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Stratigraphical and palaeontological data from the Early Pleistocene Pirro 10 site of Pirro Nord (Puglia, south eastern Italy)

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ABSTRACT

The Pirro Nord palaeontological and archaeological locality has been the object of recent field research to investigate the fossil content of its Early Pleistocene vertebrate palaeocommunities, and to understand the genesis of the karst network and related deposits that delivered the lithic industry representing the earliest human occupation of Europe known so far, spanning 1.7–1.3 Ma. The succession of the Pirro 10 site has been described in terms of facies and fossil vertebrate content of the 37 distinguished Sedimentary Units (SU). On the whole, the succession is made of chemical and clastic sediments that include debris fall and alluvial deposits. SU are distinguished according to lithology, colour, discontinuities, lamination, fossil concentration, and taphonomical parameters. Palaeomagnetic data and biochronological characteristics refer the Pirro 10 site to the latest Late Villafranchian Mammal Age of the Italian biochronological mammal scale.

The fossil content is quite homogenous. Common taxa are *Axis eurygonos*, *Hystrix refossa*, *Ursus etruscus*, *Canis mosbachensis* together with small mammal remains mainly represented by Chiroptera and the arvicolid *Microtus* (*Allophaiomys*) ex gr. *ruffoi*. A significant change in the taxonomic record occurs in SU 22 and 108, where a clear increase of *Equus altidens* and *Bison* (*Eobison*) *degiulii* remains indicates shifting towards drier and more open environments and possibly deteriorating local climatic conditions. In general, for all phases, taphonomic evidence suggests that (1) bone accumulation results from carcass transport into the cave system by accident, (2) skeletons were decomposed and partially disarticulated near the cave entrance, (3) the cave environment caused corrosion, desquamation and pitting, and (4) bones were moved within the cave system by water flow, usually for short distances.

Pirro 10, Pirro 13 and all karst structures of the Pirro Nord locality during Early Pleistocene were part of a complex interconnected karst system. Dissolution was more effective along the highly fractured core-zones of the Pliocene fault that bounded the "Apricena horst" to the south, where Pirro 10 gallery and Pirro 13 shaft are located. At that time, Pirro 10 was developed within the vadose zone whereas Pirro 13 represented a vertical structure connecting the surface to an underground karst floor. In general, the filling of Pirro 10 indicates fluctuations of the base level: water flow circulation in phreatic and epiphreatic conditions led to the deposition of clastic sediments, whereas flowstones reflect base level lowerings.

1. Introduction

The Early Pleistocene fossil vertebrates of Pirro Nord (locality also known as Cava Pirro or Cava Dell'Erba) were discovered in the early 1970s after the work of the NCB/Naturalis Museum of Leiden studying Late Miocene vertebrates (Freudenthal, 1971). The locality lies in the municipality of Apricena, near Foggia in one of the quarries exploiting the Mesozoic Calcare di Bari Fm. (Fig. 1a and b). The Pirro Nord palaeontological record is preserved inside a karst network at the top of the Mesozoic limestones and filled with continental sediments, often containing numerous vertebrate

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remains, both macro and micro, representing highly diversified palaeocommunities (Abbazzi et al., 1996; Pavia et al., 2010). The gallery and sinkhole fillings have been investigated in the last thirty years by various research groups of the Firenze, Roma Sapienza and Torino Universities. After the pioneering report of Freudenthal (1971) and the paper of De Beaumont (1976), who described some carnivores from a not well specified location in the quarry area, the first important reports are those of De Giuli and Torre (1984), illustrating and discussing the small mammal assemblage of a fissure filling named "Pirro Nord 1", and De Giuli et al. (1986), where the assemblages from several fillings from the Pirro quarry are described as the "Pirro Nord Fauna". Several taxa were illustrated and described for the first time in that paper. The vertebrate assemblages, with more than 100 recognized taxa, have been found in different sites. Nevertheless, they can be considered almost contemporaneous from a biochronological point of view on the basis of the evolutionary degrees of the analyzed taxa (Arzarello et al., 2007). These fossils refer to a homogeneous vertebrate fauna aged late Early Pleistocene that, more precisely, represents the last Faunal Unit of the Villafranchian Mammal Age in the Italian biochronological scale (Gliozzi et al., 1997). From a geochronological point of view, the Pirro Nord Faunal Unit can be attributed to an interval between 1.3 and 1.7 Ma (Arzarello et al., 2009), even if not all the authors agree with this dating (e.g. 1.2–1.5 Ma following Masini and Sala, 2007, or 1.3–1.5 Ma following Bertini et al., 2010).

Recently, during field research carried out by the Torino University, a lithic industry was found together with the typical elements of the Pirro Nord vertebrate assemblage, thus representing the earliest human occupation of Europe known (Arzarello et al., 2007, 2009; Arzarello and Peretto, 2010). This discovery renewed the interest on the Pirro Nord locality. Field activities included new systematic excavations and the stratigraphical analysis of the encasing Plio–Pleistocene marine succession of the whole quarrying district (Pavia et al., 2010). Palaeomagnetic measurements were also done in order to better constrain the palaeontological age of such an important archaeological record. Since 2004, many karst fillings were discovered and numbered Pirro 1 to Pirro 33; Pirro 10 and Pirro 13 are the most cited in literature and, together with Pirro 21, are the only sites to yield lithic artifacts (Pavia et al., 2008, 2010; Arzarello et al., 2009).

The lithic artifacts from Pirro 10 are extremely rare, whereas they are frequent at Pirro 13 (Arzarello et al., 2009; Arzarello and Peretto, 2010). Up to now only two flakes have been found in the upper part of the succession (Phase 6 of the Early Pleistocene sedimentary cycle: see chapter 4.2.6) of the Pirro 10 site, and they have already been described in Arzarello et al. (2009). The stratigraphical excavation campaigns of 2007–2009 did not supply any flakes or flint nucleii, demonstrating the scarcity of lithic artifacts in the Pirro 10 site.

The aim of this work is to illustrate the Pirro 10 site from the stratigraphical point of view and the palaeontological content of the

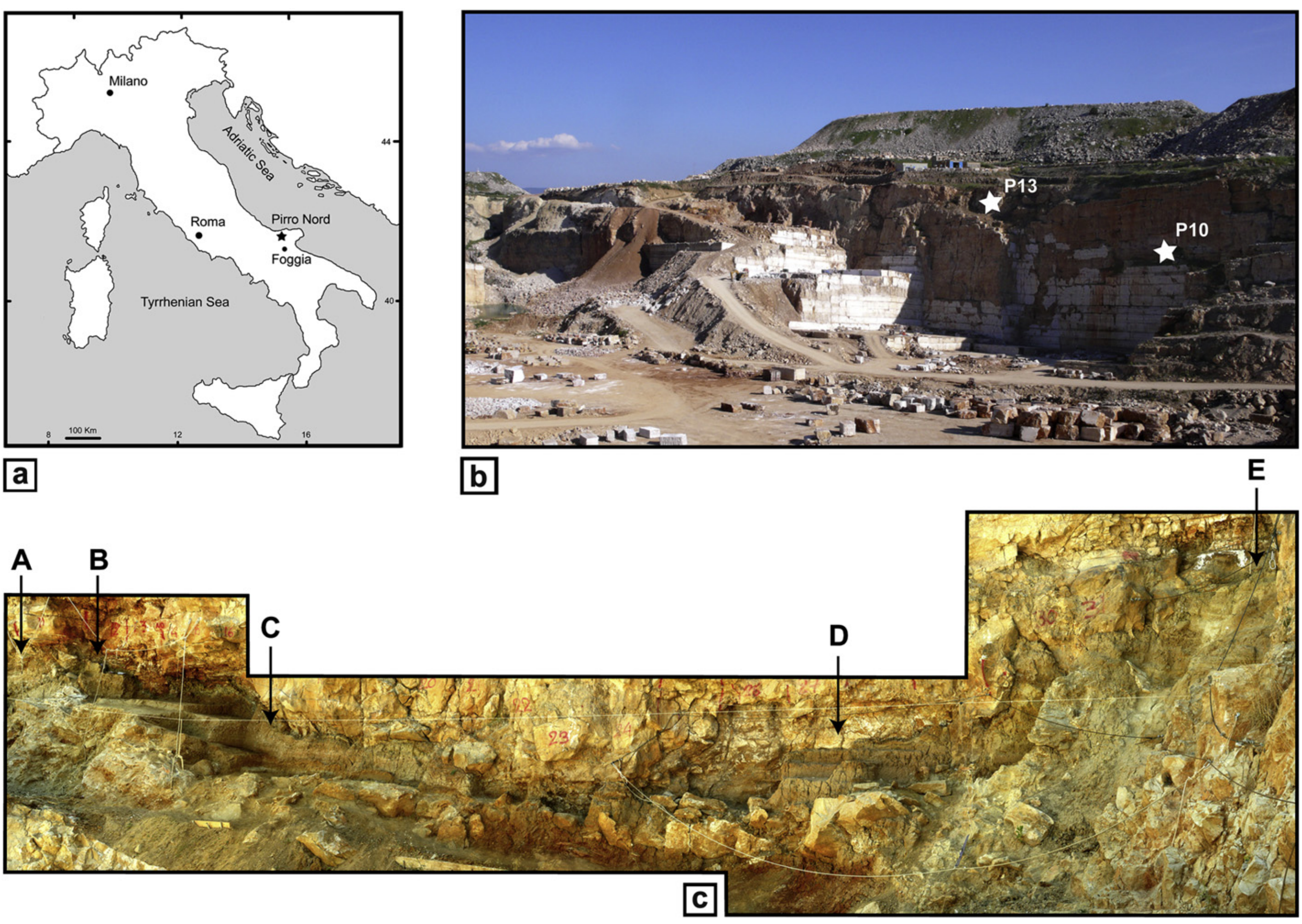

Fig. 1. a. Geographic location of Pirro Nord. b. The southern side of Dell'Erba's quarrying complex, former Pirro Nord quarries. Numbered asterisks mark the position of the palaeontological–anthropological diggings at Pirro 10 and Pirro 13. c. Photomosaic panoramic view of Pirro 10 site. Capital letters indicate the position of the stratigraphic logs reported in Fig. 2.

various recognized sedimentary units, evaluated after three excavation campaigns and the analysis of more than 5000 vertebrate remains. Information includes (1) the genesis of the fossil-bearing deposit reconstructed after sedimentological and micromorphological analysis, (2) taphonomical observations, (3) the biochronological significance of the whole association based upon the taxonomic composition and the evolutionary stage of the microtine *Microtus* (*Allophaiomys*) ex gr. *ruffoi*, and (4) the updated results of palaeomagnetic analyses.

