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First dated human occupation of Italy at ~0.85 Ma during the late Early Pleistocene climate transition

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ABSTRACT

A candidate for the oldest human occupation site in Italy is Monte Poggiolo where the lithic tool-bearing levels are currently dated to ~1 Ma based on electron spin resonance (ESR). The low analytical precision of ± 30% at 2σ makes it unclear whether the date actually conflicts with a recent reassessment of age constraints on key hominin sites from Italy, France, and Spain pointing to a uniformly young timing for the earliest habitation of southern Europe during the late Early Pleistocene climate transition within reverse magnetic polarity subchron C1r.1r (0.988–0.781 Ma). Our new magnetostratigraphic and biostratigraphic results show a sequence of stable normal and reverse polarities in a regional lithostratigraphic context that indicate the Monte Poggiolo tool-bearing site post-dates the Jaramillo normal polarity subchron, most probably occurring at ~0.85 Ma immediately after the pronounced cooling that culminated with marine isotope stage 22 when the associated regression may have opened new migration routes through the Po Valley for large mammals and hominins.

1. Introduction

The Cà Belvedere site near Monte Poggiolo in northern Italy (Fig. 1) yielded a major industry of in situ-knapped Mode 1 pebbles and flakes (Peretto, 2006; Peretto et al., 1998) considered as manufactured by the earliest hominins of Europe (e.g., Carbonell et al., 2008). Previous paleomagnetic analyses indicated the presence in the tool-bearing levels and elsewhere in the area of reverse polarity magnetizations attributed to the Matuyama Chron (1.778–0.781 Ma; ages of Lourens et al., 2004 used throughout) (Gagnepain et al., 1998; Peretto, 2006; Peretto et al., 1998). Electron spin resonance (ESR) dates on quartz grains obtained directly from the archeological levels (Gagnepain et al., 1998; Peretto et al., 1998) were calculated (Falguères, 2003) to give a mean age of 1.06 ± 0.16 (1σ) Ma, which would place the tool-bearing levels in the late Matuyama either just before or after the Jaramillo normal polarity subchron (C1r.1n; 1.072–0.988 Ma). The low precision ESR dating, which is associated with potential analytical errors of up to 30% (Ludwig and Renne, 2000), thus makes it unclear whether the timing of hominin occupation at Monte Poggiolo actually conflicts with a recent reassessment (Muttoni et al., 2010) of available magnetostratigraphic and/or radiometric age constraints on key hominin sites from Italy, France, and Spain that point to, or at least are not inconsistent with, earliest human habitation in southern Europe during reverse magnetic polarity subchron C1r.1r, an interval between the end of the Jaramillo (0.988 Ma) and the beginning of the Brunhes (0.781 Ma) straddling the late Early Pleistocene global climate transition (Berger et al., 1993; Shackleton, 1995). This uncertainty prompted us to conduct a new magneto-biostratigraphic study of the sedimentary sequence cropping out in the area of Monte Poggiolo (sections A to E) and in the subsurface of the Po Plain (deep core 239-S1; Benini et al., 2009) (Fig. 1) with the aim to pin down the age of the sediments containing the lithic industry.

2. Regional stratigraphy

Among the Pliocene–Pleistocene stratigraphic units cropping out in the sampling area, two are particularly relevant for this study, namely the marine clays of the Argille Azzurre and the overlying littoral deposits of the Imola Sands (Amorosi et al., 1998a, b; Benini et al., 2009) (Figs. 1, 2). The Argille Azzurre is of Early Pliocene to Early Pleistocene age (Capozzi and Picotti, 2003) and characterized at the top by a regressive trend from offshore to shoreface deposits (Qm1 member), which are overlain disconformably by a few meters of

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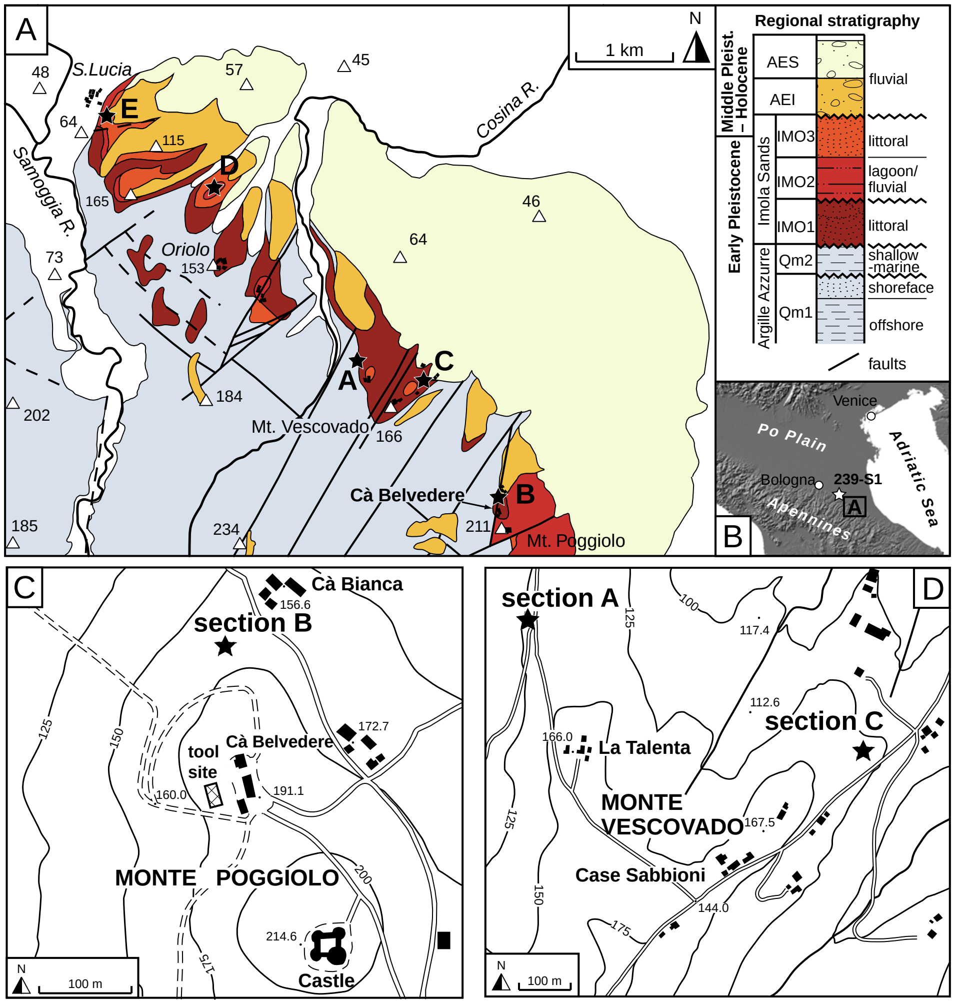

Fig. 1. (A) Geologic map and stratigraphy (Amorosi et al., 1998a, b; Benini et al., 2009) of the Apennines margin of northern Italy (B) with location of the Monte Poggiolo hominin site and sections A–E; star in panel B shows the location of core 239-S1. Detailed topographic maps of the Monte Poggiolo area (panel C) and of the Monte Vescovado area with location of sections A and C (panel D) are also provided. Geographic coordinates of sections and core are as follows: Section A = 44.218122°N, 11.931687°E; Section B = 44.204699°N, 11.948503°E; Section C = 44.215455°N, 11.939315°E; Section D = 44.233970°N, 11.913401°E; Section E = 44.241404°N, 11.901478°E; Core 239-S1 = 44.359503°N, 11.742601°E.

transgressive swamp to shallow marine deposits (Qm2 member). Above follow the ~50 m-thick Imola Sands consisting of three members: a lower IMO1 member that lies disconformably above the Argille Azzurre (Qm1 or Qm2) and consists mainly of littoral sands, a middle IMO2 member that consists of alluvial plain sediments passing upward to lagoonal-estuarine sediments, and an upper IMO3 member consisting of littoral sands; IMO2 and IMO3 constitute altogether a transgressive sequence (Amorosi et al., 1998a, b). Above follow fully continental alluvial deposits (AEI and AES) (Benini et al., 2009). The lithic industry was found in a ~4 m-thick sequence of sandy gravels deposited in fluvial settings close to sea level, and resting on the Argille Azzurre (Peretto, 2006; Peretto et al., 1998). Based on these and additional observations (Cremaschi, 1982), we attribute the tool-bearing levels to the IMO1 member of the Imola Sands.

