when planning tests.

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

CONCLUSIONS

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

Fig. 7: Colima Volcano, Mexico

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

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

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

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

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

Introduction

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

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

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

<u>History of the lewis bolt</u>

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

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

The lewis bolt

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

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

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

Other lifting devices

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

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

Lewis bolt holes

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

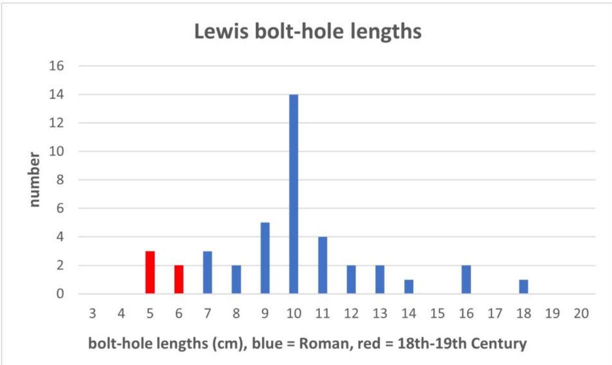

Fig. 8: Histogram showing range of lengths of 34 bolt holes from Roman stone blocks and 5 from 18-19th C stones from the Roman Baths and stone store, Bath

Origin of the term lewis

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

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La Soufrière Volcano, St. Vincent. Eastern Caribbean.

By Graham Hickman

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

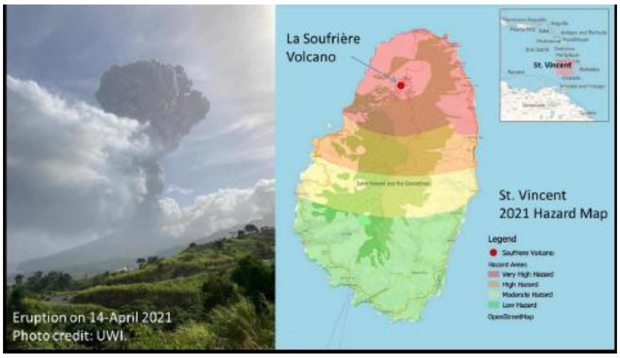

Fig. 1: St. Vincent and La Soufrière Volcano.

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

My 2013 Visit to La Soufrière.

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

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