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Human-Woodland interactions during the Pre-Aksumite and Aksumite periods in NE Tigray, Ethiopia: insights from the wood charcoal analyses of Mezber and Ona Adi.

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ABSTRACT:

The Tigray region witnessed the rise and fall of the Pre-Aksumite and Aksumite polities between the mid-2nd millennium BCE and the late-1st millennium CE. Despite the importance of these entities in recent African prehistory, the issue of how they interacted with their surrounding environment has only been addressed very recently. Here, we present the first systematic anthracological analysis in the region. Wood charcoal samples from two archaeological sites were analyzed: the Pre-Aksumite rural site of Mezber (c. 1600 BCE – 1 CE) and Ona Adi (c. 600 BCE – 700 CE), an urban center occupied continuously from the Late Pre-Aksumite period to the fall of the Aksumite kingdom. A total of 2708 charcoal fragments from 25 samples and 9 archaeological phases were analyzed, and 19 plant taxa associated with at least 3 different vegetation types were identified. The results demonstrate rather continuous environmental conditions at a local level, with no major or abrupt environmental changes. They also evidence a process of landscape degradation as a result of human activity during the early-to-mid 1st millennium BCE, as well as a subsequent recovery that occurred gradually throughout the next c. 1,500 years. Finally, differences in firewood exploitation were identified in relation to the rural/urban nature of each settlement, showing an evolution in wood selection, management and exploitation strategies which indicates that both Pre-Aksumite and Aksumite populations featured a significant degree of resilience and adaptation capacity.

KEYWORDS:

Archaeobotany; Charcoal analysis; Pre-Aksumite period; Kingdom of Aksum; Tigray; Ethiopia.

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CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

AVAILABILITY OF DATA AND MATERIAL

Reference collection is available at https://repositori.upf.edu/handle/10230/43106

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Introduction

Pre-Aksumite and Aksumite communities, which flourished in the Tigray region of Ethiopia between the mid-2nd millennium BCE and the late-1st millennium CE (Harrower and D'Andrea 2014; D'Andrea et al. 2018; Taddesse 2019) represent two of the most notable ancient cultural horizons of recent African prehistory. During this period, these communities transformed from farming communities into a complex literate civilization spanning across the Ethiopian/Eritrean Highlands (Fattovich 2012). Nonetheless, these ancient polities of the Horn are still incompletely known, as archaeological research there has been overshadowed by other contemporaneous civilizations such as ancient Egypt, Meröe, and the Greco-Roman world. Recent research in Tigray has provided important insights to our understanding of human-environment relationships during these millennia (Boardman 1999, 2000; D'Andrea et al. 1999, 2008a, b, 2011, 2018; Cain 2000; D'Andrea 2003, 2008; Lyons and D'Andrea 2003; Sernicola 2008; French et al. 2009, 2014; Terwilliger et al. 2011; Harrower and D'Andrea 2014; Sulas 2014; Graniglia et al. 2015; Woldekiros and D'Andrea 2017; Harrower et al. 2020). However, the issue of woodland exploitation remains largely unexplored, as no anthracological analyses from anthropic deposits have been published so far (but see Gebru et al. 2009). This paper presents the results of anthracological analyses from two archaeological sites in the Gulo Makeda district in the eastern Tigray (Fig. 1): the Pre-Aksumite rural site of Mezber and the Aksumite urban center of Ona Adi, both excavated in the frame of the Eastern Tigray Archaeological Project (ETAP) (D'Andrea et al. 2008a). As such, this work constitutes pioneer research in defining human-woodland interactions using archaeobotanical data by reconstructing how people exploited woodlands and exploring the socio-ecological behaviors that underlie the gathering and use of wood resources during the Pre-Aksumite and Aksumite periods.

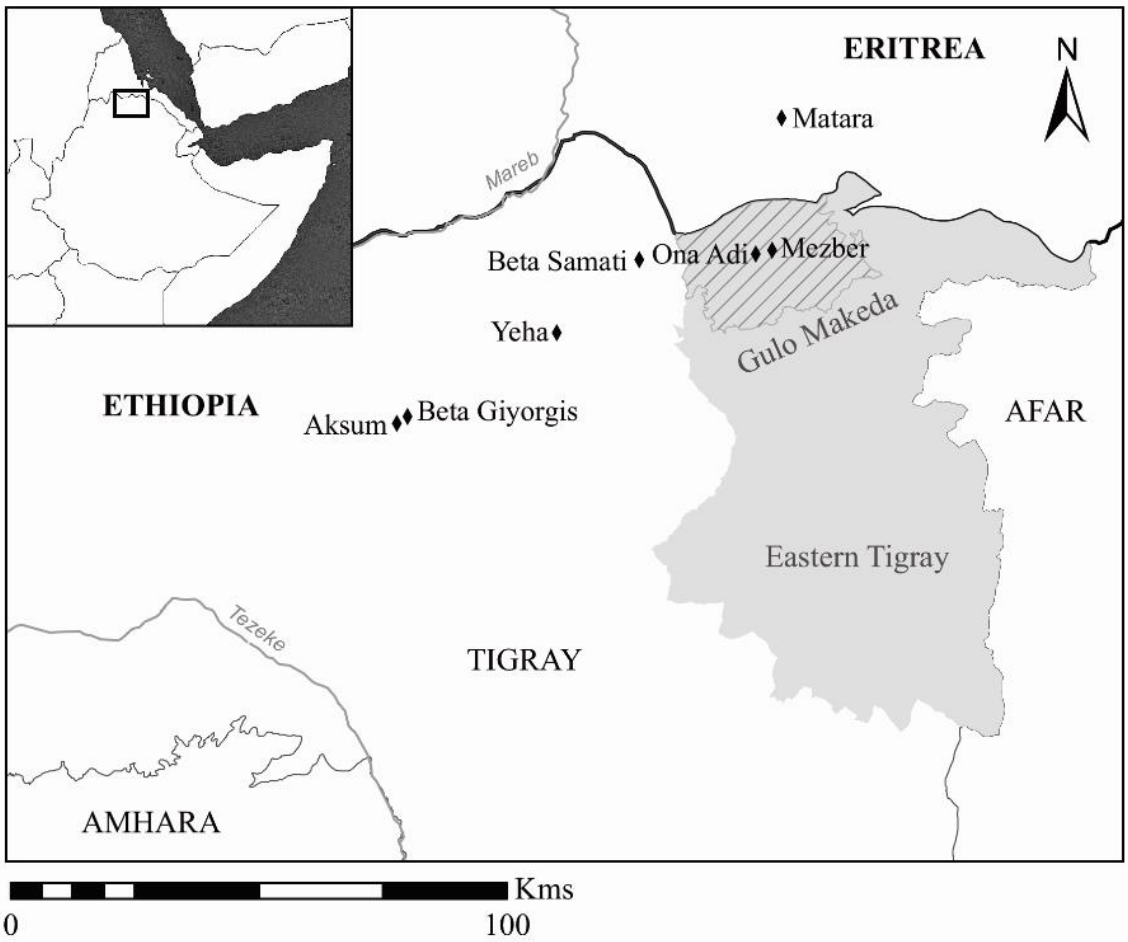

Fig. 1 Map of the study area with the location of Mezber (14.417167º N, 39.40781079º E), Ona Adi (14.28583067º N, 39.01690588º E) and other archaeological sites mentioned in the text.

Cultural background

The Pre-Aksumite period (>800 - 50 BCE)

The term Pre-Aksumite refers to human occupations in the northern Highlands between the 1st millennium BCE and the rise of the Aksumite civilization (c. 50 BCE). During these centuries, the region experienced a substantial increase in settlement density, accompanied by the appearance of diverse agropastoral economies and social differentiation (Phillipson 2009). Based on ceramic traditions, this horizon is usually divided in three subphases –Early, Middle and Late Pre-Aksumite– with radiocarbon dates that vary significantly between subregions (Fattovich 2004; Michels 2005; Bard et al. 2014). Recently chronologies older than 800 cal. BCE have been obtained at the site of Mezber (Harrower and D'Andrea 2014), hence introducing a fourth subphase named Initial Pre-Aksumite (1600-800 BCE).

Excluding the Initial phase at Mezber, two types of settlements have been documented in the northern Highlands during the Pre-Aksumite period: (a) elite settlements such as Yeha (see Fattovich 2009, Phillipson 2012: 24-32), which contained elaborate monumental architecture and dedicatory inscriptions – both considered symbols of power; and (b) non-elite villages built of undressed dry-stone (Phillipson 2012) that seem to represent the majority of occupations in Tigray (D'Andrea et al. 2008a; Sernicola 2008). Settlement pattern analysis shows associations between sites and their surrounding environment –including preferential selection for agriculturally more productive and water outflow areas (Sernicola and Sulas 2012; Harrower and D'Andrea 2014). Cultivated crops are well attested as both African C4 cereals and Near Eastern C3 crops have been documented throughout the region (Boardman 1999, 2000; D'Andrea et al. 2008b, 2011; Schmidt 2009; Beldados et al. 2015) along with zooarchaeological evidence of domesticated species such as cattle, caprines, chicken, dog and donkey (Cain 2000; Shoshani et al. 2008; Lesur et al. 2014; Woldekiros and D'Andrea 2017).

The Aksumite Kingdom (50 BCE - 700 CE)

The emergence and development of the Aksumite civilization was a gradual process. Its origins can be traced back to the last centuries of the 1st millennium BCE, specifically in the Aksum area, where a polity centered on Beta Giyorgis has been identified as "Proto-Aksumite" (c. 400 – 50 BCE). This phase has been called "Pre-Aksumite to Aksumite Transition" (PA-A Transition) elsewhere in Tigray (see Taddesse 2019: 339). From Beta Giyorgis, Aksumite regional and interregional influences rapidly consolidated during the Early/Classic Aksumite period (c. 50 BCE – 350 CE) (Bard et al. 2014; Taddesse 2019), allowing this new polity to extend its political and economic control over the previously distinct Pre-Aksumite populations (Phillipson 2012). Settlement patterns show a general continuity in occupation from previous Pre-Aksumite sites (e.g. Anfray 2012; Taddesse 2019), as does subsistence economies (Bard et al. 2000; Boardman 2000; Cain 2000; D'Andrea et al. 2008b, 2011).

According to exogenous historical sources (see Kobishchanov 1979; Munro-Hay 1991; Phillipson 1998), the 3rd century CE witnessed an important territorial expansion, with various kings of Aksum incorporating new territories into a centralized state, which adopted Christianity in the 4th century CE, marking the beginning of the Middle Aksumite phase (c. 350-500 CE) (Bard et al. 2014; Taddesse 2019). This polity featured a stratified society with urban centers such as Matara (Anfray 2012) or Beta Samati (Harrower et al. 2019) –organized by complex political, administrative and military structures– which minted its own official currency and maintained varying degrees of contact with foreign populations, both adjacent and distant (see Phillipson 2012: 71-106, 181-208; Fattovich 2019 for details). Nonetheless most Aksumite sites were rural, food-producing settlements; the number in mid-sized urban centers registered a steady increase until the 6th century CE. Available information points to differences in productive activities between urban and rural areas: the former featuring industrial activities which included metalworking and the manufacture of glass and ivory artifacts (Phillipson 2012), although the division was rarely rigid and available archaeological data is still incomplete.

The Late Aksumite period (c. 500-700 CE) marked the beginning of the Aksumite decline (Bard et al. 2014; Taddesse 2019). Archaeological evidence attests a social and economic crisis at Aksum during the 6th and 7th centuries CE, as reflected by the gradual reduction of the metropolis occupation and economic

wealth (Fattovich 2010; Phillipson 2012). Nonetheless, a considerable number of rural compounds persisted (Sernicola and Sulas 2012) not only around Aksum, but also in other areas of the kingdom where population is believed to have only slightly decreased (Sernicola 2008; Philipson 2012; Harrower and D'Andrea 2014).

Environment and vegetation

The Tigray plateau extends over a total area of circa 50,000 square kilometers along the northern Ethiopian Highlands and is drained by the Tezeke and Mareb rivers. The geology of the area is mainly shaped by the volcanic activity associated with the East African Rift system, which has resulted in a landscape dominated by an irregular plateau ranging from 1,000 to 3,500 m.a.s.l. (Machado et al. 1998; Bard et al. 2000; Hagos et al. 2002; Gebru et al. 2009). Current Tigray shows a semi-arid, subtropical climate, characterized by a strong seasonality (Machado et al. 1998) with a main rainy season from June to mid-September (Araya et al. 2010). The marked variations in topography and altitude greatly influence environmental conditions, producing different microclimates within short distances (Hagos et al. 2002): mean annual temperatures range from 15º to 25ºC while mean annual rainfall ranges between 500 and 750 mm (Hadgu et al. 2013).

The region is highly sensitive to environmental changes due to its geographical position and mountainous terrain (Machado et al. 1998). As shown by paleoclimatic records from fluvio-lacustrine sediments (see Trauth et al. 2007; Lanckriet et al. 2015 for further explanation), marked environmental variation has characterized the Tigray Plateau since at least the Early Pleistocene (c. 2.5 mya), with a general tendency towards aridification, alternating with relatively humid periods until the beginning of the Holocene when the East African Humid Period begun (c. 9000 – 3600 BCE) (Nyssen et al. 2004; Tierney et al. 2011). Nonetheless, dry events have been documented during these moister millennia (Marshall et al. 2009, 2011), which finally gave place to a period of landscape destabilization and reduced precipitation, reaching its minimum level from 2200 BCE onwards (Lanckriet et al. 2017) –when present-day climatic conditions were established (Bard et al. 2000). The subsequent centuries featured a significant increase in sediment supply (Machado et al. 1998) and colluvial activity (Moeyersons et al. 2006), while C4 plants became increasingly abundant (Gebru et al. 2009). Such a tendency would have reached its peak between 800-500 BCE, when there was a rapid decline of Afromontane forests, substituted by Afromontane woodlands and grasslands that persisted until the beginning of the 2nd millennium CE (Bard et al. 2000; Darbyshire et al. 2003; Sulas et al. 2009). The shift to a relatively wetter climate between 450 BCE and 500 CE, along with decreased soil erosion rate (Ciampalini et al. 2008) and diminished sediment supply (Machado et al. 1998) allowed landscape stabilization (French et al. 2009). At this period, palynological analyses indicate a predominance of grasses together with some arboreal plants and scrubs related to wooded grassland environments, as well as Afromontane forests (see Bard et al. 2000; Darbyshire et al. 2003; Sulas et al. 2009). After 500 CE, the landscape in the highlands started to degrade once again. Geoarchaeological research has shown that deforestation and intensification of land-use related to the Aksumite kingdom led to erosion and soil degradation (French et al. 2014). This tendency would have lasted for at least 300 years, until the beginning of the 9th century CE –coinciding with the decline of the Aksumite Kingdom– when geoarchaelogists have identified the last major period of landscape recovery (Machado et al. 1998; Bard et al. 2000).

Presently the area is largely devoid of forest vegetation, with almost all available land under cultivation or pasture. Nonetheless, based on colonial sources most scholars agree that a large area of the northern Highlands of Ethiopia was forested in earlier times (see references in Bard et al. 2000). Due to the lack of paleobotanical research, scholars have used ecological and bioclimatic data to reconstruct the distribution of past vegetation communities. According to Bard et al. (2000: 67-69) the Tigray region featured great floristic complexity, especially in relation to altitude: the primary vegetation of Tigray was dry evergreen montane forest dominated by *Juniperus procera* and *Olea europaea* subsp. *cuspidata* at altitudes above 2,200 meters, mixed *Podocarpus-Juniperus* forest on more humid areas between 1,400-2,200 meters and *Acacia* wooded grassland at altitudes below 2,200 meters. Available pedo-anthracological data confirms the presence of both *Juniperus-Olea* forests and *Acacia* wooded grasslands in the Tigray Plateau from 7,800 years ago until today (Gebru et al. 2009; Terwilliger et al. 2011). How such natural woodland landscape

evolved into the current vegetation patterns has yet to be resolved. Most explanations coincide in the double effect of climate change and human activities (Butzer 1981; Bonnefille and Mohammed 1994; Machado et al. 1998; Bard et al. 2000; Darbyshire et al. 2003; Gebru et al. 2009) though the details about their relative significance remain unknown. Modern botanical surveys (Friis 1992; Friis et al. 2010; Kindt et al. 2011a, b, c; van Breugel et al. 2015) over the past 30 years have added further complexity to the current vegetational landscape of Tigray (Table 1). According to van Breugel et al. (2015), the Northeastern regions of modern Tigray are covered by a combination of predominant undifferentiated (DAF/U) and dry-single dominant (DAF/SD) Afromontane forests, along with significant areas of Afromontane woodlands, wooded grasslands and grasslands (DAF/WG). Friis et al. (2010) notes that Afromontane forests (DAF) can be understood as a gradient from wetter (DAF/U) to drier (DAF/SD and DAF/WG) types. More importantly, DAF/WG represents a degradation type of DAF, sharing an increasing number of taxa with more arid vegetation units from lower altitudes such as *Acacia-Commiphora* woodlands and bushlands proper (ACB), *Acacia* wooded grasslands of the Rift Valley (ACB/RV) or desert and semi-desert scrublands (DSS) (Friis et al. 2010). ACB and ACB/RV are recorded in the lower margins of the Tigrinya Highlands, especially in the eastern escarpment leading to the lowlands of the Afar region, mostly characterized by DSS (Friis et al. 2010; Breugal et al. 2015). The rest of the province is dominated by *Combretum-Terminalia* woodlands and wooded grasslands (CTW) (van Breugel et al. 2015). Finally, small patches of vegetation associated with the Ericaceous (EB) and Afroalpine (AA) belts can be found throughout the entire Tigrinya Highlands at altitudes above 3,000 m.a.s.l. (Friis et al. 2010; van Breugel et al. 2015).

Table 1 Main vegetation units in modern Tigray with their dominant woody genera (adapted from Friis et al. 2010, van Breugel et al. 2015)

Vegetational unit	Altitude (m.a.s.l.)	Main genera	Secondary genera
Undifferentiated Afromontane forests (DAF/U)	1,500 - 2,700	*Juniperus, Podocarpus, Olea, Croton, Ficus*	*Allophylus, Apodytes, Bersama, Carissa, Celtis, Discopodium, Dombeya, Dovyalis, Dracaena, Ekebergia, Erythrina, Hagenia, Halleria, Millettia, Lepidotrichilia, Lobelia, Maytenus, Myrsine, Olinia, Pittosporum, Prunus, Teclea, Vepris*
Dry single-dominant Afromontane forest (DAF/SD)	(1,600 -) 2,200 - 3,200	*Juniperus, Olea*	*Carissa, Calpurnia, Clausena, Clutia, Discopodium, Euclea, Grewia, Hagenia, Maesa, Morella, Psydrax, Teclea, Rhus*
Afromontane woodlands, wooded grasslands and grasslands (DAF/WG)	1,400 - 2,200	*Acacia, Euclea, Dodonaea, Maytenus, Rhus*	*Acanthus, Buddleja, Grewia, Heteromorpha, Myrsine, Nuxia, Osyris, Podocarpus, Protea*
Combretum-Terminalia woodland and wooded grassland (CTW)	400 - 1,900	*Combretum, Terminalia*	*Acacia, Anogeissus, Balanites, Boswellia, Cussonia, Dalbergia, Grewia, Lanea, Lonchocarpus, Piliostigma, Pterocarpus, Vitex*
Acacia-Commiphora woodland and bushland proper (ACB)	400 - 1,900	*Acacia, Commiphora*	*Boswellia, Balanites, Boscia, Cadaba, Combretum, Terminalia*
Acacia wooded grassland of the Rift Valley (ACB/RV)	400 - 1,800	*Acacia*	*Capparis, Carissa, Croton, Dodonaea, Euphorbia, Grewia, Rhus, Scutia, Tarenna*
Desert and semi-desert scrublands (DSS)	0-400	*Acacia, Boswellia, Commiphora, Gyrocarpus, Kissenia, Ochradenus, Diceratella, Cadaba, Ziziphus*	
Ericaceous belt (EB)	> 3,000	*Erica, Hypericum, Myrsine*	
Afroalpine belt (AA)	> 3,000	*Erica, Hypericum*	

Study area

Located 15 kilometers north of Adigrat, the Gulo Makeda region was recognized as a part of the Pre-Aksumite and Aksumite territories long ago (Anfray 1973; Michels 1988; Munro-Hay 1991). Available archaeological evidence indicates that people have occupied Gulo Makeda for at least 3000 years (Harrower and D'Andrea 2014) and several archaeological sites have been described (Rossini 1928; Coulbeaux 1929; Mordini 1941; Caquot and Drewes 1955; Anfray 1966, 1972, 1973, 1974; D'Andrea et al. 2008a; Sernicola 2012; Harrower and D'Andrea 2014). Although numerous, these sites are generally smaller than those in western Tigray (Harrower and D'Andrea 2014).

The Eastern Tigray Archaeological Project (ETAP) is currently carrying out interdisciplinary studies with the aim to better understand how Pre-Aksumite and Aksumite populations interact with the surrounding environment. The present paper explores the cultural and socio-ecological behaviors that underlie the gathering, management and utilization of wood resources as fuel, analyzing charcoal samples from Mezber and Ona Adi. Both sites were inhabited during times of critical cultural developments, and together they provide a unique occasion to question the differences between rural and urban, and domestic and elite status in terms of wood availability and use, but also to investigate human-environmental interactions, and their evolution between the mid-2nd millennium BCE and the late-1st millennium CE.

Mezber

The site of Mezber (Aby Adi, Tabia Addis Alem) covers approximately 0.83 ha and lies on a slightly raised hillside situated in a valley bottom adjacent to an intermittent stream at 2,242 m.a.s.l. (Woldekiros and D'Andrea 2017). Archaeological work has documented an extended occupational sequence dated from 1600 cal. BCE to 1 cal. CE. No other site in the region has recorded such an early occupation with associated Pre-Aksumite cultural materials. Based on ceramics, stratigraphy and radiocarbon dating, four pre-Aksumite horizons with at least two building construction phases have been described. The earliest occupation of the site dates to the Initial phase (c. 1600-900 BCE) and is followed by Early (c. 850–750 BCE), Middle (c. 600–400 BCE) and Late (c. 400 BCE–1 CE) pre-Aksumite phases. The site is one of only a few known Pre-Aksumite sites that have been undisturbed by later settlement. Archaeobotanical, zooarchaeological and isotopic evidence at Mezber document a fully developed agropastoral economy (Woldekiros and D'Andrea 2017; Beldados pers. comm.). The site has produced large-scale domestic architecture, suggesting the presence of wealthy or elite individuals in the Early phase, as well as evidence of specialized hide-working craft production in the Middle phase (Peterson 2017). The site was abandoned at the beginning of the 1st century CE for unknown reasons.

Ona Adi

Ona Adi is located near the villages of Menabeity and Etchmare (Tabia Shewit Lemlem) at 2,452 m.a.s.l. The site is estimated to cover around 10 ha (Harrower and D'Andrea 2014) and was occupied between c. 750 BCE – 700 CE (Taddesse 2019). The ceramic sequence demonstrates that the site was occupied during the Pre-Aksumite to Aksumite (PA-A) transition, documenting 5 occupational phases: Mid/Late Pre-Aksumite (c. 750-400 BCE), PA-A Transition (c. 400 BCE – 1 CE), Early Aksumite (c. 1 – 330 CE), Middle Aksumite (c. 330 – 500 CE) and Late Aksumite (c. 500 – 700 CE) (Taddese 2019: 339). Noteworthy, it is the only systematically investigated site that has a record of occupation during the PA-A Transition, a period of cultural transformation which involved changes in leadership and settlement abandonment in the regional centers of Yeha and Aksum (D'Andrea et al. 2008a). Further analyses of lithics, animal bone, phytoliths and radiocarbon dating are currently ongoing.

Materials and methods

Sampling

Bulk soils samples were recovered between 2007 and 2015 at both sites, following a systematic sampling strategy. They were then floated using a recirculating bucket flotation system. Screens of both 1 mm and 0.25 mm mesh size were used in order to separate heavy and light fractions, which were subsequently air

dried. Charcoal remains were sorted from the light fraction samples using a stereo microscope Leica EZ4 (7x-30x). Anthracological samples for analysis were selected according to stratigraphical criteria in order to represent the complete chrono-cultural sequence of both sites. They were all recovered from non-specialized long-term deposits to get a reliable environmental signature. A total of 25 samples from 9 different archaeological phases were weighted and separated for analysis (Table 2).

Table 2 Mezber (MBR) and Ona Adi (OA) charcoal samples by phase

Site	Phase	Field:Locus	Pail	Archaeological context	Sample number	Flotation volume (L)	Charcoal remains (g)	Analyzed fragments
MBR	Initial Pre-Aksumite	A1:54	108	Living surface	1126	0.2	0.28	232
		A1:54	109	Living surface	1337	5	1.55	
		A1:55	110	Living surface	1345	3.25	0.61	
	Early Pre-Aksumite	A1:61	114	Midden	1585	9	7.88	315
		A1:67	146	Infill	1908	10	6.86	
		A1:74	156	Infill	2106	10	5.40	
	Middle Pre-Aksumite	A1:72	154	Infill	2096	8	2.87	310
		A1:73	155	Living surface	2102	7.25	3.59	
		A1:73	155	Living surface	2110	4	7.55	
	Late Pre-Aksumite	A1:10	42	Infill	18	0.3	0.58	306
		A1:10	45	Infill	20	0.55	8.06	
OA	Late Pre-Aksumite	D1:13	23	Infill	1127	5	0.55	305
		D1:13	26	Infill	1139	7	0.89	
		D1:16	30	Infill	1163	4.5	7.35	
	PA-A Transition	D1:13	22	Living surface	769	6	4.26	310
		D1:14	24	Infill	1131	4	8.05	
		D1:15	29	Infill	1157	2.5	3.04	
	Early Aksumite	D1:10	18	Infill	1106	4	5.19	319
		D1:10	19	Infill	1110	6	24.95	
		D1:10	20	Infill	1118	5	3.26	
	Middle Aksumite	D1:7	13	Infill	811	7	2.56	305
		D1:9	14	Infill	818	4	5.50	
		D1:10	17	Infill	843	4	5.85	
	Late Aksumite	D1:3	5	Living surface	711	7	8.18	306
		D1:6	7	Infill	722	8	9.70	

Identification, reference collection and data analysis

Microscopic identification of charcoal fragments was routinely carried out at the archaeobotanical laboratories of the National Museum of Natural History, Paris (MNHN), and Pompeu Fàbra University, Barcelona (UPF), using a reflected light microscope with incident light and magnifications between 50x and 1000x. Botanical taxa were described following the codes proposed in the International Association of Wood Anatomists (IAWA) list of microscopic features for both hardwood (Wheeler et al. 1989) and softwood (Richter et al. 2004) identification. Taphonomic features such as charcoal size (<5 mm/5-10 mm/<10 mm), and the presence of natural (wood compression, tree ring alteration), biological (collapsed cells, xylophage activity, fungi alterations), combustion (radial cracks, vitrification), and diagenetic (post-depositional alterations, cell structure deformation) alterations (Fig. 2) were recorded as proposed by Allue et al. (2009).

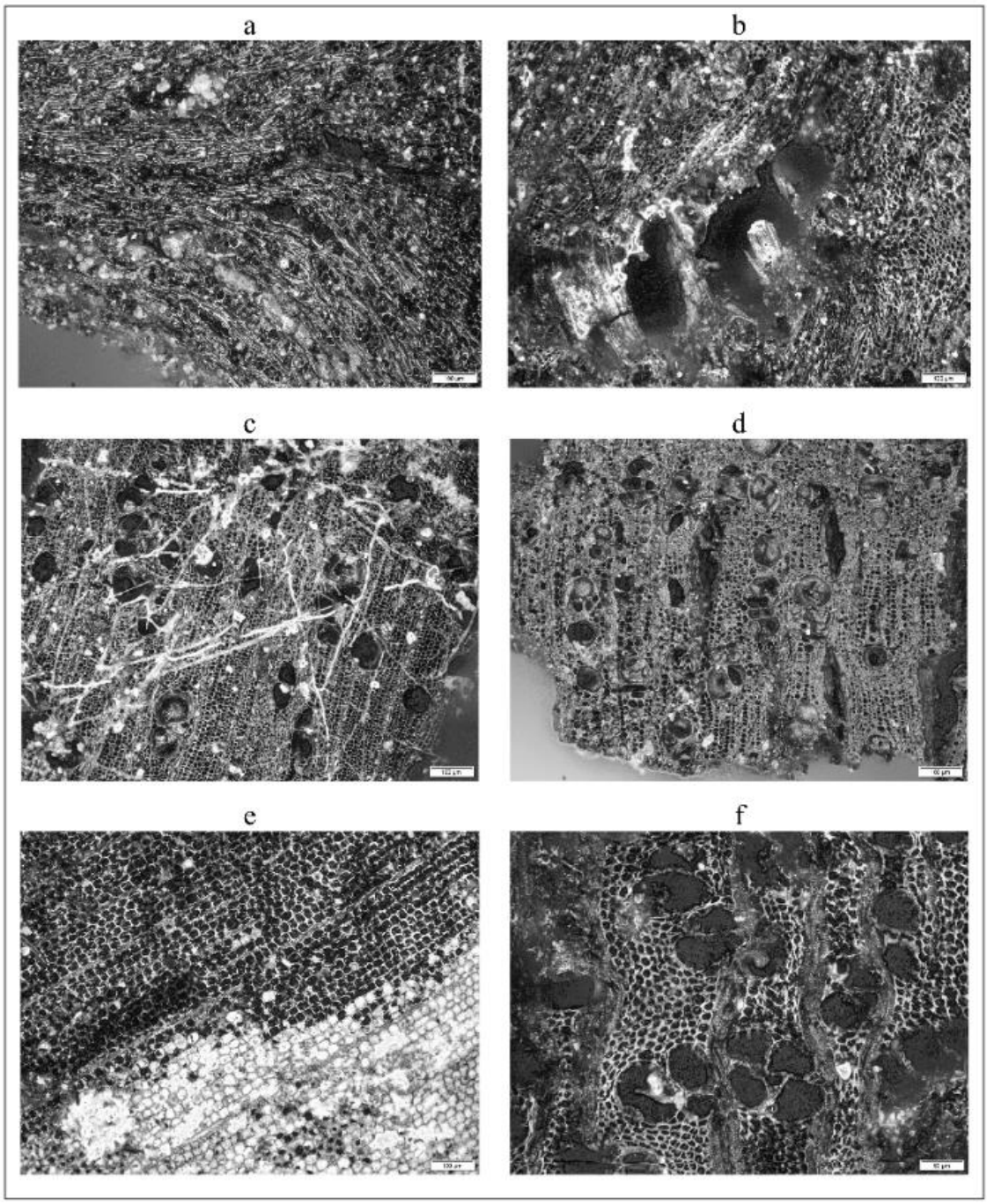

Fig. 2 Microscopic photos showing examples of different alterations observed on Mezber and Ona Adi charcoal assemblages: a) Wood compression, b) Cell collapse due to xylophage activity, c) Fungi hyphae infestation, d) Radial cracks and vitrification, e) Post-depositional alteration, f) Cell-structure deformation

Taxonomic identification was achieved following the methodology proposed by Höhn and Neumann (2018) for charcoal identification in species-rich environments and comparing with modern reference material produced specifically for this study with samples obtained from the wood collections of the MNHN in Paris, and charcoal reference collection of the AASPE unit (UMR 7209, CNRS-MNHN). Plant taxa for this reference material were selected according to their importance amongst the vegetation units published by Friis et al. (2010) and their availability in the collections. The unburned wood samples were prepared for microscopic observation at the MNHN, following an adaptation of the procedure described by Orvis et al. (2005). Anatomical descriptions and images of all reference materials are available at the UPF e-Repository (https://repositori.upf.edu/handle/10230/43106). Online databases (InsideWood 2004-onwards) and

published atlases were used to help and refine the identifications (e.g. Fasolo et al. 1939; Metcalfe and Chalk 1950a, b; Neumann et al. 2001; but see references in Supplementary Materials 1).

Data analysis was performed using relative frequencies of number of remains by charcoal type but also according to the vegetational units proposed by Friis et al. (2010), associating each taxa to the ecological groups in which they are common or predominant (Table 3) following previous research (Friis et al. 2010; Kindt et al. 2011a, b, c; van Breugel et al. 2015). The main vegetational units present in modern Northeastern Tigray were included (van Breugel et al. 2015). The frequencies of the vegetational units were calculated by summing the frequencies of the taxa associated with them. Undeterminable fragments were excluded from the data analysis. Various indexes and ratios were employed in order to assess taphonomic processes –Fragmentation/Preservation index (Lancelotti 2010), Density index (Asouti 2003)– as well as assemblage biodiversity and taxa distribution –Simpson's Diversity Index (Branch et al. 2005), Pielou's evenness index (Pielou 1966), and the Ubiquity rate (Miller 1988; Popper 1988) (see Supplementary Materials 2 for further explanations). In order to evaluate assemblage representativeness of the original deposits, we used effort curves, both qualitative and quantitative (Chabal et al. 1999; Asouti and Austin 2005). The Gini-Lorenz Index (Scheel-Ybert 2005; Dotte-Sarout et al. 2015) was applied to measure the ecological representativity of the assemblage. Statistical analyses were performed using PAST (Hammer et al. 2001), whereas graphic representations of the results were constructed using Microsoft Excel (2013) and Tilia (Grimm 1992) software.

Results

Taphonomy

Taphonomical alterations are presented in Fig. 3. No phase overcomes 60% of taphonomically affected charcoal fragments and accumulated means by site for Mezber and Ona Adi are 38% and 48% respectively. Alteration ratios are rather similar throughout the sequence of both sites. The most common alterations are associated with combustion (X=27%) and diagenetic processes (X=18%), whereas natural and biological agents show very low impact degrees in all phases (<4%). Despite such a degree of alteration, the Fragmentation/Preservation index (F/P) remains low (X=10%), meaning the general state of preservation allowed proposed taxonomic identifications for 90% of the charcoal fragments. Density, Simpson's diversity and Pielou's evenness indexes were calculated and compared against the taphonomical data by phase and type of context. The results show no correlation, indicating that taphonomy did not severely impact charcoal density nor plant biodiversity hence suggesting the studied assemblage was well preserved. Raw data is available electronically as supplementary material (Supplementary Materials 3).

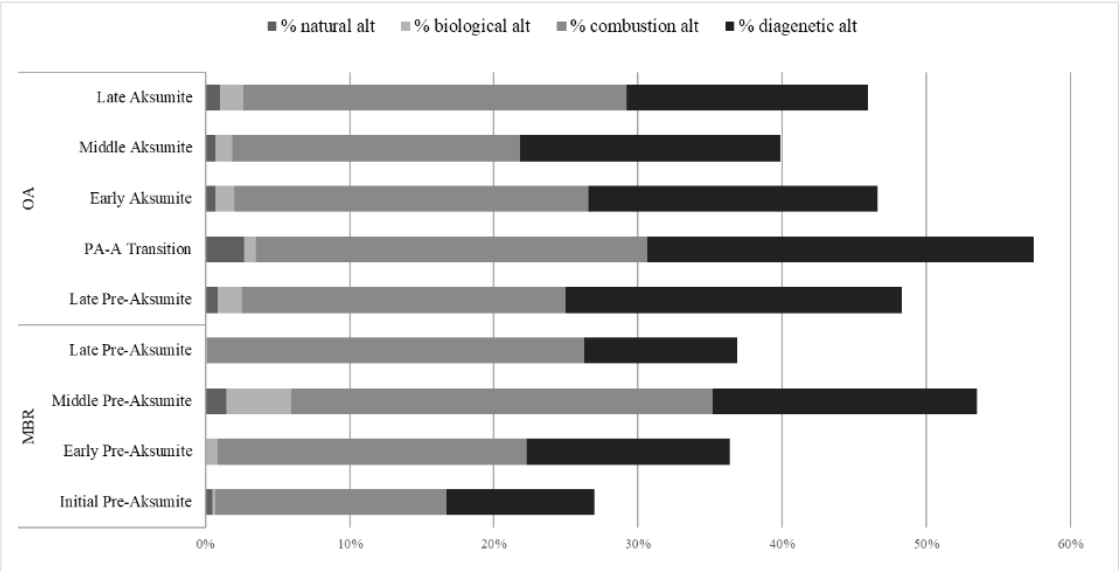

Fig. 3 Summary of taphonomical alterations by phase (including all analyzed fragments)

Quantitative and taxonomic curves (Supplementary Materials 4) from all phases are recognized as saturation curves, showing a clear stabilization tendency after 200 fragments analyzed hence indicating that species frequencies by phase are a fair representation of the originally deposited assemblage and that every significant taxon is represented. Finally, Gini-Lorenz index results (Supplementary Materials 4) vary between 30:70 and 23:77, with a rounded media of 26:74 for Mezber and 29:71 for Ona Adi. As such, both assemblages can be considered as representative of the past vegetation and no taxa appears to be significantly overrepresented.

