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NEW EVIDENCE FOR THE COROTOMAN RE-USE HYPOTHESIS FOR THE STONE FLOOR OF COLONIAL CHRIST CHURCH, IRVINGTON, VIRGINIA[1]

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Abstract

We hypothesize that the Purbeck Stone pavers of Robert "King" Carter's Corotoman mansion were re-used after Corotoman burned down in 1729 to pave the floor of Christ Church, which Carter began building the following year. We originally tested the Corotoman re-use hypothesis in 2010 using the size, number, and area of the Purbeck Stone pavers from both locations. In this study we provide four additional pieces of evidence that support the Corotoman re-use hypothesis for the stone floor of Christ Church: 1) presence and chemistry of melted lead on the stone pavers from Corotoman as well as on the stone pavers in Christ Church, 2) matching color of fire-damaged stone pavers from Corotoman and Christ Church, 3) spacing of tool marks in stone pavers recovered from Corotoman matches those in Christ Church, and 4) close proximity of Christ Church to Corotoman by land and/or water for the transport of the stones.

Introduction

Due to the physical and chemical stability of the minerals that compose rocks, lithic artifacts dominate the archaeological record (Kooyman 2000). This applies as well to historic archaeology sites in the Chesapeake Bay region which often contain bricks and building stones (Noël Hume 1963). The scarcity of natural stones in the Chesapeake Bay area (Pazzaglia 1993) means that nearly all stone used during the early colonial period was imported from England at some cost (Whiffen 1960; Crowell and Mackie 1990; Yetter and Lounsbury 2019). Like most of the other goods at this time, a variety of stones were imported into Maryland and Virginia from England, including paving stones and tombstones (Mackie 1988; Breen 2004; Key et al. in review).

Colonists imported stone from England for important buildings, such as many of the parish churches in Virginia (Rawlings 1963; Davis and Rawlings 1985; Upton 1997), the main public buildings in Williamsburg (Virginia Gazette 1756; Whiffen 1958, 1960), and exceptional private residences like Corotoman (Glenn 1899; Key et al. 2010). Although there was a cost associated with importing stone from England, the Chesapeake economy could afford it. Despite accounting for only 30% of the population in the 13 English colonies in America, the Chesapeake area accounted for 60% of the exports back to Great Britain (Price 1964).

Much of that wealth came from tobacco, which grew well in the fertile soils (Price and Clemens 1987). No planter accumulated more wealth or power from tobacco than Robert "King" Carter, who was born in 1663 at his father's Corotoman plantation along the Rappahannock River. At his death in August 1732, Carter owned 48 plantations, 300,000 acres of land and 734 enslaved people, more than half of whom spent sunup to sundown cultivating the crops that would make Carter a leading figure in the transatlantic economy and fund construction of Corotoman and Christ Church (Wharton 1950; Naisawald 1986; Brown 2010). The Carters could afford to import other stones from England including Portland Stone for Robert Carter's table tomb outside of Christ Church (Slavid et al. 2003) and John Carter's black "marble" tombstone from Belgium inside Christ Church (Key et al. 2021). Chesapeake's slave-based, tobacco economy created for a few very wealthy planters the ability to import building materials like the Purbeck Stone pavers. They were expressions of the Carters' extraordinary wealth, transatlantic connections, and skewed distribution of wealth in the region. Christ Church is registered with the U.S. National Park Service (National Historic Landmark Number

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66000841), the Historic American Buildings Survey (HABS VA,52-KILM.V,1), and the Virginia Department of Historic Resources (ID number 051-0004). In 2010, we proposed that the stone pavers in Christ Church in Irvington were reused from the Corotoman mansion (Site 44LA13) in Weems, both in Lancaster County in the Northern Neck of Virginia (Figure 1) (Key et al. 2010). The mansion house was one of 18 buildings in Robert Carter's Corotoman compound (Hudgins 1979, 1985; Kimball and Henson 2017). At a time when most colonists lived in frame houses often no larger than 6 by 5 m (20 × 16 ft) (Carson et al. 1981), Corotoman was a Georgian brick house that stretched 27 by 12 m (90 × 40 ft), rising two and a half stories above a full English basement and arcaded gallery (Waterman 1945; Kornwolf and Kornwolf 2002; Malon 2005; Carson 2013). Both the English basement and the arcaded gallery were paved with Purbeck Stone (Hudgins 1979:fig. 9, 1985:fig. 14; Key et al. 2010:fig. 5; Carson 2013:fig. VIII). Corotoman burned down in late January to early February of 1729 and was never rebuilt (Hudgins 1985, 1990).

The following year, Robert Carter began construction of a brick Christ Church to replace the wooden one built on the same site by his father John Carter in 1670 (Neblett 1994; Harpole et al. 2007). But like his father John, who died six months before the completion of this first Christ Church, Robert Carter never saw the completion of his brick church because of his death in 1732. That task fell to his sons who oversaw its completion in 1735. In a landscape originally dominated by small, wooden, earthfast structures (Carson et al. 1981), Christ Church has stood as one of Virginia's most distinctive buildings (Stanard 1908; Upton 1986; Brown and Sorrells 2001; Lounsbury 2002). Today this remarkable building, a 21 by 21 m (70 × 70 ft) cross-plan Georgian design, appears much like it did nearly three centuries ago. Included in its outstanding collection of original architectural features are the subjects of this study, the interior stone floor pavers (Neblett 1994; Key et al. 2010).

