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Dating the late Villafranchian (Pliocene) vertebrate collections of the Upper Valdarno (Tuscany, Italy) by the magnetostratigraphic framework of the basin fill

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ABSTRACT – The Upper Valdarno fossil vertebrates in the collections of the Natural History Museum of Firenze include faunas of the Villafranchian events, but more than 70% of their specimens are catalogued without precise stratigraphic position, and most of them from the old collections. Magnetostratigraphy has dated the earlier two successions of the basin fill, from the late Gauss chron throughout the Olduvai, in the interval from 3.3 Ma to about 1.75 Ma, and the fossil faunas there collected can be placed in a chronological asset with time resolutions up to few ky. A relevant part of collections labelled in the Museum inventory with ages of Pleistocene or early Pleistocene is now dated in the last 200 ky of the Pliocene, and shortly after the P/P boundary, which has been fixed in the stratotype at 1.8 Ma. The new accuracies range from ± 50 ky for the ones of lesser grade to ± 30 ky for most of the old collections when their position is reconstructed from the catalogue information to lie in one of the lithostratigraphic units which are now well dated. Dates better than this are provided for the best repositioned ones, as Nesti's *Rhinoceros* of 1811 dated 1.83 ± 0.01 Ma, and Azzaroli's *Elephant* of 1953 at 1.850 ± 0.015 Ma, while the new finds reported with 1 m accuracy in the Faella magnetostratigraphic type section are dated with ± 2 ky.

RIASSUNTO – [Le collezioni a vertebrati del Valdarno Superiore di età tardo-villafranchiana calibrate dalla ricostruzione magnetostratigrafica della serie sedimentaria del bacino nel Pliocene.] – Le successioni continentali sono state datate attraverso il contenuto fossilifero discontinuo delle faune a vertebrati: tale criterio è oggi completato da quello magnetostratigrafico (Lindsay, 2001), come appunto è stato realizzato nel Valdarno Superiore. Qui la datazione biocronologica ha potuto essere affinata, fino alla correlazione con quella biostratigrafica, per mezzo della calibrazione paleomagnetica della gran parte delle sezioni da cui provengono i fossili delle raccolte del Museo. Lo scopo attuale è di illustrare i risultati magnetostratigrafici ottenuti nella serie continentale del bacino che permettono di datare i rinvenimenti più recenti (Mazzini M. et al., 2000) e le collezioni classiche (Cioppi & Napoleone, 2001). L'assetto magnetocronologico della serie (Albianelli et al., 1995; 1997; 2002; Napoleone et al., 2001b) consente l'uso di una età cronostatigrafica di dettaglio a corredo dei singoli reperti censiti nella catalogazione automatizzata delle collezioni (Cioppi et al., 1996).

La ricostruzione magnetostratigrafica del bacino, e specialmente quella del secondo ciclo sedimentario di Montevarchi, che appunto ha fornito la gran parte dei fossili delle collezioni del Museo, assegna le sue tre unità litostratigrafiche agli ultimi 300.000 anni del Pliocene e poche decine di migliaia del Pleistocene. D'altra parte, l'escursione stratigrafica delle faune rinvenute ricopre tutta l'estensione della sezione di Faella, per un totale di 220.000 anni: quindi, nel peggiore dei casi, tutti i reperti sono compresi entro limiti di ca. 100.000 anni, compresi quelli privi di una qualsiasi indicazione stratigrafica entro la serie di Montevarchi. Invece, alcune indicazioni sono reperibili nel catalogo, e permettono di risalire alle loro posizioni con varie approssimazioni. Gli eventi principali nella serie hanno inizio da prima del crono Olduvai (1.95 Ma), e oltrepassano il limite del Pleistocene, fissato nello stratotipo della Vrica a 1.796 Ma (Van Couvering, 1997). I primi valori temporali ottenuti dalla calibrazione dei loro siti riguardano i giacimenti più recenti: Matassino a 1.950 ± 0.005 Ma e Poggio Rosso a 1.870 ± 0.005 Ma (Napoleone et al., 2001b). Con analoga accuratezza sono datate le collezioni di cui non è riportata in catalogo la quota precisa, ma da riscontri di campagna e altri indizi è stata ricostruita una posizione con pochi metri di incertezza: è il caso di due reperti esposti nel Museo, il *Rinoceronte* di Nesti del 1811 a 1.83 ± 0.01 Ma (Napoleone et al., 2001a) e l'*Elefante* di Azzaroli del 1953 a 1.850 ± 0.015 Ma (Azzaroli & Napoleone, in manoscritto).

L'ubicazione delle altre faune prive di indicazioni del sito è comunque riferibile alle tre unità litostratigrafiche individuate nella serie di Montevarchi, aventi spessori medi di ca. 30 m e una durata di ca. 100.000 anni. Quindi la loro posizione è in massima parte ricostruibile entro ± 15 m, il che conduce ad una incertezza di età inferiore a ± 50 ka. La raccolta di Faella è invece particolare, poichè si estende per quasi tutto lo spessore della serie, raggiungendo 220 ka a partire da prima dell'inizio dell'Olduvai (Napoleone & Azzaroli, 2002); nei livelli più bassi della serie, esposti nella sezione di cava Pratigliolini, sono stati rinvenuti gli ultimi reperti, dell'aprile 1999 e gennaio 2000 e datati 1.980 ± 0.002 Ma e 1.990 ± 0.002 Ma. Queste date sono le più antiche per le faune del secondo ciclo e quelle con l'accuratezza più alta, essendo l'ubicazione dei siti precisa entro 1 metro.

Viene così fissato il criterio stratigrafico nella classificazione delle collezioni, in modo che il valore numerico delle loro età pone termini temporali precisi alle relazioni di diversificazione delle faune del VS che erano sempre risultate molto tenui tra le varie associazioni raggruppate nel Villafranchiano superiore e che nella nuova calibrazione magnetostratigrafica si collocano fino al limite del Quaternario e intorno a questo.

