Vegetation History and Archaeobotany

Human-woodland interactions during the Pre-Aksumite and Aksumite periods in northeastern Tigray, Ethiopia: insights from the wood charcoal analyses from Mezber and Ona Adi

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ESM1: Taxonomical results: anatomical descriptions and ecological features.
Taxonomic classifications were proposed by following Höhn and Neumann (2018) methodology for charcoal identification in species-rich environments. Descriptions of the wood anatomy are accompanied by a list of the main diagnostic characters of each charcoal type, a discussion of each identification and photos of the transverse (**TS**), tangential longitudinal (**TLS**) and radial longitudinal (**RLS**) sections, as well as brief summaries of the ecological distributions and economic features of the taxa in each case.

The description of charcoal types follows the standard terminology of the International Association of Wood Anatomists (IAWA) (Wheeler et al. 1989; Ritcher et al. 2004) with minor adaptations for characters not listed by IAWA (e.g. intervessel pits coalescent). Note that not all IAWA characters could be evaluated as some are usually difficult to identify in archaeological charcoal (e.g. length of parenchyma strands). The only quantitative feature included is mean diameter of vessel lumina, which was calculated by measuring a minimum of 10 vessels in 5 different charcoal fragments when possible. Microscopic photographs were taken using the *Olympus Stream Basic* commercial software and a Olympus BX51 reflected light microscope - available at the laboratory of Environmental Archaeological of *Universitat Pompeu Fabra* (UPF) - with incident light and magnifications 50x, 100x, 400x and 1000x, which are indicated in each photograph by the scales - 200 µm, 100 µm, 50 µm and 20 µm respectively . The allocation to northern Ethiopian taxa is done in relation to available wood and charcoal reference materials from Ethiopia at the *Muséum National d'Histoire Naturelle* (MNHN) deposits, but also using pre-existing literature and collections from other areas of the world since the available reference samples of Ethiopian taxa are still very limited. As a general rule, the naming of the different taxa follows Friis et al. (2010), who does not mention authorship. However, authorship is included for reference collection samples when available, as well as when quoting botanical synonyms. Botanical synonyms accepted by the International Plant Names Index database (IPNI 2020) are considered to refer to the same taxa when comparing their wood anatomies (e.g. *Dodonaea angustifolia*, and *D. viscosa*, see below). Vernacular names in Tigrinya (November et al. 2002, Bekele-Tessema 2007) are transcribed without phonetic characters following the example of Bekele-Tesemma (2007; but see November et al. 2002: 2). The ecological distributions of the species related to each charcoal type are assigned according to Friis et al. (2010) classification into the following vegetational units: i) Desert and semi-desert scrubland (**DSS**); ii) *Acacia-Commiphora* woodland and bushland proper (**ACB**); iii) *Acacia* wooded grassland of the Rift Valley (**ACB/RV**); iv) *Combretum-Terminalia* woodland and wooded grassland (**CTW**); v) Afromontane woodlands, wooded grasslands and grasslands (**DAF/WG**); vi) Undifferentiated Afromontane forests (**DAF/U**); vii) Dry single-dominant Afromontane forest (**DAF/SD**); viii) Ericaceous Belt (**EB**); ix) Afroalpine belt (**AA**); and x) Riverine forest (**RV**). Presence (1) or absence (0) of each taxa in each vegetation unit is indicated using tables.

***Rhus* spp. (Anacardiaceae)**

- Definition of charcoal type

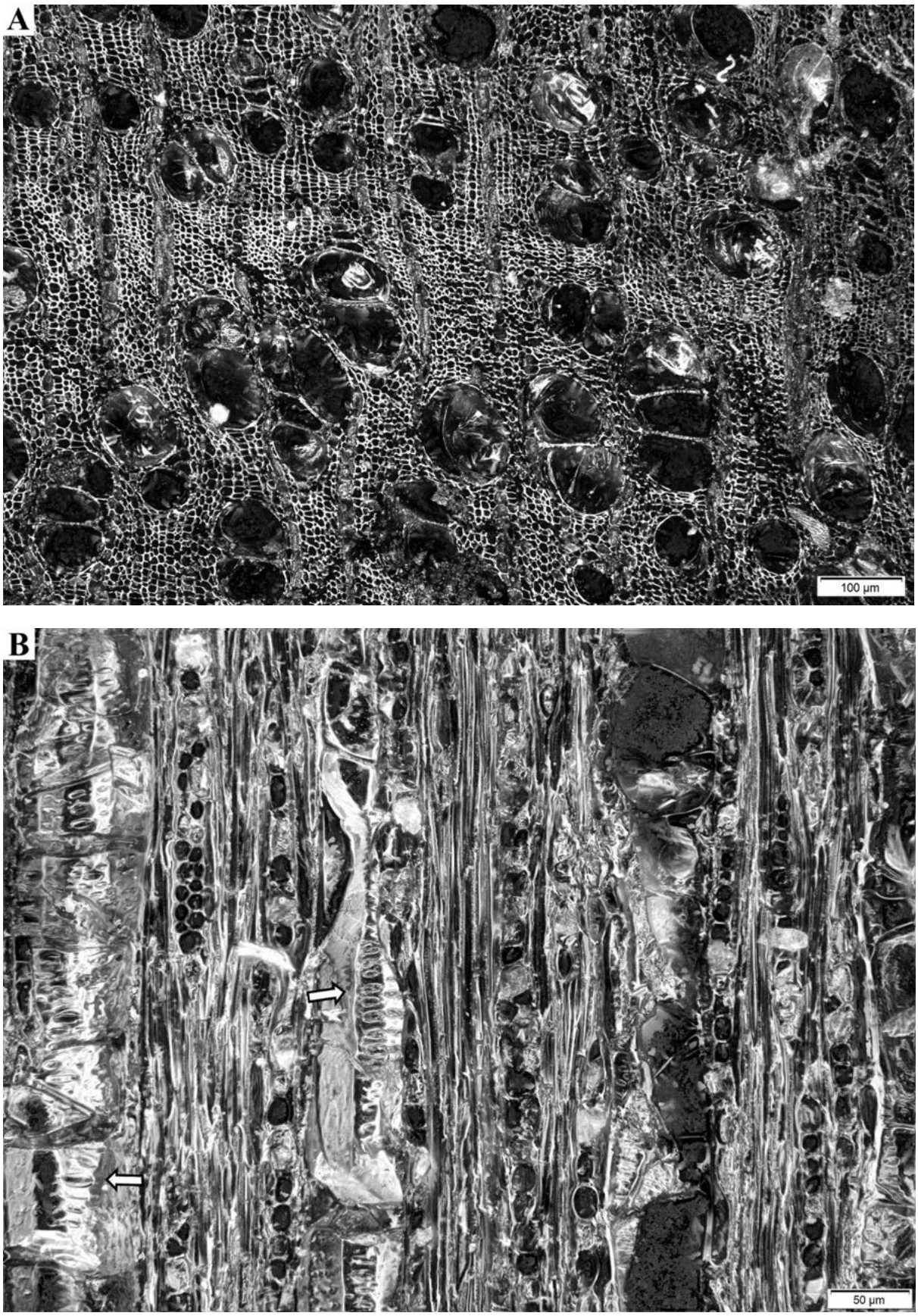
Growth ring boundaries distinct. Wood diffuse-porous. **Vessels** grouping sometimes in radial multiples of 2-3, sometimes solitary. Vessel clusters common. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular; sometimes horizontal (scalariform, gash-like) to vertical (palisade). Mean tangential diameter of vessel lumina between 50-100 µm. Tyloses common. **Fibres** with simple to minutely bordered pits. Axial **parenchyma** paratracheal scanty. **Rays** width 1 to 3 cells. Body ray cells with 1-4 rows (sometimes more) of upright and / or square marginal cells, sometimes with procumbent, square and upright cells mixed throughout the ray. **Prismatic crystals** present. Prismatic crystals located in procumbent and upright/square ray cells.

- Main diagnostic features

Growth rings distinct. Mean tangential diameter of vessel lumina between 50-100 µm. Vessel clusters common. Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular. Tyloses common. Prismatic crystals located in procumbent and upright/square ray cells.

- Discussion

The wood anatomy of this charcoal type matches the reference samples of an unknown Ethiopian species of *Rhus* sp. from the MNHN xylothèque. The combination of the main diagnostic features in InsideWood (2004-onwards) identifies a total of five species that share these characteristics, including *Comocladia glabra*, *Pistacia atlantica*, *Pistacia khinjuk*, *Rhus copallinum* and *Rhus glabra* - all pertaining to the Anacardiaceae family. Even though none of the resulting Anacardiaceae species are present in tropical Africa, InsideWood showed no other family sharing these characteristics. According to Friis et al. (2010), there are five genera of Anacardiaceae present in modern Ethiopia including *Lannea* sp., *Sclerocarya* sp., *Ozoroa* sp., *Rhus* sp. and *Pistacia* sp. Previous studies on Anacardiaceae have highlighted the presence of radial canals as a diagnostic feature of this family (e.g. Metcalfe and Chalk 1950). The presence of these secretory elements is constant amongst species of *Lannea* sp. (Dong and Baas 1993; Gupta and Agarwal 2008), *Sclerocarya* sp. (Prior and Gasson 1990), and *Pistacia* sp. (Dong and Baas 1993; Gupta and Agarwal 2008), while *Rhus* sp. has been recurrently found both with (Prior and Gasson 1990; Gupta and Agarwal 2008) and without radial canals (Heimsch 1940; Dong and Baas 1993 and references therein; Neumann et al. 2001). Even though *Ozoroa* sp. also does not show radial canals, the genus is characterized by the absence of growth rings - as it is *Sclerocarya* sp. (Prior and Gasson 1990) - as well as the presence of larger rays (commonly 4- to 10 seriate) and vasicentric axial parenchyma (InsideWood 2004-onwards) - both shared by *Lannea* sp. (InsideWood 2004-onwards; Dong and Baas 1993; Gupta and Agarwal 2008). Finally, *Pistacia* sp. wood has been reported as ring-porous, showing vessels in radial groups (Dong and Baas 1993; Gupta and Agarwal 2008), or arranged in diagonal to dendritic patterns (Heimsch 1940) which are not visible in the studied charcoal fragments. Some temperate species of *Rhus* sp. share these characters though *Rhus* sp. wood in tropical environments is diffuse-porous - growth rings distinct due to thick-walled latewood fibres - with no evident pattern in vessel arrangement (Gupta and Agarwal 2008).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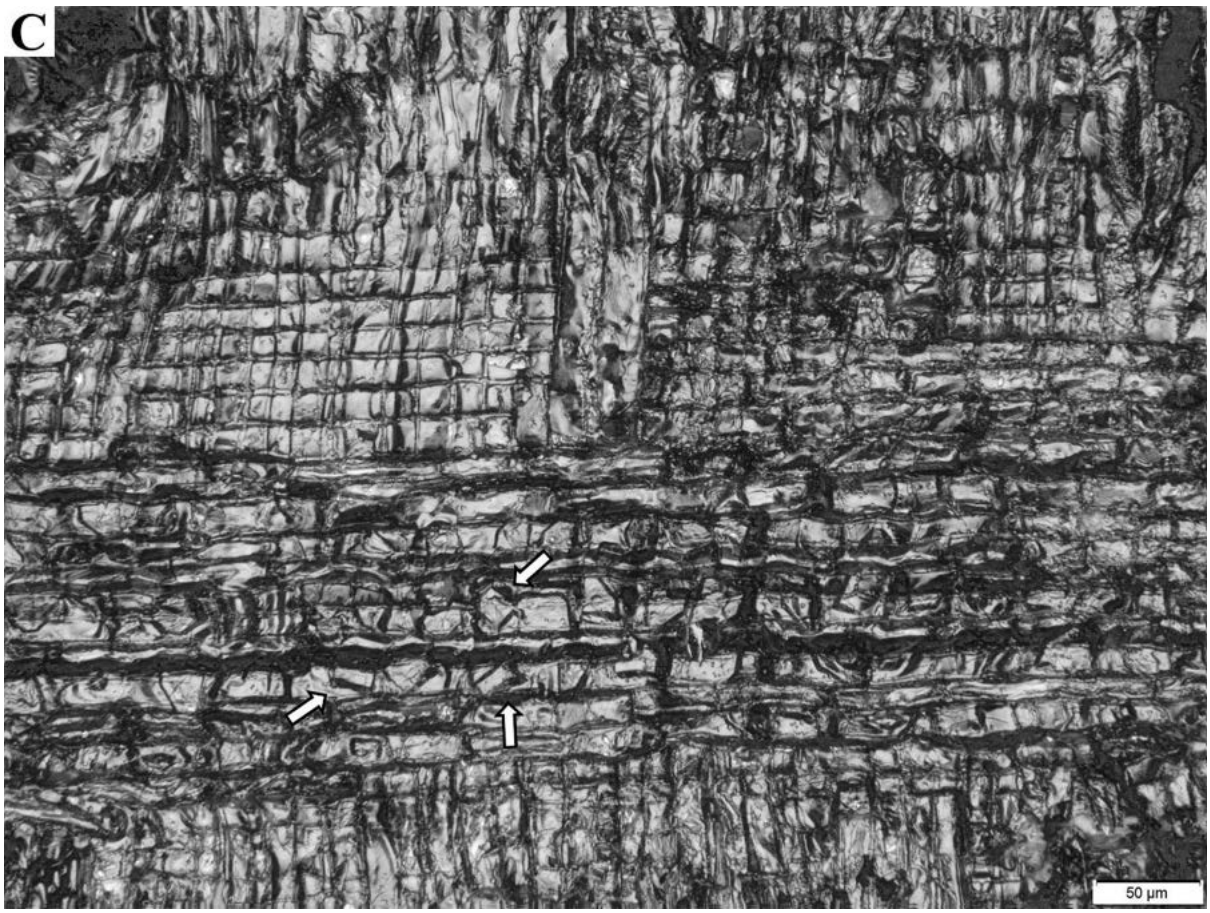


Fig. 1: A) TS: Growth ring distinct. Vessels forming clusters with mean diameter between 50-100 µm. Tyloses common. B) TLS: Vessel-ray pits rounded / angular, uniseriate and biseriate rays. C) RLS: Prismatic crystals in ray cells.

- Ecological distribution and economic features

Rhus sp. is a genus of shrubs and small trees that can reach a height of 1-10 meters (Miller et al. 2001). During pre-Aksumite and Aksumite times, *Rhus* sp. has only been identified as a minor genera (<5%) in the palynological record of Lake Hayk (Darbyshire et al. 2003). According to Friis et al. (2010), six species of *Rhus* sp. are present in modern northern Ethiopia (Table 1).

Table 1 Ecological distribution of *Rhus* species in northern Ethiopia (Friis et al. 2010: 215-216).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Rhus natalensis	*Tetale*	700-2500	0	1	0	1	1	0	1	0	0	0
Rhus quartiniana	*Thathalo*	900-1800	0	0	0	0	1	0	0	0	0	1
Rhus ruspoli	?	1200-2150	0	0	0	1	1	0	0	0	0	0
Rhus glutinosa	*Shemut*	1500-2600	0	0	0	0	1	0	0	1	0	0
Rhus retinorrhoea	*Thathalo*	1450-2700	0	1	0	0	1	0	0	0	0	0
Rhus vulgaris	?	1500-2800	0	1	0	1	1	0	0	0	0	0

Rhus sp. is generally harvested in the wild for local use as medicine (leaves, roots). It is also sometimes grown to stabilize the soil (Bekele-Tesemma 2007). The wood is generally light colored (yellow to olive-green), soft, fine-to-medium grained, non-durable and susceptible to insect attack. It is considered to be a good fuel and suitable to make charcoal (Ruffo et al. 2002). Other uses include the manufacture of household items, tool handles and poles for building (Ruffo et al. 2002; Bekele-Tesemma 2007).

***Carissa* spp. (Apocynaceae)**

- Definition of charcoal type

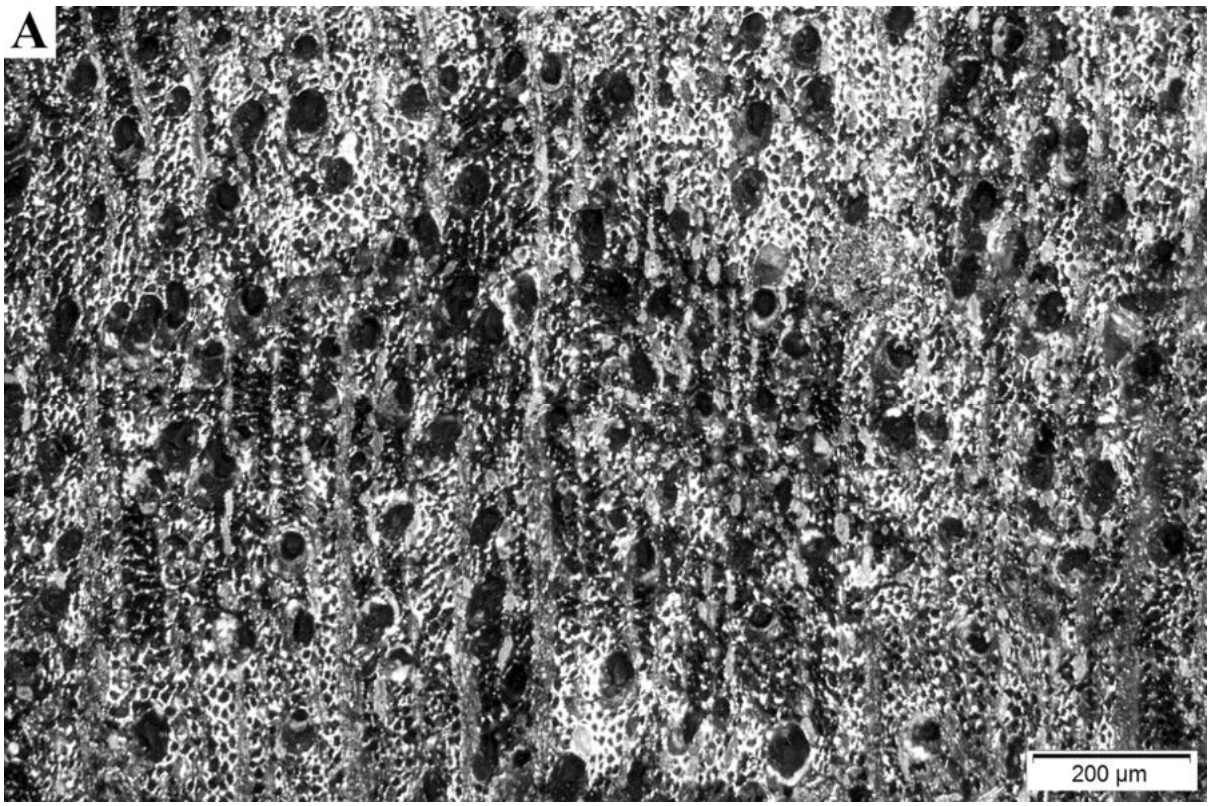
Growth rings boundaries indistinct or absent. Wood diffuse-porous. **Vessels** exclusively solitary (90% or more). Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel lumina smaller than 50 µm. **Fibres** with simple to minutely bordered pits. Fibres with distinctly bordered pits. Axial **parenchyma** apotracheal diffuse. **Ray** width 1 to 3 cells. Body ray cells procumbent with 2-4 rows (sometimes more) of upright and / or square marginal cells. **Prismatic crystals** present. Prismatic crystals in axial parenchyma cells.

- Main diagnostic features

Mean tangential diameter of vessel lumina smaller than 50 µm. Vessels exclusively solitary (90% or more). Ray width 1 to 3 cells. Heterocellular ray structure, body ray cells procumbent with 2-4 rows (sometimes more) of upright and / or square marginal cells. Prismatic crystals in axial parenchyma cells.

- Discussion

The wood anatomy of this charcoal type matches the reference samples of *Carissa schimperi* A.DC. - a synonym of *Acokanthera schimperi* (A.DC.) Schweinf., accepted by IPNI (2020) - from Somalia at the MNHN xylothèque. Neumann et al. (2001) notes that *Carissa* sp. can easily be mistaken with woods of the Rubiaceae family such as *Feretia* sp. and *Mitragyna* sp., the main difference being the presence of abundant crystals in axial parenchyma cells of *Carissa* sp. This feature also occurs in some Rubiaceae, including *Homollea* sp., *Nichallea* sp., *Oldenlandia* sp., *Rondeletia* sp., *Tarenna* sp. and *Timonius* sp. (Jansen et al. 2002) though none of them have been recorded in northern Ethiopia (Friis et al. 2010), and show distinct anatomical characters absent in the studied charcoals: *Tarenna* sp. has been recorded in southern Ethiopia (Friis et al. 2010), but its wood is characterized by ray width up to 5 cells and the presence of sheath cells (Jansen et al. 2002). Sheath cells are also found in *Homollea* sp., *Nichallea* sp. and *Rondeletia* sp., while 5-seriate rays are present in *Timonius* sp. (Jansen et al. 2002). Finally, vessels are not exclusively solitary in wood from *Oldenlandia* sp. (Jansen et al. 2002). Further diagnostic characters of Rubiaceae wood anatomy include the presence of growth rings (though often indistinct in smaller charcoal fragments) and narrow uni- and biseriate rays with long uniseriate margins (Jansen et al. 2002 and references therein), which do not occur in *Carissa* sp.



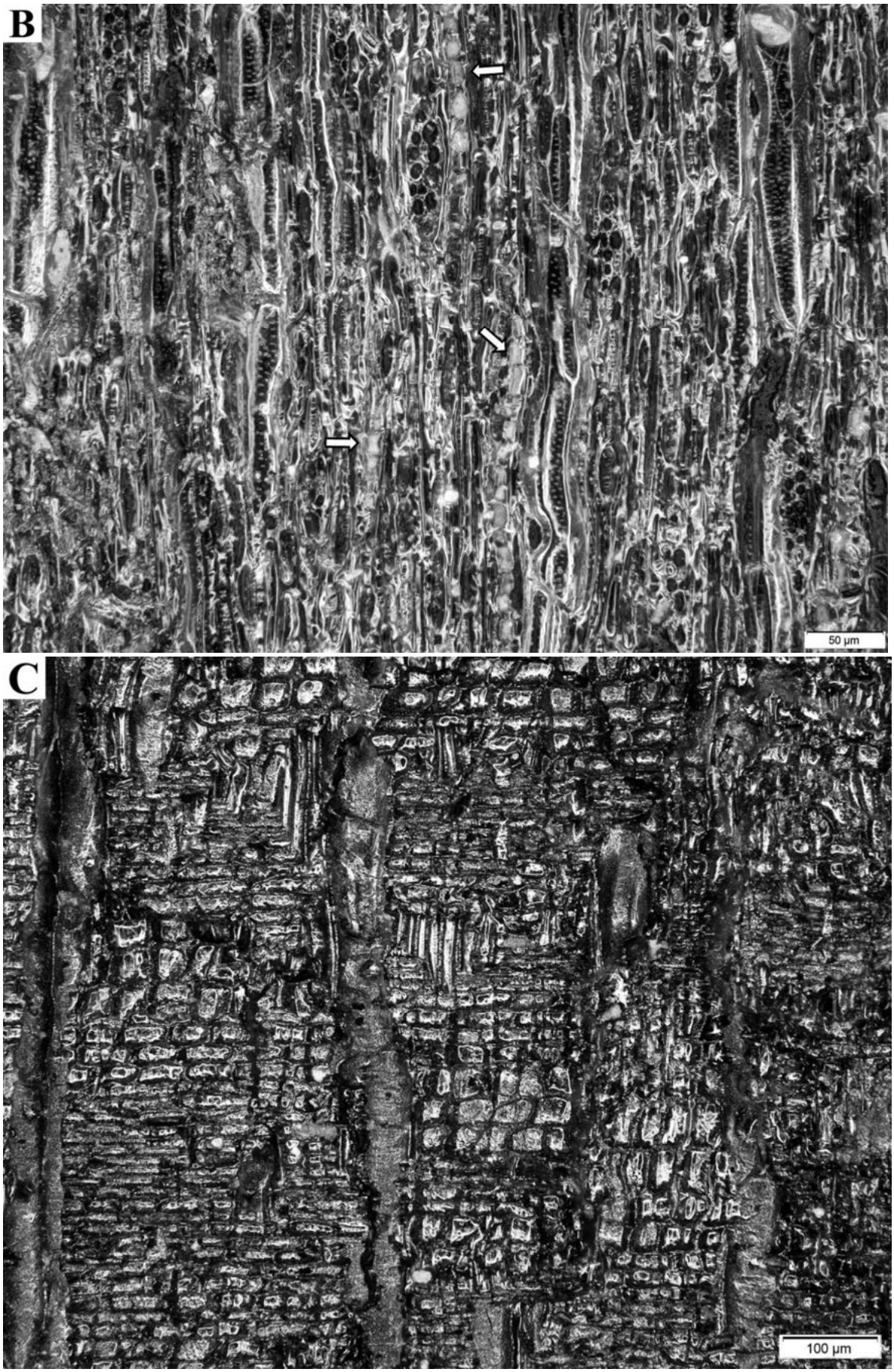


Fig. 2: A) TS: Vessels exclusively solitary, with mean diameter of lumina smaller than 50 µm. B) TLS: Short rays, 1- to 3 cells wide. Prismatic crystals in axial parenchyma cells. C) RLS: Body ray cells procumbent with 2-4 rows of upright and / or square marginal cells.

- Ecological distribution and economic features

Distinct species of *Carissa* sp. grow as shrubs or trees, attaining heights of 2 to 10 m tall (Boning 2006). Their presence in pre-Aksumite and Aksumite chronologies has not been documented so far. Friis et al. (2010) lists two species present in the northern Highlands of Ethiopia nowadays (Table 2).

