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Timescales and cultural process at 40,000 BP in the light of the Campanian Ignimbrite eruption, Western Eurasia

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ABSTRACT

Significant new information shows that the Campanian Ignimbrite (CI) eruption from the Phlegrean Fields, southern Italy, was much larger than hitherto supposed and in fact one of the largest late Quaternary explosive events. The eruption can be dated to 40,000 calendar years ago, within the interval of the so-called Middle to Upper Paleolithic 'transition'. Its position can be precisely correlated with a number of other environmental events, including Heinrich Event 4 (HE4), the Laschamp excursion, and a particular cosmogenic nuclide peak. In view of this unique combination of factors, we studied the CI volcanic catastrophe with particular attention to its impact on climate and human ecosystems, including potential interference with ongoing processes of cultural evolution (biological evolution is best left aside for the moment). The contribution of this research is chronological and ecological. The CI volcanic event provides an unequalled means of correlating stratigraphic sequences across Western Eurasia, either directly or indirectly, and affords a unique opportunity to establish the age and climatic context of important archaeological sequences. Ecologically, the CI eruption inevitably interacted with the beginning of HE4 in terms of atmospheric feedback systems. Their combined forcing produced a sudden and at least hemispheric climatic deterioration; a 'volcanic winter' scenario cannot be ruled out. Paleolithic occupation was severely altered throughout the direct-impact zone of the eruption and likely along fringe areas in southern and southeastern Europe. The above observations call for a reconsideration of the processes and rhythms involved in the Middle to Upper Paleolithic 'transition'. A tentative model is suggested that links the exceptional environmental stress at 40,000 BP with processes already active in Paleolithic societies, leading to a period of accelerated change in cultural configurations. These eventually evolved into an Upper Paleolithic proper at a later date. The evidence to invoke allochthonous cultural input or invasionist scenarios is not considered compelling.

Introduction

In this paper we examine some critical temporal aspects of what is commonly called the 'Middle to Upper Paleolithic transition,' here neutrally understood as one of several intervals of faster-paced changes in human Paleolithic societies. We take a particular and, until now, underrated perspective: a detailed investigation of a very large volcanic eruption that occurred at a crucial moment within the 'transition.' From its point of origin in southern Italy and its widespread deposits, or tephra, this eruption is known as the Campanian Ignimbrite (CI). Recent work has shown that an acute cooling caused by arctic ice discharge, Heinrich Event 4 (HE4),[1] starting at ca. 40,050 BP$_{GISP2}$,[2] was soon followed by this explosive eruption (Fedele et al., 2002, 2003). The CI explosion took place in

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[1] The following abbreviations will be used throughout for recurrent stratigraphic terms and units related to the late Pleistocene record (the informal expression late Pleistocene, as different from Upper Pleistocene, is used sensu Klein, 1999): D-O = Dansgaard-Oeschger cycle; GI = Greenland Interstadial; GS = Greenland Stadial; HE = Heinrich event; MIS = Marine Isotopic Stage (formerly OIS, Ocean Isotopic Stage). Correlations with the Greenland ice sheet tephro- and chronostratigraphy—cores GRIP, GISP2, NorthGRIP—are based on the depth-age models of Meese et al. (1997), Johnsen et al. (2001), Shackleton et al. (2004), and Andersen et al. (2006), as explained in the main text. See also Hammer et al. (1997).

[2] Chronometric age will be reported as follows (e.g.): '40,000 ^{14}C BP' for radiocarbon measurements; '40,000 cal BP' for calibrated radiocarbon dates; and '40 ka BP' for radiometric determinations different from radiocarbon (often in this paper BP$_{40Ar/39Ar}$ = ^{40}Ar/^{39}Ar years before present). The colloquial expression '40,000 BP' or 'years ago' will occasionally be used to suggest calendar age in descriptive passages where no need exists of formal specification; ca. = circa.

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the 40,000 ± 100 $\text{BP}_{\text{GRIP/GISP2}}$ time range (ca. 40 ka $\text{BP}_{40\text{Ar}/39\text{Ar}}$), and possibly at '40,012 BP_{GISP2},' according to a correlation with Greenland ice core tephrostratigraphy (Fedele et al., 2007). An approximate figure of 40,000 years ago is not only the best available date for the CI eruption (De Vivo et al., 2001; Pyle et al., 2006; see below), but a convenient shorthand for the purposes of the present paper.

This date alone draws attention to the close temporal relationship between the eruption and the Middle to Upper Paleolithic 'transition.' In addition, the interplay between eruptive catastrophe and hunter-gatherer lifeways is graphically exhibited in archaeological stratigraphies in parts of Southern and Eastern Europe. In this paper, we update the available information on the geophysical dimensions, stratigraphic position, and chronology of the CI eruption and the importance of its ecological influence. It will be shown that the CI is one of the few truly large volcanic eruptions in the northern hemisphere during the past 200,000 years. Thus, the CI deserves attention as a time marker and correlational tool of primary importance. At the same time, the potential implications for human groups must be closely examined. Against this background, we endeavor to show how the CI and other factors demand a reconsideration of the processes and rhythms that took place in Western Eurasia around 40,000 years ago, and presumably are a fundamental part of the perceived 'transition.'

Dates and coincidences play a key role here. The near coincidence between the eruption and the onset of sudden cooling connected with HE4 is environmentally significant. The coincidence of these events led to at least continental (Western Eurasian) and possibly hemispheric climatic deterioration, such that one can speak of a HE4-CI crisis. Other coincidences involve society and culture. The Middle to Upper Paleolithic 'transition' spans an interval across the CI age and exhibits peculiar phenomena in Western Eurasia. Previously, this broad coincidence of eruption and supposed cultural divide has usually been neither recognized nor properly addressed, in spite of a plethora of archaeological evidence in southern Italy and elsewhere of the connection. The 'transition' can be viewed as a rupture, or can be equally recognized as the culmination of a much longer period of innovative cultural trends. Discrete developments in adaptive systems technology, ideology, and perhaps social organization seem now to have appeared at various times well before the 40,000 BP timeline, and possibly as early as 55,000–60,000 BP, as will be discussed below. The occurrence of a significant environmental accident at 40,000 BP, during a glacial period and within an ongoing or incipient epoch of cultural change (and gene flow?), necessarily raises questions.

Background, approach, and theory

Notes on nomenclature, analytical units, and the cultural framework at 40,000 BP

In spite of a growing awareness of the problems and limitations of the current terminology, we believe that some terms and concepts still hinder students of 'modern human origins' archaeology (Clark, 1999). Three points stand out: the 'transition' conceptual package, the mixing of biological and cultural discourse, and the notion of human 'modernity' (this will be dealt with in greater depth later in the paper). An additional danger results when the three are intertwined (Fedele and Giaccio, 2007; Fedele et al., 2007).

We admit that 'as part of a widely accepted lingua franca' the term 'transition' may be unavoidable (cf. Clark, 1984). However, the European Transition with a capital T gets inevitably tempered when cast in a broader Old World and Stone-Age-wide perspective (Brantingham et al., 2004; Hovers and Kuhn, 2006). More substantially, there are two dimensions to the 'transition': the first and most hotly debated is biological, the second cultural. The biological transition is predicated on a perceived anatomical contrast between two different variants of skeletal morphology within *Homo*, the Neandertal and the 'modern.' More recently, the analysis of ancient DNA extracted from fossils has begun to offer prospects for an evaluation of genetic distances within our genus (e.g., Templeton, 2002; Relethford, 2003; Pääbo et al., 2004; Willerslev and Cooper, 2005; Noonan et al., 2006). The results have so far led to an extraordinary mix of restraint—in our opinion, the judicious attitude for the moment—and hurried interpretive claims (for a sample of views see, e.g., Tobias, 1995; Omoto and Tobias, 1998; Crow, 2002; Gutierrez et al., 2002; Relethford, 2002, 2003; Pearson, 2004; Templeton, 2005; Zilhão, 2006b; cf. Pennisi and Balter, 2006, and contributions to Harvati and Harrison, 2007).

The cultural dimension of 'transition' has to do with modifications in the making and utilization of artifacts, including ideological artifacts. It is in this field that the perceived change is still conventionally phrased as a transition between two eras of humankind, the Middle and the Upper Paleolithic, a notional framework suggested by French érudites in 1865–1869 and last formalized by Gabriel de Mortillet a century ago (de Mortillet, 1900). In addition, it was Émile Cartailhac and Henri Breuil that established the view of a sharp, epochal boundary between the two Paleolithic periods, with the Aurignacian as the revolutionary beginning of a wholly new era for Western Europe—and thus for humankind (see Breuil 1906, 1912). Significantly, Cartailhac and Breuil were the foremost students of 'cave art,' bent on emphasizing the discovery of a leap forward of the human mind. Moreover, for Breuil the Aurignacian had the hallmark of invasion, into what he rightly called 'a cul-de-sac' (Breuil, 1912: 9). Discussion is still largely cast in the Cartailhac-Breuil mold (e.g., Barroso Ruíz et al., 2005). Rarely has an archaeological paradigm resisted change for so long, surviving its early merits.

These subdivisions, however, are mere 'accidents of history' (Clark and Lindly, 1991: 577). Along with several 'industries' identified in European techno-cultural classifications, they are only analytical constructs not to be reified as facts (Straus, 1995, 2005; Clark and Willermet, 1997; Riel-Salvatore and Clark, 2001); hence their congruity with the shifting constellation of data should be subjected to critical scrutiny time and again (e.g., Clark and Riel-Salvatore, 2006b). The most obvious case is the Aurignacian. 'The contribution of poorly-defined cultural terminology to the misunderstanding of what happened during the Initial Upper Paleolithic times cannot be emphasized enough. The worst example is the indiscriminate use of the term "Aurignacian"' (Bar-Yosef, 2006: 475). As 'a real thing, an identifiable and ethnically bounded cultural entity,' the Aurignacian has indeed become 'an obsession' (Straus, 2003: 13), while in fact it has no integrity (Clark and Riel-Salvatore, 2006a; cf. Fedele et al., 2003: 317). However, if a rethinking has just begun (e.g., Bon, 2002, 2006; Bar-Yosef and Zilhão, 2006) and similar units are undergoing renewed scrutiny (see Zilhão and d'Errico, 2003a; Conard, 2006, for samples of views), a critical attitude towards other constructs lags behind. The Upper Paleolithic, in particular, has perhaps become the most obsolete and dangerous of the uncritical paradigms (e.g., Shea, 1995; Fedele, 2006). We should realize that the 'Middle/Upper Paleolithic industries,' as defined below, did not mark a break anywhere near as sudden or momentous as has been conventionally thought.

The two different transitions, anatomical and cultural, hardly constitute a unity. Their underlying mechanisms were not identical nor were the events simultaneous. The available evidence from many parts of Western Eurasia (e.g., Akazawa et al., 1998; Fox, 1998; Bar-Yosef and Pilbeam, 2000; Brantingham et al., 2004; Conard, 2006) indeed suggests that they were temporally and processually distinct, although authoritative opinions are still voiced to the contrary (e.g., Klein and Edgar, 2002; Mellars, 2004, 2006). Most of the latter reflect a tendency to equate the biological and cultural units—or putative units—and nowhere is this attitude more pronounced than in Europe. Neandertal is used as synonymous with Mousterian or indeed any maker of Middle Paleolithic tools. The Aurignacian is a century-old surrogate for both the early Upper Paleolithic and early 'modern humans' in Europe, or 'Cro-Magnon.' It is ironic that Crô-Magnon is employed as a synonym for Aurignacian (e.g., Klein, 2003) when the original finds, including people, date from the Gravettian (Henry-Gambier, 2002; Henry-Gambier and White, 2003). It is now imperative to decouple anatomical-biological from sociocultural change, unless their mutual dependence is firmly proved (e.g., Fedele et al., 2003; Brantingham et al., 2004; Hovers, 2006: 66). Unless Klein's (1999, 2003) claim turns out to be correct, even a genetic/genomic demonstration that Neandertal and *Homo sapiens* are different species has nothing to do with the *cultural* issues of the European Middle to Upper Paleolithic shift.

In the cultural field itself, two interrelated errors of logic continue to be made that should instead be avoided. One is projecting expectations, a glaring form of *petitio principii*. This is the mistake one makes when he/she demonstrates what in fact they have assumed in advance. In our case what is expected beforehand is the existence of an evolutionary break called the Middle to Upper Paleolithic boundary. Not surprisingly, whenever the beginning of an 'Upper Paleolithic' is taken for granted in advance, it is normally found, no matter the evidence.

The second error is judging historical novelty from the consequent, not the antecedent, and has to do with heuristic approaches and the historical method. It is an application of the chief principle of historical contingency: a given situation—a 'before'—can evolve into a subsequent situation—an 'after'—in many different ways. Novelties must be understood first of all with an eye to what preceded (in our case the 'Middle' Paleolithic), not to what followed (the 'Upper' Paleolithic). For instance, labeling innovations 'Upper Paleolithic elements' may be inherently misleading (Fedele et al., 2003: 318). In the first place, one should research what was going on in the Paleolithic at the time in question, how that situation had been reached in any given area, and in what direction—if any—the societies in existence were moving. Steps to this effect are being taken, as recent research suggests, with revealing results (e.g., Slimak, 2004; several contributions in Conard, 2006); however, the dynamics inherent in the Mousterian societies of the Interpleniglacial, although apparent, are still greatly underplayed. There is an effective 'blindness with respect to Middle Paleolithic dynamics in Eurasia' (Hovers and Kuhn, 2006: 3). The range of temporal and regional variation within the 'later' Mousterian is considerable. Variation in tool making around and after 40,000 BP now appears to be the culmination of a much longer phase of artifactual instability and experiment, and some long-term trends were perhaps set in motion as early as 60,000–55,000 BP (e.g., Kozłowski, 1990; Dibble and Mellars, 1992; Féblot-Augustins, 1993, 1999; Stiner, 1994; Kuhn, 1995; Gamble, 1999: Ch. 6; Roebroeks and Gamble, 1999; Vermeersch and Otte, 1999; Riel-Salvatore and Clark, 2001; Straus, 2005; cf. Shea, 1995).

Context and models

The questions we address in this paper are focused on the potential forcing of the HE4-CI crisis on ecosystems and human groups. Especially interesting is the context upon which the crisis acted (Fedele et al., 2003; Fedele and Giaccio, 2007). Abundant data hint at a rich and fairly dynamic culture and population scene at the time of the CI eruption. The European situation probably comprised a fairly enlarged human biomass by comparison with earlier parts of the late Pleistocene. This, and the presence of Mousterian groups throughout a broad range of habitats, may have been favored by a brief phase of climatic amelioration shortly before the HE4-CI crisis, the Hengelo Interstadial in Northern European terminology (usually equated with GI12). Hominin populations, it appears, were more widely based both ecologically and geographically and were interacting in more complex ways with resources and landscape. They were adaptable and resourceful, with efficient tool-kits, an ability to hunt and forage for a variety of species, and large territorial ranges. In Western Eurasia, humans had evolved adaptations to seasonal, demanding habitats for tens of millennia, both culturally and physiologically. The Mousterians, or the Neandertals if one prefers, were capable of experimenting on their own—they 'were not stuck in their ways' (Straus, 2005: 54). Incidentally, this is shown by the way they were effectively circulating within the mountains (e.g., the Alps; Fedele, 1978, 1981; Bona et al., 2007).

