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Post Terminal Pleistocene Reconstruction of Ancient Fire Wood and Human-Environment Relations in the Afro-Alpine Region of the Bale Mountains, Ethiopia: an Anthracological Study

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Abstract

This research presents the result of analysis of anthracological remains excavated from four archaeological sites located in the Bale Mountains. The samples were collected from the early Late Stone Age occupation phase to the early arrival of pastoralists in the Bale Mountains (46.5 ka-1.2 ka). The aims of the study are: to reconstruct firewood collection, vegetation history, to shed new light on the poorly understood environmental conditions during human occupation phases in the Bale Mountains, and to understand interactions between past humans and their environment in African high-altitude ecozone. The investigation was conducted on a total of 485 charcoal macro-remains, from which, a total of 328 were identified into taxa and seven different plant species were recorded. The recorded taxa include Erica cf. arborea type (n=75), Myrsine type (n=69), Solanum type (n=48), Artemisia cf. afratype (n=44), Hagenia abyssinica (n=42), Hypericum type (n=29) and Juniperus type (n=21). This study addresses various important issues, including firewood collection, vegetation cover, palaeoenvironment, prehistoric human ecological preferences, and adaptation strategies in the afro-alpine region of the Bale Mountains.

Keywords: anthracology, ecological adaptations, palaeoenvironment, vegetation history

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Introduction

An ongoing archaeological investigation under the “Mountain Exile Hypothesis” (MEH) project at the Bale Mountains (BM) in Ethiopia is shedding new light on the human adaptation to high-altitude environments in Africa (Ossendorf et al., 2019). In the BM, several sites including Fincha Habera, Mararo, Fish Shelter, and Simbiro with an altitude of 3469, 3779, 3423, and 3519 meters above sea level (m asl) respectively have been the focus of archaeological investigations. A range of archaeological materials such as stone tools, pottery, and fauna and flora remains have been uncovered. The archaeological remains coming from BM suggest that the African high-altitude ecozones were occupied by hunter-gatherers during the Late Pleistocene due to its environmental stability during times of environmental uncertainty in lowlands. Chronologically, the sites are dated between the late-Pleistocene to Holocene epochs based on radiocarbon dating (C^{14}) (Ossendorf et al., 2019; Vogelsang et al.; 2018). According to Ossendorf et al. (2019), hunter-gatherers occupied most sites in the BM in times when resources were depleted in the lowlands, either as a result of rapid population increases or ecological changes.

Since the discovery of archaeological sites in the BM, different scholars have contributed to the understanding of patterns, processes, and occupational history of the region from various points of view based on the material culture recovered from the aforementioned sites. Understanding past human adaptation to a certain type of environment is also a key and significant precondition for conceptualizing patterns, processes, and natural selection pressures that may affect the course of human biological and cultural evolution (Ambrose, 1984). Among more than a few archaeological remains, anthracological collections are the other significant materials from BM that need to be analyzed. Investigating these materials allows establishing nomenclature to family, genus, and species levels. This, in turn, helps to understand the interactions between humans and their environments in settlement contexts. At the BM sites, though there are other material remains that shed light on human cultural activities, the environmental context is not yet properly defined and understood. A well-defined environmental context will help us to understand the cultural changes that occurred during the Late Pleistocene and Holocene. The present research is, thus, designed to fill this crucial gap.

Descriptions of selected sites and overview of their occupation sequences

Previous studies have recorded a total of 331 rock shelters in the Bale Mountains (Reber et al., 2018). Among these, four sites (Fincha Habera, Mararo, Simbero, and Fish shelter, figure 2) were selected for this study based on criteria such as traces of human presence, altitude, and concentrations of charcoal.

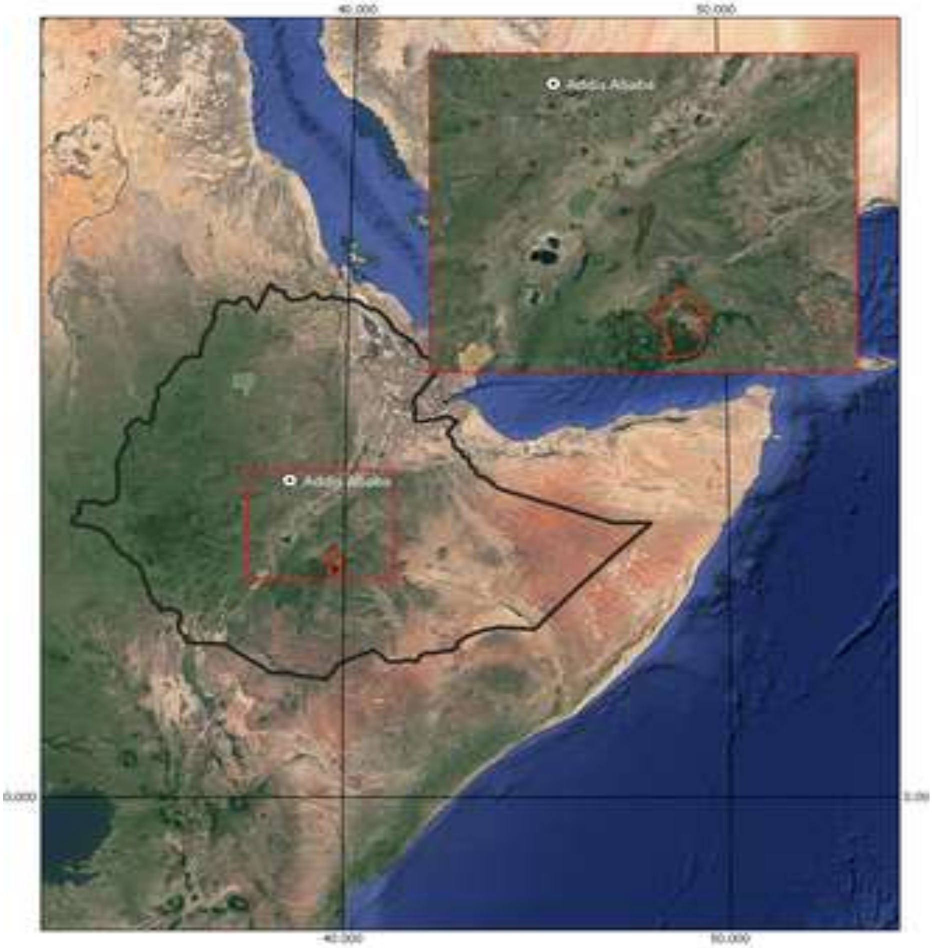

Figure 1: map of the study area (**Source**: Mountain Exile Hypothesis Project data base)

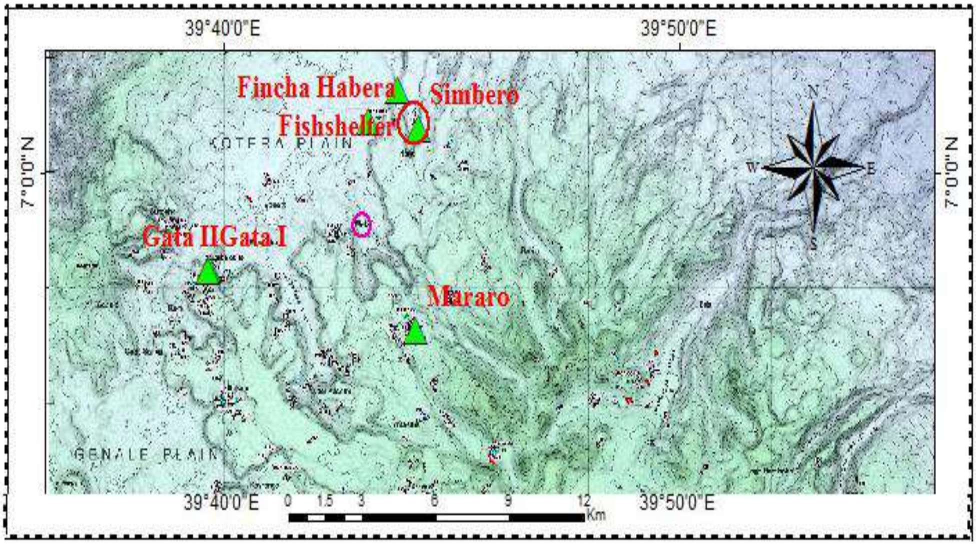

Figure 2: Map showing the location of sites in the BM selected for the present study (developed by Ayele Akirso, 2021).

