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MAGNETOBIOSTRATIGRAPHY OF THE STURA DI LANZO FOSSIL FOREST SUCCESSION (PIEDMONT, ITALY)

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Abstract. Along the Stura di Lanzo River, 20 km north of Turin (Italy), several large mummified stumps in growth position crop out, thus providing a well-preserved example of fossil forest. This is formed by conifers which bear the *Glyptostrobus europaeus* type of cone and foliage as well as the *Glyptostroboxylon rudolphii* wood-type. Stratigraphic and plant taphonomic analyses of the outcropping succession clearly indicate that the palaeoenvironment was a densely-vegetated swamp, laying nearby one or more active fluvial/deltaic channels, in which coarse cross-bedded sands were deposited. The fossils are embedded in fine-grained continental sediments referred to the «Villafranchiano» unit, a term used in the Piedmont region (north-western Italy) to designate coastal to continental deposits which conformably overlay Pliocene marine successions. In this paper we present new data which better characterize the chronostratigraphy of the Stura di Lanzo Fossil Forest (FF) succession and similar deposits studied at the Front Canavese (FR) site, 10 km to the NE. The integrated magnetobiostratigraphic approach, applied to both outcropping sections and subsurface deposits, permits to attribute the FF to the subchron Kaena. On the basis of these new magnetobiostratigraphic data, a strongly supported correlation between the FF and the Villafranchian "type-section" of Villafranca d'Asti is proposed. Furthermore, the well-constrained FF chronostratigraphy adds new data to the Middle Pliocene vegetation history, since an adequate palaeofloral documentation for the time interval corresponding to subchron Kaena was still lacking in Italy.

Riassunto. Lungo il Torrente Stura di Lanzo, 20 km a nord di Torino, affiorano numerosi ceppi mummificati in posizione di crescita, che costituiscono un esempio ben conservato di foresta fossile. Le analisi tafonomiche e paleoecologiche dei resti vegetali, integrate con l'analisi di facies della successione affiorante, hanno permesso di ricostruire che la foresta cresceva in un ambiente di tipo palustre, riccamente vegetato, sviluppato in prossimità di un corso d'acqua. L'essenza arborea dominante era una conifera i cui coni e foglie sono indicati con il binomio *Glyptostrobus europaeus,* mentre il legno è riferibile alla morfospecie *Glyptostroboxylon rudolphii*. I fossili sono inglobati in depositi continentali sabbioso-pelitici riferiti al «Villafranchiano», unità litostratigrafica informale del Piemonte che comprende depositi di transizione marino-continentale di età pliocenica, seguiti da sedimenti francamente continentali in sostanziale continuità stratigrafica. L'analisi magnetostratigrafica è stata condotta su sezioni stratigrafiche affioranti e su carote provenienti da sondaggi geognostici condotti in prossimità della Foresta Fossile (FF) e in un sito localizzato circa 10 km a NE di quest'ultima (Front Canavese = FR). I dati ottenuti hanno permesso di attribuire la successione della Foresta Fossile al subchron Kaena, per il quale si può fornire una più completa documentazione paleofloristica, con un contributo consistente alla storia della vegetazione mediopliocenica in Italia settentrionale. Sulla base di questi nuovi dati magnetobiostratigrafici viene proposta una cronocorrelazione con la "sezione-tipo" del Villafranchiano di Villafranca d'Asti.

Introduction

Several upright mummified stumps have been exposed by river erosion from 1987 to 2006, nearby Turin, in the north-western termination of the Po River Plain (Fig. 1). The fossil-bearing outcrop extends for 2 km along the Stura di Lanzo River, allowing a detailed observation of facies associations and their lateral variation. The stumps are characterised by a complete preservation of the root system within the sediments, till to the finest rootlets, thus proving that they were buried in the growth place to form an authentic fossil forest (Fig. 2).

The earliest records of fossil plants from the Stura di Lanzo Fossil Forest (FF) area, reported by Sismonda

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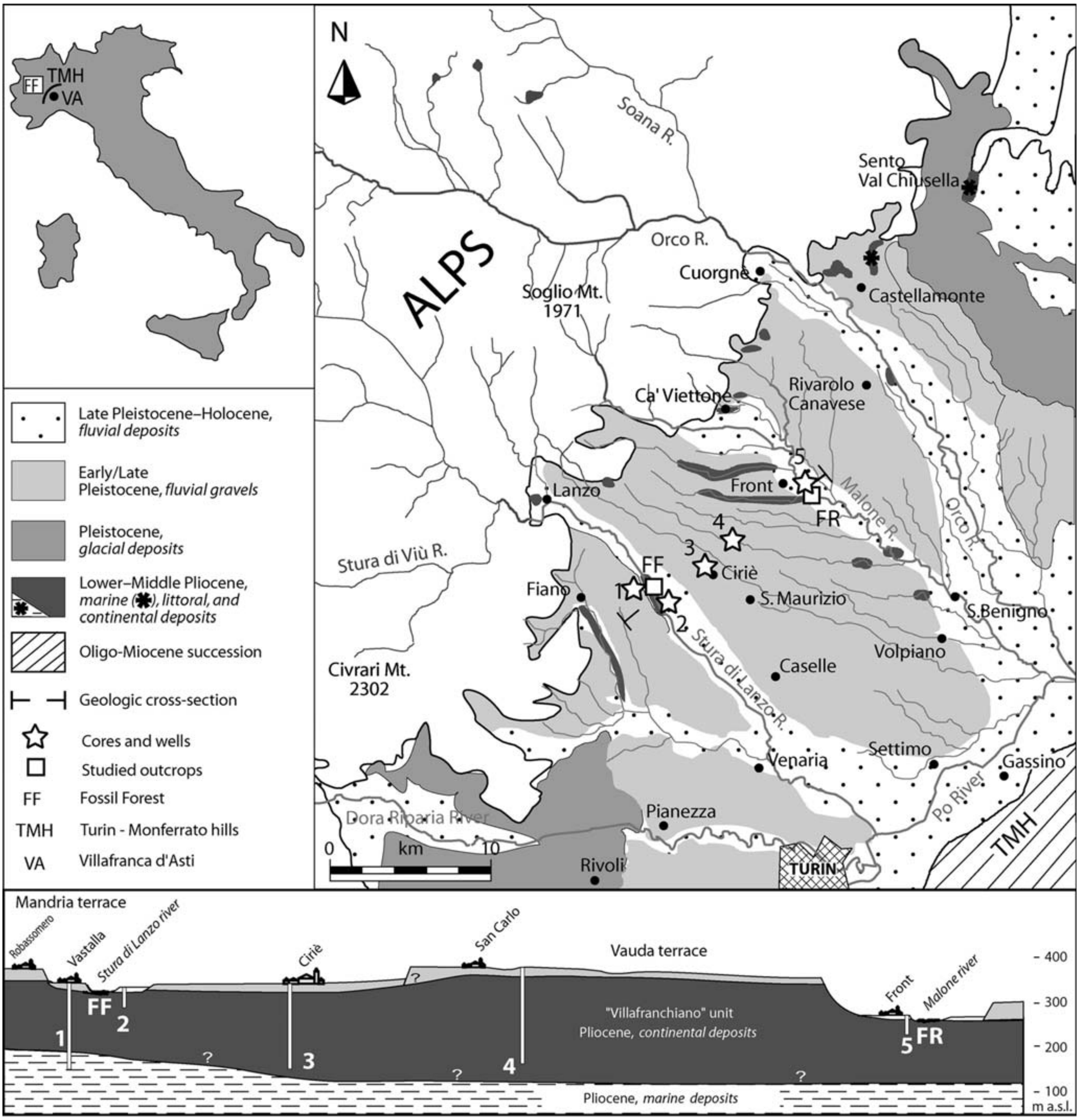

Fig. 1 - Sketched geological map of NW Piedmont indicating the position of the outcrops, cores and wells studied in the present paper. The Pliocene succession is covered by coarse-grained gravels of the Early-Middle Pleistocene Stura di Lanzo alluvial fan (Allason et al. 1981), which has partly preserved its ancient morphology (Mandria and Vauda terraces).

(1859, 1865) and Peola (1896), consisted in few leaf remains from two still existing outcrops ("Caccia" = La Cassa, and Grange di Nole = FF). Among the few plant taxa identified by these authors, only *Glyptostrobus europeaus* was confirmed by successive studies. In more recent times, Cerchio et al. (1990), Martinetto (1994a) and Bertoldi & Martinetto (2001) dealt with micro- and macroscopic plant fossils from the FF site (Fig. 3), which permitted reconstruction of a rich palaeoflora. A very similar plant assemblage was detected at the Front Canavese site (FR), 10 km to the NE of the FF (Martinetto 1995).

The stumps of the FF are all embedded in the same stratigraphic interval, located in the uppermost, continental portion of the local Pliocene succession, referred to the «Villafranchiano» informal unit (Caramiello et al. 1996). This unit overlies a rather thick (more than 800 m) marine succession (Bonsignore et al. 1969; Cerchio et al. 1990), generically assigned to the Early and Middle Pliocene, on the basis of foraminiferal as-

Fig. 2 - View of the Stura di Lanzo River bed at the Fossil Forest site (year 2001), where several large stumps in growth position crop out from the continental sediments of the «Villafranchiano» unit.

semblages studied in the AGIP well of San Benigno Canavese (ENI 1972). In the surroundings of Ca' Viettone (Levone Canavese: Fig. 1), Violanti (2001) detected benthic foraminifer species indicative of the Early-Middle Pliocene transition and the same biostratigraphic indication (MPl4a) was obtained for the marine portion of the Sento section, 20 km northeast of Ca' Viettone (Basilici et al. 1997). Evidences from rich plant assemblages, studied in the transitional and continental sediments overlying the Early/Middle Pliocene marine ones, both in the Ca' Viettone (Bertoldi & Martinetto 1995; Martinetto 1999) and in the Sento succession (Basilici et al. 1997), suggested an age older than the FF, also supported by the regional geological setting (Allason et al. 1981; Martinetto 1995).