2. Geological, geomorphological and stratigraphical setting of Pirro 10

The former Pirro quarry, now Dell'Erba quarrying complex, is located within the Apricena–Lesina–Poggio Imperiale quarrying district on the "Apricena horst", a positive structure connected with the regional fault system of the northwestern sector of the Gargano Promontory (Branckman and Aydin, 2004). In particular, since Late Miocene the Apricena horst formed an emerged, E–W elongated structure that was further flooded with deposition of ramp to shelf sediments spanning latest Early Pliocene to Early Pleistocene. This marine succession is composed of carbonate to siliciclastic sediments unconformably resting on the Mesozoic limestones of the Calcare di Bari Fm. (Spalluto and Pieri, 2008). The marine succession is comprised between two karst cycles that are represented, at the base, by the residual Terre Rosse with the well-known Late Miocene to Early Pliocene "*Mikrotia* fauna" and, at the top, by the sandy-clayey fossiliferous deposits of the Early Pleistocene Pirro Nord Faunal Unit.

The Pliocene to Pleistocene marine succession, formerly described in detail by Abbazzi et al. (1996, and references therein), was deeply revised by Pavia et al. (2010). The succession is arranged in two lithologic bodies: a lower carbonate complex (Lago di Varano and Calcari a Briozoi Fms.) spanning the late Early Pliocene to the Gelasian, i.e. the earliest Pleistocene according to the most recent definition (cf. 2009 IUGS: Gibbard and Head, 2009), and an upper siliciclastic unit (Serracapriola Fm.), Early Pleistocene in age. These marine lithosomes show conspicuous facies changes and frequent unconformity surfaces that are the consequence of the activity of the E–W trending normal faults that controlled the structure of the "Apricena horst".

A series of cavities, galleries and sinkholes have been detected during the progress of the quarrying activity because the limestones were affected by karst processes since their emersion: in particular, the most recent karst cycle developed during and after the Early Pleistocene emersion of the area. Suggestions for an earliest karstification come from a beach notch that affected the barnacle-coral biostromal lithozone and was sealed by the Calcari a Briozoi Fm. (respectively BC and CB in fig. 32 in Pavia et al., 2010). This notch was part of the D3 unconformity (in Pavia et al., 2010) and documents the early contacts between salt and fresh waters (Carobene, 1978; Carobene and Pasini, 1982) and therefore the activation of hyperkarstic phenomena that are among the more effective dissolution processes as also evident in the Orosei Gulf (De Waele and Forti, 2002; De Waele, 2004). This was accelerated by syndepositional fault activity that delimited a series of marine cliffs (Pavia et al., 2010). However, a major karst phase took place after the deposition of the Early Pleistocene Serracapriola Fm. that sealed the old cliffs. In this period the karst network had its local subaerial feeding system, dolines, sinkholes and other karst morphologies, in the morphologically highest sectors of the "Apricena horst", i.e. in the Dell'Erba quarries where the calcareous-siliciclastic cover was thinner or absent (Abbazzi et al., 1996). However, due to the fault activity and the fact that to the east and west these are buried under younger sediments, it is quite difficult to establish the original width of the catchment basin. Most probably, part of the alluvial plain to the west interfered with the karst system. The hypogenous system developed inside the Pliocene carbonates down to the underlying Calcare di Bari Fm. The dissolution was more effective along the highly fractured core-zones of the Pliocene fault that bounded the study area to the South such as Pirro 13 that represented a typical vertical shaft in the vadose zone connecting the surface to an underground karst floor. At depth, the phreatic zone was represented by the Pirro 10 gallery that has a classic ellipsoidal cross-section and a sub-horizontal longitudinal profile.

Further evidence of a major shifting of the regional base level is given by the very flat erosional surface present at the top of the investigated area. This surface corresponds to a terrace at 165 m above the sea, and lies in evident angular discordance upon the sedimentary units below. It thus constitutes a further (D5 in Pavia et al., 2010) discontinuity, with respect to those described in the area, which cuts both the Calcari a Briozoi and Serracapriola Formations and the main faults affecting the Apricena horst (figs. 20 and 33 in Pavia et al., 2010). Such a discontinuity could be likely thought as a surface of marine erosion modelled during a transgressive event which did not produce any significant depositional sequence (Coltorti and Pieruccini, 2002; Landis et al., 2008). A thin cover of platform detritic deposits would be easily affected by weathering and/or slope wash processes, the latter particularly efficient during cold and arid climate phases, similar to those affecting the region during Middle and Late Pleistocene (Cremaschi, 1990).

The extension of Pirro 10 gallery (Fig. 1c) is more than 25 m east–west, but the original continuation cannot be defined because at the time of discovery it was already largely destroyed by quarry works. The Pirro 10 gallery lies deep within the Cretaceous Calcare di Bari Fm., some 30 m below the stratigraphic boundary with the Pliocene calcarenites of the Lago di Varano Fm. This position is anomalous in comparison with the galleries that in the last century delivered the huge amount of vertebrate fossils described in the literature (see Abbazzi et al., 1996). Most classic Villafranchian deposits were located in the central part of the Apricena horst at or just below the boundary between the Calcari di Bari Fm. and the Lago di Varano Fm. Classic outcrops have been strictly reduced by quarrying works and, at present, only the marginal sectors of the horst are largely exposed. In particular, the syngenetic normal fault that controlled the deposition of the lower Pleistocene Calcari a Briozoi and Serracapriola Fms. crops out along its southern margin. After emersion, meteoric dissolution began on the "Apricena horst" (Pavia et al., 2010).

The filling of Pirro 10 site shows a series of fluctuations of the base level. Periods of lowering of the local phreatic level led to the deposition of flowstones, whereas water flow circulation in phreatic and epiphreatic conditions led to the deposition of clastic sediments. A series of cut and fill cycles reveal the periodic occurrence of peak flow, alternating with deposition of sandy-clayey and gravel-size sediments containing numerous taphogenic products (*sensu* Fernández-López, 2000), among which the mammal fossils and the recently recovered human artifacts are the most impressive record (Arzarello et al., 2009). Vertebrate fossils may be either concentrated in conglomeratic layers or scattered in clayey sands. Marine invertebrate bioclasts are common through the whole karst deposit and represent reworked fossils (*sensu* Fernández-López, 2000) derived by continental erosion of the Pliocene to Pleistocene carbonate and siliciclastic formations.

3. Materials and methods

A large amount of vertebrate remains has been collected from Pirro 10 since 2006. This material has been the object of a PhD

Dissertation (Petrucci, 2008) and of some systematic papers submitted to *Palaeontographica*. Starting from August 2007, three one-month excavation campaigns have been carried out with permission from the Soprintendenza dei Beni Archeologici della Puglia, and collaboration with the quarry owners, Liliana Gervasio and Alessandra Verni, and the quarry agents, Franco and Gaetano Dell'Erba. The excavations of 2007 and 2008 involved both Pirro 10 and Pirro 13, while in 2009 work concentrated on Pirro 10 in order to better understand the relationships and to correlate the stratigraphical units across the different parts of the gallery (Fig. 1c). Starting from the excavation campaign of 2007, the karst outcrop was gridded into 1 m^2 squares and divided into four sectors (Fig. 2). The first excavation concentrated on sector II, while from 2008 onward work proceeded on sectors I and III–IV. All fossils were located within the stratigraphical units, and for most of them their position inside the gallery has been recorded. Most of the specimens have been photographed *in situ* before removing.

To best preserve fossils for future studies and analyses, a large part of specimens required field consolidation and careful extraction. Paraloid B72 was used exclusively, both for coating/consolidation and to glue the specimens, whose action was favoured by the summer dry weather. Because of the excavation conditions, a light field kit of preparation was used. The major problems derived from the small working and moving space as the quarry activities resulted in the location of Pirro 10 gallery in half of an artificial cliff 90 m high; all people working there had thus to be secured using mountaineering equipment. In such conditions we develop an extracting protocol using a 30% solution of paraloid B72 (a concentration allowing sufficient coating in comparison with efficient spray function), gauze and wood sticks. In practice, the same method as to make a plaster cocoon was used, although lighter and faster. This simple protocol allowed each worker (even the less experienced ones) to extract the most damaged fossils in good condition.

The vertebrate remains were successively catalogued and stored within the collections of the Museo di Geologia e Paleontologia of the Torino University (Pavia and Pavia, 2004). All numbered specimens were classified up to the specific level, whenever possible, by

