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PLIO-QUATERNARY GEOLOGICAL EVOLUTION OF THE HIGH SALTO RIVER VALLEY (CENTRAL ITALY): THE MARANO DE' MARSI UNIT

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ABSTRACT: Chiarini E. *et al*., *Plio-Quaternary geological evolution of the high Salto river valley (Central Italy): the Marano de' Marsi unit.* (IT ISSN 0394-3356, 2009).
This paper summarizes the results of multidisciplinary researches carried out in a wide span of time on the earliest continental deposits of the high Salto River valley. The study led us to characterize sedimentary environments, to analyze their relationships and to propose a chronological attribution. Facies are referable to a complex depositional system consisting of a Gilbert-type lacustrine delta and of slope-type partly interfingered fan deltas coming from the eastern border of the basin. The geological data collected allowed us to refer the succession to a single sedimentary cycle; in Marano de' Marsi area the paleodrainage and progradation directions were also recognized.
To better constrain the chronological, paleoclimatic and paleoenvironmental context, detailed investigations have been conducted on pelitic facies of the deltaic-lacustrine system in two sampling sites (an artificial outcrop at Marano de' Marsi village and a borehole near Borgorose village). Paleomagnetic analyses show that Marano de' Marsi and Borgorose successions have a normal polarity and generally low magnetic susceptibility values. Pollen diagrams from both sites mainly record a mid to high elevation forest pollen rain. The existence of trees from different vegetation belts suggests the presence of a well developed mountain system in the surroundings. In the case of Marano de' Marsi section, these vegetation phases alternate with sudden, strong and short spreads of temperate and subtropical taxa. These alternations suggest that important climate changes occurred, with cyclical forest variations typical of glacial / interglacial periods of Pliocene and Early Pleistocene. Pollen and paleomagnetic data led us to refer both records to the Olduvai subchron, at the end of the Pliocene; nevertheless, the possibility that the records deposited during the Gauss chron cannot be, definitely, excluded.
Field geological data and magnetic fabric results suggest that the Marano de' Marsi unit sedimentation took place in a basin developed under extensional tectonic regime.

RIASSUNTO: Chiarini E. et al., Evoluzione geologica plio-quaternaria dell'alta valle del Fiume Salto: l'unità di Marano de' Marsi. *(IT ISSN 0394-3356, 2009).*
Il lavoro sintetizza i risultati di studi multidisciplinari condotti, nel corso di numerosi anni, sui depositi continentali più antichi dell'alta valle del Fiume Salto. Attraverso tali studi è stato possibile caratterizzare gli ambienti di sedimentazione e le relazioni fra essi esistenti, oltre che fornire indicazioni cronologiche più precise. Il rilevamento dettagliato di terreno ha consentito il riconoscimento delle facies che compongono tali depositi e la ricostruzione della loro distribuzione, permettendone l'attribuzione prevalentemente ad un delta lacustre di tipo Gilbert e subordinatamente a delta-conoidi, originati da canaloni o da corsi d'acqua a basso grado di maturità.
I dati di terreno raccolti in questo studio fanno ritenere che l'unità di Marano de' Marsi rappresenti il risultato di un unico ciclo sedimentario, sebbene molto articolato perché attribuibile ad un sistema deposizionale complesso. Nell'area di Marano, l'esame dei foreset e delle altre strutture sedimentarie riconosciute ha fornito dati importanti per la ricostruzione del verso del drenaggio e della progradazione del delta.
Per precisare il quadro paleoclimatico, paleoambientale e cronologico, sono state condotte indagini paleomagnetiche e palinologiche di dettaglio su due successioni affioranti nelle località di Marano de' Marsi e Borgorose, in corrispondenza delle facies pelitiche del sistema deltizio/lacustre. Le analisi paleomagnetiche indicano che entrambe le successioni studiate hanno polarità magnetica normale e valori di suscettività magnetica relativamente bassi, in accordo con la composizione dei sedimenti essenzialmente carbonatica. I record pollinici registrano prevalentemente fasi forestali con elementi di media ed alta quota. La presenza di alberi tipici di diverse fasce vegetazionali suggerisce la presenza di un sistema montano ben sviluppato nelle vicinanze. A Marano de' Marsi queste fasi vegetazionali si alternano con espansioni improvvise, consistenti e di scarsa durata di alberi temperati e subtropicali. Queste alternanze inducono a pensare che si siano verificati importanti cambiamenti climatici nel periodo considerato, con variazioni forestali cicliche, tipiche dei periodi glaciali/ interglaciali che vanno dal Pliocene Medio fin quasi alla fine del Pleistocene inferiore.
L'interpretazione congiunta dei risultati paleomagnetici e palinologici suggerisce l'attribuzione di entrambe le successioni al Pliocene. Pur non potendo del tutto escludere l'attribuzione al crono Gauss (Pliocene Medio), il confronto con lavori palinologici ottenuti da sedimenti continentali e marini italiani, insieme a considerazioni di geologia regionale, fanno propendere per un'attribuzione di entrambe le successioni al subcrono Olduvai (Pliocene Superiore).
I dati geologici e i risultati di anisotropia della suscettività magnetica suggeriscono che la sedimentazione dell'unità di Marano de' Marsi sia avvenuta in un bacino sviluppatosi sotto un regime tettonico di tipo estensionale.

Keywords: Deltaic-lacustrine facies; Pollen; Plant macrofossils; Magnetostratigraphy; Pliocene; Salto Valley; Central Apennines.

Parole chiave: Facies deltizie-lacustri; Polline, Macrofossili vegetali; Magnetostratigrafia; Pliocene; Valle del Salto; Appennino centrale.

1. INTRODUCTION

A complex interaction among tectonic uplift, normal fault activity, erosional events and depositional episodes characterizes the Plio-Pleistocene evolution of the Central Apennines. The main features of the most recent phases of this tectono-sedimentary evolution are generally well known. In the contrast, the definition of the earlier phases needs to be improved, although a general correlation of the sedimentary infill of the main intermountain basins had already suggested (Bosi & Messina, 1991; Bosi *et al.*, 2003). To this aim stratigraphic and sedimentological studies of continental deposits can be usefully integrated with analyses of erosional paleosurfaces and multidisciplinary research.

In the high valley of the Salto River, near the Latium and Abruzzi regions boundary, wide outcrops of continental deposits testify the early steps of the Plio-Quaternary evolution of the area; the sediments have been deposited on the margin of or within a lake no more recognizable in the present-day landscape.

These deposits have been studied in the framework of the field survey carried out for the Sheet n° 367 of the new Geological Map of Italy at a scale 1:50.000 (Servizio Geologico d'Italia, 2005) and of the same Sheet of the Geomorphological Map (Servizio Geologico d'Italia, 2008). The study has been integrated with paleomagnetic and paleobotanic investigations to better constrain the age of the deposits and to define the paleoclimatic and paleoenvironmental context.

In this paper we report the main results of these studies and some considerations on the geological and tectonic history of the sedimentary basin.

2. GEOLOGICAL AND STRUCTURAL SETTING

The studied area is located in the high Salto River valley (Fig. 1), between the Carseolani Mts. to the SW, and the Mt. Velino Chain to the NE. These mountain ranges are mainly formed by Lower Cretaceous-Miocene limestones and dolostones, referable to the Latium-Abruzzi carbonatic platform paleogeographic domain (Compagnoni *et al.*, 2005). The siliciclastic deposits overlying carbonatic units, related to the evolution of the Apennines Tortonian-Messinian foredeep basin (Bellotti, 1992; Cipollari & Cosentino, 1995), crop out south-eastward (Palentini Planes), northward (Malito Valley) and north-westward (Salto Lake), but are lacking in this valley sector.

Along the valley axis and in the nearby area (Fig. 2), continental deposits of gravitative, alluvial, and

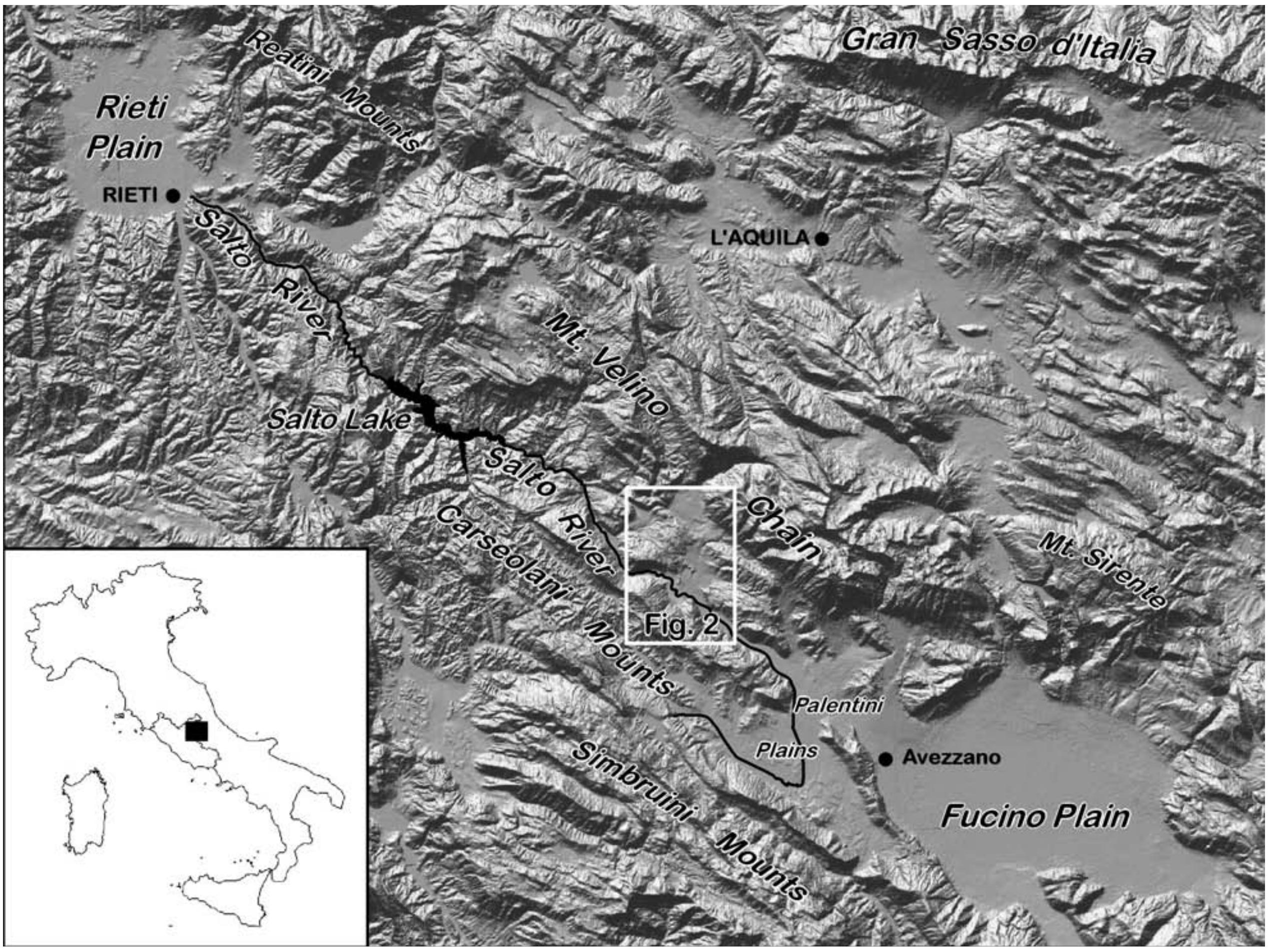


Fig. 1 - Shaded relief of the Apennine sector between the Fucino and Rieti intermontane basins and location of the study area.

Modello ombreggiato del settore appenninico compreso fra la Piana del Fucino e la Piana di Rieti ed ubicazione dell'area in studio.

lacustrine origin occur. They are organized in several depositional cycles and are separated by stratigraphic unconformities related to major erosional events (CHIARINI *et al.*, 2007; 2008).

