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Scientific Dating

St Mary's Road, Isles of Scilly

Tree-Ring Analysis and Radiocarbon Wiggle-Matching of a Shipwreck

Roderick Bale, Shahina Farid, Nigel Nayling, Chrisopher Bronk Ramsey, and Paula Reimer

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SUMMARY
Samples from three timbers associated with an unidentified shipwreck located off St Mary's Road, Isles of Scilly, were provided for analysis. The wreck itself was thought to be post-medieval but pre-nineteenth century AD in date, with artefactual evidence suggesting that the loss of the vessel probably occurred during the latter half of the sixteenth century or first half of the seventeenth century AD. Only two of the samples provided sufficient rings to merit dendrochronological analysis but neither could be conclusively dated. Following the unsuccessful dendrochronological analysis, one of the samples was subsampled and underwent radiocarbon wiggle-matching, which produced a felling date range for the timber in the first half of the sixteenth century AD.

CONTRIBUTORS
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INTRODUCTION

This previously unknown site was identified in 2012 when a geophysical anomaly was investigated by local divers off the coast at St Mary's Road, Isles of Scilly (Wessex Archaeology 2015; Figs 1a–c). A limited programme of excavation and recording was undertaken, which revealed part of the side of the hull of a wooden ship approximately 8.5m long by 2.45m long (Figs 2–3). Three iron cannons were also located, one of which lay on its gun carriage with a possibly associated swivel gun approximately 50m away. A number of small finds were also recovered.

Dating of the vessel was based on the specialist analysis of the cannons and other finds, the former greatly assisted by the ordnance expert Charles Trollope, which suggested a probable date range of AD 1565 to approximately AD 1650. No firm conclusions have been reached about the identity of the wreck.

TREE-RING SAMPLING

In 2013 Historic England (then English Heritage) commissioned Wessex Archaeology to carry out an assessment of the wreck site. The brief included the recovery of samples for dendrochronological analysis, if suitable timbers were located, by the Wessex Archaeology dive team with the subsequent analysis being coordinated by the Historic England Scientific Dating Team. It was hoped that this would provide independent dating evidence for the primary construction of the vessel and hence aid its identification and inform understanding and significance, as well as adding to the corpus of dendrochronologically dated wrecks.

Sampling had to be confined to unburied timbers and hence was highly restricted. Unfortunately only three samples were recovered from the vessel by the Wessex Archaeology dive team, the locations of which are shown in Figure 3.

TREE-RING METHODOLOGY

Methods employed at the Lampeter Dendrochronology Laboratory in general follow those described in Historic England guidance documents (English Heritage 1998). The complete sequence of growth rings in each suitable sample was measured to an accuracy of 0.01mm using a micro-computer based travelling stage (Tyers 2004). Cross-correlation algorithms (Baillie and Pilcher 1973; Munro 1984) are employed to search for positions where the ring sequences are highly correlated against each other. The ring sequences were also tested against a range of relevant reference chronologies. Where *t*-values are reported these are derived from the original CROS algorithm (Baillie and Pilcher 1973). A *t*-value of 3.5 or over is usually indicative of a good match, although this is with the proviso that high *t*-values at the same relative or absolute position must be obtained from a range of independent sequences, and that satisfactory visual matching supports these positions. Correlated positions are checked visually using computerised ring-width plots as an aid to overall quality control.

TREE-RING ANALYSIS AND INTERPRETATION

Details of the three samples supplied are given in Table 1. One sample, SMR7003, was found to contain too few rings to be worthy of further investigation. The remaining two samples contained sufficient rings to warrant analysis. The ring width series derived from these two samples (Tables 2 and 3) did not cross-match against each other. Consequently both individual series were compared with reference chronologies from Britain and elsewhere in Europe. Unfortunately no conclusive cross-dating was obtained for either series, although tenuous dating evidence was identified for one of the samples (SMR7001) against northern European reference chronologies but with an insufficient level of cross-matching and replication to be considered reliable.

Following the failed attempt through tree-ring analysis to obtain dating evidence for the vessel, the samples were reviewed with respect to their suitability for radiocarbon dating and wiggle-match analysis.

RADIOCARBON DATING

Radiocarbon dating is based on the radioactive decay of carbon-14 and can be used to date organic materials, including wood. A small proportion of the carbon atoms in the atmosphere are of a radioactive form, carbon-14. Living plants and animals take up carbon from the environment, and therefore contain a constant proportion of carbon-14. Once a plant or animal dies, however, its carbon-14 decays at a known rate. This makes it possible to calculate the date of formerly living material from the concentration of carbon-14 atoms remaining. Radiocarbon measurements, like those in Table 4 are expressed in radiocarbon years BP (before present, ‘present’ being a constant, conventional date of AD 1950).

