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CONIFEROUS WOODS IN THE EARLY PLEISTOCENE BROWN COALS OF THE LEFFE BASIN (LOMBARDY, ITALY). Ecological and biostratigraphic inferences

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Key-words: Coniferous woods, Early Pleistocene, Leffe Basin, Lombardy, Italy.

Riassunto. Sono stati identificati 49 campioni di legni fossili in gran parte autoctoni rinvenuti nei banchi di "brown coal" dell'unità intermedia (biogenica) della Formazione di Leffe (Pleistocene inferiore, Lombardia). La posizione stratigrafica dei legni è stata messa a confronto con i dati pollinici ottenuti dai medesimi livelli.

Dal livello torboso più profondo situato alla base della serie di Leffe proviene un legno di *Piceoxylon*. Gli spettri pollinici indicano foreste di conifere di clima fresco e secco. Dal banco principale di "brown coal" provengono soprattutto legni di *Glyptostroboxylon tenerum*, *Chamaecyparis*, *Pinus* aff. *tabulaeformis*, *Carya*, *Pterocarya*, *Alnus*, *Fraxinus* e *Celtis*. Questi reperti si trovano in corrispondenza di zone polliniche indicative di clima temperato caldo. Le conifere sono state descritte e sono state discusse le loro probabili esigenze paleoecologiche. Infine viene esaminata la distribuzione stratigrafica delle Taxodiaceae e delle Cupressaceae rinvenute, allo scopo di interpretarne le modalità di migrazione e di estinzione durante il Pleistocene inferiore in Italia settentrionale.

Abstract. 49 autochthonous wood samples collected in brown coal from the Leffe palustrine deposits (Early Pleistocene, Lombardy, N-Italy) have been identified and their stratigraphical position has been discussed in comparison with pollen spectra. A peat level in the lower part of the succession contains *Piceoxylon* wood. Pollen spectra point to a conifer forest of dry and cool climate. *Glyptostroboxylon tenerum*, *Chamaecyparis*, *Pinus* aff. *tabulaeformis*, *Carya*, *Pterocarya*, *Alnus*, *Fraxinus* and *Celtis* woods have been identified from the "Main" brown coal layer in the middle (biogenic) unit of the Leffe Formation. The coniferous woods are described and some inferences about their ecological requirements are presented. These trees formed part of the swamp vegetation during interglacial phases. *Pinus* occurred only during meso/oligotrophic phases.

The biostratigraphic interest of these finds and climate dynamics are discussed, in order to interpret the discontinuous record of the "Tertiary plants" in Northern Italy during lowermost Pleistocene.

1. Introduction.

The infill of the Leffe Basin (Lombard Pre-Alps, Northern Italy) (Fig. 1) consists of a 200 m thick succession of lacustrine, palustrine and fluvial deposits, Late

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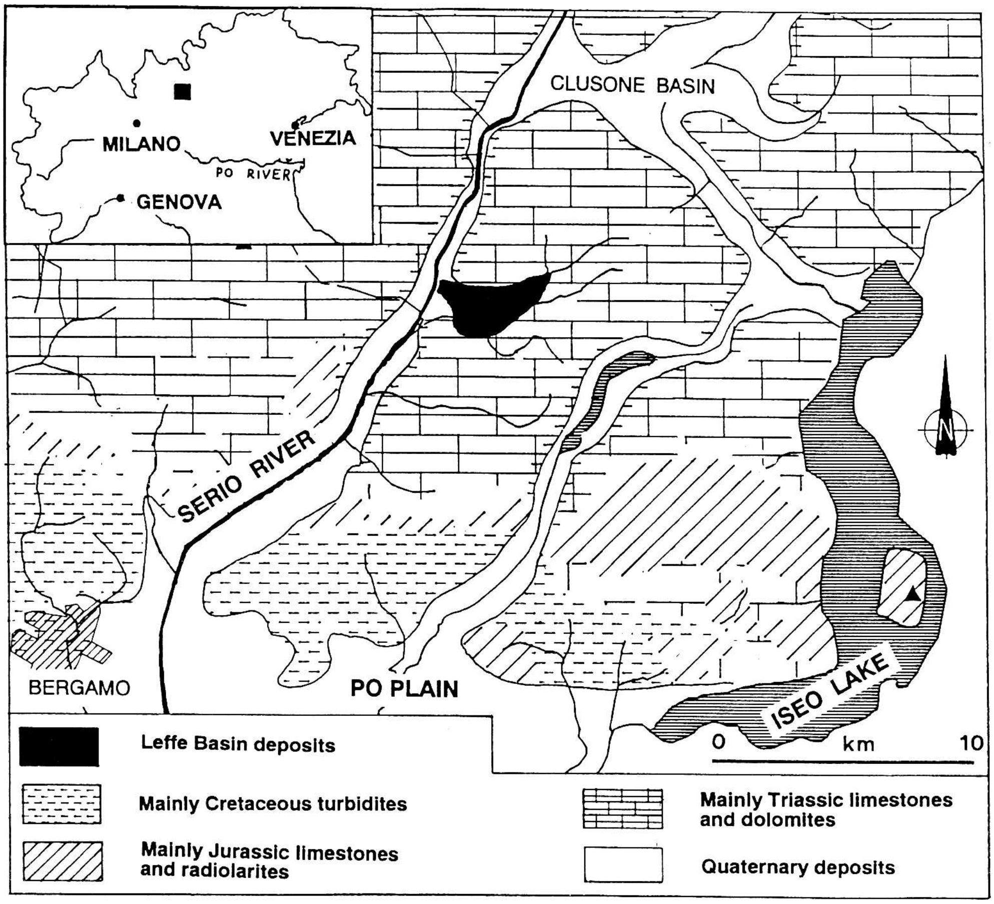

Fig. 1 - Location of the Leffe Basin.

Pliocene and Early Pleistocene in age (Ravazzi, 1993; Cremaschi & Ravazzi, in press). The 1.8 Ma BP Plio/Pleistocene boundary will be used in the present paper (Hilgen, 1991).

The middle part of the succession comprises several organic horizons (brown coals and gyttja), that provided a rich macroflora (Sordelli, 1896) and a Late Villafranchian fauna (Vialli, 1956; Azzaroli et al., 1986). The palynological studies by Lona (1950) and Lona & Follieri (1957) pointed to important vegetational and climatic changes occurred during sedimentation. These oscillations have been confirmed and illustrated in detail by a new pollen record (Ravazzi, 1993; Ravazzi & Rossignol Strick, submitted).

Although wood is quite abundant in organic layers, up till now no investigation has been carried out. Lona (1950) reported a preliminary remark about some wood samples collected from the "Main" brown coal layer. They were identified as Cupressaceae. These woods were interpreted as autochthonous, since standing stems of trees were found during the exploitation of the brown coal (Venzo, 1950).

This paper discusses the identification of some coniferous woods sampled at different stratigraphic positions. A comparison with the results of pollen analysis will be given, in order to reconstruct the ecological and climatic setting. Biostratigraphic inferences are also presented and discussed.

2. Methods.

Dried samples were boiled before slides were made. The cross and longitudinal sections were prepared with a razor blade and mounted with glycerin jelly. The wood collection of the Laboratory of Palaeobotany and Palynology of the University of Utrecht and the volumes by Greguss (1955, 1959, 1972), Grosser (1977) were used for identification.

The samples have been stored in the collection of the C.N.R. - Centro di Studio per la Geodinamica Alpina e Quaternaria (Bergamo).

3. Stratigraphic position of the samples.

The whole Leffe sequence is divided into two formations: Leffe Fm. and Gandino Fm. (Cremaschi & Ravazzi, in press). The Gandino Formation overlays the Leffe Formation, which in turn is composed of an upper unit, a middle (biogenic) unit and a lower unit (Fig. 2). The Plio/Pleistocene boundary lies just before the top of the lower unit of the Leffe Formation.

A drilling has been carried out in 1991 by the CNR - Centro Geodinamica Alpina Quaternaria (Milano) - in order to provide a core of the entire Leffe Formation (Fig. 2). The wood samples originating from this core are marked by the acronym of the drilling "MM" and by their depth in meters.

A single sample comes from the bottom peat level of the Leffe sequence (sample n. 35, MM 159.5; Fig. 2). This level belongs to the lower unit of the Leffe Formation, Late Pliocene in age.

