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RESEARCH

Absolute dating of construction materials and petrological characterisation of mortars from the Santalla de Bóveda Monument (Lugo, Spain)

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Abstract
The construction materials of the Santalla de Bóveda Monument, one of the most studied buildings in Galicia (Spain), are analysed to date the mortars and bricks of walls and vaults by combining three dating techniques: optically stimulated luminescence, radiocarbon and thermoluminescence. Petrological characterisation of the mortars themselves is carried out. Until now, the paintings on the vault have been interpreted as Roman, early Christian or Pre-Romanesque, depending on the interpretative framework used by the researcher who studied them. There is also no consensus on their functionality. A total of 21 samples were collected, and 39 datings were made. The results are conclusive: the original building dates from the second half of the fourth century AD, the paintings date from the beginning of the seventh century or the upper floor from the tenth to twelfth centuries. These results make it necessary to review the history of Galician architecture between Late Antiquity and the Early Medieval Ages.

Keywords Archaeology of architecture · Paintings and lime mortars · Optically stimulated luminescence · Radiocarbon · Petrography · Late Antiquity and Early Medieval Age

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Introduction

The Santalla de Bóveda Monument is located 15 km southwest of Lugo, in the northwest of Galicia (Spain), in a rural area of the Mera valley (Fig. 1). It is a small semi-buried building, under the Bóveda Parish Church, built in the eighteenth century, with an apsidal quadrangular floor plan, which was divided into three naves. The small apse has a rectangular floor plan and is vaulted; it is accessed through a brick voussoir arch. Only the parts of the vault in the lateral naves have survived, where paintings depicting birds and plant elements have been well preserved. There is a shallow pool in the flagstone pavement. The *aula* is preceded by a two-column portico in antis, and in its narthex, the remains of the vault that covered it, decorated with geometric paintings, have been preserved. The doorway of the *aula* has a central opening crowned by a light horseshoe-shaped brick arch, above imposts, and framed by a chambranle and a granite moulding with vegetal decoration, *alfiz* type. Two rectangular lintelled windows with a mitered arch above them are on either side of the door. There are several bas-reliefs depicting various types of birds and human figures in the portico,

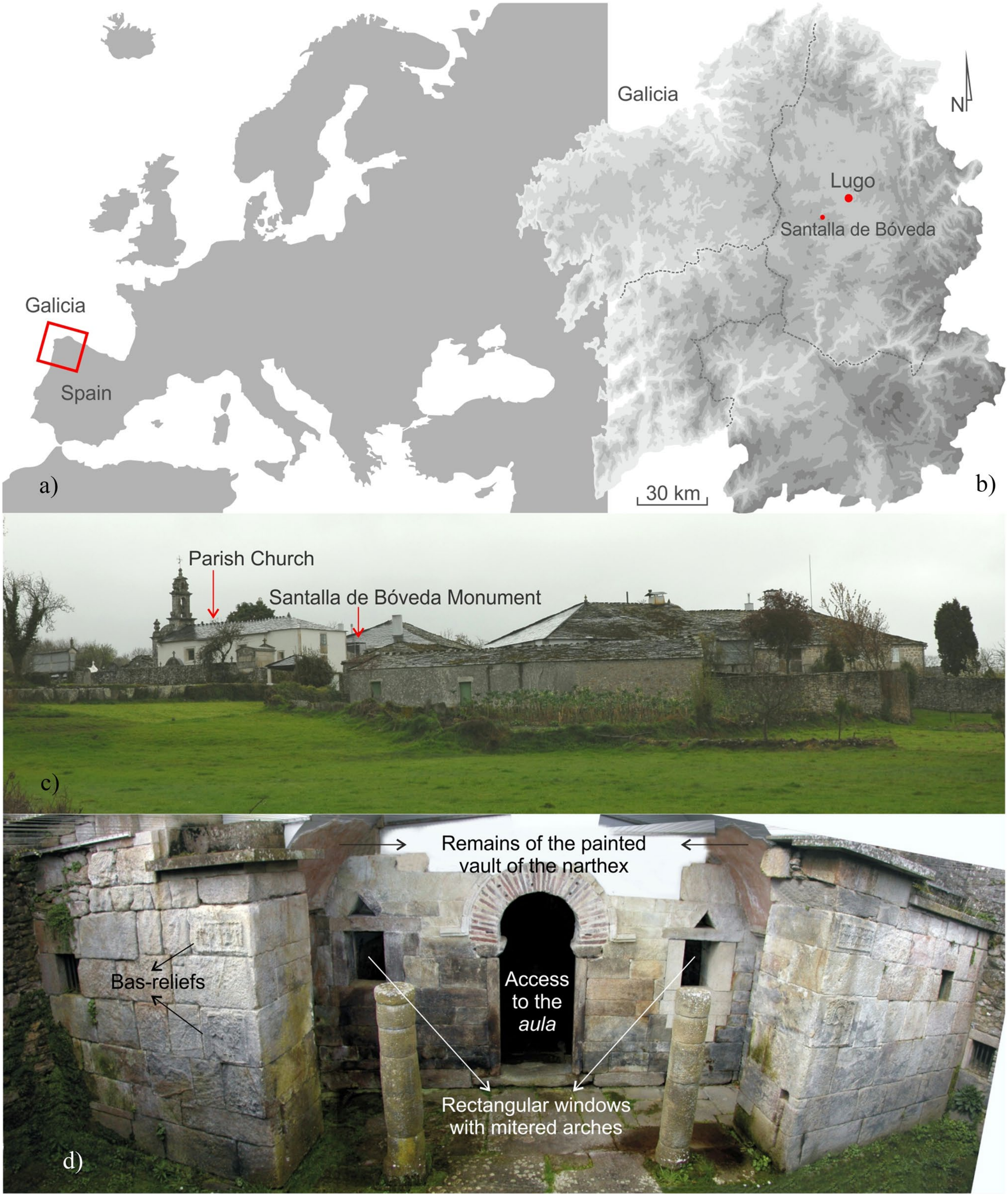

Fig. 1 **a** Map of Europe with the location of Galicia in Spain. **b** Situation of Santalla de Bóveda Monument in Lugo province. **c** Location of the Santalla de Bóveda Church and monument in Bóveda. **d** East façade of the monument and narthex with columns *in antis*

both on the outer façade and in the narthex (Fig. 1). Part of the north elevation of a first floor is preserved above this structure (Fig. 2).

The monument has aroused great interest since its discovery, both for its uniqueness and for the interpretation of its well-preserved paintings as Roman. But its chronology and functionality has always been the subject of controversy. Some of the most recurrent interpretations are as nymphaeum of the fourth century AD (Castillo López 1932; Chamoso Lamas 1952; Abad Casal 1979) or from the end of the third century AD in the orientalising style (Gómez-Moreno Martínez 1949); as a possible salutary waters place (Ares Vázquez 1962, 1963, 1964), remodelled in the second half of the fourth century (Chamoso Lamas 1952).

It has also been interpreted as a Roman funerary monument of oriental character of the fourth century AD, transformed for Christian worship around the ninth century AD following Pre-Romanesque Asturian models (Schlunk 1935), or as the baths of a villa of the fourth century AD and a later transformation, around the fifth century, into a Prisciliano tomb (Fernández de la Vega 1970) or with a Christian reuse before the eighth century AD (Guardia 2002).

Several authors define a Roman origin with later stages in the fifth, eighth or ninth centuries (Acuña Castroviejo 1973; Núñez Rodríguez 1978; Rodríguez Colmenero 1992, 2018; Singul Lorenzo 1997, 1998; Vidal Caeiro 2003; Carrocera Fernández 2016). Arias Vilas (1979, 1980) sees a single structural phase to which construction, painting and sculpture are assigned, and it is reused with the passing of time. Finally, Montenegro Rúa (2016) defends the statement of the space to an Alto Imperial funerary monument no later than the second century AD with Dionysiac character.