The «Villafranchiano» unit in the FF area never yielded vertebrate remains, thus impeding correlation on a mammal biochronological basis (Gliozzi et al. 1997) to the Villafranchian type-succession (Carraro 1996). The latter is located on the southern side of the Turin-Monferrato hills (Fig. 1) and provided abundant vertebrate remains constituting the type-assemblage of the Triversa Faunal Unit, Early Villafranchian (Azzaroli 1977; Gliozzi et al. 1997; Lindsay et al. 1997; Rook et al. 2001). Palaeomagnetic analyses were carried out in the same site (RDB quarry) and same portion of the type-Villafranchian succession by Lindsay et al. (1980, 1997), Bormioli & Lanza (1996) and Boano et al. (1999). In the present paper we accept the interpretation proposed by Napoleone et al. (2003), who dated the RDB quarry succession to the subchrons Mammoth to Kaena, due to biochronologic constraints imposed by mammal assemblages (Gliozzi et al. 1997; Rook et al. 2001).

Facies associations which are very similar to those of the Villafranchian type-succession are also present in other districts of the western Po Plain (Caramiello et al. 1996), but a complete stratigraphic overview on a regional scale is still lacking, and detailed studies have been carried out only in the Villafranca d'Asti area (Carraro 1996, also summarized by Lindsay et al. 1997), where two stratigraphic complexes have been recognized, each comprising two units. Such a succession is controlled by local palaeoenvironmental conditions, so that the foregoing lithostratigraphic scheme can hardly be exported to other districts of Piedmont. Thus, outside the Villafranca d'Asti area, the coastal to continental deposits, which seal Pliocene marine deposits, are still generically referred to the «Villafranchiano» informal unit. Apart from the stratigraphic position, these deposits are characterised by frequent alternations of gravel, sand and mud, and by diagnostic facies associations indicating a broad variety of alluvial and coastal environments (Allason et al. 1981; Basilici et al. 1997; Martinetto & Farina 2005).

In the present paper we integrate the results of an updated biostratigraphic analysis of the FF and FR palaeofloras (and the poorer records of two recently executed cores; Fig. 4) with original lithostratigraphical, sedimentological and magnetostratigraphical data, in order to define the chronostratigraphical position of the FF section and the possible correlation to the type-Villafranchian section.

Further aims of this paper are: i) to assess the palaeoenvironmental frame which controlled the formation and preservation of the FF; ii) to test previous plant biochronologic hypotheses on the basis of new magnetostratigraphic data; iii) to evaluate the contribution that fossil plant assemblages from the FF and neighbouring Pliocene sites could provide to north Italian vegetation history.

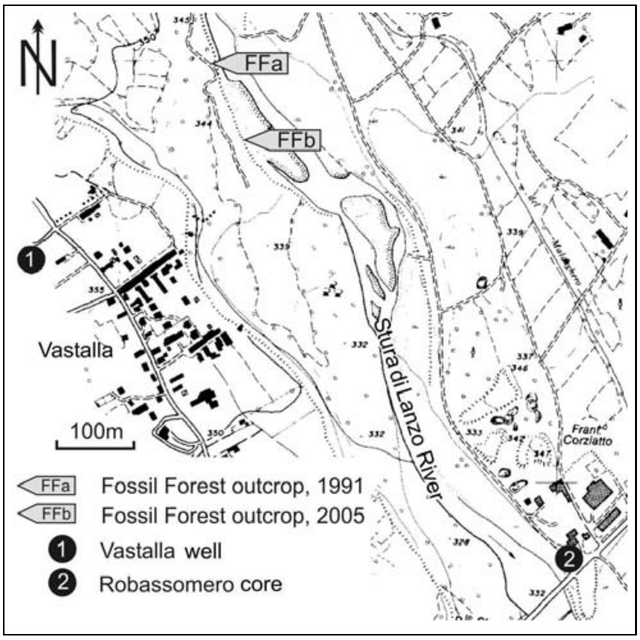

Fig. 3 - Sketched map of the FF site with location of the Robassomero core and Vastalla well.

Sedimentary facies and depositional environments

Facies analysis has been carried out in an area of about 0.2 km^2 where the FF crops out (Fig. 3). A stratigraphic section has been measured and another is available from literature (Martinetto 1994a) (Fig. 5). Due to the limited thickness of exposed succession, field observations have been completed by data obtained from drillings.

Several wells have been drilled in the last three decades for such different aims as territorial management/planning or water exploitation; for this reason, the core recovery is frequently lacking and the stratigraphic descriptions present a variable level of detail. The gathered material (Tab. 1) consists of:

- five wells without core recovery (Vastalla, 198 m deep; Nole, 170 m; Ciriè West, 200 m; Ciriè-Campasso, 200 m; Ciriè East, 180 m; San Carlo, 225 m), providing a rough lithologic description. Samples for palaeobotanical analysis were collected from a fine-grained interval in the Ciriè-Campasso well.
- two drillings (Robassomero, 50 m deep; FR-S11 = Front Canavese-S11, 40 m), providing an overall 90 m of continuous cores that have been processed for sedimentological, stratigraphical, palaeobotanical and palaeomagnetical analyses.

In the FF outcrop area, the «Villafranchiano» unit is about 150 m thick, whereas, just 3 km to the North-East, three wells (Ciriè West, Ciriè-Campasso, Ciriè East), deeper than 180 m, did not reach the underlying marine unit. This difference in thickness could indicate that the deposition of the «Villafranchiano» unit started on an irregular-articulated substrate, probably controlled by tectonic activity or by an incised valley network due to sea level drop.

Stratigraphic markers and key surfaces are often lacking and the succession is characterized by an inconstant sedimentation rate, as evidenced by the common occurrence of erosional surfaces and sedimentary bodies with lenticular geometry. For this reason, correlation between adjacent wells can hardly be traced. Only the Robassomero drilling and the two outcropping sections of the FF have been correlated on the basis of the occurrence of an evident and well-documented marker bed (lignite seam or oxidized lateral equivalent, Fig. 5). The stratigraphical-sedimentological framework tentatively permits to propose a palaeoenvironmental reconstruction.

Seven facies have been recognized in the «Villafranchiano» unit, which have been grouped into three facies associations, each of which representing a specific sedimentary environment.

F1: fluvial channel fill. This facies association comprises erosionally-based, up to 10 m thick, fining-upwards channel units. These are characterized by lenticular layers of pebbles occurring immediately above the erosional base, followed by middle to fine sands that become heterolithic in the upper part. The lithology of the pebbles (with a diameter ranging from 2 to 10 cm) reflects the source areas and it is represented by peridotites, serpentinites, orthogneiss and micaschists. Planar cross-bedded sands and ripple cross-laminated sands are the most common facies of the channel fill association. Locally, chaotically-bedded sand facies, characterized by contorted bedding and chaotic texture, are present. Rarely have been measured palaeocurrents, indicating a NW to SE direction of the stream (Martinetto & Farina 2005). Chaotic bedding is probably the results of post-depositional collapse of stems and other plant material deposited behind obstacles in the channel; similar deposits have been described by Guion et al. (1995).

F2: densely-vegetated swamps. Such deposits comprise silty clay, middle- to fine-grained sands with abundant root traces, organic-rich mud (prevailing in the lower-middle part of core FR-S11) with sand/silt laminae and very fine-laminated clays. Lignite layers and/or in place fossil trunks (FF) are enclosed in this facies association. The most common sedimentary structures are parallel lamination, soft sediment deformation and sediments disturbed by roots. Locally are present vegetation-induced sedimentary structures (*sensu* Rygel et al. 2004). The depositional environment can be reconstructed as a densely-vegetated swamp where primary deposits are modified by vegetation and where