Fincha Habera

Fincha Habera rock shelter lies at 7.014556° N, 39.720036° E, with an elevation of 3469masl. This site is more important than others; it is the world's oldest high-altitude residential site, a "base camp" of prehistoric hunter-gatherers. While there are higher and older sites elsewhere, there we know only about the presence of humans at a certain altitude, at a certain time. But at Fincha Habera we have direct evidence and many aspects of how humans used the landscape around the site repeatedly over a long time span. The site is also important because it lacks modern pastoral activities and also contains relatively undisturbed sediments (Ossendorf et al., 2019).

As indicated by Ossendorf (Pers. Comm., May 31, 2021), the occupations at Fincha Habera are classified into two broad phases. The earliest occupation phase corresponds to Middle Stone Age (MSA) that happened within the time span ranging from 46.5 to 31.4 ka cal. BP. The MSA layers can further be grouped into three broad horizons (46 to 42 ka, 39-34 ka, and 32-31 ka). The first MSA horizon at Fincha Habera is dated to 46 to 42 ka cal. BP in layer FHL-09, corresponding to the findings/samples/ of levels L12 and L13 of the H11 square, and also includes sample #726 from square F13, and#1300 and #1301 from square F15. The second MSA horizon dates between 39 to 34 ka cal. BP in layer FHL-08 lower, and this corresponds to the findings/samples/ of levels L11, L12 of square E8, L10 of square H11, and samples #492, #567, #587, #617, #637, #640, #658, #738, #763, and #764 from square F16, and samples #1253 and #1265 from square F15. The last MSA layer at Fincha Habera is dated from 32 to 31 ka cal. BP in layer FHL-08 upper, corresponding to L9 and L10 from square E8, L8, and L9 from square H11, and samples #1181 and #1186 from square F15 (see table-1 below).

The second occupation phase at Fincha Habera was recorded after a long hiatus of 30,000 years after the end of the MSA period. The only visible re-settlement with archaeological signatures took place in the 12th/13th century AD. The second occupation phase is also classified further into two different layers. For the first layer (FHL-07) there are no secure dates with clear archaeological markers. Very few MSA artifacts were collected from this layer; however, the charcoal probably must have been trickled down from layer FHL-06. This layer corresponds to the findings/samples of levels L5-9 in square E8, samples #468, #852, #856, #863, #988 of square F15, and samples #183, #191, #211, #212, #430, #453, #454, and "F15 L6 N" from square F16 (Ossendorf, Pers. Comm., May 31, 2021).

The second horizon is predominantly associated with layers FHL-02/-03/-04/-05/-06/PIT, which correspond to levels L2-4 in square E8, and samples "F13 L2 SE", "F12 L4 SE", #338, #339, #278 from square F13, sample #468 from square F15, and samples "A45 F16 PIT1", #28, #45, #141, #320, #328, and #346 from F16 square (Ossendorf, Pers. Comm., May 31, 2021). Charcoal samples obtained from five different occupational phases were examined in this study.

Table 1: Sample proveniences, layer and numbers from Bale Mountains sites for each chronological interval.

Fincha Habera	**Layer**	**Proveniences (Level or sample numbers)**
46-42 ka	FHL-09	H11 (Levels 12 & 13); F13 (#726); F15 (#1300 and #1301)
39-34 ka	FHL-09 lower	E8 (Levels 11 & 12); H11 (Level 10); F16 (#492, #567, #587, #617, #637, #640, #658, #738, #763, and #764); F15 (#1253 and #1265)

32-31 ka	FHL-08 upper	L9 and L10 from square E8, L8, and L9 from square H11, and samples #1181 and #1186 from square F15
12th/13th century first horizon	FHL-06	L5-9 in square E8, samples #468, #852, #856, #863, #988 of square F15, and samples #183, #191, #211, #212, #430, #453, #454, and "F15 L6 N" from square F16
12th/13th century second horizon	FHL-02/-03/-04/-05/-06/	L2-4 in square E8, and samples "F13 L2 SE", "F12 L4 SE", #338, #339, #278 from square F13, sample #468 from square F15, and samples "A45 F16 PIT1", #28, #45, #141, #320, #328, and #346 from F16 square
Simbero		
LSA I - 14.6 ka		Levels 8-10
LSA II - 8.1-5.0 ka		Level 7
LSA III - 3.6-2.2 ka		Levels 3-6
Late Pastoral		Levels 1 and 2
Fish Shelter		
LSA - 14.8-14.0 ka	D and F	Levels 8-15
LSA - 6.5-6.3 ka	B and C	Levels 3-6
Marano		
LSA/late Holocene - 4.7-2.6 ka		Lower level
Late Pastoral - ca. 1.2 ka		Top level

Simbero

According to C^{14} dating results, the stratigraphic sequence at Simbero comprises a considerable time depth, from 14,600 cal. BP to recent times. Based on the type of material culture retrieved from each layer and C^{14} dating results, four different occupation events with clear archaeological signatures have been reconstructed. The first occupation at Simbero (LSA I) took place during the terminal Pleistocene, around 14,600 yrscal BP, associated with retouched obsidian tools and corresponds to levels L8-10 (Ossendorf, Pers. Comm., May 31, 2021).

The second occupation phase (LSA II) happened during the early-to-mid-Holocene period between 8,100-5,000 yrscal BP, characterized by a variety of geometric microliths which are the specific tool types of this period. This occupation phase corresponds to level 7. At Simbero, the deposition of Late Holocene layers were associated with a large number of burning events. Due to this, a relatively sizable number of charcoal samples were collected from this layer. A late Holocene occupation (LSA III), which occurred between 3,600-2,200 yrscal BP, is the third occupation phase and is associated with an even higher degree of a microlithic toolkit and an abundant amount of faunal remains (reflecting especially small game- hunting). This period corresponds to levels 3, 4, 5, and 6. The last occupation phase is a very late pastoral phase associated with ceramics and corresponds to level 1 and 2 (Ossendorf, Pers. Comm., May 31, 2021).

Fish shelter

At the Fish shelter, two major occupation phases were reconstructed based on the material culture and the dating results obtained from two excavation units. Based on C^{14} dating results, the first occupation phase dated to be 14.0 to 14.8 ka cal. BP in layers D and E, corresponding to levels 8-15. The second occupation dated to be c. 6.3-6.5 ka cal. BP in layers B and C, corresponding to levels 3- 6 (Ossendorf, Pers. Comm., May 31, 2021).

