Gabriele Broll
Beate Keplin
Mountain Ecosystems
Studies in Treeline Ecology

Gabriele Broll
Beate Keplin (Eds.)

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Studies in Treeline Ecology

With 96 Figures

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Preface

Mountain ecosystems belong to the most endangered ecosystems in the world. Especially, the treeline ecotone acts as an indicator for environmental change. However, ecological processes in the treeline ecotone are not yet completely understood. The studies provided in this book may contribute to a better understanding of the interactions between vegetation, climate, fauna, and soils in the treeline ecotone. An introductory chapter is given on plants living under extreme conditions, climate change aspects, and methods for characterization of alpine soils. The following articles focus on mountainous areas in America, Europe and Asia.

The Working Group on Mountain and Northern Ecosystems at the Institute of Landscape Ecology, University of Münster (Germany), has been working on topics related to the treeline ecotone for several decades. This period under the chairmanship of Friedrich-Karl Holtmeier has come to an end now when he retired in 2004. He initiated numerous studies in high mountains and in the North. Many of his students, who became infected by the 'mountain virus', will continue these investigations on ecological processes in the altitudinal and northern treeline ecotones. With this compilation of studies in mountain ecosystems we want to thank Friedrich-Karl Holtmeier for his excellent guidance in these cold and fascinating environments.

This book could not have been edited without much valuable help of many people. We gratefully acknowledge the interesting contributions of the authors and also the constructive comments from those colleagues who reviewed earlier versions of the manuscripts. We are grateful to Dr. Hans-Jörg Brauckmann, Maja Masanneck and Marta Jacuniak (University of Vechta, Germany) for the careful preparation of the final version of the papers. Not last our thanks go to Dr. Christian Witschel and his staff (Geosciences, Springer Publishers) for the very good cooperation.

Gabriele Broll and Beate Keplin

Contents

Regional Treeline Studies in Europe

Regional Treeline Studies in Asia

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Mountain Ecosystems

Studies in Treeline Ecology

General Aspects of Vegetation and Soils in Cold Environments

Guideline for Describing Soil Profiles in Mountain Ecosystems

Gabriele Broll, Bettina Hiller, Frank Bednorz, Gerald Müller and Thomas Reineke

1 Introduction

This guideline for describing soil profiles in mountainous ecosystems is intended to provide scientists around the world with other than soil science expertise to collect useful soil data such as soil profile descriptions and soil sampling. From the collected soil profile descriptions the scientists should be able to calculate important parameters such as field capacities. In addition, the main objective of this guideline is to streamline methods for soil data collection in mountainous terrain throughout the world, which would result in comparable soil data.

The field book Schoeneberger et al. (2002) is recommended as basis for the guideline. This manual was used providing a minimum data set for descripting soil profiles in mountainous areas. Before describing a soil profile a representative site should be selected. A representative site is defined by the objective of the study. This could consist of parameters such as vegetation communities, microtopography etc. Only those parameters have to be considered, which are essential for a minimum data set. We tried to focus on the specific site conditions in mountainous areas with great heterogeneity in many ways and added special recommendations for their description and sampling. We focussed on those soil parameters, which are necessary to investigate ecological processes, like interactions between plants and soil. In this manual we do not consider genetic purposes. Interpretation of pedogenesis as well as soil mapping should be done in cooperation with soil scientists only. In connection with soil profile description some data, e. g. texture and slope gradient, are collected, which are necessary for erosion risk assessment. Examples of soil profile descriptions in alpine areas of Europe and Asia are given in order to improve the clarity of the guideline.

Basic Manual:

Schoeneberger PJ, Wysocki DA, Benham EC and Broderson WD (2002): Field book for describing and sampling soils. National Resources Conservation Service version 2.0, USDA, National Soil Survey Center, Lincoln, NE. ftp://ftp-fc.sc.egov.usda.gov/NSSC/Field_Book/FieldBookVer2.pdf (03.09.04)

2 Field Work

2.1 Site Description

2.1.1 Name

2.1.2 Date

2.1.3 Profile Number

- Photo and sketch of the profile are recommended.