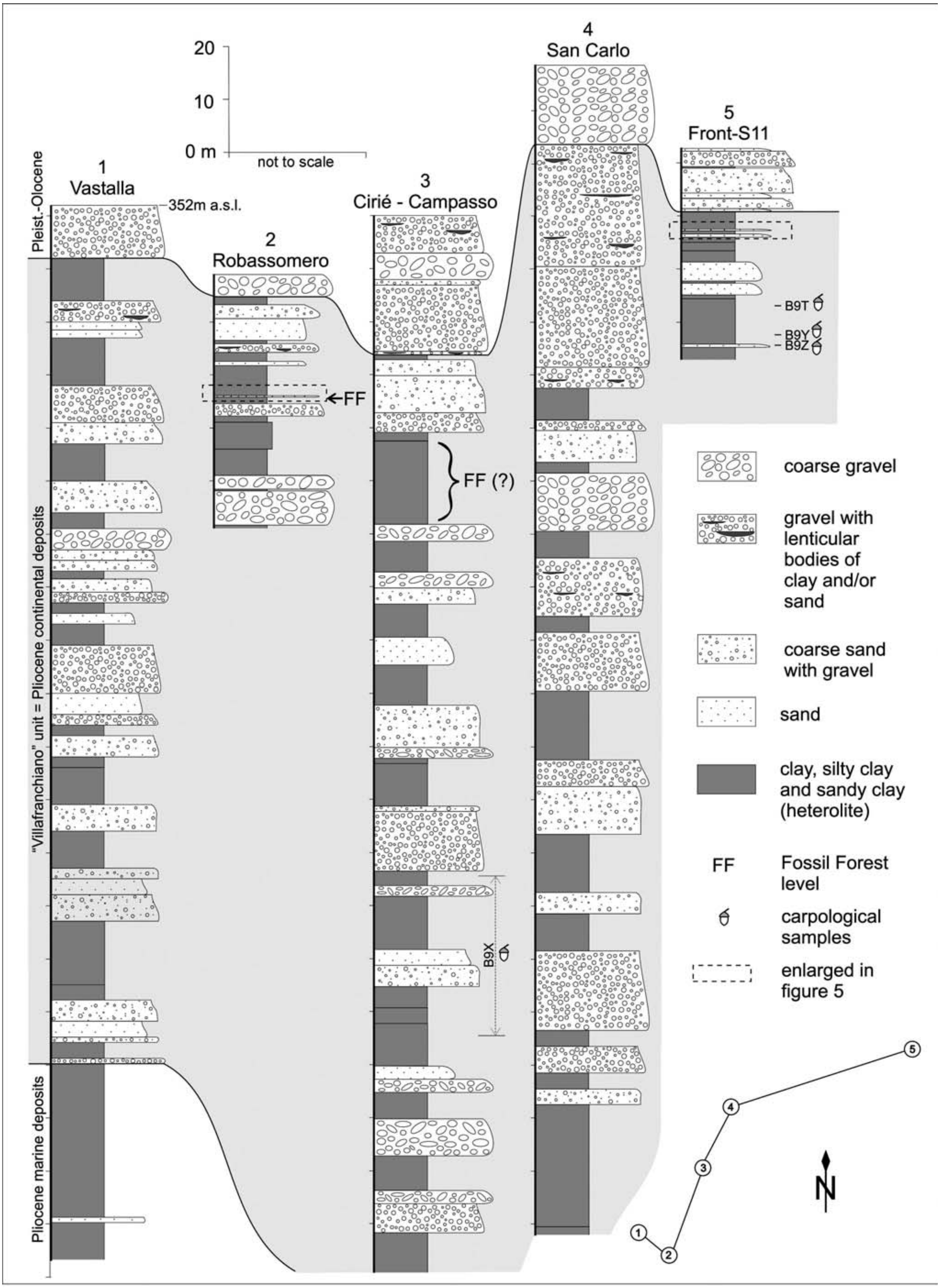

Fig. 4 - Stratigraphic sections of the cores and wells analysed in this paper. FF, position of the Fossil Forest bed, where present. The numbers at the top of the logs correspond to those indicated in Fig. 1.

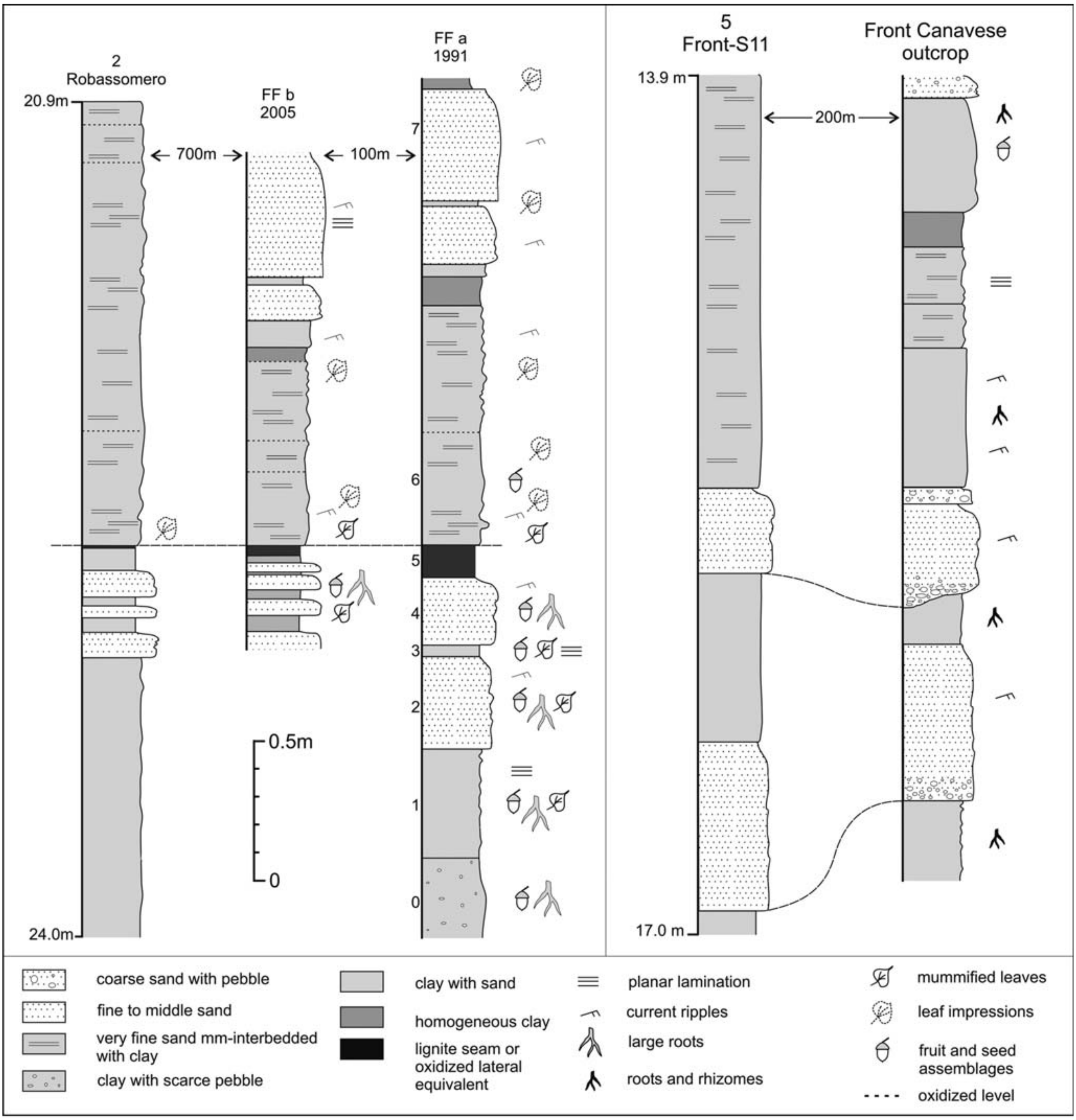

Fig. 5 - Left: detail of the stratigraphic section of the Robassomero core and correlation to the Fossil Forest sections (see Fig. 3) by means of the lignite seam which covers the fossil stumps (dash line). Right: detail of a portion of the FR-S11 core and proposed lithostratigraphic correlation of coarse-grained layers to the section of the Front Canavese outcrop.

CORE/OUTCROP	CODE	YEAR[a]	SITE			THICKNESS[b]	CORE RECOVERY
Robassomero [c]	RB	2005	45°12'24"	7°34'27"	331	38.7	91%
Fossil Forest[d]	FFa	1991	45°12'55"	7°33'49"	337	3.0	-
Fossil Forest[d]	FFb	2005	45°12'53"	7°33'51"	338	1.9	-
Front-S11	FR-S11	2004	45°16'28"	7°40'26"	261	40.5	98%
Front Canavese[d]	FR	1993	45°16'24"	7°40'38"	261	2.8	-
Ciriè-Campasso	CC	2005	45°14'35"	7°37'28"	354	200	0%
San Carlo	SC	1982	45°14'43"	7°38'39"	380	225.5	0%
Vastalla	VS	2003	45°12'37"	7°33'42"	352	200	0%

Tab. 1 - Core and outcrop data. [a] The year refers to section measurement or core execution; coordinates in latitude-longitude degrees according to WGS84, altitude in meters a.s.l.; [b] Total thickness of the core/stratigraphic section from the surface, values in meters; [c] This well had been named "Ciriè" by the executors, and actually falls in the territory of this town, however we use the name of the neighbouring village (Robassomero) in order to avoid confusion with the other wells of Ciriè. [d] Outcropping succession.

occasional alluvial events can produce a considerable input of sandy sediments.

F3: overbank deposits. This facies association comprises massive layers 20 to 30 m-thick of heterogeneous massive sediments, consisting of silty clay and clayey silt with a variable content of sands and pebbles. The sediments present different colour of alteration from grey to yellowish and red-brownish. These colours reflect different drainage conditions and time of subaerial exposure, both influencing the development of soils and/or the accumulation and preservation of organic material. The depositional environment is interpreted as a restricted floodplain where overbank sediments are deposited during flood events in waterlogged areas.

Discussion. The three facies associations are indicative of a small floodplain environment (F3) characterized by distributary and braided channels (F1) surrounded by densely-vegetated swamps in an alternatively reducing to oxidizing environment (F2).

Lithosomes deposited in poorly-drained areas comprise channel units, sheets of pebbly sands, grey clay and lignite layers. The well-drained floodplain includes yellowish mud and poorly developed palaeosols, deposited in alluvial environments with prevailing oxidizing conditions, but poor exposition through much of the time, because only locally the pedogenetic processes are completely evolved. The FF depositional environment was an area subjected to flooding, where probably the water level was constantly above the depositional plane. Thus, the base of upright stumps was buried during their life, due to frequent episodes of clastic sedimentation, probably combined with a high subsidence.