The oldest continental deposits, described in this study, crop out between Marano de' Marsi (AQ) and Borgorose (RI) villages. In previous studies, they have been attributed to different sedimentary events. In the geological sheet n° 367 "Tagliacozzo" (SERVIZIO GEOLOGICO D'ITALIA, 2005), authors described a first alluvial unit and a following succession recording a progressive evolution from an alluvial to a lacustrine environment, unconformably covered with breccias cropping out in the Spedino and Borgorose areas. All these units have been doubtingly related to the Pliocene. BUSINO (1990) and FEDERICI (1990) recognized two main depositional events. The first event, Messinian or Pliocene in age, produced lacustrine clayey sediments (Fosso S. Martino Formation); the second one consists of two formations (Torano and Marano de' Marsi formations), which correlated each other and referable to the Pliocene, composed of several members. BOSI & FEDERICI (1993) correlated part of these deposits to the first continental cycle of the Fucino basin (S. Pelino Succession of BERTINI & BOSI, 1976 and Aielli Complex of BOSI *et al.*, 1995), ascribed to Pliocene. For the general shortage of dating materials, these chronological data are essentially provided on the basis of morpho-stratigraphic observations and analogies with other successions of Central Apennines.

The Salto River valley lies just to the west of the Apennines watershed, between the Fucino and the Rieti basins, and follows regional tectonic lineaments, corresponding to a NW-SE fault system with a multiphase tectonic activity (NIJMAN, 1970; BOSI *et al.*, 1994; BIGI & COSTA PISANI, 2003). During Plio-Pleistocene a segment of the fault system (Salto valley fault), with a main normal fault activity, controlled the location and the evolution of a continental basin (GALADINI *et al.* 2000; 2003), in the intermediate segment of the Salto valley, where the artificial homonymous lake is presently located (Fig. 1). This basin has been mostly obliterated by subsequent tectonic and morphogenetic events.

In the high valley the tectonic structure shifts eastward. Indeed a morphologically evident fault along the base of Duchessa mountain range (Mt. Velino Chain, see Fig. 1) shows an *en échelon* geometry (GALADINI & MESSINA, 2001; 2004; MOREWOOD & ROBERTS, 2001) with the Salto valley fault above mentioned. An important activity phase of Duchessa Mts. fault has caused the individualization and the evolution of the small Corvaro intermountain basin (Fig. 2), since the Early Pleistocene according to BOSI & FEDERICI (1993). These tectonic events induced a dramatic change in the paleogeography of the area. They made it difficult to recognize the sedimentary basin of the oldest continental deposits and the faults responsible for its structuring.

Nevertheless, available data make it possible to assume that: 1) sedimentary events considered in this paper took place inside an extensional basin; 2) the tectonic structures that controlled the evolution of this ancient basin could be the same as that responsible for the Corvaro basin setting.

Indeed, the tilting of the succession, generally 10° to 30° toward north-east, suggests the localization of the main fault on the eastern basin flank. Moreover, the several tectonic elements affecting the studied sedimentary succession are related to extensional tectonic regime, although referable to different phases. NW-SE and NNW-SSE trending faults confine deposits in a narrow and elongated belt inside the carbonatic bedrock (Fig. 2). Along the western margin, the contact of the deposits with the Meso-Cenozoic limestones consists of rectilinear and high-angle faults, segmented by minor transversal faults. Along the eastern border, the boundary is generally tectonic as well; only locally, deposits unconformably rest on the calcareous bedrock. These faults could belong to the Duchessa Mts. fault system, even if they show a moderate morphological evidence (Fig. 2). E-W trending minor faults also displace the Marano de' Marsi unit.

At present, a wide and flat erosional surface (Colle Vena Francesca paleosurface) almost obliterates the offsetting of the above cited faults; it has been recognized at about 950 m a.s.l. on both the marine carbonatic substratum and the deposits examined in the present work (Fig. 2).

In a preliminary study, CHIARINI *et al.* (1997) have shown that the Colle Vena Francesca paleosurface had formed before the Corvaro depression setting: in fact it shows considerable displacement across the Duchessa Mts. fault.

The paleosurface results from the complex interaction of depositional events, erosional phenomena and activity phases of faults; CENTAMORE & NISIO (2002a; b) have related it to the Fontanelle surface located in the mid Salto valley.

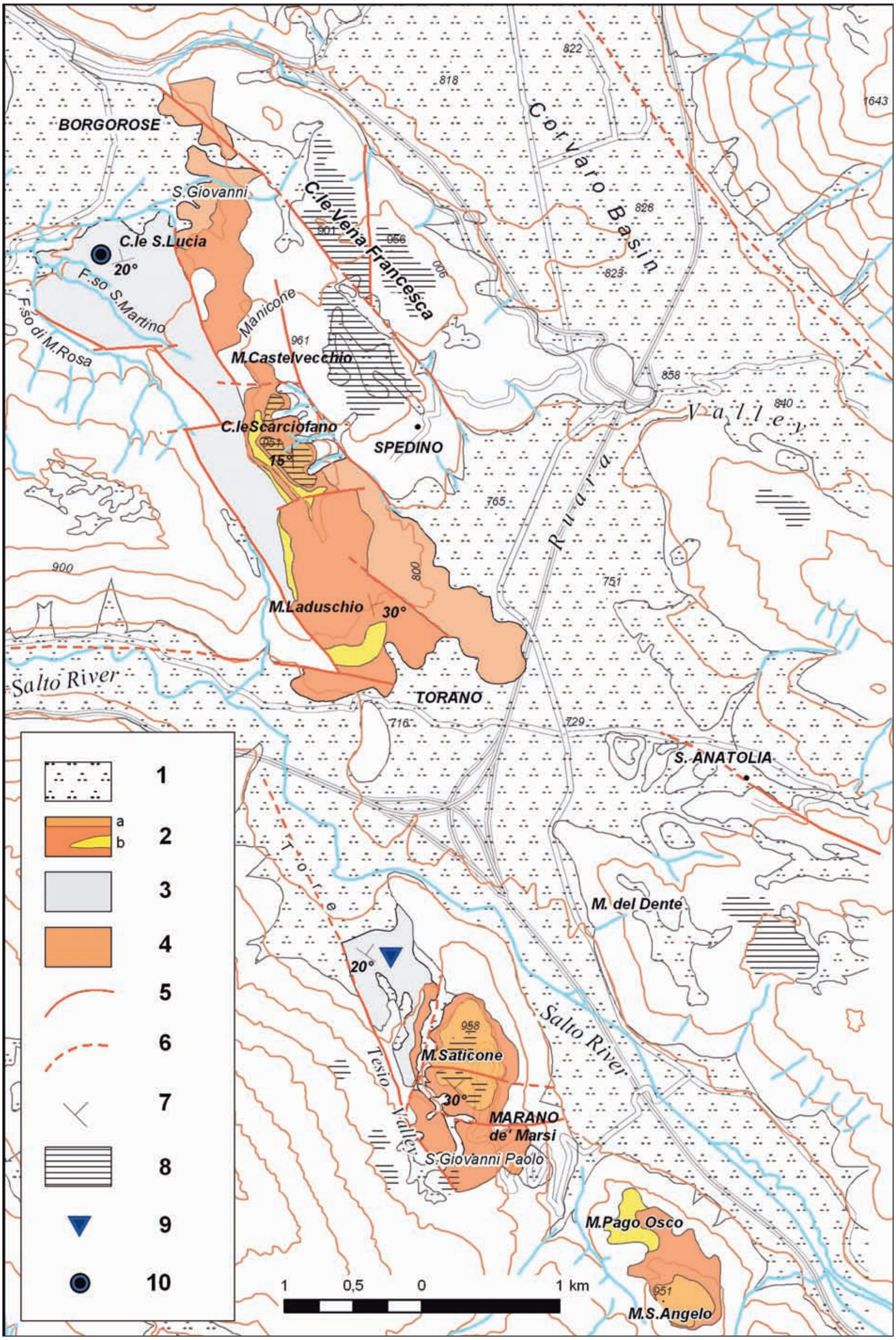
Therefore, the wide extension of the Colle Vena Francesca paleosurface would highlight its importance in the stratigraphic frame of the area and testifies an important change in the basin subsidence trend.

3. STRATIGRAPHIC AND SEDIMENTOLOGICAL FEATURES

The succession, named Marano de' Marsi unit, crops out discontinuously along the left flank of the Salto Valley, close to Marano de' Marsi village, at altitudes comprised between 959 m and 710 m a.s.l.; it also crops out between Torano and Borgorose, from 670 m to 951 m a.s.l. (Fig. 2). The maximum thickness preserved from erosion is of about one hundred meters.

It is composed of lacustrine marls, claystones, siltstones and arenites and by arenites, gravels and conglomerates of fluvial, deltaic and slope environment, which overlay the carbonatic substratum. This continental succession ends with the above mentioned Colle Vena Francesca erosional surface (Fig. 2); it is unconformably covered with the alluvial fan systems of Teve-Ruara valleys in the Torano area and of Valle Amara in the Borgorose area. Deposits of younger cycles sedimented after the infilling and dissection of the Corvaro basin and have been referred to the glacial phases of Upper Pleistocene (SERVIZIO GEOLOGICO D'ITALIA, 2008).

To collect stratigraphic and sedimentological data, a geological survey was performed at 1:10.000 scale, supported with photo-geological analysis, observations of natural and artificial outcrop sections and of


BORGOROSE
S.Giovanni
C.le S.Lucia
20°
F.so S.Martino
F.so di M.Rosa
C.le Vena Francesca
Manicone
M.Castelvecchio
C.leScarciofano
15°
SPEDINO
Corvaro Basin
Valley
Ruara
M.Laduschio
30°
Salto River
TORANO
S. ANATOLIA
M. del Dente
Torre
20°
M.Saticone
30°
MARANO de' Marsi
S.Giovanni Paolo
Tesio Valley
Salto River
M.Pago Osco
M.S.Angelo
822
818
828
823
1643
901
956
961
858
840
951
765
751
800
900
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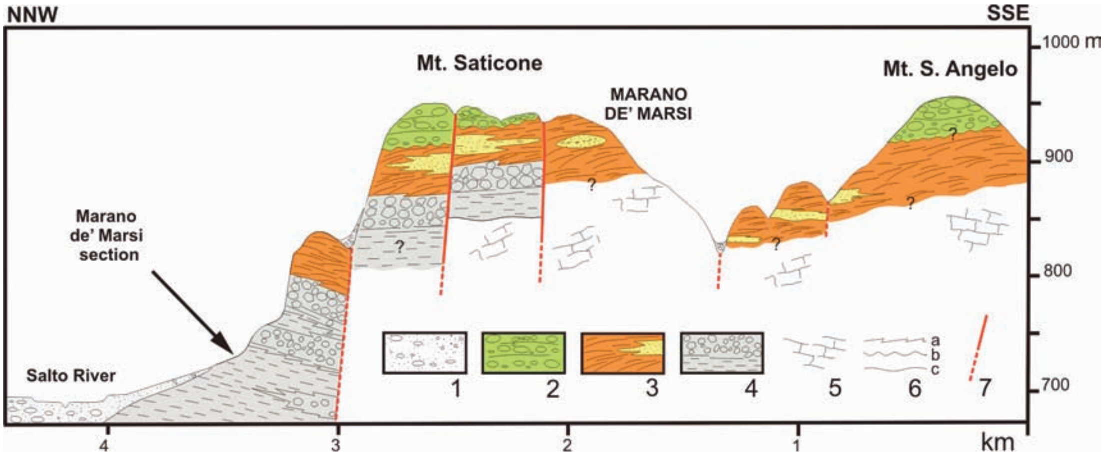

Fig. 3 - Longitudinal interpretative cross section of Marano de' Marsi area. 1) recent alluvial and colluvial deposits (Upper Pleistocene - Olocene); 2) Marano de' Marsi unit - sub-rounded to rounded coarse grained conglomerates of Gilbert-type delta topsets; 3) Marano de' Marsi unit - subangular to subrounded fine grained conglomerates with arenitic levels (a) of Gilbert-type delta foresets; 4) Marano de' Marsi unit - pelitic and ruditic deposits of Gilbert-type delta bottomsets; 5) carbonatic bedrock; 6) boundary: (a) etheropic, (b) erosional of low order, (c) erosional of high order ; 7) fault.