About 40,000 BP this scene begins to change—this much is generally agreed. Heated discussions continue concerning the tempo and agency of the observed modification, whether it entailed a break with previous conditions and whether it was directional. Either modification occurred during a relatively short period of time, or a protracted phase of more conspicuous reorganization ensued. Either way, the evolutionary relevance as a divide between major stages of human culture—the Middle and the Upper Paleolithic—is not, unfortunately, widely questioned. The fact that Europe is geographically peripheral is sometimes disregarded as well. Also debatable is the fact that many researchers tend to take as a given that an association between cultural and anatomical modifications is warranted, and, as far as Europe is concerned, they freely equate the above cultural stages with 'Neandertals' and 'modern humans,' respectively.

As is well known, the interpretations can be summarized in terms of two competing scenarios (cf. Clark, 1999, for a concise and elegant statement). The first scenario favors continuity and contends that modern humans and behaviors essentially evolved from their local predecessors in Europe and elsewhere (e.g., Frayer, 1993; Richter, 1996; Wolpoff, 1999; Wolpoff et al., 2001; Bednarik, 2006a, 2007b).[3] The other scenario argues that modern humans and behavioral 'modernity' evolved together and only in Africa, migrated out of Africa, and substituted or replaced 'archaic' hominins in the various continents (e.g., Klein, 1999, 2003; Bar-Yosef, 2002; Lahr and Foley, 2003; Mellars, 2004, 2006). This latter view has become the more mainstream and its supporters often assume that distinctions between biology and culture need not be addressed.

However, such polarized opinions appear to be losing ground (e.g., Churchill and Smith, 2000; Finlayson, 2004; cf. Balter, 2004, and such collective volumes as Omoto and Tobias, 1998; Straus and Bar-Yosef, 2001; Hays and Thacker, 2001; Brantingham et al., 2004; Harvati and Harrison, 2007). Distancing themselves from extremes, some workers have consistently argued that the European evidence shows intriguing continuities (Clark and Lindly, 1989, 1991; Straus, 1990, 2005; Clark, 2002; cf. Clark et al., 2006), while nuanced or intermediate models have been advanced from in-depth studies of particular data sets or regional records (e.g., Zilhão and Trinkaus, 2003; Ahern et al., 2004; Smith et al., 2005; Conard, 2006; see Relethford, 2003, for a balanced view of genetics). Furthermore, a debate centered on Europe may simply look simplistic or irrelevant from a non-European perspective of hominin evolution (e.g., McBrearty and Brooks, 2000; Mitchell, 2002; Bednarik, 2002, 2003

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[3] The bibliography on the subject—both the Middle to Upper Paleolithic 'transition' and the Neandertal versus 'modern humans' debate—has become so vast that 'to cite just a few items would slight many scores of others of equal significance; many can be found in the several topical symposium volumes of the last decade' (Straus, 2003: 17). Here this attitude must be shared if only for reasons of space. An absolute minimum of recent volumes and papers will be cited for orientation whenever necessary. Regrettably, the abundant literature on the Levant and the Middle East has to be omitted.

[with comments], 2007b; Bednarik et al., 2005; see also Hovers and Kuhn, 2006; Willoughby, 2006).

Although, as a standpoint, we prefer to support explanations that attribute a role to autochthonous developments, we in fact would argue that any kind of agent interfering with the '40,000 BP' scene, no matter whether originating from the inside or the outside or from both, is worthy of attention. The sole issue of importance to explain is the fundamental nature of socio-behavioral change (see Bar-Yosef, 1998, for a stimulating attempt), and, as far as the Paleolithic is concerned, we surely have a poor grasp of the driving mechanisms behind it (Brantingham et al., 2004: 3, 12). This goal requires that the analytical units and terms employed be critically evaluated and that theoretical positions be made explicit. We have suggested in a previous section that terminology is not peripheral to the issues here discussed; it is in fact a part of the problem. Explanation of change, as a highly sensitive historical problem, is only made more intractable by an uncritical use of nomenclature (cf. Clark and Willermet, 1997). Several current notions have become unsettling or need qualification, along with units and terms that risk being used dogmatically, as mentioned above (e.g., Aurignacian, Middle and Upper Paleolithic, transition, modernity). As everybody knows—and often forgets—the classifications employed to support knowledge claims are as critical as the 'facts' themselves.

In this paper, exclusively to emphasize the need for a language as free from prejudice as possible, the commonly accepted suite of cultural and biological modifications first apparent in mid-Interpleniglacial times—roughly between 45,000 and 35,000 BP—will be termed the 'European Paleolithic shift' (cf. 'European Late Pleistocene shift,' Fedele et al., 2002, 2003; Fedele and Giaccio, 2007).[4] The archaeological assemblages and/or industries of the peculiar Paleolithic phase in Western Eurasia roughly dating from the same time range will be termed the Middle/Upper Paleolithic industrial mosaic ('MUP mosaic' or 'MUP industries' for short; cf. 'transitional industries' of mainstream usage). This phase is characterized by a spectrum of stone-tool assemblages variously regarded as conservative or innovative within the overall European Paleolithic shift, including the so-called Early/Earliest Aurignacian. The word 'mosaic' is deemed appropriate in view of the unquestionable patterning of such manifestations, as eloquently articulated by Straus (2005; and earlier works). The CI offers a privileged timeline for looking at this suite or mosaic of 'transitions.'

We hasten to add that the biological problem of continuity or discontinuity between Neandertals and anatomical 'moderns' is outside the scope of the present paper, if not of the CI research project as a whole, and will not be pursued here. In fact, the mixing of biological and cultural discourse is unwarranted on theoretical and empirical grounds and is, in our opinion, a source of several intractable issues concerning the European Paleolithic shift. Preliminary to any further discussion of the issues, the safest way to approach the evidence is to acknowledge that we are dealing with two overlapping pathways of change, which it is now imperative to uncouple unless their mutual dependence is firmly proved.

The Campanian Ignimbrite eruption: a synopsis of data and theory

An appropriate temporal framework for the processes discussed in this paper implies consideration of an interval of some 5,000 years on either side of the 40,000 BP timeline. Geographically, the minimum area of concern is the Greater Mediterranean, taken to cover most of the regions in Fig. 1, including in its eastern sector parts of Anatolia, the Pontic (Black Sea) perimeter, and the easternmost East European Plain (this last region sensu Hoffecker, 2002: Ch. 2). Some arguments will require that larger geographic areas are considered. The CI factor interfered with populations and cultures in the Greater Mediterranean at least. A tentative model to account for the shift in human systems is introduced here in outline, and further reviewed in the last section of the paper. What follows should be explicitly understood as a mere summary of work in progress and suggested avenues for future research.

The CI sulphate signal has been identified in the Greenland ice core record (see below). From its position and magnitude there is reason to reconstruct that the atmospheric impact of the eruption was greatly amplified and prolonged through positive feedback with coeval climate trends. These not only included the drastic onset of HE4 but also the longer-term cooling of the preceding Bond cycle (Fedele et al., 2003, 2007; Giaccio, 2005; B. Giaccio et al., unpublished working documents). The ensuing conditions affected ecological systems including people. Beyond southern Italy, the immediate impact of the CI was the cause of a super-regional alteration that affected human ecosystems throughout southeastern Europe. We predict a highly contrasted mosaic of local situations, developing in part from the pre-existing mosaic of the biotic and cultural scene. A 'volcanic winter' was probably felt on a hemispheric scale.

Through complicated feedback circuits, the CI is modeled as having produced a sudden shift in population density and distribution, with fringe or 'cascading' effects far distant from the core area of impact. At least in the direct-impact zone, the eruption may have disrupted herbivore populations through the deterioration of pasture, altered the overall availability of habitually-exploited staple plants, and changed the availability or predictability of water resources. In other words, Paleolithic groups were critically conditioned in their capacity as upper predators in the trophic chain. A fourth kind of impact in certain areas may have been a change in the ease of procurement of familiar rock resources for stone technology. Lithic and nonlithic technologies were thus influenced in significant ways.

Concurrently, the CI is likely to have disrupted the communal, cognitive balance of social groups. We would expect far-reaching repercussions on population density and distribution as well as cultural transmission and intergroup interaction. We would posit a critical interplay between an altered resource base, population ecology (not demography per se), and social configuration, with ideology and cognition as additional major players. Cognition as a component of the social fabric leaves traces in the material record, with image-making and information-exchange devices—'art'—being a vital clue. At a date of 40,000 BP we are dealing with hunter-gatherer groups of enough complexity to organize their spatial and ecological relationships along socially constructed cognition. Of particular interest are potential implications for the enhanced visibility of the sociocultural expressions usually termed 'modern' behavior (Fedele and Giaccio, 2007; Fedele et al., 2007). Here one comes face to face with the less tangible parts of the archaeological record. 'Disruption,' however, has to be understood as forcing into new habits and opportunities, resulting in selection against populations that are unable to change.

The occurrence of a major environmental forcing of such scope and chronology brings a new factor into the study of the European Paleolithic shift. The challenge is not only to constrain this complex factor, as is being done already, but to translate it into a series of testable propositions, against a background of high-resolution data and timescales. Perhaps the single most intractable problem in reconstructing what may have happened stems from the fact that

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[4] This is a provisional, practical umbrella term; we stress 'first apparent.' Both cultural and biological modifications are subsumed for the sake of convenience. Justification for the definite article relies on the fact that no other shift in the European Paleolithic record has ever possibly attracted the same amount of attention and ink. The mention of Europe merely reflects the traditional, geographic focus of the perceived change in the above time range, without implying strict geographic boundaries. Our expression, late Pleistocene cultural shift (Fedele et al., 2002), has been adopted by Bednarik (2007b).

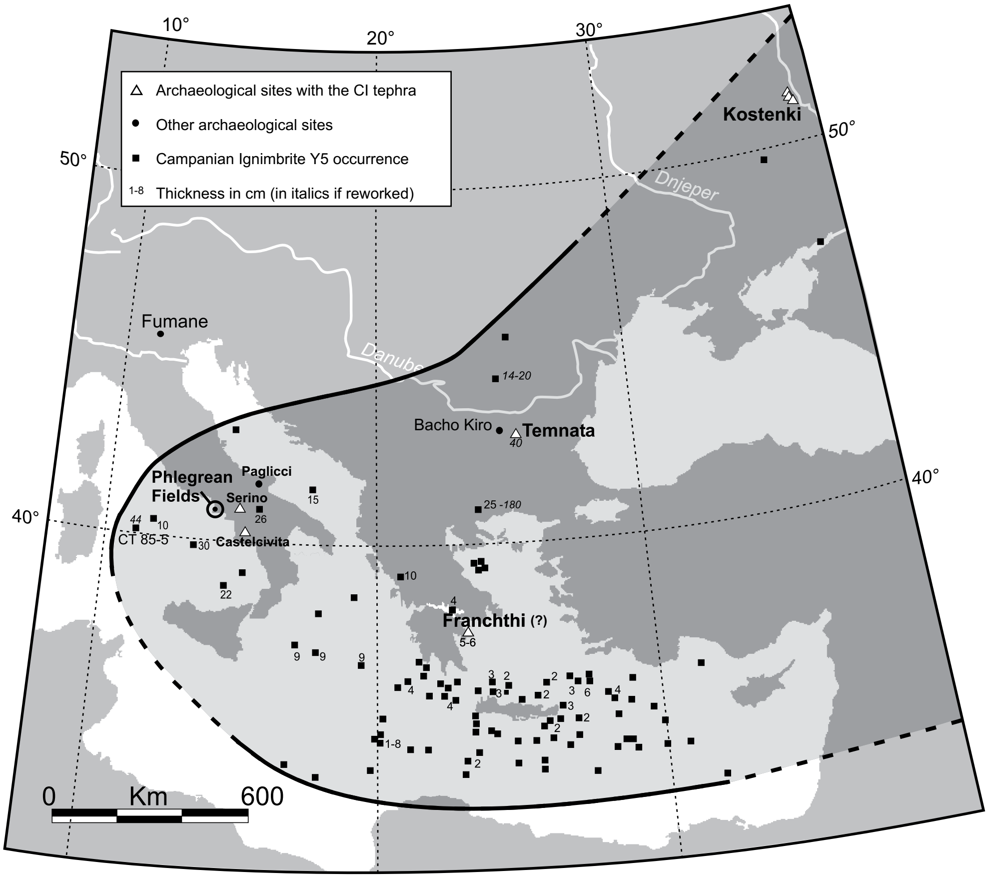

Fig. 1. Map to show the minimum extent of deposition of the Campanian Ignimbrite tephra (from Fedele et al., 2003, updated; additional information derived from Pyle et al., 2006). CI = Campanian Ignimbrite; Y5 = marine equivalent of the CI tephra.

the Western Eurasian situation at 40,000 BP is without modern analogue (cf. Stewart, 2005). One is dealing with a combination of latitudes, biomes, and peoples that no longer exist among extant hunter-gatherers anywhere. Moreover, such living communities were hit by a joint climatic and volcanic blow of peculiar magnitude. This aspect and its implications will be further examined in the final section of the paper.

The Campanian Ignimbrite eruption

Dynamics, age, and stratigraphic position

The eruption of the Campanian Ignimbrite is now regarded as an example of a super-eruption (Sparks et al., 2005). A number of studies has made very clear that it was the climax of the eruptive history of the Phlegrean Fields volcanic area, immediately north of the Bay of Naples in southern Italy (see, e.g., Barberi et al., 1991; Fisher et al., 1993; Orsi et al., 1996; Rosi et al., 1996; Ort et al., 1999, 2003; Pappalardo et al., 2002; Marianelli et al., 2006; Fig. 1). Two different, successive eruptive stages can be distinguished: an early or ultra-Plinian phase characterized by a very high column, reaching about 40–44 km (e.g., Rosi et al., 1996), and a later caldera collapse, no less than 230 km^2 in extent, accompanied by the formation of highly turbulent and mobile pyroclastic currents. Moving radially from the vent, these were able to surmount high relief, above 1,500 m above sea level, and laid down ignimbrite deposits more than 80 km from the source (Fisher et al., 1993). According to a different eruptive model, the CI was an eruption of fissural type, driven by the pre-existing fault system bounding the Campanian Plain (e.g., De Vivo et al., 2001; Rolandi et al., 2003).

In spite of remaining controversies concerning the geological origin and dynamics of the CI, there is no disagreement about its great intensity and magnitude. The eruption was one of the largest late Quaternary explosive events worldwide, ranking 7-high in magnitude (Mason et al., 2004; Self, 2006). This is unambiguously revealed by the area of at least 5,000,000 km^2 over which its distal deposits have been traced (Thunnel et al., 1979; Narcisi and Vezzoli, 1999; Fedele et al., 2003; Giaccio et al., 2006; Pyle et al., 2006; Wagner et al., 2007; Fig. 1) and by the eruptive parameters summarized in Table 1. Also reported in Table 1 are the current best-age-estimate of about 40 ka BP$_{Ar/Ar}$ and other crucial information concerning the timing and stratigraphic position of the CI.

