JOURNAL OF QUATERNARY SCIENCE (2022) 1–14 ISSN 0267-8179. DOI: 10.1002/jqs.3473

JQS Journal of Quaternary Science QRA

A step back to move forward: a geological re-evaluation of the El Castillo Cave Middle Palaeolithic lithostratigraphic units (Cantabria, northern Iberia)

DAVID M. MARTÍN-PEREA,[1] **JOSÉ-MANUEL MAÍLLO-FERNÁNDEZ,**[1,2]* **JUAN MARÍN,**[2,3,4] **XABIER ARROYO**[5] **and RAQUEL ASIAÍN**[6,7]

[1]Institute of Evolution in Africa (IDEA) University of Alcalá, Madrid, Spain
[2]Department of Prehistory and Archaeology, Universidad Nacional de Educación a Distancia, UNED, Madrid, Spain
[3]Institut Català de Paleoecologia Humana i Evolució Social – IPHES, Tarragona, Spain
[4]Histoire Naturelle de l'Homme Préhistorique – HNHP, Muséum National d'Histoire Naturelle, Paris, France
[5]Unidad de Técnicas Geológicas, CAI de Ciencias de la Tierra y Arqueología, Complutense University of Madrid, Madrid, Spain
[6]Department of Painting and Conservation-Restoration, Faculty of Arts, Complutense University of Madrid, Madrid, Spain
[7]Centro Mixto, UCM-ISCIII de Evolución y Comportamiento Humanos, Madrid, Spain

Received 3 May 2022; Revised 28 July 2022; Accepted 7 August 2022

ABSTRACT: El Castillo Cave is one of the most important sites for understanding the Middle and Upper Palaeolithic in Europe. Despite its importance, the absence of a widely used stratigraphic section with detailed lithostratigraphic descriptions and correlations between the different geological and archaeological interpretations has led to confusion in the correct identification of lithostratigraphic units in the lowermost, Middle Palaeolithic sequence. This study establishes a new lithostratigraphic framework for the site, which can be accurately correlated to previous geological and archaeological studies and generates a solid working basis for framing the Mousterian of El Castillo Cave in the Cantabrian region and southwestern Europe. The geological re-evaluation of Unit XX ('Mousterian Alpha') has expanded its chronology, now ranging from 49 130–43 260 cal BP to 70 400 ± 9600 BP. Unit XXII ('Mousterian Bet') would consequently yield an age older than 70 400 ± 9600 BP and younger than the underlying speleothem (Unit XXIIIb), dated to 89 000 +11 000/-10 000 BP. © 2022 The Authors *Journal of Quaternary Science* Published by John Wiley & Sons Ltd.

KEYWORDS: Cantabria; Early Middle Palaeolithic; Middle Pleistocene; Mousterian; Upper Pleistocene

Introduction

El Castillo Cave is one of the most important sites for understanding the Middle and Upper Palaeolithic in Europe, yielding 25 lithostratigraphic units with archaeological assemblages ranging from the Early Middle Palaeolithic to the Azilian (Cabrera Valdés, 1984; Cabrera Valdés *et al.*, 2006) and an assortment of rock art (Alcalde del Río, 1906; Valladas *et al.*, 1992; Pike *et al.*, 2012). The cave is located in Puente Viesgo village in Cantabria (northern Iberia; Fig. 1).

The site was discovered in 1903 by Hermilio Alcalde del Río (Alcalde del Río, 1906) and was excavated by him alongside Hugo Obermaier and Henri Breuil between 1910 and 1914 (Breuil and Obermaier, 1912; 1913; 1914; Obermaier, 1924). After years scattered throughout several institutions, nowadays the majority of the archaeological material is hosted at the National Archaeological Museum (MAN) and at the Prehistory and Archaeology Museum of Cantabria (MUPAC). Despite the undoubted importance of these assemblages, the archaeological materials were studied decades later (Cabrera Valdés, 1979, 1984; Castaños, 2018).

The stratigraphy of the site, initially described by Breuil and Obermaier (Obermaier, 1914; 1924), was expanded by Cabrera Valdés (1984) using Obermaier's excavation notes, and a numerical unit designation (1 being the youngest to 25 being the oldest) for the site was introduced. Archaeological and palaeontological remains hosted in the museums are organised and separated according to these designations.

Independently, Butzer (1981) carried out detailed sedimentological analyses of the El Castillo sequence, and similarly described and numerically ordered the stratigraphic levels (1 being the oldest unit, 19 being the youngest). Although Butzer (1981) produced a stratigraphic section of the Castillo sequence, it has not been used in archaeological studies because not all lithostratigraphic units could be precisely correlated to Obermaier's units and archaeological levels (Cabrera Valdés, 1984).

Excavations at El Castillo were resumed, led by Victoria Cabrera Valdés and Federico Bernaldo de Quirós, from 1980 to 2017. Cabrera Valdés (1984), with careful inspection of Obermaier's field notes, was able to confidently relate her Unit 18 to Obermaier's 'Aurignacian Delta', with the visual aid of several large boulders and its stratigraphic position between two sterile units (Units 17 and 19; Cabrera Valdés and Bernaldo de Quirós, 1996). Since then, studies have been centred around the Middle–Upper Palaeolithic transition and the Mousterian (Cabrera Valdés and Bischoff, 1989; Cabrera Valdés *et al.*, 1996; 2001; 2006; Bernaldo de Quirós and Maíllo-Fernández, 2009; Pike-Tay *et al.*, 1999; Rink *et al.*, 1997; Garralda *et al.*, 2019; Wood *et al.*, 2018, Jones *et al.*,

*Correspondence José-Manuel Maíllo-Fernández, as above.
Email: jlmaillo@geo.uned.es

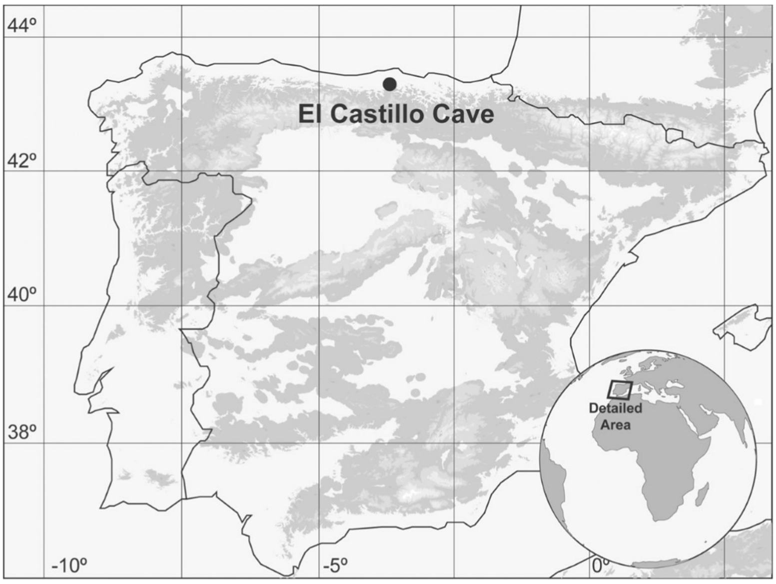


Figure 1. Map of the Iberian Peninsula showing the location of El Castillo Cave.

2019, Luret *et al.*, 2020), with less attention paid to the lowermost, Middle Palaeolithic sequence.

Despite the success of Cabrera Valdés and Bernaldo de Quirós (1996) in correctly identifying Unit 18, the absence of a widely used stratigraphic section, with detailed descriptions of levels and correlations between the different geological and archaeological interpretations, has led to some confusion in the correct identification of stratigraphic units in the lowermost Castillo sequence, as will be discussed below. Assigning archaeological assemblages to incorrect lithostratigraphic units

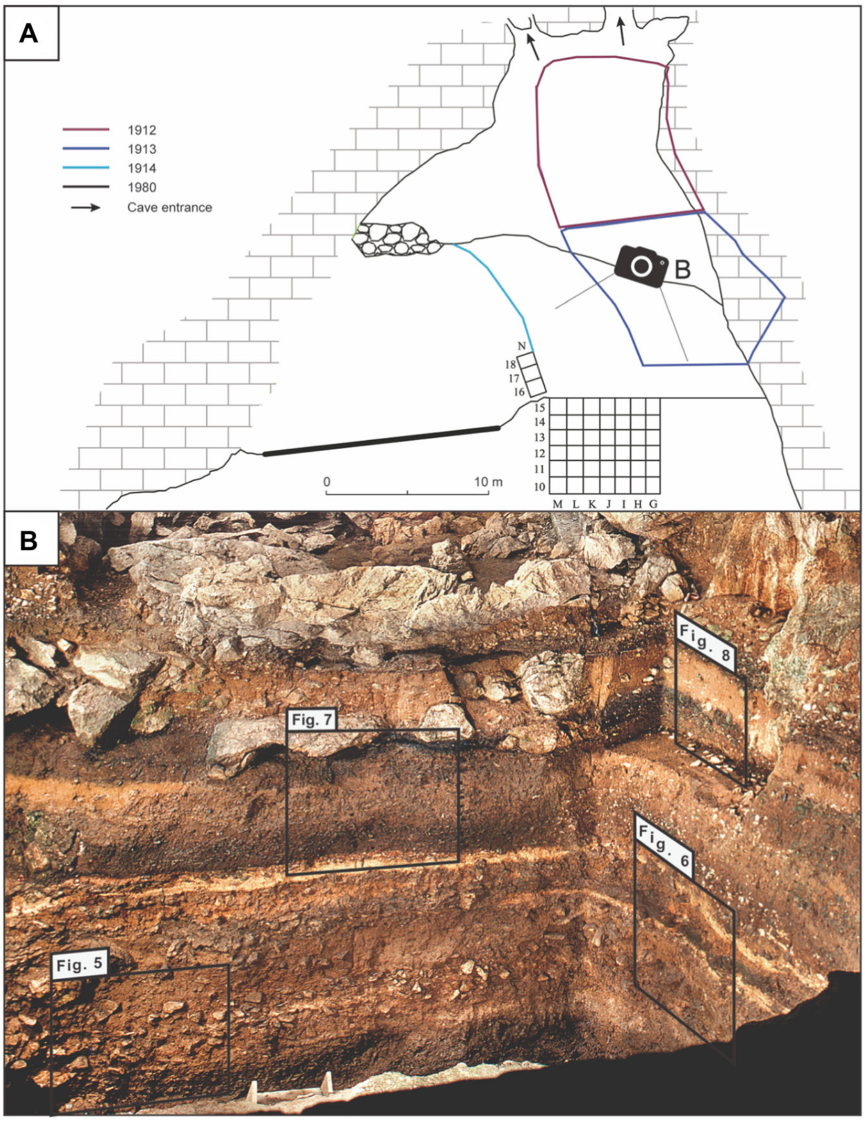


Figure 2. (A) Plan of El Castillo Cave, showing previous excavation areas, cave entrances and cave/rockshelter limits. (B) Photograph of exposed profiles of the lowermost section of the El Castillo Cave sequence (photograph taken by Pedro Saura), with insets to other photographs and profiles in this study. [Color figure can be viewed at wileyonlinelibrary.com]

can not only foster an incorrect chronology, but can also be incorrectly related to certain sedimentary environments or processes which can deem the assemblage as not maintaining its in-locus properties. Additionally, if new materials are retrieved in recent excavations from incorrectly identified lithostratigraphic units and added to the historical collection (organised and separated according to Obermaier's levels), the resulting association would be an amalgamation of archaeological and palaeontological material belonging to completely different assemblages.