Sezione interpretativa longitudinale dell'area di Marano de' Marsi. 1) depositi alluvionali e colluviali recenti (Pleistocene superiore-Olocene); 2) unità di Marano de' Marsi – conglomerati con clasti grossolani, da subarrotondati ad arrotondati, dei topset del delta Gilbert; 3) unità di Marano de' Marsi – conglomerati a granulometria fine, con clasti da subangolari a subarrotondati, con livelli arenitici (a) dei foreset del delta Gilbert; 4) unità di Marano de' Marsi – depositi pelitici e ruditici dei bottomset del delta Gilbert; 5) substrato carbonatico; 6) contatto: (a) eteropico, (b) erosionale di basso ordine, (c) erosionale di alto ordine; 7) faglia.

laboratory samples.

A great facies variability was observed. The lack of important erosional discontinuities and the interbedding of lithofacies allow us to refer this succession to a single sedimentary cycle. Depositional structures described in this paper were mainly referred to a lacustrine Gilbert-type delta for the occurrence of the typical three stratigraphic components (bottomset, foreset and topset; Fig. 3); secondly they were connected to slope-type fan-deltas with a high gradient. Sharp facies variations frequently mark the emergence of faults belonging to the main Apennine system or transversal tectonic elements as observed west of Marano de' Marsi and near Torano. The recognized facies can be grouped into three main facies associations (A, B, C; Fig. 2) on the basis of their meaning, relationships and spatial distribution.

Facies association A

This association groups prevailingly ruditic facies referred to the lacustrine Gilbert-type delta, because in many cases their differentiation is made difficult by the bad outcropping conditions.

Conglomerates with carbonatic pebbles, subangular or subrounded, sub-centimeters to centimeters in size widely crop out in the area; the sediments are clast supported, with a pebbly to muddy matrix, cross-bedded to plane-bedded foresets and moderately sorted beds and laminations; massive coarse-grained sandy beds and decimetric to metric pelitic intervals are frequently present. Pedorelicts and sequences referable to paleo-channel filling have also been recognized. These facies occur at Mt. Pago Osco and near Marano de' Marsi and Torano villages (Figs. 2, 4 and 5).

Between Torano and Colle Scarciofano (Fig. 5), in the upper portion of the outcropping succession a lenticular body of well stratified sandstones, several meters thick, occurs; it is characterized by parallel and cross bedded laminations, well cemented strata, oxides rich levels, and thin coarse grained horizons from sand-

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Fig. 2 - Geological sketch map of the study area. 1) Quaternary deposits; 2) Marano de' Marsi unit (Middle?-Upper Pliocene) - alluvial-deltaic deposits of facies association A: fine to coarse grained conglomerates and gravels of Gilbert-type delta topsets (a) and foresets with arenitic levels (b); 3) Marano de' Marsi unit - lacustrine-deltaic deposits of facies association B: marls, marly claystones, siltstones and conglomerates of Gilbert type delta bottomsets and frankly lacustrine environment; 4) Marano de' Marsi unit - slope-type fan deltas deposits of facies association C: breccias with laminated yellow siltstones, calcarenites, marls and claystones; 5) fault; 6) inferred or buried fault; 7) bedding strike and dip; 8) Colle Vena Francesca paleosurface; 9) Marano de' Marsi (Tore) section; 10) Borgorose (Fornace dei Laterizi) borehole.

Carta geologica schematica dell'area in studio. 1) depositi quaternari; 2) unità di Marano de' Marsi (Pliocene Medio?- Superiore) - depositi fluvio-deltaici dell'associazione di facies A: ghiaie e conglomerati da fini a grossolani dei topset (a) e foreset con livelli arenitici (b) del delta Gilbert; 3) unità di Marano de' Marsi – depositi deltizi e lacustri dell'associazione di facies B: marne, argilliti marnose, siltiti e conglomerati dei bottomset del delta Gilbert e di ambiente francamente lacustre; 4) unità di Marano de' Marsi – depositi di delta conoide dell'associazione di facies C: brecce con siltiti gialle, calcareniti, marne e argilliti laminate; 5) faglia; 6) faglia incerta o sepolta; 7) giacitura degli strati; 8) paleosuperficie di Colle Vena Francesca; 9) sezione di Marano de' Marsi; 10) sondaggio di Borgorose (Fornace dei Laterizi).

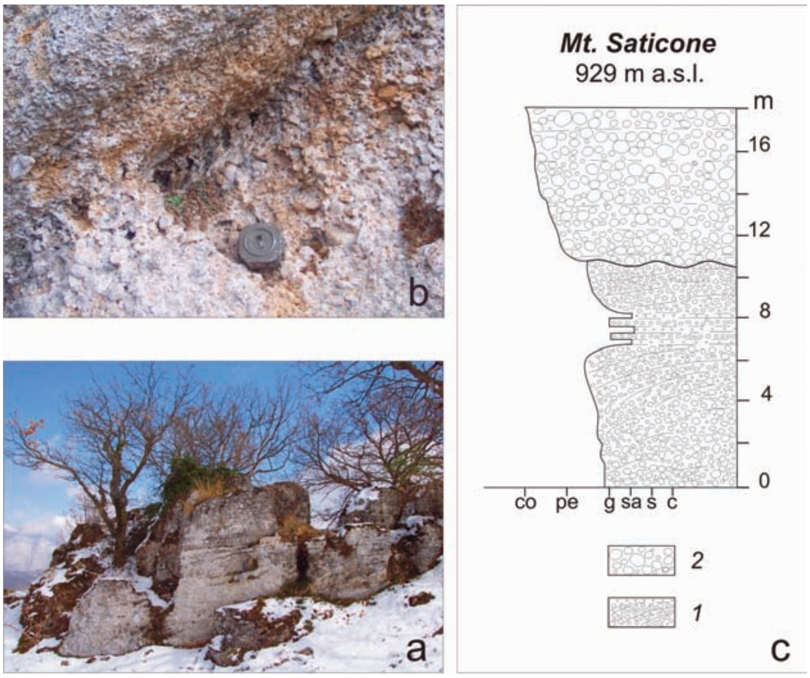

Fig. 4 - Upper portion of facies association A exposed at Mt. Saticone near Marano de' Marsi. a) Outcrop of cross-bedded fine grained conglomerates; b) Detail of moderately sorted cross-bedded foresets; c) Sedimentological log. 1) cross-bedded fine grained conglomerates of delta-front facies (foresets); 2: poorly stratified, well rounded coarse grained conglomerates of alluvial-deltaic plain facies (topsets); c: clay; s: silt; sa: sand; g: fine gravel; pe: pebble; co: cobble.

Porzione superiore dell'associazione di facies A esposta al Mt. Saticone, nei pressi di Marano de' Marsi. a) Affioramento di conglomerati a granulometria fine e a stratificazione incrociata; b) Dettaglio degli orizzonti a stratificazione incrociata moderatamente classati; c) Log sedimentologico. 1) conglomerati a granulometria fine e a stratificazione incrociata del fronte deltizio (foreset); 2) conglomerati a clasti grossolani e ben arrotondati, scarsamente stratificati, di piana alluvionale e deltizia (topset); c: argilla; s: silt; sa: sabbia; g: ghiaia fine; pe: ghiaia media; co: ghiaia grossolana.

stones to fine breccias. In these strata, small remnants of plants in a physiological position are often present.

Paleocurrents direction, evaluated using foresets geometry and clasts embrication, varies from NW to NE, suggesting a drainage from south to north.

This facies have been referred to the frontal part of the Gilbert-type delta.

Coarse grained conglomerates, moderately sorted, poorly stratified, with bedding thickness ranging from 0.5 m to 5 m crop out on top of succession; deposits are clast supported with a pebbly-sandy matrix and pebbles centimeters to pluricentimeters in size, from sub-rounded to rounded. Between the ruditic beds decimetric intercalations of finer sediments are present; these consist of thin horizons of claystones and beds of oxides-rich yellow calcarenites, with parallel and cross lamination. The transition to the overlying ruditic beds is given by a decimetric level of fine grained breccias. Moulds related to dry up cracks are noticeable between claystones and calcarenites.

These deposits extensively crop out in the area between Mt. S. Angelo and Colle Scarciofano (Figs. 2, 4 and 5) and are interpreted as topset of the Gilbert-type delta system, referred to an alluvial or deltaic plain environment.

Gravel lithology of the facies association is exclusively carbonatic, whereas finer grain-size classes are also siliciclastic.

Facies association B

This facies association is composed of prevailingly pelites, consisting of marls, carbonatic siltstones and silty claystones, with a grey to dark-grey color, massive, poorly stratified to thinly laminated. Whitish, light, limy-clayey horizons, rich of fresh water diatoms, are also present. Pelitic deposits include conglomerate bodies; in this context the transition from pelitic lithologies to the overlying ruditic beds is sharp and consists of an etherometric gravelly horizon with muddy matrix and thin levels of silty claystones with shell fragments.

These deposits crop out northwest of Marano de' Marsi village, in Valle di Tesio locality; they are also present in a narrow belt between the Rosa Mt. slope and the Laduschio Mt.-Castelvecchio Mt. relief, and then in a wide outcrop in the Borgorose area.

At the base of the Saticone Mt. slope, the facies association includes intraformational slumps consisting of a close alternation of carbonatic siltstones and clayey marls, deformed by mesofolds and joints. Ruditic facies also include carbonatic metric boulders and chaotic facies, as visible at Valle di Tesio; these elements probably indicate a tectonic instability along the depositional slope.

The observed facies have been ascribed either to a frankly lacustrine environment or to a distal portion of the deltaic system (bottomset).

Fresh water ostracods referable to the genus

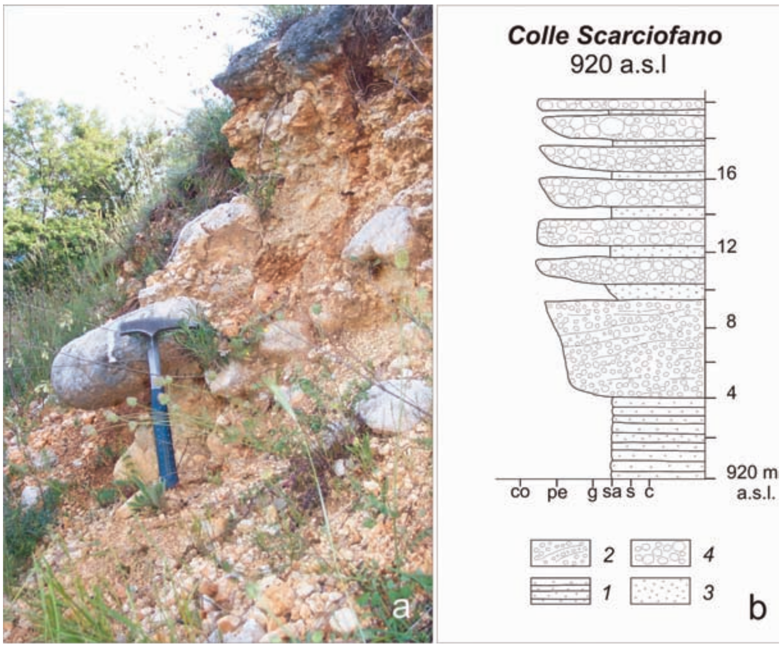

Fig. 5 - Upper portion of facies association A exposed at Colle Scarciofano. a) Outcrop of rounded coarse grained conglomerates (topsets). b) Sedimentological log. 1) stratified sandstones with parallel- and cross-bedded laminations of delta-front facies (foresets); 2) cross-bedded fine to coarse grained conglomerates of delta-front facies (foresets); 3) claystones, oxides-rich yellow calcarenites and fine grained breccias; 4) poorly stratified, sub-rounded to rounded, coarse grained conglomerates of alluvial-deltaic plain facies (topsets); c: clay; s: silt; sa: sand; g: fine gravel; pe: pebble; co: cobble.