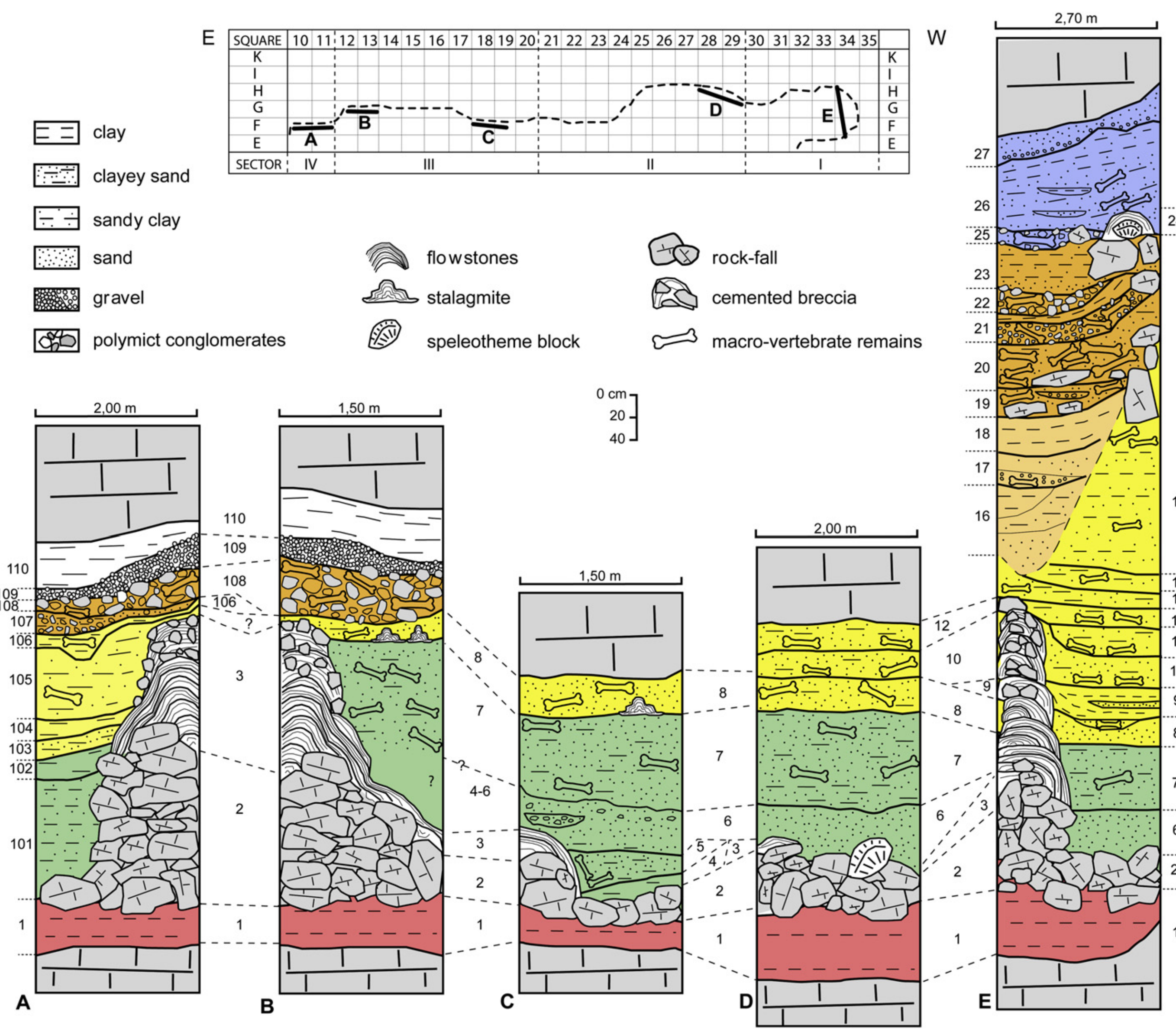

Fig. 2. Schematic logs of Pirro 10 gallery. Log capital letters refer to the upper scheme which outlines the different sectors of digging. The dotted lines represent correlations among the different Sedimentary Units. In the on-line version, colours represent the various phases described in the text.

various members of the Research Team, specialized in various vertebrate groups. The vertebrate remains found before 2007 have been analyzed and the results submitted to *Palaeontographica* for publication. The microvertebrates found during the 2007–2009 excavation campaigns have been sorted in order to obtain the information on small mammals used in this paper, particularly the teeth of *M. (Allophaiomys)* ex gr. *ruffoi*.

Large mammal bones will also be analyzed from the taphonomical point of view, in Bagnus' PhD Dissertation. In particular, the taphonomical analyses will focus on the external characteristics of the bones: colour, oxidation coating, abrasion degree due to transport, surface modification such as desquamation and corrosion related to the karst system (sensu Fernández-Jalvo et al., 1998; Kos, 2003), bone alteration as weathering (Behrensmeyer, 1978) or bitemarks of mammal predation. More detailed analyses using classical taphonomical methods (MNI, NISP, orientation, Voorhies Groups) and geochemical taphonomy are in progress (Voorhies, 1969; Lyman, 1994; Trueman, 1999). In order to support any paleoenvironmental assessment, a detailed sedimentological analysis of the deposits filling the karst conduits has also been carried out, coupled with selected micromorphological analyses of the most significant sedimentary units.

4. Stratigraphical and palaeontological data

The karst deposits of Pirro 10 can be subdivided into two main sedimentary cycles: (1) the Late Miocene–Early Pliocene cycle corresponding to the "Tertiary palaeokarst cycle" (Grassi et al., 1982) with deposition of "Terre Rosse" and fossils of the "*Mikrotia* fauna", (2) the Early-Middle Pleistocene cycle equivalent to the "Quaternary neokarst cycle" (op. cit.) containing Villafranchian vertebrate remains. The younger cycle shows further minor subdivisions based on the sedimentary characters. The outcropping succession is made of chemical (mainly speleothems) and clastic sediments; the latter are colluvial deposits (mostly belonging to the older cycle) and alluvial rock and debris fall sediments.

The stratigraphy exposed in the different sections (A–E) of the Pirro 10 gallery is schematically represented in Fig. 2, where several sedimentary units (SU) have been distinguished according to lithology, colour, erosional surfaces such as scours and channels, planar- to cross-bedded lamination, fossil concentration and taphonomic features. In the following, the succession is described by genetic phases with details on sets of SU. Despite discontinuous outcrops and lateral change of sedimentologic parameters, the correlation among sections A–E is proposed in Fig. 2. The interruption by the large flowstone in the easternmost sector III resulted in adoption of a different numbering for section A (SU 101–110); nevertheless, in this respect, the topological equivalence of SU 107–108 with SU 19–23 is supported by the coarse lithology and mainly by the fossil record, i.e. abundance of Equidae remains.

4.1. Late Miocene cycle

This cycle is characterized by reddish to brownish and blackish structureless to laminated clays and silty clays (SU 1) filling in a karst system mainly made of karren, lapiaz and more rarely sinkholes developed along the joint systems affecting the Mesozoic carbonates (Abbazzi et al., 1996; Pavia et al., 2010). The overall aspect of the karst infilling makes possible their attribution to colluviation processes of the classic "Terre Rosse" or "Modal fersiallitic red soils" (Duchaufour, 1982) or "Red Mediterranean soils" (Yaalon, 1997) that classically have been considered as polygenetic relict soils, Vetusols or pedo-sequences (Cremaschi, 1987; Durn et al., 1999). The age and the colluvial nature of sediments are revealed by the presence of a classical "*Mikrotia* fauna" (Freudenthal, 1971; Abbazzi et al., 1996; Masini et al., 2008) attributed to the Late Miocene–Early Pliocene (Mazza and Rustioni, 2008).

The presence of the vertebrate fossils indicates that sediments did not undergo carbonate leaching after their deposition. Therefore most of the iron sesquioxydes-rich clays and silts should be considered as the result of the erosion and consequent deposition within the superficial karst features of red soils developed above the unconformity cutting the Mesozoic carbonates (D1 in Pavia et al., 2010). Micromorphological observations clearly show the importance of sedimentary processes indicated by different laminated microfacies distinguishable on the basis of texture, sedimentary structures and presence of peculiar features (Fig. 3).

4.2. Early Pleistocene cycle

The Villafranchian succession crops out in Pirro 10 gallery with at least 6 m in thickness. Vertebrate fossils are encountered everywhere, although more abundant in the middle layers and mainly in the coarse and conglomeratic ones; they include all the vertebrate classes, although the most abundant ones are mammals and turtles. Marine invertebrate bioclasts are also common; they

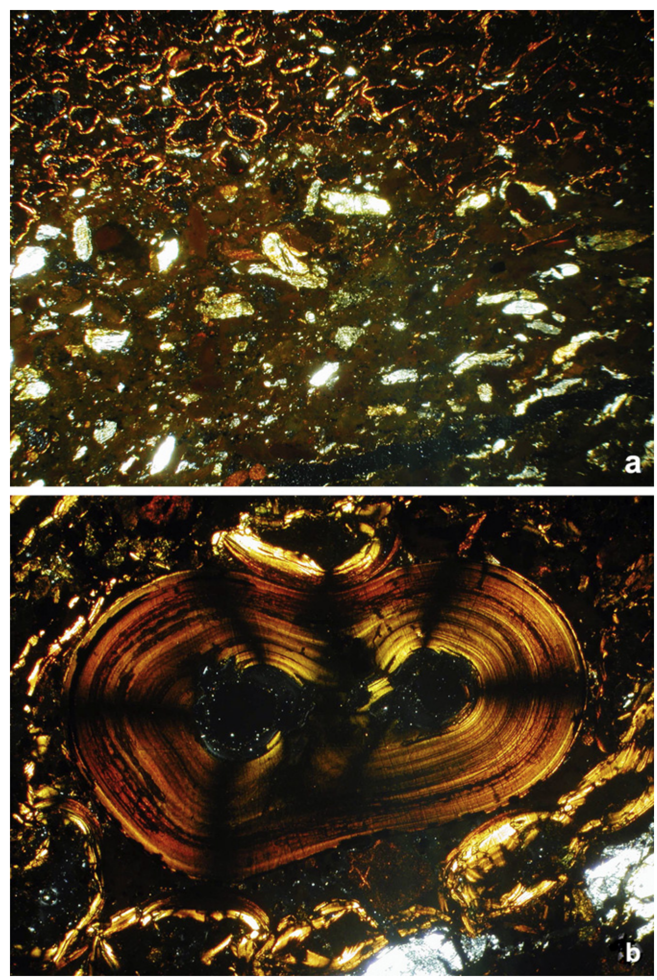

Fig. 3. Details of sediments from the Late Miocene cycle. a. Frame 8 mm. XPL. The upper laminated microfacies are mainly made of clay pseudonodular features that provide the overall spongy aspect. The lower microfacies is characterized by reddish to brownish opaques and bright clay pellets. b. Frame 2 mm. XPL. Pseudonodular clay feature made of finely laminated and oriented impure clays. This feature might be inherited by pre-existing pedofeatures formed on the surface later eroded and transported within the karst system.

Table 1
Mammal remains found in each Sedimentary Unit recognized at Pirro 10. For the large mammal remains the number of specimens is given. For the small mammals remains three categories are given: presence (X), common (XX), abundant (XXX). For the reworked "Mikrotia Fauna" remains, only the presence is reported (+). The fossil found in reworked sediments are listed as ?.

