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Combustion at the late Early Pleistocene site of Cueva Negra del Estrecho del Río Quípar (Murcia, Spain)

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Control of fire was a hallmark of developing human cognition and an essential technology for the colonisation of cooler latitudes. In Europe, the earliest evidence comes from recent work at the site of Cueva Negra del Estrecho del Río Quípar in south-eastern Spain. Charred and calcined bone and thermally altered chert were recovered from a deep, 0.8-million-year-old sedimentary deposit. A combination of analyses indicated that these had been heated to 400–600°C, compatible with burning. Inspection of the sediment and hydroxyapatite also suggests combustion and degradation of the bone. The results provide new insight into Early Palaeolithic use of fire and its significance for human evolution.

Keywords: Early Pleistocene, Palaeolithic, Acheulean, combustion, cognitive evolution

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Introduction

When do traces of combustion first appear at middle-latitude Palaeolithic sites? What do they say about cognitive evolution in early *Homo* dispersing throughout Eurasia? Inferences that European sites lacked fire before 0.5–0.4 Ma (Roebroeks & Villa 2011) rely on the absence of *hearths* enabling heat-*control*. Combustion, however, existed *c.* 0.8 Ma, *without* hearths, in the south-eastern Spanish rockshelter of Cueva Negra del Estrecho del Río Quípar (CNERQ). Cognitive versatility perhaps enabled opportunistic exploitation of bush-fires outside such that fire could be *tended* inside, albeit without heat-*control*.

Thermally affected fragments of bone, chert artefacts, nodules, fragments and spalls come from closed, deeply lying sediment in unit VI at CNERQ (lat. 38.03679; long. −1.88494; 740m asl; 10km south of Caravaca). Systematic excavation since 1990 of 5m-deep Pleistocene sediments lying on bed-rock uncovered abundant small Palaeolithic artefacts, on chert and other rock types (Walker *et al.* 2013, 2016), showing consistency throughout the stratigraphic sequence, including flakes removed by repetitive centripetal striking of small discoidal cores, fragments and flakes with steeply retouched edges, keeled forms and trihedral pieces with spurred points (cf. Debénath & Dibble 1994: 99, figs 7.22–7.27, 108–109, figs 8.29–8.37), and a bifacially flaked ('Acheulean') limestone handaxe (Walker *et al.* 2013). Chert is absent in the Upper Miocene (Tortonian) biocalcarenite cave walls; most chert came from an older Tortonian conglomerate outcrop 0.8km east of CNERQ, although comparative trace-element analyses by laser-ablation inductively coupled plasma mass-spectrometry suggests some excavated chert originated around 30km away (Zack *et al.* 2013).

Magnetostratigraphy assigns the entire cave sediment to the Matuyama chron, >0.78 Ma (Scott & Gibert 2009). Preliminary thermoluminescence dating of heated flint by author D.R. (unpublished) agrees with single-grain optically stimulated luminescence analysis by author J.-L.S (unpublished), indicating >0.5 Ma, although small sample size and signal saturation preclude accuracy; hitherto, less accurate multiple-grain OSL methodology suggested 0.3–0.5 Ma (Walker *et al.* 2006). Regrettably, ^{26}Al/^{10}Be analysis implausibly indicated Plio-Pleistocene antiquity (R. Braucher *pers. comm.*).

Biostratigraphy of micro- and macro-mammalian remains assigns the deposits to <1.0–>0.7 Ma (Walker *et al.* 2013, 2016). Extinct Arvicolid rodents (Table 1) of the Iberian

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Table 1. Some extinct small mammal species excavated at Cueva Negra. Numbers are of finds identified for each species.

	Excavated units				
Taxa	Unit II	Unit III	Unit IV	Unit V	Unit VI
Pliomys episcopalis	1	9	–	–	1
Mimomys savini	7	17	4	1	5
Microtus (*Iberomys*) *huescarensis*	21	101	42	1	26
Microtus (*Stenocranius*) *gregaloides*	–	3	–	–	–
Microtus (*Terricola*) *arvalidens*	–	2	–	–	–
Microtus (*Allophaiomys/Victoriamys*) *chalinei*	40	45	49	8	13
Allocricetus bursae	9	3	2	–	–
Apodemus cf. *sylvaticus*	13	13	16	1	3
Eliomys quercinus	1	1	2	–	–
Crocidura sp.	8	39	27	1	13
Neomys sp.	2	11	4	–	–
Erinaceus europaeus	43	29	6	–	–
Oryctolagus cf. *giberti*	87	84	24	4	30
Prolagus calpensis	12	21	20	–	11

For Arvicolid rodents (*Pliomys*; *Mimomys*; *Microtus*) numbers refer to mandibular first molars; for other Rodentia (*Allocricetus*; *Apodemus*; *Eliomys*) and for Eulipotyphla (*Crocidura*; *Neomys*; *Erinaceus*), they refer to maxillary and mandibular molars; for Lagomorpha, in *Oryctolagus* they refer to mandibular third premolars; and in *Prolagus* they refer to different molars.

late Early Pleistocene occur from top to bottom of the sedimentary sequence (note that upper units II, III and IV have been excavated over a wider area than deeper units V and VI). Once surmised as faunal atavisms *c.* 0.5 Ma (Walker *et al.* 2006), the now extensive Arvicolid sample is comparable to Iberian late Early Pleistocene samples from Atapuerca and the Guadix-Orce Basin (Walker *et al.* 2016). Macro-mammalian revision by J. van der Made (Walker *et al.* 2016) shows the presence, even in upper units, of late Early Pleistocene taxa (e.g. *Dama vallonnetensis*), correcting misguided designations (e.g. *Stephanorhinus hemitoechus* in Walker *et al.* (2004), which is either *S. etruscus* or *S. hundsheimensis*) unduly influenced by older publications (Martínez Andreu *et al.* 1989).

