Reconstruction of Environmental and Vegetation Changes on the Sanetti Plateau since the Last Deglaciation Based on Biogeochemical Analyses of Sediments

By

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Reconstruction of Environmental and Vegetation Changes on the Sanetti Plateau in South Ethiopia, since the Last Deglaciation Based on Biogeochemical Analyses of Sediments

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Acronyms

BC - Black Carbon

BP - Before Present

BPCA -Benzene Polycarboxylic Acids

Cal - Calibrated Age

EC - Electrical Conductivity

GC - Gas Chromatograph

GMP - General Management Plan

HCl -Hydrochloric acid

LGM -Last Glacial Maximum

MAP - Mean Annual Precipitation

Om -Organic matter

SOM - Soil Organic Matter

TFA - Trifluoroacetic Acid

TOC - Total organic carbon

pyr –pyrogenic

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Abstract

Reconstruction of Environmental and Vegetation Changes on the Sanetti Plateau since the Last Deglaciation Based on Biogeochemical Analyses of Sediments

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The aim of the study was to contribute to a better understanding of the environmental and vegetation changes of Erica arborea and Erica trimera at the Sanetti plateau community, in the upper Afroalpine vegetation zone of the BMNP (Bale Mountain National Park) South Ethiopia. A sediment core was recovered from a small glacial depression at 3990m altitude in the Bale Mountains of Ethiopia. Accumulation $\delta^{13}C$ *and* $\delta^{15}N$ *values of the soil organic matter (SOM) in the sediments were analyzed with the objective to get information about environmental changes. The results support hypotheses about climate influences or vegetation changes onδ13C values of SOM during the late Glacial and Holocene* $\delta^{15}N$ *values showed a negative trend with increasing sediment depth, indicating that after deglaciation N cycles were very closed but opened with pronounced fluctuations towards the beginning of the Holocene. δ15N maxima during the Late Glacial and Early Holocene roughly correlate with BC maxima supporting the hypothesis that also fire might influence* $\delta^{15}N$ *values of SOM. If differences in land use history have larger effects on δ13C values than climate fluctuations then* $\delta^{15}N$ *values of SOM may be valuable in conjunction with δ13C analyses for reconstructing aspects of land use and climate variability. Erica shrub and forest decreased in area with increasing altitude and the Afroalpine ecosystem expanded on the plateau. Human impact on the high-altitude Afroalpine and Ericaceous vegetation has been relatively minor, confirming that the endemic biodiversity of the Ethiopian mountains is an inheritance of natural Holocene vegetation change. The aim was to test the potential of Black carbon (BC) analysis in order to make clear the input from grass and wood fires and discuss the potential limitations of the method on sediments of the Garba Guracha. Sediments cover the cultural transition from hunter gatherers to food-producing communities during middle of Holocene.*

Key words; Bale Mts., Sanetti Plateau, Erica shrubs, fire history, stable isotope ($\delta^{13}C$, $\delta^{15}N$) and BC

CHAPTER ONE

1. INTRODUCTION

1.1. Back ground

The Bale Mountains in Southeast Ethiopia and especially their highland part, the Sanetti Plateau, are characterized by a great biological diversity and special sensitivity to climatic and anthropogenic changes. Modern climatic conditions of the Bale Mountains have a prominent altitude zoning, which is also reflected in the vegetation. The highest elevation is the Tullu Dimtu with an altitude of 4377 m a.s.l. and the Sanetti Plateau is mainly covered by afroalpine vegetation typical for the East Africa highlands. According to Miehe & Miehe (1994) and Kuzmicheva *et al*. (2014) the afroalpine belt of the Bale Mountains is the largest throughout the entire African continent.

The Sanetti Plateau is widely perceived as little disturbed (Hedberg, 1964; Beck *et al*., 1986; Wesche, 2002, Yohannes *et al*., 2012). So far, the history of human interference in the Bale Mountains is assumed to date back to about 2000 years only (Umer *et al*., 2007; Kuzmicheva *et al*., 2013). The evolution and perseverance of high number of endemic species throughout a wide range of taxonomic groups, including the afroalpine landscape-engineering of the Giant Molerat (*Tachyoryctesmacrocephalus*; Yalden, 1975; Yaba *et al*., 2011) and its main predator, the flagship species of the Bale Mountains, the Ethiopian Wolf (Sillero-Zubiri& Macdonald, 1997), support the view that the world’s largest afroalpine ecosystem remained comparatively little transformed.

The Bale Mountains are uniquely exposed to all main wind directions (SW monsoon, SE monsoon, NE trades, and NW disturbances) and their plain highland relief provides best preconditions for snow accumulation and glaciation, in contrast to the East African volcanic cones that are for geometrical reasons least suited to develop significant glacial features. The hitherto surveyed moraines (Miehe & Miehe, 1994; Osmaston *et al*., 2005) suggest that the glaciers are not necessarily the cause of loss, but a source of melt water attracting wildlife and hunters.

Regarding the paleoecology of African mountains, Quaternary environmental science and prehistory are especially challenged through the fact that it remains largely unknown where humans retreated to during the dry Last Glacial Maximum (LGM) (Basell, 2008). As a simple consequence of the arid climates during the LGM in Africa, life was likely forced to retreat to humid refugia. Because the archipelago of African mountains is well known for its higher humidity, afroalpine environments are a potential glacial refuge. As a consequence, we challenge the long-held belief of a late afroalpine landnám, and instead posit a new “Mountain Exile Hypothesis”, those African mountains and their valleys were ice age refugia - not only for plants and animals – but for humans too. The current evidence however is scarce and unclear. But in case that this assumption is realistic, human induced fires most likely have seriously influenced the present scarce distribution of Erica at the Sanetti Plateau. Also Schüler *et al*. (2012) assume that the present distribution of *Erica*ceous heath lands in the East African highlands basically reflects man made fires.

Accordingly, there is a lot to be done in the future, generally in the Bale mountain area and specifically in the study area, the Sanetti Plateau, to explain and understand the influence and intensity of fire threats on key ecological attributes like vegetation patterns, soil seed banks, chemical and physical soil properties, and soil nutrient pools.

1.2. Statement of the problem

Bale Mountains including the Sanetti Plateau make it a likely refugium and thus seem to be better suited than the comparably small volcanic islands of the East African backbone to trace climate change driven human immigration to African mountains, and to identify the ecological consequences of such human invasion like fire induced destruction of *Erica*. Whether a human footprint can be detected in the area already from before the Last Glacial Maximum (LGM), only after deglaciation or even in the younger past must be studied in more detail in the future (Kuzmicheva *et al*., 2013 and 2014).

Most biodiversity hotspots and nature conservation in the Bale Mountains National Park are challenged by increased human demands of natural resources (Vial, 2010). But in a wider perspective of nature conservation, the area can be seen as a major test site to investigate how human land use has increased habitat diversity and favors population stability of Ethiopia’s most endangered endemic species.

1.3. Research Questions

1. Was the Sanetti Plateau after deglaciation and during early phases of the Holocene more or less completely covered by Erica species?

2. If yes, when was the Erica stands reduced to their present low extension and was this mainly due to climate change or by human induces fire?

3. Which environmental information is stored in the depth functions of BC, TOC, N and pH?

4.) How does $\delta^{13}C$ and $\delta^{15}N$ in the sediments vary since the late Glacial and is there any information about C3 and C4 plants, as well as about the N-cycle?

1.4. Objectives

1.4.1. General Objectives

- To contribute to a better understanding of the environmental and vegetation changes on the Sanetti plateau since the last deglaciation based on biogeochemical sediment analyses

1.4.2. Specific Objective

i. To evaluate the potential of $\delta^{15}N$ analyses for detecting N-dynamics in high-mountain ecosystems.

ii. To detect whether the organic matter in the sediments under study derived mainly from C3 or C4 plants

iii. To investigate the accumulation of Cpyr products in the sediments as potential indicators of the timing and intensity of fire events destroying Erica stands on the Sanetti Plateau

iv. To determine the drivers and processes of environmental change and quantify the respective impacts from the molecular to the landscape, fires as well as biotic factors such as landscape engineering animals and the anthropogenic impact

1.5. Hypothesis

After deglaciation the plateau soils were indeed covered by Erica due to warmer and more humid environmental conditions. As a consequence of human invasion, fire destroyed most of the Erica stands at the plateau causing accelerated soil erosion. Studying sediments in concave topographic positions should give information about biogeochemical processes along the surrounding slopes of the depressions, like burning of Erica, accelerated erosion after burning and input of slope sediments rich in pyrogenic carbon as fire proxy. Also TOC and N contents, $\delta^{13}C$ and $\delta^{15}N$ values as well as grain size proxies stored in such sediments may inform about environmental changes in the catchment, like fire, accelerated organic matter mineralization after burning and opening of the N cycle. The special geomorphological features of the Sanetti Plateau, characterized by the occurrence of frequent rock shelters and vast, swampy depressions, may favor on the one side the reconstruction of early human occupation in shelters, and on the other side, the reconstruction of the late Quaternary landscape and vegetation evolution by multi-proxy studies of the corresponding sediments and soils deposited in concave positions.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Effects of fire

Fire is a natural ecosystem process in biomes covering more than half of the global land area (Krawchuk *et al.*, 2009). In such flammable systems, fire influences vegetation composition, and the vegetation reciprocally influences fire behaviour. Fire has been acting as an evolutionary force ever since the first terrestrial plants appeared, and ecosystems and plants have co-evolved with their own distinct fire regimes (Pausas & Keeley, 2009).

For fire to occur, fuel, oxygen and a source of ignition is necessary. Wildland fuel is composed of live and dead plant biomass. In order to carry fire, the fuels need to be of enough quantity and incessantly distributed across the surface (Bradstock & Gill, 1993). Also the vertical arrangement of fuels is important, particularly in forests. If the tree cover is too widely separated from the surface fuels on the ground, normally fire cannot climb up in the canopy (Albini, 1985) and the fire regime will be dominated by surface fires rather than crown fires. A continuous cover of surface fuels (i.e. field-, moss- or litter layers) is necessary for forest fires to occur; crown fire cannot be sustained without support from surface fire below, unless under extreme wind conditions or steep slopes (Raymond & Peterson, 2005).