SU	Reworked "Mikrotia Fauna"	Lipotyphla and Chiroptera	*Erinaceus praeglacialis*	*Hystrix refossa*	*Apodemus flavicollis*	*Microtus (Allophaiomys) ex gr. ruffoi*	*Oryctolagus aff. lacosti*	*Meles meles*	*Mustela palaerminea*	*Pannonictis nestii*	*Ursus etruscus*	*Canis mosbachensis*	*Xenocyon lycaonoides*	*Vulpes alopecoides*	*Pachycrocuta brevirostris*	*Lynx issiodorensis*	*Megantereon withei*	*Homotherium latidens*	*Panthera gombaszoegensis*	*Acinonyx pardinensis*	*Puma pardoides*	*Mammuthus meridionalis*	*Stephanorhinus cf. hundsheimensis*	*Equus altidens*	*Axis eurygonos*	*Premegaceros obscurus*	*Capreolus* sp.	*Bison degiulii*
?	+	XXX	1	108	XX	XX	XX	1	1	4	88	55	25	17	26	2	7	18	1	2		12	19	177	493	9	5	69
5	+	X															1								4			
6		XX			X		X					5						1							4			1
7	+	XXX		109	X	X	X				52	45	37	6	26		5	31	4	2		1	2	33	371	4	1	19
8	+	XXX		15	X	X	X				10	10	7	1	2			6				2	1	6	64	1		3
9		XX			XX	XX	XX				1				1													
10	+	XX		1	XX	XX	XX			1	1	5	1				2	1						2	12			1
10-12				4							5	4	2		6		1	3				1	2	3	34			3
11	+	XX		1	X	X	XX				2														3			
12		X					XX				1														6			
13		X			X	X	X				2														5			
14		X	1	1			X				3	1	1		1	1		2	1				1	2	23			4
15		XX			X	X	X			1	2	1			1								1	1	12			
16		X		1			X								1	1						1	1		6			1
17		XX		1			X																	1		1		
18		X		1			X																		4			
19	+	X		5		X	X				10	3		2	3		1	1		1		3	1	8	45	1		2
20	+	X		29	X	XX	X				17	11	2	8	4	1		1	2			5		34	144	3		27
21		X		13		X	X				4	5	3	2	2				1					16	30	1		5
19-22			1	14							28	17	3	2	15	1	5	13	1			2	3	52	296	3	2	59
22	+	X		19	X	X	X				7	5	2		5			1	1					67	41	1		9
23	+	X		2	X	X	X				1	1		1					1					6	5			2
25	+	XX			X	XX	XX					1	1				1							1	4			1
26		X			X	X	X																		1			
101	+	X																										
104	+	XX										2													1			1
105	+	XX		1	X		X				2	2	1												9			
108	+	X		26		X					23	5	2	3	11	2	1	3			1	13	5	222	167	3		76
109																								3				1

constitute the reworked tapho-record derived from erosion of the Pliocene to Pleistocene marine deposits (Pavia et al., 2010). In the following chapters the main systematic and taphonomic features are summarized, whereas the vertebrate content of each sedimentary unit is listed in Table 1. This table also lists the determined remains found *ex situ* in the detritus at the gallery floor, produced by erosion or by cleaning of the filling wall, because they are numerically significant for some taxa.

4.2.1. Phase 1

Phase 1 was the dissolution of the calcareous sediments unconformably overlaying the Mesozoic limestones and to the erosion of karst sediments belonging to the Miocene cycle. This phase is characterized by the reopening and possibly enlargement of the hypogene conduits of the Miocene cycle, so that Pleistocene karst structure, among which Pirro 10, acted as traps of Villafranchian sediments and fossils. The conduits formed a mostly horizontal phreatic network and later underwent to remodelling in the epiphreatic and vadose zones. The presence at the bottom of the impermeable clayey sediments of the Miocene cycle may have played an important role. The karst network was located close to the local base level, most probably the sea-level. The horizontal conduit system was fed by a series of vertical to oblique conduits connected to a surface karst (dolines, karren fields, etc.) which are presently visible both on the quarry wall between Pirro 10 and Pirro 13, and within the Pliocene to Pleistocene calcareous cover. The presence of a horizontal entrance can be hypothesized following the taphonomical observations (see chapter 5.1). An example of the vertical conduits is represented by Pirro 13, although the karst features on top of the summit terrace (fig. 33 in Pavia et al., 2010; see also section 7 of the present article) have been mostly eroded and locally buried.

4.2.2. Phase 2

The first evidence of sedimentation is made of very coarse angular to subangular gravels and boulders forming an almost continuous lag (SU 2); clasts are heterometric, up to 1.5 m in diameter. They represent rock falls from the conduit walls indicating the transition from the phreatic to the vadose zone with the lowering of the base level. The rock falls might be attributed to the desiccation of the conduits as well as to seismic events. Matrix, where present, consists of *Mikrotia*-altered silty clays; fossils are sporadic reworked bones of "*Mikrotia* fauna".

4.2.3. Phase 3

Large and up to several metres long laminated pink flowstones (SU 3) are developed on top of the rock falls and coat gravels and boulders of SU 2. In sectors I, III and IV the upper part of the concretionary structure is increased by cemented breccia with Calcare di Bari Fm. blocks. The flowstone structure suggests a long-lasting vadose chemical precipitation. Several studies on the Last Glacial–Interglacial cycle speleothems in Italian, French, Brazilian and South African caves demonstrate that their formation can be attributed mainly to the Interglacials and in a lesser extent to the Interstadials (De Lumley, 1976; Bocchini and Coltorti, 1990; Campy and Chaline, 1993; Brain, 1995; Brook et al., 1997; De Waele and Forti, 2002; De Waele, 2004; Auler et al., 2006).

4.2.4. Phase 4

SU 4–7 buried the rockfalls (phase 2) and the flowstone (phase 3). Textures range from clays to very coarse gravels and boulders. Sediments are subdivided according to SU grouping (Fig. 2). They are made of greyish fine to coarse structureless sands, silts and clays. Two sets of SU are distinguished.

The vertebrate assemblages present in the deposits of Phase 4 are dominated by frequent, well preserved, poorly weathered and unabraded bones with dendritic Fe–Mn oxides and brown to orange coatings resulting from ground-water level fluctuations (Fig. 4a).

SU 4–5: localized in the morphological depressions originated among blocks and flowstone deposits in squares 18–19 (Fig. 2, section C). They are reddish to brown sandy clays with millimetric to pluricentimetric carbonate pebbles. Micro- or macrovertebrate fossils are rare and consist of few remains of *Axis eurygonos* (following Di Stefano and Petronio, 2002) and a mandibular fragment of *Megantereon whitei*. The majority of bones are well preserved and unabraded with scarce Fe–Mn oxide coating. Some bones are highly fractured, crushed on flowstone by trampling.

SU 6–7: at the base, brown-grey to reddish sands, laminated and enriched in iron–manganese oxides in the middle part of the level. In SU 6 macrofossils are mixed with reworked specimens from "*Mikrotia* fauna", together with *in situ* Chiroptera remains. A similar fossil assemblage is present in SU 101 of the sector IV. The sandy-clayey SU 7 is ubiquitous and supports correlation with bed 102 of sector IV due to the presence of partially decalcified limestone pebbles as well. In SU 7 vertebrate remains are arranged in two main fossiliferous levels located in the middle part of the layer where bones lie sub-horizontal with strong alignment along their maximum axis. Fossils show a low degree of sorting and abrasion that reflect moderate and discontinuous transport by waters saturated with sediments on the cave floor; sporadic pits and gnawing are present. Fossil assemblages are very rich and comprise most of the taxa found at Pirro 10, with the exception of the rarest ones. The associations are dominated by *A. eurygonos* and *Hystrix refossa*, with *Ursus etruscus* and *Canis mosbachensis* as common elements. Among the several fossil remains found in SU 7 it is worth mentioning an almost complete emimandible of *Xenocyon lycaonoides* (Fig 5g) and a complete emimandible of young *Homotherium latidens* with the deciduous teeth still in place and the definitive ones already developed (Fig. 5e).

4.2.5. Phase 5

A short-lived and discontinuous episode of speleothem formation is present on top of SU 7. The stalagmites are small and scattered, and not found in sectors I and IV. Therefore, a short period of chemical precipitation could not be excluded.

4.2.6. Phase 6

This is one of the main filling phases. The sediment texture ranges from clays to very coarse gravels and boulders. Sediments are subdivided in three SU groups: 8–15 (vs 103–106), 16–18, 19–23 (vs 107–108), following textural characteristics and major surfaces of channel erosion.

SU 8–15: in the lower part of this sediment set, greyish to green, fine to coarse structureless sands, silts and clays fill erosional scours and small channels. Sub-horizontally laminated sands with yellowish to reddish oxidation bands are frequent. SU 10 and 11 are made of matrix-supported carbonate pebbles and clay-chips in a lenticular layer covered by horizontally laminated fine sands and clays. The sedimentation of this SU group ends with 1.5 m of structureless clays and silts (SU 15) covered by a large limestone boulder. Correlation between sections E and A in Fig. 2 is difficult; only in a speculative way, SU 105–106 may be equivalent to a part of SU 8–15, whereas the basal facies SU 8 may be correlated with facies 103 and 104. On the other hand, the basal, erosive surfaces 19 and 107 could be regarded as homologous, as they reflect the beginning of new sediment supply with coarsal texture. The fossiliferous content varies from one layer to another. The base of SU 10–12 is marked by concentrations of reworked fossils, mainly bioclasts of marine molluscs such as Pectinidae and Ostreidae. Vertebrate remains are frequent at the base of layers, locally concentrated in sandy horizons. Bones of macrovertebrates are

