Magnetic Susceptibility analysis of sediments at the Middle-Upper Paleolithic transition for two cave sites in northern Spain

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ABSTRACT We have used the magnetosusceptibility event and cyclostratigraphy (MSEC) method to compare two cave excavations in northern Spain, at El Castillo and L'Arbreda caves, which have sedimentary sequences that span the interval for the Middle-Upper Paleolithic transition. Both caves contain Aurignacian cultural deposits with very early radiocarbon dates. Our interpretation of the results indicates that the Aurignacian occupations in these caves began at essentially the same time, and in both caves the Aurignacian occupations correspond to a warm MSEC zone which we equate with the Hengelo warm climate zone, identified palynologically ca. 40-38 ka BP.

Introduction

A major issue in understanding the Middle-Upper Paleolithic transition is the nature of the many assemblages, ranging geographically from southwestern Asia to western Europe, that are commonly grouped together as "Aurignacian." What is the relationship of the Aurignacian to the Mousterian? To so-called "transitional" industries of the early Upper Paleolithic such as the Châtelperronian and Uluzzian? To what extent is the "Aurignacian" meaningful as a culture-stratigraphic unit? Clearly, the answers to these much-debated questions are in no small measure dependent on the reliable ordering in time — chronometrically or, at least, relatively — of assemblages from archeological sites.

Our ability to date the archeological assemblages crucial to these questions has improved over what it was a generation ago, and yet still inadequate to allow general agreement on the answers. We now have hundreds of radiocarbon dates (including AMS dates) from the late Middle and early Upper Paleolithic of western Eurasia. However, the period in question, extending beyond 40 000 years BP, is at the extreme range of the method, which at this age is susceptible to contamination and without an agreed-upon calibration method. Several other chronometric methods, such as thermoluminescence and uranium series dating, have been applied to a number of sites. But so far, dates are few, with rather large error ranges, and have not generally been directly calibrated to radiocarbon dates. Climatostratigraphic frameworks based on pollen or cave sedimentology have been proposed for a number of regions. However, problems of adequate sampling, of unrecognized stratigraphic lacunae, and of reliable intersite and interregional correlation have reduced the confidence of many workers in the ability of these schemes to reliably correlate sites and their contents. The effect of these problems is illustrated by the new "battle of the Aurignacian" (Zilhão and d'Errico, 2000) which has witnessed a fundamental disagreement over the chronology of the Aurignacian and Châtelperronian in Western Europe, the best-known province of Paleolithic Eurasia.

Here we discuss a relatively new method for tracing paleoclimate and effecting intersite correlations, and its applicability to the chronology of the Middle to Upper Paleolithic transition (Ellwood et al. 2001). We believe that it can be added to our armamentarium of methods as an independent line of evidence that can help resolve some dating uncertainties in the period under discussion. We will here briefly discuss the essentials of this method, and then will briefly illustrate its application at two key sites relevant to the chronology of the early Aurignacian.

The method

Magnetic susceptibility (MS) is a property of sediments, including cave sediments, that can be measured and, under the proper circumstances, is indicative of paleoclimate. MS is not to be confused with remanent magnetism, the intrinsic magnetization that accounts for the magnetic polarity record contained in some materials. This method is instead based on the fact that all materials become magnetic when placed in a magnetic field; MS is an indicator of the strength of the induced magnetism within a sample.

In a geoarcheological context, MS is considered to be an indicator of iron mineral concentration and can be quickly and easily measured on small, unoriented samples. MS works as a proxy for climate in many cave sediments because climate controls this magnetic property of the sediments deposited in the cave, primarily as the result of pedogenesis outside the cave. Pedogenetic processes produce abundant magnetic minerals such as maghemite and magnetite, and it is primarily their abundance that determines the magnetic susceptibility of soils. These sediments are then eroded, deposited and preserved in caves. The measurement of the sediments' MS and its change over time through a cave's stratigraphic profile allows inference of climatic change, opening the door to correlation between the stratigraphic sequences of multiple sites in which MS measurements have been made.

Application of the method involves sampling sediments in 2 cm^3 plastic boxes in a continuous vertical series from stratigraphic profiles at each site. Each sample thus measures MS in a 2-cm-thick accumulation of sediment. Sampling is performed in close coordination with site excavators so that the stratigraphic provenience of MS samples is known and can be related to that of isotopic dates and artifactual and ecofactual materials from each site. Each sample is sieved and the <1 mm fraction is measured three times using the susceptibility bridge in the Rock Magnetism Laboratory at Louisiana State University.