3. Magnetostratigraphy

We conducted comprehensive paleomagnetic analyses on a total of 141 samples from the 5 outcrop sections and the long core. All samples were subjected to thermal demagnetization and the magnetic remanence was measured on a 2G-Enterprises DC squid cryogenic magnetometer. Standard least-square analysis was used to calculate component directions from selected segments of vector end-point diagrams. Rock-magnetic properties were studied on representative fresh samples with isothermal remanent magnetization (IRM) backfield acquisition curves and thermal demagnetization of a three-component IRM.

Section A to the NNW of Monte Vescovado (Fig. 1) starts with ~7 m of gently tilted (~20°) blue clays with millimeter-thick sandy-silty intercalations attributed to the offshore facies of the Argille Azzurre (Qm1) overlain with angular unconformity by a ~1.8 m-thick flat-lying sequence starting with gravels followed by sands and clays attributed to the shoreface facies of the Argille Azzurre (upper Qm1) (Fig. 2). A total of 37 stratigraphically superposed oriented core samples were taken for paleomagnetic analyses in fine-grained levels. The blue clays are characterized by the presence of a dominant magnetic phase that saturates at fields of ~300 mT (Fig. 3) interpreted as magnetite in agreement with previous detailed rock magnetic studies on the Argille Azzurre of the northern Apennines (Mary et al., 1993). Characteristic magnetic components have been isolated in 25 (out of 30) samples from the tilted strata below the angular unconformity from room temperature to ~250 °C (Fig. 4). These components are rotated clockwise in both in situ (Dec. = 41°, Inc. = 37°, k = 23.5, α95 = 6°) and tilt-corrected (Dec. = 40°, Inc. = 18°, k = 23.5, α95 = 6°) co-ordinates (Fig. 5), and display only down-pointing (positive) inclinations that are shallower than expected probably as a result

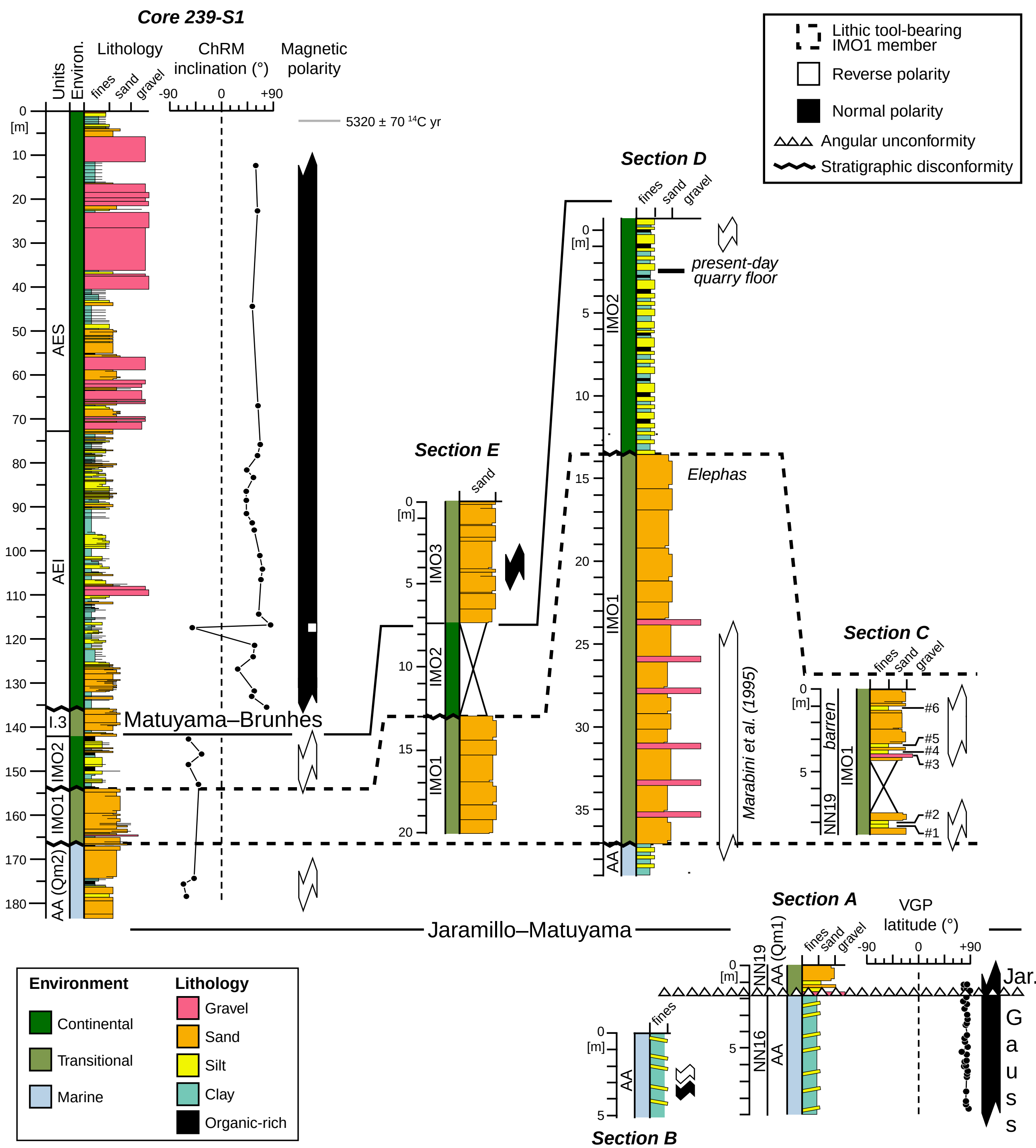

Fig. 2. Magnetostratigraphic correlation of core 239-S1 and outcrop sections A–E. Inclinations of the characteristic component vectors (ChRM) were used to develop a magnetic polarity stratigraphy in core 239-S1, whereas Virtual Geomagnetic Pole (VGP) latitudes from the ChRM vectors were used for polarity stratigraphy in sections A–E. Notes: AA = Argille Azzurre; I.3 = IMO3; NN16 and NN19 are Neogene Nannoplankton Zones 13 and 19, respectively (details on biostratigraphic data in Table 1); Jar. = Jaramillo. Stratigraphic disconformities after Amorosi et al. (1998a, b).

of compaction and deformation (e.g., Fig. 4, sample AA6). Characteristic magnetic components isolated in 6 (out of 7) samples from the flat-lying strata above the angular unconformity from room temperature to ~250 °C (e.g., sample AS5, Fig. 4) bear positive inclinations associated with declinations virtually unrotated with respect to geographic north (Dec. = 10°, Inc. = 44°, k = 43.5, α95 = 10°; Fig. 5).