2.1.4 Location

- Location: Country, latitude / longitude (GPS coordinates)
- Physiographic location
- Elevation [m a.s.l.]

2.1.5 Topography / Relief

- Landform. For detailed definitions and further landforms see also Schoeneberger et al. (1998a).

Depressional landforms

basin floor	saddle
col	trough
depression	valley
intermontane basin	valley floor
mountain valley	

Eolian landforms

blowout	loess hill
deflation basin	sand sheet
dune	

Erosional landforms – Water erosion (overland flow) related and excluding fluvial, glaciofluvial, and eolian erosion

arete (sharp ridge)	pediment
col	saddle
meander scar	scarp slope
peak	

Fluvial landforms – dominantly related to concentrated water (channel flow), both erosional and depositional processes, and exclusing glaciofluvial landforms

bar	levee
delta	meander
fan	pediment
flood plain	stream terrace

Glacial landforms (including glaciofluvial forms)

arete	moraine
cirque	end moraine
col	ground moraine
drumlin	lateral moraine
esker	medial moraine
glacial drainage channel	outwash
glacial lake (relict)	till plain
hanging valley	U-shaped valley
kame	

Mass movement landforms (including creep forms)

block glide	landslide
fall	slide
flow	
debris flow	
earth flow	
mud flow	
sand flow	

Slope landforms

dome (rounded summit)	mountain
escarpment (steep slope)	peak
gap	plain
headwall	plateau
hill	ridge
horn	rim

- horst
- knob (round-shaped mass)
- knoll (small hill)
- meander scar
- mesa
- scarp
- spur
- U-shaped valley
- V-shaped valley

Tectonic, structural and volcanic landforms

- anticline
- caldera
- dome
- graben
- horst
- lava plain
- shield volcano
- stratovolcano
- syncline

Wetland terms and landforms

- bog
- fen
- peat plateau

•Slope aspect
•Slope gradient
•Slope shape (figure 1)
•Site position on slope

- Crest
- Upper slope
- Middle slope
- Lower Slope
- Toe slope
- Depression

•Microfeature

- Gilgai
- Gully
- Mound
- Rib
- Solifluction lobe
- Solifluction sheet
- Solifluction terrace
- Terracettes

Periglacial patterned ground microfeatures

- circle
- non-sorted circles
- sorted circles
- earth hummocks
- peat hummocks
- palsa, palsen
- polygons
- high-center polygons
- ice wedge polygons
- low-center polygons
- stripes
- trough (hollow)