Other effects on magnetic susceptibility

As already noted, the predominant explanation for the MS trends observed in cave sediments is the production of magnetic minerals in open-air soils by pedogenesis, erosion of soils and their transportation into caves, and finally the deposition and preservation of the sediment. Under certain circumstances, other factors may modify MS levels in such sediments, potentially disrupting the climatic signal. However, we believe that with due care these sources of error can be avoided or allowed for. Some of these include sediment sources other than soils, gaps in the sedimentary record due to nondeposition and/or erosion, post-depositional alteration and sediment mixing. Many of these problems can be avoided by careful, high-density, continuous sampling, sample treatment before measurement (such as screening out the coarse fraction), and careful evaluation of sedimentary sections being sampled, avoiding problem areas where possible.

While the effect of hearths burning within sites can affect the MS signal of immediately adjacent sediments, our work (Ellwood et al., 1995, 1996) has shown that this effect is relatively small compared to the overall MS variation observed. Finally, because pedogenesis occurring in sediments has a major effect on MS, it is important to sample cave sediments sufficiently protected from outside processes so that within-site pedogenesis has not taken place, or is minimal. It is also important to look for and to isolate zones of alteration within sampled sequences, and when identified these anomalous sediments should not be used in building a CRS composite.

MSEC

Using the method of graphic correlation (see Shaw, 1964), an MSEC composite reference section can be built and then expanded, as data from more sites are gradually added and correlated with the existing CRS (Ellwood et al., 2001). The compositing process begins with the construction of time/depth graphs based on ^{14}C ages. One of these is initially chosen as the reference standard (i.e. that section into which data from the other sections will be graphically compiled), which, by convention, is placed on the x-axis.

In our earlier work (Ellwood et al., 2001), excavations at Konispol Cave, Albania, served as the standard of reference. Graphic comparison of sections produces a scatter of data points through which a two-segment line of correlation (LOC) is placed (see Fig. 1). This LOC is offset by unconformities, here illustrated by the thick dashed line in the center of Fig. 1,