INTRODUCTION

Recent discoveries of rich vertebrate deposits, in the Montevarchi Succession (MS) of the Upper Valdarno (UV) sediments (Mazzini M. et al., 2000), led to reconsidering the problem of dating the

palaeontological collections in the Natural History Museum of Florence University (NHMFU) with the high resolution of magnetic stratigraphy (Cioppi & Napoleone, 2001). This was particularly viable in the MS, as its profile was almost fully covered by the magnetostratigraphic type section established at the

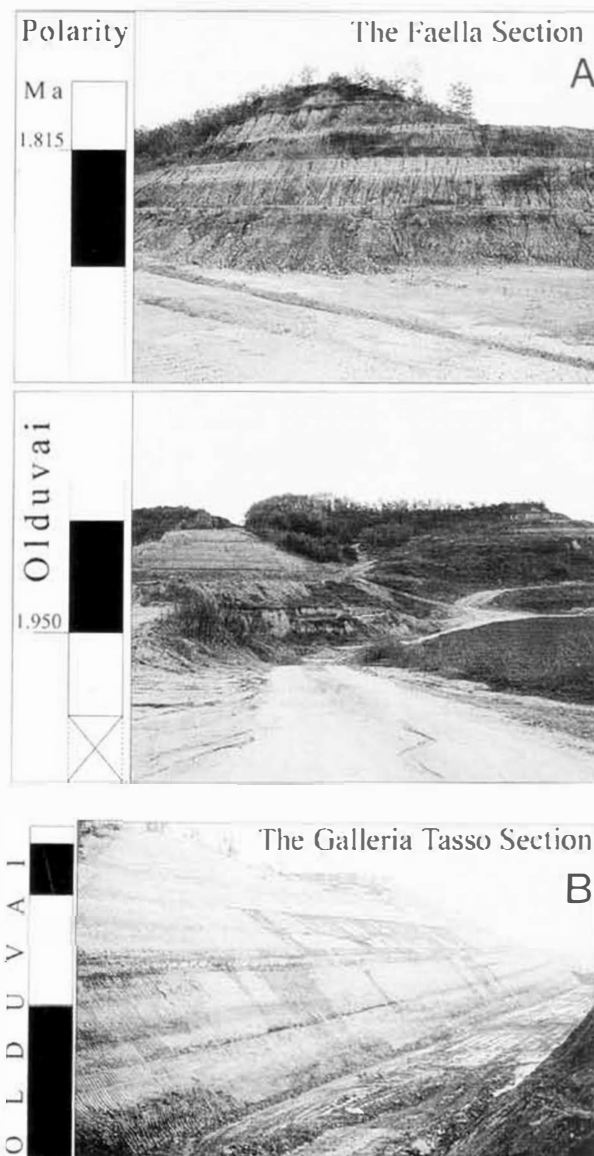
Faella clay pit (Albianelli *et al.*, 2002). Moreover, most of the UV fossils are sited in the MS, thus favouring the present aim of numerically dating the classical findings of the past two centuries stored in the NHMFU collections by the chronostratigraphy revised by Berggren *et al.* (1995) and based on the Geomagnetic Polarity Time Scale (GPTS). The present work intends to illustrate the new magnetostratigraphic setting of the UV sedimentary sequence containing the late Villafranchian faunal assemblages, dated by the changes of the fossil magnetic vector through its short interval of continuous deposition in the MS lacustrine and palustrine series.

The first profile was reconstructed in the basal silty sequence (Torre *et al.*, 1993), by assembling a few short sections as usual for natural exposures in such soft and flat deposits, but soon aided by the ones produced by quarrying operations for the clay exploitation at the Matassino pit. The best profile was produced for nearly 80 m (Text-fig. 1), by quarrying the Pratigliolmi clay pit in the Faella territory (Text-fig. 2), that cuts almost the whole MS except a few meters on its extremes, and this series will be often reported here as the Faella magnetostratigraphic type section.

This high resolution dating was also applied to the early Villafranchian sequence (Albianelli *et al.*, 1997), and is now being carried out on the post-Villafranchian short sequence (Albianelli *et al.*, in preparation), with the aim of producing the magnetostratigraphic reference for other intramontane sequences of the Apennine basins (Sagri *et al.*, 1994). They could assume a new arrangement by correlation with the UV magnetostratigraphy, the first calibrated succession and the one with the earliest terms (Torre *et al.*, 1996). A straight confirmation of these dates was produced by the continental sequences outside the UV. The Lower Valdarno one, West from Florence, has yielded two short profiles confining the long sequence of shallow marine deposits reconstructed by Benvenuti *et al.* (1995), and dated nearly 300 ky in the latest Gauss (Albianelli *et al.*, unpublished data), up to the Montopoli fauna dated 2.58 Ma (Lindsay *et al.*, 1980) at the Gauss/Matuyama boundary.

A larger interval was recorded in the lacustrine sequence of Valtiberina (in the upper Tiber Valley), ca. 100 km South from the UV. Its continuous basal sequence lasted more than 600 ky, when it was interrupted by the severe tectonics of the Apennine uplift that produced a master fault of the basin and the tilting of the clay beds by nearly 30°. The deposition of the sequence took place during 200 ky in the latest Gauss and more than 400 ky until the post-Reunion Matuyama chron, beginning at 2.14 Ma (Abbazzi *et al.*, 1997; Pontini *et al.*, 2002).

A correlation of recent findings from North of Rome was done with the UV fauna of late Villafranchian, based on the biochronologic point of view (Mazzini *et al.*, 2000); actually, the present

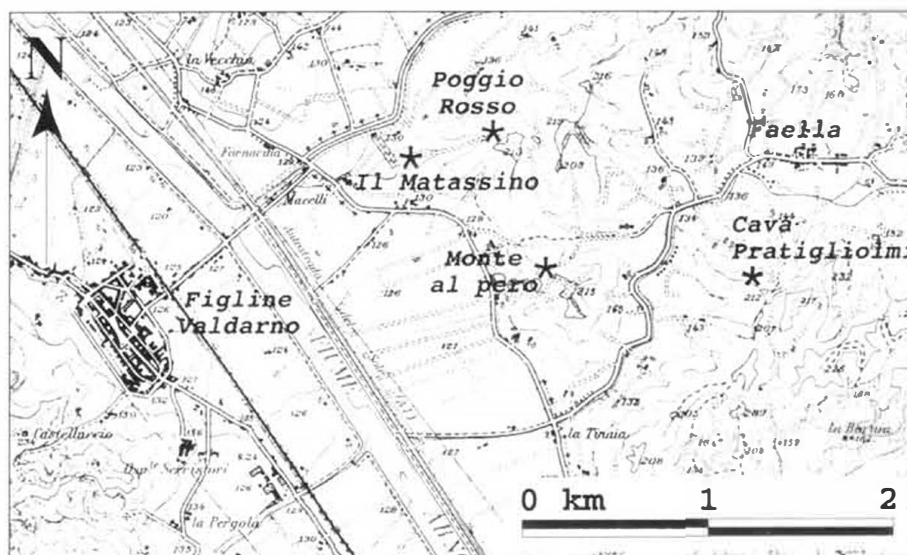


Text-fig. 1 - View of the sections used to construct the magnetostratigraphic profile of the MS. A) The Faella pit section during the clay quarrying: the lower part is 35 m thick, the upper 28 m, the results of the paleomagnetic surveys are also reported by their sides with the Olduvai magnetozones. B) The Galleria Tasso section open to construct the lining of the railway tunnel, near the Tasso creek for a 32 m thickness.

calibration can correct the high uncertainty of such a dating by adding a high resolution to it (Napoleone *et al.*, submitted).