Research carried out by our team in 2007–2008 identified a complex stratigraphic sequence thanks to an archaeology of architecture study of the monument, applying stratigraphic analysis of walls (Benavides and Blanco-Rotea 2008; Blanco-Rotea et al. 2009) (see Fig. 6):

- Phase I. First underground building consisting of a narthex, the vaulted *aula* without division into three naves and with a swimming pool, and the W apse, also vaulted
- Phase II. Alterations to the *aula* modifying its appearance: division of the aula into three naves, decoration of the interior of the *aula* with paintings and possibly decorated plaques, possible alteration of the entrance door to the monument and a possible modification of the main façade
- Phase III. Construction of a vaulted room above the *aula* and with access from the W
- Phase IV. Specific alterations affecting the W door of the *aula*, the vault of the narthex or the vault of the upper floor
- Phase V. Interventions in the contemporary period, which took place between its discovery in 1929 and the last intervention by the architect César Portela in 2006–2007

Stratigraphic reading is a well-proven method of archaeological analysis of architecture (Domingo Fominaya and Sánchez Luengo 2010) that provides a relative sequence of construction phases. To date absolutely, other methods are used, such as the use of chronological indicators or absolute dating techniques applied to materials, such as radiocarbon or optically stimulated luminescence (OSL).

But, in case of using chronological indicators, three points must be considered at the Santalla de Bóveda Monument:

1. It is a *unicum*, there is no known similar example in the Iberian Peninsula and even less in the NW that would allow us to establish a comparison on which to build an interpretative model for the Santalla de Bóveda Monument, although some parts of the complex could have similarities with other constructions.
2. The materials and construction techniques used in the Santalla de Bóveda Monument, as well as the motifs of the paintings, are documented in a wide chronological range, from Roman times to the Early Middle Ages. This has meant that each author has given greater or lesser weight to one or other chronology, depending on the interpretative framework used. This is the case, for example, of the decorative scheme of the central part of the vault which has now disappeared, which is compared both with the motifs of Roman *villae* and with the paintings of Pre-Romanesque Asturian art (Blanco-Rotea et al. 2009: 192–196).
3. The scarcity of studies of Galician Early Medieval architecture from an archaeological point of view that would allow us to establish well-defined contexts, on a stratigraphic basis, between the fifth and tenth centuries, there is an aspect that it has changed today thanks to the development of different projects focused on the archaeology of Early Medieval architecture (Blanco-Rotea et al. 2015; Sánchez Pardo et al. 2017, 2020; Sanjurjo-Sánchez et al. 2020).

Taking these points into account, in the present study, it was considered essential to characterise and date precisely the construction materials used at the Santalla de Bóveda Monument. Construction materials of historical monuments generally come from the vicinity of the building (Drdácky et al. 2013; Furlan 2017; Freire-Lista and Fort 2019). The geological setting where the Santalla de Bóveda Monument was built conditioned its construction materials, especially the aggregates of the mortars which come from the grinding of granite. The historical quarries are superficial in the area, and the granite is weathered to

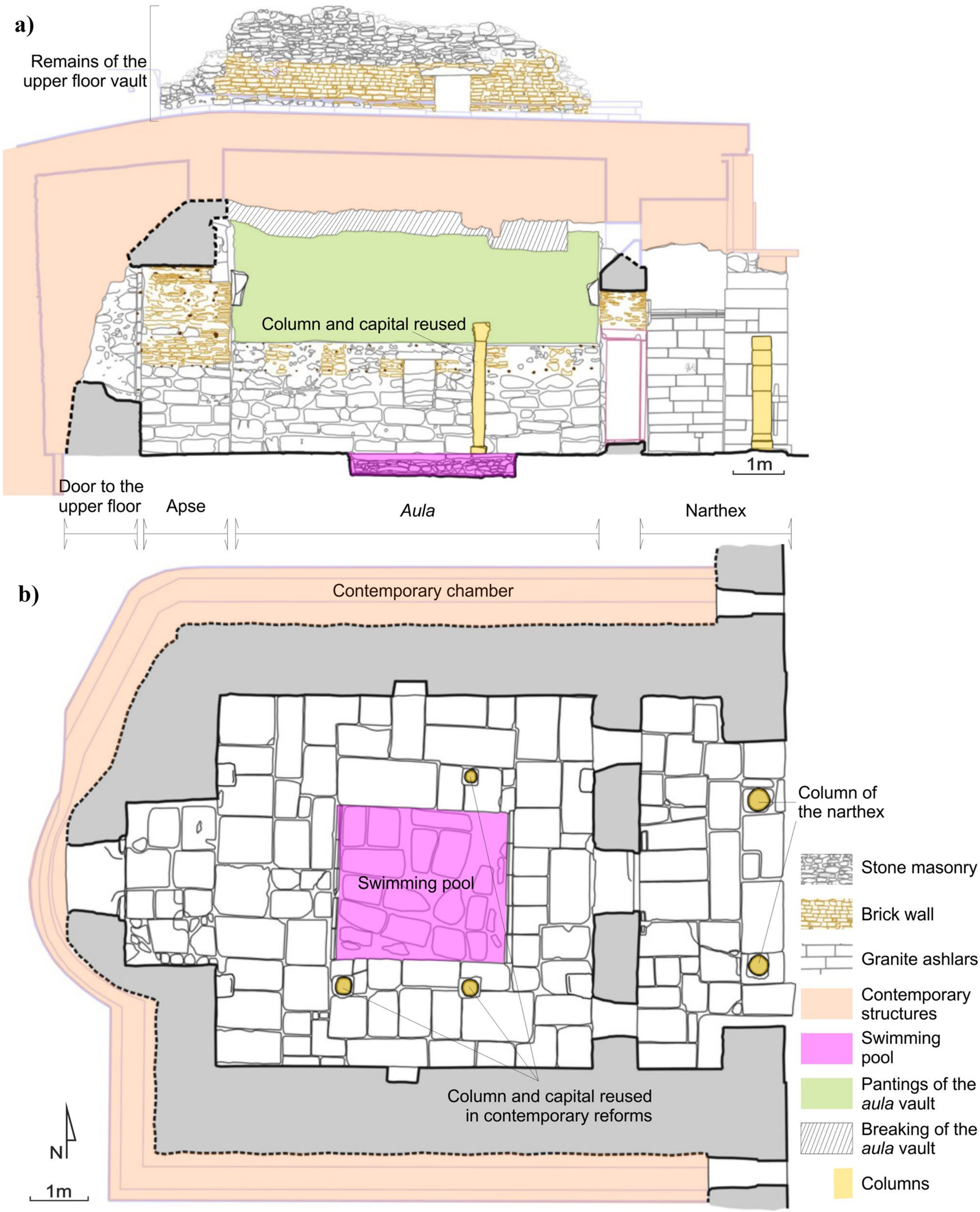

Fig. 2 **a** North elevation of the aula and remains of the upper floor. **b** Plan of the underground building of the Santalla de Bóveda Monument

different degrees. While quartz is resistant to chemical weathering, clay minerals are a product of the weathering of feldspars and micas. Therefore, aggregates from weathered granite have more clay minerals than aggregates from fresh granite. The aggregates will have a large amount of clay if the aggregates are extracted from a highly weathered and sandblasted granite saprolite, which reduces the mortar quality. Masons could improve the mortar quality made with granite aggregates from saprolites by concentrating the quartz grains. That is, washing and removing the clay minerals.

From a geological point of view, the Santalla de Bóveda Monument is in the south of Hombreiro-Santalla (HS) pluton, on a syn-kinematic two-mica granite (Aranguren 1997). Two-mica granites occur usually as small plutons late in a plutonic sequence that intrudes high-grade metamorphic rocks of an orogen. They are usually leucocratic, massive, hypidiomorphic granular granitoids that consist of about 31% volume percent quartz, 26% K-feldspar, 31% plagioclase and about 10% mica in which muscovite may exceed biotite. In some, muscovite is absent in which event total mica is about 5%, except for a few types that contain abundant biotite. In two-mica granites, hornblende is absent, magnetite is sparse and sphene is rare. Common accessory minerals are apatite, zircon, monazite, garnet and tourmaline.

Petrographic characterisation is a very useful technique for construction materials (Germinario and Török 2019; Parracha et al. 2020; Careddu et al. 2021). It allows for the techniques and source materials used in the preparation of historical mortars to be identified (Elsen 2006; Ergenç and Fort 2019; Freire-Lista et al. 2020).

In terms of obtaining the date of the materials, in recent years, both ^{14}C and OSL dating of mortars have made it possible to obtain ages of historic buildings (Sanjurjo-Sánchez 2016; Urbanova et al. 2020). Radiocarbon AMS dating enables the dating of the layering of a mortar from the analysis of the lime binder, although the calcite can be mixed with geogenic calcite, secondary calcite due to dissolution and re-precipitation, or affected by very slow setting processes that can cause the overestimation or underestimation of ages (Ringbom et al. 2014; Sanjurjo-Sánchez et al. 2010; Urbanova et al. 2020). OSL dating of quartz aggregates has also been used (Goedicke 2003). However, OSL dating can also overestimate the age if the quartz aggregate has not been well exposed to daylight when the mortar was prepared before layering (Sanjurjo-Sánchez 2016; Urbanova et al. 2020).