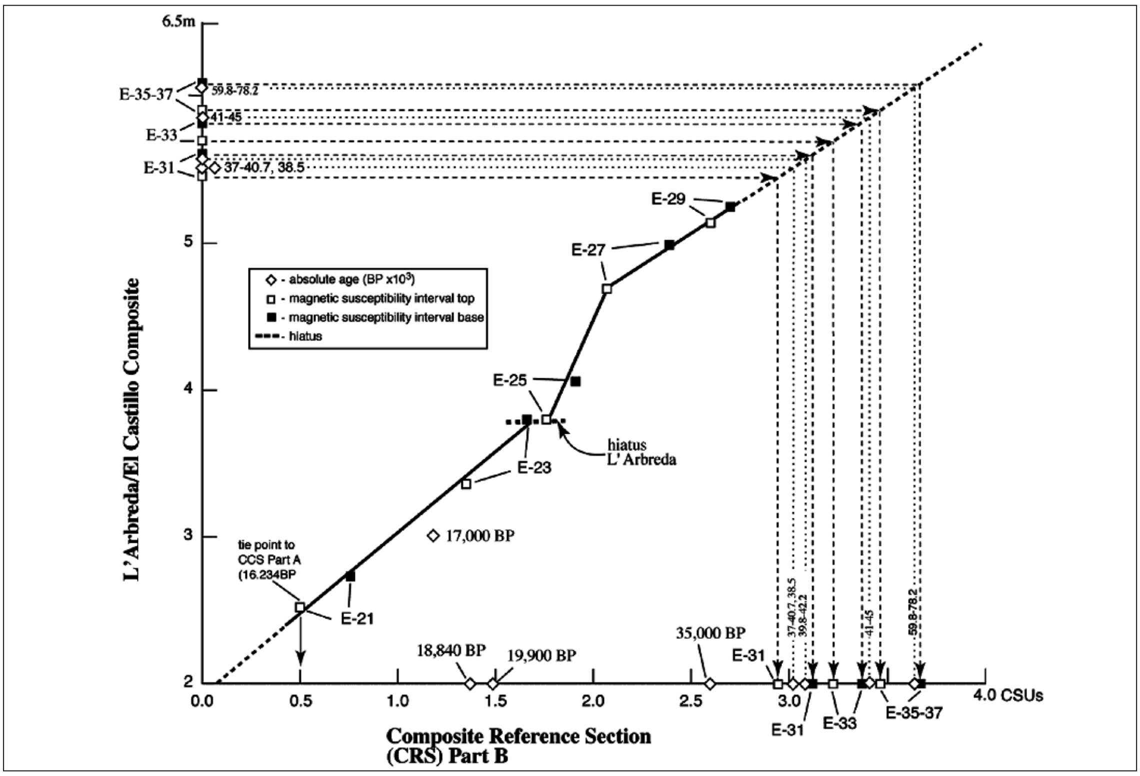

FIG. 1 – MSEC composite reference section (CRS) for Europe for the period ca.44 000 to ca.16 000 years BP, uncalibrated ^{14}C ages. Ages defining the CRS are derived from the graphic correlation method (see text; Shaw, 1964) and modified from Ellwood et al. (2001). This composite represents a compilation of MSEC bar logs drawn from Konispol Cave, Albania; El Mirón Cave (two sections El Mirón 1 and Top El Mirón 2), El Castillo Cave and L'Arbreda Cave, Spain; Almonda Oliveira Cave, Caldeirão Cave and Picareiro Cave, Portugal (Fig. 2).

labeled ‘hiatus L’Arbreda.’ Data points unique to any new cave section (y-axis) enter the standard section by projecting these points horizontally into the LOC and then vertically down into the x-axis; the standard section at this point becomes the Composite Reference Standard (CRS Part B: In part B we have connected CRS Part B to CRS Part A using the Caldeirão Cave [Portugal] section by projecting the Caldeirão data set into the top of MSEC Zone E-21). In Fig. 1 we are using as the y-axis a composite of both L’Arbreda and El Castillo (developed later in this paper). By projecting the LOC backward in time, it is possible to extend data past the physical limits of the initially chosen reference section. This process is illustrated by the projection of MSEC intervals E-31 to 37 in Fig. 1 (dashed arrows). Therefore, the CRS is a graphic construct that grows and becomes better defined with the addition of each new data set. This method is explained in greater detail than is possible here, in Ellwood et al. (2001).

It is crucial to remember when using these methods, that while MSEC in combination with the graphic correlation method can be a powerful correlation tool, it cannot stand alone. Independently derived age estimates are needed for the sections sampled, so that correlation among sites depends not only on similar patterns of climate change, but also on chronometric dates. Also needed and critically important is close coordination and interaction with archeologists working at each site to identify and resolve any ambiguities or anomalies that may arise during the sampling or interpretation phase of the work. In our work here and following our published work in 2001 (Ellwood et al., 2001), we were able to establish that lower portions in one of the caves used in building the CRS, El Mirón Cave, may have been altered (Straus and Farrand, personal communication). In addition, according to Straus and Farrand, radiocarbon dates for El Mirón 2 were previously reported incorrectly in Ellwood et al. (2001). Therefore, we have removed the problematic portion of El Mirón 2 from the data set, have corrected the affected ages, rebuilt the CRS and represent the changes in Fig. 1, extending from ca.16 000 to 45 000 BP and in Figure 2, a bar log representing climate changes for the last ca.44 000 years. Adjusted ages for this new result are given in Table 1.

TABLE 1

Adjusted uncalibrated ages for warm periods determined for the MSEC CRS

Zone	Top Age	Bottom Age	Zone	Top Age	Bottom Age
E-1	3000	3300	E-19	15 100	15 400
E-3	3700	4200	E-21	16 000	16 400
E-5	4500	4800	E-23	19 500	22 000
E-7	5000	5500	E-25	23 000	25 700
E-9	6300	6700	E-27	27 900	32 000
E-11	7000	7600	E-29	34 000	35 900
E-13	8800	10 000	E-31	38 800	40 500
E-15	11 000	11 300	E-33	43 000	43 800
E-17	13 200	14 000	E-35	44 500	46 000

Ages for E-1 to E-21 Top are as in Ellwood et al. (2001). Ages from E-21 Base modified from the CRS of Ellwood et al. (2001) by the addition of El Castillo Cave data and deletion of the bottom portion of El Mirón 2 data, suggested to be suspect, and the slight correction of El Mirón 2 ages that were previously reported incorrectly (Ellwood et al., 2001). Tops are youngest ages and Bottoms are oldest ages for the warm MSEC zones given here. Errors (±500 years) are estimated from the graphic process and also account for some of the ^{14}C uncertainties. At this time the base of E-35 is poorly constrained.