PREVIOUS WORK FOR DATING THE UPPER VALDARNO FAUNAS

A geochronological outline of the UV sequence containing the vertebrate faunas will be resumed, and its dates reviewed in order to illustrate the results of



Text-fig. 2 - Topographic setting of the area near the Faella village, where the reference section for the magnetic stratigraphy of the Montevarchi Succession is fixed at the Cava Pratigliolmi clay pit. Some of the oldest and newest fossil sites are located in its area: Cocchi's collection of 1862 was retrieved at the foot of the Monte al Pero hill close to the Faella creek, while on its top Nesti's *Rhinoceros* was located, while the Poggio Rosso Locality of 1995 is the largest fossil assemblage ever collected in the Museum record.

the magnetostratigraphy applied to the Museum collections, from the oldest ones of two centuries ago to those of April 1999 and January 2000 (Napoleone & Azzaroli, 2002). The UV fossil collections formed a relevant nucleus within the findings which gave origin to the institution of the Museum, at the end of the 17 hundreds (Cioppi, 1999). From the first UV catalogue of 356 specimens compiled by Filippo Nesti in 1845, the fossils now consist of nearly 4,000 specimens, in a collection harbouring over 20 thousand specimens, which have not yet been fully inserted in the automated GEF catalogue (Cioppi *et al.*, 1996). Such a development took place thanks to the contribution of gifts by amateur-collectors to the Museum since the "Grand Duke age" of late 17 hundreds, and to recent recoveries by the Museum. While the acquisitions of the last 100 years do not exceed 30% of the Museum patrimony, the bulk of the old collections formed the base for the ordination of the UV faunas in the biostratigraphical system (Azzaroli *et al.*, 1992). Then, the biostratigraphical correlation was attempted in order to integrate a regional classification of the European faunas in the chronostratigraphic system, and finally magnetic stratigraphy has provided the geochronology of the sedimentary sequences and of their fossil content by assigning them a numerical age.

These steps in dating the UV history emphasize the role played by the MNHFU collections of vertebrates in focusing the studies on the basin evolution.

A) BIOCHRONOLOGICAL SUCCESSION OF FAUNAS

Chronological classification of faunas in the intramontane Plio-Pleistocene basins and littoral deposits of the Apennines and lowlands received a fundamental contribution from the UV collections and other

sites in Tuscany, although many findings lack the reference of a firm topographical or stratigraphical position. Biochronological affinities of faunas collected in various sites of the Northern Apennines were used for dating their associations, whose basic characteristics were first described by Pareto (1865, in Azzaroli, 2001). A complete asset of these characters provided the Villafranchian Stage (Azzaroli, 1977a), which was used for the Italian faunas until a new chronological framework for Mammal Neogene (MN) Age Classification of the European faunas was introduced (Mein, 1990).

For the Villafranchian part, six groups were established in Faunal Units (FU). The Triversa FU is the earliest of the MN16, later divided into MN16a and MN16b by Azzaroli, and represents the base of the Villafranchian. In the UV, the Castelnovo dei Sabbioni local fauna is referred to this unit. It includes fossils from the old lignite mines and clay quarries (among which are those of Gaville, Tegolaio, Montetermini, and the large one at Santa Barbara), on the left bank of the Arno river. The next middle Villafranchian is formed by Montopoli FU from the Lower Valdarno (the unit MN16b), Saint Vallier FU from France and Costa San Giacomo FU in central Italy, which are not represented in the UV. Then, the Olivola FU from northern Tuscany (ca. 100 km North from the UV) marked the onset of the late Villafranchian and is first represented in the UV by the Matassino fauna, in the clay pit near Figline (Text-fig. 2). It may be pointed out that the age of this fauna was initially equated to that of the Olivola FU and then assumed shortly younger (Azzaroli, 1983). Most significant, in fact, was seen in the UV the association of *Equus stenonis* and *E. steblini* all through the MS, while the latter species is lacking at Olivola (Azzaroli, 1950), and other species of Olivola

were present at St. Vallier and not in the UV. The Villafranchian age ends in the UV with the Tasso FU, collected in the area of the Tasso village, and continues in the Italian peninsula with the Farneta FU and Pirro FU, as lately reviewed by Azzaroli (2001).

B) BIOSTRATIGRAPHICAL RESOLUTION

The need to insert the FU from continental sequences into chronostratigraphy had always prompted studies to search common elements to link biochronological and biostratigraphical classifications. The influence exerted by Gignoux since the early 19 hundreds was fundamental in finding the best Italian Plio-Pleistocene sites for fixing the Neogene stratotypes. In contrast, more recent analyses were partial and scanty (Azzaroli & Berzi, 1970; Ambrosetti *et al.*, 1972; Azzaroli, 1977a; 1983; Torre, 1987). In former years, the onset of the late Villafranchian was assumed coincident with that of the Pleistocene, and this induced to correlate biochronologic events with the biostratigraphical ones by equating their ages. The Olivola FU was correlated with the *Globigerina cariacensis* biozone (De Giuli *et al.*, 1983; 1986).

This brought to place also the first UV faunal assemblage of late Villafranchian, the Matassino Locality, to a younger age in the early Pleistocene, thus moving the Tasso FU to an even younger age. The Triversa FU indeed was correlated with the *Globigerina punctulata* biozone of the middle Pliocene, after the Montopoli FU was dated at the beginning of the Matuyama chron (Lindsay *et al.*, 1980), which also marks the boundary of late Pliocene with the middle Pliocene. During 20 years of attempts (Azzaroli, 1977a; Gliozzi *et al.*, 1997), such a chronostratigraphic setting of the UV could not be stringent, as the response of the continental habitat (and its Olivola-like fauna) to the transition from the Pliocene to the Quaternary represented a rather tenuous turnover for the mammalian faunas (Azzaroli, 1983; 2001; Torre *et al.*, 2001). However, the Villafranchian events recorded through the UV basin fill may be now correlated with the biostratigraphic zonation by means of the chronological asset provided by the GPTS magnetostratigraphy (Berggren *et al.*, 1995). Also the global distribution of the mammalian faunas has been updated and their classifications in different sequences correlated with the GPTS magnetostratigraphy have recently been reviewed by Lindsay (2001).