Section B near Monte Poggiolo (Fig. 1) consists of ~5 m of gently folded blue clays with millimeter-thick sandy-silty intercalations attributed to the offshore facies of the Argille Azzurre (Qm1) overlain by a pedogenized horizon (Fig. 2). A total of 10 oriented core samples were taken from three closely superposed levels of the blue clays. Samples showed the presence of a low coercivity phase interpreted as magnetite sometimes associated with a much higher coercivity phase

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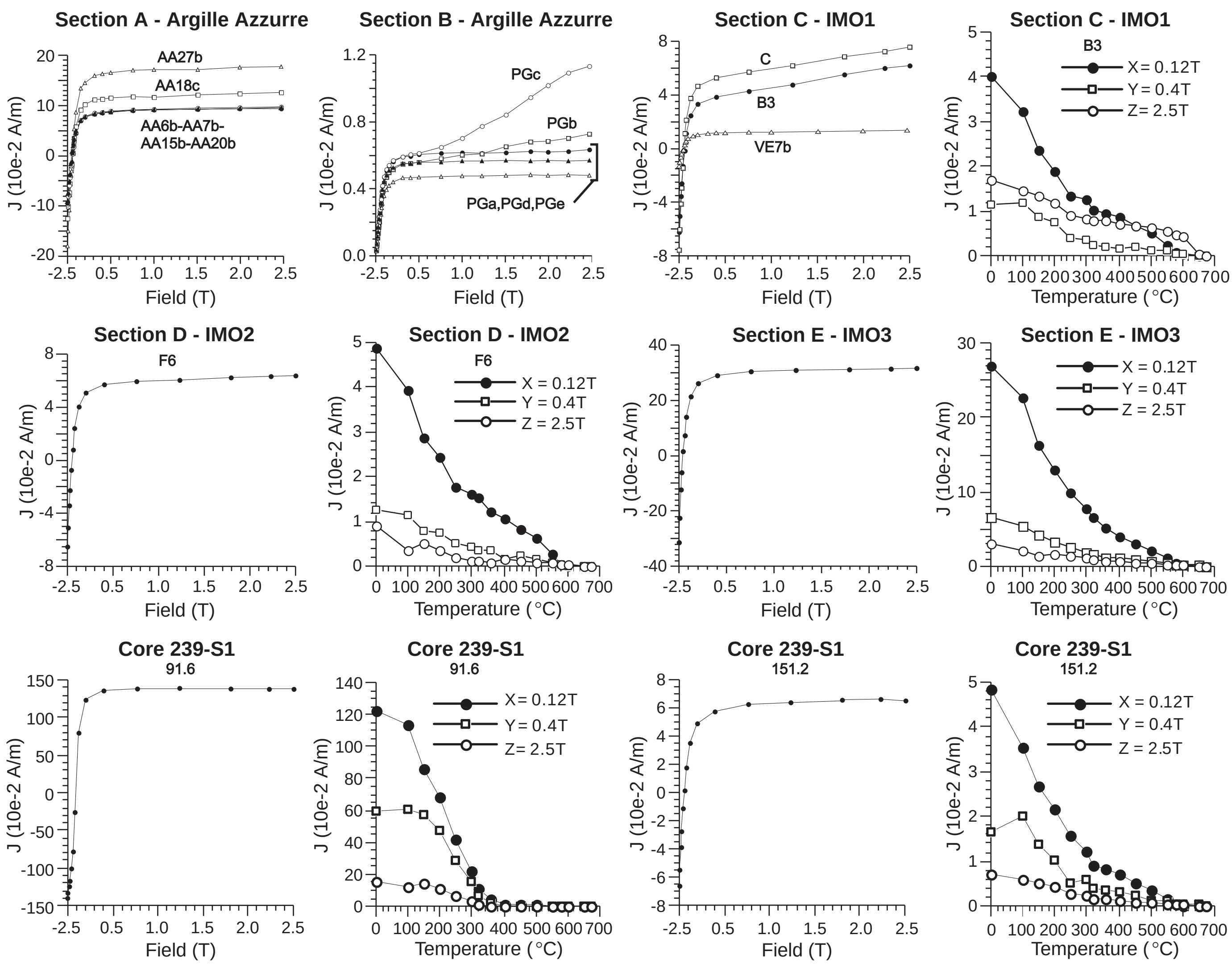

Fig. 3. Rock-magnetic data of sections A–C and core 239-S1 obtained with isothermal remanent magnetization (IRM) backfield acquisition curves and thermal decay of a three-component IRM (acquired in 2.5 T, 0.4 T, and 0.12 T fields).

interpreted as hematite or goethite (Fig. 3). Stable end-point magnetic component directions isolated in six samples from room temperature to ~250–300 °C (maximum of 425 °C) are oriented either northwest-and-down or southeast-and-up (negative inclination) (e.g., Fig. 4, samples pog9, pog5). These components, corrected for bedding tilt, are rotated ~50° counter-clockwise with respect to geographic north as a consequence of tectonic deformation (Dec. = 311°, Inc. = 20°, k = 6, α95 = 29°; Fig. 5).

Section C near Monte Vescovado (Fig. 1) straddles a ~9 m-thick flat-lying sequence of decimeter-thick yellow sands and conglomerates interbedded with silty levels attributed to IMO1 (Fig. 2). A total of 38 oriented core samples were taken in 5 distinct silty levels and 1 gravel level (for a conglomerate test) through the section (Fig. 2, levels #1–6). Sediments are characterized by the presence of a magnetic phase that saturates at fields of ~200 mT (Fig. 3, sample VE7b) sometimes associated with a higher coercivity phase that shows no tendency to saturate up to fields of 2.5 T (samples B3, C). Thermal demagnetization of a three-component IRM showed that these contrasting coercivity components are magnetite, with maximum unblocking temperatures of ~570 °C, and hematite, with maximum unblocking temperatures of ~680 °C (Fig. 3). Well-defined stable end-point magnetic components oriented south-and-up were isolated in samples from levels #1 (4 samples), #4 (6 samples), and #6 (3 samples) from room temperature to ~250–300 °C or a maximum of 575 °C (Fig. 4, samples VE2, VE4, E1); these magnetic components yielded an overall mean of Dec. = 180°, Inc. = −53° (k = 43.5, α95 = 6°; Fig. 5). In 9 samples from level #2, a southerly-and-up magnetic component isolated from room temperature to 150–200 °C (mean of Dec. = 166.5°, Inc. = −45°, k = 11, α95 = 16°) is followed up to temperatures of 400–550 °C by poorly defined and highly scattered magnetic components of dubious origin (Fig. 4, sample A3). In level #3 gravels, we took 10 oriented samples from individual, ancient (Cretaceous–Cenozoic) limestone and sandstone cobbles, obtaining northerly-and-down directions from room temperature to ~150 °C oriented broadly along the present-day field direction, followed at temperatures up to a maximum of 450 °C by highly scattered characteristic component directions (Fig. 4). These results exclude a pervasive remagnetization and thereby support the presence in section C of primary magnetization components, notably the reverse polarity component found in silty levels throughout the section (notably from levels #1, #4, and #6).

Section D on the western wall of the disused Salita di Oriolo sand quarry (Fig. 1) consists of a ~2 m-thick alternation of thinly bedded silts and fine- to medium-grained sands with root marks, asymmetric ripples, and carbonate nodules attributed to alluvial plain settings of