According to Menaut et al. (1993) “massive amounts of C are released by burning; however, if the system is not disturbed, comparable amounts of C are taken up by renewed biomass, so is true for N, the process by which N is captured in soil organic matter or in microbial biomass and released may be strongly affected by fire.” By burning C, N, and S are easily volatilized, whereas most other minerals like P and major cations (e.g. Ca, Mg, K, Na) are mainly accumulating in the ash. Higher temperatures, hence are these former elements general indicators of high and/or low severity level of fire and, while the earlier element (organic and/inorganic P) indicates higher severity level of fire in most cases. The amount of N lost by burning of the vegetation is related to temperature (degree of heat) and soil moisture (DeBano *et al*., 1998), and also strongly depends on the proportion of biomass combusted (McNaughton *et al*., 1998). Accordingly, under low-severity level of fire type (temperatures below 200°C) no N is volatilized, while at higher temperatures proportionally higher amounts of N are lost, and at temperatures above 500°C the entire biomass N is volatilized, At such high temperatures also some soil N is lost, especially N accumulated in the organic matter rich surface soil layers.

2.2. Stable Isotopes

Stable isotope signatures of light elements (δ^{13}C and δ^{15}N) in soils, sediments and plants are valuable proxies for the identification of biogeochemical processes and their rates in the pedosphere, lithosphere and biosphere (Glaser, 2005; Amelung *et al.*, 2008). They also may contribute to the reconstruction of (paleo) environmental changes. For instance, it is well known that δ^{13}C values of soil organic matter (SOM) can be used to document vegetation changes (Boutton, 1996). This is based on the finding that plants with C3, C4 and CAM photosynthetic pathways have $\delta^{13}C$ values of about -27‰, -13‰ and -30 to -10‰, respectively. Thus, $\delta^{13}C$ values of SOM indicate to which extent plants of different photosynthetic pathways have contributed as source to SOM production. Several studies revealed that in wooded landscapes $\delta^{13}C$ values of ~ -27‰ in surface soil layers and $\delta^{13}C$ values of < ~20‰ in the subsoil were connected with the invasion of C3 woody vegetation into C4 grasslands due to climate change or as a consequence of land use changes (Aucour et al., 1999; Freitas *et al*., 2001). In studies, where the point of time of vegetation change is known, $\delta^{13}C$ values of SOM have also been utilized to calculate turnover rates (Balesdent and Mariotti, 1996; Freier *et al*., 2010). Apart from C3-C4 vegetation changes, climate factors, SOM degradation and other soil processes can also influence $\delta^{13}C$ values. For instance, Liu *et al*. (2005) and Stevenson *et al*. (2005) have shown for plants and soils, respectively, that $\delta^{13}C$ decreases (up to 5‰) with increasing rainfall along precipitation gradients in arid regions of China and the USA. This can be attributed to plant physiological effects (Farquhar *et al*., 1982; O´Leary, 1988) resulting in a stronger isotopic discrimination against the heavy $^{13}CO_2$ under more humid climatic conditions. Often observed more positive $\delta^{13}C$ values (1-3‰) in subsoils compared to topsoils can be explained by increasing atmospheric CO_2 concentrations in subsoil layers but also with an isotopic ^{13}C enrichment caused by SOM degradation (Bol *et al*., 1999; Chen *et al*., 2002; Krull *et al*., 2002).

2.3 δ^{13}C values

δ^{13}C is a soil property proportional to the ^{13}C:^{12}C isotopic ratio which highly retains the signature of the parent vegetation. Due to this fact, δ^{13}C has been extensively used in soil research for paleo-environmental studies of changes in vegetation and climate and to investigate soil carbon dynamics.

All carbon isotope values are presented in the δ nomenclature (Craig, 1953) as δ^{13}C, and are calculated according to

δ_{sample} (‰) = [($R_{sample}/R_{standard}$) - 1] × 1000,

Where δ_{sample}(‰) represents the δ^{13} value. R_{sample} = ^{13}C/^{12}C, or ratio for the samples, and $R_{standard}$ = ^{13}C/^{12}C ratio of the carbon reference standard (VPDB)

The analysis of δ^{13}C in soil organic matter or in organic matter (=OM) of sediments may inform about the sources, that means whether the OM derived from C3 or C4 plants because δ^{13}C values tend to be similar to those of their original plant sources (Boutton, 1998) although some changes may occur during OM-decomposition (reviewed in Krull and Skjemstad, 2003; Terwilliger et al., 2008).

2.4 δ15N values

δ^{15}N is a signature proportional to the ^{15}N:^{14}N isotopic ratio, and has been used most prominently by environmental scientists to study nitrogen pollution in the hydrosphere and atmosphere; but has also been used significantly for studying issues such as δ^{15}nitrogen cycling in plants, soils and in lakes and coastal regions.

All nitrogen isotope values are presented in the δ nomenclature (Craig, 1953) as $\delta^{15}N$ and are calculated according to

$$\delta_{sample}\ (‰) = [(R_{sample}/R_{standard}) - 1] \times 1000,$$

Where δ_{sample} (‰) represents the $\delta^{15}N$ value. R_{sample} = $^{15}N/^{14}N$ ratio of the sample, and $R_{standard}$ = the $^{15}N/^{14}N$ ratio of the nitrogen reference standard (AIR N_2)

Nitrogen (N) is an essential building block of amino acids and nucleic acids and, therefore, an essential element for living organisms. Variations of ^{15}N natural abundance in plant–soil systems are caused by isotope fractionation occurring during N-cycle processes. The enzymes involved in these processes discriminate against the molecules with heavy ^{15}N. As a consequence, products are depleted in ^{15}N and substrates left over become enriched in ^{15}N (Zech *et al*., 2011).

Accordingly, NH_4^+, NO_3^- and N_2O are depleted in ^{15}N, whereas the residual total N becomes ^{15}N-enriched. Furthermore, plants assimilating the isotopically lighter NH_4^+ and NO_3^- have more negative $\delta^{15}N$ values than the respective soils. Notably, as long as the N cycle of an ecosystem is closed and no losses of isotopically depleted or enriched N occur, the overall $\delta^{15}N$ signature of the ecosystem does not change (Zech*et al*., 2011). However, due to climatic conditions N losses by leaching, degassing or by frequent fire events are favoured in some ecosystems, thus resulting in typical global and altitudinal pattern, i.e. more negative δ^{15}N values at higher latitudes and altitudes (Amundson*et al*., 2003; Männel*et al*., 2007). Additionally, human land use practices like cultivation of N-fixing plants, application of N containing mineral fertilizers or burning favours the “opening” of N cycles and leads to more positive d^{15}N values in soil and sediments.

2.5 Benzenepolycarboxylic acids

For a long-term storage of atmospheric CO_2 in soils, C must be incorporated into refractory structures which are only slowly modified by the soil microbial community and, therefore, do less respond to global warming and land use effects than it might be expected from mere assessment of the total C stocks in soils (Liski *et al*., 1999). Aromatic compounds are especially resistant against chemical and microbial degradation (Glaser *et al*., 1998, 2000; Goldberg, 1985; Schmidt and Noack, 2000; Seiler and Crutzen, 1980; Skjemstad *et al*., 1996). As reviewed by Schmidt and Noack (2000), pyrogenic C (Cpyr) consists almost exclusively of aromatic C. It may resist decomposition over geological time-scales and as dated back to the Devonian (Taylor *et al*., 1998). Thus it was assumed that Cpyr (= black C) significantly contributes to C sequestration in soils and sediments in the global C cycle (Kuhlbusch, 1998; Kuhlbusch and Crutzen, 1995). Obtaining information on the distribution of Cpyr across soils from different climatic regions might therefore inform about the potential of these soils to sequester C in a recalcitrant form.

Cpyr is produced by incomplete burning of organic matter (e.g. plants, wood), whereas complete burning at high temperatures results in the formation of $CO_{2.}$ As shown in Plate

1b burning of *Erica* frequently results in the formation of dark, incompletely burnt charcoal being rich in Cpyr. That means, charcoal as well as Cpyr are proxies indicating fire events. Assuming that during warm and humid periods after deglaciation Erica stands expanded on the Sanetti Plateau but later on were burnt by invading humans, the analyses of charcoal and Cpyr in suitable archives, like sediments in concave sites, should allow reconstructing fire history.

2.6. pH and electrical conductivity (EC)

The electrical conductivity (EC) of a soil or sediment informs about the concentration of salts and ions, respectively. The particle shape of sediments, soils, and rocks, moisture contents have influences on important transfer properties, such as electrical conductivity, dielectric permittivity, soil resistivity, thermal conductivity, and hydraulic conductivity. Soil electrical resistivity depends on soil water content as well as dry density of data fields. Soil resistivity also depends on soil texture (especially on clay contents), soil type and water holding ability and the amount of dissolved ions in pore water (Chik and Islam, 2011).

pH is the negative logarithm of the H^+-concentration. The analysis of the pH-value in soils and sediments informs about their acidity (pH <6), alkalinity (pH >7) or neutral (pH = 7) reaction. Soil acidity is produced by leaching of basic cations like Ca^{2+}, Mg^{2+}, K^+, Na^+. Also the decomposition plant material combined with the production of organic acids (e.g. fulvic acids) may contribute to the production of H^+. In soils and sediments with redoximorphic properties, periodical drying out is correlated with lowering of the pH-values. (Chik and Islam, 2011).

CHAPTER THREE

3. MATERIAL AND METHODS

3.1. Description of the study area

Geographically, the study area is located in Southeast Ethiopia, in the so-called Goba Woreda region of the Bale Zone. It extends between N: 06°53´20, 6´´ E: 39°54´31, 3´´; 3980 m a.s.l.) . Distance to Addis Ababa is approximately 450 km. The study site is nearly 20km southwest of Goba town.

The major socio-economic problems pressurizing the BMNP generally and the study area in particular result from the extension of agriculture and settlements due to unbraked population growth. Major ecological problems concern the protection of wild animals (Ethiopian Wolf) and uncontrolled fires set by humans (Mekonnen Getahun, 2009).