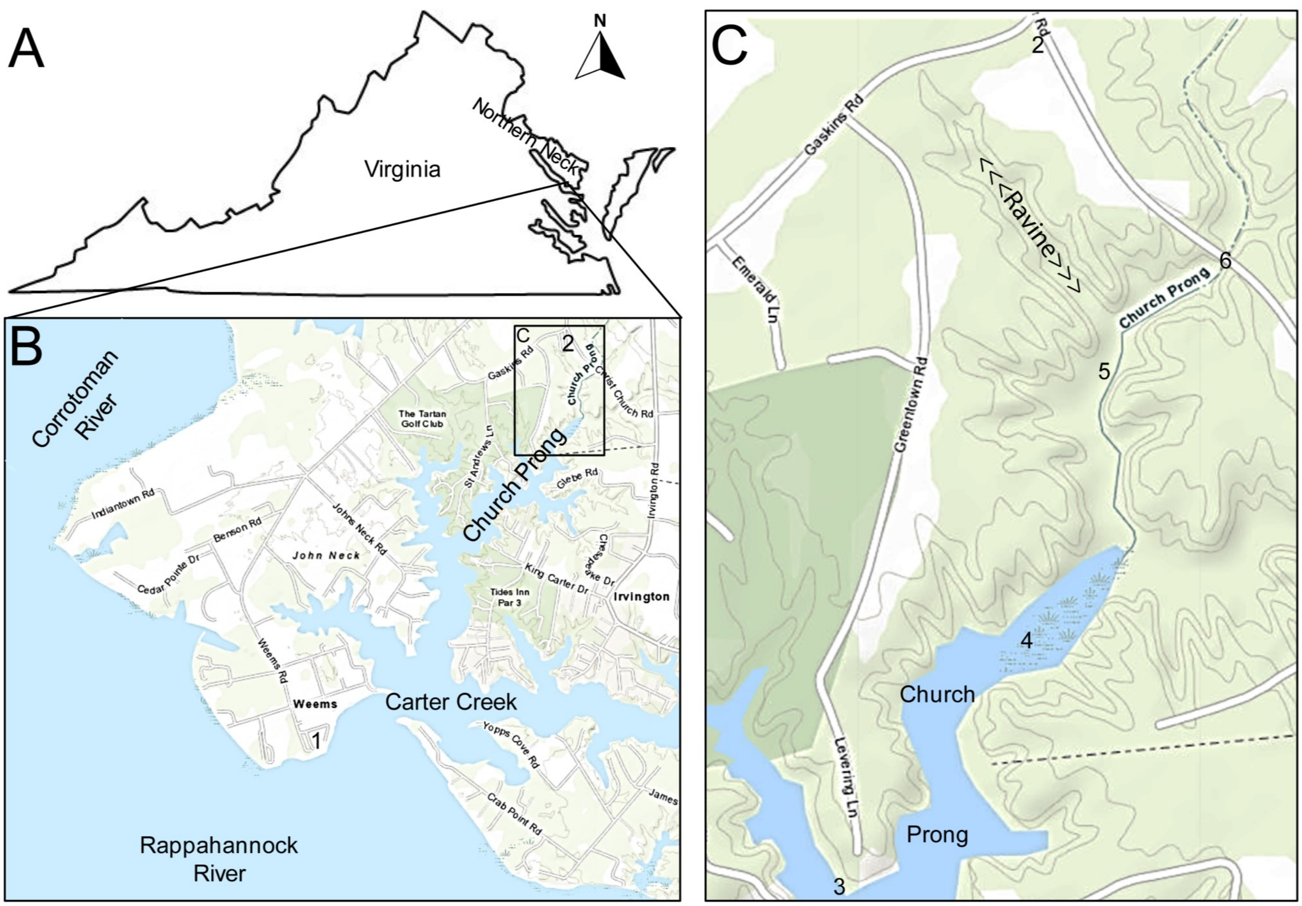

Figure 1. Map showing location on Virginia's Northern Neck (A) of Christ Church relative to Corotoman plantation, Carter Creek, Corrotoman River, and Rappahannock River (B), and Christ Church relative to Church Prong (C). 1=Corotoman mansion, 2=Christ Church, 3= Church Landing, 4=last boat dock, 5=last visible channel, 6=intersection of Christ Church Rd. and Church Prong (Modified from Esri WorldTopo (https://www.mindat.org/feature-4756753.html).

By matching the fossil clams and oysters preserved in the pavers of Christ Church with those of the Intermarine Member of the Durlston Formation of the Purbeck Limestone Group, we determined that the stone pavers in Corotoman and Christ Church are both made of Purbeck Stone (Key et al. 2010). The Purbeck is of Early Cretaceous age and outcrops along the Dorset coast of southern England.

From the 1600s, Purbeck Stone was a well-known paving stone in England (Neve 1703, 1726; Knoop and Jones 1935; Clifton-Taylor and Ireson 1983; Dimes 1990). Purbeck Stone was also known in the Virginia colony at this time as it was listed as one of the stones commercially available in the *Builder's Dictionary* (Neve 1703, 1726). This architectural guide to professional builders was in common use in Virginia at that time by the Carter family (Lounsbury 2005) and by Thomas Jefferson as evidenced by a copy in his personal library (Gilreath and Wilson 2010). The dictionary lists Purbeck Stone as a hard, greyish rock used for pavements. It was sold in various sized slabs, but the price was more for specific sized squares (a.k.a., mitchels). A mitchel is a Purbeck Stone specifically for paving, and while they range from 15 to 24 inches square (Neve 1726), those in Christ Church average 18 inches square (Key et al. 2010; see below for more data on size of Purbeck pavers). In the English Chesapeake colonies of Maryland and Virginia before about the year 1700, Purbeck Stone was imported mostly for ledger stones (i.e., tombstones laid flat on the ground), and in the 18th century it was more commonly used for paving stones (Table 1; Morriss 1914; Key et al. 2010). Inside Christ Church, it was used for both (Table 1; Key et al. 2010).

Building	Location	Approximate year(s) of installation	Use	Reference(s)
Jamestown Memorial Church	Jamestown, VA	unreadable	John (unreadable) ledger stone	This study
Warner Hall	Gloucester, VA	1662	Mary Warner ledger stone	This study
Christ Church	Irvington, VA	1674	David Miles ledger stone	Neblett 1994; Key et al. 2010
Warner Hall	Gloucester, VA	1674	Augustine Warner ledger stone	This study
Grace Episcopal Church	Yorktown, VA	1674	George Read ledger stone	This study
State House	Annapolis, MD	1695	floor pavers	Riley 1905; Maryland State Archives 2020
Grace Episcopal Church	Yorktown, VA	1696	Elizabeth Martiau Read ledger stone	This study
Governor's Palace	Williamsburg, VA	1706-1710	floor pavers in both entry hall and basement	Kocher 1952; Schlesinger 1981
Ware Episcopal Church	Gloucester, VA	1718/1719	floor pavers	Jones 1991; this study
Corotoman	Weems, VA	1720-1725	floor pavers in basement	Hudgins 1979, 1985; this study
Christ Church	Irvington, VA	1730-1735	floor pavers	Neblett 1994; Key et al. 2010, this study
Capitol	Williamsburg, VA	1756	floor pavers in portico	Fleming 1756; Whiffen 1958; Schlesinger 1981

Table 1. List of known uses of Purbeck Stone in Maryland and Virginia during the colonial period arranged by installation date.

Unfortunately, the Corotoman mansion, with its Purbeck Stone paved basement and arcaded gallery or "piazza," as Robert Carter called it (Carter diary 8 March 1724/25), did not last long. The Maryland Gazette of 11 February 1729 reported that "The fine, large House of Col. Carter, on Rappahannock, was also burnt lately. The Particulars of his Loss we can't give you, but we are inform'd it is very great" (Hudgins 1985:101). Robert Carter refers to the burning of Corotoman in a 2 July 1729 letter to London merchant Alderman Perry, "The terrible disaster I underwent by fire of which you will hear" (Wharton 1950; Hudgins 1985; Carson 2013).

One product of the fire of use for this study is the presence of melted lead that fell onto the stone pavers during the intense heat. Following archaeological excavations at Corotoman, Noël Hume (1963:137) reported "sizable lumps of badly burned lead were … found and presumably came from the roof. One small piece resembles a stalagmite and was created in much the same way, the lead dripping down as the house burned, the drips hardening as they reached the ground and piling up one upon another." Following his 1978 excavation, Hudgins (1984:279) wrote that, "During the fire that destroyed the house, household furnishings, or pieces of them, fell into the basement of the collapsing mansion where they lay until retrieved by archaeologists in 1977 and 1978." When the main building of the College of William and Mary in Williamsburg burned down in 1705, eyewitnesses reported molten lead dropping down from the roof during the fire (Whiffen 1958). A similar incident happened when Notre Dame Cathedral in Paris burned in 2019 as firefighters reported molten lead dropping from the lead roof onto the floor (Lesté-Lasserre 2020). There was so much lead found during the Corotoman archaeological excavation that Hudgins (1985:fig. 28) mapped the weight of recovered lead artifacts per square excavation block.

Due to the shortage of naturally occurring stone and the cost of importing it from England to the Chesapeake Bay, when a building burned down, any stone was regularly reused from one building to the next (Schlesinger 1981; Key et al. 2010, 2016; Yetter and Lounsbury 2019). In fact, Corotoman's builder Robert Carter had his own history of reusing building materials: when he made his proposal in 1730 to the vestry of Christ Church Parish to build a brick church at the site of his father's church the vestry gave him "the liberty to use whatever of the old church he might find useful" (Ball 1835). In particular, Harpole et al. (2007) suggested the ceramic floor tiles from the 1670 Christ Church were used elsewhere by Carter.

In 2010, we provided eight pieces of circumstantial evidence that the stone pavers in Corotoman were reused at Christ Church (Key et al. 2010): 1) Corotoman burned down in 1729 which predates the construction of Christ Church which began in 1730. 2) Both Christ Church and Corotoman were financed and constructed by Robert Carter, and thus he was free to transfer the pavers from Corotoman to Christ Church. 3) Despite detailed historical records of Robert Carter and his children ordering stone pavers for Corotoman and imported manufactured items for Christ Church, there is no record of ordering stone pavers for Christ Church. 4) 90% of the stone pavers in Corotoman had been removed by the time archeologists excavated its ruins in 1978. 5) There was more than enough surface area of stone pavers in Corotoman to cover the floor of Christ Church. 6) The number of stone pavers in Corotoman was more than enough to cover the floor of Christ Church. 7) The average size of stone pavers in Corotoman was identical to that of Christ Church. 8) Some of the stone pavers in Christ Church have evidence of fire damage.

In this study we provide four additional pieces of evidence that support the Corotoman re-use hypothesis for the stone floor of Christ Church: 1) presence and chemistry of melted lead on the stone pavers from Corotoman as well as on the stone pavers in Christ Church, 2) matching color of fire-damaged stone pavers from Corotoman and Christ Church, 3) spacing of tool marks in stone pavers recovered from Corotoman matches those in Christ Church, and 4) close proximity of Christ Church to Corotoman by land and/or water for the transport of the stones.