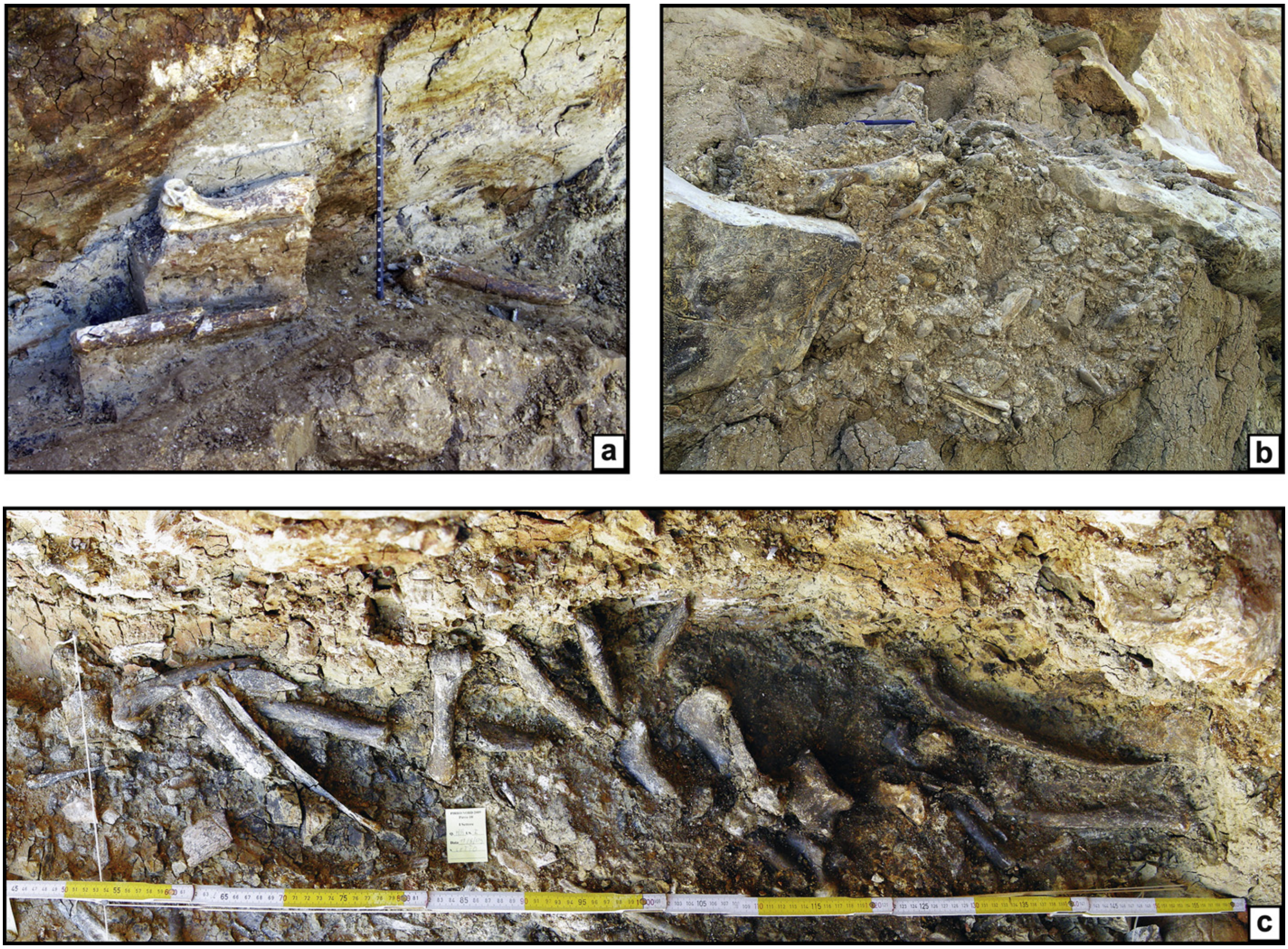

Fig. 4. Details on various SU during systematic digging. a. Bones of large mammals exposed in the SU 7, Sector III, during 2005 field activities. b. SU 108, Sector III at the time of the discovery of the site, in September 2004. c. SU 20, Sector I, during 2009 excavation campaign.

usually well preserved with intense Fe–Mn coatings, often unabraded with little desquamation except in SU 8 and SU 12 where bones are badly preserved with strong decalcification and corrosion. SU 13–15 are characterized by significant degree of pitting and corrosion of bone surface. SU 10–12 are rich in microvertebrate remains (Lagomorpha, Chiroptera), whereas large mammals are rare, with the exception of *A. eurygonos*; worth mentioning is a nearly complete emimandible of *Pannonictis nestii* found in SU 10, a new element of the Pirro Nord local fauna (Colombero et al., in press). Fossils in the SU 13–15 are scarce, both micro- and macrovertebrates. As in other SU, the most common elements are *A. eurygonos* and *U. etruscus*.

SU 16–18: an erosional surface, up to 1.5 m in depth, cuts the previous sediments; this channel is filled by small gravely lenses (SU 17) and structureless to laminated (concave up) silts and clays. Macrovertebrate remains are very scarce with scattered turtles and *A. eurygonos* remains, whereas small mammals are locally abundant, as in the upper part of SU 17. In general, bones are well preserved and not abraded. The cortical surface often presents pittings and discontinuous Fe–Mn coatings.

SU 19–23: a new erosional surface cuts the succession; it is buried at the base by flat laying karstified limestone blocks. Upward, a complex facies association occurs. It is characterized by the presence of small channels cutting each other and filled by matrix-supported gravels. SU 19, 40–60 cm thick, consists of green sandy clays with coarser-grained lenses; SU 20–23 are composed of dark brown to yellowish, sandy to clayey matrix-supported gravels, coarse sands and bones frequently coated by Fe–Mn oxides. The upper part of this SU group is made of large limestone blocks buried by and within horizontally laminated sands and structureless to laminated silts and clays. Micromorphological observations of the clayey facies revealed the presence of thin laminae with different textures, from fine sands (Fig. 6a) to clays. Although rare, evidence of biological activity such as burrowing (Fig. 6b), pseudomorphs of charred vegetal tissues and secondary carbonate precipitation has been detected together with evidence of soil colluviation. All these features suggest periodic drying up of the karst conduit and relative proximity to the external environment.

Vertebrate remains have to be differentiated by SU.

SU 19: vertebrate remains are common and consist of dark bones with a high percentage of Fe–Mn oxides. Bones are abraded; pitting and light corrosion are present on the cortical surface. Vertebrate assemblage is dominated by *A. eurygonos* and *U. etruscus*, with few remains of *Equus altidens* as well.

SU 20: constitutes one of the richest fossiliferous levels of the whole Pirro 10 site. Bones are usually complete with high degree of abrasion and polishing. The cortical surface is slightly coated by Fe–Mn oxides, often characterized by pitting and desquamation; sporadic signs of pit-marks and gnawing are present. The layer was

Fig. 5. Fossil remains from the various SU of Pirro 10. a. *Axis eurygonos*, proximal portion of left antler PU 123517, external view, SU 108; b. *Hystrix refossa*, right emimandible PU 125756, labial view, SU 7; c. *Stephanorhinus* cf. *hundsheimensis*, right P4 PU126950, occlusal view, SU 15; d. *Homotherium latidens*, fragmentary skull PU 126277 and left emimandible PU123135 from the same individual, labial view, SU 20; e. *Homotherium latidens*, juvenile right emimandible PU 104875 with the deciduous teeth in place and the definitive ones extracted during the restoration, labial view, SU 7; f. *Praemegaceros obscurus*, upper left teeth row PU 106772, occlusal view, SU 19-22; g. *Xenocyon lycaonoides*, right emimandible PU126273, labial view, SU 7; h. *Pachycrocuta brevirostris*, right ulna PU 106024, lateral view, SU 7; i. *Megantereon whitei*, right humerus PU 126658, cranial view, SU 7; j. *Otis tarda*, right tarsometatarsus, SU 108. The scale bars represent 1 cm.

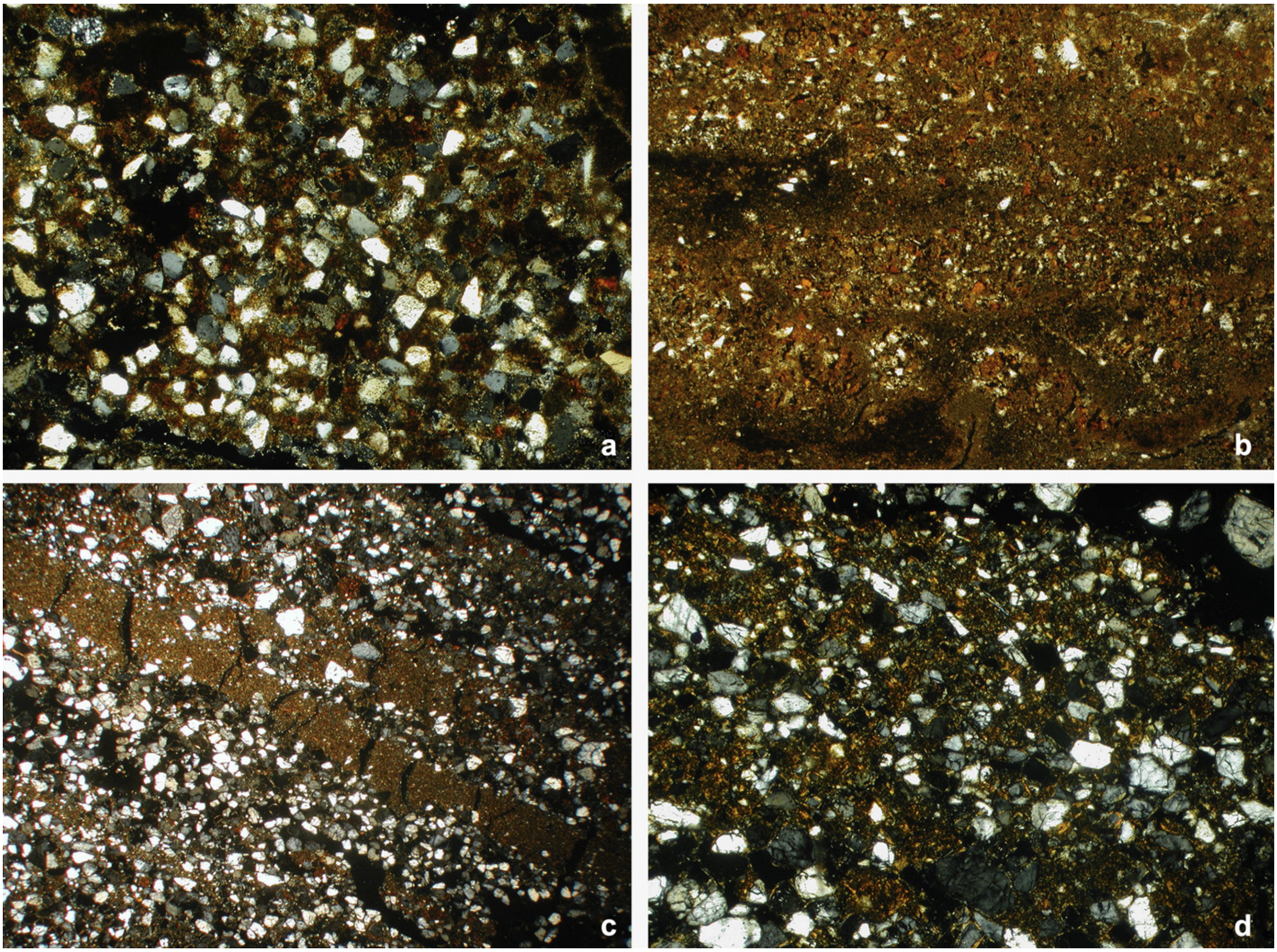

Fig. 6. Details of sediments from the Early Pleistocene cycle. a. Frame 2 mm. XPL. Sandy facies made of subrounded to subangular quartz grains with rare flinty granules. b. Frame 2 mm PPL. Burrowing feature filled with clay rich material. c. Frame 2 mm. XPL. Alternating sandy and clayey laminae. The coarser-grained laminae show a good sorting suggesting the selective character of the flows. d. Frame 700 μm. XPL. Badly sorted microfacies with fine sands supported by clayey matrix. In evidence also the mainly subangular shape of the monomineral grains.

deposited by a single event, as demonstrated by the chaotic orientation of the bones (Fig. 4c). The vertebrate assemblage contains most of the taxa found at Pirro 10 and is characterized by the abundance of *A. eurygonos*. Other common species are *H. refossa*, *U. etruscus*, *Bison* (*Eobison*) *degiulii* and *E. altidens*. In this layer, some very spectacular bones have been found, such as a partial cranium and emimandible of *H. latidens* (Fig. 5d) and some complete long bones of *U. etruscus*.