Plant assemblages

Methods. Sediment bulk samples have been processed for palaeocarpological analysis with the method described by Martinetto (1994a, 1995) and Basilici et al. (1997), which requires immersion in 3% H_2O_2 and sieving of floating material with 0.3 mm mesh size. The samples from the Ciriè-Campasso well (Fig. 4) and FR-S11 core had a sediment volume dramatically smaller than the quantity (30-40 dm^3) needed for an adequate representation of the carpological assemblage (Martinetto 1994a). However, the study of such small samples has been carried out with the purpose to evaluate whether the resulting assemblages could or could not represent the same palaeoflora and plant communities of the richest ones.

Determination of plant taxa has been essentially carried out by reference to previous papers (Martinetto 1994a, 1995) and to the palaeocarpological collection of the Earth Sciences Department of Turin. Plant biostratigraphic hypotheses have been formulated according to the distribution charts and "vegetational phases" reported by Bertoldi (1988, 1990, 1996), Bertoldi et al. (1994), Bertoldi & Martinetto (1995), Martinetto & Ravazzi (1997) and Martinetto (1999). Better resolved pollen zones from individual sections have also been considered for comparison (Bertini 1994a, 1994b, 2001, 2002; Bertini & Roiron 1997; Monegatti et al. 2002; Rio et al. 1997).

Fossil Forest (FF). The fossil plant assemblage of the FF is obviously dominated by remains of the authochtonous *Glyptostrobus* plant (Martinetto 1994b), which produced foliage, seeds and cones assigned to the morphospecies *Glyptostrobus europaeus* (Brongniart) Unger. Recent investigations (Vassio et al. submitted) on the wood anatomy of upright stumps showed that they can invariably be assigned to the morphospecies *Glyptostroboxylon rudolphii* Dolezych & Van der Burgh, most similar to the single living species of the conifer *Glyptostrobus* (Taxodiaceae, or Cupressaceae s. l.). These stumps are associated to other macro- and microscopic plant remains which provided good evidence of the local and extralocal plant communities, as summarized below.

The pollen assemblage of the FF section, reported by Bertoldi & Martinetto (2001), is dominated by three arboreal taxa with high, though fluctuating, pollen percentages: *Pinus*, *Alnus* and *Taxodium*-type (*Taxodium/ Glyptostrobus*). Among the AP only *Picea*, cf. Cupressaceae, Juglandaceae (*Carya, Engelhardia-Platycarya, Juglans, Pterocarya*) and Ulmaceae show consistent pollen percentages, while the remaining taxa occur with low percentages (e. g. *Sciadopitys, Tsuga, Cedrus, Abies, Fagus, Liquidambar* and Hamamelidaceae) or even with a few grains (e.g. *Sequoia*-type, *Liriodendron*, *Magnolia*-type, *Nyssa, Quercus, Castanea, Corylus, Carpinus, Ostrya, Acer, Tilia, Betula*, etc.).

Fruit and seed assemblages were studied (Martinetto 1994a; Bertoldi & Martinetto 2001) in 50 sediment samples of 4 dm^3 collected from layers 0, 1, 2, 3, 4 and 6 of the FFa section (Fig. 3). A high-diversity carpoflora was recovered from layer 0 (Fig. 5), which contains a concentration of transported plant remains, as indicated both by sediment facies and by the abundant remains of mesophytes (Martinetto 1994a). As a whole the FF carpoflora includes nearly 100 taxa (revised and updated list in Tab. 2) and, floristically, is characterized by the co-occurrence of *Boehmeria lithuanica, Carex flagellata, Cryptomeria rhenana, Itea europaea*, *Liriodendron geminata, Magnolia cor, Meliosma wetteraviensis, Nyssa disseminata, Parrotia reidiana, Proserpinaca reticulata, Sequoia abietina, Stewartia beckerana* and *Styrax maximus*. It also includes a few relic "subtropical" elements, such as: *Cinnamomum costatum, Sabia europaea* and *Toddalia rhenana*.

Angiosperm leaf remains, very common in layers 1, 3 and 6 (Fig. 5), mostly belong to a few plants typical for Neogene swamp facies (Mai 1995): *Alnus cecropiaefolia, Alnus gaudinii*, *Acer tricuspidatum* ssp. *lusaticum*.

Species	Family	Hab.	Ecol.	FF	FR	B9 T	B9 Y	B9 Z
Abies sp. (needles)	PINACEAE	tree	mes	x				
Actinidia faveolata	ACTINIDIACEAE	wc	mes	x			x	
Alisma sp.	ALISMATACEAE	herb	eaq	x	x		x	x
Alnus sp.	BETULACEAE	tree	hyg	x	x	x	x	
Ampelopsis ludwigii	VITACEAE	wc	mes	x				
Apiaceae indet.	APIACEAE	herb	/	x				
Araliaceae indet.	ARALIACEAE	/	/		x			
Azolla tegelensis	AZOLLACEAE	herb	faq		x			
Betula sp.	BETULACEAE	tree	mes		x			
Boehmeria lithuanica	URTICACEAE	herb	hyg	x	x		x	
Brasenia victoria	CABOMBACEAE	herb	raq	x			x	
Carex aff. *atrofusca*	CYPERACEAE	herb	/	x				
Carex aff. *fusca*	CYPERACEAE	herb	/	x				
Carex aff. *pendula*	CYPERACEAE	herb	hyg	x				
Carex aff. *remota*	CYPERACEAE	herb	/	x				
Carex brizoides	CYPERACEAE	herb	/	x		x	x	
Carex cf. *aquatilis*	CYPERACEAE	herb	hyg	f				
Carex cf. *loliacea*	CYPERACEAE	herb	hyg	x				
Carex flagellata	CYPERACEAE	herb	hyg	x	x			
Carex paucifloroides	CYPERACEAE	herb	/		x			
Carex plicata	CYPERACEAE	herb	hyg	x				
Carex pseudocyperus	CYPERACEAE	herb	hyg	x		x		
Carex rostrata	CYPERACEAE	herb	hyg	x				
Carex szaferi	CYPERACEAE	herb	hyg		x			
Carpinus betulus	BETULACEAE	tree	mes	x			x	x
Carpinus cf. *europaea*	BETULACEAE	tree	mes	x	x			
Carpolithes cucurbitinus	?	/	/	x				
Carpolithes gratioloides	?	/	/	x				
Carpolithes montioides	?	/	/	x				
Cephalanthus pusillus	NAUCLEACEAE	shrub	hyg		x			
Ceratophyllum demersum	CERATOPHYLLA-CEAE	herb	saq		x		f	
Cinnamomum costatum	LAURACEAE	tree	mes	x				
Cladium sp.	CYPERACEAE	herb	eaq	x				x
Corylus avellana	BETULACEAE	tts	mes	x	x			
Cotoneaster gailensis	ROSACEAE	shrub	mes	x				x
cf. *Craigia*	TILIACEAE	wc	mes	x				x
Cryptomeria rhenana (seeds)	CUPRESSA-CEAE s. l.	tree	mes	x				
Cyclocarya nucifera	JUGLANDACEAE	tree	mes					x
Decodon globosus	LYTHRACEAE	herb	eaq		x		x	
Dulichium arundinaceum	CYPERACEAE	herb	eaq	x			x	
Eleocharis ovata	CYPERACEAE	herb	eaq	x	x			
Epipremnites reniculus	ARACEAE	?	/	x				
cf. *Euphorbia* sp.	EUPHORBIA-CEAE?	/	/	x	x	x		
Fagus decurrens	FAGACEAE	tree	mes	x				
Ficus cf. *carica*	MORACEAE	tree	mes	x	x			
Fragaria sp.	ROSACEAE	herb	mes	x				
Frangula alnus	RHAMNACEAE	tts	mes	x	x			
Glyptostrobus europaeus	CUPRESSA-CEAE s. l.	tree	hyg	f	x	f		
Hypericum septestum	GUTTIFERAE	herb	/	x	x		x	
Hypericum sp.	GUTTIFERAE	herb	/	x				
Hypericum sp. A	GUTTIFERAE	herb	/	x	x	x		
Ilex cantalensis	AQUIFOLIACEAE	tts	mes	x				
Ilex fortunensis	AQUIFOLIACEAE	tts	mes	x				x
Ilex saxonica	AQUIFOLIACEAE	tts						x
Ilex thuringiaca	AQUIFOLIACEAE	tts						x
Itea europaea	HYDRANGEA-CEAE	shrub	hyg	x	x			
Juncus sp.	JUNCACEAE	herb	hyg	x				
Liriodendron geminata	MAGNOLIACEAE	tree	mes	x				
Lobelia pliocenica	CAMPANULA-CEAE	herb	hyg		x			
Ludwigia sp. A	ONAGRACEAE	herb	hyg	x	x			
Lycopus europaeus	LAMIACEAE	herb	hyg	x			x	
Lysimachia cf. *vulgaris*	PRIMULACEAE	herb	hyg		x			
Magnolia cor	MAGNOLIACEAE	tts	mes	x	x			
Malus sp.	ROSACEAE	tts	mes	x				
Meliosma wetteraviensis	SABIACEAE	tree	mes/ hyg?	x				
Melissa elegans	LAMIACEAE	herb	/	x				
Mentha cf. *aquatica*	LAMIACEAE	herb	hyg	x				
Morus sibirica	MORACEAE	tree	mes	x				
Najas lanceolata	NAJADACEAE	herb	raq		x			
Nuphar canaliculatum	NYMPHAEACEAE	herb	raq	x	x		x	
Nyssa disseminata	NYSSACEAE	tree	hyg	x	x			
Oenanthe cf. *lachenalii*	APIACEAE	herb	eaq	x				
Parrotia reidiana	HAMAMELIDACEAE	tts	mes/ hyg?	x				
Paulownia cantalensis	BIGNONIACEAE	tree	mes	x				x
Phellodendron elegans	RUTACEAE	tree	mes	x	x			
Picea sp. (needles)	PINACEAE	tree	mes	x				
cf. *Pinus peuce*	PINACEAE	tree	mes		x			
Polygonum hydropiper	POLYGONACEAE	herb	eaq		x			
Polygonum sp.	POLYGONACEAE	herb	/	x	x			
Potamogeton cf. *polymorphus*	POTAMOGETONA-CEAE	herb	raq	x	x		f	
Potamogeton sp. C	POTAMOGETONA-CEAE	herb	raq	x				
Potentilla sp.	ROSACEAE	herb	/	x				
Potentilla supina	ROSACEAE	herb	hyg/ mes?	x	x			
Proserpinaca reticulata	HALORAGACEAE	herb	saq	x				
Prunus aff. *padus*	ROSACEAE	tree	mes	x				
Pseudolarix schmidtgenii	PINACEAE	tree	mes		x			
Pterocarya limburgensis	JUGLANDACEAE	tree	mes	x				
Quercus cf. *robur*	FAGACEAE	tree	mes		x			
Ranunculus gr. *aquatilis*	RANUNCULACEAE	herb	saq	x				
Ranunculus pseudoflammula	RANUNCULACEAE	herb	eaq	x	x			
Ranunculus reidii	RANUNCULACEAE	herb	/	x				
Ranunculus sceleratus	RANUNCULACEAE	herb	eaq	x	x			
Rubus cf. *laticostatus*	ROSACEAE	herb/ frutex	hyg/ mes?	x				
Rubus cf. *microspermus*	ROSACEAE	herb/ frutex	hyg/ mes?	x	x	x		
cf. *Rumex* sp.	POLYGONA-CEAE	herb	/	x				
Sabia europaea	SABIACEAE	woody	mes	x				
Sagittaria sp. A	ALISMATACEAE	herb	eaq		x			
Salvinia tuberculata	SALVINIACEAE	herb	faq	x	x			
Sambucus pulchella	SAMBUCACEAE	pws	hyg/ mes?	x	x			
Sassafras cf. *ludwigii*	LAURACEAE	tree	mes/ hyg?	?	x			x
Schizophragma polonica	HYDRANGEA-CEAE	wc	mes	x				
Scindapsites crassus	ARACEAE	?	mes?	x	x			
Scirpus mucronatus	CYPERACEAE	herb	eaq	x	x			
Scirpus radicans	CYPERACEAE	herb	eaq	x	x			
Scirpus sylvaticus	CYPERACEAE	herb	eaq	x				
Selaginella cf. *malesovicensis*	SELAGINELLACEAE	herb	mes	x				
Selaginella jeannettae	SELAGINELLACEAE	herb	mes		x			
Selaginella kunovicensis	SELAGINELLACEAE	herb	mes	x				
Selaginella magdae	SELAGINELLACEAE	herb	mes		x			x
Sequoia abietina (cones)	SELAGINELLACEAE	tree	mes	x				
Sinomenium cantalense	MENISPERMACEAE	wc	mes		x			
Solanum cf. *dulcamara*	SOLANACEAE	herb	mes/ hyg		x			x
Sparganium nanum	SPARGANIACEAE	herb	eaq	f	x		x	f
Sparganium neglectum	SPARGANIACEAE	herb	eaq		x			
Styrax maximus	STYRACACEAE	tts	mes	x	x			
Swida cf. *gorbunovii*	CORNACEAE	tts	/		x			
Symplocos casparyi	SYMPLOCACEAE	tts	mes					f
Ternstroemia sp.	THEACEAE	tree	mes	x				
Teucrium tatjanae	LAMIACEAE	herb	mes		x			
Thalictrum minimum	RANUNCULACEAE	/	/	x				x
Thalictrum sp.	RANUNCULACEAE	herb	mes		x			
Tilia sp.	TILIACEAE	tree	mes		x			
Toddalia rhenana	RUTACEAE	wc	mes	x	x			x
Trapa sp.	TRAPACEAE	herb	raq		x		x	
Trichosanthes fragilis	CUCURBITACEAE	wc	mes		x			
Tsuga sp. (needles)	PINACEAE	tree	mes	x				
Typha sp.	TYPHACEAE	herb	eaq	x				
Urtica cf. *dioica*	URTICACEAE	herb	mes/ hyg		x			
Viola bergaensis	VIOLACEAE	herb	hyg/ mes?	x	x	f		
Viola neogenica	VIOLACEAE	herb	hyg/ mes?	x				
Viola sp. A	VIOLACEAE	herb	/	x				
Vitis parasylvestris	VITACEAE	wc	mes/ hyg?	x	x			x?
Wikstroemia thomasii	THYMELEACEAE	shrub	mes	x				