Materials and Methods

An historical geoarchaeological approach was used to test our Corotoman re-use hypothesis. Due to its isolation by the Chesapeake Bay to the east, Potomac River to the north, and Rappahannock River to the south, many of the Northern Neck's (Figure 1A) written records were never destroyed in the Civil War (e.g., Key and Gaskin 2000; Key et al. 2000). This provided a rare opportunity to correlate the archaeological evidence from Corotoman with the historical record, including Robert Carter's letters and diaries (Hudgins 1979). To this historical archaeology approach, we added the diverse analytical techniques of geoarchaeology (Rapp and Hill 2006; Gilbert et al. 2017).

We chose lead for two reasons to test our hypothesis that the Purbeck Stone pavers from Corotoman were reused to pave the floor of Christ Church. First, it was a commonly recovered artifact from Hudgins' 1978 archaeological excavation of Corotoman, and droplets were reported on fire-damaged Purbeck Stone in the excavation's artifact catalog (Hudgins 1985). Therefore, it should be found on the stone pavers in Christ Church. Second, lead is a stable metal that does not dissolve readily in archaeological sites (Mattias et al. 1984). Under most archaeological conditions where there is prolonged exposure, lead carbonate and lead oxide generally form a protective layer on lead artifacts that prevents further oxidation (Hamilton 2010). So, if lead did drop onto the stone pavers at Corotoman during the fire, it should still be found on the stone pavers in Christ Church. Finally, lead has been successfully used by others to source archaeological artifacts (e.g., Badreshany 2014).

To use the presence of lead on Purbeck Stone pavers from Christ Church as evidence that the stone pavers were reused after the fire at Corotoman, we first had to demonstrate that there is no lead naturally occurring within the Purbeck itself. According to El Shahat and West (1983:tbl. III), the compacted limestones of the Intermarine Member of the Durlston Formation of the Middle Purbeck Limestone Group, which was quarried for stone pavers, lack lead. To confirm this, we sampled the interior of the pavers, which would not have been contaminated by molten lead from the fire.

Second, we sampled what we thought was lead on the Purbeck Stone pavers. Since lead has a hardness of 1.5 on the Mohs hardness scale, which is less than the hardness of a human fingernail (2.5), it was easy to identify without a microscope. Along with the ability to scratch lead using our fingernails, lead also displays a metallic luster and gray color that we were able to use to identify lead drops.

We followed this identification protocol to avoid sampling drops of paint as lead-based paint was used from the time of Christ Church's construction (Neve 1726) to well into the 20th century (Warren 1999). Based on preserved invoices, we know that lead-based paint imported from England was used in Colonial Virginia (Morrison 1987:295). In 1724, the typical house in Williamsburg was described as a timber frame painted with white lead and oil (Hudgins (1984:207). Neighboring and contemporaneous Rosewell, home of Robert Carter's daughter Judith Carter Page, also used lead-based paint (Lounsbury 2002:10). It is likely that the original "wainscot" brown color on the pews contained lead-based paint (Neblett 1994). Therefore, our sampling methodology was designed to avoid paint, but one source of lead we could not avoid was any atmospheric deposition (Renberg et al. 2001).

We obtained seven fragments of Purbeck pavers from the Corotoman artifact collection at the Virginia Department of Historic Resources (VDHR) in Richmond, Virginia and seven from Christ Church. We made sure to sample pavers from Christ Church that were original to its construction. This involved avoiding modern replacements set with concrete as opposed to the original dry-laid/butt-jointed pavers. In the 1970s and/or 1980s and perhaps earlier, masons re-used stone pavers from Corotoman to replace a few deteriorated pavers in Christ Church.

Using a Dremel tool, we cut small (<5 mm) sub-samples from each sample. These were mounted using conductive double-sided tape onto 12.2 mm diameter by 10.0 mm tall cylindrical aluminum stubs. They were carbon coated in a Structure Probe Inc. (SPI) SPI-Module Carbon Coater with a carbon fiber head controlled by an SPI-Module Control unit model #11425 running in pulse mode at 6.5 V. The chemistry of the samples was then determined with a JEOL JSM-5900 Scanning Electron Microscope with an integrated Oxford 7274 Energy Dispersive X-ray Spectrometer (SEM-EDS) running their INCA Nanoanalysis software version 4.15. The software automatically calculates the weight% (wt%) of up to 26 elements per analysis. We chose this approach since calculating wt% lead from SEM-EDS analysis has been successfully used in the past to source archaeological artifacts (Badreshany 2014). Once the subsamples were created, the remnant samples and the SEM stubs were returned to VDHR to be archived.

In order to compare the Purbeck samples between Christ Church and Corotoman, we calculated the ratio of calcium (Ca) to magnesium (Mg). We did this for two reasons. First, Ca and Mg were the two most common elements (other than C and O discussed below) in the Purbeck samples. This is to be expected as the compacted limestones of the Intermarine Member of the Durlston Formation of the Middle Purbeck Limestone Group are made of 86.9 wt% calcite, CaCO3 (El Shahat and West 1983). In the mineral calcite, Mg often naturally co-occurs with Ca, as Mg can substitute for Ca with increasing amounts of Mg leading to the mineral dolomite, CaMg(CO3)2 (Chave 1952). Second, the Ca/Mg ratio is often used in the Earth sciences to characterize a variety of materials such as soils (Nayak et al. 2005) and water (Paliwal and Gandhi 1976) and as a paleotemperature proxy (Mitsuguchi et al. 1996).

Figure 2. Parallel tool marks on the surface of Purbeck Stone pavers from the floor of the nave of Christ Church.

To compare the lead samples between Christ Church and Corotoman, we calculated the ratio of lead (Pb) to arsenic (As). We did this for two reasons. First, Pb and As were the two most common elements (other than C and O discussed below) in the lead samples. This is to be expected as As often naturally co-occurs with lead (Petz et al. 1961). Second, the Pb/As ratio is often used in the Earth sciences to characterize a variety of materials including soil (Embrick et al. 2005), water (Smith et al. 2006), and dust (Lambert and Lane 2004).

To capture the spatial variability in the chemistry of each sample, two sites of interest (SOI) were analyzed on each sample. The SOIs were either a possible lead drop or a Purbeck fossil shell fragment. To obtain replicate measurements for quality control, 5-15 spectra (mean: 11, standard deviation: 2) were collected at each SOI. Therefore, there were 13-28 separate chemical analyses performed for each sample for a total of 644 analyses. Spectra were collected at a 15 kV accelerating voltage with a typical magnification of 700×, 9 mm working distance, and 45 nm spot size. The data were normalized to a total 100 wt% for each spectrum. Only C and O were present in all samples, and both were excluded from further analysis. C was excluded because the samples were C coated as required for our SEM-EDS analysis. O was excluded because it was not measured but automatically calculated by the INCA Nanoanalysis software using stoichiometry. Of the other 24 elements measured, most were very rare except for Ca, Si, Pb, Mg, and As.

While samples are normally polished to minimize analytical “noise” in the results due to irregularities in the surface of the samples (Newbury and Ritchie 2013), our samples were not polished to reduce harmful lead dust contamination. In order to minimize the analytical “noise,” first we simply excluded samples with overly concave surfaces and chose flat samples. This would not have eliminated all the “noise.” Second, we further reduced the “noise” by using backscattered electrons which come from deeper in the sample than secondary electrons which come from the surface (Reimer 1998).

To look for fire damage on the stone pavers, we applied the standard Munsell (2009) rock color classification to both fire-damaged and pristine Purbeck Stone pavers from both Christ Church and Corotoman. The Christ Church paver colors were classified in place on the interior floor of the church. The Corotoman paver colors were classified on the fragments removed during Hudgins’ 1978 excavation and now archived at VDHR in the Corotoman artifact collection. Pavers were designated as fire-damaged if they exhibited spalling and/or discoloration as listed by Oster et al. (2012) and Ryan et al. (2012) or were identified as such by the original archaeologists as fire-damaged (Hudgins 1985).

To reduce transportation weight and cost, the hand-dressed Purbeck Stone pavers were probably dressed at the quarry in or near Swanage, England (Key et al. 2010). Purbeck Stone pavers typically have a pattern of tool marks on the flattened upper face. The traditional finish for Purbeck Stone pavers in England is a pattern of parallel continuous furrows called a batted or tooled finish (Benfield 1940; Natural Stone Institute 2016). This is commonly seen in the Purbeck Stone pavers in the town of Swanage, England where they were quarried (Key et al. 2010) and in the streets of nearby Corfe Castle. One can also see this in Christ Church (Key et al. 2010:fig. 2). The flatter the original bedding plane of the Purbeck limestone, the shallower the chisel marks and the less noticeable the pattern is. In some pavers, this pattern is preserved; in others it has worn away (Figure 2). If the stone pavers from Corotoman were reused in Christ Church, the tool marks should have similar spacing. To that end, we measured the spacing of tool marks to the nearest 1 mm using digital calipers.