For this reason, the main objectives of this study are: 1) to produce a detailed stratigraphic section of the lowermost, Middle Palaeolithic sequence; 2) describe exhaustively each level, in order to facilitate their correct identification in future studies; 3) using this geological information, correlate the different archaeological and geological levels historically used in the Middle Palaeolithic sequence; and 4) to create a lithostratigraphic framework, taking into account all these data, to provide a reference for future archaeological, palaeontological and geological studies carried out in this important Palaeolithic site.

Materials and methods

The southern and western profiles, from the base of Cabrera Valdés (1984) Unit 18, were exposed and freshly scraped (Fig. 2). Lithostratigraphic units were described, measured, logged using scaled drawings and photographed. Level limits were measured and recorded with a Total Station. For clarity in distinguishing Cabrera Valdés (1984) units (using Arabic numerals) with the units here described, Roman numerals will be used.

Representative samples of each unit were collected for granulometrical analyses from freshly scraped exposures. Sieves sized -1–4 φ were used for measuring grain size distribution. Sediment types have been classified based on particle size distributions, following Blott and Pye (2012).

For detailed mineralogical analyses of the units, exposures were freshly scraped and ~5 cm-thick unaltered samples were collected. Fifteen grams of each sample were homogenised by quartering and ground manually with an agate mortar until they could be sieved completely through a 53 μm metallic mesh. Bulk mineralogy powder X-ray diffraction (XRD) spectra were produced using a Philipps Analytical PW 1752 Cu Kα radiation X-ray diffractometer (graphite monochromator radiation Kα1 = 1540.6 nm). Diffraction spectra were recorded continuously at 2θ angles from 2° to 68° with 0.02 stepping intervals and 1 s per step. A semi-quantitative analysis was carried out with EVA software, following Chung (1975).

Results and discussion

El Castillo Cave stratigraphic section and profiles

The exposed southern and western profiles (Fig. 2) below Cabrera Valdés (1984) Unit 18 revealed a ~3.6 m sequence, containing a total of 16 lithostratigraphic levels. A detailed stratigraphic section of this lowermost, Middle Palaeolithic sequence (Units XXV to XIX) is shown in Fig. 3. Detailed stratigraphic profiles are shown in Figs 4–7 and discussed below.

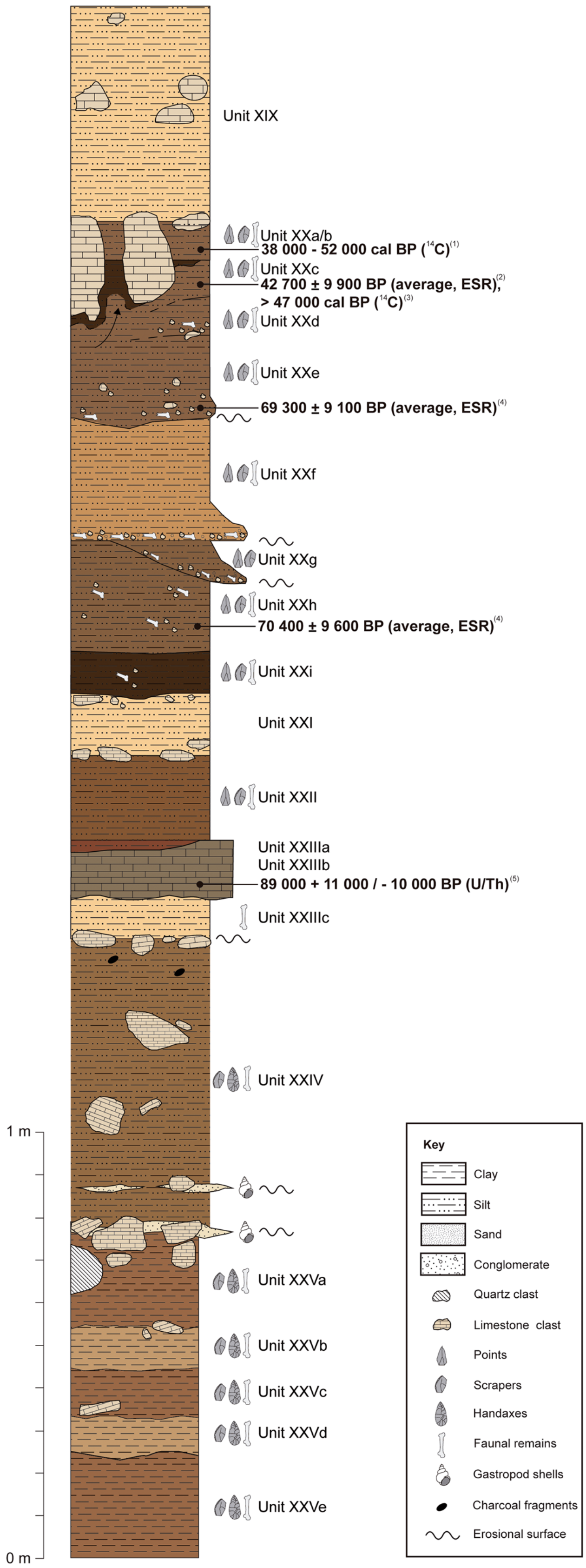


Figure 3. Detailed stratigraphic section of the lowermost, Middle Palaeolithic, sequence of El Castillo Cave. (1) Cabrera *et al.* (1996). (2) Liberda *et al.* (2010). (3) Wood *et al.* (2018). (4) Rink *et al.* (1997). (5) Bischoff *et al.* (1992). [Color figure can be viewed at wileyonlinelibrary.com]

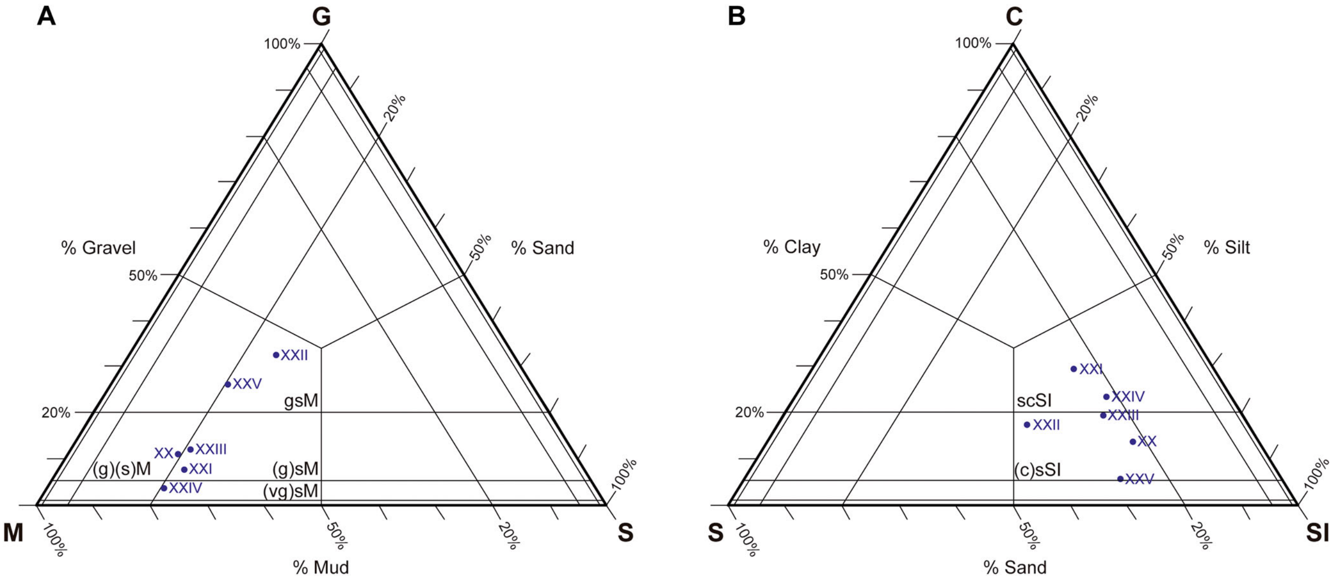


Figure 4. El Castillo cave stratigraphical units granulometries projected on ternary diagrams according to Blott and Pye (2012). (A) Granulometries projected on a gravel-sand-mud trigon. (B) Granulometries projected on a clay-silt-sand trigon. [Color figure can be viewed at wileyonlinelibrary.com]

