ISSN-0017-0070

GIORNALE BOTANICO ITALIANO

FONDATO NEL 1844

PUBBLICATO DALLA SOCIETÀ BOTANICA ITALIANA
CON IL CONTRIBUTO DEL CONSIGLIO NAZIONALE DELLE RICERCHE

Vol. 124, n. 6, 1990

Giorn. Bot. Ital., 124: 711-724, 1990

A palm fossil closely related to Chamaerops humilis L. from the Lower Miocene of Sardinia

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Accepted: 24 March 1990

ABSTRACT. — This paper deals with the anatomical and histological study of a silicified specimen of a palm consisting of a part of the trunk surrounded by roots. The sample comes from the Lower Miocene of North West Sardinia. The comparison with fossil species and exsting species leads to the conclusion that the specimen belongs to a new fossil species closely related to *Chamaerops humilis* L., widespread throughout the Mediterranean area. Paleo-environmental considerations confirm the presence in Sardinia, in the epoch in question, of formations of Mediterranean forest corresponding in part to forest existing in North Africa today.

Key words: *Palmoxylon homeochamaerops, Chamaerops humilis* L., Miocene, Sardinia.

INTRODUCTION

The fossil wood was found in San Maurizio near Ittiri (Sassari, N.W. Sardinia), on the left bank of the Rio Mannu, (I.G.M. Tab. 193 IV N.E. Florinas), and was discovered by Dr. Giovanni Tilocca, of the Dipartimento di Scienze della Terra - Università di Cagliari.

The fossil was situated on top of a series of silicified rock formations from the Lower Miocene, in the order of 12 m deep, attributable to «Lacustrine Formations», over pyroclastic rock from the Oligo-Miocene, (refer to: Carta Geologica d'Italia 1: 100.000, F. 193 «Bonorva», S.G.I. 1961).

The specimen, a portion of a palm, is completely silicified and has a diameter of 24 cm totally covered by a continuous layer of roots 7.5 cm thick.

ANATOMICAL STUDY

STEM (Plate 1; Fig. 1)

Cortical cylinder. — When examining the trunk macroscopically, it is possible to identify an outer layer 3-5 mm deep, devoid of vascular bundles, which constitutes the cor-

tex. In fact, in transverse sections of the cortex, numerous 400 μm pure fibrous strands with an average density of 45 per cm^2, are evident. Rounded «stegmata» surround the fibrous strands - «crowned strands»

Central cylinder. — The transition from the cortex to the central cylinder is evident, due to the presence of vascular bundles and the lack of exclusively fibrous strands.

The overall dimension of the vascular bundles, their density, the ratio between the fibrous and vascular portions and the number and diameter of the vessels vary notably between the edge of the central cylinder and the centre.

In the outer layer the fibrous portion amounts to 40% of each vascular bundle. The arrangement of the vascular bundles is extremely regular: effectively, they are aligned in 2 or 3 concentric rows. Collectively they have an oval outline of 1250 μm x 512 μm. There are 125 bundles per cm^2. There are 10 to 20 vessels per bundle. The vessels are roundish or polygonal and have a diameter which varies between 50μm and 135 μm with an average value of 90 μm. The walls of the vessels appear to be very slightly thickened. The fibrous sheath is sub-triangular with a concave base and is made up of fibres of an average diameter of 40 μm with roundish, tending to polygonal, outlines. The parenchyma is of a parietal type and completely surrounds the vascular bundle. These are transition bundles originating directly from leaf traces.

When compared to the vascular portion, the sclerenchyma in the vascular bundles of the middle layer is notably developed. The bundles measure 1500 x 1260 μm. The vessels are represented by 3 or 4 metaxylem elements 270 x 240 μm in diameter. The density of the bundles is 30 per cm^2. The fibrous sheath represents 76% of the entire bundle.

The vascular portion of the vascular bundles in the inner layer is clearly less developed than the fibrous portion, which in fact makes up a good 81% of each bundle. The diameters of the entire bundle are 1700 x 1500 μm; density is in the order of 15 bundles per cm^2. There are between 2 and 4 metaxylem vessels measuring 110 x 140 μm. The walls of the vassels are very slightly thickened and are surrounded by very small roundish parenchyma cells. There is a high presence of tyloses in the vessels. The fibrous sheath is globular on the dorsal part, while on the ventral part it is practically non-existent or reduced to very few fibres. The fibres are 73 μm in diameter.