The relevance of the Fish shelter consists of the fact that it might have obtained a rare human and environmental archive for Marine Isotope Stage (MIS) 2, approximately between 29-12 ka cal. BP. This period includes the global Last Glacial Maximum as well as the beginning of the African Humid Period. Very little is known about this phase in terms of human settlement; in fact, there are very few reliably dated archaeological sites in Ethiopia belonging to this period.

Additionally, the environmental conditions of the Bale Mountains during this time were not clear. The glaciers had their maximum advance already around 40,000 years ago and retreated after 17,000 years ago, and rapid deglaciation that started after 15,000 enabled the area to be ice-free, which corresponds to the early human re-settlement at ~ 14,000 (Groos et al. 2021). The charcoal analysis would be a highly relevant contribution to understanding the human-environment interaction at that time.

Mararo

The stratigraphic sequence at Mararo comprises two major occupation events. At the bottom, a late Holocene LSA occupation probably corresponds to the last hunter-gatherers in the BM. Radiocarbon dating results place the onset of this settlement phase around the termination of the African Humid Period (4.7 ka cal. BP). The end of the LSA occupation probably occurred after 2.6 ka cal. BP, mirroring the results of A-58 Simbero. While this reflects a rather short occupation phase, there is a high degree of chronological control for the respective lithic and charcoal assemblages. The deposits of this phase feature a high number of charcoal pieces, burnt obsidian and sediments occur regularly, and the charcoal has colored the latter to a high degree (Ossendorf, Pers. Comm., May 31, 2021).

At the top, a late pastoral occupation phase with very few and undiagnostic lithic artifacts and few pottery sherds were recovered from interfingering layers consisting of loamy deposits (with ash) and fine wet and dry dung. A single date points to 1.2 ka cal. BP

Some specialist studies have already been completed (lithic technological and typological analysis, obsidian electron microprobe analysis) or are currently in process (lithic use wear and residue analysis, geo-biochemical markers) (Ossendorf, Pers. Comm., May 31, 2021). Analysis and taxa identification of the charcoal would be an essential contribution.

The present study is based on a sample of 485 specimens of archaeological charcoal collected from various unit levels of excavation sites at the Bale Mountains. The total sample includes charcoal from Fincha Habera (n=159), Mararo (n=74), Simbiro (n=106), and Fish shelter (n=146). Therefore, this study tried to investigate the archaeological charcoals collected from the aforementioned four sites situated in the BMNP to address questions relating to vegetation history, fire wood use history, and environmental setup of the study area.

Materials and methods

This study employed standard and multiple approaches to address the objectives of the study. Sorting is one of the methodological approaches used in this study. The selected anthracological samples at this stage were checked for mixed occurrences with other artifacts such as ceramic sherds, lithics, and bones. Here the charcoal specimens have to be separated from sediment by sieving. In this stage, samples were also weighed using a digital scale (‘Voltcraft’).

Documentation of anatomical features is the other method that takes place after the fresh sections of the charcoal samples were exposed by fracturing, either by using hand pressures or steel razor blade, depending on the size and nature of the sample. This produces a fresh section of the charcoal in all three anatomical planes (cross-section, radial, and tangential). This was followed by taking microscopic images through cross-sectional, radial, and tangential views. To do this, a KEYENCE electron microscope with a magnification level of 100X, 150X, and 200X was used to see the anatomical differences in 3D-views and to capture microscope images of the samples.

One way to identify archaeological charcoal samples is based on comparison with modern wood anatomy. In this study, modern wood samples were employed as a comparison to identify the anthracology samples into their family, genus, and species levels. Previous palaeoenvironmental, ethnobotanical, and ethnoarchaeological studies in the study area indicate woods like *Erica arborea, Hygenia abyssinica*, *Hypericum revolutum*, *Juniperus procera*, *Solanum gigantum*, *Myrsine africana*, and *Artimessia afra* dominated the study area. Reference wood of the species that are known to grow in the study area had been previously collected by the first author.

The comparisons were done in two different ways. The first comparison was looking for the descriptions and anatomic images of the comparison collections on the "inside wood dataset," a publicly accessible database that "integrates wood anatomical information from the literature and original observations into an internet-accessible database useful for research and teaching." The Inside Wood database contains brief descriptions of fossil and modern woody dicots (hardwoods) and modern softwoods. It is worldwide in coverage (https://insidewood.lib.ncsu.edu/citingus). For most species, we have found descriptions and anatomic images on the inside wood dataset that have the same anatomic features as our comparative collections. Hence, we have used that as a reference for comparison. The modern comparative slides obtained from Alemeseged Beldados' teaching reference collections were also used as references for comparison. These teaching reference collections were used for species such as *M. africana*, whose anatomic feature and description was not available on "inside wood dataset".

All charcoal samples were individually picked from in-situ contexts during excavation. Among the samples selected for this study, there is no charcoal recovered either through sieving or floating. Additionally, the excavation sequences of all sites are relatively free from any major disturbance factors like infill, except at Fincha Habere where slight disturbances were observed.

As described by Ossendorf (Pers. Comm, May 4, 2021), a recent pit which cut into older Pleistocene layers was observed at Fincha Habera site. However, charcoal from this feature was clearly labeled as "pit 1"/"pit 2". Two very small animal burrows (one with backfill, one without), and one large animal burrow spanning several levels (square F16, profile wall of SE corner, from Level 6 to Level 12) were also observed. All charcoal from these contexts has been labeled accordingly because it was found associated with coprolites in these burrows and they are designated as originating from these burrows. The charcoal collected in-situ provide significant information to address research questions related to the type of wood selected and used for fire through time.

The preservation conditions of all samples are relatively good. The consistency of the charcoal samples ranges from large, firm chunks to powdery residues. Charcoal from Fincha Habera, Simbero, and Fish Shelter contained the most relevant charcoal fragments. The powdery residues were not helpful for identification and are therefore excluded. Attention was given to charcoal pieces with the appropriate size of 4-8 mm which enabled us to break the charcoal samples into several pieces to see transverse, radial, and tangential anatomical lines. At most sites, recovered charcoal fragments have a size of >4 mm and could thus be examined. However, Simbero and Mararo yielded some charcoal fragments less than 4 mm and in some instances, we were forced to look at charcoal fragments >2 mm.

Attempts were made to allocate all charcoal samples into their respective occupational phases based on the chronostratigraphic information provided by the project. However, these attempts were not equally applicable for all sites. This is because at Fincha Habera and Mararo,the interrelations between levels, layers, and dating results did not always correspond to each other. In all cases, to reconstruct vegetation history diachronically across time, a minimum of six charcoal fragments was identified from each occupational phase.

Distributions of charcoal fragments along with four sampling sites

All possibly identified pieces were obtained from all sampling sites identified in their respective taxa categories. From the total sample of 485 charcoal fragments selected for this study, 328(68%) were identified into their respective taxa (Table # 2), whereas the remaining 157 fragments (32%) remain unidentified due to poor preservation, the absence of a sufficient number of comparative collections, and in some cases the small sizes of the pieces.

Table 2: Analyzed sample count, number of specimens identified to taxa, and number unidentified samples (count and percentage) from each of the Bale Mountains sites.