RADIOCARBON DATING, SAMPLING, AND ANALYSIS

Sample SMR7004, with its 89-year ring sequence including 32 sapwood rings, potentially representing a framing timber was selected. The initial round of radiocarbon dating comprised a series of four blocks of five rings subsampled from sample SMR7004 at known intervals. These included the first, or earliest, ten extant growth rings on the sample, and the outermost ten extant sapwood rings. The samples were sent to the Scottish Environmental Research Centre (SUERC) but, having been treated using an acid-base-acid pretreatment

(Stenhouse and Baxter 1983) all the samples failed to produce sufficient material for AMS dating.

A second attempt at radiocarbon dating and wiggle-match analysis was undertaken on the remaining rings from sample SMR7004. This second batch of subsamples consisted of a series of five consecutive blocks containing a variable number of rings in order to maximise the weight of each subsample and hence increase yield for AMS dating (Fig 4). These subsamples were submitted to two laboratories. Three samples were sent to the Oxford Radiocarbon Accelerator Unit (ORAU) and two samples to ^{14}CHRONO, Queen's University Belfast (QUB). The samples dated by the Oxford Radiocarbon Accelerator Unit underwent an acid-base-acid pretreatment followed by bleaching (Brock *et al* 2010, table 1 (UW)). They were then combusted and graphitized as described by Brock *et al* (2010, 110) and Dee and Bronk Ramsey (2000), and dated by Accelerator Mass Spectrometry (AMS) as described by Bronk Ramsey *et al* (2004). The samples dated at The Queen's University Belfast were processed and measured as described in Reimer *et al* (2015). Both laboratories maintain a continual programme of quality assurance procedures, in addition to participation in international inter-comparisons (Scott *et al* 2017). These tests indicate no laboratory offsets and demonstrate the reproducibility and accuracy of these measurements.

The results are conventional radiocarbon ages (Stuiver and Polach 1977; Table 4), and are quoted in accordance with the international standard known as the Trondheim convention (Stuiver and Kra 1986).

RADIOCARBON CALIBRATION

Radiocarbon ages are not the same as calendar ages because the concentration of carbon-14 in the atmosphere has fluctuated over time. A radiocarbon measurement has thus to be calibrated against an independent scale to arrive at the corresponding calendar date.

That independent scale is the IntCal13 calibration curve (Reimer *et al* 2013). This is constructed from radiocarbon measurements on samples dated absolutely by other, independent means: tree rings, plant macrofossils, speleothems, corals, and foraminifera. In this report the calibrations which relate the radiocarbon measurements directly to the calendrical time scale have been calculated using IntCal13 and the computer program OxCal v4.2 (https://c14.arch.ox. ac.uk/oxcal/; Bronk Ramsey 1995; 1998; 2001; 2009). Figure 5 shows the effect of calibration on a radiocarbon determination. The distributions of the calibrated dates, shown in outline in Figure 6 are derived from the probability method (Stuiver and Reimer 1993).

BAYESIAN WIGGLE-MATCHING

Wiggle-matching uses information derived from tree-ring analysis in combination with radiocarbon dates to provide a revised understanding of the age of a timber; a review is presented by Galimberti *et al* (2004). In this technique, the shapes of multiple radiocarbon distributions can be 'matched' to the shape of the radiocarbon calibration curve. The exact interval between radiocarbon dates can be derived from tree-ring analysis, since one ring is laid down each year.

Although the technique can be done visually, Bayesian statistical analyses (including functions in the OxCal computer program) are now routinely employed. A general introduction to the Bayesian approach to interpreting archaeological data is provided by Buck *et al* (1996). The approach to wiggle-matching adopted here is described by Christen and Litton (1995).

Details of the algorithms employed in this analysis (a form of numerical integration undertaken using OxCal) are available from the on-line manual or in Bronk Ramsey *et al* (2001). Because it is possible to constrain a sequence of radiocarbon dates using this highly informative prior information (Bayliss *et al* 2007), model output will provide more precise posterior density estimates. These posterior density estimates are shown in black in Figures 6 and 7 and quoted in italic in the text.

The A_{comb} statistic shows how closely the dates as a whole agree with other information in the model; an acceptable threshold is reached when it is equal to or greater than A_n, a value based on the number of dates in the model. The A statistic shows how closely an individual date agrees with the other information in the model; an acceptable threshold is reached when it is equal to or greater than 60.

Sample SMR7004

Sample SMR7004 is from a quartered, possible framing timber (Fig 3) with 89 rings including 32 sapwood rings (Table 1). The chronological model for this sample includes the radiocarbon dates for the mid-point of each of the consecutive blocks with the known number of rings between each mid-point (Fig 4). The analysis, which included all five radiocarbon dates in the model failed by falling into a poor overall agreement (A_{comb}= 26.4, A_n= 31.6, n=5), with sample UBA-31612 having a low individual index agreement (A=9), which suggests it to be an outlier.

