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CALIBRATION OF THE UPPER VALDARNO BASIN TO THE PLIO-PLEISTOCENE FOR CORRELATING THE APENNINE CONTINENTAL SEQUENCES

Giovanni Napoleone[1,2], Andrea Albianelli[1], Augusto Azzaroli[1,2], Adele Bertini[1,2], Maurizio Magi[1], Menotti Mazzini[2]
[1]Dipartimento di Scienze della Terra, Università di Firenze, Via La Pira, 4 - I 50121
[2]Museo di Storia Naturale, Sezione di Geologia e Paleontologia, Università di Firenze, Via La Pira, 4 - I 50121
E-mail: napo19@unifi.it - albix@geo.unifi.it - abertini@geo.unifi.it - menotti@unifi.it

ABSTRACT
The Upper Valdarno continental sequence is formed by 500 m thick sediments calibrated to Gauss and Matuyama chrons, for nearly 2.5 my history. Continuity in lacustrine and fluviatile deposition is interrupted by two major pulses of the Apennine uplift. One is dated to the boundary of the Gauss/Matuyama chrons at 2.58 Ma and lasts until 2.1 Ma, the other from shortly after the Olduvai chron at 1.77 Ma until 1.05 Ma (Jaramillo), or 0.78 Ma (Brunhes). Such interruptions are recorded differently. The former by a condensed sequence containing two events of the magnetic polarity, the G/M boundary and the short normal chron Reunion within the early Matuyama, while the second missed any record. The condensed sequence is of wind-blown sands, with scanty levels of fine silt, used also for pollen analyses.
The deposition intervals, now dated in the lacustrine sequences, are similarly long. In the first basin filling, from Mammoth at 3.3 Ma, the lake deposits of uniform silty clays, the Meleto clays, began at nearly 3.15 Ma, from shortly before Kaena through the latest Gauss. This time span was separately measured by spectral content of the magnetic signal to last 400 ky; there, cyclostratigraphy enhanced periods of various lengths accounting for either different rates of deposition through the time series or the occurrence of a bimodal cyclicity at 2.85 Ma. At this time, the pollen record started moving towards a reduction of species of the subtropical forest and an increase of the altitudinal coniferous vegetation; an oscillating pattern from open to forest vegetation took place in the early Matuyama. In the second lacustrine cycle the record is less continuous, and the highest percentage of herbs is reached at nearly the P/P boundary.
Key Villafranchian faunas, from Triversa or Villafranca d'Asti sequence of north-western Italy to Pirro faunas of south-eastern Italy, were grouped in the biochronologic sequence of different faunal units, and are now correlated with the Upper Valdarno chronostratigraphic framework. After the early Villafranchian, the Montopoli fauna, the only one with a date (2.58 Ma) before the calibration of the Upper Valdarno, marked the major change with the preceding fauna of Triversa, leading to the middle Villafranchian. The other faunas formed the late Villafranchian, from Olivola of north-western Apennines to Tasso of Upper Valdarno and Farneta in central Italy to Pirro, which were little affected by the global changes occurred at the P/P boundary. After the Villafranchian age, the new fauna starts to build the asset of the present day distribution at the end of the Matuyama, and possibly at the boundary with the Jaramillo chron, as recorded also in the Upper Valdarno.
Devoid of a direct calibration, these faunas containing the Mammal Neogene (MN) age units MN16a MN16b and MN17 of western Europe faunal distribution, had always been very difficult to correlate with biostratigraphy, and even more with the geomagnetic polarity time scale GPTS. They are now placed relative to the Upper Valdarno magnetochronology, from Mammoth to Jaramillo. The high resolution of the Upper Valdarno is viable for finer enhancements in the Apennine sequences explored by direct magnetostratigraphies. These will permit the dating of their complete faunal sequences and correlate them with the European late-Neogene mammal faunas.

RIASSUNTO - La datazione dei depositi continenali del Valdarno Superiore è stata effettuata per una estensione di ca. 2.5 milioni di anni (ma), ricostruendo dai vari affioramenti, lungo 30 km di estensione del bacino, la successione sedimentaria. Su entrambi i fianchi della valle, essa è stata testimone di diverse quantità di apporto e di erosione, nel corso della sua storia intervallata da due fasi tettoniche che ne hanno segnato l'assetto. La più intensa è datata con inizio in prossimità del limite tra i magnetocroni a polarità normale Gauss (C2An.1n) e Matuyama (C1r.3r) inversa, a 2.58 Ma. Essa è responsabile della netta dislocazione del fianco orientale del bacino che ha depresso il bordo delle Argille lacustri (A. di Meleto) con un'inclinazione a NE di oltre 30°. La seconda crisi tettonica segna la fine della seconda fase deposizionale, con il riempimento del bacino in corrispondenza della crisi climatica globale alla fine del Pliocene che segna il limite con il Pleistocene. Gli ultimi depositi di questo ciclo sono datati fino a dopo il debutto della nuova fase, cioè ad un'età appena più recente del limite Plio-Pleistocene, superando di poco la fine del crono Olduvai (C2n) che è alla data di 1.77 Ma. La terza fase si apre senza apparenti discordanze nel versante a destra dell'Arno e con una di valore modesto, nel versante sinistro. Molto più consistente è invece il salto cronologico: esso coinvolge quasi tutta la porzione post-Olduvai del Matuyama (C1r.2r), per almeno 650 mila anni (ka), prima della nuova fase, segnata con una breve alternanza di magnetizzazione inversa e normale. Nella scala GPTS dei tempi magnetici la prima polarità normale dopo l'Olduvai si riscontra alla data di 1.05 Ma, Jaramillo (C1r.1n), e la seconda, Brunhes (C1n), alla data di 0.78 Ma alla quale è calibrato il limite del Pleistocene medio.
A questi punti fermi magnetocronologici si aggiungono quelli forniti dagli eventi sedimentari più rimarchevoli, che accompagnano i cambiamenti protrattisi per durate notevoli; anche queste durate, segnate dallo scorrere di una deposizione con velocità non sempre costante, sono state misurate. I primi depositi sono i conglomerati di base (Ciottolami di Spedalino), che cominciano alla data di oltre 3.3 Ma nel Mammoth (C2An.2r) e poggiano sul basamento oligo-miocenico delle arenarie del Macigno. La deposizione assume quindi un regime continuo in acque molto basse, con il breve episodio di accumulo palustre di ligniti, che lateralmente al piccolo lago poggiano direttamente sul basamento. Il livello più basso di ligniti è compreso tra la fine del breve crono a polarità normale (C2An.2n) prima del Kaena (C2An.1r) e l'inizio di quest'ultimo, cioè in un breve intervallo valutabile in qualche decina di ka a cavallo del limite a 3.11 Ma. A questa data è ricondotta l'età della prima fauna a vertebrati, che aveva fornito la datazione precedente dei depositi palustri all'inizio del Villafranchiano. Quindi il depocentro si approfondisce e si depositano argille sabbiose e limi (Argille di Meleto) la cui sedimentazione continua si estende per tutto il Gauss terminale (3.04÷2.58 Ma), senza però raggiungerne il limite, perché interrotta dal riempimento sabbioso del lago. La ricostruzione della serie deposta durante il Gauss (senza nessun reperto fossilifero) è stata effettuata attraverso l'analisi spettrale della oscillazione continua del segnale magnetico. Essa ha fornito la ciclostratigrafia della serie fino ai 60 ka prima del limite, cioè fino alla data di 2.64 Ma, dopo dei quali si depositano rapidamente le sabbie di riempimento del lago (Sabbie di S. Donato). Una foresta subtropicale di clima caldo umido è presente durante la formazione della lignite in un ambiente di palude arborata e prosegue per buona parte della successiva prevalente deposizione lacustre. Il progressivo fenomeno di raffrescamento, segnalato dai "record marini" come più evidente a partire da circa 2.77 Ma, determina una progressiva riduzione degli elementi più termofili e il contemporaneo aumento delle conifere di altitudine tipiche oggi delle foreste boreali. Non si registrano variazioni significative nei valori del-

l'umidità, i quali invece risulteranno fortemente alterati in seguito all'instaurarsi dei cicli glaciali/interglaciali a partire dall'inizio del Matuyama.
Alle sabbie di san Donato seguono in discordanza le sabbie della fase di erosione e inclinazione degli strati verso NE (Rena Bianca): nei pochi livelli limosi misurati, esse hanno fornito tratti discontinui di una polarità normale alla base, seguita da una inversa, ed interpretati come il limite Gauss-Matuyama, fino al breve crono con polarità normale, Reunion (2.15 Ma), e l'inizio di una nuova parte del Matuyama C2r.1r, con i limi della nuova fase fluvio-lacustre della serie del ciclo di Montevarchi (Limi di Terranuova). Questa serie è in continuità sulle sabbie della Rena Bianca, nella parte più occidentale in sinistra d'Arno; nella serie del depocentro affiorante in destra d'Arno il contatto non è stato mai rinvenuto. Qui, il nuovo livello argilloso affiora nel letto dell'Arno e la sua età è prossima a 2.1 Ma; il primo livello fossilifero, invece, è alla data di 1.99 Ma. Esso inaugura la nuova fauna del Villafranchiano superiore, che nella sezione di Faella si rinviene con una distribuzione stratigrafica di 220 ka ed è parimenti datata con la correlazione magnetostratigrafica poco dopo l'Olduvai. Infatti, nella sezione composita di Faella e Galleria Tasso, la serie procede con l'inizio del magnetocrono a polarità normale Olduvai a 1.95 Ma. La sua prima porzione arriva a 1.815 Ma, seguita da un breve tratto a polarità inversa fino a 1.785 Ma ed un nuovo normale fino a 1.77 Ma, secondo la calibrazione effettuata nello stratotipo della Vrica. In quest'ultimo, il limite P/P è definito a 1.796 Ma, entro la breve inversione al tetto dell'Olduvai. In ca. 300 ka intorno al limite P/P è racchiuso tutto l'arco del Villafranchiano superiore presente nel Valdarno Superiore fino all'unità faunistica Tasso, che però costituisce la grande maggioranza delle collezioni del Museo di Firenze.
Gli elementi di una foresta subtropicale-temperato calda progressivamente sempre più impoverita nei suoi elementi più termofili si alternano a quelli erbacei tipici di una vegetazione aperta nella quale trovano spazio anche numerosi elementi steppici. Nei sedimenti della Rena Bianca, il passaggio Gauss-Matuyama, è marcato dalla prima registrazione testimoniante l'espansione della vegetazione steppica con Artemisia *che raggiunge per la prima volta valori dell'ordine di oltre il 20%. Con tali punti di controllo, datati con l'accuratezza di 10 ka, entro la quale si ritiene compresa la durata di transizione da una polarità all'altra, anche le date di tutti gli eventi faunistici, pollinici e sedimentari sono fissate lungo la serie, con accuratezze cioè di qualche ka. In particolare, per quelli del secondo ciclo sedimentario di Montevarchi che risultano continui per la durata complessiva da ca. 2.05 Ma a ca. 1.75 Ma, gli eventi faunistici sono scanditi entro 2 ka e quelli vegetazionali correlati con le alternanze delle ciclicità astronomiche di Milankovitch misurate dalla distribuzione spettrale del segnale magnetico. Gli eventi faunistici sono quelli classici del Villafranchiano superiore successivi alla fauna di Olivola della Toscana settentrionale. Sono costellati da depositi fossiliferi fra i più cospicui, come la fauna del Tasso della fine dell'800 e quella di Poggio Rosso della fine del 900, nonchè dai reperti isolati che sono stati riposizionati nella serie di Montevarchi, come il Rinoceronte di Nesti del 1811 e l'Elefante di Azzaroli del 1953. Ora, queste collezioni del Museo di Firenze sono datate insieme con la calibrazione del limite P/P rapportato alla stratotipo della Vrica. Quindi, così come alla Vrica, il limite P/P è marcato dall'instaurarsi di una fase glaciale che si traduce in un'espansione della vegetazione erbacea, e tale fase è preceduta da una lunga fase calda ed umida. I successivi cicli glaciali-interglaciali si differenziano ulteriormente da quelli pliocenici per una notevole riduzione nella diversità floristica determinata dalla progressiva scomparsa nel corso del Pleistocene di numerosi taxa (ad esempio Taxodiaceae,* Cathaya *e* Tsuga*).*
Le sabbie di Oreno sovrastanti le argille di Ascione chiudono il ciclo di Montevarchi, e con esso termina il Villafranchiano nel bacino del Valdarno Superiore. La sedimentazione riprende dopo una interruzione non valutabile, sul versante destro dell'Arno, in mancanza di una serie magnetostratigrafica: nella parte SE del bacino, presso Lévane (Cava Specchiano), pochi livelli limosi nei ciottolami di Laterina e nelle sabbie di Lévane hanno fornito una polarità inversa attribuita al Matuyama superiore. Sul versante sinistro, nella zona a SW presso Bucine (Cava Gori), i conglomerati sono a polarità inversa e i limi e le argille soprastanti a polarità normale. La ricca fauna di Bucine, rinvenuta negli strati sabbioso-ghiaiosi a copertura degli ultimi depositi, nettamente post-villafranchiana, era anzi rapportata ai tempi del Pleistocene medio terminale sulla base delle evidenze archeo-antropologiche di reperti litici. Sia che il salto di polarità corrisponda ai tempi magnetici del crono Jaramillo che a quelli del Brunhes, rimane l'importante indicazione che il tempo trascorso dopo gli ultimi depositi della serie di Montevarchi è vicino a/o raggiunge 1 ma, che è pertanto il salto dalla fauna del Tasso a quella di Bucine.
Da tale quadro cronologico emergono le condizioni per calibrare gli eventi faunistici e floristici dei bacini intermontani dell'Appennino, correlandoli con quelli del Valdarno Superiore. Il prototipo è dato dal Bacino Tiberino. Il "record" pollinico della Formazione di Fosso Bianco è stato calibrato direttamente con la magnetostratigrafia, per 600 ka, durante il Gauss terminale ed il Matuyama fino a tutto il Reunion. L'unica indicazione cronologica è data dalla ridotta associazione faunistica di Todi, rinvenuta a Cava Toppetti nella sovrastante Formazione di Ponte Naia ed attribuita al Villafranchiano medio, tra le età dell'unità faunistica di Montopoli (calibrata a 2.58 Ma) e quella di Olivola (ora datata a ca. 2.1 Ma): essa risulta perciò entro confini molto ristretti, intorno ad una età prima di Olivola, ma certamente non prima di 2.15 Ma, essendo posteriore al Reunion. Per gli altri bacini, nonostante la mancanza di controlli magnetostratigrafici diretti, le età che erano state fissate con i criteri biocronologici vengono ora circoscritte intorno a date che le hanno talvolta spostate notevolmente. La stessa durata del Villafranchiano, ritenuta nel Valdarno Superiore estendersi dal Pliocene medio a circa la fine del Pleistocene inferiore, è stata accorciata all'età biostratigrafica di poche decine di ka dopo l'inizio del Pleistocene. Nella calibrazione alla scala GPTS questo comincia nell'Olduvai terminale, a circa 1.8 Ma e l'età del Villafranchiano arriva nel Valdarno Superiore a ca. 1.75 Ma, cioè con una riduzione di 600-700 ka rispetto a quanto implicato dalle precedenti correlazioni indirette.
Con la completezza del quadro magnetocronologico del Valdarno Superiore possono essere correlate le faune principali dei bacini appenninici, e gli eventi sedimentari e floristici rinvenuti nei due versanti della catena. In particolare, viene riportata la nuova interpretazione della successione stratigrafica dei depositi faunistici, a partire da quello di Villafranca d'Asti, come rieferimento per il Villafranchiano, che risulta coevo con quello di Castelnuovo dei Sabbioni. Seguono le età di Montopoli (già nota, a 2.58 Ma) e di Olivola ora interpretata a 2.1 Ma, mentre quelle di Tasso e Farneta sono molto prossime fra loro ed entrambe appena dopo il limite Plio-Pleistocene; quella di Pirro alquanto indefinita. Il passaggio alla fase nuova che prelude alla fauna attuale è marcato al crono Jaramillo, 1.05 Ma.

Key Words: Magnetochronology, Upper Valdarno basin, Villafranchian faunas, Pliocene correlations, Pleistocene boundary, Vegetational changes, Climate changes.

Parole chiave: Magnetocronologia, Valdarno Superiore, Faune Villafranchiane, Pliocene, Pleistocene, Variazioni climatiche.

1. INTRODUCTION

The continental deposits of the Upper Valdarno represent a fundamental key for timing the major Apennine uplift during Pliocene and Pleistocene (Fig. 1). Also their fossil record of mammals became famous in the late seventeen hundreds and was studied in the early eighteen hundreds with a decisive contribution to the development of palaeontology. The first represented fossil was the proboscidean jaw reproduced by Nesti in 1808, followed by rich collections. During the last 50 years the museum collections were reconsidered, and thence arranged in the Villafranchian biochronological sequence (Azzaroli, 1977a) which was further enriched by various details (Azzaroli, 1977b; 1983; 1992; 1995; 1998; 2001; Azzaroli *et al.* 1988; 1997), until magnetostratigraphy provided the dates for the whole record beginning from nearly 3.1 Ma (Fig. 2).

In a framework related to the Geomagnetic Polarity Time Scale (GPTS), the new historical reconstruction of the Upper Valdarno faunal sequence is correlated with great confidence with the sedimentologic and climatic ones. Magnetic stratigraphy has in fact demonstrated the onset of the continental deposition at 3.3 Ma and of the lacustrine facies at 3.1 Ma, when the first faunal sequence was also recorded (Albianelli *et al.*, 1997). Its end was close to the Gauss/Matuyama boundary. A second lake developed at 2.1 Ma and a new fossil record has been dated since 1.99 Ma (Cioppi & Napoleone, 2001, Napoleone *et al.,* 2001c, Albianelli *et al.*, 2002a). In the mean time, the sedimentary features showed a marked change in the 450 ky time series of the first lake with a gradual increase of the deposition rate by more than 60% from the middle to the end of the late Gauss chron (Albianelli *et al.*, 1999, Napoleone & Albianelli, 2002). It was recorded by the magnetic signal as mainly related to Milankovitch climatic changes that were also recorded by the pollen distribution (Bertini, 1994; Bertini & Roiron, 1997). Two results emerged from these studies. One was to date the turnover of the Milankovitch precessional signal towards the obliquity one at 2.85 Ma, when also the pollen of warm-temperate forest began to change towards a cooler vegetation and later alternate with the warmer one at nearly the Gauss/Matuyama boundary. The other one was to find the Pliocene/Pleistocene boundary with the same features as in the stratotype (Van Couvering, 1997), and to record the acme of the pollen concentration up to 89% of steppe herbs in proximity of that boundary. The present contribution summarizes these results and the ones from additional studies not reported in specific accounts, with the aim of developing the comprehensive history of the basin directly calibrated to the numerical dates of the GPTS.

We briefly review the classical faunas of the Upper Valdarno as illustrated by Azzaroli et al. (1988), together with the Faella small collection now revised in its composition because of new acquisitions in the inventory of specimens from different levels of the Faella clay pit. Other specimens were also considered from the finds accurately reported in the automated catalogue of the Museum of Firenze (Cioppi *et al.*, 1996). Accuracy on their stratigraphic position reflects on their datings, with a confidence of 2 to 15 ky, that build the base for correlation of most Apennine faunas which were until now approximately placed in the biostratigraphic chronology, and fairly incorrectly related to the GPTS.

2. BIOCHRONOLOGIC HISTORY OF THE UPPER VALDARNO SEQUENCE

The early geologic reconstructions were made for the Italian peninsula, at the same time when also the Upper Valdarno chronostratigraphy was established. Its continental deposits were classified in the general asset of the marine sequences, with the Pliocene clay (Blue Clay Formation) overlain by the Pleistocene sand (Cocchi, 1856; Pareto, 1865). Both successions were believed to be of equivalent geochronologic resolution, and biochronology of the mammal age classification was associated with the biostratigraphic classification. The Villafranchian defined by Pareto (1865) for the Triversa vertebrate fauna of Villafranca d'Asti in Piemonte (north-western Italy) was later extended to the sequences of peninsular Italy, and its onset related to the early Pliocene (Azzaroli, 1977a), in its twofold definition before a third stage was recently introduced for the latest Pliocene. The mid Villafranchian is represented by the Montopoli fauna, collected in the Lower Valdarno basin, and related to the late Pliocene, while the Olivola fauna of late Villafranchian collected in north-western Toscana was assumed to mark the beginning of the Pleistocene. Magnetochronology has now

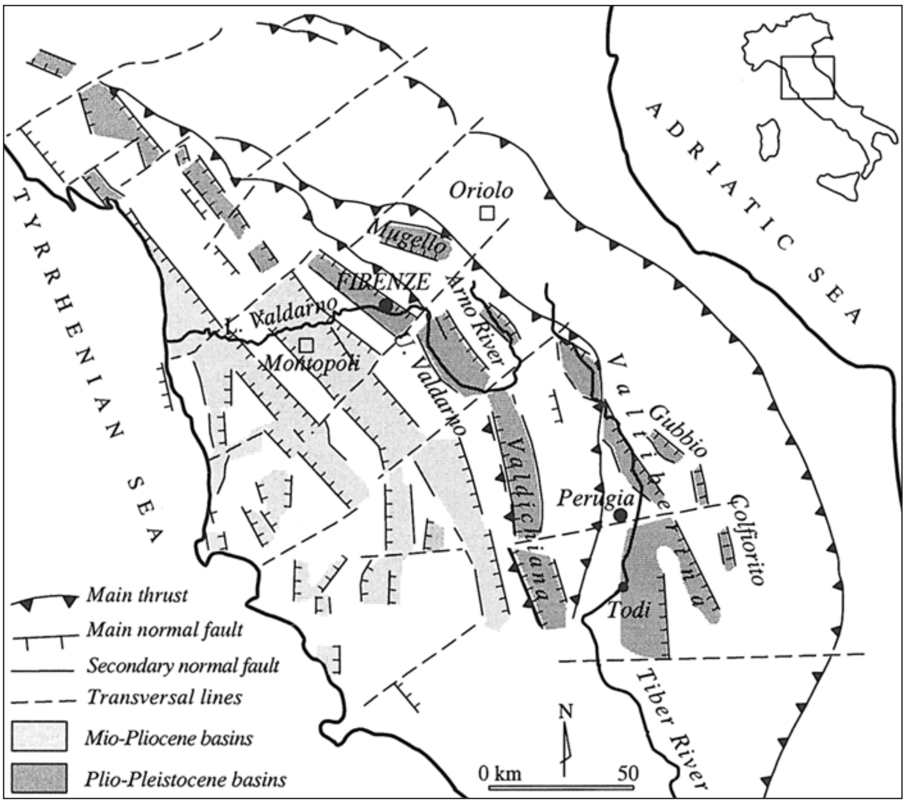

Figure 1 - General tectonic setting of the intramontane basins along the Northern Apennine belt (Modified, after Martini and Sagri, 1993). The Upper and Lower Valdarno, South and West from Florence, respectively, and Valtiberina farther south from Upper Valdarno are the only ones here taken into account for their direct calibration by magnetic stratigraphy, but their features are typical throughout the Italian peninsula.

fixed new dates for the Pliocene and Pleistocene, so that the previous correlation used for assigning an age to the major turnovers in the terrestrial fauna is recognized to diverge from the ones of the marine record. The main difference is at the Pliocene/Pleistocene boundary, which did not mark any vertebrate diversification, as pointed out from the following facts (to be discussed in the chapter on calibrations).