Site	Number of Samples	Identified to taxa	Unidentified
Fincha Habera	159	101 (64%)	58 (36%)
Fish Sheller	146	88 (61%)	57 (39%)
Simbero	106	82 (77%)	24 (23%)
Marano	74	58 (78%)	16 (22%)

Identifications

The structure of the fossilized charcoal and its anatomic characteristics were carefully compared with modern ones retrieved from the "inside wood" database to obtain similar structure and descriptions. In addition to image correlations, the anatomic descriptions were also considered while working with identifications. In this way, a total of seven different taxa were identified from among the 328 samples that could be identified to taxa from the four sites (Table # 3). To develop reasonable interpretations of the identified plants, in the following section the general characteristics such as origin, ecological preference (Phyto-geography), and other related characteristics of identified taxa will be discussed.

Table 3: Identified taxa counts and percentage ordered from most abundant to least abundant.

Taxa	Number of Identified specimens	Percentage of Identified sample
Type-1 Erica cf. arborea	75	23%
Type-2 Myrsinetype	69	21%
Type-3 Solanumtype	48	15%
Type-4 Artemisia cf. afra type	44	13%
Type-5 Hageniaabyssinica	42	13%
Type-6 Hypericumtype	29	9%
Type-7 Juniperustype	21	6%

Type-1 *Erica cf. arborea*

Out of total identified 328 anthracology samples, *Erica cf. arborea* is the most dominant taxon (Table # 3; see the anatomy of the plant in figure 4). This plant is commonly known as the tree hearth/Giant hearth (English), Adale /Asta (Amharic), and Wadadi (Afaan Oromo). It covers a wide range of geographical distributions, found from east Africa (Ethiopia, Kenya, and Tanzania) to the Mediterranean Basin and Macaronesia (De´samore et al., 2011, Azene et al., 1993).

E. arborea trees are distributed in the BM along the ericaceous zone on the Afromontane forest zone, co-occurring with Erica and Phillippa genera. *E. arborea* in the BM mostly grow in the altitudinal range between 3,400m to 3,800m and co-dominated together with plant-like *Hypericum revolutum*, and *E. trimera* (Abel, 2012; Biniam & Richman, 2013). Strangely adequate, small Erica outposts are also found even in the afro-alpine zone on the central Sanetti Plateau (Miehe & Miehe, 1994).

Type-2 *Myrsine type*

The recovered *Myrsinetype* taxa from BM constitutes among the second most abundant taxa (figure 5). *M. africana* is species of shrubs in the family of primulaceae also commonly known as African boxwood/cape myrtle in English, and Kechimo in Amharic. Its distribution in Ethiopia is confined to mountainous, shrubby grassland forest border and along (small) mountain rivers or gullies in areas with an elevation ranging between 1750-3800m (https://www.monaconatureencyclopedia.com).

Type-3 *Solanum type*

Solanumtype is the third most abundant taxa. *S. gigantum* is a semi-evergreen and moist deciduous forest tree or shrub which can grow up to 5m. It is commonly known as Red Bitter Berry, healing-leaf tree, giant bitter-apple, and red bitter. This plant is characteristic of montane zones and native to Africa (all sub-Sahara countries) and Asia (south India). This plant is widely distributed in Grassland, thickets, moist and riverine forest and -margins, bushland, evergreen thickets, and bamboo zone (http://pza.sanbi.org/solanum-giganteum).

Type-4 *Artemisia cf. afra* type

Artemisia cf. afra type is the fourth most abundant taxa (see anatomy of the plant in figure 3). It is commonly known as African wormwood (English), 'Chigugn' (Amharic), and Kapani (Afaan Oromo). *Artemisia afra* is an evergreen perennial herb that belongs to the family of Compositae (Asteraceae) and grows to reach a height of 2 meters, found in geographical locations with an altitude range of 3070 to 3600 m (Mesfin & Sebsebe 1992).

In the BM, this plant is currently confined in Northern Grasslands /Gaysay Grasslands zone with altitude ranges from 3,000m to 3,500m. It commonly grows together with plant-like *Helichrysumsplendidum* and *Hageniaabyssinica* (Binian & Richman, 2013). *Artemisia afra* is widely used for medicinal purposes to treat both internal and external diseases (Dawit & Ahadu, 1993; Abiyselassie, 2007).

Type-5 *Hagenia cf. abyssinica*

Hagenia abyssinica is the next most abundant taxa (Table 3). This plant is commonly called Africa Red wood/Rosewood, Kosso, and Heto in English, Amharic and Afana Oromo respectively. It is a dioecious tree native to Africa, belonging to the Rosaceae family which can grow up to 35m (Azene et al., 1993; Negash, 1995).

Pollen evidence retrieved from Burundi indicates the earliest colonizations of *H. abyssinica* in Africa go back to 34,000 years BP, and were introduced to

Ethiopian from this region during the Pleistocene, sometime around 16,700 years ago BP. Southern Ethiopia, including the Bale Mountains, and the surrounding regions are vegetated by *H. abyssinica* at about 2500 BP (Mohammed & Bonnefille, 1998).

In the BM, this plant is dominantly found in Juniper Woodlands, Gaysay Grasslands, and Erica Belt zones (Table 5). In Juniper Woodlands, it grows together with *H. revolutum*, and *J. procera*; in Gaysay Grasslands, it grows together with *A. afra* and *H. splendidum*; and in the Erica Belt, it is commonly found together with Erica families (Biniam & Richman, 2013). H. abyssinica tree is one of multiuse plants in Ethiopia, widely used for timber, furniture, medicine (to treat tapeworm), fuel wood, poles and for conservation of soils (Azene et al., 1993).

Type-6 *Hypericum type*

Hypericumtype is the sixth most abundant taxa (Table #). *H. revolutum* is the family of Hypericaceae, native to Arabia and Africa. It is commonly called Curry bush, Amija, Edera/Garamba/Hendi in English, Amharic, and Afaan Oromo respectively. It is a shrub or tree which can grow up to 4 m but rarely grows as high as 10m (Azene et al., 1994).

H. revolutum is characteristic of the Afromontane vegetation, often distributed in geographical regions with an elevation range from 1400 – 2593m. In Ethiopia, this species confined in Montane Forest/high altitude regions with elevation ranges between 2600-3600 m in the moist and wet Dega agro-climatic zone, where it mostly co-occurrs with *E. arborea* and/or *H. Abyssinica. H. revolutum* tree is widely used for medicine, commercial (timber) fire wood, bee keeping, and soil conservation (Azene et al 1994).

Type-7 *Juniperus type*

Juniperusprocera is the least abundant of the identified taxa (figure 5). *Juniperusprocera* is commonly known as African pencil cedar, Tid, and Gatira/Hindessa/ in English, Amharic, and Afaan Oromo respectively. It is indigenous to Ethiopia and eastern Africa and belongs to the family Cupressaceous (the cypress family), most commonly growing to 30-35m; the Ethiopia *Juniperusprocera* type can reach up to 50m which makes it the largest tree of this genus (Azene 1993; Negash 2010).

Juniperusprocera is dominantly found in the highland area of Ethiopia where it usually grows within altitudes range from 1500-3000m in moist and wet Dega and Dega agro-climatic zones. (Azene et al., 1993; Negash, 2010). In the

BM, *J. Procera* dominates the headquarters of Park in the Juniper Woodlands zone while covering a wide range of the park, extending as far as the northern slopes of the Bale massif, reaching from Dodola to Dinsho. *J. procera* in the BM found dominantly together with plants like *Hagenia abyssinica*, *Hypericum revolutum*, and *Rosa abyssinica* (Biniam & Richman, 2013).