When UBA-23612 is 'excluded' as an outlier, the model has good overall agreement (A_{comb}=122.4, A_n 35.4, n=4; Fig 6). This analysis, therefore, suggests that the last ring of sample SMR7004 was formed in in *cal AD 1505–1545 (95% probability; last ring89;* Fig 6*),* or *cal AD 1510–1530 (68% probability).*

Sample SMR7004 retained 32 sapwood rings but it is not known how many were lost either during conversion into a framing timber or through erosion since the loss of the vessel. As the last dated ring (*last ring89*; Fig 6) is the last surviving sapwood ring of 32, the distribution of the number of sapwood rings expected for English oak (Bayliss & Tyers 2004, table 1), truncated to allow for the extant sapwood rings, has been applied to the estimated date for the final measured ring of the tree-ring sequence in order to produce an estimate for the felling date of the timber. This decision to use the Bayliss & Tyers (2004) probability distribution for the number of sapwood rings, which is for native English oak, was based on the fact that most of the candidate vessels identified in the report (Wessex Archaeology 2015) appear to be British vessels, in which case the larger scantling framing timbers are more likely to be of British origin, whereas there is evidence that Baltic imports could be used for hull planks (Tyers 1996). The model was constrained by the calendar date of sampling AD 2013. This analysis indicates that the possible framing timber from this wreck was felled in *cal AD 1505–1555 (95% probability; Shift SMR7004_ felling;* Fig 7), or *cal AD 1510–1540* (68% *probability*). Hence, if this dated timber was associated with the primary construction of the vessel, a date in the first half of the sixteenth century is indicated.

CONCLUSION

The dendrochronological analysis was unfortunately unsuccessful, although with only three timbers having been sampled this was perhaps not particularly surprising. The single timber successfully dated by radiocarbon wiggle-matching provides an estimated felling date for the timber, and hence provides a possible indication of the construction date of the vessel. This is somewhat earlier than the current suggested date of late sixteenth- or early seventeenth-century for the manufacture of the guns (Wessex Archaeology 2015), and the late sixteenth- to mid seventeenth-century dates for most of the dateable finds. The difference between the possible construction date identified and those of the various vessels recorded as lost in this area in the National Record of the Historic Environment, which date to the seventeenth century as indicated by Wessex Archaeology (2015), could be accounted for by the vessel having been refurbished. However at present the suggested construction date is based on a single timber and hence should be treated with caution.

This analysis has established that dating, using scientific methods can be usefully applied to this wreck. The limited number of samples taken clearly demonstrates that some framing timbers and hull planks are in principle, suitable for dendrochronology. The recovery and analysis of additional samples from this wreck could provide the further replication required for successful dendrochronological analysis (Domínguez-Delmás *et al* 2018). The survival of partial sapwood on sample SMR7004 suggests there may be other suitable framing timbers that could yield a precise date for the construction of this vessel. Should the opportunity arise, the recovery of additional samples from the wreck is recommended in order to enhance the precision of the dating evidence obtained and to allow greater understanding of both the initial construction of, and any later repairs to, the vessel. This may in turn provide evidence relating to the longevity of the vessel and hence its potential identity.

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TABLES

Table 1. Details of samples taken from St Mary's Roads unknown shipwreck, Isles of Scilly

Sample number	Timber and position	No of rings	Mean HW ring width (mm)	Dates spanning (AD)	h/s boundary (AD)	Sapwood rings	Mean sensitivity	Felling date ranges (AD)
SMR7001	Radial hull plank fragment?	118	1.20	-	-	-	0.22	-
SMR7003	Framing timber?	15	NM	-	-	-	-	-
SMR7004	Quartered framing timber?	89	1.26	-	-	32	0.20	-

Key: NM = not measured; HW = heartwood; h/s = heartwood-sapwood boundary

Table 2: Annual ring widths for sample SMR7001

Relative Year	Annual ring width (units of 0.01mm)								
1	315	256	251	152	228	252	185	145	413	613
-	448	348	137	67	65	105	104	141	161	218
-	238	233	257	248	279	204	334	166	122	172
-	149	187	119	142	103	119	106	95	126	84
-	70	86	109	105	82	77	82	82	76	69
51	119	92	83	65	66	85	97	70	70	79
-	68	69	72	76	69	78	67	41	49	68
-	104	126	82	57	86	70	61	76	73	58
-	54	61	70	70	57	65	73	99	95	83
-	105	110	60	64	88	77	49	68	84	87
101	90	77	59	61	59	69	73	67	92	99
-	67	86	104	79	91	138	122	105		

Table 3: Annual ring widths for sample SMR7004

Relative Year	Annual ring width (units of 0.01mm)								
1	200	167	167	136	144	107	59	141	130	243
-	159	178	118	147	176	157	110	104	102	129
-	137	164	189	218	167	215	212	182	168	179
-	176	146	132	122	87	135	107	112	121	134
-	122	133	169	186	120	179	136	162	201	196
51	170	144	126	115	115	119	93	148	153	119
-	136	122	95	112	67	88	61	112	59	50
-	64	60	59	72	87	100	80	118	84	73
-	65	58	59	72	62	60	91	96	77	

