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## Vegetation zonation and nomenclature of African Mountains - An overview

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# Vegetation zonation and nomenclature of African Mountains - An overview

## Abstract

This review provides an overview on the vegetation zonation of a large part of the mountain systems of the African continent. The Atlas and Jebel Marra are discussed as examples for the dry North African Mountains. The Drakensberg range is shown as representative of the mountain systems of Southern Africa. The main focus of the review falls on the Afrotropical mountains: Mt. Kenya, Aberdares, Kilimanjaro, Mt. Meru, Mt. Elgon, Mt. Cameroon, Mt. Ruwenzori, Virunga, Simien Mts., Bale Mts. and Imatong. A new nomenclature for the vegetation belts of Afrotropical Mountains is proposed.

Key words: Africa, mountain vegetation, vegetation belts, nomenclature, Mt. Kenya, Aberdares, Kilimanjaro, Mt. Meru, Mt. Elgon, Mt. Cameroon, Mt. Ruwenzori, Virunga, Simien Mts., Bale Mts., Imatong, Atlas, Jebel Marra, Drakensberg

Geology, landforms and soil conditions

Africa is an old continent. Nowhere else is so much of the surface covered by basement rocks, and the larger part of the geology of Africa is indeed the geology of pre-cambrian material (Petters 1991). Large areas, so called cratons, have remained essentially unchanged since the early Proterozoic (~ 2000 Mio BP). The mobile belts, i.e. the huge basins and swells between these cratons, are composed of equally old rocks, but have been subject to deformation and partly to metamorphoses, mainly in the Pan-African orogenesis (700 - 500 Mio years BP). Today, relief differences are relatively small in these areas, so the continent can be described as a large, uneven plateau, which is tilted to the northwest. Extensive erosion surfaces covered by ancient, heavily leached soils are more widespread in Africa than on any other continent, and the huge relatively flat Savannahs are well known. Inselbergs are very characteristic remnants of the older surfaces in these plains, but far too low to merit treatment here.

Equally well known as the flat surfaces are, however, some much more recent geological features, namely the huge, isolated volcanoes of the tropical part of the country, and the high fault mountains in the Atlas region and in South Africa. In these three regions, true high-altitude environments are found, with several ranges reaching well above 4000 m. These are almost exclusively located in the tropical parts, with Mt. Kilimanjaro (5985 m), Mt. Kenya (5198 m) and Ruwenzori (5109 m) being the highest sites. Several other mountains reach above the treeline, with the most extensive areas being in Ethiopia. However, the High Atlas in Morocco is also high enough to support truly alpine vegetation (4165 m).

Morocco occupies an intermediate position between the tectonic domains of southern Europe and Africa. The evolution is complex, and the atlas region was formed in several successive uplifting events. The south-westernmost part, the Anti-Atlas contains Precambrian material, but was largely formed in the late Proterozoic. Uplift occurred in Hercynian times in close correspondence to some mountains in Europe, and again mainly in late Cretaceous tectonic movements that formed the several chains of the High Atlas and the Saharan Atlas. The northern Rif and the Tell Atlas in northern Algeria are the southernmost outposts of the Alpine orogen, but recent Tertiary uplift affected also the older ranges, notably the Saharan Atlas. Most of the material is acidic, but several ranges display calcareous rocks, like the central High Atlas, part of the Saharan Atlas and the Rif. Only the High Atlas reaches above 3000 m, while the neighboring ranges hardly climb above 2000 m.

The central Saharan mountains Hoggar and Tibesti rest on the relatively stable West African craton. Part of the Tibesti is of ancient, Proterozoic origin, but there has been extensive recent volcanism. Both ranges are part of a chain of volcanoes of Cenozoic age that extends southwards to the central African Mt. Cameroon and eastwards to the East African Rift Valley System.

Mt. Cameroon is a huge single structure of largely Tertiary origin, but has been active ever since with more than 10 major events in the 20th century, some as recent as 1982 and 2000 (Ndam et al. 2001). The series of volcanoes starting at Mt. Cameroon has been described to continue up to the Jebel Marra in central Sudan. This is a massif rather than a single volcano, which has been active from the Miocene to the early Holocene (Miehe 1988). Lavas are predominantly basaltic in all these ranges.

Further eastwards, the huge volcanic plateau of Ethiopia rests on ancient material, but was largely formed in the tectonic processes during the formation of the East African Rift Valley system. The EARS is the prime example for a continental rift, and its huge structure extends over more than 6000 km from northern Mozambique along all of eastern Africa and through the Red Sea. Rifting started in the Cretaceous but has intensified in the Tertiary, and is most likely a consequence of tensional forces driving the two escarpments apart. Volcanism has been intensive and complex, following the two main branches, the Albertine Rift in the west, and the Gregory Rift in the east (Schlüter 1997).

The Ethiopian Rift is an extension of the latter, mainly formed by basaltic magmas in the Oligocene to Miocene, and reaching above 4000 m at several sites, notably in Simen Mts. in the northern part of Ethiopia and the Bale Mts. in the southwestern. Relatively deep and dry basins from the isolated volcanoes in east Africa proper separate this group of well-connected ranges.

Most of these are relatively young and of Pliocene to Quaternary age. This refers to mountains such as the Aberdares, which were formed from 3 Mio. BP onwards; Mt. Kenya was formed between 2-3 Mio. years BP (Heinrichs 2001); Mt. Kilimanjaro is even younger at 1-2 and Mt. Meru appears to be of similar age as are the Aberdare Mts. Lavas on the huge shields are predominantly alkaline or basaltic, but intermediate lavas formed several strato-volcanoes.

The mineral composition is similar for Mt. Elgon, which is however an exception with respect to its age. Mt. Elgon lies at the border of Uganda and Kenya, and is thus not strictly located in the Rift Valley. Here volcanism commenced some 20 Mio years ago and lasted for about 10 Mio years. The neighboring Cherangani range is an ancient block of largely metamorphic rocks, but has been lifted to its present height in the Miocene. These two ranges have been high mountains, long before their neighbors in the eastern part of Africa, and also those in central Africa had attained high altitudes. The Ruwenzori is a huge pre-Cambrian block, but has been lifted to alpine heights later than 2 Mio years BP. The Kahuzi-Biéga west of Lake Kivu has apparently experienced a similar evolution (Fischer 1996). The other high mountains along the Albertine Rift Valley are exclusively of volcanic origin, with volcanism commencing as early as some 13 Mio years BP in the Virungas. However, most of the activity occurred in the last 2 Mio. years and continued to the present, as was so strikingly demonstrated at the city of Goma, which was largely destroyed during a catastrophic lava outpour in 2001.

These young mountains are in striking contrast to the truly ancient Eastern Arc Mountains in Tanzania and northern Kenya. They are composed of granulite gneiss complexes and have been mountains during for over 25 Mio years. However, they barely reach 3000 m and lack an alpine belt typical for the other mountains discussed here.

Faulting during the formation of the Rift Valley has formed much of the present tropical part of African. Beyond Mozambique, mountains in the southernmost part of the continent are fault mountains like the northwestern Atlas system

The lower slopes of the volcanic ranges have been subject to intensive weathering and leaching, resulting in deep reddish soil profiles, mainly Acrisols and Nitisols, occasionally Ferralsols. The dominant soil type of the upper montane belt are however well developed Andosols. The Andosols have moderately acidic soil pH values, and are exceedingly fertile and explain the intensive agriculture on the tropical mountains. The alpine regions are partly covered by Andosols, notably on the younger volcanoes, partly by various weakly developed soils on glacial deposits such as Regosols and Rankers. Very widespread are various Histosols that result from slow decomposition of organic matter due to coldness and stagnant water. They are characterized by low pH values (under 4 to 5.5) and generally low nutrient availability.

Altitudinal belts in the African mountain regions

Vegetation belts in the North African Mountains

Atlas

With respect to their geologic origin, mountains in northwest Africa are closely related to European mountains like the Alps. Correspondingly, climate, flora and vegetation display strong similarities to Mediterranean mountains like the Sierra Nevada in Spain, and mediate to the arid sites of central northern Africa.

There are three principal complexes, namely the High Atlas and its neighbors Anti-Atlas and Central Atlas; the Rif and Tell Atlas in northern Morocco and Algeria; and the Saharan Atlas in Algeria and Tunisia. These display large-scale climatic gradients, with conditions getting progressively drier with distance to the coast, so the Rif and Tell Atlas get most precipitation with annual totals above 750 mm in the northern foot zone. In the Moroccan Atlas, conditions get drier from west to east. These

differences among ranges are small in comparison to the large differences between the northern and the south (-eastern) slopes within the mountain ranges. The northern lowlands receive well above 300 mm, while the southern slopes border the Saharan basin, where precipitation quickly drops to less than 100 mm in the lowlands (Weischet & Endlicher 2000).

Montane regions clearly receive more than lowlands with a precipitation maximum at 2000 - 3000 m elevation. This is around 750 mm in the High Atlas, and above 500 mm in all regions except for parts of the Saharan Atlas. The Rif and the Tell Atlas receive annual totals of above 1000 mm, which rise occasionally up to 2000 mm. Rainfalls occur almost exclusively in winter, so the summit regions are at least seasonally covered by snow, which might last until the following year in moist conditions. Thus, moisture availability and the usual altitudinal temperature lapse rate control most of the vegetation patterns, but these are modified by edaphic components. Like in the Alps, calcareous and acidic bedrocks intersect, so vicariating plant communities are found depending on the geological background. This analogy is however limited, since the extremely harsh climatic conditions with a pronounced seasonality and the general dryness of the summit region induce excessive weathering. Thus the uppermost regions are covered with scree, which move in the frequent freeze-thaw cycles. Soils are weakly developed and conditions resemble those of dry ranges in the Sahara or even Central Asia, with an open and rather sparse vegetation cover completely different from the Alps. Human impact has been tremendous in the entire region. Agriculture and livestock keeping were introduced some 5000 BP, and, like the entire Mediterranean region, most of the natural vegetation has been replaced by various secondary plant communities, rendering inferences of the potential character of the landscapes often different.

#### *The Moroccan Atlas*

Botanical exploration the area started equally late as in the seemingly much more remote tropical parts of Africa and started in the 1870's. It has however been intense and the general patterns are known since the middle of the last century (Rauh 1952). The High Atlas displays the typical situation. The northern foot zones are covered by open shrublands with *Zizyphus* spp., *Lotus* and notably *Acacia gummifera* up to 900 m, where the dwarf palm *Chamaerops humilis* demarcates the transition to forest vegetation. *Tetraclinis articulata* forests are the natural community up to 1400 m, from where they are replaced by various communities dominated by *Quercus ilex*. Stands are dense and relatively shady with few companions as *Cistus laurifolius* on acidic, and *Buxus sempervirens* on calcareous bedrocks. Much of these forests have been replaced by various scrub communities with *Pistacia lentiscus* and *Juniperus phoenicea* in the lower regions, and by *J. thurifera* in the upper montane belt. Impressive Cedar (*Cedrus atlantica*) stands built a special forest community restricted to the moistest parts of the Atlas, but are more extensive in the Rif and in the Tell Atlas. Above 2800 m, *J. thurifera* forests dominate up to the treeline in some 3100 m. Unlike in other areas of Africa, progressively diminishing and finally shrubby growth of the dominant species do apparently not characterize the treeline ecotone. Instead, Junipers retain their single-stemmed growth up to the treeline, with stands opening progressively and distance between trees increasing.

Thorny cushion plants characterize the lower alpine region up to 3600 m. Cushions grow 0.5 to 1.0 m in height and have thick, often several meters long root. The dominant species are the widespread *Alyssum spinosum*, *Bupleurum spinosum*, joint by the flat thorny cushions of *Arenaria pungens* in upper elevations. In contrast, *Erinacea pungens* and *Vellea mairei* are restricted to calcareous bedrocks. Cushions prefer weakly inclined to level slopes where they can built almost closed stands, but have also benefited from anthropo-zoogenic human impact on the upper montane Juniper forest, where they form secondary stands on disturbed sites.