In rebuilding the MSEC CRS we have added our results from the well-dated upper levels at El Castillo Cave, northern Spain. The graph of MS results in Fig. 3, for El Castillo Cave, as well as all the results we have presented from other caves in Fig. 2, shows considerable short-term variability as well as long-term trends. We interpret these data as representing

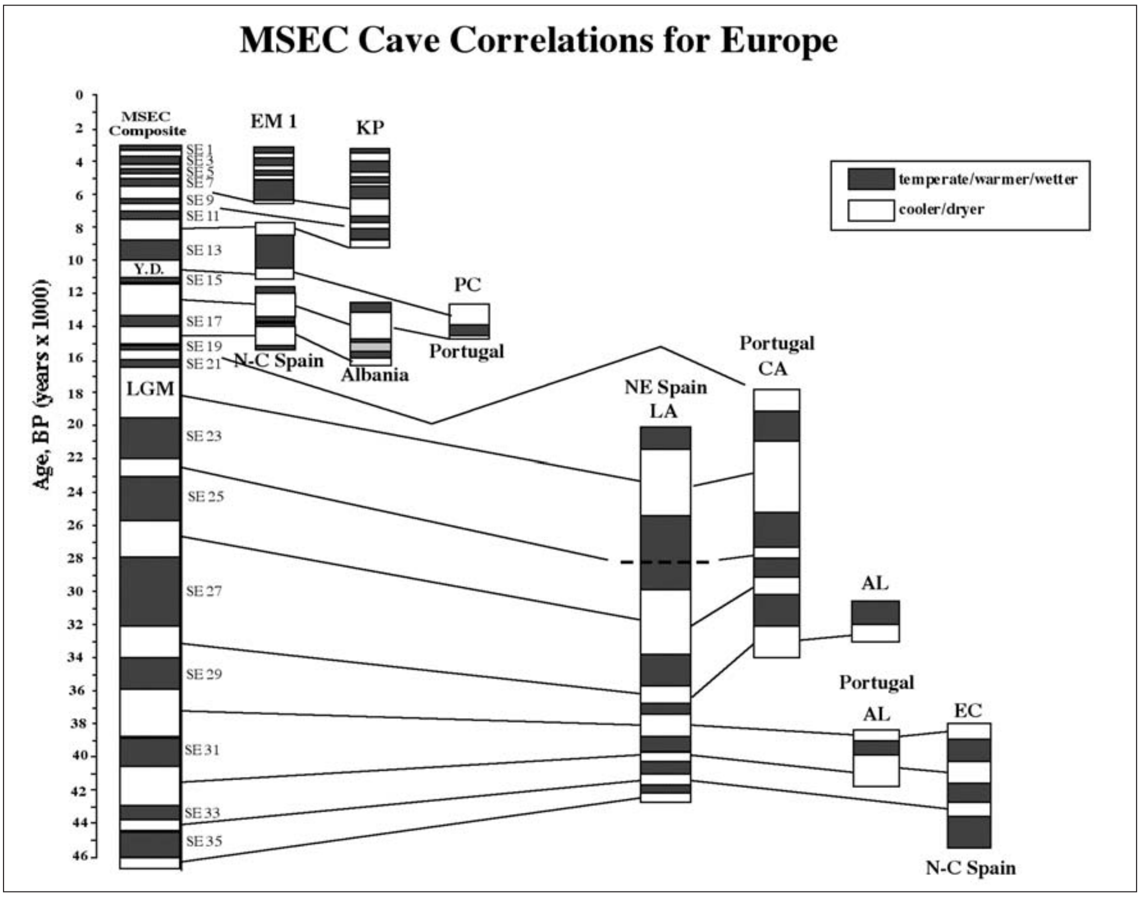

FIG. 2 – MSEC composite reference section (CRS) for southern Europe for the period ca.44 000 to ca.3000 years BP. Ages defining the CRS are derived from graphic correlation presented by Ellwood et al. (2001), modified here (Fig. 1) and are presented in Table 1. This composite represents a compilation of MSEC bar logs drawn from Konispol Cave (KP), Albania, El Mirón Cave (two sections, EM 1 and EM 2 revised), L'Arbreda Cave (LA) and El Castillo Cave (EC), Spain; Almonda Oliveira Cave (AL), Caldeirão Cave (CA) and Picareiro Cave (PC), Portugal. Tie lines connecting zones of similar ages are given in the figure. Dashed line represents a hiatus in L'Arbreda. The separation in the Almonda Oliveira, El Mirón 1 and Konispol Cave bar logs represent longer hiatuses.