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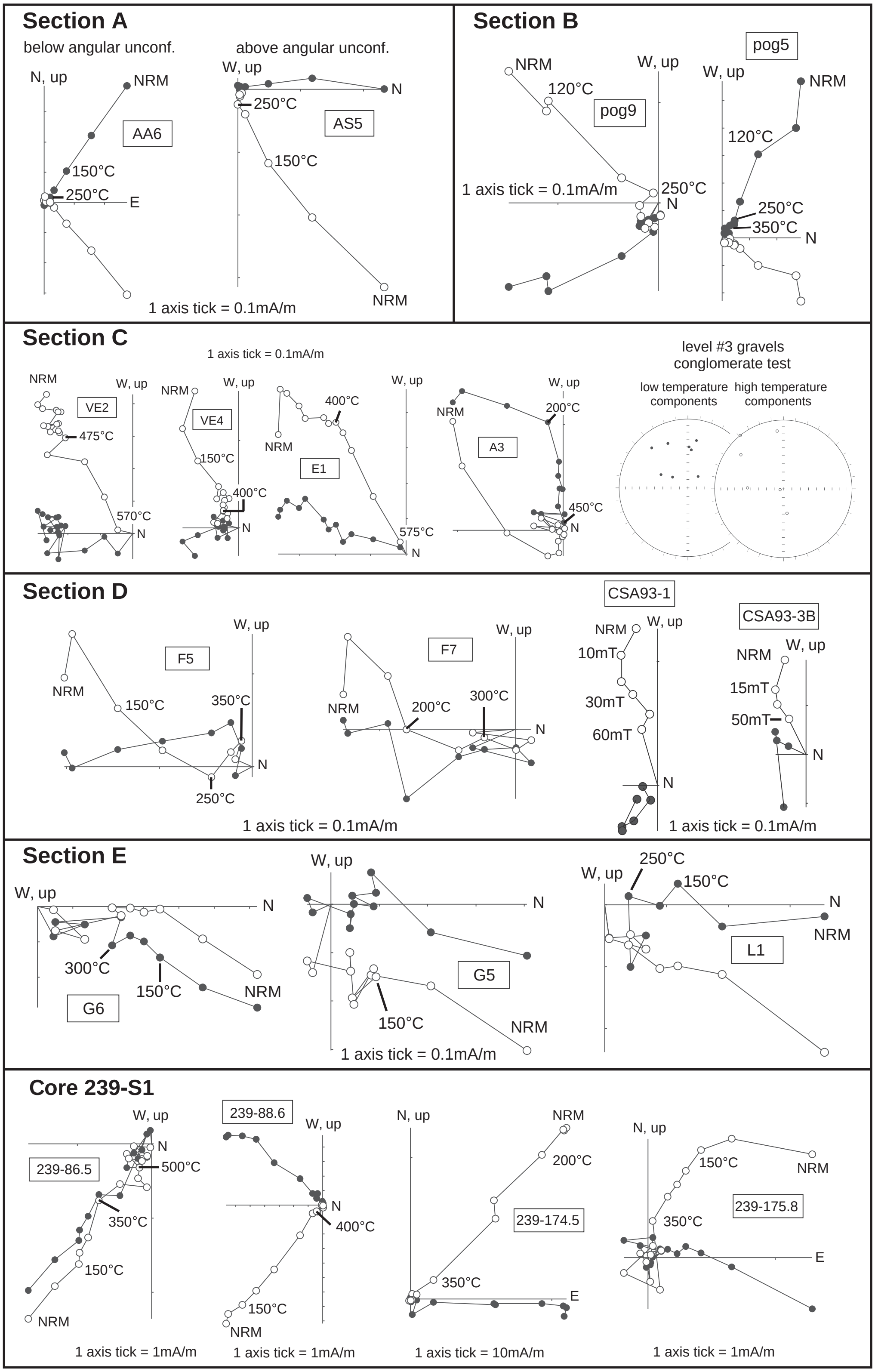

Fig. 4. Vector end-point demagnetization diagrams of representative samples from sections A–E and core 239-S1. Closed symbols are projections onto the horizontal plane and open symbols onto the vertical plane in geographic (in situ) coordinates. Demagnetization temperatures are expressed in °C.

IMO2 (Fig. 2). Sediments are characterized by the presence of a dominant magnetic phase that saturates at fields of ~200 mT and bears maximum unblocking temperatures of ~570 °C interpreted as magnetite (Fig. 3). A total of 10 oriented samples were collected in 5 superposed levels. Ill-defined characteristic magnetic components oriented broadly south-and-up were isolated in 6 samples from 3 superposed levels spanning ~1 m of section in the temperature range from ~100 to ~350 °C after removal of a viscous overprint broadly aligned north-and-down along the present-day field direction (Fig. 4, samples F5, F7; Fig. 5). When the quarry was active, a much thicker

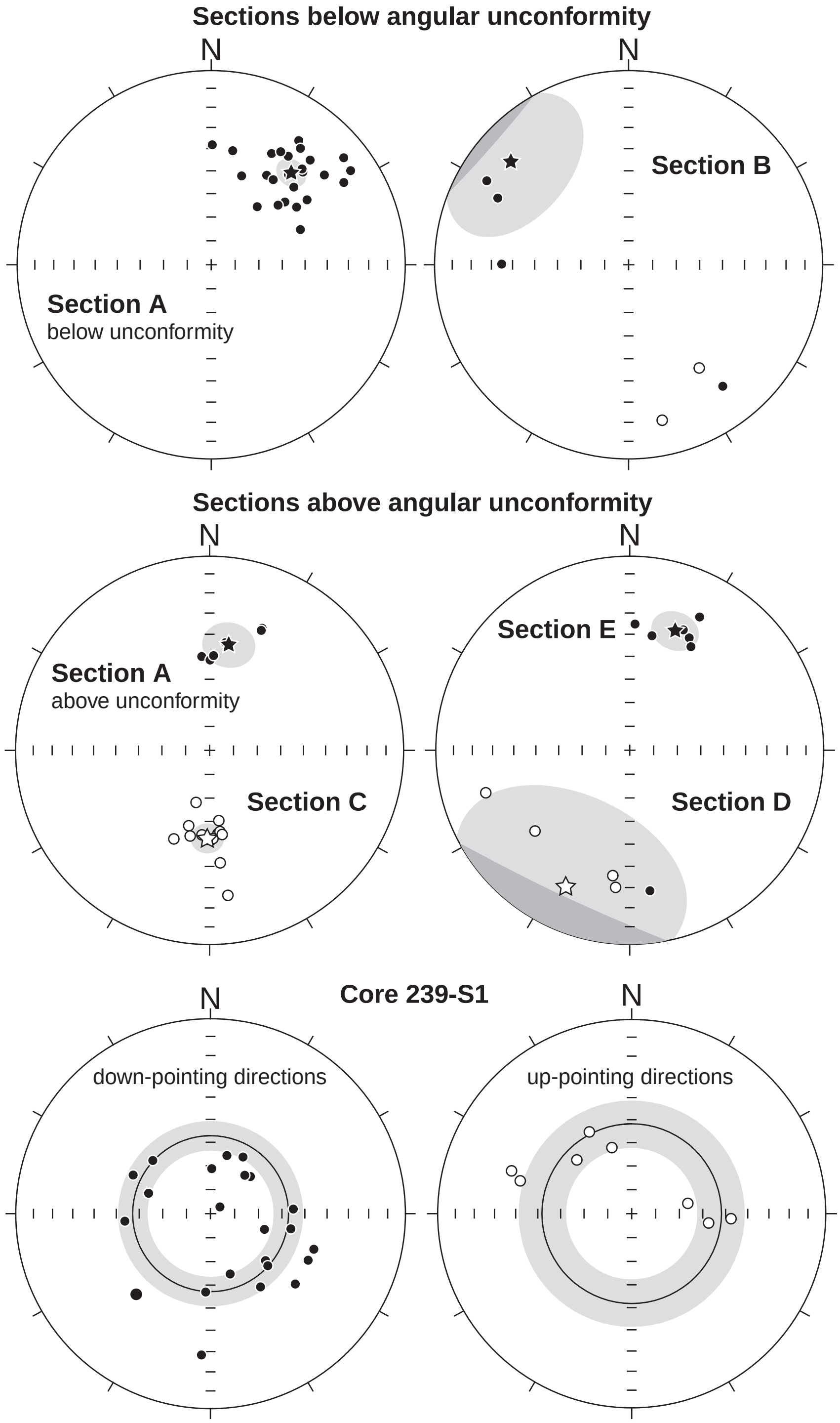

Fig. 5. Equal-area projections in bedding-tilt coordinates of the characteristic component vectors from sections A and B of the tilted Argille Azzurre below the angular unconformity and for the remainder of the flat-lying sections (A, C, D, and E) above the angular unconformity, as well as of the characteristic component vectors from core 239-S1. The core was not oriented with respect to the geographic north, therefore only the inclination of the characteristic component vectors was used to outline magnetic polarity stratigraphy. Closed symbols are projections onto the lower hemisphere and open symbols onto the upper hemisphere; closed stars represent the mean direction and the associated gray circles the cone of 95% confidence around the mean; for core 239-S1, the mean inclination of the down-pointing (normal polarity) and up-pointing (reverse polarity) vectors are displayed by small circles together with the associated band of 95% confidence (see text for details).

section was exposed below the sampled IMO2 member into the underlying IMO1 member resting on the Argille Azzurre (Marabini et al., 1995). The lower part of IMO1 (Fig. 2) yielded 15 stratigraphically superposed samples with dominant south-and-up components of reverse polarity (Fig. 3, samples CSA93-1, CSA93-3B; Marabini et al., 1995), whereas the upper part of IMO1 had yielded the skull of *Elephas meridionalis* (Marabini et al., 1995).