Table 4: Radiocarbon results for sample SMR7004

Laboratory Number	Sample	Radiocarbon Age (BP)	$\delta^{13}C$ (‰)	Highest posterior density interval - cal AD (95% probability)
OxA-33790	Oak heartwood, rings 6–14	453±32	−26.48±0.2	*1435–1485 (94%)* *1570–1580 (1%)*
UBA-31612	Oak heartwood, rings 15–25	310±24	−26.8±0.22	*1445–1495 (94%)* *1580–1590 (1%)*
OxA-33791	Oak heartwood, rings 26–35	362±31	−26.69±0.2	*1455–1505(94%)* *1590–1600 (1%)*
UBA-31613	Oak heartwood, rings 36–47	376±25	−26.4±0.22	*1470–1520 (94%)* *1605–1615 (1%)*
OxA-34052	Oak heartwood and sapwood, rings 48–75	375±26	−26.91±0.2	*1490–1540 (94%)* *1625–1635 (1%)*

The highest posterior density intervals are derived from the model shown in Figure 6

FIGURES

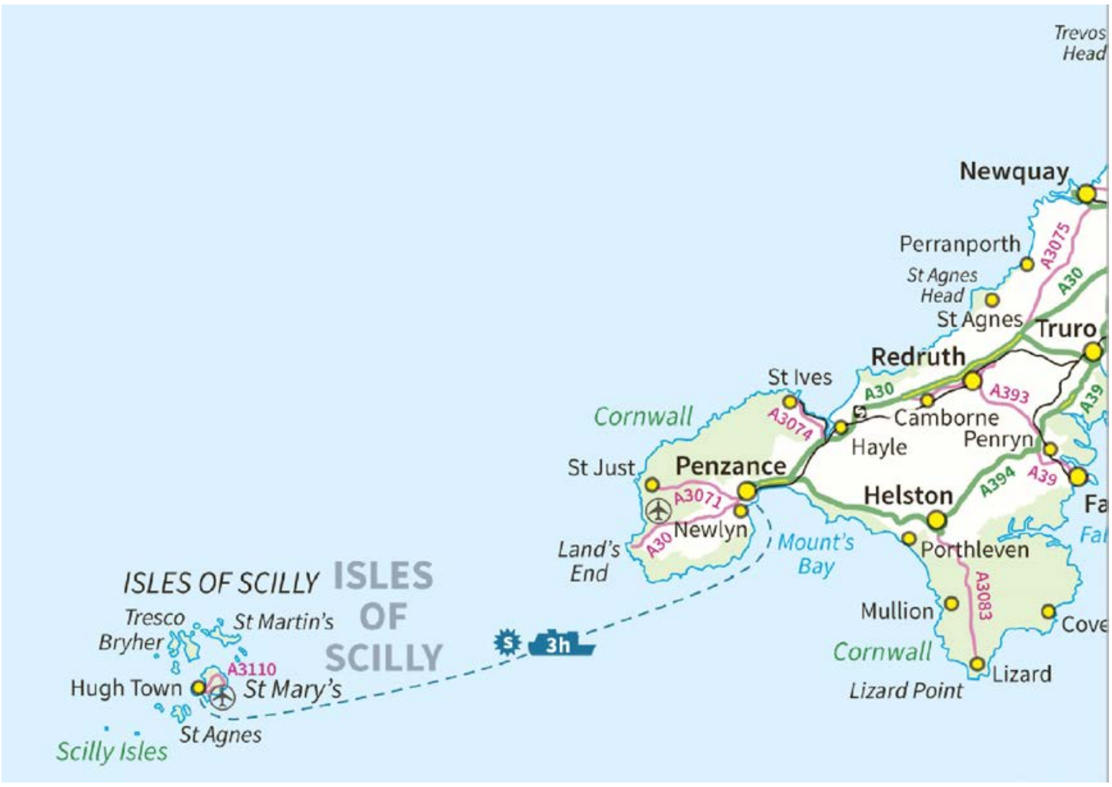

Figure 1a: Map to locate the Isles of Scilly © Crown Copyright and database right 2019. All rights reserved. Ordnance Survey Licence number 100024900 © British Crown and SeaZone Solutions Ltd 2019. All rights reserved. Product licence number 102006.006. © Historic England.