changes between generally warmer (and usually wetter) periods with more pedogenesis, resulting in higher MS levels, and cooler (and usually drier) periods, with less pedogenesis, and correspondingly lower MS levels. For purposes of climatic interpretation and correlation, the bar logs in Figs. 2 and 3 simplify the presentation of MSEC results into zones of relative high and low MS values, much as the continuous curves of $\delta^{18}O$ values of the oxygen-isotope SPECMAP are divided into numbered stages (Imbrie et al., 1984). The hatched areas represent higher MS and warmer temperatures, while open areas represent lower MS and cooler conditions. The graphic display of results (Fig. 1) incorporates the location of chronometric dates, and the raw MS data and bar logs as presented for El Castillo Cave in Fig. 3 allow presentation of cultural attributions of associated archeological remains.

Results and discussion

Our updated Composite Reference Standard (CRS; Fig. 2) is derived from data from eight sites in Europe (Spain, Portugal, and Albania) and proposed for the period from roughly 3000 to 44 000 BP, thus including the span of the Upper Paleolithic and the late

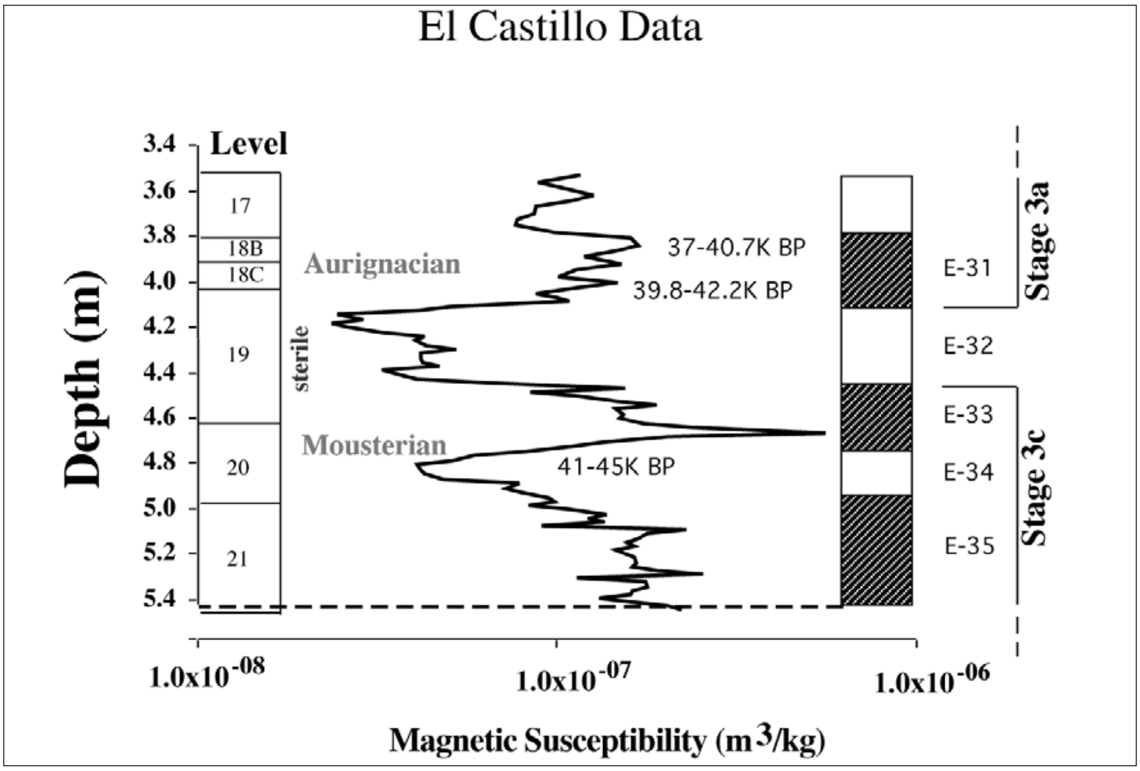

FIG. 3 – The MS curve from El Castillo Cave in north central Spain, with uncalibrated ^{14}C ages in years BP. "Level" refers to the excavation level. The bar logs in the diagram represent MSEC zones of relatively high and low MS values. Hatched areas represent higher MS and warmer temperatures while open areas represent lower MS and cooler times. Zones are differentiated based on midpoints between trends toward decreasing or increasing MS. Note the hiatus in sedimentation (dashed line). The oxygen isotopic stages are given at the right as is the MSEC nomenclature.