Surrounding the dorsal part of the fibrous sheath is an almost continous line of stegmata; these are more evident in longitudinal sections, and appear as rounded cells

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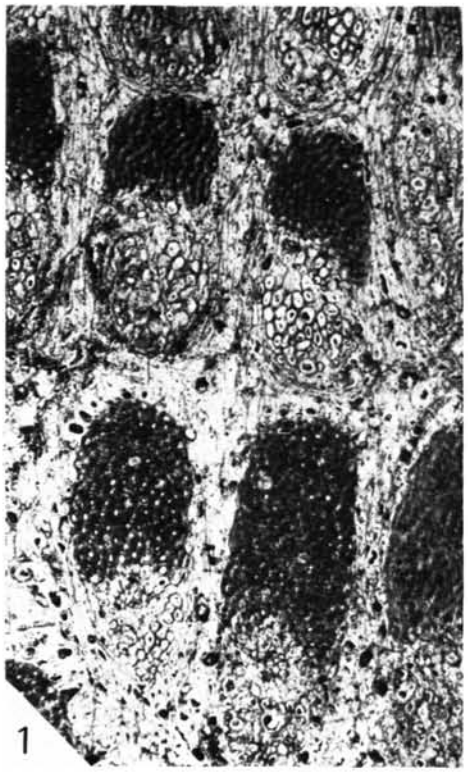
Plate I — *Palmoxylon homeochamaerops* Biondi et Filigheddu.

1. External layer of the central cylinder with transitional vascular bundle.
2. Vascular portion of transitional bundle.
3. Detail of cortical cylinder with fibrous strands.
4. Stegmata
5. Vascular bundle from the central layer of the stem.



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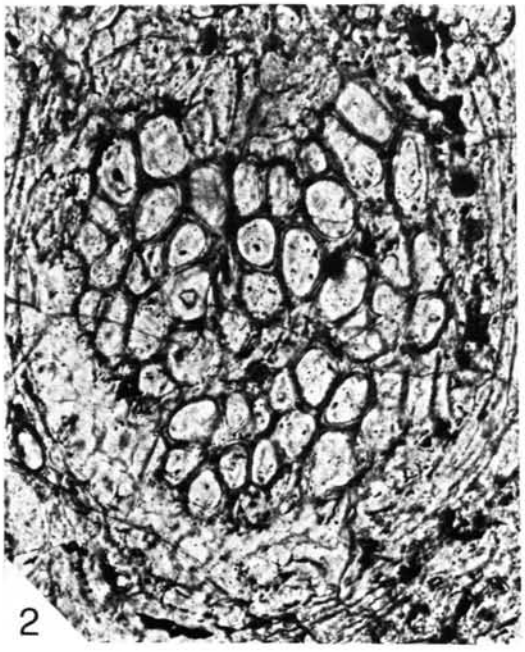

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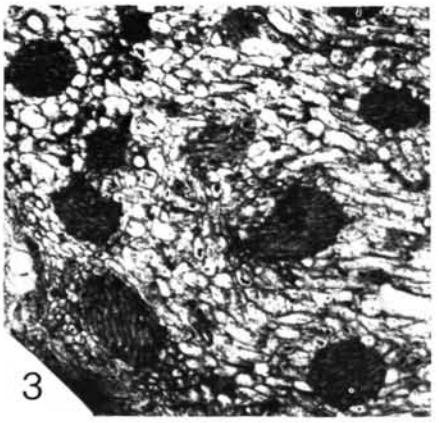

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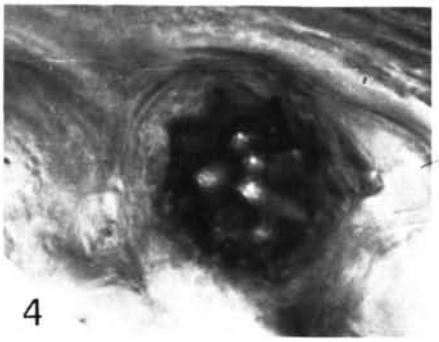