The aim of this work is to obtain an absolute chronology for the Santalla de Bóveda Monument and its different construction phases for a correct interpretation of their architecture and decoration.

Materials and methods

Dating of mortars and bricks by optically stimulated luminescence (OSL), thermoluminescence (TL) and ^{14}C

There are currently several methods for dating mortars, such as radiocarbon or OSL, as discussed above. However, the dates obtained are often flawed or have very wide margins of error that do not allow for a refined chronology. Nevertheless, there are three possible strategies to identify inaccurate ages in mortars: (i) cross-checking results with independent dating methods (e.g. ^{14}C vs. OSL), (ii) dating several samples of the same construction phase and/or (iii) comparing the ages obtained with those of other materials, such as wood, charcoal or bricks from the same structure. Such strategies have been used simultaneously in this work, allowing both the reduction of uncertainties and the removal of biased ages.

In order to obtain a robust chronology, a total of 39 datings were performed from 21 samples taken from different walls of the studied building (Fig. 3). They correspond to each of the phases previously identified in the monument (Blanco-Rotea et al. 2009), always from inconspicuous places that did not affect the paintings. Twenty OSL and fifteen ^{14}C ages were obtained for mortars, on quartz aggregates and carbonates or charcoal, respectively. Thus, for some samples, two or even three ages were obtained. Thermoluminescence (TL) dating was also performed on five brick samples. The list of samples, dated material, location in the building and age result are shown in Table 2.

The 'Cryo2SoniC' method (Nonni et al. 2018) was used for ^{14}C mortar dating, which involves several steps of cryogenic fragmentation, fragment selection, ultrasonic cleaning and centrifugation to separate the calcite of interest (archaeological calcite). This archaeological calcite was sent to the ICA laboratory (FL, USA) for AMS dating. Charcoal samples were directly sent to the same laboratory. Ages were calibrated using the curve of Reimer et al. (2020) with OxCal 4.4 software (Bronk Ramsey 1994).

Both OSL and TL dating were carried out at the Luminescence Laboratory (University Institute of Geology) of University of A Coruña (UDC). The outer part of the samples was removed, and pure quartz aggregates were extracted following the procedures described in Viveen et al. (2014). Multigrain aliquots were mounted and analysed in two readers: a Riso DA-15 TL/OSL and a Lexsyg Research, equipped with ^{90}Sr/^{90}Y beta radiation sources providing doses of 0.095 ± 0.003 Gy s^{-1}.

OSL dating requires the assessment of the accumulated charge in the quartz grains. This is estimated as the

Fig. 3 Samples' location. **a** North wall of the aula. **b** South wall of the aula. **c** East wall of the aula. **d** West wall of the aula. **e** Remains of the vault of the upper floor

equivalent dose (D_e) by measuring the luminescent signal. The radiation dose rate is also estimated as the dose-rate (D_r) (Aitken 1985). For OSL dating, to estimate D_e, the SAR (single-aliquot regenerative dose) protocol of Murray and Wintle (2000, 2003) was used. For TL dating, the Additional Dose (AD-TL) protocol (Aitken 1985) was used. The D_r was estimated by analysing the U, Th and K content in the samples and surrounding materials by X-ray fluorescence (XRF) combined with inductively coupled plasma mass spectrometry (ICP-MS) in some cases, and instrumental neutron activation analysis (INAA) in others. Conversion factors of Guérin et al. (2011) were used to assess the beta dose. For the gamma dose, a geometric model similar to the one proposed by Feathers et al. (2008) was used, estimating the cosmic dose according to Prescott and Hutton (1994). The result was compared with the estimations obtained using both Al_2O_3 OSLD/TLD dosimeters and a portable gamma spectrometer GF Instruments Gamma Surveyor Vario.

Mortars' petrographic characterisation

Four mortar samples, one from each construction phase of the Santalla de Bóveda Monument, were embedded in resin in a vacuum chamber to consolidate them and to avoid disintegration in the preparation of thin sections. The thin sections were studied under a Leica DM750P polarised light microscope.

Table 1 Luminescence dating results with both dating methods (OSL and TL), dose rate (Dr), number of aliquots accepted (N), equivalent dose (D_e), age (years before sampling) and historical age and age range

Sample	Method	D_r (mGy a-1)	N	D_e (Gy)	Age (y)	Age AD	Range AD
Phase I							
BOV20MU001A	OSL	5.79 ± 0.12	35	9.59 ± 041	1656 ± 78	364 ± 78	286–442
BOV20MU001B	OSL	6.38 ± 0.11	33	10.3 ± 0.4	1610 ± 73	410 ± 73	337–483
BOV20MU002B	OSL	5.91 ± 0.11	58	9.37 ± 0.26	1586 ± 53	434 ± 53	381–487
BOV20MU003A	OSL	5.98 ± 0.11	2	7.06 ± 1.08	1180 ± 182	840 ± 182	658–1022
BOV20MU003B	OSL	7.58 ± 0.11	38	12.9 ± 0.5	1700 ± 76	320 ± 76	244–396
BOV20MU003C	OSL	6.51 ± 0.11	25	10.7 ± 0.4	1636 ± 63	384 ± 63	321–447
BOV20MU003C	TL	6.51 ± 0.11	20	10.0 ± 0.8	1537 ± 119	483 ± 119	365–602
AUE105	OSL	11.1 ± 0.1	19	18.9 ± 2.5	1708 ± 228	300 ± 228	72–528
AUE114	OSL	7.21 ± 0.15	29	13.0 ± 1.3	1800 ± 180	208 ± 180	28–389
BUE114b	TL	7.69 ± 0.10	30	13.8 ± 1.2	1794 ± 159	214 ± 159	55–372
Phase I–II							
AUE126	OSL	11.0 ± 0.1	20	15.2 ± 3.2	1376 ± 288	632 ± 288	344–920
UE083B	OSL	8.20 ± 0.18	18	13.2 ± 1.2	1606 ± 154	402 ± 154	248–557
BUE126	TL	8.96 ± 0.05	20	12.4 ± 2.4	1379 ± 265	629 ± 265	364–894
BUE083B	TL	6.41 ± 0.14	36	11.2 ± 2.1	1741 ± 330	267 ± 330	63 BC–497 AD
Phase II							
BOV20MU008	OSL	4.11 ± 0.11	53	6.51 ± 0.33	1584 ± 90	436 ± 90	346–526
BOV20MU004	OSL	6.65 ± 0.12	40	5.90 ± 0.16	886 ± 30	1134 ± 30	1104–1163
Phase III							
AUE108	OSL						-
AUE109B	OSL	7.38 ± 0.11	20	6.46 ± 0.77	875 ± 105	1133 ± 105	1028–1238
AUE110	OSL	6.77 ± 0.06	41	31.7 ± 4.0	4687 ± 588	2679 ± 588 BC	3267–2091 BC
AUE025	OSL	5.54 ± 0.17	20	4.92 ± 1.6	888 ± 355	1120 ± 355	764–1475
AUE017	OSL	6.24 ± 0.17	24	14.2 ± 0.8	2280 ± 145	272 ± 145 BC	417–127 BC
AUE013	OSL	5.17 ± 0.17	14	5.24 ± 0.54	1013 ± 110	995 ± 110	884–1105
AUE014	OSL	4.44 ± 0.18	37	3.91 ± 047	880 ± 112	1128 ± 112	1016–1239
BUE013	TL	5.51 ± 0.14	16	8.11 ± 1.09	1471 ± 202	537 ± 202	336–739
BUE017	TL	6.21 ± 0.14	24	7.60 ± 0.82	1225 ± 135	783 ± 135	648–919

Date abbreviations: *AD* anno Domini, *BC* before Christ

Results

Dating of mortars and bricks by optically stimulated luminescence (OSL), thermoluminescence (TL) and ^{14}C

Very high D_rs were obtained, ranging from ≈ 3 to ≈ 11 mGy a^{-1} (see Table 1). This is due to the high concentration of U, Th and K in the building granite and mortar aggregates. The observed OSL and TL signals were bright. The Central Age Model (CAM) proposed by Galbraith et al. (1999) was used to assess the D_es for most of the mortar samples (Table 1), as the measured aliquots provided symmetrical dispersions with low overdispersion values. Asymmetric and more overdispersed distributions were observed only in few samples. In such cases, the Minimum Age Model (Galbraith et al. 1999) was used. The brick TL analyses provided bright signals, but the uncertainty obtained was high for the assessed D_es (20%), except for one sample (Table 1).