Tab. 2 - List of fruit and seed taxa so-far identified in the Fossil Forest (FF), Front Canavese outcrop (FR) and FR-S11 core samples B9T, B9Y, B9Z. Abbreviations – Ecol. = ecology: eaq, emergent aquatic; hyg, hygrophyte; mes, mesophyte; faq, free-floating aquatic; raq, rooted aquatic; saq, submerged aquatic. Hab. = habit: pws, perennial herb or woody shrub; tts, tree or tall shrub; wc, woody climber. x=present, f= frequent.

Front Canavese outcrop (FR). A short portion of the «Villafranchiano» unit was exposed during the years 1985-2000 close to the Front Canavese village, at the confluence of the Valmaggiore brook with the Malone River (more details in Martinetto et al. in press). The 4 m thick succession (Fig. 5) comprised a layer with compressed plant remains in its upper part, which provided rich palaeocarpological assemblages. Earlier, Martinetto (1995) listed 54 fruit and seed species, and further sampling in the last decade allowed to add other 10 species of prevalently woody plants (Tab. 2).

Plant remains from the subsurface. The succession of the Ciriè-Campasso well (Fig. 4) proved to be extremely poor in fossils, most commonly represented by root traces within a massive sediment (49-55 m; 150-156 m). Mummified plant remains (named "peat" by the executors) were only observed in the interval between 150 and 156 m of depth, from which a 6 dm^3 sample (B9X) of grey, micaceous sandy-clayey silts has been recovered and processed. The prevailing angular shape of phytoclasts, which was also observed before extraction from the embedding sediments, indicated that the plant assemblage was allochthonous, made up by fragments of woody axes which had been transported far away from their growth place, and therefore could not be used to reconstruct the sedimentary environment. Identifiable plant parts were only represented by a few small shoots of *Glyptostrobus europaeus* and three fruit/seeds (*Ficus potentilloides*, *Magnolia allasoniae, Sinomenium cantalense*).

The muddy sediments of the FR-S11 core (Fig. 4) often contained mummified plant remains, which have been analysed in 3 samples respectively spanning 37.50 to 37.30 m (B9Z), 35.60 to 35.45 m (B9Y) and 30.30 to 30.00 m (B9T). The carpological analyses allowed identifying a limited number of species, as indicated in Tab. 2.

Discussion. The species-rich FF assemblage permitted an accurate palaeofloral reconstruction (Martinetto 1994a). The FR assemblage is slightly poorer and most of its 64 plant taxa also occur in the FF carpoflora, with the relevant exception of *Azolla tegelensis*, *Cephalanthus pusillus, Decodon globosus, Lobelia pliocenica*, *Pseudolarix schmidtgenii*, *Sinomenium cantalense*, *Swida* cf. *gorbunovii*, *Tilia* sp. and *Trichosanthes fragilis*. Information available for Neogene carpofloras of Europe (Mai 1995; Günther & Gregor 1990) suggests that these peculiar occurrences can be more likely attributed to random factors, rather than definite palaeofloral differences linked to the age of the deposit and/or environmental conditions.

As for the Ciriè-Campasso assemblage (B9X), the four recorded species (see above) do not permit either to confirm or to exclude the similarity with FF palaeoflora.

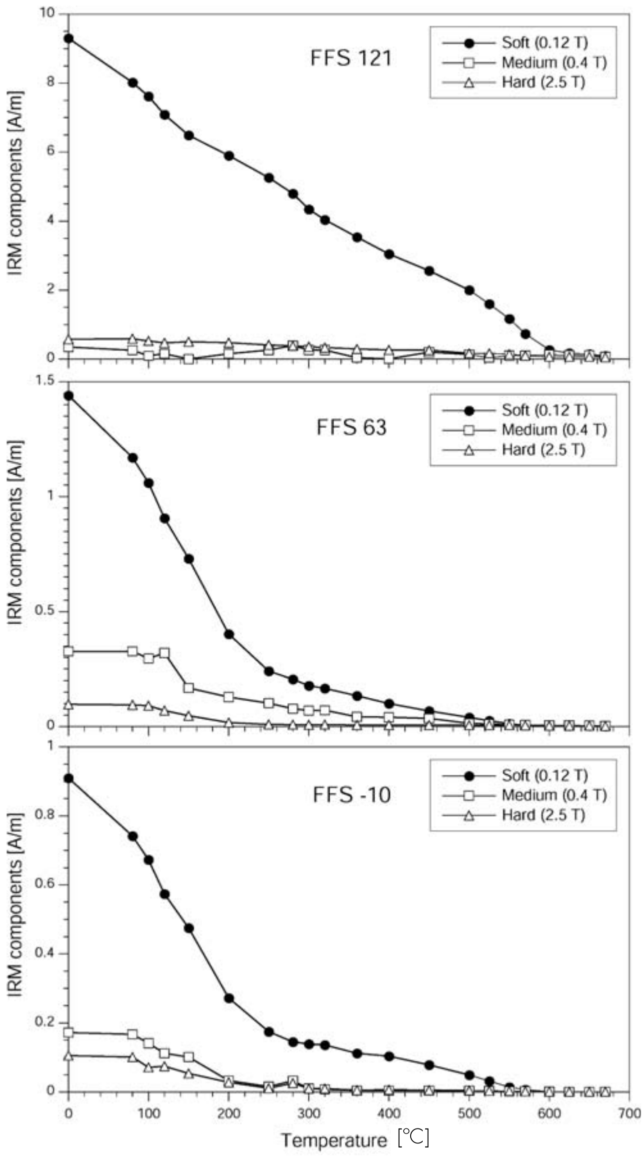

Fig. 6 - Experiments of IRM acquisition and thermal demagnetization of a three-component IRM performed on representative samples from the FF section. See text for discussion.