The assessment of the CI calendar age derives from a number of completely concordant chronological determinations, both numerical and 'non-numerical' (Table 2). The former include a series of $^{40}Ar/^{39}Ar$ measurements from the proximal to intermediate deposits of the CI (De Vivo et al., 2001; Lanphere, 2003; Rolandi et al., 2003). Non-numerical age determinations derive from the stratigraphic relationships of the CI tephra with some climatic and geophysical events recognized as important temporal-stratigraphic markers. Previous studies (e.g., Fedele et al., 2003; Giaccio et al., 2006) have shown that in several Mediterranean sedimentary records the CI tephra falls in proximity of (1) the onset of HE4, (2) the Laschamp geomagnetic excursion, and (3) a distinct peak of ^{10}Be and other cosmogenic nuclides, ^{14}C included (see below). Very possibly this latter was causally connected with the Laschamp excursion (Fig. 2). All of these separate events are independently dated and, as a whole, provide a unified, concordant stratigraphic and chronological framework for the CI eruption.

Table 1
A summary of information on the Campanian Ignimbrite eruption and its impact (Fedele et al., 2007: Table 2.1, updated)

Place of origin[a,b]	Phlegrean Fields, Campanian Volcanic Zone, S Italy
Best estimated date(s)[c,d]	40.012 ka BP_{GISP2}; 39,395 ± 51 ka $BP_{40Ar/39Ar}$
Correlated geophysical, cosmogenic, and climatic events[c–e]	Laschamp, ^{10}Be and ^{14}C peaks, onset of Heinrich Event 4
Wind direction and prevalent impact[f]	Towards E, NE
Maximum height of plinian column[f]	ca. 44 km
Minimum height of co-ignimbrite clouds[c]	ca. 30–35 km
Volume of extruded magma[g]	ca. 300 cubic km (dense rock equivalent)
Estimated discharge rate[h]	ca. 10^{10}–10^{11} kg s^{-1}
Eruptive temperature[i]	ca. 1000 °C
Sulphur injected into the atmosphere[g,j]	$2.1 \pm 0.8 \times 10^{15}$ g; 1.17×10^{15} g
Sulphate signal in Greenland ice core GISP2[c]	375 ppb SO_4^{2-} (second largest of the whole record)[m]
Minimum area covered by pyroclastic currents	30,000 square km
Minimum area affected by ash fallout	5,000,000 square km
Cooling induced[k]	3 ÷ 4 °C
High-latitude (>60° N) amplifying factor for cooling[l]	× 4 ÷ 7 (ca. 12–20 °C)
Sudden abandonment of Paleolithic sites or locales[c]	Yes (S Italy, ?S Balkans)

[a]Orsi et al., 1996; [b]Rolandi et al., 2003; [c]Fedele et al., 2003; [d]De Vivo et al., 2001; [e]Giaccio et al., 2006; [f]Rosi et al., 1999; [g]Giaccio, 2005; [h]Legros and Kelfoun, 2000; [i]Signorelli et al., 1999; [j]Scaillet et al., 2003; [k]extrapolated from Sigurdsson's (1990) curve; [l]Jacoby et al., 1999; [m]GISP2 volcanogenic record according to Zielinski et al., 1997.

According to the Greenland ice sheet age models (e.g., GISP2, Meese et al., 1997; GRIPSS09sea, Johnsen et al., 2001; NorthGRIP-GICC05, Andersen et al., 2006; SFCP04, Shackleton et al., 2004) the beginning of the HE4 cooling event can be dated within a narrow interval, between 40,100 and 40,030 $BP_{GRIP/GISP2}$. The Laschamp excursion and the cosmogenic nuclide peak (^{10}Be, ^{36}Cl, ^{14}C) span the interval between the interstadials 10 and 9 of the Greenland isotope stratigraphy (i.e., GI10–GI9) approximately dated at 42,000–40,000 $BP_{GRIP/GISP2}$ (Fig. 2). The Laschamp excursion has recently been dated by $^{40}Ar/^{39}Ar$ and K/Ar methods to 40.4 ± 2.0 ka BP (Guillou et al., 2004), which is in substantial agreement with the Greenland timescale(s).

Thus, all the available numerical and non-numerical age determinations for the CI cluster around 40,000 years BP, on a calendar scale. In addition, and more importantly, there is the close stratigraphic relationships between the CI and the above listed climatic and geophysical events, these latter spanning a distinct and relatively short interval of the Greenland isotope stratigraphy. Such relationships provide an invaluable tool for correlating any sequence containing the CI tephra with the Greenland record, independent of dating methods and timescales employed. It is on the basis of the distinctive stratigraphic position of the CI that its volcanic signal has been convincingly identified in the Greenland sulphate-record stratigraphy (Fedele et al., 2003; Giaccio et al., 2006; Fig. 2).

Table 2
Numerical (non-^{14}C) age determinations and stratigraphic age estimates for the Campanian Ignimbrite eruption[a]

Site or context	Method	Age (years BP)	*n*	References
CI proximal deposits	$^{40}Ar/^{39}Ar$	39,395 ± 51 (1σ)	38	De Vivo et al., 2001
»	»	38,100 ± 800	9	Lanphere, 2003
»	»	38,833 ± 250	8	Rolandi et al., 2003
»	»	37,100 ± 400	3	Deino et al., 1994
Lake Monticchio TM-18	»	37,000 ± 3,000	–	Watts et al., 1996
C-13 marine tephra	»	41,000 ± 2,100	21	Ton-That et al., 2001
Y5 marine tephra	$\delta^{18}O$ stratigraphy	38,000 ± 2,000	–	Thunnel et al., 1979
GISP2 volcanic peak[b]	Annual layers[c]	40,012	–	Fedele et al., 2003

[a] See references for sample and measurement details; *n* = number of measurements.
[b] GISP2 volcanogenic sulphate record according to Zielinski et al. (1997).
[c] GISP2 age model according to Meese et al. (1997).

Inferred climatic impact

The potential impact of the CI eruption on climate, and environment more generally, has been examined in previous studies (e.g., Fedele et al., 2003, 2007), where more detailed information can be found; here we only refer to the points which appear to be relevant for the present discussion. The CI impact has to be assessed on two different temporal scales: the short-term atmospheric effects, and the potential, prolonged atmospheric perturbations. Concerning the immediate but temporary atmospheric impact, empirical historical observations have shown that sulphur is the chief agent responsible for the global or semi-global lowering of temperature (e.g., Robock, 2000; Self, 2006). The degree of cooling is indeed a function of the mass of sulphur injected into the stratosphere (Sigurdsson, 1990), rather than the eruption's magnitude. The current estimates of the mass of sulphur emitted during the CI eruption range between ca. 1.17×10^{15} g (Scaillet et al., 2003; Fedele et al., 2007) and $2.1 \pm 0.8 \times 10^{15}$ g (Giaccio, 2005). This accords well with an intensity of 375 ppb sulphur aerosol in Greenland's volcanogenic record (Zielinski et al., 1996, 1997; Table 1; Fig. 2).

Such a high value of emitted sulphur is closely comparable to those of super-eruptions, including Youngest Toba Tuff from Lake Toba, Sumatra (ca. 73.5 ka BP, various methods; e.g., Chesner et al., 1991; Bühring and Sarnthein, 2000; Gathorne-Hardy and Harcourt-Smith, 2003; Self, 2006), and Bishop Tuff from Long Valley, California (ca. 770 ka BP, various methods; e.g., Wilson and Hildreth, 2000; Hildreth and Wilson, 2007). With due consideration for tropospheric aerosol transport, the intensity of the peak attributed to the CI is second only to Toba's (466 ppb) among the late Quaternary eruptions. This finding makes the CI one of the most sulphur-rich eruptions ever identified in the geological record (Scaillet and Pichavant, 2003). By plotting the CI range of values on the empirical curve of Sigurdsson (1990), the predicted semi-global or global cooling induced by the CI eruption should have been on the order of 3–4 °C. This transient perturbation caused by the CI eruption may have lasted between two and three years and is in itself quite noteworthy.

However, the CI is expected to have interacted with the Last Glacial climatic system in a much more effective way. As revealed by Johnsen et al. (1992; see also Dansgaard et al., 1993), the Last Glacial climate was highly unstable and led by extremely sensitive threshold mechanisms (e.g., Ganopolski and Rahmstorf, 2001; Rahmstorf, 2002), particularly during the Interpleniglacial or MIS3 (e.g., Allen et al., 1999; van Andel and Davies, 2003; Sánchez Goñi and d'Errico, 2005; see also Stewart, 2005). In such a context, almost inevitably, the CI eruption represented a major interference whose effects far exceeded the mere eruptive impact. This inference comes from two key considerations: the close temporal-stratigraphic proximity of the CI eruption to the onset of the HE4 cooling; and the anomalous, pronounced climatic signal associated with HE4 itself. This signal, as revealed by climatic proxies, is substantially more marked than all other similar episodes of the Last Glacial (Fig. 3). The at least hemispheric importance of HE4 is demonstrated, inter alia, by the detection of its signal in central-eastern Asia (Prokopenko et al., 2001). On this basis, a hypothesis has been advanced whereby positive climatic feedbacks, triggered

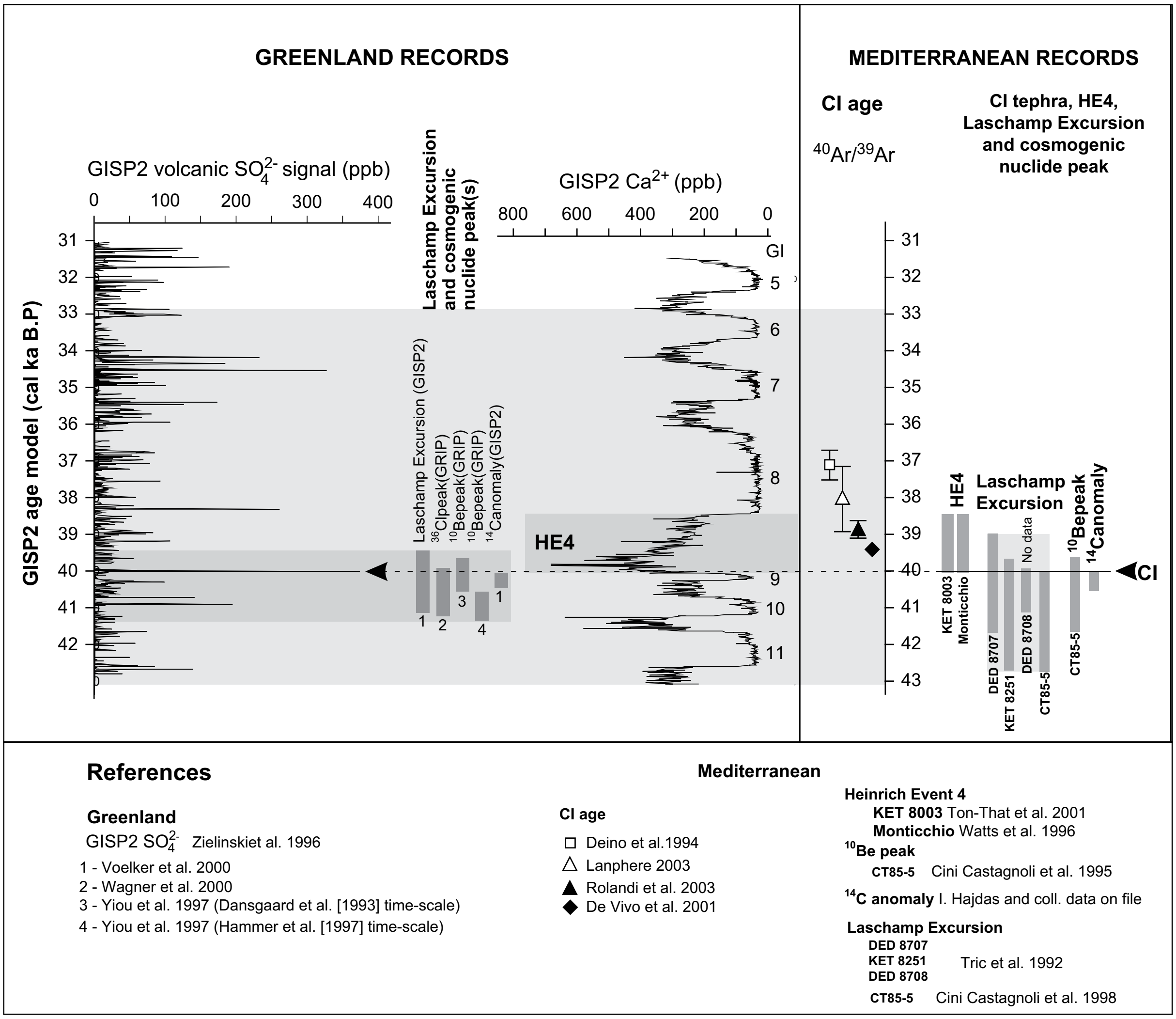

Fig. 2. A summary of the age and position of the Campanian Ignimbrite (CI) in relation to some stratigraphically and chronologically well-defined paleoclimatic, paleomagnetic, and cosmogenic-nuclide events of Marine Isotope Stage 3 (from Fedele et al., 2007: his Fig. 2.2, modified). The identification of the putative Campanian Ignimbrite peak within the volcanogenic record of the GISP2 ice core is shown.

by the concurrence and combination of HE4 and the volcanic factor, greatly amplified and prolonged the individual atmospheric effects of HE4 and the CI alone (Fedele et al., 2003, 2007; Giaccio, 2005; cf. Rampino and Self, 1993, among others, for the guidelines of the feedback model). We predict that the climate-ocean-volcano system effectively established conditions of 'volcanic winter,' at least on a hemispheric scale, and quite possibly prolonged such conditions on a decennial if not centennial time span. The consequences of this impact will be examined in greater detail below (cf. Figs. 6 and 7).

An eruption of magnitude 7-high originating from 42°N, the CI might have triggered different atmospheric effects in the two hemispheres (Robock, 2000; Robock and Oppenheimer, 2003). Unfortunately, until now, a numerical simulation of the CI cloud and its global behavior could not be performed. As a conservative estimate we would predict that there were substantial effects over the whole northern hemisphere. The combined HE4-CI forcing would have generated volcanic-winter conditions over mid- and high-latitude Eurasia in particular. If there was a volcanic winter that would have affected land and people hemispherically, we should expect interference with ecosystems and humans well beyond the area of ashfall, both east and west. However, the recognition of this kind of interference would require well-dated stratified sequences with a very high degree of temporal resolution, possibly investigated within the framework of specific research. This is rarely the case at the moment; some examples will be given in subsequent parts of the paper.