Moist sites in the lower alpine zone near small brooks are the habitat of communities called "Pozzines". These are meadows, physiognomically similar to alpine meadows in Europe, and thus colorfully flowering in summer. However, they are of very limited spatial extent, and are restricted to soils with impeded drainage over acidic bedrocks.

Substrate movement in the upper alpine region becomes increasingly strong above 3300 to 3600. The cushions become more and more restricted to the few level sites, and plants truly adapted to scree slopes and rock crevices take over. Again, we find vicariant taxa on acidic and calcareous substrates, like *Viola dyris* var. *orientalis* on calcareous rocks and *Viola dyris* var. *typica* on acidic bedrocks. The latter is an endemic taxon of the Atlas, other examples are *Linaria lurida*, *L. heterophylla* ssp. *galioides* and *Vicia glauca* var. *rerayenssis*, all growing on scree slopes. The relative importance of endemic species increases with altitude in the Atlas, and is around 30% in the lower alpine zone, while it reaches some 75% in the upper alpine and summit regions. There is no

truly nival belt and plants occur up to the summit region.

The zonation on the southern slopes is somewhat different because of the greater aridity. The foot zone is covered by succulent *Euphorbia* species or open shrublands like on the northern slopes up to 1500. *Juniperus phoenicea* partly replaces *Tetraclinis articulata* and the belt of *Quercus ilex* forests is smaller and widely replaced by open Juniper scrub. *Cedrus* forests are entirely absent. The timberline is formed by *J. thurifera* as on the northern slopes, and the alpine vegetation is similar as well.

#### *The Rif and the Tell Atlas*

The Rif reaches barely 2500 m and the Tell Atlas is even lower, but affinities to the Moroccan Atlas are strong in the montane belt (Knapp 1973), so the description is kept short. The most widespread montane forest communities are also built by *Quercus ilex*, which forms dense and rather shady stands. *Quercus suber* forms extensive forests at the relatively moist coast of Algeria and Tunisia up to some 1000 m asl., but small stands of the Oak are also found in Morocco. Like *Quercus coccifera*, it has rather high moisture demands and is restricted to the coastal regions below 1200 m. Much of the areas have been cleared for agriculture, especially *Olea europaea* plantations. The olive forms (semi-)natural stands with *Pistacia lentiscus* in drier parts of the lowlands, which might however be secondary in nature. Aleppo Pine (*Pinus halepensis*), often mixed with *Quercus ilex*, dominates much of the lower montane zone at 500 - 1500 m in the Rif and Tell Atlas, but is also occasionally found in the Moroccan Atlas. *Cedrus atlantica* forest is common in the moister ranges above 1500 m. However, the moistest sites there are covered by deciduous oak forests (e.g. *Q. faginea*) and coniferous forests with *Abies maroccana* and *A. numidica*. *Juniperus phoenicea* forests in the drier parts of the montane belt have suffered heavily from anthropo-zoogenic disturbance but occur up to 2400 m under natural conditions. Replacement communities include mixed scrub with various Cistaceae, Fabaceae and Ericaceae species in the lower montane belt, and shrublands with the dwarf palm *Chamaerops humilis* and *Rosmarinus officinalis* in the montane belt.

There is no truly alpine vegetation in the Rif and in the Tell Atlas simply because the ranges are too low.

#### *The Saharan Atlas in northern Algeria*

The Saharan Atlas forms a second chain leeward of the Tell Atlas and is thus relatively dry. Much of the natural vegetation has been replaced by widespread steppes with *Stipa tenacissima*, that is an important species of secondary grasslands in the western Mediterranean region. It is accompanied by *Lygeum spartum* or *Artemisia herbae-alba*, mostly on dense or compacted soils. The natural montane vegetation closely resembles the situation in the Moroccan Atlas described above, notably in the western part of the country near the inter-state boundary. Communities with higher moisture demands are almost exclusively absent, and forest with *Quercus ilex* and occasionally *Pinus halepensis* would be the zonal vegetation of much of the northern slopes. The southern slopes are influenced by the arid Saharan climate and dry vegetation types with succulents climb up well into the montane belt. Where the mountains are high enough, alpine vegetation types occur, which are also similar to the High Atlas. Thorny cushions are relatively common, as are scree communities, but communities of moist rock crevices are impoverished and Pozzines are entirely absent. The alpine vegetation shows the typical differentiation of vicariating species depending on the presence of acidic or calcareous bedrocks as was described for the High Atlas.

#### *Dry mountains in central Sudan - the Jebel Marra*

The Jebel Marra is a highly isolated volcanic massif in the center of Africa, more than 1500 km away from the nearest coast and more than 1000 km distant to the next mountain, with the Simen Mts. in northern Ethiopia being the most "closely" related range. The Jebel Marra emerges from a pedi-plain in 1000-1200 m, with a semi-arid climate with down to 280 mm of annual precipitation (Miehe 1988). The mountain slopes receive more rain, and the southwestern side is clearly moister than the eastern. The belt of maximum precipitation is situated at around 2000 m asl., where totals can be as high as 1800 mm in extreme years, but 800 mm appear to reflect the average conditions better. For the summit region (max. 2976 m Times Atlas 3071) 600 mm have been estimated.

The vegetation shows correspondingly clear altitudinal gradients. Drought deciduous woodlands cover the piedmont and *Acacia* scrub, interspersed with lowland gallery forests along watercourses and in moist ravines and valleys, mainly in the southwest. These can be regarded as remote outposts of tropical evergreen forest. Typical species include evergreen *Ficus ingens*, *F. thonningii*, *F. sur*, *Syzygium guineense* and *Trema orientalis*, indicating affinities to tropical montane forest described below..

The dominant vegetation type in the submontane belt are, however, communities with *Combretum molle* and *Boswellia papyrifera*, which are replaced by wooded grasslands with *Entada abyssinica* and *Acacia albida* as a transitional belt to the montane communities.

The transition from these submontane lowlands to the montane, sparsely wooded grasslands occurs at some 2000 m. The principal tree species is *Olea laperrinei*, which forms riverine forests above 1900 m with *Ficus palmata*. The olive is also found in the Saharan mountains and indicates the relationships to Hoggar and Tibesti. However, the dominant vegetation are grasslands with *Andropogon-Hyparrhenia*, and *Themeda triandra-Conyza hochstetteri*. Scattered trees of *O. laperrinei* can be found on scree slopes and in the grasslands, indicating that at least part of these grasslands are suitable for tree growth. The upper montane grasslands above 2800 m are composed of *Pentaschistis* species and *Festuca abyssinica*. Occasionally, remnants of ericaceous vegetation, notably *E. arborea*, occur in the upper montane region. Ericaceous vegetation dominates the timberline ecotone in much of tropical Africa, but the Jebel Marra is not high enough for a true alpine belt.

Thus, with respect to the temperature and moisture availability most of the montane belt should be suitable for dry afro-montane forests dominated by *O. laperrinei*, which have presumably been cleared by large-scale woodcutting, grazing and fire. This would clearly indicate parallels to the tropical mountains described in the following chapter.

Vegetation belts in the tropical African mountain regions

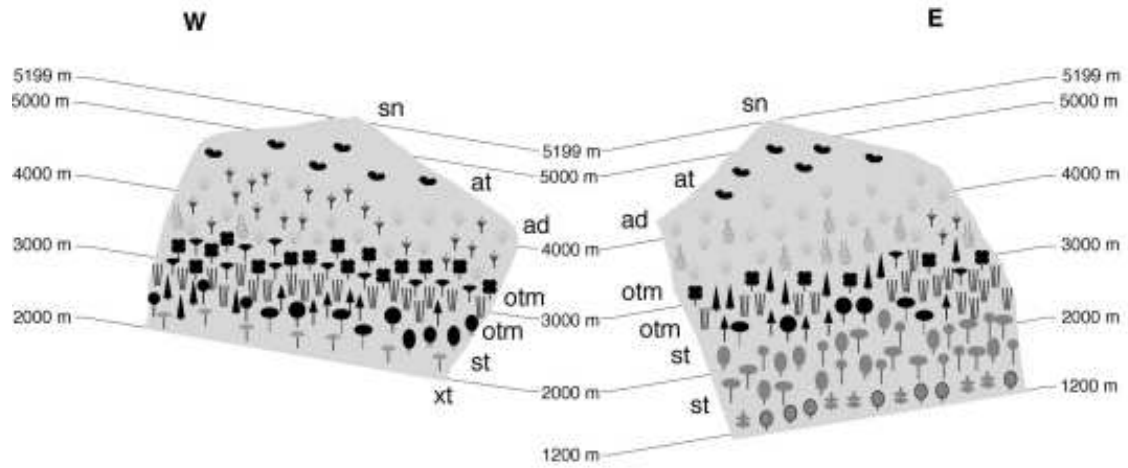
Mount Kenya - A typical example for the altitudinal zonation of tropical African mountain vegetation

Mt. Kenya (Figure 1 a & b) is intermediate among the mountains in tropical Africa in terms of geographical position and climate. Research there has started early in the last century, so the available data are relatively comprehensive. Hence, we will discuss the vegetation zonation of Mt. Kenya in some detail, while descriptions for the other mountains are kept shorter and focus on the differences to the typical situation in central Kenya.

Mount Kenya, located about 180 km north of Nairobi on the eastern side of the Great Rift Valley, is a widely isolated volcano. The base diameter is about 120 km; the northern foothills reach the equator. With its main peaks Batian (5198 m) and Nelion (5188 m), Mt. Kenya is, after Kilimanjaro (Kibo 5899 m), the second highest mountain in Africa. It is broadly cone-shaped with deeply incised, in the upper parts U-shaped valleys, indicating extensive former glaciations. Most parts of Mt. Kenya are still covered with forests up to approximately 3400 m in the South and 3000 m in the North, where a sharp boundary separates the forest from the lower alpine zone. Shape and location of the upper treeline has been severely influenced by fires. The present lower timberline is a result of extensive forest clearance and agriculture with cultivation reaching up to 1800 m on the southern, up to 2400 m on the eastern and western, and nearly up to 2900 m on the northern slopes. Without human impact, the mountain would be almost completely surrounded by dense forests.

As an important water catchment, Mt. Kenya contributes mainly to the Ewaso Nyiro and Tana River drainage systems, and is therefore of utmost importance for the water supply of about 50 % of the Kenyan population. Moreover, since other power stations did not fulfill the expectations hydropower from these rivers continues to generate more than half of the country's production of electrical energy (Berger 1985; Decurtins 1985, 1992; Leibundgut 1986). Densely populated farming areas surround the whole mountain, and large parts of the forest suffered heavily from encroachment in the last decades. The vertical zonation of the mountain has already been described in the early 20th century (Engler 1895; Allaud & Jeannel 1914), but the first comprehensive accounts are from the 1950s (Hedberg 1951).