Taxonomic results

A total of 2,708 charcoal fragments were studied, of which 2,428 were identified at different taxonomic levels. Raw data is available electronically as supplementary material (Supplementary Materials 5). 23 different plant types were documented, both angiosperms (21) and gymnosperms (2). Taxonomic identifications were proposed for all types except 3 angiosperms which remain unidentified. We found 4 distinct *Acacia* types, although their identification to species level was not possible and therefore, they were grouped and listed as *Acacia* spp. Detailed anatomic descriptions and images of the 17 identified charcoal types, as well as a discussion of each taxonomic classification can be found as supplementary materials (Supplementary Materials 1). Tables 3 and 4 synthesize both ecological distribution and wood features of the identified taxa.

Table 3 Summary of the identified taxa ecological distribution after Friis et al. (2010), Kindt et al. (2011a, b, c) and van Breugel et al. (2015): 0 = absent or not recorded; * = present, but minoritary, ** = common, *** = predominant; Grey = included in analysis as a part of the vegetational unit.

Identified taxa	Altitude (m.a.s.l.)	DAF/U	DAF/SD	DAF/WG
Acacia spp.	0 - 3,100	0	0	***
Carissa spp.	550 - 2,500	*	***	*
cf. *Boscia* spp.	50 - 1,900	0	0	**
Croton spp.	500 - 2,350	**	0	***
Dodonaea angustifolia	500 - 2,900	*	**	***
Hagenia abyssinica	2,450 - 3,250	**	**	*
Juniperus procera	1,100 - 3,500	***	***	0
Maerua spp.	0 - 2,100	0	0	**
Maytenus spp.	380 - 3,500	**	*	***
Nuxia spp.	800 - 3,800	*	**	**
Olea spp.	1,250 - 3,200	***	***	*
Pittosporum spp.	1,400 - 3,200	**	*	*
Podocarpus falcatus	1,350 - 2,900	***	0	0
Rhamnus spp.	1,175 - 3,200	**	***	*
Rhus spp.	700 - 2,800	0	*	***
Rubiaceae cf. Ixoroideae	400 - 3,000	**	**	**
Ziziphus spp.	0 - 2,400	0	0	**

Table 4 Summary of the identified taxa wood features and uses (von Maydell 1990; Ruffo et al. 2002; Bekele-Tesemma 2007; Louppe et al. 2008; Gebreselassie et al. 2014)

Identified taxa	Hardness	Quality as fuel	Resistance to pests	Durability	Other uses than fuel
Acacia spp.	Hard	Good	Variable	Durable	Instruments
Carissa spp.	Hard	Good	Medium	Durable	Instruments
cf. *Boscia* spp.	Hard	Good	High	Durable	Instruments
Croton spp.	Soft	Good	Low	Perishable	Construction, instruments
Dodonaea angustifolia	Hard	Good	High	Durable	Instruments
Hagenia abyssinica	Soft	Good	Low	Perishable	Construction, instruments
Juniperus procera	Medium	Good	High	Durable	Construction
Maerua spp.	Hard	Good	Variable	Durable	Instruments
Maytenus spp.	Hard	Good	Variable	Durable	Construction
Nuxia spp.	Hard	Good	Variable	Durable	Construction
Olea spp.	Hard	Good	High	Durable	Construction, instruments
Pittosporum spp.	Soft	Bad	Low	Perishable	Instruments
Podocarpus falcatus	Soft	Good	Low	Durable	Construction
Rhamnus spp.	Hard	Good	Variable	Durable	Instruments
Rhus spp.	Soft	Good	Low	Perishable	Construction, instruments
Rubiaceae cf. Ixoroideae	Variable	Variable	Variable	Variable	Variable
Ziziphus spp.	Hard	Good	High	Durable	Construction, instruments

Descriptive and quantitative results of Mezber.

A total of 19 taxa - 3 of which remain unidentified - were recorded amongst the 1,163 charcoal fragments analyzed from Mezber samples. Angiosperms account for 98% of the total assemblage, which is dominated by the Afromontane woodlands, wooded grasslands and grasslands (DAF/WG) genus *Rhus* spp. (27%) and the undifferentiated (DAF/U) and dry-single dominant (DAF/SD) Afromontane forests genus *Olea* spp. (24%). Despite the plant diversity and the *Rhus*-*Olea* predominance, the assemblage shows a rather high species evenness: 79% of the taxa range between 1 and 7% of the identified charcoal fragments. Indeed, results by phase reveal a rather stable degree of biodiversity, as 13 taxa have been found to be present at all phases. Still, diachronic variation is evident in plant distribution (Fig. 4).

The Initial pre-Aksumite phase features a weaker dominance of *Rhus*-*Olea* than the site average. *Olea* and *Rhus* spp. are accompanied by the DAF/WG genus *Acacia* spp. and the DAF/SD genus *Carissa* spp. Unlike the following occupations of Mezber, during this phase the exploitation of wood appears undifferentiated, with all vegetational groups exploited similarly and a more even distribution of species (see Figure 4). The subsequent Early Pre-Aksumite phase indicates a higher rate of DAF/U and DAF/SD exploitation, whereas DAF/WG percentage is reduced. This occupation' assemblage is widely dominated by *Olea* spp., accompanied by *Rhus* spp., *Dodonaea angustifolia* and *Croton* spp. The DAF/U and DAF/SD gymnosperm species *Juniperus procera* and DAF/U *Podocarpus falcatus* both score under 3% - despite their potential dominance in the DAF/U and DAF/SD vegetational units, both taxa reach their highest values of the site sequence in this phase. This situation changes during the Middle Pre-Aksumite phase, when *Olea* spp. presents its lowest occurrence values in favor of *Rhus* sp. During this phase, DAF/U and DAF/WG are significantly reduced, whereas DAF/WG significantly rises: its presence is well attested by lower-storey taxa such as cf. *Boscia* sp. and *Dodonaea angustifolia*, even though the DAF/WG emblematic taxon, *Acacia* spp., scores under 1%. Lastly, the Late Pre-Aksumite phase at Mezber shows a relative recovery of the *Olea* spp. exploitation versus *Rhus* spp., while the rest of the taxa remains relatively stable. As a result, DAF/U and DAF/SD feature a meaningful increase though DAF/WG maintains its predominance.

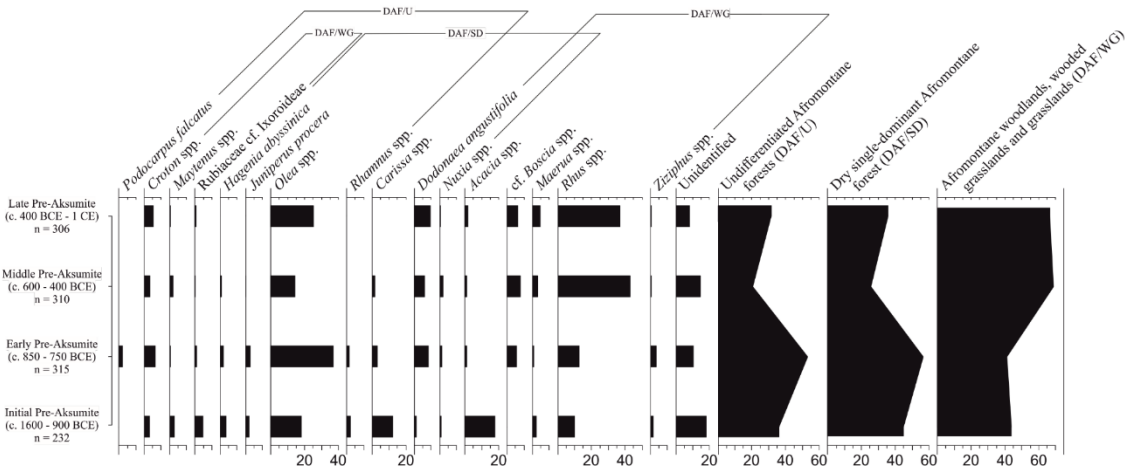

Fig. 4 Anthracological diagram of Mezber by chronocultural phase

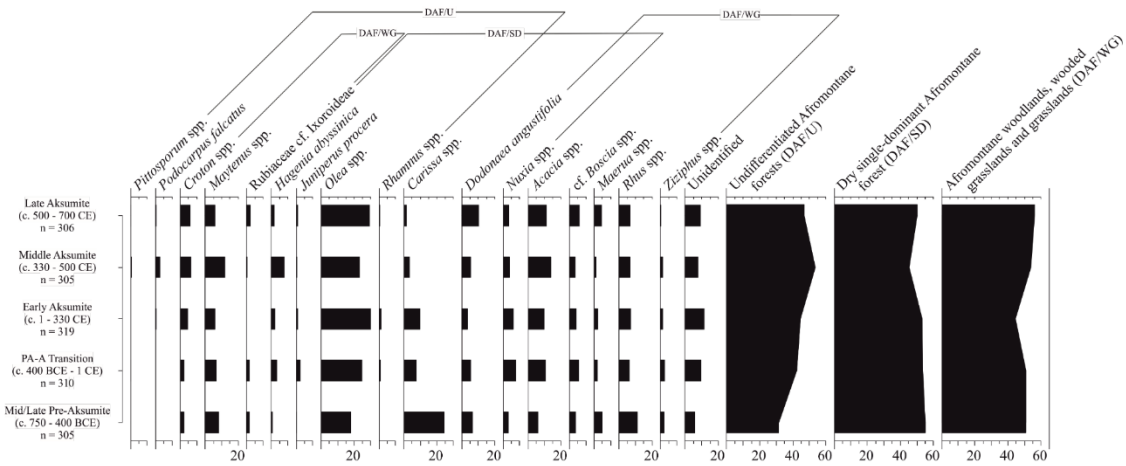

Fig. 5 Anthracological diagram of Ona Adi by chronocultural phase

Descriptive and quantitative results of Ona Adi.

As for Ona Adi, 1,545 charcoal fragments were studied and a total of 20 plant types were identified, including 3 unidentified angiosperms. Angiosperms account for 98% of the total assemblage. The assemblage is dominated by DAF/U and DAF/SD genus *Olea* spp. (25%) along with the DAF/WG genus *Acacia* spp. (10%), and the DAF/SD genus *Carissa* spp. (9%). Ona Adi assemblage features high biodiversity in all phases: 80% of the taxa are present in all phases. Fig. 5 presents taxa distribution and its variation throughout occupational phases.

Late Pre-Aksumite samples are dominated by *Carissa* spp. followed by *Olea* and *Rhus* spp. This phase features the lowest occurrence of the main DAF/WG genus *Acacia* spp. During the Pre-Aksumite to Aksumite Transition phase, the assemblage primarily features *Olea* and *Acacia* spp. The main secondary taxa are from the DAF/WG vegetational unit namely *Rhus* and cf. *Boscia* spp., as well as *Dodonaea angustifolia*, *Nuxia* spp. (both also present in DAF/SD), and *Maytenus* spp. (also in DAF/U) showing values between 5 and 8%. The DAF/U and DAF/SD gymnosperm *Juniperus procera* scores 3%. During this phase, there is a rather even distribution between the three vegetational units that will continue during the Early Aksumite phase, with mild differences on the most common taxa: whereas *Olea* spp. and *Carissa* spp. slightly increase during this phase, the presence of *Acacia* spp., as well as other secondary taxa from the DAF/WG (e.g. cf. *Boscia*, *Ziziphus* spp.) is similarly reduced. This continuity extends to the Middle

Aksumite occupation even though some differences are recorded as *Olea* spp. dominance decreases in favor of *Acacia* spp. At the same time, however, other DAF/U and DAF/SD taxa such as *Hagenia abyssinica* and *Podocarpus falcatus*, as well as the DAF/U and DAF/WG *Maytenus* and *Croton* spp. respectively feature their highest occurrence. Some of the secondary species exclusively associated with the DAF/WG formations (e.g. cf. *Boscia, Maerua* spp.) score their lowest values. Finally, even though the Late Aksumite phase witnesses a relative recovery of the *Olea* spp., the overall distribution of the vegetational units maintained its stability: the small decrease of *Acacia* spp. is balanced by relatively higher scores of the secondary taxa from the DAF/WG unit (e.g. cf. *Boscia, Maerua* spp.), while the secondary species of DAF/U and DAF/SD (e.g. *Hagenia abyssinica*, *Podocarpus falcatus*) appear slightly reduced.

Discussion

Landscapes and woodland vegetation

Despite the well-known problems with paleoenvironmental interpretations derived from anthropic anthracological assemblages (see Chabal et al. 1999; Asouti and Austin 2005; Dotte-Sarout et al. 2015), the general homogeneity of plant taxa distribution through the archaeological sequence of both Mezber and Ona Adi suggests that no major climate changes took place in Northeastern Tigray during the Pre-Aksumite and Aksumite periods, in accordance with pedo-anthracological and isotope geochemical analyses developed in the region (Gebru et al. 2009; Terwilliger et al. 2011). The anthracological data from Mezber and Ona Adi show that people were exploiting taxa originating from at least three separate vegetation units –both Undifferentiated (DAF/U) and dry single-dominant (DAF/SD) Afromontane forests, as well as Afromontane woodlands, wooded grasslands and grasslands (DAF/WG)– throughout the entire sequence of occupation at both sites. This is consistent with the current vegetational landscape as described by van Breugel et al. (2015), and it is also in accordance with present vegetation distribution by altitude: Friis et al. (2010) records the presence of DAF/U, DAF/SD and DAF/WG between 1,400 and 3,200 m.a.s.l., concurring with the locations of both Mezber (2,242 m.a.s.l.) and Ona Adi (2,452 m.a.s.l.).

Previous palynological studies in more southern areas of the northern Ethiopian Highlands have suggested a significant decline of Afromontane forests (DAF/U and DAF/SD) between 800 and 500 BCE in the Tigray province, and their almost complete substitution by afromontane wooded grasslands (DAF/WG) by the 2nd millennium CE. (Bard et al. 2000; Darbyshire et al. 2003). According to these studies, this deforestation process was the combined result of drier environmental conditions and anthropic activity (Bard et al. 2000; Darbyshire et al. 2003). However, the present study indicates that even if the use of wood from taxa associated with the DAF/U and DAF/WG units declined after the Early Pre-Aksumite phase (c. 750 BCE), they continued to be consistently exploited after 400 BCE at both Mezber and Ona Adi sites. On the one hand, this supports the argument of anthropogenic deforestation - as DAF/WG represent a degraded type of Afromontane vegetation, mainly through human impact (Friis et al. 2010). On the other hand, it indicates that such inflection was not as widespread in space and time as previously suggested by the palynological record (Bard et al. 2000; Darbyshire et al. 2003). This discrepancy could be attributed to intra-regional heterogeneous environmental conditions, similar to what has been described for modern Tigray (Hagos et al. 2002), where a wide array of microclimates within very short distances are recorded. In this sense, changes at regional-scale level might have affected the studied area differently than other areas, hence explaining contradictions with the palaeoecological studies from southernmost regions (e.g. Bard et al. 2000; Darbyshire et al. 2003; Sulas et al. 2009).

The rapid reestablishment of the exploitation of Afromontane forests species after the Late Pre-Aksumite phase overlaps with a shift to a relatively wetter climate and landscape stabilization documented at c. 450 BCE by several authors (Machado et al. 1998; Ciampalini et al. 2008; French et al. 2009). The use as fuel of species associated with the DAG/WG formation such as *Acacia* spp. increases by 10% from the PA-A Transition (400 BCE - 1 CE) onwards at Ona Adi. This could be associated with the aforementioned expansion of DAF/WG. Recent studies have shown no evidence of general changes in climate and suggested that land-clearing practices played a more meaningful role in shaping the surrounding landscape (Terwilliger et al. 2011). The results presented in this study support the hypothesis that such increase is the product of anthropic selection and may not be related to environmental shifts. A comparable situation can

be observed between c. 500-800 CE, when a period of environmental degradation has been documented (Marshall et al. 2009; French et al. 2014). During these centuries, Middle and Late Aksumite phases at Ona Adi show continuity in woodland exploitation as no significant changes are identified. This indicates that the abandonment of Ona Adi after c. 700 CE - which coincides in time with the disappearance of the Aksumite Kingdom - was not related to an extreme anthropogenic deforestation process resulted from intense land-clearing activities.

Firewood selection and management strategies at Mezber and Ona Adi.

The anthracological data from both Mezber and Ona Adi show that a high variety of woody species was exploited. 23 plant types have been identified in the anthracological record, associated with at least 3 vegetational types. The exploited taxa mostly featured hard and durable wood, performing well as fuel. Notable exceptions, characterized by soft and easily perishable wood, include *Rhus* spp., *Hagenia abyssinica* and *Croton* spp. (von Maydell 1990; Ruffo et al. 2002; Bekele-Tesemma 2007; Louppe et al. 2008). Preferences and selection criteria are evident in both assemblages: favored species include *Rhus* and *Olea* spp. at Mezber, representing more than half of the assemblage whereas at Ona Adi the most common taxa are *Olea*, *Acacia*, and *Carissa* spp., composing almost half of the total analyzed charcoal fragments. The presence in the record of lower quality firewood can be related to the accidental or deliberate burning of woody construction elements and instruments at the end of their life cycles. For example, *Pittosporum* spp. is known to be employed in basketry production. The use of taxa featuring bad-smelling wood at firing, such as *Dodonaea angustifolia* or *Hagenia abyssinica* (Liu and Noshiro 2003; Gebreselassie et al. 2014) could be associated with a similar phenomenon, since the wood of both species is known to be suitable for construction and instrument manufacture (Ruffo et al. 2002). Finally, Afromontane forest gymnosperms such as *Juniperus procera* or *Podocarpus falcatus* were rarely exploited, although their presence in the studied region is well attested by pedo-anthracological analyses, constituting up to 50% of the past woodland vegetation during Pre-Aksumite and Aksumite times (see Gebru et al. 2009: 76). While the latter does not perform well as fuel and it is not a durable wood, the former features a high-quality firewood (Chudnoff 2007). They both produce high quantities of dead biomass and are thornless. The virtual absence of *Juniperus procera* could be explained by both functionalist or symbolic reasons: even though a cultural taboo is possible –as it has been documented amongst the Konzo of southwestern Ethiopia (Amborn 2002)– we argue that its low occurrence was probably due to the fact that these species grow in closed forest. By examining the anthracological records from Mezber and Ona Adi it would seem that both Pre-Aksumite and Aksumite people did not enter closed forests to recover wood, but they rather gathered firewood from open forests and forest margins instead, as they were more accessible.

Despite the high degree of homogeneity in both assemblages, we argue that selection strategies may have changed through time based on the distinctive characteristics of the wood used. First, during the Initial Pre-Aksumite phase at Mezber, a generalist approach is observed: main and secondary taxa from all vegetation types are used in similar proportions. According to Asouti and Austin (2005), this type of strategy is characteristic of mobile hunter-gatherers and nomadic pastoralists. The presence of nomadic and semi-nomadic cattle herders in Eastern Tigray since at least the 2nd millennium BCE is attested by the rock art (see Fattovich 2019: 254-255). The Initial Pre-Aksumite phase at Mezber thus represents one of the oldest Pre-Aksumite occupations of the Ethiopian highlands (c. 1600-900 BCE), which origin has been linked to previous seasonal movements of pastoral communities from the Sudanese lowlands, as suggested by their ceramicware and lithic equipment, both associated with an agro-pastoral economy (see Fattovich 2012; Phillipson 2017).

The Early Pre-Aksumite phase shows signs of selection criteria and specialization. From this phase onwards, Afromontane forests (DAF/U and DAF/SD) taxa, and especially *Olea* spp., were preferred over other taxa at Mezber: availability, caliber and state of the firewood were surely crucial factors, but its high quality as fuel, along with its hardness, durability and resistance to pests cannot be overlooked (Bekele-Tesemma 2007; Gebreslassie et al. 2014). As very few Pre-Aksumite settlements have shown an occupation as ancient as Mezber, the importance of the presence of specific desirable resources such as high-performance firewood could have played a vital role in the prolonged occupation of the site. However, the overexploitation of *Olea* spp. - along with the mentioned period of forest degradation between 800 and 500

BCE (Darbyshire et al. 2003) - would have rendered *Olea* spp. wood less easily accessible, hence forcing a change in the main source of firewood. As so, the Middle and Late Pre-Aksumite phases at Mezber witnessed the substitution of *Olea* for *Rhus* spp. as the principal focus of wood exploitation. During these phases, *Rhus* spp. exploitation was as predominant as *Olea* spp. was during the previous phases, hence indicating that there was not a change in the firewood selection strategy, but merely the election of a newly preferred taxon based on its availability and performance as fuel. The choice of *Rhus* spp. as the *Olea* substitute can be understood if we consider that both species share a similar ecological niche in their respective vegetational units - occurring in well-drained soils with good access to sunlight (Ruffo et al. 2002; Bekele-Tessema 2007) - hence after DAF/U and DAF/SD degraded into DAF/WG, *Olea* spp. would have retreated in favor of *Rhus* spp. Despite the presence of a new focused taxon, *Olea* spp. was still collected and used as firewood during Middle and Late Pre-Aksumite times, indicating how valued its wood was.

A different situation can be observed at Ona Adi during the Late Pre-Aksumite phase, when the exploitation of *Olea* spp. seems to have been complemented mainly with *Carissa* spp. –a DAF/SD genus which also grows in well drained soils requiring sunlight access. The wood selection pattern at Ona Adi remained fairly steady throughout the entire occupation of this Aksumite site, featuring a more generalized wood selection strategy than the community at Mezber. Although the recovery of the DAF/U and DAF/SD units re-established *Olea* spp. hegemony as the preferred taxon, the exploitation of DAF/WG taxa such as *Acacia* spp. remained fairly constant –even increasing through time in detriment to *Carissa* spp. We argue that this trend is associated with the introduction of new selection criteria. These taxa provide not only excellent firewood, but also are highly resistant to pest attack (von Maydell 1990; Ruffo et al. 2002). This would have been fundamental for an urban site such as Ona Adi, where most of the inhabitants –and especially the elites– were unlikely to gather firewood themselves. Instead, they would have acquired and stored it, as suggested by the presence of fungi infested wood in the Ona Adi charcoal assemblage –absent at Mezber. The recorded taxa at Ona Adi are mainly local, so the acquired wood was not from external tradesmen as suggested by Phillipson (2012). Another possible explanation is related to the introduction of industrial production activities at Ona Adi by its Aksumite inhabitants (see Phillipson 2012 for a review of industrial production during Aksumite times). The wood requirements of a manufacturing community such as Ona Adi are different from those of rural settlements such as Mezber, and differences in wood selection can also be produced by the quality for charcoal production - e.g. *Acacia* spp. is commonly preferred for charcoal production in modern Ethiopia (Bahru et al. 2012; Bekele and Girmay 2014). High quantities of fuel are needed to carry out industrial activities such as pottery or metal production, for which storage suitability is again a crucial factor. Since all analyzed samples were retrieved from generalized contexts, and no differences by type of contexts have been documented, this question remains unsolved.

Conclusion

The anthracological study performed on Mezber and Ona Adi charcoal assemblages has revealed insights into the past socio-ecological systems and human-woodland relationships in northeastern Tigray during Pre-Aksumite and Aksumite times. The analyses have recorded the presence of plant taxa related to undifferentiated (DAF/U) and dry-single dominant (DAF/SD) Afromontane forests as well as Afromontane woodlands, wooded grasslands and grasslands (DAF/WG) at both Mezber and Ona Adi. Furthermore, our results show coherence and consistency at both intra- and inter-site levels. This continuity of plant diversity points to rather stable environmental conditions at a local level, with no major climatic or environmental changes. Our data also shows an important process of anthropogenic deforestation during the early-to-mid 1st millennium BCE. However, this process of landscape degradation does not appear to be as dramatic as previously suggested by the palynological record. As so, we suggest that the current mosaic of microclimates and short distance environmental variation was in existence during the mid-2nd BCE to late-1st millennium CE. Further palaeoecological analyses are needed, in order to build a data corpus that allows palaeoenvironmental reconstruction at both local and regional levels.

Our results also suggest that both Mezber and Ona Adi populations exploited most of the surrounding habitats as a wide variety of woody plants were used as fuel. There are, however, some points to be emphasized. On the one hand, the ecological features of the identified taxa suggest that wood collection

was mostly carried out in open forests and forests margins. On the other hand, the economical features of the wood exploited point to the existence of selection criteria employed at both sites. In this sense, at least 3 different approaches to the use of firewood resources, as well as a diachronic evolution through time, were identified: a generalist strategy; a burning quality-oriented selection criterion; and a storage-oriented strategy. The differences between strategies seem to respond to a functionalistic cause, mainly related to the type of occupation by ancient settlers at Mezber and Ona Adi. The generalist approach has been identified at the earliest occupation of Mezber, the Initial Pre-Aksumite phase. We argue that this first occupation could have been started by a small group of people featuring low intensity agro-pastoral activities. The burning-quality oriented strategy developed at Mezber from the Early Pre-Aksumite phase onwards would be consistent with an established self-sufficient non-elite rural community. Finally, an elite urban center such as Ona Adi would have employed diverse selection criteria in order to be able to secure the proper storage of the wood resources and perhaps support industrial activities. At any rate, new anthracological analyses of specialized contexts related to both domestic and industrial activities are needed in order to further test these hypotheses. Nonetheless, we reckon that wood exploitation strategies were an important aspect of both Pre-Aksumite and Aksumite cultures and that they evolved accordingly to both human necessities and woodland availability, hence playing a significant role in the development of ancient complex societies in the northeastern Ethiopian highlands.

References

Allue E, Euba I, Sole A (2009) Charcoal taphonomy: the study of the cell structure and surface deformation of Pinus sylvestris type for the understanding of formation processes of archaeological charcoal assemblages. J Taphon 7:57-72

Amborn H (2002) Concepts in wood and stone—socio-religious monuments of the Konso of Southern Ethiopia. Z Ethnol 127:77-101.

Anfray F (1966) La poterie de Matara. Rass Stud Etiop 22:5-74.

Anfray F (1972) L'archéologie d'Axoum en 1972. Paideuma 18:60–78.

Anfray F (1973) Nouveaux sites antiques. J Ethiop Stud 11:13-27.

Anfray F (1974) Deux villes axoumites: Adoulis et Matara. In: IV Congresso Internazionale di Studi Etiopici. Accademia Nazionale dei Lincei, Rome, pp. 745–765.

Anfray F (2012) Matara: the archaeological investigation of a city of ancient Eritrea. Palethnologie 4:11–48

Araya A, Keesstra SD, Stroosnijder L (2010) A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. Agric Forest Meteorol 151:1047–1064.

Asouti E (2003) Woodland vegetation and fuel exploitation at the prehistoric campsite of Pinarbas I, south-central Anatolia, Turkey: the evidence from the wood charcoal macro-remains. J Archaeol Sci 30:1185-1201.

Asouti E, Austin P (2005) Reconstructing woodland vegetation and its exploitation by past societies, based on the analysis and interpretation of archaeological wood charcoal macro-remains. Environ Archaeol 10:1–18. https://doi.org/10.1179/146141005790083867.

Bahru T, Asfaw Z, Demissew S (2012) Indigenous knowledge on fuel wood (charcoal and/or firewood) plant species used by the local people in and around the semi-arid Awash National Park, Ethiopia. J Ecol Nat Environ 4:141–149. https://doi.org/10.5897/JENE11.105

Bard KA, Coltorti M, DiBlasi MC, et al (2000) The environmental history of Tigray (northern Ethiopia) in the middle and late Holocene: a preliminary outline. Afr Archaeol Rev 17:65–86. https://doi.org/10.1023/A:1006630609041

Bard KA, Fattovich R, Manzo A, Perlingieri C (2014) The chronology of Aksum (Tigrai, Ethiopia): a view from Beta Giyorgis. Azania Archaeol Res Africa 49:285–316. https://doi.org/10.1080/0067270X.2014.943484

Bekele M, Girmay Z (2014) Reading through the charcoal industry in Ethiopia: production, marketing, consumption and impact. Forum for Social Studies, Addis Ababa

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

Boardman SJ (1999) The agricultural foundation of the Aksumite empire, Ethiopia. In: van der Veen M (ed) Plants and people in Africa: recent archaeobotanical evidence. Plenum Publishing, New York, pp 137–147

Boardman SJ (2000) Archaeobotany. In: Phillipson DW (ed) Archaeology at Aksum, Ethiopia, 1993-1997. The British Institute in Eastern Africa and The Society of Antiquaries London, London, pp 363-470

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

Branch N, Clark P, Canti M, et al (2005) Environmental archaeology: theoretical and practical approaches. Hodder Arnold, London.

Butzer KW (1981) Rise and fall of Axum, Ethiopia: a geo-archaeological interpretation. Am Antiq 46:471-495.

Cain CR (2000) Animals at Axum: initial zooarchaeological research in the later Prehistory of the northern Ethiopian highlands. Dissertation, Washington University.

Caquot A, Drewes AJ (1955) Les monuments recueillis à Maqalle (Tigrei). Ann Ethiop 1:18-26.

Chabal L, Fabre L, Terral JF, et al (1999) L'anthracologie. In Ferdière A (ed.) La Botanique. Eds. Errance, Paris, pp. 43-104.

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

Ciampalini R, Billi P, Ferrari G, et al (2008) Plough marks as a tool to assess soil erosion rates: A case study in Axum (Ethiopia). Catena 75:18-27

Coulbeaux JB (1929) Histoire d'Abyssinie. Paul Geuthner, Paris.

D'Andrea AC (2003) Social and technological aspects of non-mechanised emmer processing. In: Anderson PC, Cummings LS, Schippers TS, et al (eds) Le Traitement des récoltes: un regard sur la diversité, du néolithique au présent. Éditions APDCA, Antibes, pp. 47-60

D'Andrea AC (2008) T'ef (Eragrostis tef) in ancient agricultural systems of highland Ethiopia. Econ Bot 62: 547-566.

D'Andrea AC, Lyons D, Haile M, et al (1999) Ethnoarchaeological approaches to the study of prehistoric agriculture in the highlands of Ethiopia. In: van der Veen M (ed) Plants and people in Africa: recent archaeobotanical evidence. Plenum Publishing, New York, pp 101-122.

D'Andrea AC, Manzo A, Harrower MJ, et al (2008a) Pre-Aksumite and Aksumite settlement in Eastern Tigrai, Ethiopia. J Field Archaeol 33:151-176.

D'Andrea AC, Perry L, Nixon-Darcus L, et al (2018) A Pre-Aksumite culinary practice at the Mezber Site, northern Ethiopia. In: Plants and people in the African past. Springer International Publishing, Cham, pp 453–478

D'Andrea AC, Richards MP, Pavlish LA, et al (2011) Stable isotopic analysis of human and animal diets from two pre-Aksumite/Proto-Aksumite archaeological sites in northern Ethiopia. J Archaeol Sci 38:367–374. https://doi.org/10.1016/j.jas.2010.09.015

D'Andrea AC, Schmidt PR, Curtis M (2008b) Palaeoethnobotanical analysis and agricultural economy. In: Schmidt PR, Curtis M, Teka Z (eds) The archaeology of Eritrea: Recent Advances. Red Sea Press, Trenton, pp. 207-216

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

Dotte-Sarout E, Carah X, Byrne C (2015) Not just carbon: assessment and prospects for the application of anthracology in Oceania. Archaeol Ocean 50:1–22. https://doi.org/10.1002/arco.5041

Fattovich R (2004) The Pre-Aksumite state in northern Ethiopia and Eritrea reconsidered. In: Lunde P, Porter A (eds) Trade and travel in the Red Sea region. Archaeopress, Oxford, pp. 71-78.

Fattovich R (2009) Reconsidering Yeha, c. 800-400 BC. African Archaeol Rev 26:275–290. https://doi.org/10.1007/s10437-009-9063-3

Fattovich R (2010) The Development of ancient states in the northern Horn of Africa, c. 3000 BC-AD 1000: an archaeological outline. J World Prehist 23:145-175.

Fattovich R (2012) The northern Horn of Africa in the first millennium BCE: local traditions and external connection. Rass Stud Etiop 4:1-60.

Fattovich R (2019) From community to state: The development of the Aksumite polity (northern Ethiopia and Eritrea), c. 400 BC-AD 800. J Archaeol Res 27:249-285.

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

French C, Sulas F, Madella M (2009) New geoarchaeological investigations of the valley systems in the Aksum area of northern Ethiopia. Catena 78:218-233.

French C, Sulas F, Petrie C (2014) Expanding the research parameters of geoarchaeology: case studies from Aksum in Ethiopia and Haryana in India. Archaeol Anthropol Sci 1–14. https://doi.org/10.1007/s12520-014-0186-3

Friis I (1992) Forests, and forest trees of northeast tropical Africa: their natural habitats and distribution patterns in Ethiopia, Djibouti and Somalia. Royal Botanic Gardens, Kew

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

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

Graniglia M, Ferrandino G, Palomba A, et al (2015) Dynamics of the settlement pattern in the Aksum area (800-400 BC): an AMB preliminary approach. In: Campana S, Scopigno R, Carpentiero G, Cirillo M (eds) CAA 2015: Keep the revolution going. Archaeopress Publishing Ltd, Siena, pp 473–478.

Grimm EC (1992) Tilia software. Illinois State Museum, Springfield.

Hadgu G, Tesfaye K, Mamo G, Kassa B (2013) Trend and variability of rainfall in Tigray, northern Ethiopia: analysis of meteorological data and farmers' perception. Acad J Agric Res 1:88–100. https://doi.org/10.15413/ajar.2013.0117

Hagos F, Pender J, Gebreselassie N (2002) Land degradation and strategies for sustainable land management in Ethiopian highlands: Tigray region. International Livestock Research Institute, Nairobi

Hammer Ø, Harper DAT, Ryan PD (2001) PAST-Palaeontological statistics. Palaeontol Electron 4: 9-18.

Harrower MJ (2019) Beta Samati: discovery and excavation of an Aksumite town. Antiq 93:1534-1552. https://doi.org/10.15184/aqy.2019.84

Harrower MJ, D'Andrea AC (2014) Landscapes of state formation: geospatial analysis of aksumite settlement patterns (Ethiopia). Afr Archaeol Rev 31:513–541. https://doi.org/10.1007/s10437-014-9165-4

Harrower MJ, Nathan S, Mazzariello JC, et al (2020) Water, geography, and Aksumite civilization: the Southern Red Sea Archaeological Histories (SRSAH) project survey (2009–2016). African Archaeol Rev 37:51–67. https://doi.org/10.1007/s10437-020-09369-8

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.

Kindt R, van Breugel P, Lillesø J-PB, et al (2011a) Potential natural vegetation of Eastern Africa (Ethiopia, Kenya, Malawi, Rwanda,Tanzania, Uganda and Zambia). Volume 2: description and tree species composition for forest potential natural vegetation types. University of Copenhagen, Copenhagen

Kindt R, van Breugel P, Lillesø J-PB, et al (2011b) Potential natural vegetation of Eastern Africa (Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda and Zambia). Volume 3: description and tree species composition for woodland and wooded grassland potential natural vegetation types. University of Copenhagen, Copenhagen

Kindt R, van Breugel P, Lillesø J-PB, et al (2011c) Potential natural vegetation of Eastern Africa (Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda and Zambia). Volume 4: description and tree species composition for bushland and thicket potential natural vegetation types. University of Copenhagen, Copenhagen

Kobishchanov YM (1979) Axum. Pennsylvania State University Press, Philadelphia.

Lancelotti C (2010) Fuelling Harappan hearths: human-environment interactions as revealed by fuel exploitation and use. Dissertation, University of Cambridge.

Lanckriet S, Rucina S, Frankl A, et al (2015) Nonlinear vegetation cover changes in the North Ethiopian highlands: evidence from the lake Ashenge closed basin. Sci Total Environ 536:996–1006. https://doi.org/10.1016/j.scitotenv.2015.05.122

Lanckriet S, Rangan H, Nyssen J, Frankl A (2017) Late Quaternary changes in climate and land cover in the northern Horn of Africa and adjacent areas. Palaeogeogr Palaeoecol 482:103–113. https://doi.org/10.1016/j.palaeo.2017.05.035

Lesur J, Hildebrand EA, Abawa G, Gutherz X (2014) The advent of herding in the Horn of Africa: new data from Ethiopia, Djibouti and Somaliland. Quat Int 343:148–158. https://doi.org/10.1016/j.quaint.2013.11.024

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.

Louppe D, Oteng-Amoako AA, Brink M (2008) Plant resources of tropical Africa. Volume 7: timbers. PROTA Foundation, Wageningen

Lyons DE, D'Andrea AC (2003) Griddles, ovens and the origins of agriculture: an ethnoarchaeological study of bread baking in highland Ethiopia. Am Anthropol 105:515-530.