35 samples originate from the the "Main" brown coal layer (= "Second" brown coal layer) of the middle (biogenic) unit of the Leffe Fm., lowermost Pleistocene in age. Among them, 11 are coming from the core MM, whereas 21 were collected during an excavation carried out in 1992 at Villa Giuseppina (acronym VG). 3 samples originate from the collection of the Museo di Scienze Naturali di Bergamo. They were collected (1983) at Leffe - Via Europa (acronym EU), but their detailed stratigraphic position is unknown.

A rough stratigraphic correlation between the VG site and the MM drilling is given by the position of the upper boundary of the "Main" brown coal layer (Fig. 3). The VG site is located at the western border of the paleo-lake, whereas the MM drilling is on its central-eastern side. A detailed correlation is difficult to derive from

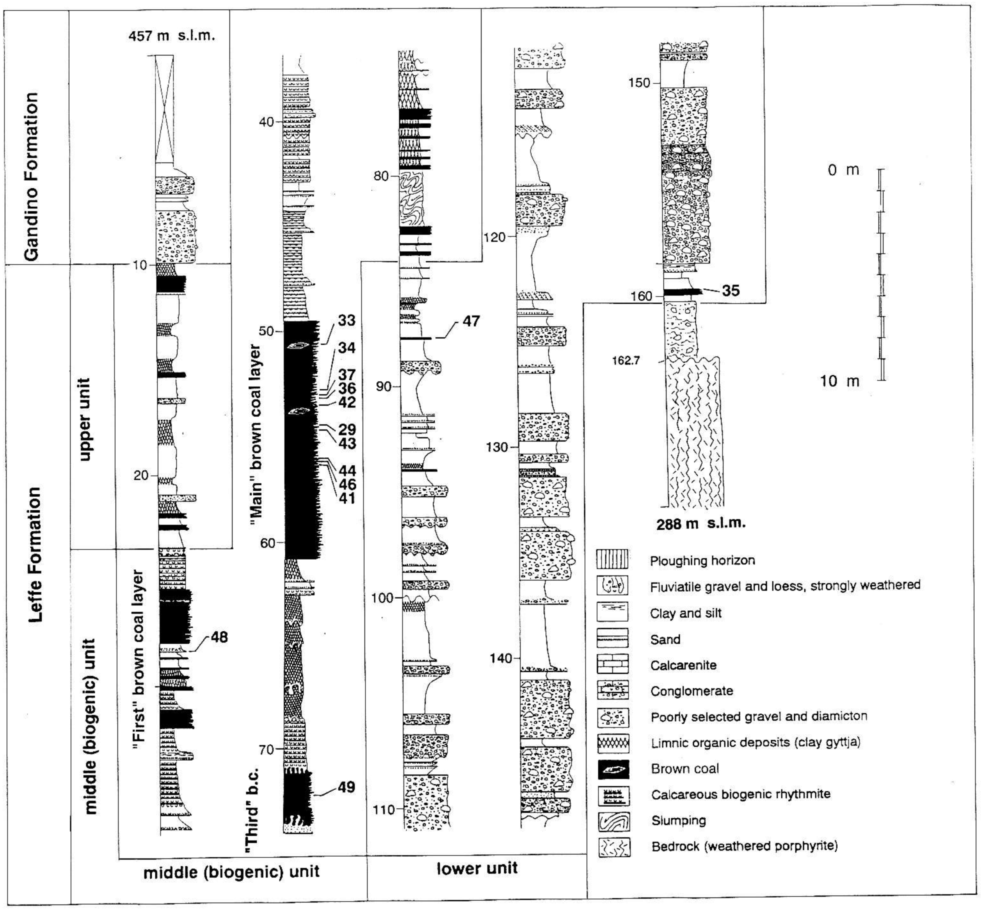

Fig. 2 - Stratigraphic outline of the Leffe Formation in the MM drilling. Only a small part of the Gandino Formation is included in the MM drilling. The position and the number of the wood samples are indicated.

lithostratigraphy, because the thickness of the main brown coal is variable (12.7 m at the site VG, 11.5 m at the MM drilling) as well as the accumulation rate of the peat. Moreover, the upper limit of the brown coal may be slightly diachronic from the central to the marginal part of the basin.

7 samples were collected in the lower part of a brown coal level which outcrops along the Re torrent (acronym RRE). This level could be correlated with the lower part of the "First" brown coal layer (Ravazzi, 1993).

Finally, two samples were examinated which originate from fluviatile sandy and silty deposits at the base of the Casnigo Cemetery series, on the western side of the Casnigo Terrace (Serio River site, acronym CS). These deposits are interfingering with the lower and the middle (biogenic) units of the Leffe Formation (Ravazzi, 1993).

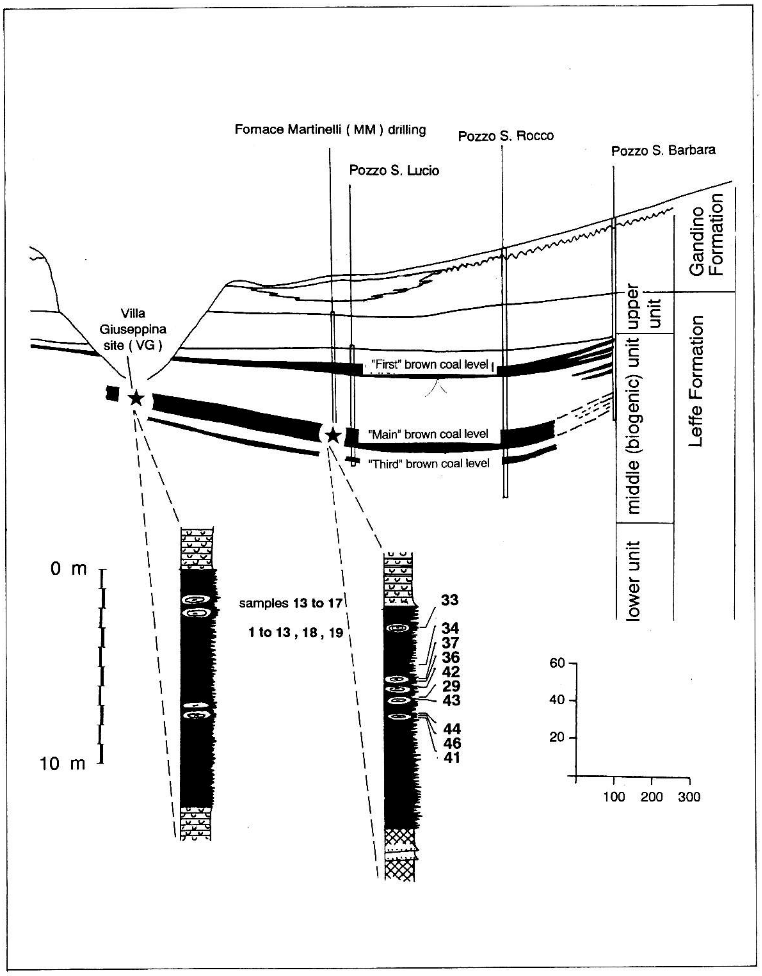

Fig. 3 - Position of the woods sampled in the "Main" brown coal layer of the middle (biogenic) unit of the Leffe Formation and correlation between the VG site and the MM drilling. Some of the old mine shafts are reported.

4. Preservation conditions.

All the specimens are preserved as coalified compression. As a rule the preservation is not very good, because of the volume reduction which occurred in the organic deposits. However, the longitudinal sections still display diagnostic characters. Nevertheless, a distinction must be made between coniferous and angiospermous wood, the latter being not only much more deformed, but also decomposed chemically to such a degree, that identification was very difficult or even impossible. Therefore only coniferous woods are described in detail here. A complete list of identifications is reported in Table 1.

