Magnetostratigraphy Of The Pleistocene Arda River Section (Northern Italy)

Monesi Edoardo*[1], Muttoni Giovanni*, Scardia Giancarlo **

*= Dipartimento di Scienze della Terra, Università di Milano, via Mangiagalli 34, I-20133 Milano, Italy.
1= edoardo.monesi@unimi.it
2= giovanni.muttoni1@unimi.it
**= Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista, Rio Claro, SP 13506-900, Brazil. scardia@rc.unesp.br

Introduction

The Arda River section is located in northern Italy near the town of Castell'Arquato at the margin of the northern Appennines facing the Po plain. It starts at the bridge immediately to the East of the town of Castell'Arquato and extends northward along the banks of the Arda River for 300 stratigraphic meters exposing marine to continental deposits in which some faunistic remaing have been found.

Aside from a few paleoecological studies (Dominici, 2001; 2004), the Arda section has not been studied in detail, especially with regard to the chronostratigraphy. In this study, we generate an age model of sedimentation for the Arda section by integrating magnetostratigraphy with nannofossil data for comparison with other sections from the literature that document the marine-continental transition in the greater Po basin (Muttoni et al., 2003; 2011; Scardia et al., 2006; 2009; 2012; Gunderson et al., 2012; 2014; Pinti et al., 2001). This transition, which occurred during the late Early Pleistocene at the onset of enhanced glacial/interglacial activity, is thought to mark the time when Europe became stably populated by a renewed mammal fauna (Galerian) characterized by far-traveled immigrants, because, possibly for the first time in the Pleistocene, vast and exploitable new ecosystems were generated along a newly formed continental Po-Danube migration gateway, as recently described in Muttoni et al. (2014; 2015) (Figure 7).

Paleomagnetic data and interpretation

185 cylindrical 10 cm³ cores specimens were subjected to thermal demagnetization, magnetic properties (Fig 2) and the NRM was measured after each demagnetization step in a shielded room. Standard least-square analysis (Kirschvink, 1980) was used to calculate magnetic component directions from vector end-point demagnetization diagrams, and standard Fisher statistics was used to analyze the mean component directions

We interpret the magnetic polarity stratigraphy by means of correlation to the Pleistocene geomagnetic polarity time scale of Gradstein et al. (2012). Starting from the top, the uppermost normal polarity interval is interpreted as a partial record of the (early) Brunhes Chron with base set at 0.781 Ma, in agreement with previous studies from the Po Plain indicating continental sedimentation during the Brunhes Chron (e.g., Muttoni et al., 2003; Scardia et al., 2012). Proceeding downsection, the second normal polarity interval from about 240 m to 223 m is interpreted as the Jaramillo Subchron (0.99–1.07 Ma), the third normal polarity interval from about 113 m to 92 m has been interpreted as the Olduvai Chron (1.77–1.95 Ma), whereas the intervening reverse polarity intervals have been interpreted as the Matuyama Chron (Fig. 2I). A lowermost normal polarity interval recorded from 23 m to 12 m has been conservatively excluded from magnetostratigraphic interpretation because it straddles a stratigraphic interval with faults (Fig. 2A) associated with high susceptibility and NRM intensity values (Fig. 2C, D).

This magnetostratigraphic interpretation is augmented with nannofossil data from three samples collected in the uppermost transitional-marine level at 275 m (Fig. 2A). *Helicosphaera sellii*, small *Gerphyrocapsa* spp., and *Reticulofenestra asanoi* whose finding indicates sedimentation of the uppermost transitional-marine level at 275 m during a generic time interval comprised between 1.14 and 0.91 Ma (Raffi, 2002; Rio et al. 1990), in substantial agreement with the magnetostratigraphic interpretation.

Age Model

We created an age versus depth plot for the Arda River section by using magnetostratigraphy and correlation with the $\delta^{18}O$ record of Shackleton (1995), which is substantially consistent with the more recent record of Lisiecki and Raymo (2005) (Fig. 5). Five magnetochronologic tie points have been used: the Matuyama–Brunhes boundary, top and base Jaramillo, top and base Olduvai. The last occurrence of *R. asanoi* (0.91 Ma; Raffi, 2002) provides an upper age limit for the transitional-marine level at 275 m, which is considered to have deposited during the MIS 25 highstand (~0.95 Ma) (Fig. 5).

According to the above, the proposed age model implies that:

1) The long-term sediment accumulation rate between the base of the Olduvai and the base of the Jaramillo is of ~15 cm/ky (=150 m/Ma); this represents the average between faster turbidite and slower hemipelagic sedimentation typical of this part of the section. The base of the section should be older than 1.95 Ma (= base Olduvai) and younger than the top of the Gauss (2.58 Ma), which was not found in the studied section but recorded in the nearby and older Stirone section (Mary et al., 1993; Channell et al., 1994).

2) The FO of *Artica islandica* at 103 m within the Olduvai has an interpolated age of 1.85 Ma in agreement with a radiometric (He/Th) age of 1.81 ± 0.1 Ma on corals from a level immediately above the FO of A. islandica in the Santerno section (northern Appennines) as reported by Kukla et al. (1979) (Fig. 5).