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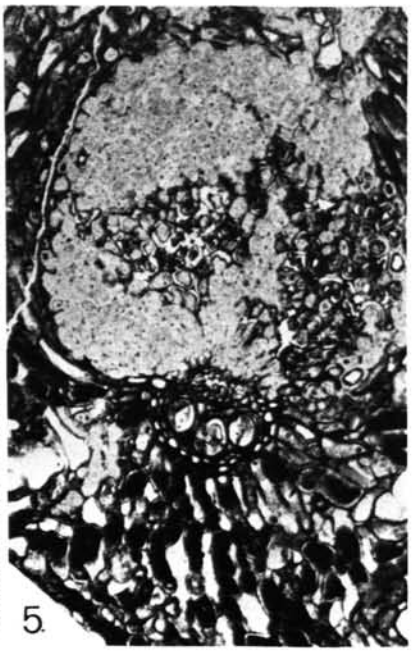

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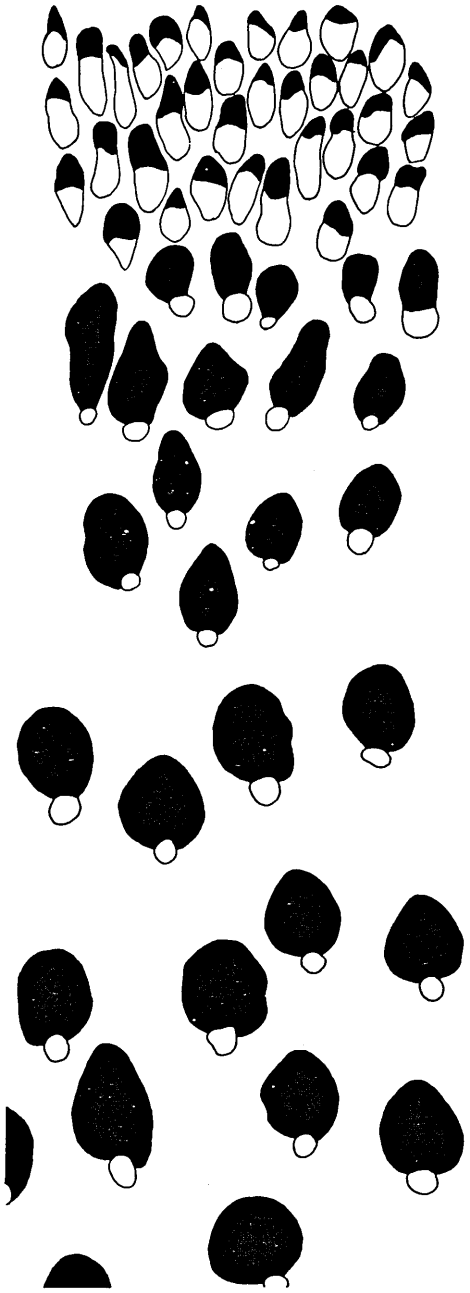


Fig. 1 — *P. homeochamaerops* Biondi et Filigheddu; Variations in the shape, the ratio between the fibrous and vascular portions and the density of the vascular bundles from the cortex to the central cylinder of the stem.

containing small spheroid siliceous bodies 12 μm in diameter, with uneven surfaces. The parenchyma surrounding the bundles is tabular, for a single line of cells, near the fibrous part, and radial near the vascular part.

Where parenchymatous cells are found at a distance from the bundles their distribution appears to be irregular despite an apparently prominent transverse pattern. In dense parenchyma a few lacunae of lysigenous origin are evident.

Roots (Plate 2; Fig. 2)

The roots, the bulk of which make up the external part of the specimen, have a subcircular section at their base, with an average diameter of 1.3 cm, 1 cm; there are also some roots which are flattened, deformed and intergrown.

Cortical cylinder. — The thickness of the cortex varies between 3 and 5 mm; it has three distinct sections: outer, middle and inner.

The outer cortex consists of a non fibrous exodermis made up of three or four concentric layers of quadrangular cells with no intercellular spaces. They are suberized and have a diameter of 11 μm. Below the exodermis there are layers of rounded and elliptical parenchymatous cells. The dimension of the cells increases progressively, from a minimum of 11 μm to a maximum of 28 μm, through the outer cortex.

The middle cortex is the most developed section of the cortex and is made up of larger rounded parenchymatous cells (40 to 56 m) arranged in more or less radial lines which in some of the roots enclose large irregularly shaped air lacunae. In this part of the cortex there are also some widely spread cells containing mucilage. Further there are clearly visible incrassate cells which through subsequent disintegration have caused the formation of intercellular spaces which have then joined together forming lacunae of clearly lysogenous origin.