The two uppermost assemblages of the FR-S11 core (B9T, B9Y) share all their species with the FF and FR ones (Tab. 1), thus they could indeed represent the same palaeoflora, however they lack really diagnostic taxa, so that we cannot exclude the similarity with other types of palaeofloras. On the other hand, the lowermost assemblage (B9Z) of the FR-S11 core shows relevant differences, since it contains a group of woody elements (*Ilex saxonica, I. thuringiaca, Symplocos casparyi*, cf. *Styphelia* – formerly assigned to *Arctostaphyloides menzelii*) which are definitely characteristic of another type of palaeoflora (Early-?Middle Pliocene), well documented at the neighbouring Ca' Viettone site (Bertoldi & Martinetto 1995) and in the Sento section (Basilici et al. 1997).

In conclusion, the high floristic affinity between the FF and FR assemblages suggests that they represent the record of the same type of palaeoflora. On the other hand, the FR-S11 B9Z assemblage (18 species) testifies a different palaeoflora, but at present we are not able to state whether it is identical to the Ca' Viettone palaeoflora (documented by 120 species: Bertoldi & Martinetto 1995) or not.

Palaeomagnetism

Palaeomagnetic properties were studied on 8 cm^3 cubic samples and 10 cm^3 cylindric samples (Tab. 1), respectively collected from Robassomero and FR-S11 cores, and from the FFb section (Fig. 3). Laboratory analyses were performed at the Alpine Laboratory of Palaeomagnetism and the natural magnetic remanence (NRM) was measured with a 2G-Enterprises three-axis cryogenic magnetometer located in a magnetically shielded room with ambient fields of ~300 nT.

The intensity of natural remanent magnetization (NRM) was generally in the 10^{-2}-10^{-4} A/m range, with rare exceptions in the order of 10^{-5} A/m; magnetic susceptibility values are in the 10^{-4} range. The thermal unblocking trends of tri-axial isothermal remanent magnetization (IRM) (Lowrie 1990) show a low-coercitivity phase with maximum unblocking temperature of 570 °C, interpreted as magnetite, as the main carrier of remanence (Fig. 6, FFS 121). In samples FFS 63 and FFS -10 (Fig. 6) a change in the slope of the curves between 200 and 300 °C would suggest the presence of a suplhide phase, whereas a small amount of remanence, carried by a medium- to high-coercitivity phase with maximum unblocking temperature of 150 °C, is interpreted as goethite.

Progressive thermal demagnetization were carried out to all samples adopting a minimum of 10 steps up to 600 °C and, if needed, up to 680 °C. Standard least-square analysis (Kirschvink 1980) was used to calculate component directions from selected segments of thermal demagnetization diagrams (Zijderveld 1967). A low-unblocking temperature component, in the 0-150 °C (sometimes up to 250 °C) temperature range, is superimposed to a moderate- to high- unblocking temperature component (Fig. 7) and is ascribed to a present-day viscous overprint of small magnitude. The higher temperature component is generally removed in the magnetite unblocking temperature range between ~300 and ~570 °C. These characteristic components of magnetization bear either positive or negative inclinations with mean values of 56° ± 19° and -50° ± 17°, respectively, and are regarded as acquired at or shortly after sediment deposition.

Cores were not oriented with respect to the geographical north, therefore only the inclination of the characteristic component vectors was used to outline

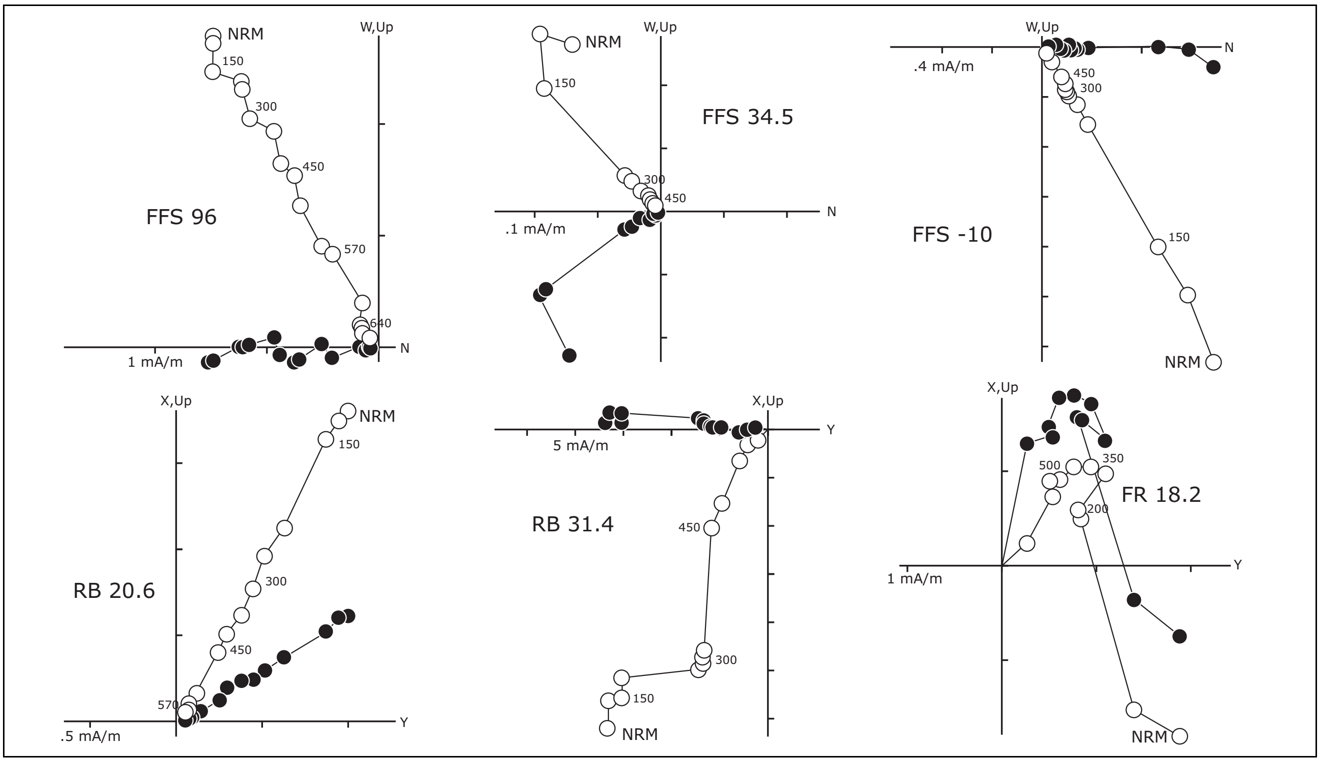

Fig. 7 - Examples of Zijderveld demagnetization diagrams and normalized thermal demagnetization curves of the NRM. Open (closed) symbols are projections onto the vertical (horizontal) plane. Horizontal projections from cores' samples have arbitrary azimuths, as cores were not oriented with respect to the geographic north.