# Mount Kenya (5199 m, Kenya)



## zonal elements of the drier Western Slope

sn	= subnival desert and nival zone	5000 - 5199 m
ad	= altodesertic cushion scrubs and herbs	4500 - 5000 m
at	= altotropical moorlands	3400 - 4500 m
otm	= orotropical cloudforest	3000 - 3400 m
otm	= orotropical bamboo forest	2700 - 3000 m
otm	= orotropical montane forest	2200 - 2700 m
xt	= xerotropical deciduous open woodland	2000 - 2200 m

## zonal elements of the humid Eastern Slope

sn	= subnival desert and nival zone	5000 - 5199 m
ad	= altodesertic cushion scrubs and herbs	4500 - 5000 m
at	= altotropical grassland and woodland	3300 - 4500 m
otm	= orotropical cloudforest	3000 - 3200 m
otm	= orotropical bamboo forest	2700 - 3000 m
otm	= orotropical bamboo forest	2700 - 3000 m
otm	= orotropical montane forest	2500 - 2700 m
st	= supratropical mountain forest	1200 - 2500 m

- |  |   |
|--|---|
| <ul style="list-style-type: none"> <li> evergreen cloudforest (<i>Hagenia abyssinica</i>, <i>Hypericum revolutum</i>, <i>Gnidia glauca</i>)</li> <li> evergreen submontane forest (<i>Ocotea usambarensis</i>, <i>Aningeria adolfi-friederici</i>, <i>Syzygium guineense</i>)</li> <li> evergreen submontane forest (<i>Lovoa swynnertonii</i>, <i>Chrysophyllum gorgunosarum</i>)</li> <li> evergreen montane xeromorph forest (<i>Cassipourea malosana</i>, <i>Podocarpus milanjanus</i>, <i>Olea capensis</i>)</li> <li> evergreen montane xeromorph forest (<i>Olea europaea ssp. africana</i>, <i>Juniperus procera</i>)</li> </ul> | <ul style="list-style-type: none"> <li> tussock grassland (<i>Festuca pilgeri</i>)</li> <li> altotropical moorlands (<i>Carex monostachya</i>, <i>Lobelia keniensis</i>, <i>Lobelia telekii</i>, <i>Dendrosenecio brassica</i>, <i>Dendrosenecio keniodendron</i>)</li> <li> Subnival shrub (<i>Helichrysum spec.</i>)</li> <li> evergreen montane ericaceous forest (<i>Erica arborea</i>)</li> <li> evergreen montane bamboo forest (<i>Sinarundinaria alpina</i>, partly with <i>Podocarpus milanjanus</i>)</li> <li> evergreen submontane deciduous forest (<i>Brachylaena huillensis</i>, <i>Croton megalocarpus</i>)</li> <li> deciduous open woodland (<i>Acacia drepanolobium</i>)</li> </ul> |
|--|---|

Fig. 1a. Vegetation zonation on Mt. Kenya, West-East Transect

## Mount Kenya (5199 m, Kenya)

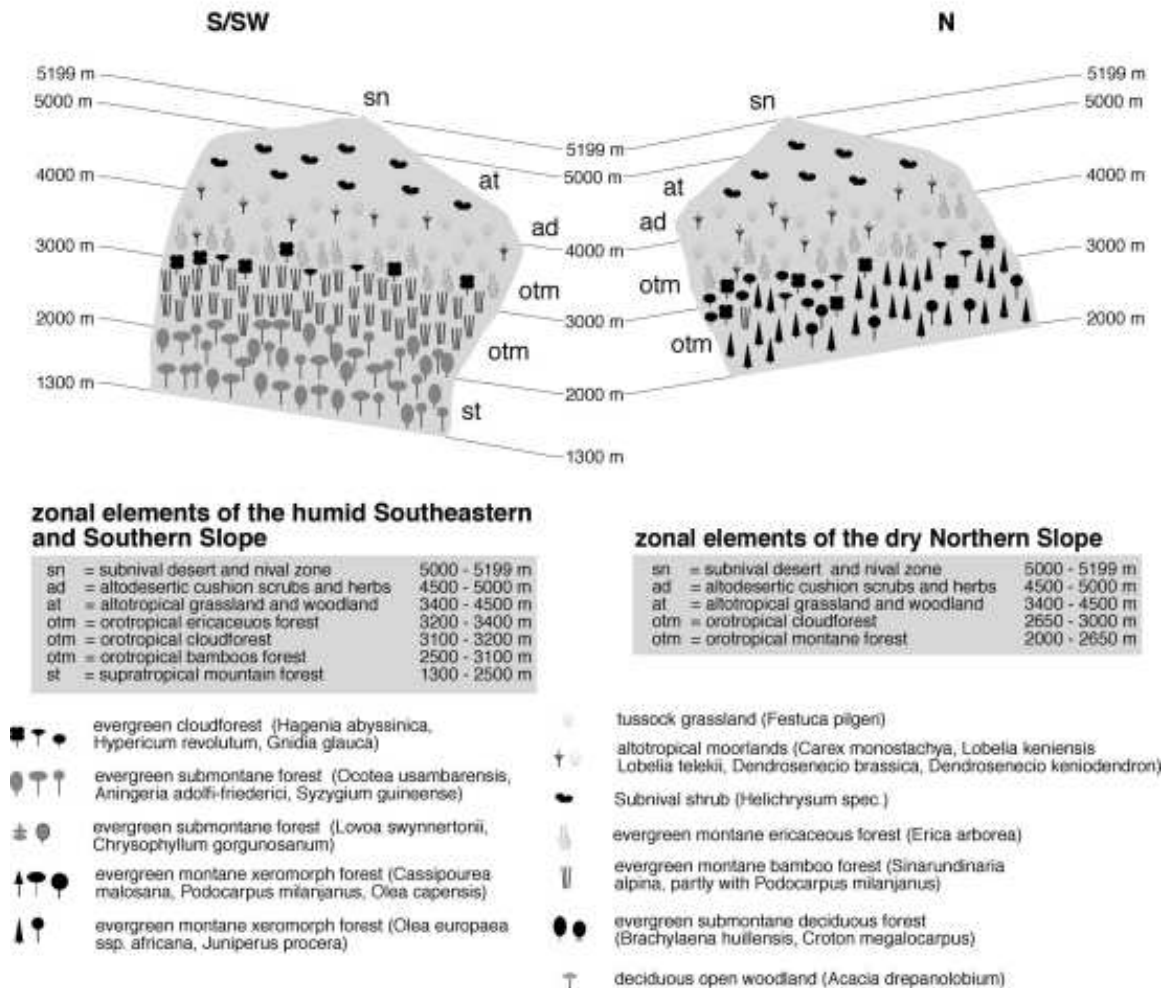


Fig. 1b. Vegetation zonation on Mt. Kenya, North-South Transect

### Supratropical evergreen montane forests

The lowermost areas on the eastern and northeastern slopes from 1200-1500 m are covered with evergreen mountain forests, which closely resemble forest types of central and western tropical Africa. *Newtonia buchananii*, *Lovoa swynnertonii* and *Chrysophyllum gorgonosanum* are prominent tree species. These have survived only in comparatively small remnants, while the principal forest formation are typical Camphor forests, with *Ocotea usambarensis*, *Aningeria adolfi-friederici* and *Syzygium guineense* being the most important canopy species. These evergreen submontane forests (Bussmann 1994, 2001, Bussmann & Beck 1995a,b, 1999) are two-storied, with huge specimens of the African Camphor tree, *Ocotea usambarensis* in the upper canopy, and *Xymalos monospora*, *Lasianthus kilimandscharicus*, *Pauridiantha holstii* and *Psychotria orophila* in the lower tree layer and the often-dense shrub stratum. Further characteristic species in the upper tree layer are *Strombosia scheffleri* and *Apodytes dimidiata* in the upper tree layer, while *Tabernaemontana stapfiana*, *Ochna insculpta*, *Macaranga kilimandscharica* and *Peddiea fischeri* form low trees and shrubs. *Asplenium sandersonii*, *A. elliotii* and *Panicum calvum* occur in the herb layer, together with *Piper capense*, *Oplismenus hirtellus*, *Plectranthus luteus*, *Begonia meyeri-johannis* and the ferns *Dryopteris kilimensis* and *Blotiella stipitata*. *Cyphostemma kilimandscharicum* is a common climber, and abundant fern epiphytes include *Elaphoglossum lastii*, *Trichomanes borbonica*, *Asplenium theciferum* and *Oleandra distenta*.

On the lowermost eastern slopes of Mt. Kenya, forests with only one closed tree layer are found, dominated by *Newtonia buchananii* and many, often very tall palms (*Phoenix reclinata*), which give these areas an appearance like an Andean cloud forest. Once, these forests covered large tracts of land especially on the eastern slopes of Mt. Kenya, and formed the lowermost submontane forest



belt in transition to the savannah lowlands, but these forests have long ago been cleared for cultivation.

On the western side of Mt. Kenya, evergreen submontane semi-deciduous forests, where drought resistant species like *Calodendron capense* or *Croton megalocarpus* are common, follow woodlands dominated by *Acacia drepanolobium* from 2000-2300 m.

On the northern part of Mt. Kenya, the woodlands lead directly into very drought-resistant xeromorphic forests, which are almost entirely dominated by Pencil Cedar (*Juniperus procera*) and Wild Olive (*Olea europaea* subsp. *africana*). A Bamboo belt is absent there, and even the narrow cloud forest belt is heavily interspersed with Cedar. Several authors mentioned a so-called "forest gap" on the drier northern slopes of the mountain (e.g. Hutchins 1909; White 1950). Whether this gap is natural or man made has been a matter of debate. According to the statements of long-term residents of the area, clearing the forest for farming purposes has widened the gap. In the late 1970's, the Kenyan government for farmland excised some areas of the Mt. Kenya Forest Reserve. In many smallholder fields (shambas) of this area, forest trees or remnants of trees are still present, indicating clearly the former extension of the forest belt. Climatic conditions are less probable to be responsible for the gap since in an even drier area exactly north of the gap on Mount Kenya, the Ngare Ndare forest with extensive stands of *Juniperus procera* is found. Therefore, there are no reasons to assume a natural reason for the existence of the forest gap. Most probably, a formerly closed forest belt must be concluded.

Riverine forests and a variety of very different forests can be also found, indicating affinities to the mountain forest communities of Central and Western Africa. *Lovoa swynnertonii*, a very tall and dominant canopy tree is a typical species, growing together with the shrubs *Rawsonia lucida*, and with *Heinsenia diervilleoides* and *Rinorea convallarioides*. In many places *Uvariadendron anisatum*, with its beautiful and very fragrant white leaves, grows abundantly in the lower tree stratum and in the shrub layer.

Pure Camphor forests are found mainly on the very wet southeastern and southern slopes of Mt. Kenya on altitudes between 1550-2550 m. They grow on humic Niti- and Acrisols and receive an annual rainfall of 1500-2500 mm. Moist forests in the lower and middle submontane region of southeastern Mt. Kenya are dominated by the evergreen species *Syzygium guineense* (Myrtaceae) and *Aningeria adolfi-friederici* (Sapotaceae), reaching a height of up to 50 m. Furthermore, the shrubs *Drypetes gerrardii* (Euphorbiaceae) and *Allophyllus cuneatus* (Sapindaceae), as well as the lianas *Adenia gummifera* (Passifloraceae) and *Jaundea pinnata* (Connaraceae) are characteristic species. The number of epiphytic mosses is limited, but a wide variety of epiphyllous and epiphytic liverworts and lichens occur.

Most stands suffered from heavy exploitation, and have been replaced by secondary vegetation types, leaving untouched evergreen forests only in steep ravines or in remote areas, which are difficult to access. *Macaranga kilimandscharica* dominates the canopy of these secondary forests, and often forms dense pure stands. It is a very fast growing species suppressing the regeneration of other trees.

Orotropical montane forest - Evergreen broad-leaved and evergreen xeromorphic montane forests

The cedar forests (*Juniperus procera*) grow on humic Acrisols (Speck 1986) at rainfall totals between 700 and 1500 mm. They represent the typical vegetation of the altitudinal range between 2500 and 2950 m of the drier exposures (Bussmann 1994, 2001, Bussmann & Beck 1995a, 1999). Evergreen-broadleaved forests cover the moister southern and southeastern slopes, at lower altitudes between 2150-2650 m. *Juniperus procera* itself is rare or completely absent, due to heavy logging and suppressed regeneration in the closed stands. The dominant tree species in these two-storied stands are *Cassipourea malosana* (Rhizophoraceae) and *Olea capensis* subsp. *hochstetteri*, the East African Olive; both forming the upper canopy. *Lepidotrichilia volkensii* in the lower tree and shrub strata, and *Ilex mitis*, the African Holly are further important woody species. Cedar forest, in contrast, is rather open and one or two-storied, with *J. procera* growing about 50 m tall under favorable conditions. Other important tree species, mainly of the lower canopy, are the Wild Olive (*Olea europaea* subsp. *africana*) and *Podocarpus latifolius*. Mosaics of dense grass layers with *Stipa dregeana* and *Brachypodium flexum*, interspersed with herbs (*Sanicula elata*, *Isoglossa gregorii* and *Achyranthes aspera*), and low shrubs (e. g. *Berberis holstii*) are also characteristic of these open cedar forests.