The knowledge about the soils of the Bale Mountains including the study area is based on sporadic studies carried out on specific sites and surrounding location. For example, Miehe (1994), Masresha Fetene and Menassie Gashaw (1997)and Fantaw Yimer (2007) and the Bale Mountains GMP (2008) reviewed the high elevation areas of the Bale Mountains, including the study area, and describing the soils and soil properties in a more general way. According to the observations during fieldwork in February 2015, the majority of the soils of the study area can be classified as Leptosols, Andosols, Cambisols and Histosols (World reference base for soil resources 2014, Update 2015).

3.1.1. Geology and Climate

The climate is dry-Wurch, characterized by high precipitation and low temperature. Mean Annual Precipitation (MAP) reaches up to 1070mm or more; while temperature varies between 13.3^{0}C (minimum value in the early wet season usually from March to June) to 14.1^{0}C (temperature maximum during dry season usually from November to February); According to Lundgren (1971) temperature decreases at a magnitude of 0.6 0C for an increase in altitude by 100m along the altitudinal gradient, and Fantaw Yimer (2007) stated that areas between or do you mean above 3200 to 3500ma.s.l receive 1064mm MAP. Temperature maxima are mainly observed during February, (= onset of the dry season) and March, (= onset of the wet season).

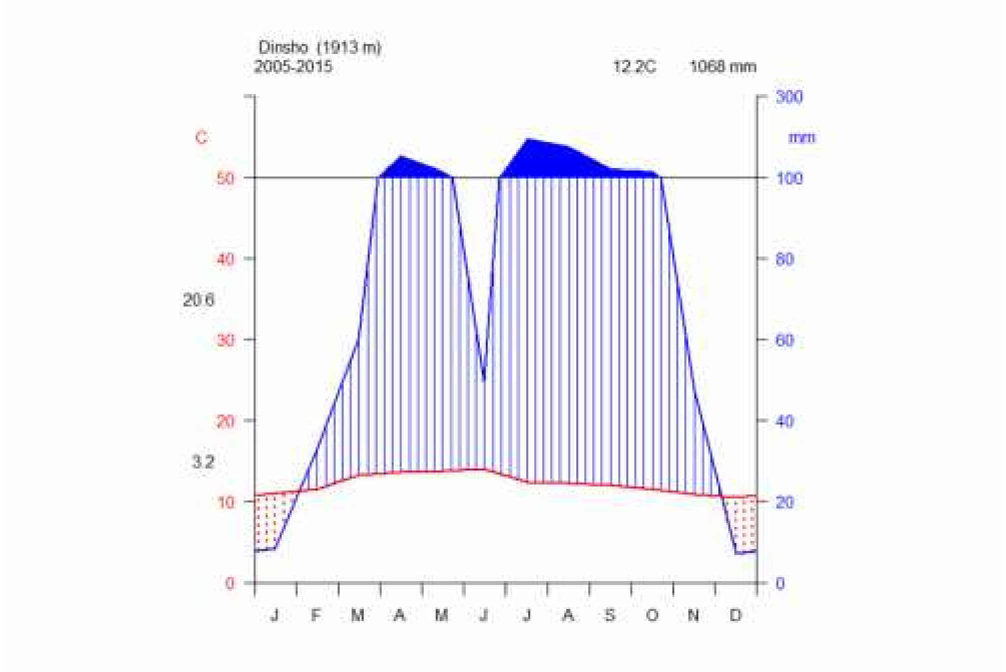


Figure 1.Shows Climatic Diagram for Dinsho (Source: EMSA 2005-2015).

3.1.2. Vegetation

The vegetation of Bale Mountains shows a distinct altitudinal zonation (Friis, 1986; Miehe & Miehe, 1994). Typically, alpine grasslands dominate above ~4000 m, and subalpine Ericaceous shrubland, or heathland, is found between ~4000–3500 m, which is dominated by multi-stemmed *Erica arborea* and *Erica trimera* (formerly *Philippia trimera*) shrubs which are generally kept short by repeated burning by pastoralists (Plate 1b). Below the heathlands a narrow belt of subalpine Ericaceous forest is situated between ~3500–3350 m, which is dominated by tree formed *E. trimera* with a few emergent *Hagenia abyssinica* and *Myrsinemelanophloeos*(formerly *Rapaneamelanophloeos*). The vegetation zones are similar on the northern and southern aspects at the highest altitudes, but show increasing differences at lower altitudes (Johansson, 2013).

In Bale Mountains the heath lands are co-dominated by multi-stemmed lingo tuberous *E. arborea* and *E. trimera* but the forest below is dominated by tree shaped *E. trimera* and here *E. arborea* is absent (Assefa *et al.*, 2011).

Shrub-formed *E. trimera* and *E. arborea* are morphologically similar and have often been collectively referred to as *E. arborea* since they are difficult to distinguish from each other, especially when co-occurring completely intermixed in the heathlands. *E. trimera* is endemic for East Africa whilst *E. arborea* is common on all high African mountains and all around the Mediterranean basin, both as a tree and as shrub (Johansson, 2013).

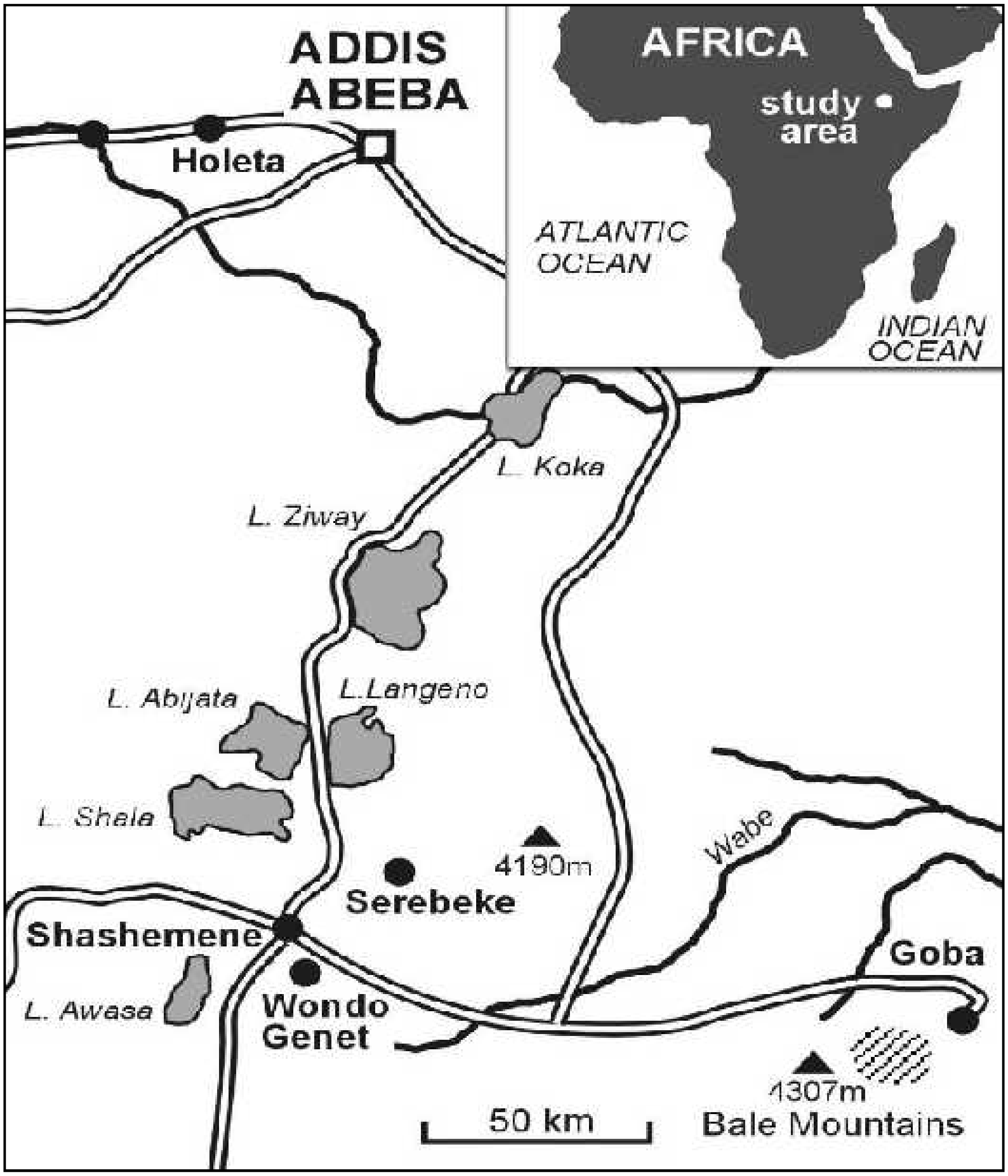
3.1.3. Fauna

The major faunal resources are the Ethiopian Wolf (*Canissimensis*), Mountain Nyala (*Tragelap husbuxton*i), and Giant Molerat (*Tachyoryctes macrocephalus*), Grass rat (*Arvicanthis abyssinicus*), Klipspringer (*Orgotra gusoreotragus*), Golden jackal (*Canisaureus*), and Abyssinian hare (*Lepuscapensis*) (Miehe, 1994; Masresha Fetene*et al*., 1997; Befekadu Refera and Afework Bekele, 2002; GMP, 2008). These faunal species were also observed in the field during reconnaissance surveying and data collection periods. Moreover, in small swamps and lakes water birds, fish species and aquatic plants, are hosted in (GMP, 2008).