The stratigraphy of the Campanian Ignimbrite and its main implications

The Campanian Ignimbrite in Paleolithic sequences

If one considers the magnitude of the explosive event and the wide area of dispersal of its volcanic products (Fig. 1), tephra from the CI eruption can be expected to occur in a number of stratified archaeological sites of Western Eurasia (Fedele et al., 2002: Fig. 1, 2003: Fig. 3). At the moment, the CI has been firmly identified both stratigraphically and petrologically in at least four sites or localities. These include, west to east, the Serino open-air site and Castelcivita Cave, both in Campania (southern Italy), Temnata Cave in Bulgaria, and the Kostenki-Borshchevo cluster on the East European Plain (Figs. 1 and 4). As they are well known or have been discussed in detail elsewhere, only a brief account of the relevant information will be given here.

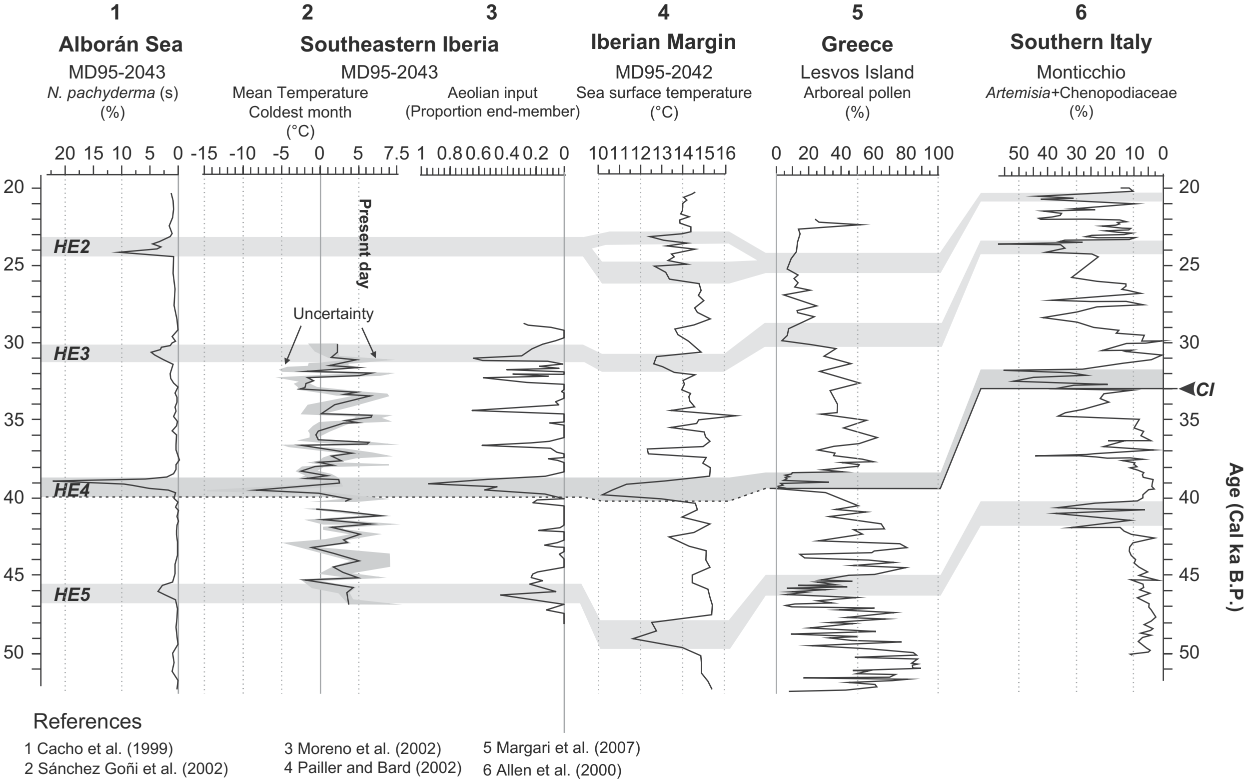

Fig. 3. Selected paleoclimatic records showing the markedly cold-arid conditions of Heinrich Event 4, compared to the conditions associated with other Heinrich events. The extent to which the HE4 peak is more pronounced contributes to the inference that there was an exceptional amplification of stadial conditions, triggered by the concurrence of climatic, oceanic, and volcanic factors and their feedbacks (see text for details). The timescale 'ka BP' to the right, with its chronological discrepancy, exclusively reproduces the varve-based age model for Lago Grande di Monticchio, southern Italy, presently undergoing revision (Wulf et al., 2004).

At the Campanian sites of Serino and Castelcivita, the CI is represented by a relatively thick pyroclastic suite, comprising both the basal Plinian pumice layer and the overlying ignimbrite or co-ignimbrite units that characterize the CI series throughout its intermediate dispersion area (e.g., Fedele et al., 2003; Giaccio et al., 2004, 2006). In Eastern Europe, the CI tephra usually occurs as a discrete ash layer exhibiting the same micro-textural features and typical chemical variability of the CI proximal products (e.g., Giaccio, 2005; Pyle et al., 2006; Giaccio et al., 2007). At all key sites, where sedimentary resolution is good, the CI tephra directly seals archaeological layers that contain assemblages of the MUP mosaic, often variants of 'Aurignacian'-like or so-called early Upper Paleolithic industries (Accorsi et al., 1979; Gambassini, 1997; Kozłowski, 1998, 2005; Sinitsyn and Hoffecker, 2006; Anikovich et al., 2007; all with references; Fig. 4). The layers above the CI tephra, where they are not culturally sterile, contain later and often much later properly-defined Upper Paleolithic industries, represented by a 'Late Aurignacian' and in most cases by the Gravettian (Fig. 4). The CI tephra thus represents a sharp and significant stratigraphic marker.

In southern Italy, in addition to the four sites or localities mentioned above, there are several other Paleolithic sequences that contain a tephra layer exhibiting a culture-stratigraphic position and/or a radiocarbon date consistent with the CI (Fedele et al., 2003: Fig. 3). However, many of these stratified deposits are presently inaccessible for a number of reasons, thus preventing ad hoc investigations to validate the presumed correlation. Among these Paleolithic sites stands out Paglicci Cave (Palma di Cesnola, 2004, 2006, with references), where the tephra in question is sandwiched between archaeological layers attributed to the Aurignacian and the Early Gravettian, anchored to numerous ^{14}C dates (Palma di Cesnola, 2001, 2004). Because of the apparently strong stratigraphic as well as chronometric consistency, we tentatively equated the tephra with the CI (Fedele et al., 2003). However, on further examination, the chemical and micro-textural analyses of the Paglicci tephra have ruled out its correlation with the CI, indicating instead that the tephra should be attributed to the poorly known Codola eruption, about 7,000–8,000 years younger (Giaccio et al., 2007). Codola is also represented in the comprehensive Monticchio record (Wulf et al., 2004).

Paglicci is a telling example of the unreliability of ^{14}C dating alone, at least in this age bracket (see Blockly et al., 2008). Furthermore, an ~8,000-year temporal extent of 'Aurignacian' manifestations at Paglicci and in southern Italy (with the Codola tephra as a marker of the last documented appearance) contributes to doubts concerning the validity of the Aurignacian as a meaningful cultural entity. The Paglicci case also suggests that extreme caution must be adopted in handling reports of tephra layers from sites where ad hoc sampling and up-to-date chemical-petrological analyses are lacking. Among the many potential sites in the southern Balkans, an important example may be Franchthi Cave, where a volcanic ash unit (Stratum Q) overlying the Middle Paleolithic deposits was dated ca. 33,000 ^{14}C BP (Farrand, 2000).

The large radiocarbon anomaly round 40 ka BP

As previously reported (e.g., Giaccio et al., 2006), a significant number of cases show extraordinary stratigraphic inconsistencies in ^{14}C age measurements a round the age of the CI, unquestionably depending on anomalous fluctuations of the atmospheric radiocarbon content. Radiocarbon ages of carbonized wood and charcoal fragments embedded in the CI pyroclasts are scattered between 42,000 and 27,000 ^{14}C BP. Anomalously young ages of ~31,000–33,000 ^{14}C BP also systematically occur in the archaeological layers below the CI tephra, as documented by the Italian and Eastern European sites (Fig. 4).

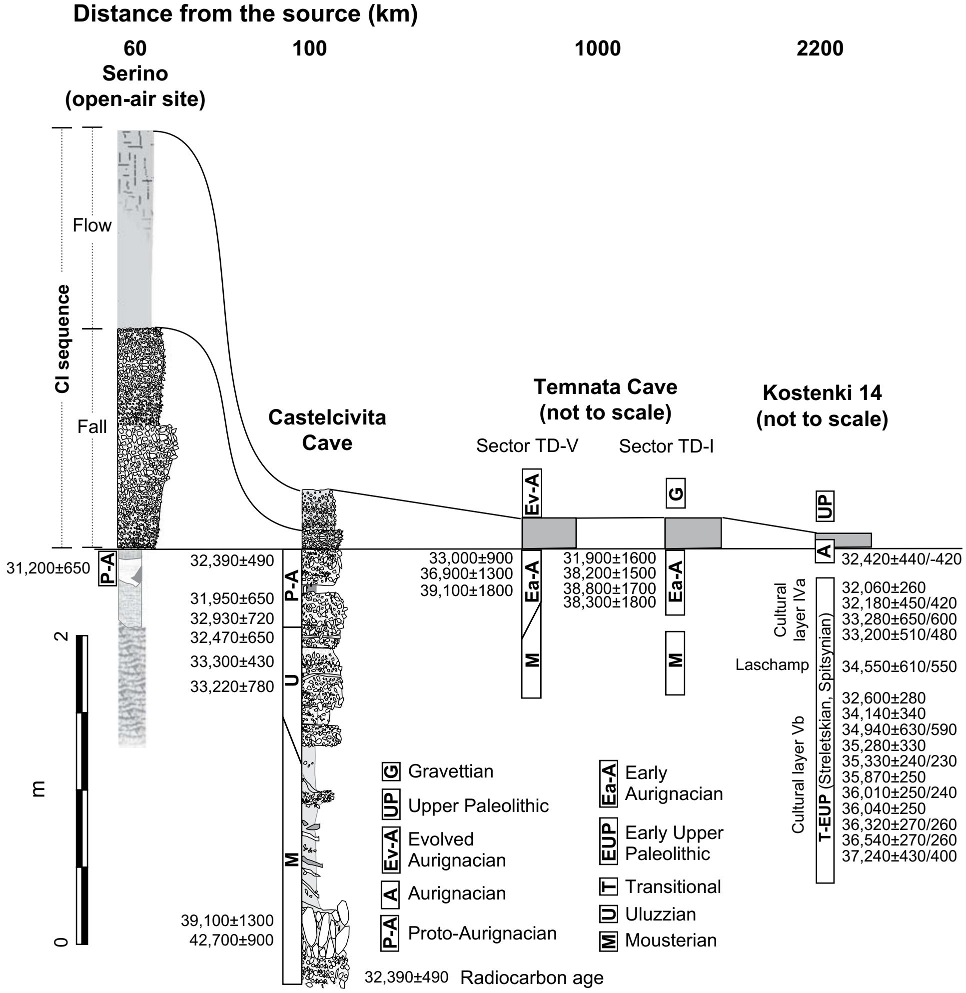

Fig. 4. Tephrostratigraphic correlation between major Paleolithic sequences containing the Campanian Ignimbrite tephra (see Fig. 1 for the location of sites). Archaeological nomenclature and radiocarbon determinations derived from: Accorsi et al., 1979 (Serino); Gambassini, 1997 (Castelcivita); Kozłowski, 1998 (Temnata); and Sinitsyn and Hoffecker, 2006 (Kostenki 14). CI = Campanian Ignimbrite.

The same excursion was observed in Tyrrhenian Sea core CT85-5, where ^{14}C dating of foraminifera across the CI layer exhibit anomalously young ages ranging from 35,000 to 25,000 ^{14}C BP (Giaccio et al., 2006; I. Hajdas and collaborators, data on file). Isotope studies of the same core show that this interval coincides with a phase of increased ^{10}Be concentration (Cini Castagnoli et al., 1995). This increase in the content of cosmogenic isotopes, overlapping with the time of the CI event, may be at least partially explained by the episode of weak geomagnetic field called the Laschamp excursion (see previous section). During this episode, the production rate of cosmogenic isotopes increased significantly due to the increased flux of cosmic rays that were able to penetrate Earth's atmosphere (Beer et al., 2002).

Although less marked, a similar fluctuation of the ^{14}C isotope around the age of the CI has been recognized in Lake Lisān, Israel (Hajdas et al., 2004), in the Nordic Sea (Voelker et al., 1998, 2000), and in the Bahamas (Beck et al., 2001). No appreciable age inversion is detectable in the long record of ^{14}C flux from the Cariaco Basin in the tropical Atlantic (Hughen et al., 2004), but nevertheless a significant enhancement in ^{14}C concentration from ca. 41,500 to ca. 39,500 $\mathrm{BP}_{\mathrm{GISP2}}$ (i.e., during the Laschamp excursion) is evident. Alternatively, the radiocarbon data set and the related, inferred calibration curve presented by Fairbanks et al. (2005) do not show any evidence of marked ^{14}C fluctuation at this particular time. However, this could be due to the low resolution of radiocarbon measurements, which is not high enough in the critical interval across Laschamp (Fig. 5).

The widely accepted recognition of the '40,000 cal BP' radiocarbon anomaly has important consequences for the radiocarbon dating of the period of interest here, concomitant with the Laschamp excursion, the CI eruption, the drastic cooling of HE4, and the European Paleolithic shift. The most dramatic consequence is that, if adequate and reliable stratigraphy is lacking, the environmental and archaeological records might be dated as younger—even much younger—than their actual age. This will produce misleading chronological frameworks for culture-historical and processual models. Duration intervals estimated from such aberrant ages might be even more incorrect.

