Impacts of Land Management on Soil Formation and Soil Degradation during Middle and Late Holocene in Schleswig – Holstein (Germany)

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Summary

The investigation of natural and human-induced soil degradation are important subjects in terrestrial ecosystem research. They involve several branches of the science. In order to study natural and human-induced soil degradation, it is necessary to use inter- and multidisciplinary approaches with respect to temporal and spatial landscape changes. Soils and sediments are geoindicators which preserve important information about the long-term human impact on the environment.

Colluvial sediments are indirect human-made parent materials. They reflect internal and external aspects of long-term soil degradation. Land-use systems determine long-term human-induced soil degradation and soil formation since the beginning of agriculture.

In order to answer several questions such as when intensive human-induced soil degradation started in Schleswig-Holstein, how soil degradation developed and what the responses of soils and sediments were to land-use changes, It was hypothesized that intensive human activities during middle and late Holocene were responsible for the modification of soils and sediments and also for the acceleration of soil degradation. An integrative assessment method was thus developed and testified.

The results of the investigation of colluvial sediments and soils in three research areas in Schleswig-Holstein (Germany) with a high resolution in space and time can be summarized as follows:

- Properties of soils and sediments vary intensively from Mesolithic until Modern times.
- Intensive soil formation took place in the colluvial layers during periods of geomorphodynamic stability in a dense woodland.
- Transport of clay minerals and leaching of soluble material as important soil formation processes were identified in the investigation areas.
- Inappropriate land-use management caused the podsolization of Cambisols and Luvisols which had developed in colluvial layers before.
- Man-induced soil formation (degradation e.g. due to podsolization), soil erosion and sedimentation (removal of the nutrients in the topsoil by erosion) modified soil fertility and soil quality often strongly.
- Land-use systems have usually accelerated, changed or prevented the specific natural processes of soil formation.
- Soil age information together with geomorphological data, physical, chemical and biological soil properties provide the database which is necessary to study the types and rates of soil formation in colluvial layers.
- Recent soil conditions are the result e.g. of the decision-making of farmers in the past. The decision-making modified soil formation processes and increased chemical, physical and biological soil degradation.

In conclusion, it could be emphasized that the impact of human activities on soils is unavoidable; in many cases negative effects will be multiplied by land mismanagement. The study of the effects of the past and current land-use changes enable the identification of the best solution to control soil degradation. A good knowledge from the past and about current soil degradation helps to identify a successful strategy against unwanted soil changes in order to achieve a sustainable management of the soils in the future.

Zusammenfassung

Die Untersuchung der natürlichen und der von Menschen ermöglichten Bodendegradierung sind wichtige Elemente der Ökosystemforschung. Sie betreffen zahlreiche Disziplinen. Das Studium natürlicher und von Menschen ermöglichter Bodendegradation erfordert den Einsatz inter- und multidisziplinärer Ansätze, die räumliche und zeitliche Dynamik von Landschaften beschreiben. Böden und kolluviale Sedimente sind Geoindikatoren, die wichtige Informationen über den Einfluss von Menschen in der Vergangenheit enthalten. Sie stehen im Fokus dieser Arbeit.

Kolluvien sind Ausgangsgesteine der Bodenbildung, deren Entstehung von Menschen indirekt ermöglicht wurde. Sie beinhalten interne und externe Aspekte der langfristigen Bodendegradierung. Die agrarische Landnutzung bestimmt seit dem Neolithikum wesentlich die Art und das Ausmaß der langfristigen, von Menschen ermöglichten Bodendegradierung.

Wann begann die von Menschen verursachte Bodendegradation in Schleswig-Holstein? Wie entwickelte sich die Bodendegradation seitdem? Wie reagierten Böden und Sedimente auf Landnutzungsänderungen? Als These wird formuliert, dass die intensiven Aktivitäten von Menschen während des mittleren und des jüngeren Holozäns verantwortlich sind für die Veränderung der Böden und Sedimente sowie auch für die Zunahme der Bodendegradation in Schleswig-Holstein. Zur Prüfung wurde eine integrative Untersuchungsmethode entwickelt und getestet. Die Resultate der Untersuchungen von Kolluvien und Böden in drei schleswig-holsteinischen Untersuchungsgebieten in hoher räumlicher und zeitlicher Auflösung können wiefolgt zusammengefaßt werden:

- Die Eigenschaften von Böden und Sedimenten haben sich vom Mesolithikum bis heute stark verändert.
- Intensive Bodenentwicklung vollzog sich in Kolluvien im Verlauf von Phasen mit geomorphodynamischer Stabilität unter dichtem Wald.
- Der Transport von Tonmineralen und die Auswaschung von wasserlöslichen Stoffen sind wichtige Bodenbildungsprozesse, die in den Untersuchungsgebieten nachgewiesen werden konnten.
- Ein nicht angepaßtes Landnutzungsmanagement verursachte die Podsolierung von Cambisolen und Luvisolen, die sich zuvor in Kolluvien entwickelt hatten.
- Die von Menschen beeinflußte Bodenbildung (Degradierung, u.a. durch Podsolierung), die Bodenerosion und Sedimentation (Abtransport von Nährstoffen im Oberboden durch Bodenerosion) veränderten die Bodenfruchtbarkeit und die Bodenqualität oftmals stark.
- Der Einsatz von Landnutzungssystemen hat zumeist die spezifischen natürlichen Bodenbildungsprozesse verstärkt, verändert oder gar verhindert.
- Informationen zum Alter von Böden zusammen mit geomorphologischen Daten, physikalischen, chemischen und biologischen Bodendaten bilden die Basis für ein Studium der Typen und Raten der Bodenbildung in Kolluvien.
- Der heutige Bodenzustand ist das Ergebnis u.a. der Entscheidungen von Landnutzern in der Vergangenheit. Diese Entscheidungen haben oft die Art und Intensität der Bodenbildungsprozesse verändert und die chemische, physikalische und biotische Bodendegradation erhöht.

Schlußfolgernd ist zunächst festzustellen, dass die Wirkungen menschlichen Handelns auf die Böden unvermeidbar ist. Oft wurden die negativen Effekte verstärkt durch ein Mismanagement des Landes. Die Untersuchung der Wirkungen von Landnutzungssystemen und Landnutzungswandel ermöglichen eine Identifizierung der geeigneten Maßnahmen, um die Bodendegradation zu kontrollieren. Gute Kenntnisse über die Bodendegradation in der Vergangenheit und heute helfen wesentlich, erfolgreiche Strategien gegen unerwünschte Bodenveränderungen und für ein nachhaltiges Management der Böden in der Zukunft zu identifizieren.

Chapter 1
Introduction

1.1. Soil Degradation Research

Soils are most important in many ecosystems as dynamic natural body and fundamental resource. Human activities often influence the natural processes in soils. According to Head (2008) humans are inextricably embedded in all earth surface processes, and often dominate them. The negative effects of humans on soils are understood and described as human-induced soil degradation. Soil degradation is a serious problem and an important environmental issue in many ecosystems. One of the most critical natural resource management needs of the 21st century is information about the dynamic nature of soils, or simply, soil changes (Tugel et al., 2005). Understanding and considering the human impact on soils is indispensable to predict soil degradation processes because a detailed knowledge of the functions of soils is necessary for human survival and human activities. In the past soil formation and soil degradation processes caused a high variety of soil and degradation types in the world with characteristics changing in time. Changes in time on the one hand and human activities (social and economical development) on the other hand created an imbalance in the relationship between humans and soils which has had significant effects on soil ecosystems. According to Vitousek et al., (1997) between one-third and one-half of the land surface of the world has been transformed by human activities. The long-term transformation of landscapes by human activities such as cultivation, deforestation, overgrazing, and conversion of rangeland have caused a decline in the physical, chemical, and biological quality of the soil resources in the world (Doran et al. 1998; Chew, 2001). These phenomena have consequently increased erosion and sediment yield, which both are generally the result of soil degradation processes and land deterioration (e.g. Van Andel et al., 1990; Lang et al., 2003; Hoffmann et al., 2007).

Soil degradation by human activity has started in Germany in the Neolithic period. Deforestation and then intensive and extensive agricultural practices enabled:

- the detachment, the transport and the deposition of soil particles by heavy rainfall or by high wind velocities (soil erosion by water and wind)
- acidification in sandy soils (decalcification, transport of clay minerals, eluviation of ions and water soluble organic substances)
- compaction of soil horizons (namely since the 1950s by machinery)
- higher infiltration rates and thus waterlogging namely on concave slope elements and in valley bottoms (Bork, 1989 a,b; Bork et al., 1998; Bork et al., 2003; Lang et al., 2003; Reiss et al., 2006).

The relationship between humans and soil is long and very complex. Soil fertility was the basis of human life. The increase in population density combined with new agricultural techniques caused the first significant human impact on the landscape – in some German landscapes with very fertile soils during Neolithic age, in others during Bronze and Iron ages or in some hilly regions during Medieval Times (Bork and Lang, 2003). Animal husbandry and the related grazing management led to intensive human interference in the natural vegetation and farming to the removal of woodland. These early human activities on soil led to soil degradation at many sites in Germany. The type and the intensity of soil degradation was determined by the types of land-use systems, by topography, soil and climatic characteristics.

Sheet erosion was common on agriculturally used slopes. The soil material that was eroded on namely steep slopes was deposited on concave downslope areas or on the adjacent valley bottom in colluvial layers. Gully erosion was caused at times by heavy rainfall on agriculturally used sites without a sufficient protection by natural plants. Fans in which most of the material was deposited that was eroded before in gullies developed just below the gully systems.

Thus the continuation of intensive human activities combined with natural processes such as heavy rainfall and storms changed the shape of landscape normally after long periods, in some exceptions (e.g. 1000-year events) abruptly. New or modified land forms were resulted. Fertile soils were often eroded totally on steep slopes or buried beneath colluvial layers. Today it is commonly agreed that agricultural activities are responsible for soil degradation (Blaikie and Brookfield, 1987; Tugel et al., 2005). Most of the soil erosion of the past 7,000 years in central Europe occurred during Late Medieval and Modern Times (Bork et al., 1998).

Today it is realized that colluvial sediments are one of the most important geoarchives to study the different aspects of historical soil degradation but this evidence has rarely been recognized. In order to study past and recent soil degradation, two types of research can be differentiated. One research branch uses several models to describe the amount of soil degradation and / or soil degradation processes. Others are used to predict the amount of soil degradation and also to recommend best land-use practices (e.g. Boardman and Favis-Mortlock, 1998; Schmidt, 2000; Morgan, 2005). One of the most relevant gaps in soil degradation research is still our lack of knowledge about soil degradation processes and the development of soil degradation forms in time. For example, heavy rainfall erodes soil aggregates. But up til now no mechanistic model exists which describes the change of the size and of the form of a soil aggregate during its transport in overland flow. Without this knowledge and additional information the amount of soil erosion can not be predicted precisely. Short term measurements of the amount of soil erosion (for a few years only) e.g. on small plots with sizes of a some square meters or a few hundreds of square meters can not be used on the one hand for long term predictions and on the other hand for larger areas such as slopes or water catchments.

Thus – additionally – another type of research is needed to understand recent land forms, recent soil erosion processes, to analyze possible future developments of soils in landscapes and to recommend appropriate land-use systems (interdisciplinary studies of past soil degradation processes and the resulting forms). Without those studies the human impact on the landscape can not be quantified.

Since the 1970s a considerable amount of research devoted to understand and interprete human-induced soil degradation in long periods has been carried out (e.g. Machann and Semmel, 1970; Hard, 1976; Bork and Rohdenburg, 1979; Bork, 1983; Abraham de Vazquez et al., 1985; Bork et al., 1998; Bork et al., 2003; Lang et al., 2003; Bork, 2006). Recently the system of four-dimensional landscape analysis (identification of key catchments and geoarchives, detailed filed investigations, sampling and dating, formulation of stratigraphy) has been developed to investigation past soil degradation and its causes in detail.

Research by Bork et al. (1998, 2003) indicates that during Neolithic Age man had a significant local effect on the vegetation in some German landscapes and thus on soil erosion at some sites. Widespread and more intensive soil erosion was reconstructed for the late Bronze Age, the Iron Age and Roman Times. Maximal rates occurred in the Middle Ages (namely during the 14th century).

Without integrative, interdisciplinary and historical approaches, the effects of early land-use changes are difficult to understand. Bork (2006) argued that – using the four-dimensional landscape analysis – in many cases not only questions about historical human-induced soil degradation can be answered but that this new methodology enables qualitative and quantitative studies of different aspects of land degradation, too. In order to explain the results of this approach some examples are outlined as follows.

Based on the stratigraphical, pedological, sedimentological and historical methods mentioned above Bork et al. (2003) and Lang et al. (2003) have carried out research in Germany. Special attention was given to a quantification, analysis and evaluation of soil erosion, which occurred during the Middle Age and Modern Times, and their causes, too. Erosion enabled by agricultural activities removed most Holocene soils and changed the natural landscape significantly. They proved that soil erosion and deposition are not new processes in our environment but that humans played a dominate role in driving these processes already centuries and thousands of years ago.

Comparable episodes of erosion and colluviation associated with prehistoric and historic woodland clearance and farming activities have been noted in many regions on all continents (Bork, 2006). Moreover several researchers confirm intensive human interference in environment for different areas in prehistorical and historical times (e.g. Harvey and Renwick, 1987; Schirmer, 1988; Starkel, 1988, 1998; Macklin et al., 1991 Rommens, et al., 2005; Vanwalleghem et al., 2005; Dreibrodt and Bork, 2005; Mieth and Bork, 2005; Reiss et al., 2006; Schmitt et al., 2006; McNiven, 2008).

Human activities in addition to external effects (such as soil erosion and colluviation) on soil have internal effects. An internal effects of human activity on soil is presented in the modification of soil formation processes. Soil formation (soil genesis, soil development) is the result of changes of soil properties in time. As a result of soil formation e.g. the content of one grain size fraction in a certain soil horizon decreases or increases, sediment layering disappears etc. These changes are very slow normally, and often can be seen only after centuries or millenia. So most soil properties that change during soil formation are relatively stable. Sometimes, however, effects of human activity on soil formation (such as management practices in agriculture, ferilisation) can be seen within hours, days, weeks or months. Most rapid processes are cyclic, however, and not are considered as soil formation processes (Van Breemen and Buurman, 1998; Cunningham et. al., 2001). When we study natural vegetation dynamics and soil interactions a good general understanding of soil formation processes and the resulting structures and soil properties is necessary because a detailed study of soil formation is a promising way to find trends in soil development (e.g. Gile and Hawley, 1966; Walker and Green, 1976; Holliday, 1988; Vanstone, 1991; Alexandrovskiy, 2000; Terhorst, 2000; Osok and Doyle, 2004; Kühn and Hilgers, 2005; Phillips, et al., 2008). But the effects of prehistorical and historical land-use changes on soil formation namely in colluvial sediments has been rarely investigated.

In order to study soil formation in late Holocene soils, Holliday (1988) analyzed buried and unburied soils which formed in comparable parent materials and topographic positions under uniform vegetation and in a basically uniform climate. He combined field and laboratory data with geochronological information (radiocarbon and archeological dates). He found that time is a significant factor to explain the variation in late Holocene soils formed under otherwise similar conditions.

Kühn and Hilgers (2005) studied soil formation in late Holocene sediment located in southern Taunus Foreland, Germany, using luminescence dating and micro morphology. They found that in the oldest colluvial sediments a Chernozem with degradation features (clay illuviation) was formed from the Boreal to the Atlantic Ages. These results are in good accordance with the general pedogenetic concept of Boreal Chernozem formation and its degradation with the beginning of the Atlantic period (Zakosek, 1962). The micromorphological and geochronological research of Kühn and Hilgers (2005) proves alternating sedimentation and soil formation phases.

According to several investigations like the ones mentioned above, the study of middle and late Holocene colluvial sediments allows to identify the processes which were responsible for past soil degradation and soil formation. They also confirm that soil degradation is not a new problem which we face today. It has occurred during a long time as a result of the mis-management of natural resources and of the intensification of cultivation in many areas. Furthermore researchers stress that there are many questions about the relationship between past soil degradation and soil formation on the one hand and human activities on the other. In order to answer these questions, research with a high resolution in time and space and in different areas is important and necessary.

1.2. Research Questions, Aims and Hypotheses

This thesis investigates the reaction of soils which developed in colluvial sediments to land-use changes in different periods in northern Germany. The research was carried out for small catchments near Albersdorf, Hof Ritzerau and near Lake Belau in Schleswig-Holstein, Germany. These areas represent long-term soil degradation and soil formation regarding land use changes. This work deals fundamentally with questions that relate to the soil formation and to soil degradation processes in response to long-term, short-term or current land-use changes. The relevant and important questions are as follows:

- ►What have been the roles of human for soil degradation processes in the long-term?
- ►What are the impacts of prehistorical and historical land-use changes on soil formation?
- ►What have been the responses of soil quality and quantity to land-use changes in the long-term?
- ►Has soil degradation caused a significant change in landscape development in a long period?

Through this study we hope to better understand past land-use changes and their effects. In order to answer questions, the aims are outlined below.

► The study of long-term human-induced soil degradation with high resolution in space and time.

► The use of environmental archives in order to create useful information for the interpretation and assessment of prehistorical and historical soil degradation.

► The use of an inter- and multidisciplinary approach as an useful method to reconstruct prehistorical and historical landscape changes and environmental events.

To pursuit these aims, hypotheses will be tested:

► Land-use changes and land management accelerate natural soil degradation; they have an important effect on soil formation.

► Changes in the rates of erosion and colluvial accumulation over a long period could be attributed to changes in land use and other agricultural activities.

► Long-term human-induced on soils have caused a significant effect on landscape development and on natural resource productivity.

Chapter 2
Effects of Land-Use Changes on Soil Degradation

2.1. Introduction

This chapter outlines the conceptual and theoretical context of this study. In its first section, natural and anthropogenic soil degradation and their consequences are described. In the second section inter- and multidisciplinary approaches to study soil degradation are discussed; then – based on this ideas – a general methodology is presented. Third section switches from the historical overview to a more detailed description of specific case studies in northern Germany.

2.2. Natural and Anthropogenic Soil Degradation

According to FAO (1993) soil degradation is the sum of geological, climatic, biological and human factors which lead to the degradation of the physical, chemical and biological potential of soil, and which endanger biodiversity and the survival of human communities. Lal (1997) stresses that land degradation leads to a decline in soil quality with a continuing reduction of productivity and a decline in water and air quality. In many cases the loss of soil productivity is caused by overgrazing, deforestation, inappropriate agricultural practices and other man-induced activities.

Recent investigations of prehistorical and historical land-use changes have proven that there are significant interactions between long-term human activities and the environment (e.g. Bork, 2006). In order to answer several questions about the current status of the environment it is necessary to refer to the past because knowledge of the past is a key for the understanding of the present and also of the future landscape developmements. Lang and Bork (2006) stress that research on the past is important to provide long-term monitoring of soil and landscape changes. They also stressed that a historical approach to analyze the effects of human activities on the environment and on soil degradation is important to unravel background or pre-human impact conditions, to extend the temporal coverage of observation, to provide historical analogues for present processes, and give a data base for a time series for developing and testing predictive models. As a result it is necessary to look at the historical development of the human environment and at important aspects of human practices with regard to the culture, the economy and social ranks, during different times (e.g. Neolithic, Bronze and Iron Ages, etc.).

Many soils tend to degradate as a result of natural processes. The natural degradation of soils is usually modified by human interferences. Both humans and the natural environment can promote or prevent processes of soil degradation.

Over time land-use changes due to human activities have caused fundamental changes in landscapes. These changes lead to further human responses based on a variety of inputs, intensification and abandonment (Oldeman et al., 1991). Factors such as climate, politics and markets (economic and sociopolitical drivers) indirectly affect humans' decision-making and thus the use of the environment (Shaxson, 1998). Results of this process are shown in Figure 2.1. According to this figure there are two driving forces in both natural and human environments which are affected by human activities. These changes in activities have caused changes of land-use systems and after a complex process they ultimately appeared to have a strong effect on soils.

Anthropogenic and natural soil degradation processes can be divided in two categories. The first is the displacement of soil particles by runoff or wind which can cause soil degradation. This process not only reduces soil fertility (on-site effect) but it has also great effects on off-site areas (e.g. Schmidt, 2000; Riksen and Graaff, 2001; Toy et al., 2002; Strunk, 2003; Rekolainen et al., 2006; McCoy and Hartshorn, 2007). The second category concerns long-term internal degradation due to chemical and physical weathering and also the downward displacement (eluviation and illuviation) of fine particles in soil horizons (Duchaufour, 1982; Henningsen, 1994; Bouma, 1997; Birkeland. 1999; Kühn, 2003; Kanev and Mokiev, 2008). In order to predict the effects of management on soil functions, to compare alternatives, and to make decisions, it is necessary to have more information about soil changes caused by anthropogenic and non anthropogenic factors (Tugel et al., 2005). Principal types of soil degradation are presented in figure 2.2.