The earliest turnover of vertebrate associations (Azzaroli, 1983) took place at 2.58 Ma, the boundary between the Gauss (C2An.1n) and Matuyama (C1r.3r) chrons, which also calibrates to the GPTS the boundary of the middle to late Pliocene (Berggren *et al.*, 1995). The next one marked the extinction of the main taxa which are no longer represented in the present-day faunal associations and was dated at the Jaramillo chron, approximately 1 Ma (Azzaroli, 1995). The mid Pleistocene boundary was calibrated to the following chron of Brunhes, while the onset of the Quaternary recorded only the so-called "wolf-event" with the arrival of a new *Canis* (*Xenocyon*) overlapping the previous mid Villafranchian one (Torre et al., 2001). This lack of major events was also one of the reasons why the Pleistocene boundary had a late recognition (Pasini & Colalongo, 1997) and correlation with it of the Italian mammal fauna was actually made through the Himalayan sequence (Azzaroli *et al.*, 1997), calibrated to the Pliocene and Pleistocene by its magnetostratigraphy (Azzaroli & Napoleone, 1981).

With calibration of the stratotype to the GPTS at the date of 1.796 Ma, also the Upper Valdarno series is defined by the same dates, including the boundary at the Pliocene/Pleistocene, and the various ages before and after it which become actually correlated at the highest resolution with their faunal events. The main aspects of the Upper Valdarno faunal record are recalled here, as they represent most reference events for the Villafranchian vertebrates of the Italian peninsula and will put the benchmarks for magnetochronologic calibration of several of them. The first fauna of Castelnuovo dei Sabbioni (early Villa-franchian) is separated from the next one of the Montevarchi sedimentary cycle (late Villafranchian) by the wind blown and unfossiliferous sands of Rena Bianca. Its intermediate position, covering the middle Villafranchian age actually missing in the Upper Valdarno, is represented by a single fossil which has been hitherto allegedly found, a partial skeleton of a mastodont described and partly figured by Nesti in 1826, and now referred to *Anancus arvernensis* by Azzaroli. The fossil was restored and is exhibited in the Museum of Firenze; its provenance was not reported by Nesti and the position in the Rena Bianca is here only inferred.

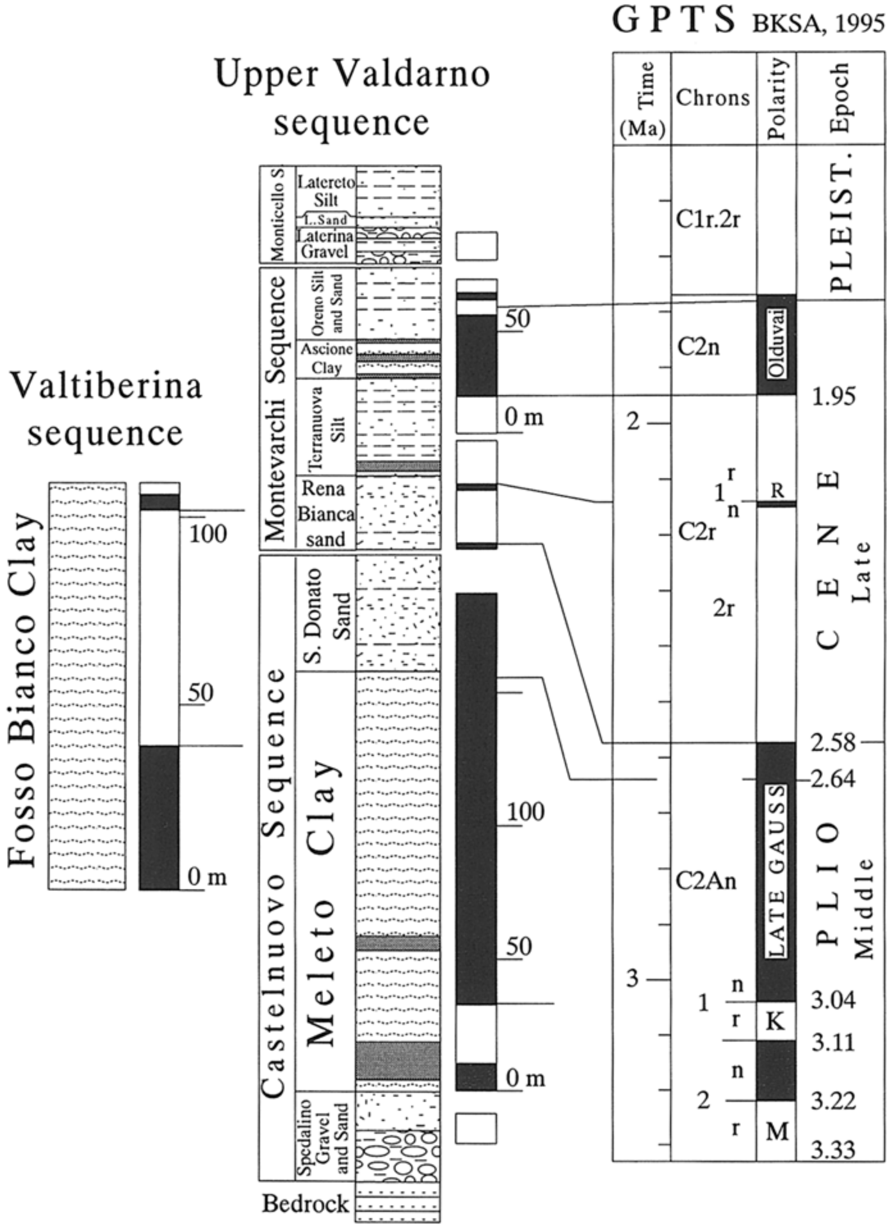

Figure 2 - Magnetostratigraphic asset of the Upper Valdarno sedimentary sequence used for dating the Villafranchian faunas and implemented by the present results. The basic figure was after Albianelli (1995), and first used in Cioppi and Napoleone (2001). An important change is now introduced, after recognizing the unconformity between Rena Bianca and San Donato sand units, so that they are split in two zones belonging to the Montevarchi cycle and to the Castelnuovo cycle, respectively. The San Donato sand represents therefore a short time span, and Rena Bianca a condensed sequence to which the Valtiberina profile at Todi provides a full extent for correlation. The Montevarchi sequence is synthesized from various profiles; the filling sediments are not reported herein.

Figure 3 - The outcrop of the Meleto clay in the Santa Barbara pit, opened for the exploitement of the lignite seam. In the foreground, the lignite-bearing level has already been removed, and the paleomagnetic survey has been carried out up to the top. The sampling for palynology was conducted earlier, in the profile on the left side of the section, 1 km away.

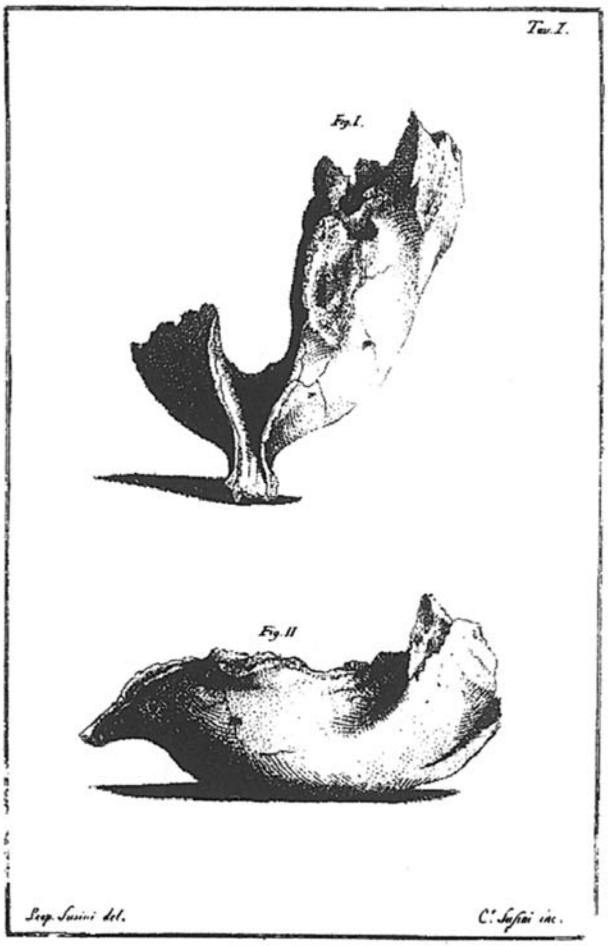

Figure 4 - The earliest illustration of a fossil specimen from the Upper Valdarno old collections (After Nesti, 1808, reproduced in Azzaroli *et al.*, 1992). This proboscidean was tentatively attributed by Azzaroli to *Anancus arvernensis*.

2.1 The Castelnuovo dei Sabbioni Locality

The mining of the lignite-bearing levels of the basal unit yielded few fossil specimens kept in the University Museum of Firenze. The small collection assembled as the Castelnuovo dei Sabbioni fauna actually came from various sites of the old small mines (Gaville, Tegolaio, etc.), distributed in the area around the small town of Castelnuovo dei Sabbioni. The last and largest one at Santa Barbara provided extended outcrops used for surveying various sedimentary aspects, but its industrialized exploitement did not allow any fossil recovery (Fig. 3).

The fauna is characterized by the mastodonts *Zygolophodon borsoni*, *Anancus arvernensis*, and by *Ursus minimus*, the perissodactyl Tapirus arvernensis, the turtle *Mauremys etrusca*, the fish *Tinca* sp. It has been correlated with the Triversa fauna occurring at Villafranca d'Asti in Piemonte and is characterized by the same faunal elements (Azzaroli, 1977a). As the Triversa assemblage was taken by Pareto (1865) to represent the Villafranchian terranes (see the discussion reported in Azzaroli, 2001), the Triversa Locality was assigned as the base of the Villafranchian Stage, and the Castelnuovo Locality was accordingly positioned at the same time level. The rough chronostratigraphy derived from broad correlations with the marine sequences gave an age of Pliocene, actually corresponding to a lower Piacenzian as defined by Pareto (1865). Therefore, the Castelnuovo fauna represents the earliest mammal assemblage from the Apennine intramontane basins developed with the Plio-Pleistocene uplifting of the chain. The present date, produced by its magnetostratigraphic determination (see in chapter 5), is calibrated to the GPTS and will be used (in chapter 6) to date more accurately the reference assemblage of Triversa by a correlation better defined.

2.2 Local faunas in the Montevarchi sequence

In this complex, forming the second depositional cycle, the bulk of the Upper Valdarno fauna stored in the palaeontological Museum of Firenze has been collected since early eighteen hundreds, and a large collection is also stored in the famous Museum of Montevarchi, the town from which the succession is named.

The first catalogue of the Upper Valdarno fossils in the Museum of Firenze was assembled by Filippo Nesti in 1845, and contained the list of 356 specimens (Azzaroli *et al.*, 1992). Some of them are in the exhibition, representing the best pieces for the study collection, and were studied in detail to create the base for the developments in palaeontology. The earliest description, dating from 1808, is a toothless jaw of a then unnamed proboscidean; it belongs to a mastodont, likely from the older lake of Castelnuovo dei Sabbioni and tentatively assigned to *Anancus arvernensis* (Fig. 4). A second fossil was the rhinoceros described by Nesti in 1811 (a pelvis and the four limbs), named *Rhinoceros etruscus,* and now *Stephanorhinus etruscus*. The detailed description of the site location has now been reconsidered for dating the embedding sequence, and the level of provenance recognized in the sequence of Poggio di Monte al Pero, which is the hill peak by the side of Matassino, another important fossil site. These localities are both dated with high resolution by magnetostratigraphy of their sequences, as reported in chapter 5.

The oldest fossils collected so far in the Montevarchi sequence are an antler of a juvenile cervid, *Pseudodama nestii* (Fig. 5) acquired in the catalogue on April 1999, and a tibia of the *Equus stehlini* acquired in the catalogue on January 2000, with specimens of a few more species. They all come from the lowermost 10÷15 m of the Faella section, 2 km away from that of Matassino, on the right (eastern) bank of the Arno river (see on map of Fig. 8). As discussed in the next sections, the Faella outcrop represented the key for new insights into the biochronologic history of the Upper Valdarno, because the whole fauna collected in two centuries from this area and resumed from the catalogue was calibrated, thus becoming the reference for the equivalent faunal collections. In fact it spans all through the Montevarchi succession from which most of the fossil sites were retrieved. The species list of the Faella small collection of 29 specimens includes *Pachycrocuta brevirostris, Leptobos etruscus, Leptobos vallisarni, Sus strozzii, Eucladoceros dicranios, Canis arnensis, Ursus etruscus, Archidiskodon meridionalis, Pseudodama nestii, Equus stehlini*. They are now dated in stratigraphical sequence, as will be discussed in the magnetochronologic section, even if a provenance of the specimens in the old collections was not reported (Napoleone & Azzaroli, 2002). Cocchi (1867) made an important recovery at the same level as the base of the Faella section, just across the Faella creek and at the foot of the Monte al Pero hill, with two additional genera: *Megantereon* and *Rhinoceros* (now *Stephanorhinus*).

The Matassino hill is the northern flank of Monte al Pero, and culminates with the peak of Poggio Rosso. At its base, the Matassino site was the first rich assemblage recovered in the UV as one single deposit (Azzaroli, 1967), in a channelled sand pocket, with two young male and female elephants, the latter shown in Figure 6. It was dated to the late Villafranchian and represented until three years ago the oldest faunal assemblage in the Montevarchi sequence, for which a close affinity with the Olivola fauna was recognized (Azzaroli, 1977a) and an age of earliest Pleistocene was since established. The Matassino local mammal fauna (lmf) is assembled in the catalogue list from 8 sites around the mentioned deposit and contains most of the species of the Faella previous list, totalling 12, including the *Canis arnensis* described by Torre (1967).

In the same sequence of the Matassino Locality, some 30 m higher up, a very rich fauna was discovered in 1995 (Mazzini M. *et al.*, 2000), the Poggio Rosso fauna, and is under preparation. A list of the specimens exhibited in the Museum during 1997÷2002 included 13 species, *Archidiskodon meridionalis, Equus stenonis, Equus stehlini, Stephanorhinus etruscus, Leptobos etruscus, Eucladoceros dicranios, Pseudodama nestii, Sus strozzii, Pachycrocuta brevirostris, Canis etruscus, Canis arnensis, Ursus etruscus, Castor plicidens*. The species are now 19 out of more than one thousand specimens restored and preliminarily examined; the complete list of more than 15 hundred specimens is not yet fully included in the automated catalogue. The fauna lies in a channelled sand pocket and was washed in by a stream during a flood. Although the association has still to be defined, all groups being under study, there appear to be present the most characteristic elements that had been attributed for their analogies to the Olivola faunal unit (reported later, in chapter 6), with the exclusion of the species endemic to that site and with the addition of *Equus stehlini, Canis arnensis, Castor plicidens and Hystrix etrusca*. The latter species was described from other sites of the basin by Bosco in late eighteen hundreds (quoted in Azzaroli, 1998). Owing to transport by a stream the elephant is represented by few

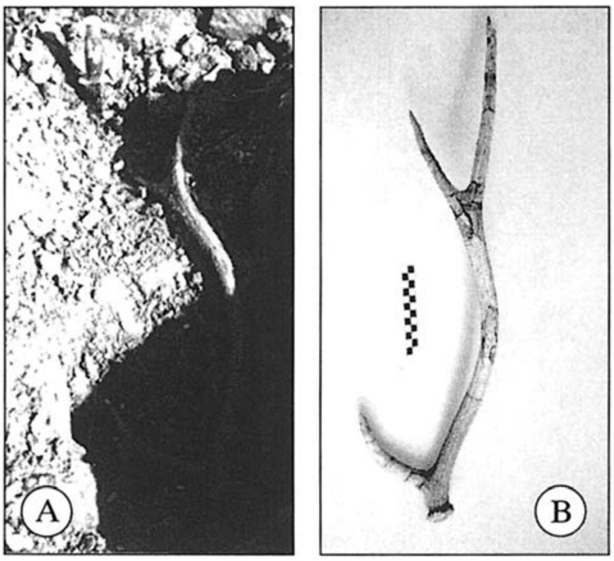

Figure 5 - One of the most recent acquisitions (April 1999) of the Upper Valdarno fossils made by the Natural History Museum of Firenze, the cervid antler of a juvenile specimen at the base of the Faella clay pit, few meters by the side of the Faella creek. In January 2000, a few meters underneath, the oldest fossils of the late Villafranchian dated 1.99 Ma have been found.

bones of the hand.

Two complete skeletons of the elephant *Archidiskodon meridionalis m.* were collected by Azzaroli in the Montevarchi territory, on the left bank of the Arno. The one collected in 1949 is stored in the Montevarchi Museum, and a male skeleton was collected in 1953 on a hilltop at the Borro Quercio creek. The find of 1949 was recovered not far and at a level slightly higher than that of the other one, and determined as a young female individual of *Elephas meridionalis* Nesti (Azzaroli, 1952). The find of 1953, stored in the Museum of Firenze, has been reappraised (Azzaroli & Napoleone, in ms) to report on its preliminary determinations and on accurate chronology of its level bed (Fig. 7).

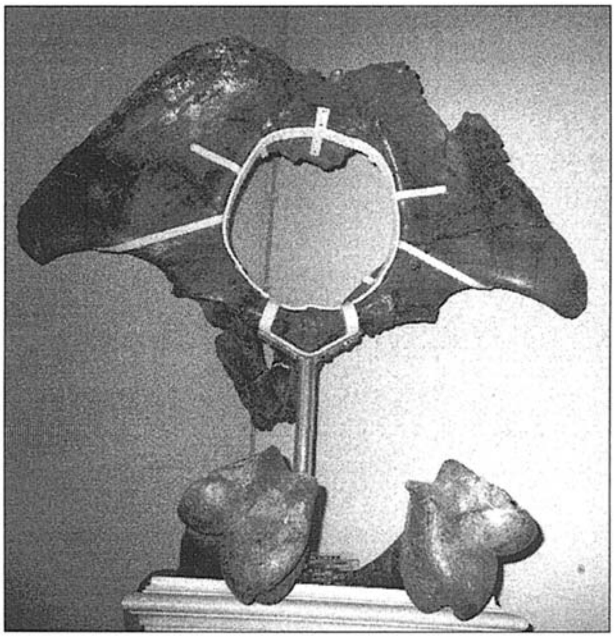

Figure 6 - A specimen of the first fossil assemblege recovered at Matassino by the staff of the Museum of Firenze, in a channelled deposit of sand and fine gravel interlayered in the Terranuova silt level which is now dated as just preceding the onset of the Olduvai chron at 1.95 Ma (Albianelli & Napoleone, 2002, unpublished data).

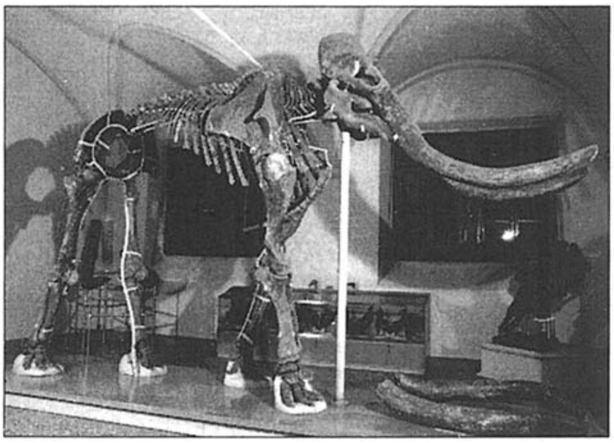

Figure 7 - The largest specimen in the exhibition of the Natural History Museum of Firenze, collected in 1953 near Montevarchi and now dated in the upper Olduvai, at nearly 1. 85 Ma (Azzaroli & Napoleone, 2002).

A fairly rich fauna was collected in recent years near Casa Frata, not far NW of the town of Terranuova Bracciolini (Borselli *et al.*, 1980; De Giuli & Masini, 1986), and is still under study. It includes *Canis etruscus, Canis falconeri* (?), *Ursus etruscus, Martes sp., Pachycrocuta brevirostris, Lynx cf. issiodorensis, Acynonyx pardinensis, Homotherium crenatidens, Eucladoceros* sp., *Pseudodama* sp., *Equus stehlini, Stephanorhinus etruscus* and the limbs of a medium-sized, heavily built bovid, which has not yet been detected in other sites of the Upper Valdarno. The sequence containing the two major deposits of the Casa Frata assemblage is not well exposed and has not been studied for palaeomagnetism.

From the vicinity of the area labeled in the Museum catalogue as Il Tasso come: *Lepus etruscus, Castor plicidens, Mimomys savini, Canis etruscus, Canis arnensis, Canis falconeri* (now *Canis (Xenocyon*) ex gr. *falconeri,* Rook, 1994), *Ursus etruscus, Martes* sp., *Pannonictis nestii, Pachycrocuta brevirostris, Lynx issiodorensis, Panthera toscana, Homotherium crenatidens, Megantereon cultridens, Stephanorhinus etruscus, Equus stehlini, Sus strozzii, Pseudodama nestii, Eucladoceros dicranios, Leptobos vallisarni, Archidiskodon meridionalis*. The occurrence of *Equus stenonis* and *Leptobos etruscus* is doubtful, that of the *Hippopotamus antiquus* included in the catalogue as belonging to this group will be discussed at the end of this chapter.

Several more localities with minor finds and/or of undetermined positions are classified in the catalogue, but their variability is not recognizable from the above mentioned localities already ordered in stratigraphic succession, as dated later by their magnetochronology. A large tusk of an elephant was collected by Azzaroli and De Giuli in 1975, west of Montevarchi and near Km 41 of the road from Siena, at an altitude of 205÷210 m. It is decidedly larger than the tusks of the Borro Quercio elephant and other tusks from the Upper Valdarno and nearly equals in size to the specimens found near the Farneta Abbey in Eastern Toscana, to be discussed in the stratigraphical reconstructions of chapter 6.

2.3 Additional faunas after the Pleistocene boundary

The basin fill is recorded in a short succession overlying the earliest Pleistocene sand. The one exposed on the right-hand bank of the Arno did not yield any fossil remains but the frontal skull of a bovid; on the left-hand side, in contrast, a rich assemblage was collected and labeled as the Bucine local fauna, even if randomly found on the surface, in the area around Pogi, South of the small town of Bucine. These sediments extend in a flat area from Bucine to Ambra, beyond the southern margin of the Valdarno basin at an altitude of 220÷240 m, unconformably sitting on the previous unit. In the late eighteen hundreds, during the reconstruction of the railroad from Firenze to Roma, a set of tunnels were opened near Bucine at an altitude of 205÷207 m. In one of these, Forsyth Major collected a set of teeth of the reported late Middle Pleistocene *Equus süssenbornensis* von Reichenau (Azzaroli, 1984). Higher up in this area, near the village of Pogi, a small fauna was collected in the 1960s and stored in the Museum of Firenze:

Mammuthus primigenius, a lower molar; *Equus ferus*, a left metacarpal; *Dama dama*, a left metatarsal; *Cervus elaphus*, a right antler; *Stephanorhinus hemitoechus*, a male skull; *Grus* cf. *cinerea*, a partial humerus, tibio-tarsus. It was assigned an age of late, but not latest Pleistocene. Three upper and two lower molars referable to *Equus ferus* (named *Equus caballus* by Azzaroli, 1984), and a left horncore of *Bison schoetensacki* from the higher levels of the eastern margin of the basin were also described by the same author and were referred to the late Pleistocene.