Porzione superiore dell'associazione di facies A esposta al Colle Scarciofano, nei pressi di Borgorose. a) Affioramento di conglomerati a granulometria grossolana (topset). b) Log sedimentologico. 1) arenarie stratificate con laminazioni parallele e incrociate; 2) conglomerati a granulometria da fine a grossolana, a stratificazione incrociata del fronte del delta; 3) argilliti, calcareniti gialle, ricche di ossidi e laminate, e brecce a granulometria fine in intercalazioni decimetriche; 4) conglomerati a clasti grossolani da subarrotondati ad arrotondati, mal stratificati, di piana alluvionale e deltizia (topset) c: argilla; s: silt; sa: sabbia; g: ghiaia fine; pe: ghiaia media; co: ghiaia grossolana.

Candona s.p. and *Erpetocypris* s.p., gasteropoda fragments and characee thalluses (PAMPALONI L. & PICHEZZI R.M., Servizio Geologico d'Italia, personal communication), are observed inside the pelitic sediments.

Facies association C

This facies association consists of breccias with metric and plurimetric bedding or poorly defined strata, containing sub-angular to sub-rounded carbonatic clasts ranging in size from 0.5 to 10 cm, within a sandy-pebbly matrix. Breccias are poorly organized, clast supported or, less frequently, matrix supported; inverse gradations also occur. Thin normal graded interbeddings of small sized breccias, laminated yellow siltstones, calcarenites, marls and claystones are present. In some cases these facies rest on top of lacustrine claystones via clastic horizons rich of shell fragments.

The association might include ruditic deposits referable to bottomsets of the main Gilbert-type delta, for the etheropic relationships between each other and the close facies similarity. It crops out in the area comprised between Torano and Borgorose villages, where it is locally covered with ruditic facies of the association A.

According to sedimentary structures, ascribed either to a mass transport or, less frequently, to tractive flows, and because of the general lack of a clear foreset facies, this association has been referred to slope-type fan deltas which was originated from stream channels of a low order with a very small and steep catchment area. The facies distribution is consistent with a sediment supply from the eastern border of the basin.

4. THE STUDIED STRATIGRAPHIC LOGS

In order to better define the age of the Marano unit and to have indications on the paleoclimate that conditioned the sedimentary events, paleomagnetic and paleobotanic investigations have been carried out on fine sediments of two successions (SADORI, 2005). A first one, called Marano de' Marsi section, is constituted by deposits belonging to the facies association B and referred to a distal portion of the Gilbert delta. A second succession has been studied through a 24 m long core, drilled close to Borgorose village and therefore called Borgorose core. It is characterized by clays and silts referred to a frankly lacustrine environment.

4.1 Marano de' Marsi section

This section is located in a marginal position of the Salto valley, at an elevation of 720 m a.s.l. (Fig. 2). The vertically cut surface is about 11 m high.

Deposits are rather homogeneous and for about 10 meters from the bottom lacking in significant discon-

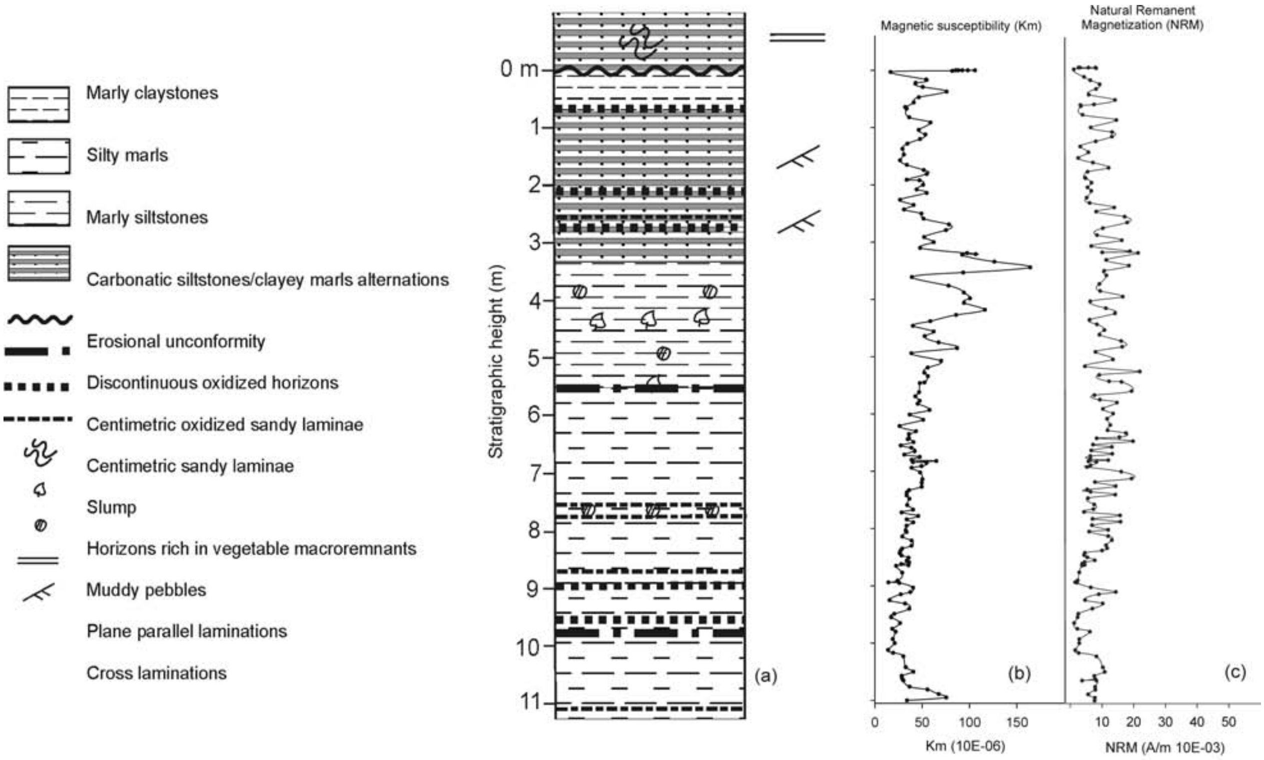

Fig. 6 - Stratigraphic log of Marano de' Marsi section (a) related magnetic susceptibility (b) and natural remanent magnetization (c) profiles.

Colonna stratigrafica schematica della sezione di Marano de' Marsi (a), profili della suscettività magnetica (b) e della magnetizzazione naturale rimanente (c).

formities; they consist of pale to dark grey silty marls and marly claystones and siltstones, with massive to thinly laminated beds and horizons (Fig. 6a). Sandy oxidized laminae, a few millimetres thick, cross-laminated levels and muddy pebbles, also occur. At the top, a weakly north verging cut surface marks the transition to an intraformational slump of laminated siltstones and marly claystones, including microfolds and fractures. At the base of the section, whitish horizons of particularly light clayey marls with fresh water diatom remnants, crop out.

These sediments have been subject of two specific samplings, i.e. paleomagnetic and pollen and macrofossil plant sampling.

4.1.1 Paleomagnetic analyses

Paleomagnetic sampling and laboratory methods

In the Marano de' Marsi section, we sampled 154, 2.5 cm in diameter, cores (Fig. 6). Cores have been drilled with a ASC-280 gasoline-powered drill and oriented *in situ* with a magnetic compass. The average stratigraphic distance between the sampled cores was 10 cm, along the whole outcropping section. The uppermost part of the section, below the slumping, was sampled more in detail in order to study the timing relationships between slump and the acquisition of remanent magnetization.

Most of the paleomagnetic analyses were carried out at the paleomagnetic laboratory of the Department of Geological Sciences of Roma Tre University, some of them at ETH Paleomagnetic Laboratory of Natural Magnetism in Zurich. In particular, low-field magnetic susceptibility (Km) and its anisotropy were measured in the paleomagnetic laboratory of Roma Tre University using an AGICO KLY-3 kappabridge. Successively, the natural magnetic remanence (NRM) was measured using a JR6 spinner magnetometer and a 2G-Enterprise SQUID cryogenic magnetometer at Roma Tre University and ETH Zurich, respectively.

Magnetic susceptibility analyses

Low-field magnetic susceptibility (Km) was measured along the whole section in 10 cm^3 volume specimens. Km values include the contribution of all magnetic minerals (diamagnetic, paramagnetic and ferromagnetic grains) present in the sediment in proportion to their susceptibility, abundance and grain size. Generally, if a sediment contains paramagnetic minerals as common constituents, susceptibility values are not higher than 100-200 x 10^{-6} SI. Magnetic susceptibility analysis has been increasingly used in the last few years as a valid proxy for magnetic minerals concentration (Verosub & Roberts, 1995; Dekkers, 1997) and then can be useful to define the presence of climatically induced cyclicity in sedimentary records (for example alternation of carbonates and clays) (Dekkers, 1997). In fact, the susceptibility fluctuations is used as a sensitive indicator of temporal variations in terrigenous input which are likely caused in changes of lake/sea level and erosion of the continental subaereal landscape (Rosenbaum *et al.*, 1996).

In the Marano de' Marsi lacustrine section the magnetic susceptibility values are low in average and range between 14 and 164 x 10^{-6} SI (Fig. 6b). In general, they display a small variation in that interval, reflecting stable and constant input of diamagnetic (mainly calcite) and paramagnetic (clay minerals) grains from substrate during the deposition. Moreover, this excludes the presence of any volcaniclastic contamination into the paleolake, such as pyroclastic fall products characterized by high content of ferromagnetic grains. Volcaniclastic deposits are typical in Middle Pleistocene lacustrine intermountain basins in central and southern Italy (Cavinato *et al.*, 1994). In detail, it is possible to see a weak increase in the values from the bottom to the top, in particular from 50 to 600 cm, with values from 14 to 70 x 10^{-6}. This part is also characterized by a weak ciclicity with a frequency of about 20-40 cm for each cycle (Fig. 6b). It is likely that this high frequency reflects the alternance of light and brown layers which have relatively major and minor content in carbonate grains respectively (i.e. minor and major content in magnetic grains).

Higher values are measured between 600 and 780 cm with a maximum value in correspondence of 756 cm. The remnant upper part of the section shows a constant trend up to the contact with the slumping, which is characterized by higher values, about 80-100 x 10^{-6} SI.

Natural Remanent Magnetization (NRM) analyses

The intensity of the NRM is in the 1-20 x 10^{-3} A/m range, without any particular variation along the Marano de' Marsi section (Fig. 6c). The widespread occurrence of diamagnetic and subordinate paramagnetic minerals is also responsible for the relatively low NRM values. As already seen in the susceptibility profile, also NRM profile of Fig. 6c shows a constant trend around a mean value of 8.8 x 10^{-3} A/m and characterized by a ciclicity with a frequency similar to that of susceptibility (see Figs. 6b and 6c). Moreover, relatively higher values are recorded in the central part of the section between 400 and 800 cm, whereas they are lower in the upper and lower part of it.