The sediments are near-horizontally bedded, laminated or cross-bedded bands or lenses of fine (silt-/sand-sized) particles of litharenite, micritic limestone and quartz, with sparse coarser components. Macroscopic inspection and micromorphology demonstrate several cycles of alluviation (Angelucci *et al.* 2013) when the cave lay beside a swampy lake that overflowed into it intermittently. Middle/Upper Pleistocene neotectonic activity and riverine incision produced today's vertical 40m separation. Throughout the sequence, there is ample evidence of Palaeolithic activity, doubtless during dry seasons. Apart from a drier episode, reflected in the upper part of the sequence by an incipient palaeosol with traces of bioturbation subsequently truncated by erosion (Angelucci *et al.* 2013), no significant discontinuity exists (*pace* Jiménez-Arenas *et al.* 2011), and the sediments

Figure 1. The Cueva Negra del Estrecho del Río Quípar excavation. The deep-lying deposit containing burnt remains is indicated by red arrows and is shown in the close-up views on the right.

remained undisturbed (save for small pits dug *c.* 1940). Pollen from the sediments attests to mild, humid conditions with gallery woodland (Carrión *et al.* 2003), and diving-duck bones require a nearby lake (Walker *et al.* 2004). The sediments probably formed in the late Early Pleistocene MIS21 (NB publications before Scott and Gibert (2009) regarded them as Middle Pleistocene).

Excavation and macroscopic consideration of thermally affected bone and chert

Findings that fire had affected both bone fragments and Palaeolithic chert came to light in 2011 during excavation in 1m^2 of sediment around 0.1m thick at the top of unit VI (Walker *et al.* 2013), 4.5m beneath the surface of the sedimentary sequence, 6–7m behind the cave mouth (Figure 1). Hitherto, thermally altered lithics were unknown among >3000 pieces excavated, and barely a score of burnt bone fragments were scattered among >40 000 faunal items recovered. The 2011 excavation uncovered >165 thermally altered chert items, around 0.5–5mm in size, shattered by combustion (and 10 of limestone, 5 of quartzite and, in 2012, a radiolarite edge-retouched 'scraper'). Among numerous charred bone fragments are several white calcined ones (Figure 2) including conjoinable fragments caused by lengthwise long-bone spalling typical of circumferential shrinkage after thermal volatilisation of organic components at 800–900°C (cf. Uberlaker 1999 [2004]: 35–38). Since 2012, more burnt fragments of chert and bone have been excavated from a further

Figure 2. Thermally altered bone fragments. The left-hand photograph shows longitudinal spalling.

1.5m^2 of the 5m^2 area where thermally altered sediment is now exposed as a combustion area, apparently continuing inwards and outwards below 4.5m of overburden, perhaps a bonfire site, although neither a circumscribed 'feature' nor 'hearth'. Methodological requirements to wash excavated overlying sediment on 2mm mesh sieves constrain excavation.

One excavated thermally altered chert nodule (Figure 3, top), split open by heat ('thermal shock'), had several minute, razor-sharp splinters still in place (implying negligible displacement), its split surface bearing shallow rippled depressions typical of thermally altered chert fracturing (cf. Richter 2007; cf. Schön 2012: 104, fig. 4). An artificially struck flake (Figure 3, bottom) was excavated with sharp conjoinable fragments in apposition. Effects of combustion on chert are well documented although far from uniform, owing to the variety and complexity of cherts. In some cherts, temperatures around 250–300°C produce changes in colour, lustre or even heat-damage or recrystallisation of quartz. In others, temperatures around 500°C are needed for heat-damage or recrystallisation, depending on the chemical and crystalline properties of the quartz or impurities in the chert, e.g. calcium carbonate or water (Luedtke 1992; Clemente Conte 1997). Combustion temperatures cannot be inferred accurately from visual inspection of burnt chert; supplementary analytical procedures and specific studies are necessary. Chert tends to shatter at around 700–800°C into splinters, spalls and chips far too small for the application of laboratory techniques, so larger burnt fragments on which they were applied had probably not undergone prehistoric heating >700°C, therefore laboratory palaeotemperature determinations probably *under*estimate temperatures reached by fire. The deep CNERQ sediment has

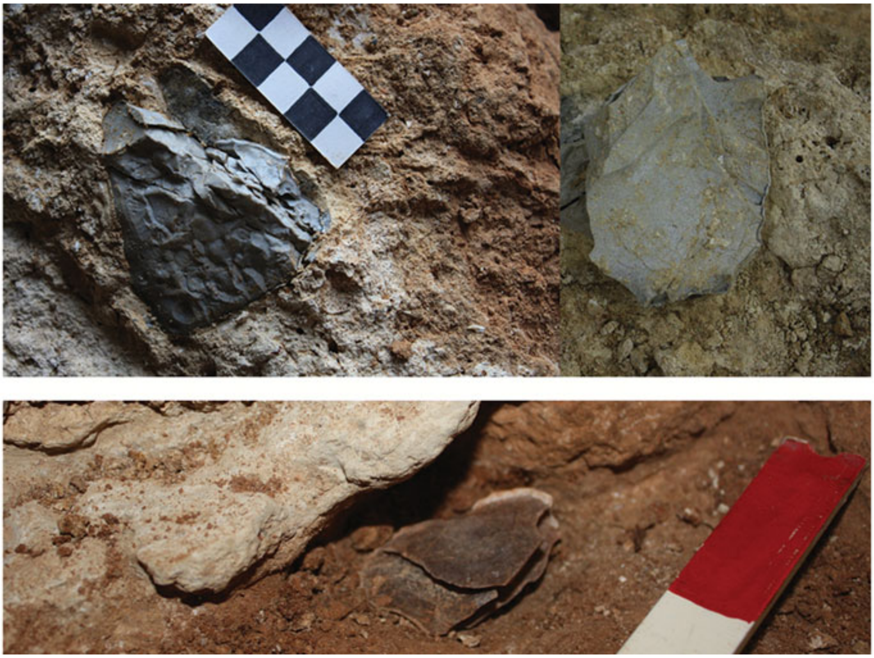

Figure 3. Top left: thermally altered chert nodule. Top right: the rippled surface of a large fragment of the same nodule that covered the fragments on the left, including several small splinters (difference in colour is exaggerated by lighting differences). Bottom: flint flake found in three fragments in situ. *Red part of scale = 25mm.*