The assemblage kept in the palaeontological collection of the Montevarchi Museum and of the High School of Bucine comes from 11 collecting localities listed by Mazza (1997), and used to reconstruct the taphonomy of their occurrence: *Elephas (Palaeoloxodon) antiquus, Mammuthus primigenius, Stephanorhinus sp., Equus gr. bressanus-süssenbornensis, Sus scrofa, Bos primigenius, Bison priscus, Cervus elaphus, Dama dama, Megaloceros* sp., *Capreolus capreolus, Ursus arctos, Canis lupus, Crocuta crocuta, Castor fiber*. The biochronologic dating of this fauna, although decidedly more derived than the Villafranchian ones, is not sufficient to resolve its age in some detail. The age of late Middle Pleistocene (latest Galerian ?) was arbitrarily assigned, lacking any stratigraphic correlation, as will be shown by its calibration. The efforts of Cocchi (1856) and Pareto (1865) to correlate continental sequences with the marine ones were not improved by the biochronologic attempts for dating deposition gaps of unknown duration. In the Upper Valdarno filling, this has been a major problem until magnetostratigraphy provided the numerical dating of their time intervals (Napoleone *et al.*, 2001c).

A 30 m thick sequence, in the upper silt and clay underlying the final thin bed of sand, was surveyed for magnetics in a gravel and sand pit, in the vicinity of Bucine. Also in a shorter section of a similar pit, ca. 1 km away, the same sequence was sampled after an elephant tusk was reported by one of us (M. Mazzini) on the 21st of October 2001, in the yellowish lenticular fluvial deposits. Several remains of *Elephas antiquus* were recovered on the 26th, 27th, and 29th of October, and the specimen is labeled in the inventory of the Museum as IGF 8215V. The fossil level was above the gravel bank and a less than 10 m section was sampled for magnetostratigraphy, including two clay and silt lenticular levels in the gravel bank.

The hippopotamus of the Upper Valdarno, descibed by Nesti and grouped with the large assemblage of specimens of the Tasso faunal unit, devoid of a position within the Montevarchi sequence, raises a problem. The fossils, which slightly differ from the living species, are plentiful. Nesti gave no details on their locality, and no fossils of this species were collected in recent years, either in the Upper Valdarno or in younger deposits of the Farneta area of Val di Chiana and the Mugello basin, North of Firenze (reported in chapter 6). This leads us to suppose that the hippopotami are of a younger age than the main Upper Valdarno fauna. The remains of a similar hippopotamus were collected in recent years farther East, at the boundary between Umbria and Marche districts of central Italy, in the Colfiorito basin, associated with other remains of post-Villafranchian fossils (Borselli *et al.*, 1988).

The Upper Valdarno fauna, owing to its richness and recent acquisitions, has not yet been studied with the detail it deserves.

3. TECTONIC AND SEDIMENTARY EVOLUTION OF THE BASIN

The Arno River makes its 240 km path running from the Casentino Valley in East Toscana, first South towards Arezzo, and before reaching the town it turns West and then North to Firenze, across the Upper Valdarno basin (Fig. 1). After the Firenze basin, it continues West cutting a series of hills and, in the Lower Valdarno basin, the shallow marine deposits of Miocene and early Pliocene. Sometimes its early and mid Villafranchian sediments interfinger with the mid Pliocene ones. However, the fairly poor biostratigraphic resolution in this area never led the accurate dating of the vertebrate fossil sites that are also scattered in younger deposits, but never indicative of a faunal assemblage of biochronological significance. The Upper and Lower Vardarno basins also had quite a different tectonic history, the latter responding to the pulses of the Apennine uplift by mild sea level changes which formed several regressive-transgressive cycles in a circa-littoral environment (Benvenuti *et al.*, 1995). Short-lived episodes of continental deposition and of minor areal extent are in contrast with the relatively long sequences accumulated in the marine facies. Also the pollen distribution was different, recording changes largely reduced in ampliture and testifying a lagunar facies in the vegetation.

Sedimentation started in the Upper Valdarno directly with continental deposits, unconformably overlying the turbiditic sandstone of Oligo-Miocene age, and was affected by two main episodes of the Apennine uplifting, which produced deep changes in its lacustrine sequences. These were in fact interrupted twice, for time spans which are now dated to represent long breaks in the history of the basin. Similar breaks are expected to be found in the several intramontane basins of the Apennine belt, and in the external Apennines where are now dated coeval with the Upper Valdarno breaks (Albianelli et al., this volume).

3.1 Setting of the basin

The general setting of the Northern-Apenninic architecture was described by Merla (1951), and the Upper Valdarno disposition in its framework by Abbate *et al.* (1971). A detailed survey of the basin led to the Lazzeri (1977) map, from which the sketch of Figure 8 is taken. In the present reconstruction only few references are quoted, without discussing the general framework developed since Merla's (1951) modern views for the Northern Apennines and later reproposed with increasing details. The Upper Valdarno basin was re-visited by Merla & Abbate (1967) and Azzaroli (1967) for their tectonic and biochronologic reconstructions. An updated tectonic and sedimentarry feature was provided by Martini and Sagri (1993), who restored the asset of the Northern Apennine basins as reported in Figure 1, while the Lazzeri (1977) map completed the scheme to which all studies on the Upper Valdarno record were later linked. A next step will be marked by the detailed new mapping, which is beginning in these days. It will be useful to report more widely on the previous works. The time implications on the history of the basin, until now established by the faunal distribution earlier mentioned, are shortly emphasized, although disregarding the tectonic reconstructions of the basin in relation to the close intramontane structures along the Northern Apennine belt.

The basin is an asymmetrical depression, bordered on the north-eastern margin by the Pratomagno Ridge, which divides the Upper Valdarno from the Casentino basin, and with a normal fault system of smaller displacements along the south-western margin by the Chianti Mts (Merla & Abbate, 1967; Magi *et al.*, 1992). These deeply regulated the sedimentary regime, which produced a number of local deposits. They have been grouped in two main sets, better exposed on either side of the Arno River bank, one on the western border containing the earliest and latest sequences, and the other on the eastern bank with the richest fossil sites and of median age between the tectonic displacements of the Apennine uplift now dated to last half a million years and nearly one million, respectively. During these ages, indeed, the deposition was also regulated by the climatic changes affecting the geologic system at the critical ages of the turnovers to the late Pliocene and to Pleistocene. They were recorded by the pollen and magnetic signatures, imprinted by their continuous changes throughout the series. Therefore, our interest is directed to timing the main events in the history of the basin, which will provide the reference for the similar ones accompanying the time span of the Apennine growth. It is notable that this growth also left traces in the external Apennine marine sequences and their detailed correlation with the Upper Valdarno ones will be the next goal in dating the ages of the tectonic phases across the mountain belt.

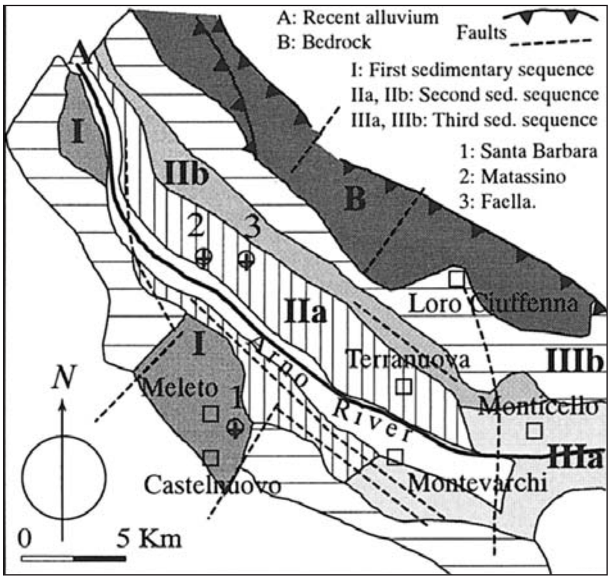

Figure 8 - Simplified sketch of the Upper Valdarno geologic map (Redrawn after Lazzeri, 1977, and Magi *et al.*, 1992). The basic sedimentary sequences are shown, together with some of the fossil sites mentioned in this paper.

3.2 Three depositional cycles

The Upper Valdarno sedimentary fill is made of three separate units, each marked by angular and/or erosional discontinuities (Billi *et al.*, 1991; Martini & Sagri, 1993); the bulk of its new asset is represented in Figure 2, the dates for their events having been provided by magnetostratigraphy (Albianelli *et al.*, 1997; 2002a). It is here used to introduce the general aspects, while a more detailed reconstruction descending from the present study is reproposed in Figure 18, with the actual series exposed on both sides of the valley and correlated by their magnetostratigraphy.

The first phase developed in the south-western margin of the basin, with the fluvial-lacustrine deposition of the Castelnuovo Succession. It started with pebble and sand of alluvial fan type; after a while, the fine grained sedimentation developed, and rapidly moved to palustrine clay with thick lignite seams and to a decidedly lacustrine facies. The basin was filled up by sandy fluvial deposits (San Donato sand) which are overlain by a more than 30 m thick level of wind-blown white sand, Rena Bianca (Magi & Sagri, 1996), recognized in recent cuts to unconformably stand on them. This deposit was the result that followed the strong Apennine uplift which displaced and tilted to the NE the lacustrine deposits. For its disposition, it is now assigned to the overlying Montevarchi sequence (Fig. 2), thus deeply modifying the previous asset of the magnetostratigraphic reconstructions reported in previous papers (Albianelli *et al.*, 1997; Cioppi & Napoleone, 2001; Napoleone *et al.*, 2001c).

The second lacustrine and palustrine phase developed in the central basin, which occupied a quite larger area than the previous one, with fan-delta deposits in the marginal sides (Billi *et al.*, 1991). The former facies is made of clayey-sandy silts, with frequent sand levels containing lignitiferous beds in their middle-upper part; the fan delta facies, in contrast, is made of coarse pebbly deposits passing to channelled sand and pebble. The lacustrine and palustrine sediments are represented by alternating sand and silt levels, grouped in the 80-90 m thick Montevarchi Succession.

The third phase marks the filling of the basin and is separated from the second one by an erosional event, which is now known as a significant one as it represents an extended gap, whose duration still needed to be defined until magnetostratigraphy provided a date for its long duration (see in chapter 4). A fluviatile facies, the Monticello Succession, crops out in the axial zone, with alluvial fan sediments of the Ciuffenna Succession (Fig. 2), in the vicinity of the Pratomagno Ridge and mainly in its south-eastern edge. In the wstern bank, indeed, the corresponding facies has released a rich fossil fauna.

3.2.1 The early lacustrine facies in the Santa Barbara profile

A direct view of an outcrop in the open mine of Santa Barbara is shown in Figure 3 and illustrates the full extent of the Meleto clays, which were removed for quarrying the 15 m thick lignitiferous level. In the marginal area of the present view, the lignite seam directly lies on the arenaceous basement, which is exposed on the left-hand side of the picture as the wall of the basin at the foot of the Chianti Mts. In the background, about 1 km away, the lowermost sediments are exposed, with the Spedalino gravel and sand derived from the Oligocene-Miocene deposits of the basement, in which few fine-grained limy beds were also sampled for magnetic stratigraphy and palynology.

Farther off the margin, a few meter thick level of clay underlies the lignite seam and represents the beginning of the lacustrine sedimentation. So, this facies shortly precedes the palustrine one of the lignite-bearing level. The rapid accumulation of the latter, then, quickly moved back to the shallow-water lake deposits in the Meleto area and in the extreme north-western edge of the basin.

The 156 m section in the foreground of the picture (Fig. 3) is in the clays above the lignites and was sampled for magnetics avoiding the more sandy beds; the one in the background was sampled for palynology a few years earlier, for nearly 300 m from the base. The lower part of the sequence, beginning with the aforesaid levels of the basal gravel and sand and nearly a half of the lacustrine clay, is entirely dominated by the pollen of warm, humid forest vegetation typical of subtropical to warm-temperate climates (e.g. *Taxodium/Glyptostrobus* type, *Nyssa, Engelhardia*, Arecaceae, *Itea, Symplocos, Cephalanthus*, Clethraceae, Cyrillaceae, *Myrica, Carya, Quercus, Carpinus, Ulmus, Zelkova*). The basin, after this phase corresponding to the development of a bog, moved toward cooler conditions, with some fluctuations, leading to an expansion of cooler forest; the herbs (including the steppe flora) remain a minor component. Then, near the top of the Meleto Clays, the subtropical forest almost vanished, giving way to a great expansion of the coniferous boreal forests (with a large component of *Picea*). This record is correlative with the Reuverian of Zagwjin (1960).

The thickness of the lithologic profile is reported from the section measured for the magnetic stratigraphy, which was correlated with that for the pollen profile by several markers (Fig. 2). It is formed by the clay and lignite seam, which were sampled in the cores of two drilling bore-holes, overlain by a thinner level of siderite before the next lignite seam; then a thick pile of silt extends upwards until the sandy beds begin to increase in thickness and frequency, progressing with the lake filling. These beds are recognized in short sequences from several sites but their total thickness is still tentative.

3.2.2 End of the Castelnuovo cycle up to the Rena Bianca sand

The time span for deposition of the San Donato sand overlying the Meleto clay and of the Rena Bianca sand is questionable, lacking adequate reference of fossil finds and sufficiently long exposures; only recent cuts for quarrying evidenced the unconformity of Rena Bianca with the underlying sand. This led to the separation of these two sandy units, which were earlier assumed as two different facies of the sand body separating the first lacustrine cycle from the second one. Therefore, the short reversal measured in the lowermost Rena Bianca unit is interpreted as the Gauss/Matuyama boundary (Fig. 2), and no more associated with the San Donato sand as previously reported (Albianelli, 1995; Albianelli *et al*., 1997; 1999; Cioppi & Napoleone, 2001). In the San Donato sands, instead, a strong resurgence of the warm forest is recorded by pollen, while at the base of the Rena Bianca sand, i.e. at the Gauss/Matuyama boundary, a drastic change has marked the withdrawal of almost all the forest taxa, leaving a profile dominated by herbs including a very large component of *Artemisia*. Above this, but still in the earliest Matuyama, a great increase in the warm forest taxa and *Cathaya* as well as a strong reduction of steppe elements are recovered. This phase can be correlated with the first glacial/interglacial cycles following the onset of the Arctic glaciation reported at 2.6 Ma and the Praetiglian of Zagwijn.

An unconformity between Rena Bianca and the overlying series was never found until the latest intensive quarrying of the Rena Bianca sands has exposed their contact. The new silty facies is the very beginning of the Terranuova unit in the Montevarchi cycle, leading thus to the connection of Rena Bianca with the second lacustrine sedimentation (Magi, unpublished data; Ghinassi et al., in manuscript) This implies that most of the tilting of the Meleto sand unit occurred before deposition of the Rena Bianca, i.e. in the very short time span preceding the Gauss/Matuyama boundary, and the rest took place in the longer interval before the new phase placed at nearly 2.1 Ma (Fig. 2). The pollen record there evidenced -at the Gauss/Matuyama boundary- the presence of an arid climate vegetation (Bertini, 1994; Bertini & Roiron, 1997). Therefore a wind blown origin for it was supported by the dates of the scanty interbedded silt levels at a time when the ice rafting of the Pliocene had already started (Shackleton *et al*., 1984). From the (lower part of) Rena Bianca presumably comes a single vertebrate fossil, the mastodont skeleton studied by Nesti (1825) but reported without any account on its location.

3.2.3 The Montevarchi cycle in the Faella pit section

The lacustrine and palustrine deposits of the Montevarchi Sequence mostly lie in flat bedding with an average thickness outcropping for 80÷90 meters, which is almost wholly included in the section of the Faella pit (Fig. 9), and its magnetostratigraphic profile is reported in Figure 17. They are subdivided into three lithostratigraphic units, the first being represented by 30÷35 m of prevailing sandy silts and sands, the Terranuova silt. The second one is a 20÷25 m thick horizon with peat or lignite and clays rich in organic matter, and with silt and sand interbeds, the Ascione clay. The third unit is a ca. 30 m thick sequence mainly of sand, the Oreno silt and sand, which also closes the lacustrine deposition in the central area of the basin.

The surveyed sequence exposed in the Faella pit, about half a km southwest of the Faella village and on the right bank of the Arno river, is ca. 70 m thick. In Figure 9 most of its extent is shown in a fresh section (Fig. 9A), starting at ca. 150 m level and slightly above the base of the present quarry (143 m). The lower sediments reach an elevation shortly above 185 m, and consist partly of the Terranuova silt and the entire Ascione clay, while in Figure 9B the overlapping portion of the Ascione unit extends in the Oreno silt and sand, which reaches 207 m in a short section further in the background. The actual thicknesses of the lithology profile are reported in the magnetostratigraphic profile Albianelli et al. (2002a), and reach 134 m at the base of the Faella section (Napoleone & Azzaroli, 2002). On the right-hand bank the horizontal Montevarchi sediments are overlain with a small angular discontinuity by the silt and sand of the successive sequence, and upstream (the south-eastern edge of the basin) the fluvial regime deposited the basal Laterina gravel (Fig. 2). The same gravel marks the unconformity of 15°÷20° dip, due NE, on the left-hand bank, although in the area NW of Bucine it seems to lie on the intermediate unit (Ascione) of the Montevarchi sequence, possibly with a minor Oreno level (Fig. 10).

In the Faella section, the Terranuova silt is represented by 25 m of mixed levels of more clayey and sandy grey silt, sometimes maculated and often bioturbated and pedogenized, and by sand with variable lime content, in widely extended flat beds. Channelled sandy bodies are also present. Some 20 m thick peaty clays of the Ascione unit overlie the Terranuova silt. Brownish to grey-greenish clays alternate in beds of various thickness from few cm to some dm; interbeds of sand and silty-sand also alternate with a similar variable thickness. About 25 m of the mainly sandy Oreno unit are exposed in the upper section, with thicker beds of sands also containing some lignite seams in a coarser sand-to-pebble facies which is usually rich in fossils. Channelled bodies are here more frequent. A similar sequence was described by Cocchi (1867) on the opposite hill of Monte al Pero, across the Faella creek, and correlates with the lowermost Faella profile.

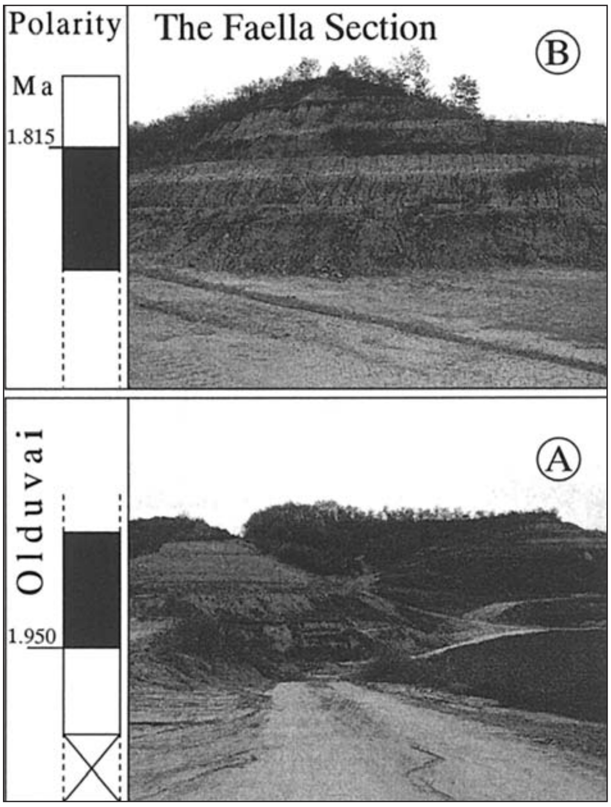

Figure 9 - The outcrop of the Montevarchi sequence is better exposed in the Faella clay pit. The profile for the lithology is controlled on the detailed survey of the area (Magi, 1999), and that for the magnetic stratigraphy is the composition from the sampled sections shown after a fresh cut: in A the lower portion reaches 185 m in elevation, and in B the upper one is exposed, but not up to the end of the sequence, which was sampled up to 207 m level in a short section slightly beyond the peak (Modified, after Albianelli *et al.*, 2002a).

In the present section, then, the Ascione clay is fully represented while the Oreno unit is interrupted, partly because its sand was removed for industrial works. A close analogy of this sequence with the one brought to light at Tasso (Fig. 10), nearly 10 km south of Faella, was found while surveying the outcrop for the new railroad tunnel. Its sedimentary sequence showed the Ascione and Oreno units as at Faella. The sedimentologic recognition on both sections led to closely correlate the upper Ascione unit and basal Oreno, and also drove more attention to the same units exposed in the Matassino pit, 2 km away and closer to the Arno river.

Even if palynological sampling was carried out in several sections, documentation of vegetational changes is less complete than in the Castelnuovo succession and less continuous (Bertini, 1994; Albianelli *et al.*, 1995). In fact the dominant silty and sandy sediments are generally barren or nearly barren of pollen and spores; in a few cases a high spore abundance along with *Concentricystes* seems due to stream concentration. Palynological data show a progressive reduction of subtropical/warm-temperate taxa that are mainly represented, although discontinuously, by *Cathaya* (plus *Pinus haploxylon* type) and *Taxodium*. A sequence of steppe-forest alternations, indicative of well established glacial/interglacial climatic cycles is recorded. Steppe assemblages are characterized by non-arboreal pollen (mainly Asteraceae included *Artemisia*, Poaceae, Cyperaceae); forest assemblages by thermophilous arboreal pollen (mainly *Quercus, Carya, Carpinus, Pterocarya, Ulmus, Zelkova*).

In particular at Matassino, in the level beds from the Poggio Rosso fossil deposit to the level of Nesti's rhino, a glacial-integlacial oscillation is recorded. In the upper part of the Oreno silt and sand, at the Tasso tunnel section, a significant increase of the herbs percentage (up to 89%) is measured; it is represented mainly by Asteraceae Cichorioideae, and marks a cold and dry phase correlated with the beginning of the Eburonian of

Figure 10 - The trench opened for the artificial tunnel of the new railroad Roma-Firenze, yielded the magnetostratigraphic profile shown by the side, and used with the previous one of Faella for reconstructing the magnetostratigraphic reference section of Figure 16 (Modified after Napoleone *et al.*, 2001c).

Zagwijn in northern Europe. This trend toward aridity coincides with a partial drying of the basin and a more frequent input of arenaceous sediments.

3.2.4 The third cycle: Cava Gori and C. Minuto pits, on the western bank of the Arno River

This sequence is rather thin. Its base is formed by a 6÷8 m thick gravel bank in the south-western edge of the basin, and by an equivalent sand bank more to the north. The gravel in the southern outcrops generally overlies the clay unit (Ascione) of the Montevarchi sequence, while the Oreno sand is lacking. This is the case with the section in the Cava Gori pit, which was thoroughly sampled in the occasion of new outcrops which uncovered a 20 m deep well of Roman age (Fig. 11).

The Ascione clay underlying the basal gravel bank is tilted 17°; a 4 m thick sand covers the gravel and is followed by 5 m of silt and 4 m of clay rich in organic matter. On top, the coarse material of the final basin fill had been already removed in C. Gori, but at Pogi, near Bucine, it released a rich fauna. Downsection, a slice of the Ascione unit is underlain by the Terranuova silt of several meters thickness; the full profile is reconstructed for nearly 40 m, almost half with Terranuova silts and half with Ascione clays but either one covered by a few meters and with a relevant displacement in the mid section. The upper lithologic profile fits that obtained in the reduced sequence shown by the side of the magnetic stratigraphy in C. Minuto (see Fig. 17). The latter is very similar to the uppermost sequence of C. Gori, although with minor changes in thicknesses, due to the irregular fluvial deposition. The gravel bank at the base is of comparable thickness, but the clay silt overlying it and containing the elephant bones reported earlier are of reduced thickness due to the nearly complete absence of the uppermost level rich in organic matter. The widespread closure horizon is also present, with a thin bed of sand on top and the gravel, just exploited by the quarrying but still visible in the vineyards by the side.