C) MAGNETOSTRATIGRAPHICAL CALIBRATION

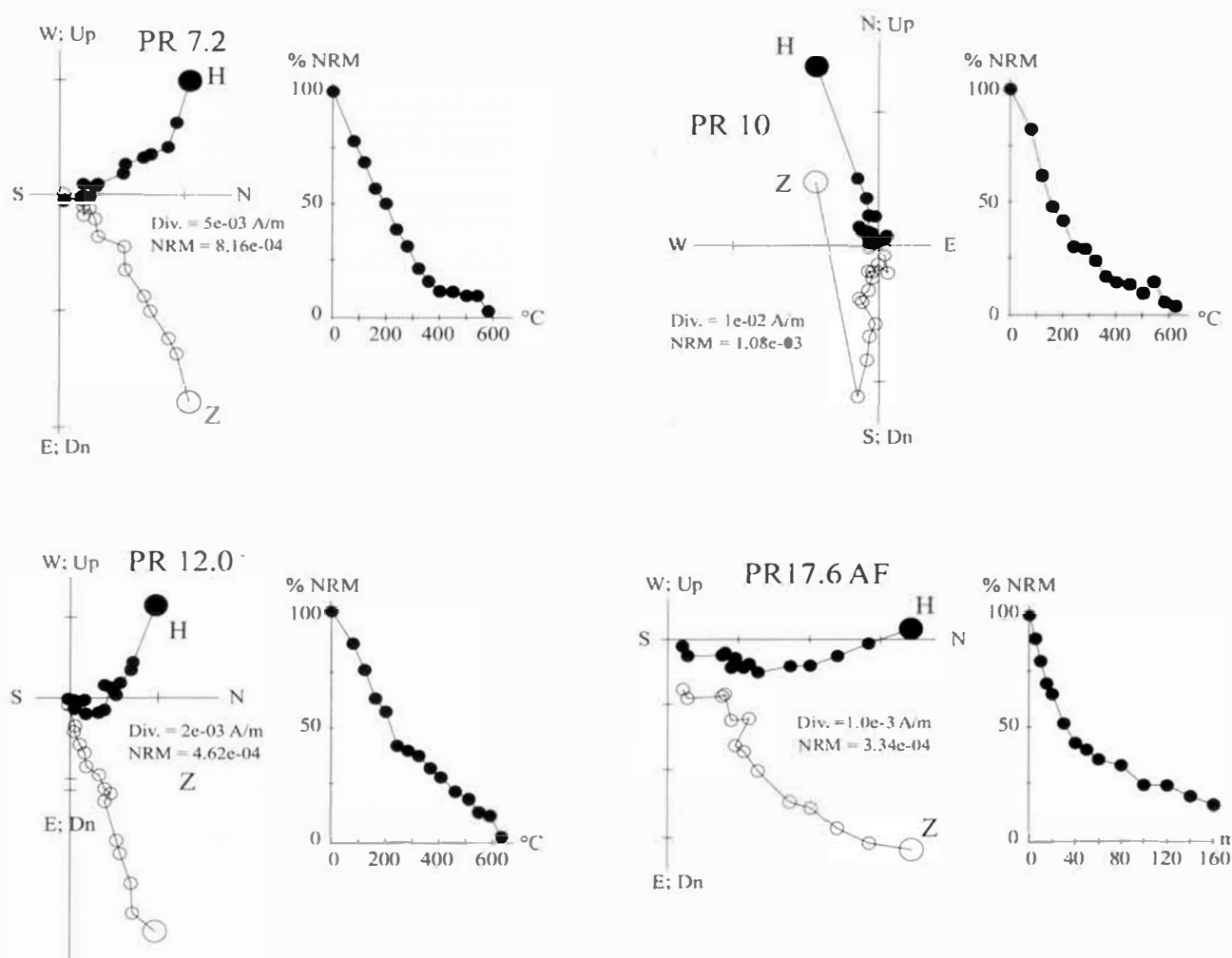
The possibility of closely correlating sedimentary sequences of different facies, and even at great distances, developed when the magnetostratigraphic criterion was introduced. In the latter, the correlation of sequences is made through a guide fossil, the mag-

netic vector, which is worldwide acting for each time interval during a geomagnetic epoch and successively changes, thus making the polarity sequence. This sequence represents the continuous flow of the geologic time measured in years, since the record of the marine magnetic anomalies and each one of its changes produced a polarity event defined within few thousand years. Therefore, the UV faunas calibrated to such a time scale were recently correlated with those from India (Azzaroli *et al.*, 1997), since the latter had also been calibrated by magnetic stratigraphy (Azzaroli & Napoleone, 1981). Calibration of the UV faunal associations (Torre *et al.*, 1993; Albanielli *et al.*, 1995; 1997; 2002) correlates the early Villafranchian fauna of the Triversa FU with the Tatrot stage in the Himalayan sequences, while the late Villafranchian containing the faunas of Matassino, Faella, Poggio Rosso, Casa Frata, and Tasso is correlated with the Pinjor. The Plio-Pleistocene boundary in India is localized within the latter.

MAGNETIC PROPERTIES OF THE UPPER LACUSTRINE ROCKS

Magnetic stratigraphy, based on the succession of the magnetic polarity events, leads to the correlation of these chronostratigraphic ages to the GPTS dates. It marks the current phase in the reconstruction of the evolutionary model of the UV, which was based before on the biochronological succession of terrestrial faunas. The magnetic stratigraphy of the MS cycle has been defined after analysing the various rock types of the lacustrine and palustrine facies, including the sandy layers embedded in them by channelled deposits in the meandering of the Arno river. Their magnetic properties were examined by the experiments carried out in the Palaeomagnetic Laboratory of the Swiss Federal Institute of Technology in Zurich, and were reported on during the various occasions mentioned in the references already quoted. The magnetic properties of the rock types have been emphasized in each occasion when dates of the UV series were discussed, as evidencing a good recording of the original magnetic vector. In the present case another example of the prominent presence of magnetite as the main carrier of the primary magnetization of these continental sediments is shown (Text-fig. 3), while a complete account to illustrate different rock types of the UV series is reported elsewhere (Napoleone *et al.*, submitted).