Calcite separation for ^{14}C dating provided enough material for AMS analyses that provided calibrated ages which are shown in Table 2. It can be observed that ^{14}C ages of calcite, charcoal and OSL in mortar and TL in bricks provide consistent results for most samples, providing very consistent ages for the different construction phases. A Phase I/II has been considered because some doubtful features were observed in some structures of both phases, being difficult to assign a clear phase to them. The obtained ages show that these structures fit better chronologically into Phase I.

The four construction phases are clearly separated chronologically. To get a straightforward chronological model, we have used OxCal 4.4, combining radiocarbon and OSL ages (Table 3). We have considered the first three phases for this purpose (There is an only age for Phase IV). After

Table 2 Results of OSL and 14C ages obtained for mortar samples and TL for brick samples. The table lists the samples in order of construction phases

Sample	Location	Method	Lab code	Uncal Age or OSL age	Year	Age range
Phase I						
BOV20MU001_A_P	Mortar, outer layer, cavity wall (CW)	^{14}C	14C-5635	740 ± 40	1250 ± 75 AD	1175–1324 AD
BOV20MU001A	Mortar, outer layer, CW	OSL	-	1656 ± 78	364 ± 78 AD	286–442 AD
BOV20MU001B	Mortar, inner layer, cavity wall (CW)	OSL	-	1610 ± 73	410 ± 73 AD	337–483 AD
BOV20MU002B	Mortar, inner layer, CW	OSL	-	1586 ± 53	434 ± 53 AD	381–487 AD
Carbon E	Carbon in mortar, inner layer, CW	^{14}C	14C-5284	1770 ± 30	299 ± 76 AD	223–375 AD
BOV20MU002_B_Carb	Carbon in mortar, inner layer, CW	^{14}C	14C-5285	1740 ± 30	324 ± 79 AD	245–402 AD
BOV20MU002_B	Mortar, inner layer, CW	^{14}C	14C-5432	3280 ± 30	1557 ± 51 BC	1607–1506 BC
Carbon D	Carbon in mortar, inner layer, CW	^{14}C	14C-5438	1720 ± 30	321 ± 63 AD	258–383 AD
BOV20MU003_A_P	Mortar, outer layer, CW	^{14}C	14C-5636	2380 ± 40	562 ± 199 BC	760–363 BC
BOV20MU003_B_P	Mortar, inner layer, CW	^{14}C	14C-5276	1950 ± 50	83 ± 126 AD	43 BC–209 AD
BOV20MU003B	Mortar, inner layer, CW	OSL		1700 ± 76	320 ± 76 AD	244–396 AD
BOV20MU003C	Brick in mortar, inner layer, CW	OSL		1636 ± 63	384 ± 63 AD	321–447 AD
BOV20MU003C	Brick in mortar, inner layer, CW	TL		1537 ± 119	483 ± 119 AD	365–602 AD
AUE105	Mortar, wall N of the *aula*, under niche	OSL		1708 ± 228	300 ± 228 AD	72–528 AD
AUE114	Mortar of the arch cut by the S niche	OSL		1800 ± 180	208 ± 180 AD	28–389 AD
BUE114bB	Brick of embedded arch, cut by S niche	OSL		1794 ± 159	214 ± 159 AD	55–372 AD
Phase I/II						
AUE126	Mortar, apse vault arch	OSL		1376 ± 228	632 ± 288 AD	344–920 AD
UE083B	Mortar, horseshoe arch, access to the *aula*	OSL		1606 ± 154	402 ± 154 AD	248–557 AD
BUE126	Brick, apse vault arch	OSL		1379 ± 265	629 ± 265 AD	364–894 AD
BUE083B	Brick, horseshoe arch, access to the *aula*	OSL		1741 ± 330	267 ± 330 AD	63 BC–597 AD
Phase II						
MUSEB-001_P	Mortar, painting base, *aula* vault	^{14}C	14C-5278	1360 ± 30	691 ± 84 AD	607–774 AD
MUSEB-002_P	Mortar, painting base, *aula* vault	^{14}C	14C-5279	1530 ± 30	519 ± 85 AD	434–603 AD
BOV20MU005	Mortar, painting base, wall W of the *aula*	^{14}C	14C-5435	1400 ± 30	634 ± 26 AD	608–659 AD
BOV20MU006_P	Mortar, painting base, wall E of the *aula*	^{14}C	14C-5277	1470 ± 30	603 ± 44 AD	559–647 AD
BOV20MU008	Mortar, painting base, wall E of the *aula*	^{14}C	14C-5637	1440 ± 40	579 ± 101 AD	478–680 AD
BOV20MU008	Mortar, painting base, wall E of the *aula*	OSL		1584 ± 90	436 ± 90 AD	346–526 AD
BOV20MU004	Mortar, SW *aula*, under marble impost	^{14}C	14C-5434	1790 ± 30	280 ± 45 BC	235–325 BC
BOV20MU004	Mortar, SW *aula*, under marble impost	OSL		886 ± 30	1134 ± 30 AD	1104–1163 AD
Phase III						
BOV20MU002_A	Lime with wood traces, CW	^{14}C	14C-5273	990 ± 30	1072 ± 79 AD	993–1150 AD
AUE109B	Mortar, *aula* vault. In niche hole S	OSL		875 ± 105	1133 ± 105 AD	1028–1238 AD
AUE110	Mortar, wall S, under marble impost	OSL		4687 ± 588	2679 ± 588 BC	3267–2091 BC
AUE025	Mortar, upper floor vault. Masonry part	OSL		888 ± 355	1120 ± 355 AD	764–1475 AD
AUE017	Mortar, upper floor vault. Brick part (W)	OSL		2280 ± 145	272 ± 145 BC	417–127 BC
AUE013	Mortar, upper floor vault. Brick part (E)	OSL		1013 ± 110	995 ± 110 AD	884–1105 AD
AUE014	Mortar, painting base. Upper floor vault	OSL		880 ± 112	1128 ± 112 AD	1016–1239 AD

Table 2 (continued)

Sample	Location	Method	Lab code	Uncal Age or OSL age	Year	Age range
BUE013	Brick, upper floor vault. Brick part (E)	TL		1471 ± 202	537 ± 202 AD	336–739 AD
BUE017	Brick, upper floor vault. Brick part (W)	TL		1225 ± 135	783 ± 135 AD	648–919 AD
Phase IV						
BOV20MU007	Mortar, *aula* vault, central rupture	^{14}C	14C-5436	220 ± 30	1723 ± 77 AD	1646–1799 AD

Date abbreviations: *AD* anno Domini, *BC* before Christ

a first combination of ages for the three phases, some of them provided an agreement index (A) below 60. This is the boundary value provided by Bronk Ramsey (1995) to identify outliers. After removing such outliers, we run again the model (Fig. 4) and obtained age ranges for the three phases. Considering the Bayesian model results, Phase I corresponds to the period 330–405 AD taken the 2σ confidence interval (95%). Phase II corresponds to the age interval (2σ) 599–649 AD. As this phase includes the base mortar of the paintings, this will be the age of the paintings. Phase III corresponds to the period 1083–1154 AD (2σ), while Phase IV (not included in the model) ranges between the second half of the seventeenth century and the eighteenth century.

Mortars' petrographic characterisation

Figure 5 shows the petrographic micrographs of the four mortar types studied. Phase I mortar has centimetre-sized aggregates of bimetallic granite (altered and unaltered) and centimetre-sized ceramic fragments. The monocrystalline aggregates are mostly quartz ≈ 70% < 1 mm.

Phase II mortar has absence of aggregates of rock fragments. It has aggregates mostly of quartz with a slightly homogeneous grain size ≈ 2.5 mm. In addition, there are small aggregates of biotite and muscovite. Also, this phase has unaltered microcline and carbon.

Phase III mortar also has absence of aggregates of rock fragments. But it has ceramic aggregates. Lime cement is very differently and, to a lesser extent, contains lumps of lime cement. The aggregates are smaller (≈ 1 mm), and the percentage of quartz is lower than in the other types of mortars (< 50%).

Phase IV mortar has aggregates with heterogeneous mineralogy: ≈ 15% biotite, ≈ 10% muscovite, ≈ 35% potassium feldspar, ≈ 40% quartz and homogeneous particle size < 1 mm.