To infer how the stone pavers were transported from Corotoman to Christ Church, we analyzed the latest bathymetric and topographic maps as well as satellite images of the area. We determined the regional and local rates of absolute sea level rise, subsidence, sedimentation, relative sea level rise, and marsh erosion. We did this for today and 1730 when Christ Church was under construction. The best estimates of rates were compiled from the published primary literature.

Lead on Purbeck Stone Pavers from Corotoman and in Christ Church

We were able to collect 644 total SEM-EDS spectra on 29 samples: 16 from Corotoman, 13 from Christ Church. Nine of the 29 we thought were lead drops on Purbeck Stone pavers from Corotoman. Six of the 29 were lead drops on Purbeck Stone pavers from Christ Church. We analyzed seven Purbeck Stone paver samples from Corotoman and seven from Christ Church. Of the 15 samples we thought were lead, 100% of the 314 acquired spectra contained measurable wt% Pb (range: 2.8-93.2 wt%, mean: 43.4 wt%, standard deviation: 14.0 wt%). Of these 314 spectra, 93 (30%) also contained measurable As (range: 0.01-0.33 wt%, mean: 0.10 wt%, standard deviation: 0.08 wt%). Of the 14 samples of Purbeck Stone, 100% of the 330 acquired spectra contained measurable wt% Ca (range: 0.3-71.5 wt%, mean: 35.4 wt%, standard deviation: 13.3 wt%). Of these 330 spectra, 209 (63%) also contained measurable Mg (range: 0.06-2.46 wt%, mean: 0.25 wt%, standard deviation: 0.18 wt%). Of the 330 Purbeck spectra, only 29 (9%) contained measurable Pb. The mean amount of lead in the Purbeck samples was 0.3 wt% as compared to 43.4% in the lead drops. This indicates there is very little naturally occurring lead in the Purbeck Stone pavers. This confirms what El Shahat and West (1983:tbl. III) reported, that the compacted limestones of the Intermarine Member of the Durlston Formation of the Middle Purbeck Limestone Group lack lead. Therefore, any lead we found was most likely from the Corotoman fire, not the Purbeck Stone itself.

The mean Pb/As ratio was not significantly different between the lead samples from Corotoman and Christ Church (Table 2, Figure 3, t-Test, $P = 0.331$). Nor was the Ca/Mg ratio significantly different between the Purbeck samples from Corotoman and Christ Church (Table 2, Figure 4, t-Test, $P = 0.602$). Even if we

	Sample location	Corotoman	Christ Church	Corotoman	Christ Church
	Sample type	Purbeck	Purbeck	Lead	Lead
	Number of spectra	114	95	45	48
wt%Ca/ wt%Mg ratio	Minimum	30.8	1.7		
	Mean	97.7	94.6		
	Maximum	214.2	228.9		
	Standard deviation	37.77	46.3		
wt%Pb/ wt%As ratio	Minimum			97	125
	Mean			823	1077
	Maximum			4865	6601
	Standard deviation			868	1541

Table 2. Summary statistics of SEM-EDS chemical data for Purbeck and lead samples from Corotoman and Christ Church.

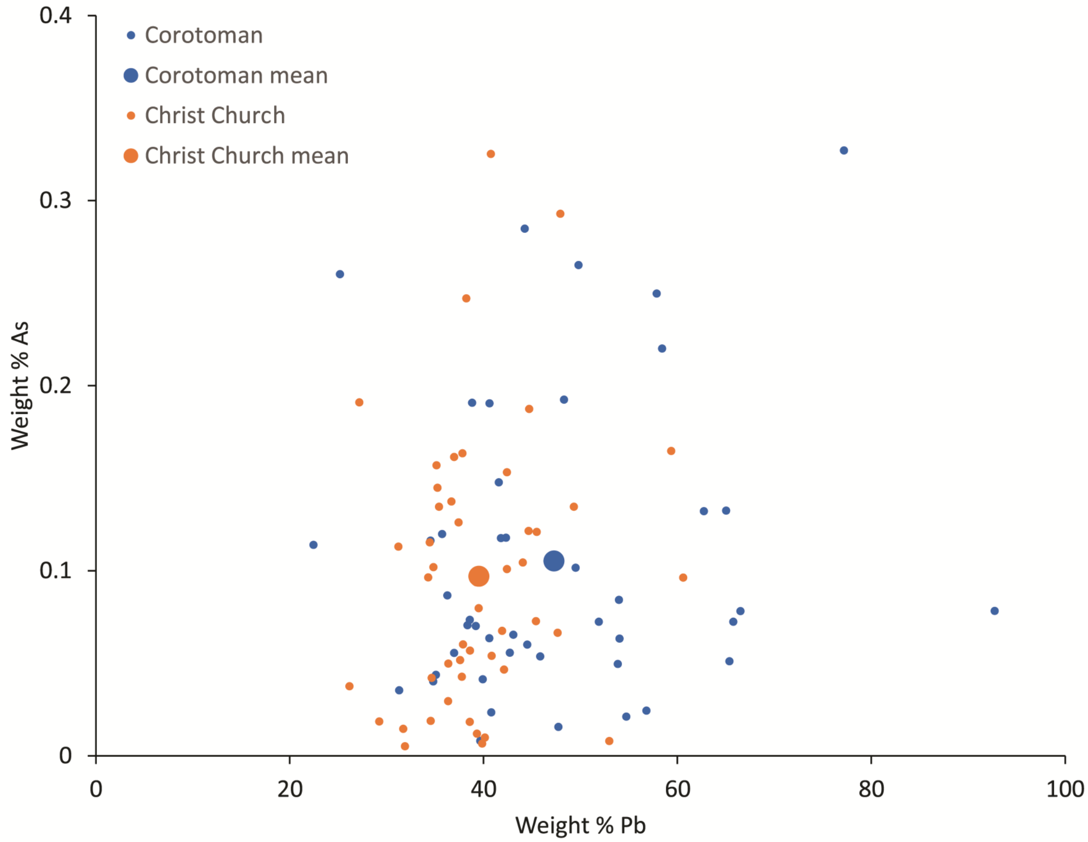

Figure 3. Plot of weight % Lead (Pb) versus Arsenic (As) in lead samples showing similar results from Corotoman and Christ Church.