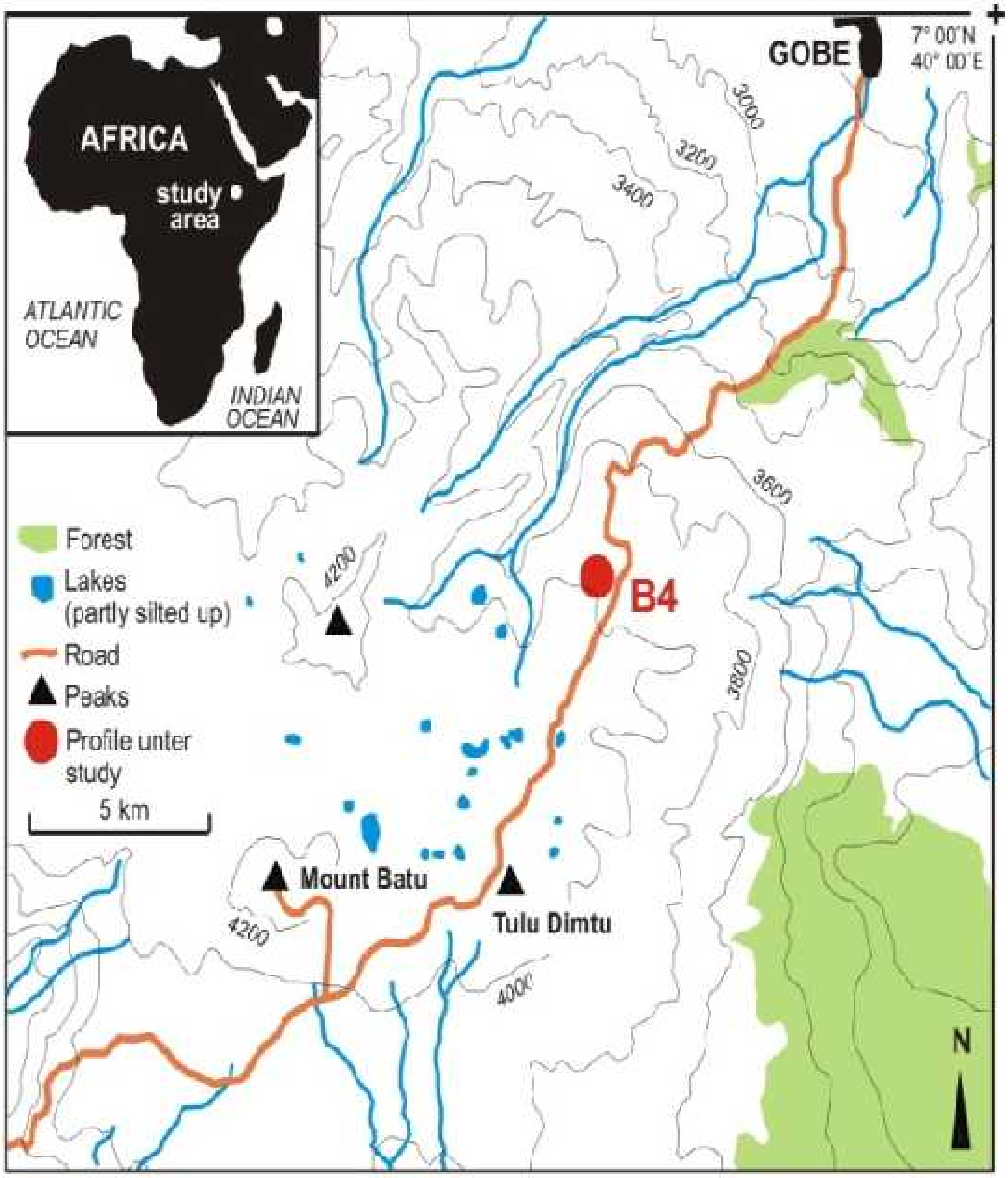
Crop production (wheat and barley are the main crop types), bee keeping, animal husbandry, coffee harvesting and timber logging are the economic activities negatively affecting fauna and flora of the Park. Destruction of the forest covers and thereby loss of habitat and potential food resources for wildlife are major ecological problems (Zerihun Woldu and Dagnachew Legesse, 2007). In the meantime, due to the increase of population and livestock, more land is needed for cropping and grazing purposes. Farming system of the study area is mixed, of which crops like barley and animal husbandry are also practiced by local dwellers settled near and around the study site.

3.2. Study site

Garba Guracha is located at6’52^{0}N and 39’49^{0}E at an altitudinal range of 3950m a.s.l (Photo 2). It lies within a glacial cirque at the head of the northeast-facing Togona valley, which shows evidence of a former valley glacier extending 10 km down to 3400m (Messerli *et al*., 1977; Osmaston *et al*., 2005). The lake is about 500-300m in size, with a maximum water depth of 6m, fed by surface runoff from the valley sides, and presumably by shallow groundwater. An outlet stream flows from its northern edge over a boulder-covered rock bar, feeding the Togona River. Moraines also enclose the lake, especially near its western margin. The site lies at the boundary between the Ericaceous and Afroalpine vegetation belts. To the southeast of the lake, a patch of *Erica trimera* forest, grasses (principally *Festuca richardii*) and a large number of herbaceous species, covers an area greater than 1500 km^2(Miehe and Miehe, 1994).Besides Garba Guracha many small lakes occur southwest at the Sanetti Plateau, some of them are at least periodically without water. During the LGM this plateau was ice covered and only after deglaciation soil formation and evolution of the vegetation cover started. To get an idea about the environment and vegetation evolution at the plateau after deglaciation, the sediments of such a concave depression (=B4 in Fig 1; N: 06°53´20, 6´´ E: 39°54´31, 3´´; 3980 m a.s.l.) were studied assuming that the geoecological processes occurring in the catchment are archived in the sediments accumulated.


ADDIS ABEBA
Holeta
AFRICA
study area
ATLANTIC OCEAN
INDIAN OCEAN
L. Koka
L. Ziway
L. Abijata
L.Langeno
L. Shala
4190m
Serebeke
Wabe
Shashemene
L. Awasa
Wondo Genet
Goba
4307m
Bale Mountains
50 km

A



B

Figure 2: Location map of the study area A in the above and B. The Sanetti-Plateau, located southwest of the village Goba.

3.3. Sample collection

Field surveys, field measurements and sample collection were conducted in February 2015. In the concave depression B4 a pit was dug and the properties of the sediments were described (Fig. 2). Above basaltic boulders in 255 cm depth, firstly dark humic sediments were accumulated; in the upper part of the profile, color became more brownish Sediment samples were taken in high resolution (every 2 cm in the lower part, every 10 cm in the homogeneous upper third) from the 3 walls of the pit and carefully mixed.

3.4. Sample preparation

Samples were air-dried, sieved (<2 mm), (measure by using beam balance) and stored in labeled plastic bags. For the analysis of TOC, N, $\delta^{13}C$, $\delta^{15}N$, and BC were finely grinded and stored in small flasks.

3.5. Analytical procedures

3.5.1 Grain size analyses

Clay (< 2 µm) and silt (2 – 63 µm) fractions were quantified with a Master sizer S (Malvern Instrument) after destruction of organic substances using H_2O_2. The sand fraction (63-2000 µm) was determined by wet sieving.

3.5.1. pH and electrical conductivity (EC)

Twenty g of fine earth is placed in a container and 20 ml of distilled water added. The suspension is shaken for 30 min and allowed to settle. Electrical conductivity and pH of the solution are then measured using a glass electrode. It is important to measure conductivity before taking the pH reading, as the potassium chloride from the reference electrode can increase the EC.

3.5.2. Total organic carbon (TOC) and nitrogen (N)

Total organic carbon (TOC) and nitrogen (N) of homogenized samples were quantified by dry combustion on a Vario EL elemental analyzer (Elementar, Hanau, Germany).

$$\text{Total Carbon} = \text{Inorganic Carbon} + \text{Organic Carbon}$$

TOC content can be measured directly or can be determined by difference if the total carbon content and inorganic carbon contents are measured. For soils and sediments where no inorganic carbon forms are present Total Carbon = Organic Carbon.

A simple test can be performed to determine if carbonates are present. The test involves adding a few drops of HCl (1N to 4N HCl are often cited) and observing if the sample effervesces. Careful observations need to be made in cases where dolomite is present since it does not rapidly effervesce like calcite. Alternatively, the pH of the soil or sediment may be determined and if the pH is 7.8 to 8.2, then calcium carbonates are indicated in the sample (McLean, 1982). However, as a safety factor to account for possible isolated pockets of carbonates, a pH of 7.4 has been used as the pH above which the sample is treated to remove carbonates.

3.5.3. Natural abundance of ^{13}C and ^{15}N

Stable isotope analysis is a powerful tool in the study of soil organic matter formation. It is often observed that more decomposed soil organic matter is ^{13}C, and especially ^{15}N-

enriched relative to fresh litter and recent organic matter (Dijkstra *et al.*, 2006). Natural abundance of ^{13}C and ^{15}N were measured by dry combustion of a 40 mg homogenized aliquot with a Fisions 1108 elemental analyzer coupled to a Delta S gas isotope ratio mass spectrometer (IRMS) with a Conflow III interface (Thermo Finnigan MAT, Bremen, Germany). Sucrose (ANU, IAEA, Vienna, Austria) and $CaCO_3$ (NBS 19, TS limestone) were used as calibrationstandards. Precision of $\delta^{13}C$ and$\delta^{15}N$measurements were 0.2‰ and 0.3‰, respectively.

3.5.4. Black Carbon (pyrogenic carbon)

Black carbon content and composition were determined by measuring benzene polycarboxylic acidic (BPCA) contents according to Glaser *et al*. (1998) using 4m trifluoroacetic acidic as first digestion step (Brodowski *et al*.,2005) and phthalic acid as first internal standard (Wiedemeier *et al*.,2011).Separation and quantification of individual BPCAS was carried out by GC/FID using an HP5 column (30 M × 0.25μ m).The sum of individual BPCAs was converted to black carbon content by multiplication with 2.27 (conversion factor for charcoal as suggested by Glaser *et al*.,1998) .

3.6. Radiocarbon analyses

Radiocarbon analyses were carried out at the Radiocarbon Laboratory of the University Erlangen, Germany, and calibration was done with Calpal-2007$^{\text{online}}$ (Danzeglocke *et al*., 2012) using “CalPal2007_HULU” as calibration curve.

CHAPTER FOUR

4. RESULTS

4.1. Stratigraphy and chronology of the B4 sediments

According to Fig. 5 the concave depression at the Sanetti Plateau became ice free at about 18 cal.ka. BP and very dark gray muddy sediments accumulated until16.5 cal.ka. BP. At that time, a thin, whitish sandy layer was deposited, probably a tephra layer. Accumulation of muddy gray sediments rich in fossil roots continued nearly until 13.7 cal.ka. BP. Then most likely with the beginning of the Younger Dryas at about 12.6 cal.ka. BP, sediments became more silty than sandy, and yellowish brown with bleached aggregate surfaces and many orange mottles indicating redoximorphic processes due to periodic water logging. These morphological features allow the conclusion that during most of the late Glacial the concave depression B4 was in generally filled with water, whereas with the beginning of the Younger Dryas and during the Holocene water logging occurred only during the rainy season.