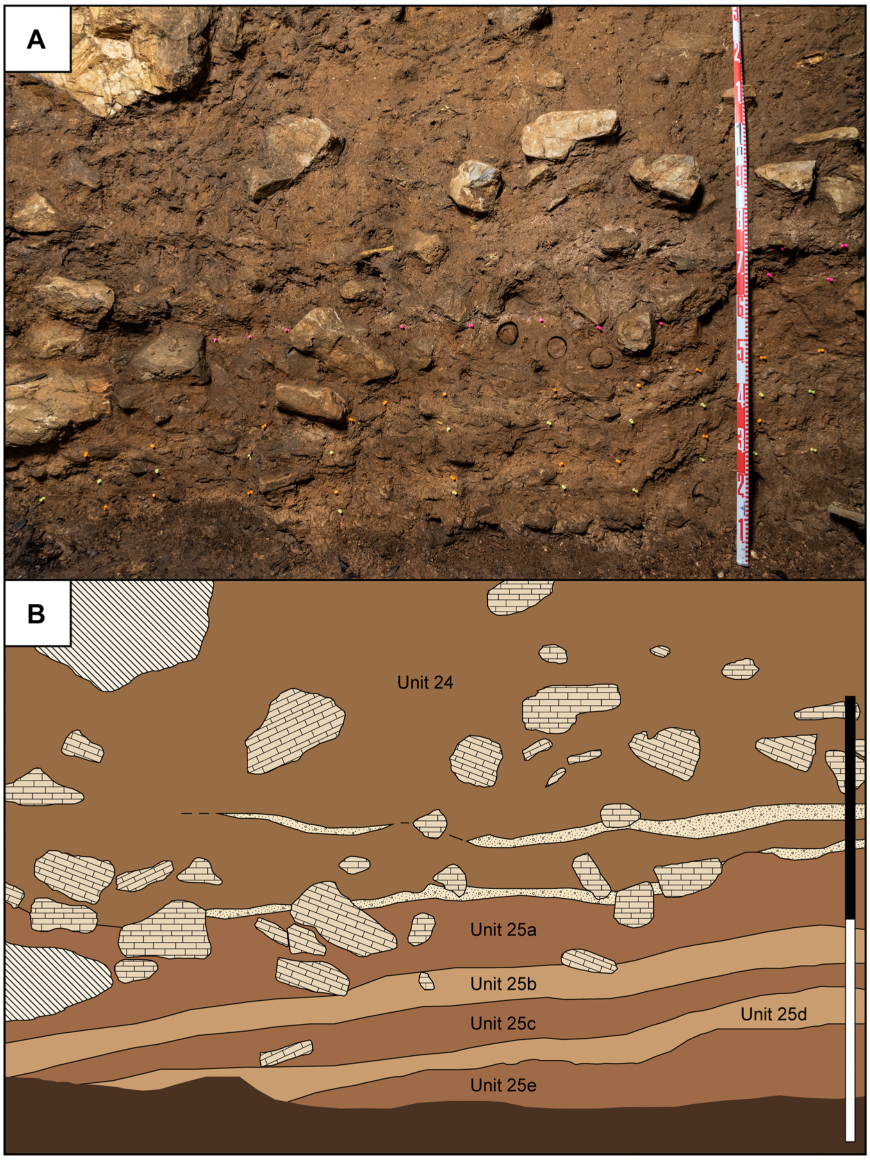


Figure 5. El Castillo cave photograph 1 (A) and profile (B), showing Units XXIV and XXV. [Color figure can be viewed at wileyonlinelibrary.com]

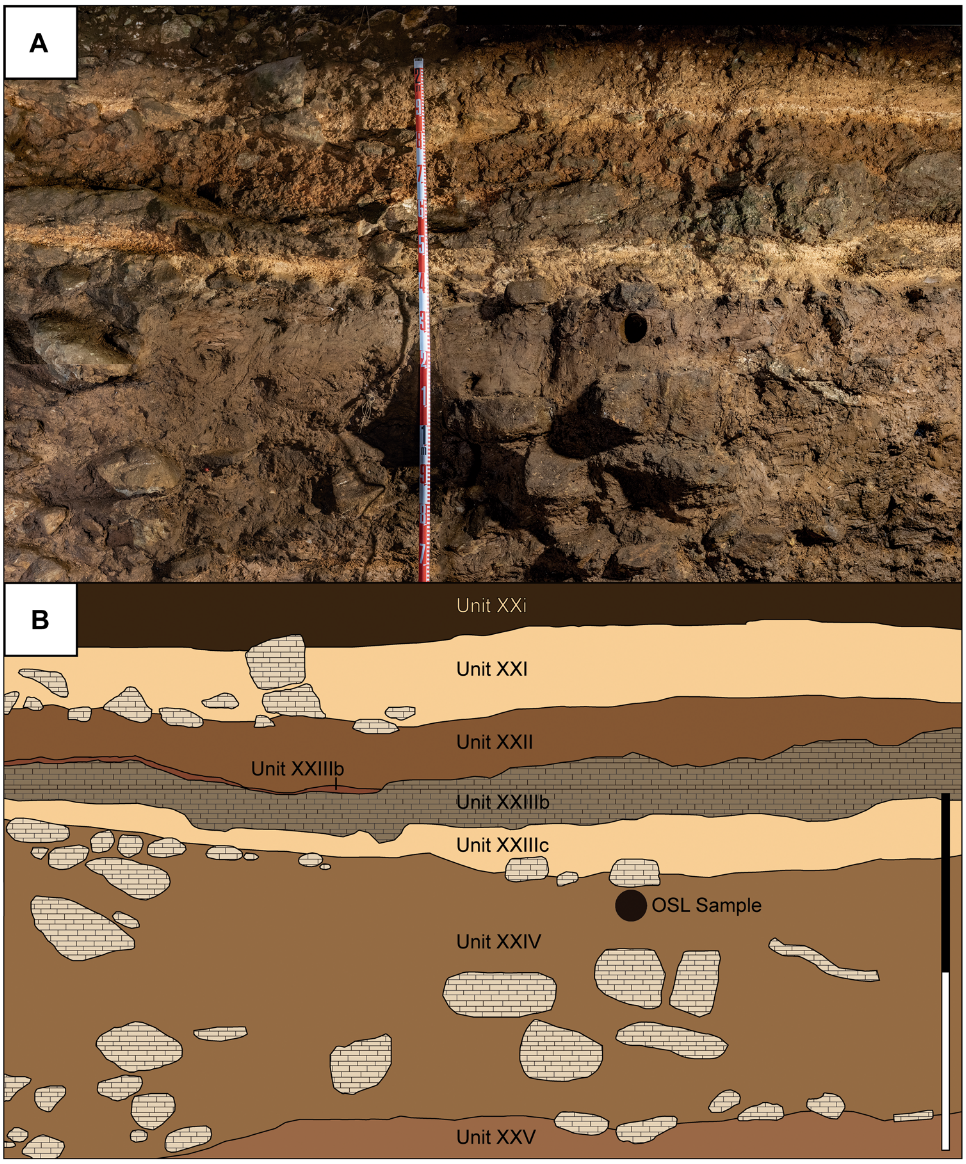


Figure 6. El Castillo Cave photograph 2 (A) and profile (B), showing Units XXi, XXI, XXII, XXIII, XXIV and XXV. [Color figure can be viewed at wileyonlinelibrary.com]

El Castillo Cave stratigraphic units: descriptions, interpretations and correlations

Unit XXV: The lowermost level of the sequence comprises massive, slightly clayey, sandy silts (Table 1; Fig. 8), with alternating ~5–10 cm-thick beige (light beige/pinkish white 7.5YR 8/2 to pinkish grey 7.5YR 7/2) and brown (10YR 3/2) levels (Figs 3 and 4). Two <2 cm-thick, ~2 m-wide, very dark grey (10YR 3/1) to very dark greyish brown (10YR 3/2) levels can be observed towards the right of the profile shown in Fig. 4. Mineralogically, quartz (41–53%) and clay minerals (21–27%) are most abundant, followed by significant quantities of calcite, plagioclase and K feldspar (Table 2). These deposits are interpreted as backswamp deposits (Gillieson, 1996; Bosch and White, 2018), deposited during, at least, five very low-energy events (Units XXVa–e; Fig. 4). These levels, most likely parallel to the underlying depositional surface (yet to be uncovered), with thicknesses ranging from 50 to 200 mm, show no internal sedimentary structures, suggesting that they were decanted from a homogeneous suspension that was steadily renewed with very low velocities (Ford and Williams, 2013). Towards the top of Unit XXVa, the abundance of limestone blocks, interpreted as *éboulis*, could reflect a major cold episode (Courty, 1989; Laville *et al.*, 1980; Macphail and Goldberg, 1999).

Unit XXV contains both archaeological and palaeontological remains. Unit XXV, originally interpreted as an ‘atypical implements assemblage’ (Obermaier, 1924; Cabrera, 1984), hosts an Early Middle Palaeolithic industry, composed of discoid cores, single platform cores and large cutting tools, especially type 0 cleavers and some bifaces. Cave bear (*Ursus spelaeus*), red deer (*Cervus elaphus*) and large bovid (*Bos/Bison*) remains are abundant in this unit (Castaños, 2018).

This unit is confidently correlated to Butzer’s (1981) Levels 1–3 (Table 3, Figs 9 and 10), which he describes as well-stratified, brown (7.5YR), pale brown (10YR) and light yellowish brown (10YR) marl and silt loam deposits. Additionally, Level XXV can be correlated to Obermaier’s level ‘a) Clay’ (Obermaier, 1924) and Unit 26, described as clays ‘underneath the Acheulean’ (Cabrera Valdés, 1984; Fig. 10).

Unit XXIV: Units XXV is overlain disconformably by Unit XXIV (Figs 3, 4 and 5). The lowermost ~5 cm are composed of a gastropod shell conglomerate with a massive, sandy clayey silt matrix (Table 1; Fig. 8). The silt, yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/4), extends over the rest of the level (~70 cm). Quartz (37–50%) and clay minerals (22–34%) are the most abundant minerals, followed by significant quantities of calcite, aragonite, apatite, plagioclase