Sample number	Site	Stratigraphic Position	Identification
35	MM	159.5 (Lower Unit)	Piceoxylon sp. 1
23	CS	Lower Unit (upper part ?)	Picea
32	CS	Lower Unit (upper part ?)	Picea
47	MM	87.92	Piceoxylon sp. 2
49	MM	72.53 (Third b.c.)	not identifiable
41	MM	56.52 (Main b.c.)	Pinus cf. tabulaeformis
46	MM	56.48 (Main b.c.)	Pinus cf. tabulaeformis
44	MM	56.45 (Main b.c.)	Pinus cf. tabulaeformis
43	MM	55.21 (Main b.c.)	cf. Carya
29	MM	55.1 (Main b.c.)	Pterocarya
42	MM	54.45 (Main b.c.)	Glyptostroboxylon tenerum
36	MM	54.05 (Main b.c.)	Alnus
37	MM	54.0 (Main b.c.)	Chamaecyparis
45	MM	53.9 (Main b.c.)	bark not identifiable
34	MM	53.65 (Main b.c.)	Chamaecyparis
33	MM	51.28 (Main b.c.)	Pterocarya
1	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
6	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
9	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
14	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
18	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
19	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
21	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
22	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
13	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
15	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
16	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
17	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
3	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
4	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
5	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
7	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
8	VG	Main b.c. (upper part)	Glyptostroboxylon tenerum
20	VG	Main b.c. (upper part)	Chamaecyparis
2	VG	Main b.c. (upper part)	Angiosperm to be identified
10	VG	Main b.c. (upper part)	Angiosperm not identifiable
12	VG	Main b.c. (upper part)	Angiosperm not identifiable
38	EU	Main b.c.	Celtis
39	EU	Main b.c.	Picea
40	EU	Main b.c.	Fraxinus
48	MM	28.85 (First b.c.)	Alnus
24	RRE	First b.c.	cf. Castanea
25	RRE	First b.c.	Fraxinus
26	RRE	First b.c.	Fraxinus
27	RRE	First b.c.	Fraxinus
28	RRE	First b.c.	Fraxinus
30	RRE	First b.c.	Fraxinus
31	RRE	First b.c.	Fraxinus

Tab. 1 - List of identifications.

b.c.=brown coal; MM=acronym of the drilling 1991; CS=Serio River site; VG=Villa Giuseppina site; EU=Via Europa site; RRE=Re Torrent. Samples are listed in the stratigraphic order.

5. Paleobotanical descriptions

Glyptostroboxylon tenerum (Kräusel) Conwentz

Pl. 1, fig. 1-9

Synonymy: see Kräusel 1949.

Material. Several (18) samples (n° 1, 3, 4, 5, 6, 7, 8, 9, 13, 14, 15, 16, 17, 18, 19, 21, 22, 42), all originating from the main brown coal layer, belong to the same species and are described under this name. Although for material of Quaternary age the recent genus (*Glyptostrobus*) is normally used, in this case, because of the relationships with older material, the "fossil genus" name is used (for more information see: Stratigraphic range).

Description. *Growth rings* (Pl. 1, fig. 1). Variable in width, ranging from 2 to ca 4 mm. The early wood is nearly everywhere compressed, in some cases however it is still intact.

Tracheids (Pl. 1, fig. 2, 8). These are wide in the early wood, 40-50 μm in the early wood, 10 x 25 μm in the late wood. They are more or less rectangular in cross section. The walls are smooth and thin (ca 5 μm) in the early wood, moderately thick (10 μm) in the late wood. In the radial walls of the early wood the bordered pits are biseriate, ca 13-16 μm occasionally up to 20 μm in diameter. Crassulae are sometimes present. In the tangential walls of the late wood tracheids also small bordered pits are present; diameter ca 10 μm.

Axial parenchima (Pl. 1, fig. 3, 4, 5, 6). This is present, sometimes in considerable quantities, suggesting a concentration in one or more zones over the growth ring. The horizontal walls are 1-4 μm, sometimes up to 5 μm thick and pitted, resulting in a few beads in the walls.

Rays (Pl. 1, fig. 3, 7, 8, 9). These are exclusively uniseriate and rather low, mostly up to 11 cells high, in one case however up to 22 cells high. The horizontal walls are 2-4 μm thick and pitted, the tangential walls are 1-3 μm thick and also pitted, sometimes beads up to 5 μm are present.

The crossfield pits are rather small, 8-10 μm in diameter and variable in type, ranging from glyptostroboid to cupressoid and taxodioid. The fact that the pits of the early wood were not easily visible (these are the widest in opening) tends to bring the number of glyptostroboid pits at a low level. The pits are present in the middle part of the rays in only one horizontal row, due to the low height of the cells (12-15 μm, sometimes up to 20 μm).

Discussion. This wood consisting of exclusively tracheids and parenchyma is the type of wood known from Pinopsida. The presence of abundant axial parenchyma, together with taxodioid or cupressoid pits points to the Cupressales and the presence of abundant biseriate bordered pits in the early wood tracheids is only known from the Taxodiaceae. Within this family the wood can be identified as *Glyptostroboxylon tenerum* due to the rather small size of the bordered pits and the relative abundance of the glyptostroboid pits in the early wood. Also the size of the beads on the tangential endwalls of the rays and on the horizontal walls in the axial parenchyma are in agreement with this identification. *Taxodioxylon gypsaceum* (Goeppert) Kräusel, the wood associated in the Neogene with *Sequoia*, has bigger bordered pits, bigger cross field pits and the horizontal walls in the axial parenchyma are as a rule thinner, some beads up to 6 μm being present, but much more infrequently. *Taxodioxylon cryptomerioides* Schönfeld has rather narrow early wood tracheids and therefore misses the biseriate position of the bordered pits.

Stratigraphic range. *Glyptostroboxylon tenerum* has been found from Cretaceous up to Late Pliocene deposits from the northern hemisphere. In Western Europe its youngest occurrence is in a deposit of Reuverian age in the lower Rhine embayment (Van der Burgh, 1978). It has not been found in the deposit of Tegelen, the Netherlands (Van der Burgh, 1974), either not in the European gisements of Quaternary age. In Italy it has been found recently in the Pliocene deposits of Dunarobba (Terni) and of the Stura River (Torino), in connection with cones of *Glyptostrobus europaeus* (Brongniart) Unger (Martinetto, in press). *Glyptostroboxylon tenerum* is considered to be the wood of *Glyptostrobus europaeus.* However, since no cones or branches and leaves have been found up to now in the Leffe deposits, the identification of our wood material with *Glyptostrobus europaeus* is not sure. Therefore in the present paper we will use the special nomenclature for isolated organs.

Chamaecyparis sp.

Pl. 2, fig. 1-4

Material. Two specimens of juvenile branchwood (n° 20, 34) and one specimen of older stemwood (n° 37) were collected of this type of wood in the main brown coal layer. In one piece the heartwood was still intact, the outer growth rings had collapsed and were compressed, the other specimen of branchwood was not compressed at all; the stemwood was very heavily compressed. Both pieces of branchwood showed very dense striation.

Description. *Growth rings* (Pl. 2, fig. 2). Up to 0.3 mm wide, with abundant parenchyma and narrow tracheids.

Tracheids (Pl. 2, fig. 3). These form the bulk of the material, are narrow (rd 20 x tg 10 μm) in the early wood, with rather thick walls, up to 8 μm. The bordered pits are small (up to 13 μm) and exclusively uniseriate.

Axial parenchyma. This is concentrated in 1-2 zones, of which one is always present in the late wood. The horizontal walls are 2-4 μm thick and pitted.

Rays (Pl. 2, fig. 1, 4). These are exclusively uniseriate and very low, up to 8 cells high. The cells are ca 15 μm high and the pits are taxodioid or cupressoid in type, diameter 5-8 μm. The horizontal walls are 2-4 μm thick and pitted, the tangential endwalls are 1-3 μm thick and smooth.

Discussion. This wood also originates from the Pinopsida. It can also be traced to the Cupressales, but the uniseriate bordered pits in the narrow tracheids, combined with the cupressoid to taxodioid small cross field pits point to the Cupressaceae. The recent wood of *Thuja* and especially *Chamaecyparis* is in structure very near this species. Despite the youth of part of the material, it is clear that the difference in width between early wood and late wood is very small. Normally in juvenile wood of the Taxodiaceae this difference tends to be much larger. So the narrowness of the early wood tracheids is considered as typical and is used for identification. The characters of the rays and the axial parenchyma are more in agreement with those of *Chamaecyparis* than with those of *Thuja*, especially the shape of the horizontal walls in the axial parenchyma, which are much more thinner in *Thuja*.