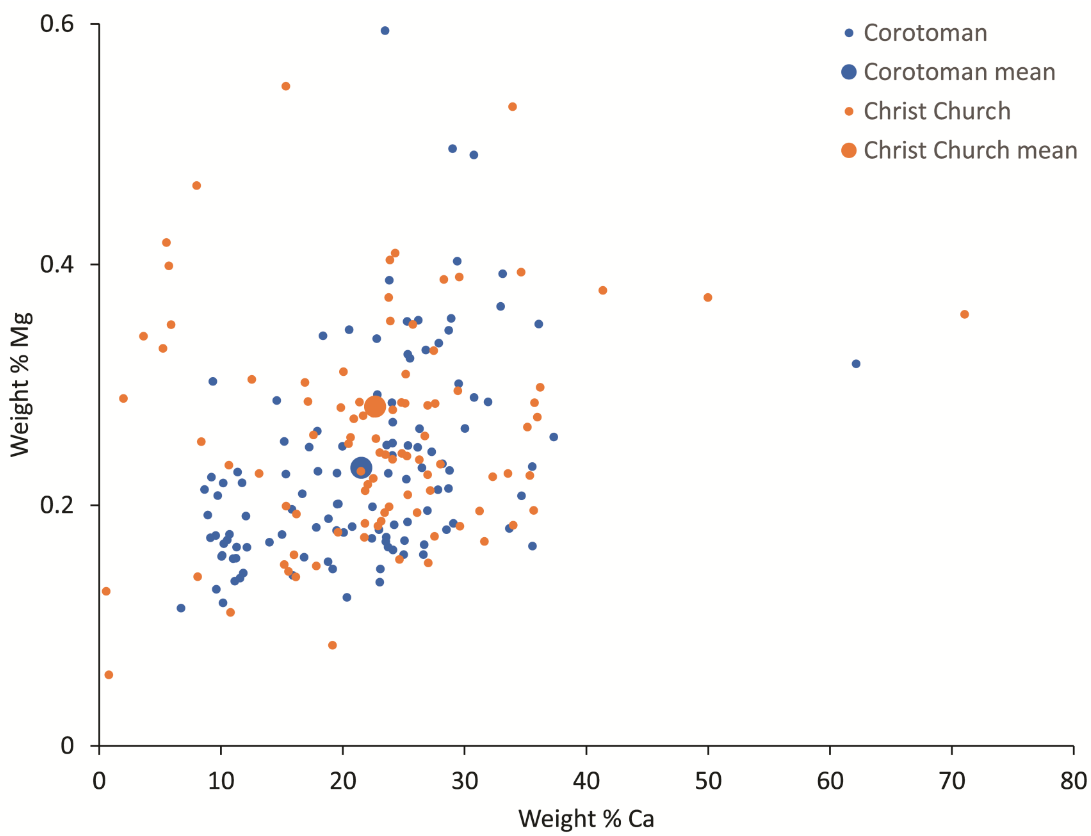

Figure 4. Plot of weight % Calcium (Ca) versus Magnesium (Mg) in Purbeck samples showing similar results from Corotoman and Christ Church.

ignore this quantitative SEM-EDS data due to surface irregularities of our samples, the very presence of lead drops on Purbeck Stone pavers from Corotoman and Christ Church supports the re-use hypothesis. 100% of the artifacts recovered from Corotoman and identified as lead by the archeologists were confirmed by our SEM-EDS analysis. 100% of what we thought were lead droplets sampled on the floor of Christ Church were confirmed by our SEM-EDS analysis. This supports the Corotoman re-use hypothesis for the Purbeck Stone pavers in Christ Church.

Where did the lead come from? Did Corotoman have a lead roof? In Neve's (1726) English builder's guide, lead is listed as the best but most expensive roof covering, and thus, was mainly used on finer "churches, prince's palaces, castles, and great men's houses." Robert Carter's Corotoman was arguably a great man's house. We know from surviving invoices that roofing lead was imported from England for use in the English colonies (Morrison 1987). The 1709 Governor's Palace in Williamsburg had a lead roof (Carson and Lounsbury 2013). We know that the house Robert Carter's daughter, Judith Carter and her husband Mann Page built at Rosewell from 1726 to 1737, 37 km (23 mi) to the south of Corotoman, had a lead roof (Waterman 1945; Kocher 1952; Noël Hume 1963; Lounsbury 2002; Carson and Lounsbury 2013). Carter considered Mann Page one of his favorite sons-in-law, and the two surely exchanged ideas on architecture and construction. In his will, Carter left Judith £300 sterling towards "furnishing" Rosewell (Lounsbury 2002). This suggests it is possible Corotoman had a lead roof as well.

On 25 August 1722 Carter recorded in his diary that the "plummer" had "layed down the Gutter leads on the east end of the Front of the building" (Berkeley 2015:folio 4). Plumber was the term used for craftsmen who work in the plumbery trade (i.e., the art of working in lead) (Neve 1726; Lounsbury 1994). So much lead was recovered during the excavation of Corotoman in 1978 that the archaeologists decided to weigh it (Hudgins 1985).

To determine if there was enough lead recovered from the Corotoman archaeological excavations to reconstruct a roof, we compared the amount of lead from Corotoman with the lead roofing sheets preserved at Rosewell. We added up all the lead listed in Hudgins' 1978 excavation artifact catalog. It totaled 107 kg (236 lb) of recovered lead (Hudgins 1985). If Corotoman had a lead roof, it would have at the minimum covered the area of the house's foundation, excluding the arcaded gallery. This assumes the roof extended laterally to the exterior of the foundation walls and was a flat roof, similar to the one at Rosewell hidden behind its brick parapets (Lounsbury 2002). This was the norm at the time for lead roofs (Neve 1726). Using Hudgins' (1985:fig. 15) architectural drawing of the foundation, we measure Corotoman's minimal roof area at 364 m2 (3,915 ft2).

Sheet number	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)
1	1764.5	338.3	161.0	3.1
2	1379.1	262.7	161.7	3.2
3	866.1	324.3	89.3	3.1
4	2167.1	352.0	158.0	4.6
5	1612.2	305.7	160.7	3.3
6	3810.2	722.0	160.3	3.4
Minimum	866.1	262.7	89.3	3.1
Mean	1933.2	384.2	148.5	3.5
Maximum	3810.2	722.0	161.7	4.6
Standard deviation	926.9	153.7	26.5	0.5

Table 3. Weight and dimensions of the lead roofing sheets from Rosewell.

How much area would 107 kg of lead cover? We can calculate this if we assume Corotoman was covered with lead sheets similar to Rosewell's. We measured the weight, length, width, and thickness of the six largest lead roofing sheets from Rosewell's archives (Table 3). They indicate each square meter of roof required 33.2 kg of lead. This assumes the sheets abutted and were not connected by standing seems which would have reduced the area of roof coverage of each sheet. Keeping in mind all these assumptions, the 107 kg of lead recovered from Corotoman would have covered 3.22 m2 (34.7 ft2) of its roof, less than 0.9%. Alternatively, using the mean Rosewell sheet thickness (3.5 mm) and a lead density of 10.7 g/cm3, the 107 kg of recovered lead is less than 0.8% needed to cover Corotoman's roof. If Corotoman had a traditional more pitched roof or the arcaded gallery is included, the percentage of roof the recovered lead could cover would decrease even more.

Even if accounting for loss of lead due to vaporization in the fire (El-Rahaiby and Rao 1982), historical evidence suggests it is unlikely Corotoman's entire roof was made of lead. This vaporization of lead was suggested by Hudgins (1979) at Corotoman and most recently seen in the 2019 fire that destroyed much of the lead roof on the cathedral of Notre Dame in Paris, France (Lesté-Lasserre 2020).

But what if some or even most of the lead was removed from the ruins of Corotoman before the 1978 archaeological excavation? A previous study suggested most of the Purbeck Stone pavers were removed soon after the fire (Key et al. 2010). Perhaps other salvageable materials were also removed at this time, including fire-damaged lead which could be re-melted and reused. Even during more recent history, Wharton (1948) reported that one local man spent months excavating melted lead from the ruins and suggested the quantity he obtained pointed to lead roofing. Hudgins (1979) reported that the ruins were used as a source of building materials, including brick and stone for the Carter family in the 1740s, 1770s, 1790s, and into the 19th century. Antiquarian and treasure hunters salvaged what they could in the 1930s and 1950s (Wharton 1948; Hudgins 1979). Hudgins (1979, 1985) wrote that local watermen searched Corotoman's ruins for lead to use as weights for their fishing nets and crab pots.

Thus, the archaeological evidence cannot definitely disprove the existence of a lead roof at Corotoman. The best evidence against it comes from the historical record. Robert Carter wrote in his diary dated 25 August 1722, that the "plummer" had shingled the east end of the front of the building (Brown 2010:33; Berkeley 2015:folio 4). Carter in his diary for 1 December 1725 notes that an enslaved man named Manuel had begun tarring Corotoman's roof (Hudgins 1985; Berkeley 2015:folio 34), suggesting it did not have a lead roof. Finally, the uneven distribution of the recovered lead in the archaeological excavation at Corotoman (Hudgins 1985:fig. 28) suggests there was not a lead roof over the entire building.

Hudgins (1985:fig. 28) contoured on a 1 ft^2 grid the distribution of melted lead fragments recovered in the Corotoman archaeological excavation. We counted the number of cells that contained lead. Of the 3,009 cells in Hudgins' map, only 2,562 cells potentially contained melted lead. That is because 447 cells were the bases of brick foundation walls whose overlying bricks were removed post-fire and could not have contained lead. Of the 2,562 cells, 63% lacked any melted lead fragments whereas 37% did. Due to the potential for time -averaging of the excavated material (Hudgins 1979, 1985; Holdaway and Wandsnifer 2008), this 37% represents a maximum expected occurrence of lead on the underlying stone pavers. Some stratigraphic time-averaging would have resulted from the collapse of the house during the fire, subsequent knocking down of the remaining walls, and the consequences of the robber's trenches and holes discovered during the 1978 excavation (Hudgins 1985). In addition, the lead was concentrated along the south side of the mansion, under the arcaded gallery; perhaps that was the location of lead gutters referenced above in Carter's papers. Lead gutters were used elsewhere in the colonies, including Williamsburg (Lounsbury 1994). Or perhaps the arcaded gallery's roof had a lower pitch than the rest of the house (e.g., Carson 2013:pl. IV) that was better served by a lead roof as opposed to shingles.