Some chronological and archaeological implications of a CI-based correlation

In addition to geographical distribution, the temporal patterning of the 'late' Mousterian and other industries belonging to the MUP mosaic features prominently in current claims about the supposed demise of the Neandertals, the invasion of modern humans, and/or the coexistence of both hominins in Western Eurasia (ca. 40,000 ± 5,000 BP). The first assumption in this paradigm takes for granted that Aurignacian-like assemblages (as commonly defined) are a technological prerogative of 'modern

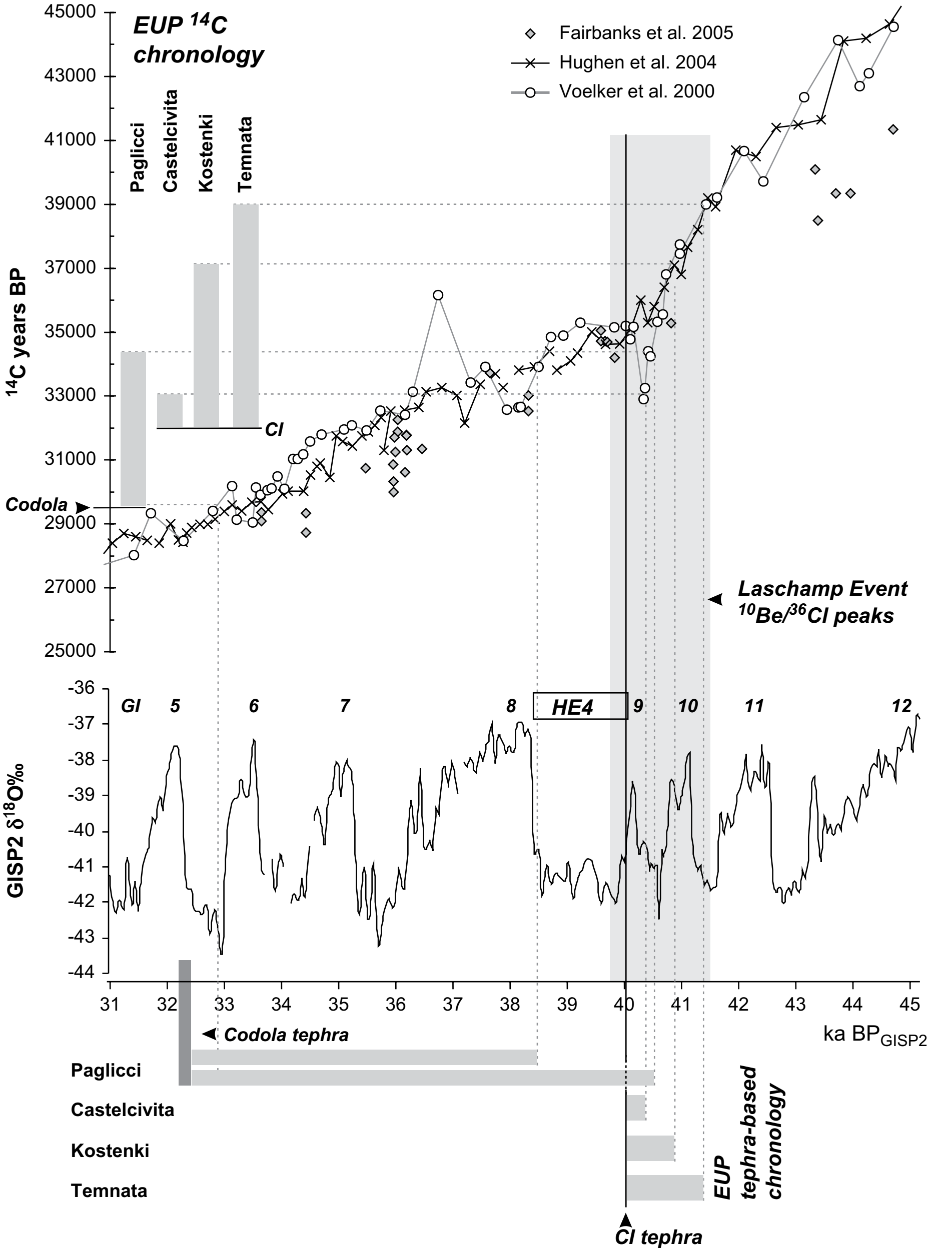

Fig. 5. A plot of radiocarbon age versus calendar age (GISP2 timescale) for the 'early Upper Paleolithic' layers from long archaeological sequences that contain the Campanian Ignimbrite tephra (Castelcivita Cave, Temnata Cave, Kostenki) and either the Codola or the TM-17c tephra (Paglicci Cave). The framework is provided by the ^{14}C-age curves obtained from Nordic Sea (Voelker et al., 2000) and Cariaco Basin (Hughen et al., 2004) marine sediments, and from Barbados pristine corals (Fairbanks et al., 2005). The tephrostratigraphic correlation provided by the CI marker is employed for the critical adjustment of the timescales. Significant differences in terms of both age and interval duration between the ^{14}C-based and the tephra-based chronologies can be noted. See text for details.

humans.' We also take issue with the validity of a second assumption: that, as a consequence of the first one, the sheer temporal distribution of such assemblages—mainly construed on the basis of ^{14}C dates or their hypothetical calibrations—can be utilized to trace the origin and pathways of the incoming modern humans, or even calculate their rate of dispersal (e.g., Bocquet-Appel and Demars, 2000; Mellars, 2006; Zilhão, 2006b). Our premise is based on the extraordinary ^{14}C excursion during the critical time interval of the 'invasion.'

In light of the anomalous behavior of the ^{14}C curve, it should be clear that radiocarbon dating alone cannot provide the required, reliable temporal framework to address the historical problem in question (Turney et al., 2006; cf. Giaccio et al., 2006). In other words, ^{14}C dating is flawed in this particular interval. As a demonstration, let us employ those sites for which both ^{14}C and robust, ^{14}C-independent chronological frameworks are available. We consider first the dating of the archaeological layers immediately below the CI tephra. There is a substantial difference between the age inferred from tephrostratigraphy of the CI, and the age derived from ^{14}C chronology (Fig. 4). These differences are on the order of 7,000–9,000 years and, it should be stressed, cannot be resolved by any one of the current available calibration proposals (contra, e.g., Mellars, 2006; Zilhão, 2006b). As a matter of fact, it is inappropriate to speak of 'calibration' beyond the present, universally accepted limit of ~21,000 ^{14}C BP, equivalent to ~26,000 cal BP (Reimer et al., 2004).

For instance, by using the CalPal2005_SFCP calibration (Jöris and Weninger, 1998, and updating by Weninger et al., on-line), or the recently published Fairbanks et al. (2005) calibration curve, we would obtain calendar ages of about 37,500–36,500 cal BP for underlying strata, which means ages 3,500–2,500 years younger than the minimum age of 40 ka $BP_{GRIP/GISP2}$ provided by the overlaying CI tephra. This seemingly minor discrepancy becomes significant when compared to the high resolution required for assessing the historical problems investigated here. What is important for the present discussion, in fact, is not so much the age itself, but the duration and tempo of a given phenomenon or process. As pointed out elsewhere (e.g., Giaccio et al., 2006), it is intervals and rhythms that can be dramatically misinterpreted by use of the radiocarbon timescale round 40,000 cal BP, no matter whether on the basis of raw measurements or calibrated estimates.

For example, let us take again a Paleolithic site associated with the CI. At Kostenki 14 ‘Markina Gora,’ there are about two meters of sediments below the CI tephra, which contain discrete occupation horizons distributed in the interval between about 37,000 and 32,000 ^{14}C BP (Sinitsyn and Hoffecker, 2006; Anikovich et al., 2007). According to radiocarbon ages this represents a period of about 5,000 years. However, because of the relatively low ^{14}C levels before 41,000 $BP_{GRIP/GISP2}$ (Fig. 5), the calendar age for the base of the Kostenki 14 archaeological series—dated at ~37,000 ^{14}C BP—can be estimated as not greater than 41,000–42,000 $BP_{GRIP/GISP2}$. Therefore, the actual time interval is much shorter, and in all probability not greater than 1,500 years.

The same applies to other long archaeological series containing the CI tephra, notably Castelcivita Cave and Temnata Cave. At these two sites, according to their ^{14}C chronology, the Aurignacian-like layers below the CI seem to span time intervals of markedly different lengths: ca. 33,000–32,000 ^{14}C BP at Castelcivita—a very short interval of a millennium at face value—and ca. 39,000–32,000 ^{14}C BP at Temnata, in this case an occupation 7,000-years long. However, if one considers the age and stratigraphic position of the CI, as well as the low value of ^{14}C flux before 41,000 $BP_{GRIP/GISP2}$ (Fig. 5), the actual difference in age between the basal Aurignacian-like layers of Temnata and Castelcivita is reduced to no more than 1,500–2,000 years, in real historical time.

Our last example deals with the nearer side of the ‘40,000 cal BP’ timeline and is based on the recent chronological re-appraisal of the ‘Aurignacian’ stratigraphic sequence of Paglicci Cave, mentioned in the preceding section. These layers are dated between ca. 34,000–29,000 ^{14}C BP (Palma di Cesnola, 2004, 2006) and are sealed by the Codola tephra, which can be correlated with a given Greenland Interstadial, GI5 (Giaccio et al., 2007). One is thus confronted with an archaeological sequence that spans the interval between GI9 (~40,100 $BP_{GRIP/GISP2}$) and GI5 (~32,000–32,500 $BP_{GRIP/GISP2}$) of ice core stratigraphy, whereas in radiocarbon time it spans an entirely different interval: from ~34,000–32,000 to ~29,000 ^{14}C BP (Fig. 5). It is clear in this case that a relatively short interval of 3,000–5,000 radiocarbon years actually corresponds to 7,000–8,000 years in calendar time. This result emphasizes the value of tephrostratigraphy, provided that the necessary caution is used in the field and laboratory identification of any given tephra.

Further implications of tephrostratigraphy: some open problems

It is important to observe that in many of the European archaeological sites that feature prominently in discussions of the ‘Early Upper Paleolithic,’ but that lack tephra layers, such as Fumane Cave in northern Italy and Geißenklösterle Cave in southern Germany, the dates for the MUP mosaic range from 38,000 to 31,000 ^{14}C BP (Richter et al., 2000; Conard and Bolus, 2003; Conard et al., 2006; Teyssandier et al., 2006; Peresani et al., 2008). This is the same radiocarbon interval of the MUP industrial mosaic below the CI at sites that contain the tephra. In the light of the observations reported above, we cannot exclude the possibility that the apparently long MUP (‘Aurignacian’) occupation from 38,000 to 31,000 ^{14}C BP at these sites actually represents the much shorter interval between GI11–GI10 and the onset of HE4 (i.e., the same interval inferred for the sites containing the CI tephra; cf. Giaccio et al., 2006). On the other hand, in the absence of unquestionable chronostratigraphic markers, the Paglicci case suggests that a longer occupation cannot be ruled out.

The only solution in such troubling cases—perhaps the majority of Paleolithic sites—is resorting to an assessment of the overall paleoclimatic trend in the interval in question, as revealed by the best paleoecological indicators. At Fumane Cave, for instance (Bartolomei et al., 1992), the paleoecological proxies show cooling and increase in aridity from base to top during the MUP-mosaic (‘Aurignacian’) interval. This would be consistent with the short occupation timespan between GI11–10 and HE4 inferred for the CI-tephra sites. At Geißenklösterle Cave, on the other hand, relatively arid-cold conditions during the lowermost ‘Aurignacian’ would be followed by milder conditions towards the top of the overall ‘Aurignacian’ interval (Conard et al., 2006: 317). A general trend of this kind might be consistent with a longer timespan, between ‘cold’ GI10–HE4 and the milder phase represented by GI8–GI6. Unfortunately, the very high resolution required for a reliable correlation between a given archaeological site and super-regional paleoenvironmental records cannot always be obtained from the terrestrial (subaerial) deposits of Paleolithic sites.

These examples show how, at least for the moment, radiocarbon is of virtually no use for dating events across the cosmogenic nuclide peak and the Laschamp excursion. The emergence of cultural and perhaps biological novelties that comprise the European Paleolithic shift is crucially involved. In the absence of additional, independent means for temporal-stratigraphic control—such as tephra layers, geomagnetic determinations, or high-resolution climatic-environmental sequences—the ^{14}C chronology alone is bound to produce a highly biased temporal framework that inevitably undermines historically meaningful reconstruction (cf. Gamble, 2007).

Towards a systemic model of the Campanian Ignimbrite impact

Modeling the impact: the environmental system, including hominins

From the ecological point of view, preliminary insights can be gained from the aftermath of an explosive eruption at high latitude, the well-studied case of Mount St. Helens, 18 May 1980 (Dale et al., 2005a). One of the important lessons, for instance, is that ecological succession is very complex, proceeding at varying paces along diverse paths, and with periodic setbacks through secondary disturbances. Consequently, ‘no single, overarching succession theory provides an adequate framework to explain ecological change’; ‘many biotic, landform, and soil legacies of the 1980 eruption will influence ecological processes for centuries to come’ (Dale et al., 2005b). These observations concern the landscapes in the direct-impact zone. They tend to support a centennial-long alteration of sensitive ecosystems as inferred for the aftermath of the CI eruption, in Northern Eurasia at least.

However, the most significant environmental impact ultimately revolves on climate. The climatic background is crucial in modulating the effects of a volcanic eruption (see, e.g., contributions in Robock and Oppenheimer, 2003). The CI short-term cooling would have been enough to cause severe ecosystem alteration even in an interglacial climate such as the present one: witness to this the environmental record from very large eruptions of the past few centuries (Self, 2006). However, in a glacial regime the consequences of the eruption were much more pronounced. As already mentioned, the climate of the Last Glacial is known to have been remarkably unstable, and much more sensitive to feedback mechanisms—hence ‘fragile’—than during Holocene-like conditions (e.g., Zielinski, 2000). The instability may have been even greater during the Interpleniglacial period, and HE4 itself was the peak of a millennial-long, highly oscillating cooling trend. As a consequence, the interaction of the CI with climate was much more severe than it would have been in a less sensitive context. What made a difference at ca. 40,000 BP was a convergence of potential disasters, each in itself nowhere nearly as effective as their combination and mutual amplification (Fedele et al., 2003, with references). A simplified suite of feedback mechanisms within the ocean-atmosphere system, in connection with the CI eruption, is suggested in Fig. 6; it also provides the geophysical basis for the model of Fig. 7.

HE4 was possibly the coldest and driest among Heinrich Events (cf. Fig. 3, with references). The extreme aridity and cooling of HE4 greatly affected not only continental Europe and its western seaboard, but at least the whole Mediterranean Basin. The impact on living systems could have been severe, and much greater at higher latitudes, where the volcanic-induced cooling was probably amplified by a factor of 4–7 (Table 1). The northern part of Europe possibly became depopulated to the point of desertion (cf. Hoffecker, 2002, 2004; Stringer, 2006; Zilhão, 2006b: his Fig. 9), although a detailed investigation is still in its infancy. In northern Russia, groups with Mousterian-like technology were able to live at 66° N on the Arctic Circle only in an interstadial phase, provisionally identified with Hengelo (Pavlov et al., 2001; Svendsen and Pavlov, 2003). The considerable problems still facing a realistic reconstruction of human-environment relationships in Central and Eastern Europe during the Interpleniglacial have only recently become a subject of concerted investigation, increasingly based on principles of community ecology and niche theory (e.g., van Andel and Davies, 2003; Bard, 2006; Banks et al., 2006; d'Errico et al., 2006; but see van Andel and Tzedakis, 1996; Clark, 1999).

Even at Mediterranean latitudes, pollen records indicate that HE4 coincided with a swift contraction of forests which were replaced by arid and cold steppe (e.g., Watts et al., 1996, 2000). It probably was the exceptional rapidity of environmental change, rather than low temperatures and extreme aridity per se, that influenced human groups (cf. Vrba et al., 1995; Finlayson and Carrión, 2007). Volcanic cooling is typically instantaneous. The predicted geo-environmental response was such that within an interval of a few years many Paleolithic groups of Western Eurasia found themselves facing altered biotic resources and water distribution. We suggest that such a rapid change would have created conditions for selectively transforming the human circulation patterns and subsistence strategies. We posit that the Bond cooling trend, the abrupt HE4, and the CI eruption jointly acted as a forceful 'catalyst' on selected human processes that were already in motion at 40,000 BP (see below). The interplay involving the CI factor and the ocean-atmosphere system is shown in Fig. 7 (upper half), on which the subsequent discussion of our impact model is based.