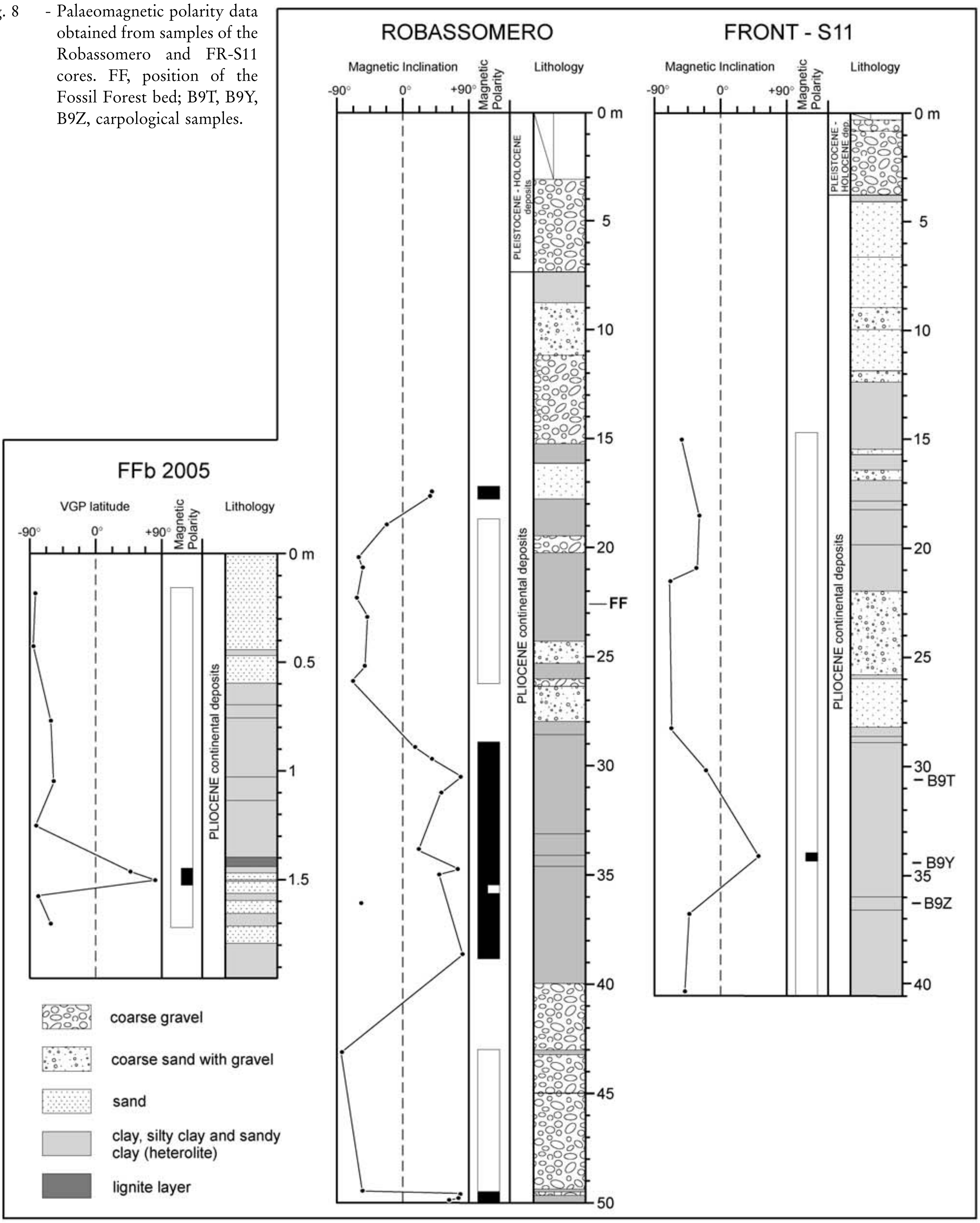

Fig. 8 - Palaeomagnetic polarity data obtained from samples of the Robassomero and FR-S11 cores. FF, position of the Fossil Forest bed; B9T, B9Y, B9Z, carpological samples.

magnetic polarity stratigraphy. Samples from the outcrop were instead oriented in the field so the virtual geomagnetic polar (VGP) latitudes (the latitude of the pole position for an individual sample relative to the mean palaeomagnetic pole for the entire section) could be retrieved. Polarity intervals were defined by at least three stratigraphically superposed samples. Single sample-based reversals may represent unresolved overprints or inverted core segments and were excluded from polarity interpretation. The FF section and the FR-S11 core bear a dominant reverse polarity (Fig. 8). The Robassomero core shows reverse polarity from 49.5 m to 35.7 m, normal polarity from 35.1 m to 29.4 m, and reverse polarity from 26.3 m to 19.1 m (Fig. 8); both the uppermost and the lowermost two samples show positive inclinations that could be ascribed to normal polarity magnetozones.

Plant biostratigraphy

The FF section, due to its rich and diversified record (pollen, leaves, seeds), is the most suitable starting point for an updated plant biostratigraphic framing of the «Villafranchiano» unit. Remarkably, the FF palynoflora (Bertoldi & Martinetto 2001) lacks some characteristic tropical-subtropical elements (*Symplocos*, *Clethraceae/Cyrillaceae*, *Rutaceae*, "archaic tricolporate Fagaceae", *Rhoiptelea*), thus excluding an hypothetic assignment to the "Macrian" vegetational phase (Bertoldi et al. 1994). Rather, the relevant pollen percentage of *Taxodium*-type and the occurrence of Hamamelidaceae and *Nyssa* suggest correlation to the "pre-Tiberian" vegetational phase and are in contrast with the feature of younger vegetational phases.

The pollen assemblage of the FF matches very well the analogous record from the whole RDB quarry succession (Bertoldi 1996), which covers part of the subchron Mammoth (3.33-3.22 Myr: Cande & Kent 1995). When compared to the Monte Falcone-Rio Crevalese diagram (late Gauss: Monegatti et al. 2002), it is only similar to pollen zones PAZ1, PAZ3 and PAZ4, but the best fit is PAZ1 for the continuous curve of Magnoliaceae and higher percentage of *Nyssa*. The Stirone zones Sti2 and Sti3 (late Gauss: Bertini 2001) do not show any similarity due to the scanty occurrence of *Taxodium*-type. The Marecchia (Rio et al. 1997) and Santa Barbara (Bertini & Roiron 1997; Bertini 2002) records are impossible to compare in detail because the authors did not provide analytic pollen data. Unfortunately, none of these pollen diagrams covers the first part of the Middle Pliocene (3.6-3.3 Myr).

The occurrence of characteristic fruit and seed taxa (Tab. 2) allows us to confirm that the rich FF assemblage postdates the first Pliocene extinction phase of thermophilous plants indicated by Martinetto (1999) and predates the second one, thus falling within the Middle Pliocene (Fig. 9). The analogous fruit and seed assemblages of the FR site (Tab. 2) contains a species association which permits us to frame it roughly within the same time interval as the FF one.

Among the plant assemblages recovered from the FR-S11 samples, only the lower one (B9Z) deserves being discussed from the biostratigraphic point of view, since it contains three species which are only recorded (Martinetto 1999) before the first Pliocene disappearance phase of thermophilous plants (*Ilex saxonica, I. thuringiaca,* cf. *Styphelia* sp.). Also the consistent representation of *S. casparyi* is remarkable, because this species is common in the Early Pliocene, but very rare in the Middle Pliocene; however, in central Italy it survived till to the Late Pliocene (Mai & Martinetto 2006).

Three out of four species identified in sample B9X of the Ciriè-Campasso well are very common in the Early and Middle Pliocene of northern Italy, and just provide a generic indication for a pre-Gelasian age (Martinetto 1999). The fourth, *Magnolia allasoniae*, in northern Italy is a very common species in the Lower Pliocene, but its occurrence in the Middle Pliocene is only demonstrated in central Italy (Martinetto 2001).

Magnetobiostratigraphy

As discussed above, the «Villafranchiano» unit in the studied area overlays a rather thick Early Pliocene and Middle Pliocene marine succession (Bonsignore et al. 1969; ENI 1972; Cerchio et al. 1990; Violanti 2001). In addition, plant biostratigraphic indications (Martinetto 1995, 1999) suggested that the FF and FR plant assemblages predate the Late Pliocene (Gelasian). This constrains the palaeomagnetic records reported in this paper (Fig. 8) between the Gilbert/Gauss boundary and the beginning of chron Matuyama. It follows that the Robassomero core succession has to be assigned to the middle part of the chron Gauss, but, due to the scarce evidence of its lower reverse interval, we are forced to suggest two options:

1. the most reasonable one admits two reverse intervals in the core (49.5-35.7 m and 26.3-19.1 m), which can easily be assigned to the subchrons Mammoth and Kaena, respectively; the FF succession would be dated to the subchron Kaena (3.04-3.11 Myr; Cande & Kent 1995).

2. the less reasonable option would neglect the lower reverse polarity interval (due to its scarce evidence), leading the FF succession to fall either within the subchron Mammoth or the Kaena.

An assignment to the Gauss/Matuyama transition would be quite unreasonable, because it would imply plant assemblages of cooler type (Bertini 2001; Rio et al. 1997).

The dominantly reverse polarity of the FR-S11 core succession, which is thicker than the reverse intervals detected in the Fossil Forest area, can be either the result of a better preservation of the succession deposited during a single subchron (Mammoth or Kaena) or the sum of two reverse polarity subchrons separated by an erosional surface (e.g. below the sand body at 22-28 m in Fig. 8). In case of confirmation of the hypothetic affinity of the FR-S11 B9Z palaeoflora to the Ca' Viettone one, correlation of the lower reverse interval to the chron Gilbert should also be considered.