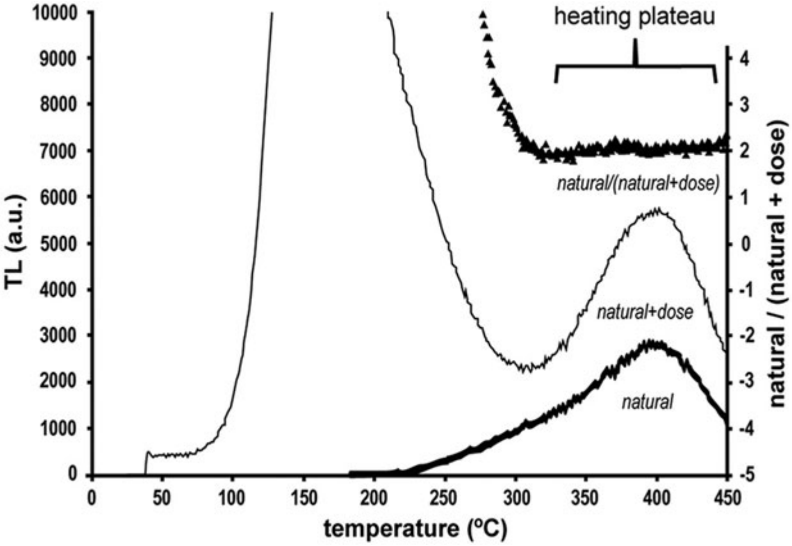

Figure 4. Thermoluminescence (TL) analysis of burnt chert. The constant ratio (heating plateau) of natural/(natural+dose) TL signals indicates heating above 400ºC.

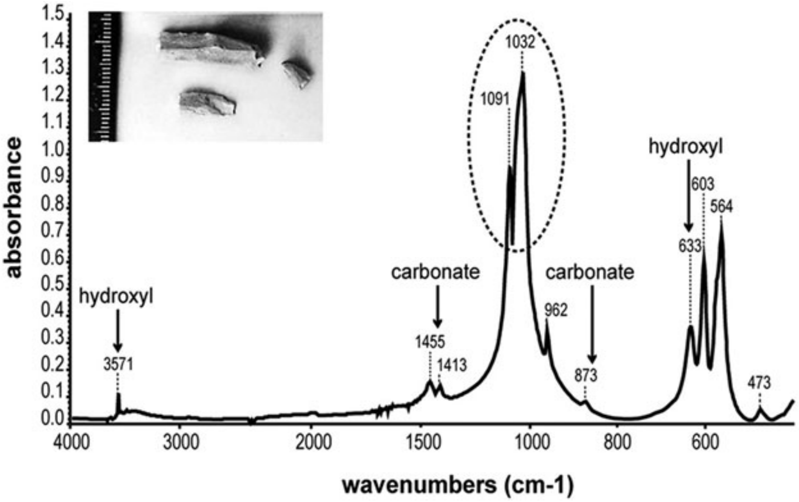

Figure 5. Fourier transform infrared (FTIR) spectroscopic analysis of burnt bone. Note the characteristic sharpening of the phosphate absorptions at 1032–1091 and hydroxyl bands when bone mineral is heated above 400–450ºC, although residual carbonate absorptions indicate an incomplete calcination process, implying a temperature <700–800ºC. Sample shown inset.

provided many splinters, spalls and chips, often with microscopic stigmata of thermal alteration.

Analytical procedures, specific studies and summary of principal conclusions

Observations made at excavation were supplemented with analytical procedures and specific studies:

a) Thermoluminescence analysis of an excavated burnt chert fragment showed that high temperature of the main TL peak, strong signal increase and presence of a well-developed heating plateau indicate ancient heating >400°C (Figure 4).

b) Fourier transform infrared (FTIR) spectroscopy of an excavated bone fragment found characteristic sharpening of phosphate absorptions at 1032–1091 and hydroxyl bands that appear on heating bone mineral >400–450ºC (Figure 5), while residual carbonate absorptions indicate incomplete calcination, at <700–800ºC.

c) ESR spectra of three excavated bone fragments were compared. Two had undergone Palaeolithic burning; an apparently unburnt fragment was heated as a control. ESR palaeothermometry (Skinner *et al.* 2004) involves identifying residual carbon fragments containing ‘soot’ radicals resulting from radiation damage to bone matrix (causing thermal fragmentation of collagen), with oxidation of manganese around 400–500ºC. Modern bones contain so much carbon that, on heating, the peak due to pure carbon (basically soot) is so wide that it conceals the other peaks. When fossil bones have lost most, but not all, of their organic carbon, ESR palaeothermometry can estimate temperatures to which bones were heated in antiquity. One burnt CNERQ fragment afforded an organic radical signal additional to that of manganese, indicating ancient heating at approximately 400–450°C (Figure 6, centre). Other CNERQ bones lacked sufficient carbon to show effects of heating, which is unsurprising because bones, being porous, both lose material over time and absorb material from the environment; moreover, organic carbon breaks down during fossilisation, aided by bacteria, and resulting fragments are leached from bone by ground water.