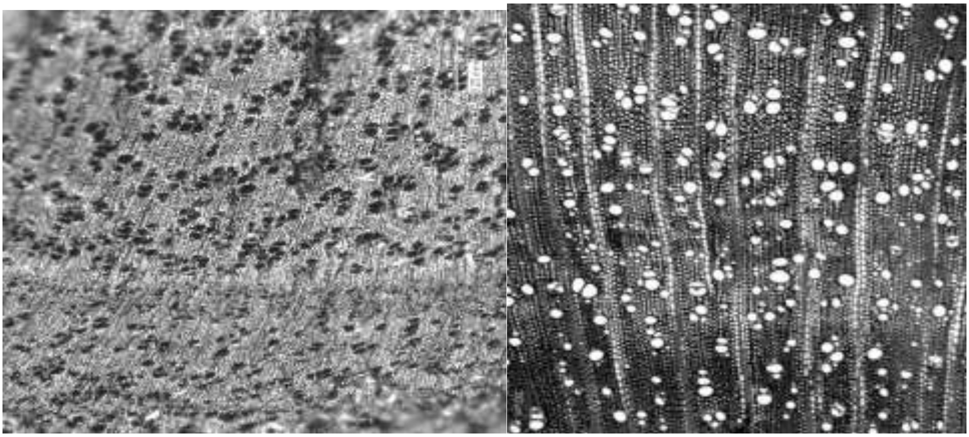

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Figure 3: Identification of archaeological charcoals by comparisons with modern anatomy of *Artemisia afra* in cross-sectional view. (A) Anthracology sample from Fincha Habera site (FH17 E8 L2 SE). (B) Modern anatomy of *Artemisia afra* retrieved from Inside Wood database. Published on the Internet http://insidewood.lib.ncsu.edu/ contributed by Elisabeth Wheeler (2011).

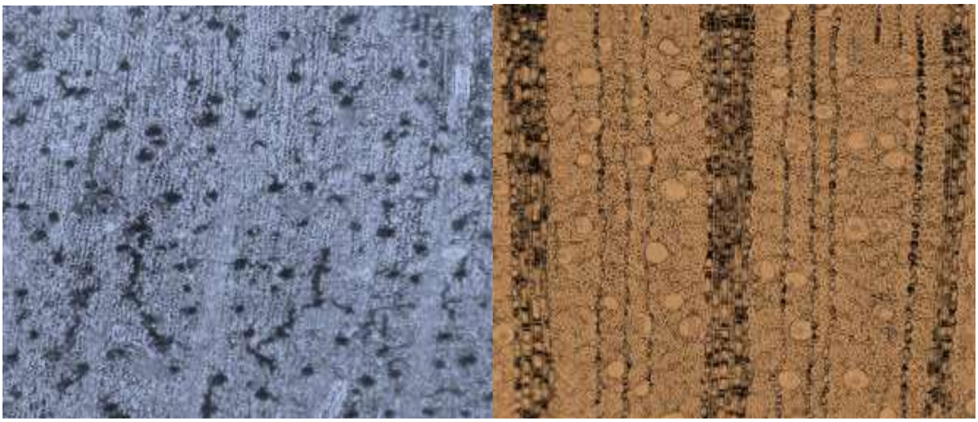
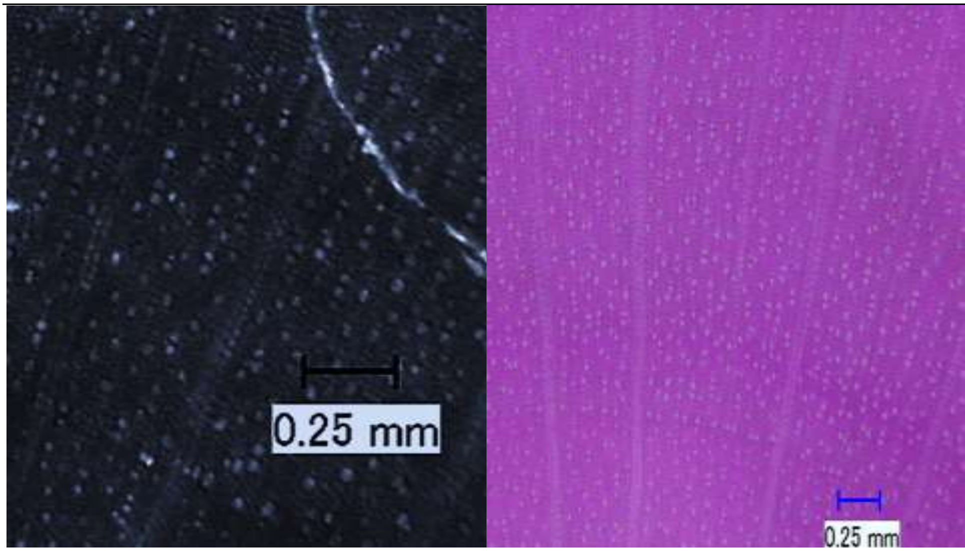


Figure.4. Identification of archaeological charcoals by comparisons with modern anatomy of *Erica arborea* in cross-sectional view. (A) Anthracology sample from Fincha Habera site (FH17 E8 L6 NW). (B) Modern anatomy of *Erica arborea* retrieved from Inside Wood database. Published on the Internet http://insidewood.lib.ncsu.edu/ contributed by Elisabeth Wheeler (2011).

A B

Figure.5. Identification of archaeological charcoals by comparisons with modern anatomy of *Juniperus cf. procera* in cross-sectional view. (A) Anthracology sample from Mararo site (MAR A05S8 SW1-130. (B) Modern anatomy of *Juniperusprocera* retrieved from Inside Wood database. Published on the Internet http://insidewood.lib.ncsu.edu/ contributed by Elisabeth Wheeler (2011).



A B

Figure 6: Identification of archaeological charcoals by comparisons with modern anatomy of *Myrsine* cf. *africana* in cross-sectional view. (A) anthracology data from Simbero (E18 1 A58 K4 L9 NE. (B) Modern anatomy of *Myrsineafricana* obtained from Alemseged Beldados's teaching collections.

The results of charcoal analysis from dated contexts at each site

Table 4: Identified taxa by site and temporal subdivision, all years cal BP.

	Erica cf. arborea	*Myrsinecf. africana*	*Solanum cf.giganteum*	*Artemisia cf. afra*	*Hagenia cf.abyssinica*	*Hypercum cf.revolutum*	*Juniperus cf.procera*
Fincha Habera							
12th/13th century first horizon	12	10	6	9	8	4	-
Simbero							
LSA I - 14.6 ka	8	5	2	1	-	1	-
LSA II - 8.1-5.0 ka	20	10	5	1	1	-	1
LSA III - 3.6-2.2 ka	8	2	1	-	-	-	2
Late Pastoral	2	2	3	-	1	1	1
Fish Shelter							
LSA - 14.8-14.0 ka	14	11	2	-	-	6	2
LSA - 6.5-6.3 ka	13	7	8	1	1	1	1
Marano							
LSA/late Holocene - 4.7-2.6 ka	5	8	2	5	-	1	1
Late Pastoral - ca. 1.2 ka	1	3	3	2	1	1	

Fincha Habera

At Fincha Habera charcoal samples retrieved only from later occupation phases (layers FHL-02/-03/-04/-05/-06/PIT1 & FHL-07) were identified. Both layers relatively yielded almost equal amounts of identified charcoal fragments by containing 52 and 49 charcoal fragments respectively. FHL-07 layer has no secure dates corresponding to archaeological materials even though it contains few MSA artifacts. For this layer, many younger charcoals were also discovered indicating they have trickled down from layer FHL-06. Due to high concentrations of charcoal fragments observed in this layer, the samples from this layer were also identified apart from FHL-02/-03/-04/-05/-06/PIT1 layer.