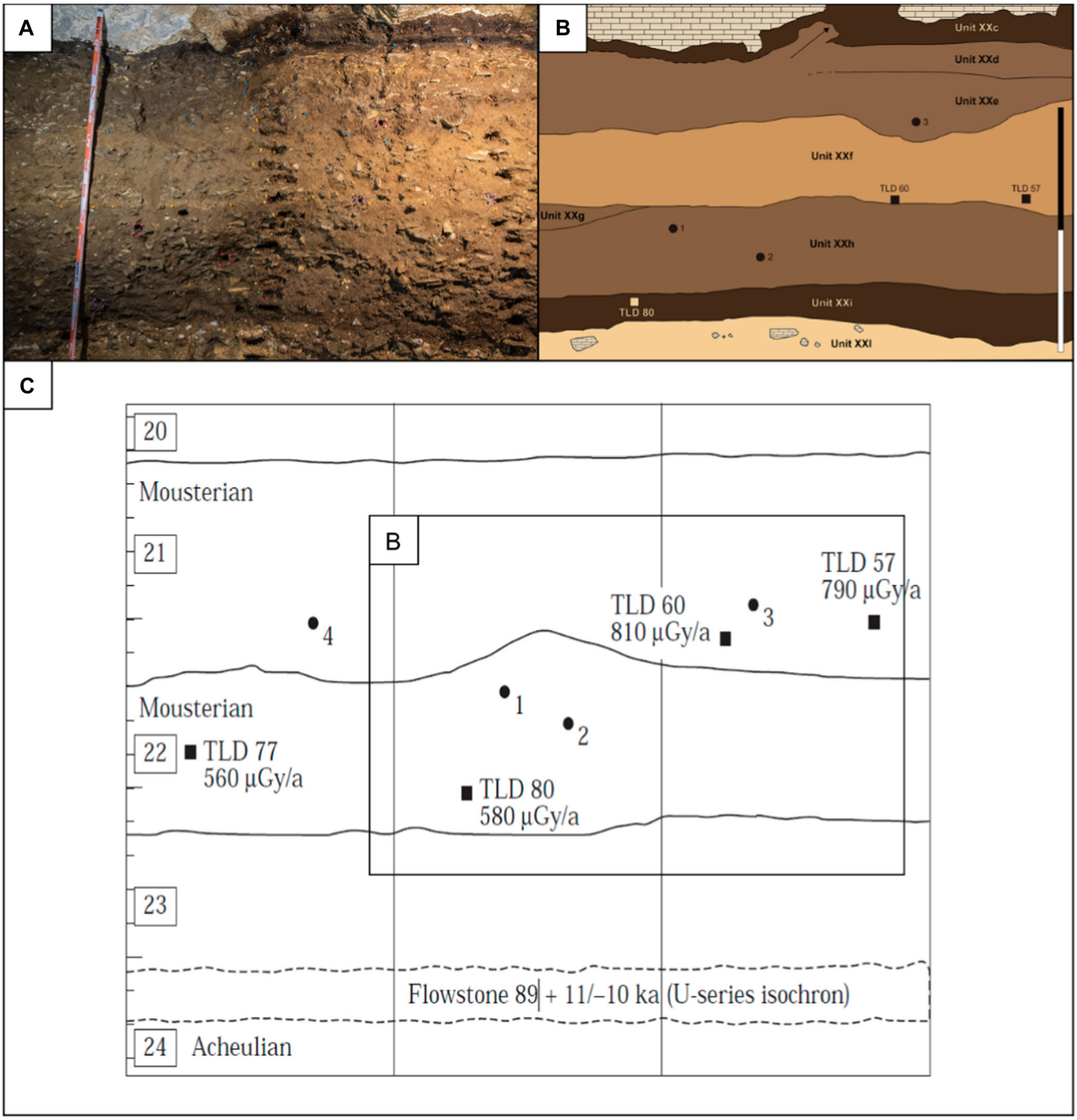


Figure 7. El Castillo Cave photograph 3 (A) and profile (B), showing Units XXc, XXd, XXe, XXf, XXg, XXh, XXi and XXI. (C) ESR sample and thermoluminescence locations (taken fron Rink et al., 1997), with inset to Figure 7B. [Color figure can be viewed at wileyonlinelibrary.com]

and K feldspar (Table 2). Limestone blocks of 5–10 cm are abundant in the lowermost 20–30 cm of the level, with some scarce 15–20 cm blocks, all interpreted as *éboulis*. Towards the left of the profile, two large quartz blocks (70 × 40 cm and 60 × 30 cm) are found. Two more levels of the shell conglomerate can be observed in the lower half of the level, pinching out laterally.

Abundant faunal remains are found embedded in this unit, including red deer (*Cervus elaphus*), large bovids (*Bos*/*Bison*) and cave bear (*Ursus spelaeus*; Castaños, 2018). Archaeological remains found in Unit XXIV correspond to the Early Middle Palaeolithic, and can be found in two archaeological levels. The uppermost section of the unit (30–40 cm), which is more clayey and where charcoal fragments are common, contains the upper archaeological level, which is characterised by discoid cores and Levallois type blanks with type 0 cleavers and bifaces (Solano-Megías, 2016), and can be correlated to Obermaier (1924) and Cabrera (1984) 'Acheulean' level. The lower section of Unit XXIV contains an archaeological assemblage similar to the upper level, but with a lower abundance of Levallois types (Bilbao-Malavé, 2016).

The massive silts comprising Unit XXIV are interpreted as backswamp facies (Bosch and White, 2018), which include three more energetic events which deposited the gastropod shell conglomerate levels. As in Unit XXVa, the presence of abundant *éboulis* is indicative of cold conditions during the deposition of the level (Courty, 1989; Laville *et al.*, 1980; Macphail and Goldberg, 1999).

Unit XXIV can be confidently related to Butzer's (1981) Level 4 (Table 3; Figs. 9 and 10), described as an exceptionally

Table 1. Granulometrical data for studied samples from El Castillo Cave.

		Unit XXV			Unit XXIV			Unit XXIII			Unit XXII			Unit XXI			Unit XX		
		%	Acc. %	Lower limit (μm)	%	Acc. %	Lower limit (μm)	%	Acc. %	Lower limit (μm)	%	Acc. %	Lower limit (μm)	%	Acc. %	lower limit (μm)	%	Acc. %	Lower limit (μm)
Fine clay	Clay	0.00	0.00	0.10	4.70	4.70	0.10	1.67	1.67	0.10	1.10	1.10	0.10	2.70	2.70	0.10	1.27	1.27	0.10
		0.00	0.00	0.15	2.34	7.04	0.15	1.04	2.71	0.15	0.69	1.79	0.15	1.46	4.16	0.15	0.56	1.83	0.15
		0.00	0.00	0.17	1.07	8.12	0.17	0.65	3.36	0.17	0.44	2.23	0.17	0.82	4.99	0.17	0.00	1.83	0.17
		0.00	0.00	0.20	0.66	8.78	0.20	0.51	3.87	0.20	0.34	2.56	0.20	0.66	5.64	0.20	0.00	1.83	0.20
Medium clay		0.00	0.00	0.24	0.54	9.31	0.24	0.48	4.35	0.24	0.31	2.87	0.24	0.67	6.31	0.24	0.00	1.83	0.24
		0.00	0.00	0.29	0.51	9.82	0.29	0.46	4.81	0.29	0.30	3.17	0.29	0.74	7.05	0.29	0.00	1.83	0.29
		0.00	0.00	0.34	0.54	10.36	0.34	0.46	5.27	0.34	0.31	3.48	0.34	0.82	7.87	0.34	0.26	2.10	0.34
		0.07	0.07	0.41	0.59	10.95	0.41	0.49	5.75	0.41	0.35	3.83	0.41	0.95	8.82	0.41	0.31	2.40	0.41
Coarse clay		0.25	0.33	0.49	0.72	11.67	0.49	0.57	6.33	0.49	0.42	4.25	0.49	1.13	9.95	0.49	0.37	2.78	0.49
		0.30	0.63	0.58	0.90	12.57	0.58	0.74	7.07	0.58	0.55	4.80	0.58	1.45	11.39	0.58	0.51	3.29	0.58
		0.38	1.01	0.69	1.20	13.77	0.69	1.02	8.09	0.69	0.77	5.57	0.69	1.97	13.36	0.69	0.76	4.05	0.69
		0.47	1.48	0.82	1.55	15.32	0.82	1.38	9.48	0.82	1.04	6.62	0.82	2.64	16.00	0.82	1.12	5.17	0.82
Very coarse clay		0.54	2.02	0.97	1.79	17.11	0.97	1.70	11.18	0.97	1.26	7.88	0.97	3.08	19.08	0.97	1.49	6.66	0.97
		0.60	2.62	1.16	1.81	18.92	1.16	1.84	13.02	1.16	1.31	9.19	1.16	3.06	22.14	1.16	1.71	8.37	1.16
		0.64	3.26	1.38	1.70	20.62	1.38	1.84	14.86	1.38	1.23	10.42	1.38	2.63	24.76	1.38	1.76	10.13	1.38
		0.70	3.96	1.64	1.64	22.26	1.64	1.86	16.72	1.64	1.16	11.58	1.64	2.25	27.02	1.64	1.80	11.93	1.64
Very fine silt	Silt	0.79	4.75	1.95	1.76	24.02	1.95	2.02	18.74	1.95	1.17	12.74	1.95	2.10	29.12	1.95	1.95	13.88	1.95
		0.93	5.68	2.31	2.04	26.05	2.31	2.30	21.04	2.31	1.27	14.01	2.31	2.16	31.28	2.31	2.21	16.09	2.31
		1.07	6.75	2.75	2.37	28.42	2.75	2.57	23.60	2.75	1.39	15.40	2.75	2.30	33.58	2.75	2.50	18.59	2.75
		1.22	7.97	3.27	2.62	31.04	3.27	2.74	26.34	3.27	1.48	16.88	3.27	2.37	35.95	3.27	2.70	21.29	3.27
Fine silt		1.36	9.32	3.89	2.79	33.83	3.89	2.83	29.17	3.89	1.52	18.41	3.89	2.36	38.30	3.89	2.84	24.12	3.89
		1.51	10.83	4.63	2.92	36.75	4.63	2.89	32.06	4.63	1.55	19.96	4.63	2.33	40.63	4.63	2.96	27.09	4.63
		1.65	12.48	5.50	3.03	39.78	5.50	2.92	34.98	5.50	1.57	21.53	5.50	2.31	42.95	5.50	3.11	30.20	5.50
		1.77	14.25	6.54	3.04	42.81	6.54	2.92	37.90	6.54	1.56	23.10	6.54	2.26	45.21	6.54	3.18	33.37	6.54
Medium silt		1.84	16.09	7.78	2.91	45.73	7.78	2.76	40.66	7.78	1.50	24.60	7.78	2.16	47.37	7.78	3.12	36.49	7.78
		1.92	18.01	9.25	2.71	48.44	9.25	2.52	43.19	9.25	1.43	26.03	9.25	2.04	49.41	9.25	2.99	39.48	9.25
		2.10	20.11	11.00	2.55	51.00	11.00	2.35	45.53	11.00	1.38	27.41	11.00	1.98	51.39	11.00	2.93	42.41	11.00
		2.45	22.55	13.08	2.53	53.52	13.08	2.28	47.81	13.08	1.41	28.83	13.08	1.99	53.38	13.08	3.02	45.43	13.08
Coarse silt		2.96	25.51	15.56	2.62	56.14	15.56	2.31	50.12	15.56	1.49	30.32	15.56	2.05	55.43	15.56	3.23	48.65	15.56
		3.51	29.03	18.50	2.73	58.88	18.50	2.38	52.50	18.50	1.57	31.89	18.50	2.11	57.55	18.50	3.39	52.04	18.50
		3.97	32.99	22.00	2.80	61.68	22.00	2.45	54.95	22.00	1.63	33.51	22.00	2.14	59.68	22.00	3.39	55.43	22.00
		4.19	37.19	26.16	2.81	64.48	26.16	2.47	57.42	26.16	1.63	35.14	26.16	2.12	61.80	26.16	3.27	58.70	26.16
Very coarse silt		4.22	41.41	31.11	2.80	67.28	31.11	2.48	59.90	31.11	1.61	36.75	31.11	2.10	63.91	31.11	3.06	61.76	31.11
		4.17	45.58	37.00	2.78	70.06	37.00	2.44	62.34	37.00	1.60	38.35	37.00	2.09	66.00	37.00	2.83	64.59	37.00
		3.97	49.54	44.00	2.75	72.82	44.00	2.35	64.69	44.00	1.59	39.94	44.00	2.11	68.11	44.00	2.62	67.21	44.00
		3.60	53.14	52.33	2.64	75.46	52.33	2.24	66.93	52.33	1.60	41.54	52.33	2.10	70.22	52.33	2.41	69.63	52.33
Very fine sand	Sand	3.17	56.31	62.23	2.47	77.93	62.23	2.14	69.07	62.23	1.61	43.14	62.23	2.07	72.28	62.23	2.22	71.84	62.23
		2.69	59.00	74.00	2.27	80.20	74.00	2.07	71.14	74.00	1.60	44.75	74.00	2.02	74.30	74.00	2.01	73.86	74.00
		2.28	61.28	88.00	2.12	82.32	88.00	2.02	73.16	88.00	1.56	46.31	88.00	1.94	76.24	88.00	1.81	75.67	88.00
		1.92	63.20	104.70	2.02	84.34	104.70	1.95	75.11	104.70	1.45	47.76	104.70	1.81	78.04	104.70	1.60	77.26	104.70
Fine sand		1.68	64.88	124.50	1.97	86.31	124.50	1.89	77.00	124.50	1.32	49.07	124.50	1.62	79.66	124.50	1.41	78.67	124.50
		1.52	66.40	148.00	1.98	88.29	148.00	1.86	78.85	148.00	1.22	50.30	148.00	1.40	81.07	148.00	1.30	79.97	148.00