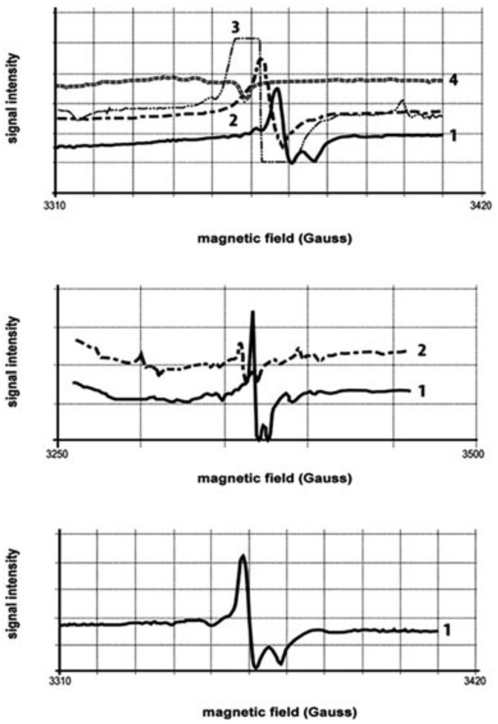

Figure 6. Electron spin resonance (ESR) analyses of bone. Top: fossil bone from Cueva Negra, used as control (1 = unheated, showing 'dating peak'; 2 = heated to 300°C; 3 = heated to 450°C; 4 = heated to 600°C). Centre: two fragments of a fossil bone from Cueva Negra, apparently heated in antiquity; both showed Mn peaks as well as organic radicals. Best estimate of heating temperature: 400–450°C. Bottom: fragment of fossil bone from Cueva Negra, described as 'calcined'. Best estimate of heating temperature: <600°C. Additional information is available in online supplementary material.

Fossil bone can show a 'dating peak' due to radiation damage to carbonate in the bone matrix. Bone heated in antiquity will show this, superimposed on other spectral features. Bones cannot be dated from this peak because the environmental radiation dose, especially internal to the bone, is incalculable. Radioisotopes, largely uranium, can leach in and out of bone during its burial history. Although this dating signal is extraordinarily stable, it decreases when heated at around 300°C for several hours. Thus, the pattern sought on artificial heating of fossil bone is the disappearance of the 'dating signal' and its replacement by a structure attributable to carbon fragments, with a central peak due to carbon (soot) radicals. Peaks at around 400–500°C appear due to oxidation of manganese by heat. By 600°C, almost everything disappears apart from, perhaps, residual carbon radical intensity (Figure 6, top).

d) Thermal discolouration of excavated bone is supported by taphonomic analysis, combined with SEM and EDX, enabling sporadic isolated deposits on bone surfaces of oxides of manganese or iron to be distinguished from discolouration attributable to thermal alteration (Figure 7, following Fernández-Jalvo & Avery 2015). A statistically significant contrast exists between the proportion of micro-mammalian bone fragments (<5kg live-weight) showing colour change, consistent with exposure to heat, as against those showing less change, when samples from upper unit VI containing burnt chert and bone were compared with samples from unit V above and lower unit VI sediment below. In a taphonomic analysis of around 2300 micro-mammalian bone fragments, identified among around 4400 micro-faunal fragments from those sedimentary units (Rhodes 2014; Rhodes