Middle Paleolithic. The timeline for the CRS is in uncalibrated radiocarbon years. The CRS identifies the MSEC stages, or zones (bar logs in Fig. 2, numbered from E-1 back to E-35), that have been identified, and notes the zones that have been correlated with the Last Glacial Maximum and Younger Dryas. It also shows how hiatuses in the profiles at some sites, due to nondeposition and/or erosion, are compensated for by sections of the sequences at other sites. Continued incorporation of more sites into the CRS will improve its accuracy and precision, but already the main lines of late Pleistocene climatic change have emerged, and these generally agree well with other lines of evidence, such as pollen data and harmonic studies that show a ca.2500 year Neo-glacial climate cyclicity (Ellwood et al., 1996, for Konispol Cave, Albania; Ellwood et al., 1998, for Caldeirão Cave, Portugal; for El Mirón Cave, Spain, unpublished data) known for the Holocene (Mitchell, 1976) and late Pleistocene (O'Brien et al., 1995).

In the time period of interest here, the climatic fluctuations associated with later portions of oxygen-isotope Stage 3 are well reflected, but, because our CRS is preliminary and needs additional data points, the error estimates for CRS dates with increasing age become larger, creating some age uncertainties. In addition, this is compounded by the age uncertainties associated with ^{14}C dates. However, we are able to correlate the well-known Hengelo warm phase, characterized palynologically (ca.40-38 ka) and often identified with the Würm II-III interstadial, with our warm zone E-31 (40 500 to 38 800 [±500] BP). This association is important when considering the two sites of significance to us in this paper, El Castillo Cave and L'Arbreda Cave (see discussion below).

Aurignacian of Northern Spain

Of particular interest in the context of this volume are two Spanish sites that span the Middle-Upper Paleolithic transition and have figured prominently in discussions of it because of early radiocarbon dates for the early (or "proto-") Aurignacian: L'Arbreda (Fig. 4) in Catalunya (Bischoff et al., 1989) and El Castillo (Fig. 3) in Cantabria (Cabrera et al., 1996). Fig. 4 shows MSEC data for L'Arbreda, indicating the stratigraphic location of the earliest Aurignacian artifacts. The CRS (Fig. 1) places the initial Aurignacian at this site in zone E-31, roughly 40 500 to 38 800 BP, and thus presumably falling within the Hengelo interstadial period. The placement in this relatively warm period is in agreement both with the radiocarbon dates for the earliest Aurignacian at L'Arbreda, and with the palynological characterization of the associated sediments as interstadial.

In Fig. 3, the MSEC data for El Castillo are displayed along with stratigraphic designations, cultural attributions, chronometric dates, MSEC zones, and suggested oxygen isotope stage correlations. The final Mousterian at the site was deposited in level 20, during