Orotropical Bamboo forest

Dense forests dominated by the African Bamboo (*Sinarundinaria alpina*) which are found on

various East African mountains, constitute a very distinct formation (Bussmann 1994, 1997, Bussmann & Beck 1995a, 1999, Bussmann 2001, Bytebier & Bussmann, 2000). *Sinarundinaria alpina* is the overwhelmingly dominant species in all strata, but *Impatiens hoehnelii*, *Pseudocarum eminii* as well as *Selaginella kraussiana*, *Cyperus dereilema*, and *Anthriscus sylvestris* are common companions. Bamboo forests are restricted to a relatively narrow ecological range, mainly depending on soil temperatures of 10-15 °C and the presence of very deep volcanic soils, namely humic Andosols. On Mt. Kenya, they are found in an almost closed belt around the entire mountain, interrupted only on the dry northern slopes. Stands are somewhat more extensive on the very wet southern parts.

On steep slopes of the western, northwestern and eastern side of Mt. Kenya, in areas with lower rainfall and higher soil temperatures, often huge individual trees protrude from the dense Bamboo layer in some 10-15 m height. The dominant species of the tree stratum is always *Podocarpus latifolius*, which is also common in the surrounding montane forest. Towards the hygric limits of the Bamboo, mainly on the dry northwestern parts of the mountain, *Juniperus procera* and *Olea europaea* subsp. *africana* are found as characteristic members of the tree stratum. Trails and heavily trampled resting places of big game occur everywhere in these forests, and seem to facilitate regeneration of trees in the otherwise extremely shady stands of *Sinarundinaria alpina*.

#### *Orotropical cloud forest*

Two forest types, namely tall and malacophyllous forest with *Hagenia abyssinica* occupy this vegetation zone, and lower stands built by various species with sclerophyllous, "ericoid" leaves. The so called "ericaceous belt" forms the transitions zone towards truly afroalpine vegetation within the timberline ecotone. In contrast, the malacophyllous forests extend from 2900 to 3300 m a.s.l., where low clouds and mist are frequent. The dominant tree is the Kosso tree, *Hagenia abyssinica* (Rosaceae), often accompanied by the Giant St. John's Worth, *Hypericum revolutum*. *Bothriocline fusca* is a common shrub, while *Polygonum afromontanum*, *Stephania abyssinica*, *Cineraria deltoidea* and *Carduus afromontanus* are common herbs. Pure *Hagenia-Hypericum* forests with a low, dense shrub layer of *Hypericum* are characteristic for the wetter southeastern to western slopes of Mt. Kenya. Here, important herbaceous companions are *Luzula johnstonii*, the large *Lobelia bambuseti*, *Rubus frieseorum*, *Agrostis schimperiana*, *Poa schimperiana*, *Helictotrichon milanjeanum*, and one of the few succulents, *Uebelinia rotundifolia*.

In the drier northern part of Mt. Kenya, the *Hagenia*-dominated forests are replaced by mixed forests with *Podocarpus gracilior* and broad-leaved species, clearly differentiated by the high frequency of *Juniperus procera*, *Olea europaea*, *Nuxia congesta* and especially *Rapanea melanophloeos*. *Hagenia abyssinica* is only a co-dominant canopy species and *Hypericum revolutum* is mostly absent.

From some 3300 m upwards, *open ericaceous communities gradually replace Hagenia forests*. They grow at the upper limit of forests, but the timberline has been lowered by several hundred meters due to fires and undulates now at 3100 to 3300 m. True *Erica excelsa* forests are poorly developed on Mt. Kenya, and most often the ericaceous belt is formed by remnant stands of ericaceous scrub with *Erica trimera* (formerly *Philippia*, Oliver 1987), *E. arborea*, *Conyza vernonioides*, and the astonishingly "ericoid" Asteraceae *Stoebe kilimandscharica* (Rehder et al. 1988). The latter, together with *Protea kilimandscharica* often indicates regular disturbance by high altitude fires. Fires are usually discontinuous, so the scrub is interspersed with various grassland types that are already afroalpine. Thus, ericaceous and afroalpine communities generally form patchy mosaics and transition communities rather than clear altitudinal belts.

#### *Altropical grasslands and moorlands*

In tropical Africa, the altitudinal belt above the timberline has been termed "afroalpine" (Hauman 1955). Communities intersect with ericaceous vegetation, and are mainly dominated by tussock grasses and stands of Giant Rosette Plants. Fortunately, a vegetation map is available, so the spatial distribution of communities is well known (Rehder et al. 1988; Beck et al. 1990). "Open Moorlands" are particularly extensive on the western slopes of Mt. Kenya at altitudes from 3400-3800 m, often found at clearings of ericaceous vegetation. The dominant species are grasses, namely the large sedge *Carex monostachya*, interspersed with tussocks of *Festuca pilgeri* in drier places. Most characteristic are the large, cabbage-like ground rosettes of *Dendrosenecio brassica* and *Lobelia keniensis*. The Giant Rosette "tree" *Dendrosenecio johnstonii* subsp. *battiscombei* is common in the lower moorlands as well as in remnant ericaceous stands.

The "Upper Moorland Zone", extending from about 3800 m upwards as high as 4550 m comprises two very characteristic vegetation units. Where moisture availability is sufficient, "Upper

Alpine Wetlands" are formed by *Dendrosenecio brassica* and *Lobelia deckenii* ssp. *keniensis*. In contrast to lower altitudes, sclerophyllous dwarf shrubs like *Alchemilla johnstonii*, *Alchemilla argyrophylla* subsp. *argyrophylla* and *Helichrysum brownei* often replace grasses. Sedges are less important than in the lower moorlands.

The typical plant community above 4300 m is the "Dendrosenecio woodland", in which *D. brassica* is replaced by the Giant Groundsel, *Dendrosenecio keniodendron*, growing together with *Lobelia telekii*. From 4500 m onwards, the Giant Groundsels recede, and an open layer of *Festuca pilgeri*, interspersed with *Lobelia telekii*, *Festuca abyssinica*, *Carduus chamaecephalus* and *Senecio keniophytum* extends to the subnival zone. Occasional specimens of vascular plants were found up to the summit region in above 5000 m (Rehder et al. 1988). In contrast to the situation on Kilimanjaro, where low precipitation creates a real alpine desert, closed vegetation on Mt. Kenya is more limited due to freezing and continuous solifluction, although moisture availability probably has some influence (Beck 1994).

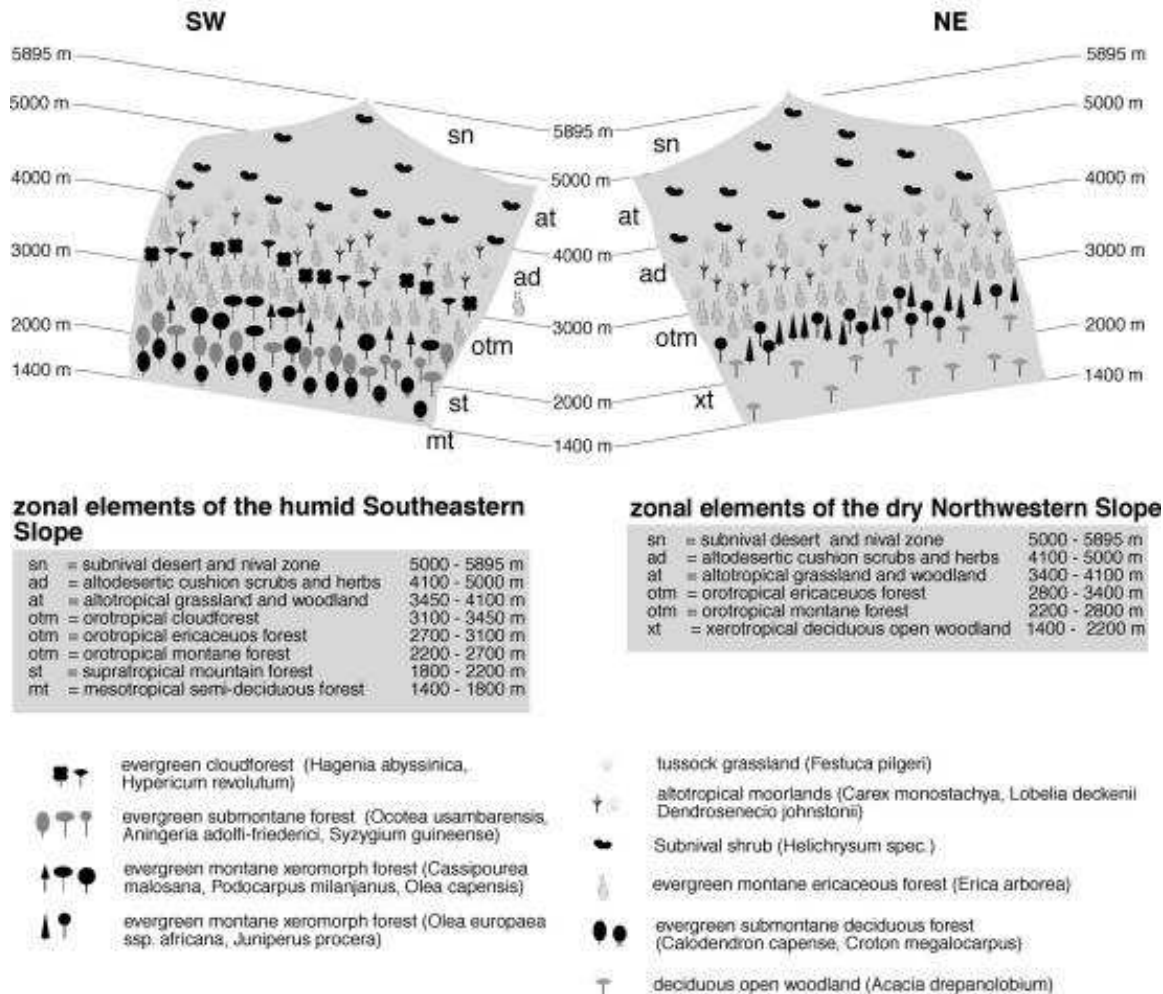
Mt. Kenya's neighbors: Mt. Kilimanjaro, Mt. Meru, Aberdare Mts. and Mt. Elgon

Although they are separated by hundreds of kilometers of lowlands, the neighboring mountains show a vegetation zonation very similar to Mt. Kenya. These striking similarities have long been known to phytogeographers (Hedberg 1951; Hedberg 1964), and have led to the general classification scheme that provided the base for the previous chapter. The vegetation belts are very distinct, as are differences between sides of the mountains, where drought-resistant forest types on their northern escarpments replace very humid elements on their southern and southwestern slopes.

Exposure differences are particularly pronounced on Mt. Kilimanjaro (Figure 2). The southern slopes are unusually moist with an annual precipitation of around 900 mm in the southern foothills, around 2000 mm at 1500 m asl. and well above 3000 mm between 2000 and 2300 m. The summit region is, in sharp contrast, an alpine desert with well below 200 mm annual precipitation (Hemp 2002). Although no exact measurements are available, the northern slopes are clearly drier as indicated on the available vegetation map and the accompanying descriptions (Hemp 2001). Below 1000 m dry savannah surrounds the entire mountain, but on the northern slopes savannahs with *Acacia drepanolobium* and forest plantations climb above 2000 m altitude, followed by a small belt of xeromorphic forests with Cedar and Olive up to 2800 m.