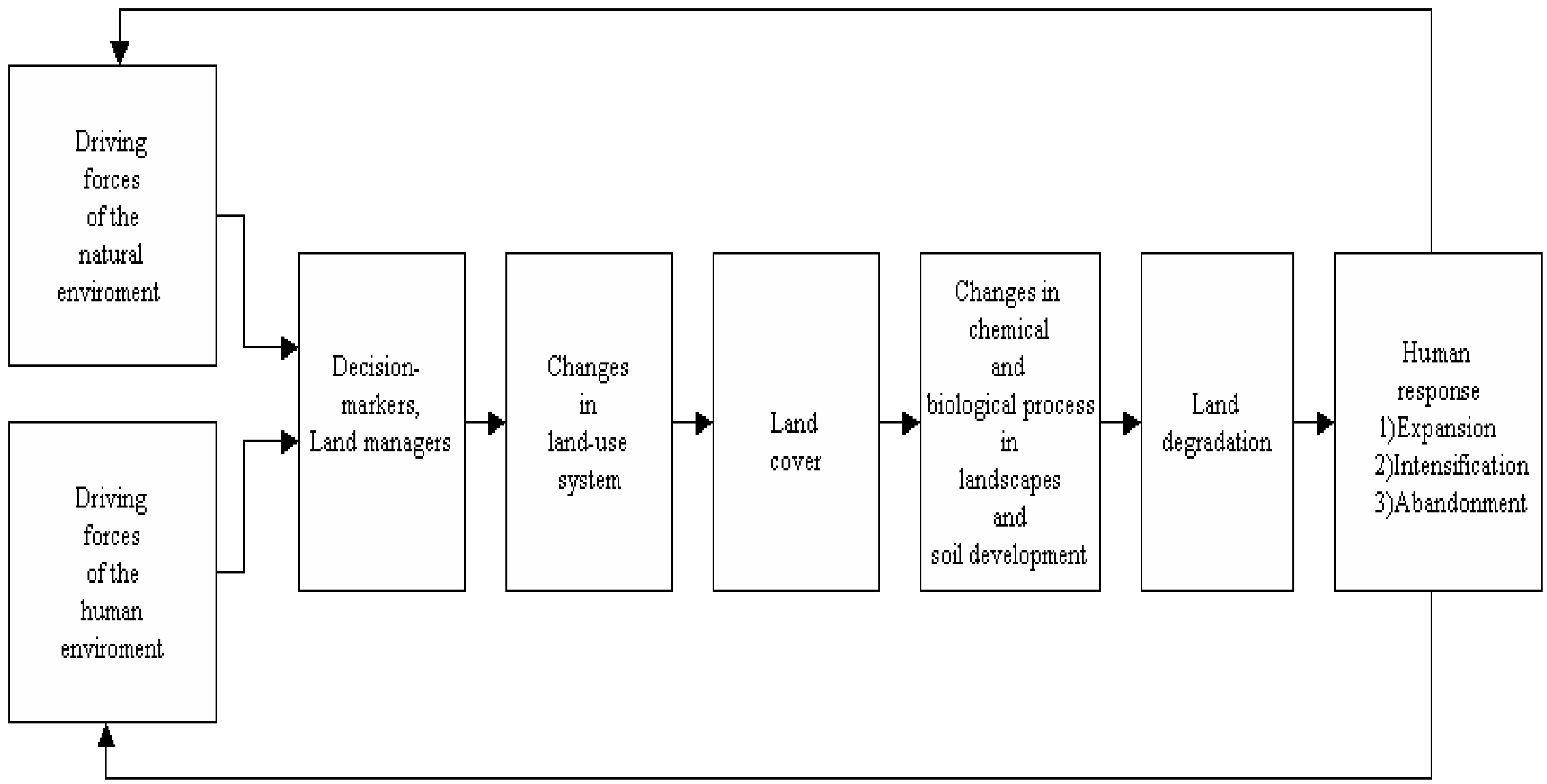


Fig.2.1 Framework for interpreting transformations of the natural environment (modified after Redman, 1999)

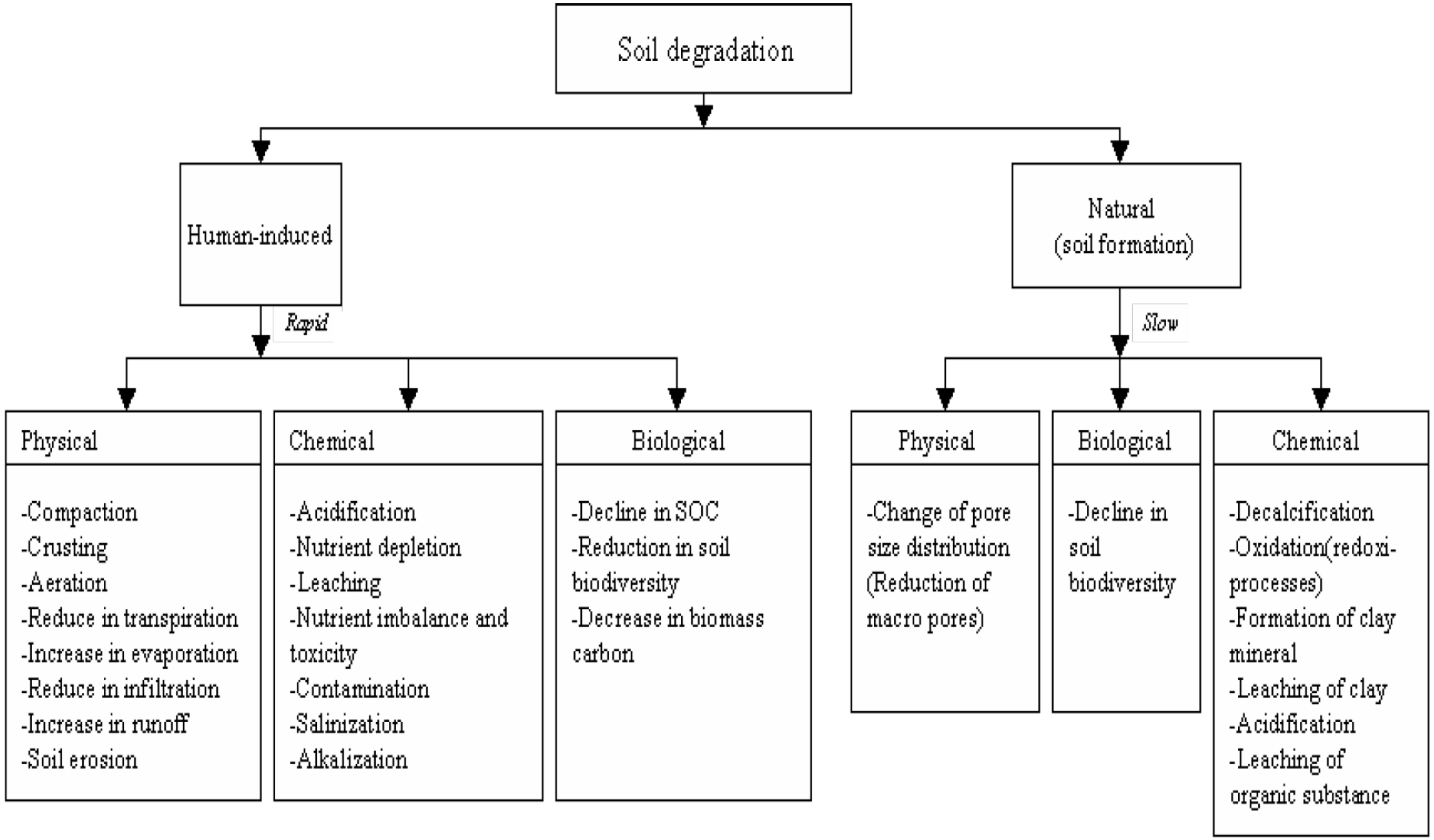


Fig. 2.2. Principal types of the natural and human-induced soil degradation (modified after Lal et al., 1997)

2.3. Relationship between Land use Changes and Soil Degradation

In this section land use and land cover are defined. Both terms are often used synonymously but actually they have different meanings and definitions.

Land use is the way and the purpose for which humans employ the land and its resources. Land cover refers to the habitat or vegetation type such as forest, agriculture, and grassland. Although land use and land cover are related, there is a slight difference between these terms. For example, an area of forest cover may be considered as different land use, including logging, or recreation (Turner et al., 2001).

Soil degradation occurs when soil cannot perform one or several of its functions. Bastian and Steinhardt (2002) argue that soil is a conversion product of the mineral and the organic substance mixed with water, air and organisms which has formed under the influence of environment conditions. Soil forming factors are parent material, climate, relief, life forms (especially soil organisms and plants), and human practices. Often with the first change of the land cover by humans in a region soil degradation started. At the beginning, this process has resulted in a significant reduction of the soil buffering capacity and its resilience, particularly through the decrease in soil organic matter content. For example in many areas of Europe, soil is being degraded as a result of pressures coming from nearly all economic sectors. Among the most important influences on the quality of the soil are the cultivation systems used in agriculture (Bogaard, 2004). The loss of organic matter, soil biodiversity and consequently soil fertility are often driven by nonsustainable practices such as deep plowing on fragile soils and cultivation of erosion-facilitating crops and the continuous use of heavy machinery which destroys soil structure through compaction (German Advisory Council on Global Challenge, 1994; EEA, 1999; Gieska et al., 2003).

Cultivation practices generally mix the soil and homogenise the upper soil horizon; therefore soil structure has changed and the original humus types are difficult to recognise (in profile descriptions this layer is referred to as an Ap horizon). An indirect effect of human activities is the degradation of vegetation which is the result of long and intensive land-use practices, particularly with regard to forests, such as excessive clearing, grazing, fire, collection of litter etc. Those activities have significant effects on natural vegetation throughout history. These practices disturb the biogeochemical cycle and cause the original vegetation to be replaced by different secondary vegetation (Duchaufour, 1982; Rodriguez, 2005). A schematic presentation about the effects of land-use changes on landscapes is presented below.

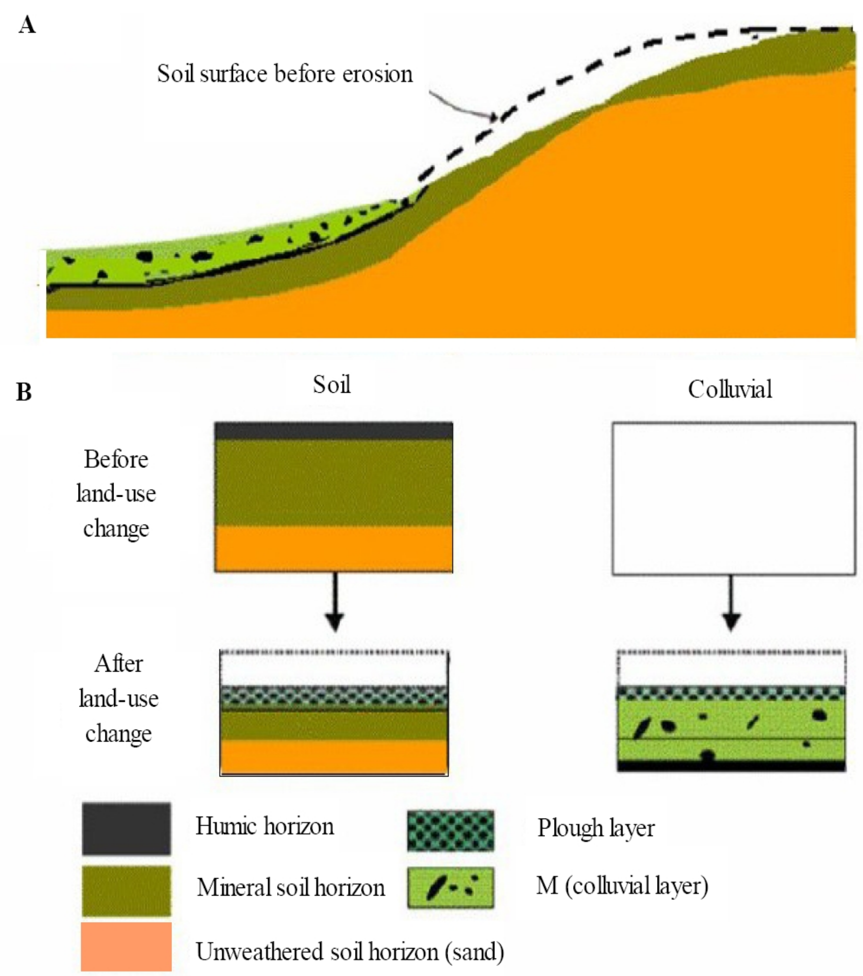


Fig. 2.3: Schematic presentation of land-use/land-cover changes, (A) Two dimensional representation of a late Holocene landform change. Soil has been eroded from upper slope areas, and redeposited as colluvial sediments in lower parts. (B) Schematic representation of the change of storage, comprised of two sediment storage units (Modified after Preston, 2001).

2.4. Soil Degradation and its Consequences

The most important consequences of soil degradation are the loss of soil quality and of soil productivity. Soil quality is defined as: the "capacity of the soil to function, within the ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran and Parkin, 1994; Wang and Gong, 1998). The sustainability of the ecosystem can be evaluated if ecosystem processes are well understood (Nael et.al., 2004). Therefore, soil quality is one of the most important indicators to determine soil degradation processes; soil quality should be monitored in different land-use systems and ecosystems.

Degradation of a soil can occur suddenly and directly as a result of management practices or slowly and indirectly by land-cover changes. These changes are responsible for a modification of the type and content of humus and also the acceleration of different aspects of weathering in soils. Hence a new kind of soil formation can take place (Pallmann et al., 1949; Van Breemen and Buurman, 1998). With these processes not only soil quality changes but also soils are ready for degradation. For instance the processes of soil degradation following land-use/land-cover changes – especially deforestation – can cause the formation of quite different soil types. Deforestation may cause the raise of water tables and poor drainage conditions which may led to the development of peat bogs. These conditions have negative effects on soil quality and natural resource productivity. Lal et al. (2003) stressed that there is a strong correlation between soil quality and soil erosion; i.e., soil quality affects the rate of soil erosion and soil erosion affects the quality of soil.

Soil erosion is an extreme form of soil degradation (Morgan, 1986). Soil erosion is a three-phase process, including:

- The detachment of individual soil particles from the soil mass,
- their transport by an erosive agent such as runoff and wind and
- the deposition of the soil particles namely at a concave downslope area (as colluvial layer) or in the valley bottom (as alluvial layer) (Morgan, 2005).

According to the Technical Note of U.S Natural Resources Conservation Service (1998) soil erosion reduces soil productivity often below an agrotechnical value named soil loss tolerance. McCormack et al. (1981) found that considerable loss in productivity occurs on most soils if they erode for several centuries.

Long-term soil erosion changes the form and the characteristics of a landscape through the transportation of huge soil masses from up land to low land areas. According to Beyer et al (1993) in Schleswig-Holstein (northern Germany) more than 50% of the original soils have been altered by erosion, because the characteristics of erodic and colluvic soils differ significantly from those of the original soils (Lamp, 1985; Blume, 1986). Consequences of soil erosion on soil productivity are exacerbated in landscapes with steep slopes where the potential for soil erosion is largely the result of the specific topography (El-Swaify, 1997). Soil erosion does not only cause appreciable differences in soil quality and productivity (Frye et al, 1982; Poudel et al, 1999); erosion also decreases the depth of soils on steep slope segments and reduces the intensity of soil development in this areas. In addition fertile soils are buried in the concave lower parts of slopes.

With respect to sediment as an environmental archive a lot of information about the nature of past geomorphological processes and events can be reconstructed. A schematic figure about long term soil erosion and the formation of colluvial layers in different historical periods is represented in figure 2.4.

As a result, the main consequences of soil degradation are summarized as follows:

- Loss of soil organic matter: decline in soil fertility and soil productivity
- Disturbance of soil structure: erosion process, increased runoff, excessive flooding and replacement of soil material.
- Adverse changes in acidity, salinity and alkalinity: loss of soil biodiversity
- Disappearance of climax vegetation and animal habitats: the appearance of invader species
- Changes on the hydrologic regime: reduction of infiltration and decrease of the water-holding capacity

- Effects of toxic chemicals: pollutants and influence on environmental health
- Economic, social and political effects : poverty and migration

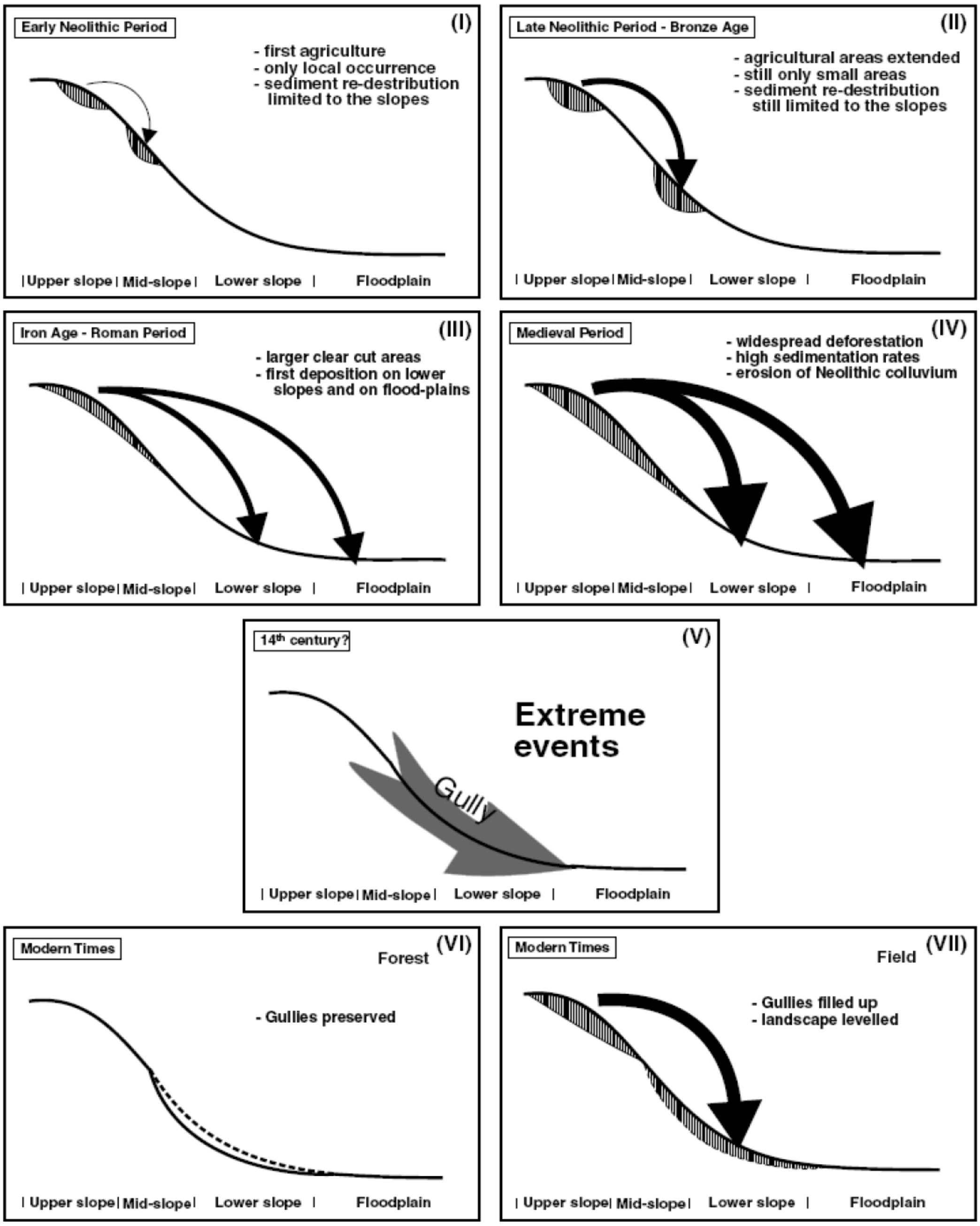


Fig .2.4. Conceptual model of changes in slope-channel coupling during the period of agriculture in central Europe (Lang et al., 2003).

2.5. Research on Past Soil Degradation in Germany

The discussion in this part switches from the historical overview of introduction to specific case studies in Germany. The dynamics of land use and soil erosion since early Medieval Times in Germany are summarized in Figure 2.5.

Two periods of extraordinary intensive soil erosion attract attention (Bork and Bork 1987, Bork 1983, 1986, 1989 a, b): Catastrophic gullying and extensive sheet erosion occurred during the first half of the 14th century; Striking are the effects of an extremely heavy rainfall from July 19th until July 25th, 1342. Huge gully systems cut into agriculturally used slopes. Shallow and fertile soils were eroded totally on the fields of the hilly regions of central Europe. As a result previously fertile land was abandoned and reverted to woodland or grassland. During the second half of the 14th century, during the 15th and 16th centuries most gullies were filled as a result of numerous local thunderstorms with runoff and slight erosion on the neighboring slopes. A second phase of gully erosion also attributed to heavy rainfall occurred in the 18th century. This phase of gully erosion was mitigateds by erosion prevention measures and was not as extreme as the earlier episode. Bork (1989a) has calculated a mass balance that demonstrates that 65% of total late Holocene (~1,500 years) soil loss occurred in these two gullying episodes and that approximately half of this was associated with the 14th century episode.

According to a case study about changes in the long-term sediment flux and storage within the Rhine river catchment, Lang et al. (2003) suggested that changes in the fluvial system during the Holocene seem to be dominated by a changing human impact. Clearing of woodland and agricultural activities made the drainage basin susceptible to soil erosion by water and wind. These changes modified the water balance and increased runoff production. River dynamics changed dramatically due to the high supply of fine sediment mobilized by soil erosion.

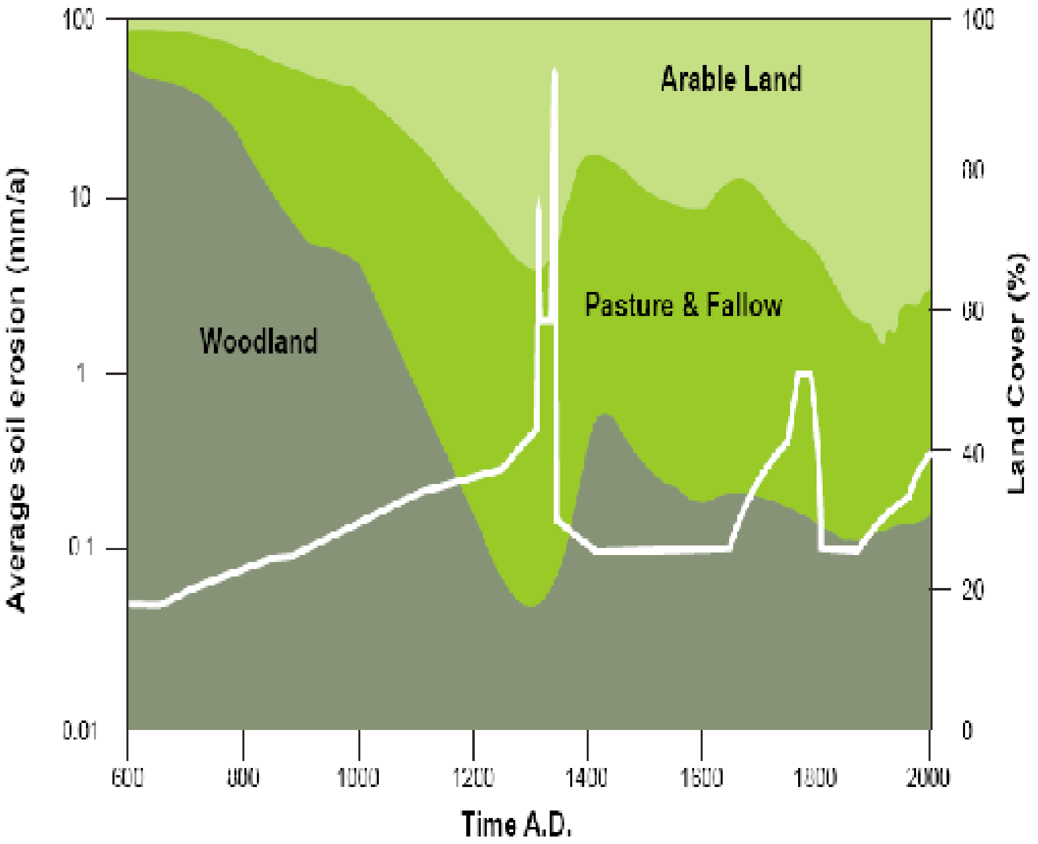


Figure 2.5. Long-term land cover changes and soil erosion (white line) in Germany (except for the Alps) since the Early Middle Ages (adapted from Bork et al. (1998)). Average soil erosion in Germany (left axis) and the percentages of woodland, fallow land and arable land (right axis) are plotted on a calendar scale. Extreme rainfall events during the 14th century which coincided with high percentages of both intensive agricultural land use and land cover changes caused extreme soil erosion (Bork, 2006).

Based on detailed field studies, chemical soil analysis, dating methods of charcoal and pottery, as well as on written documents (cultural archives) Schmitt et al. (2003) quantified the human impact on soils during the late Holocene in a small catchment near the city of Bamberg in northern Bavaria, Germany. According to this study land use was a major cause of soil erosion, especially during the late Holocene. Morever the history of land-use changes after the 12th century showed that social and economic factors, such as war and financial support can lead to significant and rapid changes of land use. Past land use enabled intensive soil erosion which was caused by heavy rainfall events, such as the most intensive precipitation event and the largest flood recorded for central Europe in July 1342.

