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LETTERS

The oldest hand-axes in Europe

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Stone tools are durable reminders of the activities, skills and customs of early humans, and have distinctive morphologies that reflect the development of technological skills during the Pleistocene epoch. In Africa, large cutting tools (hand-axes and bifacial chopping tools) became part of Palaeolithic technology during the Early Pleistocene (~1.5 Myr ago)[1–3]. However, in Europe this change had not been documented until the Middle Pleistocene (<0.5 Myr ago)[4,5]. Here we report dates for two western Mediterranean hand-axe sites that are nearly twice the age of the supposed earliest Acheulian in western Europe. Palaeomagnetic analysis of these two sites in southeastern Spain found reverse polarity magnetozones, showing that hand-axes were already in Europe as early as 0.9 Myr ago. This expanded antiquity for European hand-axe culture supports a wide geographic distribution of Palaeolithic bifacial technology outside of Africa during the Early Pleistocene.

Africa has an extensive Pliocene–Pleistocene record of hominins, with the oldest archaeological sites (~1.5 Myr old) that contain large bifacial cutting tools (Acheulian hand-axes and cleavers) found at Konso-Gardula[1], Peninj[2] and Wonderwerk[3]. There are few early archaeological sites outside Africa with Acheulian bifacial artefacts, mostly around the Early/Middle Pleistocene boundary, such as Gesher Benot Ya'aqov, Israel (palaeomagnetic age: 0.7 Myr old)[6], and Bose, China (^{40}Ar–^{39}Ar age: 0.8 Myr old)[7]. An exception is the older, eastern Mediterranean site of 'Ubeidiya, Israel (palaeomagnetic age: ~1.2 Myr old)[8]. In western Europe, hand-axes are found in sites ranging from 35 to ~500 kyr ago[4,5,9].

We are reporting Early Pleistocene (~0.9 Myr ago) and initial Middle Pleistocene (0.76 Myr ago) dates for hand-axes excavated from two western Mediterranean sites (Fig. 1). Solana del Zamborino (La Solana del Zamborino, 37.39° N, 3.11° W), long considered one of the younger Acheulian sites in the Iberian Peninsula[10], and Estrecho del Quípar (Cueva Negra de Estrecho del Río Quípar, 38.04° N, 1.88° W) were previously assumed to be from the end of the Middle Pleistocene (~200 kyr ago)[11,12]. More recent studies of micro-mammals indicated older ages within the Middle Pleistocene[13,14]. However, our magnetostratigraphic analysis (Fig. 2) at Solana del Zamborino now indicates a date (~760 kyr ago) at the boundary between the Early and Middle Pleistocene, corresponding to the last palaeomagnetic polarity reversal (Matuyama to Brunhes chrons). At Estrecho del Quípar, our new date (~900 kyr ago) is Early Pleistocene, fully within the reverse polarity Matuyama chron. These new dates expose Acheulian lithic technology in the western Mediterranean before the end of the Early Pleistocene, comparable to that found in the eastern Mediterranean ('Ubeidiya)[8].

Solana del Zamborino has been a reference for the terminal part of the Early Palaeolithic in Spain, with artefacts described as evolved Mode 2 (ref. 10) and Final Acheulian[11]. Located in the Guadix Basin, a large western tributary of the internally drained Baza Basin, the Solana del Zamborino fossil quarry is an open-air site within a long (>150 m) stratigraphic sequence dominated by fluvial deposits derived from the high southern mountains (Sierra Nevada >3,000 m). During the time of Solana del Zamborino, the fluvial deposition was displaced as an expanding palaeo-lake created palustrine (marsh) and littoral (shallow lake margin) environments. Excavations were made only during the mid-1970s, supplying an abundance of large-animal bones, tusks and charcoal (and other evidence of fire), along with several hand-axes and Palaeolithic tools made from quartzite, quartz and chert[11] (also see Supplementary Information).