So, if not from the roof, what was the source of the lead in Corotoman? Neve's 1726 English builder's guide lists lead not just for roof coverings, but also for gutters, pipes, glass windows, and paint. Hudgins (1979, 1985) attributed the lead artifacts at Corotoman to lead roof flashing, lead gutters and pipes, lead casement window components, leaded window glass, leaded glass bottles, lead glazes on pottery, and pewter flatware. Pewter contains up to 30% lead (Brownsword and Pitt 1984). In addition to its lead roof, Rosewell had belt courses with lead caps and lead window weights (Lounsbury 2002). Archaeological excavations in Williamsburg in the 1930s show that lead was used in colonial era architecture for window cames and casements as well as for joints for stone steps, and water pipes and cisterns (Wertenbaker 1953; Lounsbury 1994; Yetter and Lounsbury 2019). Thus, even without a lead roof, there were undoubtedly plenty of other sources of lead at Corotoman.

Fire Damage to Color of Purbeck Stone Pavers from Corotoman and in Christ Church

We were able to determine the Munsell (2009) color of 14 fire-damaged Purbeck Stone pavers from Corotoman and 11 that were not fire-damaged. We were able to determine the Munsell (2009) color of 15 fire-damaged original Purbeck Stone pavers in the floor of Christ Church and 15 that were not fire-damaged. The color of the 29 fire-damaged pavers ranged from light gray (2.5Y7/1) to pink (7.5YR7/4) with the most common color being light reddish brown (2.5YR7/3). 41% of the fire-damaged pavers had some reddish tint to them. The color of the 26 non-fire-damaged pavers ranged from light brownish gray (2.5Y6/2) to very pale brown (10YR8/3) with the most common being light gray (2.5Y7/1). None of the "pristine" pavers had a reddish tint to them. Lesté-Lasserre (2020) showed that when Notre Dame Cathedral in Paris, France burned in 2019, the heat altered the iron compounds in the limestone and changed its color from gray to reddish at 300°C and then to black at 600°C. These color changes suggest that some of the Purbeck Stone pavers from Corotoman that were not too badly burned were able to be re-used in Christ Church. The evidence of fire-induced spalling and oxidizing red coloration in some of the Christ Church stone pavers suggests they were re-used from Corotoman.

Some of the Purbeck Stone pavers were left in the basement of Corotoman and not reused at Christ Church (Hudgins 1985:figs. 17, 19; Malon 2005:6645; Key et al. 2010). Perhaps these were too damaged by the fire and thus left behind. For example, Hudgins (1985:fig. 19) illustrated a Purbeck Stone paver with clear stone mason tool marks like those on the floor of Christ Church (Key et al. 2010:fig. 2). This particular stone shows two different types of evidence of fire damage: color change and spalling.

Oster et al. (2012) report that fire can affect rock by smoke blackening and discoloration, including the formation of a reddish halo effect due to oxidation of iron-bearing rock. Ryan et al. (2012:13) define color change of lithic archaeological artifacts due to fire as "An observable color change of a specimen from original, pre-fire, color. Generally due to an alteration in the mineral composition of a specimen during exposure to heat." Ryan et al. (2012:13) define oxidation of archaeological artifacts due to fire as the "presence of an orange/brown discoloration on an artifact. It is generally due to the presence of oxidized sediment on a specimen where sediment had adhered to its surface prior to exposure to heating. Heating of the sediment results in discoloration that adheres or permeates the surface of a specimen." Color versions of the final Corotoman archaeological site photograph (Hudgins 1985:fig. 14) show three reddish halos, two on the sub-paver sand and one on the stone pavers. Hudgins (1985:fig. 19) included a black and white photograph of a Purbeck Stone paver with a darkened color in the center. This color change evidence for fire damage is supported by the spalling visible under the darkened part of the stone (Hudgins 1985:fig. 19). Spalling, a common result when a stone artifact is exposed to fire, is defined as the "exfoliation of a portion of the original surface of exposed rock or a specimen due to differential heating and pressure release" (Ryan et al. 2012:13). Fire can also cause thermal expansion and cracking of building stones (Chakrabarti et al. 1996). Hudgins (1979) reported the fire was hot enough to crack the stones in Corotoman. All of this evidence for fire damage supports the Corotoman re-use hypothesis for the Purbeck Stone pavers in Christ Church.

Comparison of Tool Mark Spacing on Purbeck Stone Pavers from Corotoman and Christ Church

We found two Purbeck Stone pavers in the artifact collection from Hudgins' 1978 excavation of Corotoman that had tool marks. We measured three pavers in the floor at Christ Church that had well preserved tool marks. Due to the removal of stone pavers from Corotoman that were in good shape for reuse in Christ Church, there were fewer places on which to measure tool mark spacing (n = 15) compared to Christ Church (n = 52). Despite this, the spacing was not significantly different between the Purbeck Stone pavers from Corotoman (mean = 11.9 mm) and those from Christ Church (mean = 12.5 mm) (Figure 5; t-Test, P = 0.449). This supports the Corotoman re-use hypothesis for the Purbeck Stone pavers in Christ Church.

Proximity of Corotoman to Christ Church

In the stone industry, transportation costs are often the biggest expense, not the stone itself (CBI 2010). This is simply a function of the weight of stone. With a mean of 46.7 cm (18.4 in) on a side (Key et al. 2010), a mean thickness of 15 cm (5.9 in) (Key et al. 2010), and a mean density of 2.30 g/cm3 (Smith 1999), each Purbeck Stone paver in Christ Church would have weighed 75 kg (165 lb) on average. With a total of 352 pavers in Christ Church, that is a total of 26,400 kg (58,080 lb) that would have had to be transported from the Corotoman site. With that amount of weight and the poor road infrastructure at the time (Pawlett 2003; VDOT

2006), were the stones transported by boat like most of Carter's goods at the time (Hudgins 1984, 1985; Naisawald 1986)?

Transport by water is supported by the fact that the branch of Carter Creek that heads to Christ Church from Corotoman to this day is called Church Prong (NOAA 2020) (Figure 1B). How close could a boat get to Christ Church? That is a hard question to answer as we don't know what kind of boat Carter used and what draft it had, and we don't know how much the shoreline has moved in the intervening three centuries. We do know that many of Christ Church's visitors during the colonial period would have travelled by water, and they used a disembarkation spot on Church Prong called Church Landing (Figure 1C) (Meade 1844; Alford et al. 2012). Thus, this seems a likely spot to transfer the stone pavers from boat to wagon.

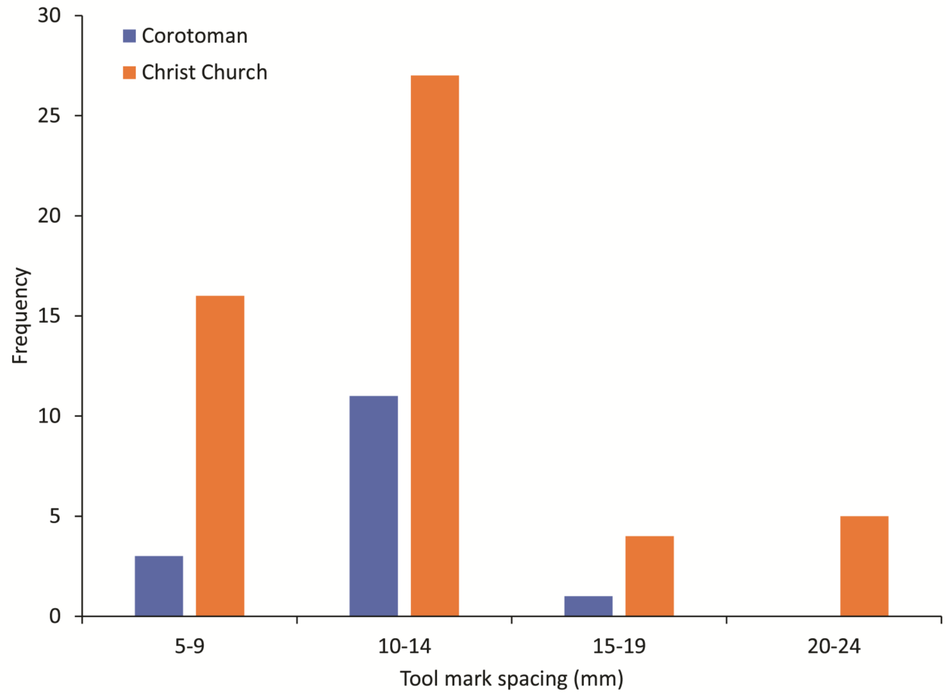

Figure 5. Frequency histogram of tool mark spacing on stone pavers showing similar results from Corotoman (mean: 11.9 mm) and Christ Church (mean: 12.5 mm).