Machado MJ, Pérez-González A, Benito G (1998) Paleoenvironmental change during the last 4,000 years in the Tigray, northern Ethiopia. Quat Res 49:312–321.

Marshall MH, Lamb HF, Davies SJ, et al (2009) Climatic change in northern Ethiopia during the past 17,000 years: a diatom and stable isotope record from Lake Ashenge. Palaeogeogr Palaeoclimatol Palaeoecol 279:114-127.

Marshall MH, Lamb HF, Huws D, et al (2011) Late Pleistocene and Holocene drought events at Lake Tana, the source of the Blue Nile. Global Planet Change 78:147-161.

Metcalfe CR, Chalk L (1950a) Anatomy of the dicotyledons (volume 1). Oxford Clarendon Press, Oxford

Metcalfe CR, Chalk L (1950b) Anatomy of the dicotyledons (volume 2). Oxford Clarendon Press, Oxford

Michels JW (1988) The Axumite kingdom: a settlement archaeology perspective. In: Gromyko AA (ed) Proceedings of the Ninth International Congress of Ethiopian Studies. Nauka Publishers, Moscow, pp. 173–183.

Michels JW (2005) Changing settlement patterns in the Aksum-Yeha region of Ethiopia: 700 BC-AD 850. BAR International Series 1446. Archaeopress, Oxford.

Miller NF (1988) Ratios in palaeoethnobotanical analysis. In Popper VS, Hastorf CA (eds) Current Paleoethnobotany. Universiy of Chicago Press, Chicago, pp. 72-85.

Moeyersons J, Nyssen J, Poesen J, et al (2006) Age and backfill/overfill stratigraphy of two tufa dams, Tigray highlands, Ethiopia: evidence for Late Pleistocene and Holocene wet conditions. Palaeogeogr Palaeoclimatol Palaeoecol 230:165-181.

Mordini A (1941) Un riparosotto roccia con pitture rupestri nell'Amba Focada. Rass Stud Etiop 1:54–60

Munro-Hay SC (1991) Aksum: an African civilisation of late antiquity. Edinburgh University Press, Edinburgh.

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

Nyssen J, Poesen J, Moeyersons J, et al (2004) Human impact on the environment in the Ethiopian and Eritrean highlands - a state of the art. Earth-Sci Rev 64:273–320. https://doi.org/10.1016/S0012-8252(03)00078-3

Orvis KH, Lane CS, Horn SP (2005) Laboratory production of vouchered reference charcoal from small wood samples and non-woody plant tissues. Palynology 29:1-11.

Peterson EA (2017) Development of craft specialization during the Pre-Aksumite period in eastern Tigray, Ethiopia: a study of hideworking traditions. Dissertation, Simon Fraser University.

Phillipson DW (1998) Ancient Ethiopia: Aksum, its antecedents and successors. British Museum, London.

Phillipson DW (2009) The first millennium BC in the highlands of northern Ethiopia and south-central Eritrea: a reassessment of cultural and political development. Afr Archaeol Rev 26:257–274. https://doi.org/10.1007/s10437-009-9064-2

Phillipson DW (2012) Foundations of an African civilisation: Aksum and the northern Horn (1000 BC- AD 1300). Boydell & Brewer, Croydon.

Phillipson L (2017) Lithic evidence for the peopling of northern Ethiopia. Afr Archaeol Rev 34:177-191.

Pielou EC (1966) The measurement of diversity in different types of biological collections. J Theor Biol 13:131–144. https://doi.org/10.1016/0022-5193(66)90013-0

Popper VS (1988) Selective quantitative measurements in paleoethnobotany. In Popper VS, Hastorf CA (eds) Current Paleoethnobotany. Universiy of Chicago Press, Chicago, pp. 53-71.

Richter HG, Grosser D, Heinz I, et al (2004) IAWA list of microscopic features for softwood identification. IAWA J 25:1-70.

Rossini CC (1928) Storia d'Etiopia. Istituto Italiano d'Arti Grafiche, Bergamo.

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

Scheel-Ybert R (2005) Teoria e métodos em antracologia 3. Validade amostral. Arq Mus Nac 63:207–232

Schmidt PR (2009) Variability in Eritrea and the archaeology of the northern Horn during the first millennium BC: subsistence, ritual, and gold production. Afr Archaeol Rev 26:305–325. https://doi.org/10.1007/s10437-009-9061-5

Sernicola L (2008) Il modello d'insediamento sull'altopiano tigrino (Etiopia settentrionale/Eritrea centrale) in epoca pre-Aksumita e Aksumita (ca 700 A.C.–800 A.C.). Un contributo da Aksum. Dissertation, University of Naples.

Sernicola L (2012) New archaeological evidence in the area of Adigrat (Eastern Tigray) and its surroundings. Rass Stud Etiop 4:61–67

Sernicola L, Sulas F (2012) Continuita e cambiamento nel paesaggio rurale di Aksum: dati archeologici, etnografici e paleoambiental. In: Bausa A, Brita A, Manzo A (eds) Aetopica et Orientalia. Studi in onore di Yaqob Beyene. University of Naples, Naples, pp. 549-573.

Shoshani J, Ghebregiorgis M, Schmidt P (2008) Interpretations of faunal remains from archaeological sites on the Asmara plateau of Eritrea. In: Schmidt P, Curtis P, Teka Z (eds) The archaeology of ancient Eritrea. Red Sea Press, Trenton, pp. 217–234.

Sulas F (2014) Aksum: environmental archaeology. In: Smith C (ed) Encyclopedia of Global Archaeology. Springer, New York, pp. 129–138.

Sulas F, Madella M, French C (2009) State formation and water resources management in the Horn of Africa: the Aksumite Kingdom of the northern Ethiopian highlands. World Archaeol 41:2-15.

Taddesse HM (2019) The Pre-Aksumite to Aksumite transition in Eastern Tigrai, Ethiopia: the view from Ona Adi. Dissertation, Simon Fraser University.

Terwilliger VJ, Eshetu Z, Huang Y, et al (2011) Local variation in climate and land use during the time of the major kingdoms of the Tigray plateau in Ethiopia and Eritrea. Catena 85:130–143. https://doi.org/10.1016/j.catena.2010.08.003

Tierney JE, Lewis SC, Cook BI, et al (2011) Model, proxy and isotopic perspectives on the East African Humid Period. Earth Planet Sc Lett 307:103-112.

Trauth MH, Maslin MA, Deino AL, et al (2007) High-and low-latitude forcing of Plio-Pleistocene East African climate and human evolution. J Hum Evol 53:475-486.

Van Breugel P, Kindt R, Lillesø J-PB, van Breugel M (2015) Environmental gap analysis to prioritize conservation efforts in Eastern Africa. PLoS One 10:e0121444. https://doi.org/10.1371/journal.pone.0121444

Von Maydell HJ (1990) 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 Bull 10:219-332.

Woldekiros HS, D'Andrea AC (2017) Early evidence for domestic chickens (Gallus gallus domesticus) in the Horn of Africa. Int J Osteoarchaeol 27:329–341. https://doi.org/10.1002/oa.2540

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

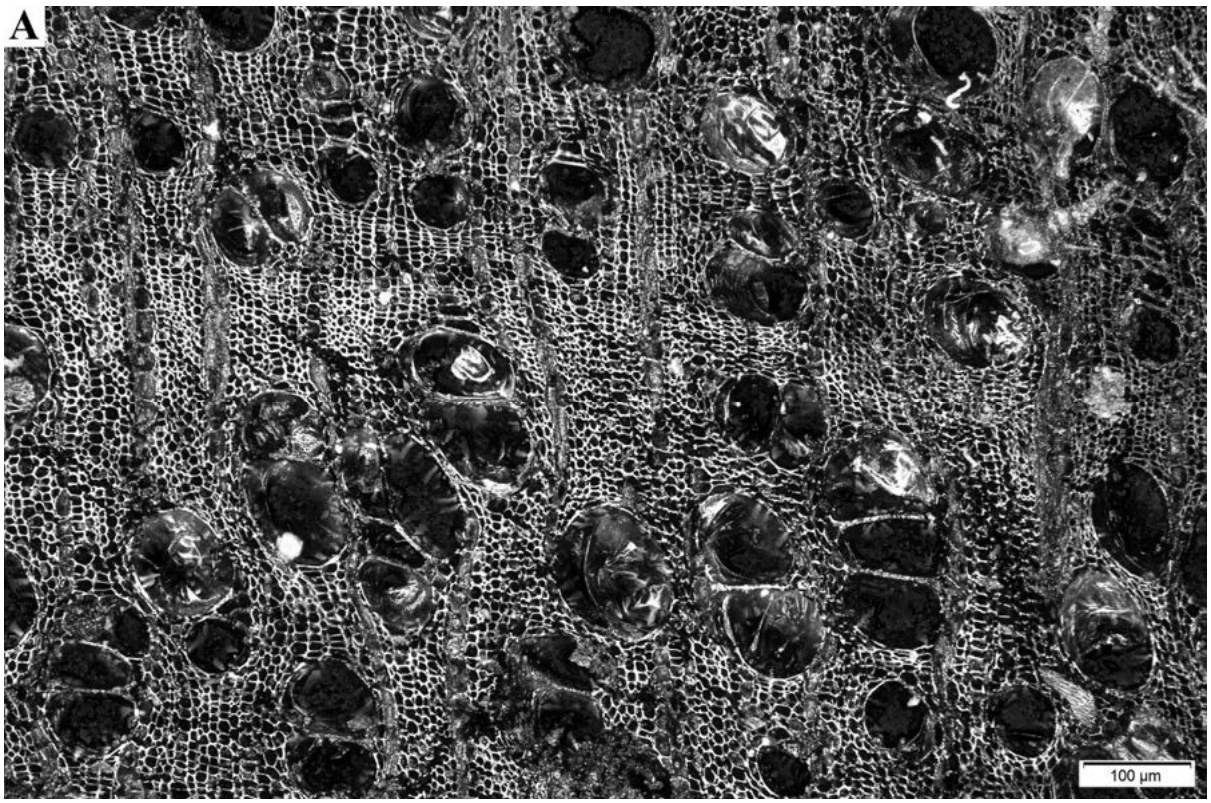
Growth ring boundaries distinct. Wood diffuse-porous. **Vessels** grouping sometimes in radial multiples of 2-3, sometimes solitary. Vessel clusters common. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular; 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.

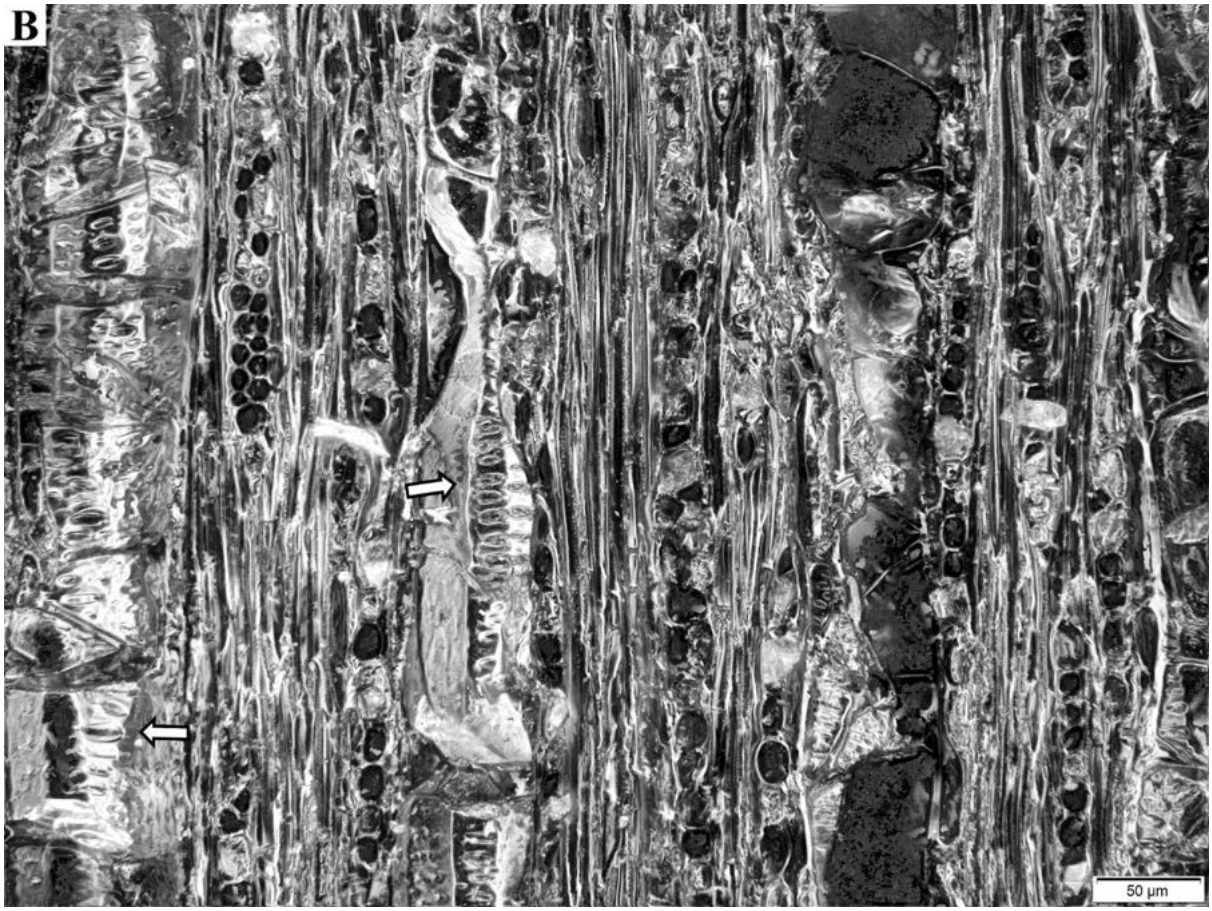
- Main diagnostic features

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).


A
100 µm


B
50 µm

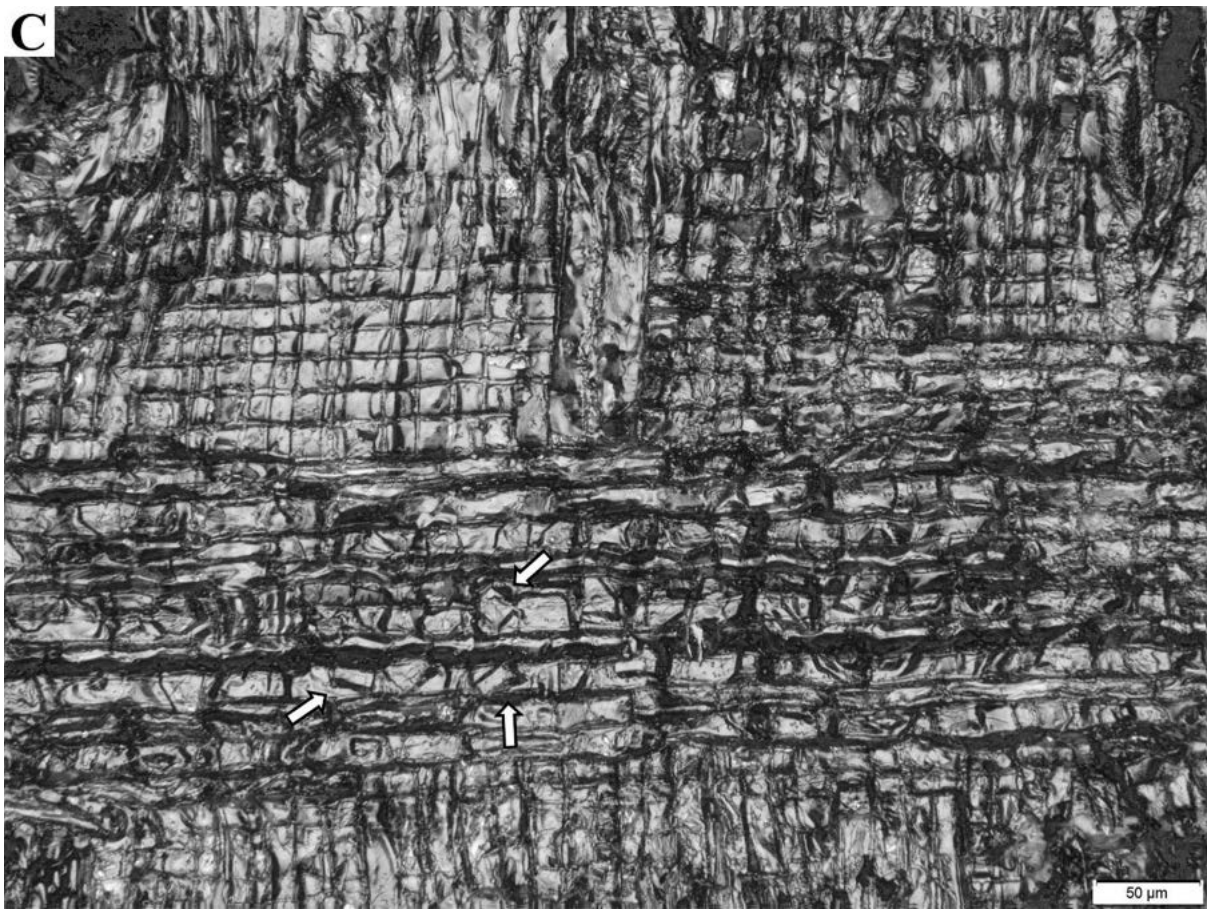


Fig. 1: A) TS: Growth ring distinct. Vessels forming clusters with mean diameter between 50-100 µm. Tyloses common. B) TLS: Vessel-ray pits rounded / angular, uniseriate and biseriate rays. C) RLS: Prismatic crystals in ray cells.

- 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

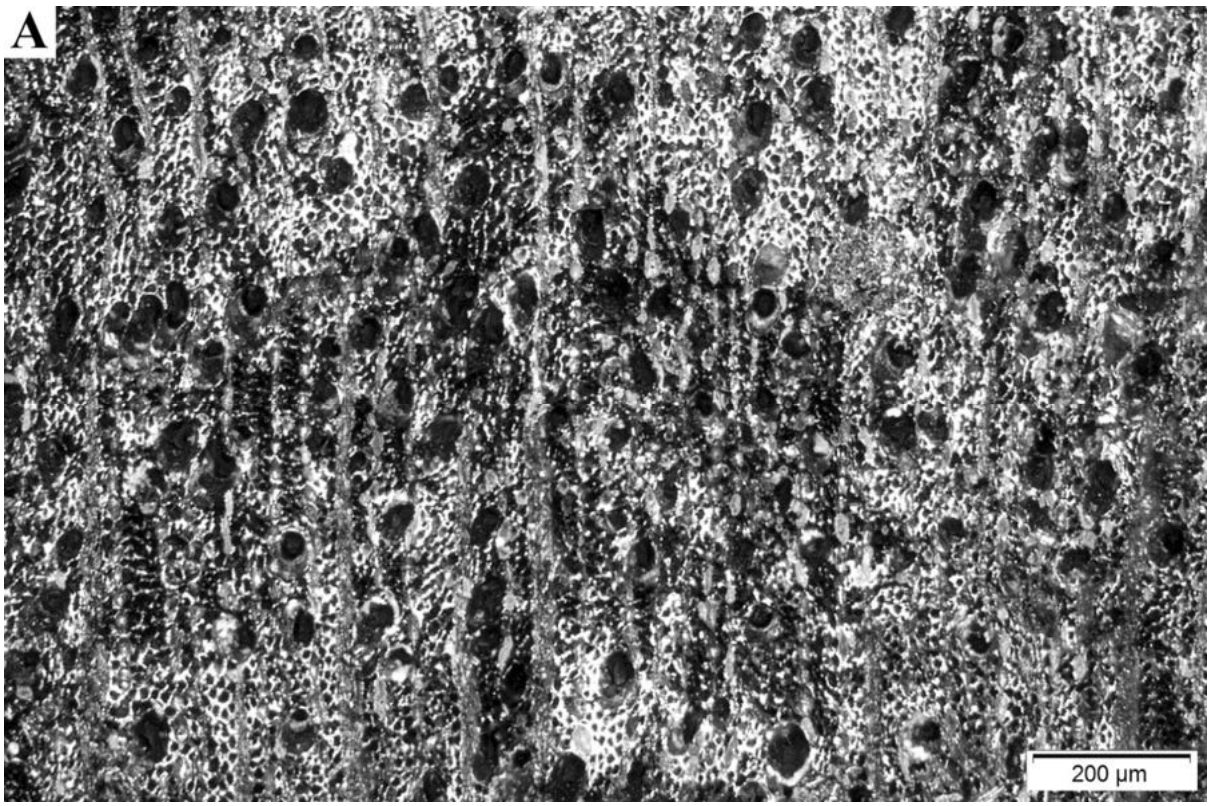
Growth rings boundaries indistinct or absent. Wood diffuse-porous. **Vessels** exclusively solitary (90% or more). Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter 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.



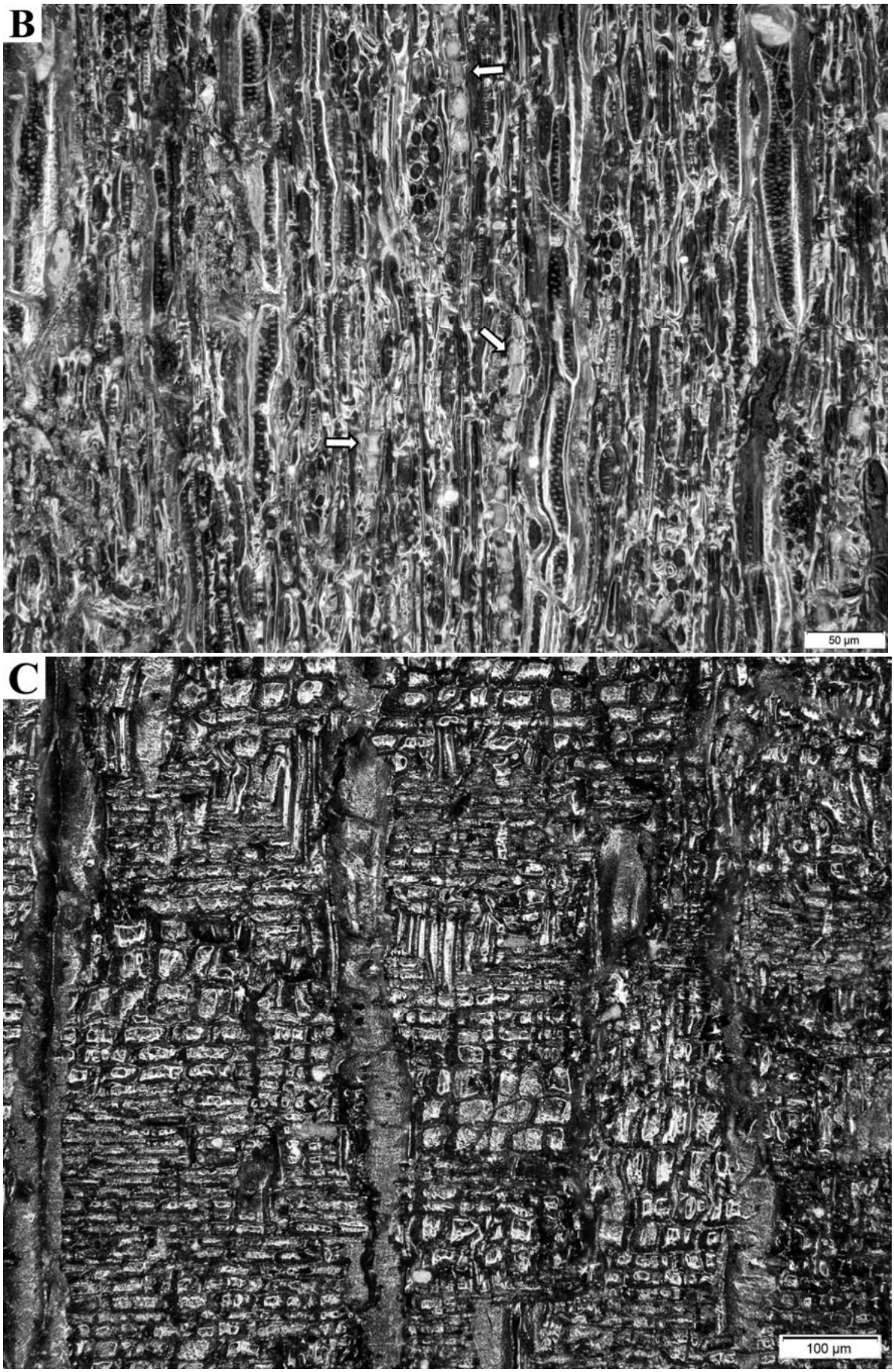


Fig. 2: A) TS: Vessels exclusively solitary, with mean diameter of lumina smaller than 50 µm. B) TLS: Short rays, 1- to 3 cells wide. Prismatic crystals in axial parenchyma cells. C) RLS: Body ray cells procumbent with 2-4 rows of upright and / or square marginal cells.

- 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

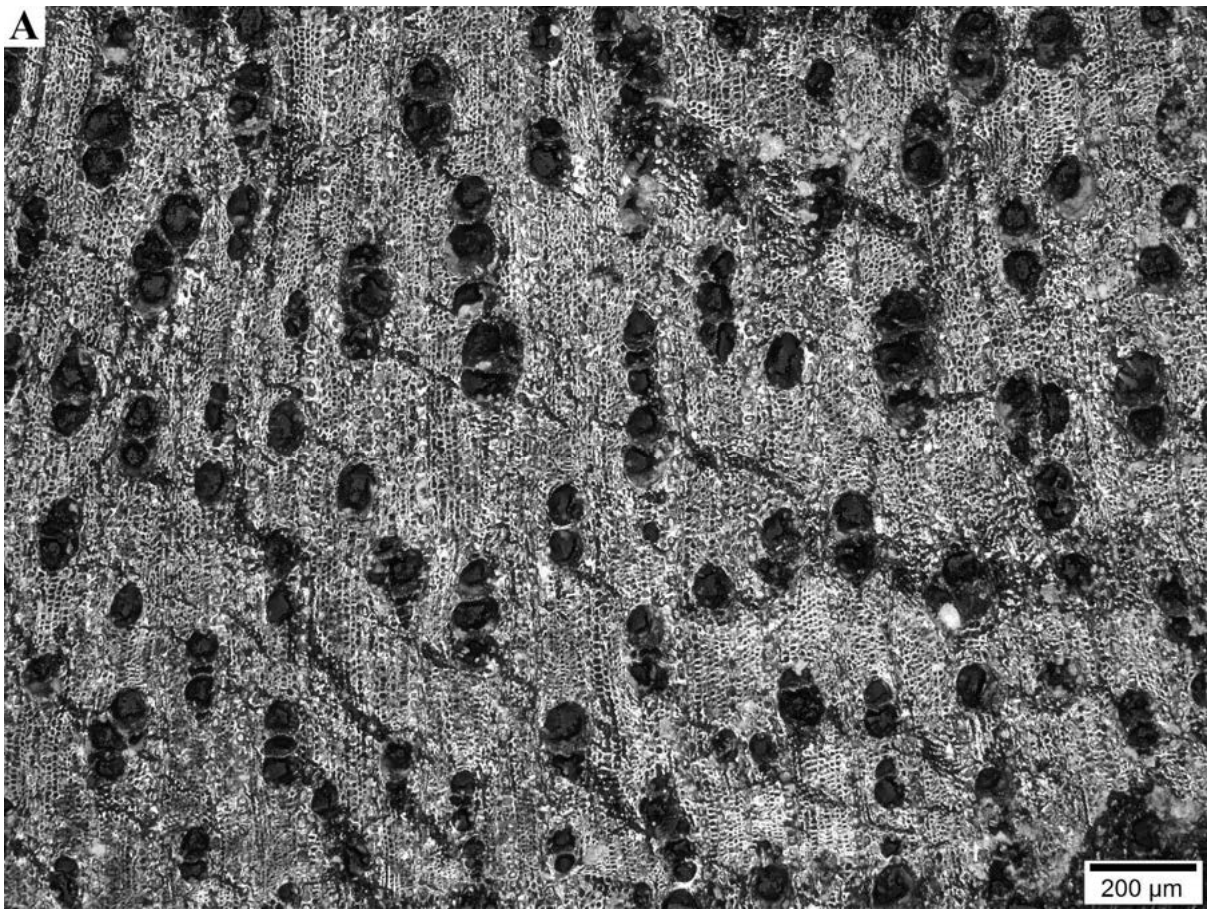
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** in diagonal and / or radial pattern. Vessels grouping sometimes in radial multiples of 2-3, sometimes solitary. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel 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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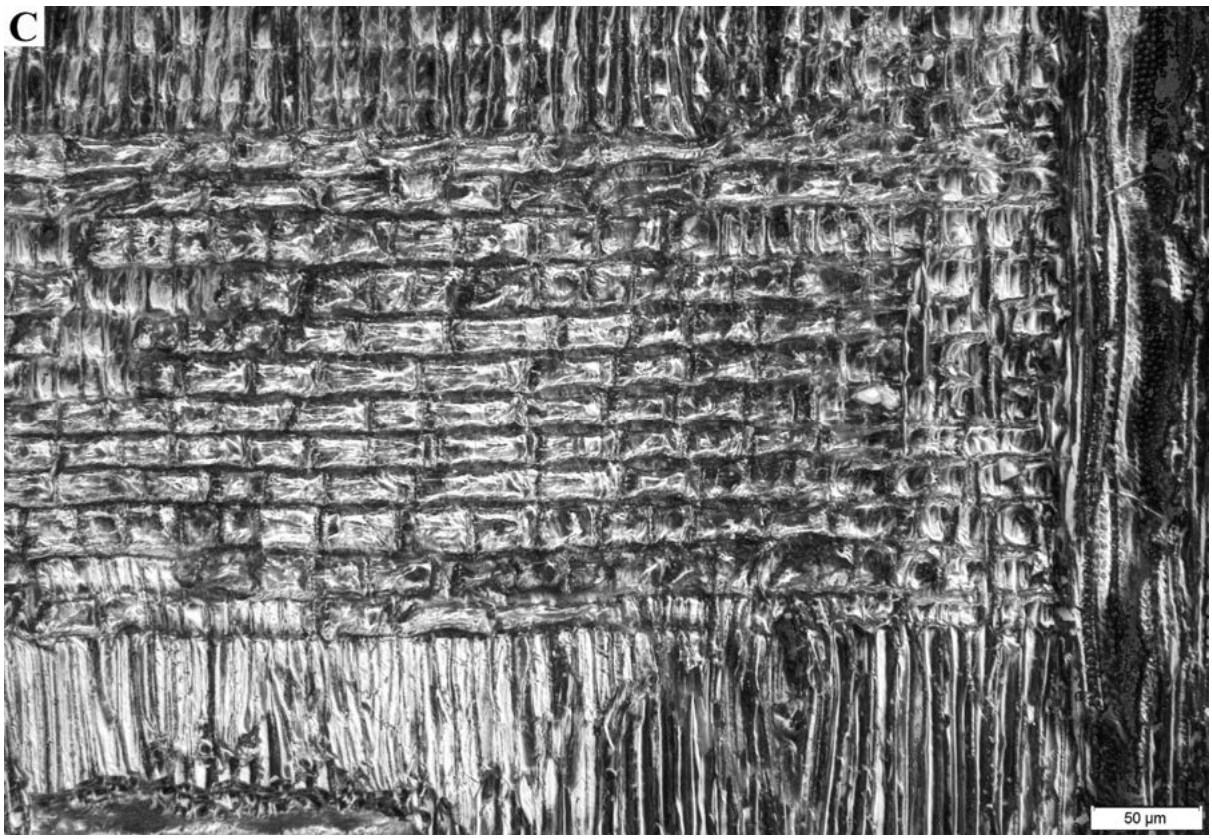


Fig. 3: A) TS: Vessels in diagonal and / or radial pattern, with mean lumina diameter between 50-100 µm. Axial parenchyma forming marginal or in seemingly marginal bands. B) TLS: Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular. Ray width 1 to 3 cells. C) RLS: Ray 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

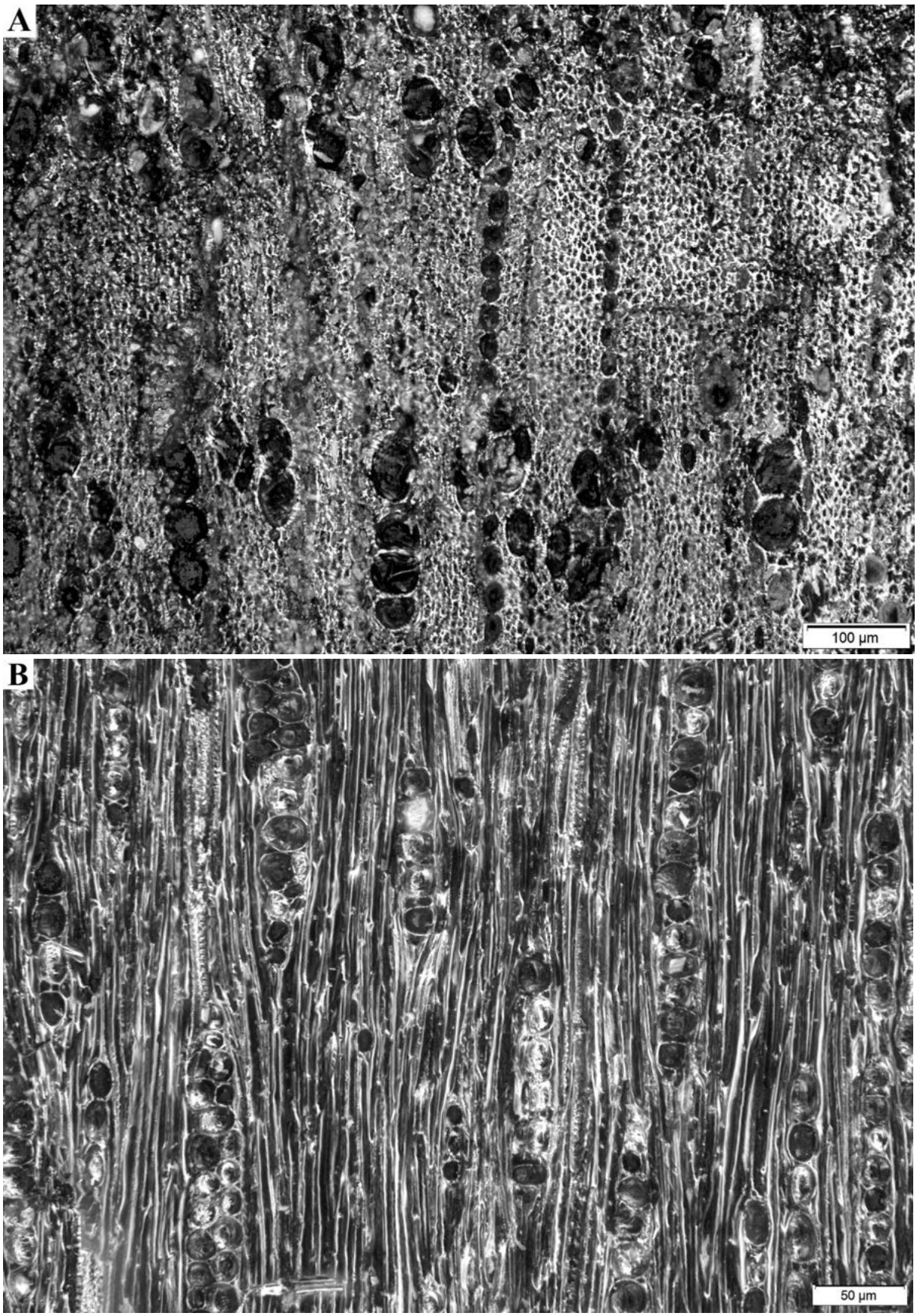
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** grouping in radial multiples of 4 or more common. Vessel clusters common. Simple perforation plates. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout 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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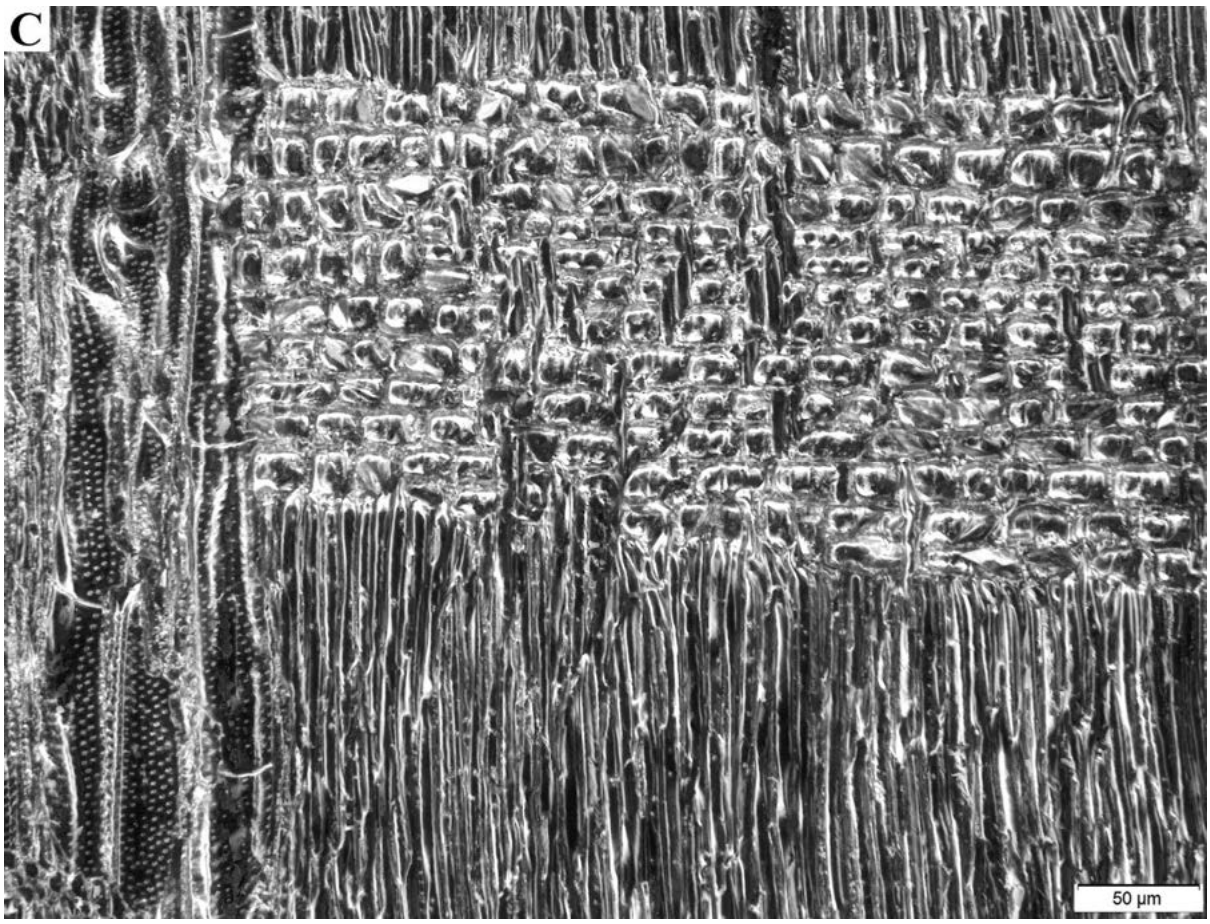