Thermal demagnetisation technique was applied for most of the specimens, whereas alternating field (AF) technique was applied only for some representative specimens. In the first kind of measurements the samples were thermally demagnetised with temperature increments of 30 and 50°C, up to 440-480°C, whereas in the second treatment the samples were progressively demagnetised in an alternating field (AF) up to 100 mT. Both measurements revealed valuable, giv-

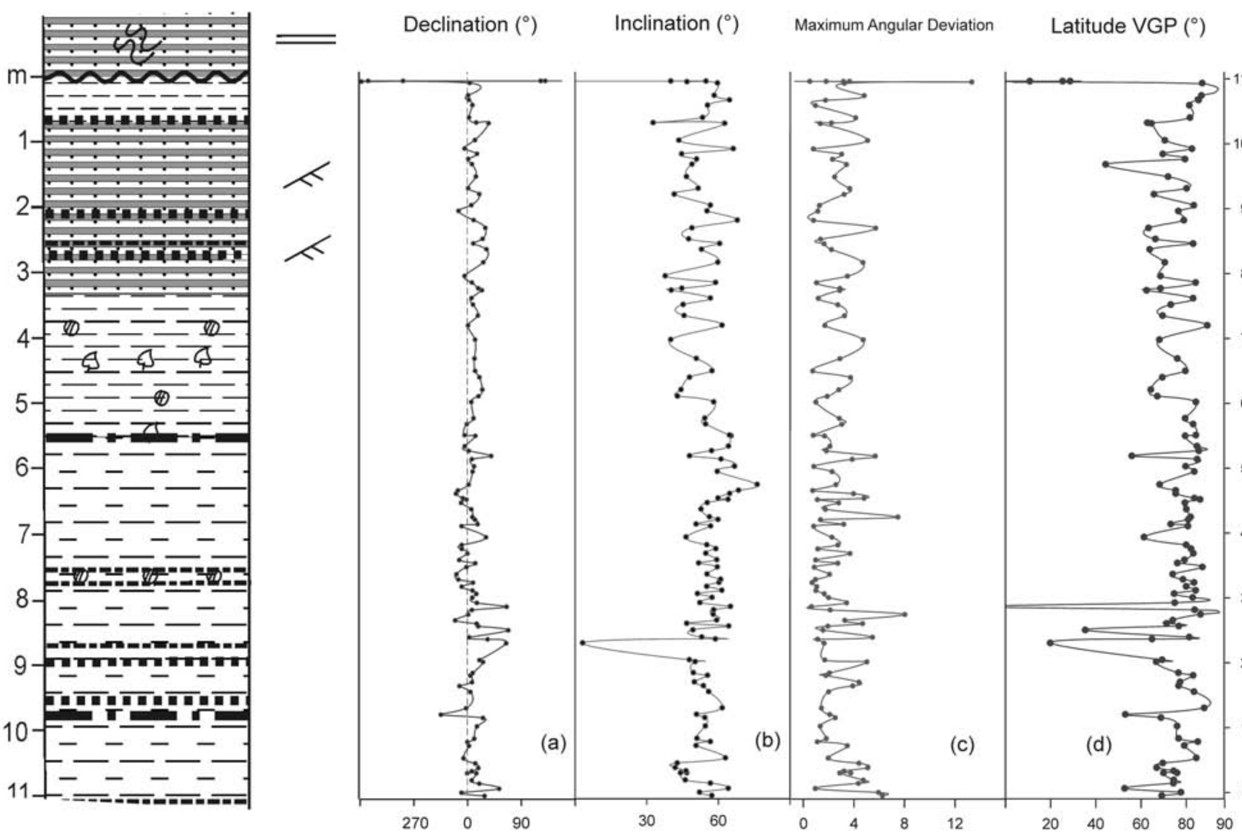

Fig. 7 - Calculated paleomagnetic declination (a), inclination (b), maximum angular deviation (c) and Virtual Geomagnetic Pole (d) for Marano de' Marsi section.

Variazione della declinazione magnetica (a), inclinazione magnetica (b), massima deviazione angolare (c) e del polo geomagnetico virtuale (d) ottenuto dai dati di declinazione, inclinazione e latitudine.

ing the same results. Demagnetization diagrams are analysed by principal component analysis (KIRSCHVINK, 1980), in order to determine the ChRM (characteristic remanent magnetization) directions for each sample. The maximum angular deviation (MAD) is generally less than 10°. Samples yielding MAD>15° were rejected for further analyses. All the characteristic components are plotted on equal area stereographic projection before (in situ) and after correction for bedding tilt (tilting value is 8° toward NNE).

Some representative paleomagnetic data obtained by thermal and alternating field (AF) demagnetisations have been shown in SADORI *et al.* (2009).

The declination and inclination of the characteristic component (ChRM) are projected versus stratigraphic height after application of bedding correction as shown in Figures 7a, b. It is evident as the declination of this component is constant in declination around N, whereas the inclination is always positive (i.e. normal polarity) with a mean value of 55°, in agreement with the expected geomagnetic field (GAD) direction expected for this locality. The small scatter of data both in declination and inclination is interpreted as due to secular variations of the Earth's magnetic field. No magnetic reversals are present in the investigated section.

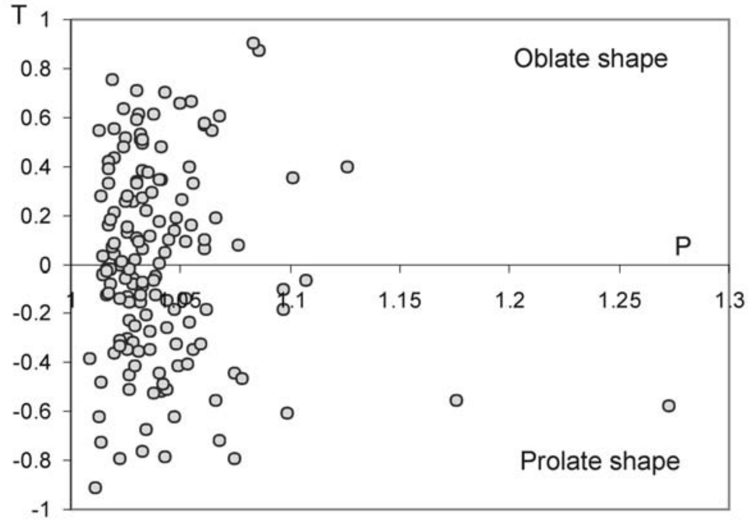

Fig. 8 - Anisotropy degree (P) versus shape parameter (T) of all the measured samples of Marano de' Marsi section. Note the scatter of the data and the low value of P values.

Grado di anisotropia (P) vs. fattore di forma (T) per tutti i campioni misurati. Si noti il grado di anisotropia molto basso e l'alta dispersione dei dati, che testimoniano un fabric magnetico poco definito.

Magnetostratigraphy

The declination and inclination obtained for the ChRM of each sample were used to calculate the virtual geomagnetic pole (VGP) latitude, yielding a magnetic polarity sequence in the studied section (Fig. 7d). Positive VGP latitudes indicate normal polarity for the whole section. In the lower part of the section from 0 to 600 cm, the profile of Figure 7d indicates a weak drift of calculated VGP from 70°N to 84°N. In the topmost part of the section (the last 15 cm), the data are not reliable because the clay samples are disturbed by the slumping emplacement.

The overall magnetic polarity stratigraphy outlined for Tore section is well within a normal polarity magnetozone (i.e. Olduvai subchron or Gauss chron of Pliocene age).

Anisotropy of Magnetic Susceptibility analyses

The measurement of the low-field AMS represents a rapid and non destructive method to define the mineral fabric of rocks (e.g., HROUDA, 1982). The magnetic fabric has proven to be closely related to the strain ellipsoid in weakly deformed or "undeformed" clay sediments both in compressional and extensional tectonic regimes, and, consequently, it constitutes a valid tool in defining the deformative pattern in weakly deformed fine-grained sedimentary sequences (BORRADAILE & TARLING, 1981; KISSEL *et al.*, 1986; LEE *et al.*, 1990; SAGNOTTI *et al.*, 1994; MATTEI *et al.*, 1999; CIFELLI *et al.*, 2004). The AMS is defined by a second rank symmetric tensor and is represented geometrically by an ellipsoid with principal axes $K_{max}>K_{int}>K_{min}$. The shape of the AMS ellipsoids and the degree of the anisotropy can be described by several parameters (see also JELINEK, 1981; HROUDA, 1982). The magnetic lineation and foliation (at the sample and site scales) are defined as the K_{max} and the plane normal to the K_{min} respectively. The AMS at both the specimen and the site levels was evaluated using the Jelinek statistics (JELINEK, 1978).

In the case of a sedimentary magnetic fabric, the magnetic foliation is parallel to the plane of sedimentation whereas the magnetic lineation is dispersed on the foliation plane and reflects the hydrodynamic conditions in the depositional basin. In the case of a magnetic fabric induced by tectonic processes, the maximum axis of susceptibility (K_{max}) is commonly aligned along the direction of maximum stretching in extensional environments (e.g. MATTEI *et al.*, 1997; CIFELLI *et al.*, 2004). In extensional environments, it is well documented that the AMS of rocks can be imparted during the very early stages of deformation (e.g. CIFELLI *et al.*, 2004).

The AMS results of Tore section are grouped in seven sites, from the bottom to the top of the section. The degree of anisotropy is generally low, with values of P' well below 1.10, and the fabric is either oblate or prolate as shown in Figure 8 (*P vs. T*). The shapes of AMS ellipsoid are also not well defined with exception of site VS04 (Fig. 9), characterized by oblate ellipsoid. The other sites show low anisotropy degree and a large variability in the shape parameter T.

A poor defined magnetic foliation has been measured in all the sites. A well defined magnetic lineation, NE-SW oriented, has been recognized in only one site (VS04) from the middle part of the section. In all the other sites the magnetic lineation is generally dispersed on the foliation plane (Fig. 9).

The overall AMS results demonstrate that the investigated deposit is characterized by a magnetic fabric poorly defined because of the low content in

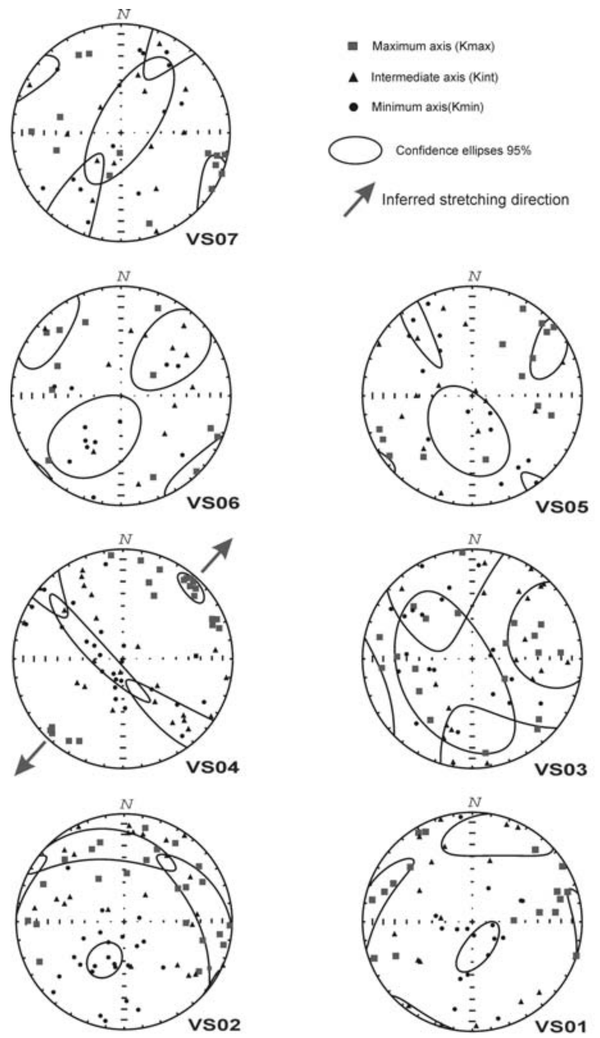

Fig. 9 - Equiareal projection of AMS principal axes for each site. Note the well defined magnetic fabric for site VS04.

Proiezione equiareale dei principali assi dell'ellissoide dell'AMS. Si noti come il fabric magnetico sia ben definito nel sito VS04.

magnetic grains. In fact, the lacustrine section is composed mostly by carbonatic marls which contain extremely few ferromagnetic or paramagnetic grains. The shape of AMS ellipsoids is therefore mostly related to sedimentary processes, where the magnetic foliation tends to reflect the deposition plane whereas the scatter of the magnetic lineation is likely related to hydrodynamic conditions of the lake at the moment of deposition. Only site VS04, which has the higher Km values (i.e. major amount of magnetic grains), is characterized by a well defined magnetic fabric with a NE-SW oriented magnetic lineation. This seems to suggest a stretching direction oriented parallel to the lineation, i.e. NE-SW, which could be the main extensional direction that has overprinted partially the lacustrine succession during tectonic deformation.

4.1.2 Plant micro- and macrofossils analyses

For plant fossils, a continuous column was taken, sampling big blocks of sediment later on subsampled in laboratory every 10 cm for pollen analyses and inspected for macrofossil ones.