Stratigraphic range. *Chamaecyparis* or *Thuja* has been found in Pliocene deposits of the lower Rhine embayment (Van der Burgh, 1974), in the Late Pliocene Vildstejn Formation of the Cheb Basin, Czech Republic (Buzek, Kvacek & Holy, 1985), in Tiglian deposits at Tegelen in the Netherlands (Van der Burgh, 1974) and in Belgium (Greguss & Vanhoorne, 1961). Mai & Walther (1988) report the genus for Thuringia.

Piceoxylon sp. 1

Pl. 2, fig. 5-7

Material. One specimen from the bottom of the MM core, at the depth of 159.5 m, could be identified as *Piceoxylon* sp. 1 (n° 35).

Description. *Tracheids.* The wood was heavily compressed and deformed, therefore no measures of the diameter of the lumina or wall thickness could be made.

Bordered pits. These are present in a single line in the radial walls of the tracheids; the diameter is ca 15 μm.

Rays (Pl. 2, fig. 5, 7). The uniseriate rays are up to 13 cells high, often a ray tracheid is visible on both upper and lower margin; the horizontal walls bear a heavy abietoid pitting, the crossfield pits are piceoid and small, 3-4 μm in diameter. Bordered pits with a diameter of 5 μm are present in the radial walls of the ray tracheids.

The fusiform rays are up to 15 cells high and up to 3 cells broad. The centre is occupied by thick walled parenchyma cells surrounding a horizontal resin duct. The thin walled epithelium cells have disappeared, but their position can be traced. The resin ducts have a diameter of ca 15 μm.

Resin ducts (Pl. 2, fig. 6). Vertical resin ducts of up to 60 μm wide are present in the late wood. They are surrounded by thick walled parenchyma.

Discussion. The genus *Piceoxylon* Gothan represents the wood of several genera (*Picea, Larix, Pseudotsuga*) of the Pinaceae. This genus has been used here while it was impossible to assign the wood specimens to any of the recent genera.

The specimen, though in a bad state of preservation, shows sufficient characters to enable an identification as belonging to the Pinaceae (abietoid pitting, horizontal and vertical resin ducts in the normal wood, absence of axial parenchyma). The thick walled surrounding parenchyma of the resin ducts is typical for wood of the genus *Piceoxylon*. However, due to the bad preservation it is impossible to give any further identification. Therefore the wood is described as *Piceoxylon* sp. 1.

Piceoxylon sp. 2

Material. A specimen (n° 47), from the base of the middle (biogenic) unit of the Leffe Fm., of juvenile wood with vertical and horizontal resin ducts, strong abietoid pitting and small crossfield pits, but without any ray tracheids, is placed in the genus *Piceoxylon*, as it is known that in juvenile wood the ray tracheids are often not present. Due to the preservation and the lack of ray tracheids any further identification is impossible. Therefore this specimen is described separately and is not included in the foregoing species.

Picea sp.

Pl. 3, fig. 1-5

Material. Two pieces of heavily striated branchwood have been found in the lower unit of the Leffe Fm., which were not very compressed, as they were included in sandy deposits (n° 23, 32).

Description. *Tracheids.* These are narrow, the diameter of the lumen is in the early wood maximum 20 μm, in the late wood narrower. The thickness of the walls is ca 5 μm in the early wood and 7-8 μm in the latewood. The walls are smooth.

Bordered pits. In the radial walls of the tracheids the bordered pits are present in one single vertical line, their diameter is 12-15 μm.

Rays (Pl. 3, fig. 2, 3, 4, 5). These consists of two types of rays:

1) uniseriate rays of up to 11 cells high with on both extremes one or rarely two ray tracheids. The latter bear tiny sharp teeth on the walls. In the walls are small bordered pits, diameter 7-8 μm. The ray parenchyma cells have thick walls (4-5 μm) which are densely pitted (abietoid pitting), the crossfield pits are small, 4-5 μm and piceoid.

2) The fusiform rays are up to 20 cells high, with ray tracheids on the extremes; they are up to 4 cells wide and bear a resin duct, 10 μm in diameter and surrounded by thick walled parenchyma cells. The extremely thin walled epithelium cells, as known from recent material and described by Van der Burgh (1973), are not preserved. Judging from the shape of other cells they have been present.

Resin ducts (Pl. 3, fig. 1). These woods have a number of vertical resin ducts in the late and early wood. The latter are accompanied by some disturbed rows of tracheids and parenchyma indicating traumatic wood. The resin ducts are narrow, ca 30 μm in diameter, surrounded by thick walled parenchyma and show places where thin walled epithelium cells have been present.

Discussion. The combination of the following characters: lack of parenchyma in the normal wood, the presence of both vertical and horizontal resin ducts in the normal wood, the abietoid pitting in the rays and the piceoid crossfield pits are only found in the Pinaceae, especially in *Picea* and *Larix*. These two genera are very difficult to separate on wood anatomical features. The narrow tracheids which are moreover not very different in width between early wood and late wood, are typical for *Picea*. Due to the not very satisfying preservation and the amount of traumatic wood it is impossible to identify any further. So the identification is *Picea* sp.

Stratigraphic range. Several species of *Picea* and *Piceoxylon* were described from Pliocene, Tiglian and Quaternary deposits in Western Europe (Mädler, 1939; Van der Burgh, 1974, 1978).

Pinus cf. **tabulaeformis** Carrière

Pl. 3, fig. 6, 7

Material. Three wood specimen are identified (n° 41, 44, 46), all from the "Main" brown coal layer and very much compressed.

Description. The individual shape of several elements was no longer observable. However, vertical and horizontal resin ducts (Pl. 3, fig. 7) with thin epithelium were observed. In addition radial sections of the rays showed a fair number of ray tracheids with dentate margins, dentation gradation 7 (scale of Hudson, 1960) (Pl. 3, fig. 6).

Anastomoses between opposite dents are frequent. In the narrow ray tracheids these dents reach to one quarter of the lumen, in high cells it is less. The ray parenchyma cells show fenestrate crossfield pits.

Discussion. These three pieces of wood, although slightly differing from one-another, belong to the same species of pine which has to be placed in the section *Pinus*. Within this section there is a close similarity with the wood of *P. tabulaeformis* and its Tertiary counterpart *Pinuxylon cuiavicum* Kownas. This species also shows several ray tracheids on the top of each other, all with comparable dentation. So despite the bad preservation, this wood can be assigned to *P.* cf. *tabulaeformis.*

Stratigraphic range. *P. tabulaeformis* has been described from Tiglian deposits in the lower Rhine embayment (Van der Burgh, 1978), Tegelen in the Netherlands (Van der Burgh, 1974) and Belgium (Greguss & Vanhoorne, 1961). *P. cuiavicum* Kownas has been described from Miocene deposits of Poland (Kownas, 1951) and from Pliocene deposits in the lower Rhine embayment (Van der Burgh, 1978).

6. Taphonomical, Ecological and Climatic setting.

All the woods (except n° 23, 32 and 35) originate from brown coal layers interbedded with lacustrine deposits. The accumulation of the organic matter occurred during periods of low level of the Leffe Basin, when mire vegetation invaded the entire basin surface (Ravazzi, 1993). No terrigenous silty or sandy material supplied by rivers is present in this facies. Consequently, woods must be regarded as originating from autochthonous swamp vegetation growing in the brown coal, in agreement with the previous hyphotesis by Lona (1950).

The pollen record shows that rapid changes in regional and local vegetation occurred during the existence of the Leffe Basin. Therefore, in order to get ecological and climatic inferences from the woods identified, a discussion about their stratigraphic position compared to pollen data (Fig. 4) is needed.

6.1. Wood and pollen record of the bottom peat level of the Leffe succession.

The bottom peat level of the MM core, from where a wood of *Piceoxylon* sp. 1 has been found (n° 35, MM 159.5), is intercalated in terrigenous sediments (sand and gravel) poor in pollen. Two pollen spectra from the peat show high percentages of arboreal taxa, dominated by *Picea*, *Pinus sylvestris*-type and accompanied by moderate percentages of *Ulmus*, *Fraxinus*, *Abies*, *Salix*. Therefore it is to be expected that the *Piceoxylon* sp. 1 is representing *Picea*. The percentage of other deciduous trees is very low and Juglandaceae are very sporadic. Two main components can be distinguished in the source of the herbaceous pollen: local plants growing in the mire (Cyperaceae, *Thalictrum*, *Potamogeton*) and xerophilous plants (*Artemisia*, Chenopodiaceae, *Ephedra*). These pollen spectra, in accordance with the wood identification, point to a coniferous forest extended in a dry extralocal environment as well as in the local mire area. The climate should have been dry and cool, supporting a regional pattern of forest-steppe and partially open vegetation.