Fig. 4: A) TS: Vessels of two distinct diameter classes (wood not ring-porous), commonly arranged in radial multiples of 4 or more and forming clusters. Axial parenchyma paratracheal scanty. B) TLS: Heterocellular rays, 1- to 3- seriate. C) RLS: Rays with procumbent, square and upright cells mixed throughout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

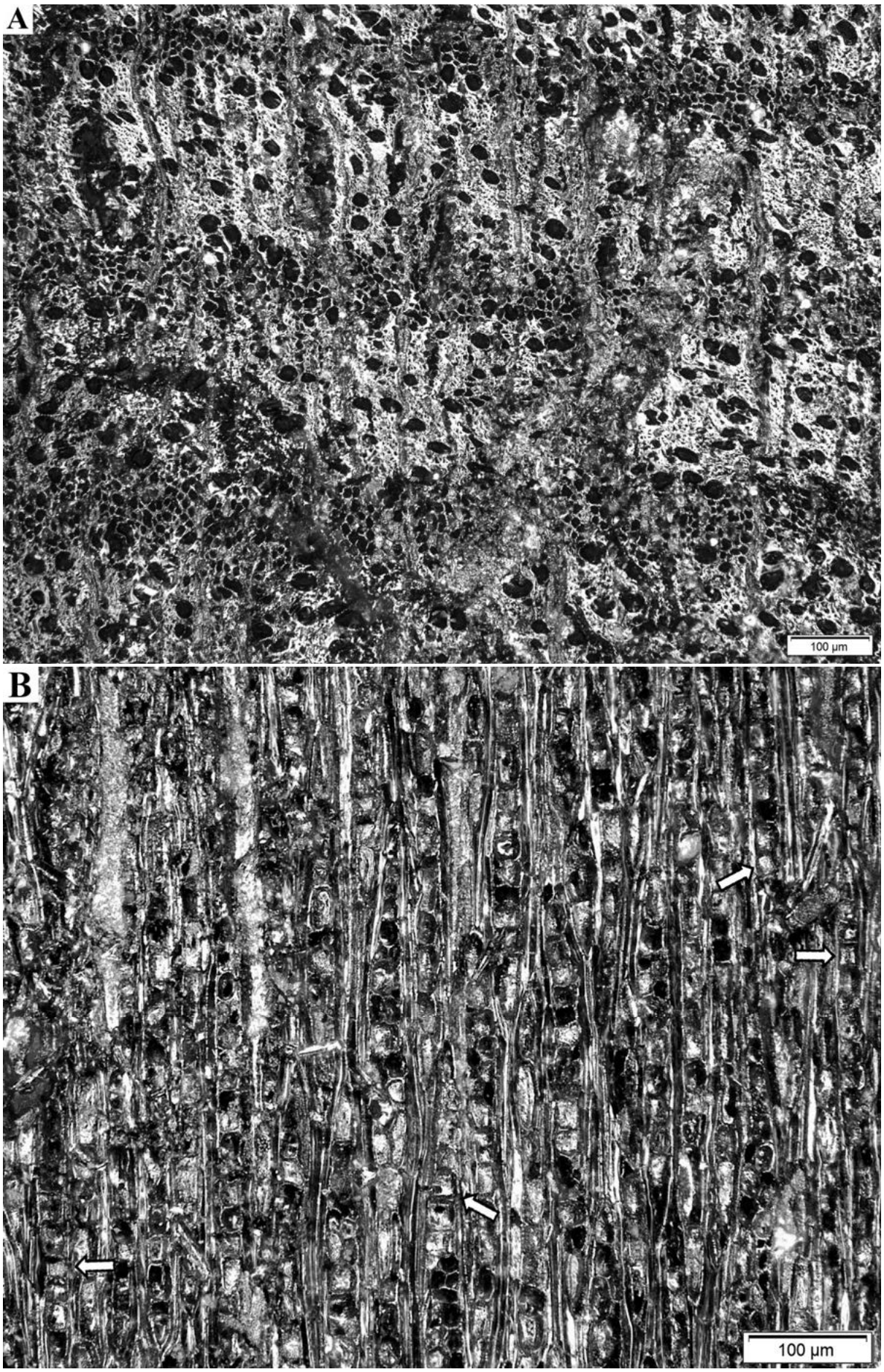
Growth ring boundaries indistinct or absent. Wood diffuse-porous. Vessels generally solitary, sometimes in radial groups of 2-3. Solitary vessel outline angular. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape 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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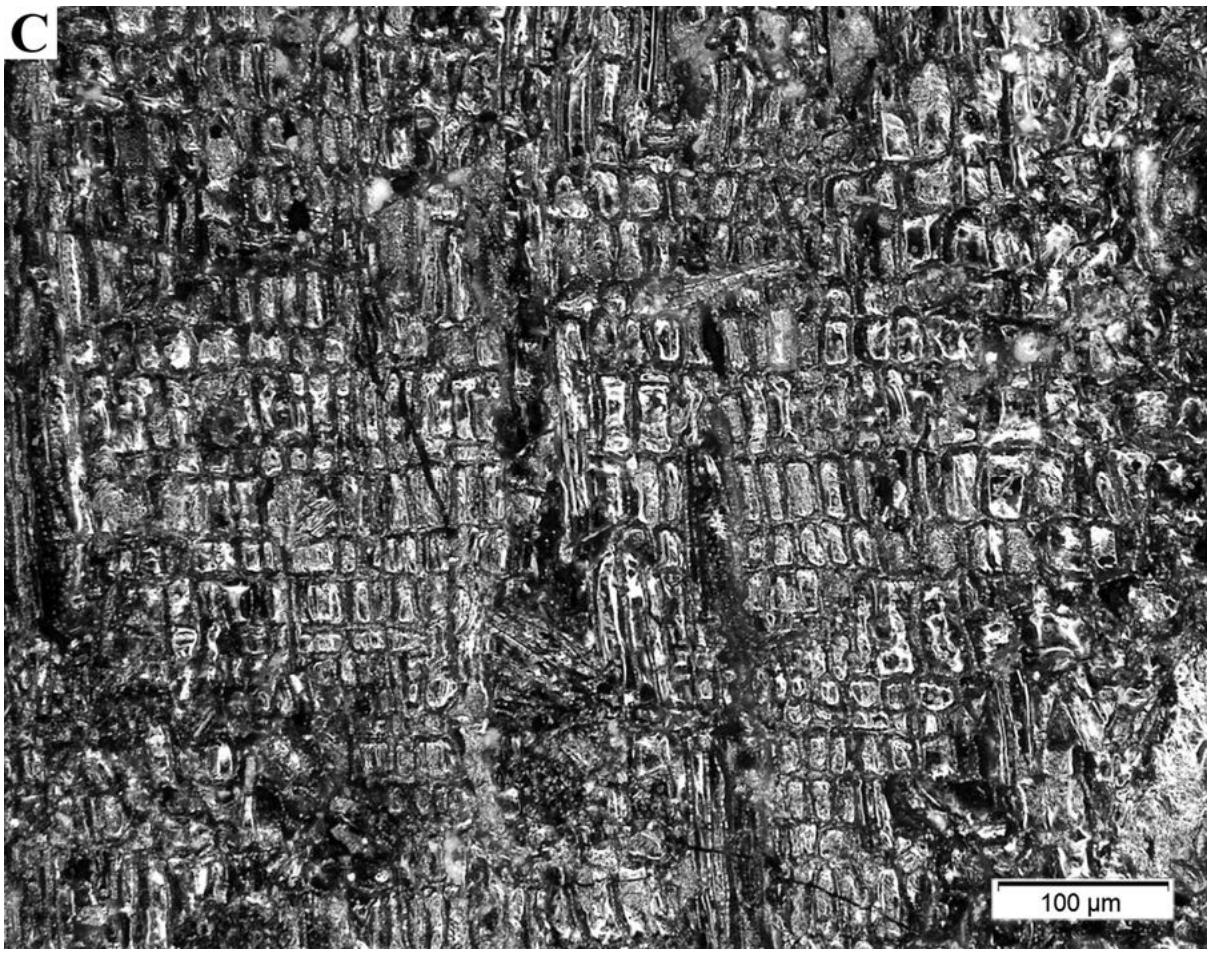


Fig. 5: A) TS: Mean tangential diameter of vessel lumina smaller than 50 µm. Parenchyma-like fibre bands alternating with ordinary fibres. B) TLS: Rays heterocellular, with prismatic crystals in ray cells. C) RLS: Rays with procumbent, square and upright cells mixed throughout the ray.

- 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

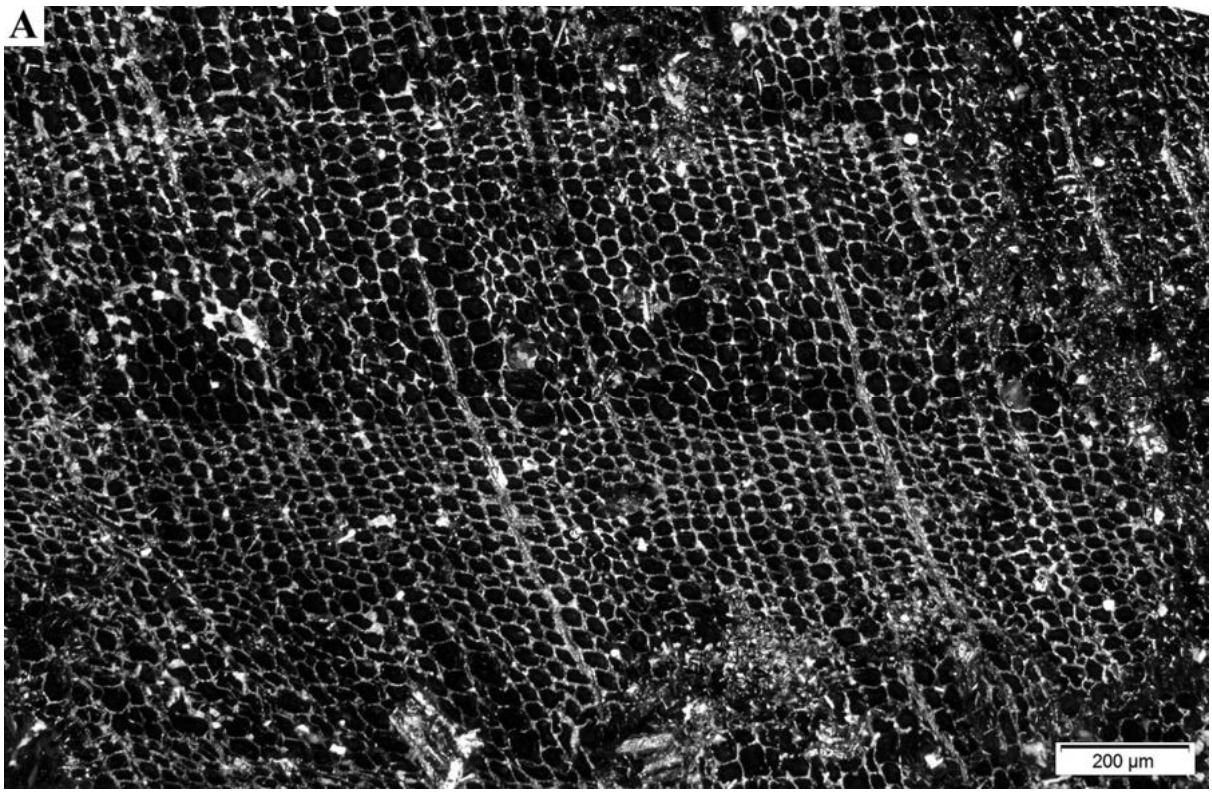
Growth ring boundaries distinct. Transition from early- to latewood gradual. **Tracheid** pitting in early wood predominantly uniseriate. Intercellular spaces throughout the wood present. Latewood tracheid wall thin-walled. Axial **parenchyma** present. Arrangement of axial parenchyma diffuse. **Ray 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.



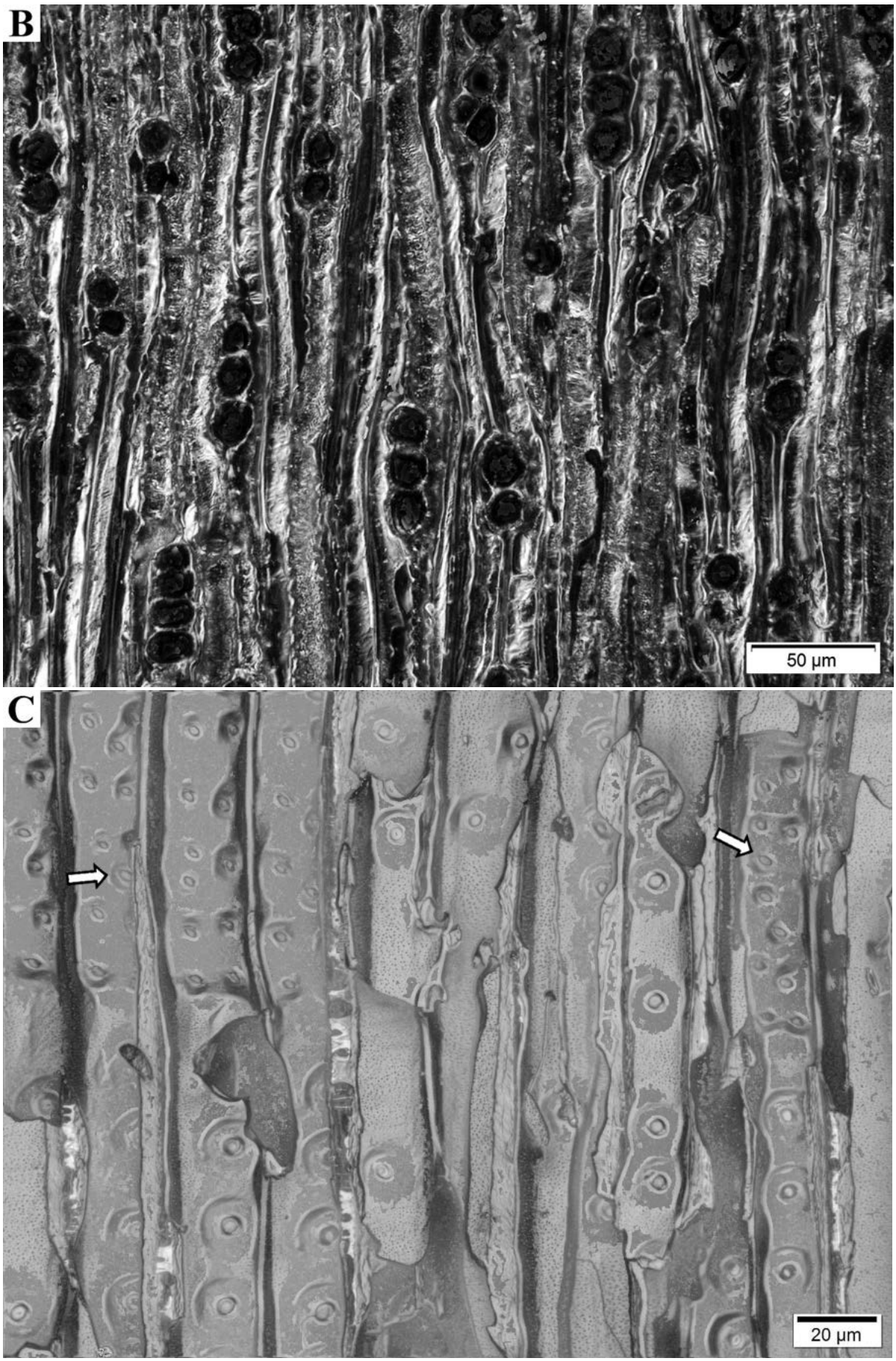


Fig. 6: A) TS: Growth ring boundaries distinct. Transition from early- to latewood gradual. B) TLS: Rays height up to 4 cells. C) RLS: Cross-field pits cupressoid. Number of pits per field 2-4.

- 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

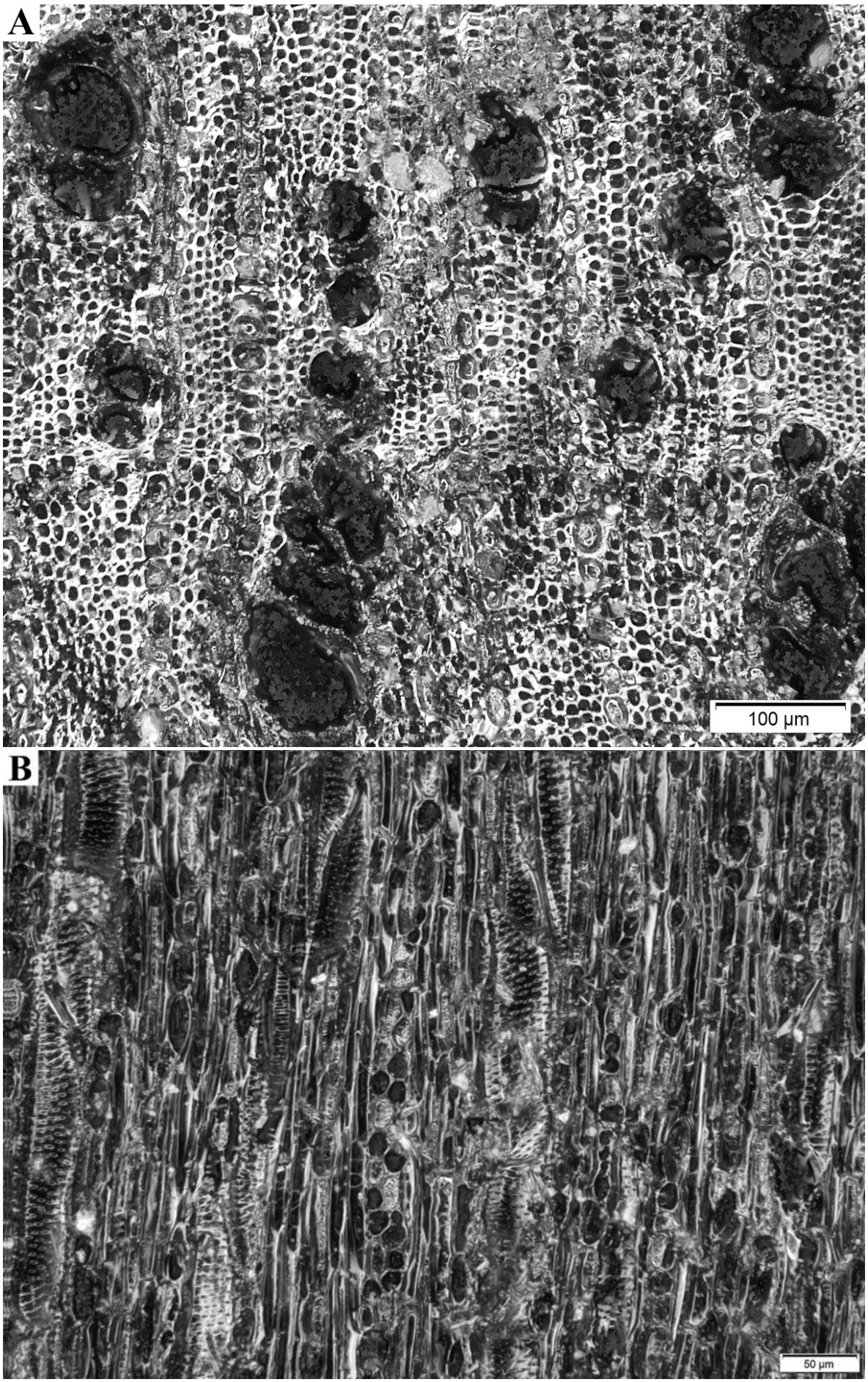
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** grouping in radial multiples of 4 or more common. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential 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
100 µm
B
50 µm

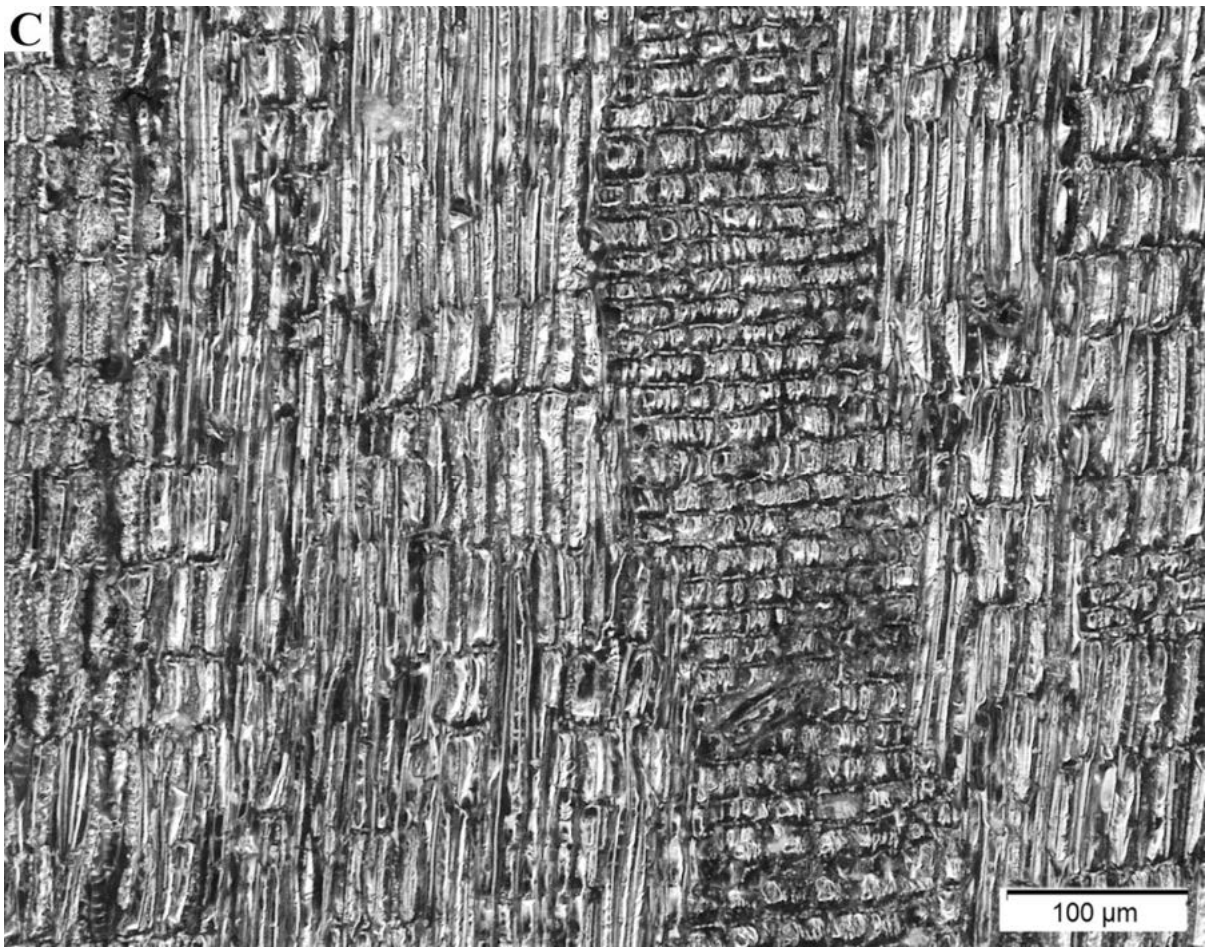


Fig. 7: A) TS: Mean tangential diameter of vessel lumina between 50-100 µm. Axial parenchyma apotracheal diffuse-in-aggregates, also in narrow bands up to three cells wide. B) TLS: Ray width 1 to 3 cells. C) RLS: Rays heterocellular, body ray cells procumbent with over 4 rows of upright and / or square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

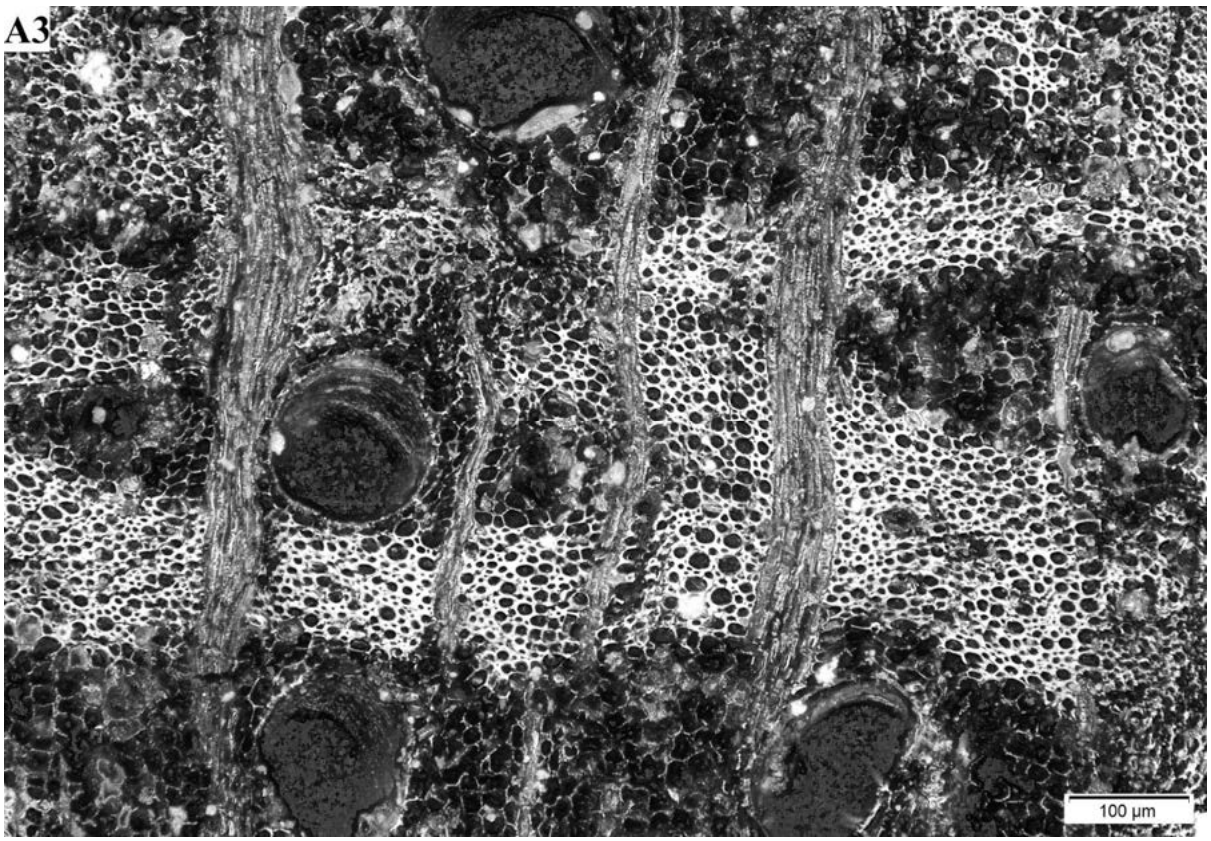
Mean tangential diameter of vessel lumina between 100 and 200 µm. Axial parenchyma paratracheal vasicentric, aliform, sometimes confluent. Ray width commonly 4 - to 10 seriate. Homocellular, all cells procumbent. Prismatic crystals in axial parenchyma cells.

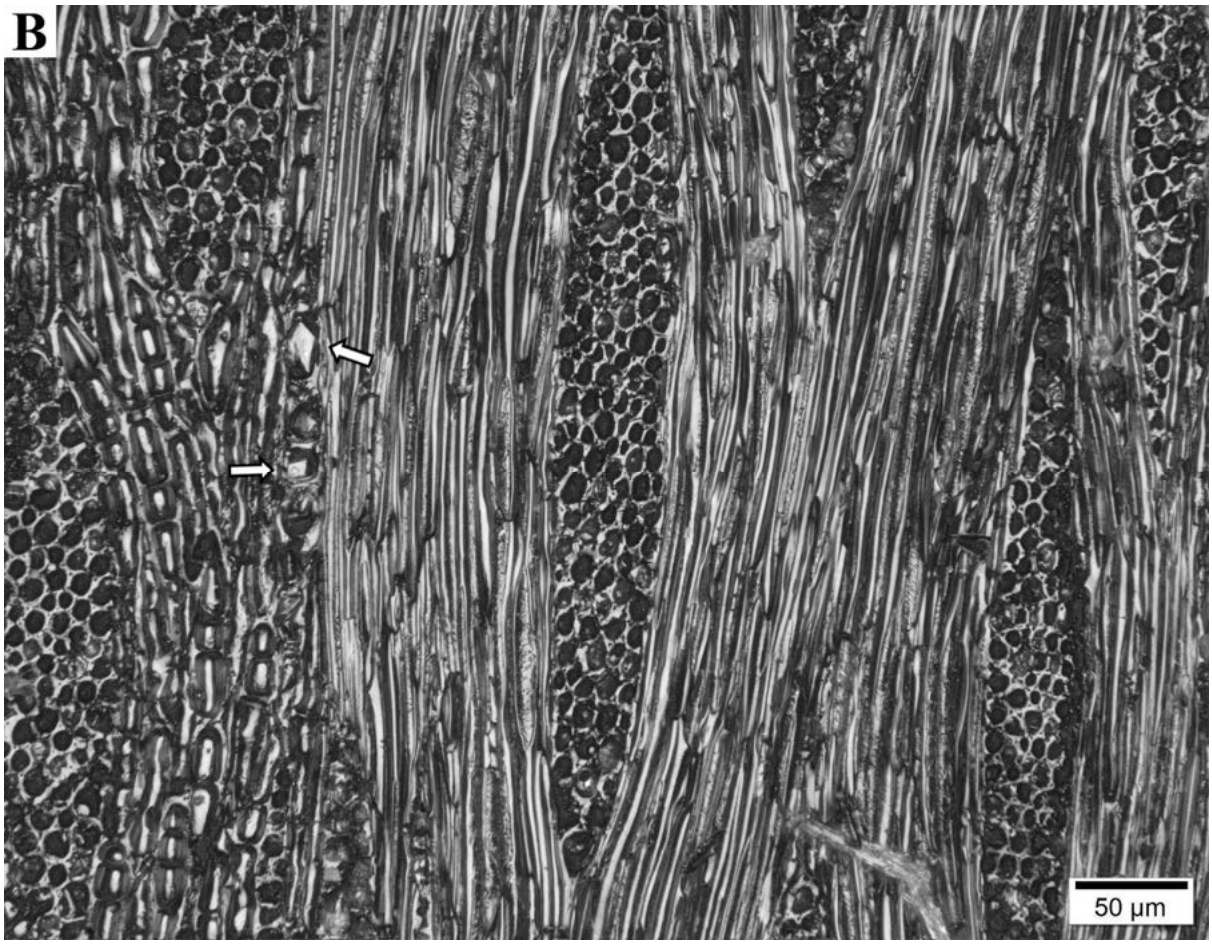
- Discussion

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.