From the total of charcoal fragments identified from this FHL-07 layer, *Erica arborea* is the most dominant taxon represented by 12 pieces of charcoal. *Artemisia afra*, *Solanum giganteum, Myrsine africana, Hypericum revolutum*, and *Hagenia abyssinica* constitute the second most abundant taxa, represented by 9, 8, 7, 6, and 6 charcoal fragments respectively. *Juniperus procera* represents the least dominant taxa from this layer, represented by only 4 pieces of charcoal.

In FHL-02/-03/-04/-05/-06/PIT1 layers *Erica arborea, Myrsine africana*, *Artemisia afra*, and *Hagenia abyssinica* were identified as the most dominant taxa by representing 12, 10, 9, and 8 charcoal fragments respectively. The reaming two taxa *Solanum giganteum* and *Hypericum revolutum* identified as the second most dominant taxon from this layer by comprising 6 and 4 charcoals fragments respectively.

Simbero

The allocation of layers, levels, and dates is quite clear in this site due to corresponding interrelations of artifact distribution, stratigraphic sequence, and dating results. Charcoal samples collected from all occupational phases were analyzed at simbero site.

The largest concentration of identified charcoal samples was observed in the late Holocene occupation phase by representing half (41) of the fragments from a total identified sample of 82 fragments. From this context, *Erica arborea* was a dominant taxon represented by half of the charcoal fragments (20) followed by *Myrsineafricana*, *Solanumgigantum, Hageniaabyssinica, Juniperusprocera, Artemisia afra*, and *Hypercumrevolutum* represented by 10, 5, 3, 1, 1, and 1 respectively.

The terminal Pleistocene occupation phase comprises the 2nd concentration of charcoal samples by containing 16 fragments from the total identified samples from this site. *Erica arborea* is also the dominant taxa, identified from this context by containing 8 fragments. *Myrsineafricana, Solanumgiganteum*, *Artemisia afra*, and *Hypericumrevolutum* ranked from the 2nd to 4th place according to their respective list by representing 5, 2, 1, 1, and 1 piece respectively.

Middle Holocene and pastoral occupation phases encompass the lowest charcoal concentrations by representing 13 and 10 pieces identified charcoal fragments respectively. At the middle occupation phase, *Erica arborea* is also the dominant taxa by containing 8 fragments. This is followed by *Myrsine africana* and *Juniperus procera* identified as the 2nd most dominant taxa, each of them representing 2 pieces. *Solanum giganteum* represented the lowest fragments by containing 1 piece of charcoals fragment.

Pastoral occupation phase contains the biggest taxa identified of all occupational phases at Simbero. From this occupational phase, a total of 11 charcoal fragments were identified into 7 different taxa. From this context, *Solanum giganteum* contains the most dominant taxa by representing 3 pieces and followed by *Myrsine africana*, *Erica arborea*, *Hagenia abyssinica*, *Juniperus procera*, *Hypericum revolutum*, and *Artemisia afra* by representing 2, 2, 1, 1, 1, and 1 piece respectively.

Fish Shelter

At the Fish shelter, two major occupation phases were reconstructed. Anthracological samples obtained from both occupation phases and interface layers (level 7) were analyzed. From the early occupation phase, two charcoal fragments from the fireplace and two from red loam were identified at the species level.

High concentrations of charcoals were obtained from the first and second occupation phases by representing 44 and 32 charcoal fragments respectively. In the first occupation phase, *Erica arborea* was identified as the most dominant taxon by representing 14 charcoal pieces from the total sample from this context. *Myrsine africana* was identified as the second most dominant taxon from the first occupation phase by containing 11 charcoal fragments. *Artemisia afra* is identified as the third most abundant taxa in this context, represented by 8 charcoal fragments. *Hypericum revolutum*, identified in lower abundance by representing 6 pieces of charcoal fragments whereas *Solanum gigantum* and *Juniperus procera* were identified in less much lower abundance by encompassing 2 pieces of charcoal from the early occupation phase at Fish shelter.

The second occupation phase at Fish shelter is also dominated by *Erica arborea* both by frequency and ubiquity, represented with 13 charcoal fragments. *Solanum gigantum* and *Myrsine africana* were the second most abundant taxon in this context with 8 and 7 fragments respectively. *Hagenia abyssinica*, *Artemisia* *afra*, *Juniperus procera*, and *Hypericum revolutum* were identified as fewer dominant taxa. Only one piece of each taxon identified from this occupation phase.

Apart from both occupation phases, level 7 was analyzed under the separated category as the interface between layers C and D. In this way level 7 was analyzed separately and contained both the smallest number of charcoal concentrations and taxa type. Only three taxa namely *Artemisia afra*, *Myrsine africana*, and *Hypericum revolutum* identified in relatively equal distributions (4, 3, and 4 respectively).

Mararo

Unlike Simbero and Fish shelter, the allocation of layers, levels, and dating results at Mararo site, are unevenly distributed. However, based on the found distribution of lithics material, LSA occupation between 4.8 and 2.4 kacal BP (layers BO and BOG) identified mainly in square S8. The younger layers (FDD, CWD, & LB) are difficult to date and probably contain mixed charcoals. Due to this, the charcoal assemblages from Mararo were analyzed according to their respective layers rather than classifying them into different occupation phases. Accordingly, five different layers Compact Wet Dung (CWD), Fine Dry Dung (FDD), Loamy Belts (LB), Black Organic (BO), and Black organic with Gravel (BOG) were identified from the S8 excavation unit at Mararo sites. Charcoal samples were collected from all layers except the CWD layer.

From all layers at Mararo, the largest concentration of charcoal samples was observed at layers BOG and BO which correspond to the major LSA occupation, represented by 22 and 17 charcoal fragments respectively. In layer BOG *Myrsine africana* was a dominant taxon, represented by 8 charcoal fragments. This is followed by *Artemisia afra* and *Erica arborea* each of which is represented by 5 pieces. The remaining taxa such as *Solanum giganteum*, *Hypericum revolutum*, and *Juniperus procera*, are presented in lower abundances, represented by only 2, 1, and 1 piece respectively.

Erica arborea is the dominant taxa identified from layer BO by containing 8 charcoal fragments. *Myrsine africana*, yielded the second most fragments from this layer by containing 4 fragments. *Juniperus procera*, *Solanum giganteum*, and *Hypericum revolutum*, are the lowest abundant taxa from this layer by presenting 2, 2, and 1 piece of charcoals respectively.

FDD and LB layers encompass the lowest charcoal concentrations, represented with 11 and 7 charcoal fragments respectively. At FDD layer *Solanum giganteum*, *Myrsine africana*, and *Artemisia afra* are the dominant taxa. Both *Solanum giganteum* and *Myrsine africana* presented with equal proportion represented by (3 pieces), whereas *Artemisia afra* by (2) pieces. The remaining four taxa namely *Hagenia abyssinica*, *Hypercum revolutum*, and *Erica arborea*, are represented by a single piece only.

Layer LB contains the smallest charcoals concentration of all layers at Mararo site. From this layer, a total of 7 charcoal fragments were identified into taxa. *Hagenia abyssinica* contains the dominant taxa by representing 3 pieces, and this is followed by *Myrsine africana*, *Erica arborea*, *Hypericum revolutum*, and *Artemisia afra* by which each of them represented by single piece of charcoal fragment.