Plant macrofossils

Preliminary analyses have shown the presence of a number of arboreal *taxa*: levels with angiosperm fossils are more abundant than those with gymnosperm ones (Fig. 10). The fossil compressions/impressions mainly consist of leaves, but also fruits/seeds, woods and cuticles were found. The still provisional fossil list comprehends many angiosperms such as *Acer* cfr. *monspessulanum, Carpinus* cfr. *orientalis, Engelhardia* sp., *Fagus* cfr. *sylvatica, Hedera* sp., *Liquidambar* sp., *Quercus* sp., *Rosa* sp., as well as *Abies* sp. and *Pinus* sp. Both *Engelhardia* and *Liquidambar* genera are extinct in Europe and have species living only in Asia the first, and both in Asia and Northern/ Central America the second. Some fossil specimens are shown in Figure 11.

Plant microfossils

61 sediment samples have been analysed every 20 cm (with sampling improving at 10 cm at key depths), but only 57 showed a sufficient pollen content to be plotted in the diagram. Known weights (ca. 2 g) of dry sediment were processed in a sterile laboratory, using a standard procedure consisting in HCl (30%), HF (40%) and NaOH (10%) chemical attacks to remove both the mineral fraction and the organic matter. *Lycopodium* spore tablets (Stockmarr, 1971) have been added to estimate the pollen concentration values.

The palynomorphs identification was carried out with a transmitted light microscope at a minimum magnification of 400X. The level of pollen conservation is low, often very low. The grains appear generally to be corroded and crumpled, slowing and making the analysis difficult.

The total pollen concentration varied from 1900 to 129,000 pollen grains/g, the arboreal pollen (AP) percentages mainly ranged between 96 and 100%. 56 pollen *taxa* (with 11 herbaceous *taxa* in all) were identified. The number of terrestrial spermatophytes pollen *taxa* per level is between 15 and 39. The highest amount of pollen *taxa* matches both very low pollen concentration values (3200 pollen grains/g) and the highest percentage values of NAP (13%) at 9.80 m. The number of extinct arboreal pollen *taxa* is high (14). Fern spores and algal remains were also identified during routine pollen analyses.

Synthetical pollen curves are presented in Figure 10. The basic sum is composed by all terrestrial spermatophytes (trees, shrubs and herbs), so excluding water plants, ferns and algal remains. For details concerning the pollen identification criteria and definition of pollen types, as well as for a complete pollen diagram see Sadori *et al*. (2009).

Among gymnosperms *Pinus haploxylon* type (plus *Cathaya*), *Pinus sylvestris* type, *Cedrus, Picea, Abies, Tsuga*, and *Taxodium* type are found with significant values. Among angiosperms, herbs are quite absent. Dominant angiosperm tree *taxa* are *Quercus, Zelkova, Ulmus, Carya* and *Pterocarya* (the last two are no longer spontaneously growing in our continent). The presence

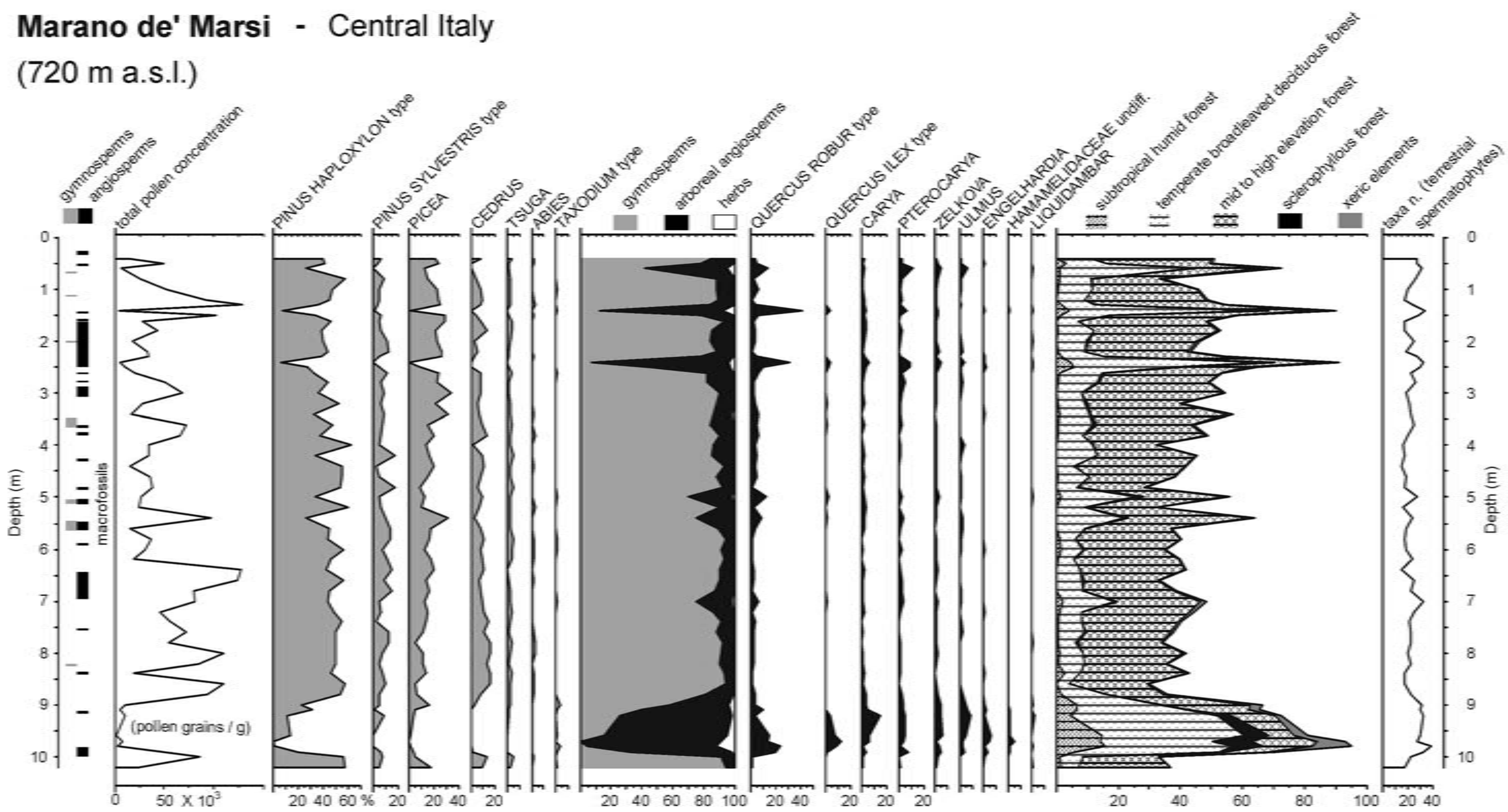

Fig. 10 - Marano de' Marsi (Rieti, Central Italy). Pollen diagram (selected *taxa* and groups). Pollen groups: subtropical humid forest (*Taxodium* type, *Engelhardia, Nyssa*, cfr. *Rhoiptelea*); temperate broad leaved deciduous forest (*Carpinus betulus, Carya, Castanea, Celtis, Corylus, Hamamelidaceae undiff., Juglans, Juglandaceae undiff., Liquidambar, Pterocarya, Quercus robur* type, *Quercus cerris* type, *Tilia, Ulmus, Zelkova*); mid to high elevation forest (*Abies, Cedrus, Picea, Tsuga, Betula, Fagus*); sclerophyllous forest (*Quercus ilex* type, *Olea*); xeric elements (herbs and *Ephedra*).

*Marano de' Marsi (Rieti, Italia centrale). Diagramma pollinico (*taxa *e gruppi selezionati). Gruppi pollinici: foresta umida subtropicale (*tipo Taxodium, Engelhardia, Nyssa, *cfr.* Rhoiptelea*); foresta temperata di latifoglie decidue (*Carpinus betulus, Carya, Castanea, Celtis, Corylus, Hamamelidaceae indiff., Juglans, Juglandaceae *indiff.,* Liquidambar, Pterocarya, Quercus *tipo* robur, Quercus *tipo* cerris, Tilia, Ulmus, Zelkova*); foresta montana e submontana (*Abies, Cedrus, Picea, Tsuga, Betula, Fagus*); foresta a sclerofille (*Quercus *tipo* ilex, *Olea); elementi xerici (erbe ed* Ephedra*).*

of pollen of subtropical *taxa* as *Nyssa*, cfr. *Rhoiptelea, Liquidambar, Engelhardia* is worth being mentioned (Fig. 12).

In the studied pollen record gymnosperms are prevailing, even if four main important, sudden and short angiosperm arboreal pollen oscillations can be observed, the oldest of which being more marked. The importance of these changes can be singled out examining the diagram of Figure 10, where pollen *taxa*, generally found in very different environments, ranging from mountain to arid ones, passing through temperate, subtropical, and Mediterranean types, have also been grouped into five "ecological groups". The more widespread vegetation types are two, one comprehending trees typical of temperate broadleaved deciduous forest and the other trees of mid to high elevation forest. Due to the wide ecological range of living *Pinus* species and to the fact that both *Pinus* pollen types comprehend other genera (e.g. *Pinus haploxylon* type includes in this paper also other genera such as *Cathaya*; in fact, for the low degree of pollen grains, preserving its methodical distinction was not possible), *Pinus* was not inserted in the ecological groups (SADORI *et al.*, 2009).

The main vegetation changes do not consist in alternations between open and close vegetation formations, that is to say between forests and steppe formations, but just in changes in the forest composition, as xeric elements are quite absent. The rapid and consistent alternations found in the pollen record, generally speaking between conifer forests and deciduous angiosperm ones, induce to consider that consistent changes in vegetation occurred. In northern Italy arboreal phases with gymnosperms and angiosperms alternately dominating characterized the glacial/interglacial cycles since the Gelasian (BERTINI, 2003). In southern coastal Italian areas, however, such cycles were featured by the alternation between steppic and arboreal phases (COMBOURIEU-NEBOUT *et al.*, 2004). More marked glacials/interglacials oscillations and a difference in their periodicity occurred only in the last 1 million years (LEROY, 2007; RAYMO *et al*., 1997; RUDDIMANN *et al*., 1989), when a change in the pattern of the orbitally driven cycles from obliquity to eccentricity occurred.

These physiognomic vegetation changes are however very strong, as the forest cover changed from a mountain forest to a temperate/subtropical one. In these forest changes, temperature and not humidity, seems to have been the main limiting factor. This was not the case of the vegetation changes from glacial to interglacial periods, which occurred in the last million of years and that were mainly triggered by changes in water availability.

Thus, the record of Marano de' Marsi appears to have been mainly deposited during a glacial period. As a matter of fact the so called interglacial periods are represented by very thin sediments horizons, in which the clear vegetation succession typical of these phases are not found (SADORI *et al.*, 2009). Another substantial aspect of the vegetation recorded in the pollen diagram is that the pollen rain reflects the presence of arboreal *taxa* requiring different climatic features, and implying the existence of several vegetation belts. It results from the mixing of mountain, mesophilous, and subtropical elements and implies the presence of mountains in the surroundings.

The hypothesis that the sediment record from Marano de' Marsi has some taphonomical problems has to be advanced: 1) the pollen samples with angiosperm trees dominating show the highest number of *taxa* and the lowest pollen concentration values. This is in clear contradiction with what happens in the pollen records in which concentration values have been estimated; 2) the vegetation changes between glacials and interglacials are sudden and all intermediate phases are missing; 3) the clear forest vegetation successions typical of interglacial periods are also not found, these phases being recorded, *ex abrupto*, by mature forests; 4) there is an apparent opposite indication from the macrofossil and microfossil record, as the presence of angiosperm leaves is overwhelming even in phases in which gymnosperm pollen is dominant.

The second and the third incongruities were investigated through thin section sediment analyses to check the possibility of important changes in the sedimentation pattern, aimed at explaining possible sediment gaps, not evidenced in the wide outcrop. Light lithological changes showed by analyses (COSENTINO D., Roma Tre University, personal communication) have been interpreted as disconformities of a low to very low order, ranging from the 0^{th}-order (lamination surface) to the 1^{st}-order (set bounding surface) *sensu* MIALL (2006), consistent with the sedimentary environment.