3) The transition from marine to fully continental conditions, represented by the regressive sequence starting with littoral sands at 200 m and evolving into the first fluvial conglomerates at 237 m, may correspond to the MIS 30 regression and lowstand at ~1.04 Ma within the Jaramillo.

4) The mammal bed with remains of *Sus strozzii*, *Stephanorhinus hundsheimensis*, *Ursus rodei*, *Pseudodoma* cf. *farnetensis*, *Bison* sp., *Hippopotamus* sp., and *Praemegaceros* sp. is approximately dated to the MIS 27–29 interval centered at ~0.99 Ma (Fig. 5).

5) The uppermost fluvial conglomerate at 275 m, immediately above the last transitional-marine ingression with R. asanoi attributed to MIS 25 (~0.95 Ma), presumably deposited during the profound glacioeustatic lowstand culminating with MIS 22 at ~0.9 Ma, which marks the first most prominent continental glaciation of the Pleistocene (Muttoni et al., 2003) (Fig. 5).

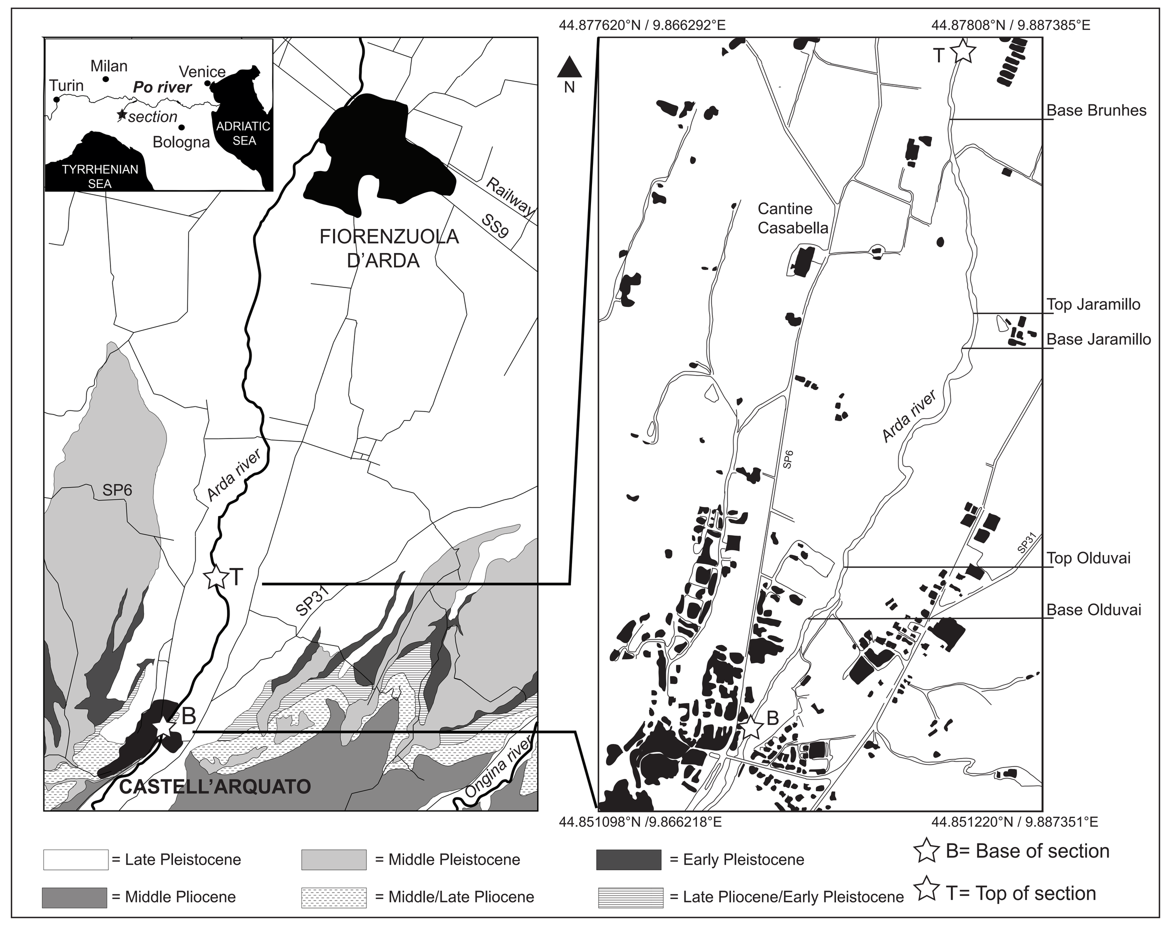

Figure 1: Geological map of the Castell'Arquato village area in the northern Apennines with indication of the Arda River section (left panel); detailed topographic map of the sampled section with location of the main magnetic polarity reversals (right panel).