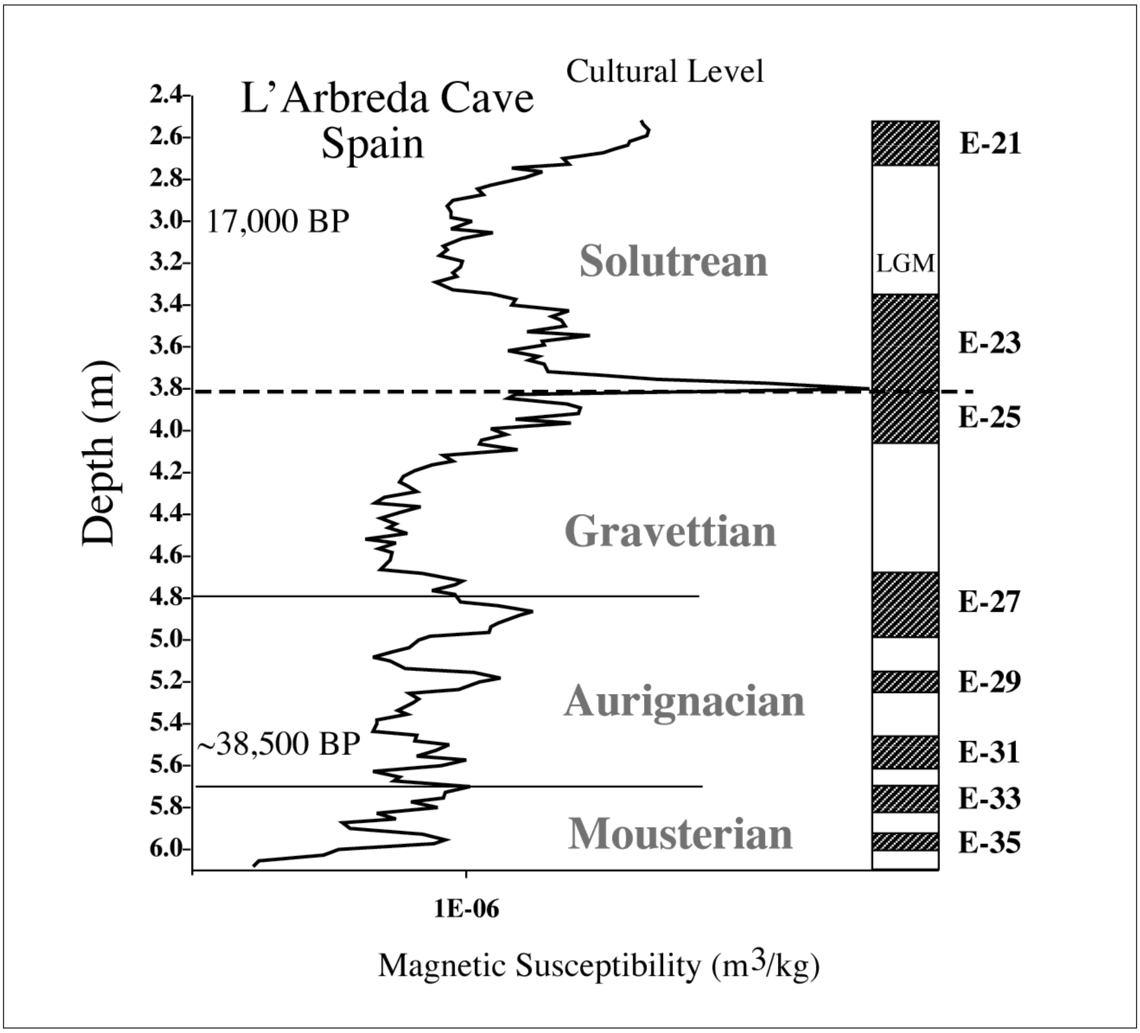

FIG. 4 – The MS curve from L'Arbreda Cave in northeastern Spain, with uncalibrated ^{14}C ages in years BP. The bar logs in the diagram represent MSEC zones of relatively high and low MS values. Hatched areas represent higher MS and warmer temperatures while open areas represent lower MS and cooler times. Zones are differentiated based on midpoints between trends toward decreasing or increasing MS. Note the hiatus in sedimentation (dashed line). This is shown and labeled in Fig. 1 and shown in Fig. 2 by the dashed line. The MSEC nomenclature is given at the right of the diagram.