In the moist south between 1000 - 1800 m, evergreen submontane deciduous forests have largely been replaced by dense agriculture. Remnants of the lowermost submontane forests are characterized by *Olea europaea* and at drier sites by *O. capensis*, but from 1700 m upwards, lower montane evergreen Camphor forests and other broadleaved forests dominated by *Cassipourea malosana* replace these. In proper montane forests above 2000 m *Podocarpus latifolius* becomes increasingly common. The most striking feature of these forests is the abundance of epiphytes, in particular Hymenophyllaceae and other fern groups, which give the stands the appearance of a true elfin forest. On all sides of Kilimanjaro, dense *Erica excelsa* forests occupy the belt between 2700-3100 m (South) and 2800-3400m (North). Lower down, in the central montane belt, such forests form replacement communities at disturbed sites (Hemp & Beck 2001). Cloud forests with *Hagenia abyssinica* and *Hypericum revolutum* are restricted to special sites such as boulder streams and moist valleys. Above 3100 m, *Erica* forests are gradually replaced by ericaceous scrub mixed with altotropical moorlands, where subspecies of *Dendrosenecio johnstonii* and *Lobelia deckenii* grow as vicariant taxa to Mt. Kenya (Knox 1993). Above 3900 m, subnival *Helichrysum* scrub takes over up to some 4600 m, where it becomes too dry for growth of vascular plants. The summit region is truly nival and devoid of vegetation.

## Kilimanjaro (5895 m, Tanzania)



**Fig. 2. Vegetation zonation on Mt. Kilimanjaro**

The northern flanks of the neighboring Mt. Meru (Figure 3) are covered by deciduous open woodlands, which are followed by a small band of cloud forest with *Hagenia abyssinica*, *Hypericum revolutum* and *Gnidia glauca* between 2500-3000 m (Hedberg 1955; Hedberg 1964?). Higher up, these are replaced by evergreen ericaceous scrub up to 3700 m, which forms the transition to altotropical moorlands, where *Carex monostachya*, *Lobelia deckenii* and *Dendrosenecio johnstonii* dominate. On the southern slopes of this mountain, however, evergreen montane xeromorphic forest with *Podocarpus latifolius*, *Cassipourea malosana* and *Olea capensis* grows at altitudes from 1700-2300 m. These merge gradually into a distinct Bamboo belt that is replaced by typical cloud forest at 2550-2700 m. The zonation of the uppermost regions shows the same features as the northern escarpment.

The Aberdare Mts. form the next neighboring mountain range west of Mt. Kenya. Climate and vegetation were comprehensively described by Schmitt 1991, who also provides a vegetation map. Climatic conditions are similar to Mt. Kenya, with highest precipitation in the southeast and a maximum in the montane belt of around 2200 mm. The vegetation zonation is also largely similar, with *Cassipourea malosana* and *Olea capensis* in the supratropical mountain forest. Above 2500 to 2700 m, forests with Cedar, *Podocarpus latifolius* and riverine forests with *Afrocrania volkensii* dominate. An almost closed belt of Bamboo, from which specimens of *P. latifolius* and *Nuxia congesta* emerge, follows these. Above 2900 m cloud forests with *Hagenia abyssinica*, *Hypericum revolutum* and *Rapanea melanophloeos* take over. *Erica excelsa* becomes important towards the upper limit of montane forests on the main plateau in some 3100 m altitude. Thus, most of the upper region of the Aberdare Mts. is well in the altitudinal range of ericaceous forests and scrub, so that grasslands are largely secondary and promoted by fires as well as grazing by wild ungulates. The

vegetation gives a very patchy impression, and altitudinal belts can hardly be inferred except towards the summits from 3600 m upwards. Ericaceous vegetation includes well-developed cloud forest of *E. excelsa*, and scrub with *E. trimera*, *Stoebe kilimanscharica* and *Cliffortia nitidula*. The altotropical grasslands are dominated by *Festuca pilgeri*, *Koeleria capensis*, the C4 grass *Andropogon lima*, and at moist sites sedges (*Carex monostachya*, *Cyperus kerstenii*). Again, vicariant subspecies of the *Dendrosenecio johnstonii* and of the *Lobelia deckenii* groups grow in the afroalpine zone.

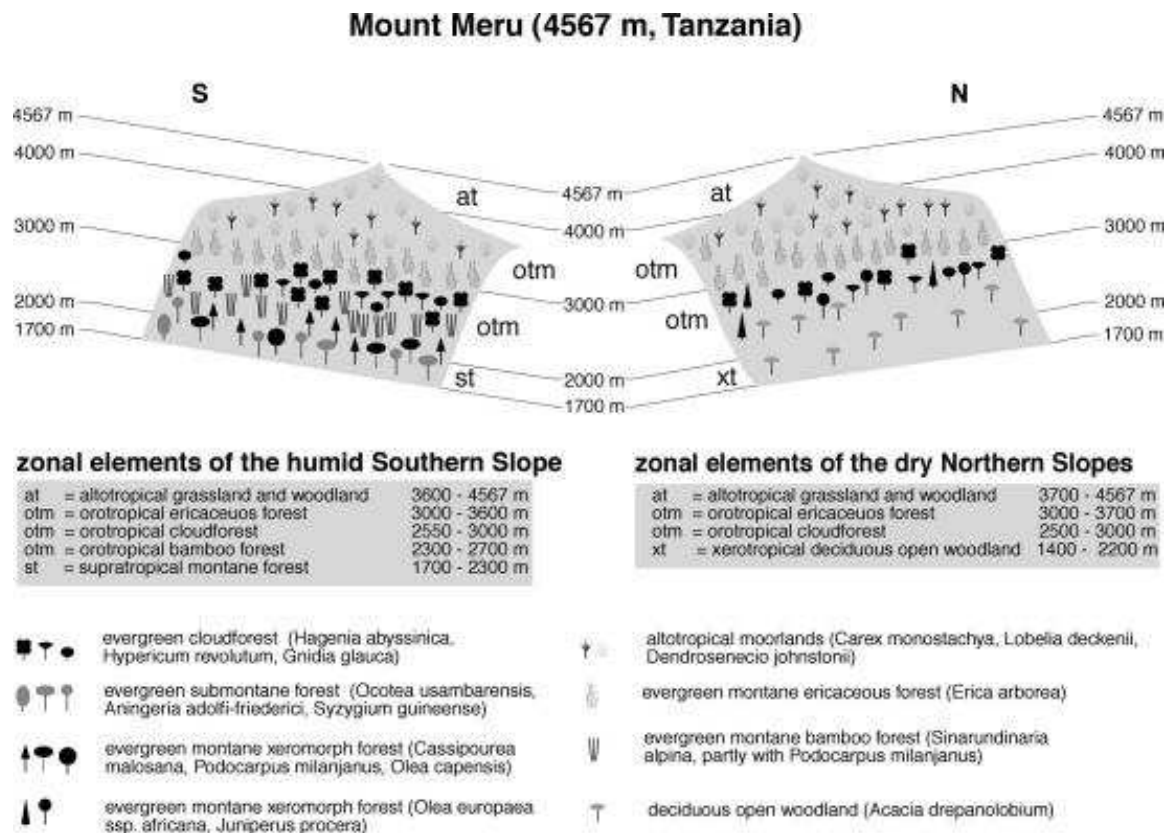


Fig. 3. Vegetation zonation on Mt. Meru

Near the boundary to Uganda, Mt. Elgon and the Cherangani Mts. form the easternmost part of these semi-humid mountain ranges. The Cheranganis are heavily cultivated and grazed on all elevations, so there is hardly any natural montane forest left. With some 3600 m altitude they are not high enough for extensive natural grasslands, so much of the present altotropical grasslands appear to be secondary (Mabberley 1975).

In contrast, Mt. Elgon is the largest solitary volcano with a full set of altitudinal belts comparable to Mt. Kenya (Wesche 2002, vegetation maps provided by van Heist 1994a; van Heist 1994b; Neville & Wesche in press). The western and southwestern slopes are clearly moister than the eastern part of the mountain, with a maximum of precipitation between 2300 and 2700 m asl. (1500-2000 mm on the western slopes, 1200-1500 on the eastern). Hardly any natural vegetation has survived the intense agriculture below 2200 - 2500 m, but higher up, large supratropical forests with scattered Camphor, *Aningeria adolfi-friederici*, *Podocarpus latifolius* and riverine *Afrocrania* forests survived. The eastern side is covered by dry orotropical forest with *P. gracilior*, *Olea capensis* and scattered Cedars. The Bamboo belt is almost closed except in the northernmost part. Cloud forests with Kosso and tree heather have mainly survived in the western part. Above the present timberline, mosaics of ericaceous vegetation with *E. trimera* and *Stoebe kilimandscharica*, *Helichrysum* and *Alchemilladwarf* scrub and altotropical *Festuca pilgeri* grassland form the vegetation up to some 3700 m. Above this, afroalpine grasslands, *Helichrysum* scrub and *Dendrosenecio* woodlands extend up to the summits. Mt. Elgon carries a separate species within the *Dendrosenecio johnstonii* complex, with one subspecies occurring up to 4000 and a second one between 4000 and 4300 m, resembling *D. keniodendron* on Mt. Kenya.

The interlacustrine highlands: Ruwenzori, Virunga Volcanoes and Kahuzi-Biéga

The mountains at the western branch of the Rift Valley form a separate group due to their perhumid rather than semi-humid climate. They border the huge rainforests of the Congo basin, so their lower slopes are covered by luxurious tropical evergreen forest with a high richness in species. Comprehensive vegetation surveys have been produced for Kahuzi-Biéga (Fischer 1996, including land cover map), the eastern half of the Ruwenzori range (Schmitt 1992; Osmaston 1996, land cover map by van Heist 1999, glaciological map by Osmaston & Kaser 2001), and for parts of the Virunga Mts. ((Snowden 1933; Biedinger 1995; Karlowski 1995).

Although the eastern side is generally drier, the vegetation of Ruwenzori (Figure 4), as of Mt. Cameroon, shows no clear distinction between the humid Western and drier Eastern side of the mountain, whereas on the Virunga Volcanoes (Figures 5 and 6) exposition differences are pronounced. The evergreen submontane forest belt of Ruwenzori stretches from 1000-1600 m. Common and typical tree species are *Ocotea usambarensis*, *Aningeria adolfi-friederici* and *Syzygium guineense*. On Muhavura and Karisimbi, submontane forest occupies both western and eastern slopes from 1300 to 2000 m. At altitudes between 2000-2300 m evergreen supratropical mountain forests with *Olea capensis*, *Cassipourea malosana* and *Podocarpus latifolius* replace lowland species in all three regions. In striking contrast to East Africa, no Cedar (*Juniperus procera*) can be found on any mountain in central Africa. Bamboo (*Sinarundinaria alpina*), mostly in stands interspersed with *P. latifolius*, is a prominent feature on Ruwenzori (from 2300 - 3000 m) and on the Virungas (2400-2600 m on Karisimbi, and stretching up as high as 2900 m on western Muhavura).

On Ruwenzori, evergreen *Erica* forest follows immediately after the Bamboo belt and forms extensive stands at 3000-3900 m. The situation on the Virunga Volcanoes is different. On Western Karisimbi (Figure 5), a small fringe of evergreen cloud forest with *Hagenia abyssinica* and *Hypericum revolutum* separates Bamboo and ericaceous belt between 2600-2700 m, from which ericaceous forests can be found up to 3800 m. The cloud forest belt is better developed on the humid eastern slope, where it extends from 2600-3500 m, followed by ericaceous scrub up to 3800 m. The drier Muhavura (Figure 6) shows an exactly inverted cloud forest distribution: on the more humid western slope, *Hagenia* prevails from 2900-3300 m, followed by the ericaceous vegetation up to 3700 m, whereas on the dry eastern escarpment the cloud forest zone is completely replaced by afroalpine grassland (Karlowski 1995).