The fourth contradiction can be explained with an almost continuous local presence of angiosperms (leaves are too liable to deteriorate if transported far away) by the lake also in periods in which the regional vegetation (and therefore the pollen rain) was dominated by gymnosperms.

The vegetation and floristic features of the plant fossils record frame the lacustrine sediment succession between the Middle Pliocene and the Early Pleistocene.

4.2 Borgorose core

The Borgorose core has a 24.50 m length and was drilled at an elevation of 725 m a.s.l., close to an outcrop of lacustrine sediments. The sediments, quite homogeneous, are characterized by a higher clay content with respect to those cropping out in the Marano de' Marsi investigated section, according to a frankly lacustrine origin; lithologies are mainly massive or thinly laminated marls and silty claystones.

4.2.1 Paleomagnetic analyses

Paleomagnetic samples have been collected every 25 cm on average in order to reconstruct the magnetic susceptibility profile and magnetic polarity of the core and eventually correlate it to Marano de' Marsi section. The samples have not been oriented with respect to the geographic north, but they have been marked only with respect to the top of the core.

In the Borgorose core, the magnetic susceptibility values are generally low and range between 81 and 249 x 10^{-6} SI (Fig. 13). These values are relatively higher than Marano de' Marsi section because the sediments of Borgorose core have a major content of clay minerals (i.e. paramagnetic fraction). The highest values are relative to the upper portion of the core, from 550 to 700 cm, whereas then are constant for the remaining lower portion.

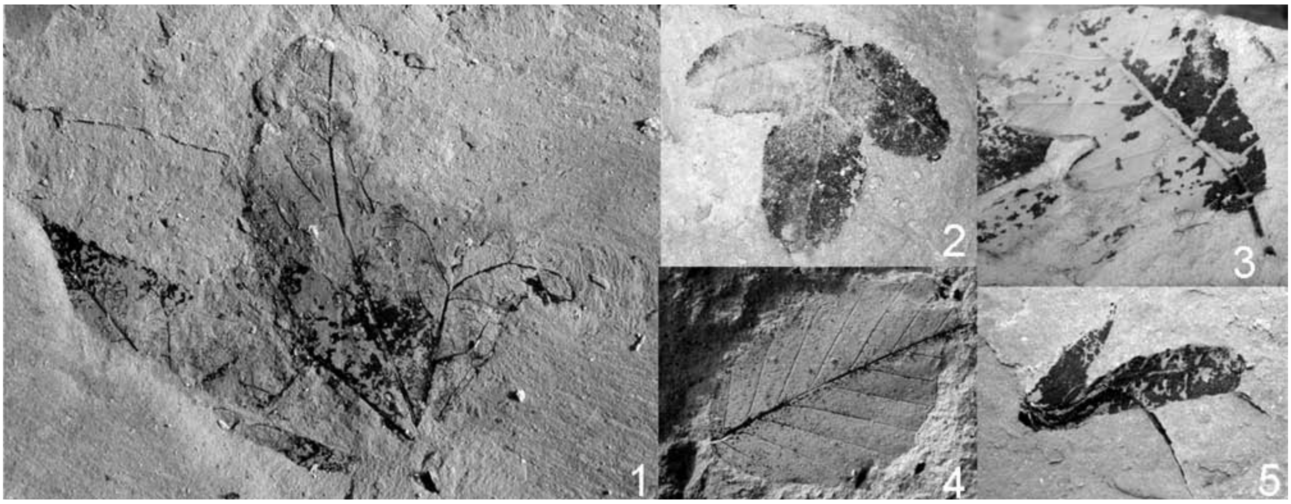

Fig. 11 - Marano de' Marsi (Rieti, Central Italy). Plant macrofossils. 1. *Liquidambar* sp. 2. Acer cfr. *monspessulanum* 3. *Quercus* sp. 4. *Fagus* cfr. *sylvatica* 5. *Engelhardia* sp.

Marano de' Marsi (Rieti, Italia centrale). Macrofossili vegetali. 1. Liquidambar *sp. 2. Acer cfr.* monspessulanum 3. Quercus sp. 4. Fagus *cfr.* sylvatica 5. Engelhardia *sp.*

The paleomagnetic analysis has been performed on 62 out of 84 total samples of the core. All the samples have been thermally demagnetised at Paleomagnetic Laboratory of Peveragno of the University of Turin. The same standard techniques described in the previous section have been used to define the principal component and the characteristic remanent magnetization for these samples. The overall results indicate a positive inclination, with an average inclination of 52°, for all the investigated samples, suggesting a normal polarity magnetozone without magnetic reversals. The mean paleomagnetic inclination has been defined without taking into account the tectonic tilting of the succession, that is of about 20°, as measured on the nearby outcrop of the same lacustrine deposits.

4.2.2 Plant microfossils

Pollen samples have been taken every 10 cm from 2.60 to 24.50 m. 41 samples have been analysed, but only 15 (from 3 to 8.60 m) showed a sufficient pollen content to be plotted in the diagram.

Known amounts of dry sediment (ca. 2 g) have been chemically processed following the treatment illustrated for the Marano de' Marsi outcrop.

The preservation of the pollen grains was also poor in this record, being generally degraded, corroded and broken, causing problems in the identification. The mean count of only the terrestrial spermatophytes pollen was 304 pollen grains.

Problems in the pollen preservation are clearly evidenced in the lower part of the core (9-24.2 m) and in the uppermost 3 m. In the related samples the very low pollen concentration values (from 100 to few thousands pollen grains/g) did not allow us to reach significant pollen counting.

The total pollen concentration of the selected pollen samples varied from 9000 to 113,000 pollen grains/g at Borgorose, with AP (arboreal pollen) percentages ranging from 97 to 99%. Synthetical pollen percentage and total pollen concentration curves are presented in Figure 14. 46 terrestrial plants pollen *taxa* (of which 8 herbaceous ones) were identified at Borgorose. The number of pollen *taxa* per level varies from 12 (matching the lowest pollen concentration values) to 31.

The diagram does not record either important vegetation changes or a clear vegetation development. Gymnosperms pollen always prevails on that of angiosperms.

Pinus haploxylon type, always dominant, was mainly accompanied by *Picea, Pinus sylvestris* type, *Taxodium* type, *Cedrus*, and *Tsuga. Picea*, showing percentages between 8 and 19%, can be considered locally present (Huntley & Birks, 1983). Deciduous oaks and *Carya* show high percentage values among the angiosperms, mainly accompanied by *Fagus, Pterocarya, Juglans, Ulmus*, Hamamelidaceae, and in minor quantities by *Engelhardia, Nyssa* and cfr. *Rhoiptelea.*

It is worth mentioning the consistent presence of water demanding trees (riparian plants), possibly indicated by the presence of *Taxodium* type, *Nyssa*, and *Carya*.

Considering the ecological groups, mid to high elevation forest trees are more abundant than those typical of the temperate broadleaved deciduous forest. Subtropical humid forest elements are always present with significant values, while sclerophyllous and xeric elements appear to be less abundant.

The sediments are likely to have been deposited during a cool and wet period, and do not show the important angiosperm tree expansions featuring warmer phases. Notwithstanding, angiosperms show a continuous and similar behaviour, suggesting that they were present at lower elevations and, possibly, in wet areas (see for example *Taxodium* type) by the lake. The high amount of *Taxodium* type pollen is the main reason for the considerable amount of subtropical humid forest *taxa* found in the pollen record.

Four common features can be singled out in the two investigated successions: 1) the scarce number of pollen *taxa*, that can be partially explained with the very

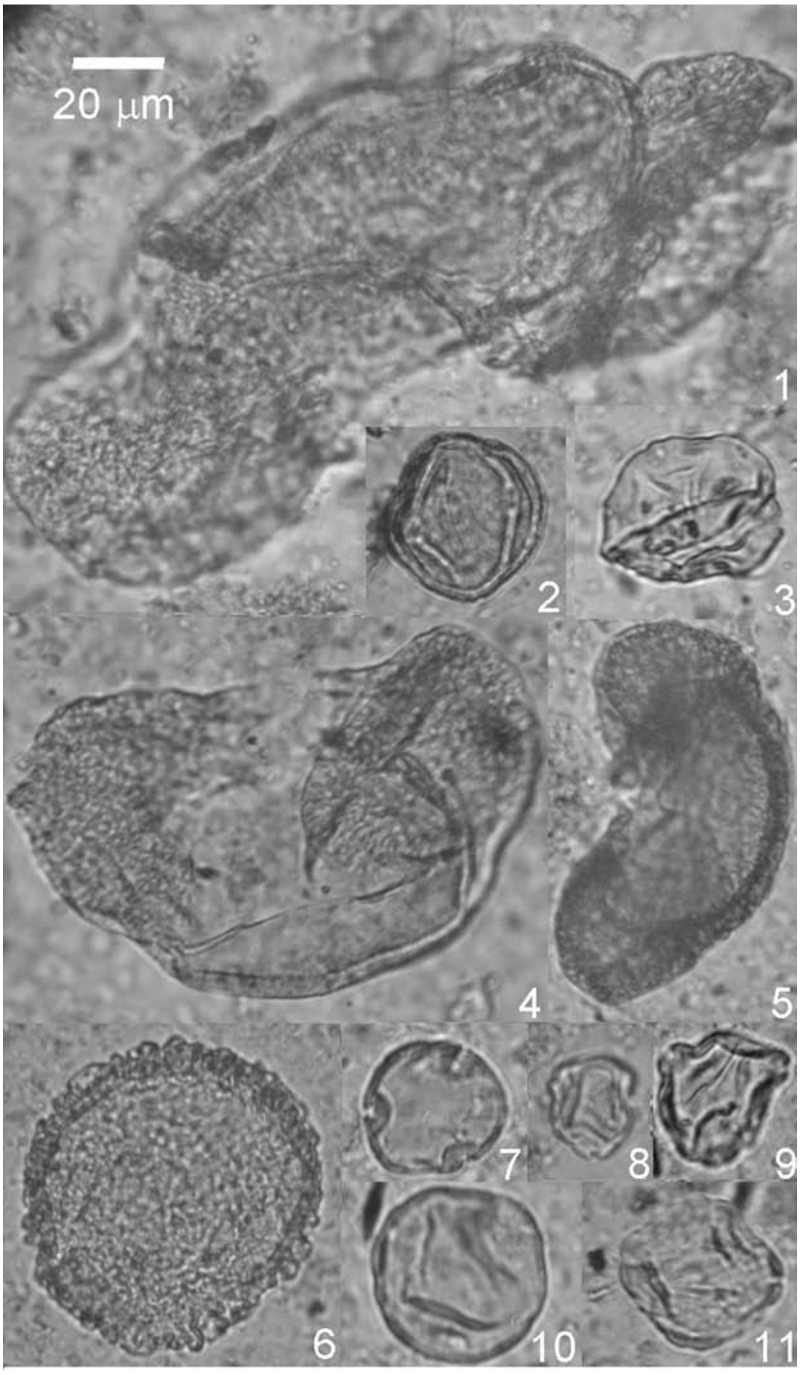

Fig. 12 - Marano de' Marsi (Rieti, Central Italy). Pollen grains. 1. *Abies* 2. *Nyssa* 3. *Pterocarya* 4. *Picea* 5. *Cedrus* 6. *Tsuga* 7. *Tilia* 8. *Engelhardia* 9. cfr. *Rhoiptelea* 10. *Carya* 11. *Zelkova*.

Marano de' Marsi (Rieti, Italia centrale). Granuli pollinici. 1. Abies *2.* Nyssa *3.* Pterocarya *4.* Picea *5.* Cedrus *6.* Tsuga *7.* Tilia *8.* Engelhardia *9.* cfr. Rhoiptelea *10.* Carya *11.* Zelkova.

low amount of herbs; 2) the similarity in the pollen lists of the two sites, with 43 pollen *taxa* in common; 3) the same list of extinct arboreal pollen *taxa*; 4) the contemporary presence of plants with different ecological requirements, indicating the presence of vegetation belts developed along an altitudinal gradient.

Similarly for the Marano de' Marsi outcrop, a Middle/Upper Pliocene or Early Pleistocene age appears to be consistent with the palynological data.