Table 2 Ecological distribution of *Carissa* species in northern Ethiopia (Friis et al. 2010: 219).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Carissa schimperi	*Mbetti*	800-2100	0	1	0	0	1	0	1	0	0	0
Carissa spinarum	*Agam*	550-2500	0	1	0	0	1	1	1	0	0	1

Carissa species are valuable plant resources for local people: the fruits are gathered in the wild for use as food, while leaves, roots and bark are employed in medicines (Bekele-Tesemma 2007). The white or yellow wood is hard, smooth and well considered as fuel (Ruffo et al. 2002). It is also useful for fashioning spoons, combs, household utensils and miscellaneous products of turnery (Bekele-Tesemma 2007).

cf. *Boscia* spp. (Capparaceae)

- Definition of charcoal type

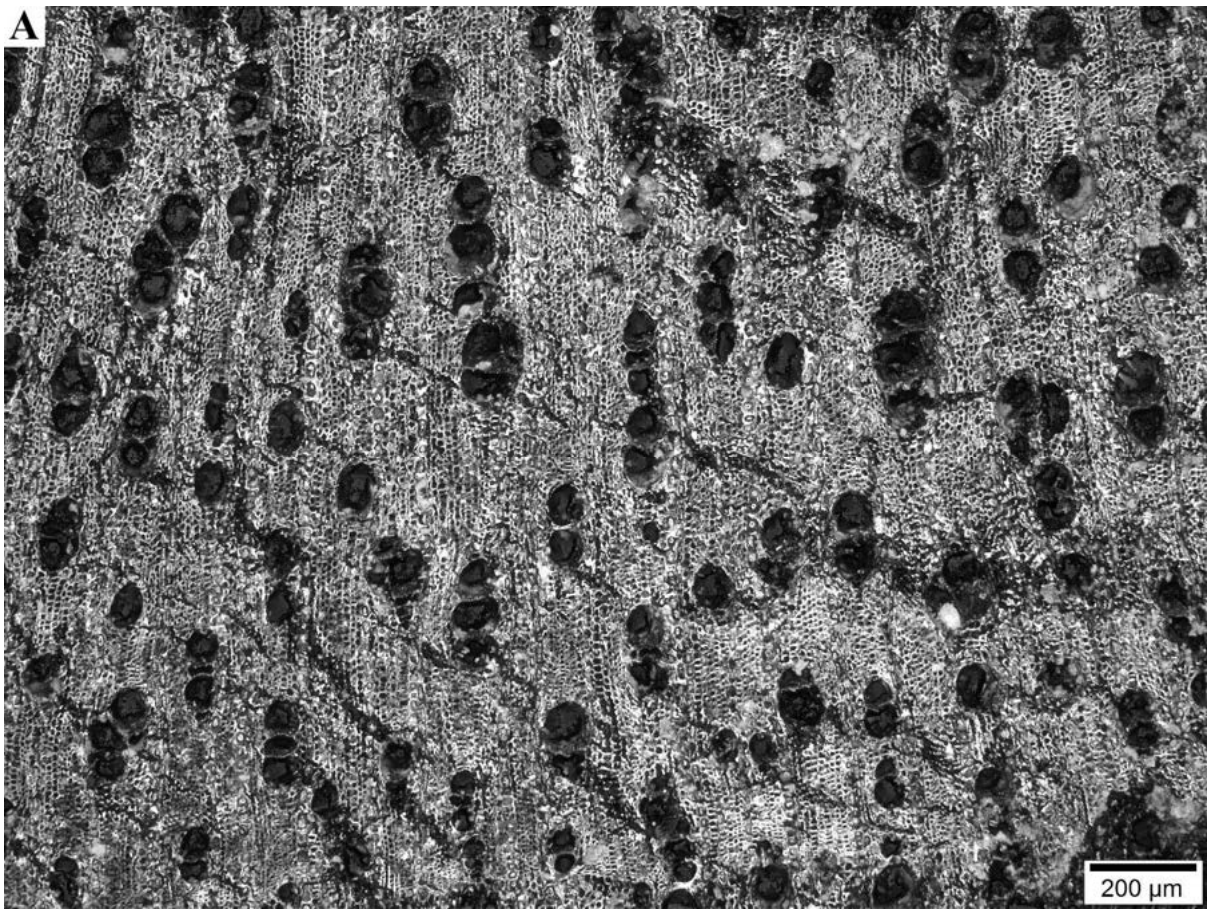
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** in diagonal and / or radial pattern. Vessels grouping sometimes in radial multiples of 2-3, sometimes solitary. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell, but sometimes with much reduced borders to apparently simple: pits rounded or angular. Mean tangential diameter of vessel lumina between 50-100 µm. **Fibres** with simple to minutely bordered pits. Axial **parenchyma** apotracheal diffuse. Axial parenchyma paratracheal scanty to vasicentric. Axial parenchyma in marginal or in seemingly marginal bands. **Ray** width 1 to 3 cells. Homocellular, all ray cells procumbent; sometimes heterocellular, with procumbent, square and upright cells mixed throughout the ray.

- Main diagnostic features

Mean tangential diameter of vessel lumina between 50-100 µm. Vessels in diagonal and / or radial pattern. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell, sometimes with much reduced borders to apparently simple: pits rounded or angular. Axial parenchyma in marginal or in seemingly marginal bands. Ray width 1 to 3 cells.

- Discussion

The identification of this charcoal type as *Boscia* spp. is preliminary due to lack of reference samples and disagreement about wood anatomy key characters within the anthracological community (e.g. Metcalfe and Chalk 1950; Neumann et al. 2001; InsideWood 2004-onwards). The combination of the main diagnostic features in InsideWood (2004-onwards) for tropical Africa results in *Boscia angustifolia* and *Gluema ivorensis* - however, the latter shows reticulate axial parenchyma and heterogeneous rays with body cells procumbent and 1-4 (or more) rows of upright and / or square marginal cells, both characters absent in the studied charcoal. The wood anatomy of this charcoal type largely matches Neumann et al. (2001) account for *Boscia* sp. - including *B. angustifolia, B. salicifolia* and *B. senegalensis*, the main difference being the presence of wider rays up to 5 seriate though they indicate that rays of branchwood are much narrower (see Neumann et al. 2001: 182). This is in accordance with Metcalfe and Chalk (1950: 93) who describe *Boscia* sp. rays as with a maximum width of only 2 or 3 cells. Both publications note ray structure to be predominantly homocellular - all ray cells procumbent - with a tendency to weak heterogeneity - all cell types mixed (Metcalfe and Chalk 1950; Neumann et al. 2001), as seen in the studied charcoal type (Figure 3C). Another divergence from Neumann et al. (2001) is the presence of growth rings. However, *Boscia angustifolia* description at InsideWood (2004-onwards) includes both presence and absence of growth rings and hence it cannot be considered as a diagnostic character. In northern Ethiopia, only two species of this genus are recorded, namely *B. angustifolia* and *B. salicifolia* (Friis et al. 2010). According to Neumann et al. (2001: 178), these two species cannot be distinguished by their wood anatomical characters. Further species such as *B. minimifolia*, *B. mossambicensis*, *B. senegalensis* and *B. coriacea* also occur in modern Ethiopia, but they are restricted to the southern part of the country (Friis et al. 2010). Other genera from the *Capparaceae* family listed by Friis et al. (2010) are *Cadaba* sp., *Capparis* sp., *Crateva* sp., *Ritchiea* sp., and *Maerua* sp., but none of them show the combination of axial parenchyma in marginal bands and multiseriate rays (Neumann et al. 2001: 184-203; InsideWood 2004-onwards).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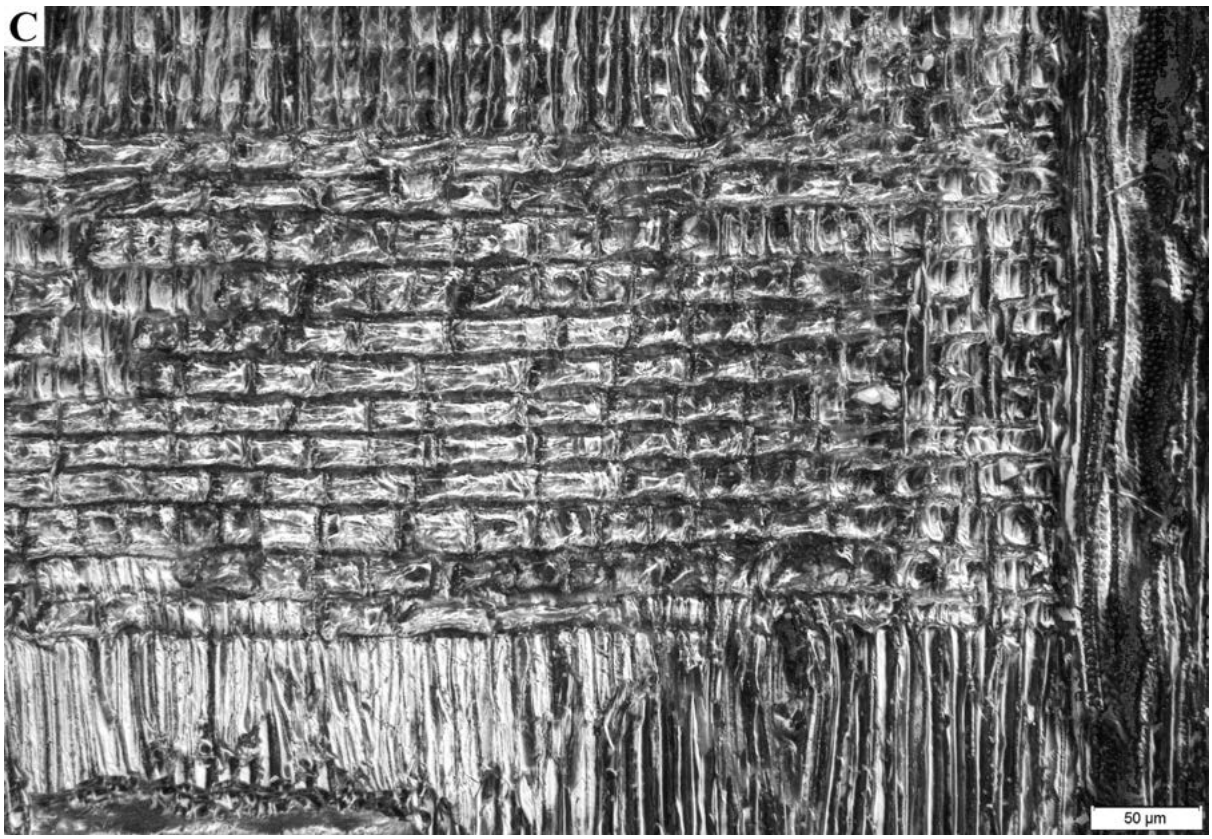


Fig. 3: A) TS: Vessels in diagonal and / or radial pattern, with mean lumina diameter between 50-100 µm. Axial parenchyma forming marginal or in seemingly marginal bands. B) TLS: Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular. Ray width 1 to 3 cells. C) RLS: Ray structure homocellular to weekly heterocellular, procumbent ray cells predominant, with a few upright / square cells mixed throughout the ray.

- Ecological distribution and economic features

Boscia sp. is a genus of shrubs and trees that can grow up to 10-15 meters (von Maydell 1986). Their presence during pre-Aksumite and Aksumite times has not been confirmed, although pollen grains of Capparaceae have been found (c. 10%) in both pre-Aksumite and Aksumite contexts from the Beta Giyorgis hill at Aksum (DiBlasi 1996, 1997). Friis et al. (2010) recorded two species that have been found recently in northern Ethiopia (Table 3).

Table 3 Ecological distribution of *Boscia* species in northern Ethiopia (Friis et al. 2010: 180).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Boscia angustifolia	*Agahini*	50-1900	1	1	0	0	0	0	0	0	0	0
Boscia salicifolia	?	800-1900	0	1	0	0	1	0	0	0	0	0

These trees have a range of edible (fruit) and medicinal uses (fruit, bark, roots), and are a secondary source of fuel (von Maydell 1986). In cultivated areas the tree is conserved for use as an emergency food when woodlands are cleared for cultivation. The wood is very hard, suitable for carpentry and charcoal production, and it is sometimes used as firewood despite its bad smell (von Maydell 1986).

***Maerua* spp. (Capparaceae)**

- Definition of charcoal type

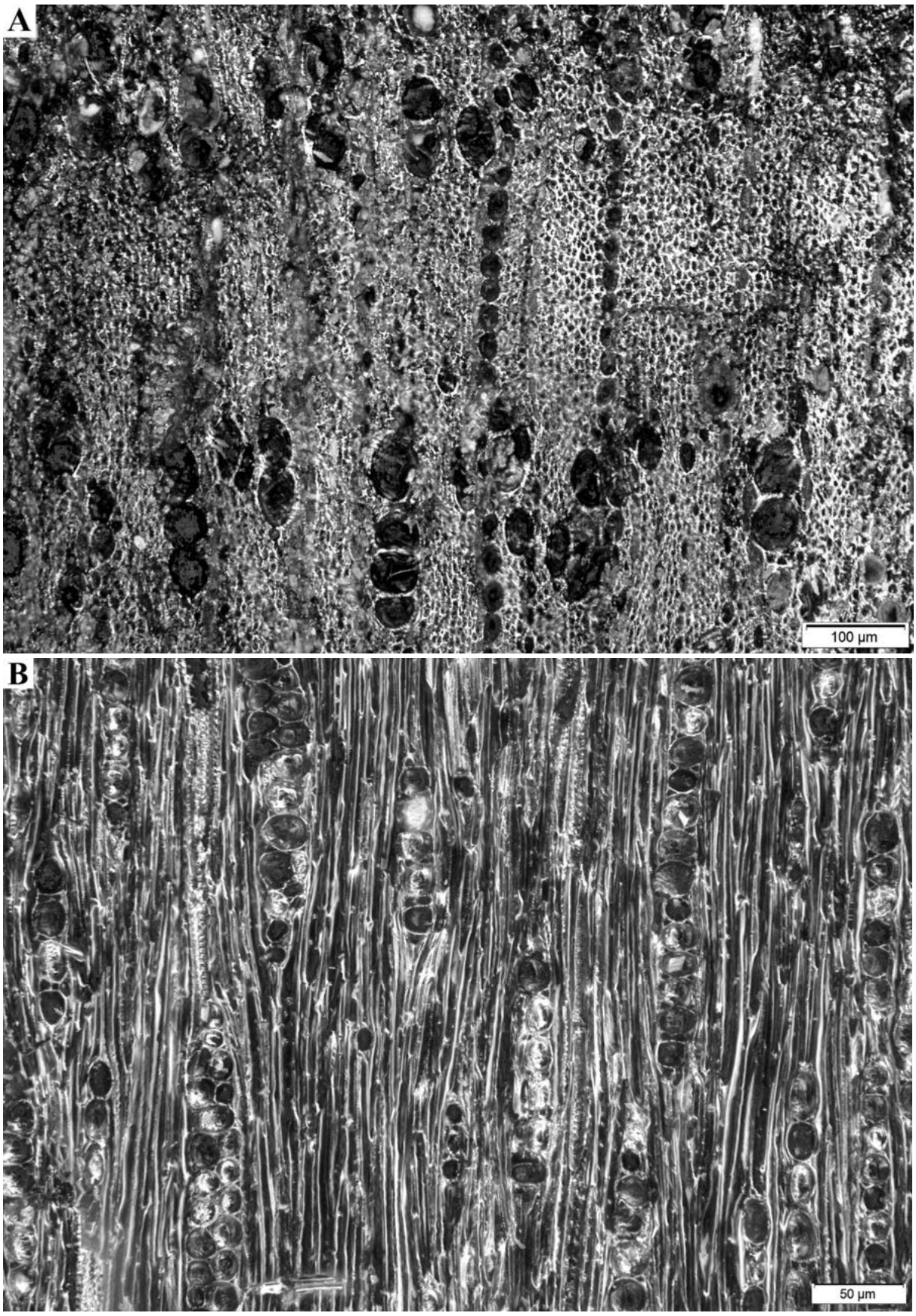
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** grouping in radial multiples of 4 or more common. Vessel clusters common. Simple perforation plates. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel lumina smaller than 50 µm. Mean tangential diameter of bigger vessel lumina between 50 and 100 µm. Vessels of two distinct diameter classes, wood not ring-porous. **Fibres** with simple to minutely bordered pits. Axial **parenchyma** paratracheal scanty. **Ray** width 1 to 3 cells. Rays with procumbent, square and upright cells mixed throughout the ray.

- Main diagnostic features

Vessels of two distinct diameter classes, wood not ring-porous. Vessels grouping in radial multiples of 4 or more common. Vessel clusters common. Axial parenchyma paratracheal scanty. Ray width 1 to 3 cells. Rays with procumbent, square and upright cells mixed throughout the ray.

- Discussion

The wood anatomy of this charcoal type largely matches the reference samples of Pakistani species *Maerua crassifolia* Forssk. from the MNHN Anthracotèque, though the archaeological samples show longer radial rows of vessels in transversal section and smaller vessels are more common. A search of the diagnostic features of this charcoal type in InsideWood (2004-onwards) in tropical Africa results in two species, including *Rhamnus prinoides* - a clear dendritic pattern in vessel arrangement is diagnostic of the genus (Schirarend 1991) - and *Maerua crassifolia* - which matches the overall description presented above. Friis et al. (2010) includes 15 *Maerua* species growing today in Ethiopia, of which only *M. angolensis* and *M. oblongifolia* are present in the northern regions. According to Neumann et al. (2001), these two species can be differentiated as *M. oblongifolia* shows distinct growth rings and larger rays (up to 5 seriate), but also due to the presence of vessel clusters in *M. angolensis.* The authors also note possible confusion with other species of *Capparis* sp. and *Cadaba* sp., the only species present in Ethiopia being *Capparis decidua* (Friis et al. 2010). Differentiation with *Maerua* sp. is straightforward as *Capparis decidua* does not feature long rows of radially arranged vessels (Neumann et al. 2001). The classification at a species level is not possible as there are other *Maerua* species with similar wood anatomy such as *M. crassifolia* (Neumann et al. 2001: 200) which could have occurred in northern Tigray during the Pre-Aksumite and Aksumite periods - even though today they are only found in the southern Ethiopian regions.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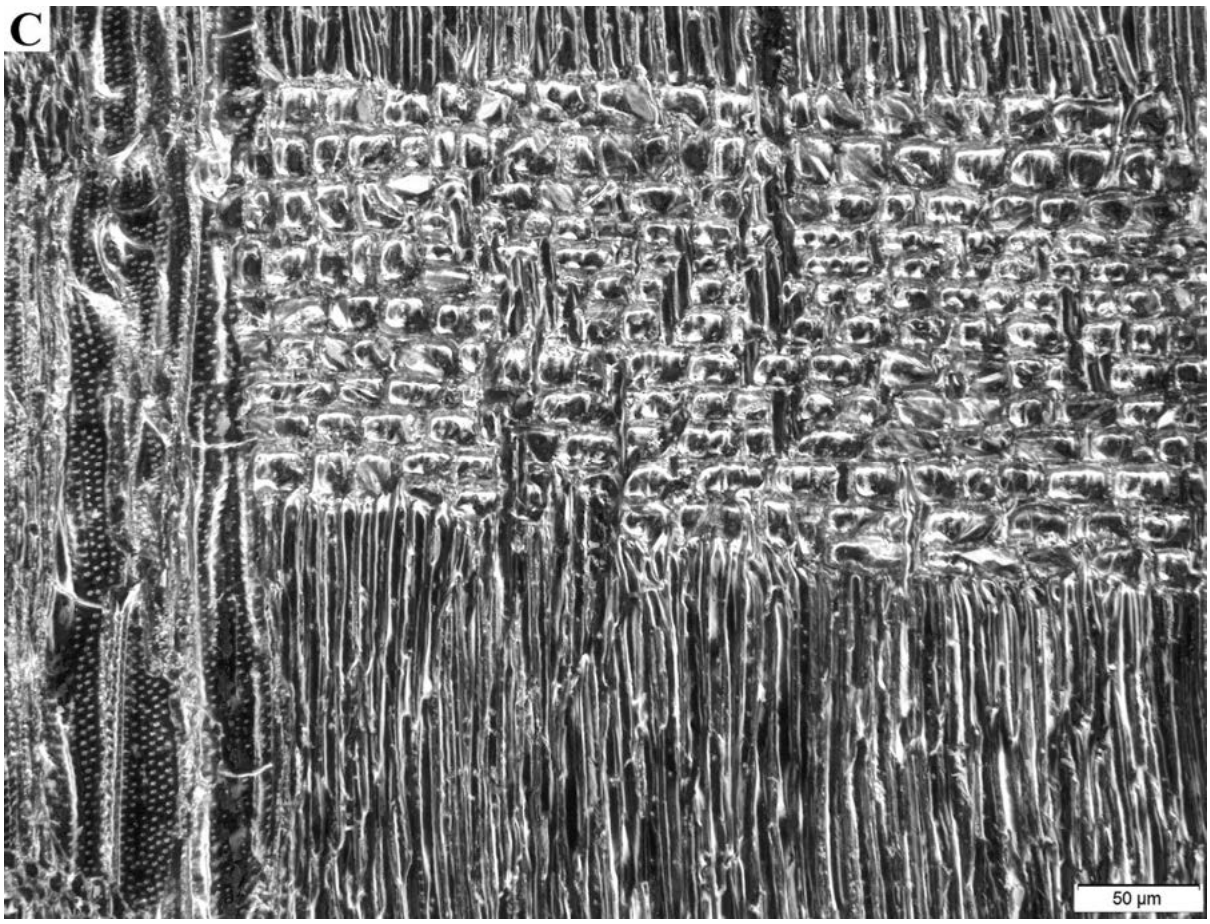


Fig. 4: A) TS: Vessels of two distinct diameter classes (wood not ring-porous), commonly arranged in radial multiples of 4 or more and forming clusters. Axial parenchyma paratracheal scanty. B) TLS: Heterocellular rays, 1- to 3- seriate. C) RLS: Rays with procumbent, square and upright cells mixed throughout the ray.

- Ecological distribution and economic features

Maerua sp. is a genus of shrubs or small trees, usually growing 1-10 meters (Louppe et al. 2008). Its presence during pre-Aksumite and Aksumite times has not been confirmed, although pollen grains of Capparaceae have been found (c. 10%) in both pre-Aksumite and Aksumite contexts from the Beta Giyorgis hill at Aksum (DiBlasi 1996, 1997). According to Friis et al. (2010), there are 15 woody species of *Maerua* sp. in current Ethiopia (Table 4).

Table 4 Ecological distribution of *Maerua* species in northern Ethiopia (Friis et al. 2010: 180-181).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Maerua angolensis	*Mere*	500-1900	0	1	0	0	1	0	0	0	0	0
Maerua oblongifolia	*Gerimo*	0-1800	1	1	0	0	0	0	0	0	0	0
Maerua subcordata	?	450-1250	0	1	0	0	0	0	0	0	0	0
Maerua intricata	?	300-400	1	1	0	0	0	0	0	0	0	0
Maerua denhardtiorum	?	0-950	0	1	0	0	0	0	0	0	0	0
Maerua boranensis	?	750-1400	0	1	0	0	0	0	0	0	0	0
Maerua triphylla	?	500-2100	0	0	0	0	0	0	0	0	0	1
Maerua candida	?	100-300	1	1	0	0	0	0	0	0	0	0
Maerua crassifolia	?	400-1350	0	1	0	0	0	0	0	0	0	0
Maerua endlichii	?	1150-1250	0	1	0	0	0	0	0	0	0	0
Maerua sessiliflora	?	600-100	0	1	0	0	0	0	0	0	0	0
Maerua aethiopica	?	650-850	0	0	0	1	0	0	0	0	0	0

Maerua macrantha	?	300-1000	1	1	0	0	0	0	0	0	0	0
Maerua glauca	?	c. 1400	0	1	0	0	0	0	0	0	0	0
Maerua gillettii	?	c. 1200	0	1	0	0	0	0	0	0	0	0

A multipurpose genus, *Maerua* sp. is harvested from the wild for local use, mainly as a medicine (fruit, leaves, roots), but also as emergency food (leaves) (von Maydell 1986; Louppe et a. 2008). The wood is hard, heavy, fine-grained, yellowish and takes a fine polish (Louppe et al. 2008). According to Louppe et al. (2008) the wood does not perform well as firewood but it can be used to produce charcoal.

***Maytenus* spp. (Celastraceae)**

- Definition of charcoal type

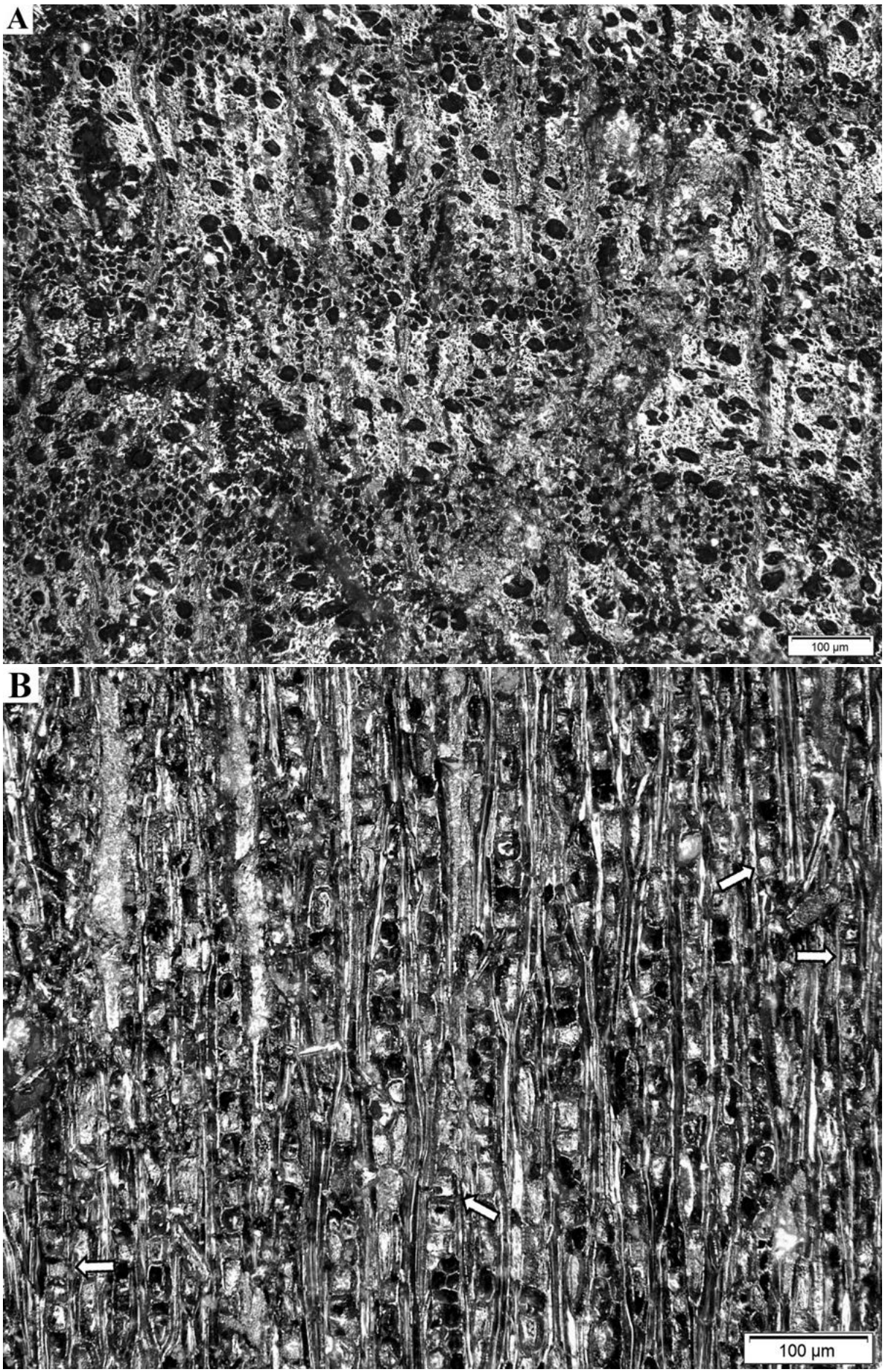
Growth ring boundaries indistinct or absent. Wood diffuse-porous. Vessels generally solitary, sometimes in radial groups of 2-3. Solitary vessel outline angular. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel lumina smaller than 50 µm. **Fibres** with simple to minutely bordered pits. Parenchyma-like fibre bands alternating with ordinary fibres. Axial **parenchyma** apotracheal diffuse. **Ray** width 1 to 3 cells. Rays with procumbent, square and upright cells mixed throughout the ray. **Prismatic crystals** present. Prismatic crystals located in procumbent and upright/square ray cells.