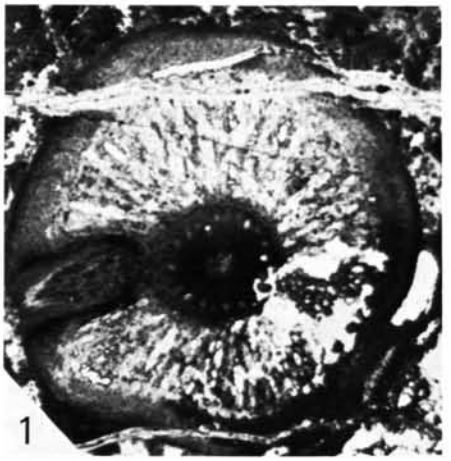
The inner cortex, immediately adjacent to the endodermis, shows a few layers of decidedly smaller cells. These cells are flattened and close together and have a dimension of between 16-21 μm x 10-12 μm, and are arranged in 2-3 concentric rows.

There is no evidence in the root cortex of fibres, either isolated or in groups.

Central cylinder. — The endodermis is single-layered, and made up of cells which show characteristic U-shaped thick walls; they are quadrangular, more or less compressed, the dimensions range from 11x28 μm to 14x34 μm. The thickened radial walls are 5 μm thick.

Plate II — *Palmoxylon homeochamaerops* Biondi et Filigheddu.

1. Small roots with lateral branching.
2. Endodermic cells with U thickening of the walls.
3. Cortical cylinder of roots with lacunae.
4. Detail of roots with medullary vessels in the central zone.
5. Detail of roots.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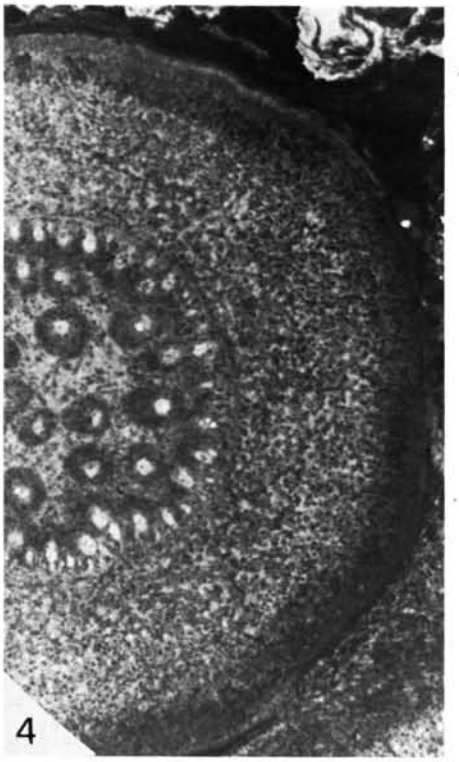
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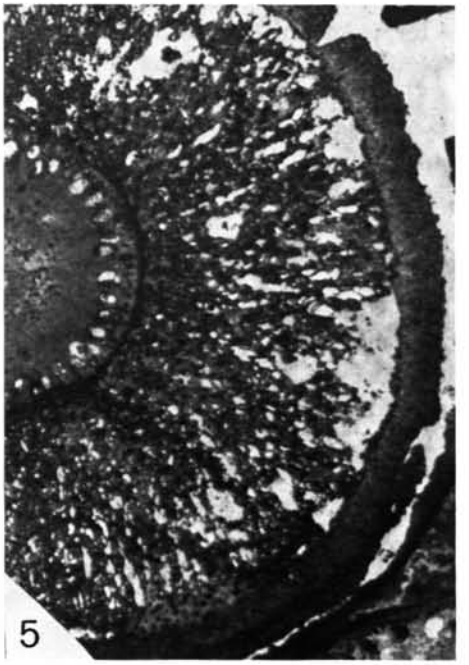
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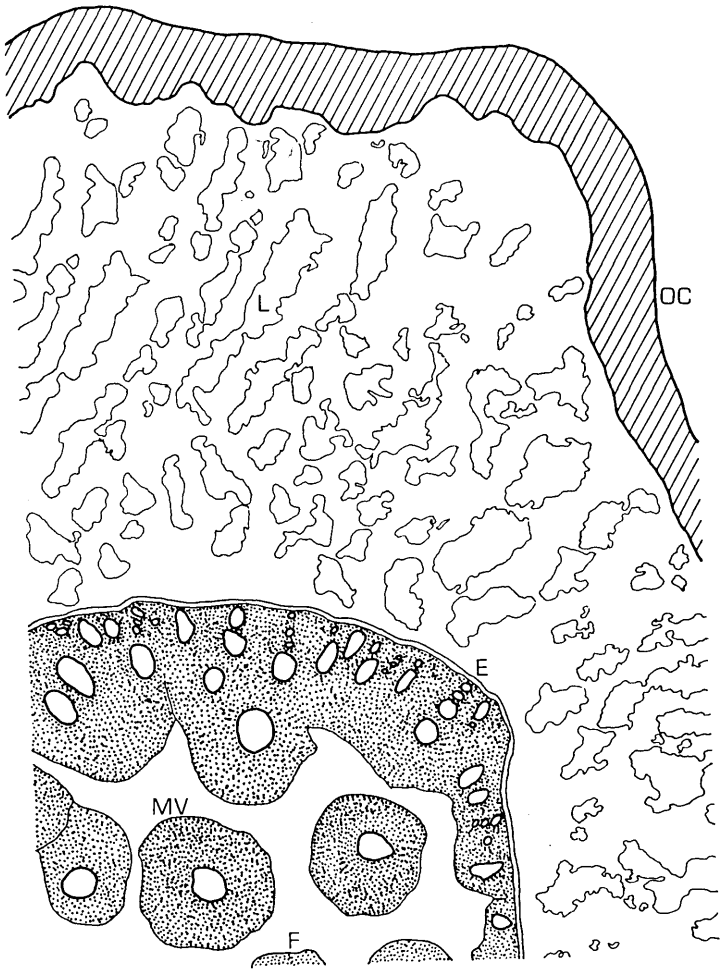

