Lower Pleistocene Hominids and Artifacts from Atapuerca-TD6 (Spain)

E. Carbonell,* J. M. Bermúdez de Castro, J. L. Arsuaga, J. C. Díez, A. Rosas,† G. Cuenca-Bescós, R. Sala, M. Mosquera, X. P. Rodríguez

Human remains dating to more than 780,000 years ago are associated with a rich faunal and lithic assemblage in the Pleistocene cave site of Gran Dolina (TD), Sierra de Atapuerca, Burgos, Spain. The micromammal species represent the late Biharian (*Mimomys savini* zone), and the lithic objects represent pre-Acheulean technology (Mode 1) and comes from the TD6 level below the Matuyama-Brunhes boundary. The Gran Dolina hominid fossils cannot be comfortably accommodated in any of the defined *Homo* species. They could be considered a primitive form of *Homo heidelbergensis*, but a new species might be named in the future if the sample is enlarged. The new human fossil evidence demonstrates that Western Europe was settled at least since the late early Pleistocene.

The very old Dmanisi mandible, from the Republic of Georgia, indicates that humans were ready to migrate to western Europe at a very early date, perhaps 1.8 million years ago (Ma) (*1*). However, although *Homo* was at the gates of Europe at the end of the Pliocene or beginning of the Pleistocene, some authors have recently stated that there was no human occupation of Western Europe before about half a million years ago (*2*). The Boxgrove tibia (England) and the Mauer mandible (Germany) would be the most ancient human fossils, with an estimated age of around 500,000 years (*3*). Other middle Pleistocene European fossils would be later, such as those from Bilzingsleben (Germany), Vertesszöllös (Hungary), Arago (France), Swanscombe (Britain), Sima de los Huesos (Atapuerca, Spain), and so on. In this paper, we describe lower Pleistocene human fossils discovered at Gran Dolina (Atapuerca, Spain), which imply an early occupation of Western Europe and fill the chronological gap between the oldest Eurasian fossils [Dmanisi and the first Javanese fossils (*4*)] and the Mauer or Boxgrove fossils.

The Sierra de Atapuerca, in northern central Spain (Duero basin) near the Arlanzón river and 14 km east of the city of Burgos (Fig. 1), contains numerous karst cavities in Cretaceous limestone that are filled with Pleistocene sediments. One of these deposits, the Sima de los Huesos (SH) site, has yielded up to the 1993 season more than 1300 human fossil remains (*5*). In an abandoned railway trench opened in the southwestern slope of the Atapuerca Hill, less than 1 km away from SH, karst fillings have been excavated since 1978 (*6–8*). One of these deposits, Gran Dolina (TD), contains 18 m of sediment, which can be divided into 11 lithologic levels, numbered from bottom to top (*9*). The paleontological record [pollen (*10*) and faunal remains] is continuous throughout the TD sequence (*7, 11*), and some levels (TD3-4, 5, 6, 7, 10, and 11) contain abundant stone tools.

Excavation of a 6 m^2 planar section was begun in 1993. During the 1994 season, excavation had reached level 6, and one of the TD6 strata, the so-called Aurora stratum (*9*), yielded a rich faunal and lithic assemblage, including more than 30 human fossil remains.

The TD faunal record shows that the small mammals from TD3-4, 5, 6, and 8 (*12*) represent the late Biharian (*Mimomys savini* zone) (*13, 14*). This zone is also seen at Huéscar 1 and Casablanca (or Almenara) 3 (Spain), West Runton and Westbury sub Mendip 1 (Britain), Tiraspol (Moldava), and Voigtsted (Germany), among others. The Biharian-Toringian boundary is marked by the last appearance of *M. savini* (*12, 15*). The beginning of the Toringian faunas is defined in southwestern Europe by the first appearance of the rootless rodent *Arvicola* and the end of the rooted arvicolids of the genus *Mimomys* [*Arvicola cantiana* zone (*14*)]. The TD10-11 levels represent the late-middle Pleistocene in Atapuerca. *Allocricerus bursae* and *Arvicola* aff. *sapidus* [data from E. Gil and C. Sesé (*11*)] are rodents characteristic of this age [*Arvicola* aff. *sapidus* zone, after J. Agustí and S. Moyà-Solà (*15*), late Toringian]. The mammal list from TD6 includes *M. savini*, *Pliomys episcopalis*, *Iberomys* sp. nov, Arvicolidae gen. sp. nov., *Allocricerus* sp., *Apodemus* aff. *flavicollis*, *Eliomys quercinus*, *Marmota marmota*, *Castor fiber*, *Hystrix major*, *Beremendia fissidens*, *Talpa* sp., *Erinaceus* sp., *Sorex* sp., *Crocidura* sp., Desmaninae indet., *Myotis myotis*, *Rhinolophus* sp., and Leporidae indet. Large mammals of TD6 include *Homo* sp., *Ursus* sp., *Felis sylvestris*, *Crocuta* sp., Proboscidea indet., *Equus caballus* ssp., *Sus scrofa*, *Cervus elaphus* aff. *acoronatus*, *Dama* cf. *clactoniana*, *Capreolus* sp., and *Bos* cf. *primigenius* (*16*).