A study of historical soil erosion and landscape development was carried out by Dreibrodt and Bork (2005) in a small sub-catchment of Lake Belau, northern Germany. Soil erosion was intensive during the Neolithic period, the Pre-Roman Iron Age, the Early Medieval Times, and the Modern Times. During early Holocene until the middle Neolithic time and from the late Roman Ages until the early Medieval Times, the soil surface was stabilized under a dense woodland cover and intensive soil formation took place. The comparison of this results with lake sediment records shows that the allochthonous inputs into the lake are coinciding with the soil erosion phases mentioned.

In northern Bavaria, Germany, Enters et al. (2006) studied effects of long-term land-use changes on deposition and composition of organic matter in the Frickenhauser See. According to this investigation they found that the anthropogenic impact, namely forest clearing and subsequent agriculture, have had major effects in the depositional system. They also indicated that a direct consequence of medieval forest clearing and agriculture is a change in the relative input of organic matter sources documented by changing C/N ratios.

To reconstruct the landscape development and past erosion during the Holocene in the region of Albersdorf (Schleswig-Holstein, Germany), geoarchaeological, sedimentological and pedological investigations were carried out by Reiss et al. (2006). They demonstrated that interactions between human and environment caused significant changes of the soil properties since the Neolithic Age. The natural landscape was transformed to a cultural landscape. First, only small areas were cleared and used for agricultural practice. During the Middle Neolithic Age (since 5,300 BP) a large part of the landscape was transformed near the valley of the Gieselau near Albersdorf. An intensive erosion event enabled by human land use was caused by heavy rainfall during the End-Mesolithic period.

These studies prove that the processes of soil degradation are very complex and that they started with the beginning of agricultural land use. Only inter- and multi-disciplinary research can help to understand long-term human-induced soil degradation dynamics and forms with acceptable accuracy. Results from several local investigations which have high resolutions in time and space may help to understand developments in large catchments, from which often only general and summarizing data are available.

2.3.1. Inter- and Multidisciplinary Approaches

Multidisciplinary approaches integrate the results of multiple disciplines and methods. Different institutions and/or research groups are cooperating in an additive manner. An interdisciplinary research team defines the geosystem and the topics that have to be investigated at the beginning using integrative approaches. Then the system under investigation is subdivided and processed by individual research groups (Barrow, 2006).

According to these definitions integrated inter- and multidisciplinary approaches are necessary because they offer a perspective for efficient research and new results related to long-term soil degradation. Therefore in this study we have to apply a wide range of scientific approaches in order to assess and interpret our hypotheses. This approach involves the disciplines geomorphology, archaeology, paleo-hydrology, paleo-pedology, paleo-ecology, and (land use) history and geoindicators such as soil parameters, sediment characteristics and landform specifications with a special view on human activities and pressures (Fig. 2.5).

According to above several main disciplines are described as follows:

Based on Oxford Dictionary, archaeology is the study of human antiquities, especially of the prehistoric period and usually by excavation. Drewett (1999), however, sees archaeology as the science of extinct people or of past cultural phases through skeletal remains and objects of human workmanship found in the earth.

Most archaeologists agree that archaeology must have a material element (involving the study of the human past through its material remains; (Renfrew and Bahn, 1991), to solve the problems of other disciplines (Rouse, 1992) and should be studied with an interdisciplinary approach (Fraser and Haber, 1986). Archaeology's aim is to understand mankind, it is a humanistic endeavor (Renfrew and Bahan, 1991), therefore, deals with the past people, societies and cultures.

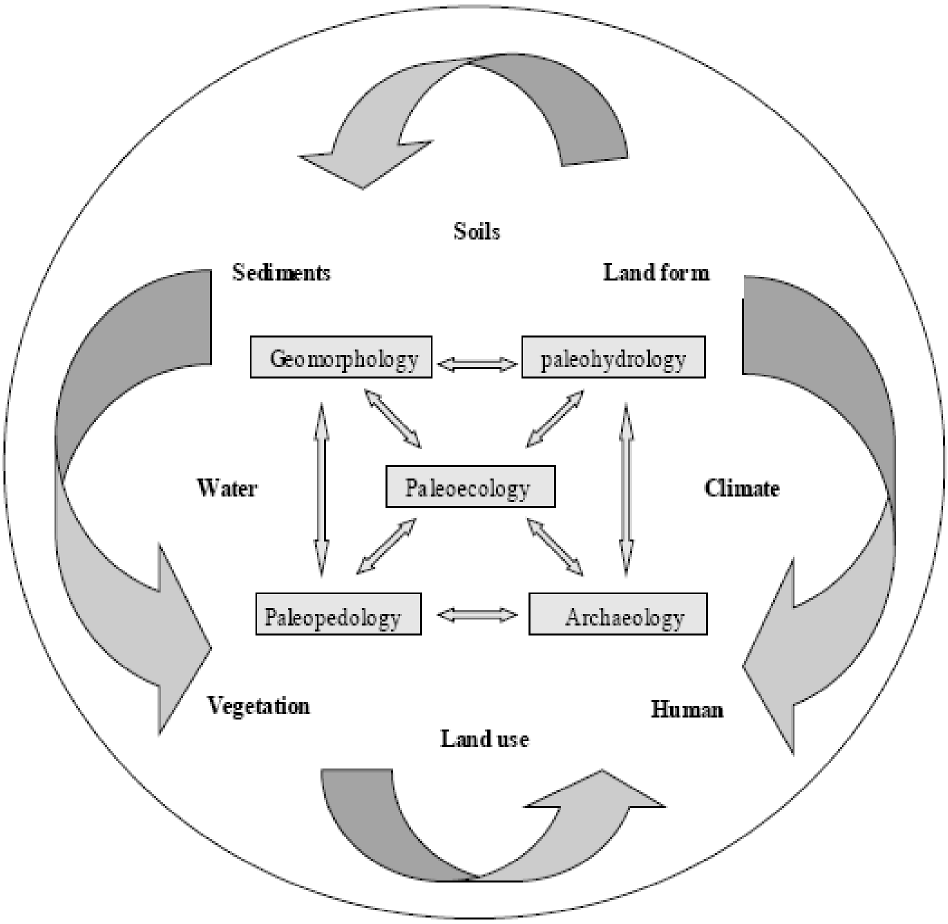


Fig. 2.5: schematic representation from an integrated interdisciplinary approach to study long-term soil degradation.

Archaeological investigations often begin with discovery of artefacts or other evidence of a past human occupation and then proceed to on-site studies that ultimately answer central questions: when the site was occupied, what occurred at the site, and what it tells about human activity. Therefore it is necessary to locate first landscapes and then there landscape elements where remains of the appropriate cultural period exist. Researchers first mine past archaeological (and geological) experiences and literature and then do field surveys. These findings of archaeology can be used as a basis for investigations of long-term landscape changes.

Pedology, the discipline for the study of soils, deals with

- the characterization of soil parameters and variables
- the classification of soils
- the formation of soils and
- physical, chemical and biological processes in soils.

An early approach to study soils was published by Jenny (1941, 1980). He described the primary factors affecting soil formation by the equation

$$S = f\,(cl;\ o;\ r;\ p;\ t, \ldots).$$

Soil (*S*) is a function of five state factors: (*cl*) climate, (*o*) organisms (biological activity), (*R*) relief (topography), (*p*) parent material, (*t*) time. The dots after *t* represent unspecified additional factors that might be important locally or even regionally (Birkeland, 1999). This was an attempt to explain the wide range in soil types and soil characteristics found throughout the world. This approach addressed the systematic variation in soil properties which is related to the five soil forming factors, in addition to random variation which could not be related to any specific cause (Wilding and Drees, 1983).

The physical, chemical and biological characteristics of soils, as determined in soil profiles, record past changes in the environment, e.g.:

- Iron and manganese oxides that accumulated due to redox processes (influenced by human activities, too).
- Charcoal fragments produced by forest fires and slash-and-burn.
- Pottery shards made by humans.

Soils analysis help to identify and to quantify soil formation processes. Pedology has several branches; one which investigates soil development and soil structures of past geological eras is paleo-pedology. For the understanding of long-term soil degradation, it is essential to integrate pedological, hydrolocial, ecological, gemorphological and archaeological methods.

Geomorphology is defined by Howell (1957) as the “systematic examination of landforms and their interpretation as records of geologic history.” Later, Ruhe (1975) defined geomorphology simply as the science of landforms. Furthermore Geomorphology is the study of landforms, including their origin and evolution, and the processes that shape them.

Geomorphologists seek to understand landform history and dynamics, and predict future changes through a combination of field observation, physical experiments, and numerical modeling. The discipline is practiced within geology, geodesy, geography, archaeology, and civil and environmental engineering.

Applied geomorphology is concerned not only with landforms but also with earth materials, denudational and weathering processes. Soils thus provide a key element in geomorphological investigation. Also soils represent the interaction between process of weathering and parent materials.

The removal and the accumulation of soil particles is a function of both time and the processes of denudation. They are therefore closely related to the geomorphological history of the site. For example, sand-textured soils with a granular structure may be directly related to their situation on an alluvial terrace. Sometime soils have been shown to vary with the age of the land surface on which they occur (Ruhe, 1956; Mulcahy, 1960). However, the soil can be thought as an indicator of geomorphological history (Cooke and Doornkamp, 1974).

Soils and sediments also are considered as geoindicators. Geoindicators are defined as magnitudes, frequencies, rates or trends of geological processes and phenomena that occur at or near the earth’s surface and that are significant for assessing environmental change over long periods (Berger and Iams, 1996). By including measures of past change, such as colluvial sediments, erosion and accumulation rates, geoindicators help us as a geological archive for monitoring of landscape changes.

An effective interdisciplinary approach to study soil degradation focuses on geo-morphology, paleo-hydology, paleo-ecology, paleo-pedology and archaeology as main disciplines.

Research methods which provide data with a high resolution in time and space enable conclusions and interpretations with a high precision and accuracy. Moreover a general and integrative methodology can provide facilities for assessment, understanding and anticipation of the results. In this case, a general interdisciplinary methodology is offered; it involves aspects of geomorphology, paleo-hydrology, paleo-ecology, paleo-pedology and archaeology. This methodology can be divided into three main groups: data sources, data analysis and scientific output, each one of them can be subdivided into several important subjects (Fig. 2.6).

According to this general methodology, the analysis of past and present land-use systems and climatic characteristics will enable a profound comparison of advantages and disadvantages of long-term environmental management.

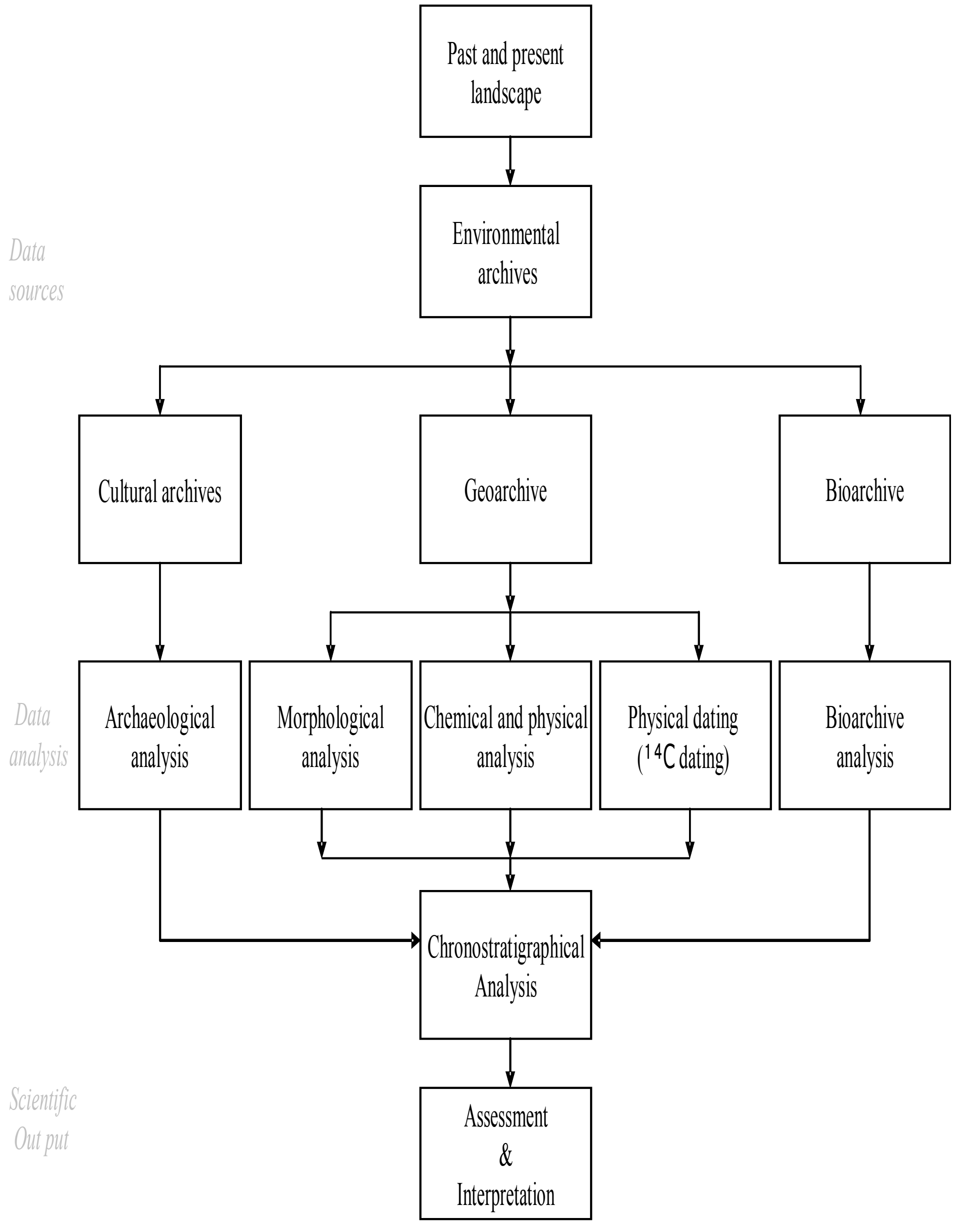


Fig. 2.6. General interdisciplinary methodology to study long-term soil degradation

Chapter 3
Methodology

3.1 Introduction

The aim of this chapter is to provide an overview of the methods used in this study and to describe their conceptual bases. Specific and detailed descriptions of aspects of the methodology are given where necessary. There are two sections in this chapter that specifically deal with methods used in this work. Firstly, the field and laboratory work are described as the basis. Secondly, an overview of different dating techniques is outlined, including luminescence technique, radiocarbon dating and archaeological age classification, in order to estimate the age of sediments as geomorphological and archeological tools.

3.2. Field and Laboratory Work

For the reconstruction of past soil degradation processes it is necessary to use the four-dimensional landscape analysis method. This method consists of the following steps as described by Bork et al. (1998):

- Definition of hypotheses
- Identification of key catchments by field survey
- Establishment and documentation of representative soil profiles
- Definition of a preliminary stratigraphy based on the processes in relative chronological and spatial sequence
- Sampling of datable material (charcoal) from the profiles
- Radiocarbon analysis and other dating methods
- Sampling for physical and chemical soil analysis
- Laboratory analysis (e.g. texture, bulk density, chemical and mineralogical properties of soils and sediments)
- Completion of the stratigraphy based on the identified processes, dates and additional information from literature and personal communications
- Reconstruction of the four-dimensional development of the investigated catchments
- Interpretation of the results from investigated catchments concerning their trans-

ferability to larger areas

The initial assessment to find the best area with the detailed geo- and bioarchives (namely with numerous colluvial layers with a high resolution in space) for field work and sampling is very important. Small catchments with initial evidence of historical land use changes and soil erosion have to be found first. After the identification of a suitable catchment, the best sites for excavations are selected. The best method and also dimension of the excavations, such as depth (depending on the thickness of colluvial layers over buried soils or bedrock) and length (depending on the size of gullies or the situation of sediments in the deposition areas), are vitally important because they must provide accurate and complete pictures of the deposition sites. According to this, soil pits were excavated using an excavator to depths ranging around 2 to 3 m, length of several decameters and widths of approximately 2 m (Fig. 3.1 a,b).

After the excavations, the walls were cleaned. The layers of sediments, soil horizons and other characteristics such as fire pits, large animal's holes and stones found on the cleaned walls were marked.

Vertical and horizon sections of the walls were drawn in the field in different scales; 1:10 is the usual horizontal scale, although large sections with little detail can be drawn at 1:20. In this case we used a horizontal scale of 1:20 and a vertical scale of 1:10. A section should be drawn from a horizontal datum fixed to the surface of the soil. The extent of all contexts visible in the section should be recorded. A description of the sediment and soil characteristics and a description of the spatial distribution of the features followed.

The colors of the sediments and the soil horizons were described using the Munsell soil colour charts (Munsell, 2000). The texture was estimated roughly in the field. In the laboratory, the four main elements were measured including particle size distribution, bulk density, pH, and organic matter content. The ages of sediment layers were estimated with charcoal dates and artifact dates, found in the sediment.

a)

b)

Fig. 3.1 Field work a) soil pits were excavated using an excavator b) after cleaning the walls, layers of sediments, soil horizons and other characteristics were marked; then the profile was ready to draw the information marked.

3.3. Dating Techniques

There are different dating techniques which were developed to estimate the age of soil formation processes, soil structures and sedimentation processes. The reconstruction of historical erosion and soil formation rates requires a chronology of sedimentation. Various techniques are available to date material from colluvial layers. In recent years considerable advances have been made in the development of these techniques that specifically date the time of sedimentation. One technique is luminescence dating which has different types. A short review of this technique is given in this part. Sediments everywhere contain low concentrations of uranium, thorium and potassium which produce, over geological time period, a constant flux of ionizing radiation. The ionizing radiation is absorbed and stored by surrounding sediments and with stimulation this stored dose can be evicted producing luminescence. The physical basis of the luminescence technique is described by Aitken (1998), while summaries of its application in geomorphology are provided by Stokes (1999) and Duller (2000) and the dating of colluvial sediments by Preston (2001) and Mauz et al. (2003). In order to understand the dynamics of the landscape changes Mauz et al. (2003) used an optical dating of colluvial layers which were deposited at foot slope areas and in gullies. From the data obtained they found that quartz-OSL (Optically Stimulated Luminescence) is a suitable tool to establish time sequences for colluvial sediments.

Another technique is the estimation of ages using the radiocarbon method. One of the most important isotopes, that are used for dating purposes, is the isotope ^{14}C which has a half-life of 5,730 years. ^{14}C isotopes are produced continuously in the Earth's upper atmosphere as a result of the bombardment of nitrogen by neutrons from cosmic rays. The radiocarbon becomes mixed with the ^{14}C in the carbon dioxide of the air, and it can be found in all living plants and animals. After the death of the organism, the amount of radiocarbon gradually decreases and it reverts to ^{14}N by radioactive decay ($^{14}C \rightarrow {}^{14}N + ß$). With the measurement of the amount of radioactivity remaining in organic materials, the amount of ^{14}C in the materials can be calculated and the time of death can be determined. This radioactive time process is simple in theory, but the laboratory processes are complex. The method is described to detail by Dincauze (2000). The ^{14}C has been a useful and efficient isotope in dating of organic remnants and thus prehistory and history of humans and it has played important role in order to study and date past soil erosion, soil formation processes and landscape changes. In order to use this technique, charcoal, is taken from different layers of sediment. The measured age of a piece of charcoal represents the maximum age of the sediment from which it was collected.

One of the most important tools to estimate the age of a sediment is the identification of datable finds. In addition to charcoal, in sediments artefacts such as pottery fragments are incorporated. Therefore according to the knowledge of the production, the forms and the composition of pottery not only the age is estimated. Pottery also may contain important information about the life of past societies and cultures. This method is also used in this study.

Chapter 4

Study Area

4.1. Introduction

The research was carried out in small catchments near Albersdorf, Hof Ritzerau and near Lake Belau. Albersdorf is situated about 65 km west of Kiel in Dithmarschen. Hof Ritzerau is located approximately 60 kilometers northeast of Hamburg in the Southeast of Schleswig-Holstein. Lake Belau is located 25 kilometers south of Kiel. All three sites are located in the capital of Schleswig-Holstein, Germany (Fig. 4.1).

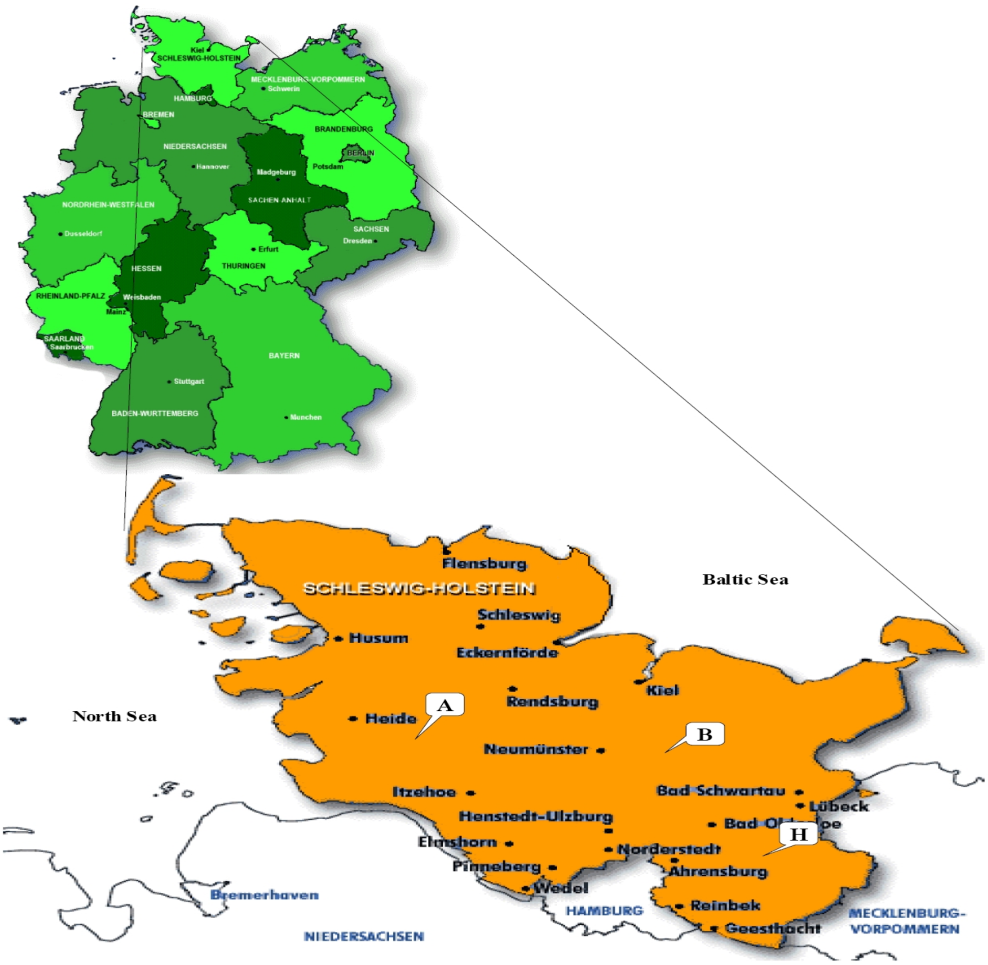


Fig.4.1 Location of the investigation sites: Albersdorf (A), Lake Belau (B), Hof Ritzerau (H)

In this chapter climate, soils and physiography are described which are important as a base information. Land use history and historical soil degradation are outlined in two sections which describe the human occupation, deforestation and agriculture activities and also soil degradation in the study area.