The youthful age (~200 kyr old)[11] assumed for Solana del Zamborino was largely based on its well-developed Acheulian lithic typology. Such a young age contrasts with our continuing lithostratigraphy and palaeoclimate research in the region[15–17], which indicates a final, major lake-forming event near the end of the Early Pleistocene (starting ~800 kyr ago) and deposition terminating in the Baza Basin (~600 kyr ago). A specific question in chronology arose after a study at the Cúllar Baza-1 fossil quarry, 50 km to the east, where a detailed magnetostratigraphy[16] found the Matuyama/Brunhes boundary just a few metres below the fossil/tool levels. Solana del Zamborino is in a similar palaeo-environmental setting, with similar micro-mammals (for example, *Arvicola cantianus*)[13] and now has a similar magnetostratigraphy with the Matuyama/Brunhes boundary only a few metres below the fossil/tool-bearing levels. Although much older at 760 kyr, this new age is more compatible with our palaeoclimate-driven model in which precipitation was the primary control for palaeo-lake levels, directly influencing

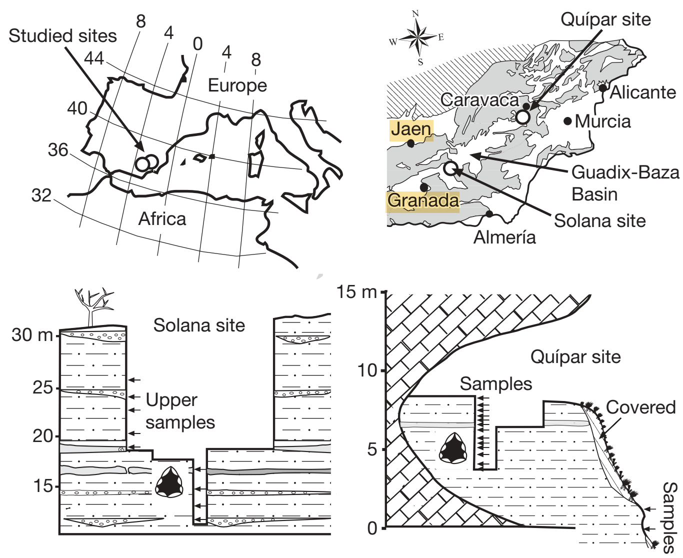

Figure 1 | Location maps and geological sketch. The two sites in the Iberian peninsula are La Solana del Zamborino and Cueva Negra del Estrecho del Río Quípar. Schematic cross-sections for each site indicate the levels with hand-axes (symbol) and palaeomagnetic samples (arrows). Four other palaeomagnetic samples were collected below the Solana quarry (not shown).

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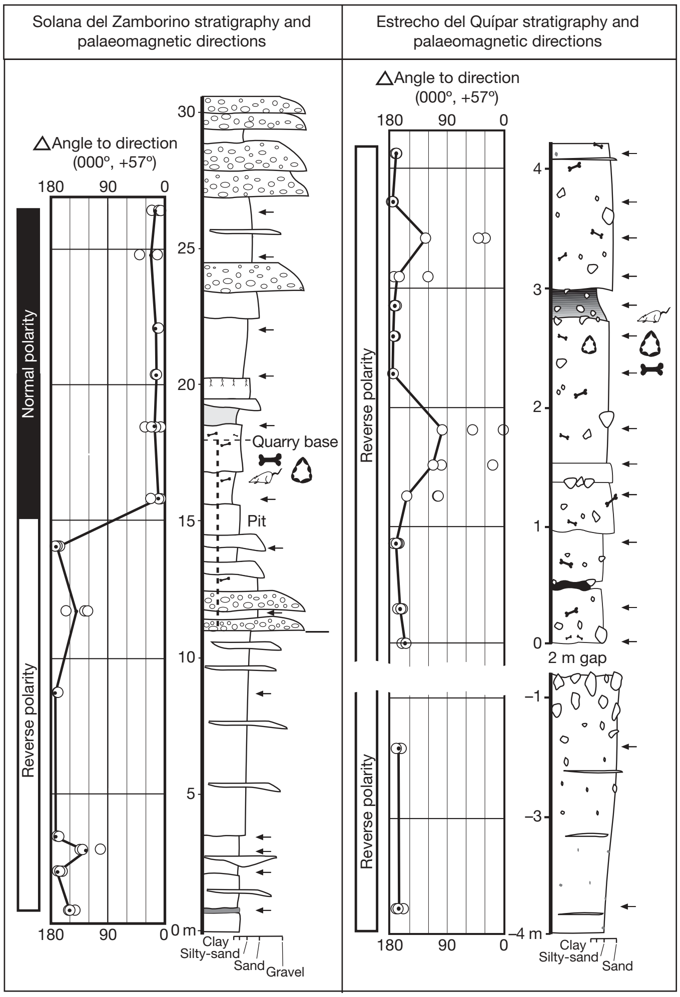