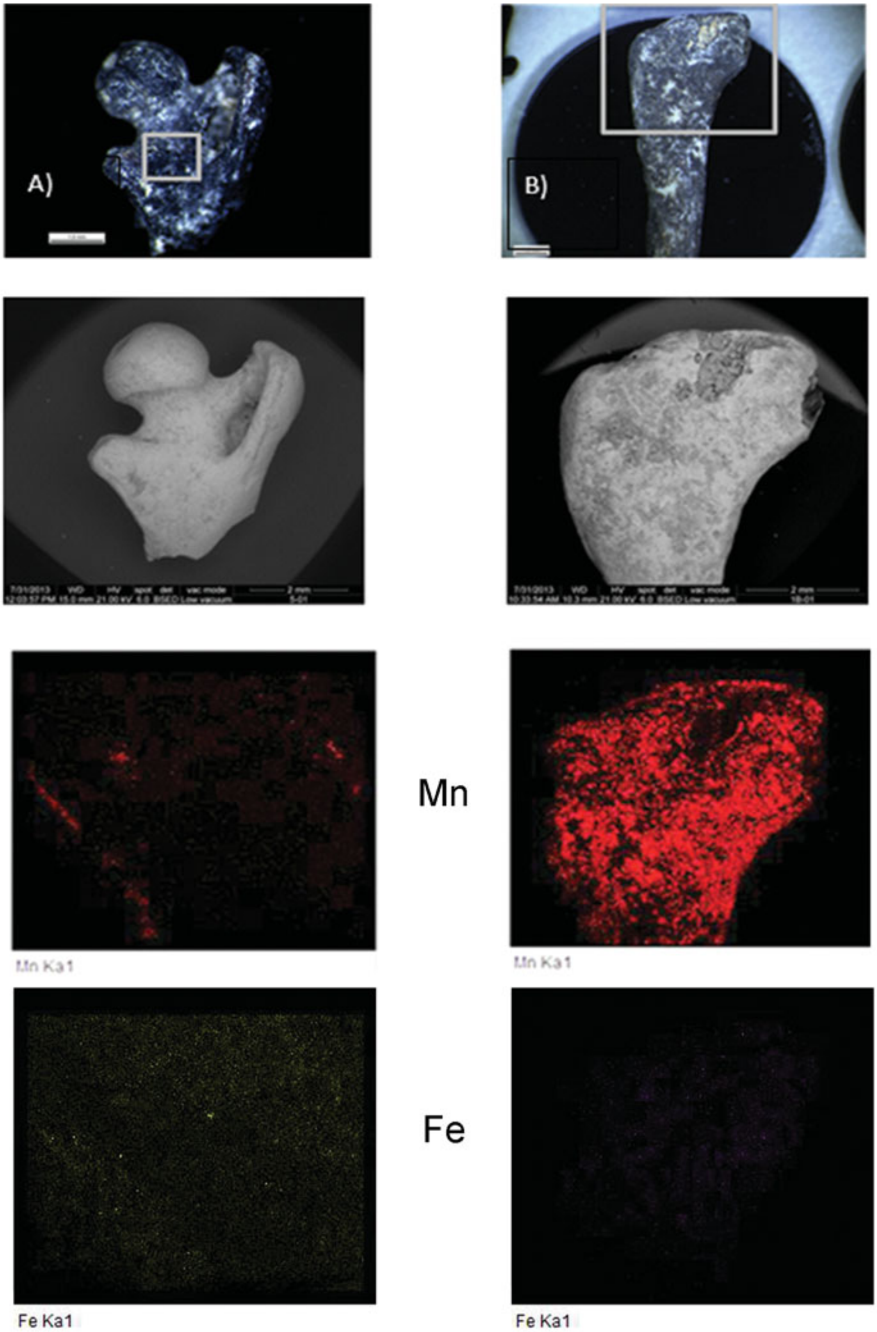

Figure 7. SEM and EDX spectroscopy; charred rodent femur (left) and heavily oxide-stained rodent metapodia (right). The femur shows minimal Mn and Fe deposits that do not follow the pattern of oxide staining. The metapodial shows, however, a high content of Mn indicating that the colour follows patterns of oxide-stained deposition. Additional information is available in online supplementary material.

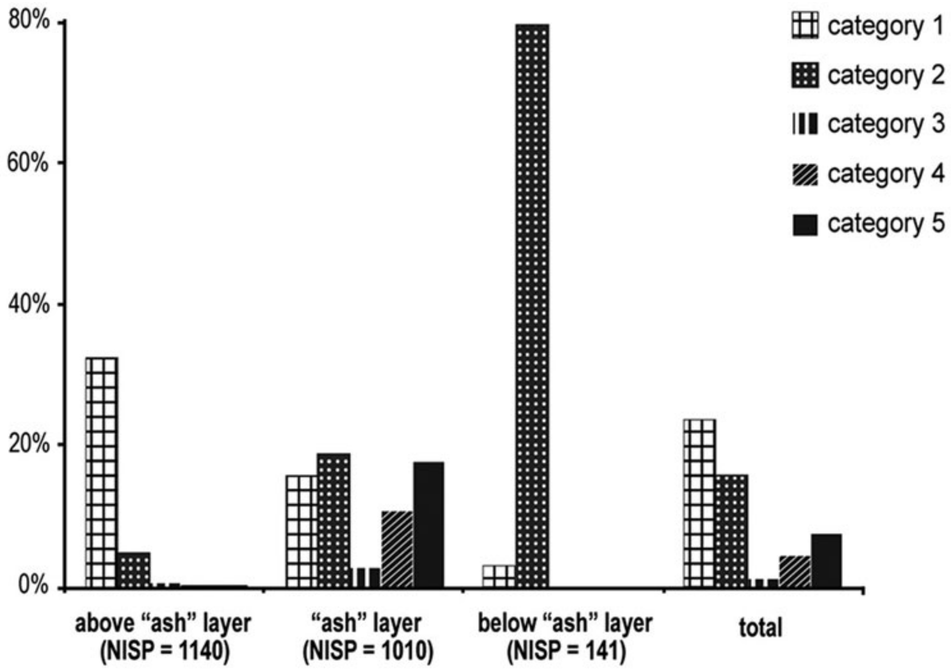

Figure 8. Comparative study of approximately 2300 small-mammal bone fragments excavated in 2011 from above, within and below the 'ash' layer. The categories of burning span minimum reddish discolouration (Category 1) to complete calcination (Category 5). 97% of all charred and calcined bone identified came from the 'ash' layer. A statistically significant difference was found in the proportion of heavily burnt bone (categories 3–5) from within the 'ash' layer versus overlying deposits ($\chi 2 = 169.2$; $p < 0.001$).

et al. 2014, forthcoming), 25% showed evidence of thermal alteration as discolouration of bone surface (Figure 8). The deeply lying sediment provided around 95% of all micro-mammalian specimens inspected from CNERQ that corresponded to categories 3–5 in Figure 8; furthermore, in that sediment, bones from different anatomical regions were affected alike, which is compatible with *in situ* exposure to high temperature. Although excavation of the deep sediment recovered fragments of large mammals (>80, around 20 of which showed signs of thermal alteration) and tortoise, the taphonomic study was devised with the particular methodological purpose of comparing and contrasting remains of micro-mammals from different parts of the site and to consider their source (following Andrews 1990), which is most likely to have been predation by owls, lynxes or foxes, doubtless during periods of absence by humans, who perhaps burnt rubbish on their return and may have roasted foodstuffs.

e) Detailed examination of the deeply lying sediment containing burnt chert and bone (Figure 9) reported that "distinct layers were observed of materials resembling ash, sometimes resting on reddened belts" (Angelucci *et al*. 2013: 198), although incontrovertible high-resolution microscopical evidence of combustion, such as *in situ* reddening, presence of