6.2. Wood and pollen record of the "Main" brown coal layer.

The record of *Picea*.

Further evidences of in situ macroremains of *Picea* have been found in the "Main" brown coal layer. Cones of *Picea abies* (L.) Karsten foss. and *Picea seriana* Sordelli (= *P. omorikoides* C.A. Weber ?) were found last century in the "Main" brown coal layer (Sordelli, 1896). The wood specimen n. 39 (*Picea* sp.) originates from the same brown coal layer. Because of lack of detailed stratigraphic information, a correlation between pollen zones and these macroremains is impossible. In fact, the synthetic pollen diagram reported in Fig. 4 shows that at least two phases of *Picea* dominance occurred in the upper part of the "Main" brown coal layer. Despite these problems, we believe that *Picea* would occur in the local bog vegetation when maxima of *Picea* in pollen diagram are observed. No Taxodiaceae, Cupressaceae and only sporadic Juglandaceae have been found in the same levels in pollen diagram.

The record of *Chamaecyparis*.

Two specimens identified as *Chamaecyparis* originate from the MM core (stratigraphic position: MM 53.65, MM 54.0; middle part of the "Main" brown coal seam). In this interval pollen spectra are dominated by Juglandaceae (mainly *Carya*; *Pterocarya* and *Juglans* aff. *cinerea* L. are less abundant) with moderate percentages of *Picea* and oscillating *Alnus*. *Pinus*, *Tsuga*, *Quercus*, *Carpinus*, *Ulmus*, *Fraxinus*, *Viburnum* cf.

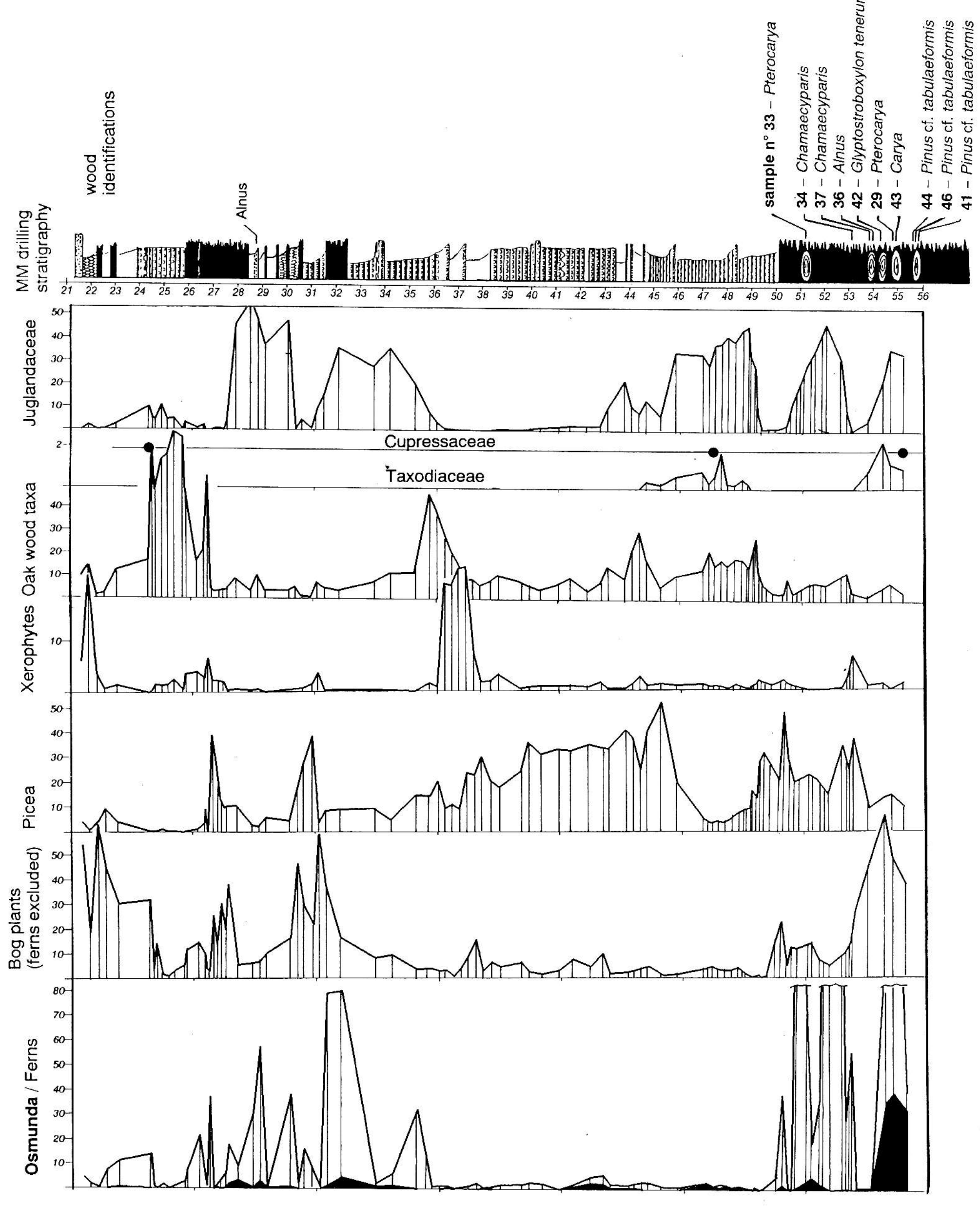

Fig. 4 - Selected pollen curves from the upper part of the middle (biogenic) unit of the Leffe Formation, to compare pollen and wood record in the MM core.
The Taxodiaceae curve has been drawn with a 10 multiplied scale. The sporadic occurrence of Cupressaceae has been represented as a circle. Ferns are not included in pollen sum. Black curve) *Osmunda*. Oak wood taxa) sum of *Quercus*, *Carpinus*, *Ulmus*, *Fraxinus*, *Tilia*, *Corylus*. Juglandaceae) sum of *Carya*, *Pterocarya*, *Juglans* aff. *cinerea*.

opulus L., *Aesculus*, Taxodiaceae (*Taxodium*-type) and *Parthenocissus* are present with low percentages. Among herbs, Cyperaceae and ferns (*Thelypteris*-type, *Osmunda regalis*-type) are abundant; *Artemisia*, Chenopodiaceae and other xerophytes are lacking (Fig. 4).

Pollen of Cupressaceae has been not found in the levels from where wood originate (MM 53.65 - 54.0). However, the sample MM 55.17, which belongs to the same pollen zone (Ravazzi, in prep.), provided few grains with low percentage (0.6 %).

These pollen data, together with finds of macrofossils (nuts of *Carya* sspp. and *Juglans bergomensis* Massalongo, woods of *Pterocarya* and *Alnus*), point to an eutrophic broad-leaved swamp forest (Juglandaceae and *Alnus* dominant), with a well developed herb layer (*Osmunda*, *Thelypteris*, Cyperaceae, etc.). The woods of *Chamaecyparis* are autochthonous, so this taxon must be regarded as a component of the local swamp forest. However, according to the palynological data, the *Chamaecyparis* stands wouldn't have been dominant in the swamp vegetation.

Van der Burgh (1978) identified wood of *Chamaecyparis* cf. *thyoides* Britton, Stern & Poggenberg in a sand-filled channel of Tegelen. Teichmüller (1958) and Zagwijn (1967) regarded Cupressaceae as a component of a relatively dry, mesotrophic swamp forest. According to Buzek et al. (1985), *Chamaecyparis* (cf. *pisifera* (Sieb. & Zucc.) Endl.) occurs together with *Picea omorikoides* Weber, at the early stages of an oligo-mesotrophic moorland including *Pinus* cf. *spinosa* Herbst. These data indicate that the occurrence of *Chamaecyparis* in the Leffe bog can be compared with other sites showing similar ecologic conditions within Europe. In the Leffe mire, such a relatively dry and oligotrophic microhabitat may have been present due to a fast accumulation of fern peat. The macrofossil analysis confirmed that ferns played an important part in peat formation in the upper part of the "Main" brown coal layer.

The record of *Glyptostrobus*.