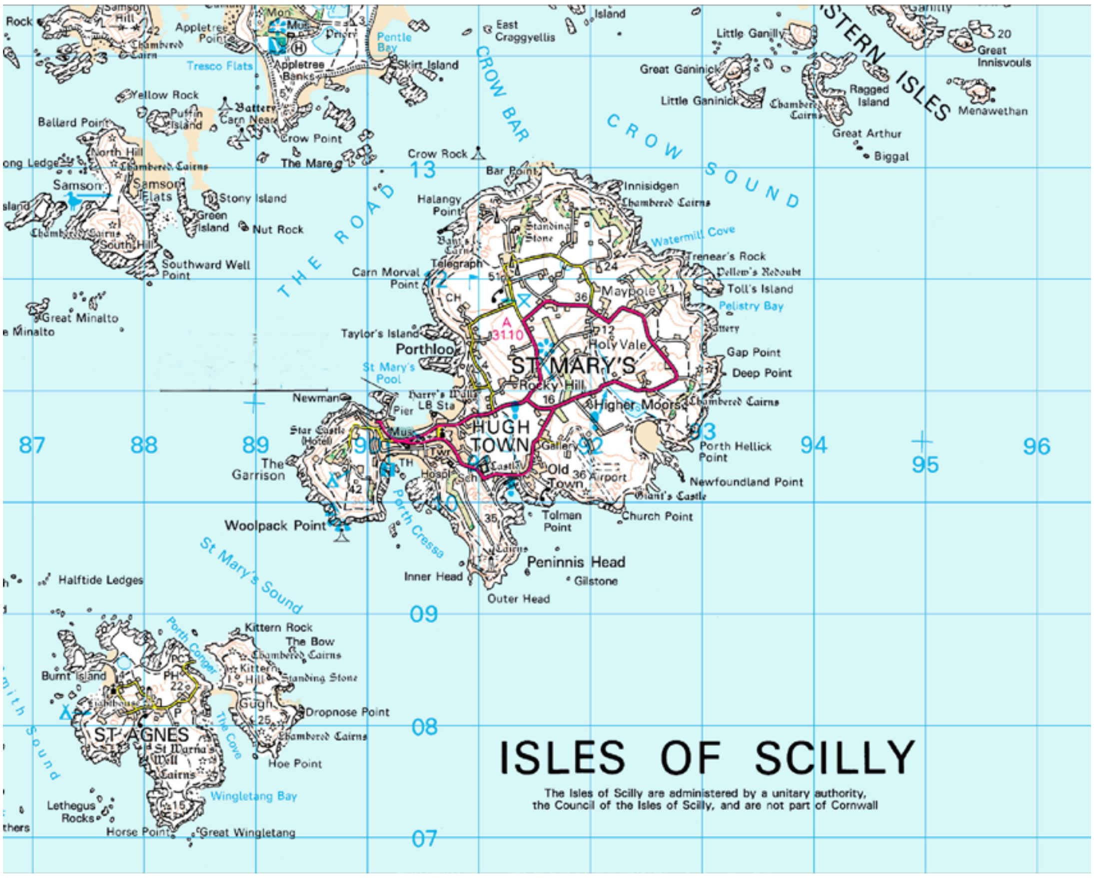

Figure 1b: Map to locate St Mary's within the Isles of Scilly © Crown Copyright and database right 2019. All rights reserved. Ordnance Survey Licence number 100024900 © British Crown and SeaZone Solutions Ltd 2019. All rights reserved. Product licence number 102006.006. © Historic England.