A1
100 µm

A2
200 µm


A3
100 µm


B
50 µm

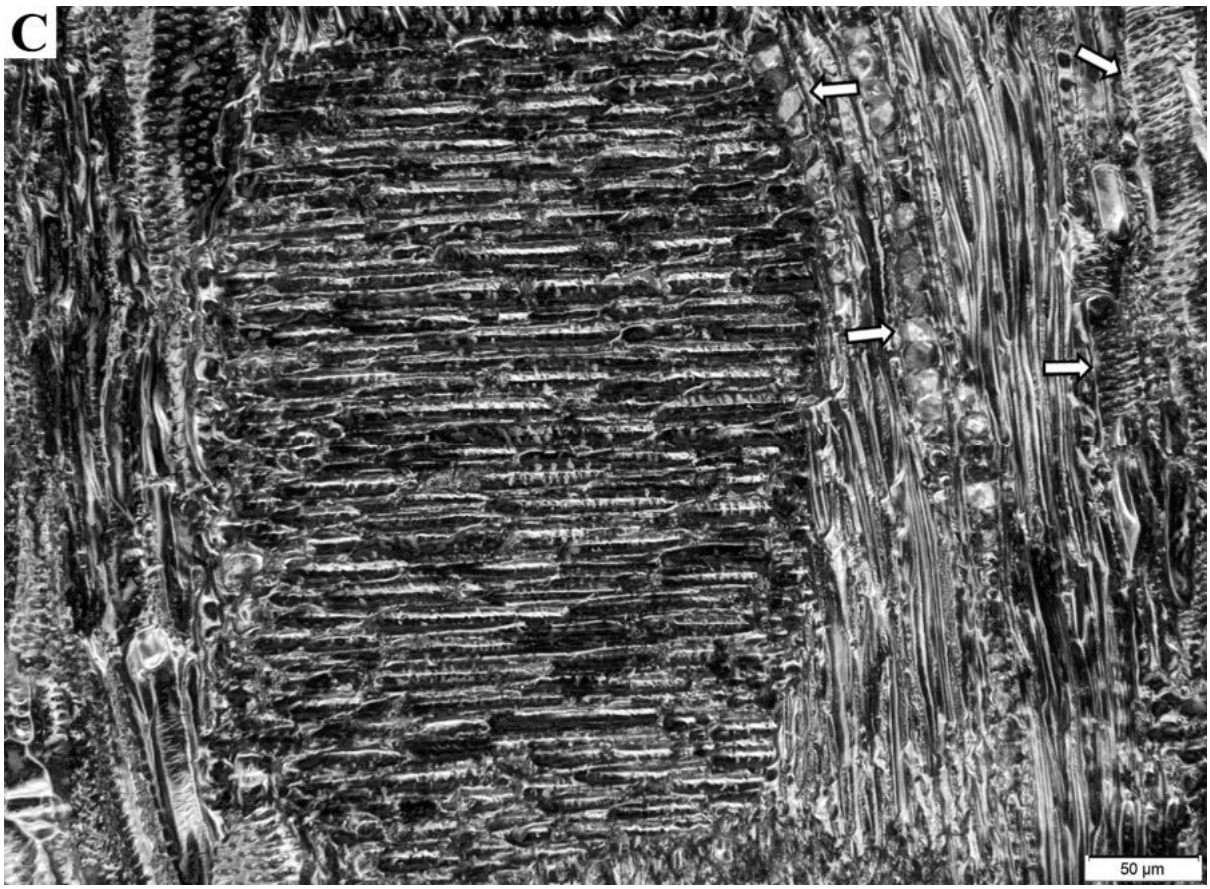


Fig. 8: A1) TS: Mean tangential diameter of vessel lumina between 100 and 200 µm. Axial parenchyma paratracheal vasicentric, aliform, sometimes confluent. A2 and A3) Variations of axial parenchyma arrangements. TS: B) TLS: Ray width commonly 4 - to 10 seriate. Prismatic crystals in axial parenchyma cells. 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

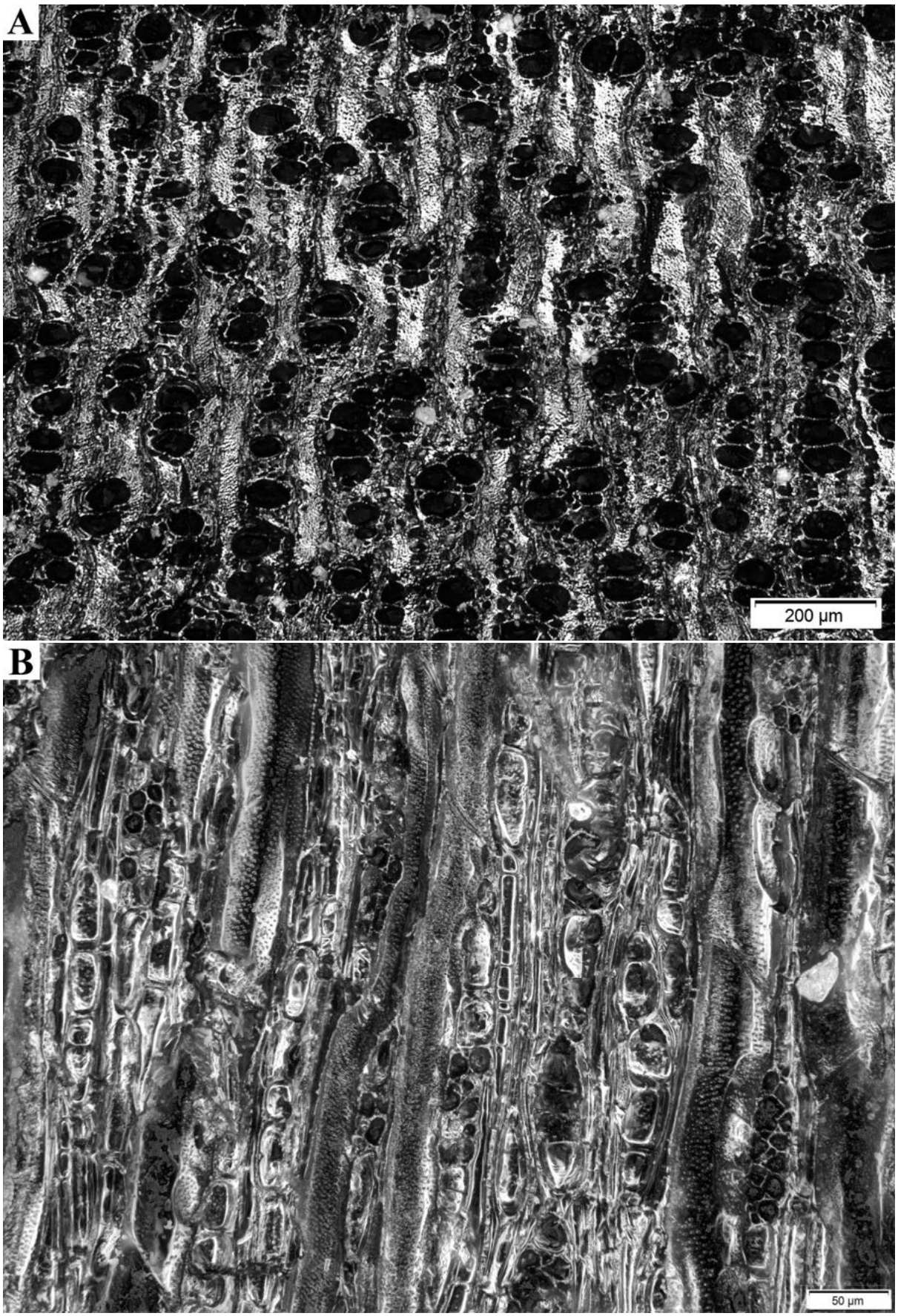
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** in diagonal and / or radial pattern. Vessel grouping in radial groups of 2-6 cells, sometimes solitary. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits 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

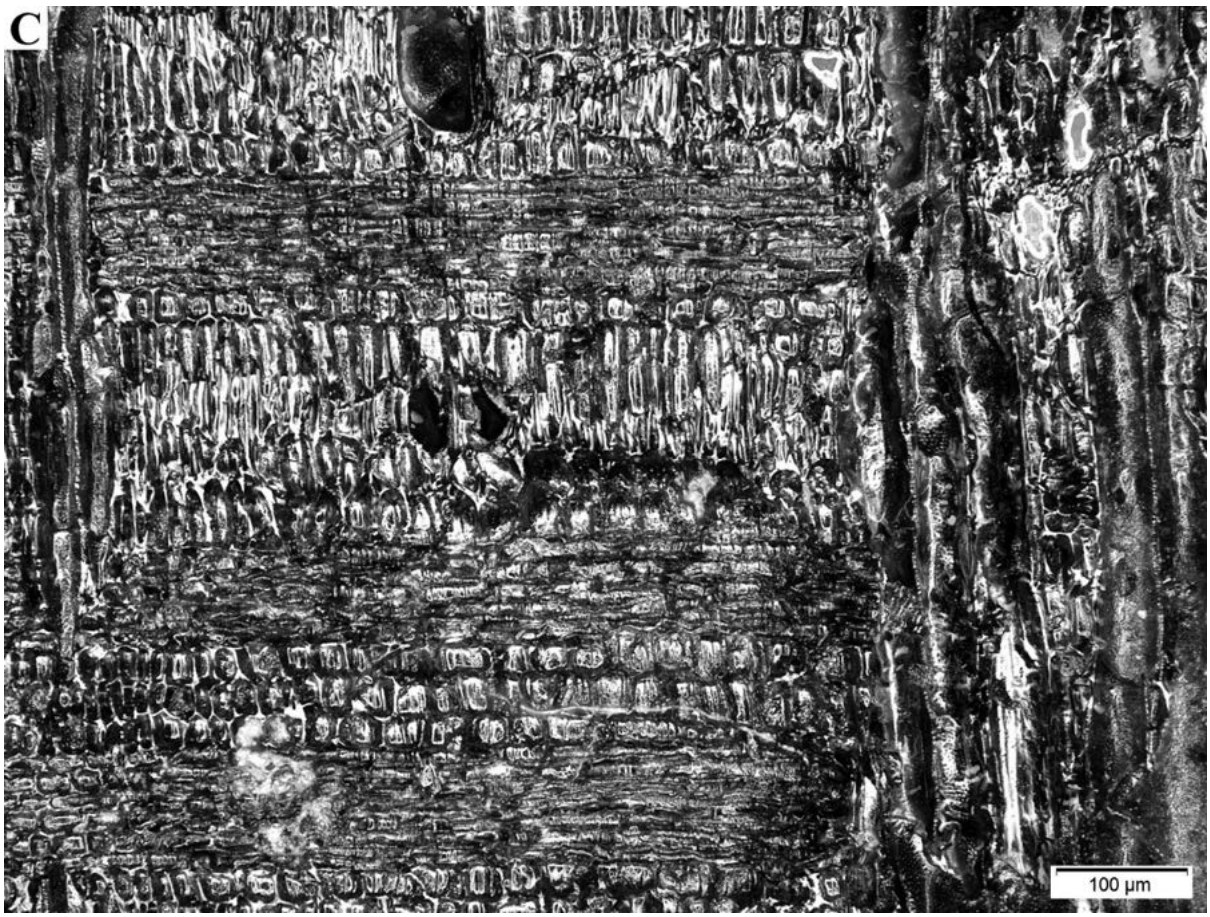


Fig. 9: A) TS: Vessels in diagonal and / or radial pattern with a mean diameter of lumina between 50-100 µm. Axial parenchyma paratracheal scanty to vasicentric. B) TLS: Ray width 1- to 3 cells, intervessel pits minute. C) RLS: Ray structure heterocellular.

- 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.

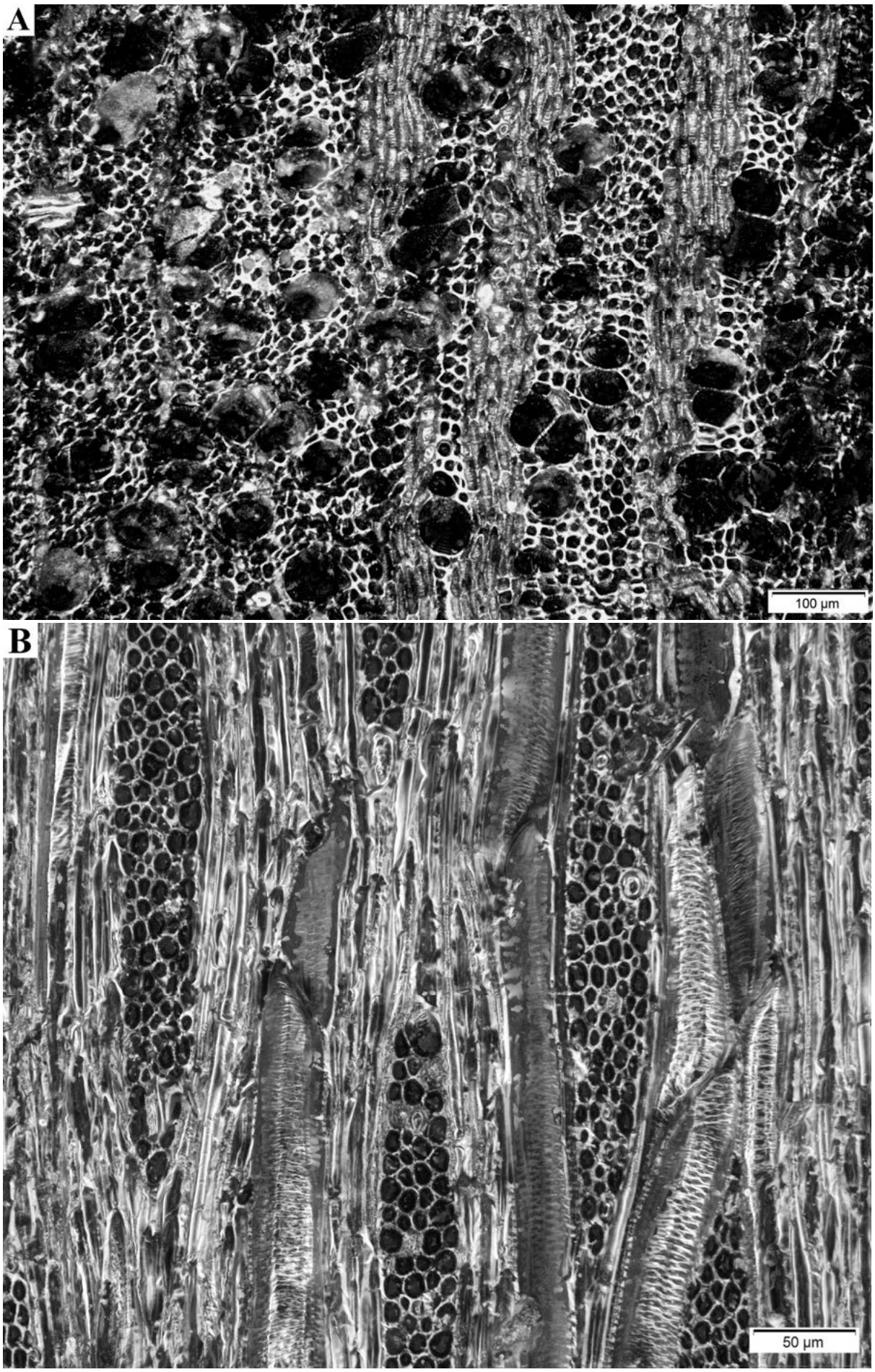

A
100 µm
B
50 µm

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

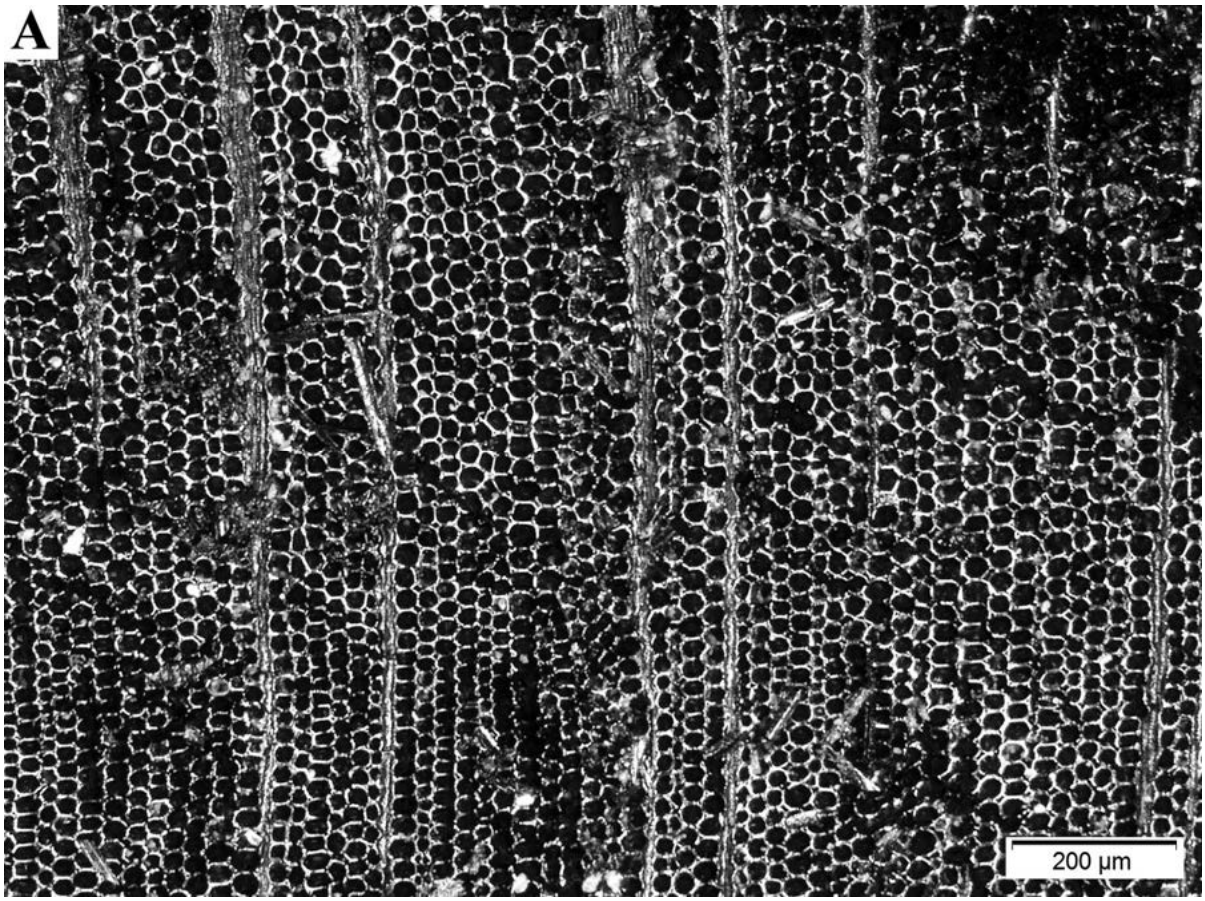
Growth ring boundaries indistinct or absent. **Tracheid** pitting in early wood predominantly uniseriate. Latewood tracheid wall thin-walled. Axial **parenchyma** present. Arrangement of axial parenchyma diffuse. **Ray tracheids** absent or very rare. **Cross-field** pits taxodioid. Number of pits per 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.



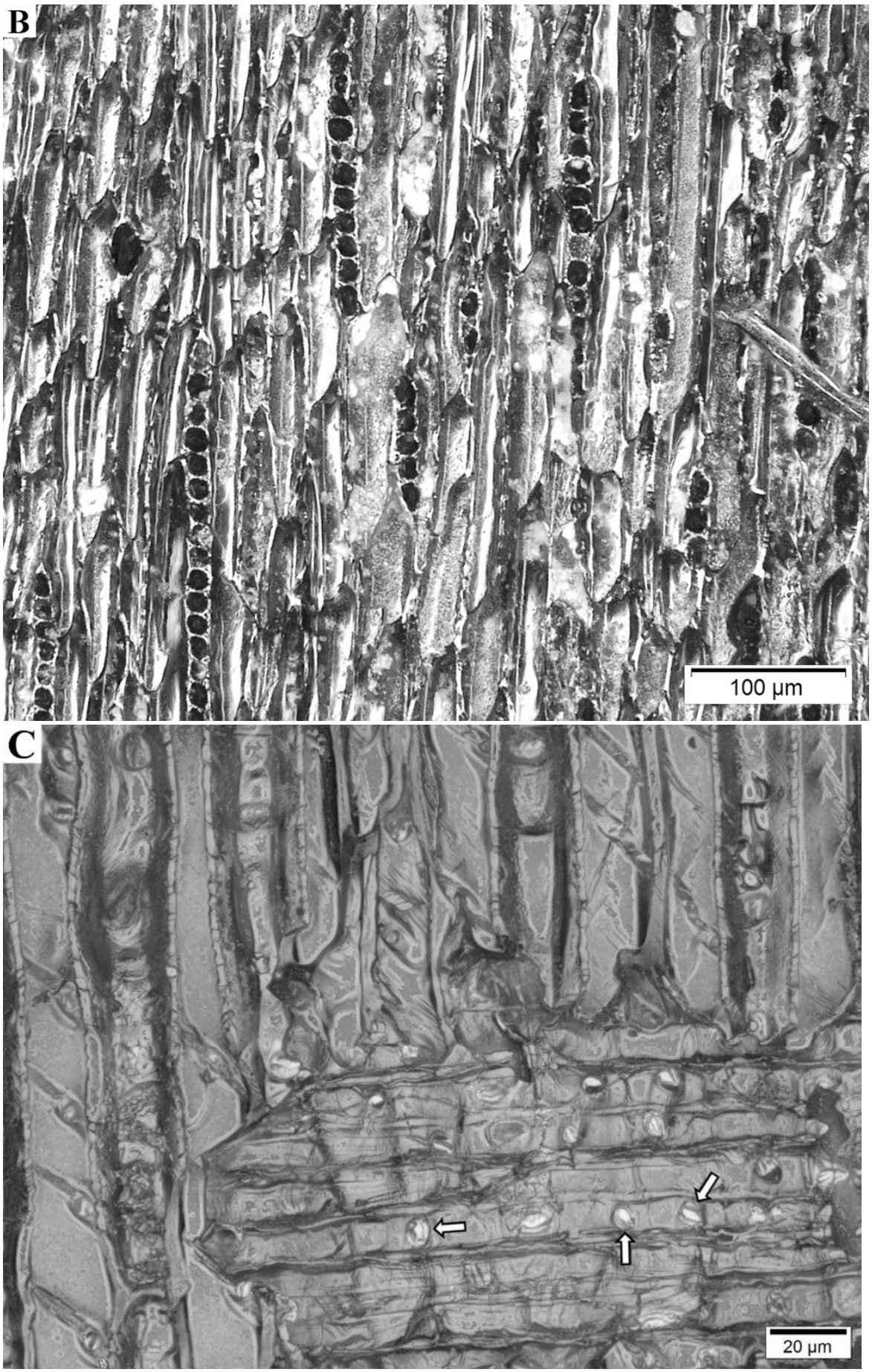


Fig. 11: A) TS: Growth ring indistinct or absent. B) TLS: Rays height up to 15 cells. C) RLS: Cross-field pits taxodioid. Number of pits per field 1-2.

- 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

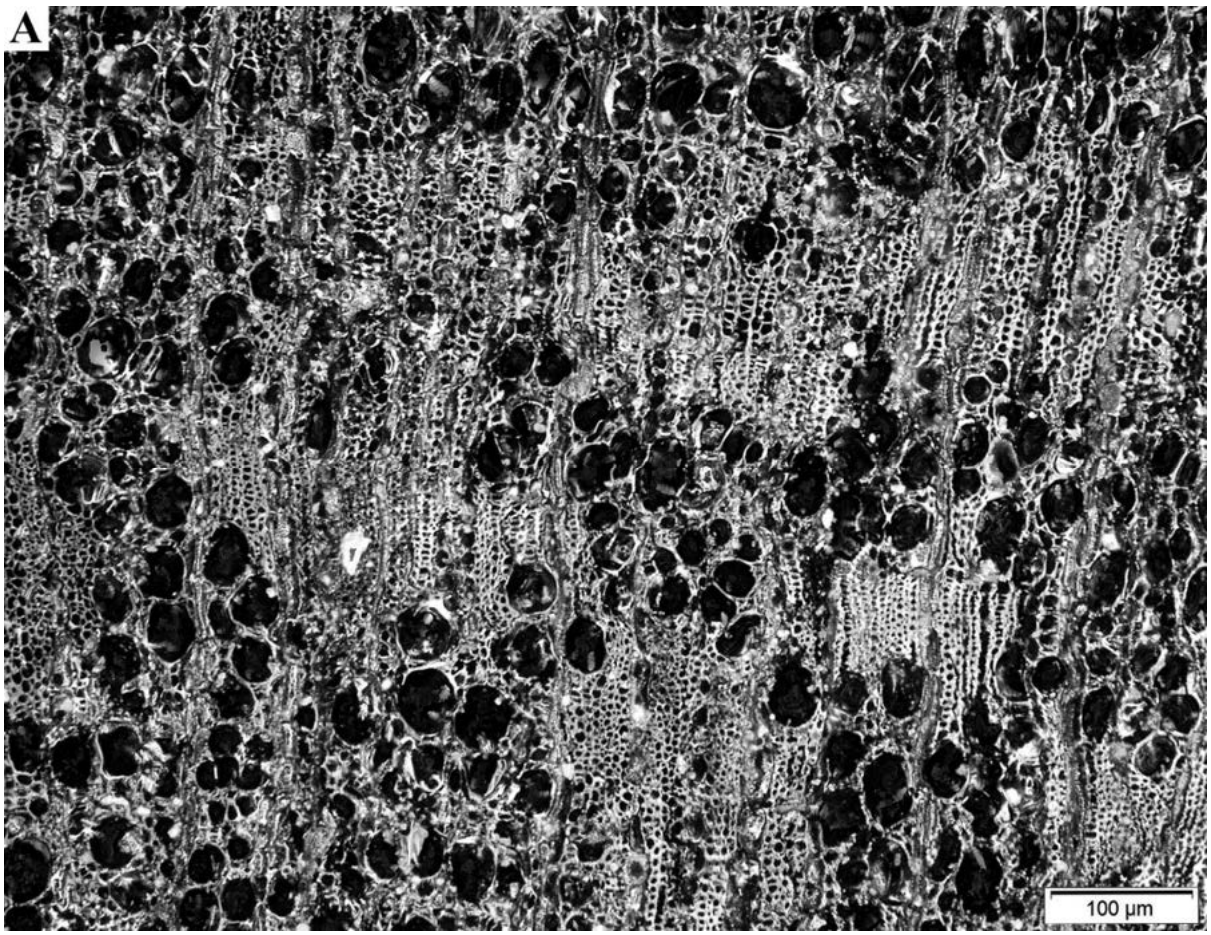
Growth ring boundaries distinct. Wood diffuse-porous to semi-ring-porous. **Vessel** arrangement in dendritic pattern. Vessels in radial multiples of 4 or more common. Vessel clusters common. Simple perforation plates. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel 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.


A
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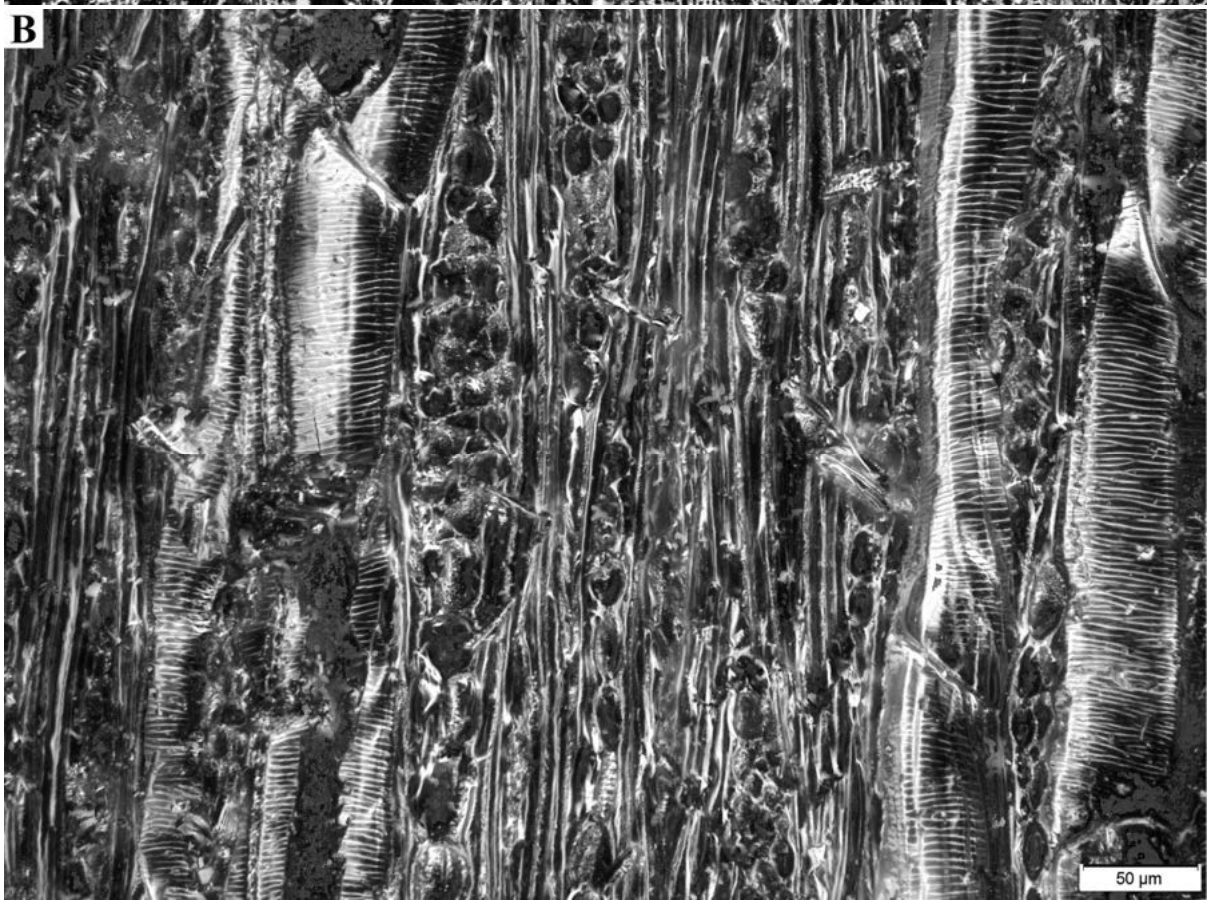

B
50 µm

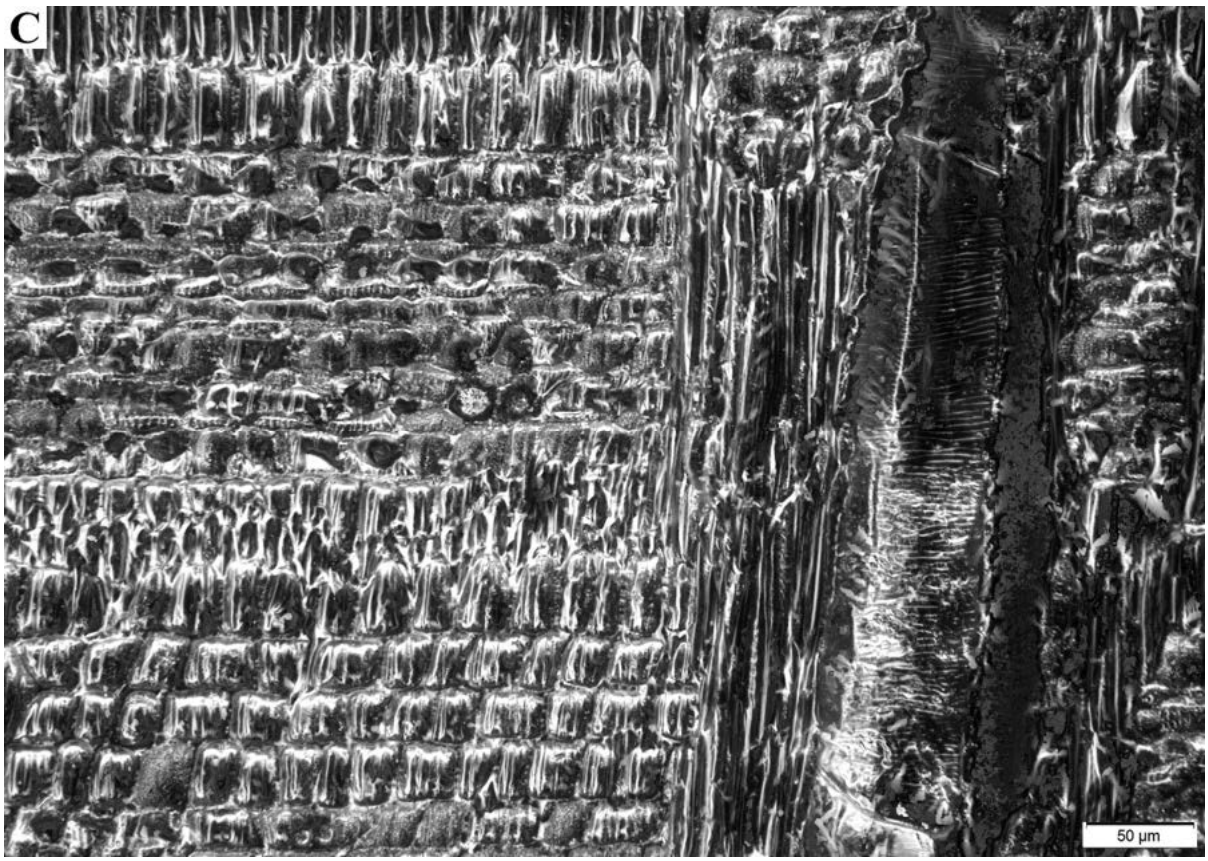


Fig. 12: A) TS: Vessels arranged in a dendritic pattern, of two distinct diameter classes, but always smaller than 50 µm. Axial parenchyma paratracheal scanty to vasicentric. B) TLS: Helical thickenings present. Ray width 1 to 3 cells. C) RLS: Ray structure heterocellular.

- 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

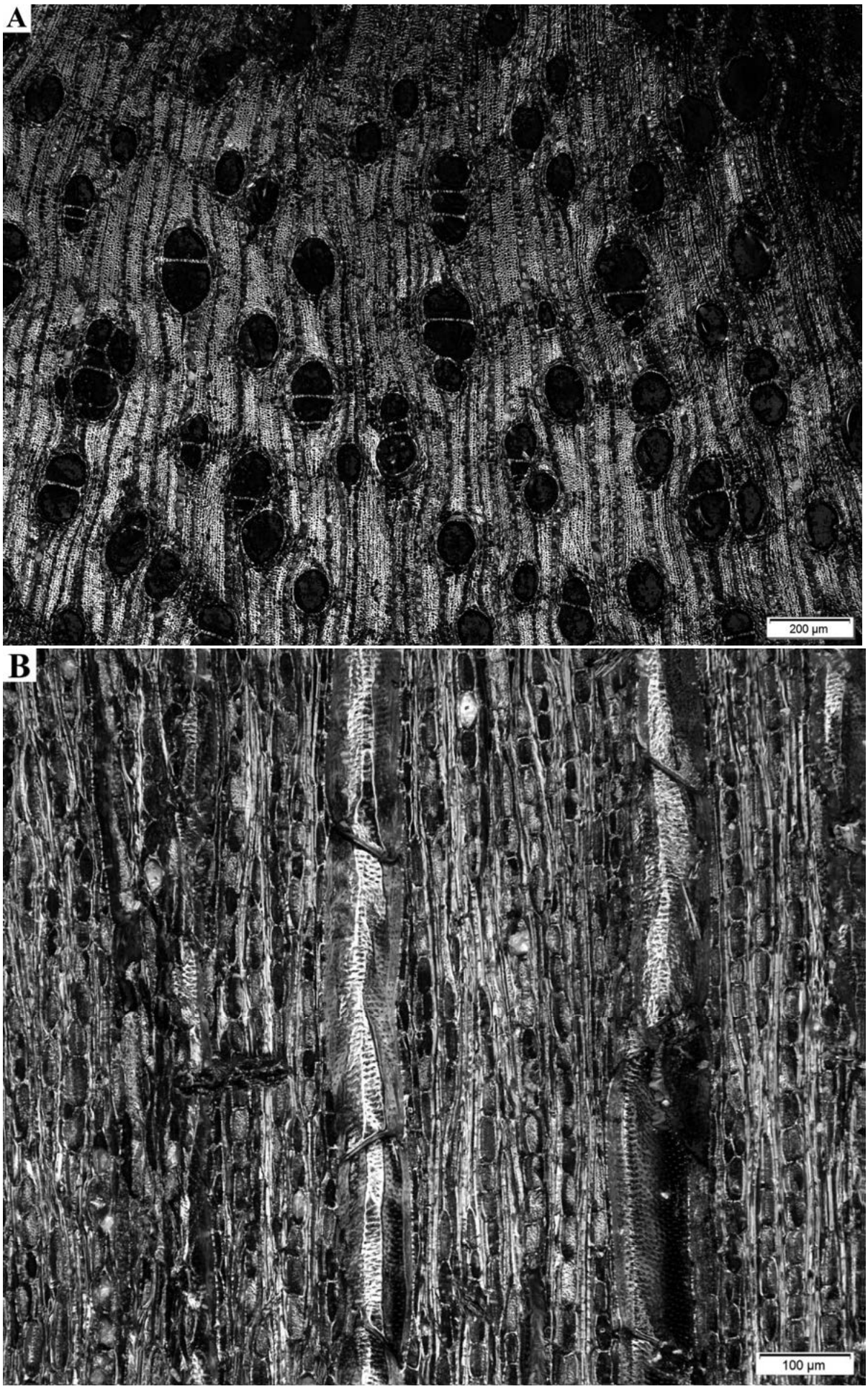
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** generally solitary but sometimes in radial groups of 2-3. Simple perforation plates. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. 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.


A
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B
100 µm

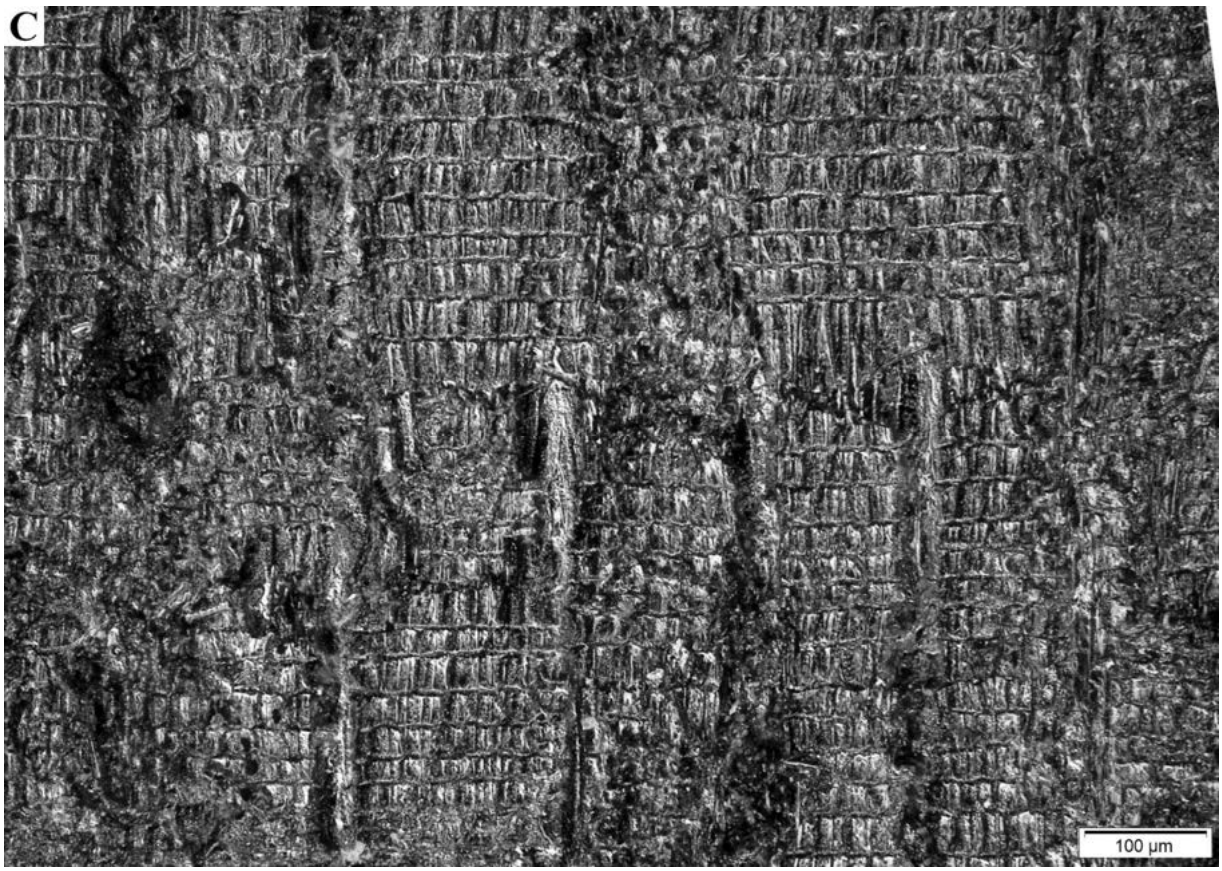


Fig. 13: A) TS: Mean tangential diameter of vessel lumina between 50-100 µm. Axial parenchyma paratracheal vasicentric to aliform and in marginal bands. B) TLS: Rays exclusively uniseriate. C) RLS: Ray structure predominantly homocellular, all ray cells upright and / or square.