- Main diagnostic features

Mean tangential diameter of vessel lumina smaller than 50 µm. Parenchyma-like fibre bands alternating with ordinary fibres. Rays with procumbent, square and upright cells mixed throughout the ray. Prismatic crystals in ray cells.

- Discussion

The wood anatomy of this charcoal type matches the reference samples of Peruvian species *Maytenus octogona* (L'Hér.) DC. from the MNHN Anthracotèque. The combination of the main diagnostic features in InsideWood (2004-onwards) for tropical Africa results in two species of the same genus: *Gymnosporia linearis* and *G. senegalensis* - *G. senegalensis* Loes. is a synonym of *Maytenus senegalensis* (Lam.) Exell, as accepted by IPNI (2020). It also coincides with Neumann et al. (2001) description of *Maytenus senegalensis*, stating that it is the only species featuring parenchyma-like fibres bands in the Sahara and Sahel regions. Friis et al. (2010) does not include *Gymnosporia* sp. as an Ethiopian genus, but it includes 8 species of *Maytenus* sp. present in the northern Highlands of Ethiopia and Eritrea - including *Maytenus senegalensis*. The identification to species level is not possible since InsideWood (2004-onwards) does not include any other of the 7 species recorded by Friis et al. (2010) and due to the lack of reference samples and publications covering intraspecific variability of wood anatomy.


A
100 µm
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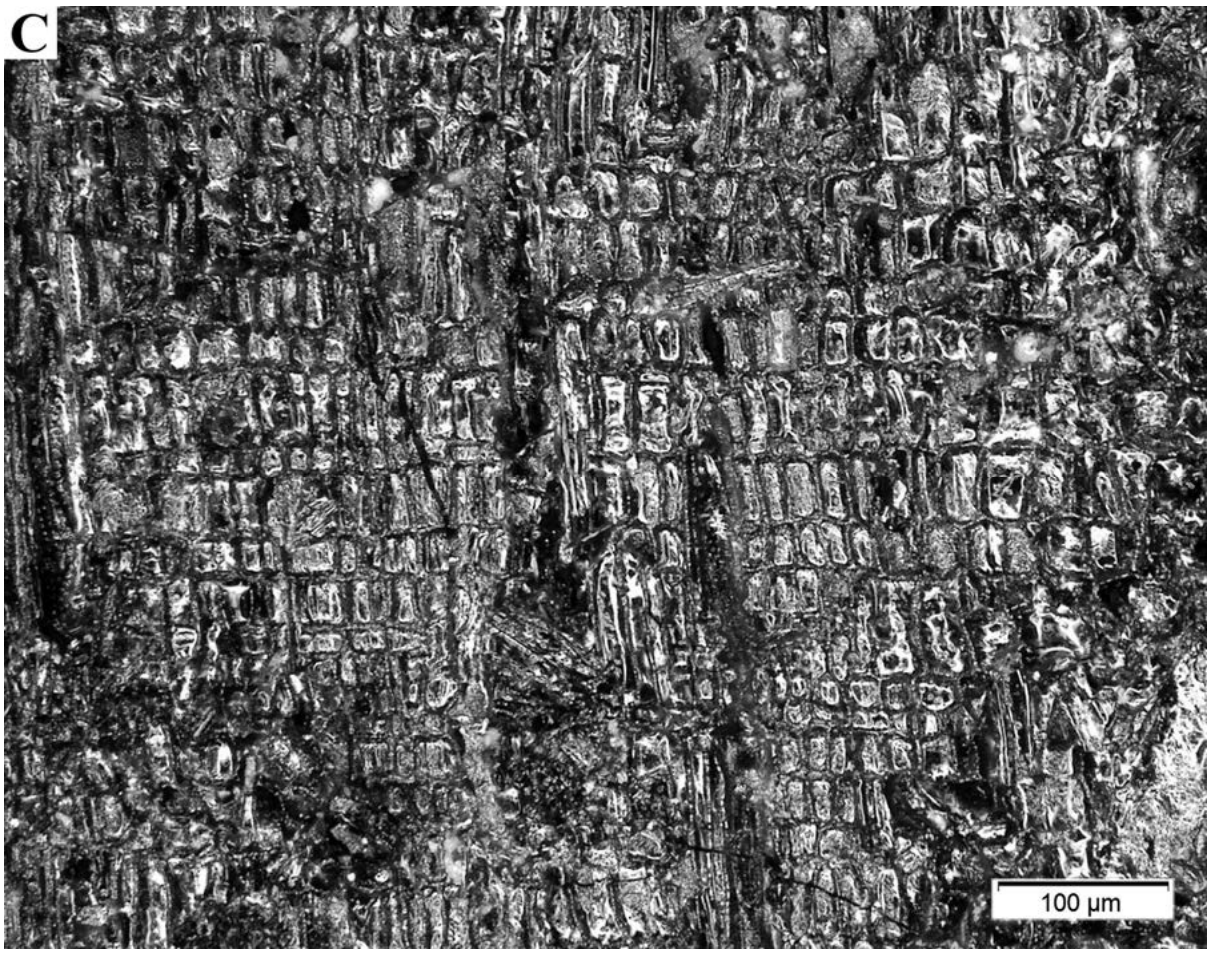


Fig. 5: A) TS: Mean tangential diameter of vessel lumina smaller than 50 µm. Parenchyma-like fibre bands alternating with ordinary fibres. B) TLS: Rays heterocellular, with prismatic crystals in ray cells. C) RLS: Rays with procumbent, square and upright cells mixed throughout the ray.

- Ecological distribution and economic features

Maytenus sp. is a morphologically diverse genus of trees or shrubs of different sizes (McKenna et al. 2011). No record of this genus during pre-Aksumite and Aksumite times has been published so far. Eight species of *Maytenus* sp. have been identified by Friis et al. (2010) in modern northern Ethiopia (Table 5).

Table 5 Ecological distribution of *Maytenus* species in northern Ethiopia (Friis et al. 2010: 206).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Maytenus gracilipes	*Degmut*	1250-2800	0	0	0	0	1	1	0	0	0	0
Maytenus serrata	?	1650-2250	0	0	0	0	1	0	0	0	0	0
Maytenus parviflora	?	450-2000	0	0	0	0	1	0	0	0	0	0
Maytenus obscura	*Atat*	1700-3100	0	0	0	0	1	0	0	1	0	0
Maytenus corttii	?	c. 3500	0	0	0	0	0	0	0	0	1	0
Maytenus arbutifolia	*Atat*	1200-3000	0	0	0	0	1	1	0	0	0	0
Maytenus senegalensis	*Qebqeb*	380-2440	0	1	1	1	1	0	0	0	0	0
Maytenus undata	*Tsellimo*	920-3100	0	0	0	0	0	1	1	0	0	0

These plants are often harvested in the wild for local use as a food (fruit), but mainly as medicine and recreational drug (roots, bark) (von Maydell 1986). Their wood is generally whitish to red-brown, hard, fine-grained and durable. It is used as firewood and timber for local construction (von Maydell 1986; Bekele-Tesemma 2007).

***Juniperus procera* (Crupressaceae)**

- Definition of charcoal type

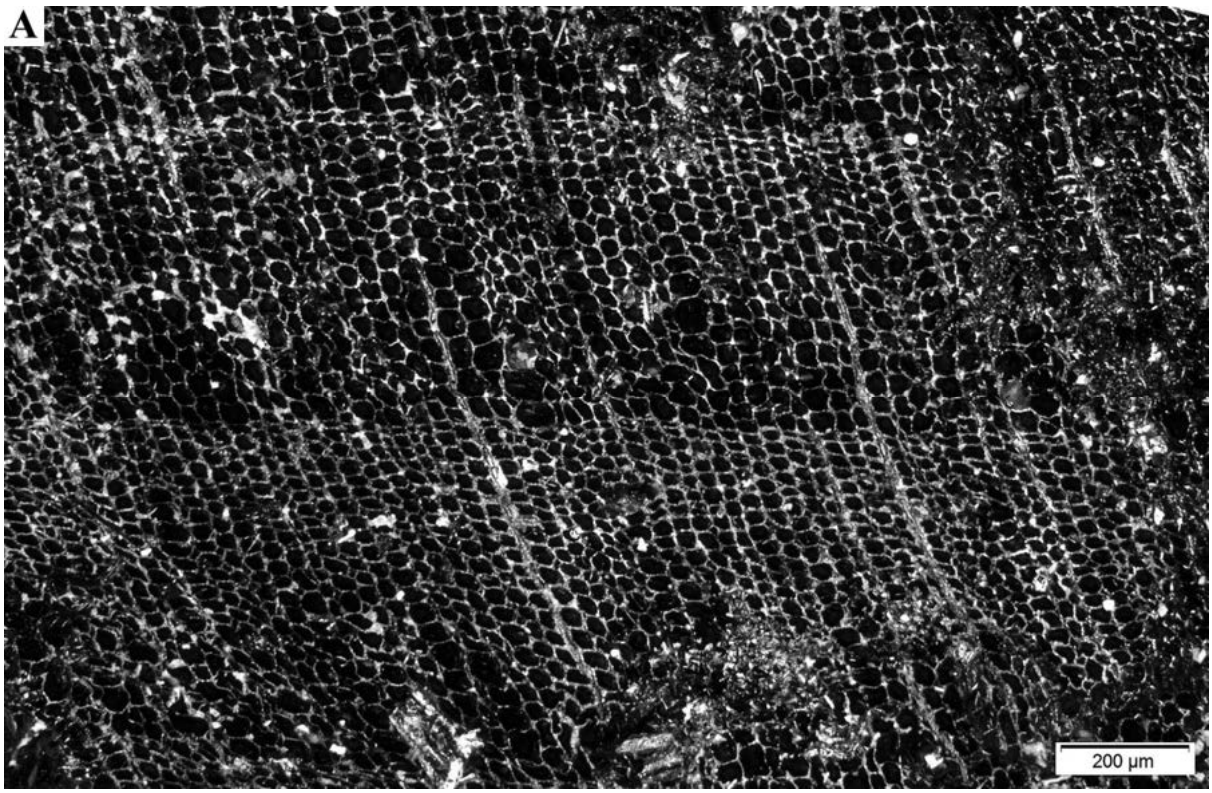
Growth ring boundaries distinct. Transition from early- to latewood gradual. **Tracheid** pitting in early wood predominantly uniseriate. Intercellular spaces throughout the wood present. Latewood tracheid wall thin-walled. Axial **parenchyma** present. Arrangement of axial parenchyma diffuse. **Ray tracheids** absent or very rare. **Cross-field pits** cupressoid. Number of pits per field 1-3 (sometimes 4). **Rays** height very low (up to 4 cells). Rays exclusively uniseriate.

- Main diagnostic features

Growth ring boundaries distinct. Transition from early- to latewood gradual. Cross-field pits cupressoid. Number of pits per field 1-3 (sometimes 4). Rays height very low (up to 4 cells).

- Discussion

The wood anatomy of this charcoal type largely matches the reference samples of Pakistani species *Juniperus macropoda* Boiss. from the MNHN Anthracotèque. However, unlike *Juniperus macropoda*, the studied charcoal fragments feature a gradual transition from early- to latewood, coinciding with *Juniperus procera* wood anatomy as described by Louppe et al. (2008) and by Fasolo et al. (1939). Friis et al. (2010) lists *Juniperus procera* as the only species of the Cupressaceae family present in Ethiopia - along with *Podocarpus falcatus* as the only two recorded gymnosperms. These species can be easily distinguished due to ray height - *Juniperus procera* shows shorter rays (up to 4 cells high) than *Podocarpus falcatus* (5- to 15 cells) - and differentiated cross-field pits, both in shape - *Juniperus procera* features cupressoid type while *Podocarpus falcatus* is characterized by taxodioid cross-field pits (Louppe et al. 2008) - and number - *Juniperus procera* displays 2-4 pits per field whereas *Podocarpus falcatus* rarely shows more than 1.



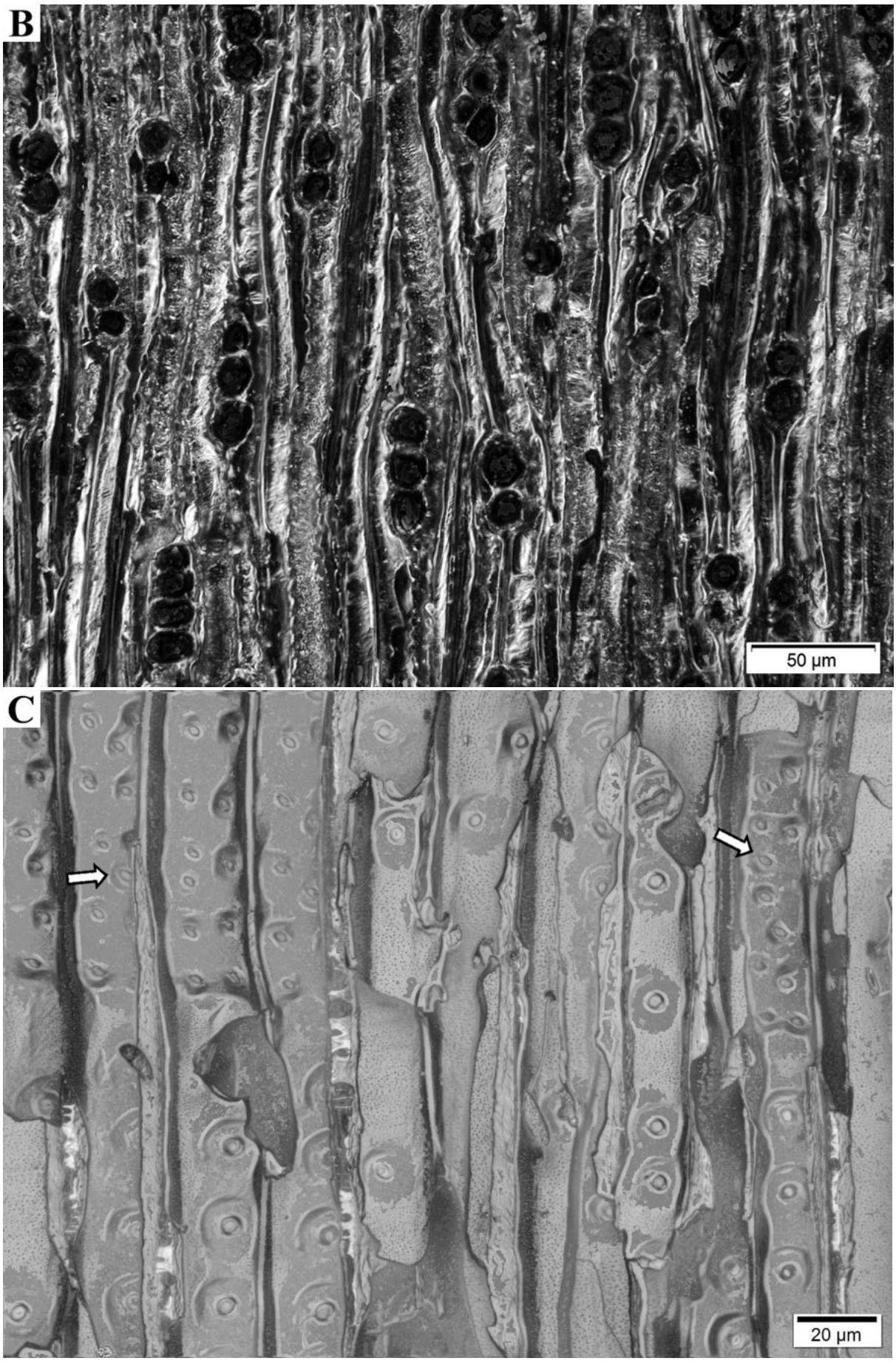


Fig. 6: A) TS: Growth ring boundaries distinct. Transition from early- to latewood gradual. B) TLS: Rays height up to 4 cells. C) RLS: Cross-field pits cupressoid. Number of pits per field 2-4.

- Ecological distribution and economic features

Juniperus procera is a medium-sized tree reaching 20-25 m (rarely 40 m) in height, with a trunk diameter up to 1.5-2 m (Farjon 2005). Palynological analyses attest to its presence during pre-Aksumite and Aksumite times at Lake Hayk, Amhara region (c. 1-3%) and Lake Abiyata, Arsi (c. 5%), increasing to 10% after the fall of the Aksumite kingdom (Bonnefille and Mohammed 1994; Darbyshire et al. 2003). These data coincide with the results of charcoal analysis carried by Gebru et al. (2009) from natural deposits. It has been found to grow in the evergreen afromontane forests, where it is one of the most ubiquitous species, and the ericaceous belt (Table 6) (Friis et al. 2010). In general, it thrives in high-rainfall areas but can survive in quite dry conditions once established, being able to survive on mountain slopes, summits, on escarpments and outcrops and in forested ravines in sand, loam or clay soils over various rock types (Bekele-Tesemma 2007).

Table 6 Ecological distribution of *Juniperus procera* in northern Ethiopia (Friis et al. 2010: 178).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Juniperus procera	?	1100-3500	0	0	0	0	0	1	1	1	0	0

The tree is extensively exploited in the wild for its wood and as a source of essential oils and various traditional medicines (Ruffo et al. 2002). The wood is pale red, yellow-brown or purple-red when freshly cut, turning reddish brown on exposure; medium-weight and very durable –it is resistant to fungi, termites and most borers (Chudnoff 2007). The wood is used as firewood and to make charcoal: it burns evenly, but fast when fresh, and the charcoal does not last long (Chudnoff 2007). Other uses include a wide variety of mobile instruments and as a building material, due to its fragrance and easy working features (von Maydell 1986; Ruffo et al. 2002; Bekele-Tesemma 2007).

***Croton* spp. (Euphorbiaceae)**

- Definition of charcoal type

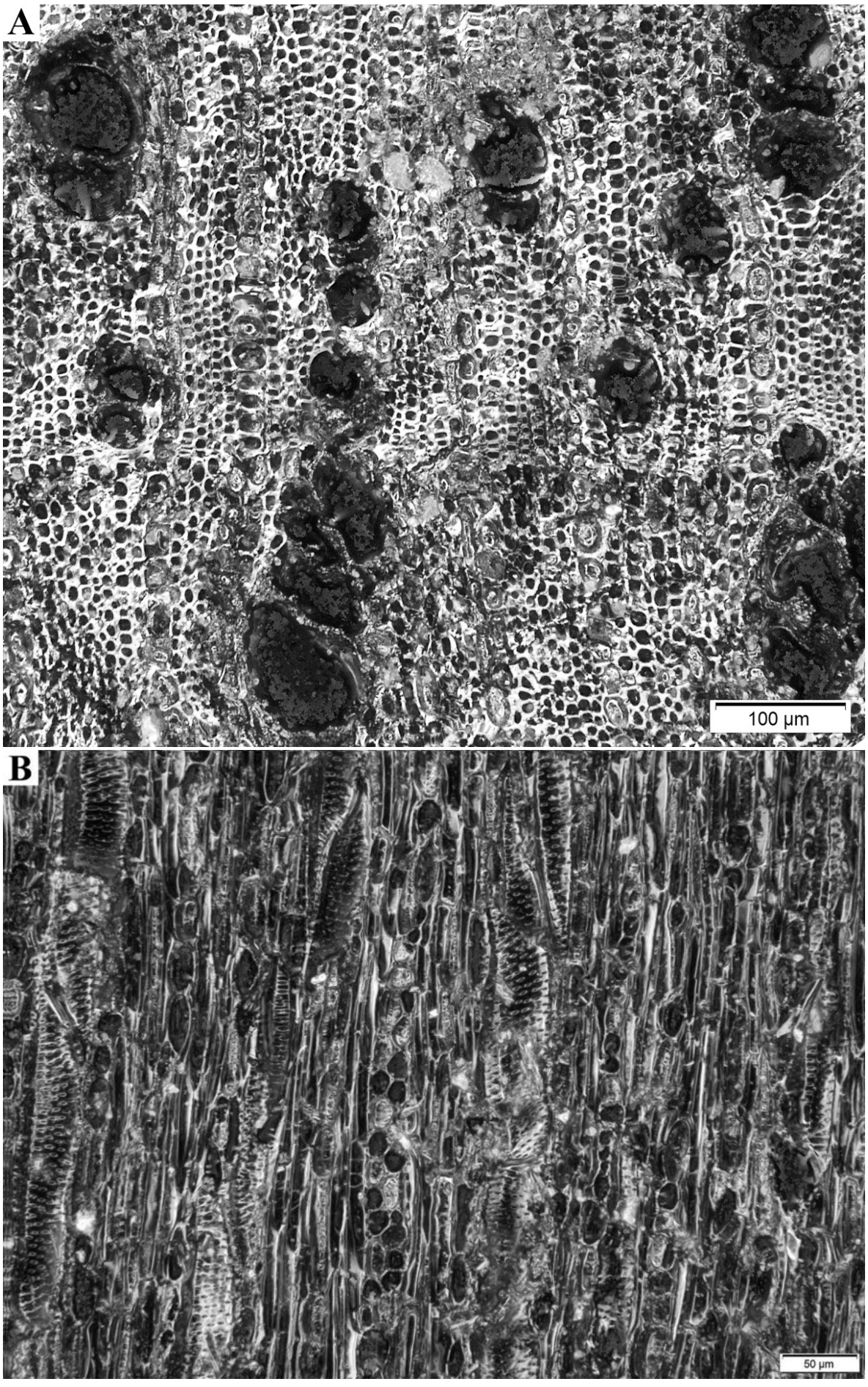
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** grouping in radial multiples of 4 or more common. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel lumina between 50-100 µm. **Fibres** with simple to minutely bordered pits. Axial **parenchyma** apotracheal diffuse and diffuse-in-aggregates. Axial parenchyma in narrow bands or lines up to three cells wide. **Ray** width 1 to 3 cells. Body ray cells procumbent with over 4 rows of upright and / or square marginal cells.

- Main diagnostic features

Mean tangential diameter of vessel lumina between 50-100 µm. Axial parenchyma apotracheal diffuse-in-aggregates. Axial parenchyma in narrow bands or lines up to three cells wide. Ray width 1 to 3 cells. Body ray cells procumbent with over 4 rows of upright and / or square marginal cells.

- Discussion

The wood anatomy of this charcoal type largely matches the reference samples of Peruvian species *Croton alnifolius* Lam. from the MNHN Anthracotèque, though the reference specimen shows smaller vessel lumina - mostly smaller than 50 µm - in longer radial rows. It also shares most diagnostic features with Fasolo et al. (1939) description of *C. macrostachyus,* though in this case the mean diameter of vessel lumina is slightly larger (c. 150 µm) than the studied type. Vessel luminar diameter varies within the *Croton* genus (see InsideWood 2004-onwards). According to Metcalfe and Chalk (1950: 1223 - 1227), the Crotonoideae subfamily shows mostly moderately small (50-100 µm) to medium-sized (100-200 µm) vessels. A similar range (70-150 µm) is given by Jangid and Gupta (2016) for Indian species of *Croton* sp. Besides vessel lumina, both publications highlight the diagnostic potential of apotracheal parenchyma organization - both diffuse-in-aggregates and forming narrow bands up to three cells wide - and ray structure - uniseriate and multiseriate rays present, heterocellular with several rows of upright and / or square marginal cells - to identify the woods of the Crotonoideae subfamily in general (Metcalfe and Chalk 1950; Jangid and Gupta 2016). In Ethiopia, Friis et al. (2010) records the presence of only two Crotonoideae genera, namely *Croton* sp. (7 species, of which only *C. schimperianus* and *C. macrostachyus* grow in northern Ethiopia) and *Givotia* sp. (1 species). These two genera can be easily differentiated as *Givotia* sp. shows exclusively uniseriate rays and rounded to elliptical vessel-ray pitting, with apparently simple or reduced borders (see Jangid and Gupta 2016: 13).