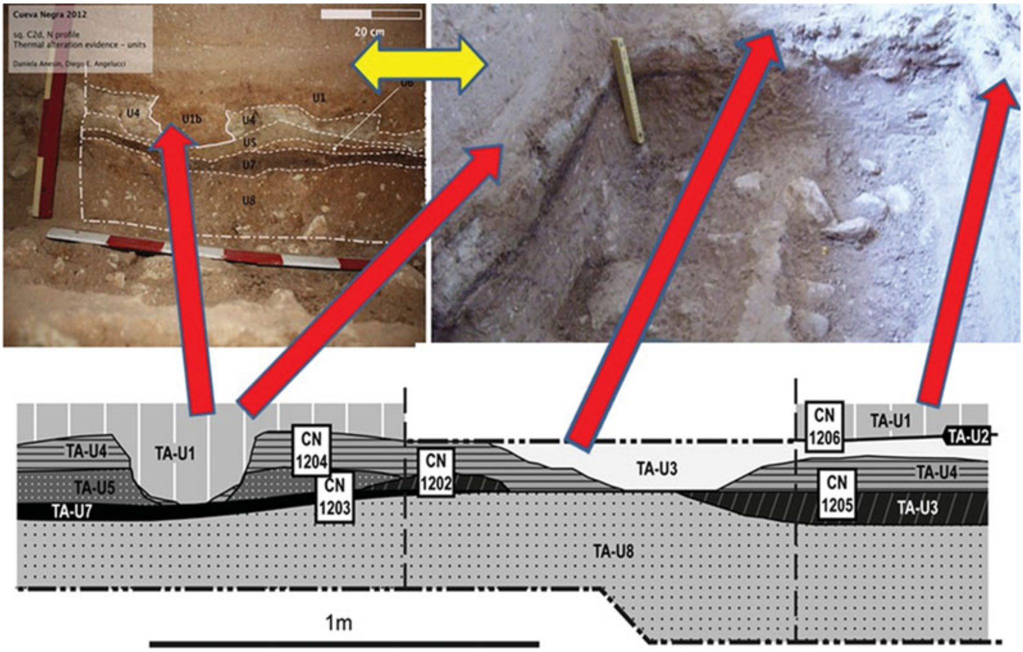

Figure 9. Photographs and stratigraphy of deeply lying sedimentary layers with burnt remains in metre-square C2d during excavation in 2012. Adapted from supplementary information in Angelucci et al. *(2013). See online supplementary material for description of unit characteristics and features.*

wood ash or charcoal fragments, was not detected in the thin sections on which sediment micromorphology was undertaken.

f) Chemical and mineral investigation compared the deep reddened sediment with sediment above and below by thermogravimetric analysis with mass spectrometry, granulometry (of the <2mm fraction) using laser diffraction, and XRF and XRD studies. Hydroxyapatite present in the reddened sediment (2.5%), and in the sediment immediately below it (1%), is compatible with the degradation of bone; it was also found in an excavated burnt chert fragment (0.2%).

Samples: sediment samples were analysed from reddish layer TA-U6 and the underlying layer TA-U7, and compared to one from overlying sediment. A burnt chert fragment was also analysed.

Principal findings: samples from TA-U6 and TA-U7 contained $CaCO_3$ inclusions as microscopic clumps and fine powder. Organic content: 1.45–1.8%. Organic CO_2: 20–21.5%. TA-U6 and TA-U7 consist mainly of $CaCO_3$ (*c.* 90.5%), and hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$ (TA-U6 2.5%P; TA-U7 1%P) (*c.* 2%), which is compatible with the degradation products of bone. Elements present at >1%: O (48%), Ca (20–24%), Si (10–12%), C (6%), Al (4–4.5%), Fe (2–2.5%), P (1–2.5%), K (1.6–1.8%), Mg (1%). Elements present at <1%: Na, S, Cl, Ti, V, Cr, Mn, Ni, Cu, Zn, Br, Rb, Y, Zr, Ba.

Mineral species identified (percentages):

	Calcite	Quartz	Muscovite	?Sanidine	Clinochlore	Hydroxyapatite	Illite	Haematite
Overlying sediment	71.0%	22.3%	2.1%	0%	2.2%	1.2%	0.7%	0.3%
TA-U6 sample	57.8%	27.6%	7.6%	1.9%	1.9%	2.2%	0.5%	0.5%
TA-U7 sample	50.6%	29.4%	7.8%	6.8%*	2.8%	1.9%	0.4%	0.2%

*Further research will attempt to improve the characterisation of this mineral, which appears to be sanidine.

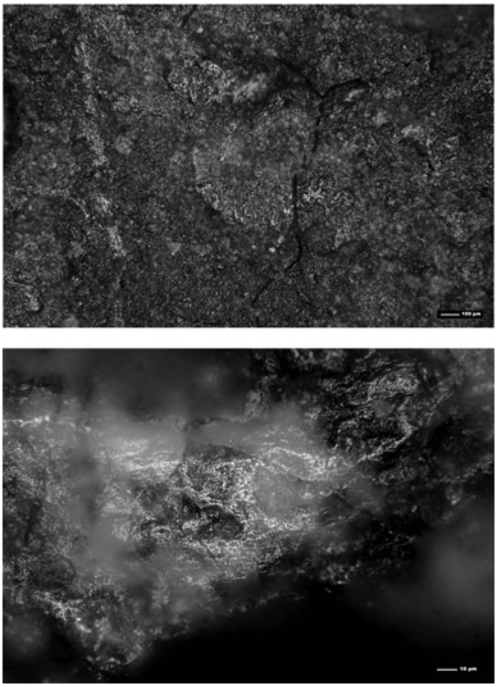

Figure 10. Microscopy of chert fragments shows thermal alteration (top) and thermal patination (bottom).

g) Microscopy reveals that grey hues predominate on surfaces of chert excavated in unit VI sediment affected by combustion. Vertical and oblique fractures are frequent (giving rise to tiny spalls), as are conspicuous oval or circular shallow depressions caused by thermal alteration of chert surfaces. Cracks and reticulate crazing are widespread, particularly on surfaces showing rubefaction. White opaque or translucid patination is frequent, as is shiny thermal lustre that can seem slightly 'greasy'. The macroscopic and microscopic observations at CNERQ are in line with similar observations at other archaeological sites showing evidence of combustion, and also with experimental findings (cf. Luedtke 1992; Clemente Conte 1997). Photomicrographs show thermal alteration and surface patination of thermally altered CNERQ chert specimens (Figure 10).