The Aurora stratum has yielded 100 lithic objects formed from limestone, sandstone, quartzite, and two varieties of flint. The natural bases (*17*) were quartzite and sandstone pebbles. Limestone is picked up as pebbles as well as in blocks. Flint was selected as blanks or in blocks (*18*). The objective of the knapping methods was to produce a large proportion of flakes (positive bases) and, to a lesser extent, retouched flakes (second generation

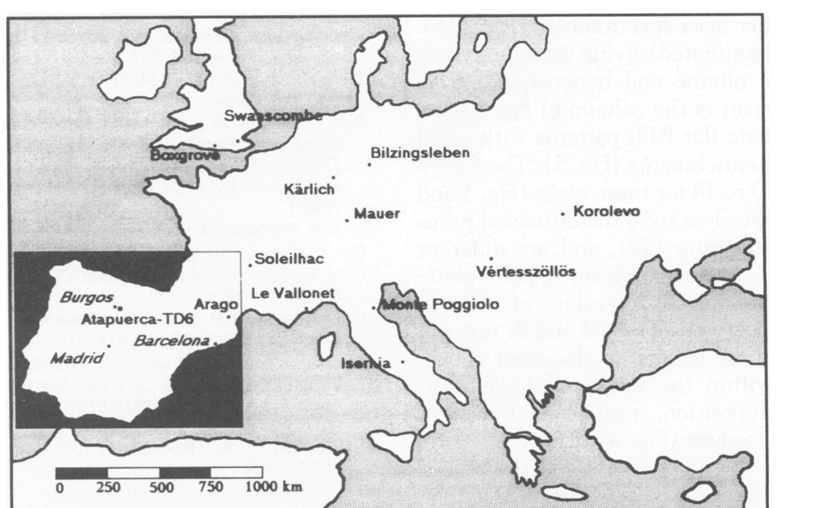

Fig. 1. Location of the Sierra de Atapuerca sites and other European sites discussed in the text.

E. Carbonell, R. Sala, X. P. Rodríguez, Laboratori d'Arqueologia, Universitat Rovira i Virgili, Imperial Tarraco, 1, 43005 Tarragona, Spain.
J. M. Bermúdez de Castro, J. C. Díez, M. Mosquera, Museo Nacional de Ciencias Naturales, CSIC, J. Gutiérrez Abascal 2, 28006 Madrid, Spain.
J. L. Arsuaga and A. Rosas, Departamento de Paleontología, Facultad de CC Geológicas, Universidad Complutense de Madrid, 28040 Madrid, Spain.
G. Cuenca-Bescós, Departamento de Geología, Facultad de Ciencias, Universidad de Zaragoza, 50009 Zaragoza, Spain.

*To whom correspondence should be addressed.
†Present address: Natural History Museum, London, Cromwell Road, London SW7 5BD, UK.

negative bases). Cores and heavy duty tools (first generation negative bases) represent 10% of the lithic record (Fig. 2, A and B). There is a low proportion of large pebble-tools, with two unifacials (choppers) standing out (Fig. 2B). The main edge morphology of the tools is dihedral, followed by the dihedral-trihedral association. The tool complex is characterized by the absence of hand axes, cleavers, picks, blade production, and well-elaborated retouched flakes. There is a high proportion of flakes coming from spherical and polihedric cores. These features imply that this lithic record is part of Mode I in the biofunctional or pre-Acheulean period (*19*).

Table 1. List of fossil hominid specimens from TD6 (*38*). All inventory numbers are preceded by ATD6-. P, proximal; M, middle; D, distal; fg, fragment.

Specimen	Inv. no.
Left LC	1
Left LI2	2
Right LP3	3
Right LP4	4
Right mandibular fg (M2-M3)	5
Fg of crown of right LC	6
Right UP3	7
Right UP4	8
Left UP4	9
Right UM1	10
Left UM1	11
Right UM2	12
Left maxillary fg (C-P3)	13
Left maxillary fg (dc-dm1)	14
Frontal bone fg	15
Fg of right temporal bone (asterionic zone)	16
Fg of right temporal (glenoid cavity)	17
Fg of left temporal bone (petrous region)	18
Fg of maxillar/zigomatic bones	19
Left temporal squama and parietal bone fg's	20
Middle one-third of a left radial diaphysis	21
Complete left adult patella	22
Eroded left adult hamate	23
Complete left adult capitate	24
Metatarsal 2-3. Left adult base	25
Metacarpal 2. Fragmented left adult head	26
P manual phalanx 2-3. Diaphysis	27
P manual phalanx. Head and distal diaphysis	28
M manual phalanx. D half	29
P pedal phalanx 1. Complete left adult bone	30
P pedal phalanx 1. Complete left adult bone	31
P pedal phalanx. D half	32
M pedal phalanx 2. Complete adult bone	33
M pedal phalanx 2-3. Complete adult bone	34
M pedal phalanx 4-5. Complete right adult bone	35
D pedal phalanx. Apical tuberosity	36