4.2. Climate

The investigation areas are located between the North Sea and the Baltic Sea; therefore they are characterized by a moderate temperate and oceanic climate with soft and moist winters and temperate, rainy summers (Liedtke, 1994).

The average air temperature during the summer months is 13,0-13,5° C. July and August are the warmest months of the year with a mean air temperature of about 17-18° C. The mean air temperatures during the winter months is 2,5-3,0° C; the coldest average temperatures are about 0-1° C in January and February. The average annual precipitation varies from more than 1000 mm in the western part of Schleswig-Holstein to less than 700 mm in the east. November is the wettest month with an average precipitation between 90 and 140 mm. February is the driest month with 40-50 mm precipitation (Westenmeier et al., 1999).

The Holocene is sub-divided into periods representing climatic fluctuations (Table. 4.1).

Table. 4.1 Climatic phases since the late Ice Age in Schleswig-Holstein (Freeden and Schnurbein 2002).

Climatic phases	Ages
Late Ice Age	More than 9600 BC
Pre-Boreal	9600 - 8000 BC
Boreal	8000 - 6800 BC
Atlantic	6800 - 4000 BC
Sub-Boreal	4000 - 800 BC
Sub-Atlantic	800 BC - 2000 AD

According to a review by Preston (2003) and Lang et al. (2003) throughout the Holocene, climate has been generally temperate, with temporal variations in Germany. The Sub-Atlantic was a period of cooler temperatures, increased storminess and fluctuations in weather patterns. Although it is generally considered that coldness lasted from 1570 to 1850, with peaks between 1570-1620, 1680-1700, in 1755 and 1810-1850, the climatic deterioration began as early as 1300 (Lamb, 1984). From this date, climate became increasingly erratic with pronounced annual and decadal variations. The decade 1310-1320 was one with very wet summers, especially from 1313 until 1317 (Lamb, 1984). Cool and wet summers also characterized the 1340s. In the summer of 1342 much of central Europe experienced record flood levels associated with rainfall calculated to have a return period of well over 1,000 years (Flohn, 1949, 1958, 1967,1993; Pfister, 1980, 1985; Lamb, 1984; Alexandre, 1987; Bork, 1988).

4.3. Soils

At the end of the Weichselian cold period the thawing glaciers and their melting waters changed the landscape. Global warming caused the transition from late Pleistocene to Holocene. Natural woodland vegetation formed first in southern and later in northern Germany. Beginning in the Neolithic the ecosystems were influenced by human land use. As a result of the morphology and the land-use, different soil types formed. Cambisols (FAO, 1998) developed on glacial and fluviglacial sands. Luvisols in loamy glacial deposits, Gleysols and Histosols on lowlands, colluvial soils on lower slopes (Schleuss, 1992). Partly eroded Cambisols and Luvisols dominate today in the study area (Fig.4.1. a,b). Many of these soils developed in the remnants of eroded soils on the upper slopes, or in the correlated soil sediments (Dreibrodt and Bork, 2005; Reiss, 2005). In colluvial layers there is a progressive change of the soil development depending on the age of the layers. In some parts of the investigation area initial Podzol were also been recognized (Fig. 4.2).

a)

b)

Fig.4.1 Luvisols dominate in the study areas a) near Belauer See and b) Hof Ritzerau

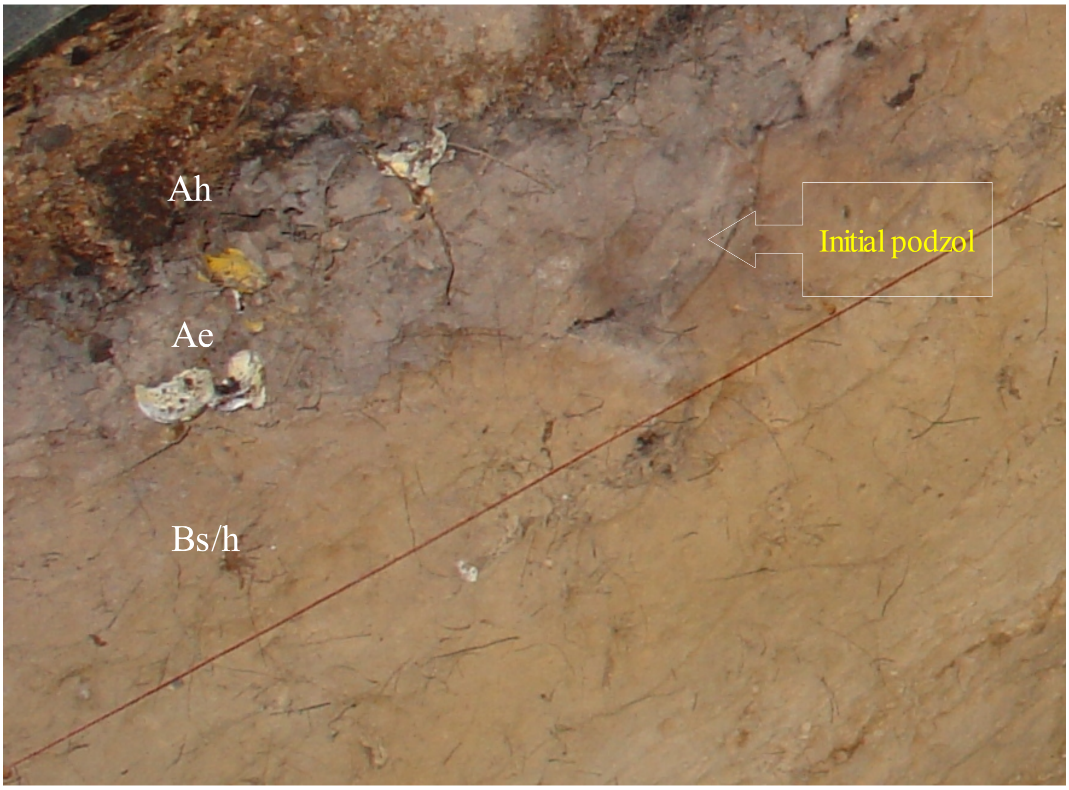


Fig. 4.2. This profile represents the initial podsolization of a Cambisol and a Luvisol. Organic matter is accumulated mainly on the surface. The white, bleached zone (Ae horizon) is nearly free of humus. It overlies a brownish layer of accumulation (Bs/h horizon) which contains sesqui-oxides and organic matter

The particle size distribution shows sandy loam and loamy sand textures. Gravel deposits are the result of extreme runoff evnets with rill and gully erosion in the past. The high pH values in agriculturally used sites are due to fertilization. Under forest soil pH values are generally lower. In agricultural land no Ah-horizons were found at the recent soil surface; Tillage practices have mixed former Ah-horizons with lower horizons. At other sites Ah-horizons were eroded.

Intensive soil formation reflects geomorphodynamic stability and no soil erosion and sedimentation processess. The clearing of woodland enabled soil erosion and sedimentation processes and thus caused a transition from a period of geomorphodynamic stability (with soil formation) to a period of geomorphodynamic partial activity with modifications of the topography.

4.4 Physiography

In Schleswig-Holstein the major land forms are almost exclusively the result of glacial and periglacial processes. Most land forms have developed in glacial and periglacial deposits. The landscapes of Dithmarschen and Western Nordfriesland in the western part of Schleswig-Holstein were formed mainly during the before last glaciation, the Saalian. A smooth topography is the result of fluvial and periglacial processes during the Weichselian in this region near the North sea coast. In contrast the eastern part of Schleswig-Holstein is characterized by a hilly landscape which is the result of glacial deposits and glacial erosion during the Elster cold period, the Saalian and namely the Weichselian. The Weichselian ice sheet reached its maximum extent in Schleswig-Holstein about 20,000 years ago. In the glaciated area to the east of the former ice margin, long, deep subglacial tunnel valleys and a landscape of young moraines with numerous Knobs and Kettles characterize the surface (Liedtke, 1989). The terminal moranines of the young moraine landscape in the investigation area are relatively linear and often also inconspicuous features. Some end moraines are only a few meters high in one location but rise to 70 meters in another where the ice movement had been impeded by higher relief (Gripp, 1964).

The research area near Albersdorf is located at 45° 06′ N and 9° 18′ E. It covers an area of about 40 ha with moderately inclined slopes on the groundmoraine plain and steep slopes bordering the valley of the Gieselau. The predominant landcover comprises today forest; a small part of the area is used as pasture and farmland. The research area is managed by a non-profit organization, the AÖZA (Archaeological-Ecologcial-Centre Albersdorf). Near Albersdorf three sites were selected: Bredenhoop, Falloh and Reddersknüll (Fig. 4.3).

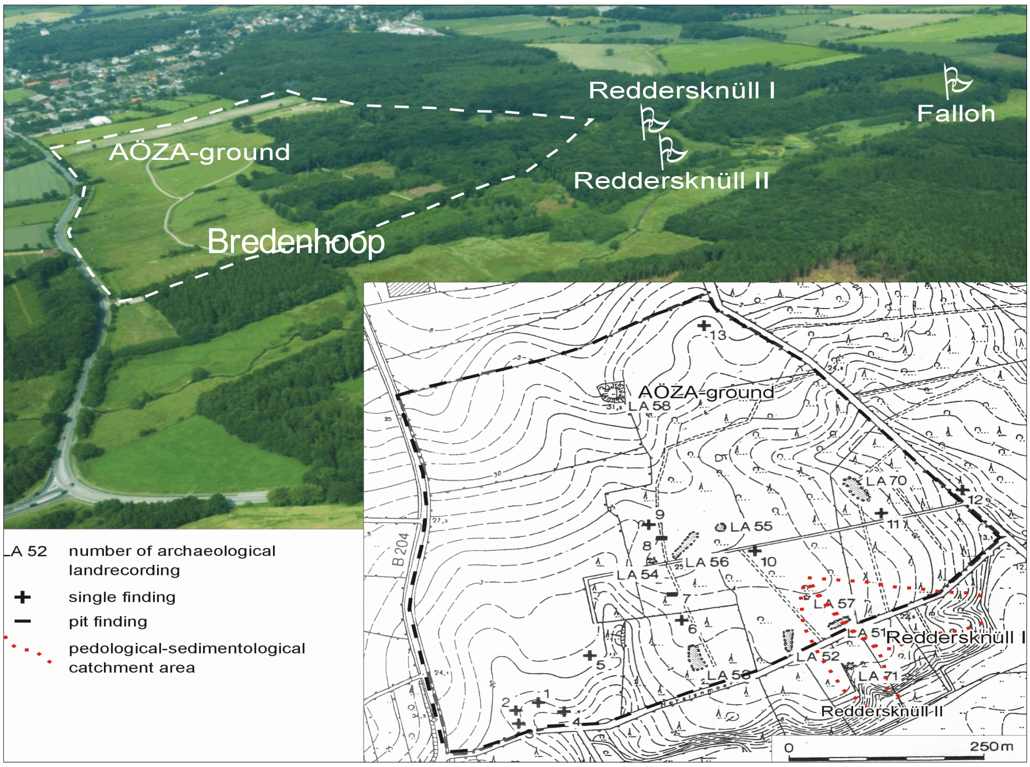


Fig. 4.3 Location of the investigation sites near Albersdorf (Reiss, 2005)

Bredenhoop is a small catchment with a size of 12,99 ha area which is farmland today. The central dell in this catchment which was formed in the late Weichselian by periglacial processes has a width of 150 m and a length of about 800 m in north-south direction. Falloh has a depression with a surface of 2,16 ha, with a dell that has a width of about 100 m. It is covered with forest. Reddersknüll consists of two afforested subcatchments. Reddersknüll I covers an area of 1,15 ha, Reddersknüll II an area of 1,24 ha. The dell of Reddersknüll I has a width of 50 m and a length of 80 m in west to east direction. A north-south oriented dell with a width of 50 m and a length of 100 m is located in Reddersknüll II (Fig.4.4) (Reiss, 2005).

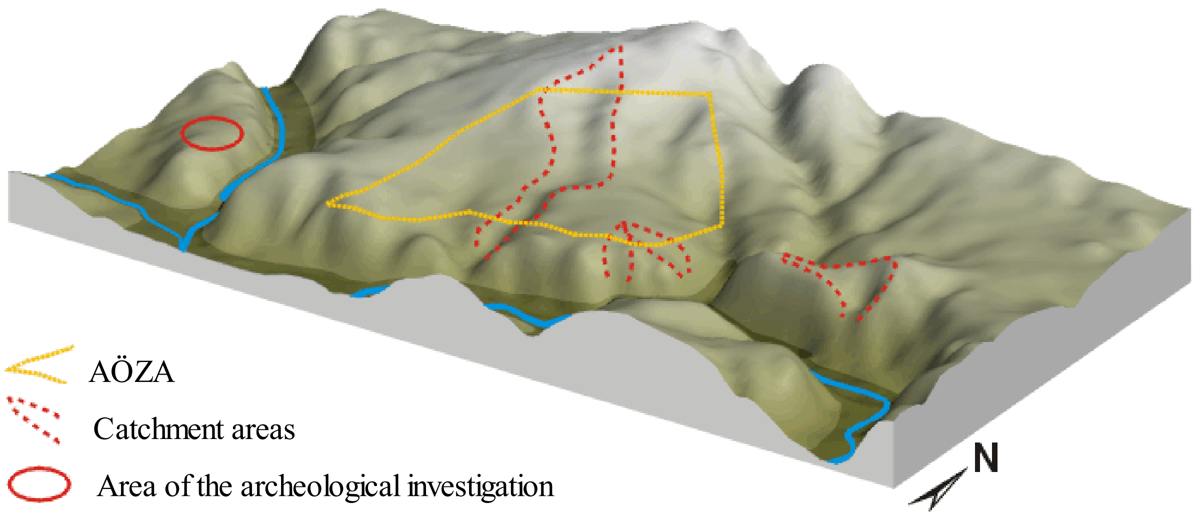


Fig.4.4. Physiography of the research area near Albersdorf (Reiss, 2005).

Lake Belau is located in the border region of the Weichsalian glaciation at 54° 06' N and 10° 16' E. It is a part of the hilly joungmoraine landscape of eastern Schleswig-Holstein and of the Bornhoeved lake chain . As a result of human activities the water level of lake Belau decreased by 1 meter in 1934; since then visible terrace surround the lake (Blume et al., 1992) (Fig. 4.5). The relief is dominated by ground moraines, with heights of 20 m above the lake level (Jelinek, 2000). As a result of the glacial processes, there is a high variability of the morphology, the geology, the past land use, and the soils around the lake (Garniel, 1988). The catchment of investigation area covers around 16 ha.

Hof Ritzerau is located at 53° 49' N and 10° 35' E. The catchment area covers 188 ha. It is located in the hilly joungmoraine landscape of eastern Schleswig-Holstein (Fig. 4.6). The relief is dominated by ground moraines.

Fig. 4.5 Investigation area at the western shore of Lake Belau.

Fig. 4.6 Investigation area Hof Ritzerau

4.5 Hydrology

4.5.1 Drainage System and Surface Water

The soil surface of Schleswig-Holstein is marked by heights of a maximum of 167 m a.s.l. Most areas are below 80 m a.s.l. During the last three cold periods, the Elsterian, the Saalian and the Weichselian, glaciers and the melting waters formed the mesotopography and thus the position of the river systems of Schleswig-Holstein. A high variety of river types was a result of these processes (Sommerhäuser and Schuhmacher, 2003). The divide between the catchments of the North Sea and the Baltic Sea crosses Schleswig-Holstein from north to south. Due to the effects of the last glaciation this divide is not positioned in the centre but in the east of the state. The Eider which drains to the North Sea is the largest natural river in the investigation area (Fig. 4.7).

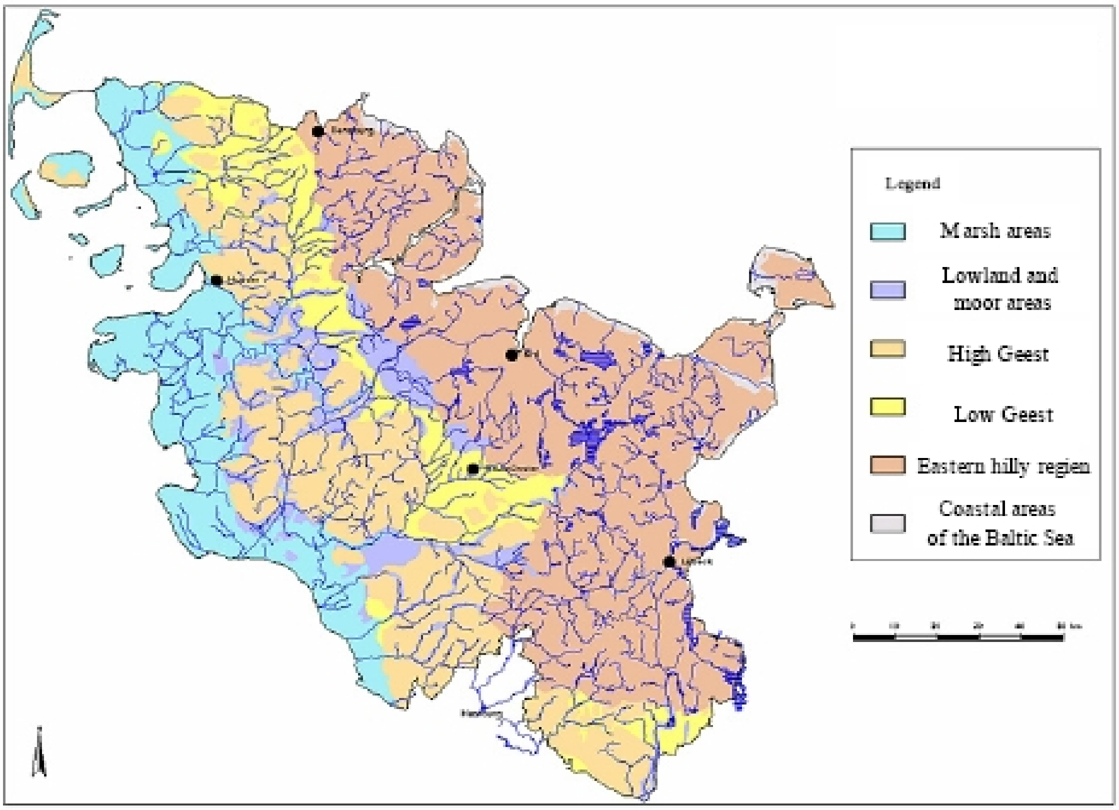


Fig. 4.7 Landscapes and drainage systems of Schleswig-Holstein (www.wasser.sh)

Human activities have changed the natural hydrological system since Neolithic Age, namely during Middle Ages and Modern Times (Wohlrab et.al., 1992). A widespread deforestation in the Middle Ages enabled agricultural land use. The wood was used namely as building material and fuel. The change of woodland into open land caused considerable changes of the water cycle. Namely the transpiration rates were reduced, the infiltration rates and thus groundwater recharge increased considerably. Surface sealing on fields that were not protected by crops during some months of the year enforced runoff (and erosion). The average river discharges increased significantly, too. Floods occurred (Bork et al., 1998).

The introduction of water mills since the high Middle Ages required weirs, pond systems and channels in the floodplains. Drainage systems which were installed e.g. during the 19th and 20th centuries increased the discharge of the rivers.

4.5.2 Ground Water

The water supply of Schleswig-Holstein – about 300 million cubic metres per year – depends on ground water. These are about 25 percent of the yearly renewed ground water recharge (www.wasser.sh). The infiltration capacities of the soils are medium to high. Ground water is to be found in valley bottoms which are not drained during the humid periods near the surface and in the dry periods 50-80 cm below the soil surface (ground water map of Schleswig-Holstein 1:25000).

4.6. Land-Use History, Human Occupation, Deforestation and Agriculture

As a result of intensive palynological, archeological and historical research, the history of land use and settlement is well known in wide parts of northern Germany (Dreibrodt and Bork, 2005; Reiss et.al., 2006). According to those investigations initial agricultural and cattle husbandry started more than 6000 years ago. At first, rural life had only local effects. Humans lived on small cleared “islands” in the forest, where a few houses and the cultivated areas were laying. With the development of agriculture, human sought fertile soils. A gradual increase in deforestation combined with a better technology, led man to make a defined impact on the landscape. Erosion and sedimentation are directly correlated with forest clearance and than agricultural land use. Cultural periods since the Palaeolithic in the northern Germany are present in table 4.2.

Table 4.2 Cultural periods since the Palaeolithic in Schleswig-Holstein (Freeden and Schnurbein, 2002).

Cultural periods	Ages
Palaeolithic	More than 9600 BC
Mesolithic	9600 - 4000 BC
Neolithic	4000 -2000 BC
Bronze Age	2000 - 800 BC
Iron Age	800 BC - 1 AD
Roman Age	1 AD - 300 AD
Early Medieval times (Migration period)	300 - 1000 AD
Late Medieval times	1000 - 1500 AD
Modern times	1500 - 2000 AD

Hof Ritzerau was farmed with conventional methods. Since 2001 the new owner altered the management to organic farming. About 70 % of the farmland is arable land, 10 % is grassland, and the rest is composed of small water bodies, hedgerows, shrubs etc (Hoernes and Roweck, 2004).

The current land use of the study areas is dominated by different types of (coniferous and deciduous) forests and agriculture (grassland and arable land). Near the shore zone of Lake Belau some areas are used for grazing cattle; large areas are forested (Jelinek, 2000).

The dominat regional species in the investigated areas include: *Erica tetralix, Calluna vulgaris, Pinus sylvestris, Picia abies, Betula Pendula, Quercus robur, Fagus sylvatica*.

These plant species reflect the edaphical sites conditions.

4.7. Past Soil Degradation

The processes of soil degradation following woodland clearance often increase the heterogeneity of the soilscape and thus the number of soil types significantly. With respect to chapter 2, past changes in vegetation and soils are well exemplified by several investigations in the study area. The transition from Mesolithic to Neolithic cultures changed the vegetation from woodland to arable land – at least at some sites. This vegetation change caused minor local soil degradation. Following soil degradation and the deposition of colluvial layers on small areas namely on concave downslope areas and at the borders of small valley systems, the soilscape changed slightly and the soil formation processes were modified locally. Soil development in colluvial layers began for the first time.

Chapter 5

Results and Discussion

5.1. Introduction

In this chapter at first soil formation processes and subprocesses are described for a better understanding of their complexity. In addition, the results of investigation will be presented in detail. Finally in this chapter the relationship between soil stability and soil organic matter content with respect to the effect of land-use systems on soil instability will be investigated.

5.2. General Soil Formation Processes

Soil formation consists complex processes which take place under a sequence of events, including complicated reactions and the rearrangement of matter. Numerous events occur in a long period of time under especial pressure from natural and antropogenic effects. Predominantly the vertical transport of water and minerals leads to the formation of soil horizons. External pressures have important effects on soil development processes. Land-use changes play a fundamental role. They may cause a change of the type and of the intensity of soil formation processes as well as erosion by water and wind.

According to Simonson (1978) and Anderson (1988) soil horizons form as a result of the horizon development processes of additions, transformations, transfers, and removals. These processes which determine the characteristics of soil horizons are summarized by Ritter (2006) in figure 5.1.