4. MAGNETOCHRONOLOGY OF THE DEPOSITIONAL RECORD

The magnetostratigraphic dating of the Upper Valdarno sequence was first applied to calibrate single sites with known position of fossil finds, either belonging to actual recoveries (Torre *et al.*, 1993; Albianelli *et al.*, 1997; 2002a; Napoleone *et al.*, 2001b) or to the Museum old collections reappraised from the information in the automated catalogue (Cioppi & Napoleone, 2001; Napoleone *et al.*, 2001a). A thoroughly revised dating of the main Museum collections is reported in a paper submitted in January 2001 to the Bulletin of the Italian Paleontological Society and still unpublished (Napoleone *et al.*, 2001c). These Localities were placed in the new magnetostratigraphical asset, which was by the way still devoid of several results recently acquired and only now reported herein, while fresh outcrops let to better sample new sites with better behaved magnetic properties. One such sites was the Poggio Rosso profile, where even the more sandy samples of the series led to measure the acquisition of magnetization under strong applied fields as shown in the next section. The faunal site of Matassino, in the same profile, was the prominent Locality re-placed once the channelled nature of the previous section measurement produced the misleading value of its age previously reported (Torre *et al.*, 1993). Finally, the filling series was investigated thouroughly and its late Matuyama age is the newest result. This leads to an important role in the history of the growth of the Appenine range that will be plaid by the complete range of dates now recorded, the longest series in the continental deposits of the Apennines. Last but not least, all recent data were made possible by the new recognition in the sedimentary sequence of the unconformity between the San Donato and Rena Bianca sands which permitted to place the Gauss/Matuyama boundary in the basal Rena Bianca and identify in the overlying silts the short Reunion chron (Fig 2).

The tabulated data from the measurements yielded the results here illustrated in a few figures by some representative diagrams, in order to focus the main aspects in the rock-magnetic properties associated with the Upper Valdarno lithologies, which provided the fundamentals for its magnetostratigraphy.

4.1 Magnetic properties of the rock types

The problem of stability of the magnetic signal is of major concern in studying sedimentary sequences of rapid accumulation, as experienced in the present deposits on continental slopes, for the bacterial activities

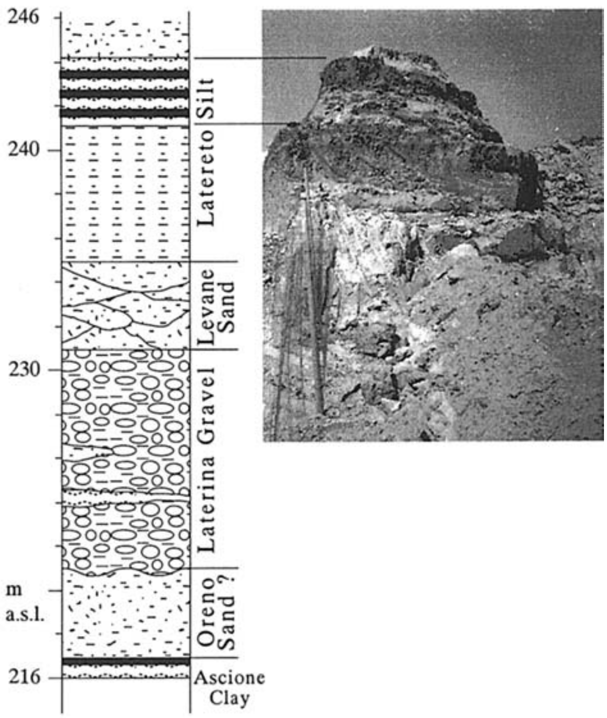

Figure 11 - The short sequence of the third depositional cycle is shown in the outcrop of the Cava Gori sand pit during the excavations for recovering the old water well of Roman age. The full sequence is represented in the profile by the lithologies surveyed in the walls of the pit and its outskirts. The base of the profile is formed by the Ascione clay of the underlying Montevarchi series, which was surveyed for almost 40 meters in a partly covered outcrop in continuity with the present section (After Albianelli *et al.*, unpublished data).

which reduce the iron oxides to sulphides. These can be very unstable under laboratory tests, by either changing with temperature into another mineral phase (magnetite) or being incapable of maintaining a regular track of their natural remanent magnetization (NRM) under applied fields with alternative currents (AF). Such a behavior was shown by the most representative early Pliocene rock type of marine facies, in southern Sicily, and by the lacustrine clay very rich in organic matter, close to the lignite seam at Santa Barbara (Albianelli, 1995). These occurrences are enhanced by the following three main precedures.

Saturation of the isothermal remanence (IRM), NRM stepwise demagnetization and the Curie balance curves are among the more usual ones used for evidencing the basic rock-magnetic properties. With the first type of experiments, the degree of IRM acquired along the three axes is shown by its demagnetization curves, which remark the low coercivity of ferromagnetic minerals. In the second one, visualised in Zijderveld's vectorial plots, the trend of the directions converging to the origin of the axes, while demagnetizing the rock sample, are indicative of a stable primary magnetization, not influenced by the secondary ones. With the Curie-balance experiment, the acquisition of the remanence by a rock sample is enhanced while it is cooling in a strong applied field after its complete demagnetization with stepwise increasing temperatures.

These tests were applied to the surveyed sections, and their lithologies showed a variety of different behaviors. Sometimes such changes assumed a wider range within the same sequence rather than between the three main depositional series. Depending on minor changes in the mineralogical content of their ferromagnetic particles, and related alterations suffered during their geologic past, the main types will be shortly illustrated in some examples for their good rock-magnetic properties on which the magnetostratigraphic interpretations are based.

4.1.1 Meleto clay in the Castelnuovo cycle

As for all the other units, the basic lithology formed by silt is varying in a wide range of more sandy compositions: the stage of a complete sand bed is reached with marked discontinuities within the Meleto clay. The most common representative of the rock type is here shown for only some of the measured characters. For example, in two samples of the Meleto clay, different sulphide content can be demonstrated in beds overlying the lignite seam, one (SB -12) less than 5 m above its top and one (SB 27) 44 m higher up (Fig. 12). The magnetic remanence is steadily decreasing versus temperature, to ca. 300÷400 °C, above which a remanence is added by new-formed minerals, essentially magnetite. The occurrence of sulphur compounds is common in marine and continental sediments of recent geologic ages and of rapid accumulation, depending on the redox conditions at the bottom surfaces where anoxic conditions lead the bacterial activity to reduce iron oxides of the magnetic minerals. This behavior was particularly diffused in the marine carbonates of the early Pliocene sequence in southern Italy, which showed a very unstable behavior and the diagrams for the Curie-balance experiments enhanced peaks even more prominent than the ones here reported (Albianelli, 1995).

Also the NRM reveals the presence of such perturbations in the rock composition, and is evidenced in the Zijderveld plot where the directions are projected in the vertical plane Z (Inclination) and in the horizontal one H (Declination), for every step of the demagnetization procedures. A one-component primary magnetization would show a straightforward trend to the axis origin, while perturbations at various demagnetization steps would enhance additional vectors which are being removed. The presence of a new magnetic phase, as in the previous example, would make the directions completely out of the steady demagnetization pattern: for this reason the values for a sample (SB -1) 11 m above the previous one (SB -12), are not plotted for temperatures higher than 300 °C, as the direction is suddenly diverging

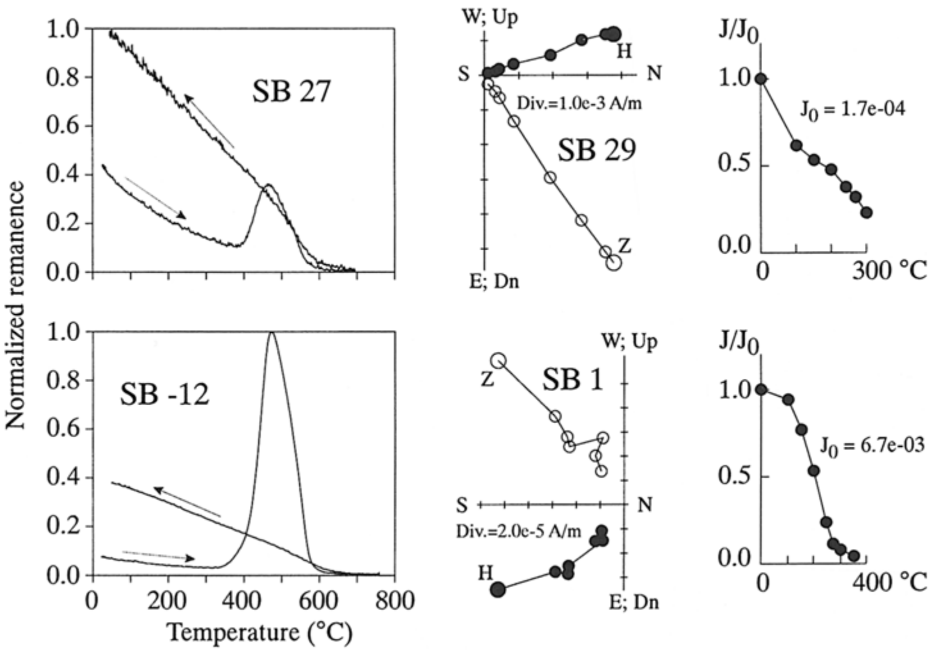

Figure 12 - Diagram of the Curie balance measurements carried out on two samples of the Meleto, one (SB -12) from a level very close to the top of the lignite seam and another one (SB 27) some 40 m higher up. Their magnetizations are decreasing at increasing temperatures, until a rapidly increasing value is measured around a critical range of 300÷350 °C, interpreted as a new magnetic mineral phase produced by oxidation of the sulphide contained in the rock. This content is markedly higher in the levels closer to the organic material, strongly decreases at 40 m level, and is absent farther up in the series.

and the susceptibility sharply increasing. In contrast, the level bed at 46 m (SB 29) is devoid of these alterations.

The latter type of diagram is available for every sample, as in all of them a number of demagnetization steps were used in order to control more accurately the changes measured, up to the highest step before alterations could interfere with the normal trend, or to the lowest magnetic moment detectable. The latter was that of the magnetometer of the ETH Paleomagnetic Laboratory in Zurich, and the measured signal provided fully reliable intensities for magnetizations in the range of 10^{-8} uem/gr.

4.1.2 The Montevarchi units

The few levels with fine-grained limy beds in the coarse grain unit of San Donato sand and finer sand in the Rena Bianca usually enhance low NRMs, which rapidly decay to undetectable values not further than 300 °C. In the overlying Montevarchi sediments the general characters of the rock magnetic behavior are similar to the Meleto types, with a more common occurrence of oxidized material of higher coercivity, able to reach higher blocking temperatures in samples with higher silt and sand contents. The experiment for IRM saturation in the orthogonal directions, with its demagnetization, adds one more evidence of different behaviors of the carriers of the magnetization. Two examples of this test are also shown (Fig. 13).

For each of them, two diagrams show the acquisition of the magnetization and its differential removal, to represent the behavior of a clay (GT 13) in contrast with a silt (F 48). In the first two diagrams on the left, the magnetization rapidly increases, in the range from 50 mT to 200 mT of an applied field up to 1 Tesla (T). The upper sample represents the saturation for the low coercivity minerals, which is normally attained in that range; the lower sample represents those of high coercivity, which do not reach the saturation, requiring stronger fields (usually up to 5 T, or more). On the adjacent two diagrams , the three components of the magnetizations acquired show their decay curves, which are in the great majority of the measured samples showing low blocking temperatures for minerals with low coercivities. In sample GT 13, the component acquired up to 100 mT contains the total amount of the magnetization and practically nothing is left to the other two. The only one blocking temperature is interpreted to be that of magnetite as the sole carrier of the magnetization. The opposite occurs in sample F 48, with a first branch of the diagram relative to a low coercivity mineral phase, and a superimposed one not reaching the saturation up to 1 T. The minor phase showing a low blocking temperature is likely associable to other ferromagnetic minerals including sulphides; another one not yet destroyed at 600 °C, is interpreted as hematite. The same properties are evidenced by the related demagnetization curves of NRM, on the right hand diagrams, for two samples, one at the same level GT 13, and the other, F 45, with the same lithology as F 48.

Another example (Fig. 14) shows two samples from the level beds close to the Poggio Rosso fossil site, whose NRM is demagnetized by thermal treatment and by alternative fields AF. The fairly straight pattern of the AF curve in also an indication of the absence of sulfides, whose instability produces random directions

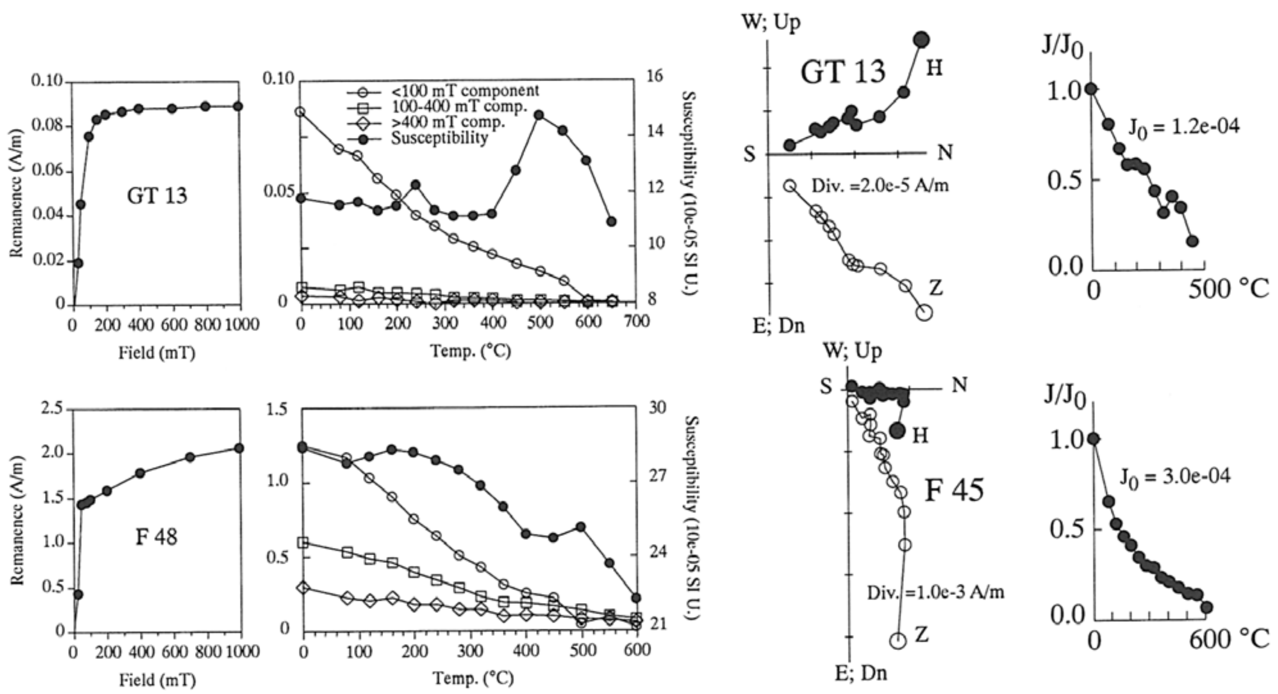

Figure 13 - An example of the IRM saturation for two samples from the Tasso section (GT 13) and Faella section (F 48); their remanence acquired on the three axes is thermally demagnetisedin order to show the blocking temperature of the minerals associable to different coercivity ranges. The next two diagrams on the rigth show the NRM demagnetization for two similar samples, plotted in the Zijderveld polar diagrams.

during successive demagnetization steps.

4.1.3 The uppermost units

The final deposits of the Upper Valdarno, exposed at the Cava Gori, are represented by a sample of the uppermost silty clay (CGN 14), which is compared with a reversed one from the unconformably underlying unit of the Montevarchi sequence (Fig. 15). Both levels are made of the same material, although their dates are nearly 1 my apart, as shown in the next section. The silt is in both cases more clayey and peaty, and the samples are taken from very fresh outcrops. The reversed one, CGV 33, shows the removal of a weak component with normal magnetization, usually due to the present normal polarity acting for the recent geologic past, which is rapidly cancelled in the initial demagnetization steps.

Both sand levels and the thin beds of fine sediment in the lower half of the Cava Gori profile (Fig. 11) revealed poor rock-magnetic properties, with their NRMs very weak and demagnetization curves of rather unstable directions, indicative of a transitional field, which was instead better recorded in Cava Minuto with a decise reversal (Fig. 17).

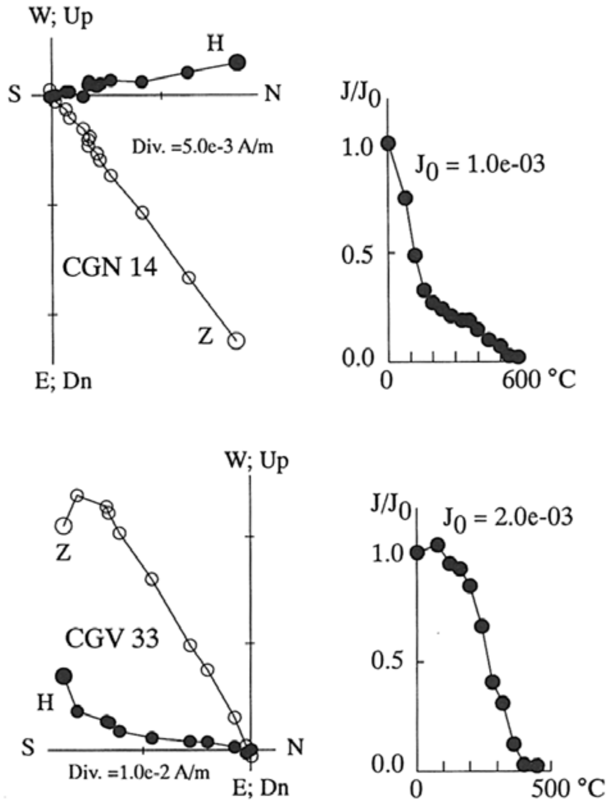

Figure 15 - In the sediments of the third cycle, at the Cava Gori sand pit, a sample with reversed magnetization is thermally demagnetized, in the same way as the previous samples, and is compared with a sample of normal magnetization collected in the underlying outcrop belonging to the Ascione unit.

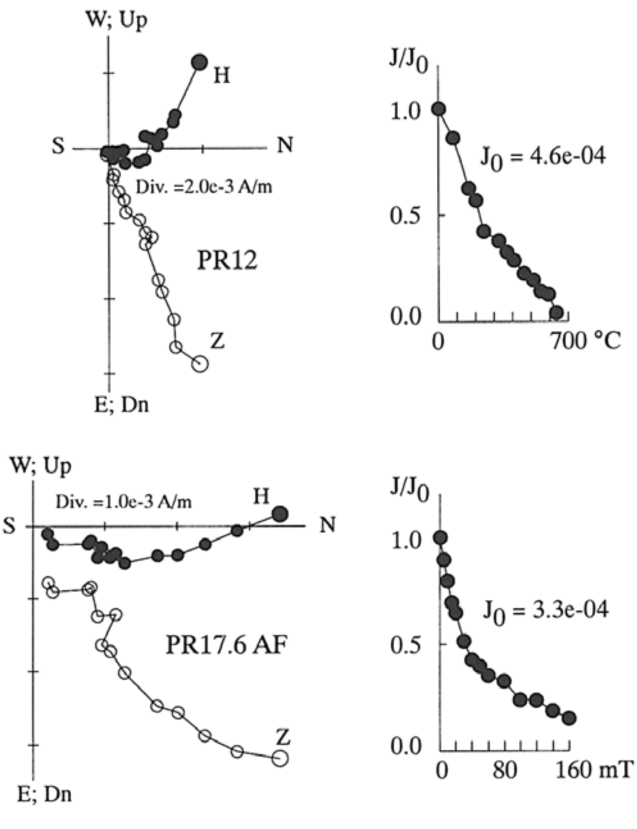

Figure 14 - At Poggio Rosso, in the series of the second sedimentary cycle, the demagnetization of the NRM is shown by applying either the thermal treatment to a sample of sandy silt shortly above the fossil site, or that of the alternative fields AF applied up to 160 mT. Both treatments destroy stepwise their remanences, in order to enhance any superimposed field fixed after the primary one, which is well preserved in the original directions.

4.2 Magnetostratigraphy in the reference sections

The sedimentary reconstruction of the basin is now being completed, and it led to the selection of the sections for the paleomagnetic surveys, on both sides of the Arno bank. On the left bank, the first cycle of sediments is displaced by a significant lowering on its eastern flank so that it is exposed only in the western bank, from the gravel and clay underlying the lignite seam to the Meleto clay, and up to the Rena Bianca. The dates there measured mark the steps from 3.3 Ma to 3.1 Ma, up to 2.1 Ma, respectively.

The full sequence of the second lake is represented on the right bank of the Arno river by generally flat beds, except the lowermost ones which are not exposed; it spans from nearly 2.1 Ma to 1.7 Ma and covers almost completely the Montevarchi series. In the left bank, this sequence is partial, interrupted for long intervals and dipping 15°÷20° to the NNE. The unconformity cuts there nearly half of the Montevarchi sequence, as the basal gravel of the third cycle directly overlies the Ascione unit, while the lower series of the Terranuova silt is present only with its upper portion.

The third cycle has been surveyed in two outcrops on the right bank and two on the left bank, all in quarries exploiting gravel and sand. Its basal gravel yielded on both sides reversely magnetized levels in the few limy beds, but followed by the normally magnetized ones in the silty sequence of the western bank.

4.2.1 Dates from 3.3 Ma to 2.1 Ma, Santa Barbara and Rena Bianca sections

The gravel in the earliest sediments is devoid of measurable levels, except for few thin silty beds with reversed polarity. The few-meters clay level above it was no longer exposed at the time of the paleomagnetic survey, and the section for magnetic stratigraphy was sampled in the outcrop starting above the lignite-bearing clay directly lying on the basement. It was later completed downwards by cores drilled in two bore-holes, less than 100 m away from the outcrop, towards the inner lake, where the lignite seam is followed downcore by a few meter thick clay level overlying the sandstone basement. A normal polarity is measured in the lower core, and a reversed one in the higher clay and in part of the lignite, while further up the rest of the lignite and the clay yield again a normal polarity. This persists until the end of the section. Its magnetic stratigraphy is interpreted as the latest Gauss normal polarity following the Kaena reversed one (Albianelli *et al.*, 1997). Above the lignite-bearing level, the series continues some 400 ky in the Meleto clay (Albianelli, 1995). In fact, from the magnetostratigraphic constraint of the Kaena boundary the duration of the sequence was calculated by spectral analysis of the magnetic record, which marked its continuous changes in the Milankovitch index-forced sedimentation, to last 60 ky before the end of the Gauss chron. The cyclicity-driven changes are discussed elsewhere (Napoleone & Albianelli, 2002), and they also date the onset of the alternating vegetational associations of warmer and cooler climatic intervals, starting in the mid Pliocene and preceding the ice-rafting of the Glacial-Pliocene (Shackleton *et al.*, 1984; DeMenocal & Bloemendal, 1995).

The overlying sand unit (San Donato sand) is not in continuity with the profile of Figure 3, and yields a normal polarity in the few measurable silt levels. Further up, two levels with a normal and reversed polarity are measured and labeled as marking a short interval containing the Gauss-Matuyama boundary. This latter was felt to be positioned only when the cyclostratigraphic processing of the magnetic signal through the time series of the Meleto clay yielded the full extent of the latest Gauss, except the last 60 ky before the boundary. These results were reported in several meetings, from the IAS of 1998 to the GSA of 1999, the Euromam in 2000, and on the SEPM Integrated Cyclostratigraphy in, 2001, for which the final study is in the press (Napoleone & Albianelli, 2002).