The evidence that the climatic and biotic conditions associated with HE4 were extreme, compared to the other Heinrich Events, is crucial to our model of a combined HE4–CI crisis. Equally significant is the detection of marked HE4 deterioration as far east as Siberia (Prokopenko et al., 2001), reported above. This is clear indication that the phenomenon was not restricted to Europe but was possibly hemispheric. We contend that the extraordinary intensity of HE4 can *only* reasonably be explained through feedback forcing in conjunction with the CI eruption. If that is correct, the sheer intensity of the cooling and/or biotic deterioration dating from the HE4 interval can be used as a proxy for the CI—it allows for tracing the impact of the eruption west and north of its ashfall area, 'upwind' so to speak[5] (i.e., over Western Europe). A case in point is the Iberian Peninsula, which features prominently in current discussions of the European Paleolithic shift, including the 'fate' of the Mousterian makers or Neandertals (Zilhão, 2006b; Finlayson and Carrión, 2007; Finlayson et al., 2008; all with references). During HE4 the summer sea surface temperature plummetted by 3–6 °C along the Iberian margin (Cortijo et al., 1997; Pailler and Bard, 2002). In the westernmost Mediterranean, a drop in temperature of about 5 °C is recorded, while reconstructions of terrestrial conditions suggest that several parts of Iberia experienced extremes of aridity and cooling, the coldest month reaching mean temperatures between −8 °C and −14 °C, and steppe vegetation expanding dramatically at the very onset of the HE4-CI crisis (e.g., Sánchez Goñi et al., 2002; Sánchez Goñi and d'Errico, 2005; Sepulchre et al., 2007; cf. Fedele et al., 2003: 313–316).

The likely implication is that humans were affected considerably. However, assessing the outcome is a different matter and a task for the future. A drop in the biomass of ungulates and consequent human population contraction (cf. Sepulchre et al., 2007) likely did occur regionally. For humans, the crisis generated landscapes of stress as well as opportunity, so to speak, as explosive volcanic crises perhaps always do (Grattan, 2006; cf. contributions in Torrence and Grattan, 2002; Grattan and Torrence, 2007). We suggest that the signature of the CI eruption, 'embedded' within the HE4-CI crisis, may indeed be revealed by the peculiar patterning of archaeological distributions in Iberia at the time of the Paleolithic shift and for a while afterwards (cf. Cabrera, 1993; d'Errico and Sánchez-Goñi, 2003; Finlayson, 2004; Straus, 2005; Montes Barquín and Lasheras Corruchaga, 2005; particularly Vega Toscano, 2005; Sepulchre et al., 2007: their Fig. 3; but see Straus, 1992); this could possibly be true for the entire Western Europe. Archaeological indicators of human response should be sought through specific research; they might range from the usual emphasis on the making and use of bladelets (e.g., Maíllo Fernández et al., 2004; Bon, 2006) to perhaps cannibalism (Zafarraya?;Barroso Ruíz et al., 2005). We predict that rapid landscape and resource changes favored or disfavored particular groups of residents through population selection: we *do not* imply that changes affected whole biological-cultural groups of humans, be they aboriginal residents or incoming aliens, facing each other along 'frontiers' or otherwise (against frontiers in Iberia cf. Finlayson et al., 2008). This argument will be developed in the next sections of the paper.

Modeling the impact: the sociocultural system

An outline concerning the effects on Paleolithic societies of the climate-volcanism system at 40,000 BP has been given in a previous section of the paper. In the lower half of Fig. 7 we present an attempt at a qualitative iconic model. The model is explicitly based on a human ecosystem framework and is thus systemic (Fedele et al., 2007; cf. Fedele and Giaccio, 2007: Fig. 3); its only aim is to suggest pathways to understand the impact and its consequences, including pathways for future research. In the preceding section we have summarized what in our opinion is an acceptable set of data and inferences; what follows reflects our interim preferred scenario and includes statements which, being partly based on subjective stance, are speculative and open to debate.

Occupation and land use. Predictably, the interferences of the HE4-CI crisis with human society varied widely according to impact gradient, and by implication should be explored at different geographic scales, from regional to hemispheric; the latter, however, is beyond reach at the moment, until focused research is done. At the scale of direct or substantial volcanic impact, interruption of occupation is the prime indicator of disturbance. From this point of view, the CI marks a behavioral watershed over a sizeable area between peninsular Italy and the eastern Balkans.

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[5] We owe this expression to L.G. Straus (pers. comm.).

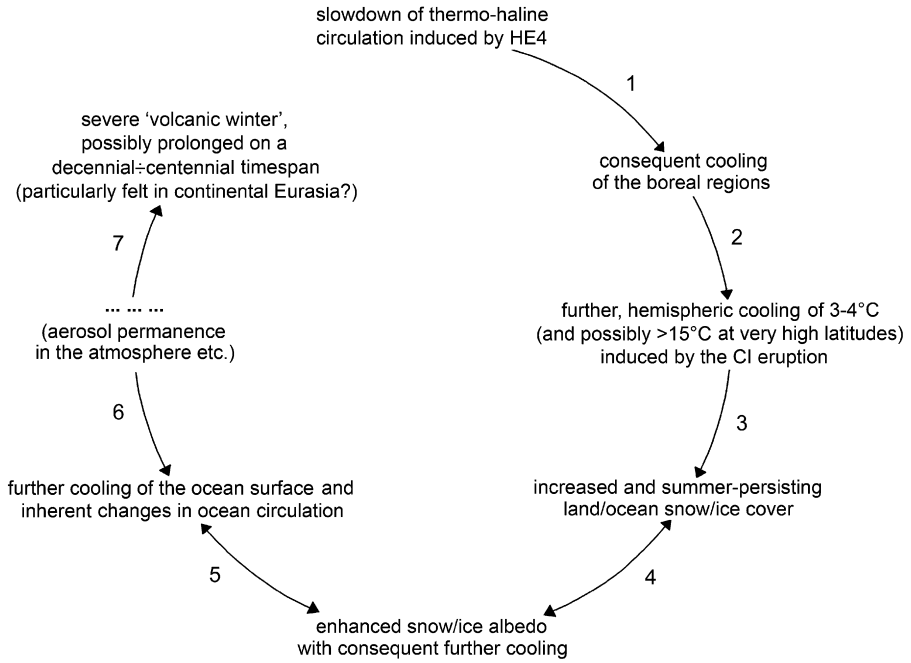

Fig. 6. A simplified diagram of linkages, including feedback mechanisms, within the ocean-atmosphere system in connection with the Campanian Ignimbrite eruption. Numbers mark the main steps in amplification.

Long series of Mousterian and MUP occupations, implying persistence in circulation habits and regional population, are sealed by CI volcanics and immediately followed by site abandonment and more or less prolonged human absence. Archaeological sites disappear in the direct-impact zone[6] and its immediate surroundings; at Serino the tephra embedded freshly abandoned remains. When human presence is eventually re-established, occupation displays different patterns of land use, if not a truly novel cultural entity, like the Gravettian (cf. Fig. 4). Even without prolonged interruption, some kind of settlement change can be observed outside the Greater Mediterranean's core (see below).

Throughout the area in which it occurs, discontinuity of occupation is a proxy indicator of change in human-land interactions and within the human ecosystem at large. The most significant changes may have involved mobility patterns (cf. Fig. 7, portion in gray). Mobility is not only an important aspect of hunter-gatherers' life, but, intertwined with settlement, is a highly sensitive social construct; mobility patterns and settlement strategies vary on the basis of group and intergroup concerns that are not limited to subsistence needs (e.g., Kelly, 1995; Conard, 2001). Admittedly, knowledge of the residential repertoire around the CI timeline may be biased. The archaeological sites in question are largely caves and, perhaps significantly, burial sites seem to be unknown (e.g., Churchill and Smith, 2000; Conard et al., 2004; Wild et al., 2005), a puzzling paucity of evidence (Fedele and Giaccio, 2007; see Trinkaus, 2005, and Bednarik, 2007b, for recent reviews of available skeletal finds). Irrespective of this limitation, however, what is observed might reasonably be construed as a variation in landscape use, caves included, coupled with population variation (i.e., distribution and density—group displacement, reduction, fission, even collapse).

The distribution of the Mousterian suggests a relatively dense and ecologically varied—hence successful—settlement of Europe during the MIS3 interval (e.g., Gamble, 1999; Roebroeks and Gamble, 1999; van Andel and Davies, 2003; cf. Stewart, 2005). Mousterian adaptations ranged through the entire spectrum of recent hunter-gatherers' settlement-subsistence strategies (cf. Zilhão, 2006b). Against this background, the HE4-CI crisis appears to introduce a dramatic contrast. As put by Zilhão (2006b: 192), 'the area available for human settlement in Europe must have contracted by as much as 30%.' He goes on to imply that, as a result, there was 'a major population crash.' This latter is not a necessary inference, or, at least, crash is not the right description, nor does it comply with the range of possibilities afforded by hunter-gatherers' population ecology (e.g., Winterhalder et al., 1988; Kelly, 1995; Lee and Daly, 1999; Panter-Brick et al., 2001; with references). We should rather think of population redistribution, particularly if we picture the Mousterian as the product of highly successful Early Pleniglacial people. Forced population redistribution was likely associated with new spatial choices and significant changes of human action both within and towards the landscape, shifts in raw material economy for instance. After all, Mousterian groups were capable of dealing with their territories in a complex 'modern' way, for instance organizing their hunting logistically (Gaudzinski and Roebroeks, 2000); similarly, in tool-making, their mental templates were ready for flexibility and innovation (e.g., Monnier, 2007).

Beyond the area of ashfall, in the perspective of a volcanic winter, do we have any evidence of altered settlement and/or landscape use? The same potential indicators outlined above—discontinuity of occupation at a given site, hints of group displacement—can be employed. Another indicator is altered procurement, to be discussed below. Breaks or changes in occupation may be especially relevant in locales and regions with a previous history of prolonged habitation. Within the limits of current research, we believe that cases can be identified from Turkey (e.g., sedimentary change and cultural interruption at Karain B Cave, Yalçınkaya and Otte, 2000; rarefied and 'atypical' human activity at Üçağızlı Cave, layers C–E, Kuhn, 2004; Kuhn et al., 2004; cf. Kuhn, 2002) and the northern Caucasus (erosional/temporal breaks between the Mousterian and post-Mousterian; e.g., Golovanova et al., 2006). Additional examples could be gleaned from contributions on continental Asia in Brantingham et al.

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[6] In an ecological sense, we define the direct-impact zone as the areal extent where pyroclastic cover was sufficiently thick to alter natural life cycles.

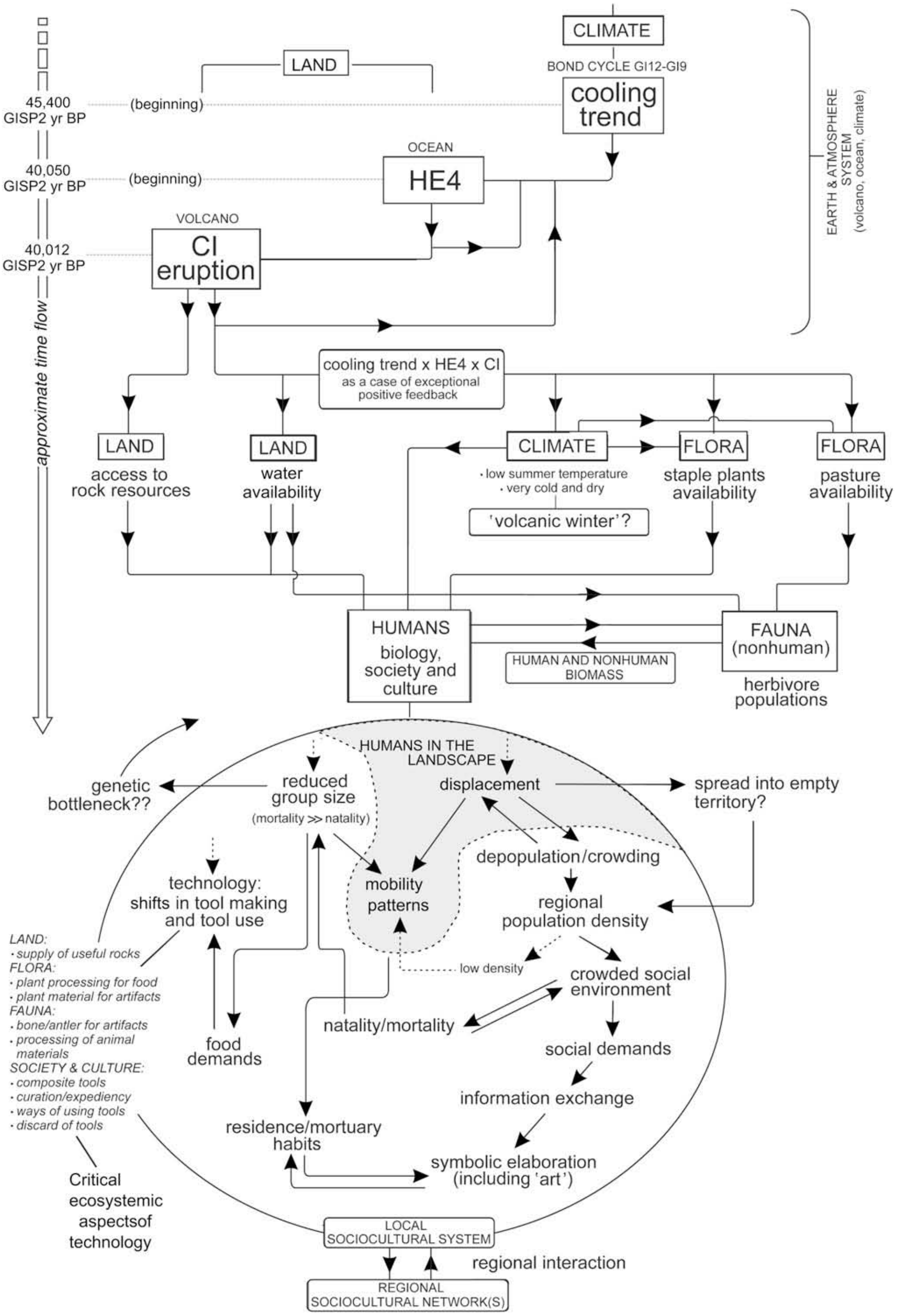

Fig. 7. A model for the study of the Campanian Ignimbrite impact on human ecosystems, ca. 40,000 BP, calendar age (from Fedele et al., 2007: Fig. 2.4, modified). In this provisional model only main variables and pathways are shown; arrows suggest modifying action. The ecosystem framework implied (cf. Fedele, 1976, inspired by Clarke, 1968) includes the sociocultural system, 'Humans,' and its interrelated environmental system, this latter arranged into abiotic ('Climate,' 'Land') and biotic components ('Flora' and 'Fauna'). Man as a biological-genetic system is subsumed under 'Humans,' although it is in fact a part of 'Fauna' both ecologically and taphonomically.