Reconstructing fire wood collection, vegetation cover, and environmental conditions

Analysis of anthracological data is one approach among various environmental data which is widely used to understand overall interactions between humans and their environments in the past. (Scheel -Ybert, 2018, Kabukcu, 2015; Asouti, 2001). Since the development of this discipline, various approaches and models were introduced by different scholars dealing with how to use and interpret anthracological results. The Principle of Least Effort (PLE) first proposed and used by George K. Zipf (1949), is one widely used model in interpretation of anthracological results. According to this model fuel wood collection would take place within a relatively small area, close to the location of the settlement. According to this model, in a high-density woodland environment, the nature of firewood collection should be characterized by selection toward a specific species based on different criteria, such as burning properties and amount of deadwood. On the other hand, in the area with limited vegetation cover either because of extreme cold (Mountainous/ Tundra) or extreme aridity (Desert), the collection of fire wood should be by non-selective.

Alternatively, Asouti and Austin (2005) proposed and used the heuristic model. This model hypothesizes that firewood collection among hunter-gatherer groups and settled communities may take different forms. In the first case firewood collection is opportunistic in nature (they collect what is available in their surrounding), which makes this the same expectation as the non-selective fuel collection strategy proposed by the PLE. In contrast in the latter case, firewood collection is mostly affected by factors such as economy, way of life, technology, and rituals.

Based on both models it is possible to suggest that in the course of terminal Pleistocene–early Holocene, we would expect firewood collection in the BM to be opportunistic, with firewood randomly gathered from the immediate surroundings and brought to the campsite. This statement is quite true for BM regions which were characterized by low-density of vegetation cover specifically in its higher-altitude parts, where most of the sites selected for this study are located. This is also true for the occupants who settled in the BM specifically in the sites located along the plateau where hunter-gatherers visited the region for a shorter period (Ossendorf et al., 2019).

In the BM firewood collections may also take different form. Hunter-gatherers probably collected firewood by "*embedded procurement*" strategy, so during hunting expeditions, or when returning, they collected firewood. Most resources (obsidian, chert, giant mole-rats, other prey, water, etc.) were available within a day's walking distance, so there was no need for "direct procurement" or to search for firewood only. This in turn means that the charcoal assemblages are a reflection of the past vegetation conditions.

Firewood collection and use in the Bale Mountains

In most LSA sites at the BM (examples Simbero and Fish shelter), 99.8% of the faunal remains are burnt, and many obsidian artifacts show different degrees of burning (Ossendorf, Pers. Comm., May 31, 2021). This is one of the very important pieces of evidence that indicates wood was brought to sites to assist in the deliberate destruction of bone. The collections of firewood in the BM were not only limited to cooking. Since all sites in the BM are characterized by high altitude environments, firewood was also collected for warming up at times when the temperature dropped.

Firewood collecting in the BM during the period under investigation was characterized by collecting of firewood with good burning properties (*Erica aroborea, Myrsine africana, Hagenia abyssinica, Hypercum revolutum*, and *Juniperus procera*) and woods with poor burning properties (*Artemisia afra* & *Solanum gigantum*). Dominantly identified charcoal taxa such as *Erica aroborea* and *Myrsine africana* are considered as types of wood preferred for firewood in most of the sites. Woods like *Hagenia abyssinica* and *Hypercum revolutum* were the second most preferred fuel wood in the study area whereas *Junipers procera* was also collected as firewood the least.

In terms of total firewood coverage in the BM during the period under investigation, *E. arborea* tree is the dominant firewood in all sites. However, charcoal of *E. arborea* showed dramatically decreasing patterns through time. In terminal Pleistocene and early-Holocene layers, *E. arborea* was the dominant taxa and *M. africana* is the second most dominant taxon. Other taxa such as *A. afra*, *H. revoltanum* and *J. procera* were present in smaller amounts in all sites where terminal Pleistocene and early Holocene layers were represented. Afterward, in the mid-late Holocene layers, there is a considerable increase in the occurrence of *H. abyssinica*, *A. afra*, and *J. procera* and a corresponding decrease of *E. arborea* charcoal. The gradual decline of the *E. arborea* charcoal towards the more recent layers reflects the continuous destruction of the *Erica arborea* tree in the catchment area.

Interestingly, in late Holocene layers specifically at Fincha Habera, Mararo, and Simbero, wood with poor burning properties (*A. afra* & *S. gigantum*) co-occurred with wood good burning properties (*H. abyssinica, J. procera,* & *H. revolutum*), indicating awareness toward specific taxa selection based on burning properties. Based on the relative abundance of charcoal fragments, it is possible to conclude that people changed their wood-collection behavior from the mid-to-late Holocene period. The co-occurrence of woods with poor burning properties with quick-burning woods after the mid-Holocene can be marked as one of the very important indications for the beginning of fuel wood selection in the BM. The change in fuel wood collection could be because of increased awareness of fuel-wood burning properties, environmental factors, or changes in the dietary system, or some combination of these factors.

Reconstructing vegetation cover and environmental conditions

The vegetation and environmental conditions of BM during the terminal Pleistocene were reconstructed based on charcoal samples obtained from Simbero and Fish shelter sites. The results show that *E. arborea* and *M. africana* co-dominated together during this period. The co-dominance of both taxa in the layers of terminal Pleistocene may result from the increased drier climatic conditions of BM at the end of LGM. This can be understood as after the ice cap/the valley glaciers had retreated, the BM experienced warmer climatic conditions (Grooss et al., 2001). The increased warmer climate of this period facilitated the expansion of *Ericaceae* and *Myrsinaceae* plants, which grew dominated the northwestern escarpment surrounding the sites of BM, and this created good conditions for prehistoric people to continuously settle in the Web Valley starting around 15ka cal. BP.

Previous palaeo environmental research in the study area, such as Addis (2017), Kuzmicheva et al. (2013), and Mohammed and Bonnefille (1998), support the results of the charcoal analysis. Addis (2017) indicated that the increased warming that happened after 16 ka created the significant conditions for the *Erica* tree to dominantly grow surrounding the Sanetti Plataea. Similarly, sediment core analysis from Garba Guracha Lake by Umer et al. (2007) and at the Fincha Habera site by Kuzmicheva et al. (2013) also indicates an arid and semi-arid environment of BM during the same period. As indicated by their findings, after the end of LGM, the BMs were dominated by *Amaranthaceae/ Chenopodiaceae, Poaceae, Cyperaceae, Ericaceae, Primulaceae,* and *Artemisia,* representing an arid and semi-arid environment. Interestingly all plant families identified by previous environmental studies could co-occur together with plant families identified by charcoal analysis (*Ericaceae* & *Myrsinaceae*) due to the same ecological preferences among them. The other interesting thing, some plant families such as *Artemisia afra* and *Ericaceae,* that were common in sediment records of the previous study, were also identified in charcoal assemblages during the same period (terminal Pleistocene).

The early-Holocene layer was represented by charcoal samples obtained only from a single site (Simbero). The result of the charcoal analysis from this site shows the domination of both *E. arborea* and *M.* Africana in relatively equal proportions, specifying similar vegetation cover during this period. The Co-dominance of both taxa may suggest that during the early Holocene, burning of *E. arboreal* and *M. africana* was common due to the sufficient coverage of *Ericaceae* and *Myrsinaceae* vegetation that resulted from the warmer climatic conditions at the end of LGM which also continued during the early Holocene. The occurrences of rare taxa such as *H. revoltanum, A. afra* and *S. gigantum* remained constant in the layer of early Holocene, indicating the same type of climatic conditions between the terminal Pleistocene and early Holocene periods.