The main additions are organic matter from vegetation and animals. Ions and solid particles are added with precipitation, runoff and wind. Transformations include the organic compounds that form during decomposition and the weathering of primary minerals. Transfers generally involve the transport of ions and solids with the moving soil water, the eluvation of substances from upper horizons and their illuviation into lower horizons. Finally, when water moves through the soil, it removes substances which are still in solution; these substances then become a part of the dissolved constituents of the groundwater or the surface waters. Surface erosion should also be included in removals (Birkeland, 1999).

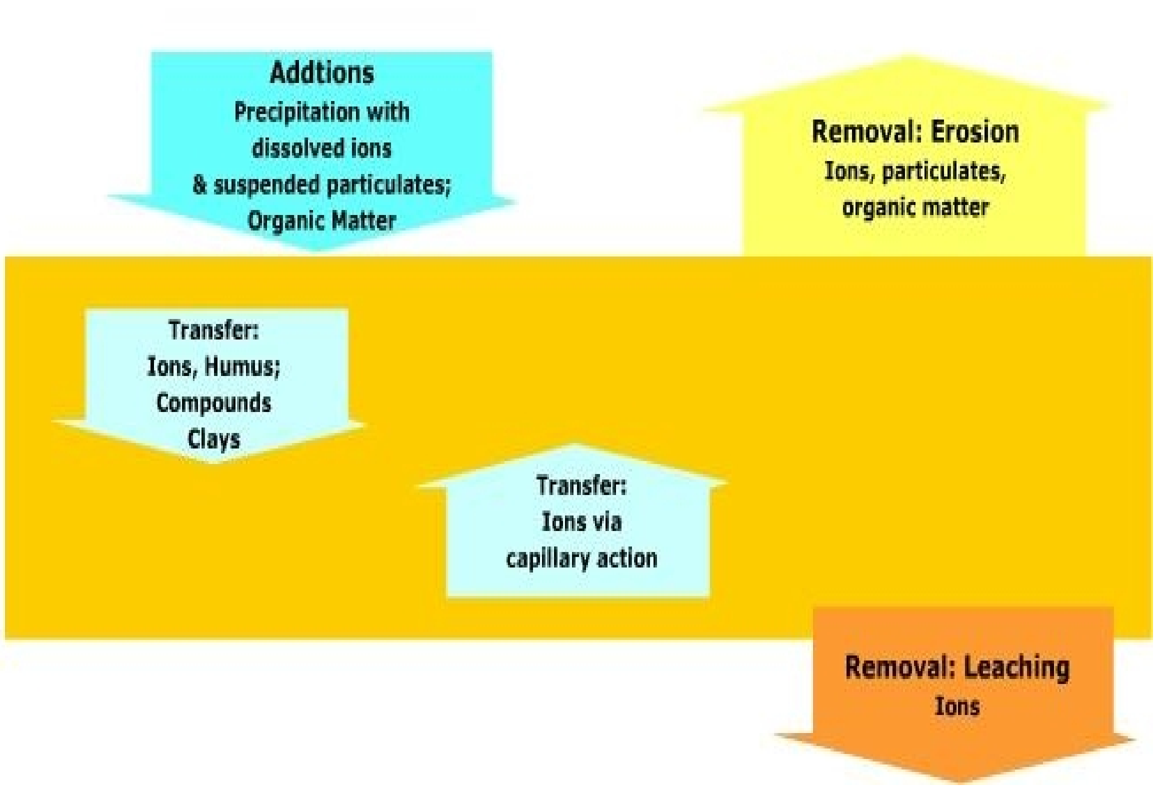


Fig.5.1. Flow chart of soil horizon development processes (Ritter, 2006)

Vegetation plays a key role in soil formation. Vegetation will prevents water and wind soil erosion, if the vegetation cover density is sufficient (above approximately 70%). Natural woodland provides a better protection than rangeland. Therefore the most developed profiles are found under woodland (Duchaufour, 1982). Removal of the natural or antropogenic vegetation terminate the geomorphodynamic stability. It alters soil constituents and reduces organic matter content. Erosion removes the upper soil horizons and then exposes the lower horizons or even the unweathered material below. At other sites, namely at concave slope segments and in valley bottoms soils may be buried under colluvial or alluvial sediments. In both cases different material is again exposed and new soil formation takes place. Therefore in order to study soil formation in different materials (namely in colluvial sediments) and in different areas it is essential and necessary to underestand the natural and antropogenic drivers of soil formation in natural and in anthropogenic ecosystems.

Soil formation has two main cycles which may be divided in short (less than 1000 years) and long periods (several thousands, several ten thousand years or even longer time spans). During the short cycles the dynamics of organic matter and biochemical weathering dominate in temperate or cold climates. Long cycles are relatively independent of the processes of humification; geochemical weathering dominates (Duchaufour, 1982).

The main short and long cycles of soil formation processes are summarized by Bronger and Catt (1989):

- Physical weathering
- Chemical weathering of minerals, including clay formation
- Downward leaching of soluble materials by percolation in humid regions
- Incorporation of decomposing organic matter (humus) from plants rooted in the soil
- Redox processes, especially gleying
- Downward translocation (illuviation) of solid particles, especially clay
- Downward movement of humus and sesquioxides (podsolization)
- Disturbance by root penetration, tree fall and faunal activity (bioturbation), repeated shrinking and swelling processes in clay-rich profiles (argili-turbation), and freeze-thaw movements (cryoturbation).

5.3. Description of the Soil Profiles under Investigation at Hof Ritzerau, near Albersdorf and at Lake Belau

5.3.1 Hof Ritzerau

North of Hof Ritzerau on a slope near the valley of the Duvenseebach with an exposition to the west or northwest two profiles with a length of 25 to 30 m were opened with an excavator (Fig. 5.2). The soils and sediments of both profiles (HRA1, HRA2) were investigated in detail in the field and in the laboratory. The ages of the soil horizons and the sediment layers were dated in both profiles based on radiocarbon dates of charcoal fragments. In the surroundings of the two profiles soil-sediment-sequences were analysed at 131 sites with an auger. HRA1 is located at a midslope and a downslope area with is used agriculturally; the profile ends at an agricultural terrace just above the recent western border of the Duvensee valley. HRA2 is located about 100 m northeast between two glacial depressions which are called „Sölle". Nine postglacial sediments and different soil horizons were identified and analysed.

Glaciers formed the Mesorelief in the last cold period. The glacier ice and the melting water caused the deposit of sandy, sandy-clayey and clayey substrates. At first, organic matter (humus) was accumulated on the top of the soil during early Holocene. A fen developed about 8000 years ago in the depressions and in the valley of the Duvenseebach. In the excavation HRA1 peat of that period was found under recently arable land in the downslope area. The peat was buried later by colluvial layers: Humans had cleared the natural Holocene woodland in the Neolithic period. In the upper and mid slope area intensive rainfall caused then soil erosion in the open land for the first time during Holocene. As a result of this soil erosion the oldest colluvial layers were deposited in this period. The charcoal which was found in fire pit has an age of about 5600 years BP.

Charcoal from the middle and the late Bronze Age as well as the Iron Age were abundant. They confirm furthermore periods of agricultural activities. A Bronze Age temporal fire pit was found in excavation HRA2. In the phases with agricultural land use the peat grew up in valley of the Duvenseebach. It also extended increasingly in the downslope areas. From the

Iron Age till the early Middle Ages first a Cambisol formed on the slopes under woodland which was then transformed to a Luvisol. Charcoal and other findings from the 9th and 10th centuries prove early medieval clearings and agriculture in the Middle Ages, soil erosion and the deposition of colluvial layers on the downslope areas.

Fig.5.2. Position of the excavations HRA1 and HRA2 in investigation area Hof Ritzerau

A colluvial layer with a thickness of about 50 cm was deposited. It is buried today about 1-1,5 m under the recent soil surface. At the downslope border of the agricultural land a farm road was established and used for at least some decades during the late Middle Ages as road.

In 16th or early 17th centuries, heavy carriages sank into the wet, loamy soil. Some lanes were preserved till today. To improve the trafficability, people brought sandy-clayey surface soil of the neighbouring slope on the road. The trafficability was improved so substantially. In a short phase of meadow land use V-and U-shaped ditches were opened (Fig. 5.3). The position and the light slope of the ditches points to an irrigation system to supply the meadows with water and to increas the yields. This land use was very significant in that time. Till the 19 th century meadows had a higher worth than the neighbouring arable land.

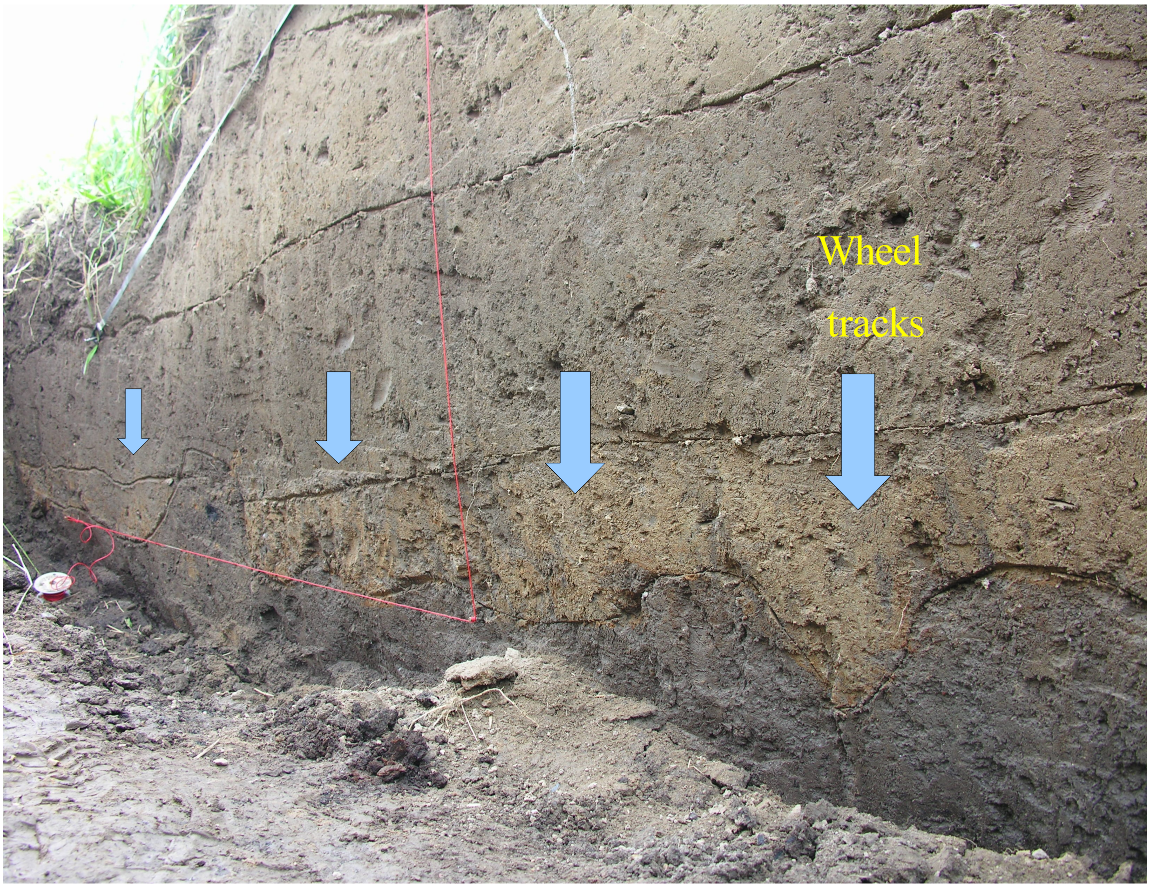


Fig. 5.3 Wheel tracks which are preserved under colluvial layers.

In the 20th century the downslope area was drained and drain tiles were buried (Fig 5.4). The effects of modern agriculture before their rearrangement to ecological agriculture are visible in the upper part of the excavations. In the second half of 20th century soil erosion and thus the deposition of colluvial layers increased extended. The lower border of the field with the agricultural terrace shifted several meters towards the Duvenseebach. Today the avarege inclination of the slope is lower than at the time of agriculture in the Neolithic period. The maximal thickness of the colluvial sequence exceeds 1.5 m.

The prehistoric, medieval and modern erosion and sedimentation processes changed the relief and the soil fertility considerably. The heterogeneity of the soil cover is high on the upper part of the slope as a result of the management and agricultural activites during Middle Ages and modern times.

Fig. 5.4 Old drainpipe which is buried under colluvial sediments.

The colluvial layers indicate long periods soil erosion and deposition in the investigation area. The morphological and analytical properties of the buried colluvial sediments show that soil formation occured in colluvial (M4): A Bs horizon reflects the stabilization of the soil surface allowing soil formation to develop. The humus content of this colluvial layer is less than in the upper layers. In the upper layers there is no evidence for intensive soil formation. This may be a result of the destruction of the top layers due to agricultural activites and previous erosion. Lower layers with a depth of more than 140 cm reflect ground water influence which caused certain hydromorphic signs (Go, Gr). These layers indicate that they were exposed to ground water frequently during the years (Fig. 5.5). The schematic representation about past soil erosion is summarized in figur 5.6.

Fig. 5.5 High groundwater levels created fens and Gleysols at the foot of the slope.

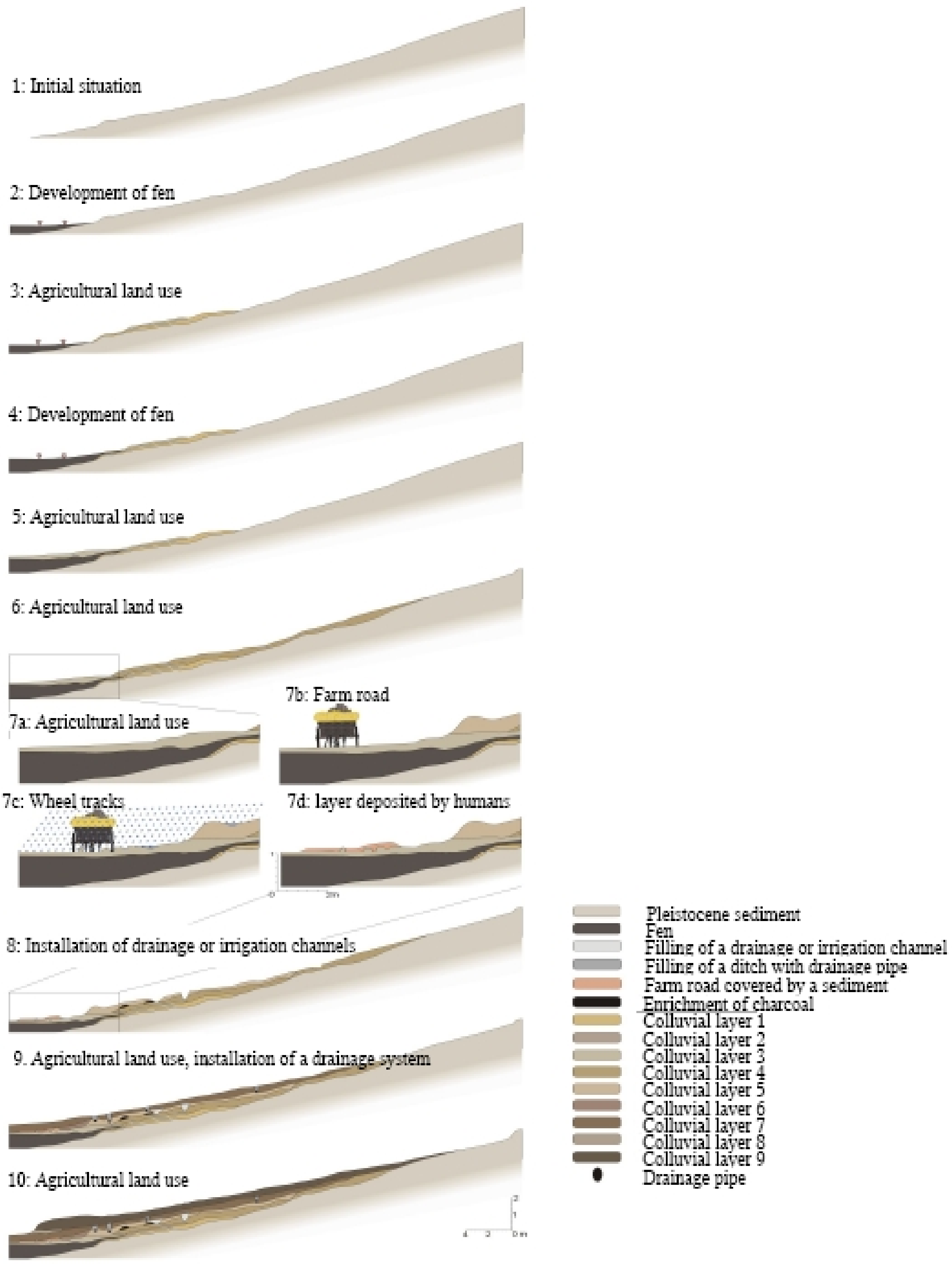


Fig. 5.5 Slope development during Holocene at HRA2 near Hof Ritzerau (Bork et al., 2006)

5.3.2. Albersdorf

The following findings, dating and conclusions are taken from Reiss (2005, pp. 89 ff.)

In the investigation area near Albersdorf colluvial sediments were accumulated on fluvioglacial sands and on gravel of Pleistocene origin. Remnants of several periods of soil formation were found. Cambisols and Luvisols with banded clay enrichment which had developed first were modified due to inetnsive land use.

Research Area Albersdorf-Reddersknüll (RA)

Four colluvial layers, two Cambisols and up to three Podsols were identified by Reiss (2005) in 12 pits in the research area Reddersknüll.

The horizons of a Cambisol were recognized at some sites. In the Ae horizon of a Podsol a box-shaped pit was identified in profile RA1b. The pit was 20-30 cm deep and 90-100 cm wide and dug during early Neolithic Age in the Pleistocene sand. Clearly the pit was made before the podsolization, because the leaching horizon of the Podsol (Ae) has covered the filling of the pit. Above the Podsol which developed in and aside the Neolithic pit the first two colluvial layers (M1, M2) with a total thickness of approximatly 40 cm were deposited. From the surface of colluvial layer M2 humans dug pits during late Bronze Age or early Iron Age e.g. in the area of profile RA1b. The pits were up to 100 cm wide and 60 cm deep. They contained in their lower part quartzites which were broken by the high temperatures of the fires. Probably the stones were cracked during rituals. In the contact area of the fire pits the sand was reddish and baked as a result of the high temperatures of the fires.

In the filled fire pits and in the two colluvial layers M1 and M2 first a Cambisol and then a Podsol developed: a Bv-Horizon of the Cambisol and a Bs(h)-horizon of the Podsol are preserved in M1, Ae- and the Ah-horizons of the same Podsol in M2. The Podsol only developed in sandy colluvial material in the depression and in sandy fluvioglacial deposits on the southern slope while in the northern part of the profile loamy material prevented the development of a Podsol. A Cambisol is preserved until today.

Colluvial layer 3 was not deposited in this profile but in neighboring dells. This sequence of colluvial layers with soil formation was directly covered by a fourth colluvial layer with a maximum thickness of 60 cm (M4). In this colluvial layer first a Cambisol and then an intial Podsol developed since late Iron Age. The following soil horizons still exist in M4 (from bootom to top): Bv (with light colour of Bs(h) in the upper part), to a weak, purplish Ae-horizon and an Ah-horizon. The podsolization is a result of the forestry of the last decades: coniferous trees which were planted in the 20th century enforced the acidification and thus the beginning of the podsolization.

Research Area Bredenhoop (BA)

Profiles at the research area Bredenhoop are crossing a dell. They contain three colluvial layers and remnants of several soils. Colluvial layer M1 was deposited during Bronze Age. In M1 first a Cambisol, then a Luvisol with banded clay enrichment and finally a Podsol developed. Then M2 was deposited in a thickness of only 10 to 20 cm. A Cambisol developed in M2. A third colluvial layer (M3) was deposited on the Cambisol of M2. In M3 another Cambisol developed from the late Iron Ages until Medieval Times. Today the area is used agriculturally. A drain tile system was installed in the 20th century.

Research Area Falloh (Excavation FA2, FA3)

Two profiles were excavated in a dell of research area Falloh. In the depth line of the profiles FA2 and FA3 a typical Regosol was identified as the early Holocene soil which had developed in Pleistocene sand and which is characterized by the accumulation of organic matter near the surface (Bork, 2001). The Ah-horizon of the Regosol is well recognizable until today. Above the Regosol five colluvial layers (M1 – M5) were deposited. Charcoal (two of pine trees, one from an oak tree) from colluvial layer M1 and from a flat and wide fire pit was dated into the end Mesolithic period. This is a unique finding in the region: Mesolithic people cleared the slopes surrounding the dell in Falloh; they enabled for the first time soil erosion during Holocene. At the borders of the dell colluvial layer M2 was deposited during early Neolithic Age. Then a Podsol developed in M2 and in the un-derlaying M1. The colluvial layers M3 and M4 were deposited during middle Neolithic Age as a result of soil erosion on the agriculturally used neighbouring slopes. Still in the same period two fire pits were dug 60 to 80 cm deep through M3 and M4 (Fig. 5.6). Then, under woodland, a Cambisol developed. Clay illuviation had just begun, when the woodland was cleared in Roman Times, when soil erosion occurred in the open land and colluvial layer M5 was accumulated. Since Roman Times first a Cambisol, then a Luvisol and recently an initial Podsol formed under woodland in M5.

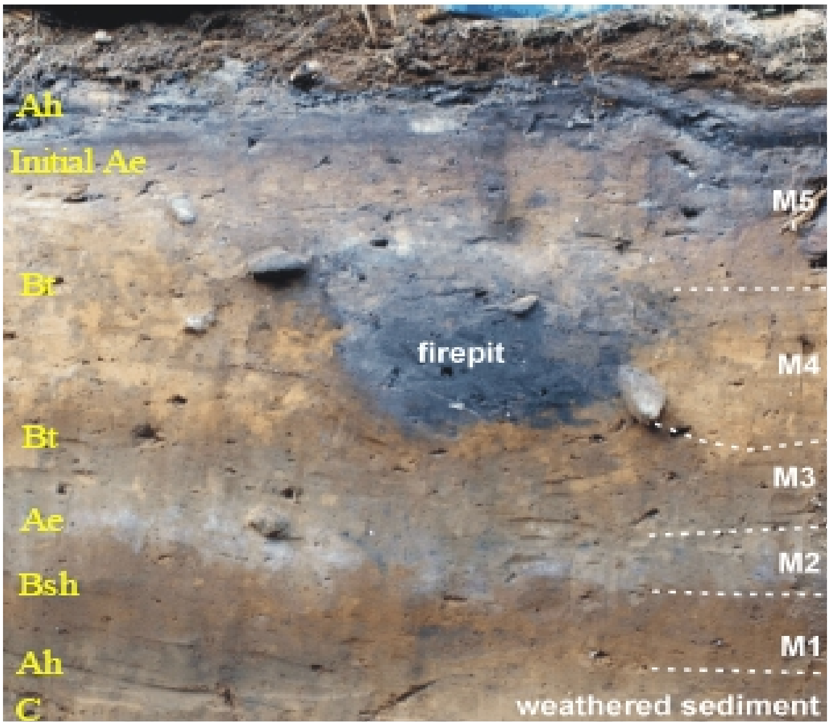


Fig. 5.6. Middle and late Holocene colluvial layers and soil horizons (modified after Reiss, 2005).