A
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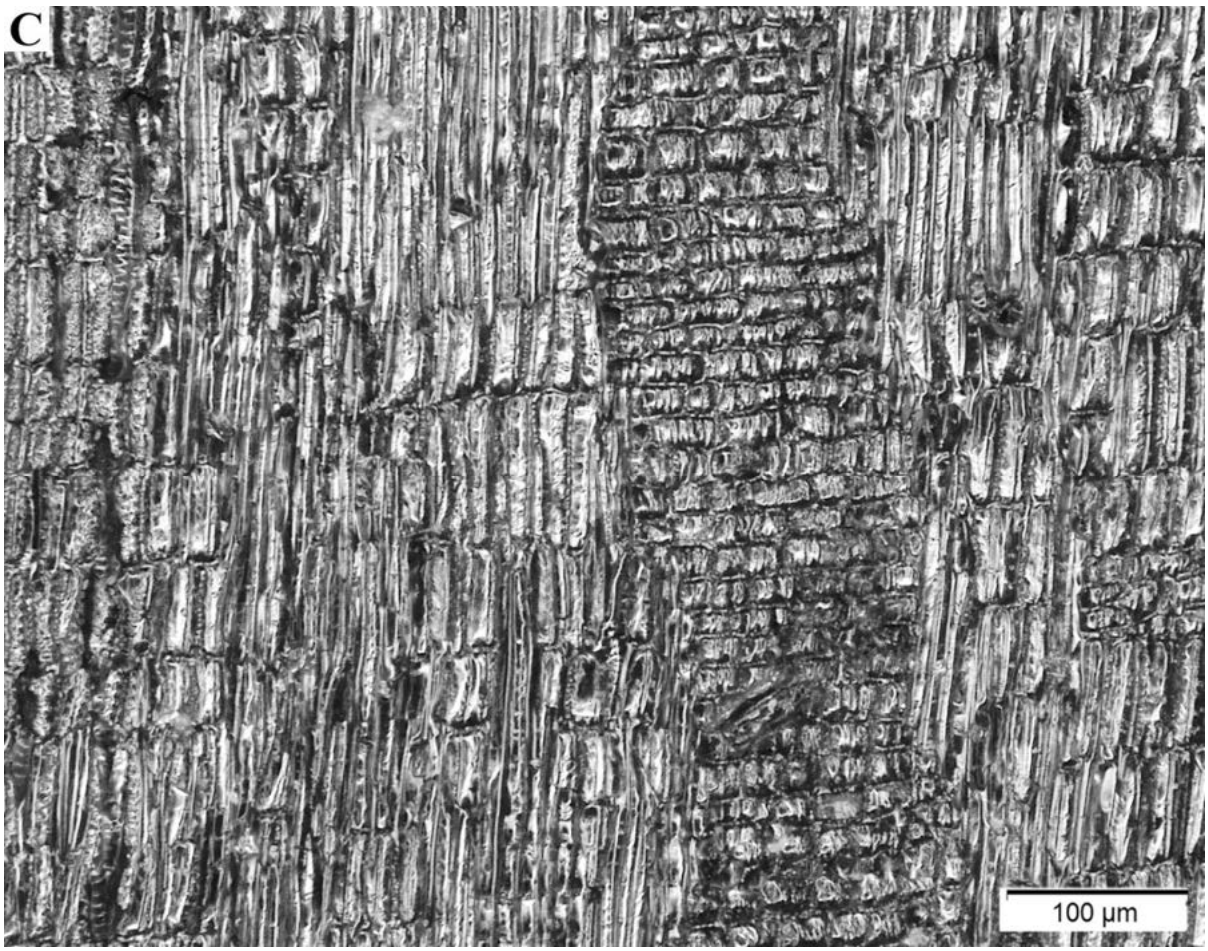


Fig. 7: A) TS: Mean tangential diameter of vessel lumina between 50-100 µm. Axial parenchyma apotracheal diffuse-in-aggregates, also in narrow bands up to three cells wide. B) TLS: Ray width 1 to 3 cells. C) RLS: Rays heterocellular, body ray cells procumbent with over 4 rows of upright and / or square marginal cells.

- Ecological distribution and economic features

Croton sp. is a diverse and complex taxonomic group of plants ranging from herbs and shrubs to trees (von Maydell 1986). During the 1st millennium BCE to CE 1st millennium, natural fire deposits of charcoal have yielded proof of its presence (c. 5%) in the Tigray region (Gebru et al. 2009). Table 7 includes the two species that have been recorded in the northern Highlands region (Friis et al. 2010).

Table 7 Ecological distribution of *Croton* species in northern Ethiopia (Friis et al. 2010: 193-194).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Croton schimperianus	?	900-1450	0	1	0	0	0	0	0	0	0	0
Croton macrostachyus	*Tambush*	500-2350	0	0	0	1	1	1	0	0	0	0

Croton species are mainly harvested for wood exploitation as fuel or timber. According to Bekele-Tesemma (2007), they can also be used as fodder (leaves), as well as to manufacture medicines and poisons (sap, leaves, roots, bark). Their wood is moderately soft, perishable and susceptible to attack by wood borers (Ruffo et al. 2002). It is mainly used for firewood and charcoal production, although it burns with a rather unpleasant odor. Other uses include heavy-duty flooring, as well as the manufacture poles and tool handles (von Maydell 1986).

***Acacia* spp. (Fabaceae subfam. Mimosoideae)**

- Definition of charcoal type

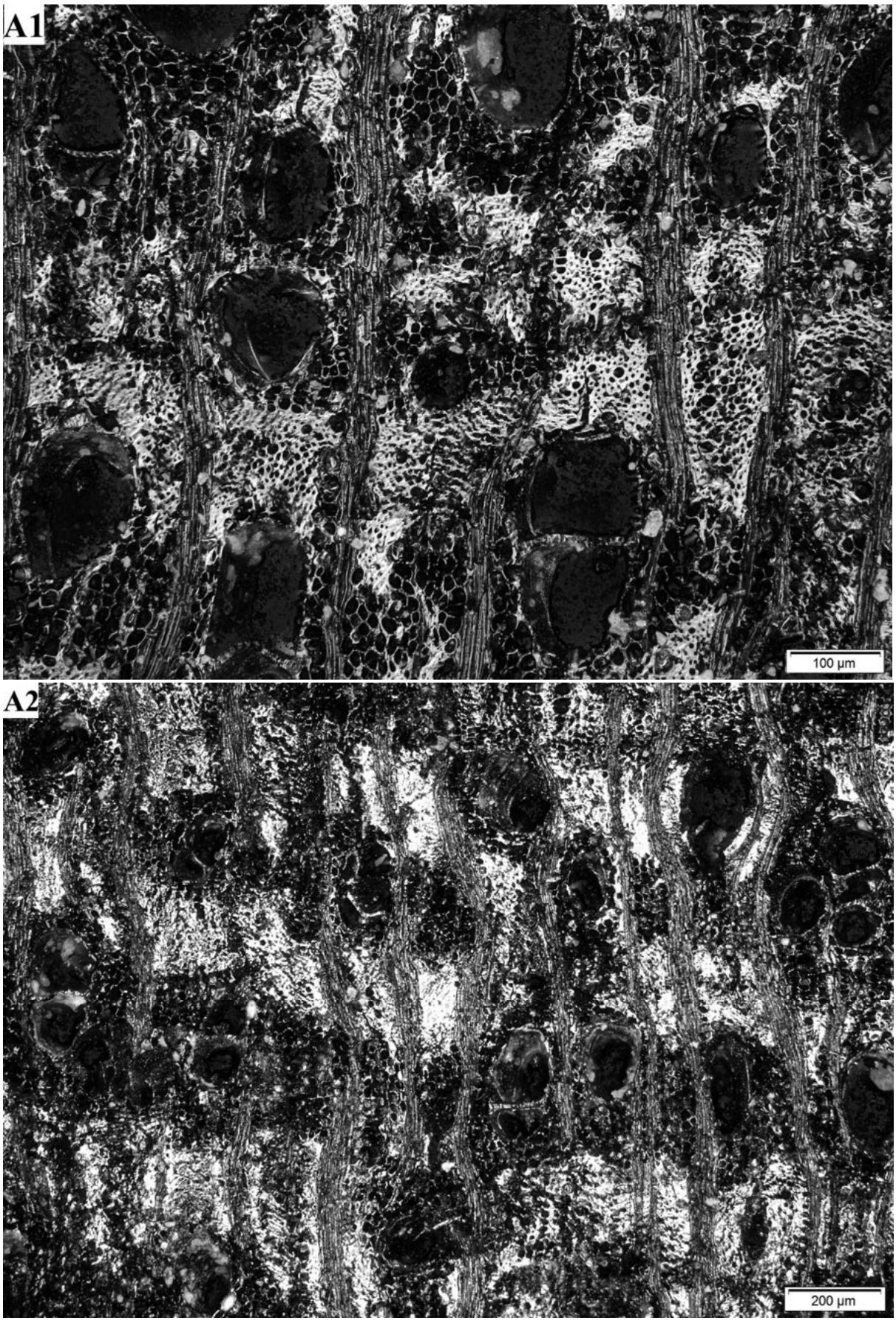
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** grouping sometimes in radial groups of 2-5 cells, sometimes solitary. Perforation plates simple. Intervessel pits alternate, coalescent. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel lumina between 100 and 200 µm. **Fibres** with simple to minutely bordered pits. Axial **parenchyma** paratracheal vasicentric, aliform, sometimes confluent. **Ray** width commonly 4 - to 10 seriate. Homocellular, all cells procumbent. **Prismatic crystals** present. Prismatic crystals in axial parenchyma cells

- Main diagnostic features

Mean tangential diameter of vessel lumina between 100 and 200 µm. Axial parenchyma paratracheal vasicentric, aliform, sometimes confluent. Ray width commonly 4 - to 10 seriate. Homocellular, all cells procumbent. Prismatic crystals in axial parenchyma cells.

- Discussion

The wood anatomy of this charcoal type matches the reference samples of Djiboutian species *Acacia mellifera* (Vahl) Benth. from the MNHN Anthracotèque. The diagnostic features match the general description of Mimosoideae provided by Evans et al. (2006), who notes that most tropical genus of this clade show diffuse-porous wood, homocellular rays, and all their anatomical elements unstoried. A search in InsideWood (2004-onwards) for the diagnostic features in tropical Africa in combination with diffuse porosity and the required absence of heterocellular rays and storied structures - both absent in the studied charcoals - resulted in 16 species of the Leguminoseae family, including the Mimosoideae genera of *Albizia* sp., *Piptadenia sp.* - *Piptadeniastrum africanum* (Hook.f.) Brenan is a synonym of *Piptadenia africana* Hook.f., as accepted by IPNI 2020 - and *Acacia* sp. as well as the Detarioideae genera of *Guibourtia* sp. and *Tessmannia* sp. Amongst them, only *Albizia* sp. and *Acacia* sp. are known to be present in modern Ethiopia (Friis et al. 2010). According to Höhn (1999), these two genera can be differentiated even when ray width overlaps - as *Albizia* sp. often presents narrower 1 to 3 seriate rays than *Acacia* sp., which mostly shows larger rays (4 to 10 seriate) - due to the presence of coalescent intervessel pits in *Acacia* sp. (see Figure 8C) and *Albizia* sp. fibres being exclusively septate - a character absent in the studied charcoals. Friis et al. (2010) lists 26 species of *Acacia* sp. growing in northern Ethiopia, but despite previous efforts (see Evans et al. 2006 and references therein), the identification of *Acacia* sp. to species level remains challenging.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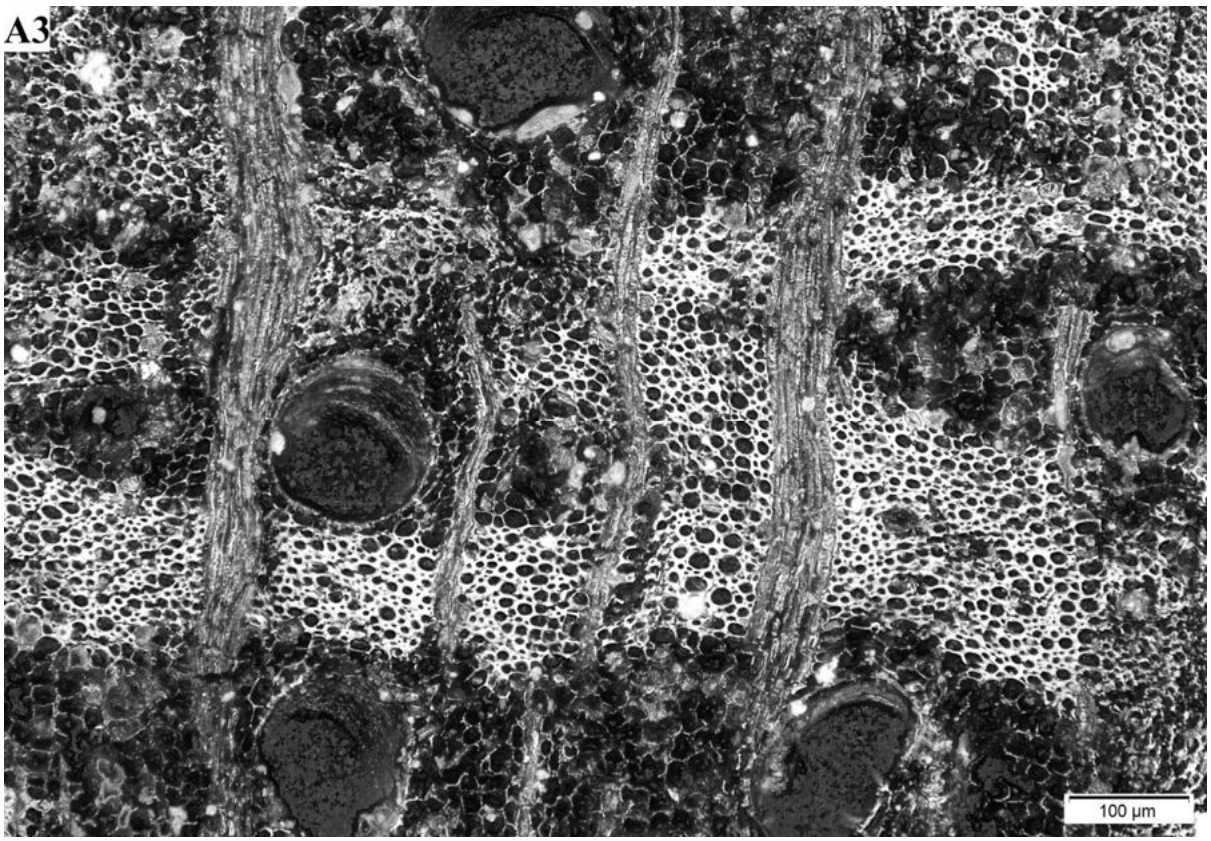
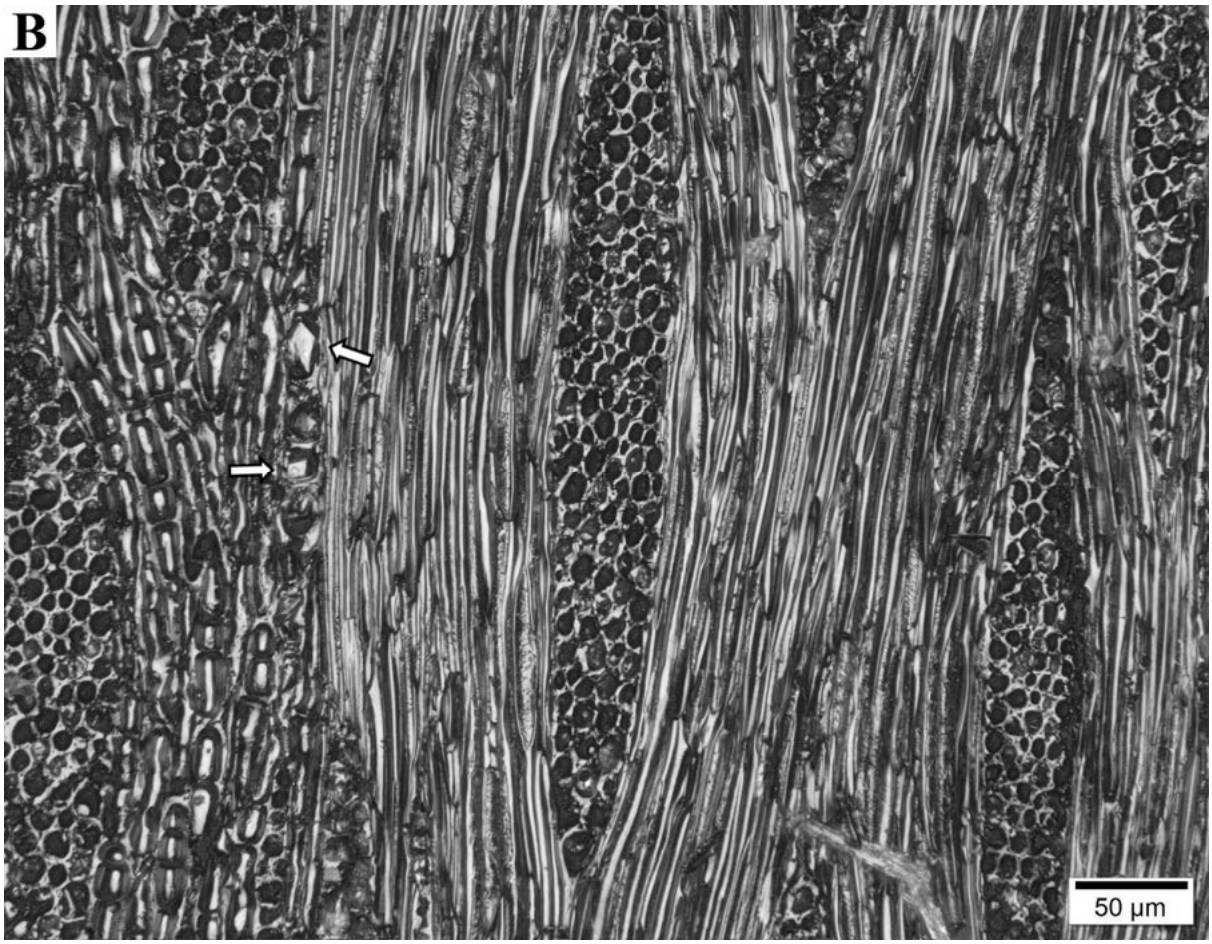
A2
200 µm


A3
100 µm


B
50 µm

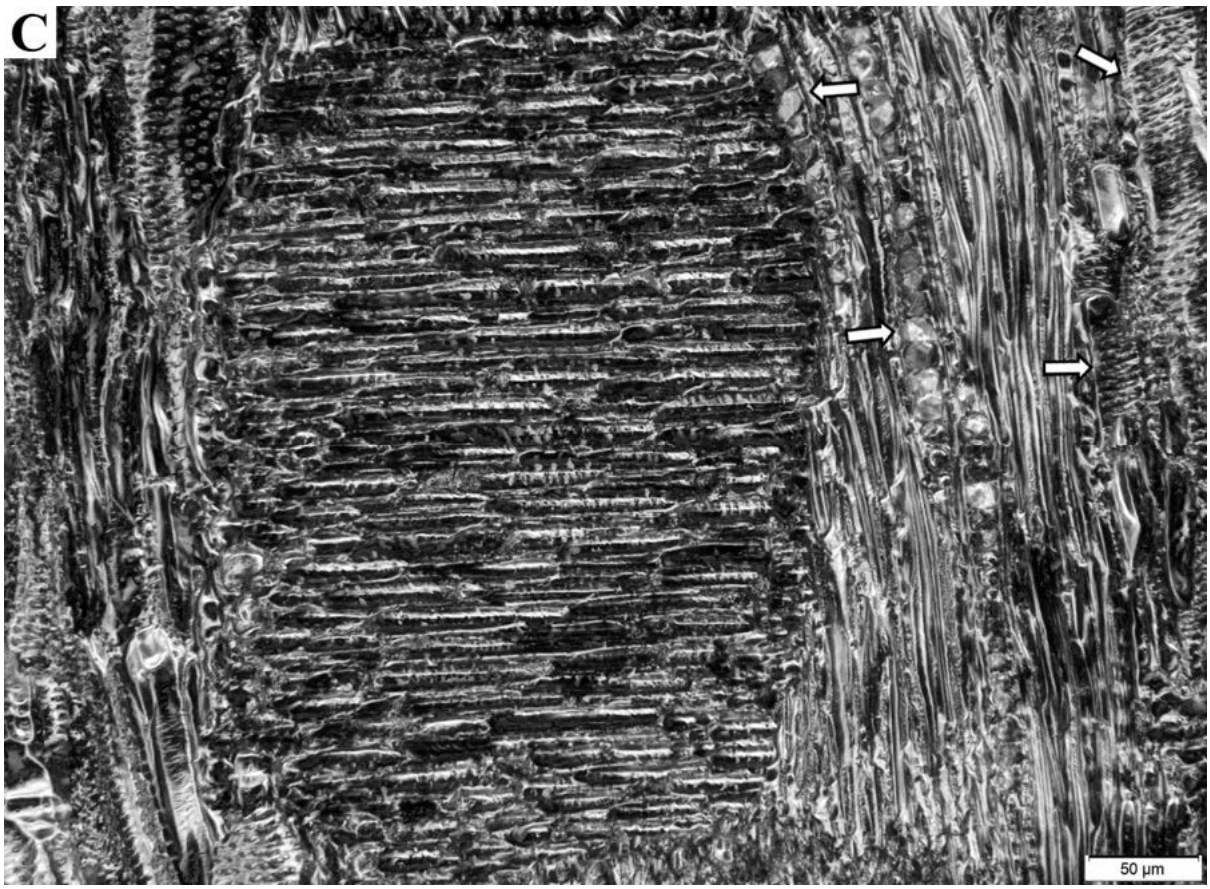


Fig. 8: A1) TS: Mean tangential diameter of vessel lumina between 100 and 200 µm. Axial parenchyma paratracheal vasicentric, aliform, sometimes confluent. A2 and A3) Variations of axial parenchyma arrangements. TS: B) TLS: Ray width commonly 4 - to 10 seriate. Prismatic crystals in axial parenchyma cells. Fibres non-septate. C) RLS: Rays homocellular, all cells procumbent. Prismatic crystals in axial parenchyma cells. Intervessel pits coalescent.

- Ecological distribution and economic features

Acacia sp. is a large genus of shrubs and trees featuring assorted sizes and morphologies (Brummit 2010). As shown in Table 8, a vast variety of species have been documented in the northern regions of Ethiopia (Friis et al. 2010). Their presence in the past is attested both in the palynological and anthracological records: during the pre-Aksumite and Aksumite periods, Darbyshire et al. (2003) documents *Acacia* spp. pollen in Lake Hayk (<1%). Gebru et al. (2009) found 15% of acacia charcoal in their natural fire deposits around Adigrat, Tigray. Charcoal remains of *Acacia* spp. have also been found on both pre-Aksumite and Aksumite contexts around the Aksum site (Chittick 1976; Higham et al. 2007).

Table 8 Ecological distribution of *Acacia* species in northern Ethiopia (Friis et al. 2010: 198-200).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Acacia brevispica	?	900-2000	0	1	0	0	1	0	0	0	0	0
Acacia senegal	*Qentb*	600-1700	0	1	1	1	0	0	0	0	0	0
Acacia asak	*Tsellewa*	400-1900	0	1	0	0	0	0	0	0	0	1
Acacia oliveri	?	0-500	1	0	0	0	0	0	0	0	0	0
Acacia mellifera	*Qentb*	400-2500	0	1	0	0	0	0	0	0	0	0
Acacia laeta	?	?-1800	0	1	0	0	1	0	0	0	0	0
Acacia venosa	?	1890-2400	0	0	0	0	1	0	0	0	0	0
Acacia polyacantha	*Gwmero*	500-1600	0	0	0	1	0	0	0	0	0	1
Acacia hecatophylla	?	1450-1700	0	0	0	1	0	0	0	0	0	0

Acacia albida	*Garsha*	1500-2600	0	1	1	0	1	0	0	0	0	0
Acacia lahai	*Lahay*	1700-2600	0	1	0	0	1	0	0	0	0	0
Acacia dolichocephala	?	1100-2130	0	1	0	1	0	0	0	0	0	0
Acacia seyal	*Qeyeh-chea*	1200-2100	0	1	1	1	1	0	0	0	0	0
Acacia ehrenbergiana	?	0-450	1	1	0	0	0	0	0	0	0	0
Acacia amythetophylla	?	1300-1450	0	0	0	1	0	0	0	0	0	0
Acacia nilotica	*Gered-chea*	0-600	0	1	0	0	0	0	0	0	0	0
Acacia tortillis	*Anqeeba*	600-900	1	1	1	1	0	0	0	0	0	0
Acacia prasinata	?	500-1300	1	1	0	0	0	0	0	0	0	0
Acacia etbaica	*Seraw*	1200-2000	0	1	1	0	1	0	0	0	0	0
Acacia pilispina	?	1650-3100	0	0	0	0	1	0	0	0	0	0
Acacia abyssinica	*Alla*	1500-2800	0	0	0	0	1	0	0	0	0	0
Acacia sieberiana	*Tsada-chea*	500-2200	0	0	0	0	1	0	0	0	0	0
Acacia negrii	?	2000-3100	0	0	0	0	1	0	0	0	0	0
Acacia origena	?	1700-2600	0	0	0	0	1	0	0	0	0	0
Acacia bavazzanoi	?	1680-2400	0	0	0	0	1	0	0	0	0	0
Acacia oerfota	*Gwmero*	100-1600	1	1	0	0	0	0	0	0	0	0

Generally, *Acacia* spp. trees are mainly exploited for firewood and timber, although some medicinal applications have been also documented (Ruffo et al. 2002; Bekele-Tesemma 2007). Their wood ranges in color from light brown to dark red (heartwood) and yellow to whitish (sapwood) and it is moderately heavy, fine grained and durable (Ruffo et al. 2002). Other uses include the manufacture of tool handles and charcoal production (Bekele-Tesemma 2007).

***Olea* spp. (Oleaceae)**

- Definition of charcoal type

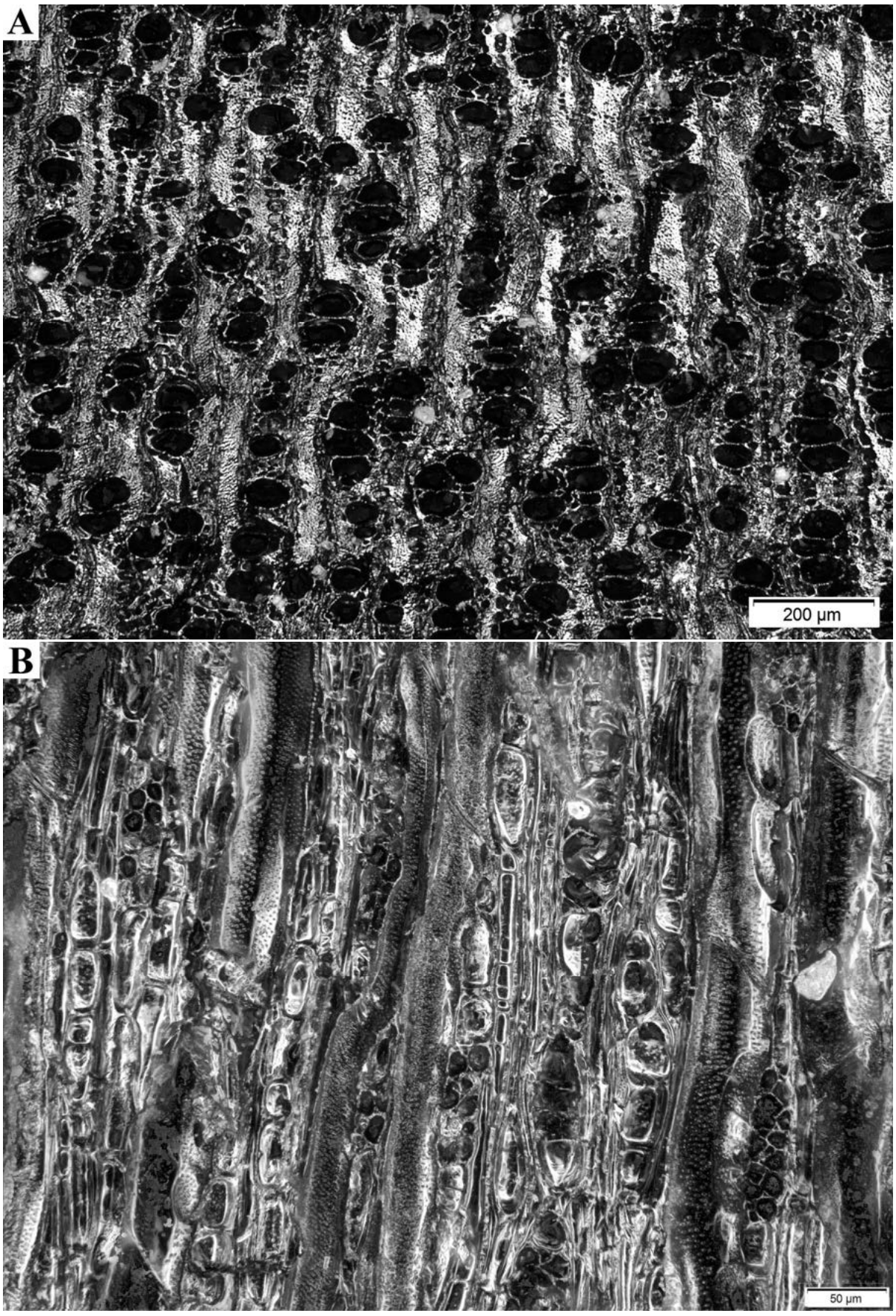
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** in diagonal and / or radial pattern. Vessel grouping in radial groups of 2-6 cells, sometimes solitary. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel lumina between 50-100 µm. **Fibres** with simple to minutely bordered pits. Axial **parenchyma** apotracheal diffuse. Axial parenchyma paratracheal scanty to vasicentric. **Ray** width 1 to 3 cells. Body ray cells procumbent with 1-4 rows of upright and / or square marginal cells.