## Ruwenzori (5127 m, border of Uganda and Democratic Republic of Congo)

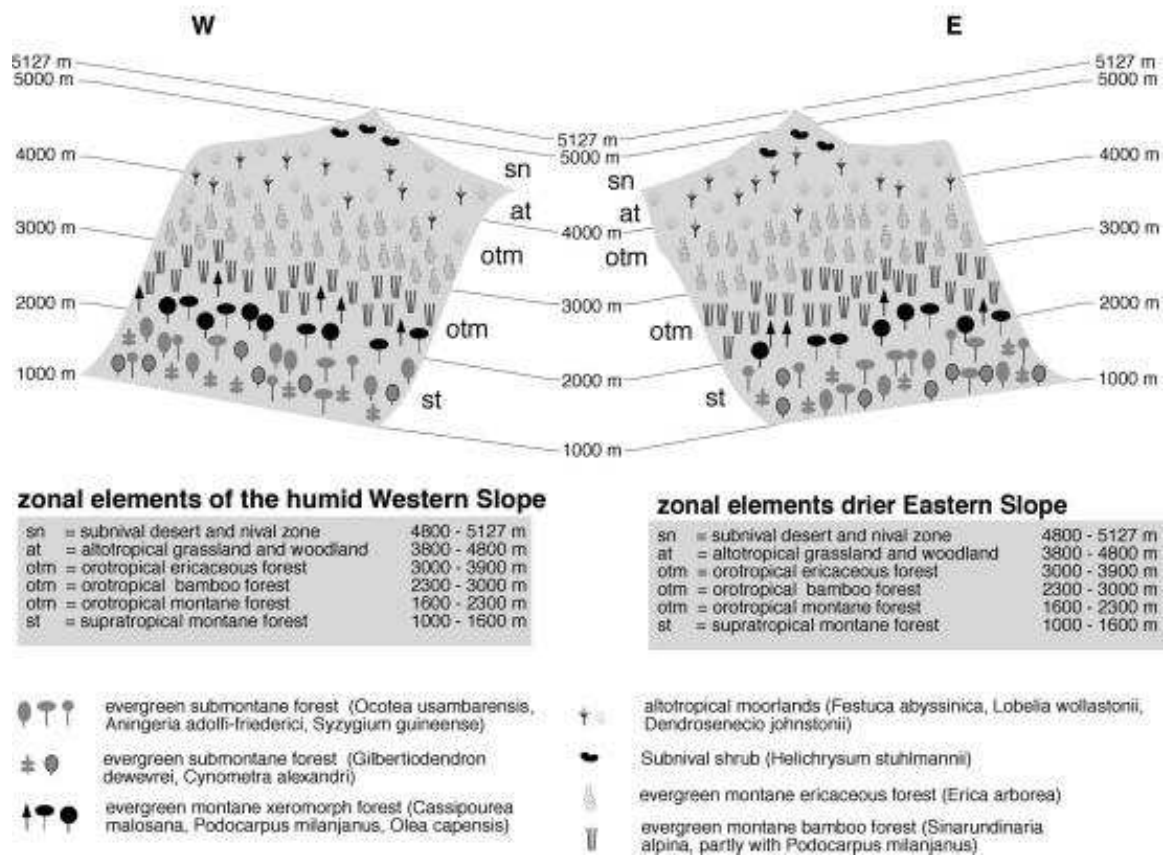


Fig. 4. Vegetation zonation on Mt. Ruwenzori

Extensive altotropical moorlands always occupy the alpine zone of the Central African Mountains. Tussocks of *Festuca abyssinica* and *Carex runssoroensis*, as well as the giant rosette plants *Lobelia wollastonii* and *Dendrosenecio johnstonii* occur on all three mountains, whereas *Lobelia stuhlmannii* grows only on the Virungas. Due to its much higher elevation, upper alpine dwarf scrub is only found on the uppermost parts of Ruwenzori, where *Helichrysum stuhlmannii* forms isolated thickets. The Kahuzi-Biéga range is not high enough for a true afroalpine zone, so the summit region is covered by ericaceous scrub and *Deschampsia flexuosa* grassland. The latter indicates the regular presence of fires.

## Karisimbi (Virunga chain, 4507 m, Rwanda)

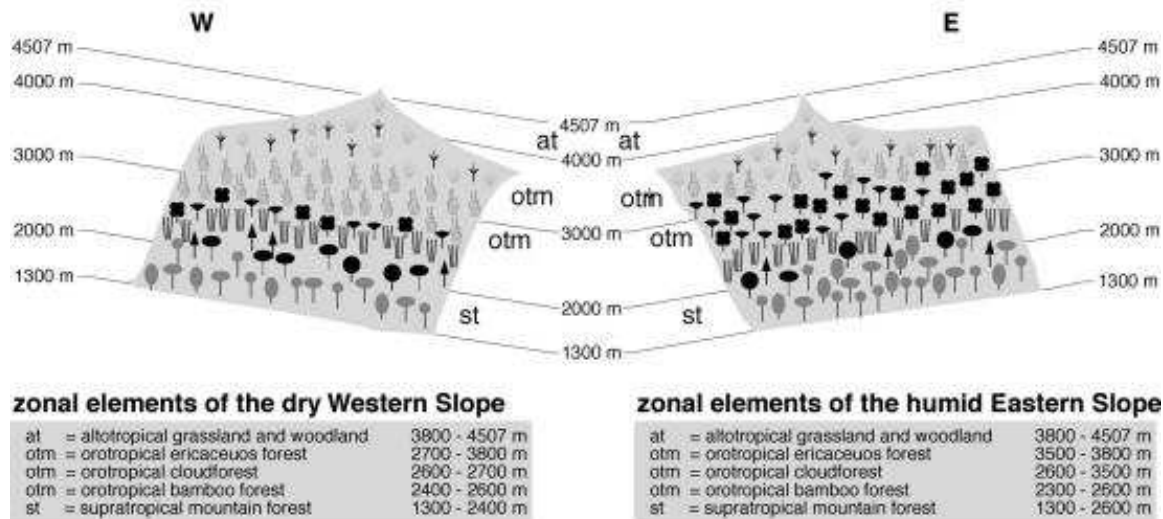


Fig. 5. Vegetation zonation on Mt. Karisimbi, Virunga Volcanoes

## Muhavura (Virunga chain, 4127 m, Rwanda)

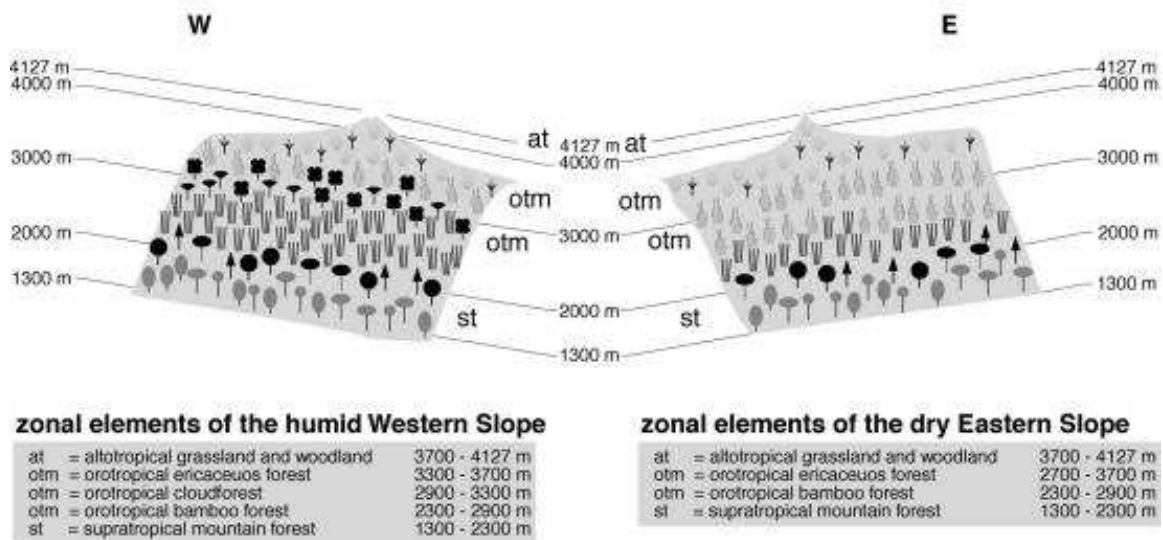


Fig. 6. Vegetation zonation on Mt. Muhavura, Virunga Volcanoes

The westernmost outpost - Mt. Cameroon

The highlands in Cameroon form a widely isolated archipelago in western central Africa. The highest peak is Mt. Cameroon (4095 m, Figure 7), an active volcano that had its most recent eruption in 1982. The climate is extraordinary moist, with up to 10000 mm annual precipitation in the foot zone and below 2000 mm in the summit region (Cable & Cheek 1998, including vegetation map). Mean air



temperature is around 20°C at 900 m and estimated to be around 4° in the summit region. Snow is rare, even on top of Mt. Kilimanjaro. Soils in the mountains are mostly young and therefore fertile, so large areas have been cleared for agriculture. About a third of Mt. Cameroon is now under legal protection, and here natural vegetation has survived partly down to the sea level (Cable & Cheek 1998). The small remnants of lowland forests are rich in various species, and have the highest number of endemics of all vegetation belts (29 vs. 49 for the entire range). Pluviotropical evergreen rain forest dominate the larger part of these altitudes, with tree species like *Schefflera mannii* or *Syzygium guineense* frequently found in the canopy, and *Allophylus bullatus* forming a second layer. These forests merge gradually into submontane evergreen forest from 800 m upwards. Species composition, however, changes only slightly, being characterized by *Syzygium staudtii*, *Schefflera abyssinica*, and still *Allophylus bullatus* (Richards 1963; Hall 1973). From 2000-2600 m orotropical cloud forest is the dominant forest type with species found on all tropical African mountains like *Nuxia congesta*, *Prunus africana*, *Xymalos monospora*, and *Hypericum revolutum*. These form the evergreen cloud forest, together with *Rapanea neurophylla*. Bamboo is completely absent from Mt. Cameroon, but occurs other ranges in western central Africa. *Hagenia abyssinica* does also not occur on Mt. Cameroon, although all other species show clear relationships to the *Hagenia*-dominated upper montane forests common in other areas of sub-Saharan Africa. At all altitudes, large parts of the forests have been replaced by grasslands due to high volcanic activity and thus frequent fires. For the same reason, scrub and thickets are frequently found all over the mountain, with Marantaceae dominating below 2000 m and ericaceous species like *Erica mannii*, *Agauria salicifolia* and *Myrica arborea* forming a patchy ericaceous belt towards the timberline ecotone. Dense altotropical tussock grasslands reach up to 3400 m, where large Poaceae as *Andropogon* sp., *Festuca abyssinica*, *Deschampsia mildbreadii* and *Loudetia camerunensis* dominate, interspersed with small tree islands (Photo). True giant rosette plants, *Dendrosenecio* or *Lobelia* species are absent from Mt. Cameroon, though *Crassocephalum mannii* and *Lobelia columnaris* show resemblances to this growth form. From 3400 m upwards to the summit region, vegetation cover becomes more open and impoverished in species (Maitland 1932). There are no clear vegetation differences with regard to slope exposition.