Two typical facies of the MS are represented at the Poggio Rosso Locality, the clayey Ascione (samples PR 7.2 and PR 10) and the sandy Oreno (samples PR12 and PR 17.6). In particular, the fossil deposit was embedded in a coarse sand with minute gravel, similar to the one described by Nesti for his *Rhinoceros* of Monte al Pero recovered in the "sansi-no" coarse sand (Napoleone *et al.*, 2001a), which is



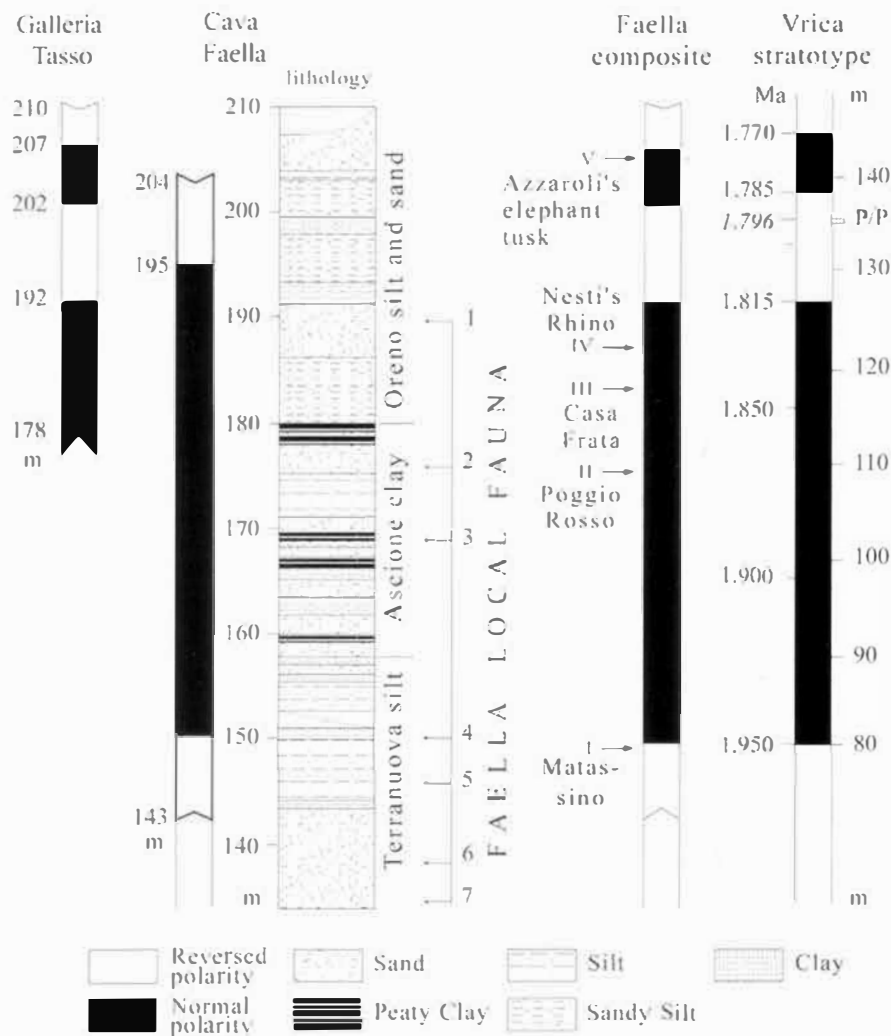
Text-fig. 3 - Rock-magnetic properties, summarised by the pattern of vector diagrams showing the demagnetization behaviour of the rock types in the profile of the Poggio Rosso Locality. The lowest sample (PR 7.2) is from the silty bed just overlying the stratum level of the fossil site, and followed by that from the sand (PR 10) of the channel deposit in the embedding silt similar to the "sansino" sand of the fossil level. The next one (PR 12) is from the clay silt. All three are demagnetized by thermal treatment up to 580 °C and 620 °C (in the diagrams to the right-hand side), to which the magnetic remanence is almost completely destroyed. The directions (in the Zijdeveld diagrams to the left) show the straightforward pattern of the primary magnetization to the origin, as not having been affected by important overprints. The uppermost sample (PR 17.6) is demagnetized under alternating fields (af) up to 160 mT (milli-Tesla). Dots are in the horizontal plane, circles in the vertical plane. The 22 m section recorded only a normal magnetization and is correlated with the upper Olduvai of the facing Faella standard section.

also known as the most common deposit in the MS sediments containing fossil bones. The rock type closest to it is sample PR 10, while the three other summarize most of the range in which the rock magnetic properties are quite similar, indicating magnetite as the dominant carrier of the magnetization. This was confirmed by the Lowrie's procedures of three-component saturation and demagnetization, which yields the same low coercivity of the basic minerals and a blocking temperature at mainly that of magnetite. The characteristic directions of each MS sample yielded the overall polarity sequence, which re-

arranges the UV fill in a stratigraphic series according to the magnetostratigraphical scheme of Text-fig. 4. The new conditions of the numerical datings there displayed, regulate the chronostratigraphical asset of the faunas in the NHMFU collections, in the following scheme.

MAGNETOCHRONOLOGY OF THE MONTEVARCHI SERIES AND ITS FAUNA

In the second lacustrine deposition, the MS units mainly formed by silt and sand, rich faunas are repre-



- Fossil sites in the Faella section: 1) Faella old collection; 2) *Sus strozzii*; 3) *Equus stenonis*; 4) *Archidiskodon meridionalis*; 5) *Eucladoceros dicranios*; 6) *Pseudodama nestii*; 7) *Leptobos etruscus*.
- I-V: Some of the Mammal Localities of the Montevarchi series, referred to the Faella profile.

sented in several sites and reference to them is made through catalogue information. The most significant collections are those of Matassino, Casa Frata and Poggio Rosso, recovered in 1964-68, 1978 and 1995, respectively, while the oldest ones are Faella and Tasso, whose earliest fossils were retrieved since the second half of 17 hundreds and beginning of 18 hundreds, respectively.