Figure 2 | Magnetostratigraphy and lithostratigraphy. The palaeomagnetic results from Solana del Zamborino and Estrecho del Quípar are shown with lithostratigraphic columns. Palaeomagnetic samples (arrows) are from vertical excavation faces, except the lower five samples at Solana del Zamborino and the lower two samples at Estrecho del Quípar. Palaeomagnetic remanence directions (Δ, from three specimens per level) are shown relative to the direction of the axial dipole field. Symbols: bone, large mammals; mouse, small mammals; broken cobble, lithic artefacts.

Table 1 | Mammals from southeast Iberian sites

Palaeomagnetic chronology	Pre-Jaramillo				Post-Jaramillo		Brunhes	
Sequences sites (Baza Basin)	VM	BL	FN-3		HU-1		CB-1	SZ
Cavern sites				CV		EQ		
Micro-mammals								
Castillomys crusafonti rivas	X	X	X	X	X	–	–	–
Microtus (Allophaiomys) cf. *pliocaenicus*	X	X	X	–	–	–	–	–
Mimomys savini	–	–	X	–	X	X	–	–
Microtus (Allophaiomys) chalinei	–	–	X	X	–	X	–	–
Pliomys episcopalis	–	–	–	–	–	X	–	–
Microtus (Iberomys) aff. *huescarensis*	–	–	–	–	X	X	–	–
Microtus (Iberomys) brecciensis	–	–	–	–	X	–	X	X
Arvicola cantianus	–	–	–	–	–	–	X	X
Large mammals								
Praeovibos sp.	X	X	X	–	–	–	–	–
Pachycrocuta brevirostris	X	X	X	X	–	–	–	–
Megantereon sp.	X	X	X	X	–	–	–	–
Ursus etruscus	X	X	X	X	–	–	–	–
Canis etruscus	X	X	X	X	X	–	–	–
Mammuthus meridionalis	X	X	X	X		–	–	–
Hippopotamus antiquus	X	X	X	X	–	–	–	–
Eucladoceros giulii	X	X	X	–	–	–	–	–
Megaloceros sp.	–	–	–	X	X	X	X	–
Homotherium sp.	X	X	X	X	X	–	–	–
Stephanorhinus etruscus	X	X	X	X	X	X	X	–
Equus altidens	X	X	X	X	X	X	X	–
Panthera gombaszoegensis	–	–	–	X	X	–	–	–
Elephas antiquus	–	–	–	–	X	–	–	–
Hippopotamus major	–	–	–	–	X	–	–	–
Bison sp.	–	–	–	–	–	X	X	X
Canis mosbachensis	–	–	–	–	–	X	X	X
Sus sp.	–	–	–	–	–	X	X	X
Dama 'nestii' vallonnetensis	–	–	–	–	–	X	–	–
Ursus sp.	–	–	–	–	–	X	–	–
Macaca sp.	–	–	–	–	–	X	X	X
Crocuta crocuta	–	–	–	–	–	X	X	–
Equus cf. *sussenbornensis*	–	–	–	–	–	–	X	X
Mammuthus trogontherii	–	–	–	–	–	–	X	X
Homo sp.	X	X	–	X	–	X	–	–
Lithic artefacts	–	X	X	–	–	X	X	X