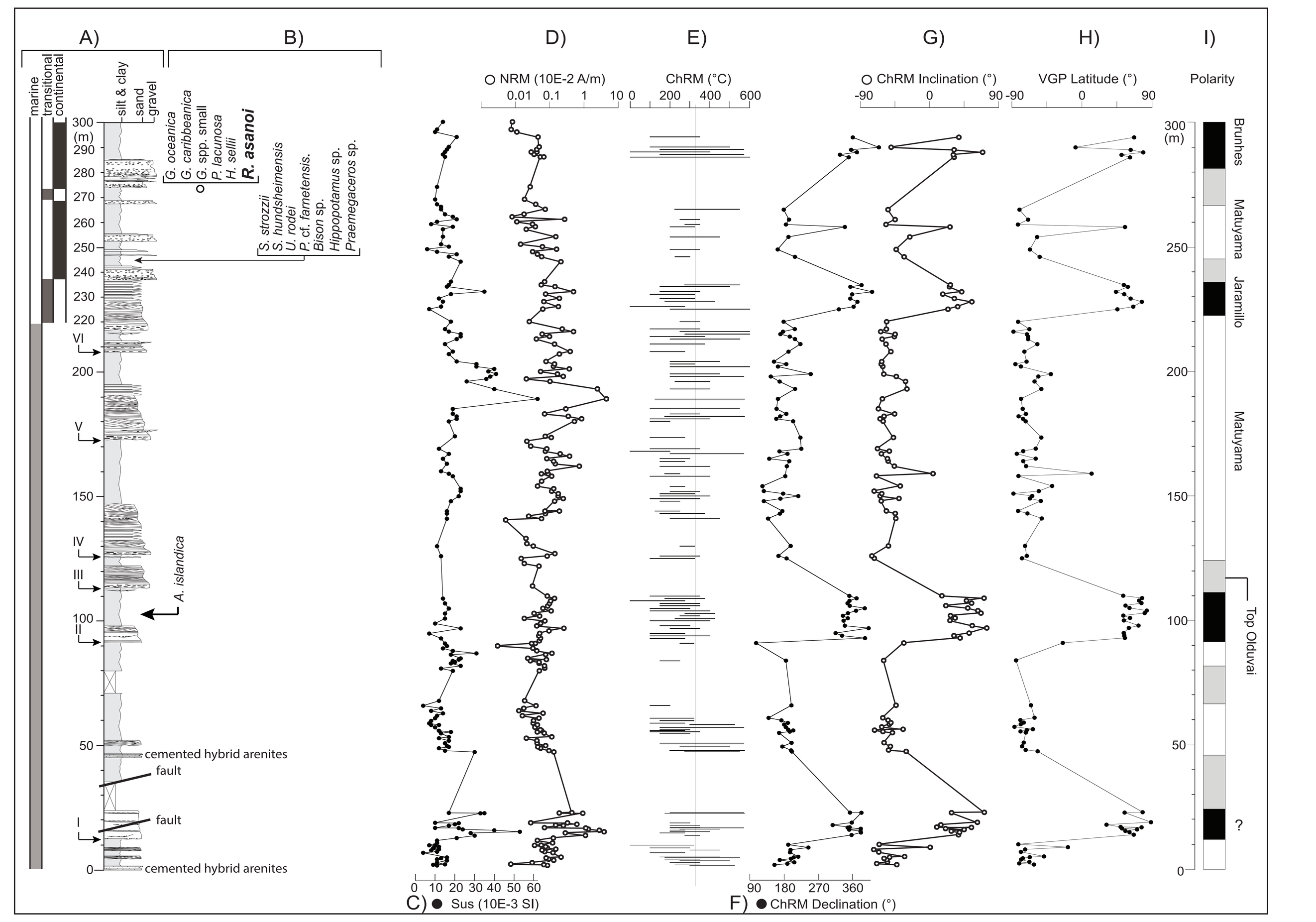

Figure 2: Stratigraphy and paleomagnetic data. A: Stratigraphic sequence; B: key fossil occurrences; C: Magnetic Susceptibility; D: NRM; E: Demagnetization temperature window of the characteristic magnetic component (ChRM); F: Declination of the ChRM; G: Inclination of the ChRM; H: Latitude of the Virtual Geomagnetic Pole of the ChRM; I: Magnetic Polarity (black is normal, white is reverse).

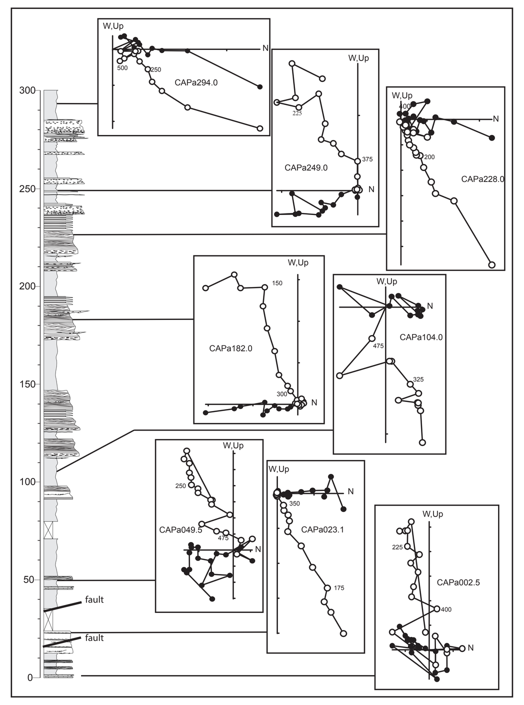

Figure 3: Vector end-point demagnetization diagrams of representative samples plotted aside the Arda stratigraphic sequence. Full symbols are projections on the horizontal plane and open symbols in the vertical plane. Demagnetization temperatures are expressed in °C.