Early fire and mid-Quaternary human evolution

The findings imply combustion *c.* 0.8 Ma at CNERQ. What are the archaeological implications? Claims of early Palaeolithic fire must be treated cautiously. Alleged evidence of fire from ancient cave sites can seem convincing (James 1989) but warning bells are sounded by much-discussed difficulties of interpretation at well-known sites. At CNERQ, previous comments (Walker *et al.* 2006) were limited to prudent cursory mention of small bones with 'signs of burning' excavated in higher sediments, and, in relation to a 1m^2 test-pit dug in 2004, to "loose sediment flecked with carbon (unit V = layer and spits 5a–5g). It passes into unit VI, which is half-a-metre thick, and is distinguished by zones of very dark, loose soil, suggestive of burning (unit VI = layer and spits 6a through 6i)" (Walker *et al.* 2006:

8), although post-depositional diagenetic decalcification could be responsible. The small test-pit reached bed-rock in 2004, but its vertical profiles and sediment with neither burnt chert nor burnt bone failed to show the sedimentary sequence of the adjacent $2m^2$ that have now provided burnt fragments of bone and chert. In these $2m^2$ the bed-rock slopes slightly downwards towards the test-pit square, determining drainage of nearby sediments. In the test-pit, deeply lying sediment (of units V and VI = layers 5 and 6 = complex 3-2 of Angelucci *et al.* 2013) contains organic residues, doubtless derived from the adjacent $2m^2$, albeit lacking both pollen and microscopic traces of charcoal. Our 2006 caution owed to a possibility that ash could have been blown inside from bush-fires sweeping past the cave mouth; it may account for burnt traces in 1.2 Ma sediments at Sima del Elefante (Sierra de Atapuerca, northern Spain): "L'abondance de micro-charbons associés à des composés organo-minéraux exogènes atteste de la récurrence d'incendies naturels dont le déclenchement semble être lié à des évènements exceptionnels d'origine cosmique" [The abundance of micro-carbons associated with exogenous organic-mineral compounds is testimony to recurring natural fires probably caused by exceptional atmospheric phenomena] (Carbonell *et al.* 2010: 12).

Roebroeks and Villa (2011: supplementary information p. 1) wrote:

> *heated flints in a cave site are unlikely to be the result of natural wild fires and may be considered a reliable indicator of anthropogenic fire if (i) there is no evidence of reworking of sediments, slope wash, or debris flow entering the cave; (ii) the excavator noted a localized concentration of heated flint and bones; and (iii) only a small proportion of heated flint occurs at the site. This combination of evidence suggests a good probability of localized fire.*

This combination occurs at CNERQ.

'Anthropo*genic* fire' refers to the *generation* of fire. Although hot sparks given off by a wooden hand-drill, or pyrite being struck with chert, could have ignited carefully prepared tinder at CNERQ, this begs the question of how cognitive appreciation arose of a possibility of making fire by bringing together two different kinds of technical behaviour—namely, selecting and preparing different kinds of wood (e.g. mullein and clematis) or suitable stones for striking sparks, and selecting and preparing suitable tinder for sparks to set alight (NB whereas pyrite occurs in some rock strata near Caravaca, none has been excavated in the cave). Prerequisites could have included advantages gained opportunistically from *tending* fire, itself a probable consequence of a *reduction* of instinctive pyrophobia (fear of fire, reinforced by skin-burns). Evidence of fire inside an early Palaeolithic cave carries implications for understanding cognitive evolution. The argument is set out briefly below.

First, it is unlikely that sparks from a bush-fire outside, perhaps caused by lightning, could set alight a chance accumulation of brushwood inside, such as to bring about a roaring blaze within, causing high temperatures. Moreover, the river and its swamp lay in front of the cave, where gallery woodland flourished in a damp environment, not a dry one. The cave roof also probably then extended outwards farther than it does today (as it may well have undergone some erosive reduction); if so, then the signs of fire we have uncovered would have been still farther back inside than the current 5–7m. Perhaps smouldering brands or embers left behind by bush-fires nearby were carried inside so that fire could be *tended* where rain or wind could not extinguish it. No fire-pit or hearth stones have been found, therefore there is no evidence of ability to control the *heat* of a tended fire. Nevertheless, from the standpoint of cognitive evolution, it is plausible that the people at the cave had less fear of fire outside than did animals seen fleeing before it. That could have led them to meddle with fire in order to drive animals towards natural death-traps, such as swamps, where they could be dismembered.

