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Silicified Miocene woods from the North Bohemian Basin (Czech Republic) and from Kuzuluk, district Adapazari (Turkey)

Miozäne Kieselhölzer aus dem nordböhmischen Becken (Tschechische Republik) und aus Kuzuluk, Distrikt Adapazari (Türkei)

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With 25 figures and 6 tables

Herrn Prof. Dr. Walter Jung zum 70. Geburtstag

Abstract

33 silicified wood remains from localities in the Czech Republic and 14 silicified samples from Turkey, geological age Middle to Upper Miocene, were examined microscopically by thin sections. The preservation of the internal wood structure is mostly sufficient for identification at genera level. North Bohemian Basin: *Taxodium*, *Castanea*, *Platanus*, *Robinia* (insect bore-holes with coproliths) and Dicot indet. Kuzuluc: *Taxodium*, *Taxus*, *Alnus* (insect bore-holes with coproliths) and ?Euphorbiaceae. The gymnosperm woods from Kuzuluk, district Adapazari, are the first anatomical record of mineralized coniferous xylem from the territory of Turkey. A rare anatomical feature in a single *Taxodioxylon* wood from Kuzuluk shows a 4-seriate ray, unusual in coniferous xylem. This is the first record of silicified wood from a previously undescribed wood-rich horizon in NW Turkey.

Zusammenfassung

33 Fundstücke tertiärer Hölzer aus der Tschechischen Republik und 14 verkieselte Holzfunde aus der Türkei wurden anhand von Dünnschliffen mikroskopisch untersucht, geologisches Alter mittleres bis oberes Miozän. Die Kieselhölzer, in ihrer anatomischen Struktur meist nur ausreichend erhalten, sind bis zur Gattung bestimmbar. NW Böhmen: *Taxodium*, *Castanea*, *Platanus*, *Robinia* (Insektenbefall) und Dicot indet. NW-Türkei: *Taxodium*, *Taxus*, *Alnus* (Insektenbefall) und ?Euphorbiaceae. Die Gymnospermen aus Kuzuluk sind der erste anatomische Nachweis versteinerter Koniferenhölzer aus der Türkei. Ein *Taxodioxylon*-Holz aus der Türkei zeigt einen 4-reihigen Holzstrahl, ein bei Gymnospermen gemäß Lehrbüchern ungewöhnliches anatomisches Merkmal.

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1. Silicified woods from the Czech Republic

1.1. Introduction
(Fig. 1)

Northwestern Bohemia, the western part of the Czech Republic, is a territory where Tertiary plants have been collected since the very beginning of palaeobotanical research (UNGER 1850). The woods described in this paper are from localities that are relatively accessible (open-cast Mine Bílina [Bilin]) and were visited by the author under the guidance of PAVEL COUFAL (Mine Nastup, Tušimice [Tuschmitz], Chomutov [Komotau]) and OLDŘICH FEJFAR (Charles University Praha) in autumn 1995. At present, Mine Bílina, situated in the northeastern part of the so-called Most [Brüx] Basin, is a gigantic open-cast mine over 200 m deep. It makes the whole geological section accessible together with the coal seam and the underlying strata. Mine Bílina, formerly Mine Maxim Gorki, is the main source of lignite in the Czech Republic. The open-cast Mine Bílina provides a window on Lower Miocene marshland environments (KVAČEK 1998). In the vicinity of the town Kadaň [Kaaden] fossil woods often occur in volcanic sediments (PRAKASH, BŘEZINOVA, & BŮZEK 1971).

The silicified woods studied in this paper, in Kadaň trunks from 20–120 cm in diameter, have been collected up to 1995 by P. COUFAL (Chomutov) and O. FEJFAR (Praha). Minerals of the North Bohemian lignite basin confined to silicified and sideritized tree trunks, branches and roots represent a large group of minerals. For a comprehensive, illustrated account of all geological aspects of the North Bohemian lignite basin and its fossil wood remains, see BOUŠKA & DVOŘAK (1997).

1.2. Taxonomic treatment

Ground cross, tangential and radial thin sections, a total of 105 thin sections, were prepared using conventional techniques by P. COUFAL, Chomutov. The maximum size of the epoxy-mounted thin sections is 35 × 40 mm. The preservation of the wood structure is predominantly

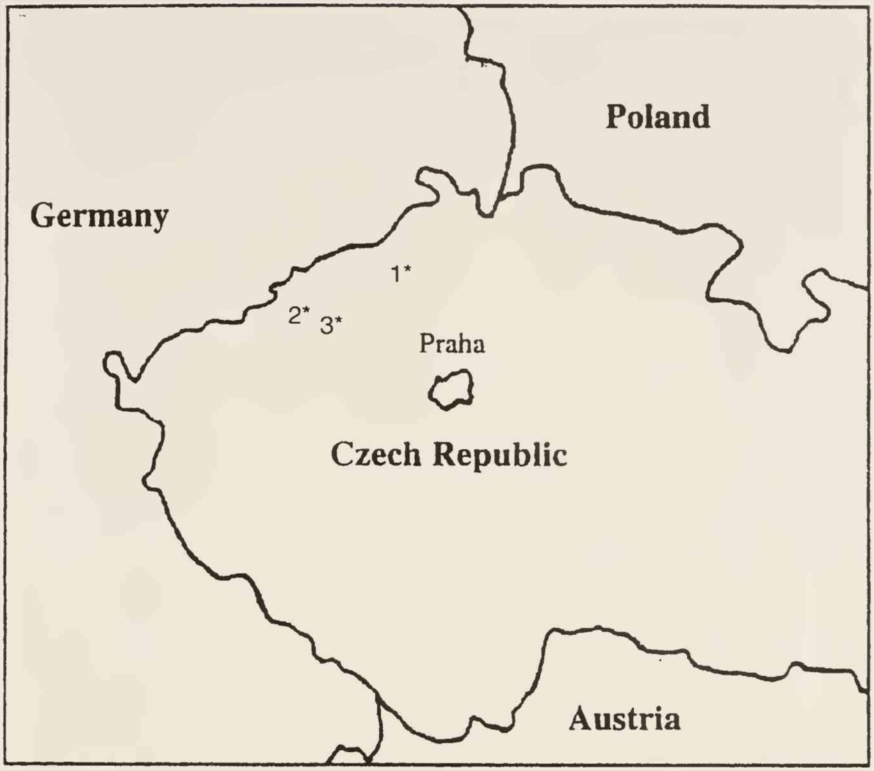

Fig. 1. Geographic position of some localities in the region of the great open-cast mine Bílina, North Bohemian Basin, Czech Republic. – Finding places of silicified woods: 1* Mine Bílina, 2* Kadaň and Libouš, 3* Velka Černoc.

fairly good, but in part very poor, especially in many longitudinal sections. Some samples are very badly compressed; measurements could only be obtained from a few portions. Therefore the descriptions often lack desirable quantitative anatomical details, but are sufficient to identify the wood remains at the generic level. Wood samples are referred to by their collection numbers. Thin sections and other fossil material is partly deposited in the Bavarian State Collection of Palaeontology, Munich, partly in the Mine Museum Chomutov, Czech Republic.

Table 1. Closely related extant genera of silicified woods from the North Bohemian Basin (Mine Bílina, Kadaň, Kadaň-Libouš [Liebisch], Velka Černoc [Groß-Tschernitz]).

Taxa	Wood samples	Thin sections
Taxodium ; Gymn. indet.	21	69
Castanea	1	4
Robinia	1	4
Platanus	5	18
Dicot indet.	1	3
	Total 29	Total 98

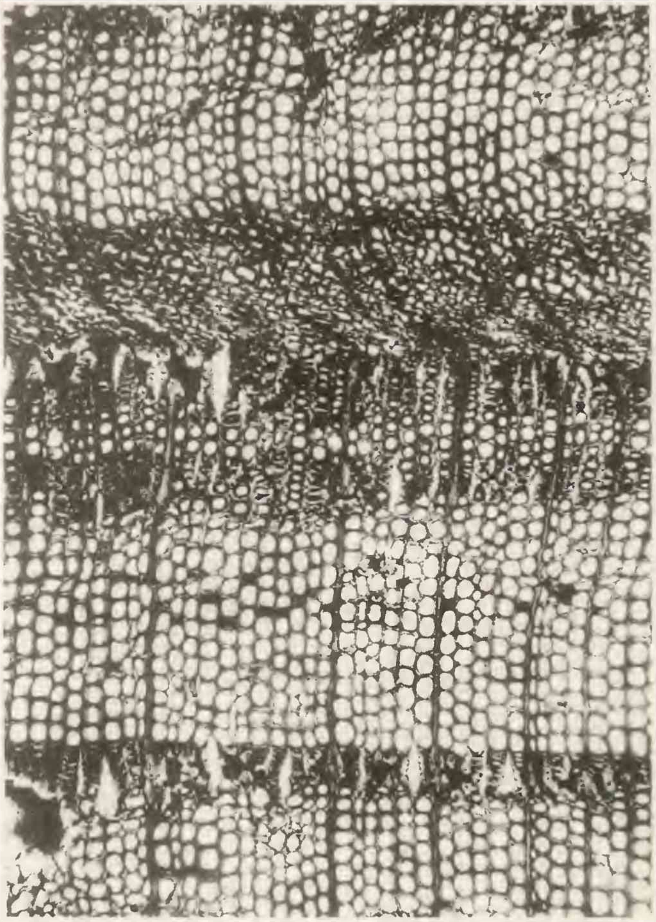

Fig. 2. *Taxodioxylon* sp., Mine Bílina, No. 4. Cross section with two growth ring boundaries, dark parenchyma cells in the early wood. × 40. – Microphotographs Fig. (2–11) and (13–25) A. SELMEIER.

Photomicrographs (Fig. 2–11)

The geological age of the wood remains is Lower Miocene, more than 20–17 million years ago. The 105 thin sections from the North Bohemian Basin are different in mineral composition, in colour, in thicknes (20–30 μm) and in the stages of wood decay. Understandably, the microscopic photomicrographs differ in the quality of reproduction. Due to compression, the cross-field and intervessel pits are often difficult to observe; anatomical features are only partly preserved and not always visible as usual in extant wood thin sections.

Literature for wood identification

Familial and generic affinities were determined by consulting literature such as BAREFOOT & HANKINS (1982), BRAZIER & FRANKLIN (1961), CARLQUIST (2001), CUTLER et al (1987), GREGUSS (1955, 1959), GROSSER (1977), IAWA list (1989), ILIC (1991), METCALFE & CHALK (1950) and searches in the "Fossil wood database" (WHEELER 1991 a, b). Comparisons were made with sections of extant wood xylothec housed in the Institute of Wood Research, Technical University, Munich (STERN 1988; Index Xylariorum, p. 229–230).