In the wind-blown sand complex above the San

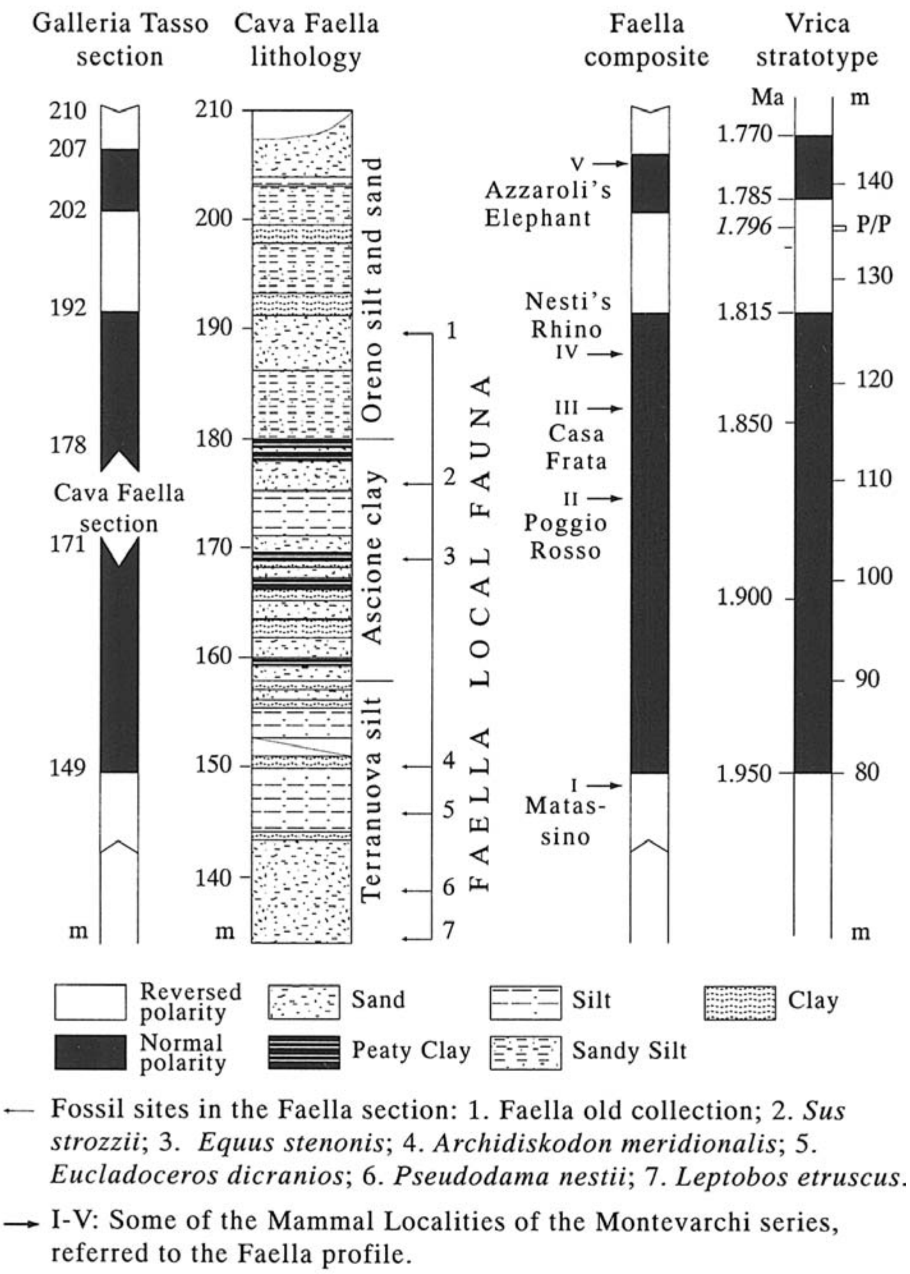

Figure 16 - The magnetostratigraphic profile of the Faella clay pit, valid for the whole Montevarchi series. The lower portion is provided by the Faella section, and the upper part, by the Tasso tunnel section,. The lithologic profile is that of Cava Faella, to wich the positions of the Museum collection of the Faella local fauna are associated. Thus, the Localities of the Montevarchi Series are calibrated to the Faella composite magnetostratigraphy and the Vrica stratotype is reported for reference.

Donato sand, few levels were useful for sampling. The final figure is still under discussion, but the results support the occurrence of a short Reunion chron, just above the end of the Rena Bianca sand and in the following Montevarchi succession. This updated version is reported here (Fig. 2), and a more detailed profile is reproduced in Figure 18.

4.2.2 The interval 2.1 to 1.7 Ma in the Faella section

After the Reunion, recorded above the condensed series of wind-blown sand, the sedimentary history and its continuity with the overlying sequence in the Matuyama has not yet been fully recognized. In the western bank, the Rena Bianca is overlain by the Terranuova silt for a few meters; in the eastern bank the Terranuova silt extends over a thickness of several tens of meters, but the contact with the underlying unit has never been uncovered. This disconformity has an estimated duration of less than 100 ky, after the magnetostratigraphic reconstructions made so far on the outcropping sections, while more data from a bore-hole core extend the series few ky earlier in the reversed magnetozone (Albianelli & Napoleone, unpublished data). In fact, the earliest fossil is dated 1.99 Ma at Faella while the Terranuova silt extends at least 20 m below it in the outcrops, and possibly 20 more meters, as cored in the bore-hole drillings at Terranuova. This sequence, at the rates of deposition calculated by Albianelli et al. (2002a) and discussed in Napoleone and

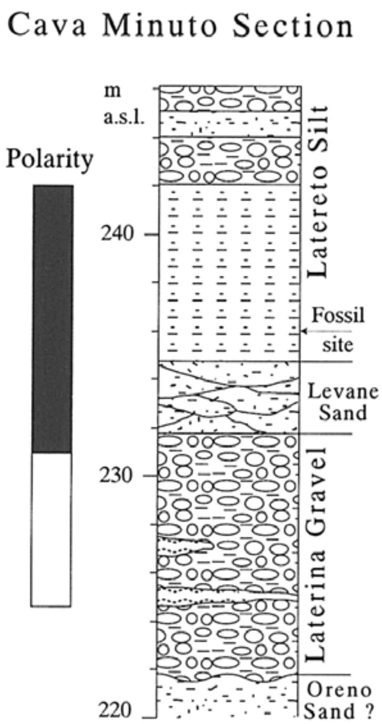

Figure 17 - At Cava Minuto, 1 km away from Cava Gori, the sediments of the third cycle are represented by a less complete sequence, but in the basal gravel two lenses of silty clay are better developed than in the C. Gori and their magnetization is with a reversed polarity. Above the gravel unit the polarity is normal as in C. Gori (After Napoleone et al., unpublished data).

Albianelli (2002), would add ca. 100 ky, and therefore the earliest date be extended to 2.1 Ma. From the bottom, the identification of the Reunion leads to a date of 2.24 Ma (in the time scale of Baksi, 1993) as a lowermost limit, with some more space available to shorten this 150 ky gap, which becomes much shorter with the date of 2.14 Ma used in the scale of Berggren et al. (1995).

The geological setting of the Montevarchi complex indicates a wide distribution of its three units, which are exposed frequently by quarrying operations. A nearly complete magnetostratigraphic succession is reconstructed on the right-hand bank. From the missing contact with the Rena Bianca sand, its lowermost exposures are at the Arno level, and not in continuity. They are overlain by the Faella section, the longest and most continuous one, forming the profile for the central lake sequence (Fig 18). In the western bank, the Montevarchi beds are interfingered with the upper levels of the aeolian sand younger than the Reunion, therefore not reaching a date of 2.14 Ma. Also the upper limit is not calibrated, the youngest date being measured in the eastern bank shortly after 1.77 Ma, in the Oreno sand; some more 50 ky may be expected in the last 20÷30 m of the highest sequences, considering the sedimentation rate calculated by spectral analysis of the continuous magnetic record (Napoleone & Albianelli, 2002) and the average rates shown by the detailed magnetic stratigraphy (Albianelli et al., 2002a). Therefore a date not younger than 1.70 Ma would be reached.

Significant geochronologic results relate to this interval. Downsection from the base of the Olduvai at 1.95 Ma, the earliest fossil occurrence dates 1.99 Ma, with the new recovery in January 2000. The top of the profile did not yield any positioned fossil site and also the end of the Olduvai was better defined in the Tasso tunnel section. Therefore, the magnetostratigraphic section is produced from the composition of the two (Fig. 16), and adapted to the profile shown in Figure 18.

The entire sequence also provides the base for correlating several profiles surveyed in the Montevarchi units, usually with an accuracy within 5 ky. The most important one is the Matassino section where the base of the Olduvai was first identified (Torre *et al.*, 1993). For its geochronologic implications, see the discussion in Napoleone *et al.* (2001b). The section of Monte al Pero, adjacent to the Matassino section, was surveyed from top to 20 m above the ground-level of the Matassino clay pit; only one normal polarity was measured, as occurred also with the normal polarity in the Poggio Rosso section. Both sequences were correlated with the Faella section (Fig. 16). More implications arise after the new results from several cores drilled in the upper sequence and at its base, thus extending the magnetostratigraphic profile, downward in the Terranuova silt and upward in the Oreno sand, but details on these data will be reported elsewhere (Napoleone et al., in preparation). The preliminary results extend only by a few meters the lower profile in the reverse polarity, but they produce important implications in the upper profile because a normal polarity is measured for several meters on top of the sequence. This part is recognized in the Latereto sand of the upper series, discussed in the next section.

The total time span of the measured series ranges from nearly 2.05 Ma to 1.75 Ma, while an estimate for the remaining parts not yet found in the exposures would add some 50 ky to both extremes.

4.2.3 The upper series at Cava Gori and C. Minuto

The sedimentary cycle above the Montevarchi succession started again without any striking gap recorded by sedimentary or tectonic discontinuity. The faunal record was totally lacking in the eastern bank, except one frontal skull of a bovid, while on the western bank the faunal record occurred only in the uppermost filling, on the surface. On the right-hand side a reversed polarity was measured at Cava Specchiano, and a normal one on the opposite bank, at Cava Gori in the Monteleone area. The first magnetic polarity dating is from the fine grained levels in a less than 10 m thick gravel deposit. It stands as an isolated reversely magnetized interval in the Matuyama, and a date for it was questionable; a moderately young Matuyama date was only reported as tentative (Albianelli, 1995; Cioppi & Napoleone, 2001).

In the Cava Gori profile, which also unconformably overlies parts of the Montevarchi series, the normal polarity measured in the sand just above the gravel, correlative with that of C. Specchiano and farther up in the Latereto silt, may imply a post-Matuyama chron (Albianelli & Napoleone, unpublished data). At present, this reversed Matuyama level is considered to shortly precede the Jaramillo or Brunhes chrons. It would imply that a lack of nearly 0.7 my or 1 my, respectively, affected the sedimentary record, beginning soon after the end of the Olduvai. The sequence is there tilted by 17°, and the magnetic stratigraphy of the profile reported in Figure 11, is used to reconstruct the comprehensive Upper Valdarno series (Fig. 18). An important date is added here by new results (Napoleone & Albianelli, unpublished data) from the analogous section at Cava Minuto (Fig. 17). This profile is a little shorter than at C. Gori, its lower sand level being actually missing; the basal gravel on the contrary contains two episodes of fine grained silt, which both yield a very stable reversed magnetization; above the gravel, the silt containing the fossil site and the remaining sequence show a normal polarity. This sharp time signal can be represented as in Figure 18 and its date should correspond to a post-Olduvaian polarity change, which can only be the Jaramillo or Brunhes chrons.

In such conditions the choice of any one of them cannot be solved because the basin fill is devoid of any further step; on the other hand, the previous results provide a fundamental date to reconstruct the history of the basin. The long time span implied in the previous considerations, during which no sedimentary record was preserved, ought to be recognized in the geological processes taking place in the basin and recorded in some way.

4.3 The summarised magnetic polarity sequence

A new magnetochronology has been brought about by the results discussed so far in this chapter and its comprehensive features better enhance several details (Fig. 18). Magnetostratigraphy of the thick first sequence interval yielded a date of ca. 3.3 Ma (at the Mammoth chron, C2An.2r) for the basal Spedalino gravel and pebbly sand, and ca. 3.1 Ma for the lignite seam, which began depositing shortly before the Kaena (C2An.1r). The succeeding clay sediments attained a variable thickness (100÷200 m), and their layers became progressively more closely interbedded with sand levels while approaching the Gauss-Matuyama boundary. The sequence was calculated to end at 2.64 Ma, shortly before that boundary (2.58 Ma), while the record of the short Reunion chron C2r.1n (2.15 Ma) has now

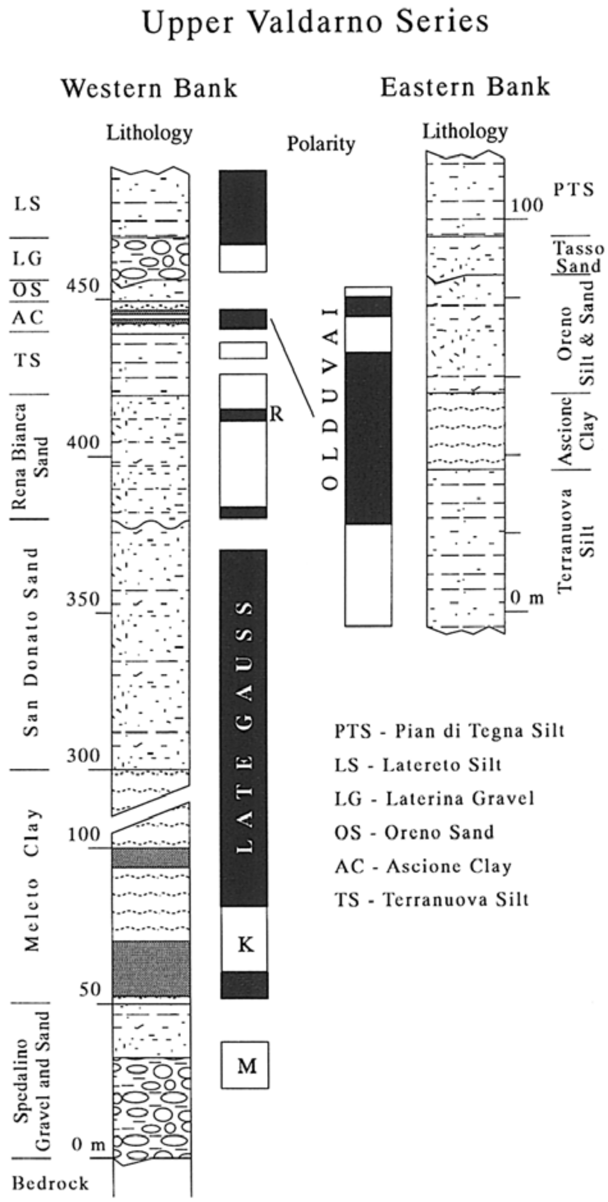

Figure 18 - The complete reconstruction of the lacustrine sediments is represented in the lithologic profiles from both sides of the Arno river bank. The first lake is represented only by the long sequence outcropping in the western bank; in the eastern side the exposures begin with the second lake, and are well developed. Correlation with the western bank is marked by the occurrence of the Olduvai chron and its underlying Matuyama; the former is interrupted in the Ascione clay unit, while the short polarity sequence above the unconformity is dated to the Jaramillo chron (or later, to the Brunhes). Its equivalent in the eastern bank has not been measured in the central area, and has yielded only one reversed polarity in the southern area, at Specchiano.

been found shortly above the Rena Bianca sand in one of its few exposures. The following Matuyama time is recorded in the lower Montevarchi silt, and the Olduvai in the overlying units. The late Olduvai however recorded an important event in the split polarity reversal, which is dated 1.815 Ma and 1.785 Ma in the P/P stratotype boundary (1.796 Ma), before the end of the chron at 1.77 Ma. The latest sediments are not calibrated by a polarity sequence, due to the short length of profiles, and the date near 1.05 Ma reported above is alternative to the one at 0.78 Ma. The litho- and magnetostratigraphic profiles are summarized in the two reconstructions made from the opposite banks of the Arno (Fig 18), while the previous magnetostratigraphic framework was reported for convenience in the introduction (Fig. 2).

The discussion on the dates for each faunal interval, for the ca. 2.5 my surveyed in the basin will follow below, while the results from cyclostratigraphy, reported in the references quoted above, mainly relate to the climate and sedimentary changes for these critical ages of the recent geological time.

5. DATES FOR THE UPPER VALDARNO FOSSIL VERTEBRATES

Most events of the Villafranchian age were recorded in this basin, and the dating of its sediments is related to calibration of the middle and late Pliocene and beginning of Pleistocene. Correlation with the bio-chronostratigraphy is updated to the revised one of Berggren *et al*. (1995), and calibration of the Pleistocene boundary is related to that of the Vrica stratotype (Van Couvering, 1997). An attempt at uniforming various stages of vertebrate associations in the Mammal Neogene (MN) age classification assigned the Villafranchian to the relative ages MN16 and MN17 (Mein, 1990). For the aforesaid reasons, Azzaroli (1995) split the MN16 in MN16a for the early Villafranchian and MN16b for the middle Villafranchian, pointing out that the major faunal turnover occur between the Triversa and Montopoli FU at the late Pliocene boundary (Azzaroli, 1983).

Whereas the faunas of Montopoli and Olivola - respectively of middle and late Villafranchian- were collected outside of the Upper Valdarno, from single pockets with a rich concentration of bones and a variety of species, the early Villafranchian fauna of Castelnuovo was dispersed, even if the few species lived for a presumably short time span within/or across the lignite-bearing level.

In contrast, the rich fossil-bearing Montevarchi succession is widely distributed and tightly constrained by several magnetostratigraphic tie-points, after a long gap occupied by the condensed series, which has now been dated to range from the Gauss-Matuyama boundary at 2.58 Ma to the Reunion at 2.15 Ma. The Montevarchi sediments extend from the vicinity of Incisa in the North-West to around Bucine in the South-West, with a length of over 20 km, and fossils are distributed in horizontal deposits ranging from approximately 130 to 230 m in elevation. The fossil-bearing levels lie in either one of the Ascione and Oreno units overlying the Terranuova silt, and in the latter as well. In the Terranuova silt , in particular, the fossils collected from the basal Faella clay pit at 134 m are calibrated before the Olduvai and correlated with the deposits retrieved in 1862 by Cocchi (1867), as emphasized in Napoleone et al. (2001c). These represent the earliest fossil finds, over 1 my younger than the fossils from the preceding Castelnuovo succession. The biochronologically youngest fauna of Tasso, elevated to the rank of reference unit (Azzaroli, 1977a; 1983), is believed to come from the upper levels. It is assembled by all unpositioned specimens from the old collections; only one site was reported by Bosco (quoted in Azzaroli, 1998) for two porcupine skulls at Le Strette, 183 m in elevation. Nearly the entire series of Montevarchi is now assigned by the magnetostratigraphic reconstruction to a late Pliocene age (Albianelli *et al*., 2002a); while the boundary of the Pleistocene is calibrated in the Oreno unit, at 195 m of the Faella composite section (Fig. 17).

The latest fauna, at the very end of the basin fill provided the greatest new results, i.e. a date for it is firstly reported herein. It is fixed at 1.0 Ma and replaces the previous age of late Middle Pleistocene by precise stratigraphical constraints for reconsidering the whole biochronologic history of the basin and its palaeoenvironmental reconstructions.

5.1 The early Villafranchian fauna MN16a at the Kaena/late Gauss boundary of 3.11 Ma

The fossil finds assembled in the Castelnuovo dei Sabbioni fauna (MN16a) were collected only in the lignite-bearing level, whose base is older than the beginning of the Kaena chron (CA2n.1r), at 3.11 Ma, and in the clay beds interfingered with the top of the lignite, at 3.04 Ma. A date shortly earlier than this boundary may be assigned, 3.07 Ma, with an uncertainty even better than ± 0.02 my, considering that the lignite seam could represent a rather short-lived event in the sedimentary record (Fig. 2). Its time span may be reconstructed by the magnetic cyclostratigraphy carried out on the Meleto clay series (Albianelli *et al*., 1999; Napoleone & Albianelli, 2002). The clay above the lignite-bearing level yielded an accumulation rate of 220 mm/ky, progressively increasing, up to 390 mm/ky on top; at that lower rate, a 15 m thick lignite bed would last 2/3 of 100 ky, and a rate only twice higher than that one for the clay would lead to the mentioned size of ± 0.02 my in the error bar on a date close to 3.11 Ma.

It is also reminded that the early Villafranchian record of the Castelnuovo fauna was classified as contemporary with the Triversa Faunal Unit from Villafranca d'Asti and the latter will be described in the next chapter. The calibration of the Castelnuovo fauna puts a tight constraint on the faunas of Triversa and Arondelli in Piemonte, the latter correlating with the other one in the Lower Valdarno provisionally taken as an undefined lmf assemblage, but dated quite younger than Triversa (to be discussed in next chapter 6).

5.2 Mid Villafranchian: the Mastodont in the early Matuyama, 2.58-2.15 Ma

Faunas of this age are labeled in the mammal classification as MN16b. Its reference Faunal Unit was the Montopoli association, not represented by an equivalent local fauna in the Upper Valdarno record, but highly significant for the major turnover it marked in the biodiversification of the terrestrial fauna in western Europe and southern Russia (Azzaroli, 1983; 2001). With the magnetostratigraphic calibration, it is established that during the mid Villafranchian age the Upper Valdarno record was mostly formed by subaerial deposits, for a more than 0.4 my time span (Fig. 2) and in a well established regime of glacial-interglacial oscillations partly recorded by the pollen distribution.

Thin limy beds within these wind-blown sands have recently shown the end of the reversed polarity alternating with the normal one, which leads to the recognition of the presence of the Reunion chron C2r.1n immediately above the transition to the silt of the following lower deposits (Albanelli & Napoleone, unpublished data). The only one finding of vertebrates, attributed by Azzaroli to possibly belong to this sequence is a nearly complete skeleton of a mastodont found in the vicinity of the Montecarlo convent, on the hilltop on the left bank of the Montevarchi basin. The fossil was excavated in early eitghteen hundred and was summarily described, without an exact indication of the site, by Filippo Nesti in 1825, who did not report on the stratigraphy of the Upper Valdarno in that occasion. In 1811, in contrast, he gave precise indication for the location of the rhinoceros of Poggio di Monte al Pero and of the geology of the Montevarchi deposits (Nesti, 1811). The *Anancus* of Figure 4 is from the Castelnuovo sequence but considered somewhat younger than the Castelnuovo dei Sabbioni fauna, although its recovery was not reported and location is unknown.

The Montecarlo convent is built on deposits of the second cycle, but not far West the hill slopes down and overlies deposits of the Rena Bianca unit. The skeleton may safely be assumed to come from the latter formation. It is practically complete (only the tusks are missing; in the exibition of the museum they were replaced). The specimen is of a large size, nearly 3 m high at the withers. It slightly exceeds the size of a mastodont from Valleandona in Piemonte, West of Asti, summarily described and figured by Capellini (1908). To judge from the shape of its pelvis, it seems to belong to a female. This famous specimen in the paleontological collections of the Museum of Firenze was ascribed to the mid Villafranchian, as it was last represented in the Montopoli fauna.