Section E near Santa Lucia delle Spianate (Fig. 1) straddles a flat-lying sequence from IMO1 at the base to IMO3 at the top, albeit the intervening IMO2 is largely covered (Fig. 2). A total of 11 samples have been taken in 3 closely superposed stratigraphic levels of silty sands of the IMO3. Samples are characterized by the presence of a dominant magnetic phase that saturates at fields of ~200 mT and bears maximum unblocking temperatures of ~570 °C interpreted as magnetite (Fig. 3).

Ill-defined characteristic magnetic components oriented northerly-and-down were isolated in 6 samples from room temperature up to ~250 °C (Fig. 4, samples G6, G5, L1; Fig. 5).

Core 239-S1 was taken by the Geological Survey of Emilia-Romagna in the Po Plain near Imola (Benini et al., 2009) (Fig. 1). The core recovered 182 m of sediments consisting of, from bottom to top, swamp to shallow marine clays and silts of the Qm2 member of the Argille Azzurre (182–167 m) overlain by a complete sequence of Imola Sands (IMO3–IMO1; 167–136 m) in turn overlain by variable alternations of fluvial-channel gravels and sands, and fine-grained crevasse splay or floodplain deposits (AEI–AES; 136–0 m); the top of unit AES yielded an uncalibrated radiocarbon age of 5320 ± 70 yr and thus extends into the Holocene (Benini et al., 2009) (Fig. 2). A total of 35 stratigraphically superposed core samples were taken for paleomagnetic analyses in cohesive, fine-grained levels. Sediments are characterized by the presence of magnetic phases that saturate at fields of ~200–300 mT and bear maximum unblocking temperatures of either ~320 °C or ~570 °C interpreted as sulfides and magnetite, respectively (Fig. 3). Vector end-point demagnetization diagrams indicate the presence in 32 samples of characteristic magnetic components with either positive (down-pointing) or negative (up-pointing) inclinations isolated in the temperature range from ~100–150 °C to ~300–350 °C up to a maximum of 575 °C (Fig. 4). The core was not oriented with respect to geographic north, therefore only the inclination of the characteristic component vectors was used to outline magnetic polarity stratigraphy. Positive (negative) inclinations were acquired during normal (reverse) polarity of the Earth's magnetic field (Fig. 5). Sulfides and magnetite appear to be distributed throughout the section more or less homogeneously and no relationship was observed between rock-magnetic properties and magnetic polarity, which shows a clear reverse to normal transition between IMO2 and the alluvial AEI deposits (Fig. 2).

4. Biostratigraphy

Calcareous nannofossil investigations were performed on 12 samples from sections A and C (Table 1). All samples were prepared using standard techniques (Bown and Young, 1998). Smear slides were analyzed using standard light-microscope techniques under crossed polarizers and transmitted light at 1250× magnification. Biozonations are from Martini (1971) whereas ages of taxa are from Lourens et al. (2004).

At Section A, a total of 6 samples from the offshore Qm1 member of the Argille Azzurre below the angular unconformity indicate the presence of *Discoaster pentaradiatus*, *Discoaster brouweri*, *Discoaster variabilis*, *Discoaster surculus*, and *Discoaster tamalis*. *Calcidiscus macintyrei*, *Helicosphaera sellii*, *Pseudoemiliania lacunosa*, and *Pseudoemiliania ovata* are also present, whilst *Sphenolithus abies* is absent. This nannofloral assemblage pertains to the Late Pliocene Zone NN16. Biostratigraphic analyses from samples of the shoreface Qm1 member of the Argille Azzurre above the angular unconformity document significant changes in nannofloral assemblages with respect to samples below the unconformity. Samples are characterized by the presence of *Gephyrocapsa caribbeanica*, *Gephyrocapsa oceanica*, and of the short-range taxon *Reticulofenestra asanoi*. These occurrences, associated with the absence of Discoaster, *C. macintyrei*, and *Helicosphaera selli* suggest that the sediments pertain to the late Early Pleistocene part of Zone NN19 (~1.08–0.9 Ma).

At Section C, four distinct levels of the IMO1 have been studied for biostratigraphy. Samples from level #2 with Gephyrocapsa sp.3 suggest that sediments deposited during the late Early–Middle Pleistocene part of Zone NN19 (~1.02–0.61 Ma). Samples from the overlying levels #4 and #6 register a drop in abundance of calcareous nannofossils. The long-ranging taxa *Helicosphaera carteri* and *Coccolithus pelagicus* are present (although it is unclear if they result from reworking) in association with reworked nannofossils of earlier Neogene, Paleogene, and Cretaceous age.

5. Age model of sedimentation

Based on these data, we summarize the stratigraphic evolution of the study area as follows.

(I) The normal polarity interval found in the offshore Qm1 member of the Argille Azzurre below the angular unconformity at section A pertains to the Gauss Chron (C2An; 3.596–2.581 Ma) based on nannofossils of Late Pliocene Zone NN16. The Argille Azzurre beds were subsequently tectonically tilted and rotated.

(II) The normal polarity interval found in the shoreface Qm1 sands of the Argille Azzurre above the angular unconformity at section A

Table 1
Calcareous nannofossils from sections A and C. Occurrences: A = abundant; F = frequent; R = rare.

Section	Stratigraphic level	Age	nannofossil zone	*Braarudosphaera bigelowii*	*Florisphaera profunda*	*Gephyrocapsa* sp.3	*Reticulofenestra asanoi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa oceanica*	*Gephyrocapsa spp.*	*Gephyrocapsa spp. small*	*Hayaster perplexus*	*Helicosphaera carteri*	*Pseudoemiliania lacunosa*	*Rhabdosphaera clavigera*	*Syracosphaera pulchra*	*Calcidiscus leptoporus*	*Coccolithus pelagicus*	*Umbilicosphaera jafari*	*Umbilicosphaera sibogae*	*Umbellosphaera tenuis*	*Calcidiscus macintyrei*	*Discoaster asymmetricus*	*Discoaster brouweri*	*Discoaster pentaradiatus*	*Discoaster spp*	*Discoaster spp. (6 ray)*	*Discoaster surculus*	*Discoaster tamalis*	*Discoaster variabilis*	*Helicosphaera sellii*	Reworked Cretaceous	Reworked Paleogene	Reworked Neogene
C	lev.#6												R					R														R	R	F
	lev.#5												R					R														R	R	F
	lev.#2	Pleistocene	NN19			R	R	R	R	F			F	R	R	R	R	R	R	R	R											A	A	A
	lev.#1				R	R		R	R	F			F	R	R	R	R	R	R	R	R											A	A	A
A	1.35 m			R	R		R	R	R	F	R	R	F	R	R	R	R	R	R	R	R											A	A	A
	1.60 m						R	R	R	R	R		F	R		R	R	R		R	R											A	A	A
Angular unconformity																																		
A	1.90 m	Late Pliocene	NN16							R	R		F	R	R	R	R	R	R	R		R	R	R	R	R	R	R	R	R	R	A	A	A
	2.95 m									R	R		F	R	R	R	R	F	R	R		R	R	R	R	R	R	R		R	R	A	A	A
	4.40 m									R	F		F	R	R	R	R	F	R	R		R	R	R	R	R	R	R		R	R	A	A	A
	6.10 m									R	R		F	R	R	R	F	F	R	R		R	R	F	R	F	R	R	R	R	R	A	A	A
	7.65 m									R	R		F	R	R	R	R	F	R	R		R	R	R	R	R	R	R		R	R	A	A	A
	8.90 m									R	R		F	R	R	R	R	F	R	R		R	R	R	R	F	R	R	R	R	R	A	A	A

most likely pertains to the Jaramillo subchron (C1r.1n; 1.072–0.988 Ma) based on the short-range taxon *Reticulofenestra asanoi* (1.08–0.9 Ma) found together with nannofossils of Pleistocene Zone NN19. Member Qm1 shows no evidence of deformation or rotation of magnetic vectors and lies horizontally above the tilted Argille Azzurre. Hence, tectonic rotation ended in the study area sometime before the Jaramillo.