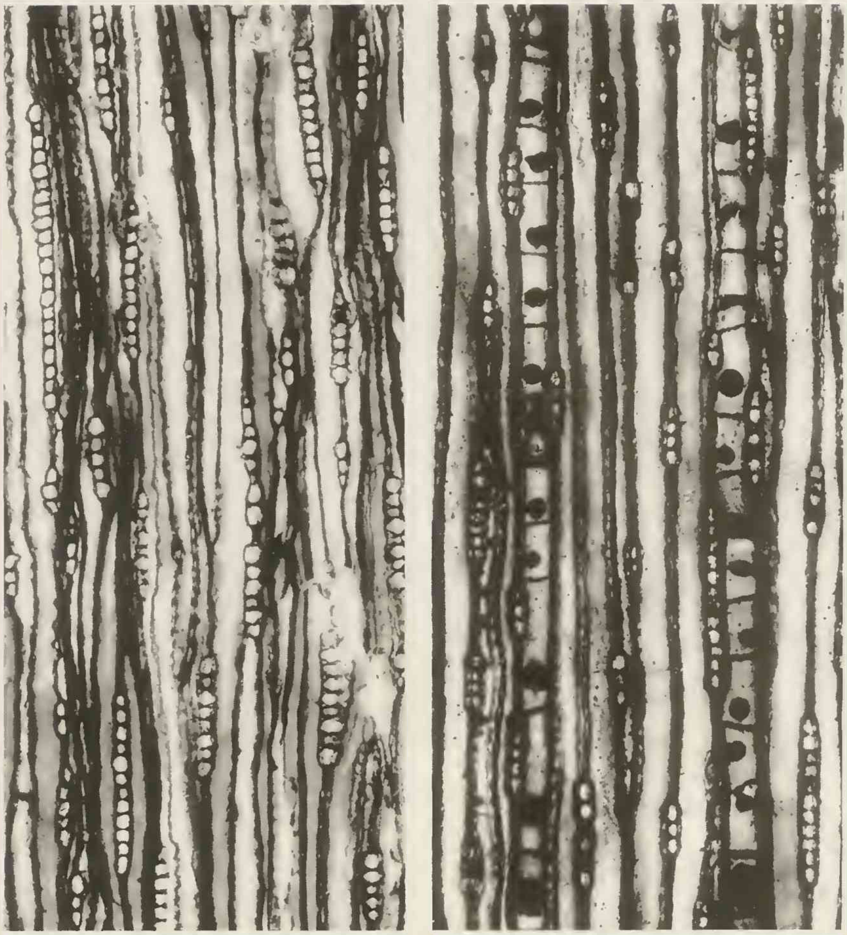

Fig. 3. *Taxodioxylon* sp., Mine Bílina, No. 4. Longitudinal tangential sections; left (× 80) uniseriate homocellular rays; right (× 90) two axial strands of parenchyma cells with dark circular deposits.

Taxodiaceae

Taxodioxylon (Hartig) Gothan 1905

Taxodioxylon sp.
(Fig. 2–4)

Locality: Mine Bílina

Material: Silicified trunks or small samples. No.1 (Merunice [Meronitz]), No. 2 (Kučlin [Kutschlin]), No. 4–5; a total number of 14 thin sections. Preservation of internal structure is best in No. 4 and 5.

Locality: Kadaň

Material: Silicified trunks or small samples, No. 3 (diameter 80–120 cm), No. 5 (diameter 80–110 cm), No. 6 (diameter 40–70 cm), No. 7 (diameter 30–40 cm), No. 8 (diameter 20 cm),

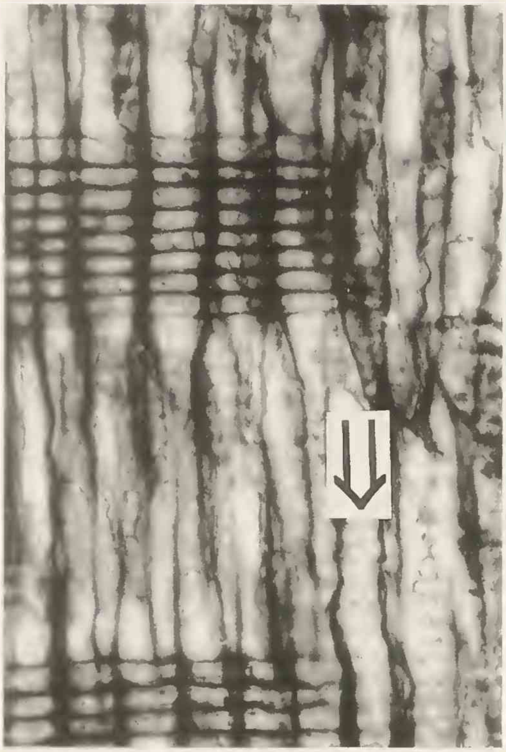

Fig. 4. *Taxodioxylon* sp., Mine Bílina, No. 2. Longitudinal radial section; radial tracheid walls with opposite (arrow) pits and cross field pitting. × 90.

No. 9 (diameter 50–70 cm), No. 10 (diameter 70–90 cm), No. 11 (diameter 15–20 cm), No. 13 (diameter 40–50 cm), No. 15 (diameter 60 cm), No. 17 (diameter 10–15 cm), No. 18 (diameter 40–55 cm), No. 20 (diameter 30–50 cm), No. 21 (diameter 20 cm); a total of 44 thin sections with great differences in preservation and stages of wood decay. – Gymnosperms indet: 35 thin sections from trunks or small samples, preservation of internal structure extremely poor.

Locality: Libouš, eight km east of Kadaň

Material: Silicified trunk, 80 cm in diameter; Libouš No. 1, three thin sections.

Description

Silicified secondary woods of homoxylous structure without bark or pith.

Growth rings variable in width, ranging from 0.2–5.2 (mean 1.7) mm. Tracheids angular in cross section, very wide in the early wood, tangential 20–30 µm, radial 40–55 µm; narrow in the late wood, tangential diameter 15–20 µm, radial 7–10 µm. Bordered pits in the radial walls of the early wood bi-seriate, diameter 14–20 µm. Axial parenchyma diffuse in cross section, cells between 115–380 µm high, horizontal walls thin and smooth, frequently nodular, however the nodules are generally very small; parenchyma cells in tangential view often with circular dark deposits. Rays exclusively one cell wide and up to 37 cells high; height of the cells 12–16 µm; cross-field pits partly in horizontal line, taxodioid or glyptostroboid, diameter 8–10 µm.

Affinities

The samples are characterized by a) distinct growth rings, b) wood tissue consisting of axial tracheids, axial parenchyma, parenchymatous rays, c) bordered pits on radial walls of tracheids arranged in one or two rows, d) cross-field pits fairly large and with wide taxodioid / glyptostroboid apertures, e) axial resin canals absent. All these features agree with those of *Taxodioxylon*, which is similar to the extant species of *Taxodium*.

The coniferous wood tissue of many specimens from Mine Bílina and Kadaň is decayed and locally crushed. But the anatomical features that are preserved make it more than probable that all the above listed wood samples (Table 1) must be assigned to *Taxodioxylon* sp.

Note: *Taxodioxylon* is found throughout the whole Tertiary and is one of the most common Tertiary coniferous woods in Europe and the rest of the Northern Hemisphere. Most of the Tertiary (not Upper Cretaceous) wood remains are to be assigned to *T. gypsaceum* (VAN DER BURGH & MEIJER 1996, Table 3). *Taxodioxylon gypsaceum* is a highly variable polyphyletic species. According to the standard literature the cross-field pits vary from taxodioid to glyptostroboid or cupressoid.

Cross-field pitting is one of the most important anatomical features for identification of coniferous woods. In the standard literature, references almost exclusively use the five "classical" cross-field pit types published by PHILLIPS (1968). As part of a large-scale investigation (GROSSER & VOGEL 1996), a total of 86 species from 56 genera of the class Pinatae were studied; the great variety in cross-field pit form was divided into eight newly defined pit types, in contrast to PHILLIPS' 5 types.

Fagaceae

Castanoxylon NAVALE 1962

Castanoxylon sp.

(Fig. 5)

L o c a l i t y : Velka Černoc

M a t e r i a l : Silicified trunk, No. 22; wood tissue bleached and with poor contrast, preservation of internal structure is sufficient for identification; 4 thin sections.

Description

Silicified secondary dicotyledonous wood without bark or pith.

G r o w t h r i n g s distinct, wood ring-porous, growth rings 1.7–6.2 (mean 3.2) mm wide. V e s s e l s of early wood very large, plainly visible to the naked eye, forming a broad, conspicuous band, solitary and arranged in 2 or 3 layers, oval or elliptic in cross section, tangential diameter max. 285 µm, transition from early to late wood abrupt, late wood vessels small, arranged in oblique or radial pattern, broader rings with flame-shaped arrangement, vessels in the late wood numerous to very numerous, tangential diameter 35–78 µm. Perforation plates simple, intervessel pits not observed. A x i a l p a r e n c h y m a indistinct, scanty paratracheal and apotracheal-diffuse. R a y s unstoried, exclusively uniseriate, homocellular, heigth 3–33 (75–650 µm) cells, ray-vessel pitting not observed.

Affinities

This wood is characterized by a) distinct ring porosity, b) large circular vessels in the early wood with an abrupt transition to small polygonal vessels in the latewood, c) flame-like

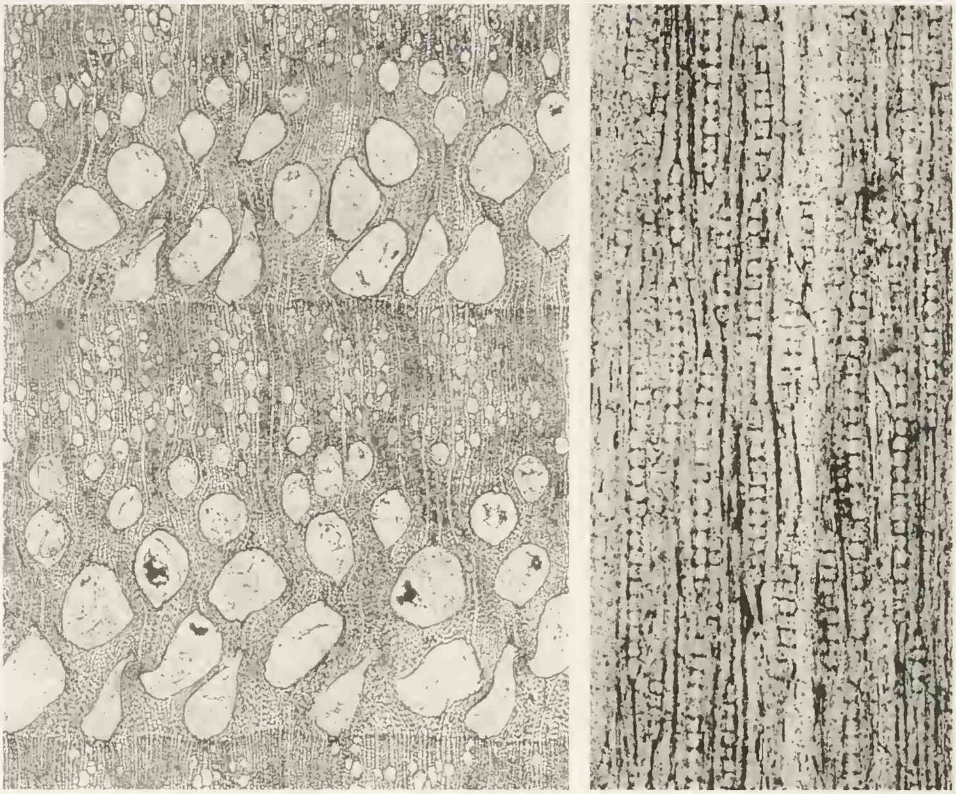

Fig. 5. *Castanoxylon* sp., Velka Černoc, No. 22, ring-porous wood. Left (× 15), cross section with two growth ring boundaries; right (× 80), longitudinal tangential section with exclusively uniseriate homocellular rays.

latewood vessel pattern in the broader growth rings, d) rays exclusively uniseriate, unstoried, homocellular. These features occur in *Castanea* L. and *Castanopsis* Spach., both in family Fagaceae. *Castanea* has continuous vessel zones in the early wood and differs from *Castanopsis* with early wood vessels distinctly separated by usually libriform fibres or banded axial parenchyma (Suzuki & Terado 1996).