Thirty-six fragments of hominid bones have been recovered from the Aurora stratum of the TD6 level (Table 1). These fragments belong to at least four individuals, among which an early adolescent (hominid 1) and a child (hominid 2) are represented by cranial, mandibular, and dental remains (Table 2 and Figs. 3 to 5). The most complete cranial fragment is a large piece of frontal squama, ATD6-15 (mostly the right side, reaching the coronal suture), with parts of the glabellar and right orbital segments of the supraorbital torus. Though this fossil exhibits extensive sinuses, the pattern of surface bone configuration and the sharp edge of the orbital margin suggest that it belongs to an adolescent (*20*), possibly hominid 1 (see Fig. 3). If that is true, the supraorbital torus shape of the Gran Dolina specimen is probably close to that of an adult, but the thickness and projection of the torus, as well as the frontal squama thickness, could be substantially less. Compared with other hominid fossils, the estimated minimum frontal breadth of ATD6-15 (around 100 mm) is much greater than the early *Homo* values, and it is well above that of ER-3733, ER 3883, Sangiran 2, or Trinil (all of them skulls with cranial capacities below 1000 cm^3). It is also larger than the Zhoukudian sample or OH-9, and is similar to Sangiran 17, Sambungmachan, or the smallest Ngandong specimens. Finally, the minimum frontal breadth of the Gran Dolina specimen could be accommodated in the middle of the

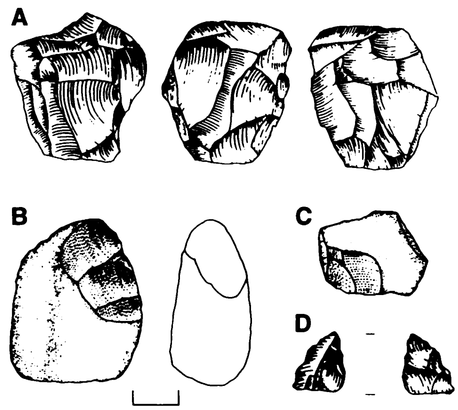

Fig. 2. Lithic industry of TD6. (**A**) Core (FGNB) made on neogene flint, with multiple rotation on preferential axes. (**B**) Unifacial heavy-duty tool (FGNB) made on limestone. (**C**) Flake (PB) made on quartzite. (**D**) Denticulate (SGNB) made on cretaceous flint. Scale bar, 3 cm.

Table 2. Tooth measurements (in millimeters) of hominids 1 and 2 from TD6. M, mesiodistal; B, buccolingual.

Tooth	Side	Maxillary		Mandibular	
		M	B	M	B
		Hominid 1			
I2	Left			7.0	7.8
C	Left	8.9	11.0	8.1	10.0
P3	Right	8.4	11.7	8.8	10.6
P3	Left	8.3	11.5		
P4	Right	8.1	11.6	8.2	10.2
P4	Left	8.0	11.7		
M1	Right	12.1	13.1	12.2	11.8
M1	Left	12.1	12.9		
M2	Right	12.1	13.7	13.5	12.0
		Hominid 2			
dc	Left	7.8	6.7		
dm1	Left	8.2	10.4		

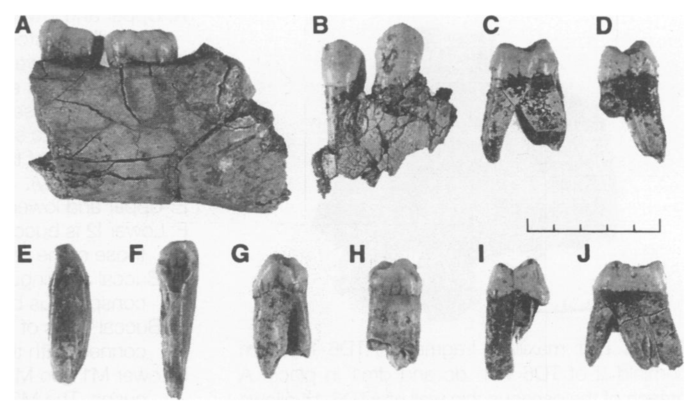

Fig. 3. Some of the fossil remains belonging to hominid 1. (**A**) Fragment of right mandibular body with M1, M2, and M3 in place (internal view). (**B**) Left maxillary fragment with C and P3 in place (buccal view). (**C** through **J**) Isolated permanent teeth of hominid 1 from TD6. (C) Left UM1, distal view; (D) left UP4, distal view; (E) left LI2, distal view; (F) left LC, distal view; (G) right LP3, mesial view; (H) right LP4, distal view; (I) right UM2, mesial view; (J) right UP3, mesial view (see the inventory numbers in Table 1). The criteria to determine the association of these teeth include the fit of the interproximal wear facets, the compatibility of the degree of oclusal wear, and the presence of a narrow, linear, hypoplastic enamel defect surrounding the whole crown of the upper and lower canines, third and fourth premolars, and second molars, caused by a stress episode during early childhood. The apices of the roots of the upper and lower second molars (seen by radiographic observation) were still not closed. The lower third molar did not erupt, and the distal root of this tooth is 2.0 to 2.5 mm long. The degree of root development of the latter would be approximately equivalent to that in modern humans 14.8 ± 2 years old (*36*). The occlusal wear stages and degree of root development of the premolars and second molars suggest an age at death between 13 and 15 years, also according to modern human standards (*37*). Thus, this individual probably died around age 14. The small size and smooth relief of the mandible suggest that these remains probably belonged to a female individual. Scale bar, 2.5 cm.

