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Luminescence dating and palaeomagnetic age constraint on hominins from Sima de los Huesos, Atapuerca, Spain

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ABSTRACT

Establishing a reliable chronology on the extensive hominin remains at Sima de los Huesos is critical for an improved understanding of the complex evolutionary histories and phylogenetic relationships of the European Middle Pleistocene hominin record. In this study, we use a combination of 'extended-range' luminescence dating techniques and palaeomagnetism to provide new age constraint on sedimentary infills that are unambiguously associated with the Sima fossil assemblage. Post-infrared-infrared stimulated luminescence (pIR-IR) dating of K-feldspars and thermally transferred optically stimulated luminescence (TT-OSL) dating of individual quartz grains provide weighted mean ages of 433 ± 15 ka (thousands of years) and 416 ± 19 ka, respectively, for allochthonous sedimentary horizons overlying the hominin-bearing clay breccia. The six replicate luminescence ages obtained for this deposit are reproducible and provide a combined minimum age estimate of 427 ± 12 ka for the underlying hominin fossils. Palaeomagnetic directions for the luminescence dated sediment horizon and underlying fossiliferous clays display exclusively normal polarities. These findings are consistent with the luminescence dating results and confirm that the hominin fossil horizon accumulated during the Brunhes Chron, i.e., within the last 780 ka. The new bracketing age constraint for the Sima hominins is in broad agreement with radiometrically dated *Homo heidelbergensis* fossil sites, such as Mauer and Arago, and suggests that the split of the *H. neanderthalensis* and *H. sapiens* lineages took place during the early Middle Pleistocene. More widespread numerical dating of key Early and Middle Pleistocene fossil sites across Europe is needed to test and refine competing models of hominin evolution. The new luminescence chronologies presented in this study demonstrate the versatility of TT-OSL and pIR-IR techniques and the potential role they could play in helping to refine evolutionary histories over Middle Pleistocene timescales.

Introduction

The endokarstic system of the Sierra de Atapuerca, north-central Spain, comprises an extensive network of cavities, passages and galleries spanning more than 4.7 km (Fig. 1). The 50 or so sediment-filled cavities explored to date have yielded an unparalleled archive of Early to Late Pleistocene hominin remains, lithic tools and associated faunal assemblages (e.g., Arsuaga et al., 1993, 1997a, 1999; Carbonell et al., 1995; Carbonell, 2008; Bermúdez de Castro et al., 1997, 1999; Cuenca-Bescós et al., 2010; Rodríguez et al., 2011; Ollé et al., 2013). One of the most prolific palaeoanthropological sites discovered at Atapuerca is Sima de los Huesos or the 'Pit of Bones' (herein abbreviated to 'Sima'), a small phreatic chamber in the lowest level of the Cueva Mayor-Cueva del Silo karst system, located >500 m from the cave entrance of Cueva Mayor and ~35 m below the present-day surface (e.g., Arsuaga et al., 1997a; Ortega et al., 2013) (Figs. 1 and 2a and b). The site is renowned for its unique accumulation of hominin fossils (Arsuaga et al., 1993, 1997a,b), which totals more than 6500 remains from at least 28 individuals (Bermúdez de Castro et al., 2004) and represents ~80% of the global Middle Pleistocene fossil record for the genus *Homo*. This fossil collection grows in number with every excavation season, providing new opportunities to assess intra- and

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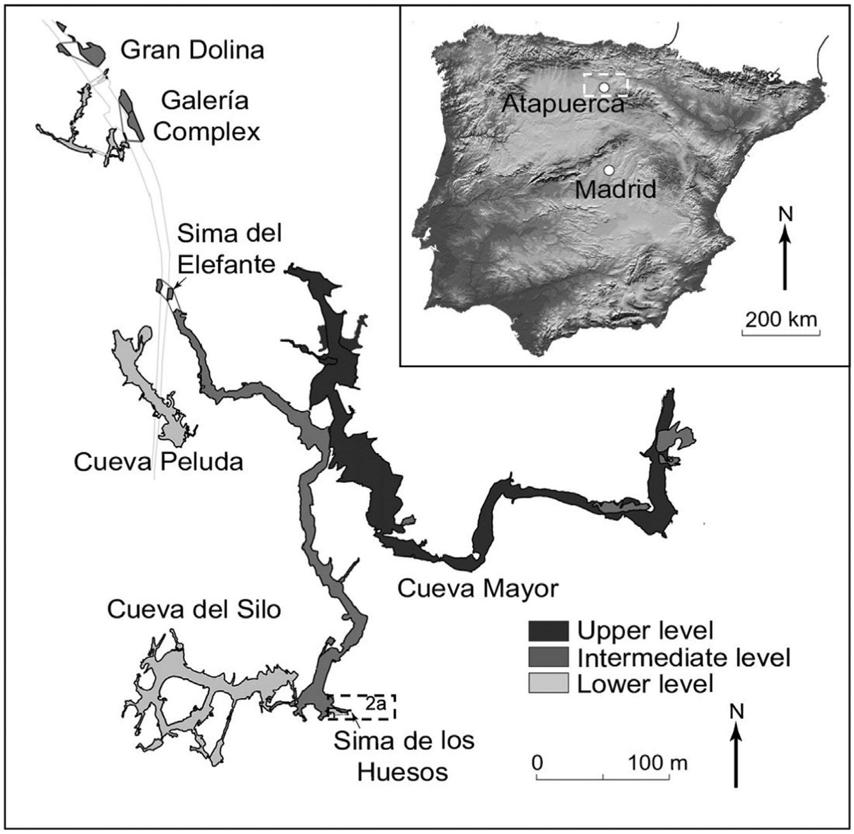