Fig. 2 — *P. homeochamaerops* Biondi et Filigheddu: Roots: OC outer cortex; L air lacunae; E endodermis; MV medullary vessels; F fibres.

It is difficult to identify the pericycle as it is made up of fairly small (about 15-20 μm) quadrangular cells, which are closely packed and are without intercellular spaces.

The structure of the stele varies in relation to the overall diameter fo the root. The smaller roots (stele diameter 1 mm) have from 25 to 30 arches; che centre of the vessels are arranged in radial groups, with an average dimension of 190 x 140 μm. The larger roots (stele diameter around 4 mm) have between 50 to 75 arches. The vessels are arranged in peripherical radial series; further in, the metaxylem elements have an average dimension of 390 x 220 μm; many of the vessels are obstructed, due to the

presence of a large number of tyloses. Medullary vessels are present in the central zone of stele, where they are scattered, isolated and surrounded by a thick sheath of fibres with a cross-section diameter of 22 - 26 μm. Medullary vessels with a circular cross-section have an average diameter of 370 μm. The fundamental parenchyma is distributed in irregular form among the islets of fibres which surround the vessels in the central zone; the cells are rounded or elliptical and have a dimension of between 34 μm and 62 μm.

COMPARISON WITH EXISTING PALMS

Since the specimen under study consists of a portion of trunk and a number of root remains, it is possible to make an anatomical comparison with corresponding parts of existing palms.

The lack of isolated fibres or fibres in groups in the cortex of the root can be taken as a distinguishing factor, which, according to TOMLINSON (1961) is common to the genera: *Ancistrophyllum, Astrocaryum, Bactris, Borassus, Calamus, Chamaedorea, Chamaerops, Cocos, Crysophila, Daemonorops, Elaeis, Geonoma, Howeia, Licuala, Livistona, Nypa, Phytelephas, Plectocomia, Pritchardia, Raphis, Roystonea, Sabal, Salacca, Serenoa, Thrinax, Trachycarpus, Trithrinax.* Other distinguishing characteristics on the level of genus concern the air-lacunae, the parenchyma of the cortex, the exodermis, the endodermis, the medulla, the presence or absence of medullary vessels and the arrangement of the vessels (TOMLINSON, 1961; MAHABALE and UDWAIA, 1960). The examination of these characteristics in the above mentioned genera led to the identification of similarities between the specimen under study and the genus *Chamaerops* and certain species of *Sabal.* The latter however, have a 2-3 layer pericycle and the cells of the cortical parenchyma are elongated transversally.

According to TOMLINSON (1961) the genera which have more than two large vessels in the vascular bundles of the trunk are: *Chamaerops, Phytelophas* and *Trachycarpus. Chamaerops* is considered to be the genus which more closely resembles the specimen, since *Phytelephas* has fibrous strands in the central cylinder and *Trachycarpus* has small vascular bundles with a highly developed fibrous sheath in the cortex, and an extremely uniform parenchyma which is not subject to secondary transverse expansion.