Based on Google Earth Pro's latest satellite image of 14 November 2015 and following the estuary's main channel up Carter Creek and Church Prong, it is 3.89 km (2.42 mi) from Corotoman to Church Landing. That would leave a 1.37 km (0.85 mi) overland wagon ride using the same roads as today (Figure 1C). Due to the weight of the stones, it would have been in Carter's best interest to transport the stones as far as possible up Church Prong toward Christ Church. Assuming Church Prong was at least as navigable as it is today, the distance from Corotoman to the last boat dock visible on the 14 November 2015 satellite image is 4.39 km (2.73 mi) (Figure 1C). This would leave a straight-line overland distance of 0.72 km (0.45 mi) to get to Christ Church. Assuming a boat at the time could go at least as far as the last visible channel on Church Prong, that would be a distance of 4.78 km (2.97 mi) from Corotoman (Figure 1C). That would leave 0.39 km (0.24 mi) across land to Christ Church. A winter satellite image taken on 31 January 2007 when there were no leaves on the trees shows the channel extending an additional 0.22 km (0.14 mi) leaving only 0.21 km (0.13 mi) over land to Christ Church. These waterway distances from Corotoman assume a boat travelling directly up the main channel, presumably being paddled. If the stones were transported by sailboat, tacking would add some distance, but the channel is not very wide, so the increased distance would be minimal. Some maps (e.g., ESRI's National Geographic map layer) show Church Prong heading further ENE so that is crosses Christ Church Rd., 0.69 km (0.43 mi) from Christ Church. Other maps (e.g., ESRI's WorldTopo map layer) show Church Prong heading further NNE so that is crosses Christ Church Rd. (Figure 1C), only 0.29 km (0.18 mi) from Christ Church.

Undoubtedly in the intervening ~290 years since Christ Church was built, the distance from navigable water on Church Prong to Christ Church has changed. Rising sea levels would have made the distance to the church from navigable water decrease over that time, and siltation would have made the distance increase. How much has sea level risen? Relative sea level (RSL) refers to sea level relative to land level, and RSL is rising in the Chesapeake Bay due to a combination of absolute sea level (ASL) rise and land subsidence. ASL refers to the global mean sea level, and it is rising due to increasing volume and mass in the world's oceans. Water volume is increasing due to thermal expansion of the oceans as they warm (Sallenger et al. 2012). Water mass is increasing due to continental ice sheets melting adding liquid water to the oceans (Lambeck et al. 2014).

RSL is also affected by local uplift and subsidence of the land surface. Local land subsidence is generally due to groundwater withdrawal and compaction of sediment below due to the overburden pressure of the sediment above (Eggleston and Pope 2013). RSL rise along the U.S. Atlantic coast is highest in the mid-Atlantic due to the added regional subsidence from glacial isostatic adjustment as the once glaciated regions to the north rebound and the mid-Atlantic's postglacial forebulge collapses (Dyke and Peltier 2000; Engelhart et al. 2011). This seesaw effect was initiated after the weight of the northern ice sheet melted beginning 16,000 years ago following the last glacial maximum (Lambeck et al. 2014). This subsidence is augmented by the current ASL rate of rise of 3.3 mm/yr (Cazenave et al. 2014).

Earlier long-term subsidence rate in the Bay varied from 1.4 mm/yr (Newman and Rusnak 1965) to 1.7 mm/yr (Ellison and Nichols 1976) to 2.1 mm/yr (Donoghue 1990). According to the latest data from Boon et al. (2010:tbl. 5), the current rate of subsidence at two sites closest to Christ Church, Lewisetta (35 km (22 mi) north) and Gloucester Point (49 km (30 mi) south), are 3.35 mm/yr and 2.50 mm/yr, respectively. Therefore conservatively, the current rate of subsidence at Christ Church is probably ~3 mm/yr today. This is slightly higher than the mean for the Chesapeake Bay region which is 2.20 mm/yr (Boon et al. 2010:tbl. 5) and higher than the previous estimate for the Christ Church area of 2.0 mm/yr (Holdahl and Morrison 1974:fig. 13). Thus, along Church Prong, RSL has increased due to ASL rise combined with subsidence. The most recent data shows RSL is rising at Lewisetta and Gloucester Point at 5.1 mm/yr and 4.1 mm/yr, respectively (Boon et al. 2010:fig. 9b). These rates are supported by those of Zervas (2009) who reported 4.97 mm/yr for Lewisetta and 3.81 mm/yr for Gloucester Point as well as those of Snay et al. (2007) who reported 3.95 mm/yr for Gloucester Point. So conservatively, the rate of RSL rise at Christ Church today is probably ~4 mm/yr. This is more than estimates by Kearney and Stevenson (1991) 30 years ago of 3.17 mm/yr but matches the mean rate of RSL rise for the entire Chesapeake Bay area of 4.00 mm/yr (Boon et al. 2010:tbl. 4). At a rate of 4 mm/yr over the intervening 290 years, Church Prong's RSL would have increased 1.2 m (3.8 ft).

Rising sea level also leads to coastal erosion which would make navigable water closer to Christ Church today than it was ~290 years ago. Erosion rates have been measured along the Rappahannock River at 0.2-0.4 m/yr (0.5-1.0 ft/yr) (Hardaway and Anderson 1980; Halka et al. 2005). Marshes, which are at the heads of estuaries like Church Prong, are even more vulnerable to erosive retreat in the face of sea level rise (Kearney and Stevenson 1989, 1991; Wray et al. 1995). Rosen (1980:fig. 7) measured the rate of marsh erosion in Lancaster County at 0.6 m/yr (2 ft/yr). If we apply this rate to the headwaters of Church Prong and assume it has not changed over the intervening 290 years, this would mean the estuary has encroached toward Christ Church 170 m (570 ft).

It becomes harder to determine how much farther away navigable water was ~290 years ago because at the time Christ Church was being built, RSL was slower (0.56-0.9 mm/yr) due to slower ASL rise (Kearney 1996:fig. 2; Cronin et al. 2019:fig. 7)) and less groundwater withdrawal (Kearney and Stevenson 1991). Moreover, channel siltation has caused the navigable water to retreat farther downstream away from Christ Church (Harpole et al. 2007). Siltation is caused by soil erosion from land clearing for farming which chokes streams with excess sediment runoff (Gottschalk 1945).

In response to development around the Chesapeake Bay, the area deforested for farming has increased (Cooper 1995:fig. 2; Benitez and Fisher 2004:fig. 7; Kemp et al. 2005:fig. 4b) and sedimentation rates in the Bay have more than tripled above the pre-colonization rates (Brush 1989:tbl. 1; Brush 1999:tbls.1-2; Donoghue 1990:tbl. 1; Cooper 1995:tbl. 1; Cronin et al. 2003:tbl. 6.1). Focusing on the western shore of the Chesapeake Bay, sediment accumulation rates in channels have increased from 1.4 mm/yr pre-European settlement to 1.9 mm/yr during the period of early agriculture when Robert Carter was building Corotoman and Christ Church to 3.0 mm/yr since then (Brush 1984).

The closest estuarine sedimentation data to Christ Church is from the Ware River 37 km (23 mi) south of Christ Church which saw an increase from 0.3 mm/yr pre-settlement to 1.7 mm/yr post-settlement (Valette-Silver et al. 1986:tbl. 3, fig. 4). This more than 5-fold increase in sedimentation rates in the Bay was largely due to increased soil erosion (Valette-Silver et al. 1986; Pasternack et al. 2001; Colman and Bratton 2003). The initial culprit was deforestation for tobacco farming (which Carter did a lot of (Brown 2010)) then later for wheat and corn (Walsh 1989; Benitez and Fisher 2004). The hoes and hills for growing tobacco were replaced by even more erosive plowing for mixed grains (Neiman 2008).