Until now, Tertiary *Castanea* woods have been reported from Japan, from Germany (Selmeier 1970, 1991) and France (Privé-Gill & Watélét 1980). At a distance of only 100 km west of the Kadaň locality, Czech Republic, there is the first European record of a silicified Tertiary *Castanea* wood (basalt quarry at Weidersberg, NE Bavaria; Selmeier 1970). More than 40 wood remains of geological age Miocene/Pliocene, collected in the Neuburger Forest near Passau, Bavaria, form the largest collection of silicified *Castanea* woods at present known (Selmeier 1991).

Platanaceae
Platanoxylon ANDREANSKY 1951

Platanoxylon sp.
(Fig. 6–7)

Locality: Kadaň

Material: Silicified trunks and smaller samples; No. 4 (diameter 30–40 cm), No. 12, No. 14 (diameter 50–70 cm), No. 16 (diameter 40–50 cm), No. 19 (diameter 50 cm); a total of 18 thin sections. Preservation of internal structure is best in No. 14.

Description

Silicified secondary dicotyledonous wood without bark or pith.

Growth rings often a little indistinct, boundaries partly arched, 3 growth rings 2.7–4 mm wide. Vessels very numerous, moderately small, 50–100 µm mean tangential diameter, barely visible to the naked eye, solitary and in radial to tangential pairs and radial multiples, tending to be more numerous at the beginning of a growth ring. Perforation plates simple for

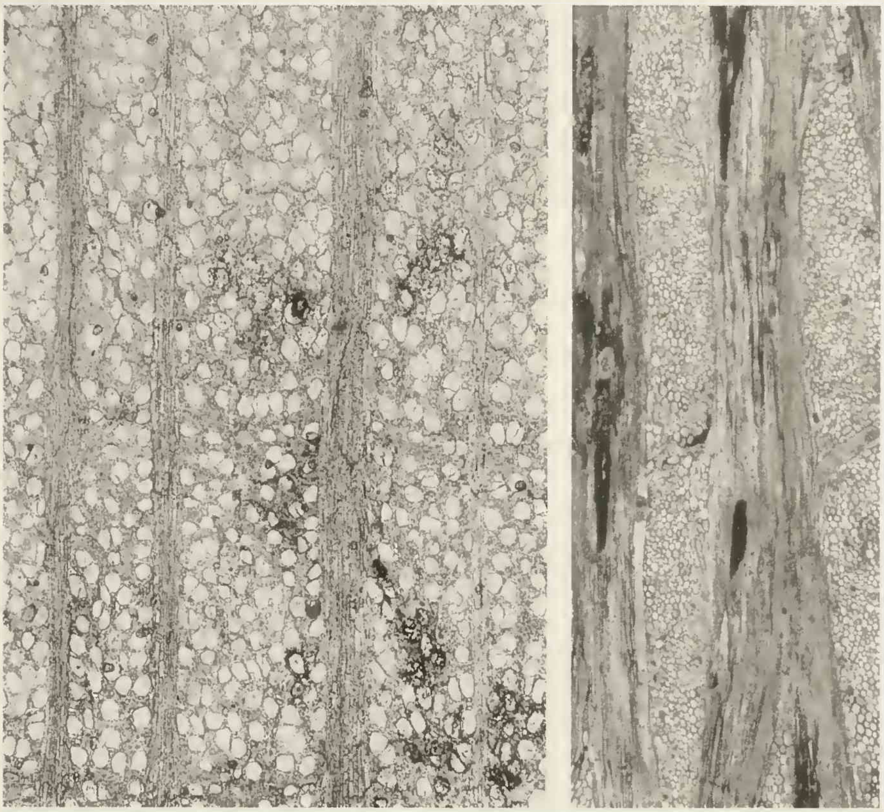

Fig. 6. *Platanoxylon* sp., Kadaň, No. 14, diffuse porous wood. Left (× 50), cross section with four rays, weakly enlarged on the growth ring boundaries; right (× 60), longitudinal tangential section with large, multiseriate rays.

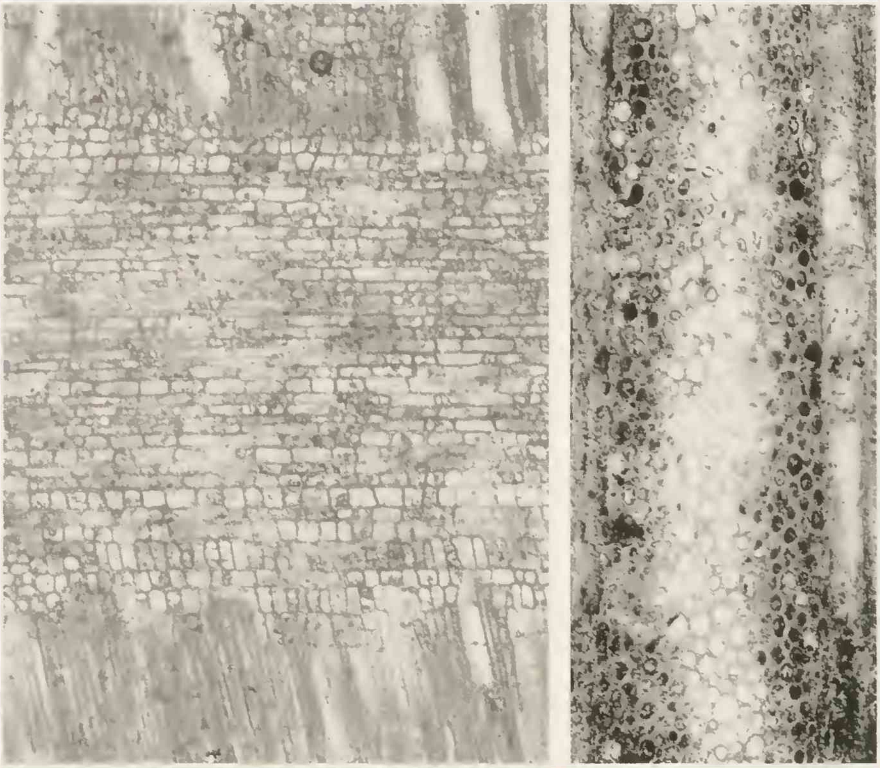

Fig. 7. *Platanoxylon* sp., Kadaň, No. 19. Left (× 100), longitudinal radial section, procumbent and quadratic ray cells; right (× 100), longitudinal tangential section, outline of ray cells predominantly oval, tendency to heterocellular structure.

the most part, occasionally scalariform with a few bars. Intervessel pits not observed. Axial parenchyma scanty paratracheal and diffuse. Rays unstoried, visible to the naked eye, at the growth ring boundaries swollen and broader, mainly 4–14 cells wide, up to 2 mm in height, sometimes dissected into shorter units, homocellular with a tendency to heterocellular ray tissue.

Affinities

The combination of structural features exhibited by these fossil woods indicates their resemblance to modern woods of the Eupteleaceae (*Euptelea*), Fagaceae (*Fagus*), Icacinaceae (*Citronella*, *Ottoschulzia*) and Platanaceae (*Platanus*). However, on closer comparison the fossil wood specimes appear to be closer to *Platanus* than to any other genera mentioned above. *Euptelea*, *Citronella* and *Ottoschulzia* differ in possessing distinctly heterogenous rays, *Fagus* differs in having oak-type rays. The silicified woods most closely resemble the anatomical features of the extant genus *Platanus*. The minute structure of these fossils agrees better with the anatomical features of *Platanoxylon* ANDREANSKY (1951), than with *Plataninium*, sensu PAGE (1968).

A great number of Cretaceous and Tertiary *Platanus* woods are known from various localities in the world (Europe, North America, Japan). At about 200 km distance from the Kadaň locality, Czech Republic, more than 30 *Platanoxylon* woods from 17 different localities have been reported from Tertiary sediments in Bavaria and Austria (SELMEIER 1989, 1996, 1998). Comprehensive information about fossil nomenclature, an emended specific diagnosis, and the fossil record of Platanaceae is given by SELMEIER (1996).

The only extant genus of the Platanaceae is *Platanus,* which includes about eleven species of large trees, three in southern Europe and Asia (Laos), eight in temperate North America, Mexico and Guatemala. Five species are found only in Mexico. *Pl. orientalis* L. grows in North America, in South and Central Europe, in Asia Minor and Iran.

Platanoid Types, 84 million years ago

Angiosperm woods of the platanoid/icacinoid type occur throughout the Upper Cretaceous (84–66 million years old) in the continental strata of Big Bend National Park, Texas, USA. The platanoid wood type is common in the Cretaceous and Lower Tertiary, and is among the earliest known, already occurring in the Albian (Cretaceous). Such woods with heterocellular rays are usually assigned to *Icacinoxylon*; woods with homocellular or near homocellular rays are usually assigned to *Plataninium*. A comprehensive reevaluation is needed for all specimens with platanoid/icacinoid structure (WHEELER & LEHMAN 2000). The ray tissue of the Miocene sample No.14, locality Kadaň, is homocellular with a distinct tendency to heterocellular structure. This ray pattern is presumably a late stage in wood evolution since the Upper Cretaceous.

Leguminosae
Faboideae

Robinioxylon PLATEN 1908
Robinioxylon sp.
(Fig. 8–9)

Locality: Mine Bílina

Material: Silicified trunk, sample No. 3 with 4 thin sections; preservation of internal structure is fairly good.

Description

Silicified secondary dicotyledonous wood without bark or pith.

Growth rings distinct, 19 rings 0.4–1.6 (mean 0.8) mm wide. Vessel arrangement ring porous, solitary, only one layer in the early wood, tangential diameter 168–280 µm, late wood vessels in clusters with wavy arrangement. Perforations simple, transverse inclination more or less horizontal; intervessel pits crowded alternate, angular in outline, vessel element length ca. 180 µm, thin-walled tyloses obviously decayed due to mineralisation, helical thickenings in some narrow latewood vessel elements. Axial parenchyma predominantly paratracheal, parenchyma cells fusiform and storied, also chambered axial parenchyma strands with one crystal per chamber, strands usually with up to 8 crystalliferous cells. Rays spindle-shaped, one to 6-seriate, multiseriate rays up to 43 cells high, homocellular with procumbent ray cells, multiseriate rays partly in contact with chambered crystalliferous parenchyma strands.

Note: *Robinioxylon* wood No. 3 shows insect attack in cross section. Diameter of a round bore-hole 650 µm, an oval bore-hole 1.7:0.8 mm; diameter of the brown coproliths 75:31 µm.