Analysis of the anatomical features of the specimen under study, and their subsequent comparison with the characteristics of existing species has shown that the specimen bear strong similarities, both in the trunk and in the root, to *Chamaerops*, a monospecific genus represented today by *Chamaorops humilis* L., a sabaloid palm widely distributed throughout the Mediterranean area (Tab. 1).

The most obvious of these similarities are:

— small lysigenous lacunae in the parenchyma of the trunk, a characteristic which, according to KAUL (1960), is exclusive to the genus *Chamaerops*;

— vessels in the root stele arranged in several circles, a characteristic which, according to MAHABALE and UDWAIA (1960), is exclusive to the genus *Chamaerops.*

TABLE 1

Comparison of anatomical characteristics between P.homeochamaerops and related genera of existing Palmae (+ = present; - = absent).

	Trachicarpus	*Chamaerops*	*Sabal*	*Phytelephas*	*P. homeochamaerops*
ROOT					
medullary bundle	—	+	+	—	+
absence of medullar lacunae	—	+	—	+	+
vessels in more than circle	—	+	—	—	+
STEM					
vascular bundle with more than two vessels	+	+	—	+	+
parenchyma with air-lacunae	—	+	—	—	+
absence of fibrous strands	+	+	+	—	+

Further, both the literature and direct observation of histological preparations taken from the trunk and root of *Chamaerops humilis* have shown that the following characteristics are identical:

- — trunk cortex with a large number of fibrous strands;
- — vascular bundles in the stele with a highly-developed fibrous sheath; this does not affect the vessels, which are surrounded only by parenchyma;
- — non-sclerotic phloem;
- — more than two vessels in the vascular bundles;
- — a non-fibrous exodermis;
- — air-lacunae of lysigenous origin in the middle layer of the root cortex, arranged in several rows and irregular in shape;
- — absence of exclusively fibrous strands in the parechyma of both the trunk and the root;
- — absence of air cavities in the root medulla;
- — presence of medullary vessels in the root.

COMPARISON WITH FOSSIL SPECIES

The anatomical study of the palm fossil trunk resulted in the identification of the following principal characteristics:

- — cortex made up of entirely fibrous strands with an average diameter of 400 μm and density of 45 per cm^2,
- — transitional vascular bundles numbering 125 per cm^2, with 10 - 20 small vessels,
- — vascular bundles with 3 - 4 large vessels, with a density varying between 29 per cm^2 in the outer zone and 10 per cm^2 in the central zone,
- — compact parenchyma with small lacunae of lysogenous origin,
- — absence of exclusively fibrous strands in the central cylinder.

Under STENZEL's classification (1904) as refered also in STOCKMANS & WILLIERE (1943)

the speciemen should be placed in the *Corypha* group. This group is characterized by vascular bundles which in the outer zone of the central cylinder are closely grouped and have a much larger fibrous than vascular portion, whereas in the less closely grouped bundles in the inner zone, the fibrous portion is much more highly developed than the vascular. However, certain analogies can be made with the species of *Palmoxylon* from the *Cocoides* group.

A comparison with samples of fossil species from the above mentioned groups found in North Africa, Central Northern Europe and from all over the Mediterranean basin, has resulted in certain resemblances being identified with the following: *P. libycum* Stenzel Kräusel, 1924, *P. zitteli* Schenk, 1883, *P. giarabubense* Chiarugi, 1929, *P. ligerinum* Crié, 1892, *P. lacunosum* (Unger) (Felix, 1882), *P. lovisatoi* (Sterzel, 1899), *P. cavallottii* Lovisato et Sterzel 1899, *P. aschersoni* Schenk 1883, *P. benadirense* Chiarugi 1933. Of these *P. libycum, P. giarabubense, P. cavallottii, P. aschersoni* and *P. benadirense* show a greater resemblance to the specimen under study. There are however significant differences (Tab. 2).

Palmoxylon cavallottii (the Oligo-Miocene of central Sardinia - Zuri - Soddì deposit) has entirely fibrous strands in the parenchyma. The cells in the parenchyma are arranged radially around the vessels and have a tabular arrangement around the fibrous portion of the bundle (STERZEL, 1899).