(Continued)

Table 1. (*Continued*)

	Unit XXV			Unit XXIV			Unit XXIII			Unit XXII			Unit XXI			Unit XX		
	%	Acc. %	Lower limit (µm)	%	Acc. %	Lower limit (µm)	%	Acc. %	Lower limit (µm)	%	Acc. %	Lower limit (µm)	%	Acc. %	lower limit (µm)	%	Acc. %	Lower limit (µm)
	1.45	67.85	176.00	2.05	90.33	176.00	1.87	80.73	176.00	1.23	51.53	176.00	1.22	82.28	176.00	1.33	81.30	176.00
	1.42	69.27	209.30	2.05	92.38	209.30	1.86	82.58	209.30	1.40	52.93	209.30	1.10	83.39	209.30	1.53	82.83	209.30
Medium sand	1.43	70.70	248.90	1.89	94.26	248.90	1.80	84.38	248.90	1.91	54.84	248.90	1.12	84.51	248.90	2.12	84.94	248.90
	0.00	70.70	296.00	0.00	94.26	296.00	0.00	84.38	296.00	0.47	55.31	296.00	1.31	85.82	296.00	0.00	84.94	296.00
	0.00	70.70	352.00	0.00	94.26	352.00	0.00	84.38	352.00	0.54	55.84	352.00	1.81	87.63	352.00	0.00	84.94	352.00
	0.00	70.70	418.60	0.00	94.26	418.60	0.00	84.38	418.60	0.00	55.84	418.60	0.00	87.63	418.60	0.00	84.94	418.60
Coarse sand	0.00	70.70	497.80	0.00	94.26	497.80	0.00	84.38	497.80	0.00	55.84	497.80	0.00	87.63	497.80	0.00	84.94	497.80
	0.00	70.70	592.00	0.00	94.26	592.00	0.00	84.38	592.00	0.00	55.84	592.00	0.00	87.63	592.00	0.00	84.94	592.00
	0.79	71.49	700.00	0.65	94.91	700.00	1.04	85.42	700.00	3.32	59.16	700.00	1.50	89.13	700.00	1.27	86.22	700.00
Very coarse sand	2.62	74.10	1000	1.70	96.61	1000	2.98	88.41	1000	8.53	67.69	1000	3.72	92.85	1000	3.22	89.43	1000
Gravel	5.01	79.11	2000	2.35	98.95	2000	5.19	93.60	2000	7.54	75.23	2000	4.41	97.26	2000	2.84	92.27	2000
Gravel	20.89	100.00	4000	1.05	100.00	4000	6.40	100.00	4000	24.77	100.00	4000	2.74	100.00	4000	7.73	100.00	4000

poorly sorted brown (7.5YR) loam with coarse- to block-grade rubble and archaic bifaces. Unit XXIV can also be correlated to Obermaier's level 'b) Acheulean' (Obermaier, 1924) and Units 24 and 25, described as brown silts and clays with charcoal fragments (Cabrera Valdés, 1984; Fig. 10).

Unit XXIII: Unit XXIII is subdivided into three units (Figs 3 and 5). Unit XXIIIc is a ~10 cm-thick unit of a dark yellowish brown (10YR 4/4) slightly clayey sandy silt (Table 1; Fig. 8) with abundant fossil remains and some scarce limestone blocks, with a channel-like incision into Unit XXIV in the centre of the southern profile, and overlies it conformably throughout the rest of the site (Fig. 5). The incised section contains 10–15 cm blocks. Although the cross-section is channel-like in the incised section, textural characteristics (massive deposit, matrix-supported, chaotic, unbedded and unsorted), point to a diamicton cave deposit (debris flow; Bosch and White, 2018). Mineralogically, Unit XXIII is very similar to Units XXIV and XXV, with quartz (43%) and clay minerals (27%) being the most abundant minerals, with significant quantities of calcite, aragonite, apatite, plagioclase and K feldspar (Table 2).

Unit XXIIIb is a stalagmitic flowstone (reddish yellow; 7.5YR 7/6, 7.5YR 6/6), which overlies Unit XXIIIc conformably (Fig. 5). This flowstone has been dated by the uranium-series isochron method to 89 000 +11 000/-10 000 BP (Bischoff *et al.*, 1992; Table 4). Unit XXIIIa is a thin reddish (5YR 5/6) sterile clay layer with phosphate precipitation, found locally directly above the speleothem (Fig. 5).

According to Cabrera Valdés (1984), Unit 23, equivalent to Obermaier's (1924) level 'c) Stalagmitic deposit', is described as a stratigraphic unit composed of various deposits, considered archaeologically sterile: '23a) Thin layer of reddish silts with phosphate precipitation'; '23b) Thick stalagmitic scab with clay level'; and '23c) Thin (0.05 m) silt layer' (Cabrera Valdés, 1984), which correlates perfectly with our description of Unit XXIII and with Butzer's (1981) Levels 5a–c (Table 3; Figs 9 and 10). Rink *et al.* (1997) correctly identify the flowstone, but do not include it in Unit 23. Their Unit 23 is placed directly above the flowstone (Rink *et al.*, 1997; Fig. 6C), in what in this study is described as Units XXIIIa, XXII and XXI (Figs 6 and 10), as will be further discussed below.

Unit XXII: Unit XXII is a 25 cm-thick slightly clayey sandy silt marl (Table 1; Fig. 8), ranging in colour from yellowish red (5YR 5/6) to reddish brown (5YR 4/3), containing some 5–7 cm limestone blocks, interpreted as *éboulis* (Figs 3 and 5). Very clear, sharp and horizontal contact with the overlying Unit XXI. The most abundant mineral is calcite (46%), followed by quartz (26%) and clay minerals (15%; Table 2).

Unit XXII contains both archaeological (Mousterian) and palaeontological remains. Discoid knapping methods on quartzite and flint are common in this level, which includes abundant sidescrapers, denticulates and notches (Cabrera Valdés, 1983, 1984). The faunal assemblage is dominated by *Equus caballus*, followed by *Cervus elaphus* and *Bos*/*Bison* remains (Castaños, 2018).

Unit XXII can be confidently correlated to Cabrera Valdés' (1984) Unit 22, described as a reddish and compact silty level (subdivided into three units), to Obermaier's level 'd) Mousterian Beta' (Obermaier, 1924), and to Butzer's level 5d, described as a 20 cm-thick light brown (7.5YR) silty clay loam, very positively skewed (Table 3; Figs 9 and 10). Unit XXII is erroneously included in Unit 23 in Rink *et al.* (1997; Fig. 6C).

Unit XXI: Unit XXI is a sterile, very pure yellow (10YR 8/6) sandy clayey silt marl (Table 1; Fig. 8), overlying Unit XXII conformably with a very discrete contact (Fig. 5). The unit

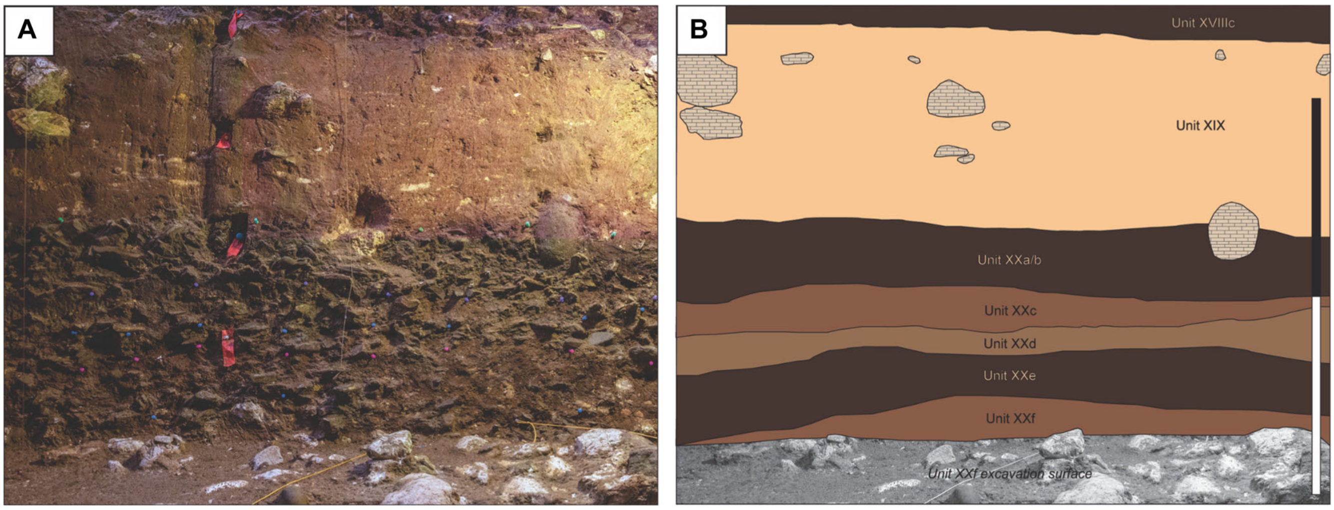


Figure 8. El Castillo Cave photograph 4 (A) and profile (B), showing Units XIX, XXa/b, XXc, XXd, XXe and XXf. [Color figure can be viewed at wileyonlinelibrary.com]

Table 2. XRD results for the studied samples, showing the Reference Intensity Ratios of the existing phases, allowing the intensity calculations to be normalised on the assumption that the sum of all phases in the sample is equal to 100%.