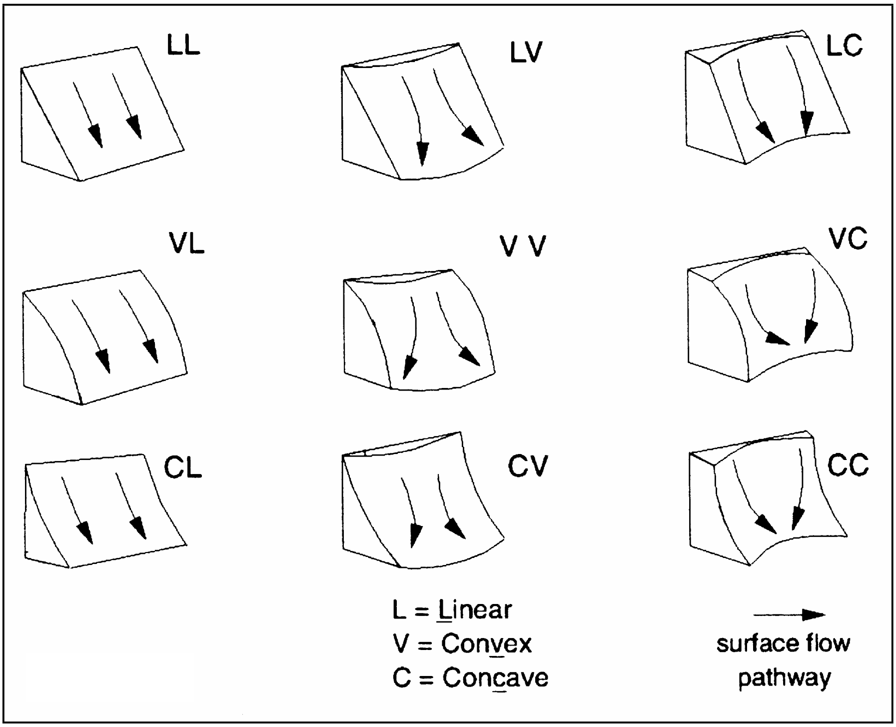


Figure 1 Slope shape is described in two directions: up-and-down slope (perpendicular to the contour), and across slope (along the horizontal contour); e.g. *Linear, Convex* or LV (Schoeneberger and Wysocki 1996; cited in Schoeneberger et al. 2002, adapted)

2.1.6 Water Status

- Drainage classes (See figure 2 next page)
- Depth to water table [cm]
- Depth to impermeable layer [cm]
- In permafrost regions: Depth of thaw [cm]

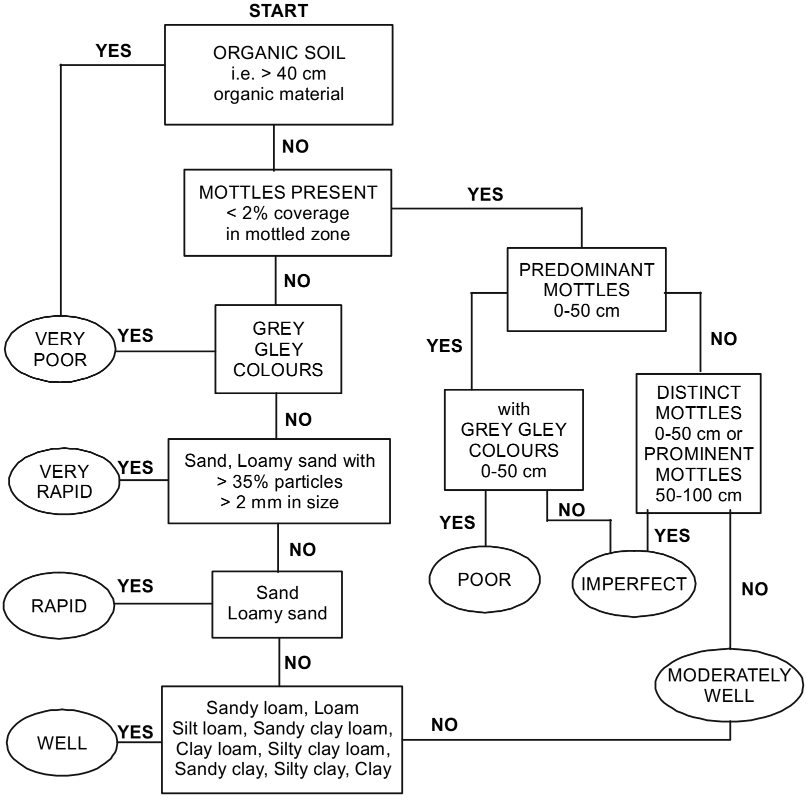


Figure 2 Drainage classes (Denholm and Schut 1993, modified)

2.1.7 Vegetation - Land Use

- Percentage of ground cover

  Total trees [%]
  Total shrubs [%]
  Total vascular y plants [%]
  Total lichen [%]
  Total moss [%]

  Total vegetation [%]
  Bare ground [%]

For further informations see also Miehe and Miehe (2000).

•Land use (FAO 1990, modified)

Crop agriculture (e.g. annual field cropping, shifting cultivation)
Animal husbandry (e.g. extensive grazing, intensive grazing)
Forestry (e.g. natural forest and woodland)
Mixed farming (e.g. agro-forestry)
Extraction and collection (e.g. hunting and fishing, exploitation of natural vegetation)
Nature protection (e.g. parks, wildlife management)
Not used and not managed