1 - MATASSINO

This fauna (267 file cards in the GEF catalogue) consists of 13 species, the most common of which is *Leptobos etruscus*, with 31% of specimens. Its

biochronological dating was first based on the affinity with the Olivola fauna, which in turn marked the onset of the Late Villafranchian, and therefore classified as the earliest fauna in the UV late Villafranchian. As aforesaid, the latter was considered the beginning of the Pleistocene before its boundary had been fixed in the Vrica stratotype and calibrated to 1.796 Ma (Van Couvering, 1997). The initial affinity of the Matassino fauna with Olivola was thereafter disregarded, and the former one considered slightly posterior to the latter (Azzaroli, 1983). Then, its biochronological position was further rejuvenated by Gliozzi *et al.*, (1997), being placed midway between the ages of Olivola and Tasso faunas, and

eventually fixed proximal to the Tasso FU (Masini *et al.*, 1998). The latest figure, by Torre *et al.* (2001), groups all faunas closer to the Plio/Pleistocene boundary. In contrast, the Matassino fossil deposit is contained in the upper part of the Terranuova silt - the MS lower unit - and is now calibrated to the onset of the Olduvai chron at 1.95 ± 0.005 Ma (Text-fig. 5), while it had been previously misplaced in proximity of the end of the polarity zone (Torre *et al.*, 1993). This date actually is 150 ky before the P/P boundary, which implies a deep change of the UV geochronology, moving back all (ancient and new) collections to older dates (Cioppi & Napoleone, 2001; Napoleone *et al.*, 2001b).

2 - CASA FRATA

The faunal association of Casa Frata (115 GEF cards) was largely brought to light in 1978 and referred to the late Villafranchian (Borselli *et al.*, 1980), successive to the Olivola FU (De Giuli & Masini, 1986). The site is lithostratigraphically higher than that of the Matassino fauna, being in the upper MS, at the boundary between its middle and upper units. Moreover it was also believed younger than most UV finds, although has not been further studied and its direct calibration is not yet available. Its position is placed in Text-fig. 4 just above the Ascione clay, and calibrated in the Faella magnetostratigraphic section. However, the correlation of its site with the magnetic type section of Faella, and with the youngest representatives of the Faella collection, to be discussed below, are already the strongest means to pull down its position to a much lower level than that based on the biochronological age, which is assigned close to that of the Tasso FU (see later). The represented species are 17, predominant among which is *Equus stehlini*, with 27% of specimens.

3 - POGGIO ROSSO

Collected in 1995 and now being catalogued (with 560 file cards by the end of 2000), this fauna came from the new section opened in the clay pit above that of Matassino and at a level bed 30 m higher than the Matassino fossil site (Mazzini M. *et al.*, 2000). It comprises more than one thousand specimens, whose essential elements indicate a late Villafranchian age, even if detailed biochronological data are not yet available but only preliminary excerpts were announced (Torre *et al.*, 1999). The palaeomagnetic analysis carried out in its 22 m long exposure showed a single normal polarity, which was referred to the Olduvai chron. However, recent magnetostratigraphic dating of the MS, also with the continuous cyclostratigraphic analysis of the magnetic record in the Faella section, enhanced a steady deposition rate based on the astronomical precession and obliquity cycles, for a time span of 220 ky (Napoleone & Albianelli, 1998).

The Poggio Rosso fauna, already dated within 15 ky accuracy, in the Olduvai chron (Napoleone *et al.*, 2001b), has now been more accurately placed at 1.87 ± 0.005 Ma (Napoleone *et al.*, in manuscript).

4 - FAELLA

The Faella fauna (29 GEF cards) is quite different from the previous localities, as the old collection of 13 specimens, assembled during one century until the second half of the 18 hundreds, was made with specimens not precisely located, but whose provenance was reported from the area around the Faella village. All the new ones were recovered in the section of the Pratigliolmi clay pit and mostly in well located places (Text-fig. 4). The collection consists of 10 species, of which *Leptobos eurus* represents 45% of the total. The 13 specimens of the old collection, representing 7 species, were considered by Azzaroli to have been retrieved on the surface, from the shallow MS levels in the Faella area, i.e. in the Oreno sand, and therefore dated as the youngest ones. The 16 new specimens were acquired in the last 35 years, all recovered from excavations in the Faella section and mainly from the intermediate and basal part of the pit (Napoleone & Azzaroli, 2002). Moreover, the latest findings added to the collection in April 1999 and January 2000 were retrieved at the level of the Faella creek, i.e. at the same level of the Casanuova site of Cocchi's recovery in 1862, at the base of Monte al Pero. The high-resolution lithostratigraphic profile enhanced a magnetic polarity sequence correlated with the whole Olduvai chron (Albianelli *et al.*, 2002), which in the GPTS scale extends 180 ky, and further 40 ky prior to it considering that the recent findings mostly came from the 15 m section below the base of the Olduvai.

The available positions of recent specimens from the catalogue are often within 1 m accuracy, which yields dates with better than ± 2 ky accuracy; when they are for some specimens with ± 5 m incertitude, the dates become accurate to ± 15 ky, and with ± 10 m (almost the thickness range of the MS lithostratigraphic units) to ± 30 ky. The upper sedimentary unit, the Oreno sand, is thicker but doubtfully covers a time span larger than the other units; meanwhile, the incertitude in positioning the fossils has been taken to a cautionary level of ± 50 ky (Napoleone & Azzaroli, 2002) although this error bar may be reduced applying the accumulation rates calculated after the cyclostratigraphy of the palaeomagnetic vector (Napoleone *et al.*, 2002).

Correlation with the Matassino section, and its faunal deposit dated at the onset of the Olduvai, allows to recognize these lower Faella specimens as the first ones of the late Villafranchian fauna in the UV, 200 ky prior to the Pleistocene.

5 - TASSO

The Tasso fauna (205 GEF cards), acquired for its second half in 1882, is the most varied, with 23 species, among which the deer *Pseudodama nestii* predominates with over 30% specimens. Localities related to the Tasso creek and Tasso little town are also varied (Il Tasso, Le Strette al Tasso, S. Maria al Tasso) and all sites belong to the MS higher sandy unit of Oreno. The whole collection, however, provided the bases to define the Tasso FU. But, contrary to the Faella collection, magnetostratigraphical dating for it is not available in a long nor in a continuous outcrop, and its biochronological position was equated to that of Casa Frata. In the present calibration, the Oreno sand of the Faella area is partly placed in the late Olduvai, and the old collection of the Faella fauna contained in the Oreno sand is dated to the end of the chron and very close to the P/P boundary. Also the Casa Frata Locality lies in the lowermost levels of the Oreno sand, at the contact with the Ascione clay, thus yielding an age older than the Faella early collection. As the Tasso FU is made of specimens found in the Oreno sand, possibly at a shortly higher position in the sequence than the Casa Frata fauna, also their date may be shortly younger, at most by few tens of ky. It remains anyhow very close to the younger dates of the Faella specimens, its extent in the Quaternary being drastically lowered towards its earliest beginning, for a delay of occurrence from the Matassino fauna of nearly 200 ky.