	Quartz	Clay minerals	Plagioclase	K feldspar	Calcite	Aragonite	Dolomite	Goethite	Hematite	Magnesite	Apatite
Unit XXc	42	39	3	3	-	-	-	-	-	-	13
Unit XXd	46	35	2	2	-	3	3	-	-	-	9
Unit XXe	54	29	5	4	1	-	-	1	1	-	5
Unit XXf	42	34	2	4	-	5	-	2	-	-	11
Unit XXg	46	41	4	6	-	-	-	-	-	1	2
Unit XXh	44	38	3	3	5	3	-	-	-	-	4
Unit XXi	47	31	3	3	2						14
Unit XXI	3	20	5	3	68	-	-	-	-	1	1
Unit XXII	26	15	7	4	46	-	-	1	-	1	-
Unit XXIII	43	27	5	5	8	3	-	1	-	1	7
Unit XXIV	37	22	-	5	13	13	3	1	-	-	6
Unit XXIV	43	34	2	5	5	4	-	1	-	-	6
Unit XXIV	37	31	5	10	8	3	1	-	-	1	4
Unit XXIV	50	27	5	5	4	3	-	-	-	1	5
Unit XXIV	49	26	5	3	4	5	-	1	-	1	6
Unit XXV	45	27	7	7	9	3	-	-	-	-	2
Unit XXV	41	21	5	4	24	3	-	-	-	-	2
Unit XXV	53	25	4	4	10	-	-		1	1	2

contains some phosphate precipitation. The upper half of the unit contains very few 5–10 cm blocks, and abundant 2–4 cm blocks (mostly limestone, but some quartz; Figs 5 and 6). Colour changes progressively to reddish brown (5YR 5/4) passing through reddish yellow (7.5YR 6/6), whereas the upper 1–2 cm are very intense dark red (2.5YR 3/6) to dark reddish brown (2.5YR 3/4). Calcite (68%) dominates the mineral assemblage, followed by clay minerals (20%) and small quantities of quartz, K feldspar and plagioclase (Table 2).

Unit XXI can be confidently related to Butzer's (1981) Level 5e (Table 3; Figs 9 and 10), described as a well-stratified pink (7.5YR) marl, and to Obermaier's level 'e) Clay layer' (Obermaier, 1924) and Unit 21, described as 10 cm-thick light yellow silts with phosphate concretions 'between Mousterian Alpha and Mousterian Beta' (Cabrera Valdés, 1984; Fig. 10). Although this correlation is unequivocal, here lies the main problem faced in this study. As explained by Rink *et al.* (1997), recent studies are said to describe Unit 21 as a much thicker (60 cm) layer, with presence of Mousterian artefacts as well as faunal elements, despite the level being originally described as sterile (Obermaier,1924; Cabrera Valdés, 1984). This new description and interpretation (Rink *et al.*, 1997; Cabrera Valdés *et al.*, 2006) led to the erroneous identification of Unit XXI (a sterile, diagnostically yellow marl; Unit 21 in Cabrera Valdés, 1984) when in fact it was just the extension of Unit XX (sandy silts with abundant remains; Obermaier's 'Mousterian Alpha', 1924; Cabrera Valdés' Unit 20, 1984), described below. This has ultimately led to the incongruities observed between lithostratigraphic units from Units XX to XXIII (Fig. 10).

Unit XX: Unit XX is subdivided into eight slightly clayey sandy silt units (Table 1; Fig. 8), separated by unconformable basal contacts (Figs 5, 6 and 7), with a higher abundance of archaeo-palaeontological remains at the base. Colours range from brown (10YR 5/3; Units XXa/b, XXd–e and XXg–i) to light brown (7.5YR 5/4; Unit XXf), with Unit XXc being very dark brown to very dark grey (5YR 3/1) due to the presence of abundant hearths. Mineralogically, quartz (42–54%) and clay minerals (29–41%) dominate the assemblage, with a significant presence of K feldspar, plagioclase and apatite (Table 2).

All Unit XX deposits contain abundant archaeological (Mousterian) and palaeontological remains. Archaeological remains consist of sidescrapers, denticulates, notches and cleavers, the majority on quartzite (Cabrera Valdés *et al.*,

Table 3. Butzer (1981) El Castillo Cave unit description synthesis alongside correlation and descriptions in this study.

Butzer (1981)					This study				
Unit	Thickness	Colour	Lithostratigraphic description	Industry	Unit	Thickness	Colour	Lithostratigraphic description	Industry
10	55 cm	Light brown (7.5 YR)	Loam, angular blocky structure	-	Unit XIX	50–55 cm	Light Brown (7.5 YR)	Silt	-
9a	25 cm	Brown (10 YR)	Clay loam, angular blocky structure	Mousterian	Unit XXa/b	10–12 cm	Brown (10 YR 5/3)	Slightly clayey sandy silt, abundant faunal and lithic remains	Mousterian
8b	20 cm	Black (5 YR)	Loam	Mousterian	Unit XXc	8–10 cm	Dark Brown (5 YR 3/1)	Slightly clayey sandy silt, abundant faunal and lithic remains	Mousterian
8a	25 cm	Yellowish brown (10 YR)	Loam, dispersed lime grit	Mousterian	Units XXd and e	30 cm	Brown (10 YR 5/3)	Slightly clayey sandy silt, abundant faunal and lithic remains	Mousterian
7b	65 cm	Brown (7.5 YR)	Loam, angular blocky structure.	Quina Charentian	Units XXf, g and h	50–60 cm	Brown (10 YR 5/3)	Slightly clayey sandy silt, abundant faunal and lithic remains	Mousterian
7a	27 cm	Brown (7.5–10 YR)	Loam, angular blocky structure, local concentrations of lime grit	Quina Charentian					
6b	40 cm	Brown (10 YR)	Sandy loam, abundant angular lime grit and coarse- to block-grade rubble	Quina Charentian	Unit XXi	10–12 cm	Brown (10 YR 5/3)	Slightly clayey sandy silt, abundant faunal and lithic remains	Mousterian
6a	0–20 cm	Pink (7.5 YR)	Loam, abundant lime grit, medium- to coarse-grade spall	Quina Charentian					
5e	20 cm	Pink (7.5 YR)	Marl and clay, medium- to coarse-grade spall	-	Unit XXI	15 cm	Pure Yellow (10 YR 8/6) to Dark Red (2.5 YR 3/6)	Sandy clayey silt marl, abundant 2–4 cm blocks	-
5d	20 cm	Light brown (7.5 YR)	Silty clay loam, angular blocky structure, dripstone and limestone rubble	-	Unit XXII	25 cm	Reddish Brown (5 YR 4/3)	Slightly clayey sandy silt marl	Mousterian
5c	12 cm	Pink (7.5 YR)	Oxidised, partly-calcified and laminated clay	-	Unit XXIIIa	0–5 cm	Reddish (5 YR 5/6)	Clay	-
5b	7–16 cm	White (10 YR)	Laminated, vertically crystallised flowstone	-	Unit XXIIIb	10–15 cm	Reddish Yellow (7.5 YR 7/6)	Flowstone	-
5a	8–15 cm	Very pale brown (10 YR)	Marl with silt loam. Lower contact abrupt and wavy	-	Unit XXIIIc	10 cm	Yellowish Brown (10 YR 4/4)	Slightly clayey sandy silt, channel-like incision in centre of southern profile	-
4c	0–30 cm	Brown (7.5 YR)	Silt loam, charcoal powder and bone fragments	Archaic bifaces	Unit XIV	70 cm	Yellowish Brown (10 YR 5/4)	Sandy clayey silt, abundant limestone blocks, charcoal fragments	Early Middle Palaeolithic
4b	50–110 cm	Brown (7.5 YR)	Loam, exceptionally poorly sorted, coarse- to block-grade rubble	-					
4a	0–25 cm	Reddish yellow (7.5 YR)	Loam, poorly sorted, angular blocky structure, medium- to coarse-grade limestone and dripstone spall	-					
3	20–25 cm	Pale brown (10 YR)	Well-stratified marl with silt loam	-	Unit XV	80 cm	Brown (10YR 3/2) and Light Beige (7.5 YR 8/2)	Slightly clayey sandy silt	Early Middle Palaeolithic
2	35–40 cm	Brown (7.5YR)	Silt loam	-					
1	60 cm	Light yellowish brown (10 YR)	Weakly mottled laminated silt	-					

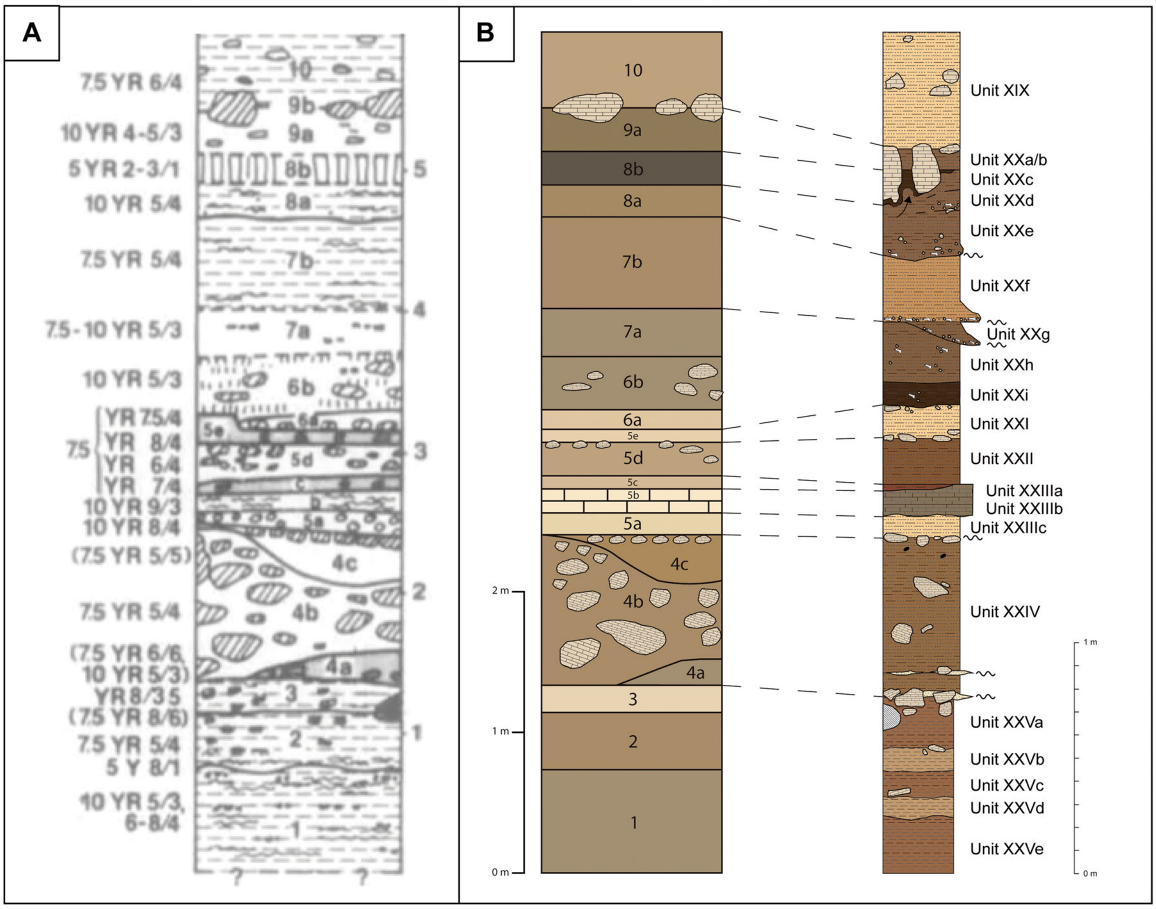
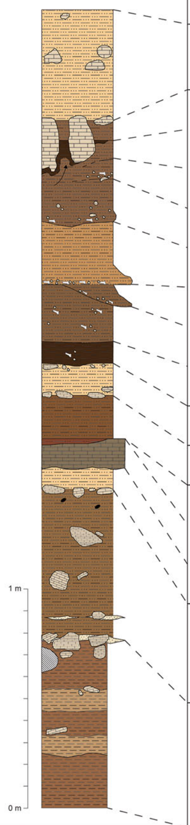