4.2. Depth profiles of the silt, sand and clay fractions (fig 6)

Sand contents of the sediments under study are generally very low; only the grayish layer deposited at about 16.5 cal.ka BP and the upper part of the Holocene deposits contain sand maxima. Such sand maxima usually indicate accelerated soil erosion in the catchment. According to the morphological features it can be assumed that the thin whitish layer in 160 cm depth most likely indicates a tephra, whereas the sand maximum in the upper 50 cm of the sediments may indicate increased soil erosion probably in connection with the disturbance of the vegetation cover in the catchment. It can be hypothesized that fire induced destruction of Erica is responsible for this phenomenon. This hypothesis is supported by the BC maxima detected in the sediments deposited during the Younger Dryas and early Holocene in about 70-50 cm depth (Fig. 7 C). This result will be discussed below in more detail.

Clay contents are relatively high in the older muddy dark gray section of the late Glacial sediments but they generally decrease during sedimentation with pronounced minima at about 16.5 calky BP and during the Holocene when sand inputs increased. Silt dominates in the sediments showing slight decreases with increasing profile depth.

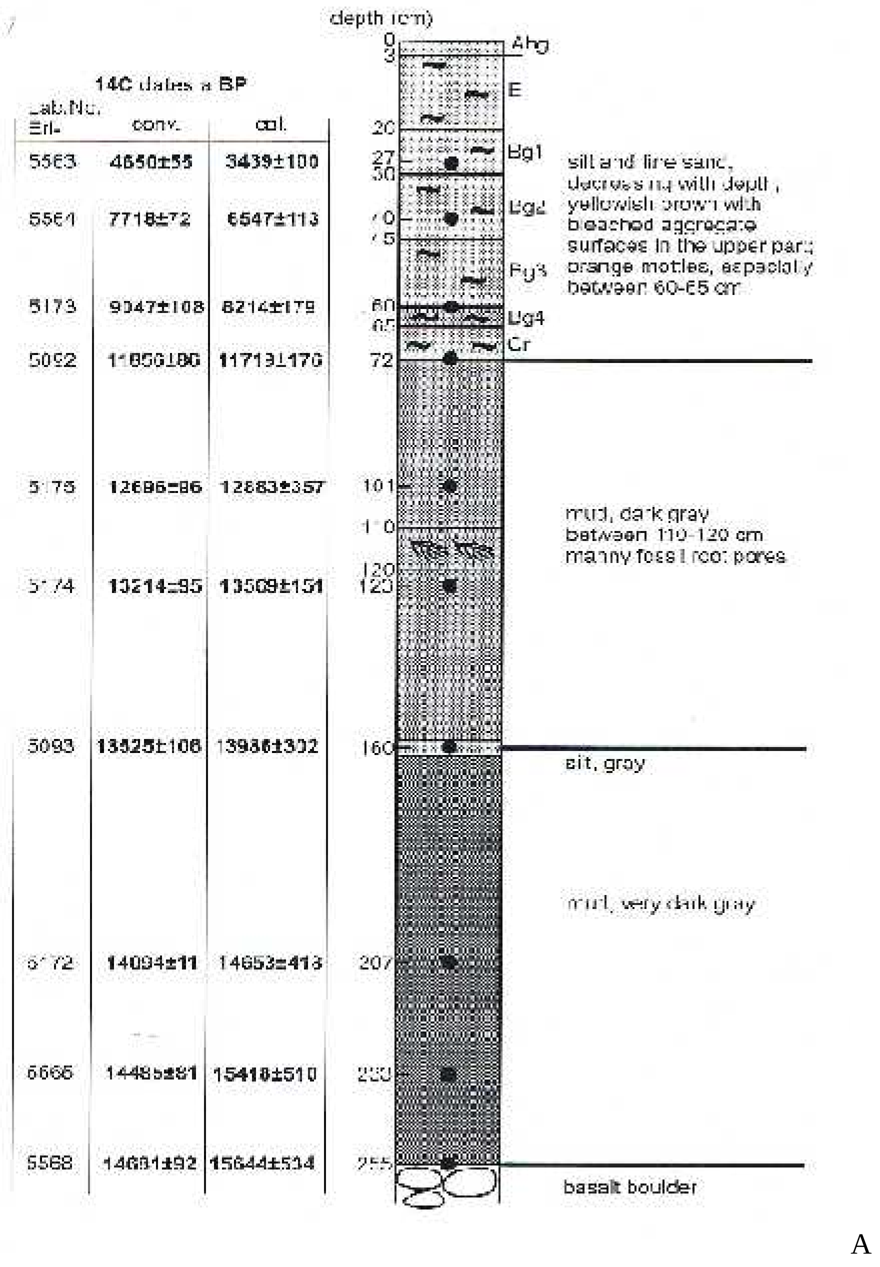


Figure 3: Stratigraphy of the B4 sediments with conventional and calibrated 14C ages

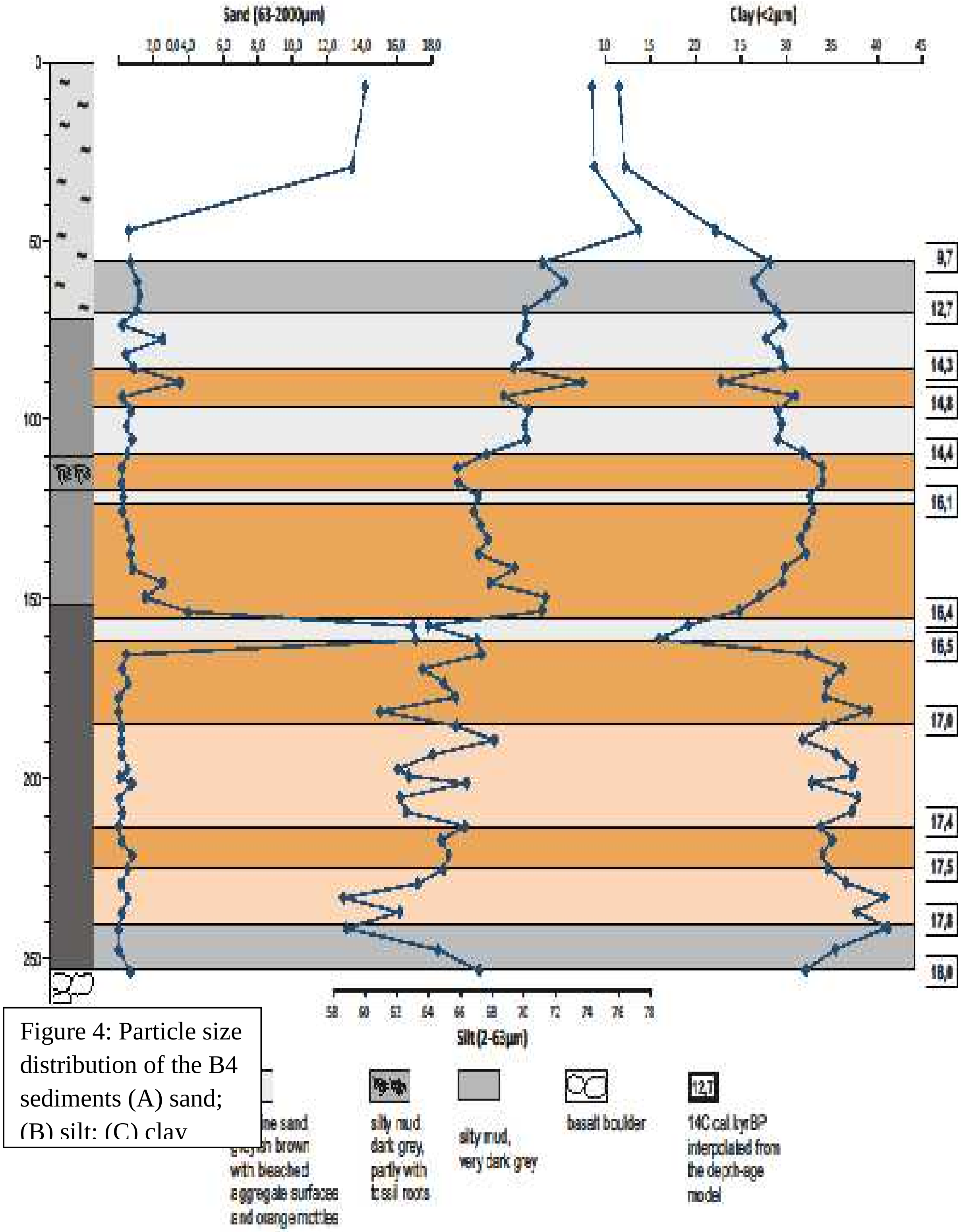


Figure 4: Particle size distribution of the B4 sediments (A) sand; (B) silt; (C) clay

4.3. Depth profiles of other biogeochemical proxies analysed

Overall, $\delta^{13}C$ values varied between about -21 to -14‰. (Fig.7A).Maximum values of -13‰ characterize the OM deposited immediately after deglaciation at about 18 cal.ka. BP. During the late glacial$\delta^{13}C$ values decreased more or less continuously to -18/19‰ until ca.13.7cal ka BP (sediments in about 80 cm depth). Then during the Holocene they firstly became again more positive (ca. -15‰) but finally decreased in the recent surface sediments to -21‰. (Fig. A, B, C) methanogenesis show clearly.