## Mount Cameroon (4070 m)

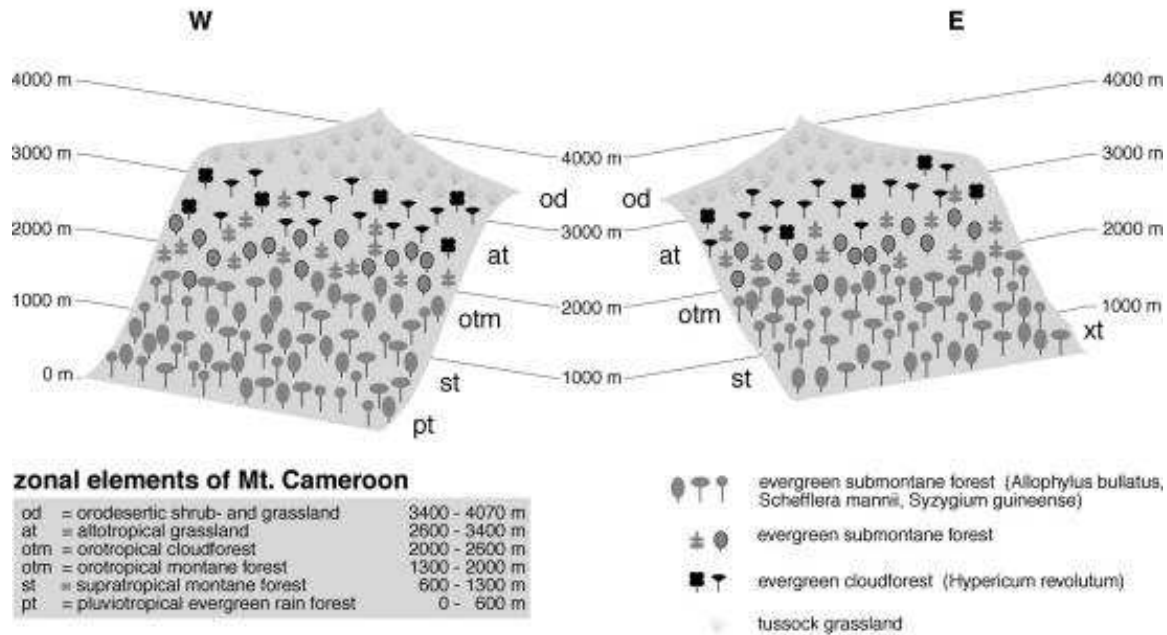


Fig. 7. Vegetation zonation on Mt. Cameroon

### The Sudano-Ethiopian Mountains: Imatong, Simien, Bale

In striking contrast to the mountains in the strictly tropical part Africa, the Sudano-Ethiopian mountains emerge from dry vegetation and semi-arid surroundings. Thus, the mountains of southern Sudan and Ethiopia are characterized by steep climatic gradients and correspondingly, by clear altitudinal changes in the vegetation zonation. All ranges are widely isolated from the eastern African mountains, with the Imatong Mts. in southern Sudan being the least distant.

Their foot zone receives some 800 mm, while at 1900 m asl. some 2200 mm have been recorded; the highest figure in Sudan. The lower slopes of the Imatong Mts. (Figure 8) are covered with lush evergreen submontane forest, where *Ocotea usambarensis*, *Olea welwitschii* and *Chrysophyllum fulvum* are common species (Jackson 1956). Above 2000 m, these forests merge into evergreen montane xeromorphic forest with *Podocarpus latifolius* and *Olea capensis*. Above 2600 m, a mixture of evergreen Bamboo and evergreen cloud forests with *Hagenia abyssinica* replaces these. The highest zones, above 3000 m, are covered with dense thickets formed by *Erica arborea* and *Myrica salicifolia* up to the summit region.

## Imatong Mountains (3200 m, Southern Sudan)

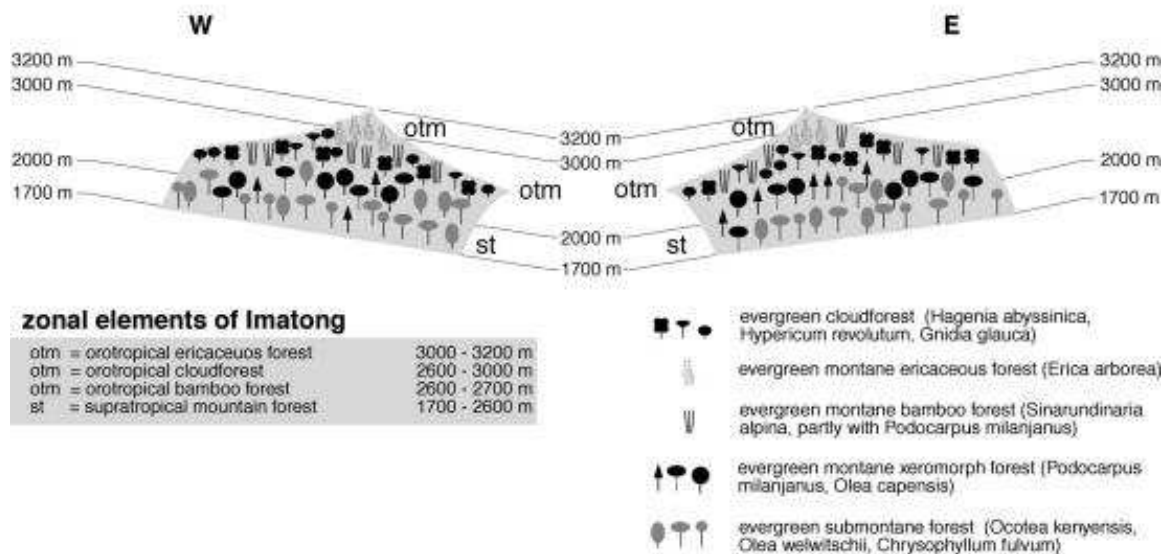
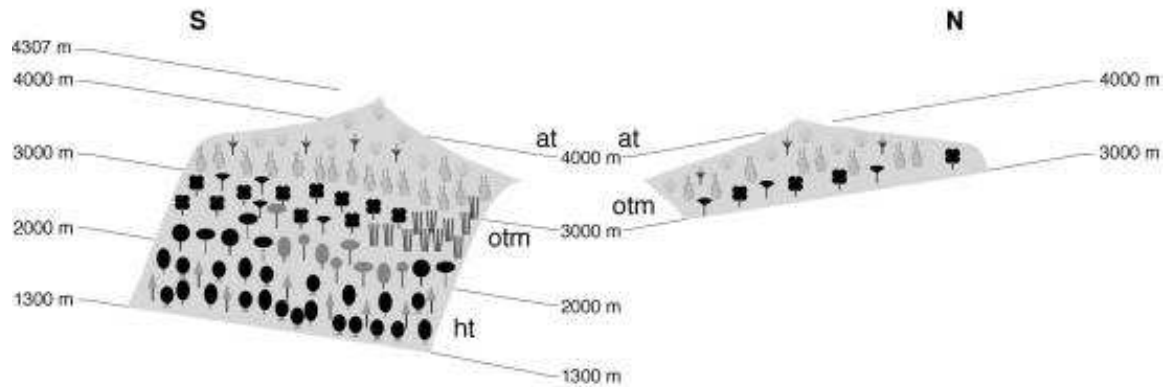


Fig. 8. Vegetation zonation in the Imatong Mts.

The by far largest area of afromontane and afroalpine environments is found in Ethiopia. This huge country displays notable differences in climate, and consequently relatively moist ranges as the Bale Mts. in the southern part are found, as well as extremely dry areas like the Simen Mts. in the north. The Bale Mountains (Figure 9) form the single largest afroalpine area, with a flora and vegetation being transient between East Africa and the drier northern part of Ethiopia (Weinert 1983). The southern foot zone emerges from dry *Combretum-Commiphora* savannah at 390 mm annual precipitation, but the southern Haremma escarpment receives around 850 mm at 3000 m asl. The central part of the range is a huge plateau in some 4000 m asl., where conditions become progressively moister towards the northern slope, which receives around 1000 mm (Miehe & Miehe 1994). This induces a clear zonation of very well pronounced vegetation belts. The lower southern slopes are covered with dense evergreen submontane deciduous forest from 1450-1900 m, where *Podocarpus gracilior*, *Filicium decipiens* and *Celtis africana* as well as *C. gomphophylla* form an open canopy (Lisanework & Mesfin 1989; Bussmann 1997). The undergrowth is often dominated by very dense thickets of wild coffee (*Coffea arabica*). Mid-altitudes from 1900-2300 m are covered by evergreen submontane forest (with *Ocotea kenyensis*, *Aningeria adolfi-friederici* and *Olea welwitschii* as most characteristic tree species), and thus resemble the Imatong Mountains closely. Above 2300 m, *Cassipourea malosana*, *Schefflera abyssinica* and *Croton macrostachyus* form the evergreen montane forest, which slowly gives way to cloud forest communities with *Hagenia abyssinica* and *Hypericum revolutum* from 2400 m onwards. Large areas of Bamboo are found between 2800-3100 m altitude. Cultivation has been more intense on the drier northern slopes, so only remnants of the natural vegetation survived. Dry orotropical Cedar and *Podocarpus* forests have been described up to 3000 m (Weinert 1983), but cloud forest with Kosso and Giant St. John's Worth is restricted to a band from 3000-3400 m.

Ericaceous vegetation with *E. trimera* sl. start to dominate the vegetation from this zone upwards to 4000 m. As elsewhere, the vegetation of the ericaceous belt has been severely altered by human influence, so mosaics of forests, scrub and afroalpine communities result. On the central Sanetti plateau, woody vegetation is restricted to sheltered sites as outcrops or boulder streams up to 4 up to 4000m. Instead, *Helichrysum* scrub and to a lesser extend tussock grasslands prevail up to the highest peaks (Menassie & Masresha 1996). Many of the grass and shrub species demonstrate clear affinities to the eastern African Mts. (e.g. *Pentaschistis pictigluma*, *Helichrysum citrispinum*), but the Giant Lobelias are present with only one endemic species (*Lobelia rynchopetalum*), and the widespread forest species *Lobelia gibberoa*. Giant Groundsels are not found in Ethiopia. Strangely, an endemic thistle (*Echinops longisetus*) has developed a stem here resembling giant groundsels.

## Bale Mountains (4307 m, Southern Ethiopia)



### zonal elements of the humid Southern Bale Escarpment (Harena)

at	= alltropical grassland and woodland	3800 - 4307 m
otm	= orotropical ericaceous forest	3250 - 3800 m
otm	= orotropical cloudforest	2400 - 3250 m
otm	= orotropical bamboo forest	2800 - 3100 m
otm	= orotropical montane forest	2300 - 2600 m
st	= supratropical montane forest	1900 - 2300 m
mt	= mesotropical deciduous montane forest	1450 - 1900 m

### zonal elements of the dry Northern Bale Escarpment (Dinsho)

at	= alltropical grassland and woodland	3800 - 4000 m
otm	= orotropical ericaceous forest	3400 - 3800 m
otm	= orotropical cloudforest	3000 - 3400 m

- evergreen cloudforest (*Hagenia abyssinica*, *Hypericum revolutum*)
- evergreen submontane forest (*Ocotea kenyensis*, *Aningeria adolfi-friederici*, *Olea welwitschii*)
- evergreen montane forest (*Cassipourea malosana*, *Schefflera abyssinica*, *Croton macrostachyus*)
- evergreen submontane deciduous forest (*Podocarpus faicatus*, *Filicium decipiens*, *Coffea arabica*)

- tussock grassland (*Festuca abyssinica*)
- alltropical moorlands (*Carex erythrorhiza*, *Lobelia rhyngopetalum*)
- evergreen montane ericaceous forest (*Erica arborea*)
- evergreen montane bamboo forest (*Sinarundinaria alpina*, partly with *Podocarpus milanjanus*)

Fig. 9. Vegetation zonation of the Bale Mts.

Much of the Ethiopian highlands would bear montane forests if untouched, hence remnants of these forests still occur in the central part of the country (Tamrat 1993). The plant communities are still strikingly similar to those described for Mt. Kenya, but differences increase north-westwards, until the dry Simen Mts. (Figure 10) form the second largest afroalpine region in Ethiopia. Here, the precipitation regime finally becomes unimodal; the foot zone is rather dry but near the timberline 1500 mm have been measured (Hurni 1982). Savannahs below 2000 m are followed by evergreen montane forest with Cedar, *Olea europaea*, *Rapanea simensis* and finally Kosso between 2000-3500 m (3300 m in the southwest). Between 2900 and 3700 m ericaceous vegetation takes over, but here *Erica arborea* is the only tree heather; joined by *Hypericum revolutum*, as well as *Nuxia congesta* in the lower elevations (Klötzli 1975; Verfaillie 1978; Nievergelt et al. 1998). Above this belt, *Festuca macrophylla*, *Carex erythrorhiza*, and *Lobelia rhyngopetalum* occur, the latter with an inflorescence up to 5m tall. In the highest regions, stands are gradually replaced by *Festuca abyssinica* and finally by *Helichrysum citrispinum* scrub up to the summit region.