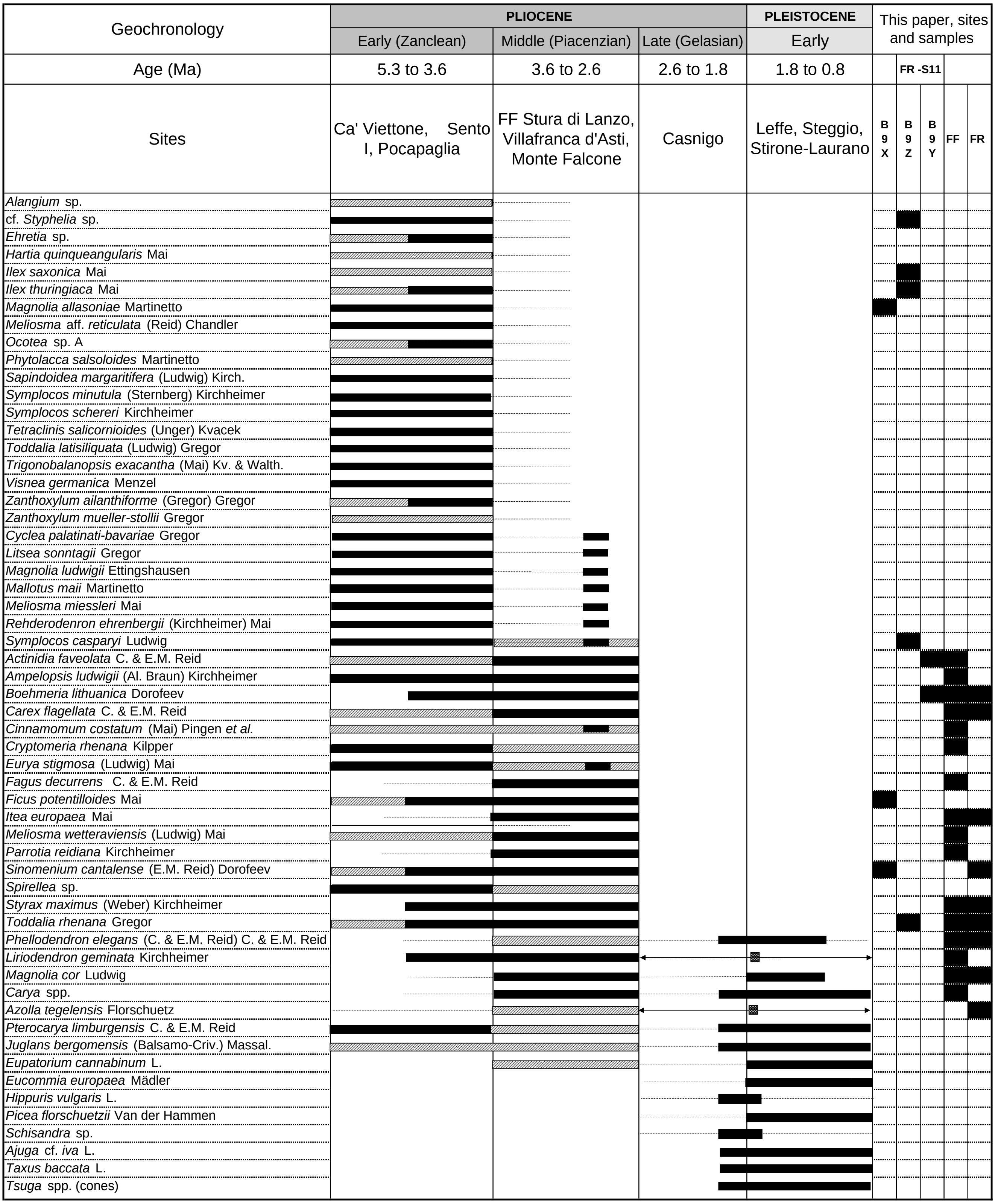

Fig. 9 - Pliocene-Early Pleistocene biostratigraphic scheme for plant macrofossil taxa in northern Italy, updated from Martinetto (1999). The hatched bar indicates time intervals in which the occurrence of the species is much probable, but not definitely demonstrated by independent dating elements. A few taxa which were previously supposed to disappear at the Early/Middle Pliocene transition, have been recently discovered (Martinetto, unpubl. data) in a layer of the Monte Falcone section (near Castell'Arquato, Piacenza province, N-Italy), referred by Monegatti et al. (2002) to the upper part of the chron Gauss (2.8-2.9 Myr).

Conclusion

The trees of the FF grew in an alluvial environment, much later than the retreat of the sea (not precisely dated) from the Grange di Nole area, after deposition of 130 m of continental sediments. Preservation of mummified stumps has been favoured by a high subsidence combined with sedimentation of muds, which hampered interstitial water circulation.

The FF most likely falls within the subchron Kaena in the Piacenzian Stage, and cannot be univo-

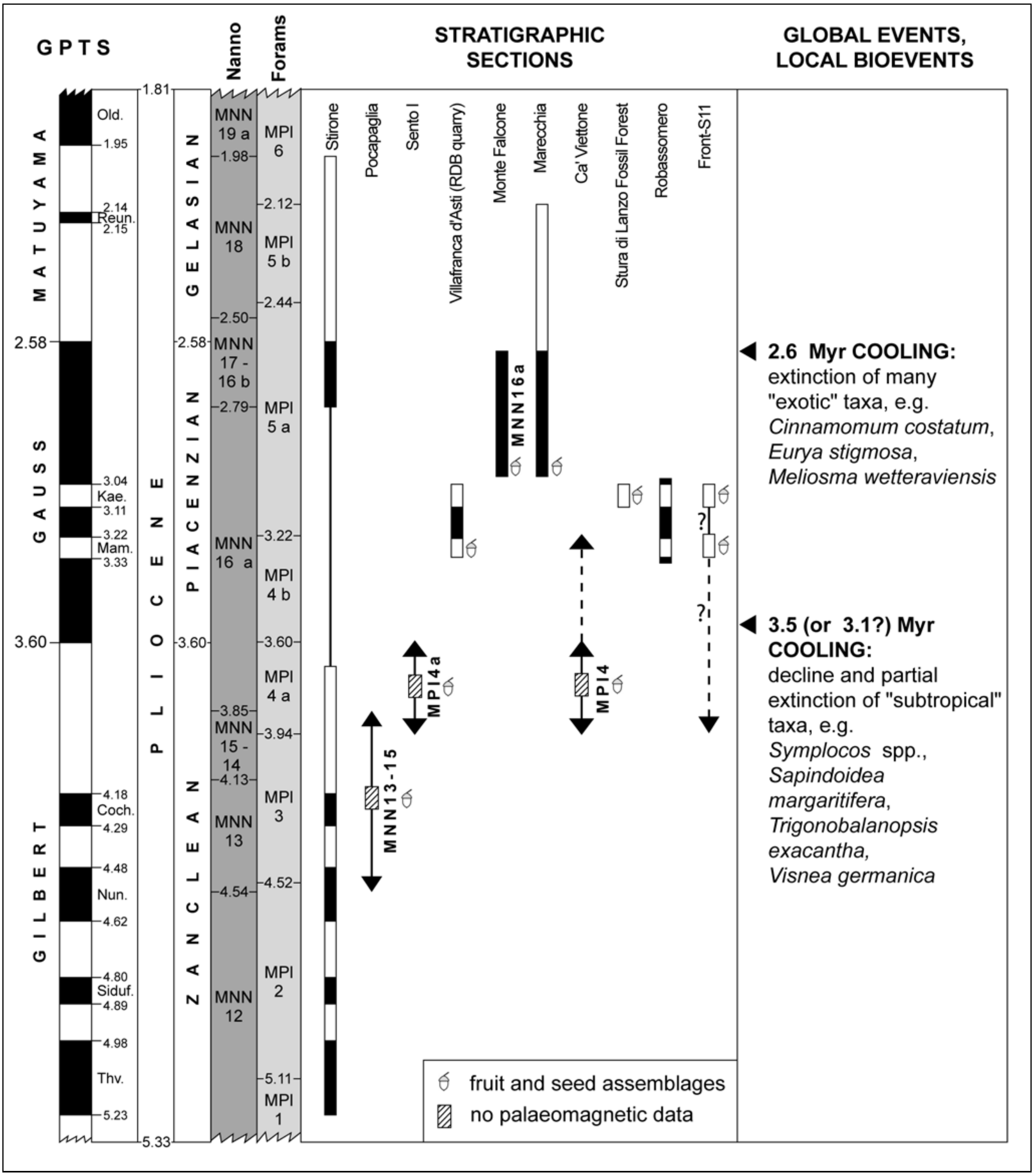

Fig. 10 - Bio-chronostratigraphic scheme for the Pliocene of the Mediterranean area, with the reference sections Stirone (Bertini 2001), Pocapaglia (Martinetto 1999), Sento I (Basilici et al. 1997; Martinetto 1999), Villafranca d'Asti – RDB quarry (Napoleone et al. 2003), Monte Falcone (Monegatti et al. 2002), Marecchia (Rio et al. 1997), Ca' Viettone (Bertoldi & Martinetto 1995), and the new sections presented in this paper.

cally correlated to the FR-S11 succession, whose upper part, however, is assigned either to the subchron Kaena or Mammoth (Fig. 10). These chronological interpretations are compatible with previous hypotheses based on sole plant biochronological inferences (Martinetto 1995). However, combined magnetostratigraphic and palaeobotanical studies should be extended to other long plant-bearing successions (e.g. Sento: Basilici et al. 1997) and core logs, in order to improve the biostratigraphic scheme proposed by Martinetto (1999).

The new magnetobiostratigraphic results provide an unprecedented tool for a precise time correlation of the Pliocene continental successions across the Turin-Monferrato Hills, which were earlier compared on the basis of facies analogy (Bonsignore et al. 1969) and palaeobotanical content (Allason et al. 1981; Martinetto 1995, 1999). Assignment of the FF to the subchron Kaena implies that it slightly postdates the rich R1 plant assemblage (Martinetto & Mai 1996) of the type-Villafranchian RDB quarry site (subchron Mammoth: Napoleone et al. 2003). Since the FF palaeoflora (Tab. 2; Bertoldi & Martinetto 2001) has nearly the same composition of the RDB quarry-R1 one (Bertoldi 1996; Martinetto & Mai 1996), we conclude that the floral and vegetational features during the time interval corresponding to the subchrons Mammoth and Kaena were almost the same in the studied region.

Future palaeobotanical investigations of Pliocene continental successions in the studied area could provide important contributions to north Italian vegetation history, because long lacustrine successions, with continuous records of vegetation dynamics, are not available in the lower Piacenzian-upper Zanclean of the Po Basin. Therefore, the fluvial-alluvial sediments of Piedmont's «Villafranchiano» unit represent the best alternative to the taphonomically biased (Bertini 2001) marine successions as a future source of floral and vegetational records for such time interval (even if inevitably discontinuous). In terms of choice of favourable localities for such investigations, the Front Canavese area seems to be more suitable than the FF one, because the sediments of the FR-S11 succession proved to be finer and richer organic matter than those of the FF area; if these same features would be shared by the underlying layers (not yet cored), these are likely to provide good palaeobotanical (incl. pollen) and palaeomagnetic records.

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