Another specimen of *Anancus* was reported in the Marchesa Paulucci collection, donated in the early 19 hundreds to the Museum of Firenze (Cioppi *et al.*, 2001); it consists of a tusk and a molar whose position is believed by Azzaroli at the base of the hill on top of which her villa is positioned at Sammezzano, on the right bank of the Arno, in the middle of the area of the Montevarchi terranes, but the fossil site cannot be better identified.

5.3 Late Villafranchian: faunas of Olduvai time dated 1.99-1.77 Ma

This mammal age is covered in the Upper Valdarno by the Montevarchi sequence which is represented by the outcrops on the eastern bank of the Arno forming the profile of the central lake (Fig. 18). The whole sequence is particularly well documented by the detailed dates of its finds, but it is unfortunate that the majority of fossils of the older collections, ca. 75% of the Upper Valdarno vertebrates in the Museum, do not bear an indication of the locality nor of the exact level of provenance. Almost all of the series has been calibrated to the late Pliocene age, and the dated fossil record spans 220 ky from 1.99 Ma in the Faella section, including the Pleistocene boundary sited in the Oreno unit. As said before, this section has recently provided the oldest specimens.

Out of Faella, the Matassino deposit represented until recently (Gliozzi *et al.*, 1997; Torre et al., 2001) the first fauna of the late Villafranchian, which had been classified as coeval with the Olivola faunal unit for their affinities (Azzaroli, 1977a). Magnetic stratigraphy of the Matassino section identified this locality to stand ca. 10 m above the base of the Olduvai, and its date to be quite younger than 1.95 Ma (Torre *et al.,* 1993). A new determination has been made in the summer of 2002, sampling a profile adjacent to the previous one and where parts of an elephant have been later collected. It shows that a 12 m thick normal polarity was brought in by channelled sand embedded in a reversed magnetozone (Napoleone & Albianelli, unpublished data). A further profile, sampled closely by the side of the channelled deposit, led to the reconstruction of the classical old Locality as sited just at the base of the Olduvai, and its date at 1.95 Ma, replacing the previous profile which produced the misleading date of latest Olduvai.

In the same clay pit, the Poggio Rosso site is 30 m above the Matassino site, and its fauna forming the richest assemblage collected in the Upper Valdarno is dated 1.87 Ma. This value is the result of the cyclostratigraphic analysis of the magnetic signature (Napoleone & Albianelli, 2002) and of the correlation with the Faella magnetostratigraphic section (Napoleone *et al.*, 2001b).

To the SE of the Matassino hill, the rhinoceros studied by Nesti in 1811 was collected near the top, at Poggio di Monte al Pero and located shortly above the Poggio Rosso fauna: it was dated ca. 1.83 Ma, being correlated with the Faella reference section. The same date has been given the rhinoceros skeleton recovered in 1999, while the elephant collected by Azzaroli in 1953 is estimated to be slightly older, 1.87 Ma (Azzaroli & Napoleone, in manuscript). The old collection of Faella is centered at a level higher than the latter site and a younger date was assigned to this part of the Faella lmf, at 1.82 Ma, while the elefant of 1949 would be even younger. The large tusk collected on the road to Siena, West of Montevarchi, was excavated in the upper Oreno sand and represents the youngest dated specimen of the Montevarchi series (Fig. 16); it is labeled as Azzaroli's elephant only for graphic covenience.

Several other large collections do not have a magnetic stratigraphy, or their sites are not positioned. However, from the previous results some inferences restrict their dates to a narrow range of uncertainty. First of all, the Casa Frata fauna was collected near the section of the Tasso tunnel, in the upper Ascione beds close to the transition to the Oreno sand, which in that profile is in the portion of the Olduvai ending at 1.815 Ma. The Casa Frata fauna is therefore placed in Figure 16 quite older than this date and likely close to 1.85 Ma.

The problem with the Tasso faunal unit is similar. Few detailed indications were given only on the porcupine of Bosco (Azzaroli, 1998), referred as positioned at Le Strette al Tasso, an area around the small water gap of the Tasso creek, where the farm labeled as Le Strette on the official map of the national topographic survey is reported at 183 m. As a consequence, the biochronologic constraint that the Tasso faunal unit (to which this porcupine belongs) follows the Poggio Rosso and Casa Frata faunas imposes that all specimens of the assemblage should have been recovered in level beds quite higher in the series and not in the lower Oreno unit still datable in the late Olduvai. Although not fully calibrated, the Oreno sand would not reach the date of 1.70 Ma: at most, the Tasso faunal unit, sited in the short interval of the Oreno sand would be dated from shortly before the P/P boundary to shortly later, for example between 1.8 Ma and 1.75 Ma. In Figure 20 its position is stretched towards this upper limit. The totality of the fauna dated so far did not range beyond the late Pliocene; only a minor part, before its calibration, is expected to actually be of early Pleistocene age, and lasted very few ky.

Also another proxy is in the same condition, the pollen record, which does not reach the Pleistocene boundary, as reported elsewhere (Albianelli *et al.*, submitted). At very few ky before the boundary the pollen record attains the highest percentage of herb sporomorphs, indicating a steppe vegetation of glacial facies. Deposition becomes more sandy and its rate close to that of the San Donato sand. All fossils from this succession were assigned a wide range of dates in the early Pleistocene, and with this age are reported in the GEF automated catalogue (Cioppi *et al.*, 1996). No site has been measured yet in the Pleistocene, as it is located in the P/P stratotype (Van Couvering, 1997). Therefore one might argue that early Pleistocene representatives are barely present in the palustrine sequence of the Upper Valdarno, considering that the two skulls of *Hystrix etrusca*, from Le Strette, SE of Terranuova, were found in a site which lies near the unfossiliferous wall opened for the Tasso tunnel. In this section the end of the Olduvai chron was measured at 205 m level and the Pleistocene boundary placed at 195 m (Figs.10, 16).

The remaining fauna from the undefined localities of the Tasso mammal unit might be considered in a similar condition. It was never fully studied from the palaeontological point of view, and none of its specimens was sited precisely in the several findings from the Tasso localities, Le Strette al Tasso, Il Tasso, Ville al Tasso, etc. These all belong to the upper Montevarchi series, but a stratigraphic resolution better than ± 20 m would add a slightly more precise age of no more than 50 ky around the end of the Olduvai at 1.77 Ma, except to slip back and forth across the Pleistocene boundary.

5.4 The post-Villafranchian of Bucine at the Jaramillo boundary, 1.05 Ma

The rich faunal assemblage collected on the surface in several sites of the Pogi area near the town of Bucine, belongs to the gravel of the latest filling of the basin, best represented by the Cava Gori lithologic profile. The magnetostratigraphic profile of the adjacent Cava Minuto gives, instead, a prime result for the history of the Upper Valdarno: the lower portion, in the reversed magnetozone, puts the lower limit of the basin fill not younger than the transition from Villafranchian to the Galerian mammal age. In the meantime, the fossil site of Cava Minuto would summarize the thin horizon of the Bucine fauna and yield a date of the onset of the normal polarity interval. However, its range would be very narrow, as the recoveries at Pogi had been in the upper gravel, no more exploited, but in the same horizon which closes the basin fill at Cava Minuto, and just following in the normal polarity the elephant bed. Therefore, a younger limit could reach the date of 0.78 Ma, to which the beginning of the middle Pleistocene is calibrated to the GPTS, and an older one would be dated shortly more than 1 Ma. A date very close to 1 Ma or to 0.8 Ma would be provided for both, the fossil collected at Cava Minuto and the ones at Pogi. These dates build a completely new framework for the history of the basin, which now is more clearly understood also in relation to the other Northern Apennine basins. The calibrated faunas there recovered (see in the next chapter) do not exceed a date younger than the Brunhes boundary and more likely Jaramillo. Only the Bucine lmf would have reached an age as young as a late Middle Pleistocene, which has to be rejected in absence of stratigraphical supports, while the present magnetochronologic framework puts immediately the constraints on the age of the *Elephas antiquus* recovered in October 2001.

6. CHRONOSTRATIGRAPHIC FRAMEWORK FOR TERRESTRIAL FAUNAS OF THE ITALIAN PENINSULA

The time span elapsed for the deposition of the Upper Valdarno sediments, during the Villafranchian mammal age, is now calibrated by magnetic stratigraphy to the middle and late Pliocene, and to the earliest Pleistocene. These accurate dates are applied to date the fossil sites and the palaeoenvironmental changes which affected the Apennine basins. For these ages, in fact, the faunas of the main localities of the Italian peninsula, recently reconsidered by Azzaroli (2001), are now recognized in stratigraphic order. Their distribution is mainly located in the Northern Apennines (Fig. 19), and correlation is made with the same criteria as for the biostratigraphical series, so that the previously established biochronologic dating can be now formulated on the base of the GPTS dates, with a decidedly improved accuracy (Fig. 20). This chronostratigraphic asset of the faunal events is also valid for the main events of the global climatic changes, which were recorded in the Apennine continental sediments using the magnetic signal for processing the spectral distribution of its changes, and detecting the oscillations of the pollen percentage affecting vegetational assemblages of cooler and warmer climates. Both proxies were investigated in parallel over three sequences, whose time series were constrained by a direct magnetostratigraphic zonation. In the Upper Valdarno, the interval 3.1÷2.64 Ma showed the shift from the precessional to the obliquity cyclicity at 2.85 Ma; in the Valtiberina, the interval 2.8÷2.1 Ma showed the same shift, but shortly later; in the San Arcangelo basin of Southern Apennines, dated shortly before the Jaramillo, the eccentricity cycle period was already established along with that of obliquity (Albianelli et al., unpublished data).

Climatic changes in the geological system were inferred from palaeotemperature oscillations in the oceanic waters (Shackleton, 1995). They consist of frequent fluctuations, at a rhythm of approximately 40 ky, which took place after a steady decline to cooler temperatures occurring between 3.1 Ma and 2.5 Ma. The 40 ky signal dominated until ca. 1.0 Ma, and was followed by a marked change in amplitude and frequency with a shift to fluctuations of 100 ky and to a further decline in temperature involving major climatic changes on the continents.

A marked change of climate in China was shown by Deng *et al*. (1999) to coincide with the beginning of loess deposition, at about 2.6 Ma. Also magnetic stratigraphy enhanced in the loess deposits the onset of an alternating signal during wet and dry conditions with alternations of paleosols producing distinctive magnetic characters (Heller *et al.*, 1991; Spassov *et al.*, 2001).

In Western Europe a direct influence of the climatic changes on the vegetation was evidenced by the pollen distribution with drastic changes during the late Pliocene and Pleistocene (Zagwijn, 1974; Suc *et al.*, 1995). In the Vrica stratotype area, the series yielded a pollen record representative of the central Mediterranean realm (Combourieu-Nebout, 1993; Combourieu-Nebout & Vergnaud-Grazzini, 1991).

In the Northern Apennines such changes were searched in the Upper Valdarno, where details in the vegetational associations were dated since 3.1 Ma with the stratigraphic resolution of the GPTS. The subtropical forest of warm-temperate climate, already established since the early Pliocene, was still steadily persisting in the mid Pliocene Meleto clay, and gradually replaced by a conifer vegetation of cooler climate (Bertini, 1994), beginning in the middle of late Gauss, at 2.85 Ma. This date was focused by a marked change in the spectral content of the magnetic susceptibility profile, with the amplitide of the dominant cycle at 20 ky period of the precessional index in the early Pliocene drifting to the 40 ky period of the obliquity (Albianelli *et al.*, 1999; Napoleone & Albianelli, 2002). A similar drift was recorded by the magnetic signal in the deposits produced by the climatic changes in the subtropical Africa (DeMenocal & Bloemendal, 1995).

The measured periods of the cycles were in the range of the Milankovitch changes of the astronomical parameters affecting the solar radiation. It may be assumed that temperature changes in the Boreal Hemisphere were triggered by the insolation, and that deep ocean sediments reflected with a definite lag events which had taken place on the surface of the Earth. The lag, from the observations on continental faunas and loess deposition, was possibly of the order of 100 ky, or may be even larger according to pollen and magnetic records. The Villafranchian terrestrial faunas of the Apennine basins were deeply influenced by climate changes at the Gauss/Matuyama boundary when the Pliocene ice-rafting took place (Shackleton *et al.*, 1984), and at the Jaramillo. In contrast, at the Pliocene/Pleistocene bondary their turnover was much less notable, as shown in the following faunal distribution, reconsidered after its magnetochronologic asset.

The present paper discusses faunal events that took place in central and southern Italy (Fig. 19) during the period from nearly the onset of the late Gauss, through Reunion and Jaramillo, up to the onset of Brunhes, approximately from 3.1 Ma to 0.8 Ma. Magnetostratigraphic calibrations made in the Upper Valdarno involved sequences not much younger than the end of Olduvai (1.77 Ma), thus not reaching 1.70 Ma. Then two short sections, at Colle Curti and Cesi in the Colfiorito basin and the one at Oriolo in the littoral deposits of the external Apennines (to be discussed at the end of this chapter), were respectively dated to the Jaramillo and beginning of Brunhes. Most of the middle Pleistocene is now being studied through one single section in the Southern Apennines, although with a poor faunal record. Preliminary studies dated its base shortly prior to the Jaramillo (Sabato *et al.*, 2002), and new detailed results extended the series into the Brunhes (Albianelli & Napoleone, unpublished data).

All the assemblages reported in the following sections will be assigned a position on the GPTS, summarized in Figure 20, to which a numerical date will correspond for calibration. As discussed before, the late Villafranchian faunas of Tasso and of the close Farneta area are inferred to date in the proximity of the end Olduvai, but their stratigraphic position is still drawn at a younger age, so partly maintaining the biochronologic setting. Their range of uncertainty is visibly wide, at the scale of the GPTS geochronology, but the faunas lacking a direct magnetostratigraphic calibration are positioned with dates in the most appropriate approximation inferred from what reported below. Some faunas discussed in the next sections but not shown in Figure 20 can be accordingly located with the same cautions used for the accuracy of their numerical dates, which anyhow can benefit from an improved accuracy by the new position of the faunal units, displayed in the last column on the right-hand side.

6.1 The deposits of early Villafranchian age

The earliest continental sedimentation of the Apennine basins is the one of the Upper Valdarno, as it is enhanced by magnetostratigraphy, and marked to occur in the second half of the Gauss chron, to which a middle Pliocene age is correlated. The earliest deposit

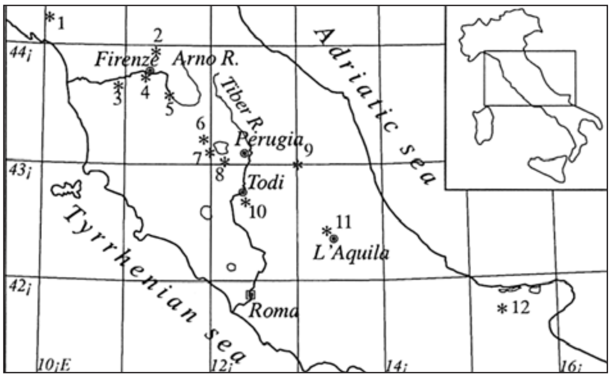

Figure 19 – Map of the main sites of faunal distribution in peninsular Italy. The earliest fauna, out of the Triversa site located in the western corner of the Po Valley and North of the area here represented, was believed to lay in the area of Aulla underneath the Olivola site. A general trend of more evolved faunas was recognized, moving from West towards the more easterly basins. The present magnetostratigraphic dates are reported in chapter 6 for the sites here labeled: 1, Olivola; 2, Mugello; 3, Montopoli; 4, Firenze; 5, Upper Valdarno, in its bulk; 6, Farneta; 7, Selvella; 8, Pietrafitta; 9, Colfiorito; 10, Todi; 11, L'Aquila; 12, Pirro Nord.

was identified on the north-western border of the mountain belt while the intramontane basins developed in Upper and Lower Valdarno, and Sarzana. Their record is based on a mammal fauna that correlates with the MN16a because of absence of *Equus* from it as well as from the sites od western Europe (e.g; Gea in Spain, quoted in Lindsay *et al*., 1997), readily correlated with late Gauss and early Matuyama. Direct calibration to the

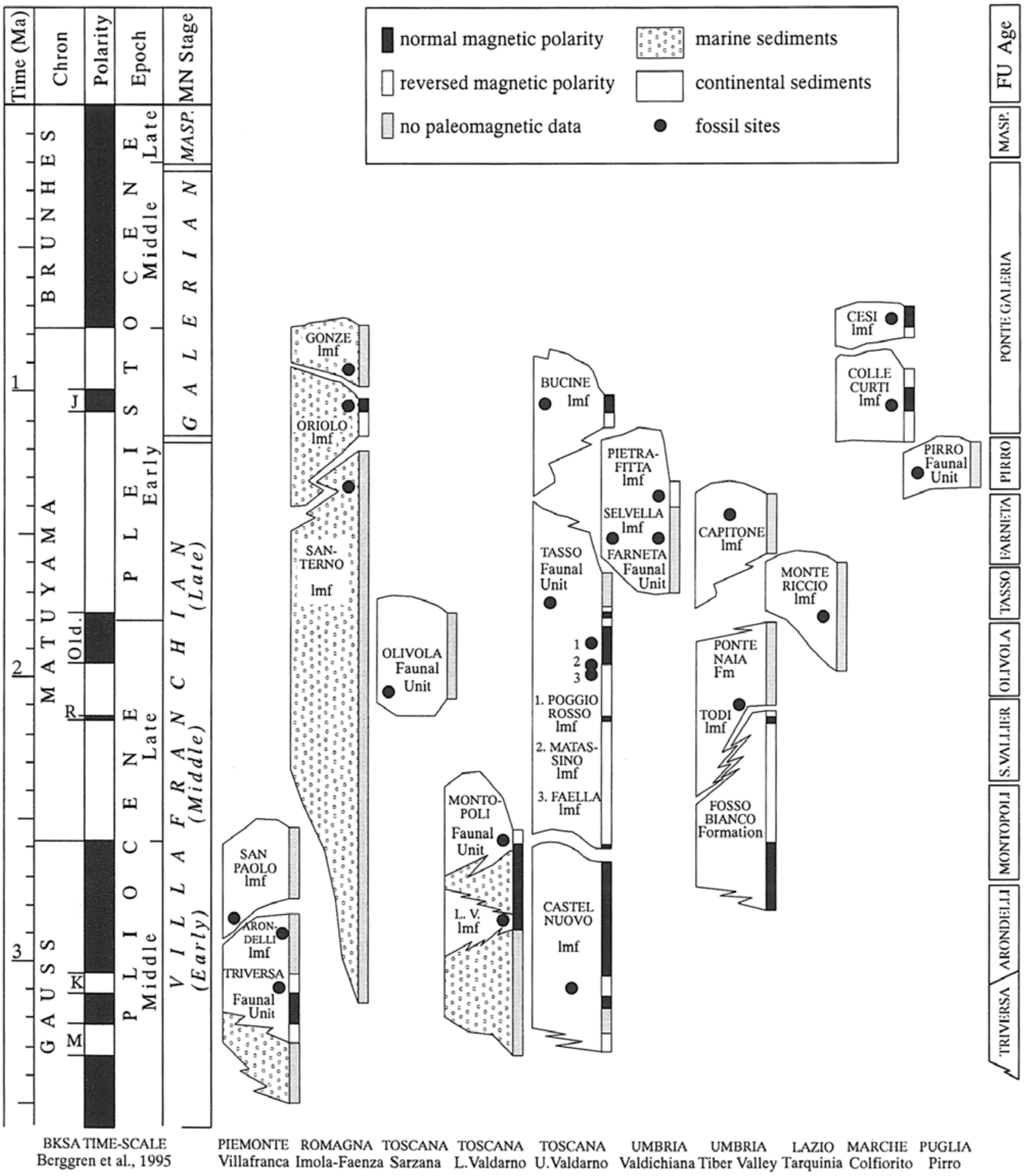

Figure 20 - The overall recostruction of the stratigraphic position for the main mammal sites in the Northern Apennines is shown in the draft assembled by Ambrosetti in 1994 and reported in Cita & Castradori (1994, quoted in Albianelli *et al*., 2002b), and updated for all the results discussed in the present work. The calibrated faunas (positioned by the dots) are sided by the magnetostratigraphic column with normal (black) and reversed (white) polarities; the others (not calibrated, and with the shadowed column) are correlated with the GPTS of Berggren *et al.* (1995) by a lesser tight constraint, due to the faible stratigraphic resolution of their biochronological ages. The display follows a general disposition from west to east, to which correspond the dates of each site readable on the GPTS, while the faunal units grouping them in the biochronological setting are shown on the vertical scale in the other extreme. For the confidence range of the faunal units dates, see the discussion in the text.

GPTS of continuous long profiles in the Upper Valdarno clears up any biochronological uncertainty leading to different scenarios, such as those discussed by Lindsay *et al*. (1997) for the Triversa fauna in its Villafranca d'Asti type area. There, the lower Triversa sequence was correlated with the MN15 faunal sequence and with the late Gilbert chron.

However, this area is out of the Northern Apennine Range while the equivalent fauna of the Upper Valdarno was directly calibrated in a long magnetostratigraphic series; but the Triversa fauna of the type area, with its rather rich sequence, is emphasized because it marks the onset of the Villafranchian and its diversification is now estimated during a long time span which as compared with the Upper and Lower Valdarno ones. It is noteworth to recall that the geologic setting was reappraised in great detail (Carraro *et al*., 1995), but its stratigraphic updating by Lindsay *et al*. (1997) seems not correlatable with the Upper Valdarno series.

6.1.1 The Triversa sequence at 3.1-2.9 Ma of the Kaena/late Gauss chrons

The Triversa sequence (MN16a) comes from several sites along the Triversa River near the town of Villafranca d'Asti in Piemonte, and is mainly characterized by its typical elements *Zygolophodon borsoni, Anancus arvernensis, Ursus minimus*, and the turtle *Mauremys etrusca* (Azzaroli, 1977a). The Triversa fauna at Fornace RDB site is considered the oldest one, and the previous list in all alike the fauna of Castelnuovo dei Sabbioni is thence dated in the Kaena chron, at 3.1 Ma. The specimens of Fornace RDB were recovered in an unknown position through a short profile of silts and silty sands in the lower part, and sands higher up. Its list contains also other species, *Macaca florentina, Castor* sp., *Acinonyx pardinensis, Tapirus arvernensis, Stephanorhinus jeanvireti, Procapreolus* cf. *cusanus, Leptobos stenometopon*.

Among several other sites, the Arondelli and San Paolo faunas are considered to overlay by few meters the RDB site although the species list is poorer, containing the former one with insectivores (*Talpa* cf. *minor*) rodents and few carnivores. They were not measured for palaeomagnetism and are placed correlative to the upper late Gauss, according to the stratigraphic inferences of Azzaroli (1977a). The Fornace RDB profile includes a tiny normal polarity magnetozone between the two reversed ones, i.e. a nearly 25 m outcrop with a less than 2 m thick magnetic zone of normal polarity at 12 m level. The two reversals are therefore associable to the Mammoth and Kaena events in the Gauss chron. As a consequence we reject Lindsay's *et al.* (1997) assignement of the earlier Triversa fauna to the Gilbert chron - an assignment that would make it one million years older than the same faunas in the Upper and Lower Valdarno basins. In our interpretation, then, the Triversa faunal unit stems from the Gauss chron, close to and/or within the Kaena event (Fig. 20).

The Arondelli local fauna, few meters above the main Triversa fauna, has not yet been found in the more easterly basins, but is most likely of Gauss age as well. Its age could match that of the new fauna collected in the Lower Valdarno (to be discussed in the next section) that has been grouped in the occasion of the magnetostratigraphic exploration of the series, downwards from the Montopoli Locality and is now dated to not reach 2.9 Ma as a lower limit.