Affinities

The combination of ring-porosity, latewood vessel clusters arranged in a tangential wavy pattern, simple perforations, fusiform and storied parenchyma cells, chambered crystalliferous

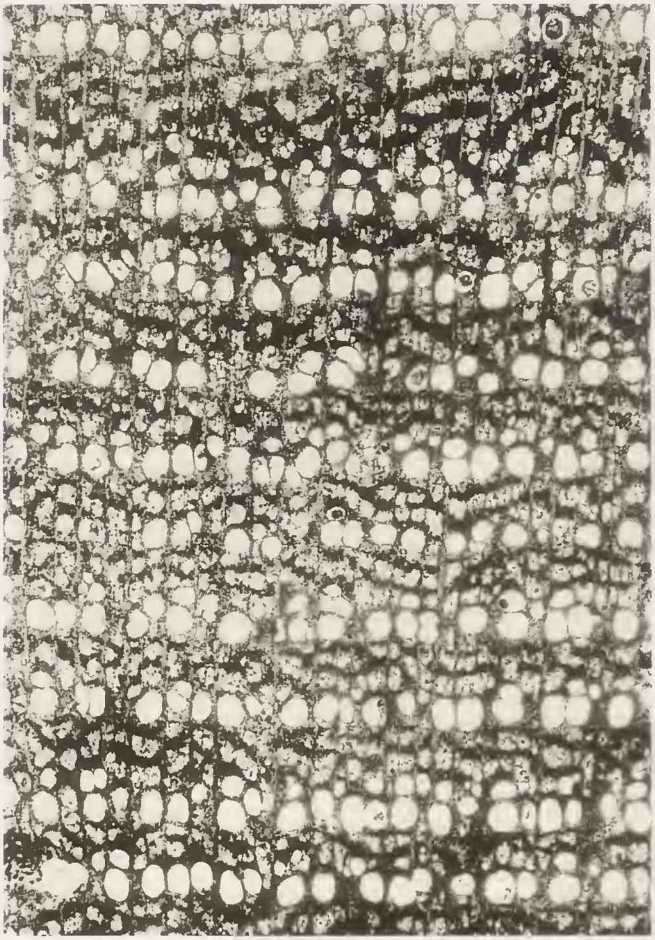

Fig. 8. *Robinioxylon* sp., Mine Bílina, No. 3, ring-porous wood. Cross section with ten growth ring boundaries, late wood extremely small, vessels in clusters and in wavy arrangement; presumable part of a branch. × 20.

parenchyma cells is typical of *Robinia* L. (Faboideae). Extant trunk woods of *Robinia* are characterised by a concentration of large vessels in 2 or more loosely defined rows. PAGE (1993) has given a detailed analysis of selected quantitative features of secondary xylem from trunk, branch and root (*Robinia pseudoacacia* L.). The results of the survey show considerable overlap in ranges of variation in the fossil Miocene and extant woods. Differences noted between trunk, branch and root wood of extant *Robinia* make it possible to distinguish these organs among the fossils also. According to PAGE (1993: 302), the most noticeable differences between stem and branch wood are in shape, size and distribution of early-wood vessels and in the frequency of solitary vessels. Both large and small roots appear diffuse-to semi-ring-porous. Branch wood, however, has narrow growth rings and only a very small amount of latewood, comparable with the specimen from Mine Bílina, No. 3. The wood under investigation can therefore be identified as typical in xylem structure to a branch.

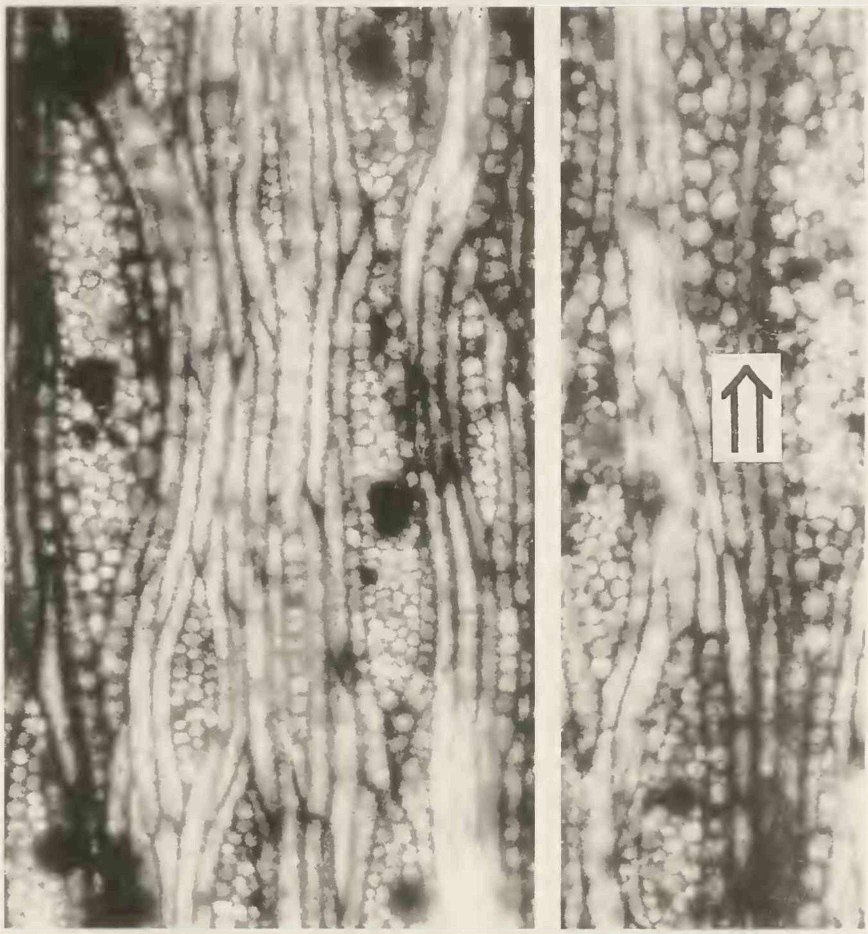

Fig. 9. *Robinioxylon* sp., Mine Bílina, No. 3. Longitudinal tangential sections. Left (× 110), homocellular rays and storied parenchyma cells; right (× 110), rays in contact with strands of chambered parenchyma cells (arrow), solitary rhomboid crystals in the chambered cells.

There have been numerous reports of fossil woods of *Robinia*, which may be due to (a) its abundance in Tertiary vegetation, and/or (b) its resistance to decay. *Robinia* wood is noted for its durability and would have a "longer" time and greater chance to be permineralized rather than be decayed by fungi (WHEELER & LANDON 1992). The fossil record for *Robinia* woods has been reviewed by MATTEN et al. (1977) and SELMEIER (1984). Records in Europe: Sardinia (1907), France (PRIVÉ-GILL & WATÉLÉT 1980) and the northalpine Molasse basin of Bavaria: 29 different Tertiary localities with a total of 83 silicified *Robinia* woods (SELMEIER 1998).

Dicot indet.
(Fig. 10–11)

L o c a l i t y : Kadaň

M a t e r i a l : Silicified trunk, No.12. Preservation of internal structure is poor, especially the longitudinal sections; 3 thin sections.

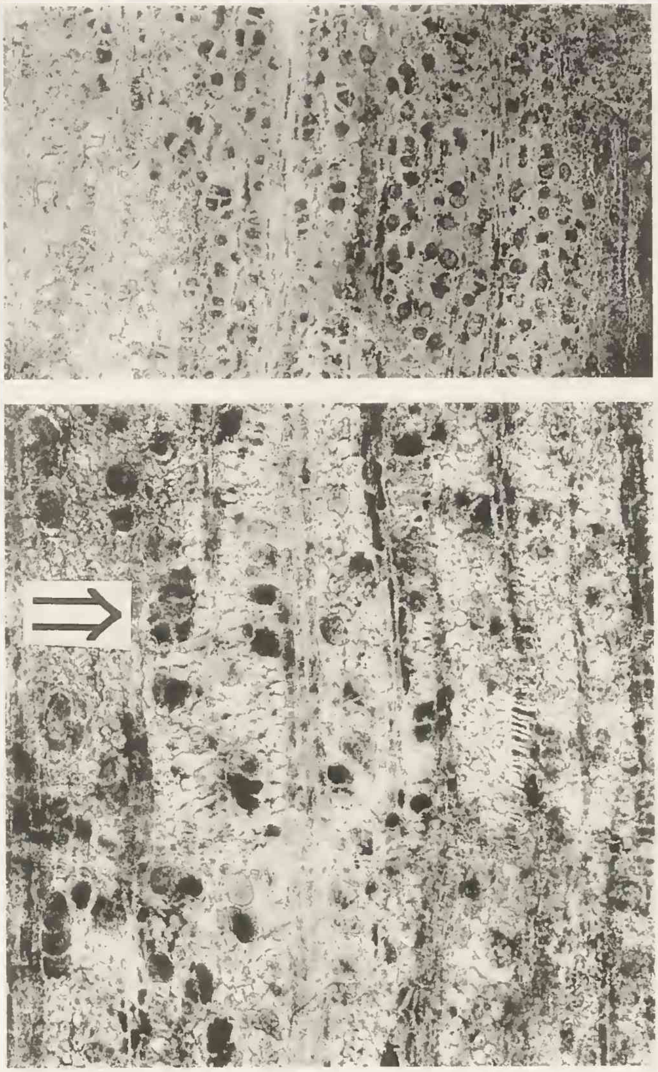

Fig. 10. Dicot indet., Kadaň, No. 2. Cross sections, above (× 30), below (× 70); small vessels evenly distributed, pores solitary, multiples and partly in small clusters (arrow).

Description

Silicified secondary dicotyledonous wood without bark or pith.

G r o w t h r i n g s indistinct, 2–3 layers of radial flattened fibres. V e s s e l s minute, evenly distributed, tangential diameter less than 100 µm, solitary and in radial multiples of 2–4, tangential diameter 45–60 µm, partly in small clusters; vessels filled with yellow-darkbrown deposits; clusters e.g. (7 cells), radial diameter 140 µm, tangential diameter 75 µm. Perforations simple; intervessel pits minute. R a y s 3–4-seriate with marginal cells, almost homocellular, ray cells in tangential view distinctly polygonal, rays e.g. 21 (350 µm) cells high, 4 (52 µm) cells wide. Wood tissue locally destroyed by crystals due to diagenetic processes of mineralisation.