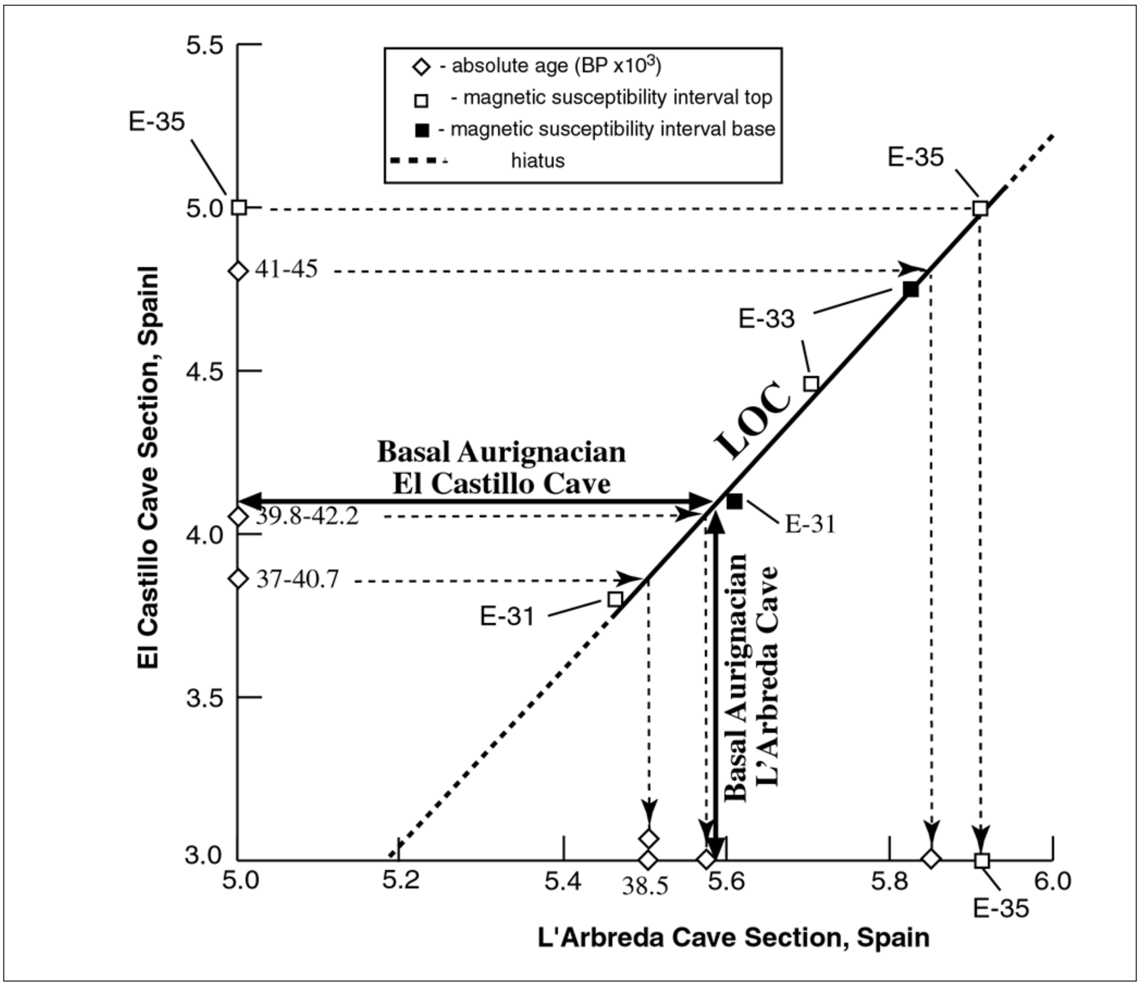

FIG. 5 – Graphic correlation diagram beginning with a graph of El Castillo (y axis in meters) that is correlated against L'Arbreda (x axis in meters). The MSEC zones that are common to the two caves are plotted. The top of E-35 is projected from El Castillo into the L'Arbreda axis as are the dates from for El Castillo (dashed arrows). Note the excellent correspondence with the one date at this level available for L'Arbreda (ca.38 500; see Fig. 4). Also presented are the basal Aurignacian cultural levels for each cave, projected through the LOC (Line of Correlation) into both cave excavation lines (solid arrows). The agreement is perfect within the age uncertainties.

our zone E-34 (and perhaps the beginning of zone E-33). Zone E-34 is a cold period, and sedimentological evidence also indicates cold conditions during deposition of level 20 (Cabrera et al., 1996). Level 19, now characterized as archeologically sterile (Cabrera et al., 2001), was deposited during warm zone E-33 and cold zone E-32 times. The earliest Aurignacian artifacts come from level 18C, identified by the CRS with warm E-31, and hence representing the Hengelo interstadial period. This is again consistent with site sedimentology and faunal evidence, according to which level 18 is climatically mild. Given the uncertainties in ages, this attribution is consistent with the radiocarbon dates from level 18 (Fig. 3).

Thus MSEC results from L'Arbreda and El Castillo support the implication of their radiocarbon dates that these sites indeed see early occurrences of the Aurignacian, dating to the Hengelo interstadial period. The close similarity between the two sites is graphically shown in Fig. 5, where El Castillo is plotted on the y-axis and L'Arbreda on the x-axis. Ages and MSEC zones determined from the El Castillo excavation are projected through the Line of Correlation (LOC - solid line in Fig. 5) into the L'Arbreda data set for comparison (dashed arrows in Fig. 5). This graphic comparison shows the close similarity in ages (^{14}C and

MSEC zone boundaries) and climatic (MSEC zone) character, and illustrates the close agreement between the two caves. In fact, when the basal Aurignacian excavation level from L'Arbreda is graphically compared with the corresponding level at El Castillo (bold solid arrows in Fig. 5), it is clear that, within the age uncertainties, the basal Aurignacian is identical in age between the two sites. Therefore, we interpret our data to indicate that the El Castillo Aurignacian and the L'Arbreda Aurignacian, both assigned to MSEC zone 31, are probably equivalent in age and in climatic phase. Whether the Aurignacian is an intrusive (Zilhão and d'Errico, 2000) or an autochthonous (Cabrera et al., 2001) phenomenon in Spain, this inference supports the case that the earliest appearance of the Aurignacian in northern Spain is contemporary with the late Mousterian, rather than subsequent to it.

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