Most woods identified as *Glyptostroboxylon tenerum* (17 samples) originate from the upper part of the "Main" brown coal layer at the VG site, together with *Chamaecyparis* (1) and unidentifiable Angiosperms (2). No pollen spectra are available at the present time from this site. A detailed stratigraphic correlation of the *Glyptostroboxylon* level with the MM drilling is difficult to realize on the basis of lithostratigraphy and only a new pollen diagram in the "Main" brown coal layer at the VG site could allow for it.

However, important inferences about the occurrence and the ecology of *Glyptostroboxylon* can be derived from the pollen diagram in Fig. 4.

The pollen of *Glyptostrobus* cannot be distinguished with certainty from *Taxodium*, *Cryptomeria* and *Cunninghamia*, so that the morphotype of these genera is brought together in the "*Taxodium*-type". The pollen grains from the MM record are rather big (30-35 μm) and densely granulate-rugulate, so they resemble more *Glyptostrobus* than *Taxodium*. We have not data about the occurrence of *Cunninghamia* and *Cryptomeria* in Italy during the latest Pliocene, but leaves and branches of *Cryptomeria* have been found in some italian sites, Early Pliocene in age (Martinetto, com. pers.). Despite these doubts, in our opinion the pollen record of the *Taxodium*-type from the "Main" brown coal layer might be entirely referred to *Glyptostrobus*.

The occurrence of *Taxodium*-type is not dependent from the lithological and edaphic variations showed by the stratigraphic column. *Taxodium*-type is not restricted to the brown coal levels: its maximum value is recorded at the level 46.9, in calcareous lacustrine deposits. A marginal zone of peat accumulation should have existed continuously during the evolution of the Leffe lake. According to Teichmüller (1958), Zagwijn (1967) and Schneider (1990), *Glyptostrobus* and *Nyssa* formed part of a wet, eutrophic, swamp forest, subject to water level variations. A seasonal regime of water level oscillation could be understood when considering the Leffe lake as isolated from the main drainage system of the Southern Alps, and supplied only by a small catchment area (Ravazzi, 1993).

The pollen record of *Taxodium*-type is discontinuous and highly correlated with the oscillations of the thermophilous deciduous trees (Fig. 4). *Taxodium*-type is recorded in the interval MM 55.1-53.7 (up to 2 % and 200 grains/g), together with *Chamaecyparis-Thuja* type. Coherently, a wood of *Glyptostroboxylon* has been found in the MM core at the level 54.45 (sample n° 42). Another maximum of *Taxodium*-type occurs slightly above the top of the "Main" brown coal layer (Fig. 4 - MM 48.8-44.6, up to 4% and 1870 grains/g). Both the intervals showing the occurrence of Taxodiaceae and Cupressaceae in the pollen record are Juglandaceae-dominated and display low values of *Picea*.

As discussed elsewhere (Ravazzi & Rossignol Strick, in press), the Juglandaceae-dominated pollen zones represent the warmest intervals, defined by a wet, maritime, warm-temperate climate, characterized with about 14-16°C mean annual temperature and a long growth season with abundant available moisture.

Therefore, the occurrence of *Glyptostrobus* and *Chamaecyparis* in the local vegetation of the middle part of the Leffe Formation is restricted to the warmest and wet intervals.

Above the level 44.6, no fossils of Taxodiaceae have been found throughout the uppermost Leffe Formation, although intervals of warm-temperate conditions have been traced.

The record of *Pinus* cf. *tabulaeformis*.

Three woods of *Pinus* cf. *tabulaeformis* originate from the lower part of the "Main" brown coal layer. They are found together in a small interval (MM 56.45-56.52). The pollen spectrum of level 55.6 shows a dominance of Juglandaceae (*Carya, Pterocarya*), *Pinus*, *Tsuga*, *Alnus*, *Betula* and *Sphagnum* spores. *Taxodium*-type is also present. The occurrence of *Sphagnum* and its parasite *Tilletia sphagni* Naw., together with the thecamoeba *Amphitrema* (cf. Van Geel et al., 1989, type 31A) and Ericaceae indicate oligotrophic conditions. The presence of *Pinus* in peaty environments of Quaternary age in Europe is linked to oligotrophic and ombrotrophic bogs. *P. sylvestris* L.

is characteristic of the initiation of a raised bog above a fen stage, or of the drier portions of raised bogs (Goodwin, 1975; Walter, 1985). *P. uncinata* Mill. ex Mirb. and *P. mugo* Turra occur in peaty environments in e.g. the Alps, Pyrenees and Vosges.

It should be emphasized that the occurrence of *Sphagnum* spores in the Leffe pollen record is very sporadic and that it is correlated to high values of *Pinus* or *Picea* (Ravazzi, 1993). Nevertheless, in the level 56.6 the pollen of deciduous trees is also well represented (especially Juglandaceae). This suggests that *Pinus* stands occupied a strictly local habitat in the central part of the bog (dry and oligotrophic), whereas *Glyptostrobus* and deciduous trees were restricted to the marginal part (wet and minerogenic). According to this hypothesis, the oscillations of *Pinus sylvestris*-type in the pollen diagram are not directly linked to the regional climate dynamics.

7. Biostratigraphic inferences.

Lona & Bertoldi (1973), Bertoldi (1990) and Bertoldi et al. (1994) defined the floral succession of the Upper Pliocene/lowermost Pleistocene in Italy on the basis of the "Limite Tiberiano" (Tiberian boundary), marked by the disappearance of Taxodiaceae pollen and many elements characteristic of the subtropical vegetation (Celastraceae, Sapotaceae, *Actinidia*, Magnoliaceae p.p., ecc.). The Tiberian boundary should be easily recognized because it occurs above a zone displaying high values of Taxodiaceae pollen (the "Fase Tiberiana"). According to Lona & Bertoldi (1973), the Leffe record should start later than the Tiberian boundary, because no abundance of Taxodiaceae pollen was found all along the Leffe succession.

More recently several authors expressed doubts about the chronostratigraphic value of the Tiberian boundary, because the disappearance of the Taxodiaceae is apparently not synchronous in the Mediterranean region (Bertolani Marchetti et al., 1979; Michaux et al., 1979). Gregor (1986, 1990), on the basis of the macrofloral assemblages from the Stirone sequence, states that no vegetational and climatic break occurred during the latest Pliocene and no abrupt floristic changes have been recognized.

The record of the Taxodiaceae in the Leffe section, as documented by the present study and by the pollen investigations (Ravazzi, 1993; Ravazzi & Rossignol Strick, in press), can be summarized at present as follows:

- At the basis of the middle (biogenic) unit of the Leffe Formation (90-84 m depth in the core; lowermost Pleistocene), Taxodiaceae and Cupressaceae pollen is abundant (up to 25 % of the pollen sum, 65% of the arboreal pollen, 320.000 grains / g). Among Taxodiaceae, the *Taxodium*-type (incl. *Taxodium*, *Glyptostrobus*, *Cunninghamia* and *Cryptomeria*) is dominant, but the *Sequoia*-type (incl. *Sequoia*, *Sequoiadendron*) has also been recorded (Ravazzi, 1993). At present no macroremains have been studied from this interval.

- From the "Main" brown coal layer (50.3-61 m depth in the core; lowermost Pleistocene) and from the carbonatic deposits overlying it, a detailed pollen diagram is available. As previoulsy discussed, the Taxodiaceae and Cupressaceae records are discontinuous and restricted to the zones with abundance of thermophilous deciduous trees, interpreted as warm phases. Their pollen values are low. Among Taxodiaceae pollen, *Taxodium*-type (cf. *Glyptostrobus*) is dominant. The woods identified as *Glyptostroboxylon tenerum* and *Chamaecyparis* are found in the same stratigraphical interval as *Taxodium*-type in pollen record.

- Above the level 44.6 of the core, up to the top of the Leffe Formation, no remains (both macro and microfossils) belonging to the Taxodiaceae have been found, not even in the pollen zones dominated by deciduous trees, which have been interpreted as representing the warm phases.