2.1.8 Parent Material and / or Bedrock

•Kind of parent material

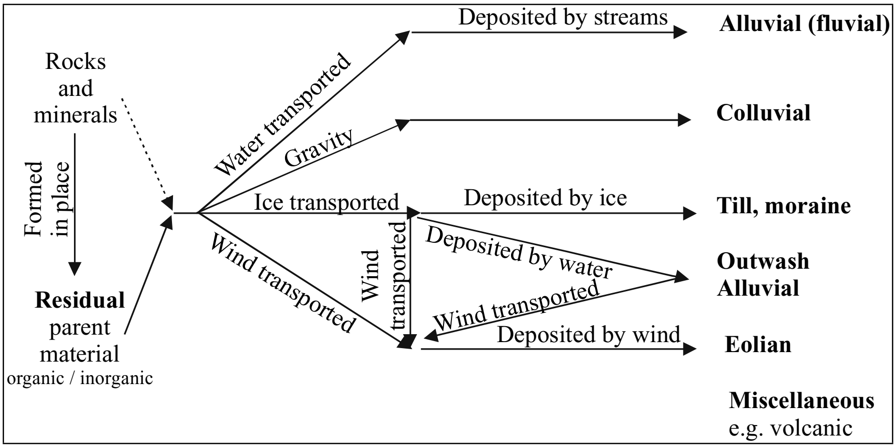


Figure 3 How various kinds of parent material are formed, transported, and deposited (Brady and Weil 1998, modified)

Following is recommended:

Percentage of saprolite (cf. glacial deposits mixed with saprolite)
For more detailed informations see also Catt (1986).

•Kind of bedrock material

Igneous	Metamorphic
Sedimentary	Pyroclastic

Stratigraphic and petrographical classification is recommended.

2.1.9 Surface fragments

- Classes of percentage of surface cover (for surface coarse fragments and rock outcrops) (FAO 1990)

None	0 %	Many	15 - 40 %
Very Few	0 - 2 %	Abundant	40 - 80 %
Few	2 - 5 %	Dominant	> 80 %

- Size classes (FAO 1990)

Fine gravel	0.2 - 0.6 cm	Boulders	20 - 60 cm
Medium gravel	0.6 - 2.0 cm	Large	
Coarse gravel	2.0 - 6.0 cm	Boulders	60 -200 cm
Stones	6.0 - 20 cm		

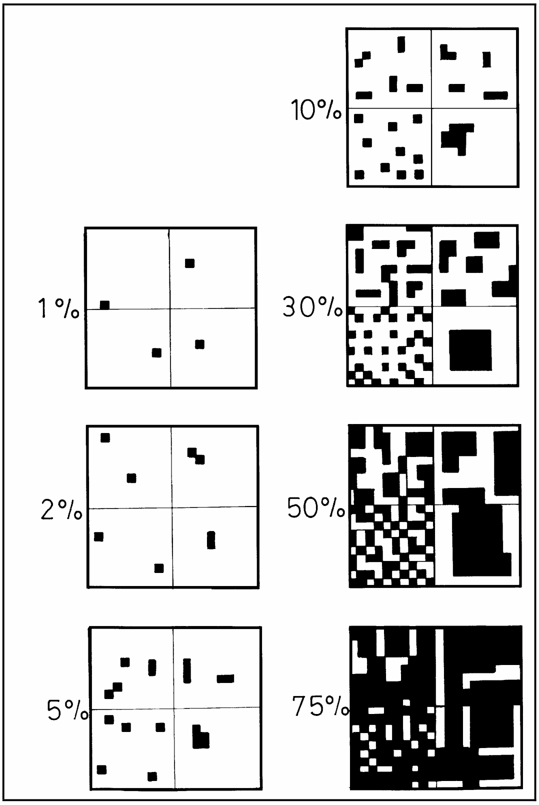


Figure 4 Estimation of percentage of area covered (AK Standortskartierung 1996)

2.2 Profile Description

2.2.1 Horizon Nomenclature

- Master, transitional and common horizon combinations. Only the most important master horizons and horizon suffixes have been considered.