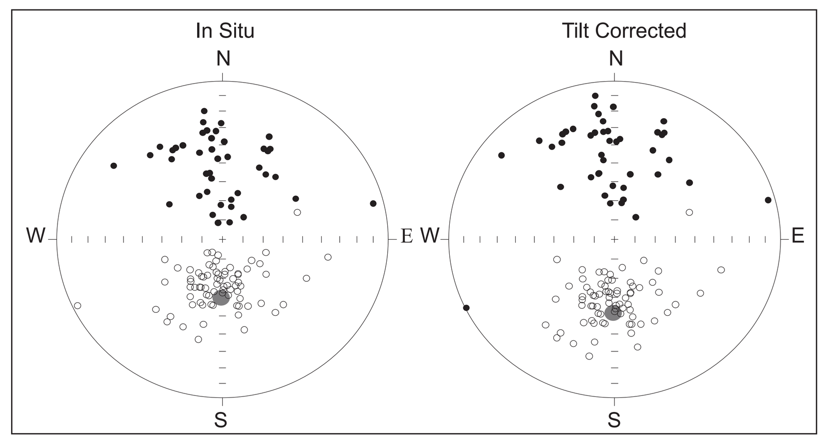

Figure 4: Equal area projection of the characteristic (ChRM) component vectors in in situ and tilt corrected coordinates. Full symbols represent down-pointing vectors (normal polarity), open symbols represent up-pointing vectors (reverse polarity).

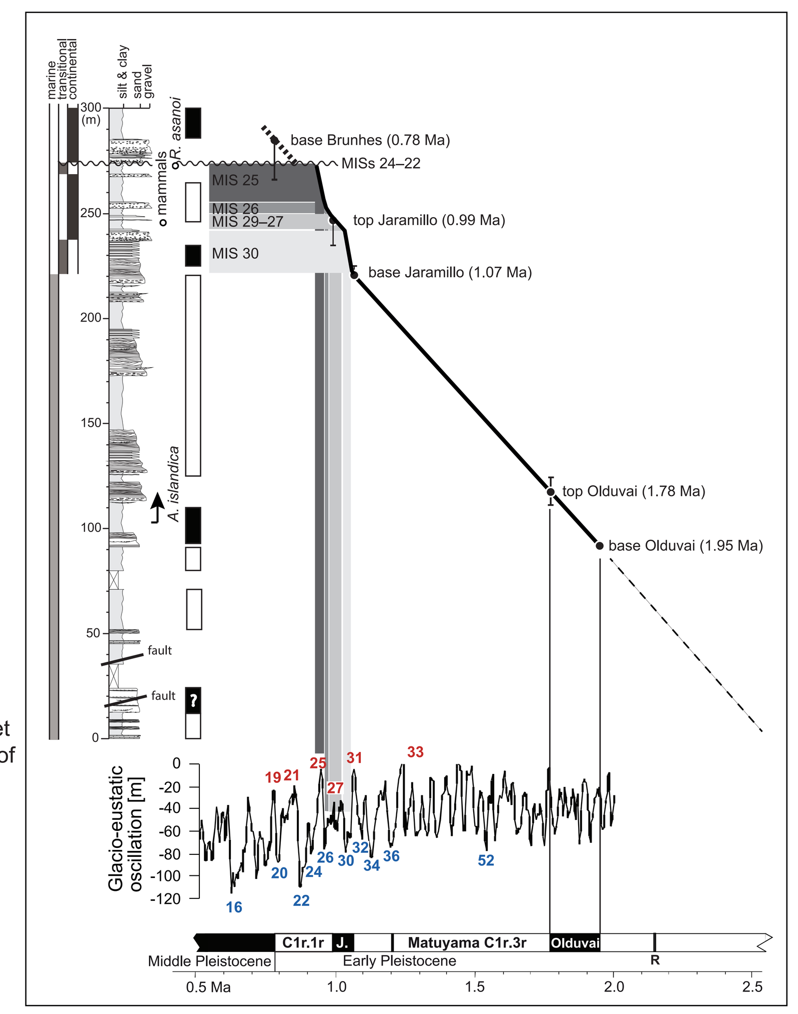

Figure 5: Age model of sedimentation of the Arda section correlated to the geomagnetic polarity time scale (GPTS) of Gradstein et al. (2012) placed aside the δ18O record of Shackleton (1995) scaled to the glacio-eustatic drop at the last glacial maximum time (Fairbanks, 1989).