Palmoxylon libycum (found in several deposits from the Upper Oligocene and Miocene in North Africa, from Egypt to Libya) has between 25 and 50 bundles per cm^2. The number of large vessels are almost constant, with two bilateral vessels, and the parenchyma, of the tabular type, is welll developed around the bundles (KRÄUSEL, 1924). KOENIGUER (1970) found specimens of palm fossil in the Mio-Pliocene of Lybia which are listed as *Palmoxylon* aff. *libycum* and in which the above mentioned characteristics are almost constant.

Palmoxylon giarabubense (Miocene of Libya) has two big bilateral vessels and large lacunae in the parenchyma. (CHIARUGI, 1929).

Palmoxylon aschersoni (Mio-Pliocene and Eo-Oligocene of Algeria, Egypt and Libya) has, in 70% of cases, one large vessel in the vascular bundle and a compact parenchyma, at times with small lacunae. There are 25 to 70 bundles per cm^2 with dimension of 600-300 x 1700-1600 μm. In 5% of cases the vessels are in groups of three and measure from 90 to 150 m (DELTEIL-DESNEUX. and KOENIGUER, 1974).

Palmoxylon benadirense was described for the South of Somalia by CHIARUGI (1933). Chiarugi considered the area to be Cretaceous. The specimen is made up of a vascular bundle with two large bilateral vessels, the walls of the fibres are very thin. Although *P. benadirense* is very similar to *P. libycum*, Chiarugi discounts the similarity, because the size of the vascular bundles differs, the difference is however, so minimal that the two species could in fact be considered as one.

The anatomical study of the fossil roots has resulted in the identification of the following principal characteristics:

— cortex with air lacunae in the middle section, which are separated by layers of cells of lysigenous origin, but with no specific arrangement,
— absence of exclusively fibrous strands in the cortex and in the central cylinder,
— xylematic arches arranged in several concentric series,

TABLE 2

Comparison of the principal anatomical characteristic of P. homeochamaerops and related species of Palmoxylon.

	P. libycum	*P. giarabubense*	*P. cavallottii*	*P. aschersoni*	*P. benadirense*	*P. homeochamaerops*
vascular bundles						
vessels	2 bilateral	2 bilateral	2,3 or 4	1	2 bilateral	3 (10 to 20 in the leaf traces)
fibrous sheath	reniform	semilunar	reniform	reniform	reniform	reniform
fibrous strands	absent	absent	few	absent	absent	absent
parenchyma	dense	with lacunae	dense	dense with some lacunae	dense	dense with some lacunae

— medullary vessels,
— the centre of the stele completely filled with fibrous foundamental tissue or with parenchyma set among the medullary vessels.

Specimens of the fossil palm roots described in the literature are relatively scarce. Among those available, the specimens which most closely resemble the specimen under study are *Rhizopalmoxylon libycum* Koeniguer 1970 and a root of *Palmoxylon aschersoni* described by CHIARUGI (1929). There are however certain obvious differences.

Rhizopalmoxylon libycum (Mio-Pliocene of Lybia) has an abundance of exclusively fibrous strands with stegmata in the thickness of the cortex, 20 - 30 xylematic arches in the central cylinder, absence of medullary vessels and a large lucuna in the centre of the medulla.

The root of *P. aschersoni* (Oligocene, Miocene and Pliocene of Libya and Lower Egypt) has a large number of fibrous strands in the fundamental parenchyma of the cortex.

A comparison of anatomical data on the trunk and the root of the specimen with data on the other fossil species has led to the conclusion that the specimen under study cannot be attributed to any of these species, and therefore should be described as a new species.

DIAGNOSIS

Palmoxylon homeochamaerops sp. nov.

Cortical cylinder of the stem well developed. Fibrous strands - diameter 400 μm - density 45 per cm^2. Presence of stegmata around the bundles.

Central cylinder with transitional vascular bundles arranged in 3 - 4 rows, with a density of 125 per cm^2. Vascular bundles in the inner layers of the trunk with 3 - 4 large vessels and a density of between 30 and 10 bundles per cm^2. Stegmata present around the fibrous portion of the bundle. Parenchyma radial in the area of the vascular portion of the bundle; a tabular tendency, consisting of a single layer of cells, in the direction of the fibrous portion. Parenchyma compact, with few lacunae of lysogenous origin. Absence of exclusively fibrous strands in the central cylinder.

Roots with cortical cylinder well developed: exodermis of 3 - 4 layers of cells, without strands of fibres and with abundant cells containing mucilage. Cortical parenchyma cells rounded enclosing, in some cases, air-lacunae of irregular form, lysogenous and arranged in several rows. Endodermis single layered with U-shaped thickening. Polyarch stele with 25 - 30 arches in the smaller roots and 50 - 70 in the larger. Metaxylem vessels between 140 and 390 μm. Medullary vessels present in the larger roots. Medulla without central air cavity or lacunae.