5.3.3 Lake Belau

In the investigation area Belau four pits were opened with lengths of approximately 3 to 8 m (Fig. 5.7). In all profiles a series of five colluvial layers was distinguished. In M1 a Luvisol formed during a long period of soil formation in Neolithic Age and Bronze Age. Since only the Bt horizon of this soil is preserved, the Ah- and Al-horizons must have been eroded thereafter. Directly below the erosional surface (top of colluvial layer M1) then a humic horizon developed. Colluvial layer M1 has a very dark grey colour with a thickness of 10 cm. Probably the Ah-horizon developed in grassland. This Ah-Cv-soil proves gomorphodynamic stability after the partial erosion of M1 (Fig. 5.8). M2 was deposited during Bronze Age and M3 during Iron Age.

Fig. 5.7 Profiles investigated across the dry valley and in the direction of the dry valley at the western shore of Lake Belau.

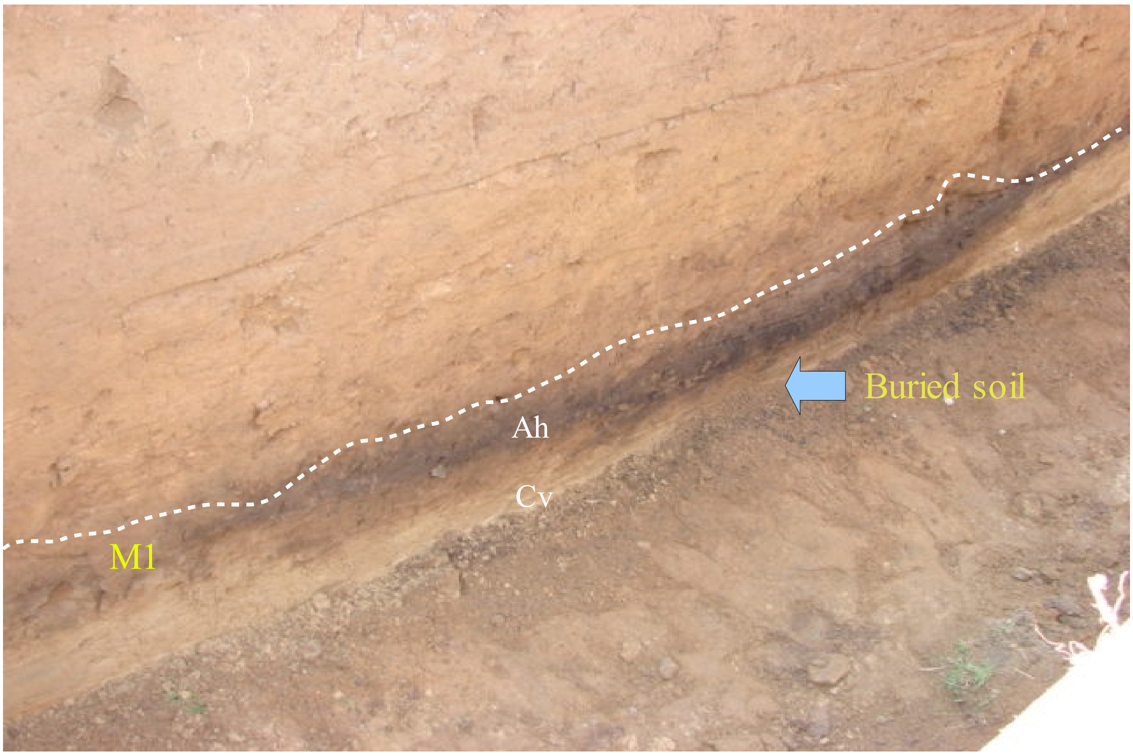


Fig. 5.8 Buried soil which formed in colluvial layer M1 under gomorphodynamic stability.

Colluvial layer M4 was deposited very probably during Middle Ages. M5 is the colluvial deposit of the last approximately 150 years. An Ap horizon with a greyish brown colour in colluvial layer M5 and at the recent soil surface is the result of the homogenization of M5 as the result of farming practices (namely ploughing).

In the colluvial layers M2 and M3 a Cambisol developed from Iron Age until Middle Age (Fig. 5.9). The upper part of this soil was eroded during Middle Age before the deposition of colluvial layer M4. A development of a Cambisol or a Luvisol from Iron Age until Middle Age was identified by Dreibrodt (2005) for several sites in the surrounding area, too. The soil bulk density varies in the colluvial layers (M1 – M5) from 1.4 g/cm^3 to 1.6 g/cm^3.

Fig. 5.9. Development of the Cambisol in colluvial layers.

5.3.4 Integrative Interpretation

The description and interpretation of the soil profiles and colluvial layers in the three investigation areas indicate that the colluvial sequences provide an important record of the past soil degradation in Schleswig-Holstein from the Neolithic time, Bronze Age, Iron Age, Medieval and Modern times. Moreover they prove periods with intensive soil erosion and deposition namely in agricultrual land on one hand and periods with soil formation under woodland on the other hand. The soil-sediment-sequences prove the intensive interference of humans on the environment.

According to the description of the soil profiles with respect to soil and sediment stratigraphical and pedological analyses in a high resolution, several results can be sumarized as follows:

- The temporal and spatial variation of soils and sediments from Mesolithic until Modern times were identified.
- Erosion and sedimentation occurred as a result of the land clearance and agricultural land use in the investigation areas since the Neolithic time.
- Soil formation took place in the colluvial layers during periods of gomorphodynamic stability with a dense cover of woodland.
- Hydrogeomorphic changes occurred as a result of the changes of the topography, of drainage catchment characteristics and of sedimentation (different thickness in colluvial layers).
- Leaching of soluble materials (eluviation and illuviation of clay minerals) as an important soil formation process was identified in the investigation areas.
- Inappropriate land-use practices and management caused the podsolization of Cambisols and Luvisols which had developed in colluvial layers before.
- A large amount of soil was displaced namely on convex middle slopes during Bronze Age, Iron Age, Middle Ages and in the Modern times.
- Several fire pits were identified in the investigation areas which indicate the intensive exploitation of the woodland in the past.
- Buried soils and colluvial layers are geoindicators to reconstruct long-term human-induced soil degradation.
- An intensive change in soil fertility and quality with respect to soil erosion and sedimentation (removal of soil nutrients in the topsoil by erosion, and decline soil productivity) and also soil formation (a degradation due to the formation of Podsols) was found.
- The substitution of woodland by arable land changed the water balance; transpiration rates were reduced, infiltration rates and runoff generation increased, ground water tables were raising.

- The compaction of surfaces by intensive human activities in farmland reduced infiltration capacities and thus increased runoff and soil erosion.

5.4. The Effects of Past Land-Use Changes on Soil Formation in Colluvial Layers

Colluvial layers as an important geoarchive are very important in order to study soil formation processes under different land-use systems. The soil horizons in colluvial layers reflect the soil formation processes in specific time periods. The soil formation mainly takes place in periods of geomorphodynamic stability. Therefore, when we study soils which developed in colluvial layers, it is necessary to apply a historic approach. According to this idea the ages of colluvial layers combined with their physical, chemical and biological characteristics, regarding the historical land use changes, were used to study the nature and behavior of the pedogenesis in colluvial layers which were deposited during middle and late Holocene.

In order to investigate soil formation processes for a long period of human interference it is necessary to have an explanation about land degradation history with regard to deforestation and then agricultural activities. The detailed examination of colluvial layers with a historical approach helps us to find what happened in the past and what is the result of human activity on soil development. According to our detailed soil stratigraphical analysis with high resolution in time and space and with respect to historical documents related to the research area mentioned, the duration of soil formation processes can be summarized in two parts. One part is based on a pedological approach and another is the important role of human activities on soils during middle and late Holocene.

5.4.1. Soil Formation Processes

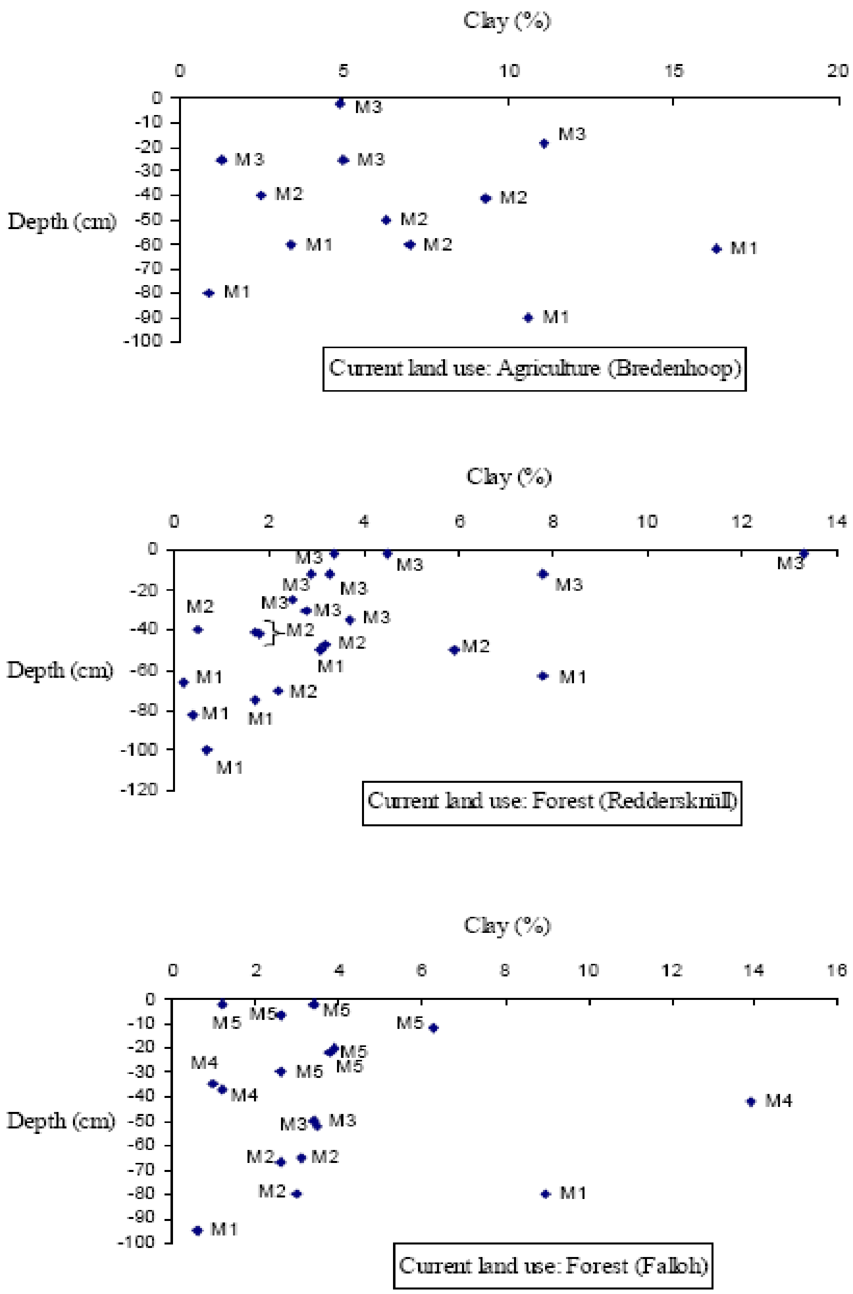
The comparison of soil properties such as the content of soil organic matter and the particle size distribution (content of clay, silt and sand) indicates that different soil formation processes in colluvial layers took place in different times and spaces and under different land-use conditions. The results of our investigations based on data (Table. 5.1) are summarized as follows:

Table. 5.1 Field and laboratory data for soil horizons and colluvial layers from Albersdorf (modified after Reiss, 2005).

duration of soil formation (year)	Age(BP)	Depth (cm)	C/N	C%	Clay%	Silt%	Site	Colluvial layer
100	100	2	13,3	0,8	4,9	20,8	Ba	M3
100	100	25	16,9	0,7	1,3	27,5	Ba	M3
100	100	18,5	16,2	1,1	11,1	14,8	Ba	M3
100	100	25	16,6	1,4	5	28,5	Ba	M3
100	200	41	18,4	0,9	9,3	21,3	Ba	M2
100	200	60	21,2	0,6	7	21,2	Ba	M2
100	200	50	19,8	1	6,3	35,3	Ba	M2
100	200	40	16,7	0,5	2,5	37,9	Ba	M2
3400	3600	90	23,8	0,8	10,6	24,7	Ba	M1
3400	3600	60	17,3	0,8	3,4	34,6	Ba	M1
3400	3600	62	26,6	1,1	16,3	31,7	Ba	M1
3400	3600	80	25,4	1,4	0,9	38,1	Ba	M1
1900	1900	2	30,1	3,1	3,4	29	Fa	M5
1900	1900	7	36,8	1,2	2,6	29,2	Fa	M5
1900	1900	12	27,7	2,1	6,3	26,8	Fa	M5
1900	1900	22	19,6	1,1	3,8	35,4	Fa	M5
1900	1900	30	28,4	1	2,6	30	Fa	M5
1900	1900	2	28,5	2,6	1,2	25,6	Fa	M5
1900	1900	20	31,7	0,8	3,9	25,2	Fa	M5
3400	5300	35	25,5	0,6	1	29,1	Fa	M4
3400	5300	37	39,6	0,4	1,2	24,5	Fa	M4
3400	5300	42	29,5	1,4	13,9	34,2	Fa	M4
50	5350	52	36	1,3	3,5	34,2	Fa	M3
50	5350	50	27,1	0,9	3,4	35,6	Fa	M3
1000	6400	65	35,6	1,1	3,1	32,9	Fa	M2
1000	6400	67	26,5	0,6	2,6	34,4	Fa	M2
1000	6400	80	31,2	0,5	3	33,2	Fa	M2
200	6600	95	30,2	0,8	0,6	28	Fa	M1
200	6600	80	33,5	1,3	9	35,3	Fa	M1
200	2600	2	21,9	11,6	3,4	25,1	Ra	M3
200	2600	12	27,9	1,9	2,9	18,4	Ra	M3
200	2600	35	24,9	0,9	3,7	18,5	Ra	M3
200	2600	2	20	9,3	13,3	16,4	Ra	M3
200	2600	12	26,8	1,2	7,8	17,9	Ra	M3
200	2600	30	22,1	1,2	2,8	18,5	Ra	M3
200	2600	2	21,5	11,9	4,5	20,9	Ra	M3
200	2600	12	25,6	2,4	3,3	17,3	Ra	M3
200	2600	25	30,5	1,4	2,5	30,7	Ra	M3
1200	3800	41	21,3	0,2	1,7	17,6	Ra	M2
1200	3800	50	19,8	0,5	5,9	32	Ra	M2
1200	3800	42	23,6	0,6	1,8	24,8	Ra	M2
1200	3800	47	21,4	0,5	3,2	24,7	Ra	M2
1200	3800	70	23,3	0,6	2,2	44,1	Ra	M2
1200	3800	40	29,3	1	0,5	13,3	Ra	M2
1000	4800	50	26,4	0,8	3,1	12,4	Ra	M1
1000	4800	82	21,7	0,7	0,4	31,3	Ra	M1
1000	4800	100	17,1	0,2	0,7	18,4	Ra	M1
1000	4800	63	21,4	0,5	7,8	37,3	Ra	M1
1000	4800	66	22	0,4	0,2	22	Ra	M1
1000	4800	75	23,3	0,7	1,7	30,9	Ra	M1

Soil formation processes are evident in colluvial layers. The transition from lighter soil colors in deeper layers to darker colors in the upper layers, indicates a decrease in organic matter content with depth in each sequence of colluvial layers. With increasing depth, the clay content increased in several colluvial sequences. This reflects the process of clay migration which resulted in the development of Luvisols (Fig. 5.10 a, b). Silt and sand content fluctuated in the profiles under investigation. When silt contents decreased sand contents increased (Fig. 5.11 a, b)

a)



b)

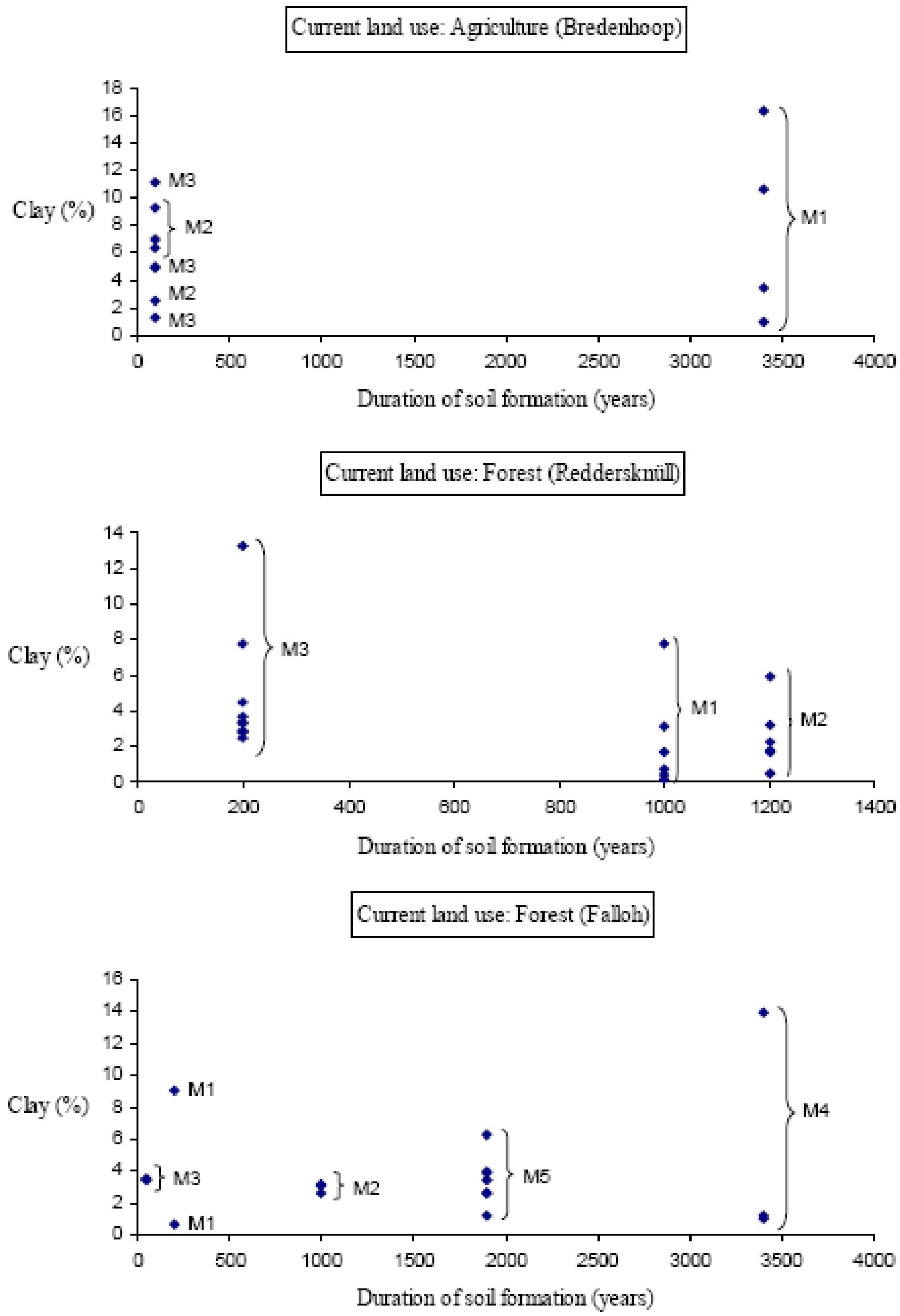


Fig. 5.10 Comparison of soil properties in different depths in colluvial layers (M) under different current land use: a) percent of clay with depth; b) percent of clay with duration of soil formation.

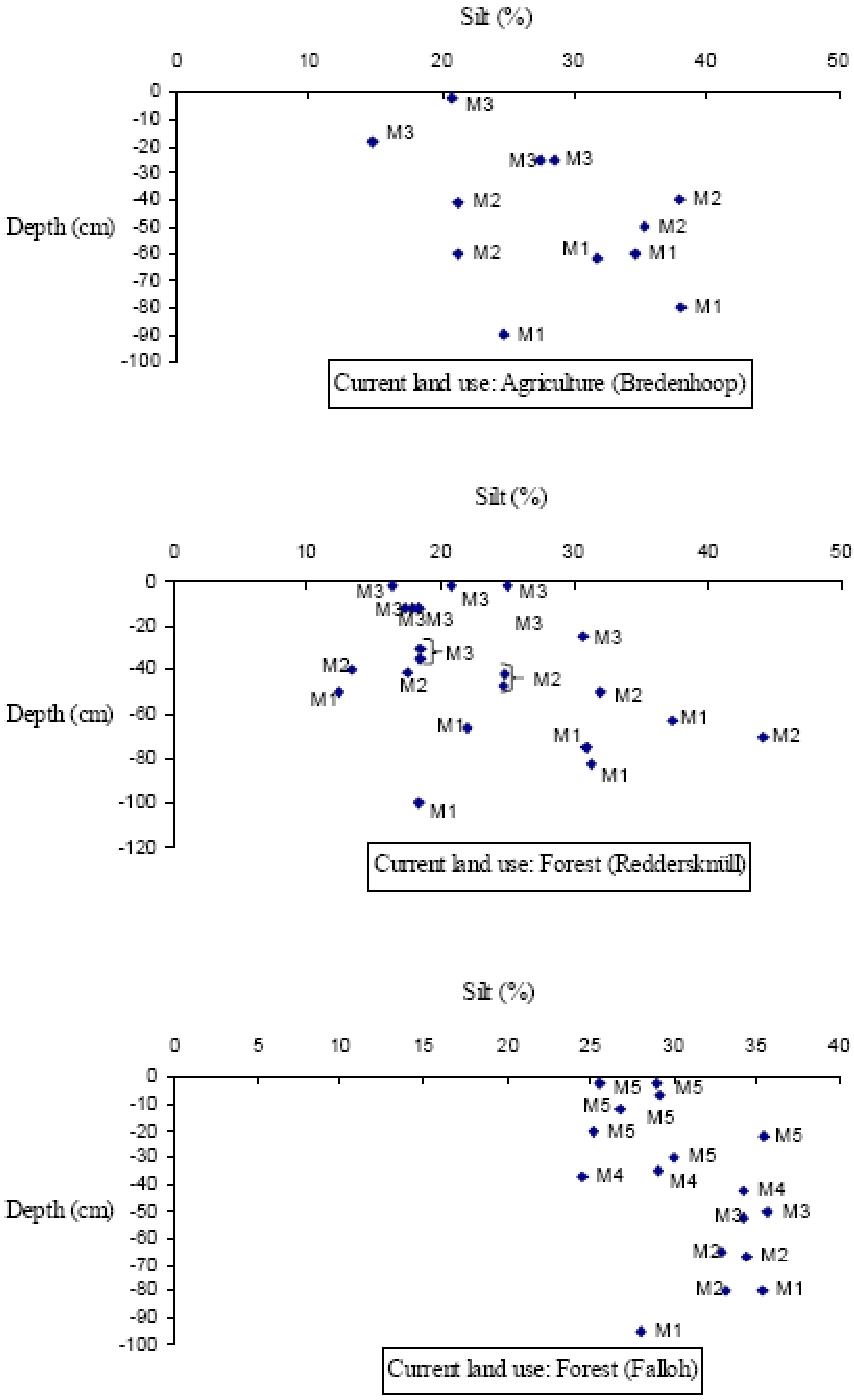


Fig. 5.11 Comparison of percent of silt in different colluvial layers (M) with depths under different current land use

The content of total soil organic carbon in forest ecosystems near the soil surface is significantly higher than in agricultural ecosystems because more organic mater is produced under forest. Agricultural activities, namely the export of crops, have caused lower contents of soil organic matter (Fig. 5.12). Agricultural management practices have mixed organic matter in the uppermost 20 to 30 cm of the soils. Ah, Al and Ae horizons are often eroded on agriculturally used convex slopes. The content of organic carbon varied as a result of recent and past land management (Fig. 5.12).