Figure 1. Map of the Atapuerca endokarst system showing the location of the Sima de los Heusos site (modified from Ortega et al., 2013). The inset map shows the location of the study area in north-central Spain.

inter-population variability in the Middle Pleistocene hominin record (e.g., Arsuaga et al., 1997b,c; Lorenzo et al., 1998; Martinón-Torres et al., 2006, 2012). The Sima hominin assemblage is also of importance for understanding the origins of the Neanderthal lineage since the fossils display some Neanderthal traits and have been cited as evidence for a *Homo heidelbergensis*–*Homo neanderthalensis* continuum in Europe (e.g., Arsuaga et al., 1993, 1997a,b; Rosas, 2001; Bermúdez de Castro et al., 2004; Hublin, 2009; Martinón-Torres et al., 2012). Debate continues, however, over the phylogenetic relationships of Early to Middle Pleistocene hominin populations, and the nature and timing of evolutionary divergences in the Eurasian hominin lineage (e.g., Arsuaga et al., 1997b; Endicott et al., 2010; Dennell et al., 2011; Stringer, 2012; Bermúdez de Castro and Martinón-Torres, 2013). Establishing unequivocal age constraint on the Sima fossils is therefore critical for understanding the palaeoanthropological history and palaeoclimatic context of this site and has broader implications for evaluating competing models of Middle Pleistocene human evolution.

Reliable dating of unheated sedimentary material within Middle Pleistocene karstic cave systems remains a challenge for many geochronological techniques. Two approaches that offer good potential for establishing age control in such settings are palaeomagnetic reversal dating and luminescence dating techniques. Palaeomagnetic dating has been extensively applied to the endokarstic infill sequences at Atapuerca (e.g., Parés and Pérez-González, 1995, 1999; Parés et al., 2000, 2006, 2010, 2013) and has been integral in establishing a Lower Pleistocene age for the *Homo antecessor* fossils at Sima del Elefante and Gran Dolina (Carbonell et al., 1995; Carbonell, 2008). Luminescence dating techniques, particularly single-grain optically stimulated luminescence (OSL) dating of quartz (e.g., Murray and Roberts, 1997; Duller, 2008), are increasingly being used to date Late Pleistocene archaeological deposits in cave and rock shelter settings (e.g., Bowler et al., 2003; Bouzouggar et al., 2007; Petraglia et al., 2007; Jacobs et al., 2008; Armitage et al., 2011). However, conventional quartz OSL methods are limited in their application to Middle Pleistocene sites because the main signal used for dating (the so-called 'fast component') becomes saturated with respect to radiation dose over longer timescales. Dose saturation effects typically impose a practical upper age limit of ~100–200 ka (thousands of years) for quartz OSL, depending on sample-specific luminescence properties and the specific activities of radionuclides in the sedimentary matrix. Nevertheless, the last decade has seen the emergence of several 'extended-range' luminescence dating techniques that make use of alternative luminescence signals with significantly higher dose saturation limits (e.g., Fattahi and Stokes, 2000; Singarayer et al., 2000; Huot et al., 2006; Wang et al., 2006a,b; Jain et al., 2007; Thomsen et al., 2008).

Two such extended-range luminescence dating techniques offer particularly good potential to circumvent conventional OSL restrictions at Middle Pleistocene sites such as Sima de los Huesos: namely, thermally transferred OSL dating of quartz (TT-OSL; Wang et al., 2006a,b) and post-infrared-infrared stimulated luminescence dating of K-feldspars (pIR-IR; Thomsen et al., 2008; Buylaert et al., 2009). Thermally transferred OSL is the light-sensitive signal observed following initial depletion of the main OSL signal and application of a preheat treatment to induce a transfer of charge into the conventional quartz dating trap (e.g., Duller and Wintle,