From these evidences it comes that Taxodiaceae were living in the Leffe swamp during the lowermost Pleistocene. Their record is strongly discontinuous and clearly affected by the climatic variability characteristic of this time interval. The disappearance above the level 44.6 (still earliest Pleistocene in age) seems to be of importance, because Taxodiaceae were not migrating back in the Leffe area even in the subsequent intervals of favourable climate. Nevertheless, the present authors are not able to establish if such disappearance is representing their last occurrence in Southern Alps. During the Early Pleistocene the region at the foot of the Alps toward the Po Plain has been affected by a rapide progradation of fluviatile conoids (Orombelli, 1979), due to sea regression. This evolution could support a pattern of a gradual reduction of the distribution of the flood-plain vegetation including *Glyptostrobus*, linked to submerged lowland areas.

8. Conclusion.

The identification of wood samples from the brown coal levels of the Leffe succession enabled to recognize the main preserved arboreal taxa growing in situ under different ecologic and climatic conditions.

The development of a *Glyptostrobus-Chamaecyparis-Nyssa* swamp was possible only during full interglacial conditions. Inversely, the spreading of *Picea* on the peaty environment is linked to the disappearance of thermophilous trees in the pollen spectrum. *Pinus* cf. *tabulaeformis* was also a component of the local vegetation, but it was linked mostly to azonal conditions.

From a biostratigraphical point of view, the present study demonstrate the persistence of *Glyptostrobus* and *Chamaecyparis* during the lowermost Pleistocene deposits in Northern Italy.

Pollen diagrams previously carried out from the Upper Pliocene and Lower Pleistocene deposits in Northern Italy have been used to support a biostratigraphy that highlights a progressive disappearance of Tertiary plants. The present study suggests that climatic oscillations occurring during this time interval allow for a cyclic, repetitive appearance and disappearance of the Tertiary elements. This consequence of migration produced by climatic variability can be recorded here only for the local vegetation, due to the isolated position of the Leffe Basin. That should be taken into account when defining the floristic stage boundaries, because a temporary disappearance, produced by vegetation dynamics, can easily be misidentified as a stratigraphic extinction.

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PLATE 1

Fig. 1 - *Glyptostroboxylon tenerum* (Kräusel) Conwentz. Prep. n° 1, cross section; x 100.

Fig. 2 - *Glyptostroboxylon tenerum* (Kräusel) Conwentz. Prep. n° 4, radial section, tracheid with bordered pits; x 400.

Fig. 3 - *Glyptostroboxylon tenerum* (Kräusel) Conwentz. Prep. n° 13, tangential section, ray and axial parenchyma; x 400.

Fig. 4 - *Glyptostroboxylon tenerum* (Kräusel) Conwentz. Prep. n° 1, tangential section, horizontal wall in axial parenchyma; x 400.

Fig. 5 - *Glyptostroboxylon tenerum* (Kräusel) Conwentz. Prep. n° 13, tangential section, horizontal wall in axial parenchyma; x 400.

Fig. 6 - *Glyptostroboxylon tenerum* (Kräusel) Conwentz: Prep. n° 13, tangential section, horizontal wall in axial parenchyma; x 400.

Fig. 7 - *Glyptostroboxylon tenerum* (Kräusel) Conwentz. Prep. n° 17, radial section, ray with crossfield pits; x 400.

Fig. 8 - *Glyptostroboxylon tenerum* (Kräusel) Conwentz. Prep. n° 13, tangential section; x 100.

Fig. 9 - *Glyptostroboxylon tenerum* (Kräusel) Conwentz. Prep. n° 9, radial section, ray with crossfield pits; x 400.

PLATE 2

Fig. 1 - *Chamaecyparis* sp. Prep. n° 37, radial section, ray with crossfield pits; x 400.

Fig. 2 - *Chamaecyparis* sp. Prep. n° 37, cross section tracheids and axial parenchyma; x 100.

Fig. 3 - *Chamaecyparis* sp. Prep. n° 37, radial section, bordered pits in early wood; x 400.

Fig. 4 - *Chamaecyparis* sp. Prep. n° 37, tangential section, ray; x 400.

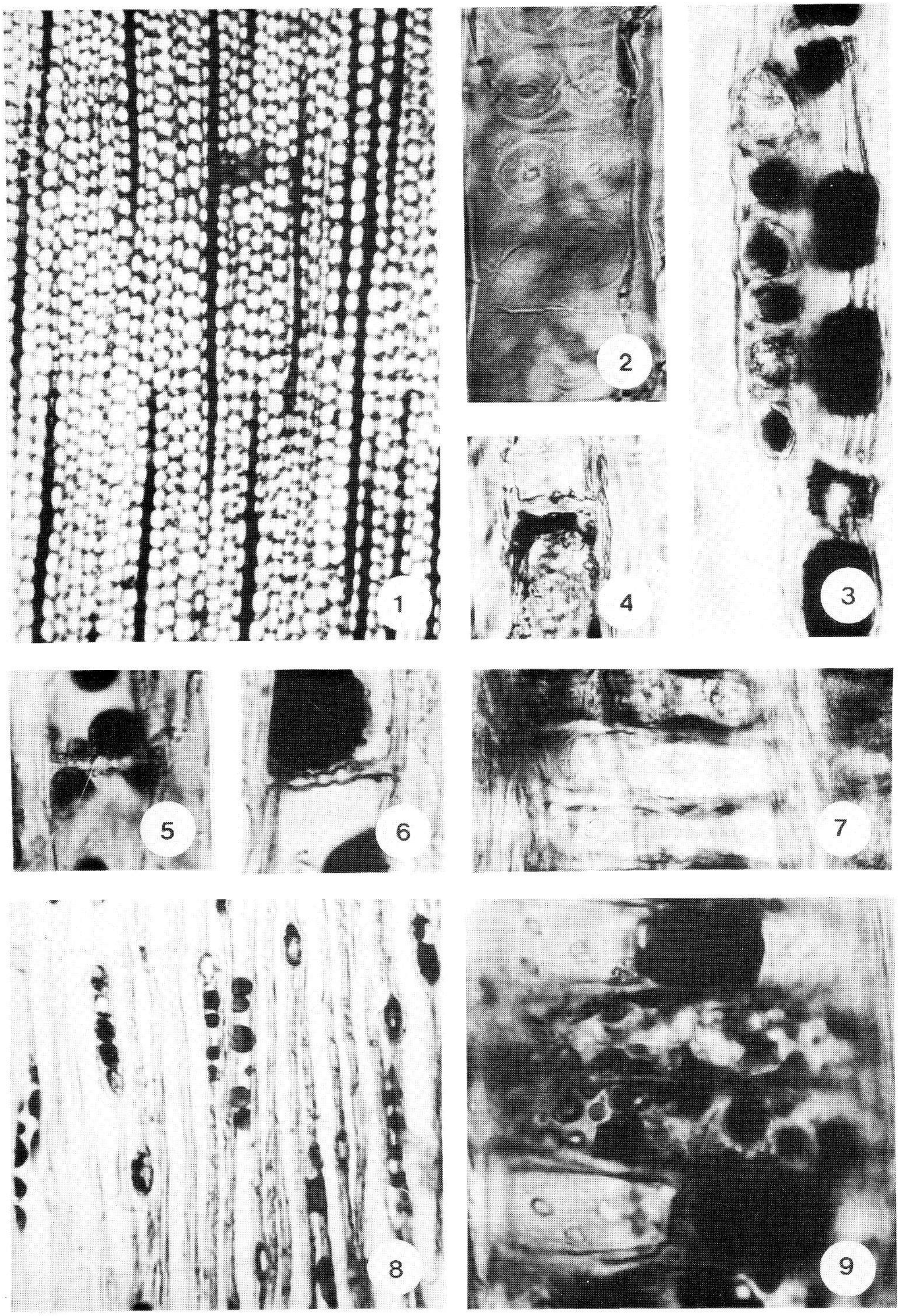
Fig. 5 - *Piceoxylon* sp. 1 Prep. n° 35, radial section, ray with ray tracheid; x 400.

Fig. 6 - *Piceoxylon* sp. 1 Prep. n° 35, radial section, vertical resin duct; x 40.

Fig. 7 - *Piceoxylon* sp. 1 Prep. n° 35, tangential section, fusiform ray; x 400.