- Main diagnostic features

Mean tangential diameter of vessel lumina between 50-100 µm. Vessels in diagonal and / or radial pattern. Axial parenchyma paratracheal scanty to vasicentric. Ray width 1 to 3 cells.

- Discussion

The wood anatomy of this charcoal type largely matches the reference samples of European species *Olea europaea* L. from the MNHN Anthracotèque. The main differences are in the axial parenchyma, as *O. europaea* features both marginal bands and confluent parenchyma. It also largely coincides with Neumann et al. (2001) description of *O. laperrinei* despite showing the same dissimilarities - *O. laperrinei* Batt. & Trab. is a synonym of *O. europaea* subsp. *laperrinei* (Batt. & Trab.) Cif., as accepted by IPNI (2020). A search of the diagnostic features of this charcoal type in InsideWood (2004-onwards) in combination with required absence of confluent and banded parenchyma results in two species for tropical Africa, that is, *Rhamnus prinoides* - which shows a clear dendritic vessel pattern (Schirarend 1991) and helical thickenings (Metcalfe and Chalk 1950) that are absent in these specimens - and *Olea capensis* - which matches the overall description presented above. Friis et al. (2010) lists *O. welwitschii, O. capensis* subsp. *macrocarpa* and *O. europaea* subsp. *cuspidata* as present in Ethiopia. *O. welwitschii* Gilg & G.Schellenb, which is a synonym of *O. capensis* subsp. *welwitschii* (Knobl.) Friis & P.S.Green - as accepted by IPNI (2020) - is restricted to central and southern Ethiopia. According to Oleaceae anatomical typologies by Baas et al. (1988: 146-147), both *O. capensis* and *O. europaea* (and their subspecies) woods pertain to Olea type A, whose description agrees with the main diagnostic features of the studied type - though they add minute intervessel pits, these are visible in Figure 9B (see Baas et al. 1988: 175-176 for a wood anatomy key of the genera of the Oleaceae).


A
200 µm
B
50 µm

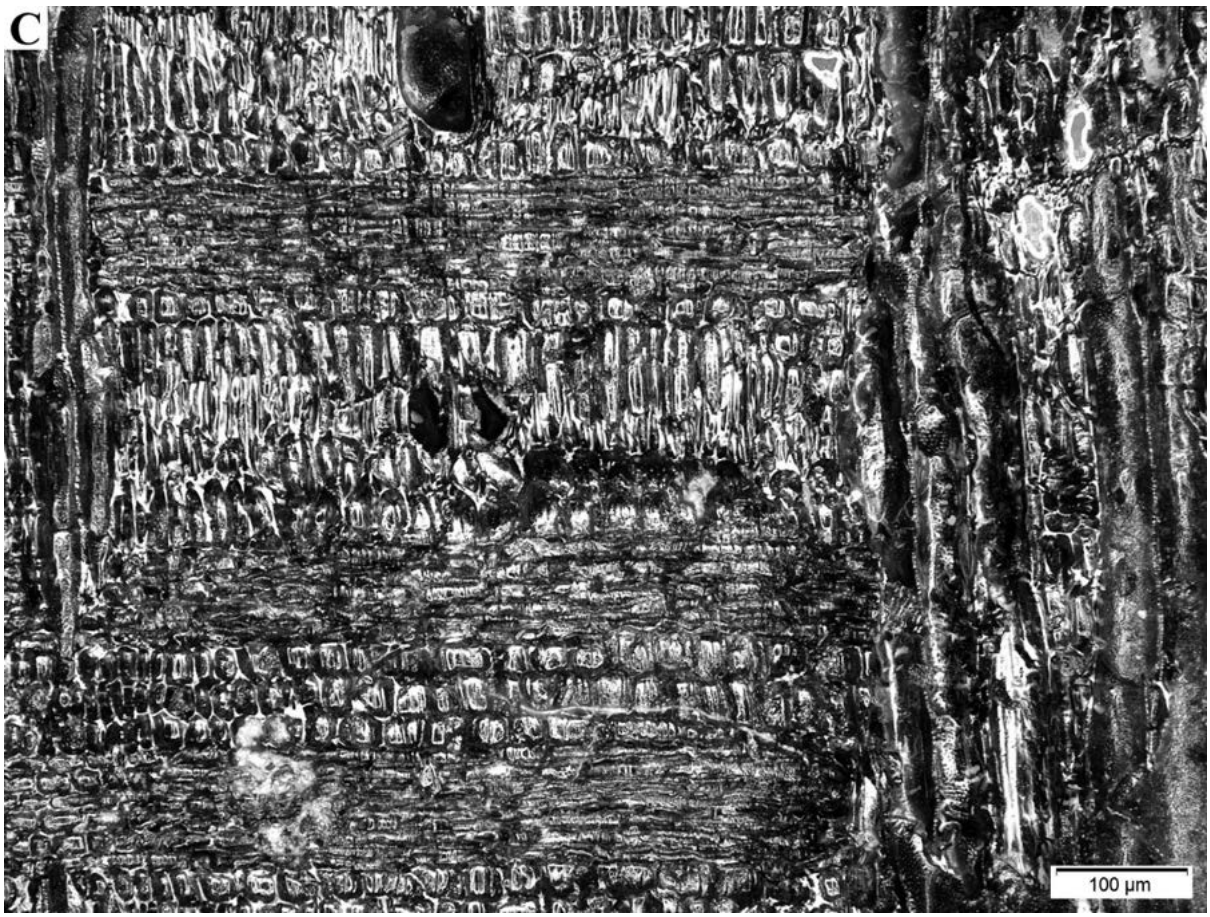


Fig. 9: A) TS: Vessels in diagonal and / or radial pattern with a mean diameter of lumina between 50-100 µm. Axial parenchyma paratracheal scanty to vasicentric. B) TLS: Ray width 1- to 3 cells, intervessel pits minute. C) RLS: Ray structure heterocellular.

- Ecological distribution and economic features

Olea sp. is a genus of shrubs or trees that can grow from 2 to 12 meters tall (von Maydell 1986). The presence of *Olea* sp. during pre-Aksumite and Aksumite times has been attested by lacustrine palynological records (Bonnefille and Mohammed 1994; Darbyshire et al. 2003), featuring a stable presence (c. 2%) which significantly increased (c. 10%) after the disappearance of the Aksumite society. At Aksum, the pollen retrieved from contexts at the Beta Giyorgis hill shows a discrete presence of *Olea* sp. (<1%) during pre-Aksumite times (DiBlasi 1997). Friis et al. (2010) records it in the undifferentiated afromontane forests, where it is one of the most ubiquitous species, and the ericaceous belt (Table 9).

Table 9 Ecological distribution of *Olea* species in northern Ethiopia (Friis et al. 2010: 217).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Olea europaea subsp. *cuspidata*	*Wogret*	1250-3000	0	0	0	0	1	1	1	0	0	0
Olea capensis	*Afsholer*	1350-3200	0	0	0	0	0	1	0	1	0	0

Olea spp. are harvested in the wild as a source of firewood and medicine (roots) (Bekele-Tesemma 2007). The wood is dark or pale brown, fine-textured, hard, heavy and even grained. It is considered as a good fuel and suitable to make charcoal (Louppe et al. 2008). Other uses include the manufacture of household items, tool handles and poles for building (Ruffo et al. 2002; Bekele-Tesemma 2007). It is also used for purposes such as quality furniture, decorative building, carving and tool handles (Bekele-Tesemma 2007), but it is also considered as a high-quality fuel (Gebreslassie et al. 2014) and used in charcoal production (Ruffo et al. 2002).

***Pittosporum* spp. (Pittosporaceae)**

- Definition of charcoal type

Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** grouping sometimes in radial multiples of 2-3, sometimes solitary. Vessel clusters common. Solitary vessel outline angular. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Helical thickenings present. Mean tangential diameter of vessel lumina smaller than 50 µm. **Fibres** with simple to minutely bordered pits. Axial **parenchyma** apotracheal diffuse. Axial parenchyma paratracheal scanty. Large **rays** commonly 4 - to 10 seriate. Rays homocellular, all cells procumbent.

- Main diagnostic features

Mean tangential diameter of vessel lumina smaller than 50 µm. Helical thickenings present. Large rays commonly 4 - to 10 seriate. Rays homocellular, all cells procumbent.

- Discussion

The wood anatomy of this charcoal type matches the reference samples of Ethiopian species *Pittosporum abyssinicum* Delile. from the MNHN xylothèque. It also agrees with the description by Carlquist (1981) who mentions small vessels (< 50 µm), axial parenchyma paratracheal scanty and presence of helical thickenings and multiseriate (up to 10 cells wide), predominantly homocellular rays as characteristic of the Pittosporaceae family. In addition to these characters, Metcalfe and Chalk (1950) also highlight the width of *Pittosporum* sp. rays amongst Pittosporaceae. A search of the diagnostic features in InsideWood (2004-onwards) for tropical Africa results in only *Sophora denudata* - featuring confluent axial parenchyma - and *Pittosporum verticillatum* - which matches the overall description presented above. According to Friis et al. (2010), two species of *Pittosporum* sp. grow nowadays in Ethiopia, that is, *P. abyssinicum* and *P. viridiflorum*. However, differentiation to species level is not possible.

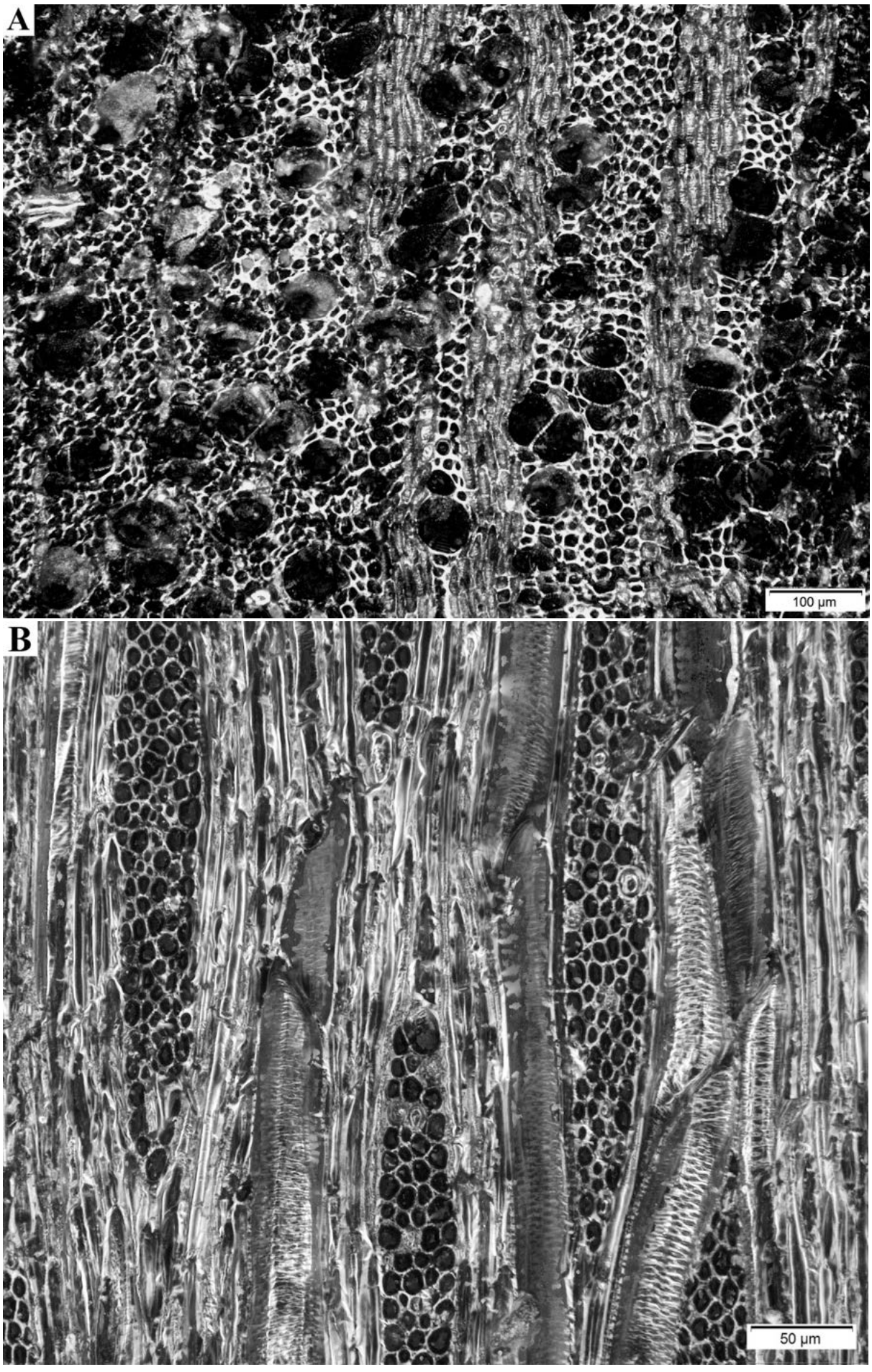

A
100 µm
B
50 µm

Fig. 10: A) TS: Mean tangential diameter of vessel lumina smaller than 50 µm. B) TLS: Large rays commonly 4 - to 10 seriate. C) RLS: Helical thickenings present. Rays homocellular, all cells procumbent.

- Ecological distribution and economic features

Pittosporum sp. is a genus that varies from shrubs about 4 metres tall to large forest trees up to 30 metres tall (de Sanctis et al. 2013). No record of any *Pittosporum* species between the 1st millennium BCE and CE 1st millennium has been published so far. According to Friis et al. (2010), there are currently two species of this genus growing in the northern Highlands (Table 10).

Table 10 Ecological distribution of *Pittosporum* species in northern Ethiopia (Friis et al. 2010: 195).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Pittosporum abyssinicum	*Besso-atal*	2300-3200	0	0	0	0	1	1	0	1	0	0
Pittosporum viridiflorum	*Chequente*	1400-3000	0	0	0	0	0	1	0	0	0	0

The genus has local medicinal uses (bark), but it also yields a red dye (Bekele-Tesemma 2007). The use of branches and roots for basketry production has been documented (Ruffo et al. 2002). The soft, white wood is little used as fuel due to its bad quality as fuel (Ruffo et al. 2002).

***Podocarpus falcatus* (Podocarpaceae)**

- Definition of charcoal type

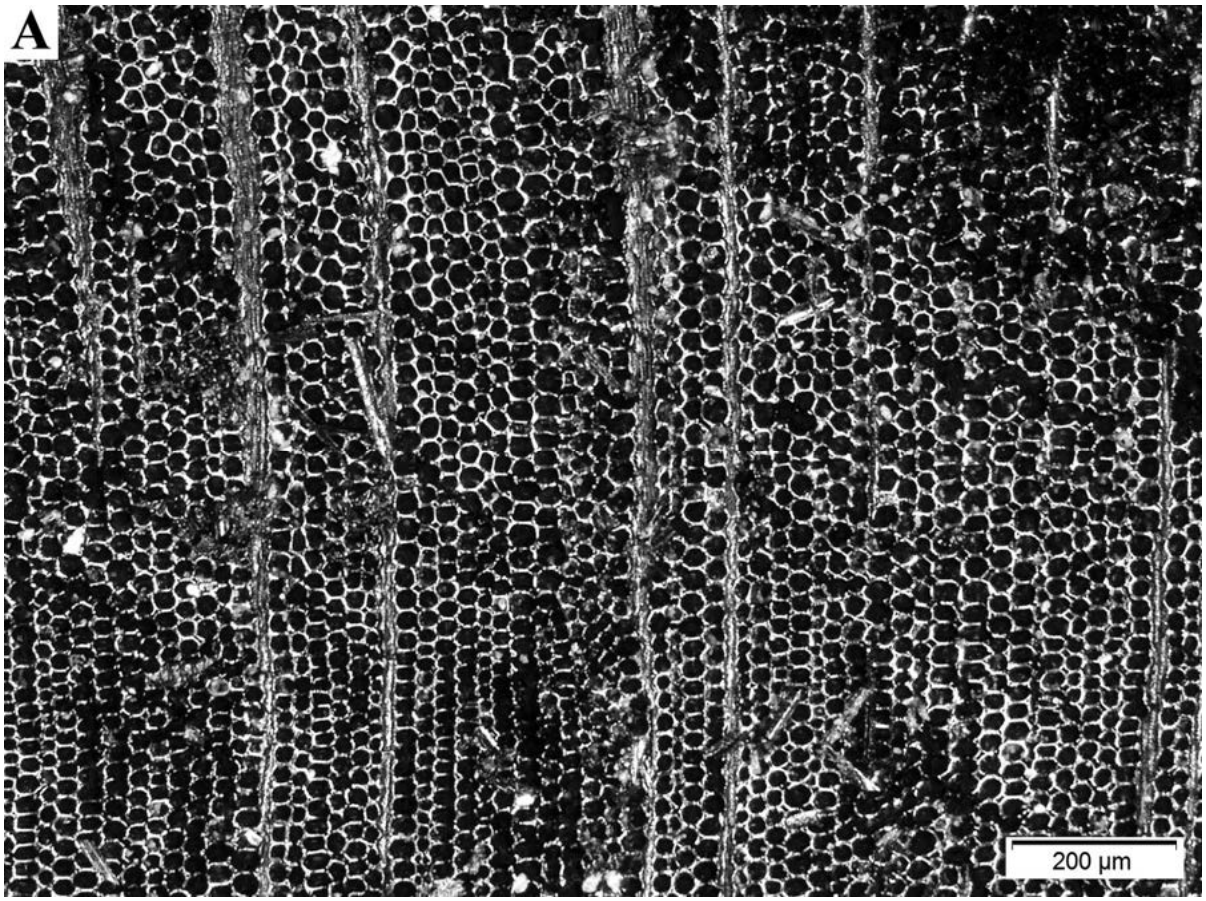
Growth ring boundaries indistinct or absent. **Tracheid** pitting in early wood predominantly uniseriate. Latewood tracheid wall thin-walled. Axial **parenchyma** present. Arrangement of axial parenchyma diffuse. **Ray tracheids** absent or very rare. **Cross-field** pits taxodioid. Number of pits per field 1-2. **Rays** height predominantly medium (5-15 cells), sometimes very low (up to 4 cells). Rays exclusively uniseriate.

- Main diagnostic features

Growth ring boundaries indistinct or absent. Cross-field pits taxodioid. Number of pits per field 1-2. Rays height medium (5-15 cells).

- Discussion

The wood anatomy of this charcoal type matches the reference samples of South African species *Podocarpus elongatus* (Aiton) L'hér. ex Pers. from the MNHN xylothèque. Friis et al. (2010) lists *Podocarpus falcatus* as the only species of the Podocarpaceae family present in Ethiopia. The charcoal type description also coincides with the wood anatomy of *Afrocarpus falcatus* (Louppe et al. 2008) - a synonym of *Podocarpus falcatus*, as accepted by IPNI (2020). See discussion of *Juniperus procera* type above for the main differences between the two conifers.



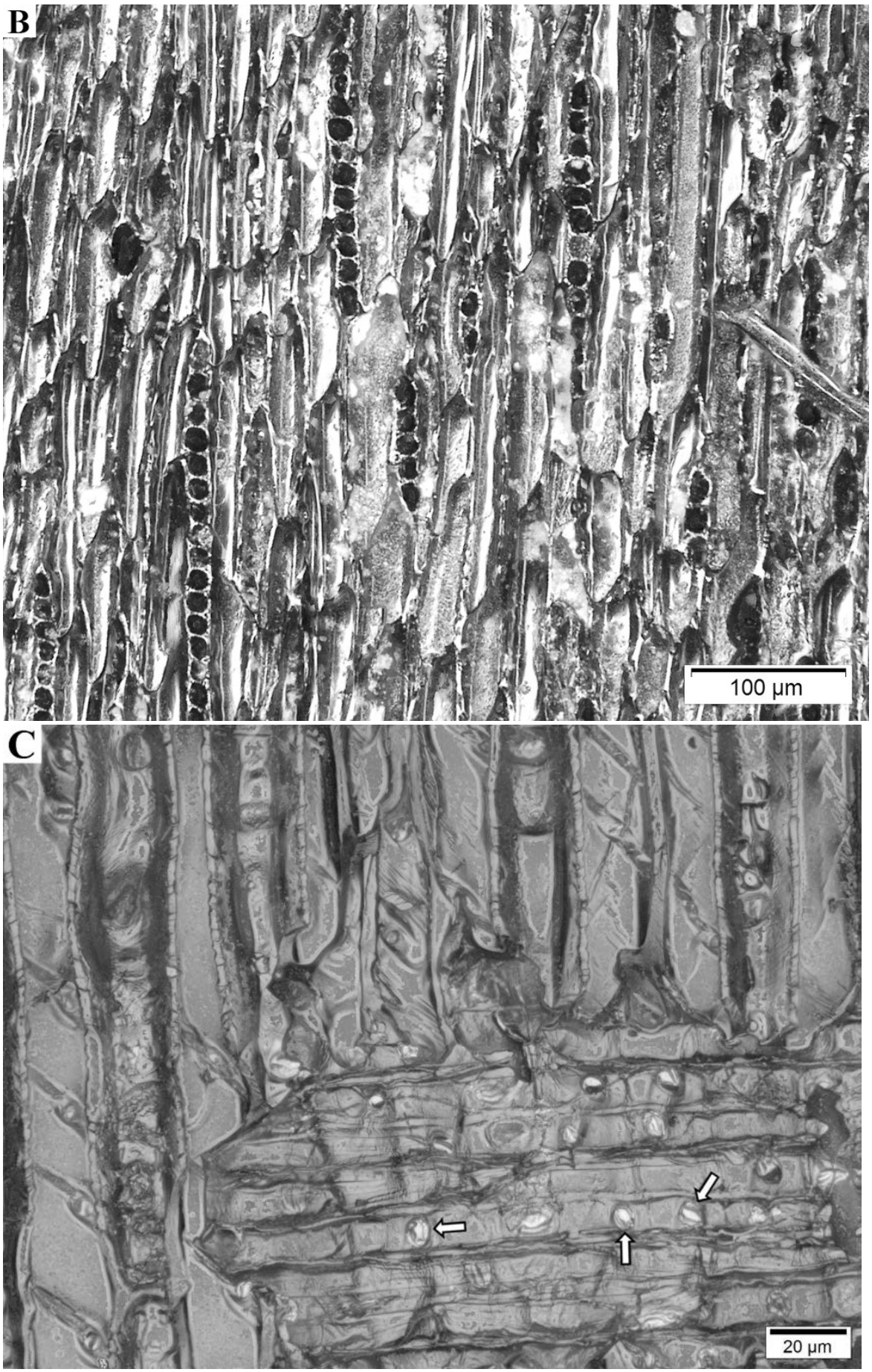


Fig. 11: A) TS: Growth ring indistinct or absent. B) TLS: Rays height up to 15 cells. C) RLS: Cross-field pits taxodioid. Number of pits per field 1-2.

- Ecological distribution and economic features

Podocarpus falcatus is an evergreen conifer often growing up to about 45 meters in height but known to reach up to 60 meters (Farjon 2013). Palynological analyses attest to its presence during pre-Aksumite and Aksumite times at Lake Hayk, Amhara region (c. 5%) and Lake Abyiata, Arsi (c. 12%), decreasing to 3% and almost disappearing after CE 1000 (Bonnefille and Mohammed 1994; Darbyshire et al. 2003). These data coincide with the results of charcoal analysis carried by Gebru et al. (2009) from natural fire deposits. Ecologically, it is assigned to the Ethiopian semi-humid lower highland forests by Friis et al. (2010) (Table 11).

Table 11 Ecological distribution of *Podocarpus falcatus* in northern Ethiopia (Friis et al. 2010: 178).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Podocarpus falcatus	?	1350-2900	0	0	0	0	0	1	0	0	0	0

The tree has a number of local uses for food (fruit), medicine (seeds, bark) and fuel (wood) (Bekele-Tesemma 2007). The wood is pale yellow to pale yellowish brown, moderately lightweight and non-durable, being susceptible to decay and wood borers activity (Louppe et al. 2008). It is considered as a good fuel (Gebreslassie et al. 2014). Other uses include building construction (Bekele-Tesemma 2007).