5. DISCUSSION AND CONCLUSIONS

The succession cropping out in the high Salto River valley, called Marano de' Marsi unit in this paper, has been the object of a few works, differently from successions of Fucino and middle Salto valley basins. Previous authors have interpreted the high Salto valley succession as the result of more than one sedimentary event, probably related to Pliocene (SERVIZIO GEOLOGICO D'ITALIA, 2005), or to Pliocene and to Messinian (BUSINO,1990; FEDERICI, 1990).

Stratigraphical and sedimentological data illustrated in this study, on the contrary, allow us to refer the unit to a single sedimentary cycle organized in a complex depositional system. Recognized etheropic facies – from alluvial to lacustrine via transitional forms - have been referred to a Gilbert-type lacustrine delta and to small scale fan-deltas originated from the eastern border of the basin. Anomalous sharp facies variations observed in the field have been reported to tectonic activity which significantly displaced the sedimentary unit. Two main unconformities bound the unit: the lower one marks the erosional contact with the carbonatic bedrock; the upper unconformity corresponds to the Colle Vena Francesca paleosurface.

The prevalence of carbonatic lithologies marks a significant difference with earliest continental deposits of Fucino (Aielli complex, BOSI *et al.*, 1995) and middle Salto valley (Sabbie di Piagge, BERTINI *et al.*, 1986); in the lower part of the sedimentary successions of these basins, siliciclastic lithologies actually prevail, according to a wide spread of Messinian turbidites in the catchment area (BOSI *et al.*, 2003) during the first erosional phase of the chain (CENTAMORE & NISIO, 2002a; b). Therefore it is not possible to correlate the Marano de' Marsi unit with the Fucino and the middle Salto valley on the base of lithological affinities.

In the framework of a general shortage in chronological data, paleobotanic and paleomagnetic analyses have been conducted on the finer sediments of the Marano de' Marsi unit to obtain dating elements, also providing interesting paleoenvironmental and paleoclimatic results.

Pollen records of the two sampling sites (Marano and Borgorose) suggest the presence of a well developed mountain system in the surroundings, as indicated by the presence of trees belonging to different vegetation belts. Pollen rain coming from mid to high elevation forest *taxa* is generally prevailing throughout the investigated successions. A pollen assemblage of this kind suggests ascribing the investigated levels to glacial periods (BERTINI, 2003).

Nevertheless, pollen typical of temperate forests (and of interglacial periods) is always present in low quantity, and, at times, overwhelming at Marano de' Marsi. The moderate expansion of *taxa* typical of the subtropical humid forest (all extinct at present in Europe) is noteworthy and useful for the chronological framing. The similarity of the pollen assemblages induces us to think that the two sediment records were deposited in the same period or at very close times.

The plant fossil assemblages, the high amount of *taxa* at present extinct in Italy indicate that the sediments were likely deposited during the Middle/Upper Pliocene or the Early Pleistocene.

As no magnetic reversals are present in the investigated section, the combination of pollen and paleomagnetic data allows to constrain both records to Gauss chron (Middle Pliocene) or Olduvai/Reunion subchrones (Late Pliocene). A close comparison (see SADORI *et al.*, 2009) with other Italian palynological records of Pliocene and Pleistocene age (URBAN *et al.*, 1983; ARIAS *et al.*, 1990; SUC *et al.*, 1995; BERTINI, 2000, 2001, 2003) seems to better frame both successions in the subchrones of Late Pliocene, more likely to Olduvai one, for its longer duration.

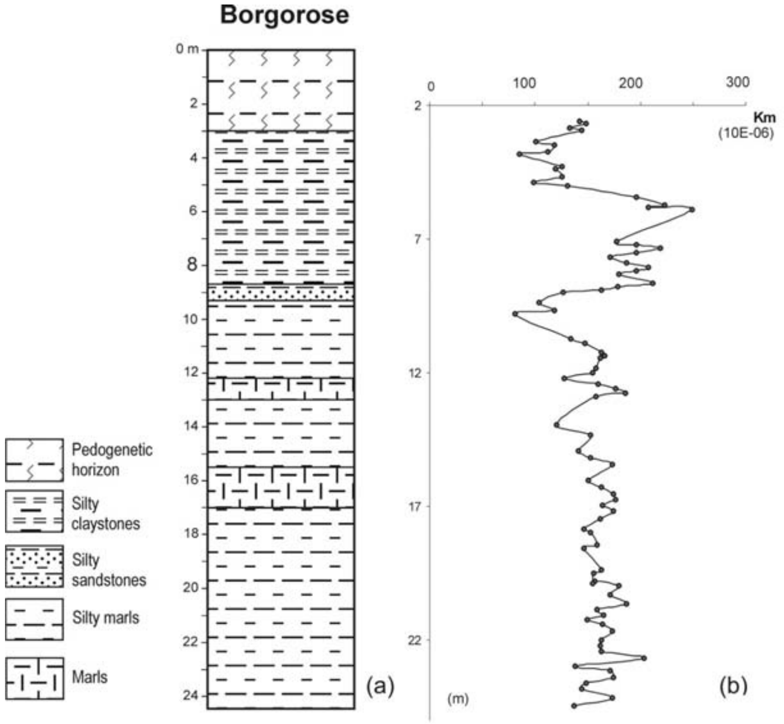

Fig. 13 - Stratigraphic log (a) and magnetic susceptibility profile (b) for Borgorose core.

Colonna stratigrafica schematica della sezione di Borgorose (a) e profilo di suscettività magnetica (b).

The possibility that the records deposited during the Gauss chron cannot be, definitely, excluded.

The presence of Pliocene continental deposits is widely documented in the Central Apennines and it has been related mainly to extensional tectonic activity: since Pliocene a prevailingly lacustrine sedimentation took place in the main intermountain basins like the Turano valley, the middle Salto valley and the Fucino basins (BOSI *et al.*, 1995; BOSI *et al.*, 2003; GALADINI & MESSINA, 2004). Intermountain basins in Central Apennines are thought to be progressively younger eastward, for the effects of extensional tectonic migration from the western sectors to the eastern ones (CAVINATO & DE CELLES, 1999; GALADINI & MESSINA, 2004).

The quite complex structural setting, outlined in this paper, neither allows us to define the configuration of the basin where the Marano de' Marsi unit sedimented, nor to certainly establish which tectonic structures guided the basin settlement.

Geological field data and AMS results suggest that the Marano de' Marsi unit was deformed in an extensional tectonic regime, with a stretching direction oriented NE-SW. The development of a Gilbert-type delta also implies the occurrence of a steep margin; additionally the presence of slumps and big boulders in some horizons of succession indicate a tectonic instability along the depositional slope, giving value to the tectonic control on the basin evolution. Finally the structural setting of succession shows a general NE tilting. All these features are consistent with the activity of faults located on the eastern border of the basin.

Previously exposed data and the lack of compressive features inside deposits allow us to hypothesize that the Marano de' Marsi unit deposited inside an intermountain continental basin, like the Pliocene deposits of other basins of Central Apennines. The erosion of the wide Colle Vena Francesca paleosurface testifies a significant decrease of the subsidence of this basin; during Early Pleistocene the subsequent settlement of Corvaro intermountain basin yields a new subsident area, where the following sedimentation takes place. The whole area indeed is progressively captured by the hydrographic system of the Salto River and deposits are consequently dismembered; the outlined evolution is common to that of other basins of the western Apennine flank: endorheic at first and then captured and integrated in the drainage network (D'AGOSTINO *et al.*, 2001).

In reconstructing the Fucino basin evolution D'AGOSTINO *et al.* (2001) supposed that the end of the completely internal drainage phase coincided with the capture, during the Pleistocene, of a portion of the basin by regressive headward erosion of the Salto River.

Nevertheless, a sediment supply from the eastern border of the basin has also been recognized, the facies distribution and paleocurrent directions testify a main drainage direction - i.e. the Gilbert-delta progradation - from south-east toward north-west, thus trending like the principal fault system. These arguments highlight that at the time of Marano de' Marsi unit sedimentation, the Fucino and the high Salto valley areas belonged to two different, isolated, basins.

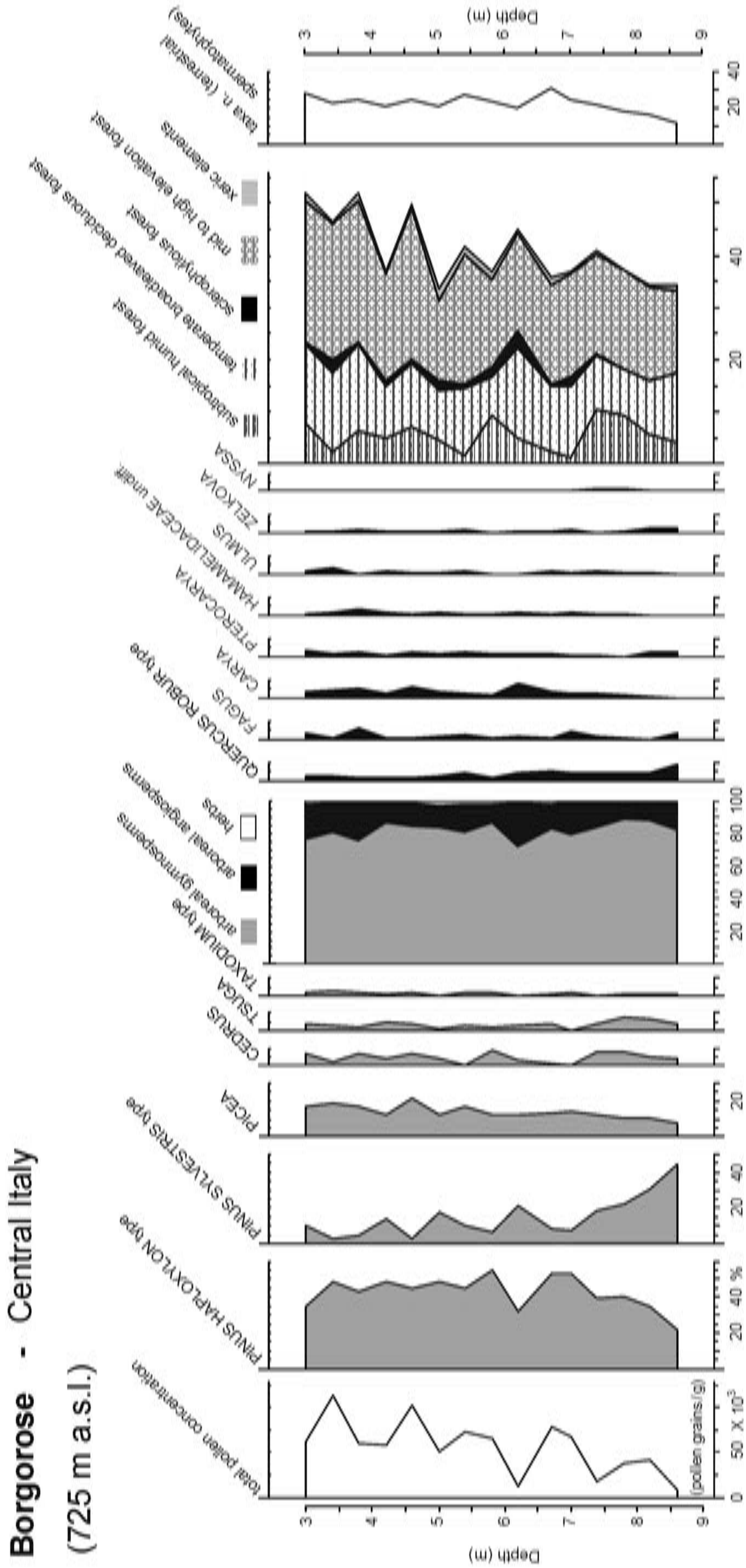

Fig. 14 - Borgorose (Rieti, Central Italy). Pollen diagram (selected *taxa* and groups). Pollen groups are listed in Fig. 12.
Borgorose (Rieti, Italia centrale). Diagramma pollinico (taxa e gruppi selezionati). Per i gruppi pollinici vedi l'elenco in Fig. 12.

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