The conclusive positioning of the Tasso FU in Text-fig. 5 is near the top of the Oreno unit, for a series of reasons which needed to be discussed elsewhere (Napoleone *et al.*, submitted). Here, the time span enclosed in this association is emphasized to range from the *Hystix* of Le Strette al Tasso (Azzaroli, 1998), in the lower Oreno and thus in the late Olduvai before the P/P boundary. The biochronological age of the several old specimens of *Hippopotamus*, which were no longer found in any UV site, pose a definite problem: they possibly reach the latest Villafranchian at the Jaramillo chron (1.05 Ma), as will be discussed in a forthcoming paper.

6 - SEPARATES

Several findings of lesser relevance, but worth to be mentioned, are in the condition of possibly being positioned in the upper lithostratigraphic unit. The Rhinoceros of Nesti and the Elephant of Azzaroli were already reported, with positions reconstructed to the base of the Oreno sand. Noteworthy is to look at the small group of 13 vertebrate specimens in the palaeontological collection of more than 13.500 invertebrate specimens assembled by Marchioness Marianna Paulucci in late 18 hundreds and donated to the Museum. These few mammalian specimens were mainly collected after she moved to the new res-

idence built on top of the Sammezzano hill (Cioppi *et al.*, 2001). The area is devoid of useful exposures for palaeomagnetism, but the occurrence of the Oreno unit may be likely inferred only for the hilltop, while the specimens of this small assemblage are of various ages. The youngest ones could be not older than the ones of the Faella old collection, but for the others the misleading indication of early or even middle Pleistocene is here rejected. In fact, the *Anancus*, the *Meganthereon cultridens* Cuvier, 1824, and the *M. nestianus* Fabrini, 1890, were collected in a small outcrop of middle Pliocene sands on the left bank of the Arno river, on front of the villa.

Two other important recoveries may be recalled, the *Hystrix etrusca* Bosco collected at Le Strette al Tasso and supposedly dated by Azzaroli (1998) to the end of the Olduvai, and the elephant large tusk recovered in 1975 by De Giuli and Azzaroli at 205 m level, ca. 20 m above Azzaroli's Elephant and ca. 2 km farther to the West. As in the correlation made for this latter with the Faella type section, also the present tusk may be assigned an age close to the Faella specimens from the old collection and shortly younger, and its position in Text-fig. 4 accordingly marked. However, its palaeontological characters led Azzaroli (1977b) to considering this elephant transitional to the ones of the Farneta FU, the association following the Tasso FU and not represented in the UV.

AGE INTERVALS BETWEEN FAUNAL UNITS

The new chronostratigraphic asset of the UV sedimentary units is now assembled, the first sedimentary cycle having been calibrated (Albianelli *et al.*, 1997) and the third one just completed (Albianelli *et al.*, in preparation). It is here represented for 1.5 my in Text-fig. 5, while all data on their Villafranchian faunas may be recalled in the index cards of the GEF catalogue. The magnetostratigraphic dates are given by values in number of years, and the time span separating them is evidenced. Each fossil deposit is thus the temporal barycenter in the biodiversification steps, beginning with the fauna associated to the Triversa FU centered on the date of nearly 3.1 Ma, the contact of the lignite with the overlying Meleto clays in the Castelnuovo dei Sabbioni Series. The latter unit ends 60 ky prior to the Gauss-Matuyama boundary of 2.58 Ma, which was found in the Lower Valdarno to lie underneath the fossil site of the Montopoli FU, a fundamental step marking the transition from the early to the mid Villafranchian. The following Olivola FU is not calibrated with magnetostratigraphy, but its date inferred as pre-Olduvai, with an upper limit not younger than 2.0 Ma, i.e. 200 ky before the P/P boundary, and a lower limit ca. 300 ky before it, according to the discussions reported in Cioppi & Napoleone (2001) and Napoleone *et al.* (2001b). Finally the Tasso FU, also not directly calibrated, is post-Olduvai only for part of its

soon followed by the fossil bearing levels overlying the lignites. From this date, 3.08 ± 0.03 Ma, the lacustrine deposits lasted with a continuous sedimentation of the Meleto clay until the latest Gauss, 60 ky before the Gauss/Matuyama boundary dated 2.58 Ma. No fossils were there found, and the next date was provided by the Lower Valdarno site of the Montopoli FU retrieved just above the polarity change, and thus dated 2.58 Ma. In the remaining Matuyama chron no faunas were found in either one of the Valdarno basins, until the next UV fauna was classified by its affinity with Olivola, another FU out of the UV, in northern Tuscany. The date inferred for Olivola has been discussed in the previous chapters, and placed some 500 ky after the Montopoli FU, while the next FU is dated shortly after the Olduvai magnetochron. The time span from Olivola is nearly 300 ky, and is the only one measured so far in the Villafranchian faunas of Italy shorter than 500 ky.

It may be remarked that all the previous FU have the biochronological intervals between them dated directly in the UV or by correlation with the magnetozone sequence of the UV. When, on the other hand, the biochronological intervals are characterized by gradual transitions between Faunal Units, they no longer have a temporal barycentrum and the evolutionary steps may be dated only with a more detailed magnetic stratigraphy. This is the case with the various UV local faunas with Olivola affinity, which are all contained in the MS until the Tasso FU, an interval between the two uncalibrated faunal units spanning from a lower limit earlier than 200 ky before the P/P boundary to soon after the Olduvai end. The ages of the MS local faunas in this way range from a rather limited time younger than the Olivola FU to shortly before the Tasso FU, i.e. they span the range of dates already measured at 1.99 to 1.77 Ma in the Faella section. The short remaining gap with the confining FU of Olivola and Tasso tightens therefore any possible diversification of these faunas, which is in fact poorly marked, within the dates of the Faella magnetochronologic standard and with its accuracy. On such bases, the main faunal associations confined in the latest interval of the UV series become the best stratigraphically defined, within the Villafranchian continental basins of Italy, and both collection types in the MNHFU attain a high accuracy. A few ky accuracy is in fact reached by the ones for which a reliable location can be reconstructed from catalogue information, or of a few tens of ky for the others with more uncertain positions. However, also the latter are dated with an accuracy of at least one order magnitude higher than the previous ages, which were indirectly correlated with biostratigraphy, as the MS fauna assigned to the early Pleistocene. This leads to a high-resolution time series for all Villafranchian faunas, which is fully apt to provide the sequence of dates for the catalogued specimens, and enrich their GEF cards by this numerical datum.