Horizon	Criteria
O	Predominantly organic matter (litter and humus)
A	Mineral, organic matter (humus) accumulation
A/B (or E/B)	Discrete, intermingled bodies of A (or E) and B material; majority of horizon is A (or E)
E	Mineral, loss of Si, Fe, Al, clay, or organic matter
B/A (or B/E)	Discrete, intermingled bodies of B and A (E) material; majority of horizon is B material
B	Subsurface accumulation of clay, Fe, Al, Si, humus, $CaCO_3$, $CaSO_4$; or loss of $CaCO_3$ or accumulation of sesquioxides (e.g. Fe_2O_3)
BC	Dominantly B horizon characteristics but also contains characteristics of the C horizon
B/C	Discrete, intermingled bodies of B and C material; majority of horizon is B material
CB	Dominantly C horizon characteristics but also contains characteristics of the B horizon
C/B	Discrete, intermingled bodies of C and B material; majority of horizon is C material
C	Little or no pedogenic alteration, unconsolidated material, soft bedrock
R	Hard, continuous bedrock
W	A layer of liquid water (W) or permanently frozen water (Wf) within the soil (excludes water/ice above soil)

•Horizon suffixes

Horizon suffix	Criteria
b	Buried genetic horizon (not used with C horizon)
d	Densic layer (physically root restrictive)
f	Permanently frozen soil or ice (permafrost); continuous ice; not seasonal
ff	Permanently frozen soil (‘Dry’ permafrost); no continuous ice; not seasonal
g	Strong gley
h	Illuvial organic matter accumulation
jj	Evidence of cryoturbation
k	Pedogenic carbonate accumulation
m	Strong cementation (pedogenic, massive)
o	Residual sesquioxide accumulation (pedogenic)
p	Plow layer or other artificial disturbance
r	Weathered or soft bedrock
s	Illuvial sesquioxide accumulation
t	Illuvial accumulation of silicate clay
w	Weak color or structure within B (used only with B)

For further information see Soil Survey Staff (2003) and Soil Survey Staff (1999).

2.2.2 Horizon Thickness [cm]

- Horizon thickness is recommended instead of horizon depth because of complications with cryoturbated soils.
- Horizon thickness of the organic layer is also recommended.

2.2.3 Horizon Boundary

•Distinctness of horizon boundaries (Schoeneberger et al. 2002)

Distinctness class	Abruptness of vertical changes [cm]
Very abrupt	< 0.5
Abrupt	0.5 to < 2.0
Clear	2.0 to < 5.0
Gradual	5.0 to < 15.0
Diffuse	≥ 15.0

•Topography (Schoeneberger et al. 2002)

Topography	Variations of boundary plane
Smooth	Planar with few or no irregularities
Wavy	Width of undulation is > than depth
Irregular	Depth of undulation is > than width
Broken	Discontinuous horizons; discrete but intermingled, or irregular pockets

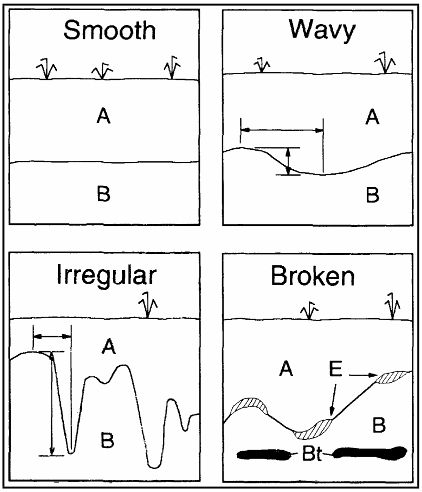


Figure 5 Topography of horizon boundaries (Schoeneberger et al. 2002)

2.2.4 Soil Color

•Munsell Color Charts (Hue, Value, Chroma), moist soil

Soil matrix color

Mottles

Color of mottles (Use Munsell Color Charts)

Quantity classes of mottles

Quantity class	Criteria: range in percent
Few	< 2 % of surface area
Common	2 to < 20 % of surface area
Many	≥ 20 % of surface area

2.2.5 Soil Texture

The particle sizes for silt and sand are different in Europe and North America. In case a particle size analysis should be done, sieves with different mesh diameters are necessary depending on the taxonomy which is used (cf. Table: Particle size classes).