Fossil mammals from Solana del Zamborino[13] (SZ) and Estrecho del Quípar[14] (EQ) compared with magnetostratigraphically calibrated sites in the Baza Basin[15,16] and the cavern/mine site of Cueva Victoria, Murcia (CV)[29]. The SZ fauna match the Cúllar Baza-1 (CB-1) site, which is also just above the Matuyama/Brunhes magnetochron boundary. The EQ fauna most closely correspond to the stratigraphically sequenced reference site Huéscar-1 (HU-1) in reverse polarity between the Jaramillo subchron and the Brunhes chron. Other site names: BL, Barranco León; FN-3, Fuentenueva-3; VM, Venta Micena. X, present at site; –, not present at site.

deposition and facies migration throughout the endorheic Guadix-Baza Basin[15–17]. Both lakeside sites have similar mammals (Table 1), revealing an initial fauna of the Middle Pleistocene (Toringian biostratigraphic stage)[16].

Below the artefact levels at Solana del Zamborino we found 14 m ($n = 7$ samples) of reverse polarity, whereas within and above these levels we found 12 m ($n = 6$) of normal polarity. Most of the section is composed of medium to coarse-grained sandstone, but for palaeomagnetic analysis we preferentially sampled finer-grained beds (siltstone and claystone). Solana del Zamborino's artefact layers are positioned immediately above the Matuyama/Brunhes polarity reversal. Using the sediment accumulation rate from the stratigraphically equivalent Cúllar Baza-1 section[16], the tool layers would be 10–30 kyr after the polarity change, giving a date of 770–750 kyr ago.

Estrecho del Quípar is a rock shelter site on the northeastern margin of the Baza Basin near Caravaca de la Cruz (Murcia). Since 1990, annual excavations have generated an abundance of complex lithic artefacts and animal remains, along with hominin teeth, a hand-axe, and a large bifacial chopper[14]. Age estimates were initially Late Pleistocene[12] and more recently changed to Middle Pleistocene[14]. However, our analysis indicates reverse palaeomagnetic polarity throughout this 10-m accumulation of palaeosols. Therefore, the age must be Early Pleistocene, the most recent period dominated by reverse polarity (1.78–0.78 Myr ago)[18].

Human fossils from the Estrecho del Quípar excavation include canine and premolar teeth with non-modern dimensions[10,14]. The large bifacial tools (hand-axe and chopping tool) were fashioned from limestone cobbles and excavated ~1.5 m below the top of the lithified Pleistocene sediment[14]. Other lithic artefacts (80% chert) and abundant knapping debris are ubiquitous to the current limit of archaeological excavation (depth ~4.5 m). Lithic artefacts include small disc-cores and flakes, some from prepared striking platforms and some with centripetal and recurrent flaking, or with abrupt or semi-abrupt edge retouch[14]. The lithic artefacts from Estrecho del Quípar reveal some of the diversity in core-reduction techniques already in use during the Early Pleistocene in southern Iberia.

The Estrecho del Quípar deposit consists of ~10 m of fine-grained fossiliferous sediment infilling one of the relict weathering cavities (tafoni) which are common features in the massive limestone cliffs in this part of the Quípar Valley. An upper 4.2 m archaeological section was densely sampled for palaeomagnetic analysis ($n = 13$). A lower ~2 m exploratory section was sampled ($n = 2$) from outcrop, outside the present roof of the rock shelter. The entire deposit has both alluvial and soil characteristics, which we interpret as a sequence of accumulating immature palaeosols. All beds have pedogenic microfabric with soil plasma incorporating variable amounts of detrital grains (rounded, sand-size limestone and quartz), tafoni weathering flakes (carbonate cemented, 1–10 mm), bone fragments plus chert/limestone artefacts (sharp-edged), and occasionally large angular limestone fragments (rock falls, to boulder size).