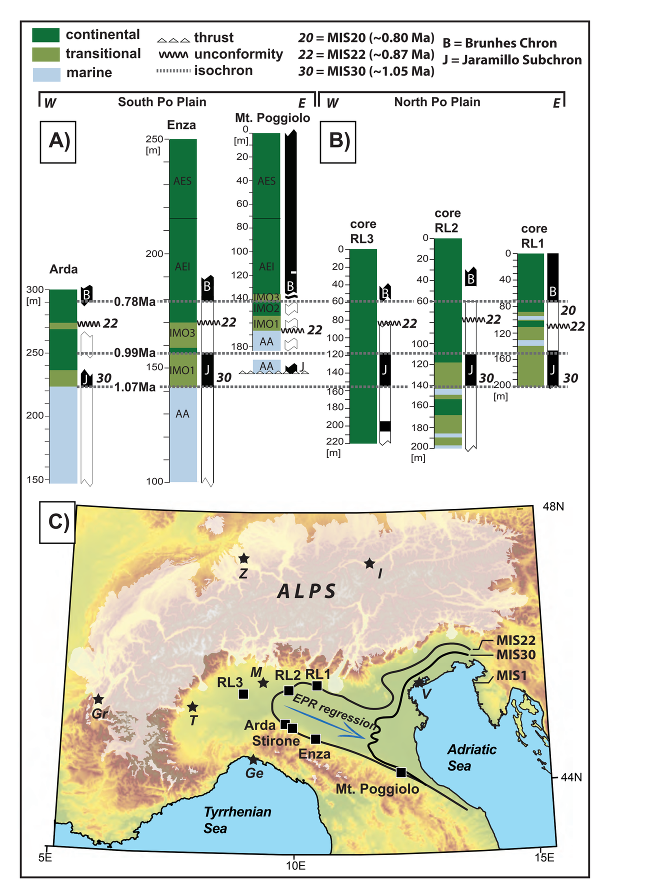

Figure 6: (A) Correlation of the Arda section of this study with the Enza (Gunderson et al., 2014) and Monte Poggiolo (Muttoni et al. (2011) sections from the northern Apennines margin (= south Po basin). IMO 1= Imola Sands 1; IMO 2= Imola sands 2; IMO 3= Imola sands 3; AEI= Lower Emilia Romagna Synthem. (B) Correlation of deep cores (RL1, RL2, and RL3) from the northern part of the Po basin (Scardia et al., 2006; 2012). (C) Paleogeography of the Po basin at the first major regression of the coastline in consequence of the MIS 22 lowstand during the late Early Pleistocene climate Revolution (EPR).