(2004). If the Caucasus Range acted as a minor barrier sparing the region to the south from the most severe climatic effects (Bar-Yosef et al., 2006: 50), it is possible that a whole belt of Asia, south of the major mountain ranges, saw in operation mitigating factors. Of course we do not claim that our hypothesis can be tested on such a limited basis. Rather, we wish to advocate closer attention to any 'indicators of disruption' at ca. 40,000 BP. The problem is a critical appraisal of each potential instance in terms of temporal/stratigraphic resolution and kind of disturbance, bearing in mind the particular environmental conditions at that point in time. Again, this is a task for the future.

Technology and economy. Two main nonbiological feedback circuits were set in motion or greatly enhanced: one has to do with the society and ideology-psychology subsystems of the sociocultural system (cf. Clarke, 1968), while the other, interrelated pathway has to do with technology and economy (Fig. 7, lower half). Concerning the latter, Paleolithic groups were affected by the sudden HE4-CI conditions as obligatory participants in the trophic chain, not necessarily—or not everywhere—as victims of a catastrophic killing or lowered temperatures. Climate variation seldom influenced humans directly. Rather, climate mostly acted on humans by modulating biodiversity and the availability of food and other resources (Fig. 7, middle part). An altered food-resource base almost inevitably demanded changes in economy as well as technology, a challenge to which the MUP populations appear to have responded in the most varied ways. In the resulting 'mosaic,' the populations that did not respond became socioculturally extinct. We contend that any changes in toolkits essentially developed from within the preceding range of variation, or indeed shifted variation in a certain direction by expanding some subsets of it (cf. Brantingham et al., 2004: 247; Clark and Riel-Salvatore, 2006a).

We envisage a fairly rich and dynamic Middle Paleolithic scene during the GI12–GI9 Bond cycle; it may be that the accelerated environmental pulse of this cycle fostered the development of a population-based variation within the Mousterian. Regionally, the Mousterian technocomplex had begun enrichment and artifactual 'instability' earlier (by artifactual instability we refer to a component of variation, cognitively and socially connected with flexibility and experiment; Fedele and Giaccio, 2007). If one looks at the 40,000 BP scene across Southern and temperate Europe, forgetting for a moment any interpretive model or bias, one sees a quickening of developments in many disparate areas: miniaturization and 'geometrization' in lithics; developments in hafting (including backing, blunting etc.) out of a need for more efficient composite tools; standardized blank production, often in the form of bladelets, alongside standardization of use as inferred from wear; emphasized local reliance on selected Mousterian tool types ('foliate' bifaces, for instance); and perhaps also locally, an interest in lighter stone and non-stone equipment, including bone elements (this list is not comprehensive[7]; e.g., Kuhn, 1995; Shea, 1997; Kuhn and Bietti, 2000; Lemorini, 2000; Cabrera Valdés et al., 2001; Elston and Kuhn, 2002; Valladas et al., 2003; Maíllo Fernández et al., 2004; Slimak, 2004; Rios Garaizar, 2005; Slimak et al., 2006; Finlayson and Carrión, 2007). Such innovations are still often termed 'Upper Paleolithic' elements in the Cartailhac-Breuil tradition (see above). These 'industries' should be viewed and classified as variously grouped sets of artifact types (i.e., on a polythetic basis; cf. Clarke, 1968; Gamble, 1999), not as essentially fixed and invariable typological packages, still usually described from a preconceived 'Upper Paleolithic' perspective.

One also sees an increased taste for personal adornment, and, in a few areas, a development—or resumed development—of image-making. By ca. 42,000 BP, particular areas seem to emerge as foci of innovation in this respect: the middle Don Valley (Sinitsyn, 2003; Vishnyatsky and Nehoroshev, 2004; Anikovich et al., 2007), possibly signaling the existence of innovation foci in less explored parts of Eastern and southeastern Europe; and perhaps, pending definitive dating, the Swabian Jura and northeastern Italy (Broglio and Dalmeri, 2004; Conard et al., 2006; Peresani et al., 2008; cf. Bednarik, 2007b: 358). Thinking of these areas as 'Gardens of Eden' (Zilhão and d'Errico, 2003b) has perhaps more merit than the jocular label would imply. Once the ad hoc theory of the arrival of a new people and culture from elsewhere is put aside, the idea is bound to foster more parsimonious and credible explanations as to how such developments could have appeared.

In the realm of technology, many of these developments likely represent a material expression of adaptive devices to cope with landscape variation, be it in the way of stress or opportunity (cf. Mellars and Gibson, 1996), with standardization of shape—a cost-efficient strategy—as a common denominator. Technology becomes more specialized and often diverse when maximum resources are available for limited periods of time and have to be procured swiftly (Torrence, 2001). Specific ecological conditions, and flexibility of strategy in coping with an unpredictable, sparse, and/or less diverse food base, may explain the greatly expanded use of microblades by MUP-mosaic groups (e.g., Kuhn and Stiner, 1998). Such European mid-Interpleniglacial developments lose most of their novelty when compared with similar phenomena at other times and places (Near East, Kenya, the Howieson's Poort industry of South Africa etc.; see, e.g., Bar-Yosef and Kuhn, 1999; McBrearty and Brooks, 2000; Mitchell, 2002; Goring-Morris and Belfer-Cohen, 2003; Brumm and Moore, 2005; Hovers and Kuhn, 2006; Willoughby, 2006; Pettitt, 2007). Blades, miniaturization, geometrization, and hafting likely formed a functional package, and there is a definite possibility that the package was a response to new demands and opportunities brought about by rapidly expanding, open, cold-dry habitats (i.e., environmental 'deterioration'; cf. Volman, 1984). Technology is almost inevitably modified by ecological changes, and there are modifications that appear to be correlated closely with temperature and diet (e.g., Torrence, 1983; Hoffecker, 2002). After all, even among apes and monkeys stresses such as low food abundance may prompt rapid tool-use readjustment and 'material culture' innovation (e.g., McGrew, 2004).

In an influential paper, Mellars (1973) argued that the early 'Upper Paleolithic' people in southwestern France focused their hunting on a single species of animal—reindeer—and that such 'specialization' marked an important, progressive distinction from the Mousterian. This kind of argument gained some currency and, although questioned (e.g., Straus, 1992; Clark, 1997), has remained central to debates on the fate of the 'Neandertals.' In fact, when open-air sites are considered (only selected caves formed Mellars' sample) and a new zooarchaeological approach is taken, there is no evidence that specialized hunting was being practiced to any greater extent during the Aurignacian than it was during the Mousterian (Grayson and Delpech, 2002; see also Stiner, 1994, 2001); numerous studies have since confirmed this conclusion. This is an additional indication of how oscillations in hunting-gathering strategies by MUP groups fundamentally reflected type of site and responded to changes in occupational and mobility patterns, within the opportunities and constraints of each ecosystem and period (cf. Burke et al., 2008).

A concurrent kind of adaptive response is the shift in raw material procurement or exchange, which shows maximum local variation coinciding with MUP industries (e.g., Féblot-Augustins, 1999; Blades, 2001). At well-stratified, carefully studied sites where the European Paleolithic shift is documented (e.g., Geißenklösterle, Fumane, Breuil Rockshelter, Temnata Cave, Bacho Kiro Cave) excavators have often noted a 'break' in behavior between the last 'Mousterian' and the first 'Aurignacian' occurrences, graphically defined by the utilization of different rock types, introduced into the site from different and sometimes much more distant source areas. However, a closer examination suggests that the perception of an abrupt rupture may have been exaggerated by the analytical tools employed as well as by expectations. In fact, problems of lithostratigraphic resolution aside, even minor changes in procurement networks, organization of technology, style and frequency of circulation and occupation, in a context of uneven population density, can give the impression of a sharp break and

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[7] An important omission, as usual, is plausibly represented by the development and/or specialization of Mousterian wooden implements (cf. Carbonell and Castro-Curel, 1992; Lev et al., 2005), about which extremely little is known. 'We should never underestimate how rich the organic component of Paleolithic material culture must have been' (Conard, 1998: S23). The extent of omissions caused by archaeological invisibility is graphically underscored by the finding that mid-latitude Mousterians were capable of making birch-bark pitch by use of pyrotechnology (Koller et al., 2001).

thus fill the expectation of a marked cultural 'transition' (cf. Kuhn, 2004, for a nuanced and thoughtful discussion).

Society and ideology. In Fig. 7 a particular role is suggested for human displacement, which we consider a key factor in the subsystem of society and space dimensions. Displacement of human groups was a predictable result of the environmental alteration, possibly sending waves outside the most strongly affected regions. Over a wide but yet undetermined area, the HE4-CI crisis indirectly forced populations away from the traditional and familiar territories, as abandoned locales seem to confirm. This displacement affected demography and culture, ideology included, and hence, society as a whole. Population displacement entailed two possible outcomes at the regional level, 'depopulation' and 'crowding' (but terms to be understood as vague and provisional). In contrasting ways, each may have been responsible for marked changes in within-group and intergroup interaction, and hence, innovative social behavior.

By physically shifting populations, or favoring a change in lifeways without actual migration, HE4-cum-CI may have produced (1) unusual population density in certain regions, and (2) an alteration or even disruption of the cognitive balance of social groups. The environmental alteration may have shifted groups into less affected regions at the periphery of the impacted area leading to changes in population density. We would predict depopulation in certain regions and crowding in others, although the geographical specifics are difficult to define until focused research is done. We would expect that regional crowding may have particularly occurred in 'fringe' areas along the continental periphery of the CI ashfall. Or crowding may have been distinctly mosaic in nature. Such population shifts might convey—again—the impression of a sudden 'invasion' by MUP groups, particularly following interruptions of occupation.

Secondly, cognitive processes involved in the forced peopling of unfamiliar landscapes (Rockman and Steele, 2003) likely were an important aspect of sociocultural pressures following the CI eruption. Socially constructed cognition, including 'locales invested with association and meaning' (Gamble, 1999: 425), can be a source of both advantages and limitations, social fragility but also social resilience, and we apply this condition to the complex hunter-gatherer groups of 40,000 BP. The accentuated visibility and quick evolution of both adornment (e.g., Zilhão, 2007) and image-making or 'art' are perhaps best understood against this backdrop and in connection with the demands of 'crowded' social environments.

Although hardly a novelty (Bednarik, 2003, 2005, 2007b), pendants and beads for personal ornamentation appear to rapidly acquire a greater social importance in European contexts of about 40,000 BP, and this 'emergence or re-emergence can be taken as a proxy for (…) increased levels of intergroup and intragroup social interaction eventually resulting in the emergence of systems of personal and ethnic identification' (Zilhão, 2006b:193, 2007; see also Vanhaeren and d'Errico, 2006). The development of image-making is perhaps even more significant as a potential correlate of social pressures and stress. Here again, once the pre-existence of a capacity for the production of imagery is accepted (e.g., Oldisleben, central European Micoquian; Bednarik, 2006b, 2006c), the evolution and fixation of 'art' in our context is best correlated to increased levels of population and/or social networking—to demographic, or rather sociogenic, factors (e.g., Shennan, 2001). We particularly stress the key role that the sharing and transmission of information and stimuli may have played in periods of hardship and forced change, and we subscribe to the view of 'art' as critically related to both cultural transmission and collective emotion.

Art is no more than an arbitrarily overemphasized component of expressive culture, still subject to huge interpretive bias. The naturalistic imagery of the European Paleolithic, in particular, is only over-attractive because it is localized and 'exaggerated,' thus exhibiting the hallmark of local invention. The middle Don Valley and southern Germany may have been 'seedbeds' of a sort, the plausible context being provided by the regional, evolving Mousterian (e.g., Conard et al., 2004, after the re-dating of Vogelherd; Bednarik, 2007b). The earliest imagery and symbolism at Chauvet Cave, southern France (Clottes, 2001; Valladas et al., 2001), may represent an additional example, not perhaps alone in the region (Ambert et al., 2005; Bednarik, 2007a,b: 358). We agree that, in general, art is best explained from an information-exchange perspective and taking into account its practical value in hunter-gatherers' life (e.g., Gamble, 1982; Conkey, 2001). 'The challenge,' as put by Clark (1994: 382), 'is to identify the conditions (almost certainly demographic) that would have selected for an increasing symbolic component to human behavior at particular places and times,' making it adaptively advantageous in a 'crowded' social environment.

Space prevents us to explore the role of 'art' and symbolism vis-à-vis the HE4-CI interference further; however, a brief mention must be made of the particularly disturbing notion of human 'modernity' as currently employed (see Stringer and Gamble, 1993, for an early, influential definition). When used as a catchword for 'us today,' it clearly has no heuristic value. Most criteria for behavioral modernity commonly used in archaeology derive from hindsight and modern European bias; the prevailing notion of modern behavior is indeed a 'moderno-centric' construct (Fedele, 2006) or the creation of 'a new origin myth' (Marks and Monigal, 2004: 64). One is forced to realize that most traits of behavioral 'modernity' have greater time depth than often acknowledged (e.g., Duff et al., 1992; Hayden, 1993; Fedele, 1994; Watts, 1999; McBrearty and Brooks, 2000; Kuhn et al., 2001; Henshilwood and Marean, 2003; Straus, 2005; Hodgson and Helvenston, 2006; Bednarik, 2003, with comments, 2006a), even in Europe (e.g., Bednarik 1995, 2006c; see also Zilhão, 2006a, 2006b, 2007). Accordingly, we object to singling out 'art' as a proxy for human 'modernity,' not least because the latter is in the eye of the beholder, and art frequently as well.

Hominin behavior cannot be easily phrased as modern versus non-modern, in view of the evolutionary timespan and multiple threads involved (Donald, 1991, 1993). The apparent booming of cognitive 'modernity'—including animal depiction—clearly sprang from a broad and very deep base; a role of nonhuman animals in making us human, and cognitively human especially, is refreshingly plausible (Hodgson and Helvenston, 2006, with comments; cf. Shepard's, 1997, title, and suggestions in Guthrie, 2006). Like language or symboling in general, image-making appears to have evolved from simpler and less manifest antecedents, and have then subsequently *exapted* (i.e., it took on other functions; Gould and Vrba, 1982; Vrba, 2002). 'It clearly was a "process" (and not an "event"), and almost certainly had nothing to do with genetic superiority' (Clark, 2003: 57). Symbolism and imagery do not qualify any more as necessary and sufficient attributes for the definition of a major new stage in human evolution around the 40,000 BP timeline, if only because they predate any such stage, along with stone blades or bone tools.

The human ecosystem as a whole. Summing up, it is expected that the HE4-CI environment influenced Paleolithic societies by variously (1) disrupting herbivore populations from deterioration of pasture; (2) altering the overall availability of habitually-exploited staple plants; (3) changing the availability or predictability of water; (4) forcing changes in the procurement patterns of habitual rock resources; (5) causing displacement of populations, hence an entirely new mosaic of depopulation and crowding, with local cases of heavy group-size reduction and other demographic consequences; and (6) exerting stresses on cognition, information transmission, and the social fabric. If it is correct to infer a hemispheric 'volcanic winter' scenario of any appreciable length, we would advocate that the above conditions and their aftermath have to be evaluated on a still unexplored scale.