Holotype: n°1I, slides 1Ia - 1If Istituto di Botanica.
Università di Sassari.

Type Locality: San Maurizio near Ittiri (Sassari, NW Sardinia).

Stratigraphic horizon: Lower Miocene.

Etymology: *homeochamaerops* refers to close resemblance to the existing *Chamaerops humilis* L.

CONCLUSIONS

The *Chamaerops humilis* has an area of distribution which includes the central and western areas of the Mediterranean where its presence contributes to the establishment of various phytocenoses which correspond to various bioclimatic conditions. This is particularly so in the area or the Atlas mountains of Morocco and in a limited area of the Iberian peninsula, in the Sierra di Cartagena, where the dwarf palm is frequently associated with *Tetraclinis articulata* Mast. Two fossil species belonging to this species have been found in deposits in Northern Sardinia which are thought to be coeval with those of Ittiri (TILOCCA, 1989). The ligneous structure of the two fossils is similar to that of the existing species. (*Tetraclinoxylon anglonae* Biondi 1979 and *Callitrixylon boureaui* Biondi 1985). It is therefore possible to hypothesize a certain similarity between the forest formations of the Miocene and those existing today. In the Sierra di Cartagena there is a formation of open forest of an evident relict character, which can be placed under the association *Arisaro-Tetraclinidetum*. In the phyto-sociological table published in RIVAS-MARTINEZ (1974), *Chamaerops humilis* has similar cover and associability value as *Tetraclinis articulata*. The dwarf palm is consistently present in other associations attributed to *Tetraclinis articulata* of Marocco (BARBERO *et al.*, 1981), even though the species is so widespread as to be found from sea-level up to an altitude of about 2.300 m. The association has also been found, among fossil remains attributable to *Tetraclinis* and *Chamaerops*, in various Oligo-Miocene deposits bearing leaf imprints (BEGUINOT, 1922). Helophytes of the type found in the Ittiri basin and other deposits in Northern Sardinia are always present in these deposits. In conclusion, at this point of the research, the discovery of a fossil attributable to *Chamaerops humilis* confirms the hypothesis of the existence, in the Lower Miocene of Northern Sardinia, or a forest dominated by *Cupressaceae* similar to the present day *Tetraclinis articulata*. The forest must have developed under climatic conditions that can be reasonably considered to be comparable to the semi-arid Mediterranean bioclimate (according to the EMBERGER classification, 1938) that distinguishes the areas where these are found by the presence of phytocenosis belonging to *Tetraclinis articulata* and *Chamaerops humilis* (BIONDI, 1983; BIONDI in BIONDI *et al.*, 1985).

The presence of other specimens, attributable to *Bombacoxylon owenii* (Carr.) Gottwald and *Palmoxylon lovisatoi* Sterzel, in the Ittiri basin do not however, confirm the above hypothesis for the bioclimate. In fact both species, also present in large numbers in the Miocene basin of Zuri-Soddì, (Central Sardinia) would suppose a dry environment of the type characteristic of the African wooded savannah (CHARRIER and MAXIA, 1970; BIONDI, 1981). However, the significance of the presence in the Ittiri basin of species which indicate diverse environmental conditions, is still to be established. Further stratigraphic studies and research on the correlation between the various Miocene basins in Sardinia, is needed before a clearer interpretation of the paleo-environmental conditions can be made.

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RIASSUNTO

Su una palma fossile affine a Chamaerops humilis L. rinvenuta nel Miocene inferiore della Sardegna (Italia). - Viene presentato lo studio anatomo-istologico di un reperto silicizzato di palma costituito da una parte di fusto con un rivestimento esterno di radici. Il campione proviene da formazioni attribuite al Miocene basale della Sardegna Nord-Occidentale. Il confronto con specie fossili e attuali ha permesso di accertare che si tratta di una nuova specie fossile che presenta notevole affinità con *Chamaerops humilis* L. e che viene perciò indicata come *Palmoxylon homeochamaerops.* Le considerazioni di ordine palcoambientale confermano la presenza all'epoca di formazioni di foresta mediterranea corrispondenti in parte a quelle che attualmente si rinvengono nell'Africa settentrionale ed in particolare nel Sud del Marocco.