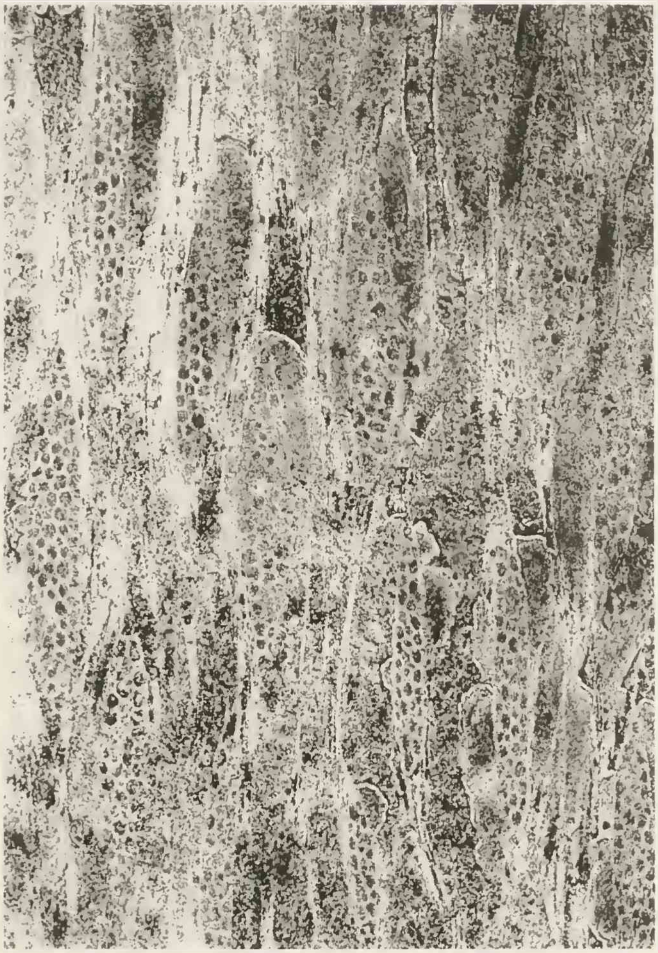

Fig. 11. Dicot indet., Kadaň, No. 2. Longitudinal tangential section; rays 3–5-seriate, ray cells polygonal in tangential view, homocellular. × 110.

Affinities

The most outstanding feature of this diffuse-porous wood is the presence of extremely minute vessels, solitary and in radial multiples, occasionally in small clusters.The structure of the vessel perforations is difficult to observe as also are other diagnostic details.

1.3. Discussion

The silicified Middle Miocene woods from the North Bohemian Basin, Czech Republic, represent Taxodiaceae (*Taxodium*), Fagaceae (*Castanea*), Leguminosae (*Robinia*) and Platanaceae (*Platanus*). The anatomical identifications agree very well with the knowledge obtained so far from other types of plant remains. Most of the informations on Tertiary plants come from the study of leaves, cones, fruits, seeds and pollen, rather than wood. The fossil woods from the North Bohemian Basin can be assigned to extant taxa with New World relatives. All woods have well defined growth rings with marked changes in wood structure within a growth ring. Distinct growth rings, shown in all the above described silicified woods, may be regarded as an adaptation to distinct seasonal change in the Miocene age. The growth rings, 102 visible in the cross sections of the Gymnosperms (*Taxodioxylon*), range from 0.2–5.2 (mean 1.7) mm in width. These rings are an important source of information about past climates and fossil environments (Table 2). Fossil tree rings are dependent on seasonality, annual growing conditions, water availability, limiting temperatures and forest productivity in the geological past. Possible "false rings" may be caused by a severe drought in the growing season resulting in the production of a few very small cells which mimic an end-of-season boundary within the growth ring (CREBER & FRANCIS 1999). In accordance with Table 2, the growth rings of *Castanea* (1.7–6.2 mm) and *Platanus* (2.7–4.0 mm) are from stem wood (? great trees). The *Robinia* wood, 19 year-to-year variations in ring width with a mean of 0.8 mm wide, must be assigned to branch wood (PAGE 1993).

Table 2. Closely related extant genera of silicified woods from the North Bohemian Basin and number of growth rings visible in cross sections.

Taxa, (No.)	Growth rings	Minimum, mm	Maximum, mm	Mean, mm
Taxodium (1)	14	0.3	5.2	1.7
Taxodium (2)	27	0.2	1.3	0.8
Taxodium (4)	27	0.2	2.8	0.9
Taxodium (5)	13	0.4	1.7	1.2
Taxodium (6)	12	1.3	3.0	1.9
Taxodium (7)	9	0.2	1.7	0.8
Castanea (22)	10	1.7	6.2	3.2
Platanus (14)	3	2.7	4.0	3.3
Robinia (3)	19	0.4	1.6	0.8

The dominance of *Taxodium*, common as wood remains in many Tertiary plant assemblages, is also typical for the Bílina open-cast mine.The internal part of coalified trees, has sometimes been found to be silicified or altered into a massive argillaceous carbonate. "Chemofossils", Duxite and its geochemical biomarkers, have been discovered some years ago in fossil trees from Bílina open-cast mine. Duxite, a mixture of hydrocarbons with resins and waxes, is usually concentrated in preserved parts of trees and mostly found in connection with the genus *Taxodium*. VÁVRA, BOUŠKA, DVOŘÁK (1997) reviewed the literature data and reported on the results of chemical studies on fossil coniferous material from the Bílina open-cast mine using methods of gas chromatography and mass spectroscope.

The Lower Miocene deposits of the North Bohemian Basin have yielded a wealth of plant fossils, predominantly leaves and pollen (KVAČEK 1998). Vegetation of coal-forming swamps, flood plains and uplands can be reconstructed. The flora includes ferns, riparian forests with conifers and angiosperms with more than 80 species. Although there were only few fossil wood specimens available for this study, the deciduous trees *Castanea* and *Robinia* can be added to the list of Tertiary leaf, pollen and wood remains (Table 3). *Castanea* and *Robinia* are not recorded by PRAKASH, BŘEZINOVA & BŮZEK (1971) or KVAČEK (1998).

Table 3. Silicified woods of this study in comparison with the fossil wood record of PRAKASH et al. (1971) and with plant assemblages of leaves and pollen in Northern Bohemia (KVAČEK 1998).

Taxa	This study, 2001	PRAKASH et al. 1971	KVAČEK 1998
Taxodium	+	+	+
Castanea	+	-	-
Platanus	+	+	+
Robinia	+	-	-
Dicot indet.	+	+	+

2. Silicified Miocene woods from NW Turkey

2.1. Introduction (Fig. 12)

In 1992, EMIL GREBER made a collection of silicified woods during work for his geological dissertation (ETH Zürich, Switzerland) in NW Turkey. 16 wood samples, geological age Middle to Upper Miocene, are available for this study. The wood remains, presumably accumulated driftwood, were found in the so-called "Kuzuluk series", district Adapazari, NW

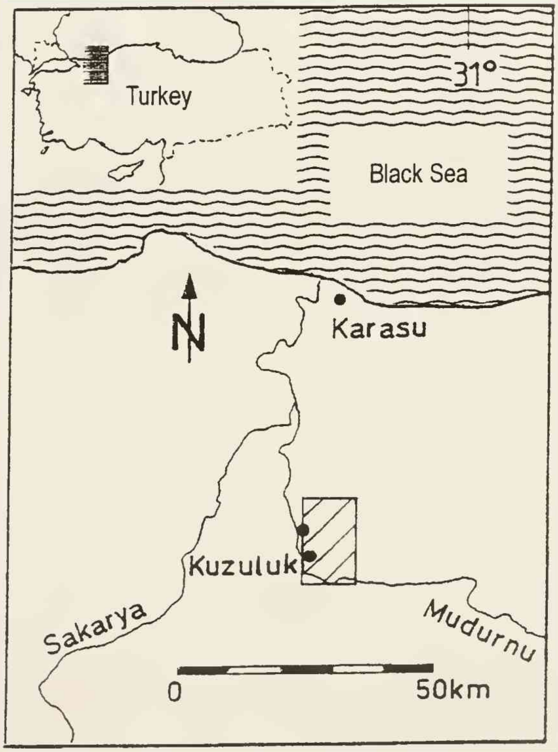

Fig. 12. Geographic position of the Kuzuluk area, NW Turkey. Localities of silicified woods in surrounding of hot and cold water springs.

Turkey. In the tectonic basin of Kuzuluk there are approximately 40 hot and cold water springs. The area is situated about 150 km ESE from Istanbul and 50 km south of the Black Sea. After the collision of Arabia and Eurasia at the end of the Middle Miocene, the "neotectonic regime" was etablished in Turkey (GREBER 1992). The landmass of Turkey broke into blocks and basins. The Kuzuluk series with vulcanic tuffs and partly silicified fluvial deposits can be considered as such a basin filling.

2. 2. Taxonomic treatment

Ground cross, tangential and radial thin sections, a total of 51 thin sections, were prepared by E. GREBER, Switzerland (Table 4). The preservation of the wood structure is predominantly fairly good, but in part poor, especially the acryl-sprayed longitudinal sections. Therefore the descriptions often lack desirable anatomical details, but are sufficient to identify the wood remains to generic level, exception being *Taxaceoxylon* cf. *rajmahalense*. Wood samples are referred to by their collection number. The wood fossils are maximum of 50 cm in length. Thin sections and other fossil material are deposited in the Bavarian State Collection of Palaeontology, Munich, and in the Natural History Museum, Basel, Switzerland.

Table 4. Closely related extant genera of silicified woods from the Kuzuluk series near water spring Kay 18, 150 m NW of Eski Hamam and near Orta-Mah (GREBER 1995).

Taxa	Wood samples	Thin sections
Taxus	2	6
Taxodium	7	21
Alnus	2	8
?Euphorbiaceae	1	5
Dicot indet.	4	11
	Total 16	Total 51

Photomicrographs (Fig. 13–25)

The geological age of the wood remains is Middle to Upper Miocene, over 14 million years ago. Therefore some anatomical features are only partly visible and cannot be observed as in extant wood thin sections. The 46 thin sections from Kuzuluk vary in mineral composition, colour, thickness (20–30 µm) and in stages of wood decay. Therefore, the photomicrographs differ in the quality of reproduction, especially photographs of the acryl-sprayed thin sections.

Taxodiaceae

Taxodioxylon (HARTIG) GOTHAN 1905

Taxodioxylon sp.

(Fig. 13–15)

Locality: Kuzuluk series; area near water spring Kay 18, 150 m NW of Eski Hamam, 86 m NN, and near Orta-Mah, 113–138 m NN.

Material: Silicified woods; sample No. 3 (8×3×10 cm), No. 5 (5×7×18 cm), No. 6 (10×8.5×14 cm), No. 7 (10×8×20 cm), No. 10 (8×9×11 cm), No.12, and No.13 (9×14×42 cm); a total of 21 thin sections. Preservation of internal structure is best in No. 3.

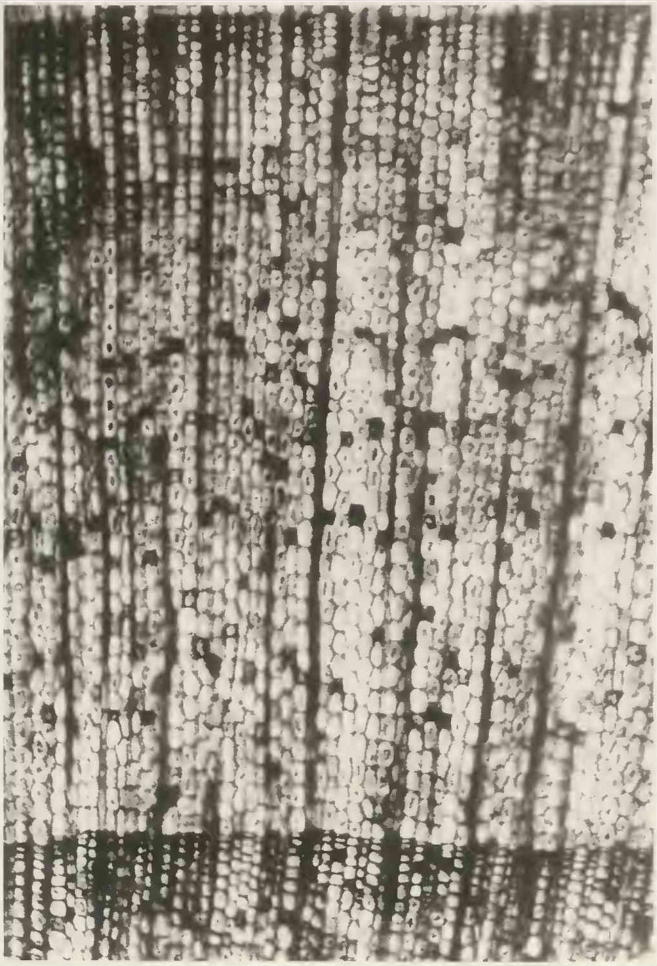

Fig. 13. *Taxodioxylon* sp., Kuzuluk, No. 3. Cross section; growth ring boundary, wood tissue with many dark parenchyma cells. × 50.