large Afroeuropean middle Pleistocene range or at the lower end of the Neandertal range. The preserved portion of frontal squama is thin, <5 mm thick. The supraorbital torus is double arched. This pattern clearly deviates from the straight (horizontal) supraorbital torus and the flattened supratoral shelf that are characteristic of Asian *H. erectus* and the African OH-9 calvaria. Dental traits B, C, E, and F (Table 3) clearly separate the TD6 hominids from *Homo habilis sensu stricto* (*21*). Dental traits B and C, as well as the size of the lower M3, indicate some reduction of the postcanine teeth in comparison with *H. habilis s. s.* and *Australopithecus afarensis*, a precocious trend in the evolution of the genus *Homo*. Other dental traits (A, D, G, H, I, J, L, and probably M and O) are plesiomorphies for the *Homo* clade and are usually found in *H. erectus* and *H. ergaster*. Dental trait M has been considered to characterize South and East African specimens from the genus *Australopithecus* (*22*). Dental trait K could represent an autapomorphic feature of the population represented by the TD6 hominids (*23*). Finally, dental trait F, and especially the mandibular traits B, C, and D that are also found in the Atapuerca-SH human fossil sample, point to an evolutionary continuity between the TD6 hominids and the European Middle Pleistocene hominids.

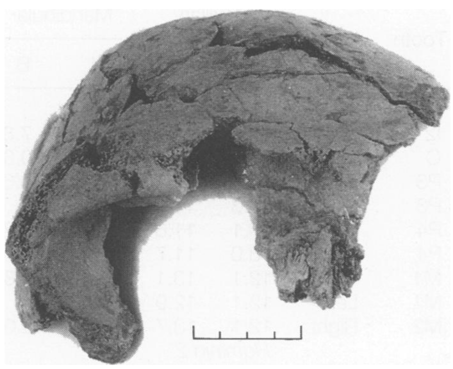

Fig. 4. Fragment of frontal bone (ATD6-15). Scale bar, 2 cm.

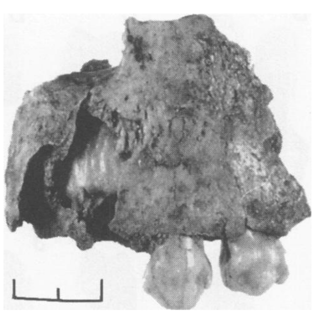

Fig. 5. Left maxillary fragment (ATD6-14) from hominid 2 of TD6 with dc and dm1 in place. A breach of the osseous thin wall of ATD6-14 allows one to observe incompletely the crown of permanent I1. The radiographic image shows the crown of permanent I2 and C, but it is not possible to discern their stage of crown formation. The radiographic image also shows that the roots of dc and dm1 and the crown of permanent I1 had completed growth. The presence of a distal interproximal wear facet on dm1, which also exhibits an incipient occlusal wear, indicates that dm2 was erupted as well. This dental development would correspond to that of a modern human child between 3 and 4 years old (*35*). Scale bar, 1 cm.

These fossils from the TD6 level establish the human settlement of Western Europe during the early Pleistocene. In consequence, this evidence will allow the reconsideration of data offered by some early Pleistocene Eurasian sites, in which the chronology has been established by geochronological dating methods as well. Farther east, paleomagnetic analyses from Le Vallonet (*24*) and Solheilac (*25*), France, have yielded a normal polarity. Following biostratigraphical criteria, the archaeological record from these sites has been assigned to the Jaramillo paleomagnetic event (from 0.99 to 1.07 Ma). In Italy, the Monte Poggiolo (*26*) and Isernia la Pineta (*27*) sites have yielded reverse polarity, presumably within the Matuyama chronology (>0.78 Ma). However, the Isernia faunal record seems to indicate a younger chronology, probably from the beginning of the middle Pleistocene. The stratigraphical series from Kärlich (Germany) (*28*) and Korolevo (Ukraine) (*29*) contain archaeological materials dated from the late early Pleistocene and middle Pleistocene. The earliest level from Kärlich has yielded a limited sample of lithic artifacts assigned to the Jaramillo event. Korolevo VIII and probably Korolevo VII are attributed to the late Lower Pleistocene. At Korolevo VIII, 400 artifacts were recovered below a sandy level dated by thermoluminescence (TL) to 0.85 Ma. In addition, the archaeological excavation conducted in 1990 in the level TD4 of the Gran Dolina site (4 m below TD6) yielded faunal remains and lithic artifacts (*30*) now assigned to the lower Pleistocene. In Eastern Europe, the lower levels of the Azykh cave (Azerbaijan) (*31*) have yielded an archaeological record assigned to the Matuyama event (>0.78 Ma). However, the earliest and least discussed Eurasian site is Ubeidiya (*32*), with a chronology that goes back to about 1.4 Ma. A similar age has been reported for the

Table 3. List of the most outstanding cranial, mandibular, and dental traits of the hominids from TD6.

Cranial traits

A. Double-arched supraorbital torus.
B. Transverse frontal diameters are expanded with respect to both early *Homo* and *H. ergaster*.

Mandibular traits

A. Mandibular robusticity is intermediate between those of the *H. ergaster* and Middle Pleistocene European samples. Height = 26.7 mm; breadth = 16.3 mm; index = 61.04 (at the M1 level).
B. Position and shape of the mylohyoid line, as well as the topology of masseteric and submaxillary fossae, are identical to those of the Atapuerca SH site specimens (*39*).
C. Internal side shows no evidence of lateral expansion of the superior transverse torus.
D. Even height along the mandibular body with absence of antegonial notch.