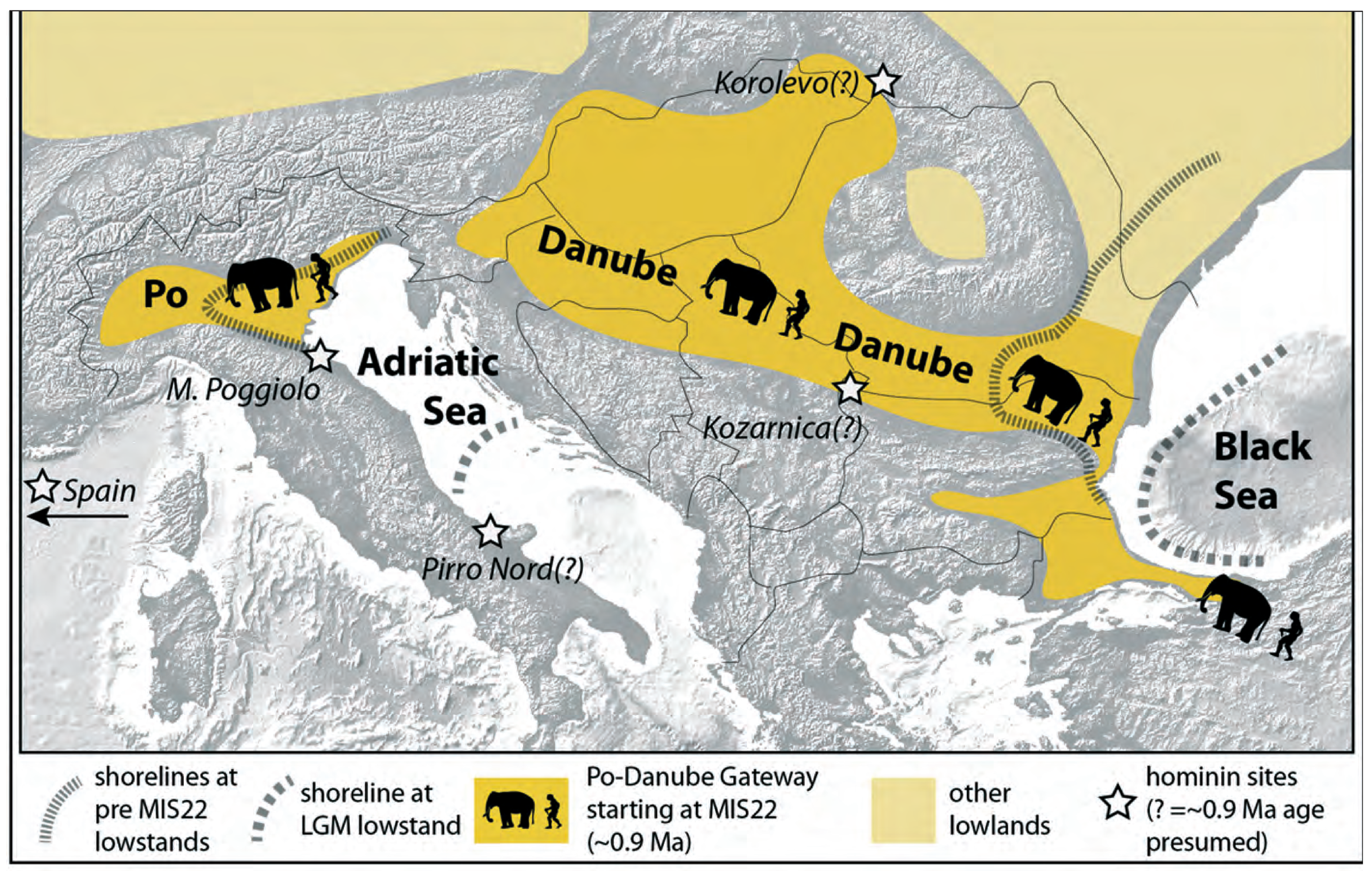

Figure 7 - Paleogeographic scenario of the migration-with-herds hypotesis of earliest expansion of hominins and large mammals from the Gates of Europe into Europe across the Danube-Po gateway during the EPR (Muttoni et al. 2014).

Conclusions

We used data from the Arda River section in conjunction with data from the nearby coeval Stirone (Gunderson et al., 2013; 2014) and Enza (Gunderson et al., 2012) rivers sections, as well as data from the Monte Poggiolo section (Muttoni et al., 2011), to reconstruct the timing of the marine-continental transition in this part of the greater Po basin (Fig. 6A). While the critical stratigraphic interval comprised between the Olduvai and the Jaramillo is substantially reduced in the Stirone river section (only 20 m-thick) probably due to the syn-depositional growth of the Salsomaggiore thrust between 1.8 and 1.0 Ma (Gunderson et al., 2012; 2013), the correlations of the more complete Arda, Enza, and Monte Poggiolo sections allow to estimate that the marine-continental transition was in these sections slightly diachronic: while marine conditions persisted at Monte Poggiolo in the early part of the post-Jaramillo Matuyama, in the western part at Arda and Enza, littoral sediments started to deposit during MIS 30 in the Jaramillo (Fig. 6A). Persistent continental to transitional conditions were first established along the ~230 km-long studied transect between Arda and Monte Poggiolo only at the MIS 22 low-stand and the ensuing MIS 22/MIS 21 sea level rise and MIS 21 high-stand at ~0.85 Ma (Fig. 6A).

A similar situation has been observed in several deep cores across the northern part of the Po basin (Scardia et al., 2006; 2012). While the western cores displayed continental sedimentation since the pre-Jaramillo Pleistocene (e.g., RL3 Fig. 6B), it is only since MISs 22–20 that continental sedimentation was established in the more eastern cores (e.g., RL2, RL1). It appears therefore that a first major jump eastward of the coastline was attained along the studied portion of the Po basin in consequence of the MIS 22 lowstand (Fig. 6C). MIS 22 represents the first major northern hemisphere continental glaciation of the Pleistocene (Shackleton et al., 1976; Berger et al., 1993; Shackleton, 1995; Head et al., 2005; Muttoni et al., 2003; Scardia et al., 2006; 2012) occurring during the so-called late Early Pleistocene climate Revolution (EPR), a term that substitutes for the often-used term Middle Pleistocene revolution (e.g., Berger et al., 1993) in deference to modern time-scales in which the base of the Middle Pleistocene is placed at the Brunhes–Matuyama boundary (Head et al., 2005). The EPR regression centered at MIS 22 had profound implication for the full opening of the Galerian migration pathway, as described hereafter.

The mammal association recovered at Arda in levels attributed to MIS 27–29 at ~0.99 Ma is characterized by mixed Villafranchian and Early Galerian taxa. The Villafranchian *Sus strozzii* is commonly regarded to have been present in the Italian peninsula up to the Early Pleistocene pre-Jaramillo (>1.07 Ma) Farneta faunal unit (Gliozzi et al., 1997; Masini et al., 2007), while our data indicates its presence up to ~0.99 Ma at the top of the Jaramillo. The occurrence of *Bison* sp. more evolved than previous *Eobison* and *Ursus rodei* represents the entrance in the Italian peninsula of new taxa. *U. rodei* may have immigrated from central Europe, where it was found at Untermassfeld (Germany) in levels attributed to MIS 31 at the base of the Jaramillo (Kahlke et al., 2011). It is however only when fully continental conditions were established in the Po basin during the EPR regression that the Galerian revolution could take place in its full extent with a total rejuvenation of the fauna. At that time is recorded the entrance in Europe of far-traveled guests: megaherbivores requiring large dietary grass supply such as the straight-tusked elephant (*Elephas antiquus*), the steppe mammoth (*Mammuthus trogontherii*), the red deer (*Cervus elaphus acoronatus*) are among the most representative species of the far-traveled Galerian elements that entered the Italian peninsula and Europe in general during the EPR since around 0.9 Ma (Muttoni et al., 2014; 2015 and references therein), and hence shortly after the Arda fauna with its mixed Villafranchian and Early Galerian elements.