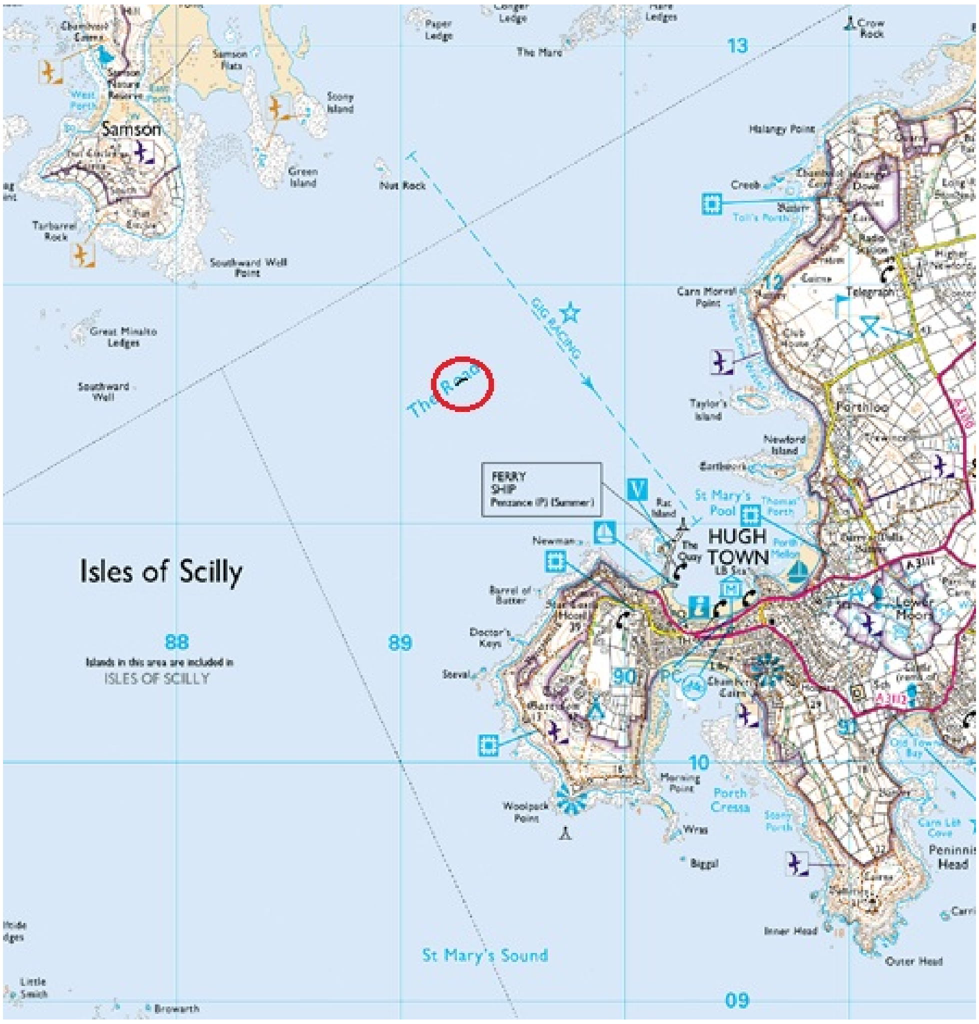

Figure 1c: Map to show the approximate location of the unidentified shipwreck (circled in red) © Crown Copyright and database right 2019. All rights reserved. Ordnance Survey Licence number 100024900 © British Crown and SeaZone Solutions Ltd 2019. All rights reserved. Product licence number 102006.006. © Historic England.

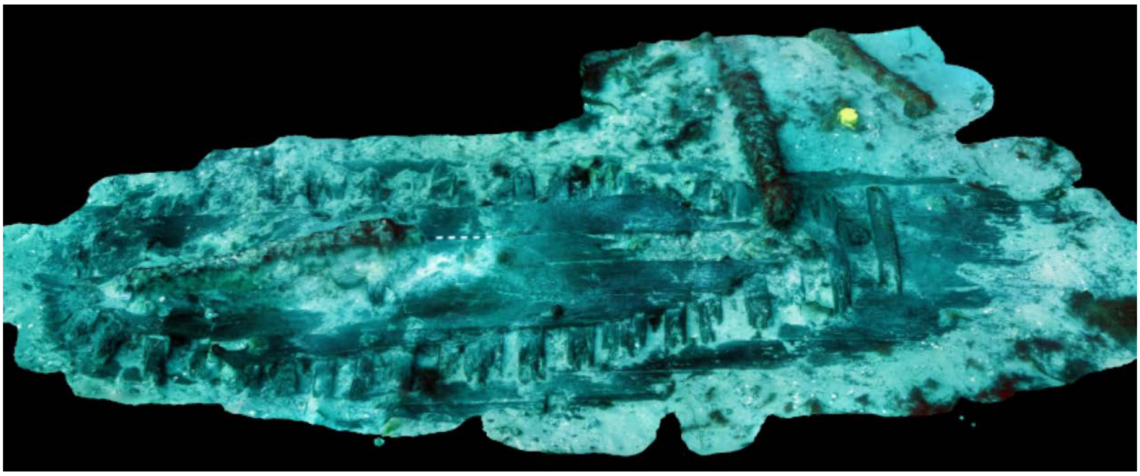

Figure 2: Photomosaic of the wreck produced by Wessex Archaeology from digital images provided by Todd Stevens. Looking NW with LC01 to the west (courtesy of Wessex Archaeology)