(III) The deposition of the swamp to shallow marine Qm2 member of the Argille Azzurre (core 239-S1) and of the overlying IMO1 and IMO2 (sections C and D, core 239-S1) occurred during a subsequent interval of reverse polarity. Nannofossils from IMO1 at section C pertain to Zone NN19 and include the short-range taxon *Gephyrocapsa* sp.3 (~1.02–0.61 Ma), constraining the reverse polarity to post-Jaramillo subchron C1r.1r (0.988–0.781 Ma).

(IV) Ill-defined normal polarity directions were found in IMO3 (section E), which suggests that a polarity reversal occurs at about the IMO2–IMO3 transition. Core 239-S1 shows a similar (reverse to normal) polarity reversal occurring at the same stratigraphic interval and shows that continental deposition (AEI and AES) continued during an interval of persistent normal polarity up to the Holocene at the core top. The polarity reversal at about the IMO2–IMO3 transition is therefore interpreted as the Matuyama–Brunhes boundary (0.781 Ma).

(V) The tool-bearing IMO1 member was therefore deposited during subchron C1r.1r, an interval between the end of the Jaramillo (0.988 Ma) and the beginning of the Brunhes (0.781 Ma). Our magnetochronology refines previous paleomagnetic analyses (Gagnepain et al., 1998; Peretto, 2006; Peretto et al., 1998) that suggested the presence in the tool-bearing section and elsewhere in the area of reverse polarity (*ergo* pre-Brunhes) magnetizations that were heavily masked by normal polarity overprints.

The chronostratigraphy can be further constrained by correlating sedimentary units above the angular unconformity with marine isotope stages (MIS) based on the benthic foraminifera $\delta^{18}O$ record (Shackleton, 1995) (Fig. 6). Shoreface Qm1 sands within the Jaramillo were likely deposited during the generally low sea levels of ~MIS 30–27 (~1.04–

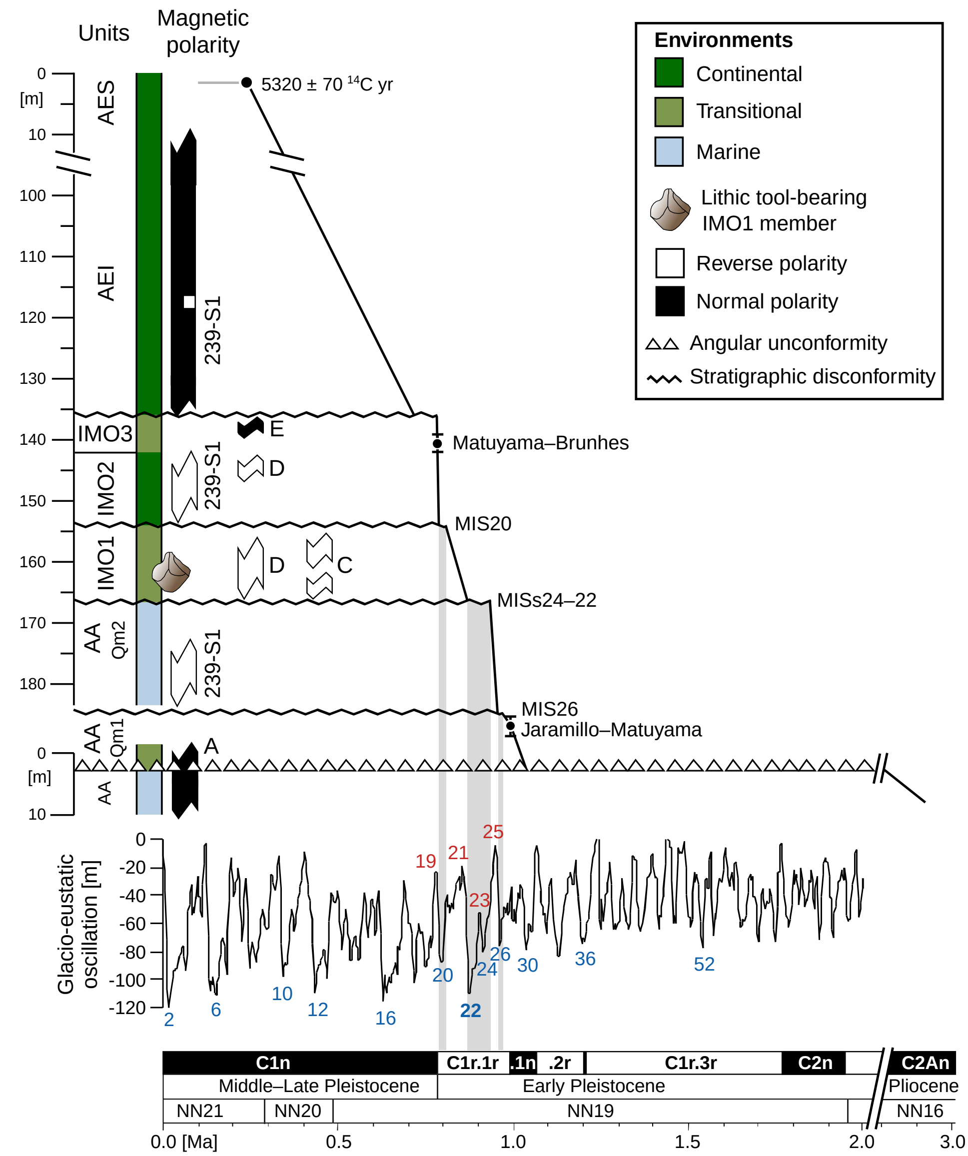

Fig. 6. Age model of sedimentation of the Pliocene–Pleistocene units investigated in this study constructed using core 239-S1 from the Po Plain subsurface and outcrop Sections A, C, D and E correlated to the time scale of Lourens et al. (2004) placed aside the $\delta^{18}O$ record of Shackleton (1995) scaled to the glacio-eustatic drop at the last glacial maximum time (Fairbanks, 1989). The Monte Poggiolo hominin site falls in the IMO1 member of the Imola Sands, dated to MIS 21 at ~0.85 Ma. A = Section A; C = Section C; D = section D; E = Section E; 239-S1 = Core 239-S1. Stratigraphic disconformities after Amorosi et al. (1998a, b).