SU 21: vertebrate remains and reworked marine fossils are frequent and irregularly distributed within the sediment. Bones are well preserved, though abraded and fractured. Vertebrate assemblage is not very abundant and characterized by the ubiquitous *A. eurygonos*, *H. refossa* and *E. altidens*.

SU 22: the rich vertebrate assemblage consists of very rounded and sorted bones and fragments of *E. altidens*, as the commonest taxa, followed by *A. eurygonos* and *H. refossa*. From this SU in 2007 were collected two samples for radiometric dating of the site (using combined U/Th ESR), still in progress at the Datation Laboratory of the Muséum National d'Histoire Naturelle of Paris.

SU 23: Vertebrate remains are rare and consist of well preserved bones of *A. eurygonos*, *E. altidens* and few other taxa.

In sectors III and IV, SU 108 is supposed to be equivalent to SU 22 of sector I. The correlation between these two layers, which are formed by clast-supported conglomerate 20–30 cm thick with sandy-clayey matrix, is supported by palaeontological information. The fossiliferous content is characterized by middle to large sized bones, most of which are complete though highly abraded and by the abundance of *Equus* and *Bison* bones that probably reflects a change in the environmental conditions during the production of the fossil remains. From this SU, among others, it is worth mentioning an ulna of *P. pardoides*.

4.2.7. Phase 7

A short-lived episode of speleothem formation is present on top of the SU 19–23 group. The stalactite block is slightly overturned and seems to derive from roof collapse. Nevertheless it appears to have been subsequently coated by thin speleotheme lamina, so that the chemical precipitation phase is confirmed.

4.2.8. Phase 8

This SU group (25–27) is characterized by reddish colours that strongly contrast with the greyish colour of the rest of the infilling. A slightly erosive surface is covered by sandy matrix-supported gravels with heterometric limestone blocks. The rest of the succession is made of laminated and structureless silts and clays locally filling small channels. The micromorphological observations on the finer grained facies revealed also that the macroscopically structureless sediments are thinly laminated. Homogeneously alternating reddish and pinkish-whitish thin laminae are evident at microscopic analysis (Fig. 6c). The reddish laminae are mostly clayey whereas the whitish ones are mostly made of sandy-silty granules. The coarse fraction is made of well sorted subangular to subrounded grains of quartz (95%), rounded almost elliptical clay pellets (4%) and rare flint grains (1%); very rare angular and rounded grains are also present. The fine mass is mainly made of reddish impure clays. The single laminae are characterized by different proportions of coarse and fine fractions. Commonly, the laminae are made of sands with abundant clay matrix and pellets (Fig. 6d) whereas the finer grained laminae are typically matrix supported. In rare cases the laminae are almost completely made of clays. Clay grain-coatings are abundant whereas thin clay coatings are also present along the planar voids. Fossil content is very poor. Sparse large mammal remains with intense Fe–Mn coating are present, except in SU 27 where no fossils have been found. In SU 26, Lagomorpha are concentrated in lenses. SU 110 and 111 of sectors IV and III are constituted by reddish-grey sandy clays and did not deliver any vertebrate remain. These characteristics cannot definitively support any correlation with SU 26–27 of sector I.

5. Palaeontological content of Pirro 10 site

5.1. General information

The taxonomic content of the successive SU is quite homogeneous. The major changes concern the number of bones and, strictly related, the number of recorded taxa. The abundance of the various taxa is also similar among SU, as *A. eurygonos* is the commonest species, followed by *H. refossa*, *U. etruscus* and/or *C. mosbachensis*. Small mammals are also well documented in SU 4–19, but their records are rare in the upper coarse-grained levels. In lower SU, the Chiroptera remains are locally very abundant, indicating the presence of breeding or wintering colonies of these animals near the entrance of the karst structure.

The only noticeable change in the mammal composition occurs in SU 22, and in the putatively corresponding SU 108, where a strong increase of *E. altidens* and *B.* (*Eobison*) *degiulii* remains has been recorded. The abundance of these species, rarer in lower SU, indicates drier and more open environments. In general, the whole Pirro FU record indicates an open, semi-dry environment with scattered wood and small to middle-sized water bodies (Arzarello et al., 2009), reflecting moderately warm climate. The particular composition of the vertebrate assemblages of SU 22 and 108 suggests local environmental modifications, possibly related to a change towards colder and more arid climatic conditions.

From a taphonomic point of view, the macrovertebrate assemblages of Pirro 10 site can be attributed to the "disarticulated but associated" and "isolated and dispersed" bone categories described by Behrensmeyer (1991). Both groups are present in sandy-clayey SU (e.g. SU 7 or SU 20), though the second category is mostly typical of coarse-grained layers (e.g. SU 108). The vertebrate remains found at Pirro 10 are normally well preserved, even if they can be broken by sediment load or sometimes decalcified. Porosities and nutrient foramina are filled with sediment, a clear indication that bones were completely lacking of soft tissue at the time of inhumation (Rustioni and Mazza, 2001). Weathering stages homogeneously vary from 1 to 2 (Behrensmeyer, 1978) within the same SU. This indicates temporary exposition on the cave floor probably near the entrance, where humidity and temperature can change and facilitate weathering processes (Carlos Díez et al., 1999). Bone modifications linked to cave environments are present, in particular, corrosion and desquamation (Andrews, 1990; Fernández-Jalvo et al., 1998; Coumont, 2009) due to alkaline soils, and pitting resulting from interaction with cave water (Kos, 2003).

The bones of Pirro 10 are characterized by dendritic to extensive Fe–Mn coatings. Rarely, different metallic coatings in the same specimen are present. This is possible evidence of reworking (López-González et al., 2006). Rare surface marks such as punctures, bitmarks or grooves are present. Bones are usually complete: however, breakage on mineralized and fresh-green bones (Lyman, 1994) is documented. Bones fractured by trampling are observed only in SU 5, the lowest fossiliferous level of the Pleistocene cycle, indicating a possible mammal frequentation of the cave during the long-lasting dry Phase 4. The frequentation of the deep part of caves is reported for various carnivores in Late Pleistocene (Diedrich, 2009). No tool-induced modifications have been found. The spatial arrangement of macrovertebrate remains is chaotic in coarse-grained layers (e.g. SU 21–22 and SU 108): such deposits are indicative of mass flows and contain highly abraded, polished and rounded bones. Finer deposits (e.g. SU 7 or SU 20) contain unabraded or slightly abraded remains that can show preferred orientation. Mixing of different Voorhies' dispersal groups was observed in these SU, indicating moderate sorting of bones related with short distance and low energy water transport in cave conduits.

Taphonomic evidence recorded at Pirro 10 suggests that (1) bone accumulation of Pirro 10 macrovertebrate probably results from animals falling in the cave system by accident, although it is possible that some animals were taken in by predators, (2) skeletons were exposed on the cave floor, decomposed and partially disarticulated near a cave entrance, (3) the cave environment caused corrosion, desquamation and pitting, and (4) bones were moved within the cave system by low to high energy water-flows, usually for short distances.

5.2. Mammal biochronology

The Pirro Nord karst complex gave its name to the latest Villafranchian Faunal Unit (Pirro Nord FU or Pirro FU) of the Italian biochronological scale (Gliozzi et al., 1997; Bertini et al., 2010) where the taxonomic content of the various Faunal Units represents the best, if not the sole, valid tool to subdivide and characterize the Late Villafranchian Mammal Age, in particular the time interval between 1.7 and 1.3 Ma that comprises the Pirro Faunal Unit and its local faunas (Gliozzi et al., 1997). The most important bioevents characterizing the Pirro FU are the first occurrence of *E. altidens*, *B.* (*Eobison*) *degiulii* and *X. lycaonoides*. Moreover, the Pirro FU represents the last occurrence for some taxa of earlier origin, such as *M. whitei* and *H. refossa*. Additional information derives from the study of the evolutionary degree of *M. (Allophaiomys)* ex gr. *ruffoi* (see Chapter 5.3). The Pirro FU is also characterized by the European FO of the genus *Homo*, as indicated by the rich lithic tool record found at Pirro 10, Pirro 21 and especially Pirro 13 (Arzarello et al., 2007, 2009; Arzarello and Peretto, 2010).