6.1.2 Lower Valdarno finds with Triversa affinity, 2.8 Ma

The oldest finds in the Apennine basins, after the Upper Valdarno local fauna of Castelnuovo, are in the Lower Valdarno. The significant site is in the eastern side of the basin, at the base of the marine sedimentary cycles mentioned earlier, in chapter 2. From there, the tapir recently found and few more remains were dated as coeval with the same fauna of Castelnuovo (Benvenuti *et al*., 1995). Their age was not fully resolved by the marine sequence, due to a poor biostratigraphic record, as the tentative biozonation assigned the bulk of the sequence to the *Globorotalia aemiliana* zone, therefore with a too large range for the resolution of the present correlation.

Also the record of the vertebrate fauna released in the lower sequence was poor, but the only one correlatable with that of the Upper Valdarno, as demonstrated by the magnetostratigraphic dating. This minor faunal assemblage comes from relatively recent discoveries: firstly a canid *Nyctereutes megamastoides* Del Campana was found in 1917 at the brick factory Chiarugi, and then two jaws of the arvicolid vole *Mimomys stehlini* Kormos, followed by a fragmental antler of *Croizetoceros* cf. *ramosus* (Azzaroli, 1992). A lower molar M1 of *Anancus arvernensis* from the Piazzano farm, was dated approximately 3 Ma by aminochronologic analysis (G. Belluomini, 1990, personal communication to Azzaroli). Near the small town of Ponte a Elsa, the antlers of a small-sized cervid were recovered and adopted as the species holotype of *Pseudodama lyra* (Azzaroli, 1992). Finally, an almost complete skeleton of *Tapirus arvernensis* was found in the clay pit of Casenuove, with other fragments (Dominici *et al*., 1994). All these specimens may be assembled in a local fauna, the Lower Valdarno lmf (MN16a), confined in a short time span of emersion between two thick sequences of shallow marine facies, and supposedly at a date not much younger than that of the Castelnuovo fauna. In fact, the magnetostratigraphic date of the latter is close to 3.1 Ma, while in the Lower Valdarno the aforesaid date of ca. 3 Ma was the only available indication until magnetic stratigraphy of the composite sequence was measured in the overlying marine silts and sands (Albianelli *et al*., unpublished data). It released only one magnetozone of normal polarity, taken as the end of the Gauss chron before the Montopoli fauna found on top of the marine sequence, and dated at the lowermost Matuyama (Lindsay *et al*., 1980). Its duration, however, could not be calculated by the magnetic cyclostratigraphy, as it was done in the Santa Barbara profile. The sequence was made of separate short sections, although well correlated, but not with the required accuracy for detecting the Milankovitch periods used in the Upper Valdarno to date its duration.

With an indicative rate of deposition of the marine sequence similar to that measured in the Upper Valdarno, and the thickness reconstructed from the various outcrops, a time span longer than 200 ky before the Matuyama boundary is estimated. So, the Lower

Valdarno fauna with affinity to the Triversa faunal unit would not reach a date as old as 2.9 Ma and therefore be at least 200 ky younger than the Castelnuovo faunal assemblage. The affinity of the latter with the Triversa fauna suggests a parallel affinity of the Arondelli fauna above the Fornace RDB site with the present Lower Valdarno fauna, based on an equivalent magnetostratigraphic date inferred for the Arondelli fauna.

6.1.3 The Aulla find near Olivola, NW Toscana, 3.1 Ma (?)

In the abandoned clay pit, 1 km out of the Aulla town, Sarzana basin (Val di Magra), two small cervid remains were recovered in a 5 m short outcrop (Abbazzi *et al.,* 1995). Part of a right shed antler was available to inferring the presence of *Procapreolus cusanus*; a *Psedodama* ex gr. *pardinensis-lyra* was also determined. Their little biochronologic resolution is even reduced by a poor preservation, which did not prevent, however, to infer an early Villafranchian age. Actually, this was assumed in order to replace the previous age of earliest Pliocene established by presence of pollen species of a vegetation still maintaining some Miocene characters. Large excavations, presently made to build the new railway station of Aulla, and drilling bore-holes added a 30 m thickness to the sequence, down to the basal lignite-bearing clay. They did not provide a polarity sequence, but only one reversed polarity, as it was also for the 5 m outcropping section (Napoleone and Albianelli, unpublished data). An expected date for this 35 m thick profile with reversed polarity would suggest a magnetization acquired in the Matuyama chron, and the age of this poor record would be assigned to a time younger than the Gauss chron. Therefore, also this site cannot be assigned a date of the Castelnuovo fauna, but quite younger than that and still fitting the very wide range of uncertainty of the biochronologic inferences. From the above discussion the reversed polarity of an early Matuyama would date this site younger than 2.58 Ma, most probably not reaching 2.5 Ma, as it is placed at least 35 m above the onset of the magnetozone and if an average sedimentation rate is assumed close to that of the Valdarno basins.

6.2 Middle Villafranchian Mammals

This mammal age was a period of scanty finds, also corresponding to a generalized time of widespread transgression on land, which reduced the continental environment. In Azzaroli's (1977a) revision of Villafranchian the Triversa fauna is the holotype of this land mammal age and represents the early Villafranchian, while Montopoli represented a new stage. Until the present dating of the Triversa-like fauna of Castelnuovo dei Sabbioni and of the subsequent Gaussian fauna of the Lower Valdarno correlated with the Arondelli lmf, the time span between Triversa and Montopoli faunal units was considered large and marked in Europe by the arrival of elephant from Africa and horse from N. America. The former event is dated now earlier than 3.1 Ma, witnessed by the tectonic phase producing the subsidence basins in the Apennine intramontane belt, the latter by the Montopoli fauna calibrated to 2.58 Ma. The half a million year lag from this event to the previous one is now covered by findings of intermediate dates reported for the aforesaid faunas in the upper Triversa sequence. For younger ages, the only finds are the poor fauna of Todi, which indeed by magnetostratigraphy is tightened very close to the upper limit of the Montopoli mammal age, with a similar lag of nearly 0.5 my, but without any intermediate finding in the Apennine basins.

The Montopoli Locality contains the richest assemblage of the few ones in Western Europe, among which that of Senèze, dated at the Reunion chron, represents the successive Saint Vallier faunal unit. In Italy, an affinity with the fauna of Montopoli (MN16b) was attributed to that of Costa San Giacomo (central Italy) (Gliozzi *et al.*, 1997).

6.2.1 The Montopoli fauna of Lower Valdarno, 2.58 Ma

It is the oldest fauna of this period (middle Villafranchian), at the base of the Matuyama chron, dated shortly after 2.48 Ma by Lindsay *et al.* (1980), but the beginning of the Matuyama has now been corrected to 2.6 Ma (see Shackleton, 1995), while the updated scale by Berggren *et al*. (1995) puts it at 2.58 Ma. The fauna was collected by Forsyth Major (1877) near a hilltop South of Montopoli, a small town in the Lower Valdarno, West of Firenze and South of the Arno river. After the detailed account by Forsyth Major (1877), the list of fossils was revised by Azzaroli and De Giuli in order to update the information in the newly created automated catalogue (Cioppi *et al*., 1996).

It is fairly rich but fossils are fragmentary:

Archidiskodon gromovi, Anancus sp., *Stephanorhinus jeanvireti, Equus* cf. *livenzovensis, Pseudodama* cf. *lyra, Croizetoceros ramosus, Procapreolus* cf. *cusanus, Pliocrocuta perrieri, Nyctereutes megamastoides, Acynonyx pardinensis*.

A similar fauna from Liventsovka in Southern Russia, near the Azov Sea, was described by Bajgusheva (1971; 1978; quoted in Azzaroli, 2001).

The relevance of the Montopoli fauna as testimony of a major dispersal event in the late Cenozoic was emphasized by Lindsay *et al.* (1980). Soon after Azzaroli (1983) brought new attention to the problem, having linked it with the mammal fauna of the Himalayan India dated by magnetostratigraphic investigation to the late Pliocene and early Pleistocene (Azzaroli and Napoleone, 1981). The faunal diversification there verified, was correlated with the late Villafranchian fauna of western Europe, and its major dispersals, which took place before and after the Pliocene/Pleistocene boundary, were emphasized (Azzaroli *et al*., 1997) in order to place in a stratigraphic order the Villafranchian faunas of the Italian peninsula. With the present magnetostratigraphic record these correlations could be revised with a much finer resolution.

6.2.2 The fauna from Cava Toppetti near Todi, Umbria, 2.13 Ma

A poor fauna was collected at Cava Toppetti, SW of Todi, in Umbria (Abbazzi *et al.* 1997), and comprises:

Stephanorhinus cf. *etruscus* - a fragmental scapula

Pseudodama cf. *rhenanus* - fragments of antlers, two damaged teeth, a hoof phalange

Procapreolus sp. - the basal portion of an antler

Apodemus cf. *dominans* - a right M1/

This small association is presumed to be younger than the Montopoli fauna, despite its poor biochronologic resolution. The fossiliferous beds crop out in the Cava Toppetti clay pit exploited for the brick factory, at Todi, in the Ponte Naia Formation. The series uncomformably overlies the Fosso Bianco Fm, which was calibrated to the latest Gauss and early Matuyama, and soon after the Reunion (Fig. 2). The fossil bearing section has not given data of its palaeomagnetism, but from the above biochronological indications it may be considered older than the Olduvai chron, and therefore of late Pliocene age. It was actually constrained between Montopoli and Olivola faunal units, whose dates are now avalaible, although the second one will be further discussed in the present work.

A major argument to the previous biochronologic assignment of an age is that the Olivola unit is now recognized older than 1.95 Ma (by possibly 150 ky), and much younger than the Reunion (2.24 Ma, in the GPTS calibrated by Baksi, 1993, or 2.15 Ma in that used by Cande & Kent, 1995 and adopted by Berggren et al., 1995). This contradicts the geological evidence because these scanty finds are overlying, with a sequence of at least 100 ky duration, the beds with normal polarity of the Reunion chron, measured in the same section, but above the major fault that affects the whole Valtiberina basin. A larger time span for it would reach the Olduvai, which is younger than the Olivola fauna, to be discussed, in the next section. More discussion on the pollen distribution and its correlation with the Upper Valdarno series is made specifically with the lower Fosso Bianco formation (Pontini *et al.*, 2002). A possible lag between their records is detected by magnetostratigraphy and attributed to climatic differences of local origin producing a microclimate.

The stratigraphic position of this fauna is visualized in Figure 20 as closely before Olivola, and therefore strongly confined by the Olivola date of nearly 2.1 Ma, which will be discussed later. This position is indeed forced against the tight limit of Reunion at 2.15 Ma and the main fault in between. It seems an evident case for evaluating the resolution power of both chronologies when compared to one another, the highly constraining numerical one of the GPTS and the faunal unit sequence of the comparative osteology, which needs very wide margins of confidence for fixing biochronologic affinities.

6.3 Late Villafranchian Mammals

This new mammalian age (MN17) was particularly well represented either in the Upper Valdarno and in the Italian peninsula. In the latter, several localities were collected, among which the richest one is at Pietrafitta, in Umbria (Gentili *et al.*, 2000). An important result seems evident: with the present numerical dates available for this continental series, the rich fossil deposits actually exhibit a monotonous composition, because they belong to almost the same narrow range of dates. It has been stressed above, for the Upper Valdarno, that biodiversification was practically undetectable in the faunal assemblages of the Montevarchi sequence, while in the same sediments the magnetic and pollen records clearly detected the severe changes which prepared the break at the Pleistocene boundary. The present dates have in fact shortened the time span of the continental sedimentation during which the assemblages remained unchanged, as summarized in the Faella collection by its stratigraphical disposition spanning over 220 ky across the Olduvai (Napoleone & Azzaroli, 2002).

Another important result can be commented. It is now quite clear that the late Villafranchian age comes to an end pretty soon in the Upper Valdarno, the first find being dated 1.99 Ma and the last ones demonstrated here to be not much younger than 1.77 Ma. In contrast, during last half a century the trend in dating their biochronologic ages was to rather expand the time intervals between various localities, and separate these latter in faunal units in spite of their tenuous palaeontological constraints. The “wolf-event” was actually the only biochronological date to make the divide between the middle and late Villafranchian (Torre *et al.*, 2001)

The example of the Matassino assemblage is typical because its first recognized affinity with Olivola (representing the basal Pleistocene), that led to assigning both of them the same age (Azzaroli, 1977a), was progressively shifted to a younger age on the statement that the next Tasso faunal unit should be substantially higher up in the early Pleistocene, to approach the major faunal turnover of the new age (Gliozzi *et al.*, 1997; Mazzini I. *et al.*, 2000; Torre *et al.*, 2001). Such a scheme was actually the basic asset for the biochronologic history of the Villafranchian, but the new data brought to light by magnetostratigraphy and reported since a decade (Torre *et al.*, 1993; 1996; Albianelli *et al.* 1995; 1997; 2002a) have drastically changed the previous framework. These results are commented stepwise, in a chronologic order mostly inferred from indirect correlations with the GPTS magnetochronology.

6.3.1 The Olivola fauna of Lunigiana, NW Toscana, 2.1 Ma

A rich fauna was retrieved in the late eighteen hundreds by Forsyth Major (1890) from silts underlying the Olivola village, which stands on a hilltop NE of Aulla, the main town of the Lunigiana district, NW Toscana, where the Sarzana basin is occupied by the Val di Magra valley. This will be discussed just after reporting that the fauna was collected in a site already known for a long time for its content of fossil vertebrates: it was visited in the mid eighteen hundreds by Igino Cocchi and by Giovanni Capellini, who collected some specimens which were stored in the palaeontological museums of the Universities of Pisa and Bologna. Several years later Forsyth Major undertook a regular excavation and obtained a large collection. Most of it was taken to the Palaeontological Museum of Firenze University, some fossils were brought to the British Museum (Natural History), where among others a fine facial skull of *Sus strozzii* is now stored.

Fossils were transported by a stream; they are white and brittle, embedded in a pink-yellowish matrix, and as a rule are disconnected, but some articulated, partial limbs were also collected. Bones were selected according to size: an elephant is represented only by a partial ulna and radius and part of the carpus; other large herbivores and carnivores are common, smaller species are rare (Azzaroli, 1950).

The most common species are:

Stephanorhinus etruscus - Skulls, jaws, limb bones
Equus stenonis - Skulls, jaws, limb bones
Sus strozzii - Fragmental skulls, jaws, limb bones
Leptobos etruscus - Fragmental skulls, jaws, limb bones
Eucladoceros dicranios olivolanus - Partial skulls, jaws, antlers, limb bones
Pseudodama nestii - Partial skulls, jaws, antlers, limb bones
Ursus etruscus - Partial skulls, jaws, limb bones
Canis etruscus - Skulls, jaws, limb bones
Pachycrocuta brevirostris - A maxillary, two jaws, isolated teeth, few limb bones

Less common elements are:

Megantereon cultridens - A partial skull, fragmental jaws, isolated teeth
Homotherium crenatidens - Few teeth
Lynx issiodorensis - An incomplete skull, a maxillary, a jaw, fragments of the pelvis and limbs.

These species are also represented in the Montevarchi succession of the Upper Valdarno, with the only exception of *Eucladoceros dicranios*, represented in the Upper Valdarno by a different subspecies (see below).

Species recorded in Italy only from Olivola are:

Procamptoceras cf. *brivatense* - An upper tooth row
Gallogoral meneghinii - A partial skull, the distal end of a humerus
Chasmaporthetes lunensis - A partial skull
Felis lunensis (also called *Felis sylvestris lunensis* by Ficcarelli and Torre, 1974, in Azzaroli 1977a) - a felid of the size of a common cat: a jaw, partial fore and hind limbs.

The first two species occur in Italy only at Olivola; they also occur in France, in the middle-late Pliocene.

The problem of dating the Olivola site, previously established to represent the base of the Pleistocene, was a critical one since the initial calibration in the Upper Valdarno sites. Its age is still lacking a direct magnetostratigraphic exploration, but inferences were made, based on the following statement (Cioppi & Napoleone, 2001). The Matassino fauna was considered, on the biochronological basis, of the same age as Olivola for the affinities between them, and then its age was moved stepwise to younger dates than Olivola (e.g. Azzaroli *et al.*, 1988; Gliozzi *et al,* 1997). Separately, the Faella fauna -in all alike the Matassino one- was dated as old as 1.99 Ma (Albianelli et al. 2002; Napoleone & Azzaroli, 2002). The Olivola must precede the Pleistocene boundary, fixed at 1.796 Ma in the end Olduvai, by more than 200 ky.

Moreover, considering that in the Upper Valdarno the new late Villafranchian fauna is retrieved from the Terranuova silt and this sequence extends more than 50 ky earlier than the basal fossil find of Faella, an upper limit for the Olivola date might be as old as 2.05 Ma and a lower limit younger than Reunion, to which the Senéze fauna of the St. Vallier faunal unit is calibrated. A date younger than Reunion is further fixed as a more recent time by the fauna of Todi, already recognized quite younger than Reunion but assumed older than Olivola. With the biochronological considerations made before, a date of 2.1 Ma with a narrow excursion (say, less than ± 50 ky) is conceivable for Olivola, and this puts its date quite older than any other one reported so far.

This shift to the late, and not even the latest Pliocene has been pushed back since the first calibration of the Matassino fauna (Torre *et al.,* 1993), when the Upper Valdarno faunas of the Montevarchi succession were already considered quite younger than Olivola. With the present magnetostratigraphic calibration, all these faunas are quite aged, as shown in the previous chapter, being dated still prior to the onset of the Olduvai chron (Albianelli *et al*., 2002a; Napoleone *et al*., 2001b). The yellowish silt of the fossil deposit is exposed at Olivola for about 1 m in thickness and is magnetized with reversed polarity: this is not in conflict with the discussion made before, but not decisive for defining a more precise date than that just inferred at 2.1 Ma.

6.3.2 The recent finds from North of Roma, 2.0÷1.75 Ma (?)

An occasional find at Monte Riccio, in the northern Lazio district, 10 km inland from the Tyrrhenian Sea and 100 km N of Roma, was the first locality from that area and dated after the analogies with the fauna of the Upper Valdarno (Mazzini I. et al., 2000). In a 30 m section of very shallow marine facies, attributed to the late Pliocene by the geological evidence in the area, a terrestrial fauna was deposited during a short episode of emersion. A biostratigraphically poor association is based on *Ostrea, Clamys, Pecten*, etc., mostly indicating the low water depth, and a similar estimate was provided by the benthic foraminifera. An ostracod with stratigraphic meaning, *Cyperideis torosa*, would be noticeable for its first appearence being at the beginning of the Pleistocene. Nonetheless, this is one of the few occasions, in the Italian peninsula, to have an indication of biostratigraphic dating for a terrestrial fauna. A fairly rich assemblage overlying the marine detrital sequence is formed by the following specimens:

Prolagus sp. - two fragmentary molars
Elephantidae cf. *Archidiskodon meridionalis* - some limb bones and a dental lamina
Sus strozzii - Fragmentary mandible and a metapodial
Hippopotamus sp. - A fragment of the skull
Leptobos cf. *Leptobos etruscus* - Two frontal bones, a metacarpal
Procapreolus sp. - Fragmentary frontal bones with the basal part of the antler
Eucladoceros ctenoides - A basal part of an antler, some molars, a tibia fragment, a calcaneum of juvenile specimen
Pseudodama? - Metapodials, fragmentary limb bones, jugal teeth
Stephanorhinus cf. *S. etruscus* - A fragmentary humerus, radius and tibia
Equus stenonis - An almost complete mandible very similar to the holotype from the Upper Valdarno, a fragmentary scapula
Vulpes cf. *Vulpes alopecoides* - Part of mandible with two molars
Canis etruscus - A fragmentary mandible with two molars and a left hand in anatomical connection
Megantereon cultridens - A metatarsal

The range of these species spans a large interval, but their association leads to a restricted age comprising the Olivola and Tasso faunal units (Mazzini I. *et al*., 2000). This indication led to assigning an age derived from the alleged age of the latter in the late part in the erly Pleistocene, still used in the catalogue and in the most recent accounts (Gliozzi *et al*., 1997; Torre *et al*., 2001). But this resulted an inference very weak for the Monte Riccio section, as the biochronological range of the Tasso fauna is actually poorly defined, and even less is the biostratigraphic timing of the profile with a generical age as Pleistocene. The presumed age, at the resolution of the Tasso faunal unit, was arbitrarily used in a stratigraphic meaning for its upper early Pleistocene age, disregarding the indication of the only fossil there recognized with a stratigraphic meaning for a presence started since the beginning of the Pleistocene. Nonetheless, the affinity with the Tasso FU still provides an age indication better constrained than that of a broader Pleistocene given by the marine fossils of this short series, and dated with the accuracy fixed for the Tasso FU by the new magnetochronologic constraints. Therefore, with a Tasso FU dating soon after the Olduvai, its age would be in the earliest Pleistocene, in a very limited range before 1.7 Ma, and anyhow quite shorter than that assigned in Figure 20 to the faunal unit.

6.3.3 The Firenze basin, 1.8÷1.7 Ma

Firenze lies in an old lacustrine basin which, unlike the Upper Valdarno, was never filled completely. Scanty fossils were collected. On the right bank of the Arno, in the centre of the town, some limb bones of an elephant were retrieved during excavations for the building of barracks. On the left bank, South of Porta Romana, in the southern outskirts of the town, an elephant tusk and few molars were collected. A fragment of a metatarsal cannon of *Leptobos* was retrieved in a railway tunnel North of the town. A portion of the nasal bone of a rhinoceros was collected near Signa, at the western end of the lacustrine basin and a fragment of a left maxillary was collected from a well near Prato, in the North of the basin.

These remains do not allow for a more accurate biochronological timing than the age of the latest Montevarchi sediments or shortly younger (the Farneta fauna?, see below). The magnetic stratigraphy is not available, due to lack of convenient outcrops, but its stratigraphic position is here assigned to an age earlier than that of the next fauna only on the basis of the biochronological indications, which were indeed recalled in several aforesaid occasions to yield a too large range of uncertainty.

6.3.4 The late Villafranchian fauna of Farneta, 1.7÷1.6 Ma

The Farneta Abbey is placed on a series of hills of fluviatile sands which run to the right (East) of the Chiana river, a southern tributary of the Arno. A rich fauna surrounds it and extends southwards until the boundary between Toscana and Umbria near Pozzuolo. In quarries North and West of the boundary with Umbria, remains of elephants and other fossils, including a beaver, were collected. A large sized subspecies of the elephant, *Archidiskodon meridionalis vestinus*, dominates the fauna (Azzaroli 1977b); the type of the species is from Scoppito, West of L'Aquila, Central Italy (Fig. 19), and was described as *Elephas meridionalis* by Maccagno (1962). Small sized deer are represented by the progressive species *Pseudodama farnetensis* (Azzaroli 1992) and the Valdarno *Eucladoceros* has been replaced by the more derived *Megaceroides obscurus*, a forerunner of the middle Pleistocene *Megaceroides verticornis*. The geological setting of the area, also described by Azzaroli (1992) to argue the slight differentiation of cervids in Toscana (Azzaroli, 1947), leads to a stratigraphic position slightly younger than the upper deposits of the Montevarchi unit in the adjacent Upper Valdarno. The quarrying is over and not sufficiently long sequences with fresh cuts are useful for palaeomagnetic sampling. A date however could be expected close to the end Olduvai, i.e. not much younger than 1.77 Ma, possibly in the range of the Tasso FU with the GPTS; as a direct magnetostratigraphy is lacking, the biochronologic indications are partly maintained for correlation with the stratigraphic setting of the Tasso unit in Figure 20.