Muttoni et al. (2014) speculated that large mammals, and possibly hominins with them, may have migrated to Europe starting at around 0.9 Ma because the EPR generated for the first time in the Pleistocene vast and exploitable ecosystems for African and Asian mammals especially along a conjunct Po-Danube Gateway connecting southern Europe with the Balkans (Figure 7). These new environments were characterized by stable continental lowlands with open grassland vegetation and reduced woody cover during the onset of glacial/interglacial transitions (starting with MIS 22/MIS 21). Our data from the Arda section confirms that the progressive infill of the Po basin driving the transition from marine to fully continental environments was established only during the EPR since MIS 22 in the same magnetochronologic window that is believed to include also some of the best-dated sites with evidence of the first entrance in Europe of far-travelled megaherbivore immigrants (e.g., Muttoni et al., 2015). This is also the same magnetochronologic window of the earliest peopling of Europe (Muttoni et al., 2010; 2011; 2014), albeit we acknowledge that the debate concerning the age of the first stable peopling of Europe, whether before – and therefore detached from – the ecologic and climatic turnover of the EPR (e.g., Carbonell et al., 2008; Toro-Moyano et al., 2013), or as its direct consequence (Muttoni et al., 2013; 2014; 2015) remains a matter of debate.

Bibliography

Berger WH, Blickert T, Schmidt H, Wefer G.1993. Quaternary oxygen isotope record of pelagic foraminifers: Site 806, Ontong Java Plateau. Proceedings ODP: Scientific Results 130: 381-395.
Channell JET, Poli MS, Rio D, Sprovieri R, Villa G. 1994. Magnetic stratigraphy and biostratigraphy of Pliocene “Argille Azzurre” (Northern Appennines, Italy). Palaeogeography, Palaeoclimatology, Palaeoecology 110 : 83-102.
Dominici S. 2001. Taphonomy and Paleoecology of shallow marine macrofossil assemblages in a collisional setting (Late Pliocene-Early Pleistocene, Western Emilia, Italy). Palaios 16 : 336-353.
Dominici S. 2004. Quantitative taphonomy in sandstones from an ancient fan delta sysemt (Lower Pleistocene, Western Emilia, Italy). Palaios 19 : 193-205.
Fairbanks RG. 1989. A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Nature 342 : 637-642.
Gliozzi E, Abbazzi L, Argenti P, Azzaroli A, Caloi L, Capasso Barbato L, Di Stefano G, Esu D, Ficcarelli G, Girotti O, Kotsakis T, Masini F, Mazza P, Mezzabotta C, Palombo MR, Petronio C, Rook L, Sala B, Sardella R, Zanalda E, Torre D. 1997. Biochronology of selected mammals, molluscs and ostracods from the middle Pliocene to the late Pleistocene in Italy; the state of art. Rivista Italiana di Paleontologia e Stratigrafia 103, 3 : 369-387.
Gradstein FM. 2012. Improving the geological time scale. Abstract with Programs Geological Society of America 44, 7 : 329.
Gunderson K, Kodoma KP, Anastasio DJ, Pazzaglia FJ. 2012. Rock-magnetic cyclostratigraphy for the Late Pliocene-Early Pleistocene Stirone section, Northern Appennine mountain front, Italy. Geological Society of London, Special Publications 373 : 1-16.
Gunderson K, Anastasio DJ, Pazzaglia FJ, Picotti V. 2013. Falut slip rate variability on 104-105 timescales for the Salsomaggiore blind thrust fault, Northern Appennines, Italy. Tectonophysisc 608 : 356-365.
Gunderson K, Pazzaglia FJ, Picotti V, Anastasio DA, Kodama KP, Rittenour T, Frankel KF, Ponza A, Berti C, Negri A, Sabbatini A. 2014. Unraveling tectonic and climatic controls on synorogenic growth strata (Northern Appennines, Italy). Geological Society of America Bulletin 126, 3/4 : 532-552.
Head MJ, Gibbard PL. 2005. Early–Middle Pleistocene transitions: an overview and recommendation for the defining boundary. In Early–Middle Pleistocene Transitions: The Land–Ocean Evidence , Head MJ, Gibbard PL (eds.). Special Publication 247. Geological Society: London; 1–18.
Kahlke R-D, García N, Kostopoulos DS, Lacombat F, Lister AM, Mazza PP, Spassov N, Titov VV. 2011. Western Palaearctic palaeoenvironmental conditions during the Early and early Middle Pleistocene inferred from large mammal communities, and implications for hominin dispersal in Europe. Quaternary Science Reviews 30, 11 : 1368-1395.
Kirschvink JL. 1980. The least square line and plane and the analysis of paleomagnetic data. Royal Astronomical Society Geophysical Journal 62 : 699-718.