The positive $\delta^{13}C$ values in the lower part of the profile can indicate different processes:

1. Input of C4 litter originating from C4 grasses covering the catchment of the B4 depression at the Sanetti Plateau during the dry and cold late Glacial. The continuous decrease between 18 and 14/13 cal.ka. BP could reflect the gradual warming from deglaciation towards the warmer and more humid Bolling/Allerod phase (corresponding with sediments deposited roughly between 14 and 13 cal.ka. BP; s. also Umer et al., 2007), thus less supporting C4 plants. The more positive $\delta^{13}C$ values of the very humus poor and more sandy-silty materials (Fig. 6 and 9) deposited especially during the early and middle Holocene, may indicate the accumulation of strongly decomposed organic subsoil substances due to accelerated erosion in the catchment. $\delta^{13}C$ value of - 21‰ in the recent surface layer (Fig. 7A) may reflect a shift from C4 to C3 components in the catchment during the late Holocene.
2. Besides input of C4 litter from the catchment into the sediments also methanogenesis can influence $\delta^{13}C$ values. Muddy sediments are prone to this process being highest in the lower part of the sediments due to low redox potentials, and decreasing with growing up

of the deposits and increasing drying out likely during the Younger Dryas at about 12.7 cal.ka. BP. supporting better aeration. The $\delta^{13}C$ maxima in the early and mid-Holocene deposits may reflect advanced SOM mineralization frequently found in subsoil layers.

3. Besides input of C4 components especially during the late Glacial and besides methanogenesis the positive $\delta^{13}C$ values in the late Glacial deposits let assume that the aquatic organism populating the small lake existing at that time and likely producing the organic matter of the mud, suffered during cold periods with long lasting ice cover from CO_2 necessary for photosynthesis because under ice there was no sufficient input of fresh atmospheric CO_2. The consequence of such an event is that the lacustrine organisms were obliged to assimilate $^{13}C\ O_2$ with the consequence that the organic matter they produced is rich in 13C. The low TOC/N ratios of <12 (s. Fig. 9) show the dominance of lacustrine primary production and therefore a mainly autochthonous origin of the organic matter. Significant inputs of terrestrial materials like C4 grasses for instance, would generate TOC/N ratios of ca. >20 due to the abundance of cellulose (Prahl et al., 1980).

$\delta^{15}N$ values (Fig. 7B) increase from about -1‰ in the sediments deposited soon after deglaciation between 18-17.5 cal.Ka. BP. to +20‰ in the younger organic matter stored between about 16.3-8.5cal Ka BP in 140-45cm depth where they strongly fluctuate. In the mid to late Holocene sediments $\delta^{15}N$ values decrease again to 4-5‰. These results allow the following conclusion: in the early late Glacial sediments, deposited below 140 cm depth the N cycles were relatively closed, most likely because it was too cold. The increase of $\delta^{15}N$ values towards the early Holocene (ca. 45 cm depth) may reflect the warming stimulating the N cycles. The pronounced fluctuation of $\delta^{15}N$ in this part of the profile may indicate strongly varying environmental conditions with respect to temperature, precipitation and increasing sediment accumulation combined with decreasing water depth, allowing frequent warming/cooling of the water body and even drying out. Such environmental fluctuations seem to stimulate periodically N dynamics. The decreases of the δ15Nvalues during the Holocene likely indicate that the depression B4 is generally dry during most time of the year.

The pH values of sediments vary between about 4 (in 100cm depth) and 6.8 in 70 cm depth. Immediately after deglaciation values of 6.2 were analysed. Values higher than 6 characterize also sediments deposited in ca. 130, 80, 75-30 cm depth. I assume that such pH maxima indicate aeolian inputs of dust rich in base cations in connection with pronounced dry periods. The pH minima in 100-90 cm depth probably correlate with favourable environmental conditions beginning in the North Atlantic region at 14.7 calKa BP (Bölling/Alleröd) allowing the formation of easily soluble organic matter. This interpretation must be verfied in future studies. But according to (Fig. 8) it is obvious that pH and EC are negative correlated and my hypothesis is that under more favorable environmental conditions more water soluble organic substances are produced, reducing pH and thus increasing EC. During more arid conditions with accelerated inputs of dust rich in base cations, pH will increase and EC decrease. But it cannot be excluded that high pH values correlate with increased erosion in the catchment and sedimentation of base rich materials in the depression.

The upper layer of the sediments representing the present day Ah horizon show a TOC maximum of 7% (Fig.7), With increasing depth TOC values sharply decrease to <1% in the Younger Dryas sediments deposited in ca. 70 cm. With increasing depth TOC values tend to increase up to about 6%. The TOC minimum in ca. 160 cm most likely indicates a tephra layer. According to Fig. 6 TOC rich materials (about 7%) were stored between 16.5-17.8 cal.Ka. BP, then towards the basalt boulders TOC decreases again to 1%.

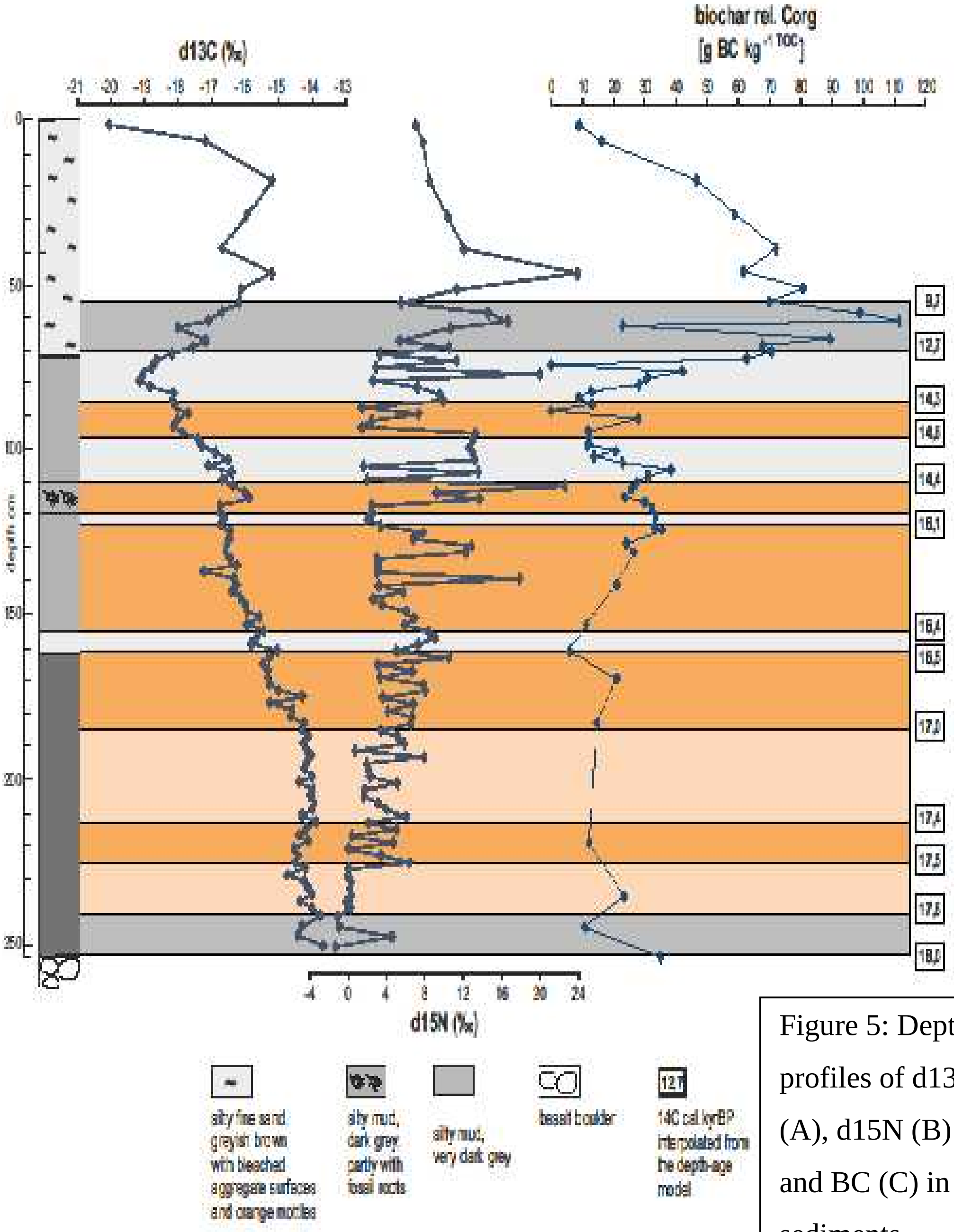


Figure 5: Depth profiles of d13C (A), d15N (B) and BC (C) in the sediments

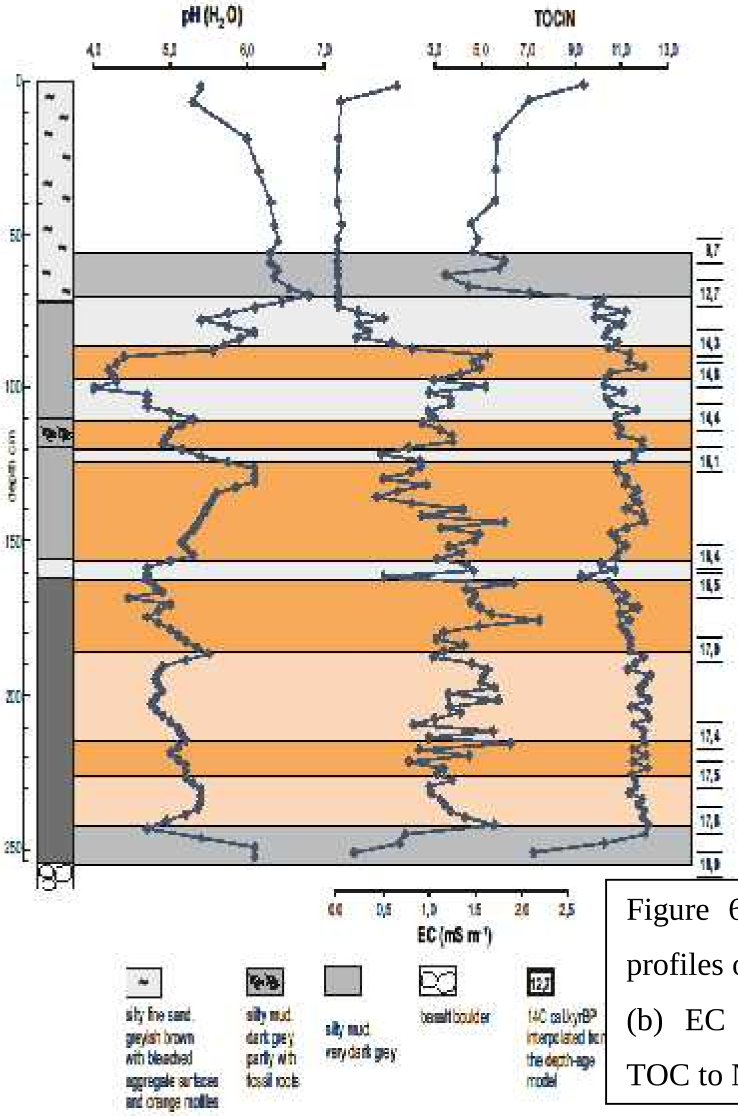


Figure 6: Depth profiles of (a) pH (b) EC and (c) TOC to N ratio.