Description

Silicified secondary wood of homoxylous structure without bark or pith.

G r o w t h   r i n g s variable in width, ranging in No. 3 from 0.5–4.5 (mean 2.5) mm, in the other seven specimens from 0.3–6.0 mm (Table 4). T r a c h e i d s angular in cross section, very wide in the early wood, tangential 18–43 µm, radial 46–81 µm; narrow and radial flattened in the late wood, tangential 25–31 µm, radial 12–18 µm. cell walls 4 µm thick. Bordered pits in the radial walls of the early wood bi-seriate, diameter 19–21 µm, apertures 6 µm, crassulae visible. A x i a l   p a r e n c h y m a diffuse in cross section, cells 140–275 µm high, horizontal walls thin, sometimes up to 4 µm thick, some horizontal walls smooth, frequently nodular; however, nodules generally very small. R a y s exclusively one cell wide and 1–17 (32–460 µm) cells high; cross-field pits in horizontal line, taxodioid (diameter 12:8 µm) or partly glyptostroboid. A multiseriate ray, unusual in a coniferous wood: 14 cells (480 µm) high and 4–6 cells (152 µm) wide (Fig. 15).

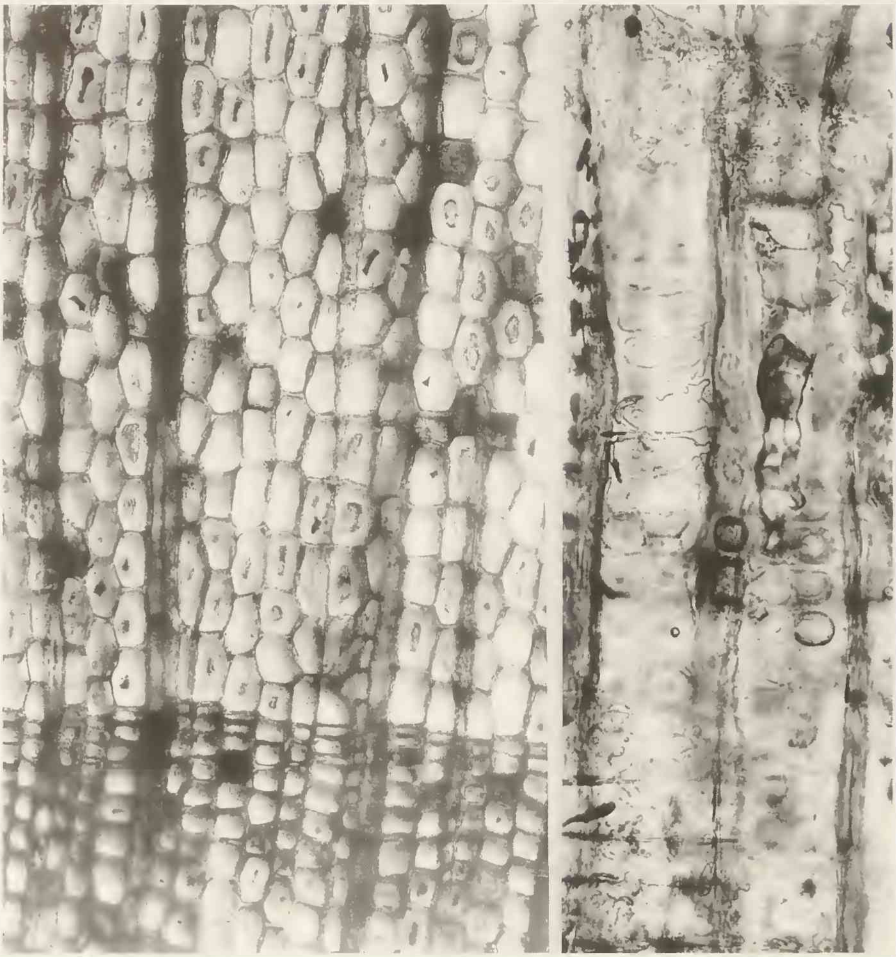

Fig. 14. *Taxodioxylon* sp., Kuzuluk, No. 3. Cross and longitudinal radial sections; left (× 125), growth ring boundary with some radial flattened tracheids, early wood with dark parenchyma cells; right (× 190), radial tracheid walls with opposite bordered pits.

Affinities

The samples are characterised by: a) distinct growth rings, b) wood tissue consisting of axial tracheids and axial parenchyma cells, c) bordered pits on radial walls of tracheids arranged in one or two rows, d) cross-field pits with wide taxodioid /glyptostroboid apertures, e) resin canals absent.

All these features agree with those of *Taxodioxylon*, which is similar to the extant genera of Taxodiaceae. As is well-known, *Taxodioxylon* is one of the most common Tertiary coniferous woods in Europe and the rest of the Northern Hemisphere. Most of the Tertiary (not Upper Cretaceous) wood remains are to be assigned to *T. gypsaceum* (van der Burgh & Meijer 1996, Table 3). Preservation of the internal structure is insufficient in some samples, especially in the longitudinal sections. But all preserved anatomical features make it more than probable that these wood remains can be assigned to *Taxodioxylon* sp.

Fig. 15. *Taxodioxylon* sp., Kuzuluk, No. 3. Longitudinal tangential sections; left (× 100), uniseriate homocellular rays; right (× 90), moreseriate ray, unusual in a coniferous wood.

Taxaceae

Taxaceoxylon (SHIMAKURA) KRÄUSEL et JAHN 1963

Taxaceoxylon cf. *rajmahalense*
(Fig. 16–17)

L o c a l i t y : Kuzuluk series; area near water spring Kay 18, 150 m NW of Eski Hamam, 86 m NN, and near Orta-Mah, 113–138 m NN.

M a t e r i a l : Silicified wood No. 2, (8×4× cm) and No. 4 (8×7×26 cm); a total of 6 thin sections. Preservation of internal structure is best in No. 2.

Description

Silicified secondary wood of homoxylous structure without bark or pith.

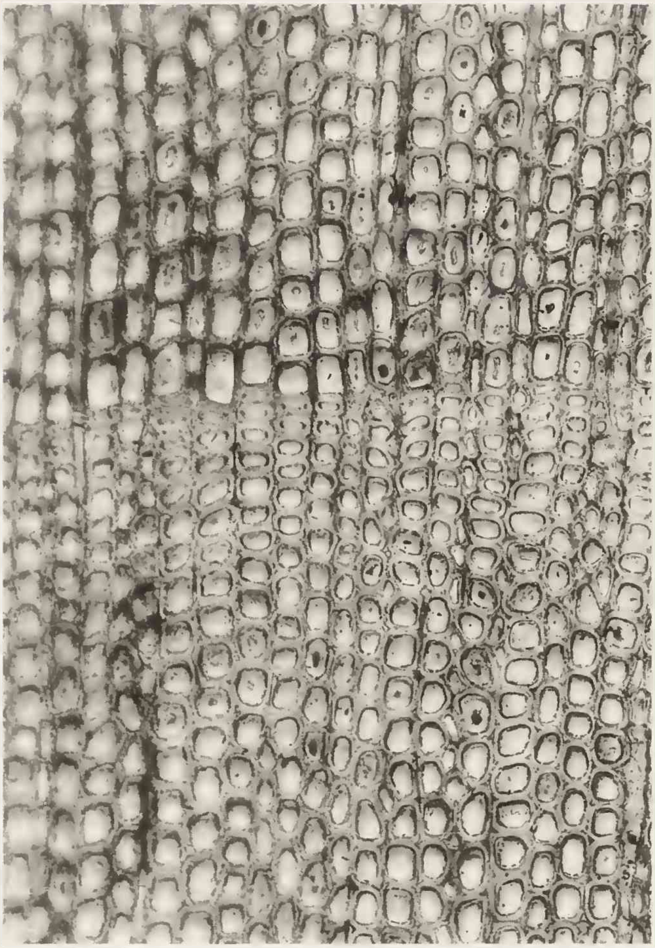

Fig. 16. *Taxaceoxylon* cf. *rajmahalense*, Kuzuluk, No. 2. Cross section with one wave-like growth ring boundary. × 140.

Growth rings distinct with 3–4 radialy flattened latewood tracheids, narrow to medium wide or broad; 19 growth rings, 0.3–1.0 (mean 0.5) mm wide, 21–37 radial tracheids wide, transition from early to late wood very gradual. Tracheids in radial rows, in cross section quadratic or more or less rounded, (1)–3–5–(8) tracheid rows between two rays, earlywood tracheids radial diameter 37 μm, tangential diameter 32 μm, last-formed late wood tracheids radial diameter 15 μm, tangential 32 μm, abundant double spiral thickenings present; partly bordered pits on tracheid walls, diameter 7–14 μm; cross-field pits 1–2–(3), presumably cupressoid. Axial parenchyma absent. Rays very fine, uniseriate or partly with 2-seriate sections, consisting entirely of ray parenchyma, (1)–2–8–(18) cells high; e.g. 1 cell (22 μm), 4 (71 μm), 7 (119 μm), 9 cells (158 μm). Resin canals normal or traumatic, absent.