- 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

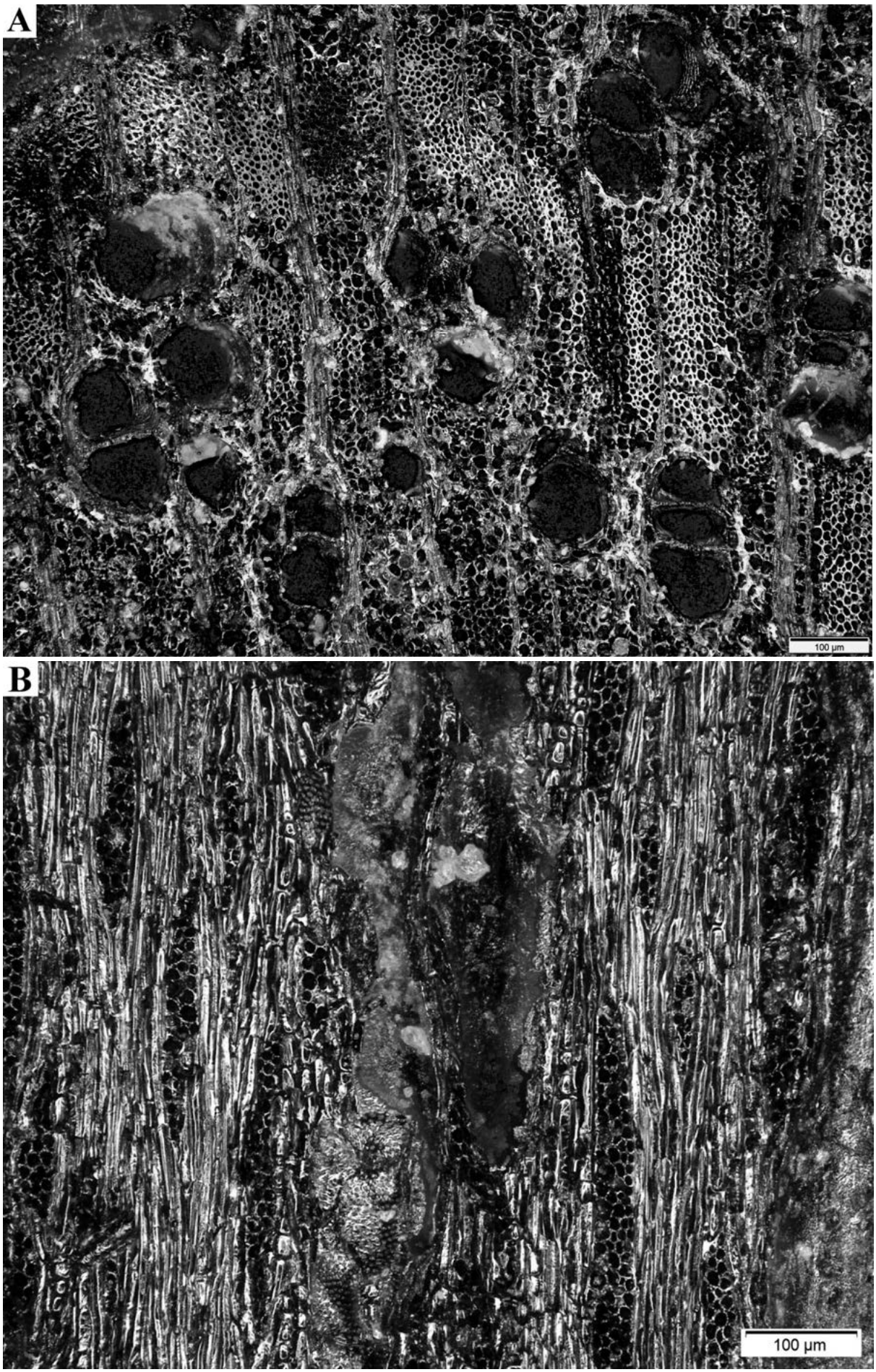
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** sometimes solitary, sometimes in radial groups of 2-3. Vessel clusters common. Simple perforation plates. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout 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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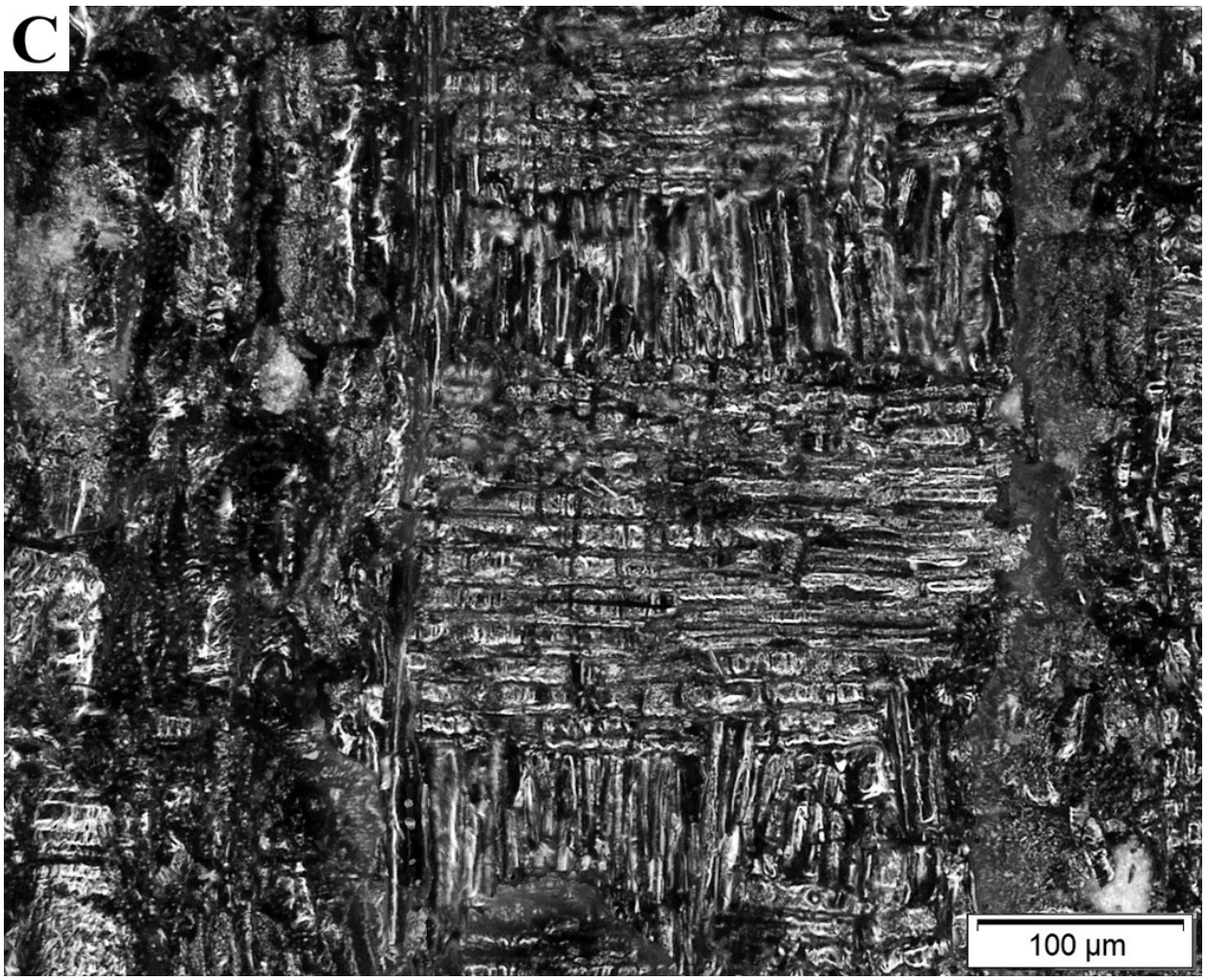


Fig. 14: A) TS: Vessels of two slightly different size classes, with a mean tangential diameter between 100-200 µm, often forming clusters. Axial parenchyma paratracheal scanty. B) TLS: Rays of two distinct sizes, the larger rays being commonly 4 - to 10 seriate. C) RLS: Ray structure homocellular, to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

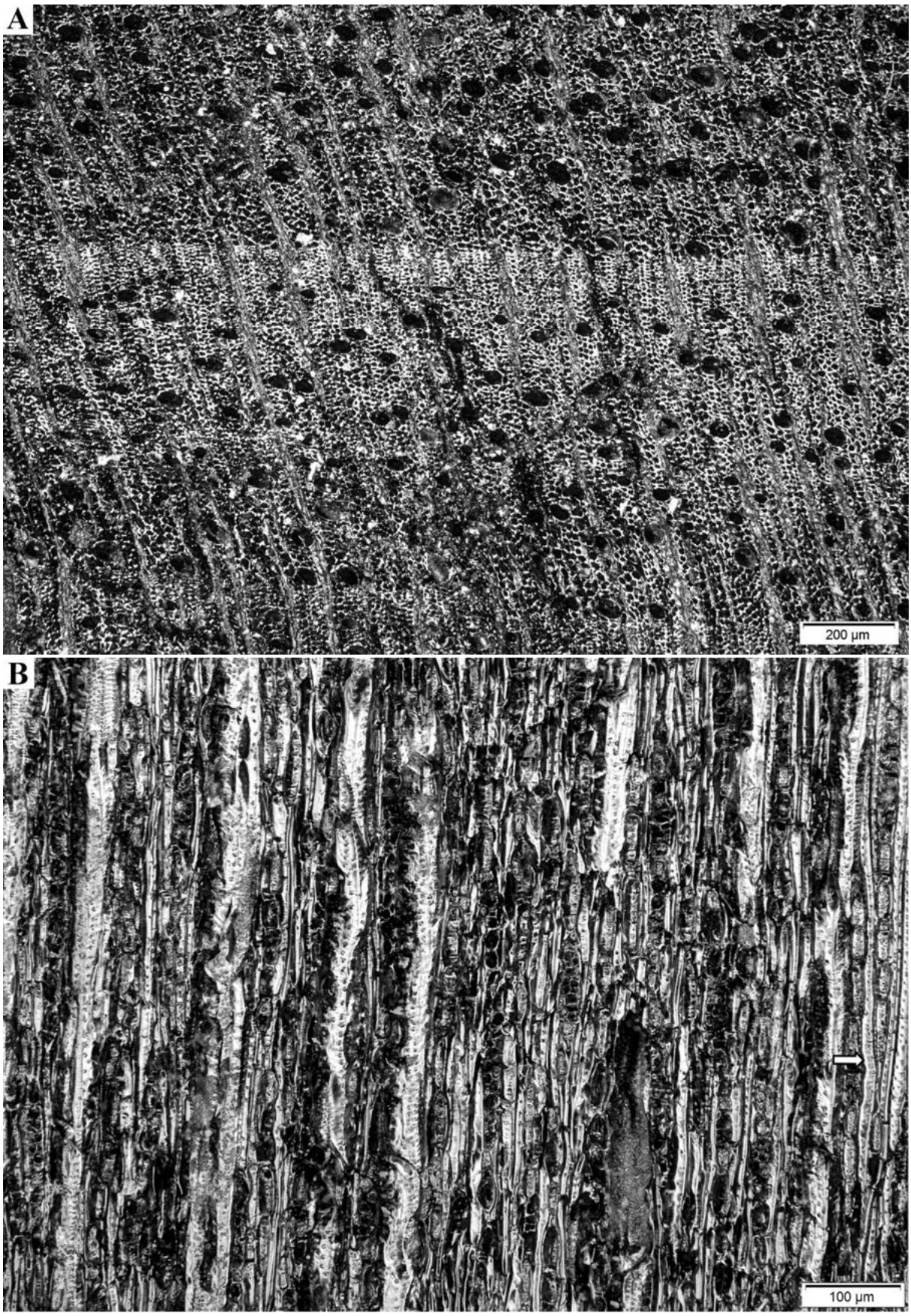
Growth ring boundaries distinct. Wood diffuse-porous. **Vessels** exclusively solitary (90% or more). Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Mean tangential diameter of vessel 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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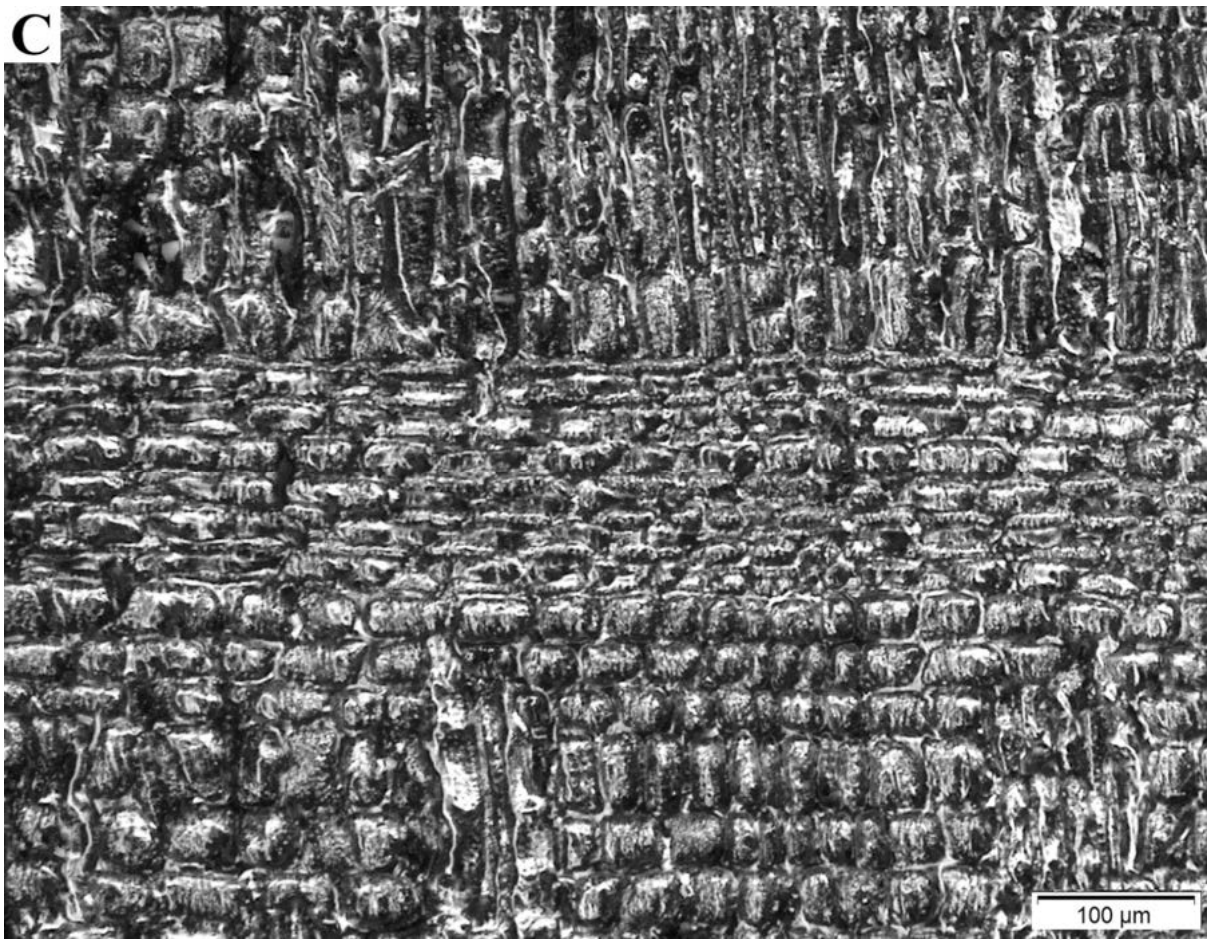


Fig. 15: A) TS: Growth rings distinct. Vessels exclusively solitary, with mean diameter of lumina smaller than 50 µm. B) TLS: Fibres with distinctly bordered pits. Rays width 1 to 3 cells, narrow, with long uniseriate margins. C) RLS: Body ray cells procumbent with 2-4 rows (or more) of upright and /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

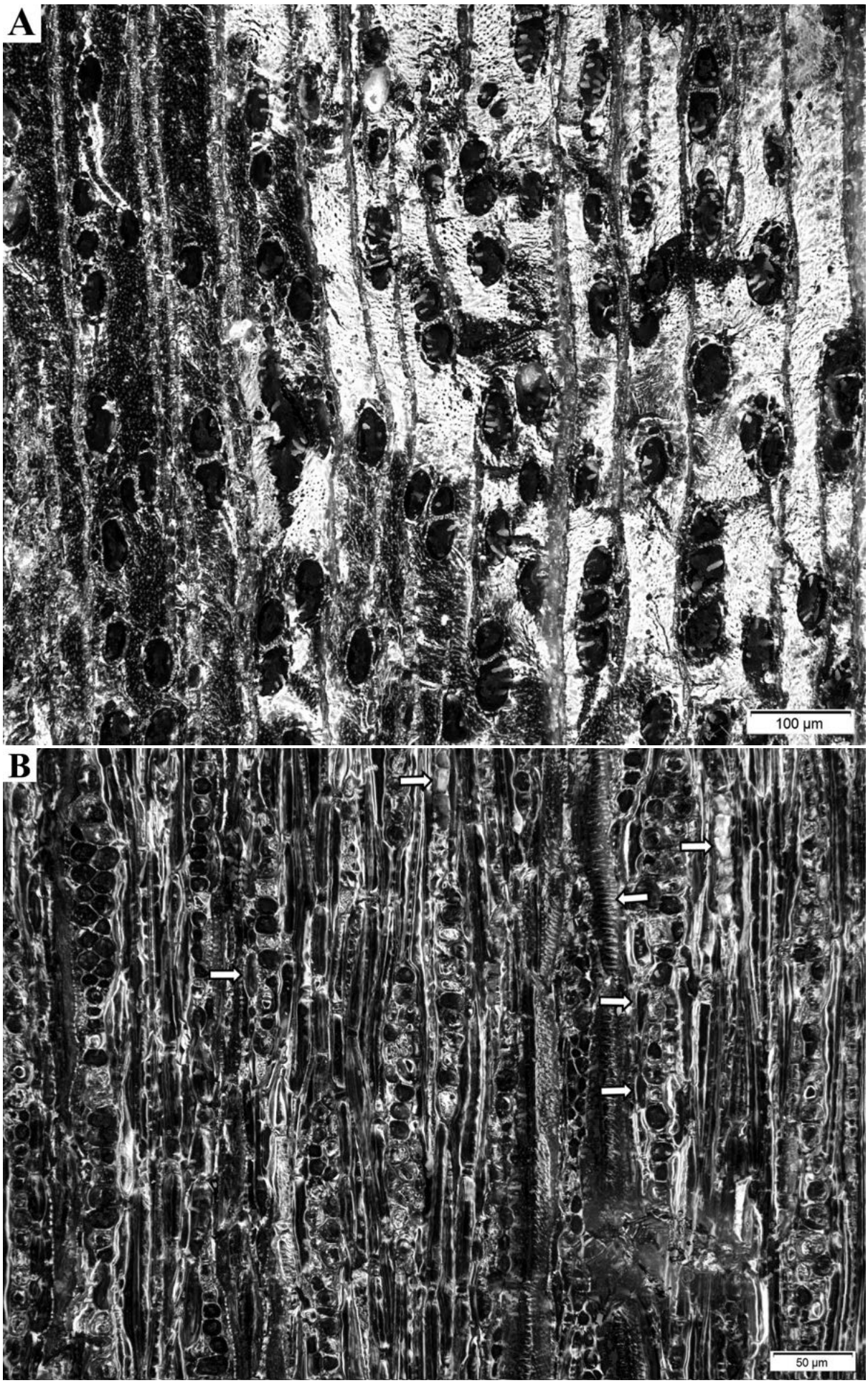
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessel** grouping sometimes in radial groups of 2-4, sometimes solitary. Simple perforation plates. Intervessel pits alternate, coalescent. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout 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.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100 µm
B
50 µm

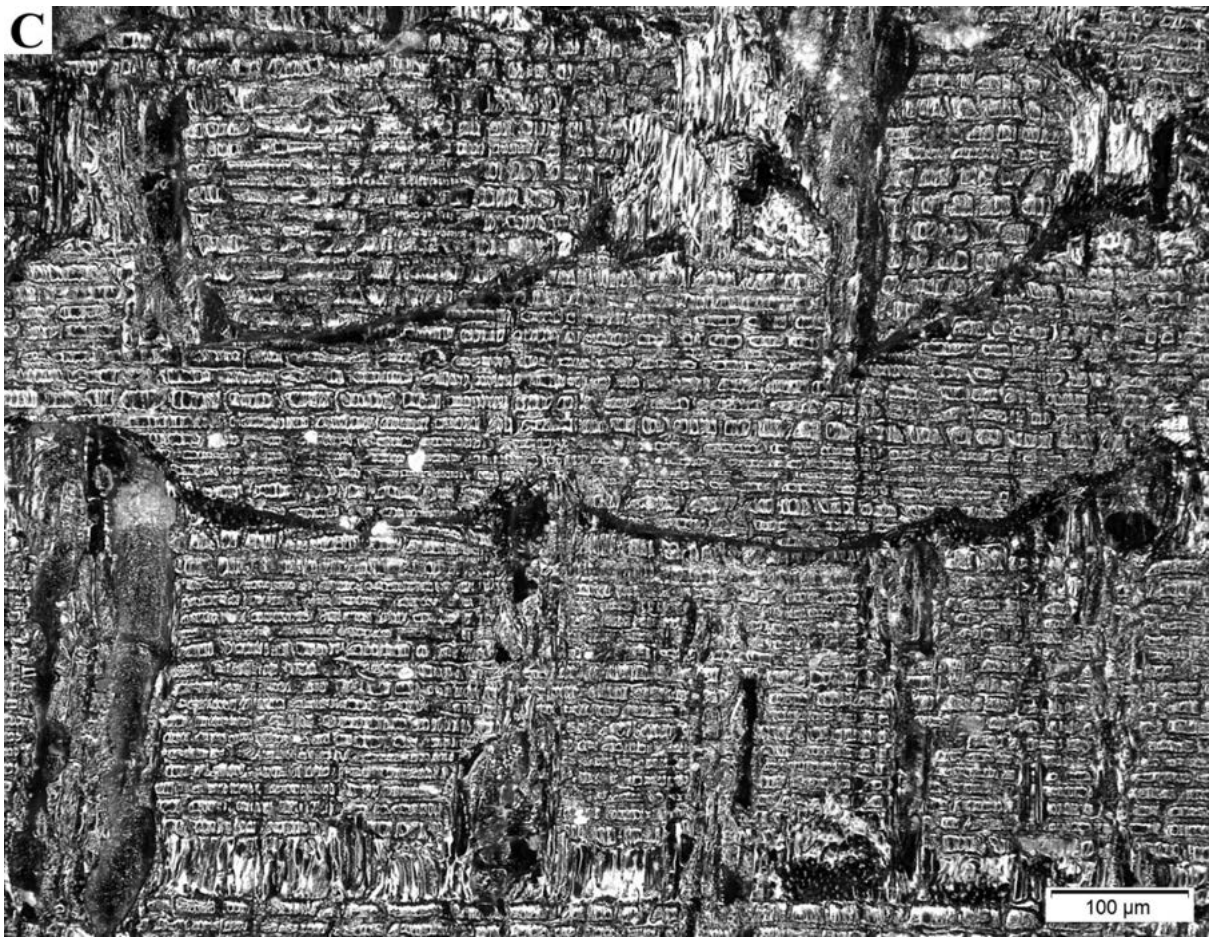


Fig. 16: A) TS: Mean tangential diameter of vessel lumina smaller than 50 µm. Axial parenchyma paratracheal scanty to vasicentric, sometimes forming marginal and discontinuous bands. B) TLS: Sheath cells present. Prismatic crystals in axial parenchyma cells. Intervessel pits coalescent. C) RLS: Homocellular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

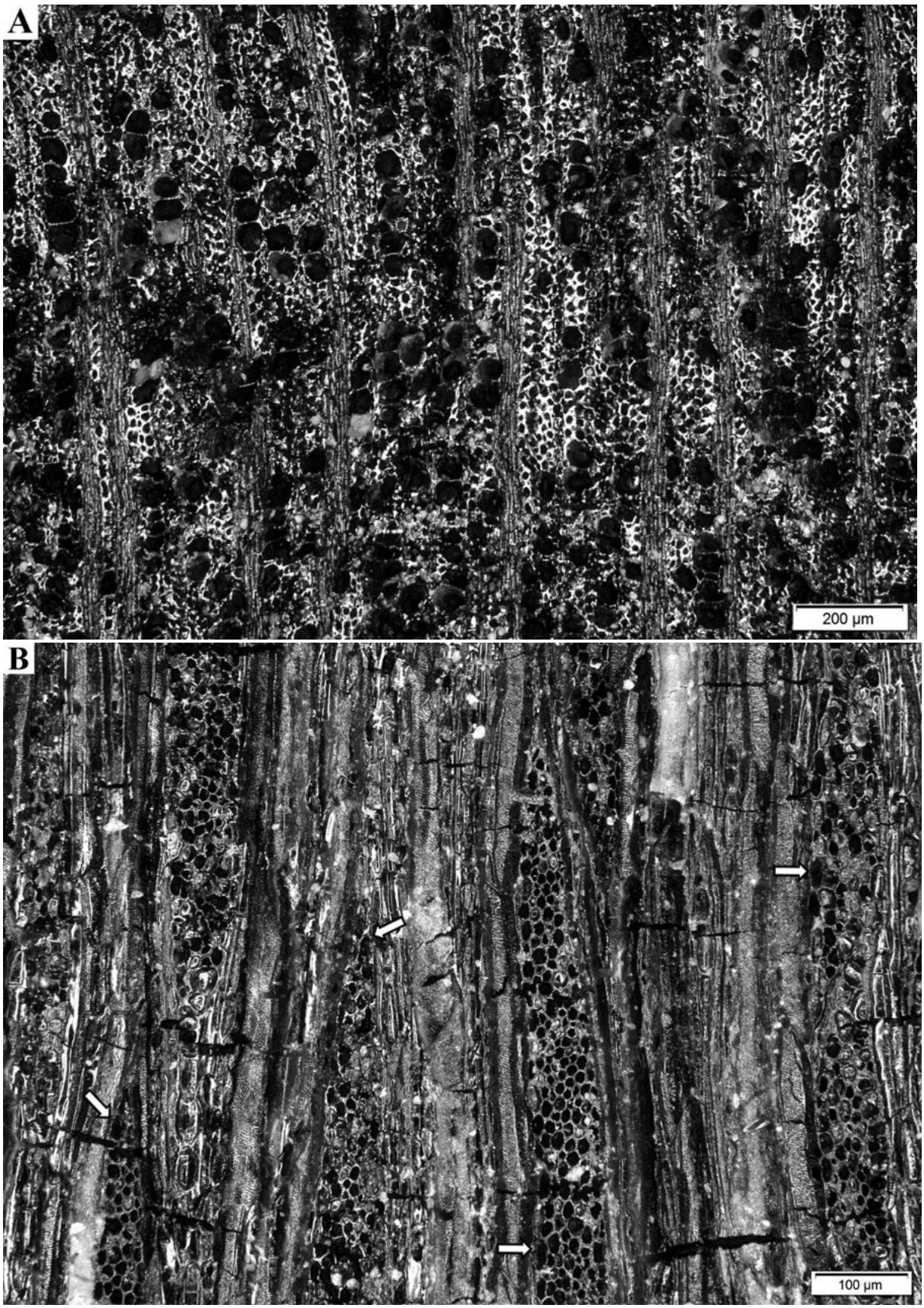
Growth ring boundaries indistinct or absent. Wood diffuse-porous. **Vessels** grouping in radial multiples of 4 or more common. Vessel clusters common. Solitary vessel outline angular. Perforation plates simple. Intervessel pits alternate. Vessel-ray pits with distinct borders; similar to intervessel 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

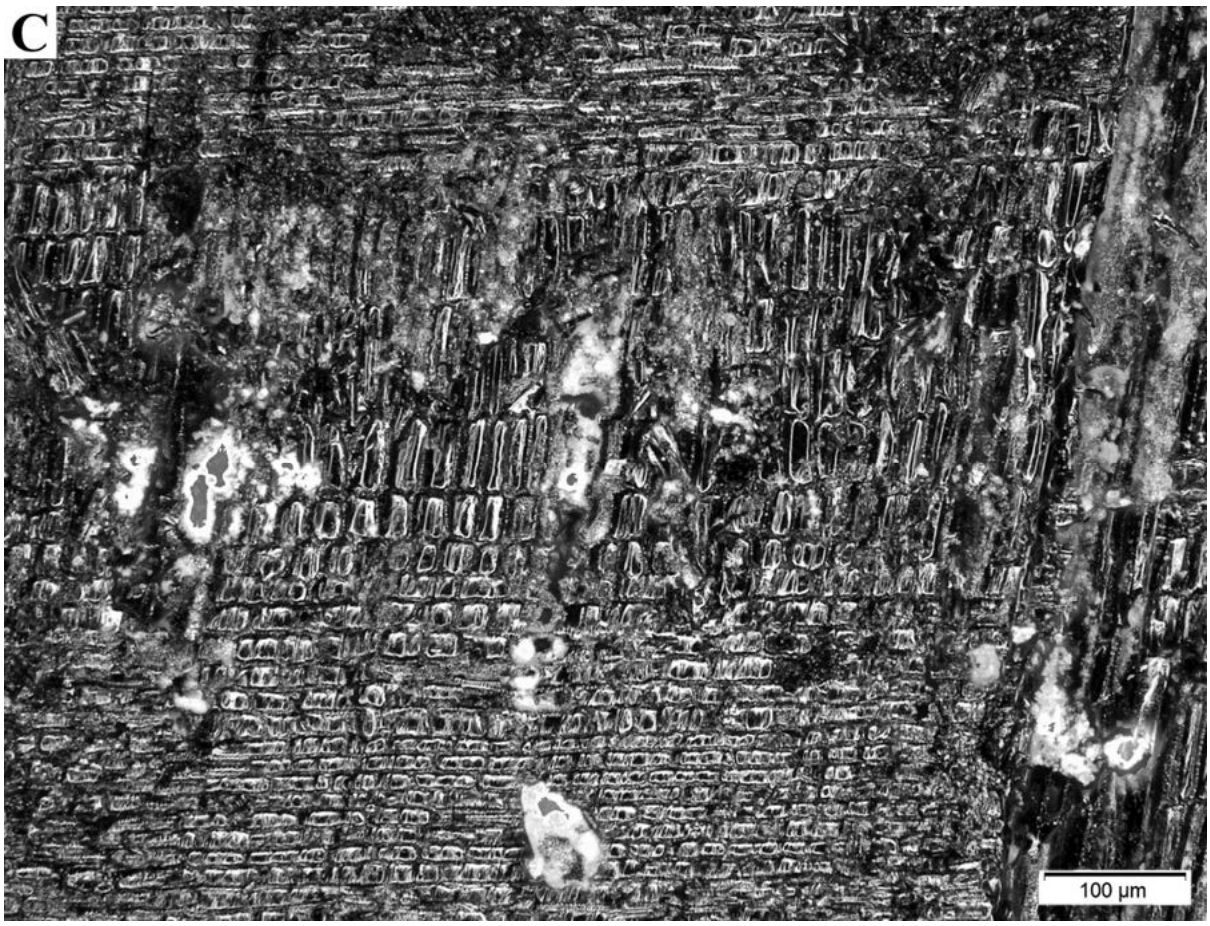


Fig. 17: A) TS: Mean tangential diameter of vessel lumina smaller than 50 µm, not exclusively solitary. B) TLS: Larger rays commonly 4 - to 10 seriate. Rays of two distinct sizes, some very long (larger than 1 mm). Sheath cells present. C) RLS: Heterocellular rays.

- 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).

Acknowledgments

This research has been developed in the framework of the projects Eastern Tigray Archaeological Project (ETAP) and Historical Ecology and Early Social Complexity in the Horn of Africa, founded by the Social Sciences and Humanities Research Council of Canada (Partnership Grant #890-215-003), and with the participation of the Authority for Research and Conservation of Cultural Heritage (ARCCH) and the Tigray Tourism and Cultural Commission. Also, we are grateful for the financial contribution of the French Minister of External Affairs (AVENIR Excellence Grant),

as well as for the economic support of the Erasmus+ programme of the European Union (Erasmus + Scholarship). Many thanks are due to Dr. Margareta Tengberg (Muséum National d'Histoire Naturelle) for granting access to the wood collection of the Muséum National d'Histoire Naturelle (Paris), as well as to the residents of the Gulo Makeda district (Tigray, Ethiopia) for their help, hospitality and participation in all ETAP excavations. ARG is a member of CaSEs, an excellence group of the Generalitat de Catalunya (SGR-0122) and Unidad Asociada of the Spanish National Research Council (IMF_CSIC), and is developing his work within the RAINDROPS Research Project (ERC-Stg2017 G.A. 759800).

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

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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ESM2: Indexes used for analysis

Throughout the analyses, various indexes and ratios were employed. In order to evaluate the taphonomic variations in our assemblage we employed various indexes and ratios:

- Fragmentation/Preservation index (F/P): shows the proportions of indeterminate vs. determinate fragments in a sample. It is used to evaluate taphonomic impact in the samples and it is evaluated comparatively rather than absolutely (Lancelotti 2010).
- Alterations rates: expressed as a percentage of the number of fragments in which a specific type of alteration occurs, over the total of fragments. Calculated rates include the percentages of compression wood as well as the ratio of alterations caused by biological –including the presence of collapsed cells, xylophage activity and fungi invasion– combustion –including the presence of radial cracks and vitrification– and post-depositional agents –including cracks, cell structure deformation and post-depositional degradation (Allue et al. 2009, 2016).
- Density index (Di): expressed as the total weight of charcoal material per litre of floated sediment (Lancelotti 2010). Density measurements provide comparative data and can be a tool for a first assessment of taphonomic processes over the samples when combined with other indices (Asouti 2003).

Regarding the measurement of assemblage biodiversity and taxa distribution, the following indexes and rates were applied:

- Simpson's Diversity Index (D): shows the presence and distribution of a specific taxon in the sample through the formula: $D=1-(\Sigma n(n-1)/N(N-1))$

  where n is the total number of remains of one taxon and N the total number of remains in the sample (Branch et al. 2005). The result is comprised between 0 and 1 with values closer to 0 representing higher homogeneity and values closer to 1 representing higher diversity. This formula can be used to distinguish between generalized and specialized assemblages (Asouti 2003).

- Pielou's evenness index (J): measures how equal in numbers are the species of a community in a given environment through the formula: $J=H/Hmax$

  where H is the number derived from the Shannon diversity index (see below) and Hmax is the maximum possible value of H –that is, if every species was equally likely (Pielou 1966).
- The Shannon Diversity index (H): calculated through the formula: $H = -\Sigma\, p(\ln p)$

where p is the numeric relation between the total number of remains of one taxon and the total number of remains in the sample (Branch et al. 2005).

- Ubiquity rate: expresses as a percentage the number of samples in which a specific taxon occurs, over the total number of samples (Lancelotti 2010). This can be done over the total number of samples as well as dividing the samples into contexts (Miller 1988, Popper 1988, Asouti 2003). Ubiquity is comparative and not absolute so the values each taxon make sense only when compared with other values for the same taxon (Lancelotti 2010).

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References

Allue, E., Euba, I., & Sole, A., (2009). Charcoal taphonomy: the study of the cell structure and surface deformation of Pinus sylvestris type for the understanding of formation processes of archaeological charcoal assemblages. Journal of Taphonomy, 7(2-3), 57-72.