Discussion of results and relation to stratigraphic reading

The stratigraphic reading of the walls had documented the existence of five phases in the Santalla de Bóveda Monument. The samples taken in 2007 and 2020 were collected considering this sequence with the aim of dating and characterising the construction materials, specifically the mortars. As can be seen, both in terms of characterisation and dating, the mortars are divided into four large groups.

In Phase I (Fig. 6), the mortars collected roughly oscillate between the year 28 and 602, with the second half of the fourth century being the time when they coincide with each other. However, there is a group of mortars dated by ^{14}C that fall outside this range, one (BOV20MU001_A_P) dating from 1175 to 1324 AD, another (BOV20MU002_B) from 1607 to 1506 BC and two others (BOV20MU003_A_P and BOV20MU003_B_P) from 760 to 363 BC and 43 to 209 BC, respectively. However, this disparity does not occur between the dates obtained by OSL. As for the bricks, the pattern is repeated, ranging from 55 to 602 AD. Thus, considering the coherence and coinciding range of the mortars dated by OSL, we have built a Bayesian chronological model that dates the phase corresponding to the construction of the *aula* was in the second two-thirds of the fourth century AD.

There is a series of mortars and bricks collected in the vault of the apse and in the horseshoe arch of the entrance, whose interval could be placed in both Phase I and II, as they present very large margins of error. In the case of the apse vault, the mortar corresponds to 344–920 AD and the brick 364–894 AD, both of which coincide quite closely with each other. Our assessment is inclined to place them in Phase I, taking into account structural aspects which indicate that the vault would have been made with the rest of the *aula*, as no cuts can be seen in it. In the case of the *aula* entrance door, the mortar dates from 248 to 557 AD and the brick from 63 BC to 597 AD. The reading of paraments placed this doorway as part of a Phase II alteration. In part, the most recent dating results lead us to a time immediately prior to the construction of the paintings, but it could also fall within Phase I, so we believe that either hypothesis would be feasible. However, looking at the obtained ages for to bricks and their adjacent mortars, we can include two of them (BUE83B and AUE83B), those corresponding to the entrance arch, in Phase I and the other two (BUE126 and AUE126), the vault of the apse, in Phase II. This example shows the importance of the study and dating of the construction materials in this building.

Table 3 Results of the chronological model performed with OxCal 4.4, with agreement indexes, unmodelled and modelled ages

Sample	Method	Unmodelled (BC/AD)		Modelled (AD)		
		1σ	2σ	1σ	2σ	*A*
Phase I						
BOV20MU001A_P	14C	1175–1324 AD				< 60
BOV20MU001A	OSL	284–444 AD	207–521 AD	342–387	330–405	136.9
BOV20MU001B	OSL	335–485 AD	263–557 AD	342–287	330–405	116.3
BOV20MU002B	OSL	381–487 AD	327–541 AD	342–287	330–405	66.2
Carbon E	14C	242–333 AD	223–375 AD	342–287	330–405	131.1
BOV20MU002_B_Carb	14C	250–365 AD	245–402 AD	342–287	330–405	84.8
BOV20MU002_B	14C	167–1506 BC				< 60
Carbon D	14C	258–383 AD	250–411 AD	342–287	330–405	110.9
BOV20MU003_A_P		760–363 BC				< 60
BOV20MU003_B_P		43 BC–209 AD				< 60
BOV20MU003B	OSL	242–398 AD	167–472 AD	342–287	330–405	114.2
BOV20MU003C	OSL	319–449 AD	257–511 AD	342–287	330–405	130.5
BOV20MU003C	TL	362–603 AD	244–721 AD	342–287	330–405	88
AUE105	OSL	70–529 AD	159 BC–757 AD	342–287	330–405	134.9
AUE114	OSL	27–389 AD	154 BC–568 AD	342–287	330–405	95.5
BUE114b	TL	53–374 AD	106 BC–532 AD	342–287	330–405	88.8
UE083B	OSL	66 BC–598 AD	395 BC–927 AD	342–287	330–405	136.8
BUE083B	TL	246–557 AD	93–710 AD	342–287	330–405	134.8
Phase II						
AUE126	OSL	342–921 AD	55–1209 AD	603–627	599–644	141.2
BUE126	TL	363–895 AD	99–1159 AD	603–627	599–644	141.2
BOV20MU008	OSL	346–526 AD	256–616 AD			< 60
BOV20MU008	14C	598–648 AD	563–659 AD	603–627	599–644	122.5
MUSEB-001_P	14C	646–679 AD	607–774 AD			< 60
MUSEB-002_P	14C	482–595 AD	343–603 AD			< 60
BOV20MU005	14C	608–659 AD	600–666 AD	603–627	599–644	73.2
BOV20MU006_P	14C	575–639 AD	559–647 AD	603–627	599–644	99
BOV20MU008	14C	598–648 AD	563–659 AD	603–627	599–644	122.5
Phase III						
BOV20MU002_A	14C	998–1148 AD	993–1155 AD	1101–1148	1083–1154	86.8
AUE109B	OSL	1028–1238 AD	923–1343 AD	1101–1148	1083–1154	137.7
AUE110	OSL	3267–2091 BC				< 60
AUE025	OSL	764–1475 AD	410–1830 AD	1101–1148	1083–1154	141.2
AUE017	OSL	417–127 BC				< 60
AUE013	OSL	884–1105 AD	775–1215 AD	1101–1148	1083–1154	75.6
AUE014	OSL	1016–1239 AD	904–1352 AD	1101–1148	1083–1154	138.8
BUE013	TL	336–739 AD				< 60
BUE017	TL	648.919 AD				< 60

Date abbreviations: *AD* anno Domini, *BC* before Christ

The mortars collected from elements of Phase II (Fig. 6) were taken, on the one hand, from the remains of the central vault conserved in the Provincial Museum of Lugo (Spain), obtaining dates of 607–774 AD (MUSEB-001_P) and 434–603 AD (MUSEB-002_P). On the other hand, the mortar used to prepare the paintings preserved in situ, dates ranging from 346 to 680 AD. In this case, they all coincide with the first half of the seventh century, although one point must be made: in Phase II, all the mortars have been dated by ^{14}C except for one BOV20MU008, slight differences in the 14C ages obtained from the lime calcite can be explained as caused by different carbonation rates. In other buildings, it has been found that the carbonation of the mortars is not immediate, but occurs some years after the time of laying