A tended fire in a cave serves several purposes: providing warmth, roasting food and deterring approach by animals. Compelling physiological arguments exist for cooking playing a part in human evolution from *c.* 1.5 Ma. Wrangham (2009: 88–90) wrote that archaeological "hints from the Lower Paleolithic tell us only that [. . .] the control of fire was a possibility, not a certainty" and "[T]he inability of the archaeological evidence to tell us when humans first controlled fire directs us to biology [. . .] At some time our ancestors' anatomy changed to accommodate a cooked diet". With regard to the evolution of human anatomy, following attainment, *c.* 1.6 Ma, of more-or-less modern stature, it is a plausible conjecture that subsequently widespread noteworthy increases in cerebral volume in *Homo erectus* and *H. heidelbergensis*, and, eventually, *H. neanderthalensis* and *H. sapiens*, were enabled by the enhanced digestion and absorption of nutrients that cooking afforded to pregnant women, lactating mothers, infants and children (cf. Fonseca-Azevedo & Herculano-Houzel 2012). Outcomes of cognitive evolution are reflected in the extensive material record of Palaeolithic technology (and pyrotechnology) from Middle and Late Pleistocene times, not to mention the late Early Pleistocene at CNERQ. The bifacial flaking of its handaxe is matched in Mediterranean Spain by that of a cleaver excavated in an even earlier deposit at Barranc de la Boella (Vallverdú *et al.* 2014), and an assemblage of small artefacts at Vallparadís (Martínez *et al.* 2010) shares several features with those from CNERQ.

As CNERQ has provided both an 'Acheulean' bifacially flaked handaxe and abundant flakes made by repetitive centripetal flaking of small, sometimes discoidal, cores for producing retouched small tools, it exemplifies the ability of those who frequented it to select and carry out different self-determining or self-constraining Palaeolithic chains of sequential behavioural activities (Walker 2009; Walker *et al.* 2013, 2016; Zack *et al.* 2013). Survival of early humans in middle latitudes laid heavy evolutionary demands on their cognitive versatility and manual dexterity, which are attested by the diversity of the CNERQ artefacts, so it is unsurprising that they may have tended fire. More than one palaeospecies of late Early Pleistocene *Homo* may have engaged, opportunistically, in behaviour with fire. The skilfulness manifested by 'Acheulean' artefacts at sites with traces of fire implies evolution of cognitive versatility sufficient for such behaviour.

Fire characterises the 'Acheulean' Gesher Benot Ya'akov site at the onset of the Brunhes chron, *c.* 078 Ma (Goren-Inbar *et al.* 2004; Alperson-Afil & Goren-Inbar 2010; Richter *et al.* 2011; Alperson-Afil 2012). Barely 140km south-west of CNERQ, magnetostratigraphy identified the "Matuyama-Brunhes boundary only a few metres below the fossil/tool-bearing levels" (Scott & Gibert 2009: 82) at the open Solana del Zamborino site, where excavation uncovered five stones surrounding a possible hearth area containing carbonised wood ("madera carbonizada", Botella López *et al.* 1976: 28) and burnt bone, although burnt remains were also excavated over a wider area; the site provided two bifacially flaked handaxes and small retouched artefacts.

Fire occurred in the South African Wonderwerk Cave with 'Acheulean' artefacts during the Jaramillo subchron, *c.* 1.07–0.99 Ma (Berna *et al.* 2012). Although other late Early Pleistocene sites with evidence of combustion are known in Africa from *c.* 1.5 Ma onwards (Gowlett *et al.* 1981; Rowlett 2000), most are open sites where bush-fires might have been responsible (Berna *et al.* 2012, who do not exempt Gesher Benot Ya'akov in that regard, contra Richter *et al.* 2011; Alperson-Afil 2012). At Swartkrans Cave, evidence of combustion (Skinner *et al.* 2004) from Member 3, containing 'Acheulean' artefacts, is subject to uncertainty about the integrity and age of the member, with dates from 1.4 to 0.6 Ma (Herries *et al.* 2009; Berna *et al.* 2012), although plausible ones are 0.96±0.09 Ma by ^{26}Al/^{10}Be (Gibbon *et al.* 2014) and 0.83±21 Ma by U-Pb (Balter *et al.* 2008).

'Acheulean' artefacts are unknown at Zhoukoudian Locality 1, where six ^{26}Al/^{10}Be estimates of *c.* 0.77±0.08 Ma (Shen *et al.* 2009) come from levels 7–10, which also have 17 estimates *c.* 0.55–0.35 Ma from ^{230}Th/^{234}U, TL, ESR and fission-track methods (Goldberg *et al.* 2001). Layer 8 is correlated with the laterally separate 'quartz horizon 2' where 'ash' was reported (Pei 1932; Teilhard de Chardin & Pei 1932; Black *et al.* 1933). Chemical signs of combustion exist in later levels 4–6 (Zhong *et al.* 2013), notwithstanding micromorphological demonstration of post-depositional diagenetic alteration. This also affected deeper layers 7–10, causing mistaken identification of 'ash' features; burnt bone from slightly above them is incompatible with *in situ* combustion (Goldberg *et al.* 2001).

In England, excavation at Beeches Pit, with 'Acheulean' artefacts *c.* 0.42–0.37 Ma, uncovered features hypothesised as putative hearths for "controlled fire-use" (Gowlett *et al.* 2005: 32), and "occurrence of bones burned to grey or white [. . .] implies more intense combustion than is usual for a natural fire, which often results in only partial and superficial burning (David 1990)" (Preece *et al.* 2006: 492). At *c.* 0.3 Ma, hearth features at Qesem Cave in Israel (Karkanas *et al.* 2007; Shahack-Gross *et al.* 2014) imply repeated use of fire in a restricted space enabling *heat*-control.

From the standpoint of mid-Quaternary human evolution, it is intriguing that in Africa, Israel and now at CNERQ, convincing signs of combustion occur at several sites where Palaeolithic assemblages include bifacially flaked stone artefacts. A tempting surmise is that the conjunction reflects the cognitive versatility and technical ability of early humans, which played a part in facilitating their dispersal into middle latitudes.

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Supplementary material

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