestone. Indeed, the visitor to the Wirral shore at Thurstaston will see numerous pieces of limestone derived from the till lying upon the beach. A limestone boulder discovered in 1922, during excavations on the Liverpool side of the Mersey at Gladstone Dock, was nearly 2.4 metres long and weighed 9 tonnes (Makinson, 1924). In general however, limestone is not a major constituent of the drift, usually accounting for only around 5% of the pebbles and boulders present (Jeffs, 1889). Mackintosh (1879) examined the largest erratic boulders eroded from the till and lying on the Wirral shore at Dawpool and found 5% of these were limestone. The same proportion of limestone boulders was found at a clay pit in Great Crosby (Morton, 1891). Glacial gravels in Wirral also contain Carboniferous limestone, such gravels generally being composed of fragments similar to those pebbles within the till (Jones, 1923). If limestone erratics are the carbonate source, then the waters of these petrifying springs presumably coincide with an unusual concentration of such boulders or pebbles, higher than the 5% norm. Such erratics could feasibly be dissolved by the spring water, although Hancox (1933) noted that limestone boulders recovered from local brick pits showed no evidence of dissolution.

It is also possible that the matrix of till containing the pebbles is calcareous in nature. Till excavated during work at Birkenhead and Liverpool docks was described as 'strongly calcareous' (Travis, 1913), but it is unknown how variable the till's composition is. The drift does contain material from the Mercia Mudstone Group, ground down by glacial action (Wedd *et al.*, 1923). As stated previously, these are calcareous rocks and Greenwood & Travis (1915) found that in some instances they contain an 'exceedingly high percentage of lime'. As a constituent of the till itself, this calcium carbonate could be dissolved by spring water. Analysis of Triassic material from the Mercia Mudstone Group did not show any significant percentage of magnesium carbonate (Greenwood & Travis, 1915). A chemical analysis of till samples could be illuminating in this respect, for showing to what extent it is calcareous. The only analysis traced relating to Wirral records a carbonate content in the drift of 7% at Dawpool and 5% at Wallasey Pool (Double, 1935a). It is unknown whether data from other exposures of local till would be comparable. It is difficult to state to what extent calcium carbonate is dissolved from the till, but it seems likely to be a factor which contributes to the saturation of the spring waters.

The spring water analysis in Table 2 shows the petrifying waters at Bromborough and Shotwick to be saturated with calcite. The high concentration of magnesium also present strongly suggests the dissolution of dolomite in both instances. Therefore, if the carbonate is dissolved out of the glacial material, both springs must coincide with dolomitic limestone erratics in the till, or flow through a glacial gravel bed containing dolomite. The similarity in the spring waters at Shotwick and Bromborough suggests a similar source for both tufa deposits. However, the random nature of erratic pebbles, boulders and pockets of gravel in glacial drift means that if this is the source, a similar arrangement and distribution of limestone erratics could only be coincidental. The presence of springs on opposite sides of the River Dibbin, at a specific point in the valley is interesting. The tract of till through which the valley is cut would seem to have composition suitable for tufa formation. The composition of the glacial deposits must be uniform across a wide enough area that distinct springs exist on both river banks.

5.3 Geological Summary

A Triassic carbonate source is just possible since Wirral's sandstones always contain calcite and dolomite as the major cementing agent. Wirral's tufas are magnesium-rich, since they are derived from waters which must have dissolved dolomite. Both Triassic and glacial carbonate sources could feasibly contain dolomite. However, if the spring waters do pass through the Triassic rock, it is not known whether dolomitic cement alone could produce spring water with such a high magnesium concentration. No examples of tufa derived entirely from sandstone cementing minerals have been discovered by the author. If Wirral's tufas were associated with the Triassic beds we might also expect them to be iron-rich, but analysis shows them to be low in iron, a result which goes against the hypothesis of a Triassic source. It should also be borne in mind that the Triassic sandstones only seem to contain high percentages of carbonates, at a significant depth below the surface.

It seems probable that Wirral's tufa-depositing springs all flow from glacial beds of sand or gravel lying within the till. The spring at Bromborough S. can be observed flowing from such a sand bed, whilst at Shotwick and Bromborough N. the springs appear to emanate from the till. These observations are crucial and seem a strong indication that the carbonate source is the glacial material, for we know that all these springs have passed through the glacial drift. Presumably a glacial source must largely be boulders or pebbles of limestone, either within the till or in glacial gravel. At least some of this limestone must be dolomitic limestone. It is still unclear what concentration of limestone within the drift would be necessary to saturate the spring water with calcium bicarbonate and lead to tufa deposition. However, it is interesting to note that other sites in this country have tufa associated with till, so this is evidently a viable source.