Figure 9. A. Butzer (1981) stratigraphic section. B. Simplified, colour version of Butzer (1981) stratigraphic section, with correlation of units between Butzer (1981) and this study. [Color figure can be viewed at wileyonlinelibrary.com]



Obermaier (1914)	Butzer (1981)	Cabrera Valdés (1984)	Rink et al. (1997)	Cabrera Valdés et al. (2006)	This study
g) Stalagmitic deposit	Level 10	Unit 19		Unit 19	Unit XIX
f) Mousterian (α)	Level 9a	Unit 20	Unit 20	Level 20a/b	Unit XXa/b
	Level 8b			Level 20c	Unit XXc
	Level 8a		Unit 21	Level 20d	Unit XXd
				Level 20e	Unit XXe
	Level 7			Unit 21	Unit XXf
			Unit 22		Unit XXg
					Unit XXh
	Level 6				Unit XXi
e) Clay layer	Level 5e	Unit 21	Unit 23		Unit XXI
d) Mousterian (β)	Level 5d	Unit 22 (a,b,c)			Unit XXII
c) Stalagmitic deposit	Level 5c	Unit 23a			Unit XXIIIa
	Level 5b	Unit 23b	Flowstone		Unit XXIIIb
	Level 5a	Unit 23c	Unit 24		Unit XXIIIc
b) Acheulean	Level 4	Unit 24			Unit XXIV
		Unit 25(a+b)			
a) Clay	Levels 1-3	Unit 26			Unit XXV

Figure 10. Correlation of the archaeological and geological units historically used in the Middle Palaeolithic sequence at El Castillo Cave to units in this study. [Color figure can be viewed at wileyonlinelibrary.com]

Table 4. El Castillo Cave geochronological data.

			Chronology (method)					
	Industry	Sample	(Wood *et al.*, 2018)[a]	(Bernaldo de Quirós *et al.*, 2006)	(Cabrera Valdés *et al.*, 1996)[a]	(Liberda *et al.*, 2010)	(Rink *et al.*, 1997)	(Bischoff *et al.*, 1992)
Unit XIX	Sterile	OxA-21974	… - 45 490 (^{14}C)[b]					
Unit XX undefined	Mousterian	OxA-10187		49 570–44 250 (^{14}C)[a,b],				
Unit XX undefined	Mousterian	OxA-10188		>47 300 (^{14}C)[c]				
Unit XX undefined	Mousterian	OxA-10327		>45 700 (^{14}C)[c]				
Unit XX undefined	Mousterian	OxA-10233		49 130–43 260 (^{14}C)[a,b]				
Unit XX undefined	Mousterian	OxA-10328		… - 46 410 (^{14}C)[a,b],				
Unit XX undefined	Mousterian	OxA-10329		>43 800 (^{14}C)[c]				
Unit XXa/b	Mousterian	GifA-89144			48 270–40 660 (^{14}C)[b]			
Unit XXa/b	Mousterian	GifA-92506			… - 43 560 (^{14}C)[b]			
Unit XXc	Mousterian	OxA-22204	65 220–43 660 (^{14}C)[b]					
Unit XXc	Mousterian	OxA-22205	68 300–44 220 (^{14}C)[b]					
Unit XXc	Mousterian	97131-97136				41 914 ± 9900 (ESR)[d]		
Unit XXd	Mousterian	95480A				44 200 ± 7600 (ESR)		
Unit XXe	Mousterian	CST1A				47 000 ± 9400 (ESR)		
Unit XXe	Mousterian	90CST3A-4A					69 300 ± 9100 (ESR)	
Unit XXh	Mousterian	90CST1+2					70 400 ± 9600 (ESR)	
Unit XXIII	Sterile	90-101 to 90-109						89 000 +11 000/-10 000 (U/Th)[d]

^{14}C: radiocarbon; ESR: electron spin resonance; U/Th: uranium series.
[a]Calibrated date (cal BP, 95.4% probability range) against IntCal13 (Reimer *et al.*, 2020) in OxCal v4.2 (Ramsey, 2009).
[b]Date may extend beyond calibration curve.
[c]Uncalibrated date (BP or years ± 1θ). d. Average of several samples.

2006; Sánchez-Fernández and Bernaldo de Quirós, 2008). The faunal associations in all levels are dominated by *Cervus elaphus* remains (between 50 and 80% of the remains, varying among levels), alongside *Equus caballus*, *Bos*/*Bison* and *Capreolus capreolus* remains in much lower abundances (Luret *et al.*, 2020).

Collapsed limestone blocks have deformed and mixed underlying Units XXa/b–e in the centre of the southern section (Fig. 6). These collapsed limestone blocks evidence the start of the disintegration of the cavern roof, and mark a shift from a closed cave system to an open rockshelter, as has also been discussed by other authors (Butzer, 1981; Bischoff *et al.*, 1992). The drastic decrease in the abundance of calcite in these levels (Table 1) also points to a more open system. For these reasons alongside granulometrical and textural data, sheet-wash and run-off processes are inferred for Unit XX deposits.

Unit XX is correlated to Obermaier's level 'f) Mousterian Alpha' (Obermaier, 1924; Fig. 10), and to Butzer's (1981) Levels 6–9a (Table 3; Figs 9 and 10), which consist of brown (7.5–10YR) to black (5YR) loams with 'blocky structure' and Mousterian industry. Since Butzer's (1981) Level 9b corresponds to a block fall event and not a lithostratigraphic unit, it is not included in Unit XX. The subdivision of Unit 20 by Cabrera Valdés *et al.* (2006) into four levels (20a/b, c, d and e) is correlative to Units XXa–e (Fig. 10). However, as previously explained, Unit 21 was mistaken for Unit XXf, and has been since then inaccurately described and placed underneath Unit XXe in recent studies (Cabrera Valdés *et al.*, 2006; Sesé, 2017; Wood *et al.*, 2018; Luret *et al.*, 2020). Additionally, Units XXg–i were erroneously identified as Unit 22 in Rink *et al.* (1997; Figs 6 and 10).

Unit XX has been extensively dated. Rink *et al.* (1997) obtained electron spin resonance (ESR) ages for Unit XXh (their Unit 22; Figs 6 and 10) and Unit XXe (their Unit 21; Figs 6 and 10), yielding average ages of 70 400 ± 9600 BP and 69 300 ± 9100 BP, respectively (Table 4). Additional ESR ages were obtained for Unit XXe (level 20e from Cabrera Valdés *et al.*, 2006) yielding an age of 47 000 ± 9400 BP, Unit XXd (level 20e from Cabrera Valdés *et al.*, 2006) with an age of 44 200 ± 7600 BP and Unit XXc (level 20c from Cabrera Valdés *et al.*, 2006), yielding an average age of 41 914 ± 9900 BP (Table 4; Liberda *et al.*, 2010). Two radiocarbon dates for Unit XXc fall between ranges 65 220–43 660 cal BP and 68 300–44 220 cal BP (Wood *et al.*, 2018) and Unit XXa/b between 48 270 and 40 660 BP (Cabrera Valdés *et al.*, 1996).

Conclusions

The new, detailed stratigraphic section, alongside the detailed descriptions and correlations of the stratigraphical levels, will hopefully facilitate their correct identification in future studies, avoiding any possible confusion. The proposed level correlations will allow future studies to incorporate and combine data from the different archaeological and geological levels historically used in the Middle Palaeolithic sequence of El Castillo Cave. This study therefore allows accurate correlation of new archaeological finds with those stored in the museums, belonging to the collections from the Obermaier excavations in the early twentieth century, and those carried out later, in the 1980s, by Victoria Cabrera Valdés and Federico Bernaldo de Quirós.

The geological re-evaluation of Unit XX (Mousterian Alpha; Obermaier, 1924) has expanded its chronology, now ranging from 49 139–43260 cal BP (^{14}C, Bernaldo de Quirós *et al.*, 2006) to 70 400 ± 9600 BP (ESR, Rink et al, 1997). Obermaier's (1924) 'Mousterian Beta', Unit XXII in this paper, would therefore yield an age older than 70 400 ± 9600 BP (ESR, Rink et al, 1997) and younger than the underlying speleothem (Unit XXIIIb), dated to 89 000 +11 000/-10 000 BP (U/Th, Bischoff *et al.*, 1992). Additionally, Units XXI and XXII from the historical Obermaier excavations, hosted throughout different museums, are now left without chronological data.

Finally, from an archaeological point of view, it is noteworthy that this study entails an important change in the archaeological conclusions of the Mousterian since the work of Rink *et al.* (1996). Previous studies analysing Units 20, 21 and 22 all refer, after our study, to different subunits of Unit XX. Although this does not substantially change archaeological interpretations of previous Mousterian techno-typological studies, it does change their stratigraphic position and overall geological interpretation.

In conclusion, this study establishes a new lithostratigraphic framework for the site, which can be accurately correlated to previous geological and archaeological studies and generates a solid working basis for framing the Mousterian of El Castillo Cave in the Cantabrian region and southwestern Europe.

Acknowledgements and funding. This study has been conducted with the funding of the Consejería de Universidades, Igualdad, Cultura y Deporte of the Cantabrian Government and by the Puente Viesgo City Council. We would like to thank Cuevas Prehistóricas de Cantabria, especially its director Roberto Ontañón and its curator, Eduardo Palacio. We also thank Raúl Gutiérrrez, the previous curator, for his support over many years. We are indebted to José Riancho and the rest of the cave guides for their support, advice and unique vision of the caves. We acknowledge the helpful comments of Federico Bernaldo de Quirós, the support of Óscar Villegas, and the invaluable help of our field team: Natalia Abellán, Irene González, Blanca Jiménez, Macarena Moral and Diego Rodríguez. We would also like to thank Aurora Ladero, from the National Archaeological Museum (MAN) in Madrid.