In the classic study of Chesapeake Bay siltation, Gottschalk (1945) showed how deforestation and agriculture, especially tobacco farming, led to soil erosion, estuarine channel siltation, and loss of navigability. He documented examples of colonial ports in Maryland now being >3 km (>2 mi) from navigable water and showed how the head of navigation (i.e., farthest up the estuary) received the most sediment runoff (Gottschalk 1945; Kearney and Ward 1986). In the early 1690s, legislators selected Queenstown as the site for the new Lancaster County courthouse (Lounsbury 2005). Queenstown was 5 km (3 mi) west of Christ church. Silting up of its navigable water way, Town Creek, led to poor water depth at the landing, which may have contributed to the county seat being moved to its present location (McIlwaine 1925). This suggests navigable water undoubtedly extended closer to Christ Church than it does today, but we don't know how much further. We do know that Meade (1844) in 1843 reported that he had to walk about a mile from what is now known as Church Landing to Christ Church. Siltation has been known for a long time as noted by Ridgely (1908:112) commenting on the problem in Maryland, "No one would have supposed that so insignificant a stream could have ever been of sufficient volume to float the craft used by the settlers on their way to worship. And yet, when we hear how the Patuxent River has in course of time lost fifty miles of its navigable waters, and that Elk Ridge Landing, a flourishing port on a branch of the Patapsco, is now high and dry, preserving only its name, we cease to find incredible the traditions about our minor water ways."

Regardless of how far a boat could carry the stones up Church Prong at the time Carter was building Christ Church, the stones would eventually have had to be carried by draught animals pulling wagons over land. The water route would have involved two transfers onto and off the wagon as well as one transfer onto the boat and one off the boat. First the stones would have to be extracted from Corotoman's ruins, placed on a wagon to carry them to the boat, unloaded from the wagon and loaded onto the boat, unloaded from the boat onto a wagon, and finally unloaded from the wagon at Christ Church. A strictly overland route has two additional benefits. First, it involves only one transfer of the heavy stones onto the wagons and one transfer off. Second, the points of disembarkation other than Church Landing do not have any roads to handle the heavily laden wagons and must cross the ravine immediately southwest of Christ Church (Figure 1C).

If we assume today's roads largely follow the paths of previous generations' roads, including the road Carter himself built from his plantation to his church (Hudgins 1985), then the journey would have been 5.77 km (3.59 mi) and followed today's King Carter Lane (Rt. 708) to Weems Road (Rt. 222) (Figure 1B). This overland route is only slightly longer by 0.59 km (0.37 mi) than the average of the combined water and overland routes (mean: 5.18 km (3.22 mi). Thus, we think the stone pavers were probably transported from Corotoman to Christ Church by draught animals pulling wagons over existing roads, not by water.

Does the historical record provide any evidence to support this? Robert Carter's diaries and letters do discuss the movements of his sloops to other properties to transport items such as hogsheads of tobacco from his outlying quarters or stones from the falls of the Rappahannock to build the breakwater at Corotoman. We could not find any references to taking a boat to Church Landing or Christ Church. Robert Carter's will and estate inventory mention multiple horses and horse-drawn coaches and chariots (Goodwin 1959). In his diary, he does refer to taking his "chariot" on 28 March 1727 to the Brick House and 30 August 1727 to his mill. A chariot is a four-wheeled carriage usually driven with four or six horses (Goodwin 1959). In December 1722 he mentions beginning the frame for his stable at Christ Church. He also talks about riding (horses we presume) to Christ Church to inspect its brickyard in September 1723. Thus, there is evidence for Robert Carter using overland horse-powered transportation to Christ Church, but not boats.

New information on the size of Purbeck Stone pavers

In our 2010 study, we reported that the Purbeck Stone pavers in Corotoman (46 cm (18 in) on a side) were similar in size to those at Christ Church (46.7 cm (18.4 in) on a side) (Key et al. 2010). New data on the size of Purbeck Stone pavers from Ware Church supports these standard dimensions. Ware Church in Gloucester County was built in 1718/1719 (Miles and Worthington 2006). Its Purbeck Stone pavers were removed from the interior of the church and used for a sidewalk when the interior floor was replaced with wood in 1854 (Jones 1991). There are 72 Purbeck Stone pavers in the church yard: 16 at the west entrance to the church and 56 at the south entrance. To compare the sizes to those in Christ Church, we measured the first 10 pavers leading from the door at the south entrance. The mean size of the Purbeck paving stones at Ware Church is 47.5 cm (18.7 in) on a side (n = 10; range = 41.2-49.7 cm; standard deviation = 1.9 cm). This represents an average difference of only 0.8 cm (0.3 in) from those at Christ Church. This was a size preferred by other builders in colonial Virginia as evidenced in a 1756 advertisement for stone pavers for the Capitol in Williamsburg which said the “Size of Stone that will best answer is 18 Inches Square” (Virginia Gazette 1756: 4:2). The arcade of the 1730 King William County courthouse was floored with 18 inch square paving stones (Lounsbury 2005). In Neve’s (1726) English builder’s guide, Purbeck Stone pavers were generally sold 15-24 inches square.

Since medieval times, Purbeck Stone pavers have come in two shapes: more expensive squares and cheaper rectangles (Haysom 2020). Rectangular pavers were used to make courses with varying widths. The porch and great hall of the Athelhampton manor house and church built in the 15th century in Dorset, England uses Downs Vein Purbeck Stone pavers 17.5 inches on a side (Haysom 2020), almost identical to the 18 inch pavers at Corotoman and Christ Church (Key et al. 2010). In 1700s England, the great halls of pretentious houses were paved with Carrara marble, or at second best Portland Stone, whereas Purbeck Stone was for paving the servants' quarters or cellars (Haysom 2020). Purbeck Stone pavers were typically 4-5” thick (Haysom 2020), same as those used in Christ Church (Key et al. 2010).

Conclusions

Eventually some of the stone pavers in Christ Church will need to be replaced. Due to the historical significance of the church, it is important to know the provenance of the stones as it assists in finding suitable replacement stone. Conservation of stone has become increasingly important as evident by the increased growth in studies devoted to dimension stone conservation, such as determining the factors that cause stone decay (Přikryl and Smith 2005), the provenance of historic building materials (Waelkens et al. 1992; Doehne and Price 2010), their variability (Fronteau et al. 2010), and recognizing and thus reducing the problems of poor substitute stone selection (Rozenbaum et al. 2008). This specialized field of study has become an important aspect of the work of conservation architects and others as they attempt to find suitable replacement material for historic structures.

This study provides four additional pieces of evidence that stone pavers in the floor of Christ Church came from the Corotoman mansion: 1) presence and chemistry of melted lead on the stone pavers from Corotoman as well as on the stone pavers in Christ Church, 2) matching color of fire-damaged stone pavers from Corotoman and Christ Church, 3) spacing of tool marks in stone pavers recovered from Corotoman matches those in Christ Church, and 4) close proximity of Christ Church to Corotoman by land and/or water for the transport of the stones. These results give us confidence that if and when any degraded stone pavers in Christ Church need to be replaced, new pavers should be made of Purbeck Stone like those from Corotoman. While finding replacement stones may be difficult, one solution could be using the remaining pavers at the Corotoman site, if approved, or quarrying new ones from the same source in England.

Future Work

The elemental chemistry of the Corotoman and Christ Church samples could be better compared using X-ray fluorescence spectrometry (XRF) which is often used in geoarchaeological sourcing studies (e.g., Colao et al. 2010). XRF results are less affected by variations in a sample’s surface texture when compared to SEM-EDS which was used in this study.

Was the lead used in Corotoman imported from England? Presumably it was, like most manufactured goods mentioned in Carter’s diary. Where his agent in London got the lead is unknown. Was it from England, elsewhere in the British Isles, or from continental Europe? In the future, we hope to eventually measure the lead isotope ratios and compare them to the lead isotope database assembled by the University of Oxford (Stos-Gale and Gale 2009). By comparing the lead isotopes to the database, we can determine the provenance of the lead since lead isotope fingerprinting is a proven geoarchaeological technique for determining the provenance of artifacts (Thibodeau et al. 2012, 2013).

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