The adjustments in repositioning the fossil sites are made for the ones dated by magnetostratigraphy. Only the Todi and Olivola ages are moved because of their stringent magnetochronological evidence. The biochronological ages of the others are partly correlated with the GPTS dates, but emphasizing that their shadowed columns, by the side, earlier represented the time span presumed for the extent of the sequences lacking the magnetostratigraphic calibration, and cover the minimum range of uncertainty in this indirect correlation or pseudo-calibration.

6.3.5 Selvella fauna, 1.7÷1.6 Ma

Farther South-East, in Umbria, a more poorly preserved fauna was retrieved by De Giuli (1986) at Selvella. It includes *Equus* cf. *stenonis, Pseudodama* sp. (*farnetensis?*), a large cervid called *Eucladoceros* cf. *dicranios* (possibly a *Megaceroides obscurus?*; see Azzaroli, 1953), *Leptobos* sp., *Canis etruscus*, *Lynx issiodorensis*, *Sus* sp. and an undetermined elephant.

Fossils are less bulky than those collected around Farneta: the stream which carried them was slowing down. *Arkidiskodon meridionalis vestinus* is poor: few limb bones. *Equus stenonis*, a large sized *Eucladoceros*, and a *Leptobos* are mainly represented by limb bones; *Pseudodama farnetensis* is also documented by fragmental antlers, carnivores are documented by a facial skull of *Canis etruscus* and a fragmental jaw of a *Lynx*.

The age of this locality matches that of Farneta, representing only a different depositional setting, more downstream; thus, the same date of the Farneta fauna is assigned to it in the representation of Figure 20, although in absence of magnetic stratigraphy.

6.3.6 Mugello basin, 1.7÷1.6 Ma

Sited North of Firenze and in a deep depression with a more than 600 m thick pile drilled in the central basin, this was another lacustrine basin where the fossil record had been collected for a long time, from scattered sites and without notes on their position. Fossils mainly come from the lignite-bearing levels, and the interfingered or overlying clays. In the latest mining operations a rhinoceros -a small skull- and an *Archidiskodon meridionalis vestinus* -a dextral femur- were recovered and kept in the Museum of Firenze. Important recoveries in the eighteen hundreds were kept in the Museums of Pisa and Bologna.

A rather fragmental fossil assemblage of 13 species is from the sands overlying the lignite-bearing clays and represents a fauna similar to the one of Farneta. It mainly includes tusks and other bones of the large sized elephant, *Ursus etruscus, Sus strozzii*, a *Pseudodama,* fragments of a large cervid not identified specifically, a derived rhinoceros recalling those from Pietrafitta (see in next section), *Mustela* sp. and a macaque (*Macaca florentina*), poorly represented by fragmentary remains. The short length of the sections with the fossil recoveries, and their correlation, not sufficiently accurate to allow a cyclostratigraphic determination of the time spans involved in a given sequence, prevented assigning a date to the three surveyed sites (Albianelli & Napoleone, unpublished data). Rock magnetic properties were among the best ones for the continental sediments so far examined in the Apennine basins, but unfortunately the main result was to have measured only one reversed polarity, which leads to a Matuyama chron younger than Olduvai. Transferring the biochronological affinities into the established asset of the numerical dates, one may figure out a date still close to 1.7 Ma used for the end of the Montevarchi sequence, which is also a date very close to that of the Farneta FU. The range of the latter is arbitrarily kept in Figure 20 too wide, as presumed by the previous biochronologic assignments, and thus placed quite younger than that of Tasso. The position of the Mugello fauna is not drawn in Figure 20.

6.3.7 Some notes on the Pietrafitta fauna, 1.6÷1.5 Ma

A very rich fauna with several elephant skeletons was collected during excavations for the extraction of lignite at Pietrafitta, in Umbria, South of Lake Trasimeno. The fauna has not been studied and only few species have been described (Gentili *et al*. 1996, Mazza *et al*. 1993). The species list contain: *Archidiskodon meridionalis vestinus, Stephanorhinus hundsheimensis, Equus* sp., *Leptobos* aff. *vallisarni, Megaloceros obscurus, Pseudodama farnetensis, Ursus etruscus, Panthera gombaszoegensis, Pannonictis nestii, Macaca* cf. *florentina, Castor plicidens, Oryctolagus etruscus, Microtus (Allophaiomys)* cf. *ruffoi, Microtus (Allophaiomys) chalinei, Mimomys pusillus, Sorex* sp., *Talpa* sp. Among other species, a large deer is documented by an antlered skull and several other remains, *Megaceroides boldrinii,* named after its collector (Azzaroli & Mazza, 1992). The best preserved specimen is a juvenile antlered skull. There are, in addition, fragmental antlers belonging to at least seven individuals, a right jaw and some limb bones. The antlers display an exceedingly high variability, which is interpreted as evidence of a genetical instability preceding the evolution leading to *M. obscurus* and in the Galerian to *M. verticornis*. For the same reasons as with the Mugello fauna, the uncertainty for the dates is relatively large, and a possible date would be quite older than the reported 1.5 Ma for the Farneta fauna in Figure 20.

The short section presently outcropping has been sampled for palaeomagnetics, and its samples showed very stable directions. It recorded only one reversed polarity (Albianelli & Napoleone, unpublished data) presumably a Matuyama date not better defined, but still not much younger than the end of the Olduvai, based on the biochronological affinities with the Farneta fauna.

6.3.8 The faunas from Pirro Nord in SE Italy

This fauna was retrieved by De Giuli and collaborators near Pirro Nord, in the surroundings of Apricena, at the eastern foot of the mountains of the Gargano promontory in the South-East of the Italian peninsula. The geologic setting is devoid of a detailed stratigraphic position, while the fauna is still under study; a preliminary note was published by De Giuli *et al.* (1986), attributing a still younger age to it, while specific aspects were also reported (Mazza, 1987; Mazza et al., 1993; Masini & Santini, 1991).

The most characteristic element of the fauna is *Eobison*, a genus of intermediate morphology between *Leptobos* and *Bison*, represented by a partial skull with a bulging forehead, a jaw and two rather short and massive metacarpals. The fauna, collected from several sinkholes, is rich. It includes an elephant, a rhinoceros (may be *Stephanorhinus*), a rather slender limbed equid with stenonid features in its dentition, a *Pseudodama* more derived than *P. farnetensis*, a *Megaceroides, Sus, Megantereon* cf. *cultridens, Homotherium crenatidens, Pachycrocuta brevirostris, Canis arnensis, Canis falconeri, Ursus etruscus, Vulpes* cf. *alopecoides, Hystrix, Apodemus, Microtus, Hypolagus, Lepus, Miniopterus, Myotis, Rhinolophus, Talpa*. With the lack of any stratigraphic indication sharper than the biochronological one (Ficcarelli *et al*., 1996), the dating of this fauna, which was distinguished in a unit representing the end of the Villafranchian mammal age, is positionable in a wide range of the GPTS. But it is also quite likely that the next dramatic change, which will occur with the turnover at 1 Ma, took place after a long sedimentation gap, due to a long tectonic activity in the Apennines and/or to a generalised unfavourable state of environmental conditions for the continental deposition. Therefore, a date still not much younger than 1.7 Ma is conceivable, also in view of the indication deriving from the evidence discussed shortly below. Meanwhile, its position is arbitrarily maintained in Figure 20 at a higher stratigraphic level.

6.4 End of the Villafranchian and transition to the new age at the Jaramillo boundary, 1.05 Ma

The alleged Middle Pleistocene following the end of the Villafranchian saw the development of a large number of mammalian species and new adaptations: the large deer *Megaloceros* and *Megaceroides*, the heavy bovids *Bos, Bison* and *Ovibos*. Equids differentiated into a large number of species, the cold-adapted *Mammuthus* made its appearance. The new age has been related to a major event in the Pleistocene, which makes the turnover to the middle Pleistocene. It is calibrated in the GPTS to the Jaramillo chron, so that a date for its onset is fixed at 1.05 Ma. In the Upper

Valdarno, the last testimony of a faunal association in the Bucine fauna was classified to an age of late middle Pleistocene, while in the present magnetochronologic reconstruction is dated at the base of the Jaramillo or at most at the base of the Brunhes. Out of the Upper Valdarno, the beginning of this new age has the first example with the Colfiorito and Oriolo faunas, because they are directly calibrated by means of magnetostratigraphy to the GPTS. Another site of comparable age had a palaeomagnetic survey, the outstanding site of Isernia with its human remains, but is not calibrated because its magnetostratigraphy yielded only one normal polarity, interpreted as an early Brunhes from biochrological and anthropological inferences (Sala, 1990; Sala & Fortelius, 1993).

6.4.1 The alleged Middle Pleistocene fossils from the Farneta area

The late Villafranchian deposits of Farneta described above are overlain by coarser sediments with a scanty fauna of Galerian age. Remains of a skull of *Megaceroides verticornis* were retrieved from the vicinity of Farneta Abbey and further South, at Pozzuolo and Petrignano in Umbria. Remains of a hippopotamus were collected near Farneta. Here it can be recalled that, lacking a time constraint until the date of 1 Ma, the time span between the Farneta fauna and these remains of Galerian age is cancelled by the coarser sediments just mentioned. The same case was reported in the Upper Valdarno where the gap between the end of the Montevarchi series at nearly 1.7 Ma and the new one overlying the conglomerate on both sides of the Arno river bank at nearly 1.05 Ma or 0.78 Ma, was, on the contrary, measured by magnetic stratigraphy thus lasting 0.7 my or 1 my. Therefore, a similar condition would be repeated in Valdichiana after the deposits of the Farneta localities. Above the gravel bed, the new faunal remains would date roughly 1 my younger than last Villafranchian deposits, as calibrated in the adjacent Upper Valdarno in the profile of Cava Minuto (Fig. 17) succeeding the late Pliocene one of Faella.

6.4.2 The fauna of Colle Curti

This fauna was recovered in the Colfiorito basin, on the Apennines not far East of the watershed between Umbria and Marche. It was palaeomagnetically dated at the onset of the Jaramillo and therefore close to 1 Ma, with an age calibrated to it for the Emilian bio-chronostratigraphic stage (Coltorti *et al*., 1998). The beginning of the great faunal revolution from late Villafranchian to Galerian is related to such an event. The fauna, still under study, is significant, represented by *Megaceroides verticornis* and *Stephanorhinus* cf. *hundsheimensis*, two typically Galerian elements, with some survivors from late Villafranchian: *Pseudodama* cf. *farnetensis, Canis arnensis, Canis* cf. *falconeri, Ursus* cf. *etruscus, Microtus (Allophaiomys)* cf. *pliocaenicus* and a large sized variant of *Hippopotamus antiquus* (Borselli *et al*., 1988; Ficcarelli & Mazza, 1990).

Its stratigraphic position is in a 12 m thick silt level, overlying a longer series of sand layers, in correspondence with the polarity change from a reversed to a normal magnetozone. The transitional characters of the Colle Curti assemblage are therefore peaked at the magnetic polarity transition, dated 1.05 Ma in the GPTS. Another date at 426 Ka was provided by the radiometric timing of the tephra contained in the paleosol level unconformably overlying the basin fill.

6.4.3 The fauna of Cesi

In the same basin of Colfiorito, at Cesi, few km away, a 10 m sequence of silt containing the fossil site and overlain by the same paleosol with the tephra dated 426 Ka was assigned a higher stratigraphic position than the previous one at Colle Curti. The polarity couplet of reversed and normal directions was referred to the only possible polarity change younger than the Jaramillo of Colle Curti (Ficcarelli *et al.*, 1997). The fauna was with more differentiated characteristics, and this led, together with the radiometric date of the overlying paleosol, to assigning the polarity chron a magnetostratigraphic date of the end Matuyama, at the boundary with Brunhes. A long separation between the deposits of these two Colfiorito faunas, from Jaramillo to Brunhes, was actually introduced on the bases of such preliminary inferences rather than by firm stratigraphic markers recognized in their distant profiles. Both sequences extended over ca. 10 m thick beds of massive fine sediments, capped by the paleosol layer containing the dated tephra. The date of an early Brunhes was therefore tentative, expecially when compared with similar results from the Oriolo fauna, reported in the next section, which in contrast supports the choice of the Jaramillo date. Both sites are positioned (Fig. 20) according to the previous constraints but are left in that yielded by the biochronologic determination, while magnetochronology would have been undetermined between Brunhes or Jaramillo boundary.

The fauna includes among others *Stephanorhinus* cf. *hundsheimensis, Hippopotamus* sp., *Megaceroides solhilacus, Cervus elaphus, Dama clactoniana, Bison schoetensacki, Homotherium*, and an indetermined elephant (*Archidiskodon meridionalis vestinus* ?) whose date at the onset of the Brunhes chron would extend its previous range of distribution (Torre *et al*., 1996), known so far until the Jaramillo.

6.4.4 The fauna of Oriolo

The finds are scarse and include scanty remains of hippopotamus, rhinoceros, horse, bison and elephant in a 20 m thick section through the transitional sequence from the sand unit overlying the main Blue Clay Formation of the external Apennines. Most representative are the skull of *Bison* cf. *schoetensacki* at the bottom and a skull of *Archidiskodon meridionalis vestinus* close to the top, in a reversed polarity and in a normal one, respectively. This disposition does not contradict an assigned date to the Jaramillo, although the sedimentary indications suggest a more recent age, while the former was preferred because the *A. meridionalis vestinus* is known until the Jaramillo and its extension to the Brunhes would deserve a stronger support by a widespread recognition rather than the generalised age of the geologic setting.

Therefore, all three sites lately measured are datable in the transition to the Jaramillo, which could also be the date of the Bucine fauna of the Upper Valdarno, leading to a conclusion that no one fauna so far examined in the Northern Apennines would be representative of the new mammal age. This time span should be searched in the records of younger basins, as are those from the Southern Apennines. One example has been reported from the San Arcangelo Basin, already mentioned (Sabato *et al.*, 2002), and with new palaeomagnetic data which calibrate a section nearly 200 m thick, spanning from the reversed polarity before the Jaramillo to the beginning of the Brunhes (Albianelli *et al.*, unpublished data). In a lateral section, where the fossiliferous site with a poor fauna of micromammal species was found (Masini *et al.*, unpublished data), the measured magnetic polarity was in the Brunhes, and the biochronologic indication suggested an age of this site related to an early Brunhes (Masini, personal communication).

7. CONCLUSIONS

Magnetic stratigraphy has now dated the Upper Valdarno series in the GPTS system, and therefore this basin results one of the oldest in age and the one of longest duration among the sequences in the intramontane basins of the Italian peninsula. It spans from middle through late Pliocene, up to the beginning of the Pleistocene, during which two major steps of the Appennine uplift brought about such extensional basins, in a time span comprised in the magnetostratigraphic framework of 1.5 my (Fig. 2). The second one, in particular, produced a long gap in the lacustrine sedimentary record, dated to last more than 0.7 my. The first interruption, instead affected the faunal and pollen records, which registered the main climatic events of the glacial Pliocene. In fact, from the magnetochronological criteria, the bases were developed for a new concept in dating faunal complexes, which provided facts of a tangible and substantial renovation (Lindsay, 2001). By themselves, they warrant a radical revision of what was established in more than one and a half centuries, until Azzaroli (1977a) decidedly pointed to the stratigraphical significance of the historical content inherent in the museological collection of fossil vertebrate faunas of the Upper Valdarno, with which the history of the Museum of Firenze was started. The awareness of the lack of basic chronological data for all ancient collections brought us to look for new ways of confering a more significant dating to the biochronological criterion which had been protracted since the first results of the comparative osteology of Cuvier (1824). Through inductive ways, comparing what had already been established with magnetostratigraphic criteria of dating continental sedimentary sequences, the mammal faunas of most Apennine basins may be reasonably dated with a highly improved accuracy, assigning them the ages of the Pliocene and Pleistocene biostratigraphic record. Also classical vertebrate fossils of the Upper Valdarno collections in the Museum of Firenze were dated with a resolution of few thousand years out of an age of nearly 2 Ma, due to the direct calibration of their sites within the magnetostratigraphic series of 2.5 my there established.

For the geological setting of the sedimentary series, the newest data provided by dating the time span between major events, such as the duration of the upheaval pulses and breaks of sedimentation, put fundamental steps for re-defining the history of the basin fill. The sedimentation started at 3.3 Ma in the Mammoth magnetochron, but the bulk of the lake deposits is dated after the short episode of the lignite seam (may be shorter than 3.13 to 3.08 Ma) across the boundary of 3.11 Ma for the Kaena chron. The thick Meleto-clay pile of silts lasted until 60 ky before the Gauss-Matuyama boundary of 2.58 Ma, and was replaced by sand deposits (San Donato sands) rapidly filling the basin. The G/M boundary was recorded during a subaerial deposition (Rena Bianca sands) when a condensed series of sand accumulated until shortly before the Reunion chron at 2.15 Ma. This dating is the most recent result, first reported in this work, and the implications need to be discussed with great attention. After this interruption (at 2.64 Ma) a lacustrine-fluviatile regime was restored with the Montevarchi sequence shortly after 2.15 Ma. The new silty sediments have been recently found in contact with the sand, and therefore the Reunion was immediately followed by the reversed Matuyama polarity. The first mammal fauna is recovered in layer beds dated 1.99 Ma, after which its blooming is recorded thoughout 220 ky and with resolutions of very high accuracy, while several important facts occur at the same time and are now dated in the Upper Valdarno series.

The main events coeval with the faunal record are the two magnetostratigraphic boundaries between Gauss and Matuyama and the end-Olduvai. The first calibrates to the GPTS the chronostratigraphic boundaries of the middle and late Pliocene, and the second the end of Pliocene and the beginnig of the Quaternary. This makes the Upper Valdarno continental sequence the reference series for correlating the Apennine continental basins on the bases of events on the global scale which produce the main changes in the geologic system. Two main climatic changes were documented in the geologic system. One was the temperature oscillations on a trend of decreasing values, observed in the oceanic record by the oxygen isotope ratios (summarized in Shackleton *et al.*, 1984). The other one observed in the continental areas was given by the pollen percentage changes, reproducing vegetational assemblages of wet/temperate forest alternating with those from herbs and sprouts of a dry/cold vegetation (summarized in Zagwijn, 1974; Leroy & Seret, 1992). The former took place as a decreasing temperarture marked by the increasing of the absolute values of the oxygen ratios, which began to cyclically oscillate with the 41 ky period, as the obliquity atronomical parameter, while approaching the boundary between middle and late Pliocene. Its calibration has been updated by Shackleton (1995). The latter confirmed the trend of decreasing temperatures by remarking a decrease in pollen percentage of the arboreal plants, from a forest vegetation of a warm and wet climate towards a cooler one, leading then to an oscillating abundance of forest and herb pollen sporomorphs. This condition spinned up in the Olduvai, when it drastically jumped to nearly 90% of the steppe vegetation representative herbs dominated by *Artemisia*, while in the ocean the oscillating ratio moved to periods of 100 ky, the short eccentricity cycle. The magnetic signal was capable of detecting both changes in the Milankovian periodicities, acting as another proxy independently to the previous ones, and to date very accurately their occurrences. The earlier one was enhanced by the onset of the obliquity cycle taking place at 2.85 Ma - a date representing the initial conditions leading to the Pliocene glacial/interglacial alternation system- and overprinting the precessional one which was prevailing before. The second one by calibrating the P/P boundary in the continental deposits where the highest percentage of herbs pollen was recorded in correspondence to the level beds just preceding the Pleistocene by few tens of ky. This is another date of critical relevance because its recording in the marine series of Vrica, Southern Italy, decidedly contributed to fixing there the 'golden spike' for the Pleistocene boundary stratotype, "just before the end of the Olduvai", at 1.796 Ma (Zijderveld *et al*., 1991).

In these ages accurately dated, also the Upper Valdarno faunas were all dated at high resolution. The range spanned from 50 ky to 2 ky, according to the degree of accuracy for their positions reported with the recovery, from the ones only located in a broad area or stratigraphic level to the ones with detailed positions, given the present magnetostratigraphical framework. It begins in the Gauss chron and extends throughout the Olduvai (1.77Ma), thus establishing an essentially continuous magnetostratigraphic reconstruction of the continental series, after which an interruption of nearly 1 my was documented in the basin fill. More outcrops of these continental deposits may be uncovered by excavations for industrial purposes, and thence more data would be added. In the prospect of new results, some of the closest ones may be suggested as an outlook.

- Improving the dates of the Museum collections. High resolution dating of the Upper Valdarno fauna from the main collections in the Museum of Firenze was made at ± 2 ky for the fossil sites with accurate positions, and at ± 50 ky for those reported in the catalogue without indication of a precise position. To this group belong almost 75% of the Upper Valdarno collections, which will have in the present magnotochronologic framework the best reference for reconsidering their broad datings of specimens labeled so far as simply Pliocene or Pleistocene. With such a resolution, a review of information available in the automated catalogue is highly recommended; as a conclusion of the present work, the ages of most of these faunas would shift from Pleistocene to the last 300 ky of the Pliocene. The first dates were already assigned, and their numerical uncertainties were close to ± 10 ky; this resolution seems viable for the specimens of several collections.
- A second point would deal with the pollen events, as changes in their percentages can be dated with the same accuracy reached in the mammal fauna, so that subtle changes can be ordered in time series in order to analyse the climatic changes. The main global events were already identified in the Upper Valdarno record: refinements at a higher order can detect minor changes between close areas, at the scale of microclimates, such as that already tested in the Apennine basins, where differential upliftings may have affected their paleoenvironments. The case of a short diachronism, measured between Upper Valdarno and Valtiberina pollen records at the Gauss/Matuyama boundary, can be extended to other basins to reconstruct the history of the climatic changes in the Italian peninsula.
- A further point would focus attention on the correlation of the marine series of the Italian peninsula with the calibrated Upper Valdarno series, by reversing the prospects for a finer resolution. The continental sequences are now very well dated series, with a time resolution extremely high and able to improve, for most sequences through the Apennines, that of the biozonation, which is in contrast rather poor in these critical ages from Pliocene to Pleistocene. The stages around the boundary, best represented in the Italian sequences, may have a number of detailed tests dealing with dated sequences to reconstruct the comprehensive sedimentary geology, produced after nearly a century since that compiled by Gignoux. The present case of the mid and late Pliocene sequence of the Marchean pelites calibrated to the GPTS (this volume) demonstrates the role represented by the Upper Valdarno magnetochronology as a reference sequence. A direct correlation between these series, documenting the upheaval of the Apennine Range on both sides of the watershed, is producing dates of various episodes of its tectonic activity.
- The conclusive Figure 20 shows the faunal distribution of the main portion of the classical sites and few recent ones that have been calibrated to magnetochronology. Some crucial faunal units remain to be calibrated, as Olivola and Tasso. For both of them only a short continuous sequence can be measured, and this will add little information. More important would be to calibrate the interval from the Olduvai to Jaramillo which includes the faunal units of Farneta and Pirro. They are now positioned in a more appropriate relationship with the GPTS reference than previously attempted without a close magnetostratigraphic reference, such as the present one of the Upper Valdarno. A new accurate timing can be used for reporting on finds which will be recovered with stratigraphic indication, and from magnetochronology trying to set up the various evidences to reconstruct for them a biochronologic history with stratigraphic criteria.

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The administrators of the Montevarchi township let us sample two cores drilled in the Arno bed, which hel-

ped to extend downwards the profile of the Montevarchi series. Two more were made available in the Rena Bianca by the owners of the pit, and their few limy beds confirmed the presence of the Gauss/Matuyama boundary at its bottom.

The enterprise people in charge (Ing. Bianchini) provided us with two cores drilled in the Aulla railway station that supported the idea of a younger date than Gauss for the Aulla site.

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