Dental traits

A. Upper and lower canines are large with respect to those of the African and Eurasian Lower and Middle Pleistocene hominids, and are large relative to premolars.
B. Upper and lower postcanine teeth are large with respect to those of the Middle Pleistocene hominids but smaller than those of most early *Homo* specimens assigned to *H. habilis s. s.* (*15*).
C. P3 > P4 size sequence for the crown area of the upper and lower premolar series.
D. M1 < M2 size sequence for the crown area of the upper and lower molar series. The mesiodistal dimension of the lower M3 is similar to that of the lower M1 (measurements taken by radiography).
E. Upper and lower premolars and first molars are broad buccolingually.
F. Lower I2 is buccolingually enlarged, and crown shape index (BL/MD) is appreciably higher than those of the early *Homo* and Zhoukoudian hominids.
G. Buccal and lingual faces of all postcanine teeth are quite swollen by the presence of a conspicuous basal prominence.
H. Buccal faces of the lower premolars show mesial and distal marginal ridges and grooves, which connect with the shelflike basal prominence or cingulum.
I. Lower M1 and M2 show a Y-pattern of the buccal and lingual grooves separating the five principal cusps. The M2 also exhibits a C7.
J. Enamel of the occlusal surface of the postcanine teeth is moderately to remarkably crenulated, though not as marked as in the Zhoukoudian teeth.
K. Root system of the lower P3 and P4 is formed by a mesiobuccal (MB) platelike root with two pulp canals and a distolingual (DL) root with a single canal. In P3 and P4, the bifurcation of the two roots is about 3 and 6 mm from the cervical enamel line, respectively. The buccal components of the MB root and the DL root are joined by an interradicular sheet, though they are free on less than its apical one-third.
L. Root system of all teeth is short relative to the crown dimensions.
M. Lingual cusp of lower P3 and P4 is mesial to the buccal cusp.
N. Upper dc shows well-differentiated mesial and distal cusplets or styles, as well as mesial and distal grooves and a clear basal prominence.
O. Upper dm1 exhibits a strong molar tubercle and a small parastyle.

human mandible from Dmanisi (Georgia) (*1*).

In central Asia, the Kuldara site is included within a broad stratigraphical series of loess with paleosoils, which have yielded a TL age of 0.85 Ma (*19*). In eastern Asia, the findings assigned to the lower Pleistocene have some dating problems. This is the case for Yuanmou, Yihoudou, and Gongwangling. In contrast, Donggutuo and Xiaochiangliang seem to have yielded more reliable dates. These sites show reverse polarity, which may be correlated either with the Matuyama event (>0.78 Ma) or with the pre-Jaramillo chronology (>1.07 Ma) (*33*). The new dates reported for two hominid sites in Java (1.81 and 1.66 Ma) have opened an exciting debate about the first hominid expansion out of Africa (*4*, *34*).

The presence in the TD6 hominids of numerous primitive traits, together with the absence of hand axes, picks, and cleavers, which allow inclusion of the lithic industry in pre-Acheulean technology (Mode 1), suggest that the settlement of Western Europe probably occurred during the early Pleistocene at an early time in the evolution of the genus *Homo*. In our opinion, the European middle Pleistocene fossils are, as a whole, ancestors of the late Pleistocene Neandertals. Moreover, the late middle Pleistocene European fossils are probably fully Neandertal. So we believe that human evolution in Europe is anagenetic in the middle Pleistocene. From a strictly cladistic point of view, if a specific name is given to Neandertals (*H. neanderthalensis*), their European middle Pleistocene ancestors should be included in the same species. However, the evident morphological differences between fossils such as those from Petralona, Arago, Steinheim, or Sima de los Huesos and the "classic" Neandertals make a European Middle Pleistocene species termed *H. heidelbergensis* acceptable. We believe that this taxon should not include African or Asian Middle Pleistocene fossils, because they belong to separate clades: either *H. erectus* or the lineage leading to modern people (*35*). With respect to the Gran Dolina fossils reported in this paper, because of their frontal morphology they are not Asian *H. erectus*–like. On the other hand, the Gran Dolina sample displays a set of primitive dental traits not previously found in European middle Pleistocene fossils, but the mandibular and cranial configuration suggest an anagenetic evolution leading to the Sima de los Huesos and other European Middle Pleistocene fossils. To sum up, on the basis of the already available information, the Gran Dolina fossils could be considered as a primitive form of *H. heidelbergensis*. Enlargement of the sample in the future may result in naming of a new species.