Reverse palaeomagnetic polarity was found throughout the Estrecho del Quípar sequence including a sample within 10 cm of the top of the deposit (Fig. 2). Therefore, the entire sequence, with >8 m of reversely magnetized palaeosols, is more than 780 kyr old, before the start of the Brunhes normal polarity chron (C1n). The youngest magnetochronological assignment is to the late Matuyama subchron (C1r.1r) in the age range 990–780 kyr ago[18]. Comparing the Estrecho del Quípar micro-mammals (for example, *Microtus huescarensis*) to the chronostratigraphic sequence from the Baza Basin (Table 1) provides a close correspondence to Huéscar-1, a reverse polarity fossil-quarry. Huéscar-1 is ~10 m below the Matuyama/Brunhes polarity boundary (~900 kyr ago)[16]. A necessarily approximate date of ~900 kyr ago for Estrecho del Quípar should be used until a zone of normal polarity lower in the sequence might be delimited, or other chronological refinements develop.

There are other possible, although less likely, correlations for the polarity zones being reported for these two hand-axe sites. These would produce older dates of 1.06 Myr ago for Solana del Zamborino, and ~1.2 Myr ago for Estrecho del Quípar. Such older correlations would conflict with the reference chronostratigraphy (see Table 1) being developed from long overlapping stratigraphic sections within the adjacent Baza Basin[15–17]. For example, *M. huescarensis*, found at Estrecho del Quípar, has not been found in reverse polarity sites in the stratigraphic sequence, such as Venta Micena or Fuentenueva-3 (1.3–1.2 Myr ago)[15], until much higher at Huéscar-1 (~0.9 Myr ago)[16].

This report confirms the utility of long reference chronostratigraphies as age constraints for more isolated sites such as caverns and short stratigraphic sections. The Baza reference chronostratigraphy[15,16] that we are using had recently clarified the chronology of sites already in use as micro-mammal calibration sites for western Europe. This recalibration generated a clearer biochronological view at the boundaries of the Pliocene to Pleistocene[15,19], and the Early to Middle Pleistocene[16]. Of specific interest for the chronology of other hand-axe sites in Europe was the early record of *Arvicola cantianus* immediately above the Matuyama/Brunhes polarity boundary (~0.75 Myr ago)[16]. This antiquity is confirmed by the polarity zonation at Solana del Zamborino. Unfortunately, deposition in the Baza Basin ended by ~0.5 Myr ago[16], leaving the biochronology of the last half of the Middle Pleistocene to be developed elsewhere.

The large change in dates for the two hand-axe sites in this report reiterates the warning against a simple connection between lithic typology and chronology[4]. The dates accepted for the numerous, widely dispersed archaeological sites in Europe should be critically evaluated and linked to developing chronostratigraphic sequences whenever available (see, for example, ref. 20) or linked to sites that have materials amenable for radiometric analysis (see, for example, ref. 21). The Middle Pleistocene remains a challenging period for chronological studies, lacking the worldwide palaeomagnetic reversals that are useful in identifying and subdividing the Early Pleistocene[18].

Overall, the Early Pleistocene was a time with widespread distribution of Palaeolithic bifacial technology outside of Africa, extending across the eastern[7], southern[8], and now the western limits of temperate Eurasia. Our palaeomagnetic analysis indicates an older than expected[4,5] Acheulian chronology in the western Mediterranean, and when these are combined with the Oldowan (uni-facial) lithic technology[22] in the Baza Basin sites at Orce, Spain (palaeomagnetic age: ~1.3 Myr old)[15], a hominin presence[23,24] in southwestern Europe is indicated for much of the Early Pleistocene (Fig. 3). This developing outline of a longer European hominin chronology also suggests that the barrier between Africa and Europe was permeable. Establishing secure chronologies for early hominin sites will continue to increase our understanding of human prehistory in Eurasia and its relation to Africa[9,24–26].