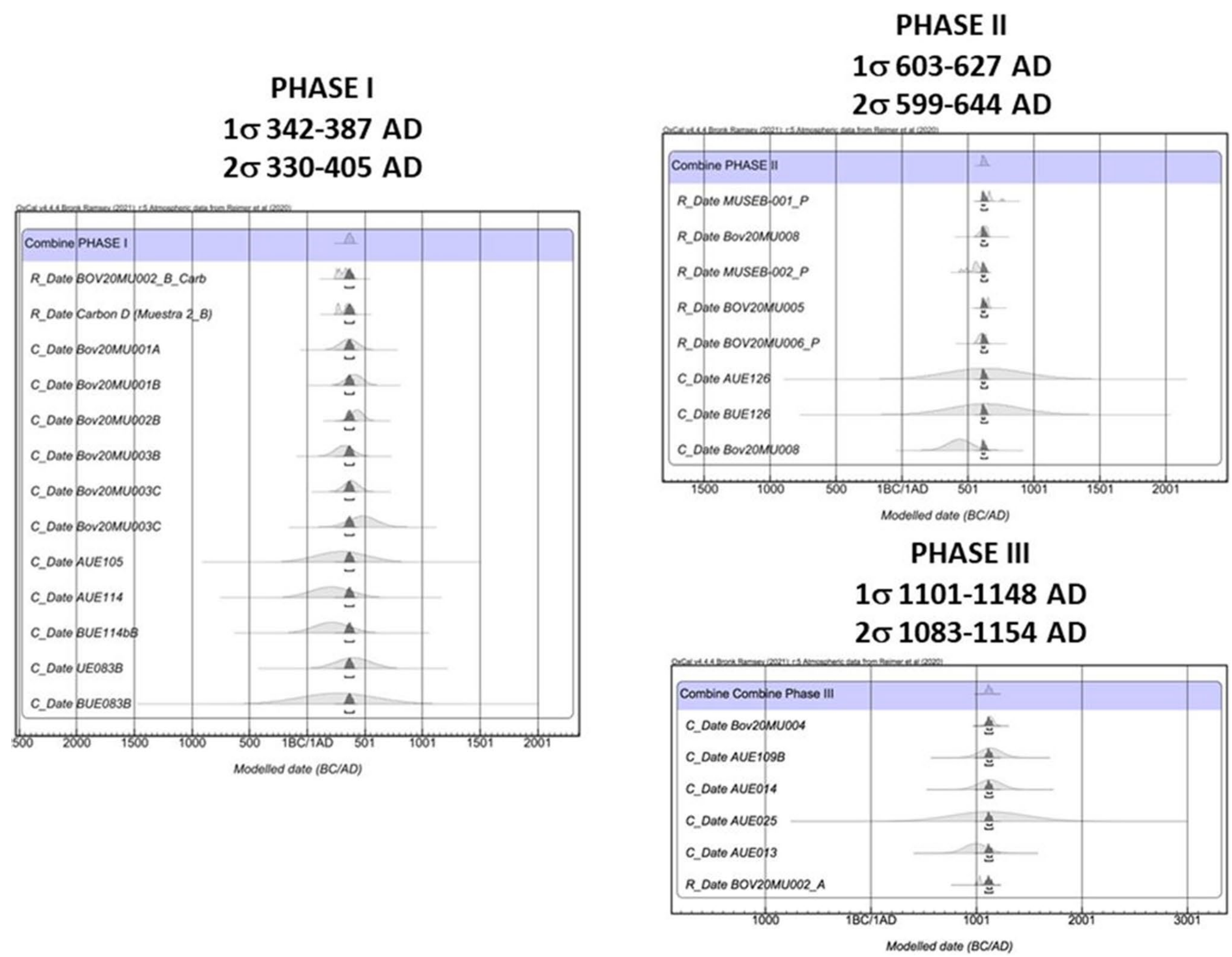

Fig. 4 Bayesian chronological model obtained for the three first constructive phases of the building. The model was obtained with OxCal 4.4, combining OSL and 14C ages. The ages that provide an agreement index (A) below 60 were removed, according to recommendations of Bronk Ramsey (1995)

(Lindroos et al. 2020; Daugbjerg et al. 2021), so it could even be hypothesised that this reform corresponds to first half of the seventh century, based on the Bayesian chronological model built for the results.

Understanding these data in context requires further research, an intensive analysis of the environment of the Santalla de Bóveda Monument and of the place where the building is located. But three aspects should be highlighted that open up new hypotheses on which to continue working. The first building is framed in a historical context in which in *Gallaecia* there was a ruralisation of the territory with the increase of *villae* and other types of rural settlements and their functions, especially in the surroundings of the cities. The fourth century sees the greatest development of this type of settlement (Carlsson-Brandt Fontán 2021: 690), a phenomenon also closely associated with the occupation of the vicinity of the roads that articulate the territory; in fact, the Santalla de Bóveda Monument is located in a central place between the XIX and XX Roman Vias, in a flat area and close to several hillforts (Gómez Vila 2005: 191), a fairly common proximity in relation to the *villae* (Carlsson-Brandt Fontán 2021: 688–689). From our point of view, the Santalla de Bóveda Monument would most probably be part of a type of Roman rural settlement that, at least, would have a phase in the second half of the fourth century, but determining its typology without a detailed knowledge of the whole is adventurous. See the current case of the Roman site of Proendos (Sober, Lugo), whose geomagnetic prospecting has identified an important complex which is currently being excavated (Alonso Toucido et al. 2021) and which yields contexts from the first to the sixth–seventh century AD. In the case of the Santalla de Bóveda Monument, there are few interventions that have been carried out in the area that allow us to advance this hypothesis. The excavations carried

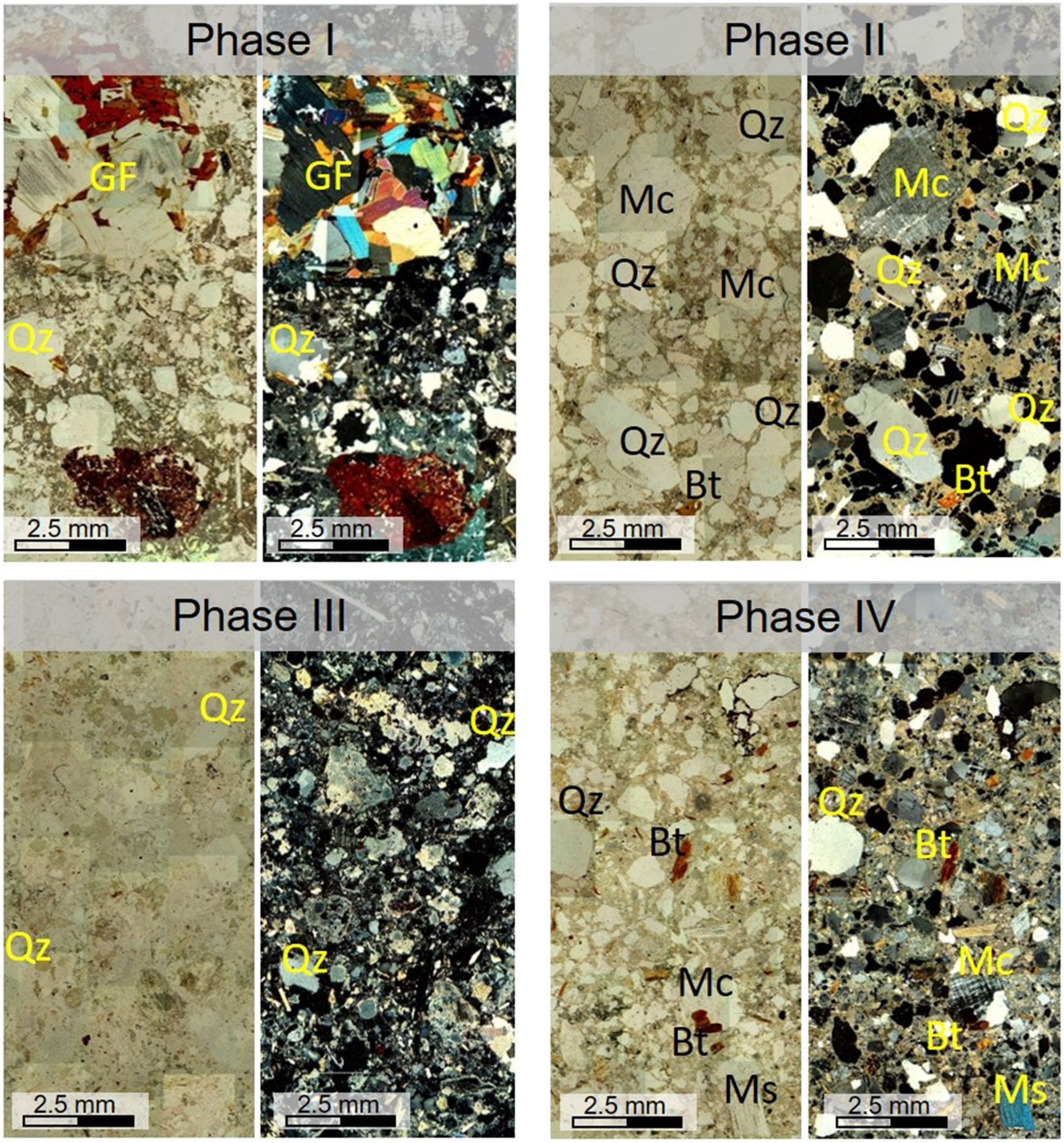

Fig. 5 Parallel (left) and polarised (right) light petrographic micrographs of the four mortar types studied. Bt, biotite; GF, granite fragment; Qz, quartz; Mc, microcline; Ms, muscovite

out by Gimeno García-Lomas 1989) point to the existence of Roman materials, most of which were dated between the third and fifth centuries (Montenegro Rúa 2016: 284), coinciding with the dating of the first phase of the building. It should be noted that in the area around the Santalla de Bóveda Monument, there are other settlements whose materials are also linked to Late Roman dates, such as the capital of Santa Cruz da Retorta Church from the fourth to fifth centuries (Gómez Vila 2005: 193). Therefore, in view of the confirmation of the initial phase of the Santalla de Bóveda Monument in the second half of the fourth century, it would be necessary to review from this perspective these nearby contexts which point, as several authors point out, to a high degree of organisation and development of the rural settlement during this period (Tejerizo García 2020: 165) which in the Santalla de Bóveda Monument has a continuity in the following centuries, if one considers the dating of the reform of the *aula* and the paintings of the vault, or the construction of the upper floor.