0.99 Ma), whereas the Qm1–Qm2 disconformity (Amorosi et al., 1998a, b) may correspond to the MIS 26 low-stand (~0.96 Ma). The overlying transgressive Qm2 within C1r.1r may correspond to the MIS26–MIS25 transgression; Qm2 contains at the top the last fully marine sediments in the area that likely correspond to the pronounced high-stand of MIS 25 (~0.95 Ma). The Qm2–IMO1 disconformity (Amorosi et al., 1998a, b) would then correspond to the pronounced regression in the ~0.94–0.87 Ma interval across MIS 24 to MIS 22 separated by a subdued MIS 23 (Clark et al., 2006). IMO1 with lithic tools may then have been deposited during MIS 21 (~0.85 Ma), whereas the IMO1–IMO2 disconformity (Amorosi et al., 1998a, b) may correspond to the low-stand of MIS 20 (~0.8 Ma). The overlying transgressive IMO2–IMO3 may then broadly correspond to the MIS 20–MIS 19 transgression and MIS 19 high stand straddling the Matuyama–Brunhes boundary (Shackleton, 1995). Sedimentation during the ensuing part of the Brunhes became fully continental in response to overall uplift of the Apennines at rates of ~1 mm/yr (e.g., Picotti and Pazzaglia, 2008). Our interpretation differs from previous interpretations (Amorosi et al., 1998a, b) insofar as the MIS 24 to MIS 22 interval is here correlated to the regional Qm2–IMO1 disconformity rather than to the Qm1–Qm2 disconformity.

Published ESR dates obtained directly from the archeological levels (MP111 = 1.19 ± 0.14 Ma, MP115 = 1.13 ± 0.13 Ma, MP118 = 0.88 ± 0.13 Ma) (Gagnepain et al., 1998; Peretto et al., 1998) were used by Falguères (2003) to calculate a mean age of 1.06 ± 0.16 (1σ) Ma. The ESR mean age is about 20% older than our preferred age of the site (MIS 21, ~0.85 Ma) but would encompass it if a more representative 2σ error margin of ±0.3 Ma was applied, especially considering the various uncertainties that affect ESR dating (Ludwig and Renne, 2000).

6. Discussion

Our preferred MIS 21 age closely associates human presence at Monte Poggiolo to the late Early Pleistocene climate transition (Berger et al., 1993) that occurred within subchron C1r.1r and was characterized by protracted cooling from MIS 24 to MIS 22, separated by a subdued interglacial MIS 23 (Clark et al., 2006). Over this time interval (MIS 24 to MIS 22; ~0.94–0.87 Ma), enhanced aridification in North Africa and eastern Europe (Clark et al., 2006; deMenocal, 2004; Muttoni et al., 2010 and references therein) likely triggered migration pulses (possibly modulated by higher-frequency climatic variability) of mammals, including hominins, from these regions into southern European refugia (e.g., Azanza et al., 2000; Muttoni et al., 2010; Palombo and Valli, 2003). In this scenario, the Po Valley of northern Italy played a fundamental role in migrations because it was largely submerged even during low-stands for most of the Early Pleistocene and became exposed – or close to sea level – only since the pronounced regression that led to MIS 22 (Muttoni et al., 2010) (Fig. 7). This emergence may have opened new migration routes for large mammals (e.g., elephants) from the east into localities like Slivia near Trieste in northeastern Italy, which records, together with Ponte Galeria in central Italy, the first appearance of middle Galerian African and Asian immigrants (*Elephas antiquus* and *Mammuthus trogontherii* among others; Masini and Sala, 2007; Milli et al., 2004; Palombo and Ferretti, 2005). This major climate-driven biotic turnover marks a total rejuvenation of the fauna throughout Europe including the first appearance of *Homo* species (Azanza et al., 2000; Palombo and Valli, 2003).

Fellow human travelers most likely reached and spread across the Po Valley at this time, inhabiting Monte Poggiolo and correlative sites along the Apennine margin (Arzarello and Peretto, 2010) (Fig. 7) during MIS 21 at ~0.85 Ma and reaching sites as far west as Spain. Clear evidence of their presence before the Matuyama–Brunhes boundary has been found at Atapuerca (Carbonell et al., 2008; Parés et al., 2006; Pares and Perez-Gonzalez, 1999) and further constrained to during subchron C1r.1r at Vallparadís in conjunction with remains of the African immigrant *E. antiquus*, which first appeared throughout Spain at around 0.9 Ma (Van der Made and Mazo, 2001) in association with *Sus scrofa*, *Stephanorhinus hundsheimensis*, *Ursus deningeri*, *Canis mosbachensis*, and *Lynx sp.* (Martínez et al., 2010). This faunal assemblage first appeared at almost the same time in Italy in the middle Galerian Slivia and Ponte Galeria FUs (e.g., Masini and Sala, 2007) dated to and immediately after MIS 22 at ~0.87 Ma (Muttoni et al., 2010 and references therein).

We recognize that our hypothesis for earliest European habitation only toward the end of the Early Pleistocene (~0.85 Ma) is seemingly at odds with older ages quoted in the literature for some key hominin sites from southern Europe (discounting the recently redated Ceprano cranium site with a revised younger age of ~0.4 Ma; Muttoni et al., 2009). Several of these apparent violations or discrepancies were discussed by Muttoni et al. (2010) and we reprise and expand upon five of the most significant cases here.

I. The Lezignan site in southern France (Crochet et al., 2009) seems to have yielded lithic tools from a level located beneath a basalt layer dated by modern Ar/Ar techniques to 1.57 Ma, which would imply that humans were present in France before then and possibly hundreds of thousands of years earlier if the allegedly associated Senèze-type fauna is dated to ~2 Ma (Delson et al., 2006). However, from the rather cursory geological and stratigraphic description of the site (Crochet et al., 2009), it is difficult to discount the possibility that the lithic tools are not in place, for example, washed down 'after autumnal rains' from a notch in the basalt.

II. The Pont-de-Lavaud tool-bearing terrace in France yielded 10 ESR dates between 0.9 ± 0.15 Ma and 1.19 ± 0.2 Ma that provide an overall mean age of 1.1 ± 0.16 Ma at the 2σ level (Voinchet et al., 2010). This is reasonably close to our preferred time window (~0.94–0.87 Ma), especially bearing in mind that the reported ESR dates at Poggiolo had almost an identical mean age that was shown to be biased ~20% too old.

III. The Sima del Elefante (Atapuerca, Spain) tools and hominin remains were retrieved in an interval of reverse polarity below the Matuyama–Brunhes boundary (Carbonell et al., 2008; Parés et al., 2006) and are associated with cosmogenic burial dates of 1.22 ± 0.16 (1σ) Ma from the hominin level (TE9) and 1.13 ± 0.18 (1σ) Ma from a few meters below (TE7) at the base of the section (Carbonell et al., 2008). These low precision dates with 2σ uncertainties of more than ±0.3 Myr do not preclude that hominin occupation occurred within subchron C1r.1r, after the Jaramillo (which in fact was not found in the section) and before the Matuyama–Brunhes boundary, essentially in the originally proposed magnetostratigraphic context (Parés et al., 2006) and very similar to hominin level TD6 at nearby Gran Dolina (Pares and Perez-Gonzalez, 1999).

IV. Fuente Nueva-3 and Barranco León in the Orce basin of southern Spain yielded thus far hominin artifacts from levels of exclusive reverse polarity (Oms et al., 2000; Toro Moyano et al., in press). Oms et al. (2000), who provided most of the magnetostratigraphy of the sections, state that 'the presence of exclusively reverse magnetization throughout the stratigraphic sections, combined with the faunal assemblages, indicates a Matuyama age for the archeological sites (0.78–1.77 Ma) [...] the presence of *Microtus nivaloides* in Le Vallonet, in sediments with normal polarity ascribed to the Jaramillo subchron (0.99–1.07 Ma), a younger species than *Allophaiomys bourgondiae* in Fuente Nueva-3, might indicate that the stone tools at Fuente Nueva-3, within the reverse Matuyama Chron, are older than 1.07 Ma. This inference needs further investigation.' So it appears that the arvicolid *A. bourgondiae* (= *A. lavocati*) is holding much of the responsibility of the current pre-Jaramillo numerical age estimates of the sites (1.4–1.2 Ma; Toro Moyano et al., in press). However, *Microtus* (*Allophaiomys*) *burgondiae* is present in Italy