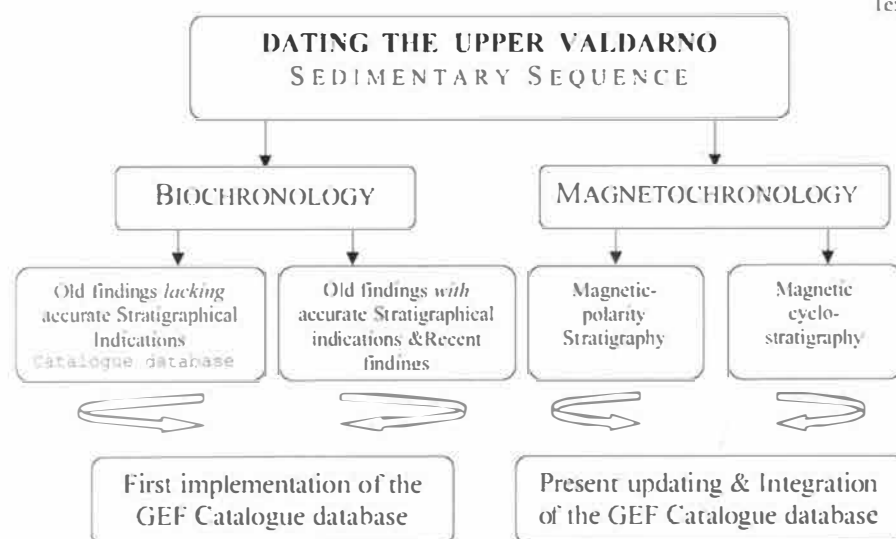
A block diagram may illustrate the results discussed so far, directly correlating the magnetostratigraphic disposition of the fossil sites with the GPTS as a calibration to the numerical time scale (Text-fig. 6). The available material for dating the history of the UV sedimentary sequence, until recently consisted of the time series made by the discontinuous faunal events, organized in the Villafranchian biochronological sequence, and now also by the continuous flow of the magnetic stratigraphy. The latter is based on the magnetic events, the polarity changes, which describe the history of the earth's geomagnetic field, and on the continuous changes of the magnetic fossil vector recorded during the deposition of the UV sequence. Altogether, biochronology and magnetochronology contribute to date the fossil record with the highest resolution, since the magnetostratigraphy provided the calibration of the former. This numerical dating of the fossil specimens may now enrich also for the old collections in the Museum catalogue, which usually lack the reference on their ages as the accurate position was not reported for more than 70% of the finds. The UV series becomes, therefore, tightly correlatable in several exposures by their magnetostratigraphic dates, and the catalogue indication of the area where the collections were recovered can receive a much more defined time constraint to the age of the fossil sites, and organised in stratigraphic succession.

SUMMARY AND CONCLUSIONS

The integration of the firmly established data of the magnetostratigraphic new criteria with the previous classifications of depositional events may be stressed as a major result of the present chronological outline. The faunas are mostly dated across the Olduvai chron (1.95-1.77 Ma) and with a few thousand years accuracy.

The poorest datings, for instance those of specimens labelled with a provenance from an area of the UV (e.g., Le Ville, Tasso, Faella, Sammezzano, etc.), and barely assigned in the catalogue only an age as Pleistocene, or at most early Pleistocene, may now be converted into a numerical date in the period of the Olduvai chron, with a low degree of accuracy but reaching in the worst cases less than ± 50 ky. It improves by more than one order magnitude the ages reported in the catalogue, while most specimens of the old collections may reach accuracies of ± 30 ky to ± 10 ky, compared with the millennial scale which is reached for recent findings.

The list of dates for the earliest fauna, the Castelnuovo dei Sabbioni, begins with the base of the Villafranchian age, at 3.08 ± 0.03 Ma. Most collections were found in the sediments of the second cycle and their faunal assemblages are now disposed in stratigraphic order. Matassino is placed at the onset of the Olduvai chron of 1.950 ± 0.005 Ma, and Poggio Rosso at 1.870 ± 0.005 Ma. Casa Frata is not



Text-fig. 6 - Block diagram representing the flow of successive phases to reconstruct the stratigraphic sequence of the Upper Valdarno sedimentary history, dated by the faunal and magnetic polarity events there recorded. The former are reported in the automated catalogue by collections with exact stratigraphic indication or mostly without it, and ordered in the biochronological scale. The latter make the present time scale, whose sequence of magnetic reversals constitutes the fundamentals of the GPTS used for geochronology, by a constant time flow (in Ma). The GEF catalogue database will be the first recipient of each dating refinement supplied to the fossil collections.

explored yet by magnetic stratigraphy but its reconstructed lithostratigraphic position yields a date very close to the latter, from its correlation with the Faella type section, while for the same reason also the date of the Tasso fauna is inferred as not much younger than 1.75 Ma. For caution, the highest uncertainty value may be considered ± 50 ky around this date. The Faella small assemblage is an exception, as the distribution range of its specimens covers more than 220 ky and contains almost all the stratigraphic excursion marked by the previous localities.

From the above range of dates produced for most fossil finds of the Museum patrimony, it may be emphasized how the old collections have shared the great improvements provided by their magnetostratigraphic dating, also the classical faunas being now dated with an accuracy comparable with that of the recent finds. More than 70% of the collections were acquired over one century ago, and for the same amount they are catalogued without an exact location in the computerized GEF system of the Museum. Rare examples of old recoveries also led to the reconstruction of the position of the fossil finds with the highest accuracy. One occurred for Nesti's Rhinoceros of 1811, whose location near the hill top of Monte al Pero was described and has been reconstructed with a ± 3 m accuracy. The site is dated 1.83 ± 0.01 Ma by the magnetostratigraphic series there measured, and correlated with the calibrated one of the facing Faella type section. Another one was represented by the well defined findings of Cocchi in 1862 (which later went unfortunately lost) at the base of the same Monte al Pero and on the Faella creek, at a stratigraphical level very close to that of the recent recoveries at the base of the Faella section, reaching the Faella creek, with a date of 1.990 ± 0.002 Ma.

As a conclusive remark, the relevance of the scientific patrimony of the Museum classical collections

can be emphasized. They are improved with the fundamental value of the numerical dating, and the role of the Museum as the depositary of a firmly established tradition is confirmed, together with that of an active proponent of further research through a continuous use of its collections for sensibilization of visitors and knowledge of scholars. Other classical collections of famous museums may be dated in a similar way when a magnetostratigraphic series may be provided for the areas of provenance of their fossils. The classical areas of vertebrate fossil-bearing formations of Tatrot and Pinjor of India were dated to the late Pliocene and early Pleistocene, and their large collections stored in the museums of India and of London are now better placed in such a time span.

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