Affinities

The feature "Spiral thickenings present in early wood tracheids" is characteristic of only two genera of commercial softwoods, i.e. *Taxus* and *Pseudotsuga*. In *Taxus* spirals are present

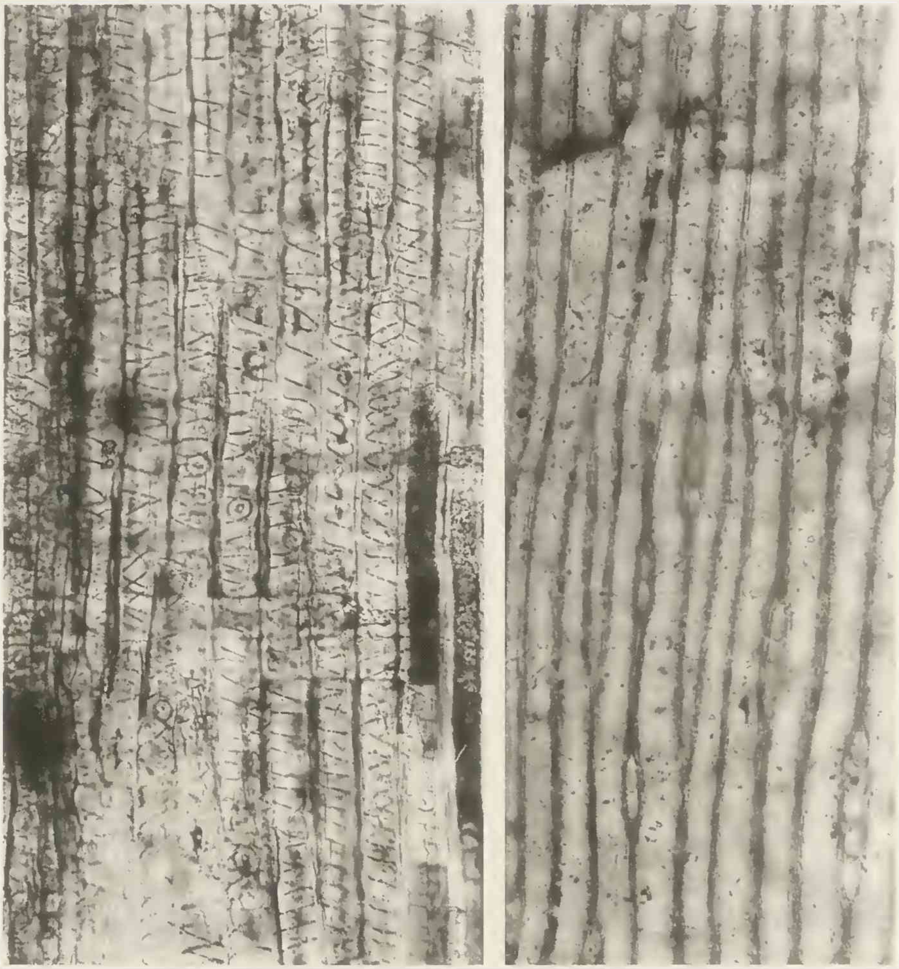

Fig. 17. *Taxaceoxylon* cf. *rajmahalense*, Kuzuluk, No. 2. Longitudinal radial and tangential sections; left (× 160), spiral thickening abundant, a characteristic feature of the genus *Taxus*; right (× 160), uniseriate, homocellular rays.

throughout the annual ring. Note should be made as to whether the spirals are single or multiple. Double spiral thickenings are abundantly visible in the longitudinal thin sections from Kuzuluk.

A total of 14 fossil *Taxaceoxylon*-woods have been studied by light microscop so far (SÜSS 1994). 12 species were collected in Jurassic and Cretaceous or Tertiary localities from East Asia (India, Japan). A detailed anatomical comparison with these 14 fossil woods of *Taxus* shows that the greatest similarity is with *Taxaceoxylon rajmahalense* (BHARDWAJ) KRÄUSEL & JAIN 1963.

The genus *Taxus* contains several species in the northern hemisphere from Japan to the Himalayas, also in Iran, Europe and North America. In Iran fossils of *Prototaxodioxylon* can be ascribed to *Taxus* (NILOUFARI 1984). The silicified *Taxus* wood from Kuzuluk is only the third record of *Taxaceoxylon* in Europe, in addition to species from Hungary and Russia.

Betulaceae
Alnoxylon (FELIX) MÜLLER-STOLL & MÄDEL 1959

Alnoxylon sp.
(Fig. 18–21)

Locality: Kuzuluk series; area near water spring Kay 18, 150 m NW of Eski Hamam, 86 m NN, and near Orta-Mah, 113–138 m NN.

Material: Silicified sample No. 8 (10×9×24 cm), No. 9 and (?) No. 14, fourtheen thin sections. Preservation of internal structure fairly good and poor, best in No. 8.

Description

Silicified secondary dicotyledonous wood without bark or pith.

Fig. 18. *Alnoxylon* sp., Kuzuluk, No. 8, diffuse-porous wood. Cross section with indistinct growth ring boundary. × 120.

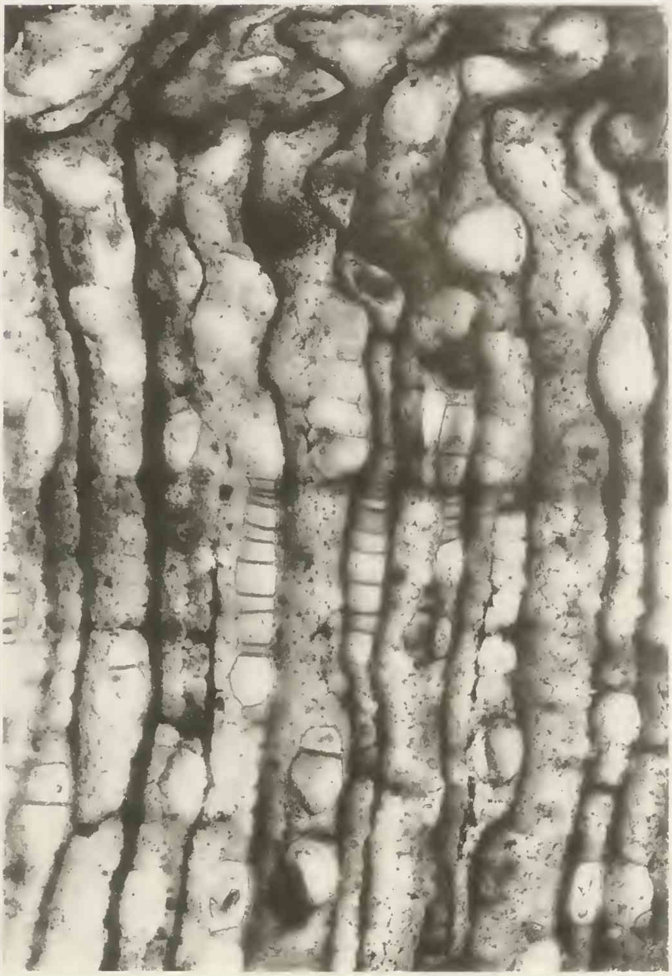

Fig. 19. *Alnoxylon* sp., Kuzuluk, No. 8, diffuse-porous wood. Cross section with evenly distributed vessels, tangential vessel diameter smaller in the latewood, growth ring boundary indistinct. × 120.

Growth rings partly indistinct, growth ring boundary marked by some radially flattened fibres. Vessels numerous, small, indistinct without a hand lens, vessels more or less densely packed, wood diffuse porous, little or no change in vessel diameter throughout growth ring, vessels solitary, in multiples of 2-several and in small clusters; tangential vessel diameter less than 100 (60–70) µm; perforation plates scalariform with 15–30 thin bars, intervascular pitting very fine, alternate and opposite; vessel element length 80–110 µm. Axial parenchyma diffuse, scanty paratracheal and apotracheal-diffuse. Rays uniseriate, homocellular, 2–20–(30) cells high; one aggregate ray visible consisting of units similar to the narrow rays and of included fibres and vessels.

Note: *Alnoxylon* wood No. 14 shows insect attack in two tangential sections with bore-holes and coproliths. An axial bore-hole is tangential 2 mm wide, diameter of an oval bore-hole axial 310 µm, tangential 170 µm; brown coproliths 78 µm long.

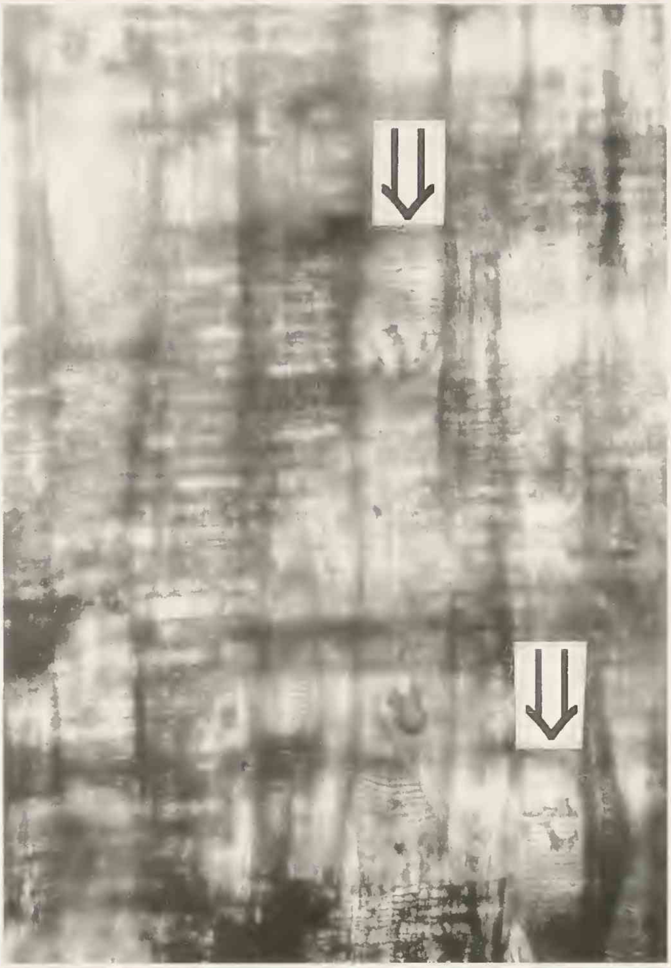

Fig. 20. *Alnoxylon* sp., Kuzuluk, No. 8. Longitudinal radial section, acryl sprayed thin slide; opposite pitting (left above) and 4 sclariform perforation plates (arrows). × 120.

Affinities

The anatomical features of diffuse-porous vessels, growth rings, numerous narrow and evenly distributed vessels, exclusively sclariform perforation plates with more than 20 bars, opposite and alternate intervessel pitting, homocellular uniseriate rays, indicate affinities with the genus *Alnus*, section *Gymnothyrsus*, family Betulaceae.

So far, about 8 fossil woods with similarity to the extant genus *Alnus* have been reported from Tertiary deposits in Austria, Germany, Romania and USA (Yellowstone National Park). A slender silicified trunk, *Alnus scalariformae*, has been reported from the widely distributed Paleogene strata in northern Kyushu, Japan (SRIVASTAVA & SUZUKI 2001). At about 400 km distance W of Kuzuluk, 4 silicified *Alnus* specimens have been found in Tertiary sediments of the island of Lesbos and in Oligocene volcanic series of Thrace, NE Greece (SELMEIER & VELITZELOS 2000).

Fig. 21. (?) *Alnoxylon* sp., Kuzuluk, No. 14, diffuse-porous wood. Cross section with deformed wood tissue. × 120.

Dicot indet.

? Euphorbiaceae
(Fig. 22–25)

L o c a l i t y : Kuzuluk series; area near water spring Kay 18, 150 m NW of Eski Hamam, 86 m NN, near Orta-Mah, 113–138 m NN.

M a t e r i a l : Silicified wood, No. 11 (11×9×27) cm, five thin sections.

Description

Silicified secondary dicotyledonous wood without bark or pith.