Focusing on the paintings, the sample collection was limited to the mortars of the preparatory layers of the painting without affecting them. In spite of this, we count on the stratigraphic analysis made by Cabrera Garrido (1992) of four samples of painting. He emphasises the polishing of

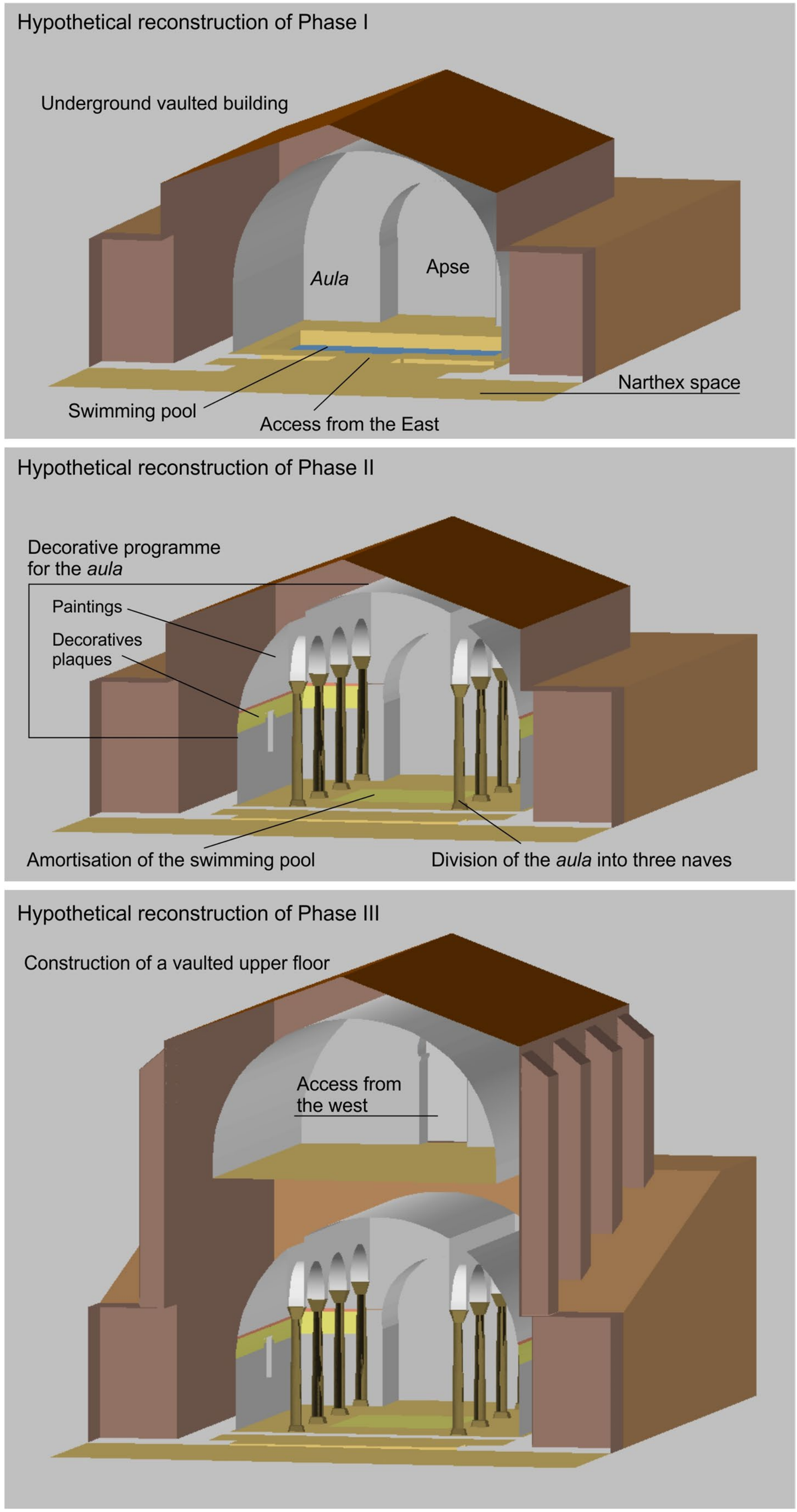

Fig. 6 Hypothetical reconstruction of the first three phases of the Santalla de Bóveda Monument, based on the previous reading of walls (Benavides and Blanco-Rotea 2008) and the results of absolute dating

intonachi and the superposition of painting layers (Blanco-Rotea et al. 2009: 186–187). The identified pigments are cinnabar, green earth, Egyptian blue, bone black, lime white and also *verdaccio* which he identifies with the description that Cennino Cennini gives for it.[1]

Recent studies about the Egyptian blue, the use of which many authors claim was abandoned in the Roman age, demonstrate that it was still being used years later.[2] Thanks to new technologies, its use has been confirmed even in the paintings of the Cinquecento.[3] As for the *verdaccio*, we have not found references to it before Cennini,[4] although it is possible that a similar technique for the flesh colour was used in the Byzantine[5] and Romanesque[6] wall paintings.

These researches allow us to confirm that the absolute dates obtained in this study are not contradictory to the use of the pigments identified by Cabrera.

The dating of the paintings to the seventh century, far from being a problem, reinforces the initial hypothesis of the survival of Roman structural techniques, both because of their wide circulation over an enormous territory and because of their efficiency, which have proved to be of great quality and durability.

Thus, the permanence of the techniques, materials and pigments used in the paintings, while leading some authors to consider them Roman, others argued that the pictorial technique used in the Santalla de Bóveda Monument remained almost intact until the first centuries of the Middle Ages (Murat 2021: 17–19, 27), it occurs here with the technical realisation, the master lines and the colours palette (Benavides and Blanco-Rotea 2008: 68–72; Blanco-Rotea et al. 2009: 184–187).

An exact parallel with the paintings of the Santalla de Bóveda Monument is yet to be found, although there existed numerous partial parallels. Also, it is true that there are not paintings of the seventh AD century so well preserved apparently without restorer interventions and not even hidden by later plasters. Maybe because of the unusual conservation in painting, it is more frequent to find parallels in mosaic of the same age, so much for the greater resistance of the materials and for the conservation of pavements with hardly any walls around them.

The decoration of the lost central part of the vault is documented in such a long period that it is possible to find parallels from the second century BC, as Polybius house in Pompeii (Croisille 2005: 74) to the Royal Palace of Caserta from the eighteenth century AD, although/even though the nearest are in the Asturian Pre-Romanesque (Arias Páramo 1999) (Fig. 7). The vases with branches and flowers that we can see in the intrados have parallels in the Byzantine world[7] and once more in the Asturian Pre-Romanesque (Arias Páramo 1999: 77).

Birds, grapes, *rosaceae* and lozenges also appear during a long time in buildings whose functions are different and in territories very far apart.

Although in wall paintings we can rarely see them, the graticules made by successions of motives are frequents in the Roman world[8] and also in much later moments as it is the case of the apodyterium of Qusayr'Amra built in the eighth century AD (Almagro et al. 1975; Vivert-Guigue 2007: 210–213; Manzano 2007: 339) or the Sala delle Oche in the Palace of Bonifacio VIII (Anagni, Italy) (1294–1303)[9] (Fig. 8).

In mosaics (Fig. 9), the model which presents more similarities with the Santalla de Bóveda Monument is the one of the vault hall of the chapel of Sant'Andrea in the Archiepiscopal Palace of Ravenna,[10] from the era of the bishop Pietro II (494–519). The floral lozenges are populated with various species of birds.

1 'Burnt sienna, bone black, lime white and cinnabar' (Cabrera Garrido 1992: 38).

2 'In the wall paintings of the church of San Saba (Rome), dating to the first half of the eighth century AD, Egyptian blue and lapis lazuli have been detected mixed together within the same pictorial layer' (Gaetani et al. 2004: 13). 'Egyptian blue has been identified positively in a Roman medieval fresco of the lower church of San Clemente' (Lazzarini 1982: 84).

3 'Egyptian blue was optically identified in a single thin section from a painting by Giovanni Battista Benvenuto from 1524, a period from which Egyptian blue is normally considered not to exist' (Bredal-Jørgensen et al. 2011:1438).

4 Cennino d'Andrea Cennini (c.1370-1440), a painter who describes the techniques of the master Giotto in *The Book of The Art*. The *verdaccio's* description is very accurate in chapter LXVII, whereas it is quite simplified in chapter LXXXV.

5 Dyonisius de Fourna (1670–1745), in his treatise *Erminia picturii bizantine* describes: 'The flesh-colours are made with green earth, (…) dark ochre, (…) lime white (…) and black. Grind them well and use as base colour' (Villarquide Jevenois 2015:117).