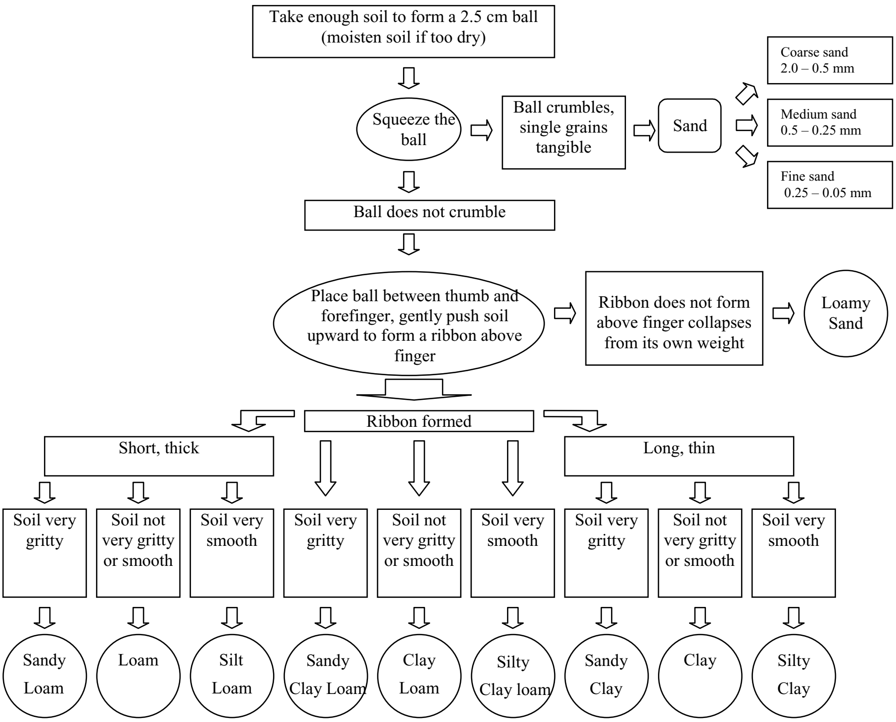


Figure 6 Soil texturing by feel (Thien 1979; cited in Tiner 1999, modified)

•Particle size classes (Schoeneberger et al. 2002, modified)

Fine Earth (USDA)								
Clay	Silt		Sand					
	fine	coarse	very fine	fine	medium	coarse	very coarse	
0.002	0.02	0.05	0.1	0.25	0.5	1	2	[mm]

•Coarse and other fragments / Texture modifiers

Content: Estimate the quantity of gravel, cobbles, stones and/or boulders on a volume percent basis (Schoeneberger et al. 2002)

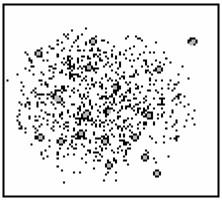
Roundness (simplified): 3 classes: 1. angular, 2. subangular, subrounded, 3. rounded

Sieving in the field is recommended in case a better quantification is necessary (Mosimann 1985)

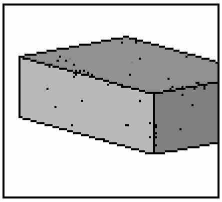
Size	Noun
> 2 – 75 mm diameter	gravel
> 75 – 250 mm diameter	cobbles
> 250 – 600 mm diameter	stones
> 600 mm diameter	boulders

2.2.6 Soil Structure

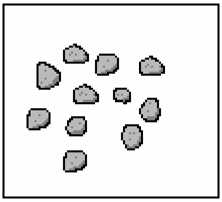
Single grain



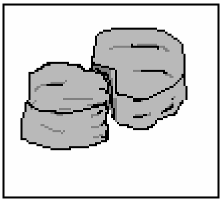
Massive, common in cemented horizonts, e.g. Ortstein



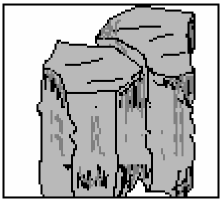
Granular, characteristic of surface (A) horizons, showing high biological activity



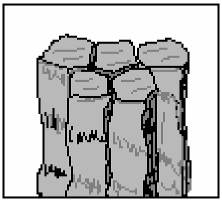
Subangular blocky, common in B horizons particularly in humid regions



Angular blocky, common in B horizons, particulary in humid regions



Prismatic, usually found in B horizons. Most common in soils of arid and semiarid regions