PLATE 3

Fig. 1 - *Picea* sp. Prep. n° 32, radial section, fusiform ray and vertical resin duct; x 40.
Fig. 2 - *Picea* sp. Prep. n° 32, tangential section, uniseriate and fusiform rays; x 40.
Fig. 3 - *Picea* sp. Prep. n° 23, radial section, ray with ray tracheid and dentition; x 400.
Fig. 4 - *Picea* sp. Prep. n° 23, radial section, ray with crossfield pits; x 400.
Fig. 5 - *Picea* sp. Prep. n° 32, tangential section, fusiform ray; x 400.
Fig. 6 - *Pinus* cf. *tabulaeformis* Carrière. Prep. n° 46, radial section, ray with fenestriform pits and ray tracheids with dentition; x 400.
Fig. 7 - *Pinus* cf. *tabulaeformis* Carrière. Prep. n° 46, longitudinal section: fusiform ray and uniseriate rays in tangential section (left), uniseriate ray in radial section (right); x 40.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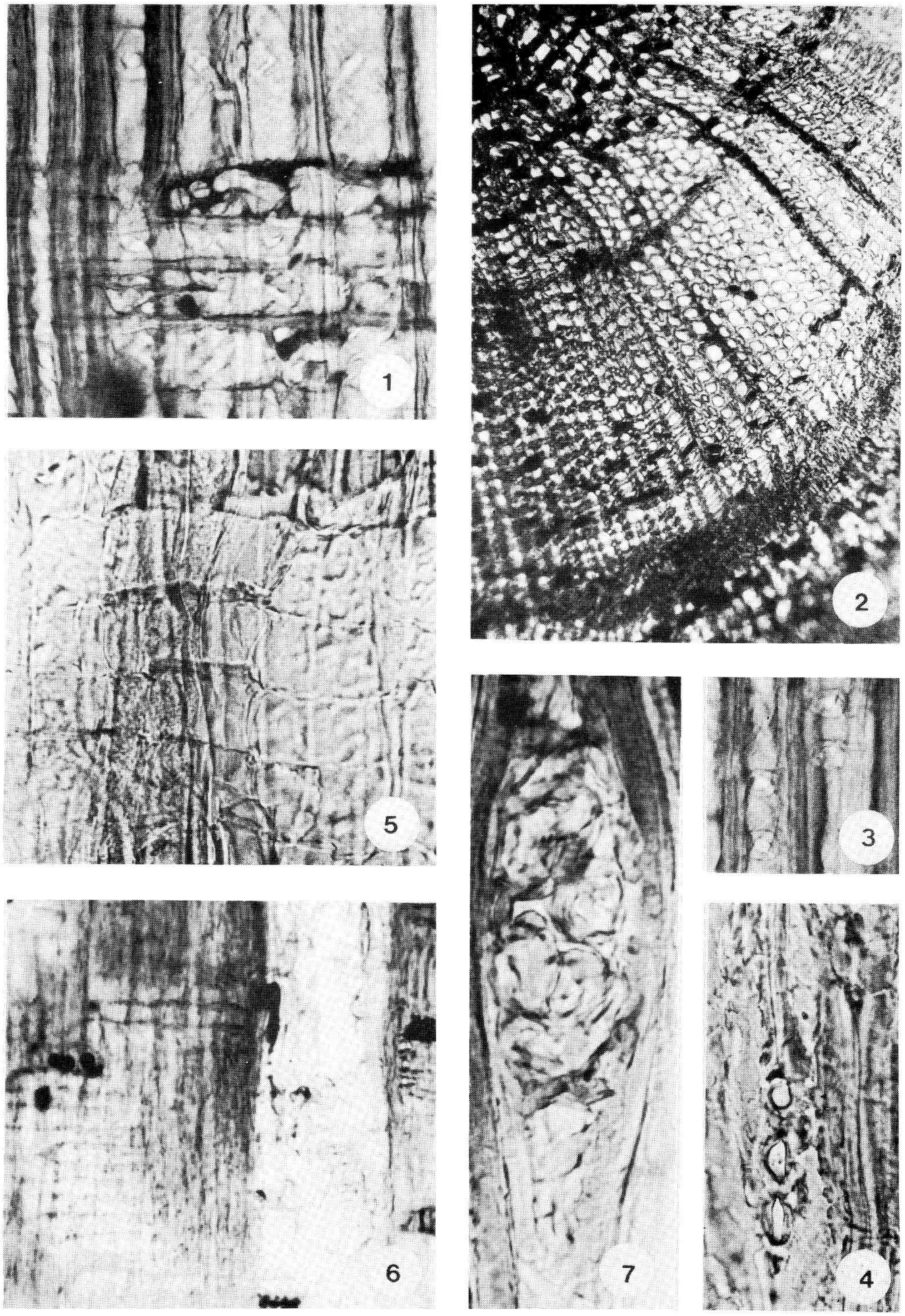

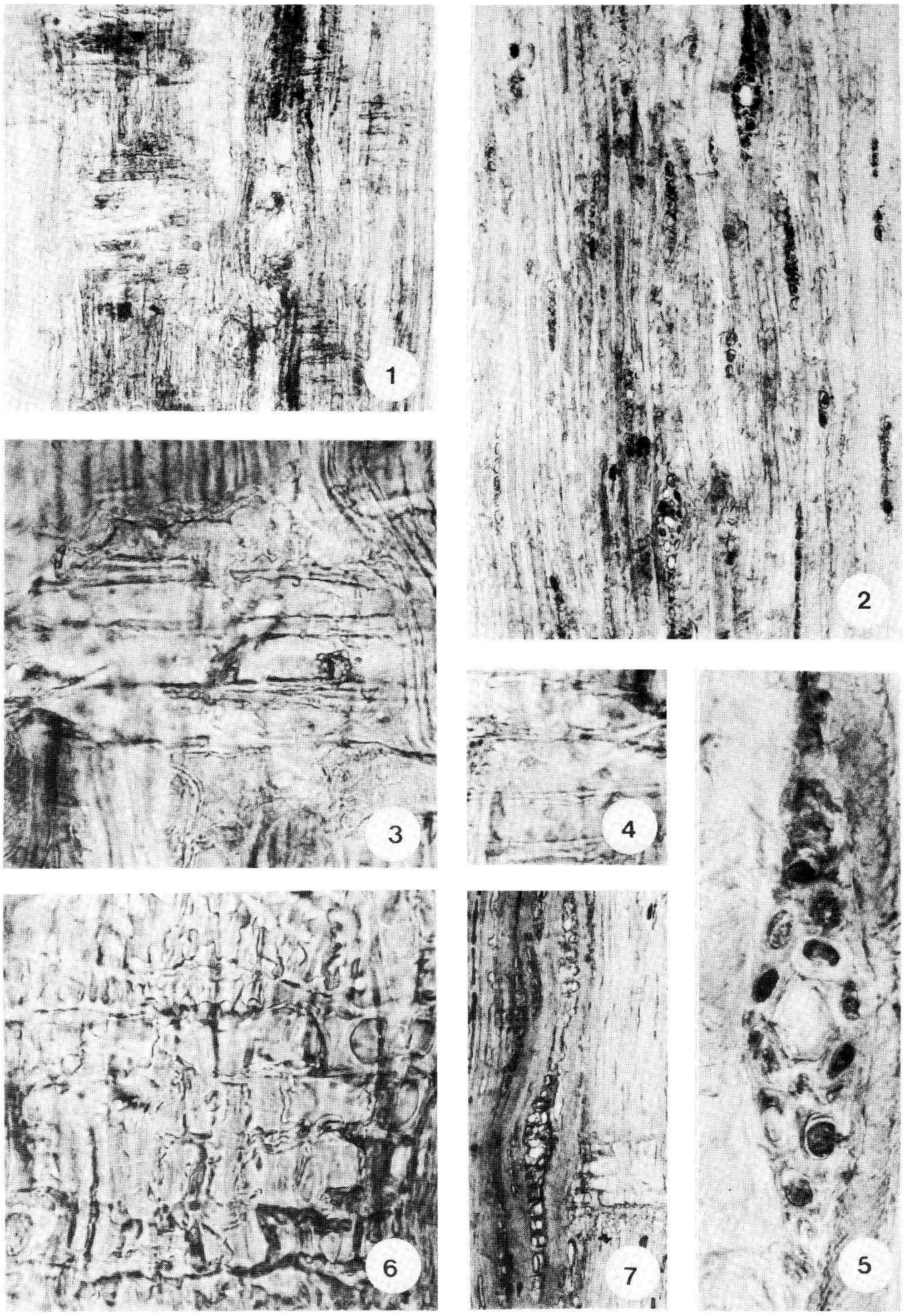
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