Fig. 8: Assorted shells

Fig 9: Shell sand (x10)

Fig. 10: Sea urchin test

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

Fig. 11: Machair, near Chaipaval

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

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

By Maurice Tucker
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Impact structures observed in geological strata record a range of completely different processes, operating on vastly different scales: from the potential devastating consequences of a meteorite strike with shatter cones in the country rock at the impact site, the imprints of rain on a muddy shoreline, the landing of volcanic bombs and the dropping of stones from melting icebergs on to the deep seafloor disturbing the strata. Marks from pebbles and fossils bouncing across the seafloor carried by a turbidity current and the footprints of dinosaurs impressed into soft sediment are other types of impact mark. Following Cardiff University's Professor Tom Blenkinsop's fascinating talk to the Bath Geological Society on 4th February 2021 on impacts from meteorites and comparisons with ballistic damage from bullets and shrapnel in conflict zones, I visited the former Labour Exchange building in Bath (Fig. 1). This is a Grade II listed building preserving the damage from the German air-raids during WW2 on 25th to 27th April 1942. There are some really interesting features of detail to be

seen there, from a geological-geotechnical point of view, which may be relevant to other impacts in the rock record. Further to this, during the 2021 lockdown, the author has been wandering the streets of Bath looking for more Bath Blitz damage and in so doing has found further examples and some other intriguing marks on the Bath Stone walls (Middle Jurassic oolite) of many buildings.

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

The Bath Blitz, April 1942

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

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

The Labour Exchange building

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

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

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

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

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

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

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

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

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

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

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

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

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

Other shrapnel impact marks

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

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

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

Machine-gun bullet marks

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

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

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

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

Fire damage

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

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

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

Curious small impact marks

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

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

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

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

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

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

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

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

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

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

Alternative explanation for small impact marks

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

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

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

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

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

Finally, in terms of man-made holes in Bath Stone, the front walls of a few heritage buildings in Bath are patterned with ridges and hollows, or pitted by circular

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

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

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

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

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

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

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

Concluding remarks

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

to those dark days of April 1942.

Acknowledgements

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

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

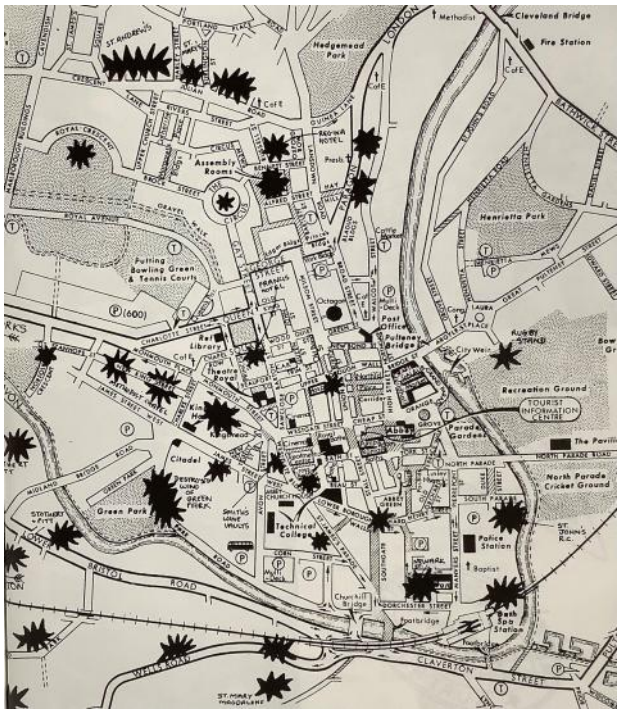

Fig. 22: Map of the bomb-sites in central Bath (from Wainwright 1992, with permission).

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Bath Geological Society Journal Issue #1 – A Review

By Phil Burge

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

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

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

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

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