Other researches, such as Kuzmicheva et al. (2013), indicated that plant families like *Poaceae, Apiaceae, Lactucoideae, Fabaceae,* and *Chenopodiaceae* dominated the BM during the same period, and grew in the same ecological region with *Ericaceae* and *Primulaceae* which were identified by charcoal analysis.

The Middle Holocene layer (7000-5000 years ago) was represented by anthracological samples obtained from Simbiro and Fish shelter. From all sites, *M. africana, E. arborea, S. gigantum,* and *H. revoltunum* were identified as dominant taxa. Even though *E. arborea* is still a dominant taxon in this layer, it shows considerable reduction when compared to the terminal Pleistocene and early Holocene period. This considerable reduction was not only observed on *E. arborea* taxon but was also common in all other taxa, which specifies the vegetation shift from evergreen forest to woodland savanna zone. However, other taxa such as *S. gigantum* and *H. revoltunum,* which were recorded as rare taxa in the early layers, began to appear co-dominant with *Erica,* indicating the environmental change that happed during this period.

The Mid-Holocene occupation layer yielded the smallest number of charcoal samples when compared to the terminal-Pleistocene and early Holocene layers. This indicates a dramatic decline in charcoal concentration during this period. This dramatic decline of charcoal is probably associated with the decline of Ericaceae vegetation cover on one hand and evergreen forest on the other hand in the BM in response to climatic change.

As indicated by Sellmer and Bates (2013), factors such as drought, temperature fluctuations, and increase in temperatures create a difficult situation for Ericaceae plants, whereas adequate humidity and moisture are essential for their continued existence. Based on this, the decline of charcoal assemblages on one hand, and the change in the relative abundance of identified taxa types recorded on the Mid-Holocene layer on the other hand, was potentially caused by the reduction of Ericaceous plants surrounding the settlement area. This can be associated with the change of adequate humid and moisture period of terminal Pleistocene and early Holocene to a much drier phase during Mid-Holocene.

Pollen and spore analysis obtained from Fincha Habera site also support the result of the charcoal analysis. As indicated by Kuzmicheva et al. (2013), the pollen record obtained from Fincha Habera from 8200 to 5000 years ago was characterized by a decline in *Podocarpus*, *Apiaceae*, and *Poaceae* while *Juniperus* and *Caryophyllaceae* increased, indicating typical characteristics of dry climate. Other research by Tsige (2015) also indicates the dramatic decline of charcoal fragments from the sediment core of Lake Chamo during the same period as a result of regionally caused aridity.

The late Holocene samples have been divided into two phases: from 5-2ka and 2-0ka. This is for the fact that the material archives of the last LSA occupation in the BM have shown a dramatic decline since 2ka. In the same way, during this period there were ephemeral occupations of pastoralists/herders in various rock shelters. This is also demonstrated by the anthological analysis in which these two phases of occupations have very different charcoal spectrums.

For the first phase, occupation corresponds to the last LSA occupation in the BM, the result of anthracological investigation has also exhibited some differences from the earlier period where the charcoal assemblages from each site display relatively different results. In all sites, taxa such as *M. Africana*, *A. afra*, *J. procera*, *H. abyssinica*, and *H. revolutum*co-occurred with *E. arborea* in relatively equal proportions.

Consequently, the decline of the Ericaceae plant that was recorded during this occupational phase is an indication of the continuous decline of the Ericaceae tree in the region. This indicates the study area experienced much drier climatic conditions during this period. Other palaeo environmental studies (Umer et al., 2007) also agreed with the result of this study. As stated by this study, during the late Holocene BM was characterized by a decrease in Ericaceae and Poaceae and an increase in *Podocarpus*, *Juniperus*, *Olea*, and *H. abyssinica* that specify a drier climatic condition.

The second phase of the late-Holocene occupation period in the BM corresponds to the "early" appearance of pastoralists in the BM. No archaeological research to answer questions about when exactly the pastorals arrived in the BMS has been conducted to date.

The results of this study suggest that the early arrival of pastorals in the BM was no earlier than 2ka. This is inferred from antrhracological assemblages of this period characterized by increased selection of specific taxa toward suitable tinder woods which are unique characteristics of this period. In this occupation phase, wood-like *Erica arborea*, *Myrsine africana*, *Hagenia abyssinica*, and *Hypericum revolutum* with good burning property co-occurred relatively in equal proportion dominating 90% of identified taxa.

The charcoal assemblages of this period, in addition to signifying the increased trend toward specific taxa selections, provide an ideal indication for the beginning of present-day vegetation formation in the BM as supposed by Mohammed and Bonnefille (1998). The charcoal assemblages of this period indicate an increased number of arboreal taxa, including *Hagenia abyssinica*, *Juniperus procera*, and *Ericaceae* as well, but Ericaceae vegetation showed gradual decreases compared to the terminal and early Holocene occupation phases.

Based on the anthracological remains of this occupation phase, it is very challenging to understand the vegetation cover and environmental proxy for the BM. This is because the wood collection trends of this period were characterized by increased selection toward specific taxa. Regardless of this limitation, the identified taxa provide significant information to reconstruct the vegetation history and environmental proxies of the study area for the past two millennia.

The co-dominance of arboreal trees with abundant Ericaceae vegetation is one indication for the occurrence of the dry and humid period. Scholars such as Jolly et al. (1994), Mohammed and Bonnefille (1996), and Umer et al. (2007) used similar interpretations in which increases in arboreal trees such as *Podocarpus*, *Juniperus*, and *Hagenia* were inferred as indicative for the dry climatic session. Additionally, the gradual decline of Ericaceae vegetation cover from its maximum during terminal Pleistocene and early Holocene into the mid-Holocene is the other significant suggestion for the increased drier climatic conditions.

Conclusion

The Bale Mountains in Ethiopia possess one of the most extensive Afro alpine vegetation both in Ethiopia and in the continent of Africa. Despite rich natural and cultural resources and several attempts by researchers, the palaeo-environmental evolutionary history, and past ecology, past human-environment interactions were not clearly outlined and understood in a multi-disciplinary manner. The Mountain Exile Hypothesis Project funded by DFG (German Science Foundation) is a reaction to deal with the paucity of data about our understanding of past environment of the BMs and change and continuity in the vegetation composition of the study area and human-environment interactions.

As part of this project, this research work focusing on anthracological analysis of samples ranging in time between Terminal Pleistocene (14,600 years ka) and to the $12^{th}/13^{th}$ Centuries AD brought to light the woody genera that were used for fire, the plant types that constituted the past environment and the vegetation composition of the region. Accordingly, the table below summarizes the vegetation zone/forest zone (IbFriis & Demsew 2011) of the identified plant types (table 5).

Table 5: Vegetation zones of the identified plant types

No.	Identified plant types	Vegetation zone/ forest zone
1	*Erica cf. arborea*	Afromontane
2	*Myrsinecf. africana*	Dry afromontane
3	*Solanum cf. giganteum*	Dry afromontane
4	*Artemisia cf. afra*	Afromontane
5	*Hageniacf. abyssinica*	Afromontane/possible extension to Dry afromontane
6	*Hypericum cf. revolutum*	Afromontane
7	*Juniperus cf. procera*	Dry afromontane

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