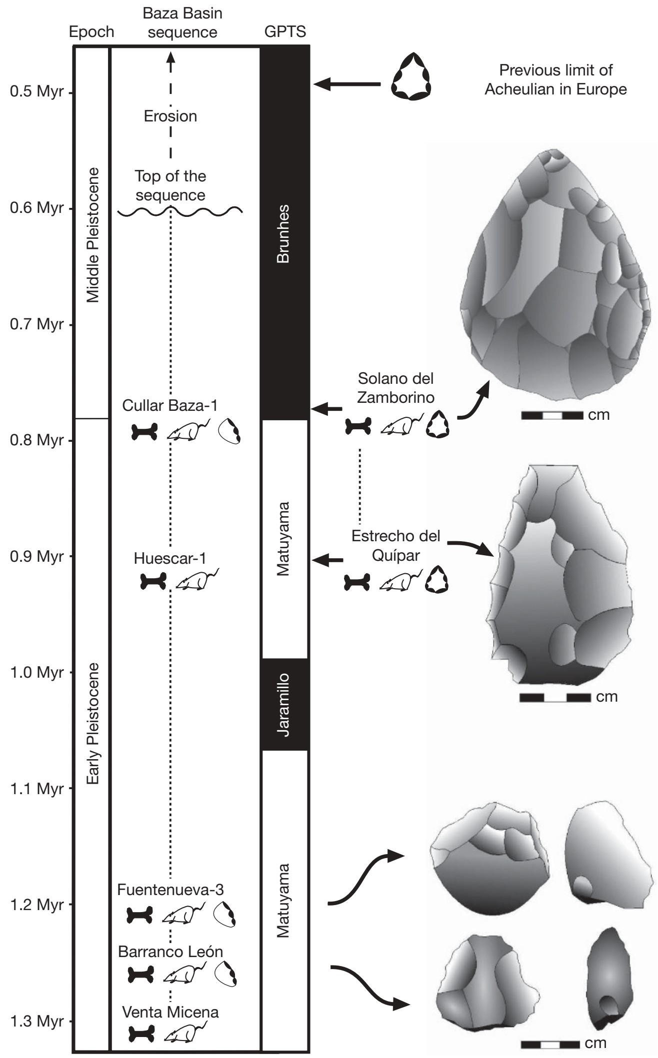

Figure 3 | Magnetochronology of Palaeolithic sites. **The chronology of Early Palaeolithic sites in southern Iberia referenced to the combined magnetochronology and biochronology from lithostratigraphic sequences in the Baza Basin[13–16]. Note the mid-Middle Pleistocene age of the assumed oldest Acheulian sites in Europe[4,5]. GPTS, geomagnetic polarity timescale (see ref. 18). Drawings of Palaeolithic tools modified from refs 11, 14 and 22; for other symbols see Fig. 2. Scale bar divisions, 1 cm.**

METHODS SUMMARY

Blocks (~12 cm on a side) were oriented while still attached to the substrate using magnetic compass and inclinometer. Each sample was sawn without water into three specimen cubes (12 cm^3 each), and the surfaces were sanded (to remove metal contamination) and cleaned with compressed air. Storage, measurements and laboratory experiments were made inside a room-sized magnetostatic shield (<350 nT), equipped with a superconducting rock magnetometer (sensitivity 10^{-12} Am^2), an inline alternating field demagnetizer (3-axis, static), a non-inductive furnace (residual field < 3 nT), and a magnetic susceptibility meter (inducing field 100 μT).

The remanent magnetism preserved in individual sedimentary strata were measured and then assembled in stratigraphic position to form palaeomagnetic polarity zones. Of specific interest is finding the last complete polarity reversal in the Earth's magnetic field, 780 kyr ago[27]. This global chronological marker is used to approximate the boundary between the Early and Middle Pleistocene[28]. Most samples from these hand-axe sites have a well-preserved remanent magnetism. Initial demagnetization experiments removed the viscous and weathering magnetizations, which are directed parallel to the modern magnetic field (north and down). Further thermal demagnetization exposed the characteristic magnetization that has either reverse or normal polarity directions (see Supplementary Information for details).

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Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

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Author Contributions The authors of this paper contributed equally. G.R.S. directed the palaeomagnetic measurements and assisted in field sampling, and L.G. directed the palaeomagnetic field sampling and assisted in laboratory measurements.

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