Platy, common in E horizons, may be in any part of the profile. Often inherited from parent material of soil, or caused by compaction

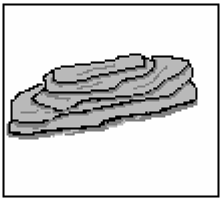


Figure 7 Soil structure types (Brady and Weil 1998; Schoeneberger et al. 2002, modified)

2.2.7 Calcarousness

•Effervescence and $CaCO_3$ content (Day 1983)

	$CaCO_3$ equivalent [%]	Effervescence (using 10% HCl)
No carbonate	0	No bubbles
Weakly calcareous	< 5	Few bubbles
Moderately calcareous	5 - 15	Numerous bubbles
Strongly calcareous	15 - 25	Bubbles form low foam
Very strongly calcareous	25 - 40	Bubbles form thick foam

2.2.8 Penetration Resistance / Bulk Density

•Penetration resistance tested in the field with a pencil, knife or penetrometer (Brady and Weil 1998, modified)

Soil at in situ moisture	Penetration resistance	Field penetration test
Soft	1	Blunt end of pencil penetrates deeply with ease
Medium firm	2	Blunt end of pencil can penetrate about 1.25 cm with moderate effort
Firm	3	Blunt end of pencil can penetrate about 0.5 cm
Very firm	4	Blunt end of pencil makes slight indentation
Hard	5	Blunt end of pencil makes no indentation

• Bulk density (ρt) of mineral soils (bulk density = the ratio of the mass of dry solids to the bulk volume of the soil after drying at 105 °C in g cm^{-3} (Blake and Hartge 1986, AG Boden 1994))

Penetration resistance	**ρt [g cm^{-3}]**	**Interpretation**
1	< 1.25	very low
1 – 2	1.25 – 1.45	low
2 – 3	1.45 – 1.65	middle
3 – 4	1.65 – 1.85	high
4 – 5	> 1.85	very high

2.2.9 Roots

Quantity *	Size *	Location
Few	Fine	Throughout
Common	Medium	Matted on top of horizon
Many	Coarse	In cracks

* in detail: Schoeneberger et al. 2002: 2-56, 2-57

Example: common fine roots matted on top of horizon

2.2.10 Root Restricting Depth

•Definition: Depth of the soil at which root growth is strongly inhibited.
•Classes of root-restricting depth

Extremly shallow	0 - 5 cm
Very shallow	5 - 15 cm
Shallow	15 - 30 cm
Moderately deep	30 - 50 cm
Deep	50 - 100 cm
Very deep	> 100 cm

2.2.11 Remarks

•For example:
- Cracks
- Roots in cracks of bedrock
- Crusts
- Biological features, like earthworm casts

Cryoturbation
Salt
Redoximorphic features
(Test: α-α-dipyridyl, cf. Schoeneberger et al. 2002: 2-66)
Charcoal

2.3 Soil Classification

It is recommended to use the US Soil Taxonomy (Soil Survey Staff 2003) because it is worldwide distributed. Moreover, the suitability of the US Soil Taxonomy has been proved at many high mountain sites.
Notice: Soil temperature data at a depth of 50 cm are necessary.

Humus Forms

The description of humus forms requires:

- Separation between organic layers (≥ 30 % organic matter mass, AG Boden (1994); > 17 % organic carbon mass, Green et al. (1993)) and the A horizon.
- Identification of the different organic horizons (see key).
- Determination of the thickness of the organic horizons as well as the A horizon.
- Determination of the structure of the A horizon (Chapter 2.2.6).

Key

Organic horizons			Description
Green et al. (1993)	AG Boden (1994)	Soil Surv. Staff (2003)	
L	L	Oi	Relatively fresh plant residues, not fragmented, usually discolored.
F	Of	Oe	Fragmented plant residues predominate over fine substances (< 70 Vol.-% organic fine substances, AG Boden 1994).
H	Oh	Oa	Organic fine substance predominate. Fragmented plant residues are generally not recognizable. The color is typically black.