REFERENCES AND NOTES

1. L. Gabunia and A. Vekua, *Nature* **373**, 509 (1995).
2. C. Gamble, *ibid.* **369**, 275 (1994).
3. Both fossils have been correlated to oxygen isotope stage 13 by M. B. Roberts, C. B. Stringer, and S. A. Parfit (*ibid.*, p. 311).
4. C. C. Swisher III *et al.*, *Science* **263**, 1118 (1994).
5. J. L. Arsuaga, I. Martínez, A. Gracia, J. M. Carretero, E. Carbonell, *Nature* **362**, 534 (1993).
6. E. Aguirre, E. Carbonell, J. M. Bermúdez de Castro, Eds., *El Hombre Fósil de Ibeas y el Pleistoceno de la Sierra de Atapuerca I* (Junta de Castilla y León-Consejería de Cultura y Bienestar Social, Valladolid, Spain, 1987).
7. E. Aguirre *et al.*, *Hum. Evol.* **5**, 55 (1990).
8. J. M. Bermúdez de Castro, E. Carbonell, J. L. Arsuaga, Eds., *Human Evolution in Europe and the Atapuerca Evidence* (Inventarios y Cartas Arqueológicas, Junta de Castilla y León, Consejería de Cultura y Turismo, Valladolid, Spain, in press).
9. J. M. Parés and A. Pérez-González, *Science* **269**, 830 (1995).
10. The pollen record of the upper half of TD6 (where the human fossils have been found) indicates a Mediterranean influence, with *Pinus, Cupressaceae*, and *Quercus* (both evergreen and deciduous taxa) predominant in the arboreal pollen content but in association with the Mediterranean genera *Olea, Ceratonia, Celtis, Pistacia*, and *Phyllirea*. The most frequent nonarboreal pollen grains are *Poaceae* [M. García-Antón, thesis, Universidad Autónoma de Madrid (1989)]. Both the faunal and the pollen record suggest temperate and wet climatic conditions for the upper half of TD6.
11. E. Gil and C. Sesé, *Cah. Quat.* **16**, 337 (1991).
12. Y. Fernández Jalvo and P. Andrews, *J. Archaeol. Sci.* **19**, 407 (1992).
13. O. Fejfar and W.-D. Heinrich, Eds., *International Symposium on the Evolution, Phylogeny, and Biostratigraphy of Arvicolids (Rodentia, Mammalia)* (Geological Survey, Prague, Czech Republic, 1995).
14. G. Cuenca-Bescós, J. I. Canudo, C. Laplana, *Revista Española de Paleontología*, in press.
15. J. Agustí and S. Moyà-Solà, *Cour. Forschungsinst. Senckenb.* **153**, 69 (1992).
16. The following colleagues have made the identification of the large mammal species: J. Cervera, J. Rosell, and T. Torres. Carnivore data are from J. Cervera. C. Laplana has collaborated in the identification of the micromammal species.
17. In order to analyze the Atapuerca lithic industry, we have differentiated four structural categories, according to the Logical Analytic System [E. Carbonell *et al.*, *Cahier Noir 6: New Elements of the Logical Analytic System* (Reial Societat Arqueològica Tarraconense, Tarragona, Spain, 1992)]. Parallel to the development of this system, other researchers also verified the need to use a logical language that is more adequate to the definition of technical processes used in the most ancient industries. G. Isaac has applied the concepts of flaked pieces to the matrices from which flakes are detached and detached pieces to the produced flakes [G. L. Isaac *et al.*, in *Las industrias más antiguas, X Congreso, Unión Internacional de Ciencias Prehistóricas y Protohistóricas*, J. D. Clark and G. L. Isaac, Eds. (Mexico City, 1981), pp. 101–119; G. L. Isaac, in *Advances in Old World Archaeology*, F. Wendorf and A. Close, Eds. (Academic Press, New York, 1984), vol. 3, pp. 1–87. According to the Logical Analytic System, when a natural object (natural base, nB) is worked on by a human, it undergoes a transformation. As a consequence of this first intervention (Time 1), two or more objects arise from the initial nB. One of them, the initial matrix (that is, the flaked piece), keeps one or several negative scars that correspond to the extractions effected, which in their turn are the "positives" (that is, flakes or detached pieces). In this way, we speak of first generation negative bases (FGNBs, the matrix) and first generation positive bases (FGPBs, the flake). As work on the FGNB goes on, new FGPBs will arise; but if any of the FGPBs is taken up again and worked, a new stage of the process will begin (Time 2). Because of this working, the old FGPB becomes a second generation negative base (SGNB), thus originating the appearance of second generation positive bases (SGPB). The process can continue, causing a third generation of objects to arise.
18. The two archaeological varieties of flint are distinguished by texture, grain, and diagenesis. One of them shows a coarse grain and texture and develops a high alteration by which the crystalline structure is disintegrated. In the surrounding area of the Atapuerca Hill, two limestone formations contain flint veins: one belonging to the Neogene period and the other to the Cretaceous period. Quartzite, sandstone, and limestone currently crop out on the Arlanzón river terraces. Sources of raw material are no more than 1 km from the sites.
19. V. A. Ranov, E. Carbonell, X. P. Rodríguez, *Curr. Anthropol.* **36**, 337 (1995).
20. This age diagnosis fits the criteria of F. H. Smith and G. C. Ranyard [*Am. J. Phys. Anthropol.* **53**, 589 (1980)] on the basis of age-related supraorbital changes in Neandertals.
21. B. A. Wood, *Nature* **355**, 873 (1992).
22. ______ and H. Uytterschaut, *J. Anat.* **154**, 121 (1987).
23. The particular morphology of the root system of the lower P3 and P4 of the hominid 1 from TD6, according to the information we have available, has not been described before now, and it probably derives from the primitive root form of the lower fourth premolars (2R: M + D) suggested by B. A. Wood, S. A. Abbott, and H. Uytterschaut [*J. Anat.* **156**, 107 (1988)] for the African ape-hominid clade. The morphology of the lower P3 and P4 from TD6 seems to be intermediate between this primitive condition and the so-called Tomes' root, which also has MB and DL roots with a single separated pulp canal and shows a variable level of bifurcation. Tomes' root is present in the lower third premolars of some early Plio-Pleistocene hominids assigned to *A. afarensis, A. africanus, A. robustus, H. habilis s. s.*, and *H. erectus* (*ibid.*).
24. H. de Lumley, A. Fournier, J. Krzepkowska, A. Echassoux, *L'Anthropologie* **92**, 501 (1988).
25. N. Thouveny and E. Bonifay, *Nature* **308**, 355 (1984).
26. J. Gagnepain, I. Hedley, J. J. Bahain, J. J. Wagner, in *Il Piu antico popolamento della Valle Padana nel quadro delle conoscenze europee. Monte Poggiolo*, C. Peretto, Ed. (Jaca Book, Milan, Italy, 1992), pp. 319–335.
27. M. Coltorti *et al.*, *Nature* **300**, 173 (1982); M. C. Delitala, M. Fornasari, M. Nicoletti, in *Isernia La Pineta, un accampamento più antico di 700.000 anni*, C. Peretto, C. Terzani, M. Cremaschi, Eds. (Calderini, Bologna, Italy, 1983), pp. 65–66; A. McPherron and V. Schmidt, *ibid.*, pp. 67–69; C. Peretto, Ed., *Isernia La Pineta. Nuovi contributi scientifici* (Istituto Regionale per gli Studi Storici del Molise, Firenze, Italy, 1991).
28. G. Bosinski, in *Il più antico popolamento della Valle Padana nel quadro delle conoscenze europee. Monte Poggiolo*, C. Peretto, Ed. (Jaca Book, Milan, Italy, 1992), pp. 51–67.
29. V. Gladiline and V. Sitlivy, in *Les premiers européens. Actes du 114e. Congrès National des Sociétés Savantes (Paris, 3 to 9 avril 1989)*, E. Bonifay and B. Vamdermeersch, Eds. (Editions du C.T.H.S., Paris, 1991), pp. 217–231.
30. E. Carbonell and X. P. Rodríguez, *J. Hum. Evol.* **26**, 291 (1994).
31. V. A. Ranov, in *Les Premiers européens. Actes du 114e. Congrès National des Sociétés Savantes (Paris, 3 to 9 avril 1989)*, E. Bonifay and B. Vandermeersch, Eds. (Editions du C.T.H.S., Paris, 1991), pp. 209–216.
32. A. Belfer-Cohen and N. Goren-Inbar, *World Archaeol.* **26**, 144 (1994).
33. K. D. Schick and D. Zhuan, *Evol. Anthropol.* **2**, 22 (1993).
34. J. de Vos, *Science* **266**, 1726 (1994); C. C. Swisher III, *ibid.*, p. 1727.
35. On the contrary, G. P. Rightmire [*The Evolution of Homo erectus* (Cambridge University Press, Cambridge, 1990)] lumps European as well as African Middle Pleistocene fossils in *H. heidelbergensis*.
36. G. Johanson, *Odontol. Revy* **22**, suppl. (1971).
37. Age at death was estimated with the summary chart elaborated by L. Aiello and C. Dean from data published by different authors [in *An Introduction to Human Evolutionary Anatomy* (Academic Press, London, 1990), p. 127].
38. The following colleagues have made the identification of the human remains (in alphabetical order): J. L. Arsuaga, J. M. Bermúdez de Castro, J. M. Carretero, A. Gracia, C. Lorenzo, I. Martínez, and A. Rosas.
39. A. Rosas, *J. Hum. Evol.*, **28**, 533 (1995).
40. Excavation and research projects were conducted