G r o w t h r i n g s indistinct. V e s s e l s moderately small, evenly distributed, vessel outline circular to oval, solitary and in radial multiples of 2–3–(4), smaller than 50 μm, e.g. tangential

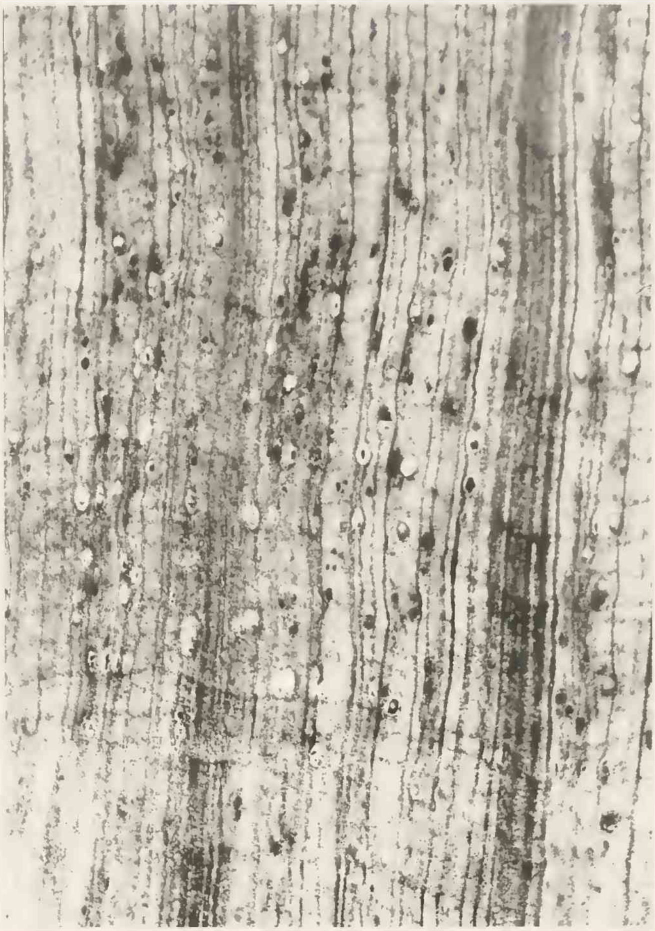

Fig. 22. Dicot indet., Kuzuluk, No. 11, Euphorbiaceae (?). Cross section, acryl sprayed thin slide; growth ring indistinct, small vessels, diffuse porous, banded parenchyma and aggregate rays. × 50.

diameter 20–30 µm. Perforation plates simple, inclination more than 45°, intervessel pits minute, alternate. F i b r e s thin-walled. Axial parenchyma apotracheal, banded, 1–3 cells wide, radial distance 70–85 µm. R a y s numerous, closely spaced, often only one or two, partly three cells wide, markedly heterocellular, vertical elongated ray cells at the margins or between multiseriate portions, the rays with multiseriate portion(s) as wide as uniseriate sections, marginal uniseriate rays 6–16 cells long, some ray cells with a single rhomboid crystal; rays 173–870 µm high, e.g. 13 cells (240 µm). Aggregate rays present, e.g. tangential 255 µm wide, ca.12 aggregate rays in a tangential distance of 2 cm (cross section); 20–26 rays per mm tangential.

Affinities

The combination of the 4 diagnostic valuable features: a) vessel mean tangential diameter less than 50 µm, b) apotracheal banded parenchyma, c) markedly heterocellular rays, d) aggregate rays is rare in Tertiary wood remains of Europe. The term "aggregate ray" has been used to describe clustering of uniseriate or multiseriate rays into larger units. Aggregate rays occur in

Fig. 23. Dicot indet., Kuzuluk, No. 11, Euphorbiaceae (?). Cross section, acryl sprayed thin slide, diffuse porous vessels, banded parenchyma and aggregate rays. × 120.

Betulaceae, Casuarinaceae, Compositae, Ericaceae, Euphorbiaceae, Fagaceae, Lauraceae, Platanaceae and Rosaceae. The combination of the two features in the silicified wood: a) apotracheal banded parenchyma, b) aggregate rays are restricted only to Casuarinaceae and Euphorbiaceae. These two families differ distinctly in the feature vessel groupings. Casuarinaceae has exclusively solitary vessels, not so the fossil wood from Kuzuluk with radial multiples of 2–4, similar to some extant genera of the Euphorbiaceae, subfamily Acalyphoideae (20 tribes, 116 genera). METCALFE & CHALK (1950: 1225) report aggregate rays in *Necepsia* and *Pseudagrostistachys*. The transverse section of *Necepsia afzelii* (HAYDEN & HAYDEN 2000: 221, fig. 2) shows a similar structure (aggregate rays, banded parenchyma) comparable to the fossil under consideration. With great probability, the fossil wood No.11 from Kuzuluk has to be assigned to the paraphyletic assemblage Acalyphoideae, the largest subfamily of Euphorbiaceae. The family Euphorbiaceae seems to be most closely related to the Kuzuluk wood, but an exact taxonomic ranking (genus, species) is at present not evident. A dicotyledoneous wood with a

Fig. 24. Dicot indet., Kuzuluk, No. 11, Euphorbiaceae (?). Longitudinal tangential section, acryl sprayed thin slide; rays heterocellular, uniseriate rays with parts of biserate sections. × 210.

vessel diameter less than 50 µm is the first in Tertiary sediments of Turkey. In a first falsly supposition the fossil wood No. 11 was provisionally assigned to Casuarinaceae (Greber 1992: 39).

2.3. Discussion

The Lower Miocene woods from Kuzuluk: Taxodiaceae (*Taxodium*), Taxaceae (*Taxus*), Betulaceae (*Alnus*) and ?Euphorbiaceae. *Taxodium*, *Taxus* and *Alnus* have well defined growth rings with faint changes in wood structure within a growth ring. Growth rings, may be regarded as a physiognomic adaptation to distinct seasonal change in the Lower Miocene. The growth rings, 164 visible in the cross sections of *Taxodium*, range from 0.07–6.0 mm. These rings are an important source of information about past climates and fossil environments (Table 5). Fossil tree rings are dependent on seasonality, annual growing conditions, water availability, limiting temperatures and forest productivity in the geological past (Creber & Francis 1999). The four growth rings of *Alnoxylon* range from 3.1–4.4 (mean 3.6) mm.

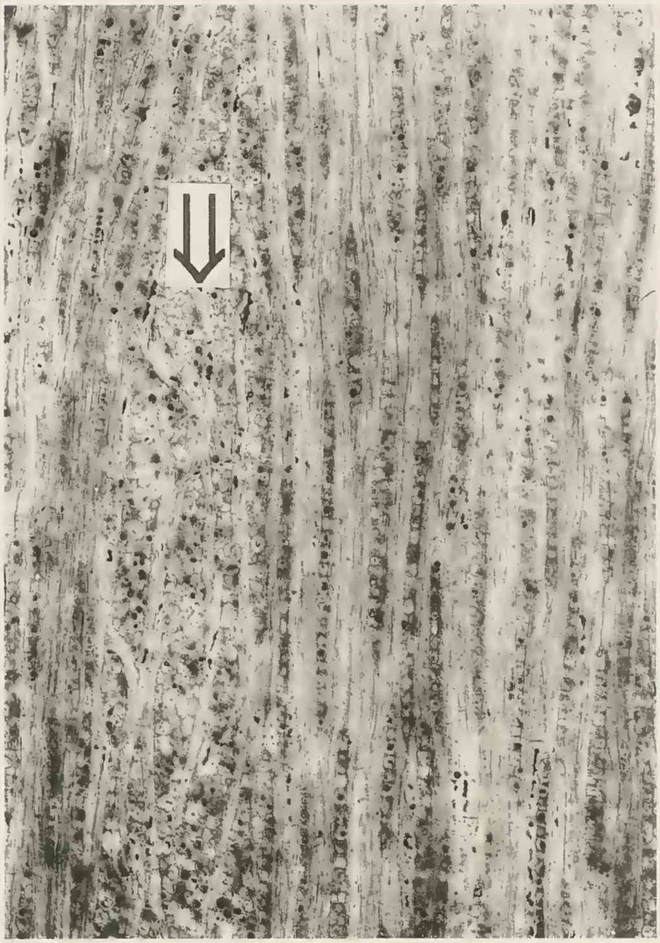

Fig. 25. Dicot indet., Kuzuluk, No. 11, Euphorbiaceae (?). Longitudinal tangential section, acryl sprayed thin slide; aggregate (arrow) and non-aggregate rays. × 100.

Table 5. Closely related extant genera of silicified woods from Kuzuluk and number of visible growth rings in cross sections.

Taxa, (No.)	Growth rings	Minimum, mm	Maximum, mm	Mean, mm
Taxodium (1)	6	0.3	0.9	0.7
Taxodium (3)	7	0.5	4.5	2.5
Taxodium (5)	24	0.6	1.6	0.9
Taxodium (6)	3	2.6	6.0	3.9
Taxodium (7)	28	0.3	0.9	0.6
Taxodium (10)	84	0.07	1.5	0.4
Taxodium (12)	87	0.15	0.7	0 4
Taxodium (13)	12	0.4	3.8	1.4
Taxus (2)	19	0.3	1.0	0.5
Alnus (8)	4	3.1	4.4	3.6
	Total 274			

The identification of some fossil woods from the Kuzuluk basin is the third anatomical study using light microscopy of silicified wood remains from Turkey (SAYADI 1973, SELMEIER 1990). This study provides the first microscopical identification of silicified coniferous wood from Turkey. In addition, a longitudinal tangential section of *Taxodioxylon* sp., specimen No. 3, shows a 4-seriate ray, unusual in coniferous wood. Fossil wood from the Kuzuluk basin, together with the great collections of silicified wood from Greece (Lesbos, Thrace, Kastoria) provide valuable information to increase our understanding of Tertiary plant evolution in the eastern part of the Mediterranean. The new fossil locality Kuzuluk documents the first known occurrence of conifers (*Taxodium*, *Taxus*) and dicots (*Alnus*, ?Euphorbiaceae) in the central region of Turkey. In the past, the two localities where fossil woods have been described are situated on the west coast of Turkey (Antalaya; Küçük Çekmece Lake). This is the first record of silicified wood from a previously undescribed wood-rich horizon in NW Turkey. The excellent preservation of abundant thin spiral thickenings in *Taxus* illustrates the potential for using fossil wood for taxonomic and palaeoecological studies.

There is still a considerable need for collecting well-dated silicified wood in Turkey. There is a particular need for anatomical identification of the material from the two "Petrified Forests" Istanbul and Kizilcahamam (Table 6). It would be helpful if anatomical information were available to know more about climatic and vegetational change across the Tertiary in the eastern Mediterranean and Turkey.

Table 6. Silicified taxa of this study and record of silicified wood remains in Turkey since the first publication (SAYADI 1973). – *) "Petrified Forest" according DERNBACH et al. (1996); wood remains at present without anatomical investigation. The two "Petrified Forests" are situated 14 km N of Istanbul and 70 km NW of Ankara.

Locality	Taxa	Family	References
Antalaya	*Dichrostachys*	Mimosoideae	SAYADI 1973
Küçük Çekmece Lake	*Dichrostachys*	Mimosoideae	SELMEIER 1990
Istanbul*)	Gymnosp., Dicots	–	DERNBACH et al. 1996
Kizilcahamam*)	Gymnosp., Dicots	–	DERNBACH et al. 1996
Kuzuluk	*Taxus*	Taxaceae	2001
Kuzuluk	*Taxodium*	Taxodiaceae	2001
Kuzuluk	*Alnus*	Betulaceae	2001
Kuzuluk	Dicot indet.	?Euphorbiaceae	2001

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