***Rhamnus* spp. (Rhamnaceae)**

- Definition of charcoal type

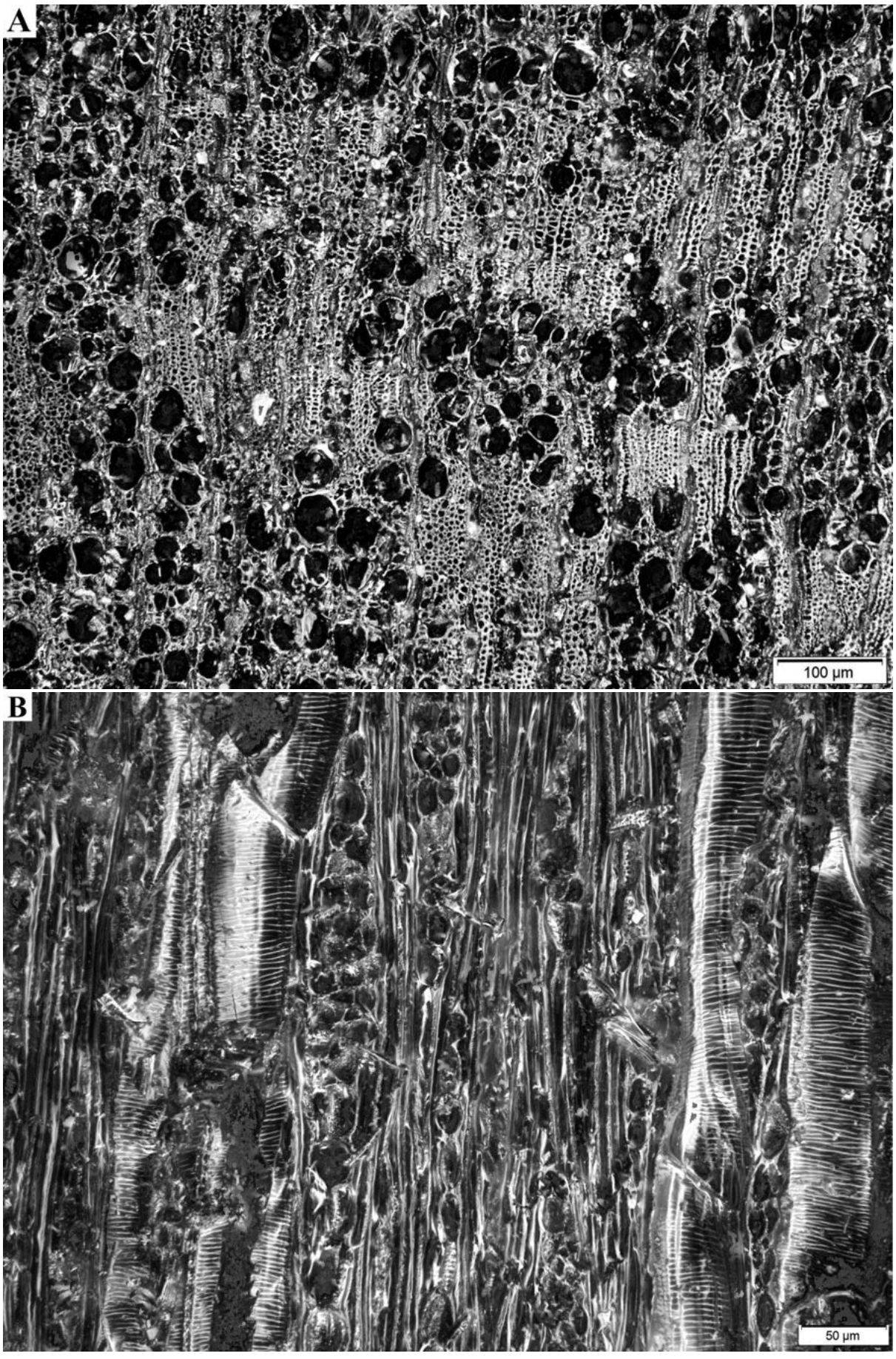
Growth ring boundaries distinct. Wood diffuse-porous to semi-ring-porous. **Vessel** arrangement in dendritic pattern. Vessels in radial multiples of 4 or more common. Vessel clusters common. Simple perforation plates. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Helical thickenings present. Mean tangential diameter of vessel lumina smaller than 50 µm. Vessels of two distinct diameter classes, wood not ring-porous. **Fibres** with simple to minutely bordered pits. Axial **parenchyma** paratracheal scanty to vasicentric. **Ray** width 1 to 3 cells. Heterocellular, body ray cells procumbent with 1-4 row of upright and / or square marginal cells.

- Main diagnostic features

Mean tangential diameter of vessel lumina smaller than 50 µm. Vessels of two distinct diameter classes, wood not ring-porous. Vessel arrangement in dendritic pattern. Helical thickenings present. Axial parenchyma paratracheal scanty to vasicentric. Ray width 1 to 3 cells.

- Discussion

The description of this charcoal type matches the reference samples of Ethiopian species *Rhamnus pauciflora* Hochst. ex A.Rich. - a synonym of *R. prinoides* L'Hér., as accepted by IPNI (2020) - from the MNHN xylothèque as well as the description of the same species at InsideWood (2004) - though the latter does not record the presence of helical thickenings, they are evident in the reference samples. Note that *Rhamnus* sp. growth rings - only visible due to differences in fibre wall thickness (Gupta and Saxena 2011) - and wood porosity - known to vary within the *Rhamnus* genus (see Metcalfe and Chalk 1950; InsideWood 2004-onwards), and not very well developed in some species (Gupta and Saxena 2011) - are sometimes difficult to identify in the archaeological samples and therefore cannot be considered as diagnostic features. Metcalfe and Chalk (1950) establish small vessels with a tendency to radial and dendritic arrangements, helical thickenings and paratracheal axial parenchyma as characteristic of several genera of the Rhamnaceae family. Amongst the Rhamnaceae, *Rhamnus* sp. can be differentiated due to the presence of a well developed dendritic vessel pattern, vasicentric parenchyma and 1- to 3 seriate rays (see Metcalfe and Chalk 1950: 407-410; Schirarend 1991: 385; Gupta and Saxena 2011: 248-249). Two species of *Rhamnus* sp. - *R. prinoides* and *R. staddo* - have been documented in Ethiopia (Friis et al. 2010) but identification to species level is not possible.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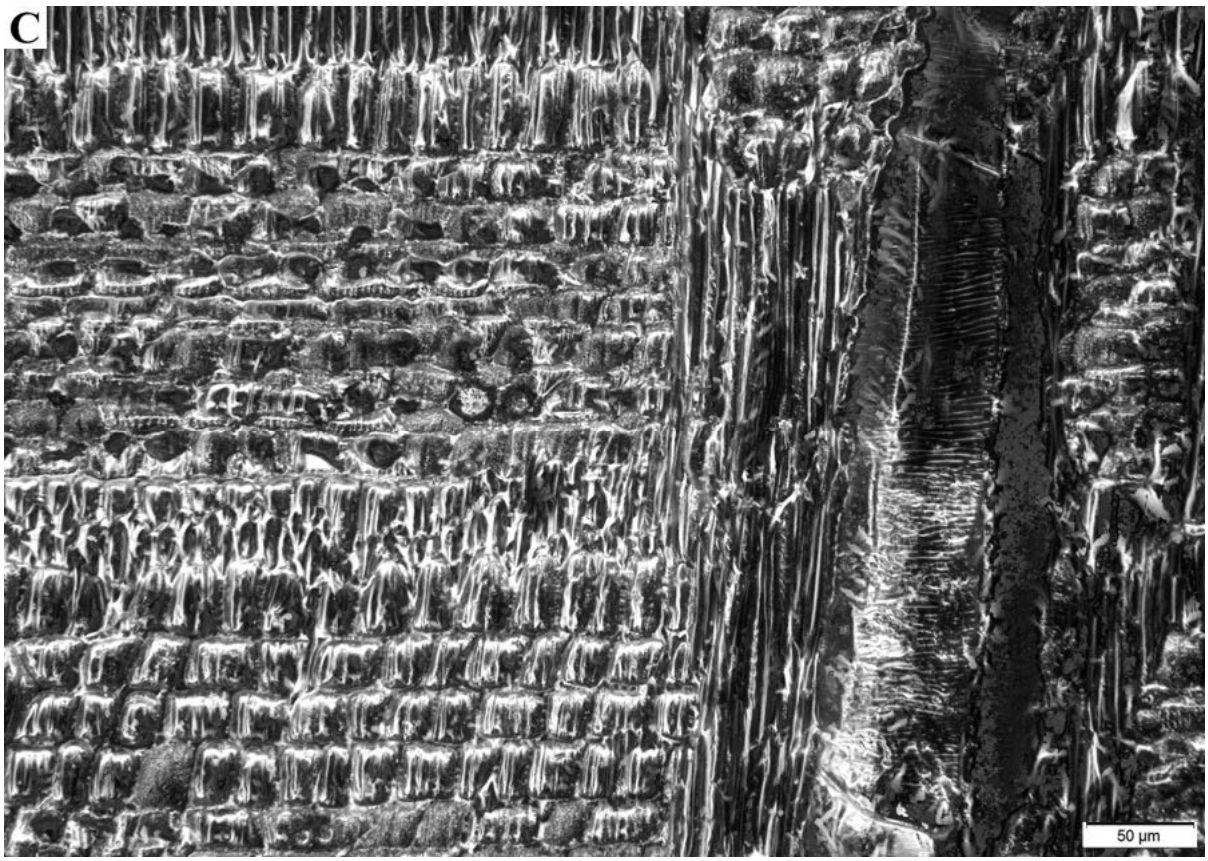


Fig. 12: A) TS: Vessels arranged in a dendritic pattern, of two distinct diameter classes, but always smaller than 50 µm. Axial parenchyma paratracheal scanty to vasicentric. B) TLS: Helical thickenings present. Ray width 1 to 3 cells. C) RLS: Ray structure heterocellular.

- Ecological distribution and economic features

Rhamnus sp. is a genus of shrubs or small to medium-sized trees (Knight et al. 2007). The genus has not been recorded in pre-Aksumite nor Aksumite contexts so far, but Friis et al. (2010) document two species in the northern area of Ethiopia (Table 12).

Table 12 Ecological distribution of *Rhamnus* species in northern Ethiopia (Friis et al. 2010: 208).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Rhamnus prinoides	*Geeso*	1175-3200	0	0	0	0	1	1	1	1	0	1
Rhamnus staddo	*Tsedo*	1400-2900	0	0	0	0	1	0	0	0	0	0

These are multi-purpose trees, providing edible fruits, medicines (leaves, roots) and fuel (Bekele-Tesemma 2007). Their wood is white to yellow, often streaked with brown, pink, red or green stripes; moderately heavy and hard, close-grained and compact (Louppe et al. 2008). Its main use is as firewood, although it is also carved into small instruments (Bekele-Tesemma 2007).

***Ziziphus* spp. (Rhamnaceae)**

- Definition of charcoal type

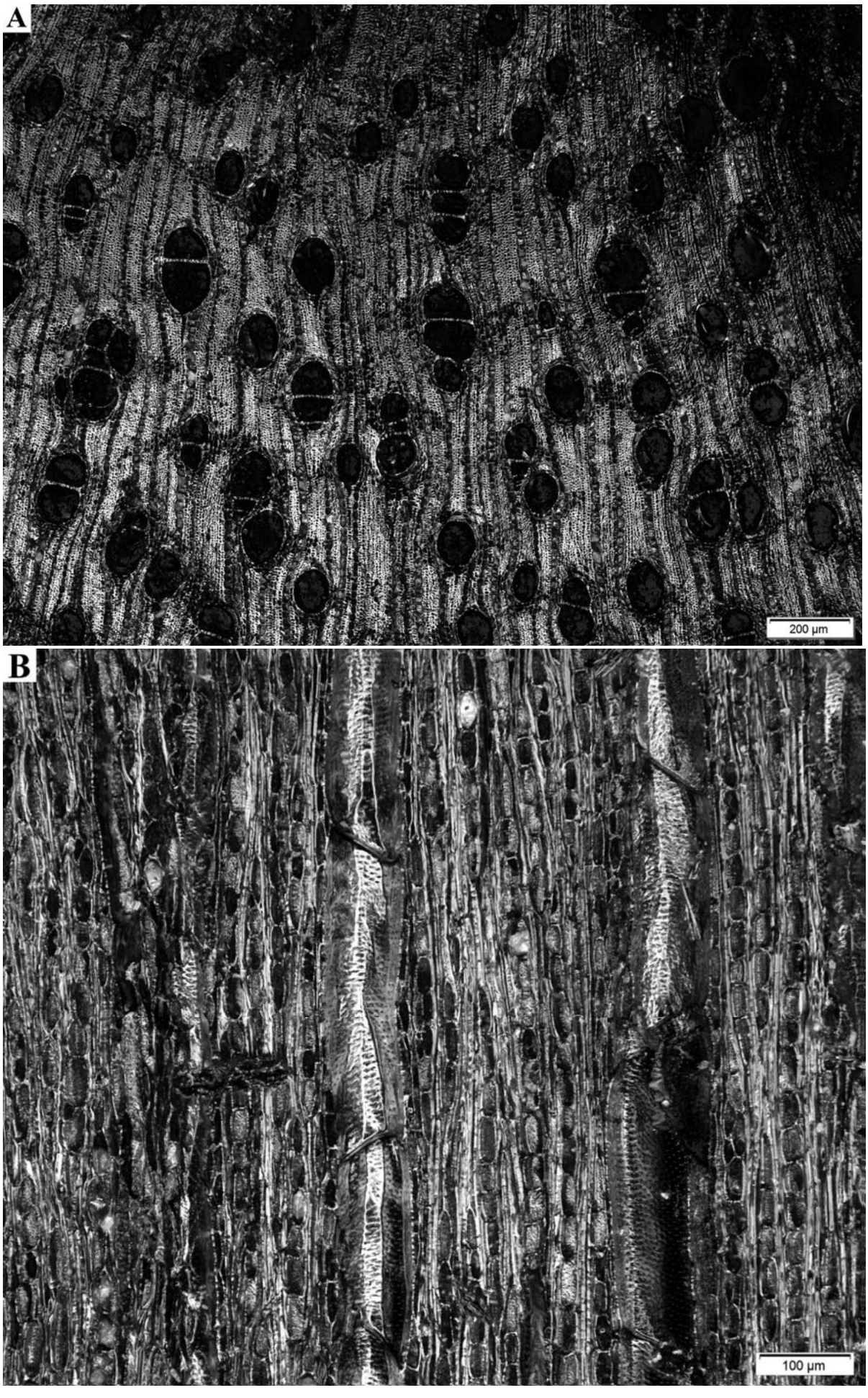
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** generally solitary but sometimes in radial groups of 2-3. Simple perforation plates. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel lumina between 50-100 µm. **Fibres** with simple to minutely bordered pits. Axial **parenchyma** paratracheal vasicentric to aliform. Axial parenchyma in marginal or in seemingly marginal bands. **Rays** exclusively uniseriate. Homocellular, all ray cells upright and / or square; sometimes heterocellular, rays with procumbent, square and upright cells mixed throughout the ray. **Prismatic crystals** present. Prismatic crystals located in upright/square ray cells.

- Main diagnostic features

Mean tangential diameter of vessel lumina between 50-100 µm. Axial parenchyma paratracheal vasicentric to aliform. Axial parenchyma in marginal or in seemingly marginal bands. Rays exclusively uniseriate.

- Discussion.

The wood anatomy of this charcoal type matches the reference samples of Pakistani species *Ziziphus nummularia* DC. from the reference collection of the laboratory for Environmental Archaeology at UPF. The main diagnostic features of the studied charcoal type also coincide with previous *Ziziphus* sp. descriptions (Fasolo et al. 1939; Metcalfe and Chalk 1950: 407-410; Schirarend 1991; Gupta and Saxena 2011: 248-249; Lancelotti 2018). Note that Solereder (1899) established the presence of scalariform perforation plates as a diagnostic character of the genus. However, more recent accounts of *Ziziphus* sp. wood anatomy have shown that they are absent in the majority of *Ziziphus* species (Metcalfe and Chalk 1950; Prior and Gasson 1990; Schirarend 1991; Neumann et al. 2001; Gupta and Saxena 2011; Lancelotti 2018). Schirarend (1991) lists three anatomically distinct *Ziziphus* groups, which can be separated due to ray width and parenchyma distribution: the studied charcoal type matches Schirarend's group A, showing uniseriate rays and vasicentric to aliform parenchyma. This group comprises most *Ziziphus* species present in modern Ethiopia, including *Z. mucronata*, *Z. spina-christi*, *Z. abyssinica* and *Z. mauritiana*, hence identification to species level is not possible.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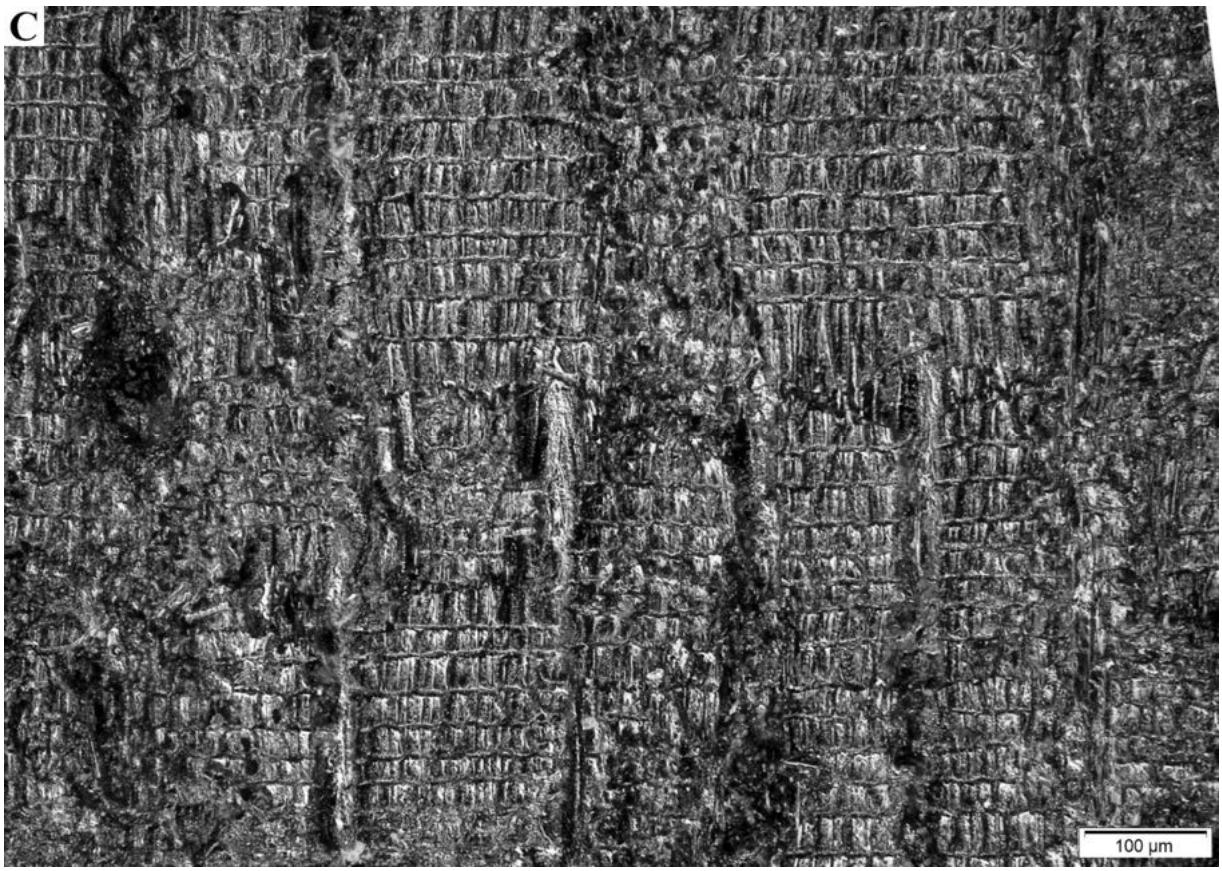


Fig. 13: A) TS: Mean tangential diameter of vessel lumina between 50-100 µm. Axial parenchyma paratracheal vasicentric to aliform and in marginal bands. B) TLS: Rays exclusively uniseriate. C) RLS: Ray structure predominantly homocellular, all ray cells upright and / or square.

- Ecological distribution and economic features

Ziziphus sp. comprises a group of woody plants ranging from spiny shrubs to small trees which can grow up to 20 meters tall, although they are usually considerably smaller (Wiehle et al. 2014). Seeds of this genus have been encountered on the pre-Aksumite site of Mezber (Beldados et al. 2015). Friis et al. (2010) lists three species of *Ziziphus* sp. currently growing in the northern Highlands of Ethiopia (Table 13).

Table 13 Ecological distribution of *Ziziphus* species in northern Ethiopia (Friis et al. 2010: 208).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Ziziphus mucronata	*Gaba-harmaz*	100-2100	0	1	0	1	0	0	0	0	0	1
Ziziphus spina-christi	*Geba*	0-2400	1	1	0	0	1	0	0	0	0	0
Ziziphus abyssinica	?	450-2000	0	0	0	1	1	0	0	0	0	0

The genus is harvested in the wild as a local source of food (fruit) and medicine (fruit, leaves, roots, thorns) (Bekele-Tesemma 2007), and it is known to be cultivated in some parts of East Africa (Bekele-Tesemma 2007). The red or dark-brown wood is hard, heavy and resistant to termites. It is considered as a good fuel and it makes an excellent charcoal (von Maydell 1986). Other uses include the production of tool handles and posts, as well as general carpentry (von Maydell 1986).

***Hagenia abyssinica* (Rosaceae)**

- Definition of charcoal type

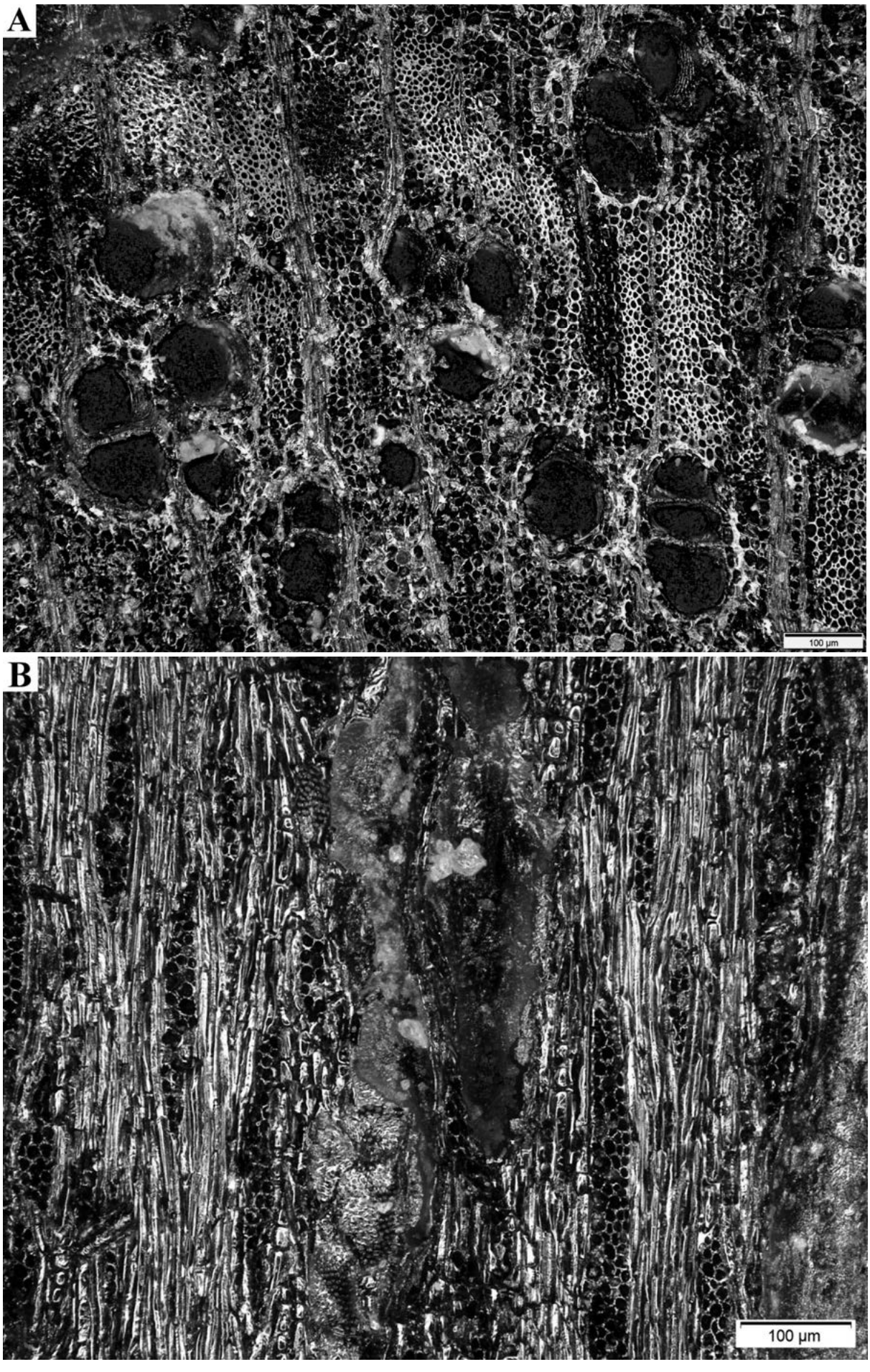
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** sometimes solitary, sometimes in radial groups of 2-3. Vessel clusters common. Simple perforation plates. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel lumina between 100-200 µm (sometimes slightly smaller, c. 90 µm) . **Fibres** with simple to minutely bordered pits. Axial **parenchyma** apotracheal diffuse, sometimes diffuse-in-aggregates. Axial parenchyma paratracheal scanty (sometimes scanty to vasicentric). **Rays** of two distinct sizes. Ray width 1 to 3 cells. Larger rays commonly 4 - to 10 seriate. Homocellular, all ray cells procumbent; to heterocellular, body ray cells procumbent with 1-2 rows of upright and / or square marginal cells.

- Main diagnostic features

Mean tangential diameter of vessel lumina between 100-200 µm. Vessel clusters common. Axial parenchyma paratracheal scanty. Rays of two distinct sizes. Larger rays commonly 4 - to 10 seriate.