6 Eraclio says in *De coloribus et artibus romanorum*: 'For the flesh-colours is sometimes used, mostly in Italy, a layer of *verdaccio* as in Byzantium, in which case the work is made basically from dark to light' (Villarquide Jevenois 2015:143).

7 In Ravena, in Gala Placidia mausoleum and Neonian Baptistery, both from fifth century AD and the Albenga baptistery, fifth–sixth AD, all of them made in mosaic.

8 Pompeii (Croisille 2005:92), Domus Aurea (Segala and Sciortino 1999: 80), Villa di Arianna (Ginouvès 1987:8–9; Formoso 2006: 87), Villa di Popea in Oplontis or Villa di Minori in the Amalfitan coast (Laken 2001: 297 and 395). In this these two last cases, the succession of motives that made the lozenges are interlaced just as in Santalla; Abad Casal (1979: 920; 1982: 368) makes an interesting reflection of on? this 'knot'.

9 Although much later than Saint Eulalia, this painting has in common with it the interlacing of the losanges, a large variety of birds—although only the geese give the room its name—and the hypothesis that the paintings were inspired by a treatise on birds (De arte venandi cum avibus in this case and the Dioscorides of Vienna in the case of Saint Eulalia).

10 In this case, it is pergolato (arbour: mosaic and tempera painting). https://www.ravennamosaici.it/cappella-di-santandrea-e-museo-arcivescovile/.

Fig. 7 Examples of motifs used in Pre-Romanesque Asturian paintings and comparison with the Santalla de Bóveda Monument, drawings by Magín Berenguer (Schlunk and Berenguer 1957): **a** San Julián de los Prados Church (Oviedo, Spain), eighth–ninth centuries; **b** San Miguel de Liño Church (Oviedo, Spain), tenth century; **c** San Salvador de Priesca Church (Villaviciosa, Spain), tenth century; and **d** Santalla de Bóveda Monument (lost central vault), seventh century

With variations on the same theme, we can find several mosaic floors, in some cases like in Apostles Church of Madaba[11] (Jordan) another mosaic is preserved with the same geometric pattern of the lost vault (Fig. 9). Also in Madaba, and from the same century, we find this scheme in the Church of al-Khadir[12] or the Church of the Martyrs, representing birds, flowers, grapes and other fruits. All of that leads to show the chronological, geographical and functional dispersion of the pattern of the *aula* vault.

Regarding the remains of the vault preserved on the upper floor, we had already raised on other occasions (Blanco-Rotea et al. 2009) the complexity of linking them to Phase I or II, as the relationship between them was severed in the reform carried out by Gallego and Portela in 1985–1993. However, the difference in the construction technique used between the vaults of the *aula* and the upper floor led us to assume that these were different phases, as corroborated by the results of the dating, which lead us to firmly establish the existence of a third phase in which a room was built above the *aula*. However, in this case, the dating is also somewhat disparate. There are two OSL mortar dates that we consider to be in error, AUE110 gives a date of 3267–2091 BC and AUE017 of 417–127 BC. The remaining ones range between 764 and 1475 AD, with the tenth– twelfth centuries being the coinciding dates. On the other hand, in the case of the bricks used in this vault, the dates range between 336 and 919 years, coinciding in the interval 648–739 AD, which leads us to wonder if they are not reused bricks from another building or from the lower structure.

We also link to this time a series of replacement mortars documented in the vault of the *aula* over earlier mortars and structures, also dating from around the late tenth to first half of twelfth centuries.

The Baroque phase, which should perhaps be associated with the time when the current Parish Church was built in 1750 and a ceiling was placed over the remains of the *aula*, now filled with rubble from the upper floor. It corresponds to a mortar dated 1646–1799 AD.

Conclusions: new perspectives

The results of the study of mortars and bricks from the Santalla de Bóveda Monument have allowed us to obtain an absolute chronology for the entire sequence previously identified, which leads us to open up new hypotheses about the interpretation of the monument and to raise a series of methodological reflections.

[11] A mosaic inscription (later destroyed) indicated the name of the church and 578 as the year of the completion. https://universes.art/es/art-destinations/jordania/madaba/church-of-the-apostles (last search 28/11/2021).

[12] https://eldiwan2010.blogspot.com/2018/07/jordania-madaba-la-ciudad-de-los.html (January 2022 consultation).

Fig. 8 Lozenges in mural paintings in different times and buildings: **a** Villa di Arianna, Stabiae (Italy) (fragment in the MANN), 54–69 AD (photography by Rosa Benavides); **b** Tepidarium of Qusayr'Amra, Jordan, 712–715 AD (Almagro et al. 1975); **c** Salle delle Oche in the Palace of Bonifacio VIII, Anagni (Italy), 4–1303 AD (www.palazzobonifacioviii.it, January 2022 consultation); and **d** Santalla de Bóveda, South wall, seventh century AD (photography by Rosa Benavides)

Fig. 9 Similar parallels in age built in mosaic. **a** Vault of the chapel of Sant'Andrea in the Archbishop Palace of Ravenna (Italy), 494–519 AD (https://www.ravennamosaici.it/cappella-di-santandrea-e-museo-arcivescovile/, January 2022 consultation). **b** Floor mosaic of Martyrs or Al Khadir Church (https://eldiwan2010.blogspot.com/2018/07/jordania-madaba-la-ciudad-de-los.html, January 2022 consultation). **c** Floor mosaic of Apostles Church (https://universes.art/es/art-destinations/jordania/madaba/church-of-the-apostles, January 2022 consultation). Both of them in Madaba (Jordan) sixth century

In terms of dating, this is a complex that was constantly reused until it was filled in the second half of the eighteenth century:

- First Late Roman building: second two-thirds of the fourth century AD
- Alterations to the *aula* and vault paintings: first half of seventh century AD
- Construction of the first floor and occasional repairs: from the late tenth to first half of twelfth century
- Occasional alterations and clogging of the monument: eighteenth century

These results are also supported by the petrographic characteristics of the mortars, which are different in each phase.

These four periods are coincident with important events of change in *Gallaecia*, and subsequently in Galicia, some of which are currently in the process of revision due to new archaeological findings, making it possible to reinterpret the transition from the Late Roman period to the Early Medieval Ages. We refer to (1) the process of ruralisation in the Late Roman period and the generation of new types of settlements that will transform the Galician rural landscape from the second half of the fourth century; (2) the moment of transformation that takes place at the end of the Suebi period and the beginning of the Visigothic period, at the end of the sixth and beginning of the seventh century, which happens to be much more complex than previously thought; (3) the great impact of the proliferation of the construction of churches in rural environments that took place in the tenth century; and, finally, (4) the transformation of these churches in the eighteenth century, a time when demographic changes and the spread of the Baroque style from urban centres led either to the abandonment of the previous temples or to a major remodelling that masked the remains of the first churches in Galicia. This opens up new working hypotheses that will have to be tested by extending the study of the Santalla de Bóveda Monument to the territory in which it was implanted and which it surely contributed to structure with other elements of which it would form part.

Finally, the work carried out, together with previous experiences, will allow to establish a working protocol which can be summarised as follows, although further specific work on this area will have to be developed: (1) Samples should always be collected after a previous archaeological study that allows us to identify the stratigraphic sequence or either original mortars. (2) In order to obtain accurate and reliable results, it is desirable to perform combined OSL and ^{14}C analysis on carbonates of lime mortars. But these techniques are destructive, so we have limited ourselves to collecting samples from the base of the paintings and the interior of the vault. If the results of Phase I are analysed, the mortars studied by OSL, the bricks by TL and OSL and the charcoal by ^{14}C, show consistent dating, although the carbonates dated by ^{14}C show inconclusive results. In Phase II, however, the results are consistent between ^{14}C and OSL, except for one sample which corresponds to a replacement mortar.

Author contributions Rebeca Blanco-Rotea wrote the main manuscript text. Jorge Sanjurjo-Sánchez wrote the sections on methods and results of mortars datings and David M. Freire-Lista on methods and results of petrographic characterisation of mortars. Rosa Benavides wrote the parts of the paintings. Rebeca Blanco-Rotea prepared figures 1-3 and 6, and with Jorge Sanjurjo-Sánchez prepared table 1; Jorge Sanjurjo-Sánchez prepared table 2-3 and figure 4; David M. Freire-Lista prepared figure 5, and with Rosa Benavides prepared figures 8-9; Rosa Benavides prepared figures 7. All authors reviewed the manuscript.

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Declarations

Competing interests The authors declare no competing interests.

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