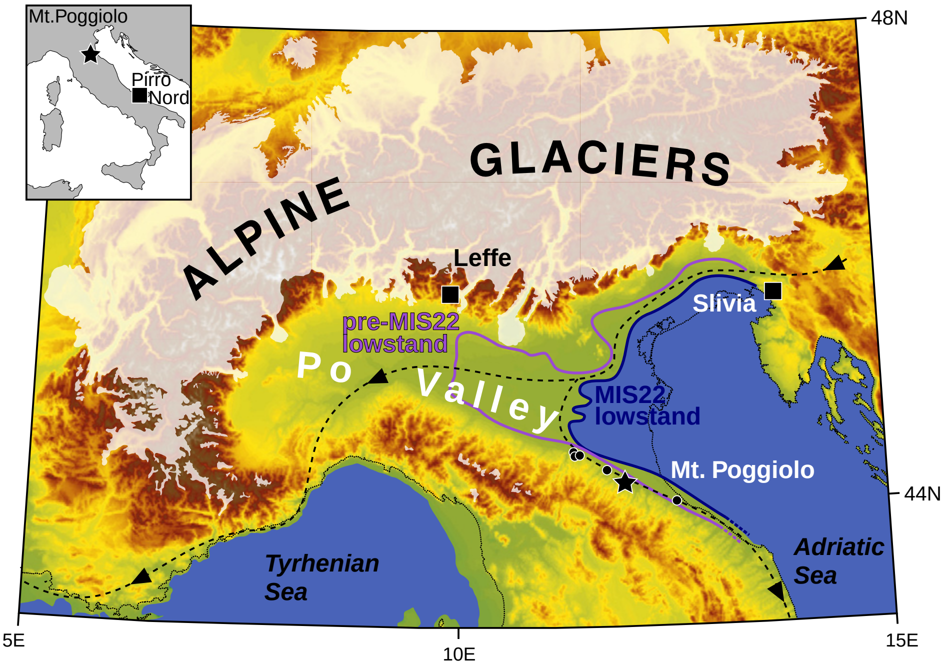

Fig. 7. Paleogeographic map of northern Italy at MIS 22 time from Muttoni et al. (2010) with indication of the immediately younger (MIS 21 at ~0.85 Ma) Monte Poggiolo site (star) and other potentially coeval tool-bearing sites from the Apennine margin (circles) (Arzarello and Peretto, 2010). The locations of other key sites discussed in the text (Leffe, Slivia, Pirro Nord) are also displayed (squares). As a consequence of the onset of high-energy sedimentation in the Southern Alps-Po Valley caused by the MIS 22 low-stand, large stretches of the Po Valley became exposed for the first time, thus potentially opening new migration pathways (blue line = MIS 22 coastline (Ghielmi et al., 2010); purple line = nominal pre-MIS 22 coastline (Ghielmi et al., 2010); black dashed line = potential migration pathway, Muttoni et al., 2010)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

in the Colle Curti Faunal Unit (FU) (Masini and Sala, 2007), which at Leffe ranges from within the Jaramillo at ~1 Ma up to MIS 22 at ~0.87 Ma (Muttoni et al., 2007; 2010 and references therein), questioning our ability to finely resolve or correlate time in the continental domain using solely mammal biostratigraphy.

V. Lastly, the tool-bearing karst fissure fills of Pirro Nord in southern Italy yielded magnetic component directions of only reverse polarity (Pavia et al., in press) indicating a pre-Brunhes (>0.781 Ma) age. The fissure sediments yielded a faunal association (Pavia et al., in press) with elements typical (but not exclusive) of the Pirro Faunal Unit (FU; e.g., *Bison degiulii*, *Ursus etruscus*, *Megantereon withei*) dated to 1.6–1.3 Ma (Arzarello et al., in press; Arzarello and Peretto, 2010) by reference to Italian mammal biochronologies (e.g., Gliozzi et al., 1997; Masini and Sala, 2007). However, mammals at Pirro Nord also include *Premegaceros obscurus* and *Acinonyx pardinensis* that, according to the aforementioned biochronologies (e.g., Masini and Sala, 2007), should pertain exclusively to FUs entirely older than the Pirro FU, as well as *S. hundsheimensis*, *C. mosbachensis*, and *Homotherium latidens* that should first appear in Italy after the Pirro FU in the middle Galerian Slivia and Ponte Galeria FUs (Masini and Sala, 2007) dated to and immediately after MIS 22 at ~0.87 Ma (Muttoni et al., 2010 and references therein). This may suggest complex and diachronous episodes of karst fillings or extensive reworking as testified also by the nearby presence of deposits with Miocene taxa pertaining to a preceding karst cycle (Pavia et al., in press). Moreover, none of the mammal localities that collectively define the Pirro FU, including the type locality of Pirro Nord, is provided with direct numerical age estimates, whereas paleomagnetic reverse polarity indicates only a generic Matuyama age (Pavia et al., in press). The inferred age (1.6–1.3 Ma) is primarily based on the inference that the Pirro FU should be younger than the Olivola and Tasso FUs from central Italy that are calibrated to around the Olduvai–Matuyama boundary (1.778 Ma) and older than the Colle Curti FU also from central Italy, calibrated to around the Matuyama–Jaramillo boundary (1.072 Ma) (see Muttoni et al., 2010 for details). However, mammals found in stratigraphic continuity at Leffe in northern Italy (Fig. 7) show that the Pirro–Colle Curti faunal transition occurs within the Jaramillo (Muttoni et al., 2007). Hence, the Pirro Nord industry may be as young as ~1 Ma, or even younger if the middle Galerian faunal turnover was not synchronous across a physiographically complex Italian peninsula.

7. Conclusions

Correlation of the Monte Poggiolo hominin site to MIS 21 is entirely compatible with the post-Jaramillo follow-the-herd hypothesis of Muttoni et al. (2010) that the initial hominin migration to southern Europe (Italy, France, and Spain) occurred in conjunction with African and Asian large mammal fellow travelers (e.g., African *E. antiquus*) in response to profound environmental changes triggered by the late Early Pleistocene climate transition at ~0.85 Ma. Falsifying our hypothesis, which makes the obvious but powerful prediction that hominin sites in Europe should be found to be no older than ~0.85 Ma, would require the acquisition of new high-resolution numerical age estimates or expanded and continuous normal-reverse-normal (Brunhes–Matuyama–Jaramillo) magnetic polarity sequences from stratigraphic sections with undisputable in situ tools or hominin remains. Such a stringent test has effectively been recently reported at the Vallparadís site near Barcelona, which has been dated magnetostratigraphically to subchron C1r.1r and yielded remains of mammals including *E. antiquus* (some of which bearing proof of human exploitation) (Martínez et al., 2010). We note that *E. antiquus* first appears in Italy in the Slivia and Ponte Galeria FUs dated to and immediately after MIS 22 at ~0.87 Ma

(Muttoni et al., 2010 and references therein), in excellent agreement with the Vallparadís site. Elsewhere and more generally, mammal biostratigraphy alone presently has inadequate age calibration or resolution in the Early Pleistocene to distinguish a pre-Jaramillo association from a post-Jaramillo association. In this respect, we regard sites like Fuente Nueva-3 and Barranco León in the Orce basin of southern Spain with their relatively thick continental stratigraphy (that yielded thus far exclusively reverse polarity: Oms et al., 2000; Toro Moyano et al., in press) as promising places to establish a more diagnostic polarity stratigraphy in order to place the hominin artifact levels (presently claimed to be dated at 1.4–1.2 Ma based on mammal biostratigraphy; Toro Moyano et al., in press) relative to the Jaramillo and therefore verify (or refute) the validity of our hypothesis that the earliest hominin presence in southern Europe occurred after the Jaramillo.

Finally, we are well aware that our hypothesis for earliest European habitation only toward the end of the Early Pleistocene (~0.85 Ma) expands the enigma of the chronological gap with the early Early Pleistocene (~1.7 Ma) attribution of the well-studied Dmanisi site in southwest Asia (Gabunia et al., 2000).

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