- Discussion

The wood anatomy of this charcoal type matches the reference samples of an Ethiopian species *Hagenia abyssinica* Willd. from the MNHN xylothèque. It also matches the description of *Hagenia abyssinica* by Louppe et al. (2008). The combination of the main diagnostic features in InsideWood (2004-onwards) for tropical Africa results in *Hagenia abyssinica* as the only match. *Hagenia* sp. is a monospecific genus of the Rosaceae family native to East Africa (Assefa et al. 2010) known to be present in northern Ethiopia (Friis et al. 2010). According to Zhang (1992: 153-156), *Hagenia abyssinica* usually present vessels of two slightly different size classes and it can be differentiated from other Rosaceae species due to the absence of growth rings, a higher degree of vessel grouping, multiseriate rays shorter than 1 mm (widest rays not narrower than 4-seriate) and the absence of helical thickenings. Even though confusion is possible with *Acacia* sp., the studied charcoal type can be separated due to axial parenchyma configuration - *Hagenia abyssinica* features scanty paratracheal to vasicentric, rarely confluent and never aliform - and rays size and structure - of two different sizes in *Hagenia abyssinica*, predominantly homocellular but usually with 1-2 rows of of upright and / or square marginal cells.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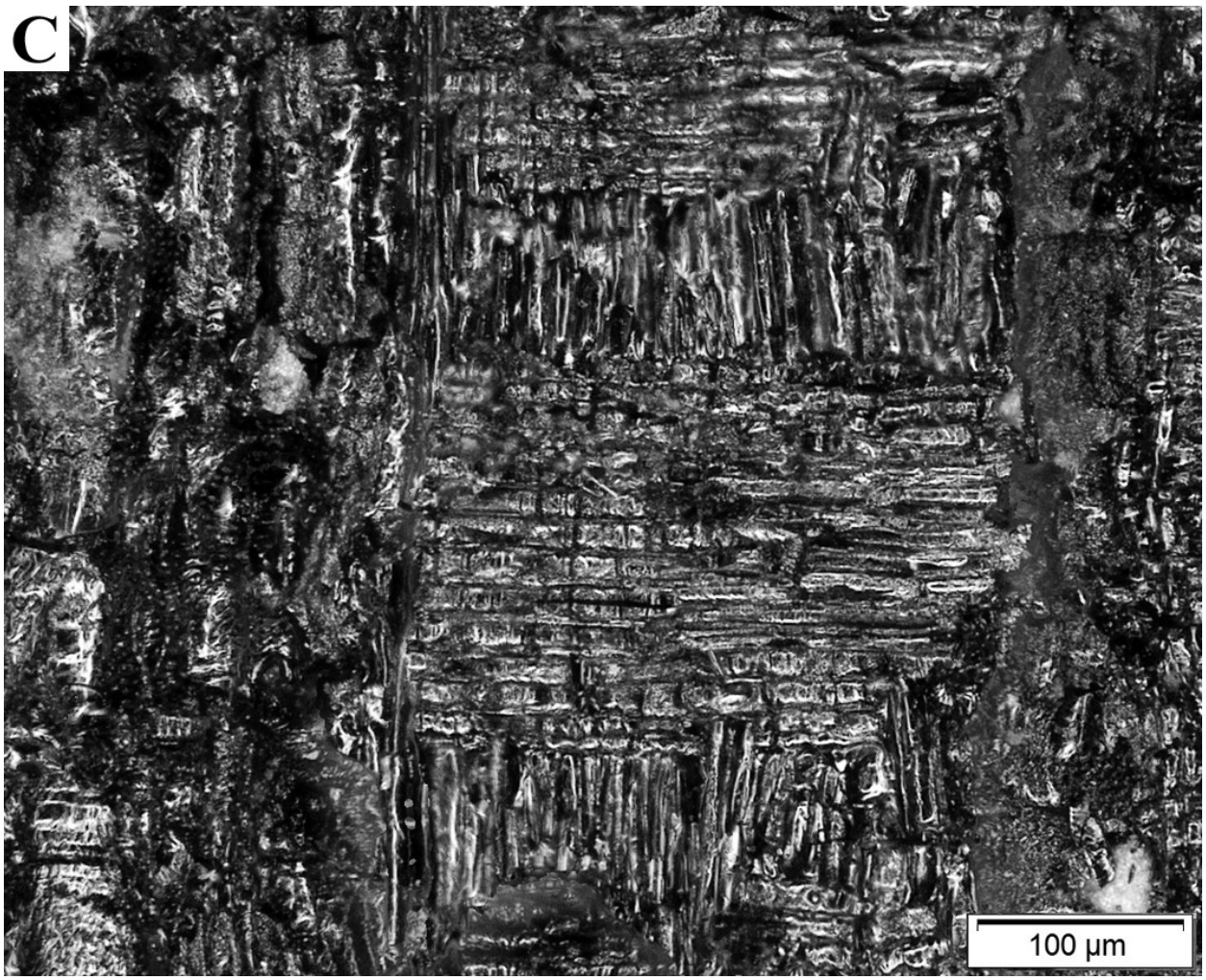


Fig. 14: A) TS: Vessels of two slightly different size classes, with a mean tangential diameter between 100-200 µm, often forming clusters. Axial parenchyma paratracheal scanty. B) TLS: Rays of two distinct sizes, the larger rays being commonly 4 - to 10 seriate. C) RLS: Ray structure homocellular, to weakly heterocellular.

- Ecological distribution and economic features

Hagenia abyssinica is a rather slender tree growing from 5 to 25 meters tall (Feyissa et al. 2005). Its presence during pre-Aksumite and Aksumite chronologies has been documented in both natural fires (c. 15%) and lacustrine palynological records (c. 10%) (Bonnefille and Mohammed 1994; Gebru et al. 2009). According to Friis et al. (2010), this species mainly occurs in Afromontane forests at high altitudes (Table 14).

Table 14 Ecological distribution of *Hagenia abyssinica* in northern Ethiopia (Friis et al. 2010: 196).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Hagenia abyssinica	*Kousso*	2450-3250	0	0	0	0	1	1	1	1	0	0

The tree is a highly valued medicinal plant (flower, bark, roots), being commonly harvested in the wild for local use (Assefa et al. 2010). The wood is dark red to red-brown (heartwood) and creamy yellow (sapwood), medium soft, moderately heavy but not durable (Bekele-Tesemma 2007). It is considered to be a good fuel (Gebreslassie et al. 2014), also making a good charcoal (Bekele-Tesemma 2007). Other uses include its manufacture for ornamentation, carving, and construction (Bekele-Tesemma 2007).

cf. Ixoroideae (Rubiaceae)

- Definition of charcoal type

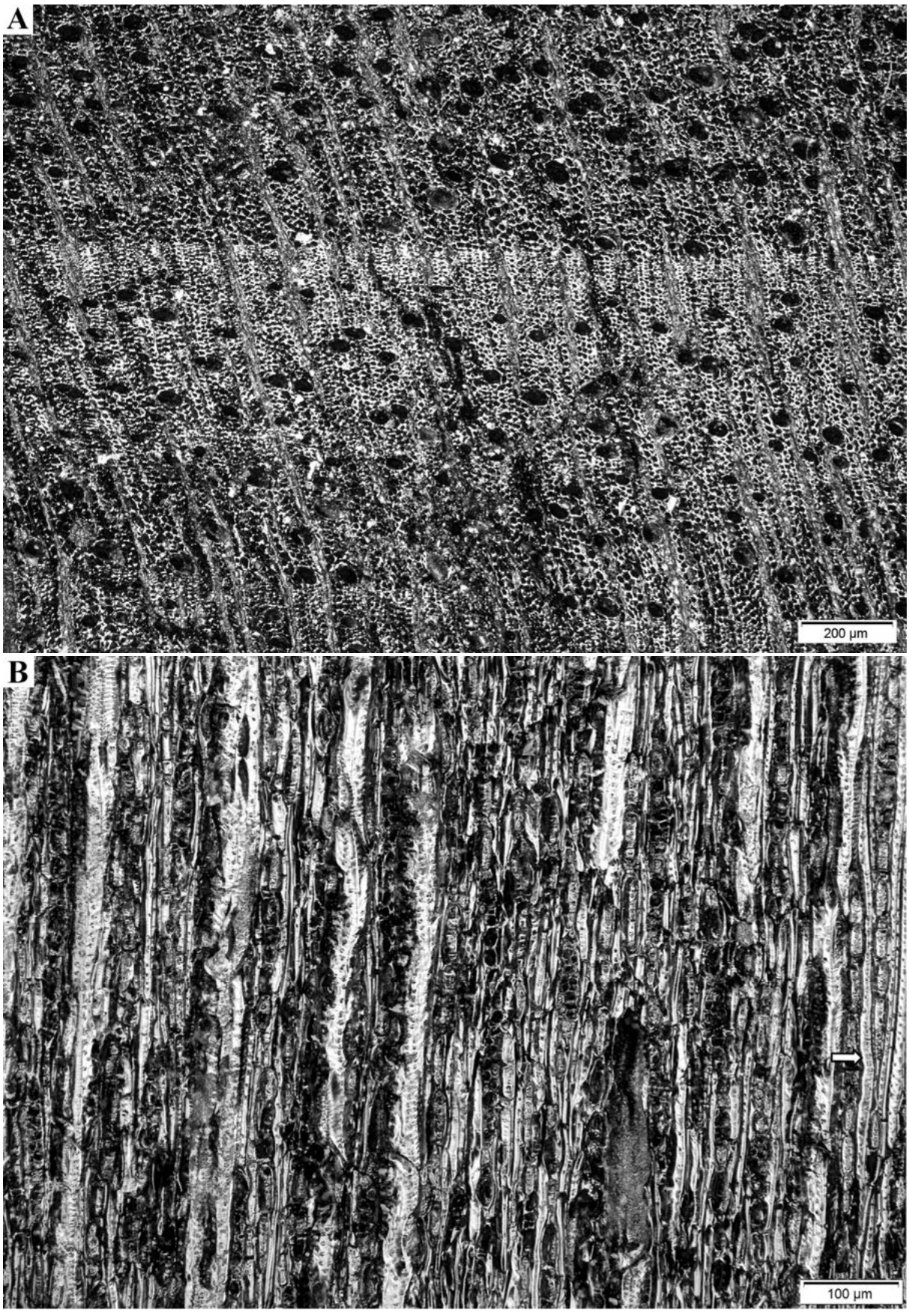
Growth ring boundaries distinct. Wood diffuse-porous. **Vessels** exclusively solitary (90% or more). Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel lumina smaller than 50 µm. **Fibres** with distinctly bordered pits. Axial **parenchyma** apotracheal diffuse. **Rays** width 1 to 3 cells. Body ray cells procumbent with mostly 2-4 (or more) rows of upright and / or square marginal cells.

- Main diagnostic features

Growth ring boundaries distinct. Mean tangential diameter of vessel lumina smaller than 50 µm. Vessels exclusively solitary (90% or more). Fibres with distinctly bordered pits. Rays width 1 to 3 cells. Body ray cells procumbent with mostly 2-4 rows (or more) of upright and / or square marginal cells.

- Discussion

The classification of this charcoal type as subfam. Ixoroideae is preliminary because species from other Rubiaceae subfamilies can share similar characteristics and might have been present during the Pre-Aksumite or Aksumite periods in northern Ethiopia. The diagnostic features of this charcoal type matches those of various genera of the Rubiaceae family from tropical Africa (InsideWood 2004-onwards), including *Coffea* sp., *Empogona* sp., *Feretia* sp., *Rothmannia* sp., *Gardenia* sp. and *Vangueriella* sp. - all of which pertain to the Ixoroideae subfamily. Other genera sharing these diagnostic features in tropical Africa include *Stephanostegia* sp., *Carpolobia* sp. and *Cassipourea* sp. (InsideWood 2004-onwards), though all of them feature vessel-ray pits with much reduced borders to apparently simple - absent in the studied charcoal type. Identification of Rubiaceae to genus or species is challenging, as there are several taxa with similar anatomical structures (Neumann et al. 2001). According to Jansen et al. (2002), two main types of secondary xylem can be found amongst the Rubiaceae. The studied charcoal type fits the diagnostic characters of Rubiaceae Type I: genera with this wood type share the presence of fibres with distinctly bordered pits, axial parenchyma apotracheal (diffuse, diffuse-in-aggregates or banded), vessels mainly solitary and narrow rays with long uniseriate margins. In northern Ethiopia, several genera matching this type have been documented by Friis et al. (2010) including *Pentas* sp. (tribe Hedyotideae, subfam. Rubioideae), *Breonadia* sp. (tribe Naucleeae, subfam. Chinchonoideae), *Hymenodictyon* sp. (tribe Hymenodictyeae, subfam. Chinchonoideae), *Catunaregam* sp., *Gardenia* sp., *Rothmannia* sp., *Oxyanthus* sp. (tribe Gardenieae, subfam. Ixoroideae), *Galiniera* sp., *Feretia* sp. (tribe Octotropideae, subfam. Ixoroideae), *Pavetta* sp. (tribe Pavetteae, subfam. Ixoroideae), *Canthium* sp., *Keetia* sp., *Psydrax* sp., *Rytigynia* sp. and *Vangueria* sp. (tribe Vanguerieae, subfam. Ixoroideae). However, the species of the subfamilies Chinchonoideae and Rubioideae feature characters such as the presence of long radial groups of vessels and vessel clusters (*Hymenodictyon* sp.) or larger 4-seriate rays (*Pentas* sp., *Breonadia* sp.) (Jansen et al. 2002) and hence can be discarded.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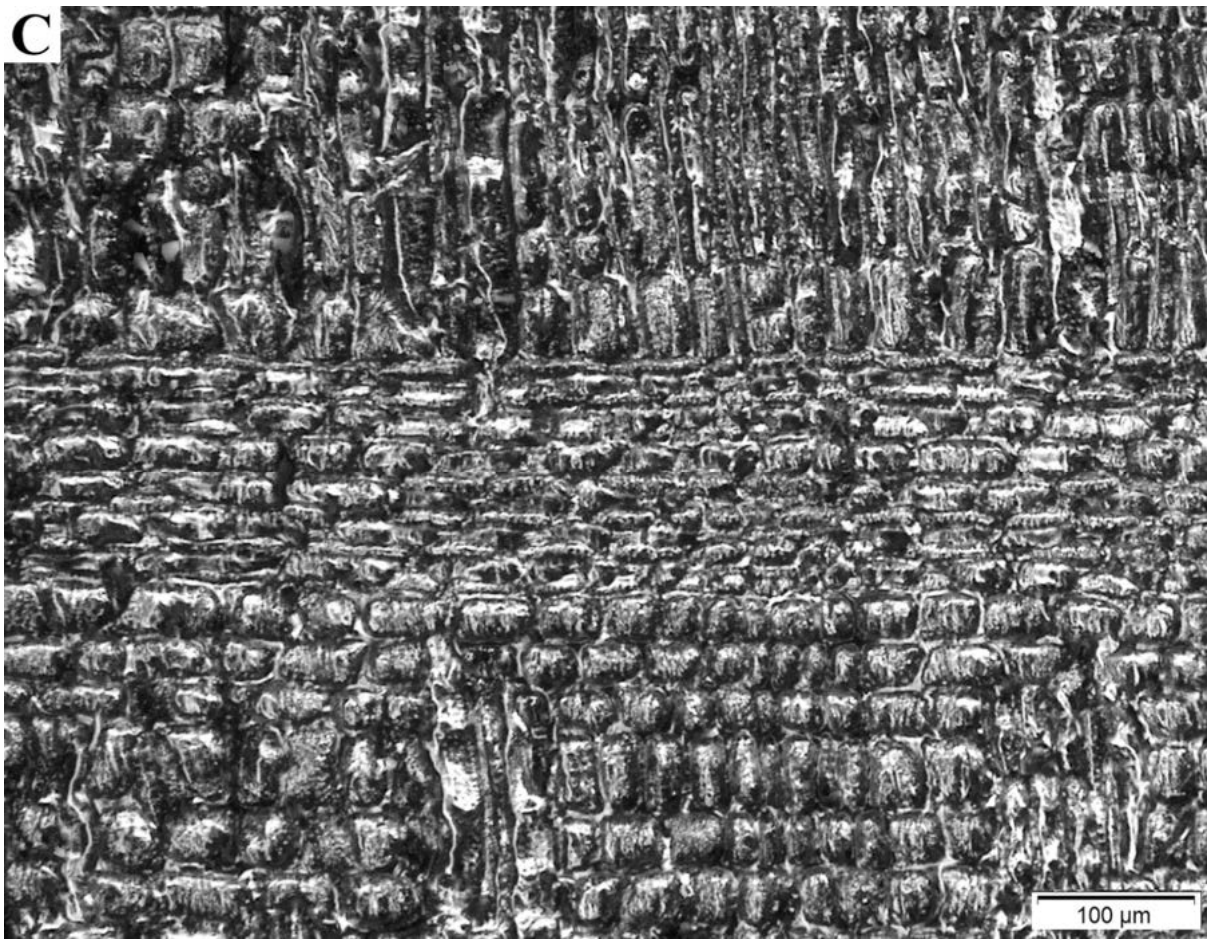


Fig. 15: A) TS: Growth rings distinct. Vessels exclusively solitary, with mean diameter of lumina smaller than 50 µm. B) TLS: Fibres with distinctly bordered pits. Rays width 1 to 3 cells, narrow, with long uniseriate margins. C) RLS: Body ray cells procumbent with 2-4 rows (or more) of upright and / or square marginal cells.

- Ecological distribution and economic features

The Ixoroideae (fam. Rubiaceae) are a large subfamily of flowering plants including terrestrial trees, shrubs, lianas and herbs (Andreasen and Bremen 2000) which are currently present in a wide range of ecosystems throughout Ethiopia (Friis et al. 2010). It consists of about 4000 species in 27 tribes, including several genus of high economic value as food, medicine and fuel (Bekele-Tesemma 2007). Table 15 lists all Ixoroideae species that have been recorded in current northern Ethiopia by Friis et al. (2010).

Table 15 Ecological distribution of Ixoroideae species in northern Ethiopia (Friis et al. 2010: 221-225).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Catunaregam nilotica	?	400-1700	0	0	0	1	0	0	0	0	0	0
Gardenia ternifolia	?	900-2250	0	0	0	1	1	0	0	0	0	0
Rothmannia urcelliformis	?	1200-2500	0	0	0	0	0	1	0	0	0	1
Oxyanthus speciosus	?	1350-2400	0	0	0	0	0	1	0	0	0	1
Galiniera saxifraga	?	1350-3000	0	0	0	0	1	1	1	0	0	0
Feretia apodanthera	?	600-1500	0	0	0	0	0	0	0	0	0	1
Pavetta oliveriana	?	1150-2450	0	0	0	1	1	0	0	0	0	1
Pavetta abyssinica	?	1350-2850	0	0	0	0	1	0	1	0	0	1
Pavetta gardeniifolia	?	800-2100	0	1	0	1	1	0	0	0	0	0
Canthium oligocarpum	?	1350-3000	0	1	0	0	1	0	0	0	0	0
Keetia zanzibarica	?	1450-2150	0	0	0	0	1	0	0	0	0	1

Psydrax schimperiana	*Zahak*	900-2600	0	1	0	1	1	0	0	0	0	0
Rytigynia neglecta	?	1200-2600	0	0	0	0	1	1	0	0	0	1
Vangueria madagascariensis	?	450-1600	0	1	0	0	0	0	1	0	0	0
Vangueria apiculata	?	1200-2100	0	0	0	0	1	1	0	0	0	1
Vangueria volkensii	?	1250-2300	0	1	0	0	0	0	1	0	0	0

***Dodonaea angustifolia* (Sapindaceae).**

- Definition of charcoal type

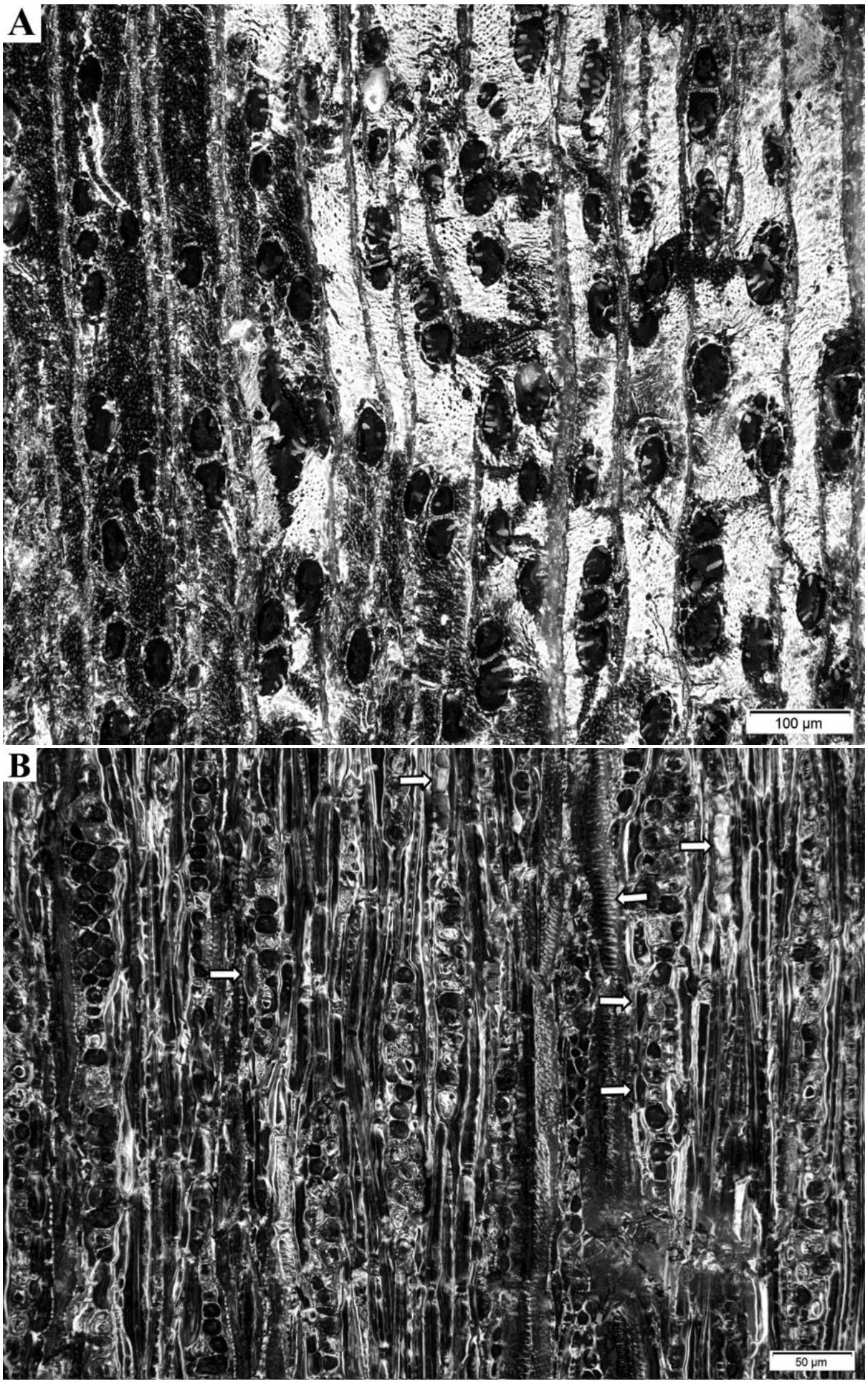
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessel** grouping sometimes in radial groups of 2-4, sometimes solitary. Simple perforation plates. Intervessel pits alternate, coalescent. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel lumina smaller than 50 µm. **Fibres** with simple to minutely bordered pits. Axial **parenchyma** apotracheal diffuse. Axial parenchyma paratracheal scanty to vasicentric. Axial parenchyma in marginal or in seemingly marginal bands. **Ray** width 1 to 3 cells. Homocellular, with all ray cells procumbent; rarely heterocellular, with procumbent, square and upright cells mixed throughout the ray. Sheath cells present. **Prismatic crystals** present. Prismatic crystals in axial parenchyma cells.

- Main diagnostic features

Mean tangential diameter of vessel lumina smaller than 50 µm. Axial parenchyma paratracheal scanty to vasicentric. Homocellular, with all ray cells procumbent. Sheath cells present. Prismatic crystals in axial parenchyma cells.

- Discussion

The wood anatomy of this charcoal type matches the reference samples of Ethiopian species *Dodonaea viscosa* Jacq. from the MNHN xylothèque. *Dodonaea* spp. is the only result for the combination of the main diagnostic features in InsideWood (2004-onwards). The studied charcoal type description also largely agrees with previous descriptions of the *Dodonaea* sp. genus (Metcalfe and Chalk 1950: 425-429; Li et al. 1995: 207; Neumann et al. 2001: 392-393; Liu and Noshiro 2003: 533-534), the main difference being the mention of occasional presence of faint winged-aliform parenchyma. Metcalfe and Chalk (1950) note that axial parenchyma in *Dodonaea* can be locally confluent, but without forming definite bands (see Figure 16A) - which if centered can look like winged-aliform parenchyma. Despite rays being predominantly homocellular, weekly heterocellular rays have been recorded by Neumann et al. (2001) and Liu and Noshiro (2003). These authors also mention the presence of coalescent intervessel pitting (see Figure 15B) as a notable characteristic of *Dodonaea* sp. (Neumann et al. 2001; Liu and Noshiro 2003). According to Friis et al. (2010), there is only one species of *Dodonaea* sp. growing in modern Ethiopia, that is, *D. angustifolia* - *Dodonaea angustifolia* L.f. is a synonym of *Dodonaea viscosa* subsp. *angustifolia* (L.f.) J.G.West, as accepted by IPNI (2020). They also list another 17 species of the Sapindaceae family, though none of them matches the studied type (see descriptions by Metcalfe and Chalk 1950: 425-429; InsideWood 2004-onwards; van der Ham 1995: 250) due to the presence of significantly larger mean diameter of vessel lumina (e.g. *Zanha golungensis*, *Lepisanthes senegalensis, Blighia unijugata*), abundant vasicentric parenchyma (e.g. *Filicium decipiens*), rays exclusively uniseriate (e.g. *Erythrophysa septentrionalis*, *Haplocoelum foliolosum, Bottegoa insignis, Allophylus* sp.) or larger than 4 cells wide (e.g. *Cardiospermum corindum, Paullinia pinnata*), and abundant prismatic crystals in ray cells (e.g. *Deinbollia kilimandscharica, Lecaniodiscus fraxinifolius, Pappea capensis*). According to Neumann et al. (2001), confusion is possible with *Grewia* sp. but *Dodonaea viscosa* has rays that are much narrower and tile cells are missing.