## Simien Mountains (4620 m, Northern Ethiopia)

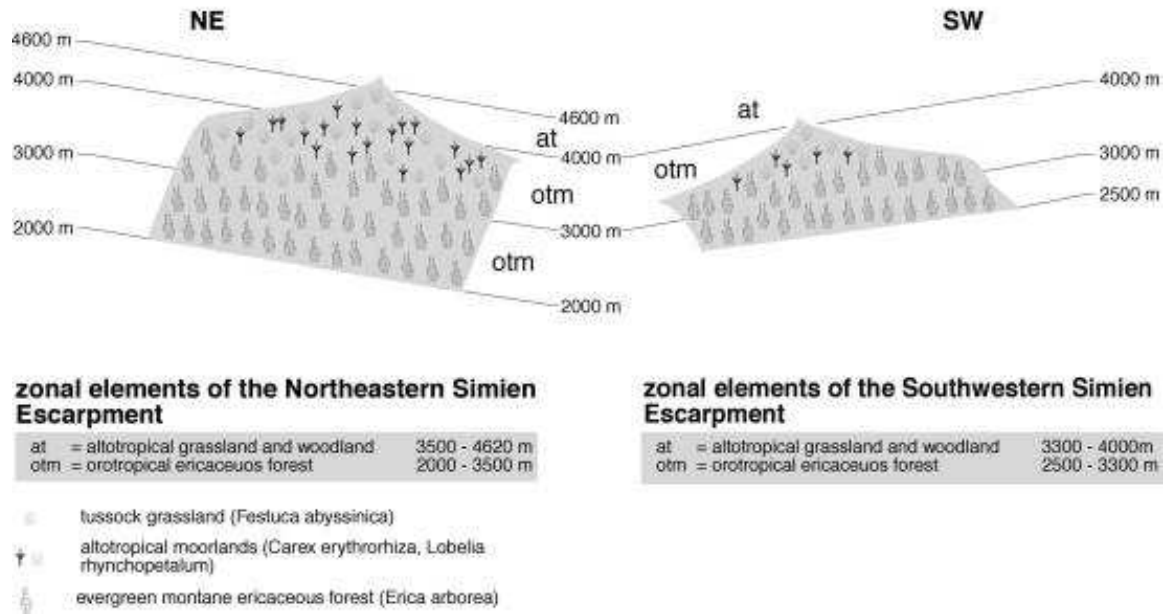


Fig. 10. Vegetation zonation in the Simien Mts.

Maloti-Drakensberg: Mountain vegetation in southern Africa

### *Environmental conditions*

The Maloti-Drakensberg forms the highest part of the Great Escarpment which bounds the interior plateau of southern Africa. The geological structure is relatively homogenous and characterized by stratified Jurassic flood basalts in the upper portion, which cap the underlying fine-grained Clarens Sandstone (c. 1800-2200 m) and other formations of the Karroo Supergroup. For approximately 200 kilometers the towering scarp of the High Drakensberg constitutes the boundary between the eastern highlands of Lesotho and South Africa. An abrupt and rugged barrier ranging from the foothills at about 1400 m to numerous peaks, buttresses, pinnacles, and cutbacks of the escarpment edge lying roughly between 2800 and 3300 m marks the declivity towards South Africa. Some long spurs (the so-called Little Berg) run out at right angles to the escarpment. The mountain divide consists of two parts: the northern Berg, a north-east-facing portion between Mont aux Sources (3282 m) and Giant's Castle (3314 m), and the southern Berg, a south-east-facing part of the escarpment between Giant's Castle and Wilson's Peak (3310 m). Towards the west, the summit plateau gently slopes down to the foothills and lowlands of Lesotho below 2000 m. Rounded slopes, small cliffs and deeply incised valleys characterize the treeless plateau. The highest peak Thabana Ntlenyana (3482 m) lies about 4 km back from the edge of the escarpment (Hilliard & Burt 1987; Killick 1990).

Mean annual precipitation in this high mountain area ranges from 1240 mm at the foot of the escarpment (1370 m) to a maximum of about 2000 mm at an altitude of 2300 m. The escarpment edge receives about 1600 mm (rainfall data from the Cathedral Peak area after Killick 1963). Letseng-la-draai (3050 m), located in the rain shadow receives 713 mm, and Mokhotlong Town (2377 m) about 35 km to the west of the escarpment receives only about 575 mm (Killick 1978b). Apart from these steep gradients in rainfall distribution, the humidity conditions are generally characterized by strong seasonal differences. Almost 80 % of the annual precipitation falls between October and March, resulting in generally humid conditions during the growing season (Killick 1978b). Frequent thunderstorms and recurrent periods of fog, which usually do not extent into Lesotho for more than 3 km contribute to summer humidity. Snow falls frequently between April and September and is usually restricted to the summit plateau and nearby slopes of the escarpment. Snow cover seldom lasts for longer periods, in exceptional years it may last for two months. Recurrent droughts force plants to sustain water stress. Generally, the southern Drakensberg is colder and drier than the northern portion. The temperature regime in the upper valley sections near the escarpment is characterized by a long frost period, lasting for approximately 180 days (Grab 1997a). Mean annual temperature is 5.7°C in Letseng-la-draai, and 11.5°C in Mokhotlong Town. Absolute minimum temperature exceeds

-20°C at the highest altitudes. Therefore, periglacial conditions with Thufur, needle ice, patterned ground, and soil movements are common at higher elevations (Grab 1994, 1997b, 1998). Prominent differences between the warmer and drier north facing slopes and the colder and moister southerly slopes result from different solar radiation income, especially during winter (Granger & Schulze 1977). Obviously, differences of snow cover duration and soil moisture are ecologically most important and mirrored by a more lush vegetation of the southerly exposures. Most plant species of the Drakensberg are adapted to intense solar radiation, long periods of low temperature and drought, and solifluction due to frost heaving. The frequency of strong winds, especially in spring and summer is considered to be "a powerful factor militating against tree growth" by Hilliard & Burt (1987).

*Phytogeographical position and altitudinal zonation: Problems of nomenclature*

The vertical sequence of the Maloti Drakensberg has been differentiated into a montane (approximately 1280-1830 m), subalpine (1830-2870 m) and alpine belt by Killick (1963, 1990). Other studies like those of Herbst & Roberts (1974) and Morris et al. (1993) follow this altitudinal division. White (1983) includes the "afroalpine" belt as an "archipelago-like region of extreme floristic impoverishment" within the "afromontane region". On the other hand, Hilliard & Burt (1987) reject the possibility to include the slopes and summits of the Maloti-Drakensberg in an "afromontane" and "afroalpine" region on the basis that floristic affinities with adjacent lowlands of southern Africa are stronger than with the tropical mountains of Tanzania and Kenya. They argue for the recognition of the area as a distinct phytochorion, the "South-eastern Mountain Regional Mosaic" instead. In the most recent overview of the vegetation of southern Africa, Cowling & Hilton Taylor (1997) include the Drakensberg and Lesotho mountains together with the mountains of the Cape Folded Belt in an "afromontane region". In his latest paper Killick (1997) describes the treeless vegetation of the summit plateau as tundra. The proposed nomenclature postulates a low-lying laural belt with supralaural forests up to approximately 2000 m and largely tree-deficient grass-savannas on the upper mountain slopes.

*Altitudinal zonation of vegetation*

*Themeda triandra* grasslands with *Trachypogon spicatus*, *Hyparrhenia hirta*, *Harpochloa falx* predominantly covers the slopes between approximately 1600 and 2750 m. Large tussocks of *Merxmuellera macowanii* (1830-2550 m) and *Festuca costata* (below 2900 m) occur along the streams. Depending on the kind of fire regime some of these grass slopes up to about 2400 m contain open *Protea* savannas, including 3-5 m high trees of *Protea caffra* and *P. roupelliae* with rounded crowns, and the fire-resistant dwarf species *Protea dracomontana*. Locally, 2-4 m high *Aloe ferox* (= *A. candelabrum*), characteristic for drier conditions can be found as a grassland constituent on steep rocky north-facing slopes in the southern Drakensberg (Loteni valley) (Hilliard & Burt 1987, Killick 1990). Small forest groves with the 12-18 m high Yellowwood (*Podocarpus latifolius*, up to 1900 m) and *Olinia emarginata* (up to 2150 m), often festooned with *Usnea* are confined to narrow valleys and southern aspects along stream gullies. These forests are larger and more numerous on the northern Berg (Hilliard & Burt 1987). The forest margins are characterized by the Rosaceae *Leucosidea sericea*, the commonest woody plant on the Drakensberg (up to 2100 m), *Buddleia salviifolia* and *Bowkeria verticillata*, or by up to 2.5 m high *Miscanthus capensis*-*Cymbopogon validus* grasslands and the Berg bamboo *Thamnocalamus tessellatus* (1800-2000 m). The altitudinal distribution of forest margins roughly extends from the valley floors to the lowermost basalt cliffs at about 2000 m; some tree clumps persist up to 2400 m (Hilliard & Burt 1987). Evergreen thickets with the Thymelaeaceae *Passerina drakensbergensis* (2100-2450 m on the northern Drakensberg), the Ericaceae *Phillipia evansii* (1800-2300 m), the Compositae *Euryops tysonii* (1800-2500 m) and the Cupressaceae *Widdringtonia nodiflora* ("Subalpine Fynbos" after Killick 1963) are limited in extent because of recurrent grass fires. Forest in Lesotho only exists to a limited extent of 1 km<sup>2</sup> (Leslie 1991, Low & Rebelo 1998) with the largest stand in Tsehlanyane (2100 m), which accommodates a 6 m high *Leucosidea sericea* forest.

The vegetation of the summit plateau of Lesotho between approximately 2850 m and the highest peaks comprise grasslands, dwarf scrub communities, wetland communities along the streams and moister slopes, and open scree and rock communities, colonized by small and scattered turf patches along the basalt outcrops. These vegetation types are best developed from December to the end of March. The grasslands are usually dominated by the Gramineae *Merxmuellera disticha*, *Festuca caprina*, *Pentaschistis oreodoxa*, *Harpochloa falx* and the Cyperaceae *Scirpus falsus* in moister places. Subtropical *Themeda triandra* grasslands are confined to the lower slopes and warmer north-facing aspects below 3000 m. Generally, species of temperate affinity like *Festuca caprina*

are more abundant on the cooler aspects and at higher altitudes. These mixed grasslands are distributed as mosaics, often interspersed by dwarf scrubs and patches of up to 1 m high *Merxmuellera drakensbergensis* stands at water surplus sites. The evergreen tussock grass is adapted to low temperatures through accumulation of dead and decaying material that acts as an insulator at the base of the plant. The most common dwarf scrubs are *Helichrysum trilineatum* and *Erica dominans*, covering considerable areas with low heathlands, especially in the vicinity of Mont Aux Sources. Apparently, this led Killick (196, 1979) to consider *Erica-Helichrysum* heathland to be the climax community of the uppermost altitudinal belt. The cushion-forming succulent *Euphorbia clavarioides* is limited to steep rocky and mostly north-facing slopes (Hilliard & Burt 1987). Furthermore, the two karroid invader species *Chrysocoma ciliata* and *Pentzia cooperi* (Morris et al. 1993) together with *Artemisia afra* dominate the dwarf scrub communities between Sani Pass and Mokhotlong. Wetlands and flat marshy grasslands in the riverheads contrast to the surrounding vegetation. The low-growing wetland vegetation contains a mixture of Gramineae (*Agrostis* sp., *Poa annua*) and Cyperaceae (*Scirpus falsus*, *S. ficinioides*, *Isolepis fluitans* and *Schoenoxiphium filiforme*). Pools and silt patches, often waterlogged in summer form a habitat for aquatic communities with *Limosella inflata*, *Aponogeton ranunculiflorus* and *Crassula inanis* surrounded by *Merxmuellera drakensbergensis* tussocks and hygrophilous forbs like *Ranunculus meyeri*, *Kniphofia caulescens*, *Moraea alticola* frequently accompanied by *Trifolium burchellianum* (van Zinderen Bakker 1955, Killick 1978c, Backéus & Grab 1995, Schwabe 1995). Thufur are often colonized by *Athrixia fontana*.

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