The faunal content of the various sedimentary unit distinguished within Pirro 10 deposits is rather homogeneous with some elements shared by most of the SU, such as *A. eurygonos*, *U. etruscus* and *H. refossa*. All the large mammal taxa typical of the Late Villafranchian Pirro Faunal Unit have been found at Pirro 10, with the exception of the extremely rare *Theropithecus* sp. (Rook et al., 2004; Rook, 2009). A few species have been found at Pirro 10 for the first time in the Pirro Faunal Unit, such as *P. pardoides* ("Felidae indet., *Puma* size" in Petrucci, 2008; Madurell-Malapeira et al., 2010) and *P. nestii* (Colombero et al., in press). The presence at Pirro 10 of *Meles meles*, previously recorded only at Pirro 13 (Petrucci, 2008), is an additional proof that the various fossil assemblages of Pirro Nord palaeontological complex are contemporaneous from a biochronological point of view. As for the large mammals, the small mammal assemblages respect the composition of the Pirro Faunal Unit, with *M. (Allophaiomys)* ex gr. *ruffoi* as the only Arvicolidae recorded so far. Marcolini et al. (in press), noted some differences in the evolutionary degree of the specimens coming from the SU starting from SU 19 that show morphologies more similar to those of *M. (A.) ruffoi* from the type population as compared to the specimens from the lower SU, representing the first differentiation from an archaic population of *M.* (*Allophaiomys*) *pliocaenicus*. Such a difference has been noted by the authors by proposing two evolutionary stages within the species. There are no hints, though, on the time-span that might be represented by these evolutionary stages, being the differences between the populations certainly not enough to differentiate two species. The small mammals are recorded in all the SU with Chiroptera as the most common taxa group, found in all sedimentary units, often in large number (Table 1).

Pirro Nord is also an important association for its abundance of carnivores, both as taxa and specimen number: in the Pirro 10 site, 14 carnivore taxa have been found. The Pirro Nord carnivore guild includes also data of biochronological interest, such as the earliest occurrence of *M. meles* and *Mustela palaerminea,* and the latest occurrence in Italy of *M. whitei* and *Acinonyx pardinensis*.

The carnivores are important elements of the dispersal events from Africa to Europe that took place at about 1.8 Ma (former Plio–Pleistocene transition), with *Pachycrocuta brevirostris*, *Panthera* ex gr. *toscana-gombaszoegensis* and *M. whitei*. In particular, the dispersal of *M. whitei* into Europe occurred concurrently with other African species, such as *Homo*, through the Levantine Corridor, i.e. the principal path of dispersal between Africa and Eurasia (Martínez-Navarro, 2004; Turner and O'Regan, 2005; O'Regan et al., 2006). These species later expanded their range into Eurasia. In this palaeobiogeographical scenario, Pirro Nord plays an important role as the oldest documentation of their occurrence known so far (Arzarello et al., 2007, 2009).

5.3. Evolutionary degree of Microtus (Allophaiomys)

Differences in morphology have been noticed in populations of *M. (A.)* ex gr. *ruffoi* coming from different fissures of the Pirro Nord complex (Masini and Santini, 1991; Masini et al., 1998) and in the values of the Quotient of Enamel Differentiation (SDQ index: Heinrich, 1978) of first lower molars (Lippi et al., 1998). Marcolini et al. (in press) compared SDQ values, morphotype frequency distribution and biometric measurements of *M. (Allophaiomys)* specimens coming from different fissures of the Pirro Nord complex, coming from the type population of *M. (Allophaiomys) ruffoi* and of populations of *M. (Allophaiomys) pliocaenicus*; they stated that *M.* (*Allophaiomys*) from P10 (considered by the authors as a single population after a Cluster analysis) presents simpler morphologies as compared to the *M. (A.) ruffoi* type population of Cava Sud (Early Pleistocene, Italy), in having a wider Anterior Cap, a shorter ACC and a more evident Mimomyan-type enamel. Moreover, a dominance of morphotypes 1 and 2 (simple morphology with slightly developed ACC, no developed T6 or T7) is evident in populations of fissure P10 while a higher frequency of morphotypes 3, 4 and 5 is evident for the type population of Cava Sud. All these observations are valid also for the specimens examined in this work and derived from the various SU of Pirro 10 site. *M. (Allophaiomys)* ex gr. *ruffoi* from Pirro 10 has intermediate features between *M. (Allophaiomys) pliocaenicus* from the type population of Betfia II (Early Pleistocene, Hungary) and *M. (Allophaiomys) ruffoi* from Cava Sud and its SDQ is always negatively differentiated. As noted above, specimens from SU 19–27 show a slightly different evolutionary degree (Marcolini et al., in press), showing a morphology more similar to the type population of Cava Sud as compared to the lower SU, and more similar to populations coming from other fillings of the karst complex of Pirro.

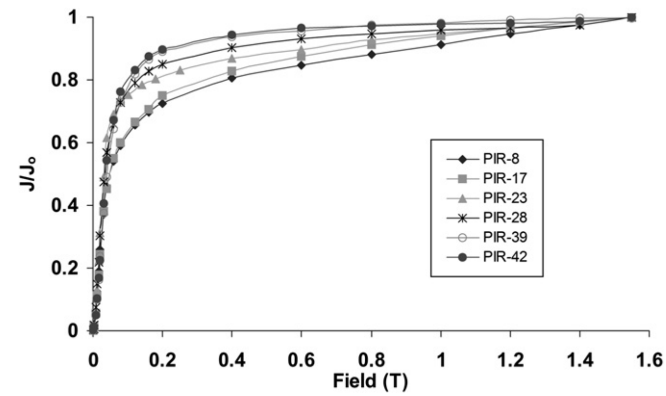

Fig 7. Stepwise IRM acquisition for representative samples.

6. Palaeomagnetic measurements and results

The palaeomagnetic sampling at the Pirro Nord locality was carried out during the excavation periods of August 2007 and July 2009. A total of 53 samples were collected from the II and III sectors of Pirro 10. The material was poorly consistent and plastic boxes of standard size were used to obtain cubic samples ($2 \times 2 \times 2$ cm). All samples were oriented using compass and inclinometer. Fourteen samples have been extracted from their plastic boxes and shaped with plaster of Paris in order to be heated and thermally demagnetized.

Palaeomagnetic measurements were carried out at the ALP Palaeomagnetic Laboratory (Peveragno), using a 2 G cryogenic and a JR-6 spinner magnetometer, a 2 G degausser and a TD-48 thermal demagnetizer. The magnetic mineralogy has been investigated by isothermal remanent magnetization (IRM) acquisition and back field curves (Figs. 7 and 8). In most samples, saturation is approached at fields of 0.3–0.4 T and only in few samples a small portion remains unsaturated at 1.6 T peak field (Fig. 7). The remanent coercive force is around 30–50 mT (Fig. 8). These results point

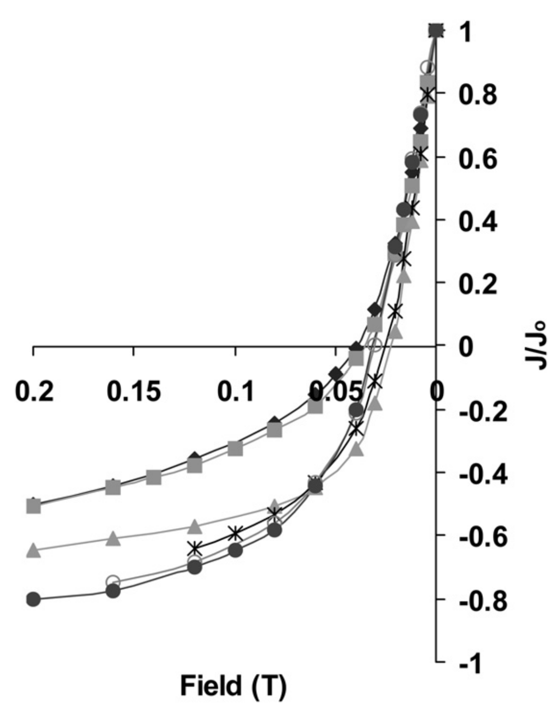

Fig. 8. IRM back field curves for representative samples.

to a low-coercivity ferrimagnetic mineral such as Ti-magnetite as the main carrier of remanence, with possible minor hematite.

The natural remanent magnetization (NRM) varies in intensity from 2 to 26×10^{-4} A/m and its direction is widely scattered. Thermal and alternating field (AF) demagnetizations show that the NRM consists of several components, although their behaviour is complex and they can be reasonably isolated only in few cases. In these cases, two NRM components can be identified (Fig. 9). A soft, low-coercivity and low-temperature component erased at around 15 mT or/and 120–150 °C respectively, and a more stable medium- to high-coercivity, high-temperature component. The direction of the stable component derived by principal component analysis, points towards south or southeast, with negative inclination (Fig. 9). It can be regarded as a primary remanence of reverse polarity. However, the high maximum angular deviation (MAD) values, the dispersion of the stable directions and the small number of samples, in which they can be clearly isolated, prevent the calculation of a statistically significant mean direction. Nevertheless, the data are enough for a safe qualitative interpretation: the stable remanence component may be regarded as the characteristic remanent magnetization (ChRM), acquired when sediments were deposited within the gallery during a period of reverse polarity, and the soft component as a viscous remanence acquired in the course of the Brunhes normal polarity chron.

These results substantiate the preliminary palaeomagnetic results by Tema et al. (2009). Together with the geological and palaeontological characteristics of the site, they suggest that the reverse polarity of the Pirro Nord sediments can be referred to the Matuyama, post-Olduvai reverse polarity Chron. This implies a time interval from 1.78 to 0.78 Ma, excluding the Jaramillo normal polarity subchron that extends from 1.06 to 0.90 Ma. Paleomagnetism confirms the Lower Pleistocene age of the Pirro Nord site, but cannot define it in better detail.

7. Concluding remarks

The sedimentary units exposed at Pirro 10 indicate different phases of aggradation interrupted by minor episodes of erosion by means of small channels. The gravelly layers of Phase 6 indicate the arrival of mass flows and their sudden deposition without any sorting. These are often rich in fossil bones. The low energy events are characterized by the deposition of finer, silty and clayey, often laminated facies. However, during the low energy stages sandy sediments were still transported within the conduit. Calcareous rock fragments are repeatedly present within the succession, in many cases with evidence of decalcification (e.g. SU 4, 7, 12, 13, 25, the whole Phase 6). Most are represented by clasts and boulders originated by rock falls from the roofs and walls of the gallery and interlayered with matrix-supported gravels. The almost exclusive quartz and flint composition of the sandy-silty fraction may indicate that erosion on the landscape affected mainly quartz-rich rocks or already decalcified soils. Nevertheless, the very abundant presence of clay pellets within the finer grained facies, associated with short distance transport of soft sediments, indicates the importance of reworking processes of the sediments present within the conduit.