A
100 µm
B
50 µm

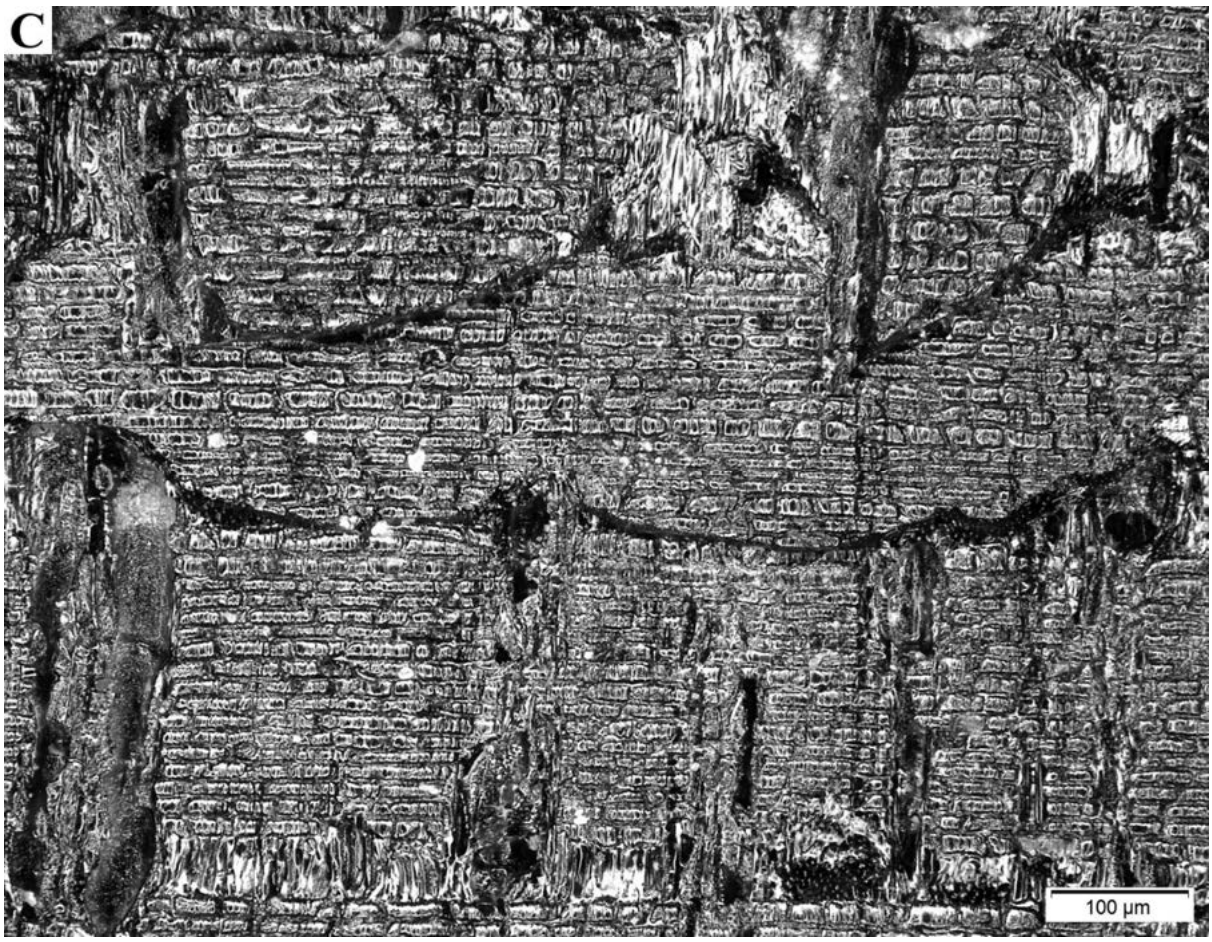


Fig. 16: A) TS: Mean tangential diameter of vessel lumina smaller than 50 µm. Axial parenchyma paratracheal scanty to vasicentric, sometimes forming marginal and discontinuous bands. B) TLS: Sheath cells present. Prismatic crystals in axial parenchyma cells. Intervessel pits coalescent. C) RLS: Homocellular to weekly heterocellular rays.

- Ecological distribution and economic features

Dodonaea angustifolia is a slender shrub or small tree that reaches a height of 3-8 meters (Bekele-Tesemma 2007). The palynological record of Lake Hayk has showed almost a 20% presence of *Dodonaea* sp. during pre-Aksumite and Aksumite chronologies – the most ubiquitous arboreal species documented until CE 1200 when its presence is reduced in favor of evergreen forest plants such as *Juniperus* and *Olea* species (Darbyshire et al. 2003). Nowadays, it grows in the Ethiopian afromontane forests (Table 16) and it is known to be a primary pioneer after deforestation (Darbyshire et al. 2003).

Table 16 Ecological distribution of *Dodonaea viscosa* in northern Ethiopia (Friis et al. 2010: 214).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Dodonaea angustifolia	*Tahses*	500-2900	0	0	0	0	1	1	1	0	0	0

The plant has a wide range of minor, local uses as food (fruit), medicine (seeds, leaves, stems, roots, bark) and fuel, for which it is gathered in the wild (Ruffo et al. 2002). The wood is extremely hard, close-grained, very heavy, tough and pest-resistant (Liu and Noshiro 2003). It makes a well-considered fuel because it can be easily ignited, and it burns slow and hot (Gebreslassie et al. 2014).

***Nuxia* spp. (Stilbaceae)**

- Definition of charcoal type

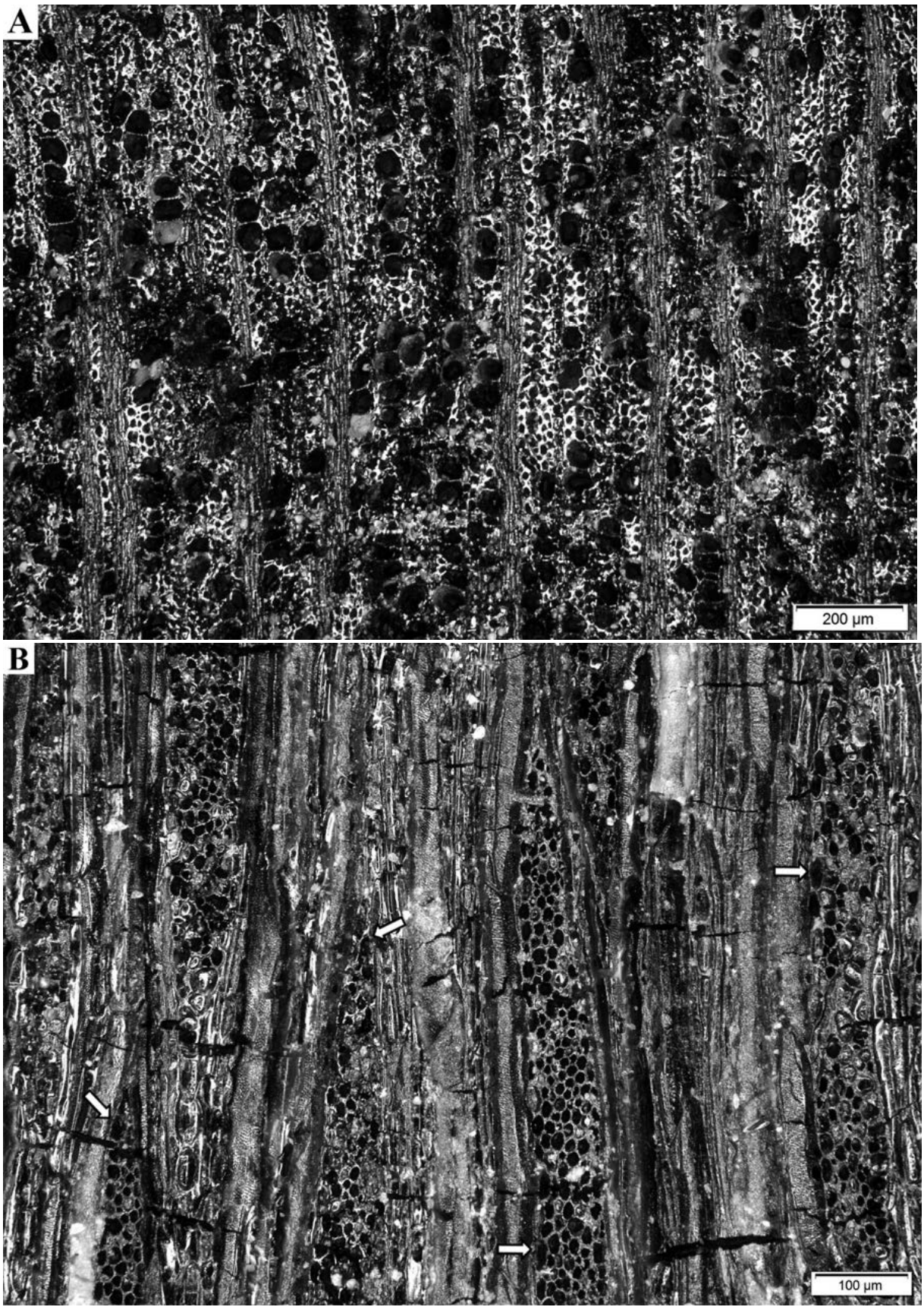
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** grouping in radial multiples of 4 or more common. Vessel clusters common. Solitary vessel outline angular. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel lumina smaller than 50 μm. **Fibres** with simple to minutely bordered pits. Axial **parenchyma** absent or extremely rare, sometimes paratracheal scanty. Larger **rays** commonly 4 - to 10 seriate. Ray height sometimes larger than 1 mm. Rays of two distinct sizes. Body ray cells procumbent with mostly 1-4 (or more) rows of upright and / or square marginal cells. Sheath cells present.

- Main diagnostic features

Mean tangential diameter of vessel lumina smaller than 50 μm. Larger rays commonly 4 - to 10 seriate. Ray height larger than 1 mm. Rays of two distinct sizes. Sheath cells present.

- Discussion

The wood anatomy of this charcoal type largely matches the reference samples of South African species *Nuxia floribunda* Benth. from the MNHN xylothèque - though vessel grouping both in radial multiples of 4 and clusters is much more common in the archaeological samples. A search of the diagnostic features - in combination with required absence of scalariform perforation plates, not observed in the studied charcoals - in InsideWood (2004-onwards) for tropical Africa results in 2 genera of the Ochnaceae family (*Diporidium* sp. and *Gomphia* sp.), 2 genera of the Rubiaceae family (*Rothmannia* sp. and *Gardenia* sp.) and *Nuxia congesta* of the Stilbaceae family. However, both Ochnaceae and Rubiaceae resulting species are characterized by exclusively solitary vessels and apotracheal parenchyma diffuse-in-aggregates (InsideWood 2004-onwards), none of which are present in the observed charcoals. In northern Ethiopia, Friis et al. (2010) records two species of *Nuxia* sp. (*N. congesta* and *N. oppositifolia*) in the Loganiaceae family following the phylogenetic classification introduced by Cronquist (1981), along with *Buddleja polystachya* and two species of *Strychnos* sp. The latter is easily recognizable due to the presence of included phloem (Metcalfe and Chalk 1950: 930). However, some authors have highlighted the difficulty of separating *Nuxia* sp. from species in the Buddlejeae tribe of the Loganiaceae family (Carlquist 1997; Allot et al 2006), especially from *Buddleja* sp. and *Pelthantera* sp. Whereas the second is not present in Ethiopia, *Buddleja* sp. presents important differences in ray size (Carlquist 1997) - of only one size class and never longer than 1 mm (InsideWood 2004-onwards). More recently, the Angiosperm Phylogeny Group (APG) has established *Nuxia* sp. to be part of the Stilbaceae family (APG 2009) along with 15 other genera. Amongst them, only *Halleria lucida* has been found to be present in modern Ethiopia (Friis et al. 2010) - *Halleria lucida* L. is a synonym of *Halleria abyssinica* Jaub. & Spach, as accepted by IPNI (2020). The wood anatomy of *Halleria abyssinica* presents important similarities with that of *Nuxia* sp. according to its InsideWood (2004-onwards) description, but it features larger rays (commonly over 10-seriate) and sheath cells are missing.


A
200 µm
B
100 µm

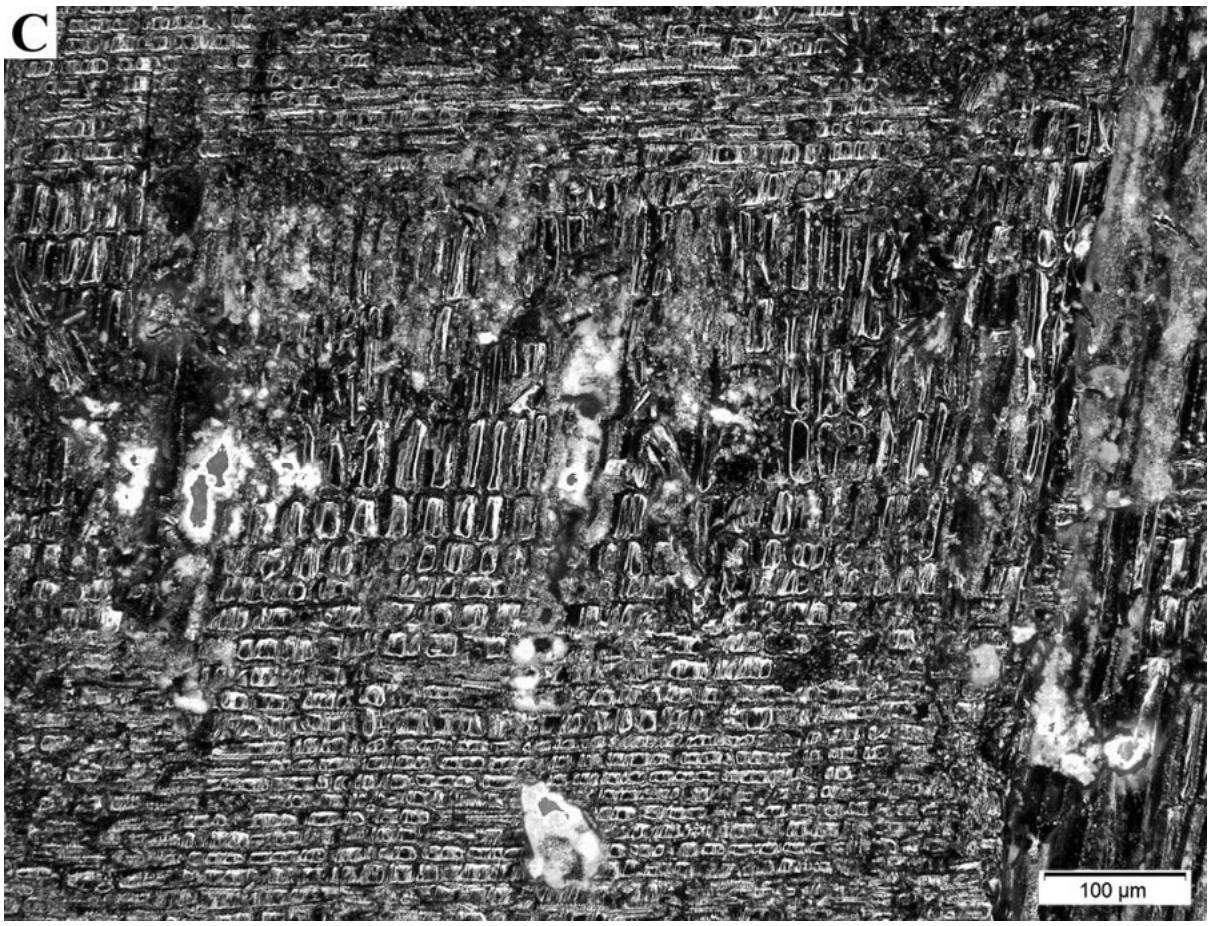


Fig. 17: A) TS: Mean tangential diameter of vessel lumina smaller than 50 µm, not exclusively solitary. B) TLS: Larger rays commonly 4 - to 10 seriate. Rays of two distinct sizes, some very long (larger than 1 mm). Sheath cells present. C) RLS: Heterocellular rays.

- Ecological distribution and economic features

Nuxia sp. is a genus composed of perennial woody herbs or subshrubs with ascending branches from a woody thickened root, as well as shrubs and small trees (von Maydell 1986). No record of *Nuxia* sp. during pre-Aksumite or Aksumite times has been published so far. In modern Ethiopia, Friis et al. (2010) have identified two species of this genus (Table 17).

Table 17 Ecological distribution of *Nuxia* species in northern Ethiopia (Friis et al. 2010: 218).

Scientific name	Tigrinya name	Altitude (m.a.s.l.)	DSS	ACB	ACB/ RV	CTW	DAF/ WG	DAF/ U	DAF/ SD	EB	AA	RV
Nuxia congesta	*Atcharo*	1100-3800	0	0	0	0	1	1	1	1	1	0
Nuxia oppositifolia	?	800-2400	0	0	0	0	0	0	0	0	0	1

These species are harvested in the wild for local use as a medicine (leaves, bark) and source of wood (Bekele-Tesemma 2007). Their whitish-yellow wood is generally hard and heavy, and it is usually employed for construction purposes and as firewood (Ruffo et al. 2002).

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References

Allott L (2006) Archaeological charcoal as a window on palaeovegetation andwood-use during the Middle Stone Age at Sibudu Cave. South African Humanit 18:173–201

Andreasen K, Bremer B (2000) Combined phylogenetic analysis in the Rubiaceae-Ixoroideae: morphology, nuclear and chloroplast DNA data. Am J Bot 87:1731–1748. https://doi.org/10.2307/2656750

APG (2009) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. Bot J Linn Soc 161:105–121. https://doi.org/10.1111/j.1095-8339.2009.00996.x

Armstrong WP (1999) The unforgettable Acacias. Zoonooz 71:28–31

Assefa B, Glatzel G, Buchmann C (2010) Ethnomedicinal uses of Hagenia abyssinica (Bruce) J.F. Gmel. among rural communities of Ethiopia. J Ethnobiol Ethnomed 6:20. https://doi.org/10.1186/1746-4269-6-20

Baas P, Esser PM, van der Westen MET, Zandee M (2014) Wood anatomy of the Oleaceae. IAWA J 9:103–182. https://doi.org/10.1163/22941932-90001064

Bekele-Tesemma A (2007) Useful trees and shrubs of Ethiopia: identification, propagation, and management for 17 agroclimatic zones. World Agroforestry Center, Nairobi

Beldados A, D'Andrea AC, Manzo A (2015) Filling the gap: new archaeobotanical evidence for 3rd-1st millennium BC agricultural economy in Sudan and Ethiopia. In: Tossatti G (ed) 8th International Workshop for African Archaeobotany. Atti della Società dei Naturalisti e Matematici di Modena., Modena, pp 151–153

Boning CR (2006) Florida's best fruiting plants: native and exotic trees, shrubs, and vines. Pineapple Press Inc, Sarasota

Bonnefille R, Mohammed U (1994) Pollen-inferred climatic fluctuations in Ethiopia during the last 3000 years. Palaeogeogr Palaeoclimatol Palaeoecol 109:331–343. https://doi.org/10.1016/0031-0182(94)90183-X

Brummitt RK (2010) Acacia: a solution that should be acceptable to everybody. Taxon 59:1925–1926. https://doi.org/10.1002/tax.596050

Carlquist S (1996) Wood anatomy of Buddlejaceae. Aliso A J Syst Evol Bot 15:41–56

Carlquist S (1981) Wood Anatomy of the Pittosporaceae. Allertorina 2:355–392

Chittick HN (1976) Radiocarbon dates from Aksum. Azania Archaeol Res Africa 11:179–181. https://doi.org/10.1080/00672707609511240

Chudnoff M (2007) Tropical timbers of the world. Verlag Kessel, Remagen-Oberwinter

Cronquist A (1981) An integrated system of classification of flowering plants. Columbia University Press, New York

Darbyshire I, Lamb H, Umer M (2003) Forest clearance and regrowth in northern Ethiopia during the last 3000 years. Holocene 13:537–546. https://doi.org/10.1191/0959683603hl644rp

De Sanctis M, Adeeb A, Farcomeni A, et al (2013) Classification and distribution patterns of plant communities on Socotra Island, Yemen. Appl Veg Sci 16:148–165. https://doi.org/10.1111/j.1654-109X.2012.01212.x

Diblasi M (1997) Pollen analysis of sediment samples from Ona Nagast IV–V, Bieta Giyorgis, Aksum. Addis Ababa, Ethiopia

DiBlasi MC (1996) Results of the analysis of archaeological pollen samples from Beta Giyorgis, Aksum. Addis Ababa, Ethiopia

Dong Z, Baas P (1993) Wood anatomy of trees and shrubs from China. V. Anacardiaceae. IAWA J 14:87–102

Evans JA, Gasson PE, Lewis GP (2006) Wood anatomy of the Mimosoideae (Leguminosae). IAWA J, Suppl. 5.

Farjon A (2005) Monograph of Cupressaceae and Sciadopitys. Royal Botanical Garden, Kew

Farjon A (2013) Afrocarpus falcatus. IUCN Red List Threat Species 2013:e.T34203A2850812. https://doi.org/https://dx.doi.org/10.2305

Fasolo U, Abbate M, Cellai G (1939) Atlante micrografico dei leigni dell'Africa orientale italiana. Erbario Coloniale di Firenze, Firenze

Feyissa T, Welander M, Negash L (2005) Micropropagation of Hagenia abyssinica: a multipurpose tree. Plant Cell Tissue Organ Cult 80:119–127. https://doi.org/10.1007/s11240-004-9157-1

Friis I, Demissew S, Paulo van Breugel (2010) Atlas of the potential vegetation of Ethiopia. The Rotay Danish Academy of Sciences and Letters

Gebreslassie T, Gebraslassie H, Mehari A (2014) Assessing households' fuel wood tree species preference, the case of Desa'a Afroalpine forest, Tigray. Civ Environ Res 6:48–51

Gebru T, Eshetu Z, Huang Y, et al (2009) Holocene palaeovegetation of the Tigray Plateau in northern Ethiopia from charcoal and stable organic carbon isotopic analyses of gully sediments. Palaeogeogr Palaeoclimatol Palaeoecol 282:67–80. https://doi.org/10.1016/j.palaeo.2009.08.011

Gupta S, Agarwal M (2008) Wood Anatomy of Anacardiaceae from India with Special Reference to Systematic Position of Rhus. IAWA J 29:79–106. https://doi.org/10.1163/22941932-90000172

Gupta S, Saxena V (2011) Wood microstructure of ligneous species of Rhamnaceae from India. J Trop For Sci 23:239–251

Heimsch C (1940) Wood anatomy and pollen morphology of Rhus and allied genera. J Arnold Arbor 21:279–291

Higham TFG, Bronk Ramsey C, Chivall D, et al (2018) Radiocarbon dates from the Oxford AMS system: Archaeometry Datelist 36. Archaeometry 60:628–640. https://doi.org/10.1111/arcm.12372

Höhn A (1999) Wood anatomy of selected West African species of Caesalpinioideae and Mimosoideae (Leguminosae): a comparative study. IAWA J 20:115–146. https://doi.org/10.1163/22941932-90000672

Höhn A, Neumann K (2018) Charcoal identification in a species-rich environment: The example of Dibamba, Cameroon. IAWA J 39:87–113. https://doi.org/10.1163/22941932-20170195

InsideWood (2004-onwards) InsideWood. http://insidewood.lib.ncsu.edu/search. Accessed June 2020.

IPNI (2020) International Plant Name Index. http://www.ipni.org. Accessed June 2020

Jangid PP, Gupta S (2016) Wood anatomy of the subfamily Crotonoideae (Euphorbiaceae s.s.) from India: systematic implications with special reference to the taxonomic delimitation of Givotia and Vernicia. Nord J Bot 34:478–495. https://doi.org/10.1111/njb.00990

Jansen S, Robbrecht E, Beeckman H, Smets E (2002) A survey of the systematic wood anatomy of the Rubiaceae. IAWA J 23:1–67. https://doi.org/10.1163/22941932-90000288

Knight KS, Kurylo JS, Endress AG, et al (2007) Ecology and ecosystem impacts of common buckthorn (Rhamnus cathartica): a review. Biol Invasions 9:925–937. https://doi.org/10.1007/s10530-007-9091-3

Lancelotti C (2018) “Not all that burns is wood”. A social perspective on fuel exploitation and use during the Indus urban period (2600-1900 BC). PLoS One 13:e0192364. https://doi.org/10.1371/journal.pone.0192364

Li B, ter Welle BJH, Klaassen RKWM (1995) Wood anatomy of trees and shrubs from China VII. Sapindaceae. IAWA J 16:191–215. https://doi.org/10.1163/22941932-90001403

Liu J, Noshiro S (2003) Lack of latitudinal trends in wood anatomy of Dodonaea viscosa (Sapindaceae), a species with a worldwide distribution. Am J Bot 90:532–539. https://doi.org/10.3732/ajb.90.4.532

Louppe D, Oteng-Amoako AA, Wageningen MB (2008) Plant resources of tropical Africa (Vol. 7): timbers. Backhuys PROTA Foundation, Wageningen

McKenna MJ, Simmons MP, Bacon CD, Lombardi JA (2011) Delimitation of the segregate genera of Maytenus s. l. (Celastraceae) based on morphological and molecular characters. Syst Bot 36:922–932. https://doi.org/10.1600/036364411X604930

Metcalfe CR, Chalk L (1950) Anatomy of the dicotyledons. Oxford University Press, Oxford

Miller AJ, Young DA, Wen J (2001) Phylogeny and biogeography of Rhus (Anacardiaceae) based on ITS sequence data. Int J Plant Sci 162:1401–1407. https://doi.org/10.1086/322948

Neumann K, Schoch W, Détienne P, Schweingruber FH (2001) Woods of the Sahara and the Sahel. Verlag Paul Haupt, Bern

Nicholson PT, Shaw I (2000) Ancient Egyptian materials and techniques. Cambridge University Press, Cambridge

November, E., Aerts R, Behailu M, Muys B (2002) Species list Tigrinya – Scientific. Technical note 2002/4.

Prior JAB, Gasson PE (1990) Comparative wood anatomy of afromontane and bushveld species from Swaziland, Southern Africa. IAWA J 11:319–336

Ritcher HG, Grosser D, Heinz I, Gasson PE (2004) IAWA list of microscopic features for softwood identification. IAWA J 25:1–70. https://doi.org/10.1163/22941932-90000349

Ruffo CK, Birnie A, Tengnäs B (2002) Edible wild plants of Tanzania (Vol. 27). Regional Land Management Unit, Nairobi

Schirarend C (1991) The systematic wood anatomy of the Rhamnaceae Juss. (Rhamnales). I. tribe Zizipheae. IAWA J 12:359–388. https://doi.org/10.1163/22941932-90000540

Solereder H (1899) Systematische anatomie der dicotyledonen. Enke, Stuttgart

Thulin M (1993) Flora of Somalia (Vol. 1). Royal Botanical Garden, Kew

Van der Ham RWJM, Baas P, Barker ME, et al (1995) Bottegoa Chiov. transferred to the Ptaeroxylaceae. Kew Bull 50:243. https://doi.org/10.2307/4110629

Von Maydell HJ (1986) Trees and shrubs of the Sahel, their characteristics and uses. Verlag Josef Margraf Scientific Books, Weikersheim

Wheeler EA, Baas P, Gasson PE (1989) Iawa list of microscopic features for hardwood identification. IAWA J 10:219–232. https://doi.org/10.1163/22941932-90000496

Wiehle M, Prinz K, Kehlenbeck K, et al (2014) The role of homegardens and forest ecosystems for domestication and conservation of Ziziphus spina-christi (L.) Willd. in the Nuba mountains, Sudan. Genet Resour Crop Evol 61:1491–1506. https://doi.org/10.1007/s10722-014-0124-3

Zhang S (1992) Systematic wood anatomy of the Rosaceae. BLUMEA 37:81–158