Author contributions—**David M. Martín-Perea**: Conceptualization; Investigation; Writing - original draft; Methodology; Formal analysis; Data curation. **José-Manuel Maíllo-Fernández**: Conceptualization; Investigation; Funding acquisition; Validation; Writing - review & editing; Formal analysis; Supervision; Project administration. **Juan Marín**: Conceptualization; Investigation; Funding acquisition; Validation; Writing - review & editing. **Xabier Arroyo**: Formal analysis; Data curation. **Raquel Asiaín**: Conceptualization; Validation; Formal analysis; Resources.

References

Alcalde del Río H. 1906. Las pinturas y grabados de las cavernas prehistóricas de la provincia de Santander. *Portugalia* **II**(2): 1–45.

Bernaldo de Quirós F, Maíllo-Fernández JM. 2009. The transitional Aurignacian and the middle-upper palaeolithic transition model in Cantabrian Iberia. In *Sourcebook of Paleolithic Transitions*, Camps M, Chauhan P (Eds.) Springer: New York; 341–359.

Bilbao-Malavé I 2016. Las primeras ocupaciones en la cueva de El Castillo. Estudio tecno-tipológico de los niveles 25a y 25b. Master Thesis Dissertation, Complutense University of Madrid.

Bischoff JL, García JF, Straus LG. 1992. Uranium-series isochron dating at El Castillo Cave (Cantabria, Spain): The "Acheulean"/"Mousterian" Question. *Journal of Archaeological Science* **19**: 49–62.

Blott SJ, Pye K. 2012. Particle size scales and classification of sediment types based on particle size distributions: Review and recommended procedures. *Sedimentology* **59**: 2071–2096.

Breuil H, Obermaier H. 1912. Les prémiers travaux de L'institut de Paléontologie Humaine. *L'Anthropologie* **XXIII**: 1–27.

Breuil H, Obermaier H. 1913. Institut de Paléontologie Humaine. Travaux executés en 1912. *L'Anthropologie* **24**: 2–16.

Breuil H, Obermaier H. 1914. Institut de Paléontologie Humaine. Travaux de l'anné 1913. Travaux en Espagne. *L'Anthropologie* **25**: 233–254.

Bosch RF, White WB. 2018. Lithofacies and transport for clastic sediments in karst conduits. In *Karst Groundwater Contamination and Public Health*. Advance in Karst Science, Springer: Cham; 277–281.

Butzer KW. 1981. Cave sediments, Upper Pleistocene stratigraphy and Mousterian facies in Cantabrian Spain. *Journal of Archaeological Science* **8**: 133–183.

Cabrera Valdés V 1979. El yacimiento de la Cueva de "El Castillo". (Puente Viesgo, Santander). Ph.D. Thesis, Universidad Complutense de Madrid, Spain.

Cabrera Valdés V. 1983. Notas sobre el Musteriense Cantábrico: El "Vasconiense". In *Homenaje al profesor Martín Almagro Basch*, Almagro M (Ed.) Ministerio de Cultura: Madrid; 131–141.

Cabrera Valdés V. 1984. *El yacimiento de la Cueva de "El Castillo": Puente Viesgo, Santander*. Consejo Superior de Investigaciones Científicas, Instituto Español de Prehistoria: Madrid.

Cabrera Valdés V, Bernaldo de Quirós F. 1996. The origins of the upper palaeolithic: a Cantabrian perspective. In *The Last Neanderthals, the First Anatomically Modern Humans: A Tale about the Human Diversity. Cultural Change and Human Evolution: The Crisis at 40 ka BP*, Carbonell E, Vaquero M (Eds.) Universitat Rovira I Virgili: Tarragona; 251–265.

Cabrera Valdés V, Valladas H, Bernaldo de Quirós F, Hoyos M. 1996. La transition Paléolithique moyen-Peléolithique supérieur à El Castillo (Cantabrie): nouvelles datations par le carbone-14. *Compte-Rendus de l'Académie des Sciences de Paris* **332**(IIa): 1093–1098.

Cabrera Valdés V, Maíllo-Fernández JM, Lloret M, Bernaldo de Quirós F, 2001. La transition vers le Paléolithique supérieur dans la grotte du Castillo (Cantabrie, Espagne): La couche 18 Anthropologie, vol. 105(4), pp. 505-532.

Cabrera Valdés V, Bernaldo de Quirós F, Maíllo-Fernández JM. 2006. La Cueva de El Castillo: Las nuevas excavaciones. In *En el centenario de la cueva de El Castillo: El ocaso de los Neandertales*, Cabrera Valdés V, Bernaldo de Quirós F, Maíllo-Fernández JM (Eds.) Centro Asociado a la Universidad Nacional de Educación a Distancia en Cantabria: Madrid; 351–365.

Castaños PM. 2018. El Castillo: historia de una fauna olvidada. La fauna de las excavaciones históricas (1919-1914) de la cueva de El Castillo (Puente Viesgo, Cantabria). *Monografías del Museo de Prehistoria y Arqueología de Cantabria* **1**: 1–300.

Chung FH. 1975. Quantitative interpretation of X-ray diffraction patterns of mixtures. III. Simultaneous determination of a set of reference intensities. *Journal of Applied Crystallography* **8**: 17–19.

Courty MA 1989. Analyse microscopique des sediments du remplissage de la grotte de Vaufrey (Dordogne). In: La Grotte de Vaufrey (Ed. Ridaud, J.P.): Mémoire de la Societé Préhistorique Français. Pp. 183-209.

Ford D, Williams PD. 2013. *Karst hydrogeology and geomorphology*. John Wiley & Sons: USA.

Garralda MD, Maíllo-Fernández JM, Higham T, Neira A, Bernaldo de Quirós F. 2019. The Gravettian child mandible from El Castillo Cave (Puente Viesgo, Cantabria, Spain). *American Journal of Physical Anthropology* **170**: 331–350.

Gillieson D. 1996. *Caves: Processes, development and management*. Blackwell, Oxford

Jones JR, Richards MP, Reade H, Bernaldo de Quirós F, Marín-Arroyo AB. 2019. Multi-Isotope investigations of ungulate bones and teeth from El Castillo and Covalejos caves (Cantabria, Spain): Implications for paleoenvironment reconstructions across the Middle-Upper Palaeolithic transition. *Journal of Archaeological Science: Reports* **23**: 1029–1042.

Laville H, Rigaud JP, Sackett J. 1980. *Rock shelters of the Perigord*. Academic Press: New York.

Liberda JJ, Thompson JW, Rink WJ, Bernaldo de Quirós F, Jayaraman R, Selvaretinam K, Chancellor-Maddison K. 2010. ESR dating of tooth enamel in Mousterian Layer 20, El Castillo, Spain. *Geoarchaeology* **25**(4): 467–474.

Luret M, Burke A, Bernaldo de Quirós F, Besse M. 2020. El Castillo cave (Cantabria, Spain): Archeozoological comparison between the Mousterian occupation level (unit 20) and the "Aurignacie de transition de type El Castillo" (unit 18). *Journal of Archaeological Science: reports* **31**: 102339.

Macphail RI, Goldberg P. 1999. The soil micromorphological investigation of Westbury Cave. In *Westbury Cave. The Natural History Museum Excavations 1976-1984*, Andrews P, Cook J, Currant A, Stringer C Eds. CHERUB (Centre for Human Evolutionary Research at the University of Bristol): Bristol; 59–86.

Obermaier H 1924. The Fossil Man in Spain. New Haven, USA.

Pike AWG, Hoffmann DL, García-Díez M, Pettitt PB, Alcolea J, De Balbín R, González-Sainz C, De Las Heras C, Lasheras JA, Montes R, Zilhao J. 2012. U-series dating of paleolithic art in 11 caves in Spain. *Science* **336**(6087): 1409–1413.

Pike-Tay A, Cabrera Valdés V, Bernaldo de Quirós F. 1999. Seasonal variations of the Middle-Upper Paleolithic transition at El Castillo, Cueva Morín and El Pendo (Cantabria, Spain). *Journal of Human Evolution* **36**: 283–317.

Reimer PJ, Austin WEN, Bard E, Bayliss A, Blackwell P, Bronk Ramsey C, Butzin M, Cheng H, Edwards L, Friedrich M, Grootes PM, Guilderson TP, Hajdas I, Heaton TJ, Hogg AG, Hughen KA, Kromer B, Manning SW, Muscheler R, Palmer JG, Pearson C, van der Plicht J, Reimer RW, Richards DA, Scott EM, Southon JR, Turney CSM, Wacker L, Adolphi F, Büntgen U, Capano M, Fahrni SM, Fogtmann-Schulz A, Friedrich R, Köhler P, Kudsk S, Miyake F, Olsen J, Reinig F, Sakamoto M, Sookdeo A, Talamo S. 2020. The IntCal20 Northern Hemisphere radiocarbon calibration curve (0-55 kcal BP), *Radiocarbon* **62**(4): 725–757.

Rink WJ, Schwarcz HP, Lee HK, Cabrera Valdés V, Bernaldo de Quirós F, Hoyos M. 1997. ESR dating of tooth enamel: comparison with AMS ^{14}C at El Castillo Cave, Spain. *Journal of Archaeological Science* **23**(6): 945–951.

Sánchez-Fernández G, Bernaldo de Quirós F. 2008. El final del Musteriense cantábrico: el nivel 20e de la cueva de El Castillo (Cantabria). *Férvedes* **5**: 117–126.

Sesé C. 2017. Los micromamíferos (Eulipotyphla, Chiroptera, Rodentia y Lagomorpha) del yacimiento del Pleistoceno Superior de la cueva de El Castillo (Cantabria, España). *Estudios Geológicos* **73**(2): e072.

Solano-Megías I 2016. El nivel 24 de la cueva de El Castillo: estudio tecnotipológico. Bachelor Degree Thesis Dissertation, Complutense University of Madrid.

Valladas H, Cachier H, Maurice P, Bernaldo de Quirós F, Clottes J, Cabrera Valdés V, Uzquiano P, Arnold M. 1992. Direct radiocarbon dates for prehistoric paintings at the Altamira, El Castillo and Niaux caves. *Nature* **357**(6373): 68–70.

Wood R, Bernaldo de Quirós F, Maíllo-Fernández JM, Tejero JM, Neira A, Higham T. 2018. El Castillo (Cantabria, northern Iberia) and the transitional Aurignacian: using radiocarbon dating to assess site taphonomy. *Quaternary International* **474**: 56–70.