from 1978 to 1991 by E. Aguirre from the Museo Nacional de Ciencias Naturales, CSIC. Since 1992, the excavation and research of the Sierra de Atapuerca sites have been conducted by J. L. Arsuaga, J. M. Bermúdez de Castro, and E. Carbonell. The excavations are supported by the Junta de Castilla y León and the Research Project by the Ministerio de Educación y Ciencia (DGICYT, project no. PB93-0066-C03). The Atapuerca research carried out by the Archaeological Laboratory of Universitat Rovira i Virgili is included in the *Human Population Origins in the Circum-Mediterranean Area: Adaptations of the Hunter-Gatherer Groups to Environmental Modifications* project, which is supported by the European Union. Special thanks are given to the Laboratorio de Parasitología de la Facultad de Biología de la Universidad Complutense, which made research possible to J.L.A. Many individuals have contributed to this research effort (we are particularly grateful to A. Martín Nájera, C. Mallol, and J. Vallverdú). We are also grateful to J. Bischoff, F. Clark Howell, R. Klein, and T. White for comments on the manuscript.

14 March 1995; accepted 6 June 1995

Paleomagnetic Age for Hominid Fossils at Atapuerca Archaeological Site, Spain

Josep M. Parés* and Alfredo Pérez-González

A paleomagnetic investigation at the Gran Dolina site excavation (Atapuerca, Spain) shows that the sediments containing the recently discovered human occupation were deposited more than 780,000 years ago, near the time of the Matuyama-Brunhes boundary. Forty-one oriented samples were obtained from 22 sites along an 18-meter section of the Gran Dolina karst filling. The lower 16 sites displayed reversed-polarity magnetizations whereas the upper six sites were normal. The reversal spans the hominid finds at stratigraphic level TD6 (the Aurora stratum), and these hominid fossils are therefore the oldest in southern Europe.