L= Litter; **H**, **h**= humified; **F**, **f**= fermented; **i**= f**i**bric; **e**= h**e**mic; **a**= s**a**pric

- The small scale variability of the site conditions in high mountain ecosystems is responsible for a high spatial heterogeneity of humus forms. Thus, it is necessary to get an overview of this variability in order to create an adequate sampling design (cf. grid point sampling within a 20 x 20 m grid).
- The sedimentation of mineral material transported by wind or water (e. g. alpine loess, 'Flugsand') may modify the properties of organic horizons. Thus, the identification of organic horizons and the differentiation of organic layer from the mineral soil may be aggravated. In case of sedimentation of mineral material the term 'mineric' can be used in the classification of Green et al. (1993).
- In high mountain ecosystems humus forms which are influenced by erosion and/or human impact are very common. Especially at exposed sites or steep slopes erosion is very effective. Erosion may destroy only the upper horizons or the whole humus profile. Within an eroded area often residues of former humus profiles are common. Some of these humus forms are called 'Hagerhumusformen' according to AG Boden (1994).
- In the European Alps some terms of Kubiëna (1953) are still used: 'Tangelhumus' and 'Pechmoder'. Both humus forms are characterized by an organic layer which overlies solid limestone. They might be interpretated as special raw humus / mor or moder humus forms. 'Tangelhumus' occurs typically in subalpine coniferous forest and dwarf shrub ecosystems. Commonly 'Pechmoder' is found under alpine plant communities.

2.4 Soil Sampling

- Especially in mountain ecosystems soil sampling should be done very carefully because of the high spatial heterogeneity.
- Figure 8 shows different sampling strategies. The kind of sampling depends on the aim of the study.
    - Catena: A sequence of soils of about the same age, derived from similar parent material, and occurring under similar climatic conditions but having different characteristics due to variation in relief and drainage (SSSA 1997).
    - Transect
    - Composite depth sampling

2.4.1 Sampling of Soil Horizons

- Composite mixed samples
  - Each horizon has to be sampled separately.
  - Composite samples
  - The rock fragment content can be determined by sieving (2 mm) and weighing in the field (Mosimann 1985).
- Undisturbed sampling

  Core samples with steel cylinders (size usually 100 cm^3)

  Sampling horizontally or vertically possible

2.4.2 Stratified Sampling for Composite Samples

- Composite depth sampling
  - The sample site should be subdivided into parts which are as homogeneous as possible. The dominant vegetation type and/or microtopography can be used for subdivisions (figure 8).
  - number of samples of each component: suggestion 20 (randomly distributed)
  - replicates in the field: suggestion 3
  - Do not mix major horizons. If an organic layer exists, sample it separately.

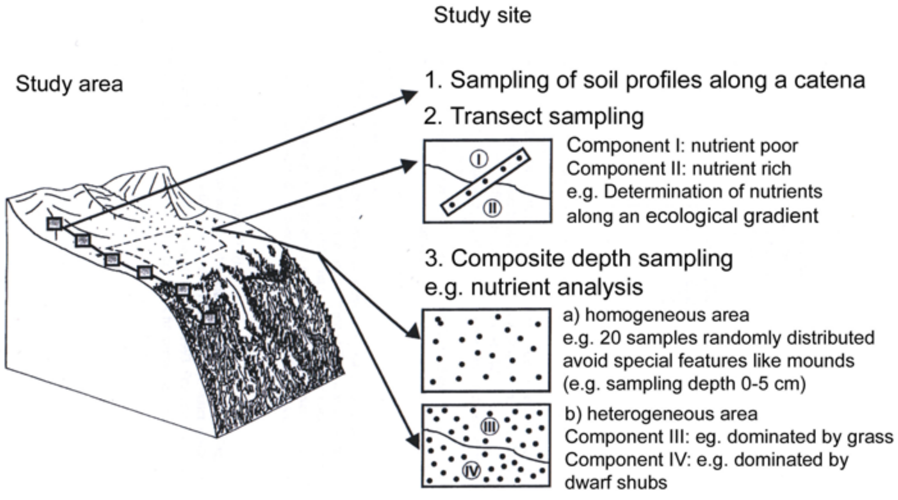


Figure 8 Sampling strategies