Allué, E., Solé, A., & Burguet-Coca, A. (2016). Fuel exploitation among Neanderthals based on the anthracological record from Abric Romaní (Capellades, NE Spain). Quaternary International, 431, 6-15.

Asouti, E. (2003). Woodland vegetation and fuel exploitation at the prehistoric campsite of Pinarbas I, south-central Anatolia, Turkey: the evidence from the wood charcoal macro-remains. Journal of Archaeological Science, 30(9), 1185-1201.

Branch, N., Clark, P., Canti, M., & Turney, C. (2005). Environmental archaeology: Theoretical and practical approaches. London: Hodder Arnold.

Lancelotti, C. (2010). Fuelling Harappan hearths: human-environment interactions as revealed by fuel exploitation and use (Doctoral dissertation). University of Cambridge, Cambridge.

Miller, N. F. (1988) Ratios in palaeoethnobotanical analysis. In V.S. Popper & C.A. Hastorf (Eds.), Current Paleoethnobotany (pp.72-85). Chicago: The Universiy of Chicago Press.

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. Journal of Theoretical Biology 13, 131–144.

Popper, V. S. (1988) Selective quantitative measurements in paleoethnobotany. In V.S. Popper, & C. A. Hastorf (Eds.), Current Paleoethnobotany (pp. 53-71). Chicago: University of Chicago Press.

Site	Phase	SN#	Charcoal size			Natural alterations		Biological alterations			Combustion alterations		Diagenetic alterations	
			<5 mm	5 to 10 mm	over 10 mm	Tree ring alteration	Wood compression	Collapsed cells	Xylophagues activity	Fungi alteration	Radial cracks	Vitrification	Cell structure deformation	Post-depositional alterations
Mezber	Initial Pre-Aksumite	1126	26	0	0	0	0	0	0	0	3	9	0	7
Mezber	Initial Pre-Aksumite	1337	131	0	0	0	0	0	0	0	9	21	0	23
Mezber	Initial Pre-Aksumite	1345	75	0	0	0	1	0	1	0	3	13	0	15
Mezber	Early Pre-Aksumite	1585	66	27	10	0	0	1	4	0	13	19	5	29
Mezber	Early Pre-Aksumite	1908	84	22	2	0	0	0	0	0	14	37	0	21
Mezber	Early Pre-Aksumite	2106	88	13	3	0	0	0	0	0	16	31	0	30
Mezber	Middle Pre-Aksumite	2096	86	15	4	0	3	2	17	0	26	44	5	45
Mezber	Middle Pre-Aksumite	2102	44	24	9	0	1	2	2	0	18	39	3	18
Mezber	Middle Pre-Aksumite	2110	81	45	2	0	0	0	3	0	22	18	0	27
Mezber	Late Pre-Aksumite	18	37	4	0	0	0	0	0	0	9	15	0	2
Mezber	Late Pre-Aksumite	20	252	12	1	0	0	1	0	0	43	77	6	47
Ona Adi	Late Pre-Aksumite	1127	39	3	0	0	1	2	0	0	6	13	5	34
Ona Adi	Late Pre-Aksumite	1139	52	0	0	0	0	0	0	0	4	20	0	25
Ona Adi	Late Pre-Aksumite	1163	175	35	1	0	0	1	0	10	15	73	4	74
Ona Adi	PA-A Transition	769	90	17	0	0	7	3	2	2	38	42	22	86
Ona Adi	PA-A Transition	1131	90	10	2	0	1	0	0	0	10	40	2	47
Ona Adi	PA-A Transition	1157	90	11	0	0	0	0	0	0	15	18	0	21
Ona Adi	Early Aksumite	1106	95	9	0	0	0	0	0	0	25	21	0	24
Ona Adi	Early Aksumite	1110	73	29	3	0	0	1	0	0	23	18	2	28
Ona Adi	Early Aksumite	1118	90	18	2	0	2	7	2	0	24	38	6	51
Ona Adi	Middle Aksumite	811	90	12	1	0	2	4	1	1	14	29	5	46
Ona Adi	Middle Aksumite	818	91	13	1	0	0	0	0	0	9	34	0	49
Ona Adi	Middle Aksumite	843	85	11	1	0	0	2	0	0	10	24	3	27
Ona Adi	Late Aksumite	711	133	15	3	0	0	1	0	1	41	59	2	37
Ona Adi	Late Aksumite	722	112	40	3	0	3	8	1	0	26	33	12	33

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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SM3 – Quantitative and qualitative curves. Gini-Lorenz index.

Two procedures were followed in relation to the effort curves in order to assess the qualitative and quantitative representation of the assemblage in relation to the original deposit (Duque 2004): the former was evaluated by plotting the total number of charcoal specimens analyzed against the floristic diversity found in the assemblage (taxonomic curve), while the latter was tested by plotting the relative frequencies of identified taxa against the number of analyzed charcoal fragments (quantitative curve). In both cases, the assemblages must draw a saturation curve in order to be considered representative (Asouti and Austin 2005); that is, they need to be represented as an exponential function where both the number of taxa and their relative frequencies rise sharply as the first charcoal specimens are examined and then stabilizes as more fragments are identified (Chabal et al. 1999).

The Gini-Lorenz index measures the ecological representativeness of the assemblage (Asouti and Austin 2005). This is achieved by calculating the ratio between the frequency of each taxa and the number of taxa in a given assemblage, hence giving a measure of how the rank and proportion of taxa are represented (Dotte-Sarout et al. 2015) −*e.g.* 20% of the taxa are represented in 80% of the fragments or plants present. The observation of the Gini-Lorenz index allows comparisons to ecological references, which have established proper representation of given vegetation formation at 20:80 in temperate regions and 25:75 in tropical regions (Chabal et al. 1999; Scheel-Ybert 2005). Out of these parameters the assemblage is to be considered not representative of the past ecological context. Instead, when the index shows a separation trend (*e.g.* 10:90), it is to be interpreted as a result of strategies of firewood selection by species, whereas approximation trends (*e.g.* 40:60) have been considered to represent imbalance in the vegetation formation (Chabal 1997; Duque 2004).

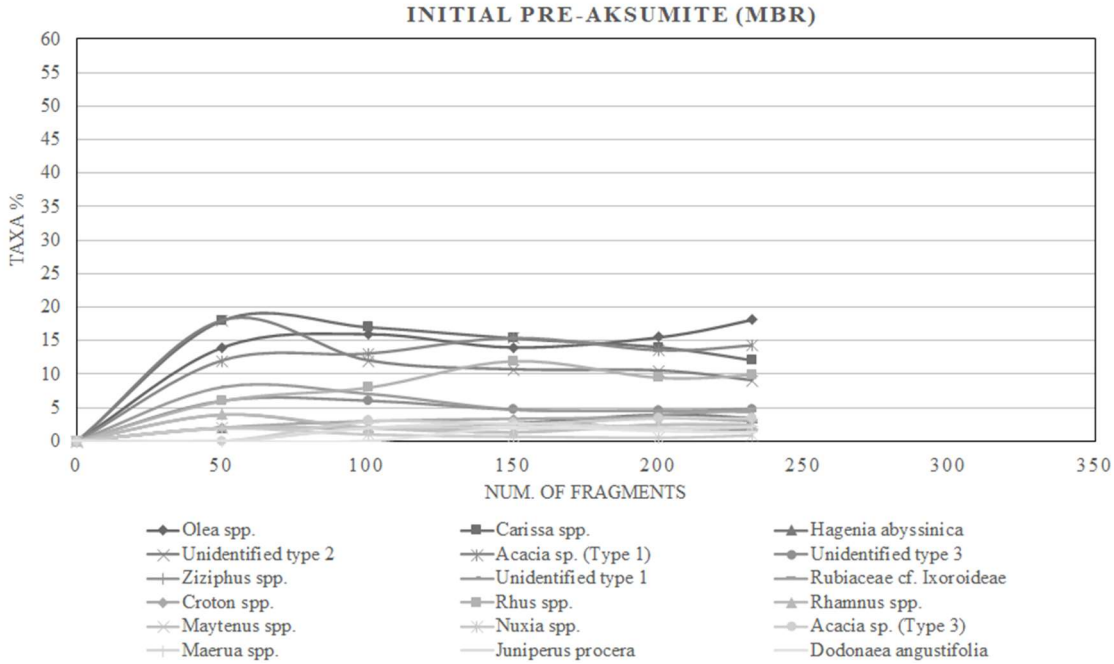

Fig. 1 Quantitative saturation curve from the Initial Pre-Aksumite phase at Mezber.

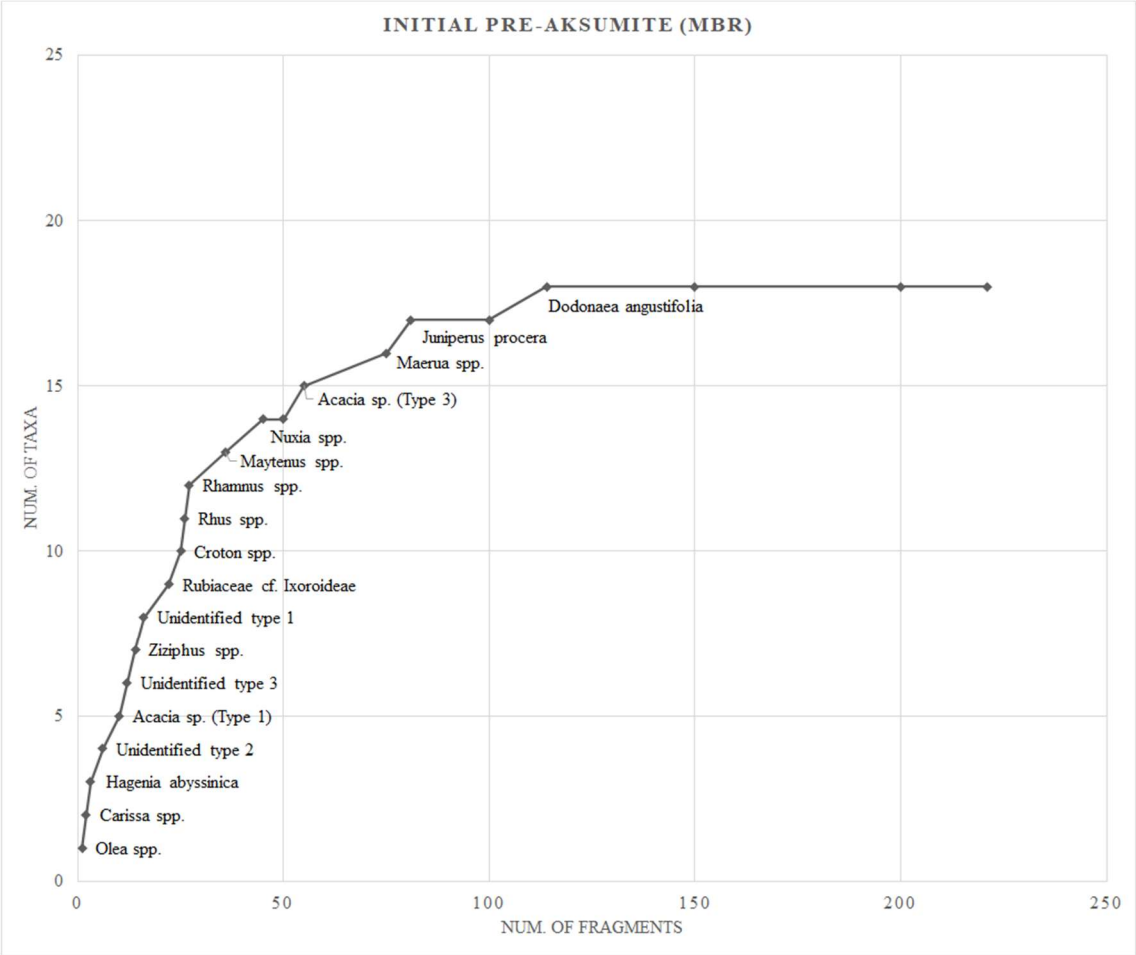

Fig. 2 Taxonomic saturation curve from the Initial Pre-Aksumite phase at Mezber.

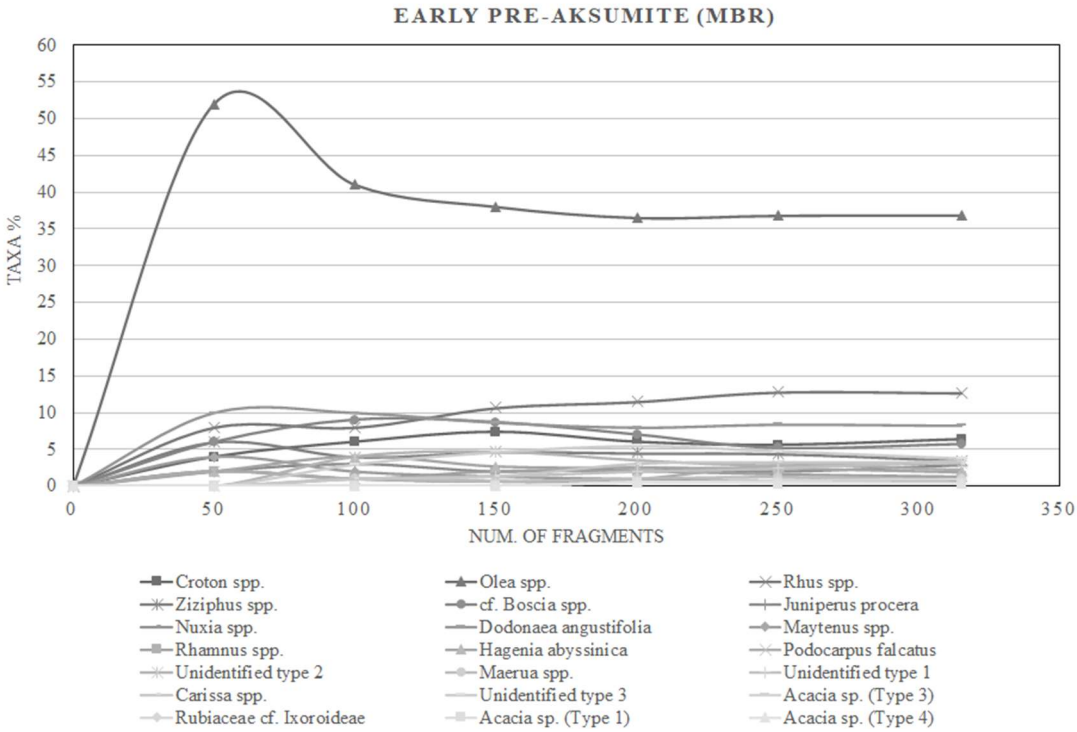

Fig. 3 Quantitative saturation curve from the Early Pre-Aksumite phase at Mezber.

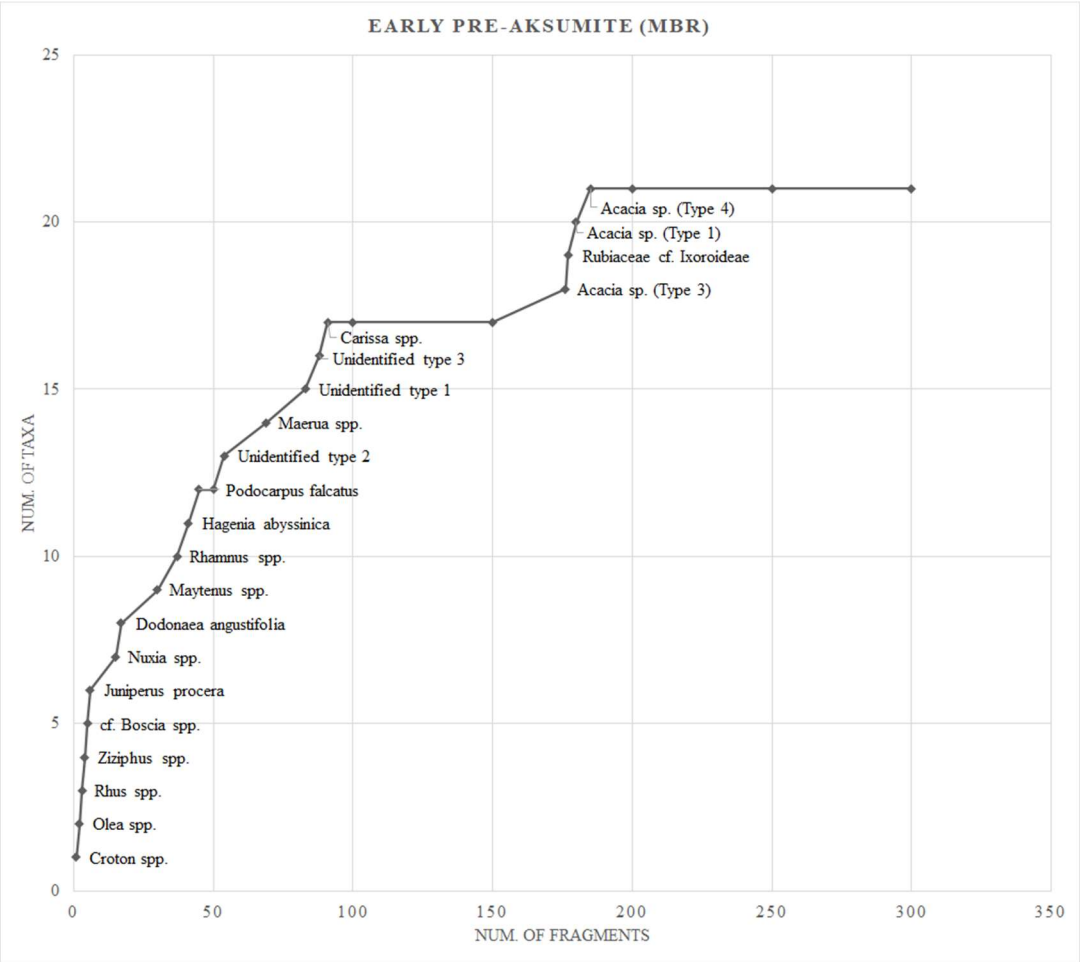

Fig. 4 Taxonomic saturation curve from the Early Pre-Aksumite phase at Mezber.

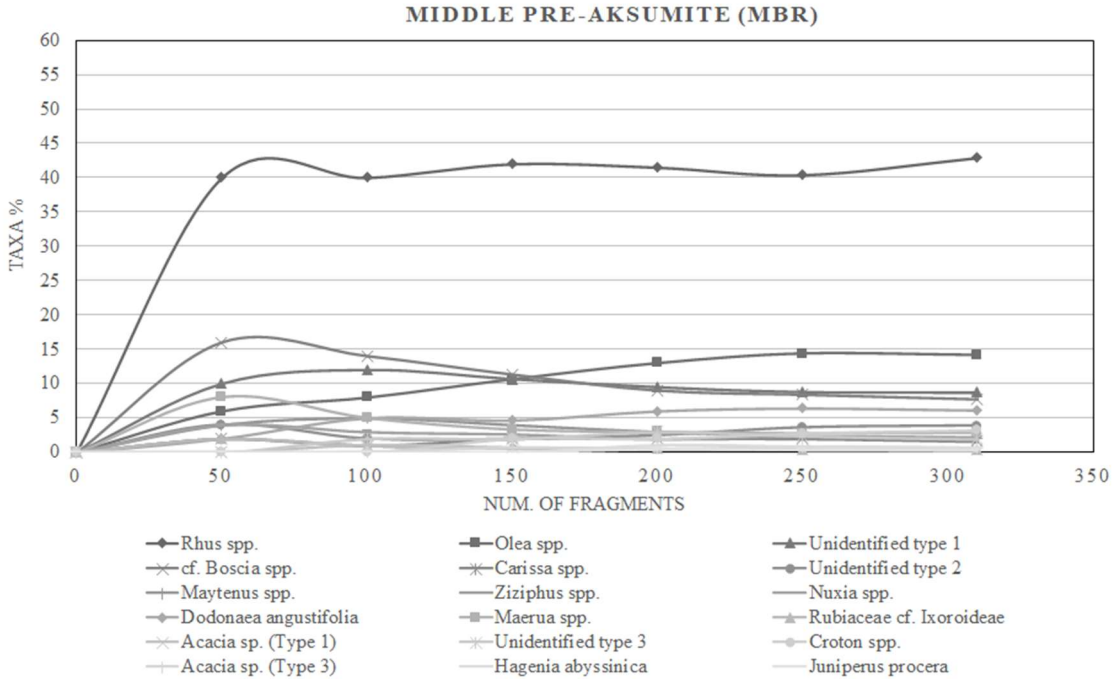

Fig. 5 Quantitative saturation curve from the Middle Pre-Aksumite phase at Mezber.

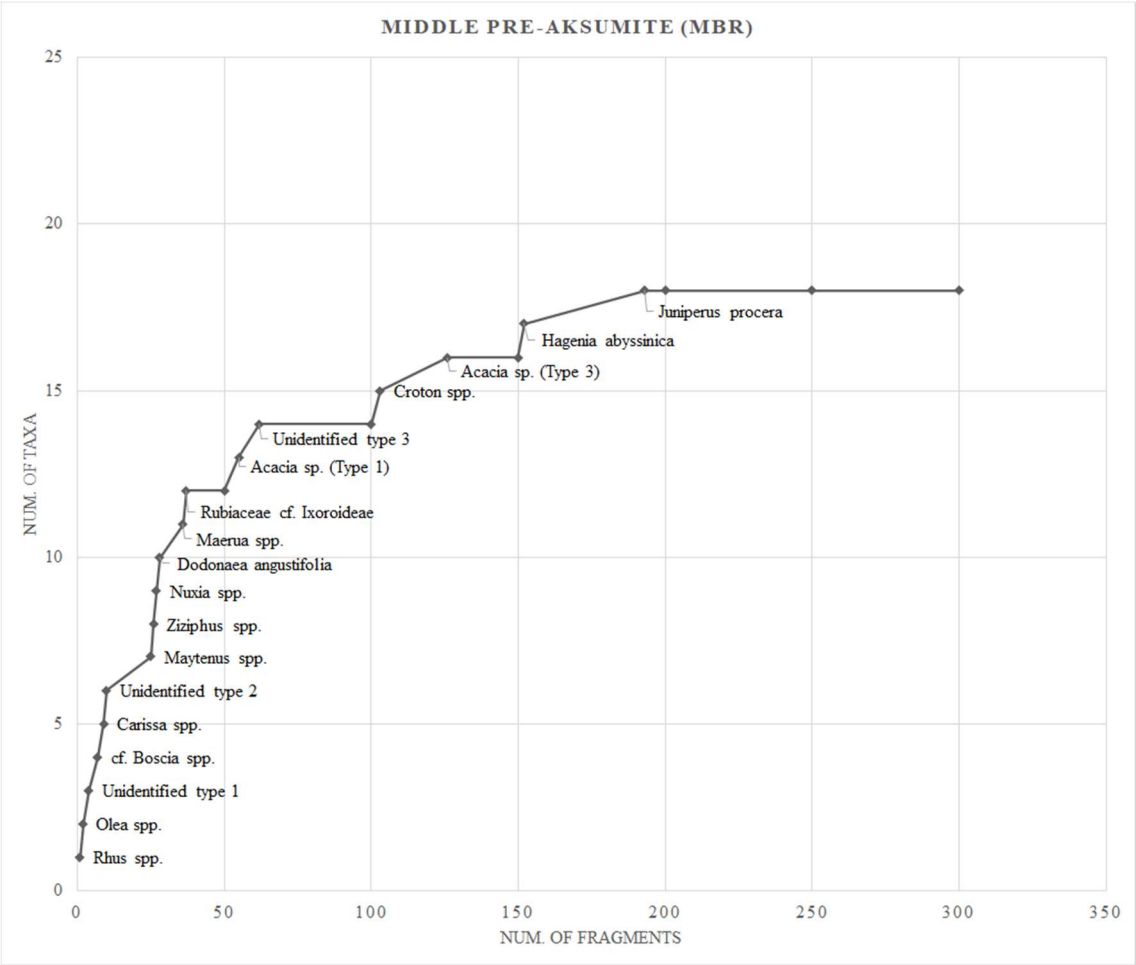

Fig. 6 Taxonomic saturation curve from the Middle Pre-Aksumite phase at Mezber.

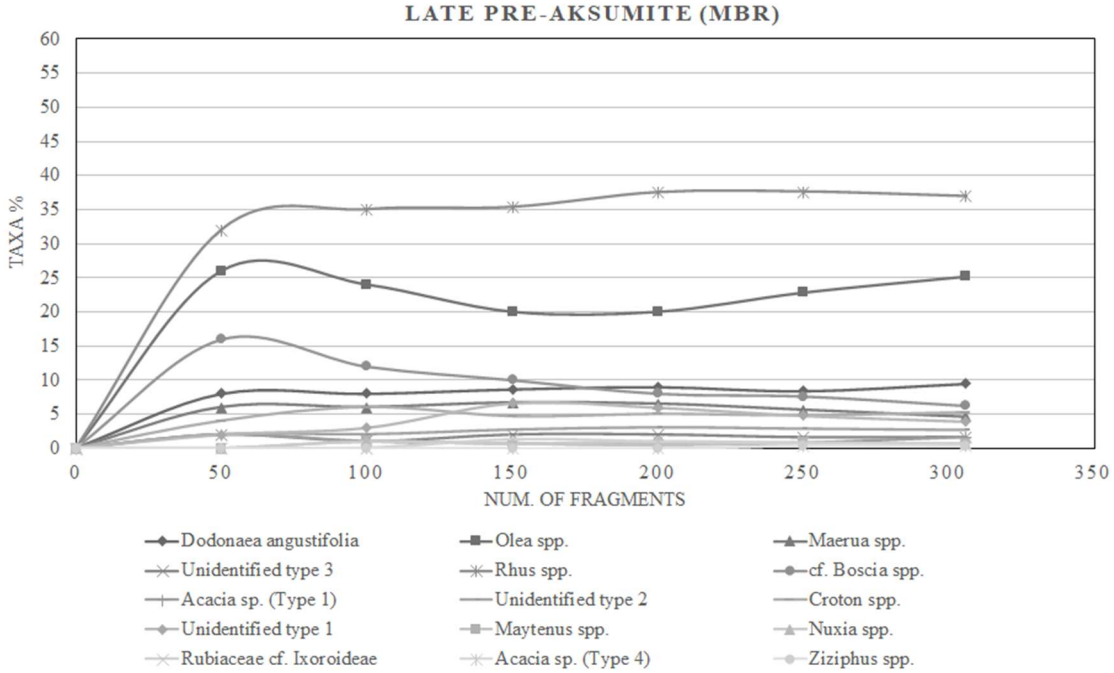

Fig. 7 Quantitative saturation curve from the Late Pre-Aksumite phase at Mezber.

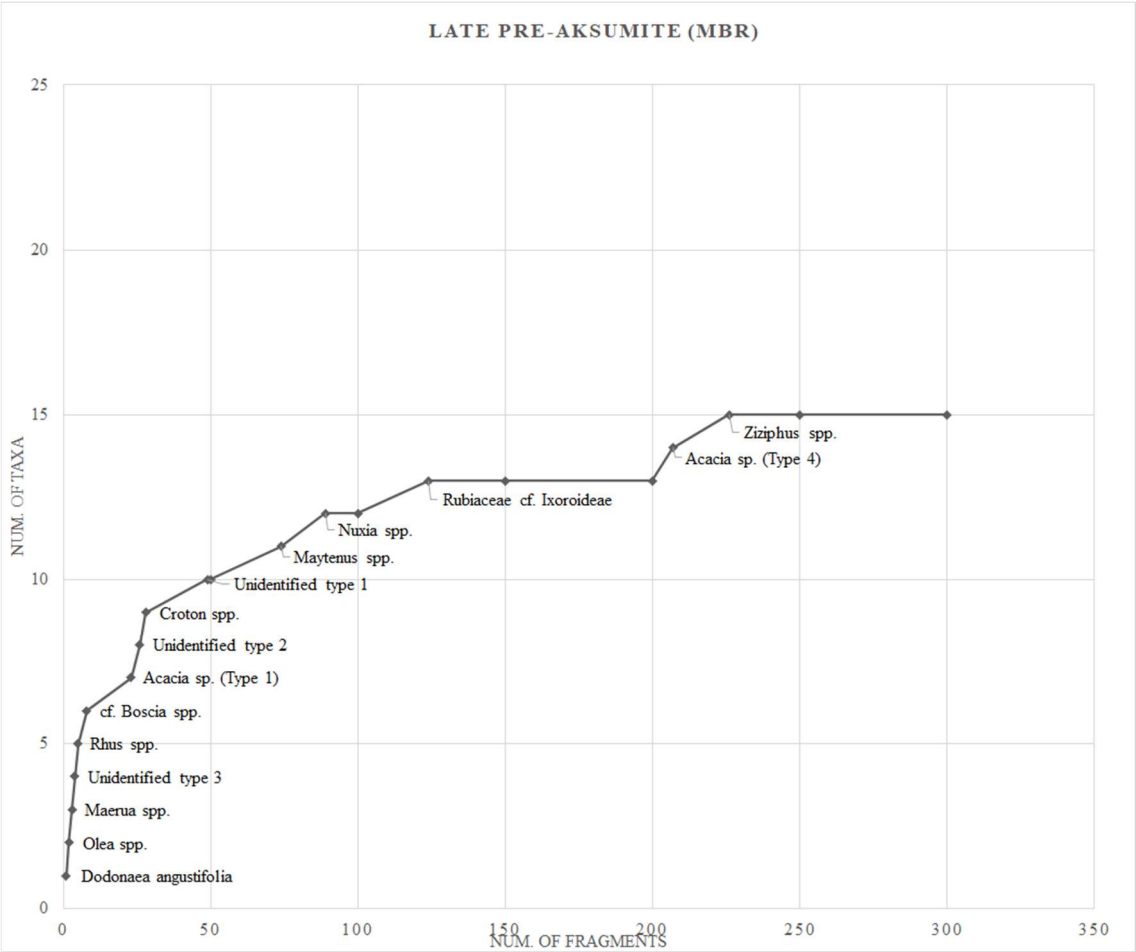

Fig. 8 Taxonomic saturation curve from the Late Pre-Aksumite phase at Mezber.

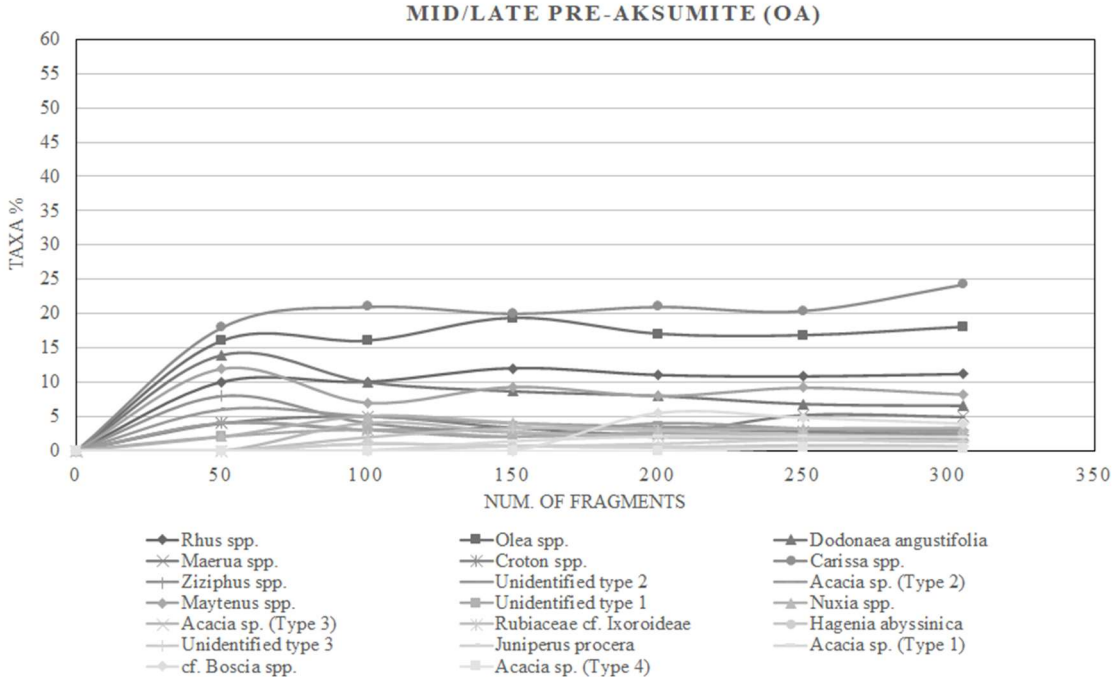

Fig. 9 Quantitative saturation curve from the Mid/Late Pre-Aksumite phase at Ona Adi.

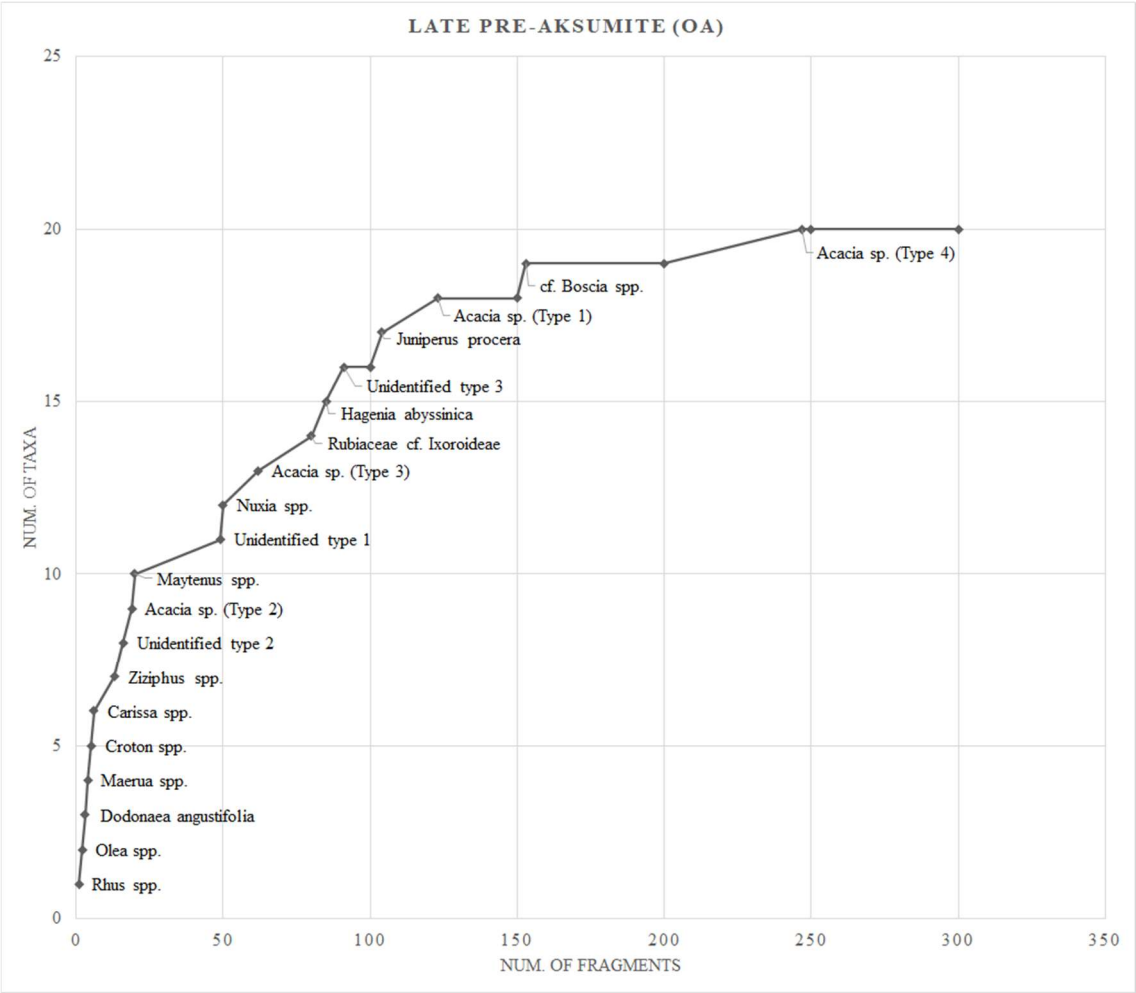

Fig. 10 Taxonomic saturation curve from the Mid/Late Pre-Aksumite phase at Ona Adi.