The decrease of organic matter content with depth in colluvial sequences of recent forest ecosystems is not only the result of the processes mentioned. Colluvial layers were deposited during periods of agriculture. They contained the organic material that was at the time of erosion present in the soil horizons near the soil surface. The content of organic carbon is higher in colluvial layers near the surface compared with deeper colluvial layers. This is on the one hand the result of the decomposition of organic material since its deposit. On the other hand the content of organic matter may have varied already when the layer was deposited (Fig. 5.13).

In colluvial layers under current agricultural land use with increasing depth the C/N ratio increased. This can be related to the variation of land systems in time. Namely during Neolithic age and Bronze age land use was characterized by a lack of fertilizers, by an export of organic matter with the yielded crops and then a leaching of the soil. In the periods without agricultural land use woodland was growing. Leaching also dominated in the woodland, namely when it was grazed intensively. Thus the early land-use systems were characterized by leaching. As a result C/N ratios were relatively high, soil fertility was low. Today the intensive use of fertilizers and of lime in agroecosystems results in relatively low C/N ratios (Fig. 5.14 a, b).

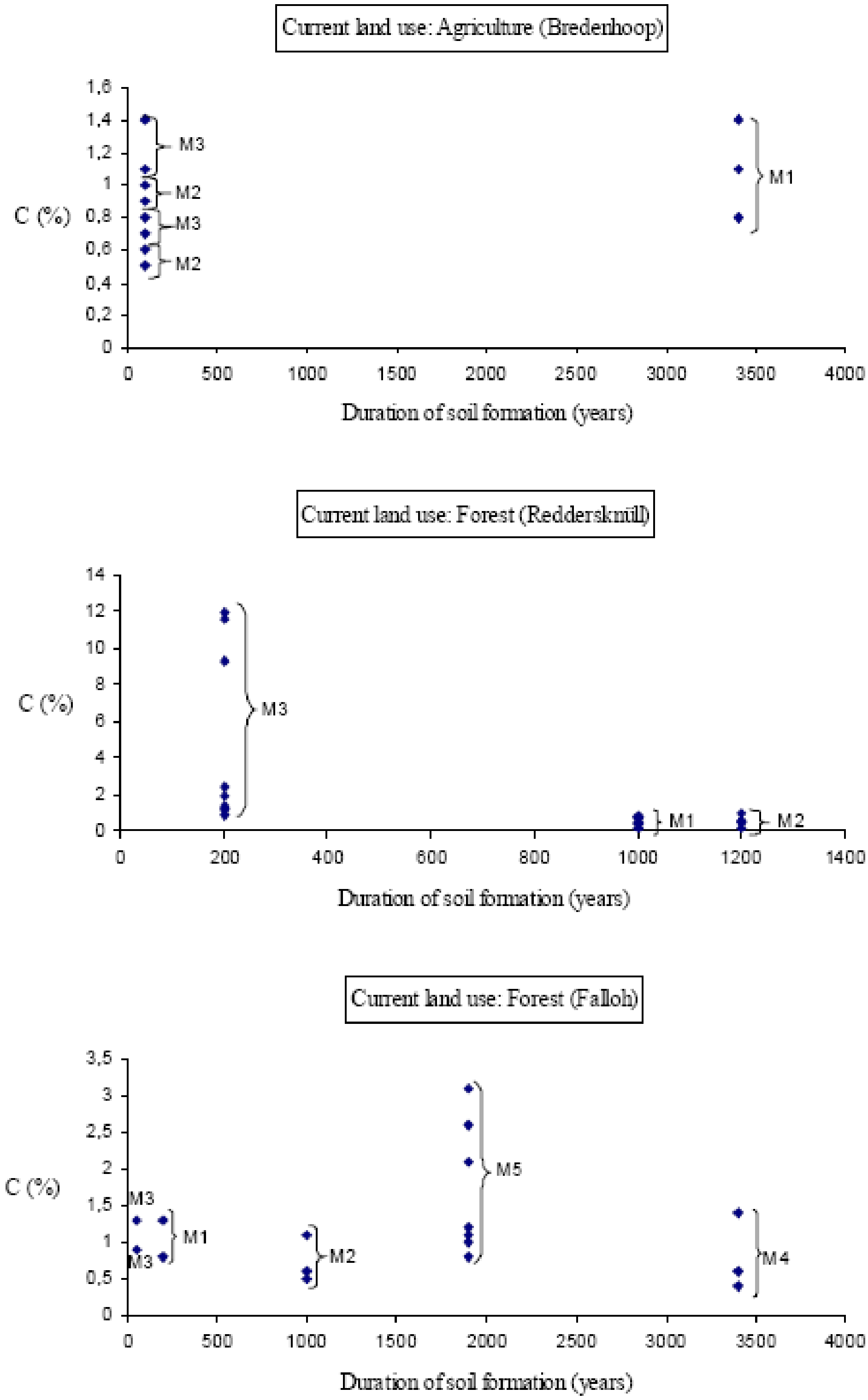


Fig. 5.12 Comparison of soil organic carbon content in different colluvial layers (M) with duration of soil formation under different current land use.

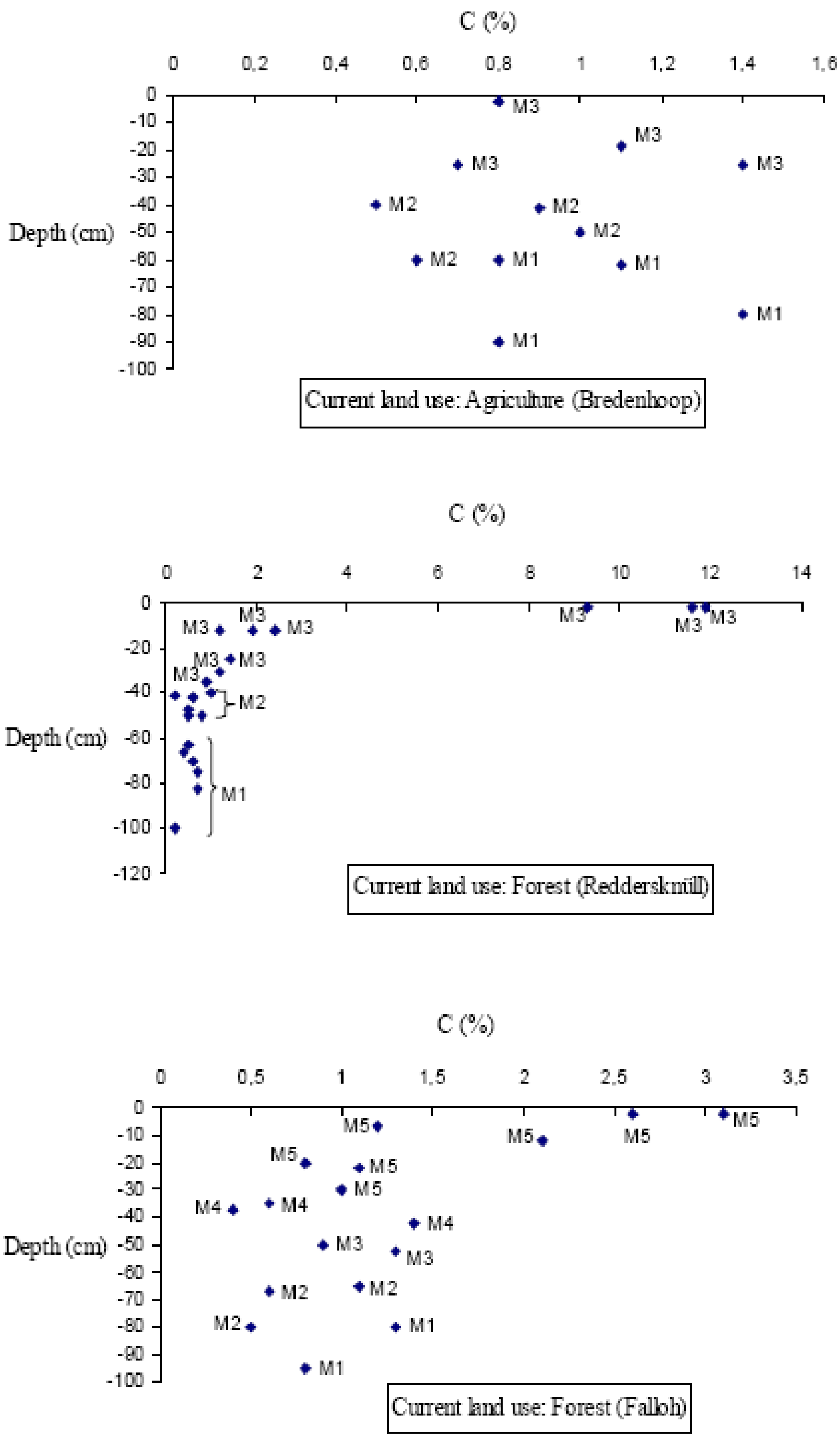


Fig.5.13 Comparison of soil organic carbon content in different colluvial layers (M) with depths under different current land use.

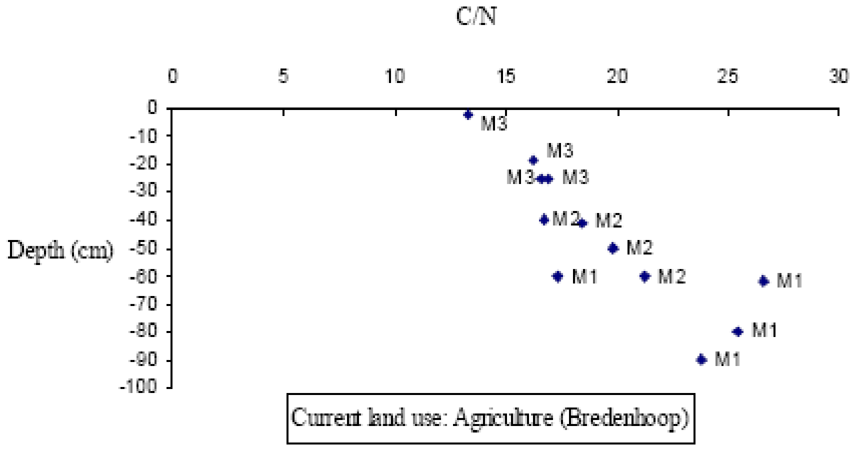
The relationships between clay content, depth and the duration of soil formation processes in colluvial layers are very complex.

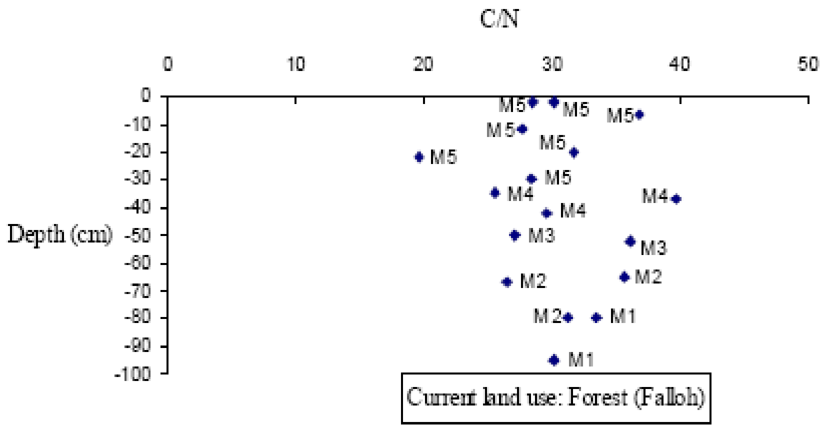
With respect to figures 5.10 ,a,b the clay content in colluvial layers is the result of erosional and depositional processes and less the result of in-situ-weathering (The primary clay content in the soils which developed in colluvial sequences is very low and the duration of soil formation is at most sites short and thus the amount of new formed clay minerals is low). At the same sites the low vertical change of clay contents is the result of initial illuviation over long periods. In lower colluvial layers (M1) there is a significant difference between clay content of different layers. This is mainly the result of the depositional processes, the local micro-topography and different intensities of the rainfall events that caused runoff and erosion. Initial leaching of clay mineral occurred and is represented in clay enrichment bands.

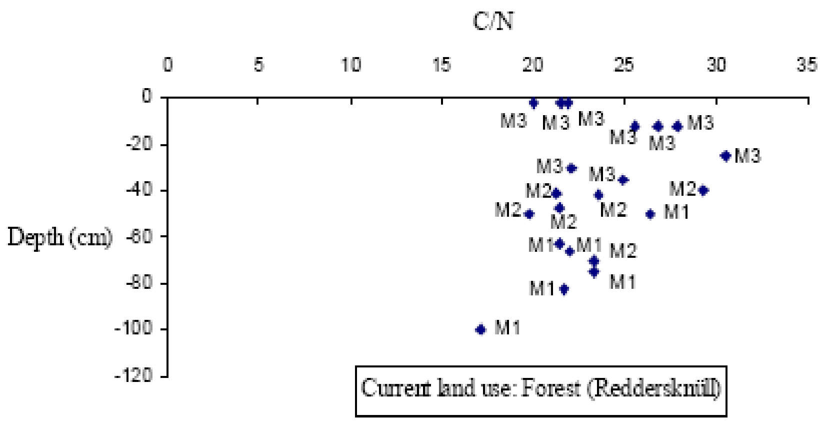
The results of soil sampling and analysis at Hof Ritzerau (Table 5.2 a,b) show that there is no significant change of the organic carbon content with depth in different colluvial layers. It is important that the content of organic carbon in colluvial layer M1 is higher than in the upper (younger) layers and more or less similar to the content in the surface layer. A comparison of the duration of the soil formation with organic carbon content indicate soil formation in colluvial layer M1 was not so intensive, especially in profile 1 where a buried soil was found (Fig.5.15).

With respect to table 5.3 a situation comparable to Hof Ritzerau was found in the soil profiles which were investigated at Lake Belau. At this site a buried soil with a high content of organic matter was found in collvial layer M1. Layer M1 with two soil horizons (Ah, Cv) represents a modification of the parent material (collvial layer) under a forest cover (Fig.5.16). No significant soil formation was found in the upper layers which indicate insufficient time for soil formation processes. Only illuviation started in these colluvial layers (initial B(t)).

a)


C/N
Depth (cm)
M3
M2
M1
Current land use: Agriculture (Bredenhoop)


C/N
Depth (cm)
M5
M4
M3
M2
M1
Current land use: Forest (Falloh)


C/N
Depth (cm)
M3
M2
M1
Current land use: Forest (Redderskmill)

b)

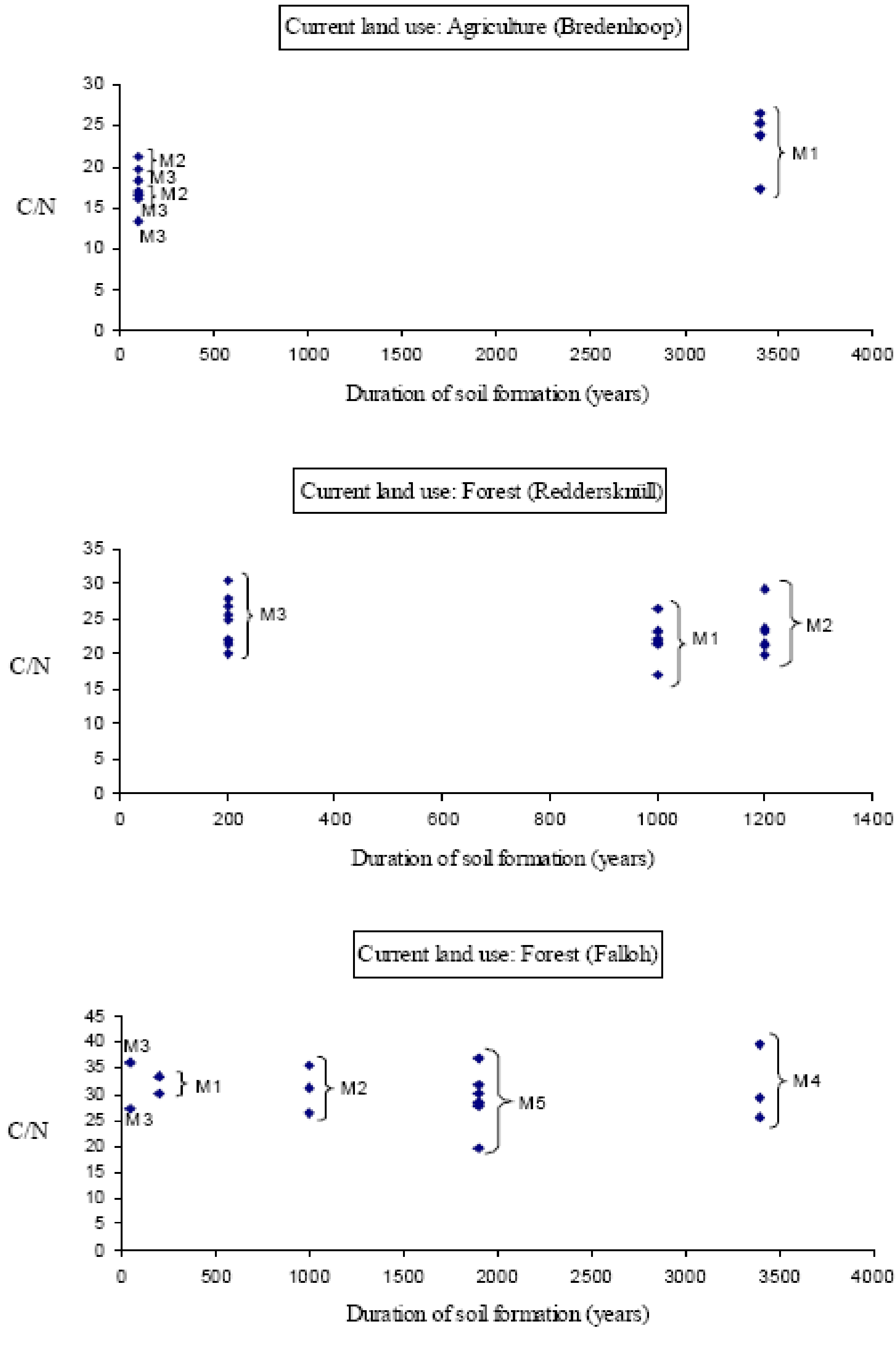
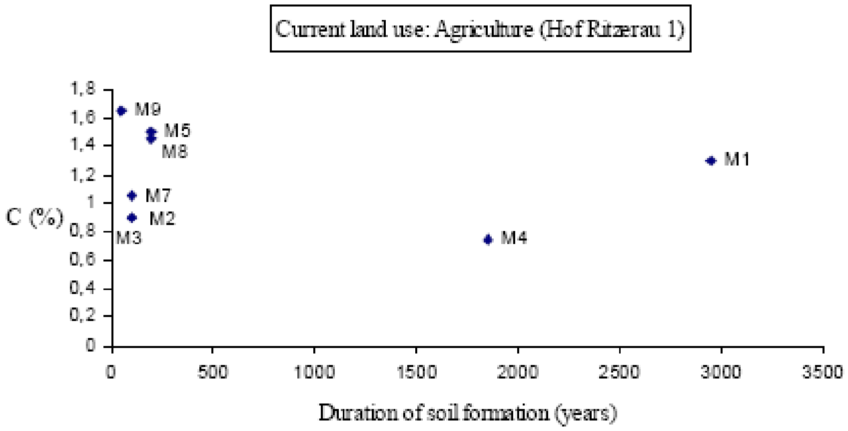
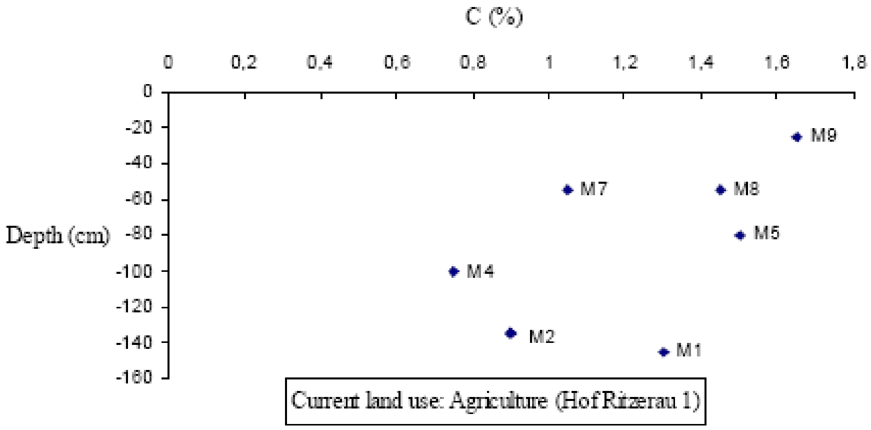


Fig. 5.14 Comparison of C/N ratio: a) with depth; b) with duration of soil formation in colluvial layers (M) under different current land use.





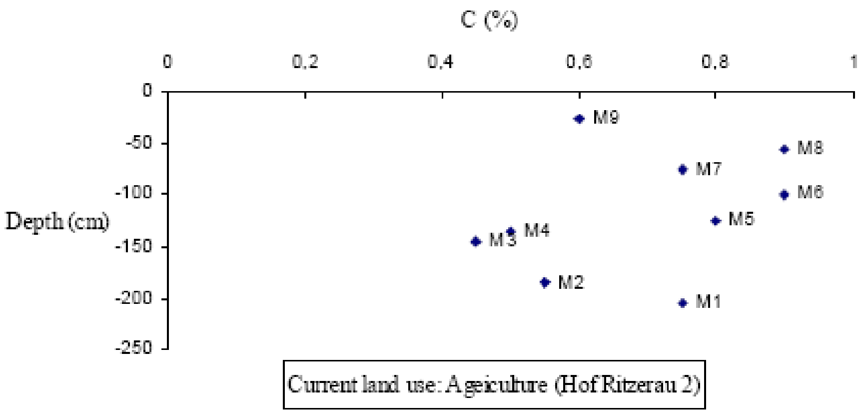


Fig 5.15 Comparison of soil organic carbon with depth and with duration of soil formation in colluvial layers (M).