This combination of variables is only a list of building blocks for a possible model (Fig. 7). Some of the variables and their states are not novel, of course, but had occurred since the Penultimate Glacial at least. What must have made a difference 40,000 years ago, in the context of Western Eurasia, were the abruptness and sharpness of environmental forcing, coupled with the past trajectory of a number of Paleolithic social systems—their recent 'history' and variation (Fedele et al., 2003, 2007). In this perspective, the crisis precipitated by the CI was not necessarily negative. Rather it plausibly acted as a filter and catalyst, either constraining or enhancing predispositions and processes. We see accelerated change, and the real novelty was that, this time, several innovations of a certain kind stuck and lasted. Eventually they became the basis for the constitution of an Upper Paleolithic millennia later, clearly after 32,000–30,000 cal BP (i.e., after GI5, ~32,000 $\mathrm{BP}_{\mathrm{GRIP/GISP2}}$; Giaccio et al., 2007), with the appearance of the Gravettian-Pavlovian tradition (cf. Bednarik, 2007b: 360).[8]

The ultimate success of innovations is a matter of viability: reduced viability of a set of adaptive options versus increased viability of others (cf. Brantingham et al., 2004: 248). Against this background, we would interpret the European Paleolithic shift in evolutionary terms based on selection—a Darwinian argument (cf. Shennan, 2000, 2001, 2003; but see Gilman, 1984). Not selection at the species and/or whole 'culture' level, however, partly because no such thing as an archaeological culture can be distinguished at a 40,000 BP date. Rather, we would argue that competition and selection were played out at the population and—so to speak—intra-societal level. One can envisage behavioral competition and selection either among segments of a population, or among populations of the same 'behavioral pool,' this being a notion equivalent to gene pool but shifted to the cultural domain. Selection should have favored innovative, mutually beneficial behavior among populations linked by reciprocal relationships, and constrained by the cost-benefit balance of their interaction. We agree that explanations should be sought in terms of evolutionary and population ecology, and suggest that archaeological data should be generated and evaluated accordingly. Of course, a framework based on selection implies that there were losers: groups or demes that were behaviorally and/or demographically selected against, and thus disappeared from the archaeological record. There is no compelling reason to invoke competition amongst different groups or species of *Homo*.

Finally, when it comes to survival in the face of sustained stress and when a premium is placed on innovation and flexibility, it frequently is young adults and women that emerge as leading social movers, possibly as much in the Interpleniglacial as it is today (cf. Mead's, 1964, 'evolutionary clusters,' admittedly in a different context). As provocatively indicated by Kuhn and Stiner (2006), the evolutionary role of women in connection with a developing division of labor should not perhaps be discounted in the behavioral changes we are discussing.

Evolutionary considerations: rigidity versus resilience. The issue of the rigidity or resilience of human societies in the face of environmental pressures is obviously relevant for the present discussion. As an approximation, the marked effects of the HE4-CI crisis may have lasted any span of time from a few decades to a few centuries, depending on region and ecosystem (cf. Dale et al., 2005b). From a certain point of view, it is true that most catastrophic events have only short-time impacts, because humans on average are much more resilient than normally thought (cf. Grattan, 2006). In fact, far from suggesting that the crisis gave the coup de grâce to the Middle Paleolithic groups, we emphasize the resilience of these groups, their inherent human ability to change, albeit selectively.

We model the crisis as having imparted strong selective pressures that set off 'MUP' human groups on a new course, and this was the truly durable impact of the catastrophe. The course was not actually new, since several innovations and trends were already in motion, but the acceleration was extraordinary—an instance of descent with rapid modification. Maladaptive solutions and 'rigid' human groups were selected against. In Western Eurasia the new course was expressed for a few millennia by the well-known development of 'late' Mousterian and 'Aurignacian' manifestations, but not before extensive (?) repopulation at the end of HE4 had occurred. This phase should still be classed as Middle Paleolithic, if chronotypological units have any meaning (cf. footnote 8); 'Late Middle Paleolithic' might be a convenient designation.

In this context, a brief reference must be made to the ca. 73.5 ka BP super-eruption of Toba Volcano in Sumatra (see above). In spite of its magnitude, Toba's impact on global climate and its subsequent effects on regional biota and the human population remain contentious (e.g., Oppenheimer, 2002; Gathorne-Hardy and Harcourt-Smith, 2003; Sparks et al., 2005). More recently, working in the Jurreru River valley of southern India, Petraglia et al. (2007) have sought to demonstrate that humans persisted regionally across this major eruptive event (i.e., that Toba's was not a catastrophe for potentially 'modern' humans). The human groups involved would have been in possession of tool-kits similar to African Middle Stone Age industries, Howieson's Poort in particular. However, although very interesting, this case from India is inadequate as a check for claims concerning the human impact of the CI eruption. First of all, the equatorial eruption of Toba is not the best reference for an eruption like the CI, which originated at 42°N, took place at the beginning of an acute cooling episode within a glacial, and affected with its ashfall a vast expanse of land, rather than sea. Position, latitude, and climate trend at the time of eruption make a great difference as to how an eruption's impact is modulated (see above; details in a recent report by volcanologists and atmosphere scientists, Sparks et al., 2005). Secondly, there is a discrepancy in scale. It appears that the stratigraphic relationships of tephra and artifacts at Jurreru imply a range of several millennia. The temporal resolution is too low to be comparable with the CI's timeframe, and accuracy is not enough to pinpoint the possible existence of a post-impact hiatus. Thus, the evidence does not say anything about the actual reactions of people, but only records generally that people persisted within the region on a millennial-scale. The same occurred after the CI eruption.

Rather, we consider relevant for modelling the CI's impact the Late Glacial case of the Laacher See Volcano, western Germany, which erupted at 12,916 cal BP (Baales et al., 2002; the dating results from a state-of-the-art exercise). In northeastern Europe and southern Scandinavia this eruption had a dramatic impact on forager demography and precipitated rapid cultural change (Riede, 2008). Among some groups these pressures resulted in marked technological innovation, such as defines the regionally-distinct Bromme culture; other populations contracted or relocated, leaving several regions depopulated—the Thuringian Basin and the British Isles, for instance. In terms of sulphur emission, the Laacher See may have been responsible for a volcanic winter in the northern hemisphere; two centuries afterwards, the sharp Younger Dryas cooling (GS1) gave the coup de grâce. Laacher See shows how

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[8] Better still, the beginning of the 'Upper Paleolithic' might be moved further on: 'What is often interpreted as typically Middle Paleolithic behavior, notably subsistence strategies and tool making, shifted to typically Upper Paleolithic patterns only after about 20,000 years ago' (Riel-Salvatore and Clark, 2001: 450, with references to earlier proposals). From a genetic viewpoint, Forster (2004) has proposed a founder-analysis placement of the most ancient European haplogroups of today only after ca. 30,000 years BP. This subject is outside the scope of this paper.

a medium-sized event can produce considerable disruption even on ‘advanced’ hunter-gatherers, to the point of inducing shifts not only in residential patterns but in technology and the material organization of culture.

Concluding remarks

(1) A major problem in modeling the HE4-CI impact on people is the lack of modern analogs. What we are attempting to study is not just a volcanic impact, but a climatic *and* volcanic impact on extinct sociocultural systems at a Middle Paleolithic level of complexity, for which the present-day hunting and gathering groups only provide vague similarities. One cannot assume identity of condition and/or reaction between the Last Glacial hunter-gatherers and the hunter-gatherers of today unless archaeological evidence proves it (Fedele et al., 2007); furthermore, one has to face the ‘non-analogue environment’ of MIS3 (Stewart, 2005). Recent studies in Southeast Asia and Siberia, however, offer some useful insights, if not a template (Jacoby et al., 1999; Gaillard, 2002, 2006; Gaillard et al., 2005, 2007), particularly concerning the potential network of negative and positive effects the eruptions of Mount Pinatubo in the Philippines had on the Aeta foragers.

In Papua New Guinea, where Torrence et al. (2000; Torrence and Grattan, 2002) have explored the interplay of volcanic eruptions and human responses during the Holocene and sub-recent times, a series of discontinuities followed by sociocultural re-arrangements have been recognized. Similarly, in southeastern Australia, the mid-Holocene eruptions of Mount Gambier determined depopulation as a result of ecological stress and collapse of the trophic chain: ‘Aboriginal stone tools occur, sometimes in profusion, below the pyroclastic layer and right up to it; above it, however, occurs a sterile layer until the stone tools reappear further up in the sequence’ (Bednarik, 2007b: 359). Grattan (2006) offers a balanced overview of the role of volcanic eruptions in documented human history, suggesting, in fact, how rigidity and resilience of human societies operated alternatively, according to environmental conditions and sociocultural background (cf. also Torrence and Grattan, 2002; Grattan and Torrence, 2007). As studies of present-day foragers show, some hunter-gatherer societies can be very flexible. They can rapidly change both technical procedures and ideology (e.g., ritual) under the pressure of external factors, and often do so through the leadership of individual members. The mechanisms of such rapid change can vary. Well-studied examples are rare but highly informative (e.g., southern Siberia; Lavrillier, 2007). Although comparisons are difficult and require caution, an examination of the HE4-CI impact in the light of such data is being developed.

(2) Peripheral to our discussion, but potentially revealing, is the related subject of persistence in memory of a volcanic catastrophe. Collective memory among hunter-gatherers is known to reach remarkable time depth, as measured precisely on the basis of natural disasters. In the case of Mount Gambier mentioned above, an Aboriginal story collected in the 19th century describes the details of the eruptions correctly (Smith, 1880, quoted in Bednarik, 2007b; R.G. Bednarik, in litteris, 22.02.2008), indicating a persistence in memory of about 350 generations (i.e., ~7,000 years). Legends of volcanic events in Papua New Guinea may lead to similar conclusions (Blong, 1982), as on a shorter timescale does Plato’s myth of Atlantis within our own western tradition, if it echoes the famous Bronze Age eruption of Thera, in the Aegean Sea, ca. 3,565 cal BP (Fedele, 1999; on the eruption’s dating see Friedrich et al., 2006). Persistence in memory deserves mention as an important cognitive factor whose archaeological correlates have rarely, if ever, been looked for in the Paleolithic record.

(3) In an elegant paper inspired by the riddle of transitions, an actualistic approach has been devoted by O’Connell (2006) to the problem of population replacement among foragers. In two late prehistoric cases where linguistic and genetic data provide evidence of replacement, the invading group appears to have succeeded because of its reliance on a broader suite of resources, a practice that not only allowed its members to persist under conditions where those of the resident group could not, but in fact may have helped create those conditions. Accepting the replacement scenario, the conclusion is then drawn that ‘the invading moderns [out-competed] the resident Neandertals not because they were somehow “better,” “smarter,” or “more capable” culturally, but because they were prepared to operate a more expensive subsistence economy’ (O’Connell, 2006: 55). These are very valuable insights, which, in our opinion, can be applied equally well to intra-species competitive exclusion (i.e., competition and selection among cultural and biological peers—resident Mousterian/Neandertal populations, as proposed above).

(4) Explanations of the European Paleolithic shift in terms of demic migration and replacement not only appear simplistic but discourage the search for local roots. The evidence, in our opinion, is not compelling—yet. A slow colonization of Europe by incoming groups—the alleged ‘moderns’—is simply not supported by the tephrostratigraphic and chronological evidence (Giaccio et al., 2006), as finally also acknowledged by some supporters of invasionist theories (Mellars, 2006). This, however, is not to say that the only alternative is a rapid, Blitzkrieg-like colonization, as currently reconstructed (e.g., Zilhão, 2006b—an otherwise elegant synthesis based on radiocarbon ‘calibration’). This result instead justifies an equally viable alternative, rapid indigenous change. Or more accurately, the HE4-IC impact is to be explored first of all against a background of highly varied, fluctuating human societies of a Middle Paleolithic continuum. We wish to emphasize that it is not the CI per se that forces a rethinking of processes round 40,000 BP, but it is the extraordinary occurrence of a positive feedback between the CI and HE4, within the cooling trend already expressed by an ongoing Bond cycle. In this perspective, the phenomenon of exaptation, initially proposed in the context of evolutionary anatomy but conveniently extended to culture, is particularly apt to account for the reorientation of behavioral and artifactual traits under the pressure of new conditions. Another example may be the formalization and expansion of bone tools. Reorientation followed by rapid and successful spread can easily look like a break or an explosion in the archaeological record, and be accordingly misconstrued (Fedele, 2006; Fedele et al., 2007).

(5) In this paper we have outlined steps towards a model of accelerated, constraining-or-enhancing change within a framework of fundamental continuity—a model of ‘change within continuity.’ We predict that a number of occasional, incipient cultural traits, available in a rich fund of behavioral repertoires, became viable options under the exceptionally stressful conditions that affected Western Eurasia (or the whole northern hemisphere?) at ca. 40,000 BP. Such sudden conditions interfered with precursor traits or processes and may have acted on them as powerful selective or catalytic (i.e., reinforcing) agents, according to situations and regions, thus precipitating conditions for change. The hominin cognitive makeup that is implicit in visually-represented symbolic expressions, and that pre-existed in ‘Neandertal’ Europe, was crucially involved. Contrary to replacement theories, both cultural and biological, we argue for a picture of accelerated change within the evolving Mousterian, hence, one in which both change and a fundamental continuity are significant (cf. Brantingham et al., 2004). To rephrase a chapter title in van Andel and Davies (2003: Ch. 13, ‘Climatic stress and the Extinction of the Neandertals’), one could speak of climatic stress and the *evolution* of the Neandertals, or more accurately, the further evolution of the Mousterian—an ‘Epi-Mousterian,’ so to speak. As succinctly put by Bednarik (2007b: 359), ‘the diversification and specialization of Mousterian traditions certainly precedes the CI event by a significant margin, and the

acceleration of this process immediately subsequent to the event produced no fundamental change in the direction of this development.' Major new configurations in Eurasian cultural evolution only took shape well after the 40,000 BP timeline, and a proper Upper Paleolithic stage can be recognized only after MIS3 (see above).

Of course, if a model of this kind is accepted, several problems remain open, pending empirical verification. Just to mention a few: may refugia have formed in certain areas, and may higher population density have effectively led to exalted intra- and intergroup interaction?; how can we be more accurate in detecting effects outside the main impact zone of the CI, or on its fringes, and particularly in Western and Central Europe, on the East European Plain, and across the Urals? Several portions of the model shown in Fig. 7 are testable.

(6) The HE4-CI interference might have also indirectly affected the biological heredity of late Pleistocene humans via population genetics and allied biological factors (sharp reduction in gene pool size, genetic drift etc.). In a series of recent papers Bednarik (2007a, 2007b, pers. comm.) has already attempted to integrate our CI impact model into a comprehensive biocultural framework. He argues for significant links between the environmental disaster and both the technological and human morphological changes. He particularly stresses the possibility of a bottleneck whose effects would have been compounded by genetic drift or introgression across contiguous populations. In principle we agree with this kind of argument. However, the HE4-CI factor is not expected to contribute directly to the explanation of anatomical change. Whether regional depopulation in parts of Europe facilitated what appears to be a dilution of Neandertal traits vis-à-vis new and evolving morphologies cannot be determined at present.

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