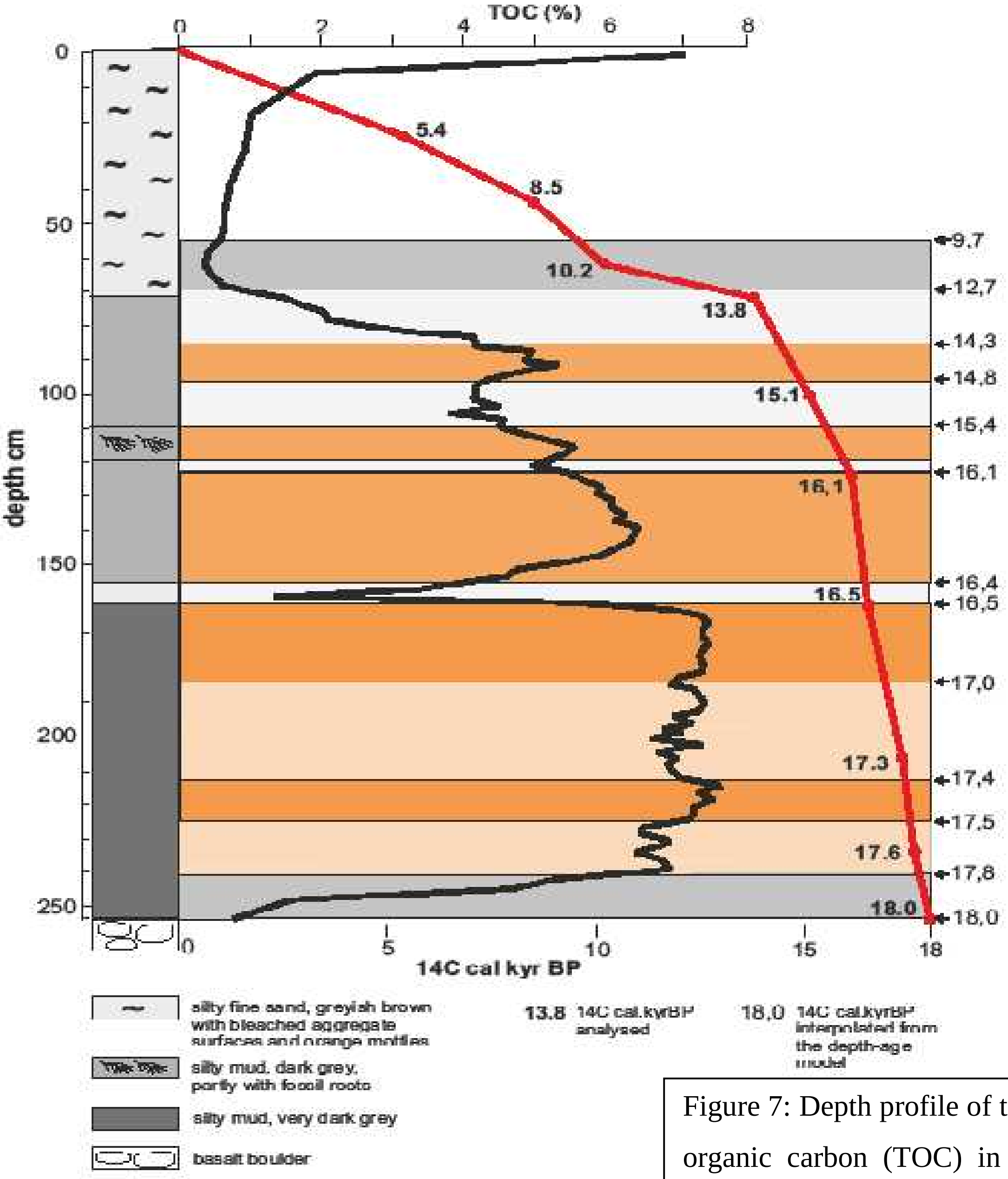


Figure 7: Depth profile of total organic carbon (TOC) in the sediments of depression B4.

CHAPTER FIVE

5. DISCUSSTION

5.1. Chronology of the sediments in depression B4 (5)

The Sanetti Plateau around depression B4 was glaciated during the LGM. The ice cover melted at about 18 cal. Ka BP and most likely was filled with water until 16.4 cal.Ka.BP. During this early late Glacial very dark gray mud was deposited mainly derived from aquatic organisms as indicated by the low TOC/N ratios. At ca. 16.4 ca. Ka BP a thin silty layer was deposited, poor in organic matter and probably indicating tephra. Above the accumulation of autochthonous dark gray mud continued until ca. 13.7 cal. Ka BP, partly rich in fossil roots. In this part of the profile proxies like $\delta^{15}N$, pH, TOC strongly varied, indicating more varying environmental conditions in comparison to the early late glacial sediments. The upper third of the profile contains sediments deposited roughly since the Younger Dryas and mainly during the Holocene. It is more sandy and silty with bleached aggregate surfaces indicating pseudogley dynamic, with redoxymorphic features due to periodic drying, and water logging during the rainy period. Most analyzed proxies showed less variation.

Details of the chronology are documented in the Figures and the depth-age model is shown in Fig. 6. It allows the conclusion that between 18-13 cal.Ka BP about 180 cm thick sediments were deposited, corresponding to an average value of 36 cm/1000 years. In comparison, during the last 13 ka only 70 cm accumulated, corresponding to an average value of 5.4 cm/1000 years.

5.2. Depth profiles of δ 13C and δ15N

In the upper third of the profile δ13C shows maxima in about 20 and 45 cm with values of –15 ‰, and minima at ~80 cm depth with values of–19‰ (Fig. 7A). Such positive δ^{13}Cvalues may indicate higher inputs of C4 plants during more arid periods or advanced methanogenesis in connection with prolonged periods of water logging. Generally subsoils have more positive δ^{13}C values than topsoil layers due to the accumulation of older SOM in deeper horizons. In addition, the low TOC/N ratios (Fig. 8C) let assume that the strongly mottled pseudogley horizons are preferentially colonized by green and brown algae having δ^{13}C values of -20.8 to -8.8‰ (Wikiperdia, Isotopic signature). In contrast, the more negative δ^{13}C values in ca. 80 cm depth correlate with increasing TOC contents and higher TOC/N ratios (Fig. 9 and 8C).

δ^{15}N values are partly astonishing high around 16 to 23.5‰, indicating extremely open N cycles, at least periodically. . According to Brodie et al. (2011), acid decalcification may not give fully reliable TOC and δ^{13}C values. The profile shows an increase of δ^{15}N from the basalt bolder at the bottom towards about 50 cm depth, likely indicating step by step warming during the late Glacial.

Interestingly, δ^{13}C values of the organic matter deposited after deglaciation around 18 and 17.6 calka BP above the basalt boulder reached maxima near-13%(Fig. 4A), whereas δ^{15}Nvalues decreased during sedimentation from about -2‰at the bottom of the profile (Fig. 4B). The high,δ^{15}N values of about +24%&may be due to accelerated microbial activities. Methanogenesis or accelerated mineralization leaving behind 13C-enriched organic matter (Glaser and Zech, 2004). There is no doubt that the environmental conditions after retreat of the Late Glacial Maximum (LGM) glaciers were still very cold and dry, with mainly winter and spring precipitation and only small amounts of monsoon summer rainfall (Schlütz and Zech, 2004) strongly influenced the dynamics of the proxies studied and discussed here.

According to Andreeva et al.(2013) $\delta^{15}N$ values of surface layers decrease with increasing altitudes probably reflecting lower rates of N-mineralization with decreasing temperature at higher elevation and also changes in the vegetation cover may influence these results. Note that such a decrease is not obvious in the A horizons, which might supply most of the plant available N. In most soils, $\delta^{15}N$generally increases with depth. Also the pseudogley shows this phenomenon with a topsoil value of 7‰ and a subsoil value of 24‰ in ca. 50 cm (Fig. 7B) indicating the accumulation of older SOM already more depleted in the lighter ^{12}N. This is in agreement with findings of Makarov *et al*. (2008) reporting consistent $\delta^{15}N$ increases with soil depth in alpine and tundra ecosystems. Denitrification above sporadic permafrost may partly contribute to more positive $\delta^{15}N$ values. This is of relevance especially in high mountain ecosystems and may responsible for the extreme short term fluctuations of $\delta^{15}N$ between 140-45 cm depths (Fig. 7B).

The analysis of $\delta^{15}N$ might give insight into N cycling (Robinson, 2001; Zech*et al*., 2007; Makarov, 2009). Typically, plants are depleted in ^{15}N compared to soils and topsoils are depleted compared to sub soils (Nadelhoffer and Fry, 1988; Högberg, 1997). This can be explained by strong isotope fractionation occurring during enzymatic reactions being responsible for soil processes such as ammonification, nitrification and denitrification.

Accordingly, NH_4^+, NO_3^- and N_2O are depleted in ^{15}N, whereas the residual total N becomes ^{15}N-enriched. Furthermore, plants assimilating the isotopically lighter NH_4^+ and NO_3^- have more negative $\delta^{15}N$ values than the respective soils. Notably, as long as the N cycle of an ecosystem is closed and no losses of isotopically depleted or enriched N occur, the overall $\delta^{15}N$ signature of the ecosystem does not change (Zech *et al*., 2011). However, due to climatic conditions N losses by leaching, degassing or by frequent fire events are favoured in some ecosystems, thus resulting in typical global and altitudinal pattern, i.e. more negative $\delta^{15}N$ values at higher latitudes and altitudes (Amundson *et al.*, 2003; Männel *et al*., 2007). Additionally, human land use practices like cultivation of N-fixing plants, application of N containing mineral fertilizers or burning favours the “opening” of N cycles and leads to more positive $d^{15}N$ values.