Geomagnetic field directional changes resulting from secular variation and reversals of Earth's field have been successfully used to date Quaternary deposits in a variety of geological environments. The karst system of Atapuerca, located about 14 km east of the city of Burgos, Spain (Fig. 1), contains one of the largest, stratigraphically most complete Middle Pleistocene sequences (*1*, *2*). A previous paleomagnetic study at the Gran Dolina stratigraphic section concluded that the Matuyama-Brunhes boundary was at the bottom of the series (*3*). The lithologies analyzed in that study consisted of red-yellow clays and silts. Most of the samples were demagnetized by the alternating field (AF) procedure and many of them yielded intermediate paleomagnetic directions. We therefore suspected that late remagnetization unresolved by AF demagnetization may be pervasive in those sediments. Consequently, we sampled the Gran Dolina section for paleomagnetic analysis (*4*). Our results imply that the boundary is higher in the section, at the near level of the discovered hominids and artifacts (*5*), and that these hominid fossils are therefore the oldest in southern Europe.

The lithostratigraphy of the Gran Dolina infilling has been divided into 11 levels (*1*). The lowermost levels are composed of thin laminated brown (7,5YR5/4) silts (TD1) and clastic sediments of gravitational origin (TD2), covered by a thick speleothem. The overlying deposits (TD3/4 to TD11) are gravel and breccia. An accumulation of bat guano is also found at level TD9. The clasts consist of pebbles, cobbles, and occasionally boulders of limestone set in a matrix of brown (7,5YR5/6) to yellowish red (−5YR5/6) sandy silt. The clastic fragments come either from outside of the cave or from the walls. However, the sediments at level TD7 indicate a hydraulic regime. The top of the Gran Dolina series is marked by carbonated reddish yellow silty clays (7,5YR7/6) and terra rossa (2,5YR4/6). The horizon that yields hominid fossil remains (the Aurora stratum) is a massive red-brownish lutite bed 15 cm thick with dispersed fine clasts. The overall sedimentary package indicates local gravitational accumulation with some fluvial processes in the cavern.

The natural remanent magnetization (NRM) intensities (*6*) were 0.35 mA m^{-1} for the speleothems, 0.63 mA m^{-1} for the yellow clays, 7.0 mA m^{-1} for the bat guano, and up to 100 mA m^{-1} for the red clays. Progressive demagnetization revealed that the paleomagnetic samples from Gran Dolina are overprinted by a large secondary component. Thus most of the NRMs were carried by two components of magnetization; one of them was unblocked at demagnetization temperatures between 20° and 300°C with the present-day field direction, and the other was unblocked above 400°C in 45 of 50 specimens (Fig. 2). Some samples showed unstable magnetizations because of alteration and possible creation of superparamagnetic magnetite at high temperatures, as indicated by large increases in susceptibility. In these samples thermal demagnetization was terminated at 540°C because the magnetizations became too erratic. The low-temperature unblocking magnetizations are directed to the north with downward inclinations and conform to

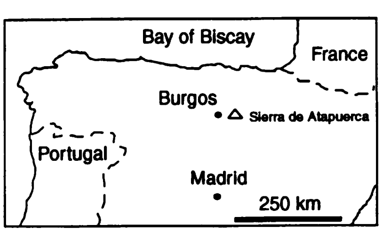

Fig. 1. Location of Sierra de Atapuerca, Spain.

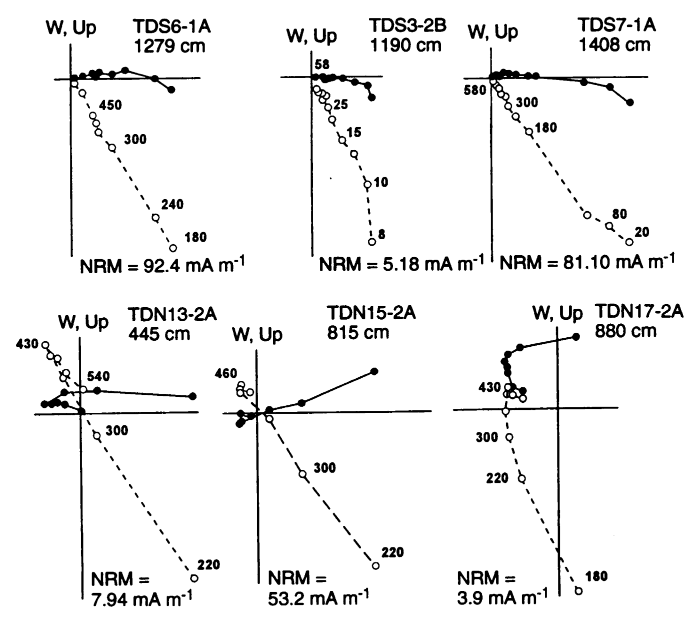

Fig. 2. Representative Zijderveld demagnetization diagrams (*14*) of the Gran Dolina sediments. Sample numbers refer to the sampling sites in Fig. 4. Solid and open circles represent horizontal and vertical projections, respectively, onto the horizontal plane. Temperature steps are given in degrees Celsius for samples TDS6-1A, TDS7-1A, TDN13-2A, TDN15-2A, and TDN17-2A; alternating field steps are given in milliteslas for sample TDS3-2B. Temperature steps below 180° or 220°C are not shown in some samples to enhance the details at higher temperatures. NRM intensities are given in each diagram in milliamperes per meter.