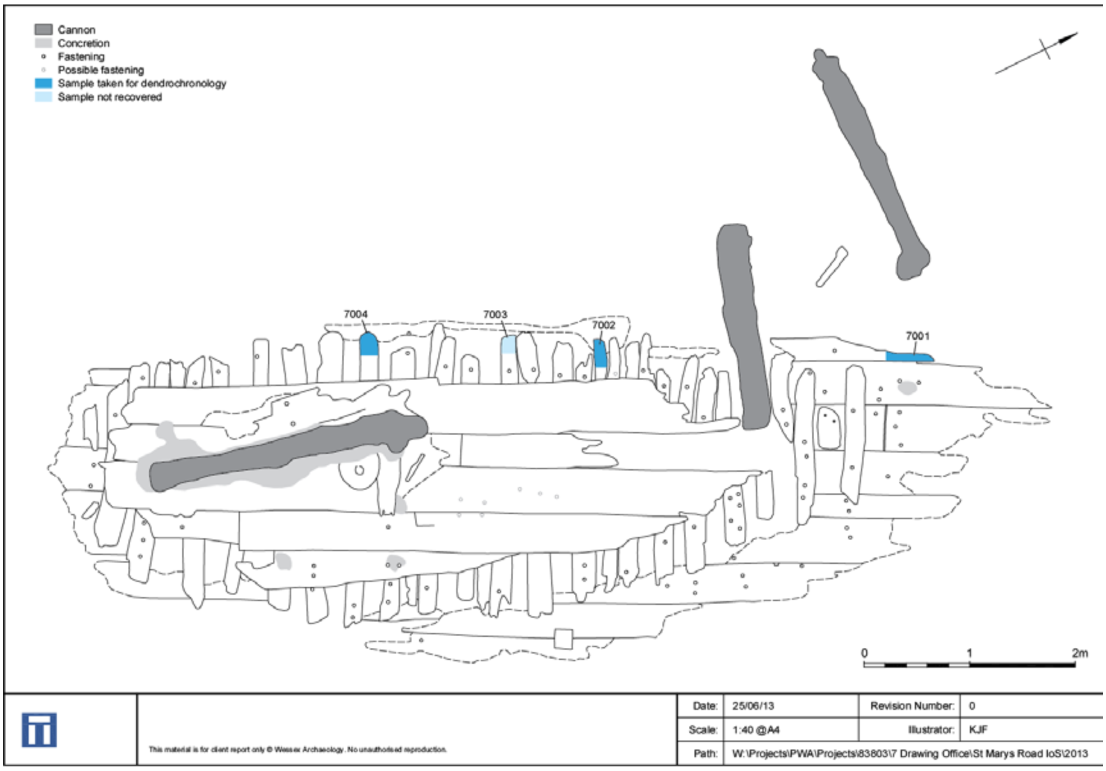

Figure 3: Site plan of wreck indicating location of sampled timbers (Courtesy of Wessex Archaeology)

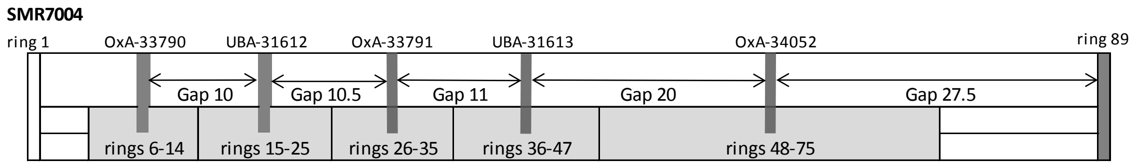

Figure 4: Schematic illustration of sample SMR7004 to locate the multi-ring subsamples submitted for radiocarbon dating

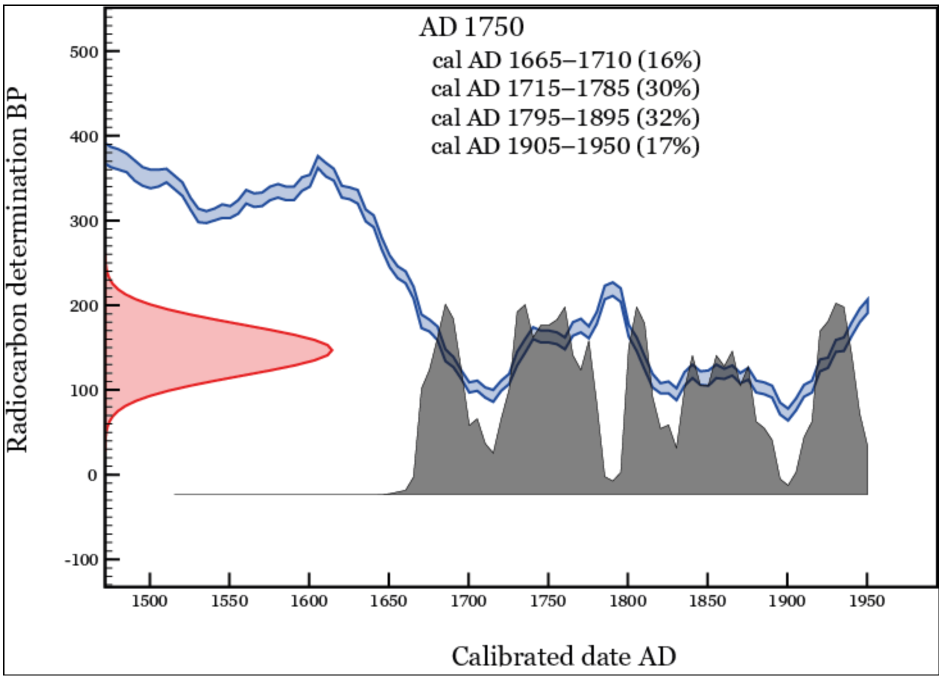

Figure 5: A simulated radiocarbon measurement for a sample with a calendar age of AD 1750 and an error on the radiocarbon measurement of ±30 years, in pink on the vertical axis, calibrated to cal AD 1665 to 1710 (16% probability), 1715 to 1785 (30% probability), 1795 to *1895 (32% probability) or 1905 to 1950 (17% probability), in black on the horizontal axis. The blue band is the relevant part of the calibration curve.*