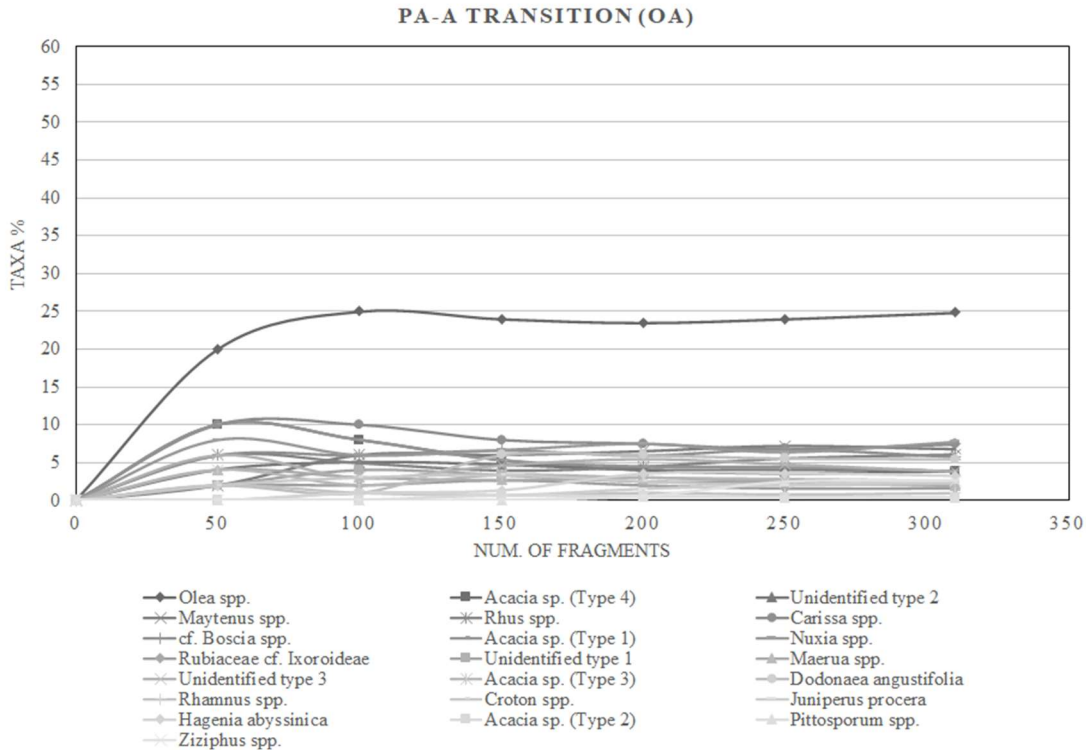

Fig. 11 Quantitative saturation curve from the PA-A Transition phase at Ona Adi.

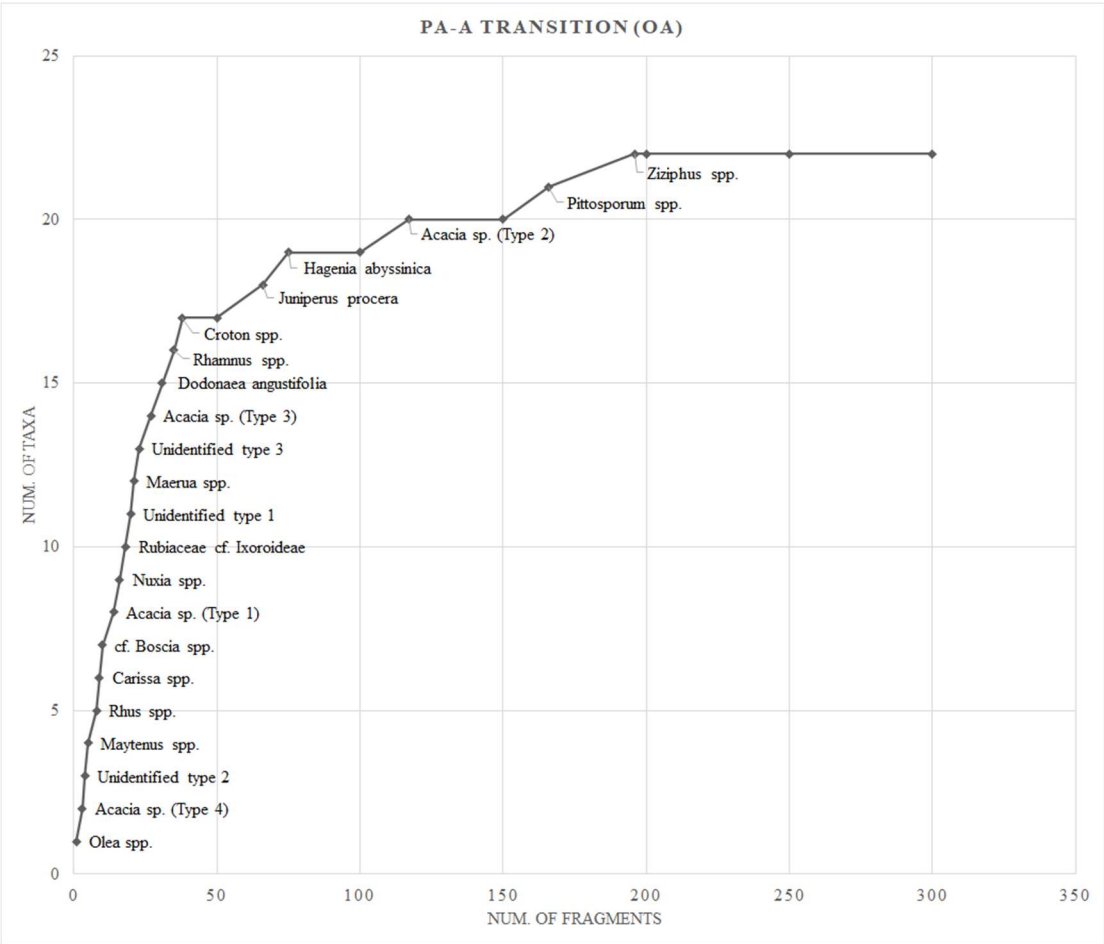

Fig. 12 Taxonomic saturation curve from the PA-A Transition phase at Ona Adi.

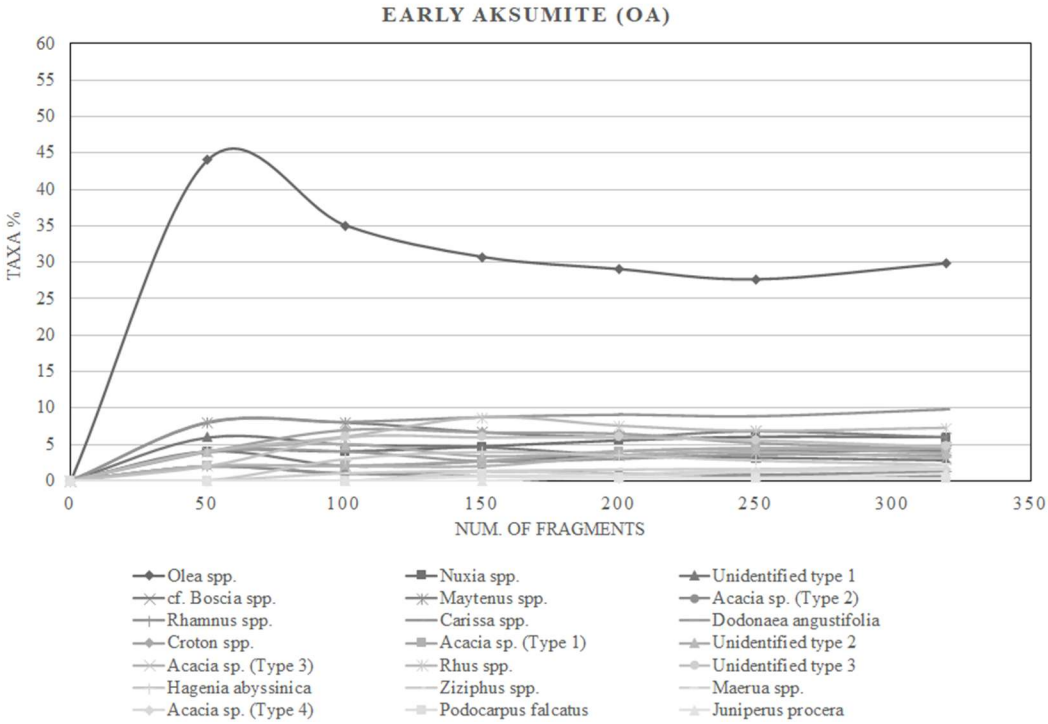

Fig. 13 Quantitative saturation curve from the Early Aksumite phase at Ona Adi.

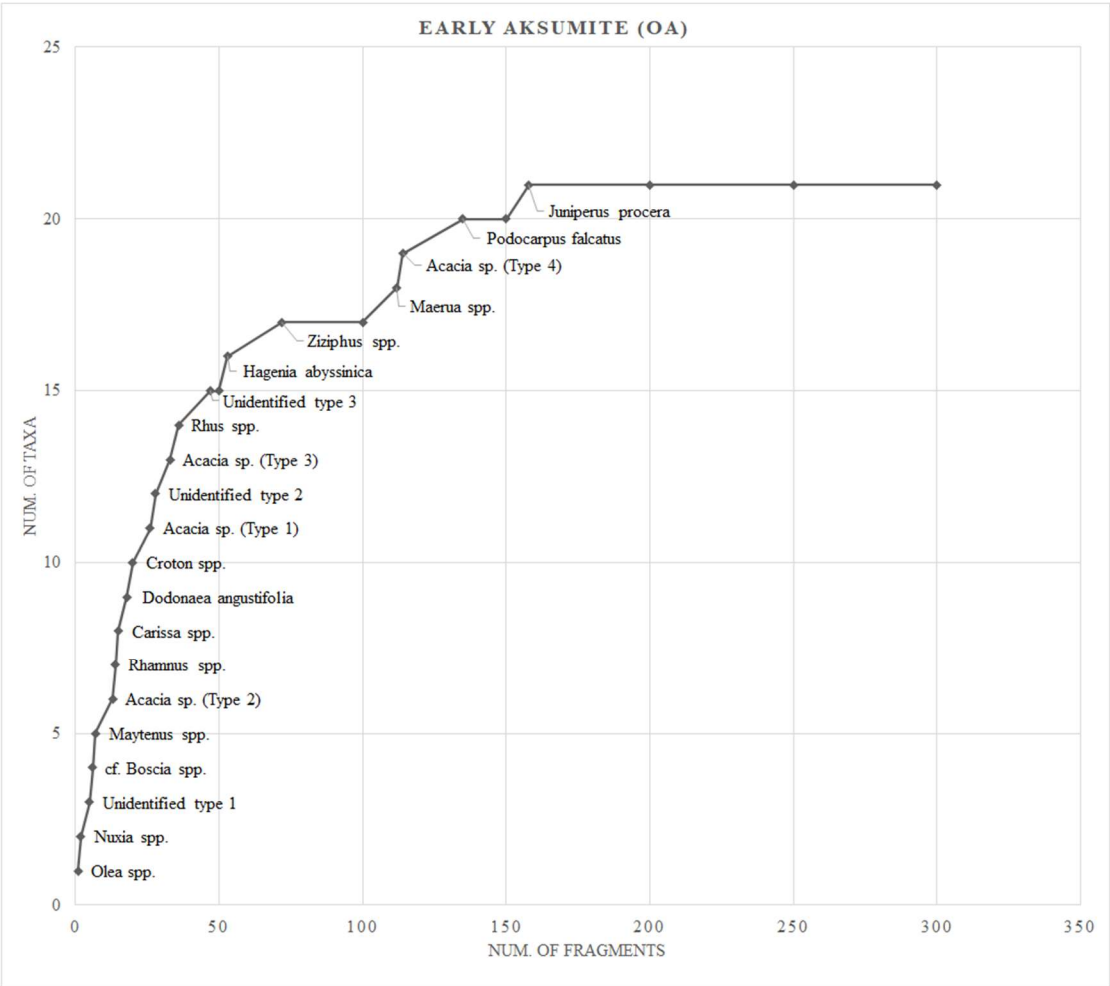

Fig. 14 Taxonomic saturation curve from the Early Aksumite phase at Ona Adi.

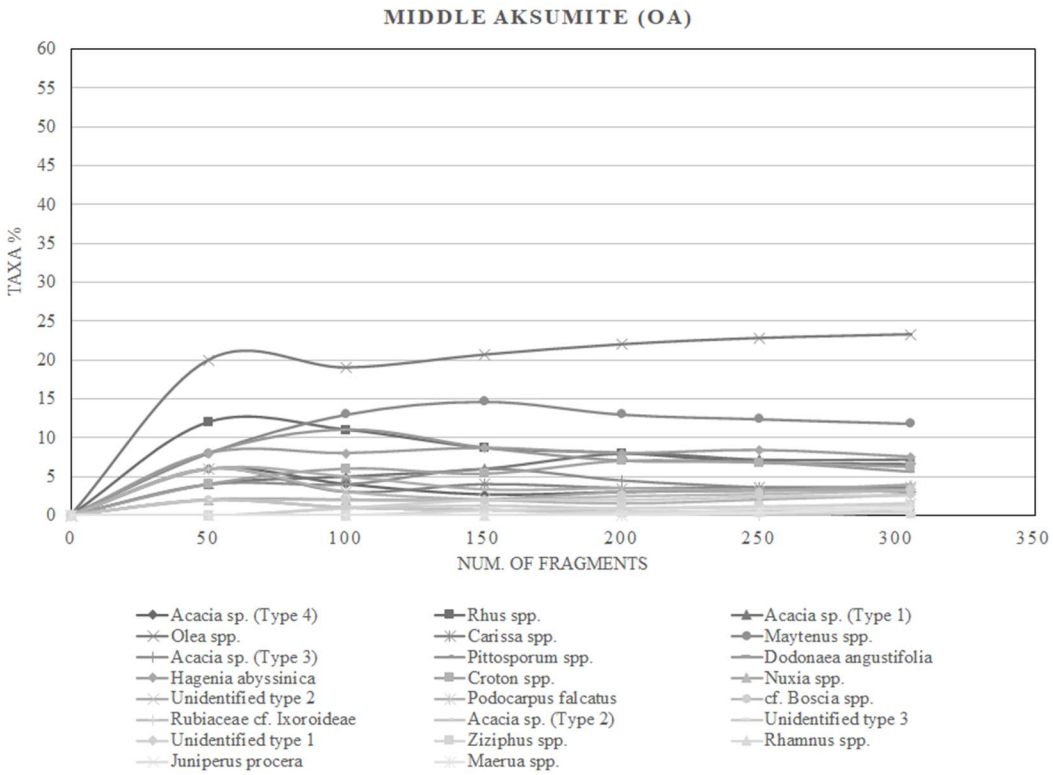

Fig. 15 Quantitative saturation curve from the Middle Aksumite phase at Ona Adi.

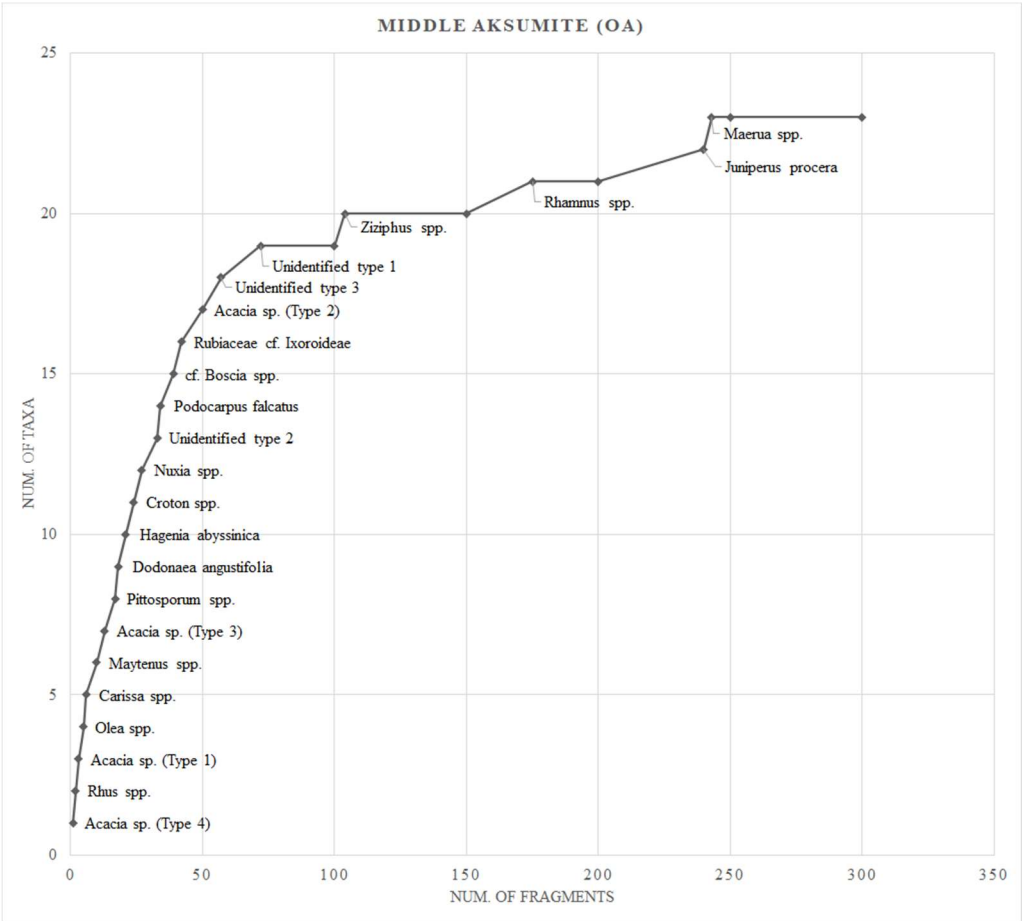

Fig. 16 Taxonomic saturation curve from the Middle Aksumite phase at Ona Adi.

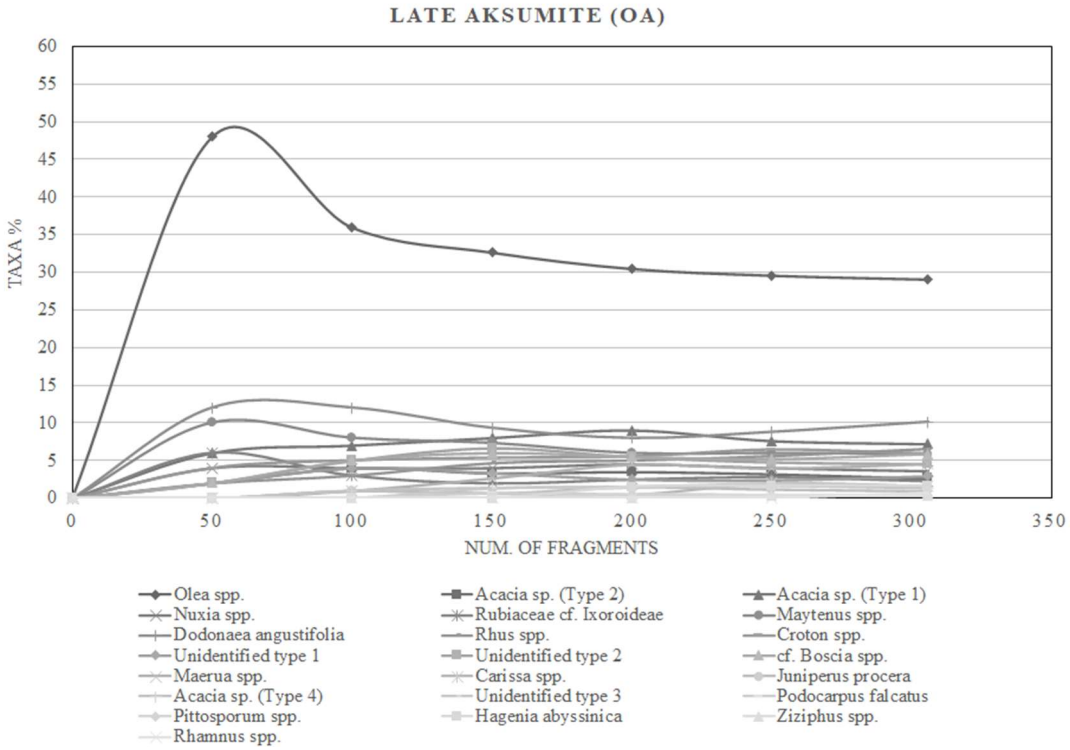

Fig. 17 Quantitative saturation curve from the Late Aksumite phase at Ona Adi.

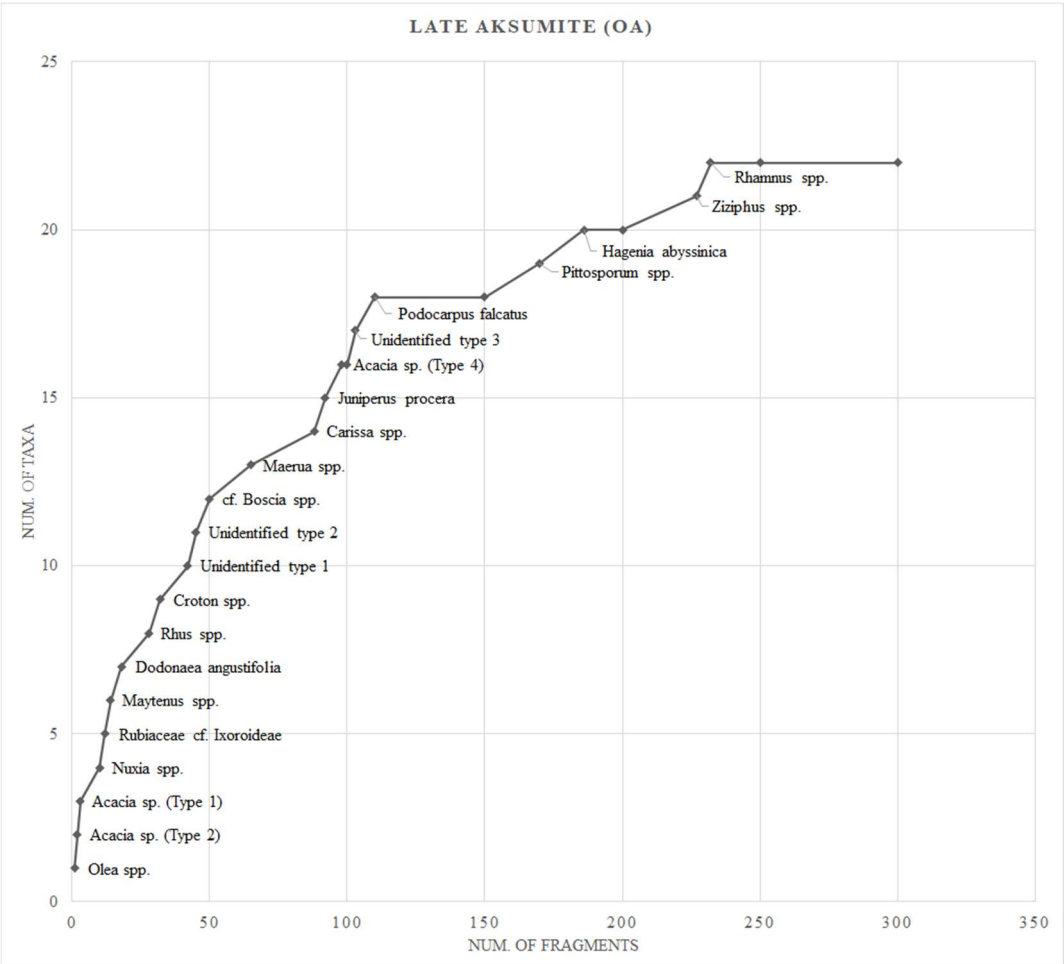

Fig. 18 Taxonomic saturation curve from the Late Aksumite phase at Ona Adi.

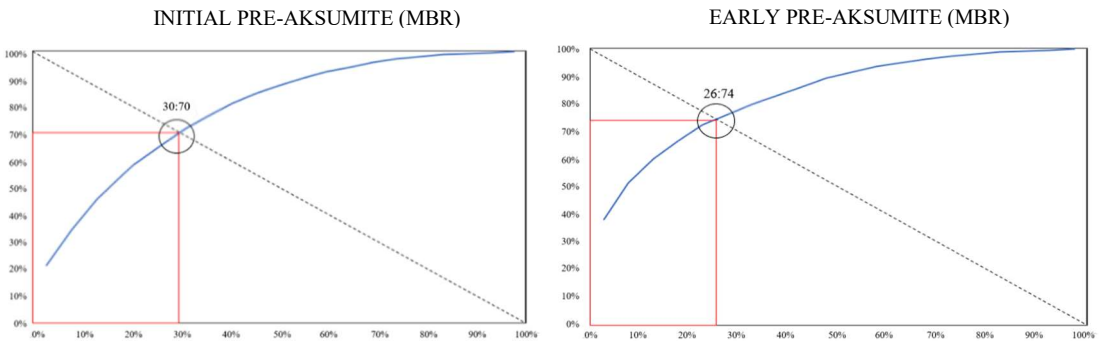

Fig. 19 Gini-Lorenz curves from Mezber Initial and Early Pre-Aksumite phases.

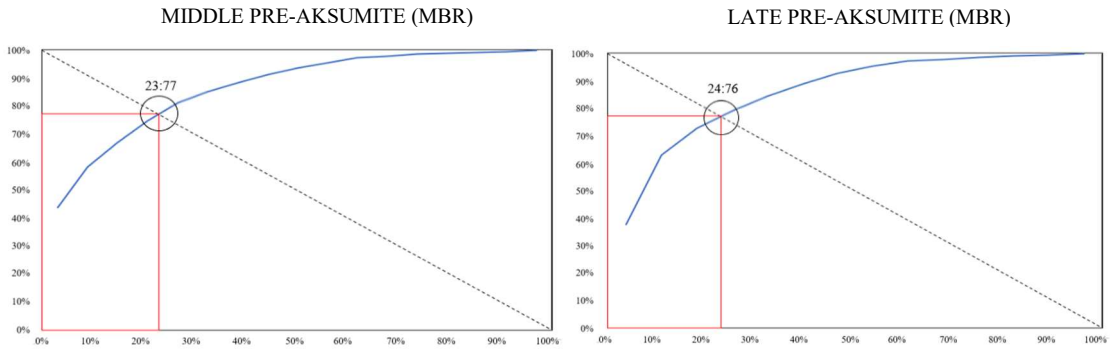

Fig. 20 Gini-Lorenz curves from Mezber Middle and Late Pre-Aksumite phases.

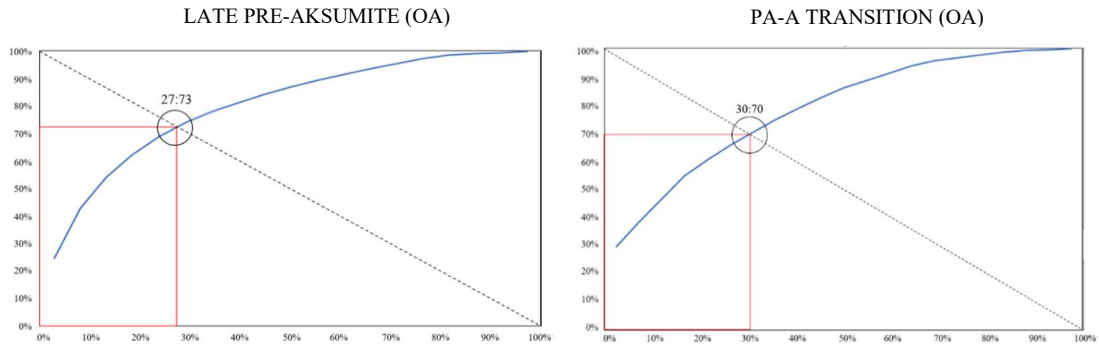

Fig. 21 Gini-Lorenz curves from Ona Adi Late Pre-Aksumite and PA-A Transition phases.

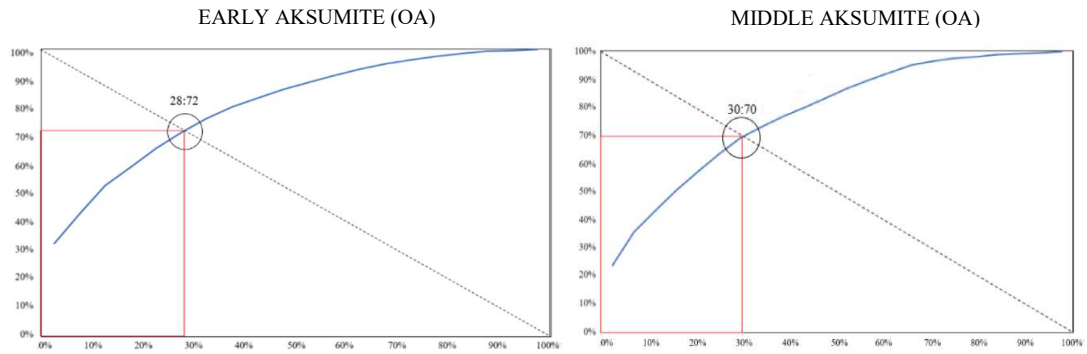

Fig. 22 Gini-Lorenz curves from Ona Adi Early and Middle Aksumite phases.

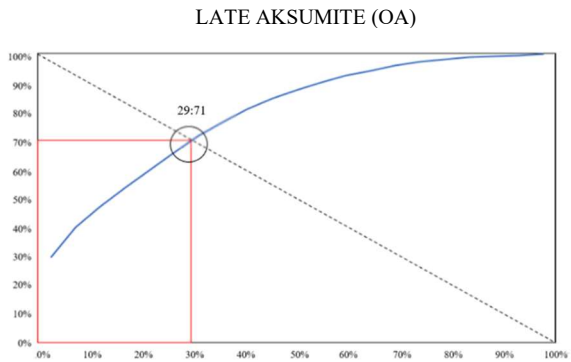

Fig. 23 Gini-Lorenz curve from the Late Aksumite phase at Ona Adi

Acknowledgments.

This research has been developed in the framework of the projects Eastern Tigray Archaeological Project (ETAP) and Historical Ecology and Early Social Complexity in the Horn of Africa, founded by the Social Sciences and Humanities Research Council of Canada (Partnership Grant #890-215-003), and with the participation of the Authority for Research and Conservation of Cultural Heritage (ARCCH) and the Tigray Tourism and Cultural Commission. Also, we are grateful for the financial contribution of the French Minister of External Affairs (AVENIR Excellence Grant), as well as for the economic support of the Erasmus+ programme of the European Union (Erasmus + Scholarship). Many thanks are due to Dr. Margareta Tengberg (Muséum National d'Histoire Naturelle) for granting access to the wood collection of the Muséum National d'Histoire Naturelle (Paris). ARG is a member of CaSEs, an excellence group of the Generalitat de Catalunya (SGR-0122) and Unidad Asociada of the Spanish National Research Council (IMF_CSIC), and is developing his work within the RAINDROPS Research Project (ERC-Stg2017 G.A. 759800).

References

Asouti E, Austin P (2005) Reconstructing woodland vegetation and its exploitation by past societies, based on the analysis and interpretation of archaeological wood charcoal macro-remains. Environ Archaeol 10:1–18. https://doi.org/10.1179/146141005790083867

Chabal L (1997) Forêts et sociétés en Languedoc (Néolithique final, Antiquité tardive) : l'anthracologie, méthode et paléoécologie. Eds. de la Maison des Sciences de L'Home., Paris

Chabal L, Fabre L, Terral JF, Théry-Parisot I (1999) L'anthracologie. In: Ferdière A (ed) La botanique. Eds. Errance, Paris, pp 43–104

Dotte-Sarout E, Carah X, Byrne C (2015) Not just carbon: assessment and prospects for the application of anthracology in Oceania. Archaeol Ocean 50:1–22. https://doi.org/10.1002/arco.5041

Duque D (2004) La gestión del paisaje vegetal en la Prehistoria reciente y la Protohistoria en la cuenca media del Guadiana a partir de la antracología. University of Extremadura

Scheel-Ybert R (2005) Teoria e métodos em antracologia. 3. Validade amostral. Arq do Mus Nac 63:207–232

Site	Phase	SN#	*Acacia* sp. (Type 1)	*Acacia* sp. (Type 2)	*Acacia* sp. (Type 3)	*Acacia* sp. (Type 4)	*Acacia* spp. (Total)	*Carissa* spp.	cf. *Boscia* spp.	*Croton* spp.	*Dodonaea angustifolia*	*Hagenia abyssinica*	*Juniperus procera*	*Maerua* spp.	*Maytenus* spp.	*Nuxia* spp.	*Olea* spp.	*Pittosporum* spp.	*Podocarpus falcatus*	*Rhamnus* spp.	*Rhus* spp.	Rubiaceae cf Ixoroideae	*Ziziphus* spp.	Total identified	Unidentified type 1	Unidentified type 2	Unidentified type 3	Total Unidentified	Grand total
Mezber	Initial Pre-Aksumite	1126	0	0	0	0	0	14	0	0	0	1	0	0	0	0	0	0	0	1	3	0	2	21	3	0	2	5	26
Mezber	Initial Pre-Aksumite	1337	12	0	8	0	20	9	0	7	0	0	2	5	4	1	34	0	0	3	9	11	2	107	6	12	6	24	131
Mezber	Initial Pre-Aksumite	1345	21	0	0	0	21	5	0	0	3	7	3	0	2	1	8	0	0	1	11	0	0	62	1	9	3	13	75
Mezber	Early Pre-Aksumite	1585	0	0	0	0	0	2	11	5	14	1	1	3	2	1	27	0	7	1	17	3	1	96	0	4	3	7	103
Mezber	Early Pre-Aksumite	1908	0	0	0	0	0	8	0	10	1	0	6	0	0	0	54	0	0	3	0	0	10	92	6	5	5	16	108
Mezber	Early Pre-Aksumite	2106	1	0	1	1	3	0	7	5	11	5	2	0	0	3	35	0	0	0	23	0	0	94	5	1	4	10	104
Mezber	Middle Pre-Aksumite	2096	0	0	1	0	1	1	7	6	3	2	0	2	0	2	16	0	0	0	51	0	1	92	6	2	5	13	105
Mezber	Middle Pre-Aksumite	2102	1	0	0	0	1	2	10	3	11	0	1	1	1	3	18	0	0	0	14	1	0	66	9	2	0	11	77
Mezber	Middle Pre-Aksumite	2110	0	0	1	0	1	2	7	1	5	0	0	6	5	2	10	0	0	0	68	0	0	107	12	8	1	21	128
Mezber	Late Pre-Aksumite	18	0	0	0	0	0	0	6	6	3	0	0	0	1	0	4	0	0	0	20	0	0	40	0	1	0	1	41
Mezber	Late Pre-Aksumite	20	5	0	0	1	6	0	13	10	26	0	0	14	1	2	73	0	0	0	93	2	1	241	12	7	5	24	265
Ona	Late Pre-Aksumite	1127	0	0	2	0	2	7	0	4	7	0	1	0	5	1	8	0	0	0	3	2	0	40	0	1	1	2	42
Ona	Late Pre-Aksumite	1139	0	3	0	0	3	4	0	1	3	1	0	1	6	4	3	0	0	0	13	1	4	44	3	5	0	8	52
Ona	Late Pre-Aksumite	1163	6	5	2	1	14	63	12	2	10	1	0	14	14	5	44	0	0	0	18	3	3	203	2	3	3	8	211
Ona	PA-A Transition	769	6	0	2	1	9	1	7	6	4	0	6	2	7	4	30	0	0	2	11	0	3	92	3	5	7	15	107
Ona	PA-A Transition	1131	1	1	1	2	4	9	8	1	12	0	0	2	9	9	27	1	0	1	5	1	2	91	3	4	4	11	102
Ona	PA-A Transition	1157	5	1	5	9	20	13	3	0	1	10	2	2	5	11	20	0	0	0	3	4	3	97	0	3	1	4	101
Ona	Early Aksumite	1106	8	0	1	4	13	14	0	3	0	6	3	2	11	9	26	0	0	1	4	0	0	92	5	6	1	12	104
Ona	Early Aksumite	1110	4	1	0	0	5	7	6	6	6	1	0	4	6	4	35	0	0	3	10	0	1	94	2	5	4	11	105
Ona	Early Aksumite	1118	2	1	9	1	13	10	7	5	5	0	0	1	2	6	34	0	1	0	9	0	4	97	2	1	10	13	110
Ona	Middle Aksumite	811	2	1	1	1	5	7	3	10	11	4	1	2	15	2	17	2	0	0	14	1	1	95	1	4	3	8	103
Ona	Middle Aksumite	818	6	0	7	9	22	1	1	4	0	12	0	0	13	0	37	0	8	1	0	0	1	100	3	0	2	5	105
Ona	Middle Aksumite	843	14	0	1	0	15	3	6	5	6	7	1	1	8	10	17	0	0	0	6	0	2	87	4	6	0	10	97
Ona	Late Aksumite	711	15	6	0	0	21	1	4	5	11	0	1	13	7	8	55	0	0	0	3	5	1	135	3	9	4	16	151
Ona	Late Aksumite	722	7	2	0	4	13	4	14	13	20	5	2	1	11	3	34	1	1	2	17	2	0	143	6	5	1	12	155