Kukla G, Collins BP, Blender ML. 1979. Radiometric age of the Arctica islandica boundary in Italy, 2 M.Y. . Annales géologiques des Pays Helléniques, hors séries 2 : 699-709.
Mary C, Iaccarino S, Courtillot V, Besse J, Aissaoui DM. 1993. Magnetostratigraphy of Pliocene sediments from the Stirone River (Po Valley). Geophysical Journal International 112 : 359-380.
Masini F, Sala B. 2007. Large- and small-mammal distribution patterns and chronostratigraphic boundaries from the Late Pliocene to the Middle Pleistocene of the Italian Peninsula. Quaternary International 160, 1 : 3-56.
Muttoni G, Carcano C, Garzanti E, Ghielmi M, Piccin A, Pini R, Rogledi S, Sciunnach D. 2003. Onset of major Pleistocene Glaciations in the Alps. Geology 31 : 989-992.
Muttoni G, Ravazzi C, Breda M, Pini R, Laj C, Kissel C, Mazaud A, Garzanti E. 2007. Magnetostratigraphic dating of an intensification of a glacial activity in the southern Italian Alps during Marine Isotope Stage 22. Quaternary Research 67 : 161-173.
Muttoni, G; Scardia, G; Kent, D.V. 2010. Human migration into Europe during the Late Early Pleistocene climate transition. Palaeogeography, Palaeoclimatology, Palaeoecology, 296, 79-93.
Muttoni G, Scardia G, Kent DV, Morsiani E, Tremolada F, Cremaschi M, Peretto C. 2011. First dated human occupation of Italy at 0.85 Ma during the Late Early Pleistocene climate transition. Earth and Planetary Science Letters 307 : 241-252.
Muttoni G, Kent DV, Scardia G, Monesi E. 2014 Migration of hominins with megaherbivores into Europe via the Danube-Po gateway in the late Matuyama climate revolution. Rivista Italiana di Paleontologia e Stratigrafia 120, 3 : 351-365.
Muttoni G, Scardia G, Dimitrijević V, Kent DV, Monesi E, Mrdjic N, Korać M. 2015. Age of Mammthus trogontherii from Kostolac, Serbia, and the entry of megaherbivores into Europe during Late Matuyama climate revolution. Quaternary Research (in press).
Pinti D, Quidelleur X, Lahitte P, Aznar C, Chiesa S, Gillot PY. 2001. K-Ar dating of an Early Middle Pleistocene distal tephra in the interglacial varved succession of Pianico - Sellere (southern Alps, Italy). Earth and Planetary Science Letters 188 : 1-7.
Raffi I. 2002. Revision of the early-middle Pleistocene calcareous nannofossil biochronology (1.75-0.85 Ma). Marine Micropaleontology 45 : 25–55.
Rio D, Raffi I, Villa G. 1990. Pliocene-Pleistocene calcareous nannofossil distribution patterns in the western Mediterranean. In Proceedings of the Ocean Drilling Program Scientific Results 107, Kastens KA, Mascle J, Aurux C, Bonatti E, Broglia C, Channell JET, Curz, P, Emeis K-C, Glacon G, Hasewaga S, Hieke W, McCoy FW, McKenzie JA, Mascle G, Mandelson J, Mueller C, Rehault J-P, Robertson AHF, Sartori R, Sprovieri R, Torii M, Stewart NJ (eds). Ocean Drilling Program, Texas A&M University, College Station, Texas : 513-533.
Sala B. 1986. Bison schoetensacki Freud. from Isernia la Pineta (early Mid-Pleistocene - Italy) and revision of the European species of bison. Palaeontographia Italica 74 : 113-170.
Scardia G, Muttoni G, Sciunnach D. 2006. Subsurface magnetostratigraphy of Pleistocene sediments from the Po Plain (Italy): constraints on rates of sedimentation and rock uplift. Geological Society of America Bulletin 118, 11/12 : 1299-1312.
Scardia G, Muttoni G. 2009. Paleomagnetic investigations on the Pleistocene lacustrine sequence of Pianico - Sellere (northern Italy). Quaternary International 204 : 44-53.
Scardia G, Donegana M, Muttoni G, Ravazzi C, Vezzoli G. 2010. Late Matuyama climate forcing on sedimentation at the margin of the southern Alps (Italy). Quaternary Science Reviews 29 : 832-846.
Scardia G, De Franco R, Muttoni G, Rogledi S, Caielli G, Carcano C, Sciunnach D, Piccin A. 2012. Stratigraphic evidence of a Middle Pleistocene climate-driven flexural uplift in the Alps. Tectonics 31, 6 : 1-18.
Shackleton NJ, Opdyke ND. 1976. Oxigen-isotope and paleomagnetic stratigrapfy of Pacific Core V28-239, late Pliocene to latest Pleistocene. Memoir Geological Society of America 145 : 449-464.
Shackleton NJ. 1995. New data on the evlution of Pliocene climate variability. In Paleoclimate and Evolution, with Emphasis on Human Origins, Vrba E, Denton GH, Partridge TC, Burckle LH (eds). Yale University Press: New Haven; 242-248.
Zijderveld JDA. 1967. A.C. demagnetization of rocks: analysis of results, In Methods in Palaeomagnetism, Collinson DW, Creek KM, Runcorn SK (eds). Elsevier, Amsterdam; 254-286.