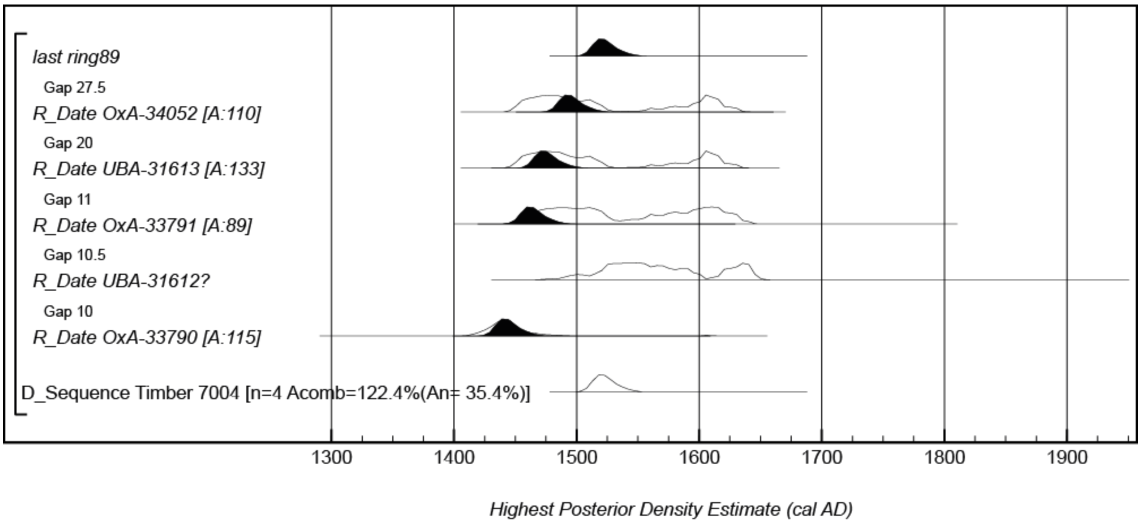

Figure 6: Probability distributions of dates from sample SMR7004. Each distribution represents the relative probability that an event occurs at a particular time. Ring 89 dates the outermost surviving sapwood ring. A question mark after the laboratory number of UBA-31612 indicates that this date is excluded from the model, for reasons explained in the text, although still shown on the graph. For each of the dates two distributions have been plotted: one in outline, which is the simple radiocarbon calibration, and a solid one, based on the wiggle-match sequence. The large square brackets down the left-hand side along with the OxCal keywords define the overall model exactly

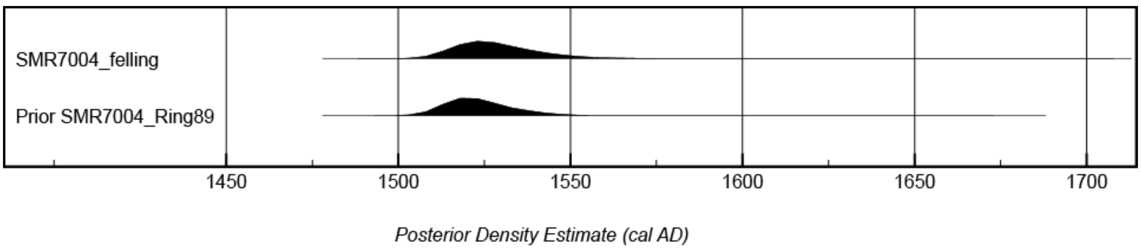

Figure 7: Probability distribution for the felling date of the timber represented by sample SMR7004 from the unidentified shipwreck using the expected number of additional sapwood rings for ancient oak trees in England

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Historic England works to improve care, understanding and public enjoyment of the historic environment. We undertake and sponsor authoritative research. We develop new approaches to interpreting and protecting heritage and provide high quality expert advice and training.

We make the results of our work available through the Historic England Research Report Series, and through journal publications and monographs. Our online magazine Historic England Research which appears twice a year, aims to keep our partners within and outside Historic England up-to-date with our projects and activities.

A full list of Research Reports, with abstracts and information on how to obtain copies, may be found on www.HistoricEngland.org.uk/researchreports

Some of these reports are interim reports, making the results of specialist investigations available in advance of full publication. They are not usually subject to external refereeing, and their conclusions may sometimes have to be modified in the light of information not available at the time of the investigation.

Where no final project report is available, you should consult the author before citing these reports in any publication. Opinions expressed in these reports are those of the author(s) and are not necessarily those of Historic England.

The Research Report Series incorporates reports by the expert teams within the Research Group of Historic England, alongside contributions from other parts of the organisation. It replaces the former Centre for Archaeology Reports Series, the Archaeological Investigation Report Series, the Architectural Investigation Report Series, and the Research Department Report Series

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