Overall, having reviewed and reconsidered the available evidence, it seems highly probable that all three of these tufa deposits are derived from the dissolution of material in the glacial drift. Hancox drew this same conclusion 85 years ago. This is a geological problem which is not easily answered. Other possibilities cannot easily be entirely discounted, but a glacial source seems the most likely explanation.

6. Conclusions

The first known petrifying spring in Wirral at Bromborough was described in 1762, whereas the second spring location at Shotwick has not been described until now, 250 years later. This new spring was discovered by the author in 2014 and was subject to a thorough investigation in 2017. As a new and interesting tufa deposit it seemed desirable to record some details of this site. Studying the Shotwick spring was accompanied by a full re-examination of the Bromborough spring. This was deemed desirable since it had not been the subject of any detailed geological examination since 1933. It was a total surprise when exploration in Dibbinsdale in 2018 revealed Wirral's third petrifying spring, on the opposite side of the valley to the original Bromborough site.

The analyses carried out show these tufa deposits to be unusual, for the spring waters contain exceptionally high concentrations of magnesium. This in turn leads to magnesium-rich tufa deposits at both Bromborough and Shotwick, which contain five times more magnesium carbonate than the average for tufa deposits found in this country. The Wirral tufa deposits seem to be associated with springs flowing from beds of sand and gravel within the till. The source of carbonate is presumed to be limestone present in the till or in glacial gravel, at least some of which must be dolomitic limestone.

It is hoped that future investigations will shed further light on the geological conditions which lead to the formation of tufa in these Wirral river valleys. It would be fascinating if yet another undiscovered tufa deposit were one day to come to light, hidden within one of Wirral's wooded dales!

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I would always be interested to learn of further tufa deposits in Wirral and surrounding areas and would be grateful for information if additional examples are known to any reader.

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http://www.geolancashire.org.uk

GeoLancashire began as the Lancashire Local Group of the Geologists' Association in 1922. The Lancashire RIGS Group was established in 1991 to identify, record and monitor sites of geological and geomorphological interest in the administrative county of Lancashire. In 2015, these two groups merged to become GeoLancashire.

A programme of illustrated talks and workshops is held during the winter months with field excursions, mainly in the summer months, to locations both within Lancashire and further afield.

GeoLancashire welcomes new members. Membership costs £12 for individuals, £20 for family membership and £5 for students in full time education.

Publications

Ribble Valley/Catchment Geotrail Guides

Preston   Brockholes   Ribchester   Dinckley Gorge
Clitheroe   Long Preston   Shedden

Other Geological Guides

White Coppice (near Chorley), 2003
Clougha, Crook o'Lune and the Conder Valley
Beacon Fell Country Park (nearest station, Preston), 2008
Geology and Landscapes of Lancashire, 2008
Jumbles Country Park (near Bolton), 2009
The Hodder Valley, 2009
Lancaster Town Geotrail Guide

Contact: Jennifer Rhodes   secretary@geolancashire.org.uk

Liverpool Geological Society

http://liverpoolgeologicalsociety.org

Liverpool Geological Society is a registered charity

2019-20 is its 161st session. During the winter months it organises a series of lectures and practical sessions on a range of topics of interest to its members, complemented by a series of field meetings during the summer months.

Publications

- The Geological Journal
- Rock around Liverpool
- Rock around Wirral
- Rock around Chester
- The William Smith map
- A field guide to the continental Permo-Triassic rocks of Cumbria and west Cheshire
- Michel-Levy charts
- Stereographic projections

Contact: Mr Gary T. Billington, Honorary Treasurer & Sales Manager
g.t.b_lgs@hotmail.co.uk

Manchester Geological Association

Founded 1925

http://www.mangeolassoc.org.uk

Manchester Geological Association

MGA was formed in 1925 to bring together professional and amateur geologists in and around Manchester.

It is actively concerned in the conservation of key geological sites in the area and supports the work of Greater Manchester RIGS Group.

During the summer, field excursions are organised to places such as the Lake District, Scotland, Peak District and North Wales. In the winter, monthly lectures by expert speakers are held at the School of Earth, Atmospheric and Environmental Sciences at the University of Manchester.

Quarterly newsletters giving full details of trips and other news are mailed to members.

Full Membership (with correspondence by email) costs £16. If correspondence by post is requested, the cost is £18 per year. Associate members residing at the same address costs an additional £2 per adult per year.

Publications

A Lateral Key for the Identification of Commoner Lower Carboniferous Coral Genera (£2.25)

Contact: Niall Clarke, info@mangeolassoc.org.uk

Geology of Knutsford's Buildings and Cobbles (£1.50)

Contact Fred Owen, fredjowen@btinternet.com

A Building Stones Guide to Central Manchester (£6.00)

Contact Jennifer Rhodes, secretary@geolancashire.org.uk