As already mentioned the TOC minima between 250-240 cm and in 160 cm depth reflect low biomass production during the first decades after deglaciation and the input of tephra, respectively. The TOC minimal between 70-10 cm depths indicate the accumulation of sandy silty humus poor materials erodet in the catchment most likely after the destruction of Erica stands by burning.

Some changes of the bulk $\delta^{13}C$ values in this study may be related to climate or other factors such as disturbances associated with land use pressure. Trends in $\delta^{15}N$ values may help discern whether it was climate or land use that most affected $\delta^{13}C$. Land use may also influence the δ values but does not change the qualitative inferences about climate and cannot be readily deciphered (Terwilliger *et al*., 2008). A negative relationship between $\delta^{13}C$ and $\delta^{15}N$ corresponds to a decrease in precipitation as $\delta^{15}N$ values increase and a decrease in land use intensity as $\delta^{13}C$ values concomitantly decline. Prolonged land use may obscure any influence of temperature on $\delta^{13}C$

5.3. Depth profile of BC and fire history

According to Fig. 4C BC sharply increases from the surface layer to about 60 cm depth. The sediments between 40-70 cm, deposited mainly during the Younger Dryas and early Holocene, are especially rich in BC in contrast to the layers below, which are very poor in BC. Assuming that BC indicates burning of Erica, then the following conclusions can be drawn:

- The low BC contents deposited between 18-16 cal.ka. BP suggests that during this period the Sanetti Plateau was not or only poorly covered by Erica because it was still too cold and dry. The BC contents analysed derived from burning of Erica stand at lower altitudes by aeolian input.
- With increasing warming after 16 cal.Ka. BP and especially since the significant climatic improvement at about 14 cal.Ka. BP (Bölling/Alleröd) Erica extended more and more in the catchment of the depression B4. The BC maxima in the sediments between 70-60 cm, accumulated mainly during the dry Younger Dryas, argue for frequent burning under environmental conditions characterized by reduced precipitation.
- Burning of Erica still frequently continued during the early Holocene when still enough Erica shrubs existed in the catchment.

- The gradual decline of the BC contents towards the topsoil layer most likely reflects the continuous destruction of Erica. At present, the catchment is only grass covered.
- At present it remains unclear whether Erica in the catchment was destroyed by wild fires or by man-made fires because it is not known whether people already invaded the Sanetti Plateau during the Younger Dryas at about 12.6-11.4 cal. BP.

These conclusions are preliminary because the BC proxy must be carefully interpreted. It is generally accepted as fire proxy.

However, changes in BC accumulation have to be evaluated carefully for influence from leaching, translocation, and degradation processes. However it is difficult to reconstruct fire activity from the amount of BC per sediment mass, since a dilution with inorganic matter might diminish the fraction of BC (Eva *et al*., 2015). In sediments, the BPCA composition might become affected by post-depositional degradation processes comparable to that of physical fragmentation of charcoal (Théry-Parisot *et al*., 2010). Fragmentation would increase the surface-to-interior ratio of BC particles, which is the most significant driver of BPCA composition, that is, the smaller the BC particle, the less mellitic acid will be produced during analysis (Brodowski *et al*., 2005; Glaser *et al*., 1998; Ziolkowski *et al*., 2011).

Differences in species composition and abundance were significant in the Erica shrub land community. From the correlation analysis made between the main factor, fire, and other potential factors, grazing and elevation; it was found that correlation did not exist between these factors. Meaning, observed significant differences were mainly attributed to fire (Papanicolaou and Fox, 2004).

CHAPTER SIX

6. CONCLUSION AND RECOMEDATION

6. 1. Conclusion

In conclusion, this study shows that the magnitude of isotope fractionation during SOM decomposition was related to vegetation change and environmental factors. Litter quality and soil sediment contents both had it own impact on BC, $\delta^{13}C$ and δ15Nvalue.

The $\delta^{13}C$ and $\delta^{15}N$ signatures of Om in the sediments of depression B4 result from multiple mechanisms, some of which are related to trophic state. Carbon isotope signatures in the B4 sediments are relatively positive compared to values in other sediments, probab ly reflecting a combination of processes, such as input of C4 biomass, methanogenesis, and assimilation of ^{13}C enriched CO_2 due to long lasting ice cover especially during early late Glacial. Also some benthic organisms may produce ^{13}C enriched biomass. In the muddy sediments under study, $\delta^{15}N$ values in general tend to increase while $\delta^{13}C$ values decrease in most of the late glacial materials between 250 and 70 cm. The isotope signatures resulted from several factors, including the nature of the community, high demand for C and N in sediments, and selective mineralization of OM.

$\delta^{13}C$is an effective indicator of different land uses, for instance if forests (=C3) were cleared and sugar cane or maize (both C4) were cultivated. Well established statistical tools can be used to adequately describe the factors considered most relevant to induce $\delta^{13}C$, δ15Nand N/C alterations. The fact that presents a high variability can be advantageous for conducting short term erosion studies as long as the prominent factors introducing such variability are understood and their variability can be statistically verifiable. Carbon isotope fractionation associated with higher plant photosynthesis differs between the Calvin-Benson (C3) and Hatch-Slack (C4) cycles. It is possible to identify both C3 and C4 plants by measuring their $\delta^{13}C$ values.

In undisturbed soils, $\delta^{13}C$ and $\delta^{15}N$ increase from the organic surface layers to the mineral subsoil due to the kinetic discrimination of heavier isotopes during SOM degradation, and likely due to increasing atmospheric CO_2 concentrations with respect to $\delta^{13}C$.

Fire proxies like BC show maximum values in the sediments deposited at the end of the late Glacial (Younger Dryas) and during the early Holocene but not during older periods of the late Glacial. This allows the conclusion that between deglaciation at ca. 18 cal Ka BP and 14 cal.Ka BP the catchment of the depression B4 was not or only not quite covers by Erica and fire played no significant role at the Sanetti Plateau. Later on, during the climatic amelioration between 14-13 cal Ka BP pyrogenic C contents drastically increase allowing the conclusion that at that time Erica extended in the catchment but parallel burning started, especially during the dry Younger Dryas. From early to late Holocene BC contents continuously decreased, most likely because the Erica stands were more and more destroyed ether by wild fires or prescribed burning of hunters and pasturalists.

Generally, the influence of fire was more advantageous for above ground canopy species than other associated under-storey plant species. However, the fact that woody cover species failed to germinate from soil seed bank samples in the Erica shrub land, fire influence for above-ground canopy species was again dis-advantageous for these species than it was on other associated under-storey plant species. In addition, although fire has been reported as integral component of the Ericaceous vegetation dynamics via maintaining its structure and composition in southeastern Ethiopia and the Bale Mountainous Areas, including the study area; the frequency of recent fires have probably been far exceeding the natural fire regime and thereby these plant species might have been forced to adaptation and/or modify mode of regeneration to frequent fires. In consequence, these species, mainly *Erica arborea* L, may shift from being a facultative seeder to only obligate resprouters, of which there would be genetic modification if such fires continue in the future (Papanicolaou and Fox ,2004)

6.2. Recommendations

Based on the research findings, the following recommendations are forwarded:

Fire ecology is best understood if explanations are given in full-fledged. Besides fire regime characteristics, charcoal, pollen and sediment analyses to reconstruct fire history should be integrated to better, even best, understand the relation and relationships between fire, climate, vegetation, society, and land use. So far, studies on fire and its influence on vegetation dynamics in the BMNP has been scant and as a result subtle information are available. The following major recommendations are forwarded here under pertinent to the study area.

- ✓ The fact that the study area is a CPEZ, fire pressure could be minimized via reducing human interferences, mainly landuse and human-wildlife conflicts.
- ✓ For future interventions, fire regime characteristics and history should be understood in various localities of the study area.
- ✓ Development and conservation should be compromised through reducing natural resources dependency and at the same time modifying human behavior .
- ✓ The Government officials and NGOs should be given special concern to the protected areas in the district and provide incentives to the pastoralists for natural forest.

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8. APPENDIX

Appendix 1.The above photos an indicator of burning are produced (source I took in 2015 in the Sanetti Plateau).Mostly humans are burning the Erica stands to create pastures for their animals and to make hunting easier.

No	Sample of soil	Glass code	Flask code
1	503.50mg	A_1	22974
2	503.56mg	A_2	22975
3	506.22mg	A_3	22976
4	500.80mg	A_4	22977
5	506.87mg	A_5	22978
6	504.81mg	A_6	22979
7	503.15mg	B_1	22980
8	505.20mg	B_2	22981
9	503.10mg	B_3	22982
10	503.24mg	B_4	22983
11	501.36mg	B_5	22984
12	505.66mg	B_6	22985
13	504.60mg	P_1	22986
14	502.26mg	P_2	22987
15	501.80mg	P_3	22988
16	504.50mg	P_4	22989
17	500.13mg	P_5	22990
18	507.27mg	P_6	22991
19	505.08mg	T_1	22992
20	503.84mg	T_2	22993
21	506.77mg	A_1	22994
22	501.01mg	A_2	22995
23	504.44mg	A_3	22996
24	504.12mg	A_4	22997
25	503.50mg	A_5	22998
26	504.58mg	A_6	22999
27	501.41mg	B_1	23000
28	504.89mg	B_2	23001
29	503.10mg	B_3	23002
30	503.25mg	B_4	23003
31	505.09mg	B_5	23004
32	502.45mg	B_6	23005
33	503.81mg	P_1	23006
34	501.62mg	P_2	23007
35	501.83mg	P	23008
36	503.73mg	P_4	23009
37	501.12mg	P_5	23010
38	501.73mg	P_6	23011
39	504.57mg	T_1	23012
40	503.84mg	T_2	23013
41	502.34mg	T_3	23014

Appendix 2. List of sample of soil were finely grinded and stored in small flasks.

Appendix 3.Instrument for preparation of stable isotopes. The laboratory provides carbon, hydrogen, nitrogen, oxygen and different chemicals isotope measuring facilities.(source Germany Halle University).