The progressive infilling of the karst structure is associated with the rising of the local base level coupled with an increased sediment availability of the water flowing inside the karst system from the

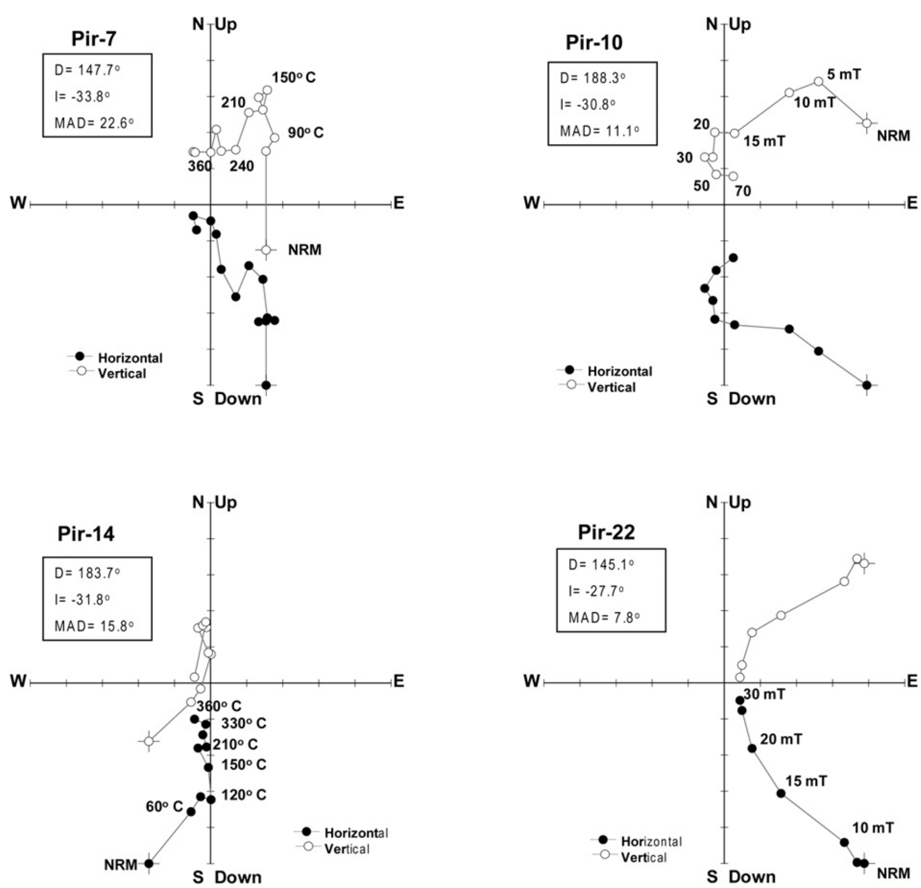

Fig. 9. Stepwise thermal and AF demagnetization results displayed by vector end point Zijderveld diagrams (Zijderveld, 1967). Symbols: full dots = declination; open dots = apparent inclination.

exterior, that is usually related to slope degradation processes typical of cold and arid conditions. These processes could have affected the walls of the sinkholes but most of the contribution came from the slope of the streams of the old catchment. This could have extended to the Gargano highlands, of which the Apricena horst represented the northernmost termination, as well as to the alluvial plain to the west that could have sunk in later times. Nevertheless, the base level rise might depend on a marine transgression and therefore be related to interglacial/interstadial phases during which flowstones could have been deposited on top of the clastic sediments. However, tectonics, particularly linked to the Appennine hinterland uplift, may have also played a role in the shifting from the phreatic to the epiphreatic and vadose zone. In other words, palaeoclimatic interpretation is not sufficiently supported by field evidence, mainly because of the reduced investigation area. Any genetic conclusion must take into account that: (1) the mammal biochronology assigns Pirro Nord Faunal Unit to a short span of time (1.5–1.3 Ma following Bertini et al., 2010, or 1.7–1.3 following Arzarello et al., 2007); (2) Pirro 10, Pirro 13 and all classic and recent fissures show strictly homogeneous fossil assemblages without taxa typical of older or younger FU, so that reworking and mixing of fossils with different chronological meaning is not tenable; (3) the faunal list for Pirro Nord palaeontological complex points to a moderately warm, semi-arid and discontinuously woody palaeoenvironment whose changes to a colder and more arid, steppe-like local scenario is suggested by the increasing horse and bison records near the top of the Pirro 10 succession.

The very flat erosional surface recognisable at the top of the Apricena horst, unconformably cutting the various formations and the intervening faults, represent a further D5 discontinuity (Pavia et al., 2010). It has been associated with a climatic induced marine transgression preserved at 165 m asl. The erosive event, reflected by the D5 discontinuity plane, assumes particular significance for karst infillings and vertebrate assemblages. In fact, no karst features are visible on the surface; the superficial structures, that supplied sediment to the deep karst network, have been cut and smoothed. Pirro 13 represents one of the sinkholes that would be opened at the surface, but it is completely filled by clast deposits up to the ground floor (Arzarello et al., 2007). Karst deposits with vertebrate assemblages were fossilized by this erosional event that has to be referred to the latest Early Pleistocene or earliest Middle Pleistocene. The karst gallery of Pirro 10 was probably well connected with the outside, at least in phase 4, as demonstrated by the trampling observed in some bones and the abundance of Chiroptera remains testifying the presence of a colony.

In general, taking into account the depositional evolution of the Pleistocene karst network of Pirro Nord locality, the aggradation trend is the major factor. Pirro 13 for a certain period continued to remain a shaft, along which a large part of the biogenic and taphogenic products was transported inside the cave system together with very large blocks resulting from rock falls. In its final stages of filling, this cave was affected by sedimentary deposition from running waters, usually transporting also coarse gravels, much coarser than the Pirro 10 filling proximal to the surface. Therefore, Pirro 10 to Pirro 13 preserves evidence of a complex karst system whose continuity has already been pointed out (Arzarello et al., 2007) (Fig. 10).

From a palaeobiological point of view, the vertebrate associations found in the various sedimentary units of Pirro 10 are biochronologically homogeneous and well referable to the Pirro Nord Faunal Unit (Gliozzi et al., 1997). The carnivore guild found at Pirro 10 site is also very rich, demonstrating the importance of the Pirro Nord complex for this group of taxa. In particular, 14 carnivore taxa have been recognized at Pirro 10, two of them (*P. pardoides* and *P. nestii*) documented only at Pirro 10 in the whole Pirro Nord complex. Any variation in evolutionary degree of the analyzed taxa within the various Sedimentary Units has been observed, demonstrating the

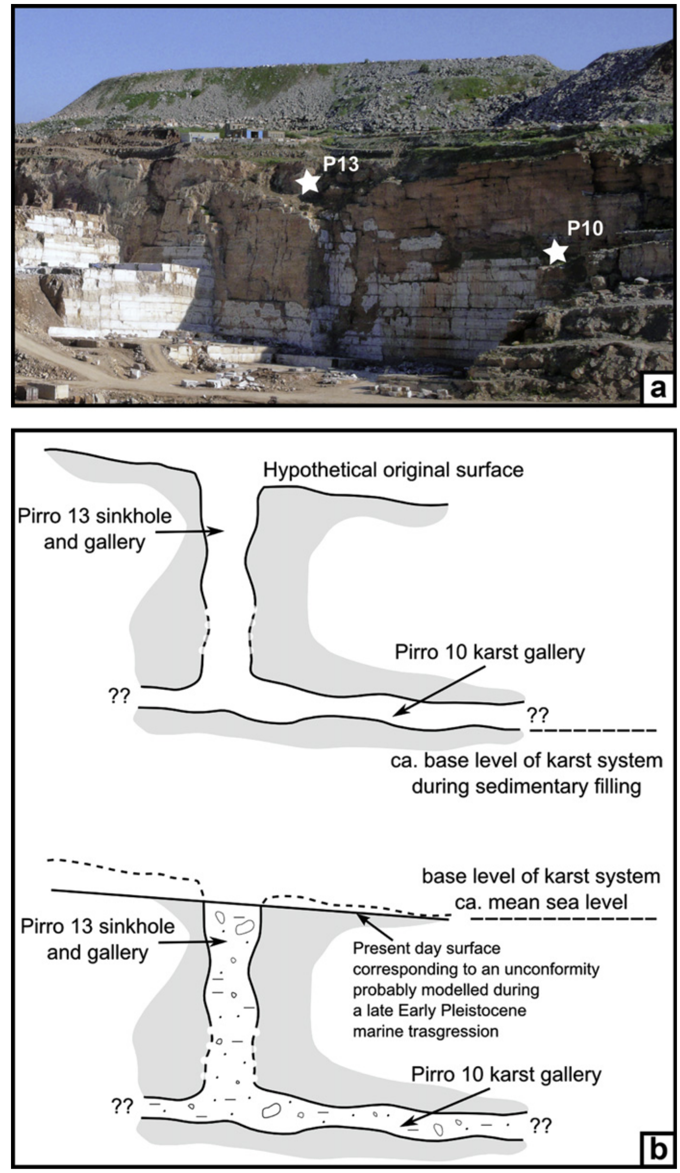

Fig. 10. a. The southern side of Dell'Erba's quarrying complex, former Pirro Nord quarries, with Pirro 10 and Pirro 13 sites in evidence. b. Schematic relationship between the two sites.

short time-span documented at Pirro 10. Furthermore, the analysis of the evolutionary degree of *M.* (*Allophaiomys*) ex gr. *ruffoi* based on the various parameters confirms the short time-span indicated by the vertebrate associations, and confirms that the *M.* (*Allophaiomys*) of the Pirro Nord complex has intermediate features between the type populations of *M. (A.) pliocaenicus* and *M. (A.) ruffoi* (Marcolini et al., in press). The taphonomical analyses carried on the mammal fossil remains reveal in some cases the presence of different status of preservation (e.g. different degree of abrasion or oxides coating) in the same Sedimentary Unit, thus indicating the presence of reworked bones. However the absence of biochronological differences between and within the SU suggests that the reworking processes affected only sediments of minimal chronological differences, possibly already deposited within the same Villafranchian karst network.

The vertebrate assemblages found in the various fissures of the Pirro Nord palaeontological complex are well diversified, and they represent a relatively short time-span and can be used as reference for palaeoenvironmental reconstructions. The fossil elements of the

Pirro Nord FU indicate the presence of open dry environment with scattered patches of woodlands eventually along water courses or swamps, some of them with temporary characteristics, with a temperate to warm climate. However, the faunal composition of the SU 22 and 108 indicates more open and drier conditions in respect to the other SU. This change is related to local ecological variation, probably linked to climatic and sedimentological variations.

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