Table 5.2 Field and laboratory data for soil and colluvial layers from Hof Ritzerau a) Excavation 1 b) Excavation 2 (modified after Bork et al, 2006)

a)

Duration of soil formation (years)	Depths (cm)	C (%)	Clay (%)	Silt (%)	Sand (%)	Colluvial layer
50	25	1,65	7,2	33,9	42,8	M9
200	55	1,45	7,3	63,7	72,4	M8
100	55	1,05	6,8	62,9	70,8	M7
200	80	1,5	7,1	88,6	97,1	M5
1850	100	0,75	7,1	107,8	115,6	M4
100	135	0,9	ns	ns	ns	M3
100	135	0,9	6,6	142,5	149,9	M2
2950	145	1,3	9,3	155,6	166,2	M1

b)

Duration of soil formation (years)	Depths (cm)	C (%)	Clay (%)	Silt (%)	Sand (%)	Colluvial layer
50	25	0.6	2,2	17,3	63,3	M9
600	55	0.9	2,5	27,1	70,4	M8
100	75	0.75	6,3	27,6	66,1	M7
50	100	0.9	2,4	28,2	69,3	M6
1600	125	0.8	1,8	27,2	71	M5
1600	135	0.5	1,0	27	72,1	M4
1600	145	0.45	1,1	22,4	76,5	M3
100	185	0.55	4,1	26,4	69,5	M2
100	205	0.75	3,8	25,5	70,7	M1

Table 5.3 Field and laboratory data for soil and colluvial layers from Lake Belau

Colluvial layers	Gravel (%)	Coarse-Sand (%)	Medium-Sand (%)	Fine-Sand (%)	Coarse-Silt (%)	Medium-Silt (%)	Fine-Silt (%)	Clay (%)	Org. matter (%)
	>2000 mm	<2000 >630 mm	<630 >200 mm	<200 >63 mm	<63 >20 mm	<20 >6.3mm	<6.3 >2 mm	< 2 mm	
M5 (Ap)	3,1	5,3	29,9	33,5	6,3	6,1	3,2	6,0	9,35
M5	5,2	6,4	33,4	33,0	6,8	5,8	3,8	5,4	3,25
M4	4,1	4,9	26,8	37,6	7,6	7,2	4,4	5,4	4,35
M3b	5,6	4,5	29,3	33,1	6,6	6,6	3,8	5,0	5,60
M3a	4,7	5,3	25,0	40,4	10,0	7,0	4,0	3,8	4,10
M2	5,3	5,1	29,4	38,9	11,6	7,4	3,9	4,3	4,00
M1 (Ah)	3,9	4,9	26,7	37,6	12,0	7,5	4,3	3,2	7,04
M1	3,5	5,9	29,4	37,6	8,8	7,6	3,9	3,2	4,1

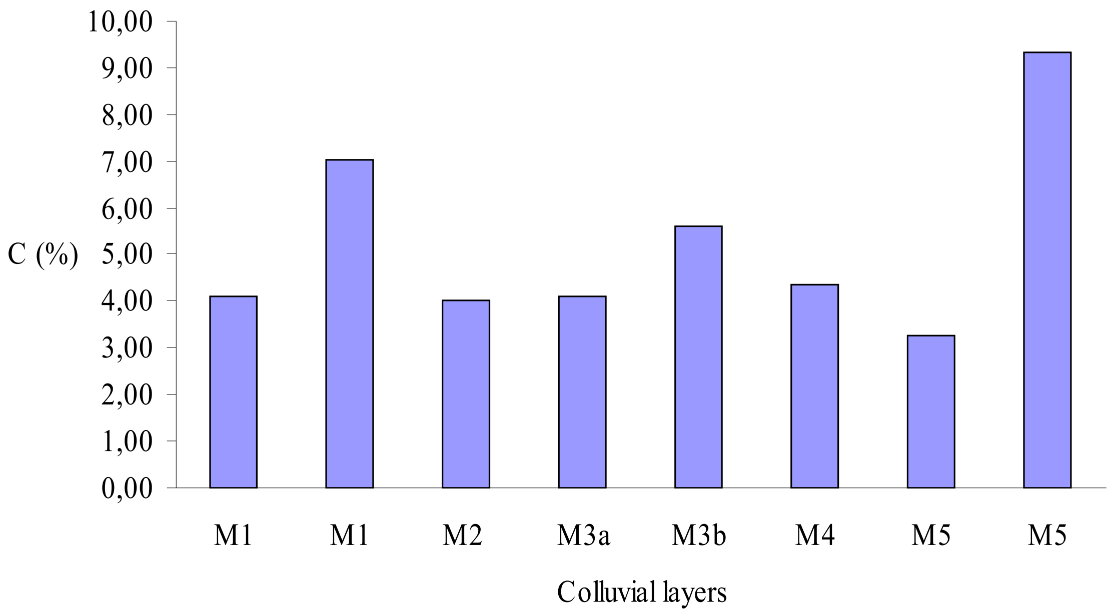


Fig 5.16 Comparison of soil organic carbon in different colluvial layers (investigation area Lake Belau).

5.4.2. Past Land-Use Changes and Soil Formation

In order to estimate how humans have influenced soil formation processes, soil structures and soil types, an outline is given from prehistoric time until the present.

After the change from cold to warm climate at the beginning of Holocene, woodland developed on Pleistocene sediments. No soil erosion occurred in the woodland since it protected the soil surface perfectly. This is proven by a total lack of colluvial and alluvial layers for the early Holocene at all sites under investigation.

Initial human interference with a local change of the woodland to agricultural land started in Neolithic Age. Soil erosion due to heavy rainfall and locally unprotected soil surfaces took place for the first time during Holocene at the sites under investigation near Albersdorf and Ritzerau. As a result of this early erosion processes the first colluvial layer (M1) was accumulated on fluvioglacial sand.

The intensification and the extension of cultivation led to accelerated soil erosion then. As a result of the removal of the upper soil horizons soil fertility and productivity decreased because the thin Cambisol which developed in early Holocene was eroded and the C-horizon was exposed. After a few years of agricultural land use soil fertility was reduced so dramatically that intensive land use had to stop. In the following decades grazing in an open landscape with heath vegetation dominated. First Combisols (Ah-Bv-Cv) and then Luvisols (Ah-Ae-Bt-Cv) developed, later Podsols (Ah-Ae-Bs/v-Bv-Cv) in the grazed areas.

Clearing of woodland by humans has been started again and soil was leached as a result of cultivation practices. Evidence in soil profiles shows that the upper horizons of the Combisol/Luvisol (Ah/Ae) were changed to an Ap-horizon. Soil stability gradually decreased under the reduction of the content of organic matter due to the export of crops from the site. This situation caused more soil erosion and soil deposition, too. The results of these processes are soil erosion and the deposition a colluvial layer (M2) and as a result the colluvial layer of M1 was buried at the investigation sites near Albersdorf and Ritzerau.

The continuation of soil erosion processes caused the reduction of soil fertility. Therefore, first grazing in open land and then the succession and formation of new woodland took place in abundant areas (third period of woodland during Holocene). This situation stabilized the surface. Therefore intensive soil formation took place under woodland in the colluvial layer M2 (formation of Cambisol/Luvisol). Moreover, with the change of woodland types (the planting of coniferous trees) during the second half of the 20th century a further intensification of soil formation occurred (development of an initial Podsol with Ah-Ae-Bs/h and Cv horizons).

The middle and late Holocene colluvial sequence with ages of the colluvial layers based on radio carbon dating in Hof Ritzuire are presented in figur 5.17.

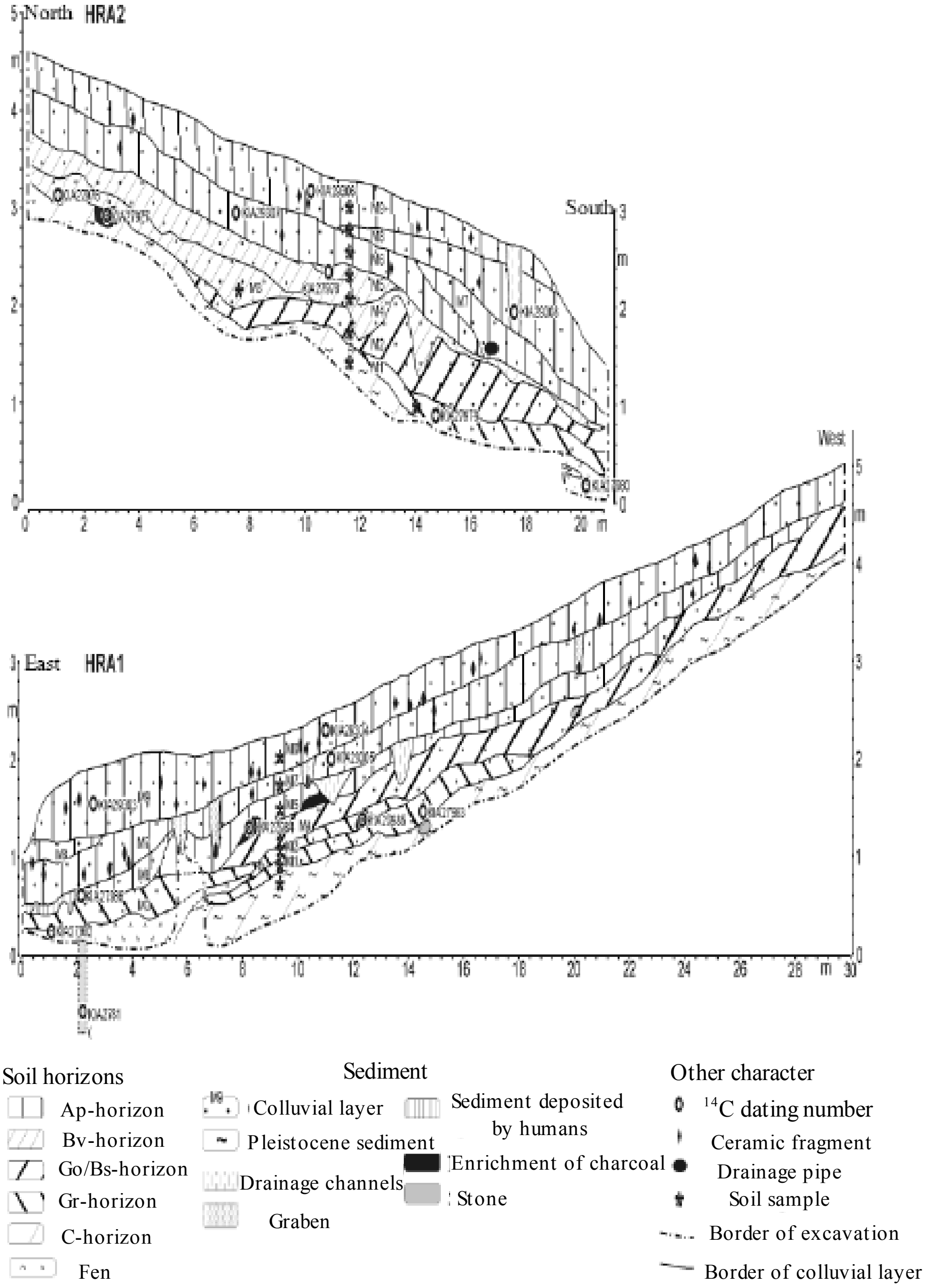


Fig. 5.17 Profile HRA1 and HRA2 at Hof Ritzerau (modified after Bork et al., 2006)

5.5. A Study of the Relationship between Soil Stability and Soil Organic Matter Content

Soil aggregate stability is an important indicator of soil physical quality (Castro Filho et al., 2002). Land use and management also influence soil aggregation and aggregate stability (Bergkamp and Jongejans, 1988; Cerda, 2000). Soil organic matter certainly improves the ability of the soil to resist erosion and enables the soil to hold more water. Important is its effect in promoting soil aggregation in a granular soil and the combination of increased water penetration (Stevenson and Cole, 1999). Soil organic matter content has a direct relationship with soil erodibility. The stability of soil aggregates is enhanced where organic material is combined with clay particles and where it contributes to chemical bonding (Morgan, 1986). Generally, soils with a higher content of organic matter and an improved soil structure have a greater resistance against soil erosion by water and wind. Continuous soil erosion has a significant effect on soil erodibility. In the research areas the material below a soil which was totally eroded is often more erodible because of its low organic matter content, its lower clay content and its different structure. Low aggregate stability enforces soil erosion.

Erodibility as a dynamic property of a soil depends on the stability of soil aggregates and the percentage of coarse primary particles that are resistant to erosion (Morgan, 1986). The soil erodibility is ‘the inherent susceptibility of soil particles or aggregates to become detached or transported by erosive agents such as rainfall, runoff, wind and etc’ (Toy et al., 2002; Morgan, 2005). With regard to this definition it has to mentioned that soil erodibility usually changes with land use, because cultivation practices modify soil structure; with the continuation of this change soil erodibility will be increased. Moreover, when subsoil with different textural characteristics is mixed into the plow layer, soil structure and water regime may be affected (Schumacher et al., 1999). In this case it is necessary to improve our understanding of the effects of land use on soil stability in order to develop a high level of soil quality and especially productivity.

The soil structure depends namely on the grain size distribution, on soil formation processes and the effects of plants, animals and humans. Freezing and thawing, water movement, the growth and decay of plant roots and the activity of soil animals (e.g. Earth worms) as natural factors on the one hand and human activities (namely management practices) on the other can cause in rearranging of particles in soil aggregates. Therefore in many cases the structure of a soil directly affects its properties (Marshall et al., 1996). A low status of organic matter (naturally low or due to soil degradation) is an important reason for the instability of soil aggregates. Many agricultural practices affect soil structure. Decrease in both the stability and the organic matter of soils under annual tillage has been observed by several researchers (e.g. Low, 1972; Allen, 1985; Gami et al, 2001; Caravaca et al., 2001).

Shrestha et al. (2007) indicated that the knowledge of soil aggregate stability is useful in the evaluation of soil properties with regard to land use systems. With respect to the review which was carried out by Shrestha et al. (2007), land use and management practices have a strong effect on soil properties, especially on aggregation and soil organic carbon dynamics. These effects vary spatially and temporally. Shrestha et al. (2007) also stressed that there is a lack of information on the mechanisms and magnitudes of soil organic carbon dynamics associated with aggregate- and particle-size fractions under different land uses.

5.6. Assesment of Soil Aggregate Stability under Different Land-use Systems

The main objective of the this part is to estimate the effects of land use on soil instability. Moreover, the relationship between instability and depth in a soil is also evaluated.

Two sites with different land-use systems were selected near Albersdorf. One site is covered today with forest (Reddersknüll) and another site is used as farmland (Bredenhoop). Soil samples were collected from the surface to a depth of 85 cm at three profiles in each site.

After field and laboratory analysis, the soil instability index was calculated (Table 5.4 a,b). This index was proposed by Combeau and Monnier (1961). It is based on soil structural characteristics which have been proved useful in predicting erosion risks for a wide range of soils (Cotler, 1998). This index is obtained from the formula:

$$\boldsymbol{Is = \frac{\%\ maximum\ (clay + silt)}{\%\ mean\ coarse\ fragments - 0.9\ (\%\ coarse\ sand)}}$$

Is: Instability index

This index varies from 0 to 3; 3 is the highest structure instability.

Table 5.4 Results from the calculation of the soil instability index a) in two current land use systems in the surface layer (0-30cm) b) in forest area from the surface to a depth of 85 cm.

a)

Forest			Agriculture		
Is	C%	N%	Is	C%	N%
0,34	9,3	0,47	1,56	1,4	0,09
0,38	11,9	0,55	1,67	0,7	0,04
0,53	1,2	0,04	1,16	0,8	0,06
1,48	1,9	0,07	0,76	1,1	0,07
1,18	2,4	0,09	-	-	-
0,89	1,4	0,05	-	-	-
0,66	1,2	0,05	-	-	-
0,07	11,6	0,55	-	-	-
0,69	**5,11**	**0,23**	**1,26**	**1**	**0,06**

b)

Is	Depth(cm)
0,4	5
1	15
0,8	25
1,1	35
1,2	45
1,3	55
1,4	65
1,5	75
1,5	85

The comparison between instability index in different land use systems at the time of sampling, clearly indicates that soils under agricultural land use (0-30cm) have an in-stability lower than forest soils. Therefore the results confirm that land use has had a significant effect ($P < 0.05$) on aggregate stability (Fig. 5.18).

A positive relationship (Fig. 5.19) was found between soil instability index (Is) and depth (0-85 cm). The graph in Fig. 5.20 demonstrates that with an increase of depth soil instability increases. This could be affected by a decrease of soil aggregate size. A sharp change of the instability index between a depth of 10-20 cm is important. This confirms that after the removal of the surface horizon a soil is highly erodible; in this case intensive soil erosion may take place. The investigation also suggests that the soil aggregate stability is important to provide a condition for the stabilization of organic matter in soils and also for chemical, physical and biological activities.

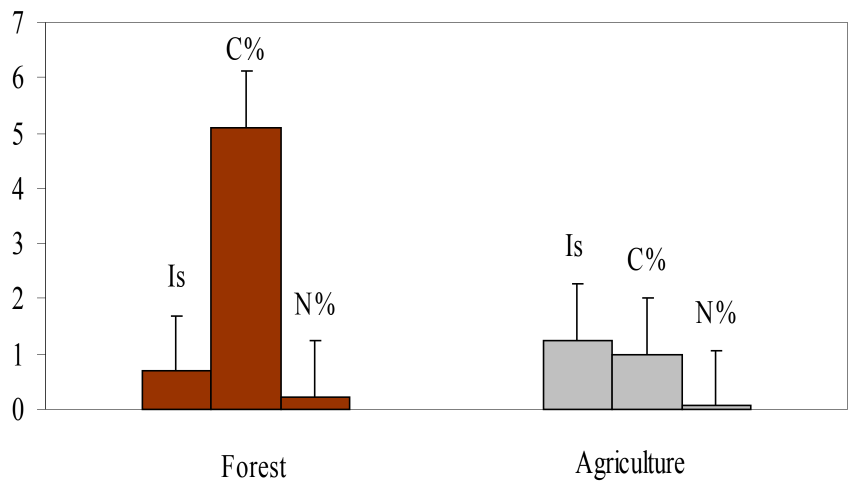


Fig. 5.18 Comparison of soil instability index, organic carbon and nitrogen content of two land-use ecosystems.

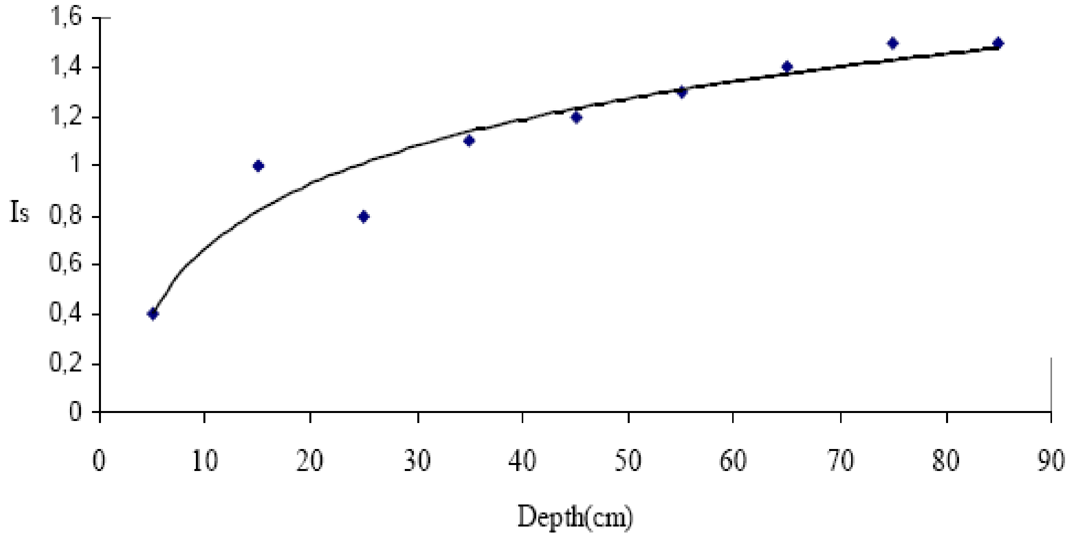


Fig. 5.19 Comparison between the soil instability index (Is) and depth in soils of the forest ecosystem.

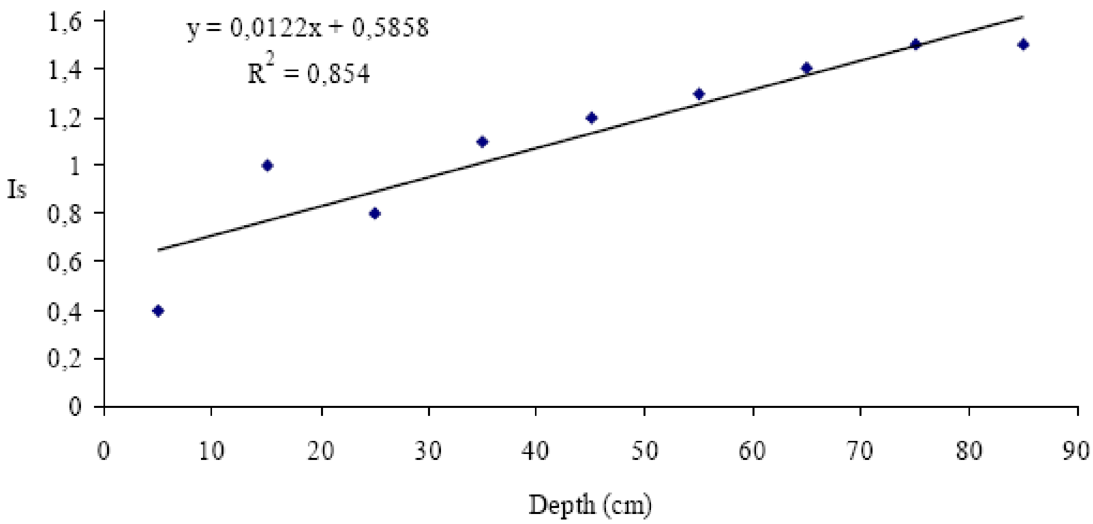


Fig. 5.20 A positive linear relationship (R^2 = 0.85) between the soil instability index (Is) and depths in soils of the forest ecosystem.

Chapter 6
Conclusions

Soil formation and soil degradation are two important and complex process-systems in ecosystems. They are closely related to land-cover and land-use changes. In order to study soil formation and degradation, there are several indexes to determine the trend and behavior of soils under different land-use systems. The indexes are classified:. One type of indicators represent the dynamics of the physical, chemical, and biological conditions of soils. A second type are external indicators which are affected by land use/land cover decision-making, and when and why the land was used and how management effected soils. According to this approach the study of soil formation and degradation was carried out in this investigation.

The results show in general that human activities, with respect to past deforestation and then intensive agricultural practices have had an effective influence on soil formation processes and the changes of soil properties.

Our investigations prove that time and parent material (characteristics of the colluvial layers) are the two main factors of natural soil formation in colluvial layers. Moreover land use changes as an anthropogenic factor have usually accelerated, changed or prevented natural processes of soil formation.

Soil age information together with geomorphological data, physical, chemical and biological soil properties provide the database which is necessary to study the types and rates of soil formation in colluvial layers.

The monitoring of soil formation in middle and late Holocene colluvial layers informs us about the past soil genesis for different time spans under different land-use systems. Under these conditions soils formed in similar parent materials (i.e. colluvial layers) and topographic positions. Attention has to be paid to the factors time, vegetation cover and land-use changes, too.

Land use and time were significant factors for the formation and degradation of soils in middle and late Holocene colluvial layers in the investigated areas. The findings about the relevance of the factors mentioned also help to evaluate scenarios of possible future formation and degradation of soils.

Long-term land-use dynamics and management have a major impact on soil productivity. The detailed investigations of the soil profiles in the research areas indicate that Cambisols (Ah-Bv-Cv) and Luvisols (Ah-Ae-Bt-Cv) with initially a moderate fertility formed under woodland dominated by broad-leaved trees such as oak trees and beech trees. Podsols (Ah-Ae-Bs/h-Bv-Cv) developed in poor sand when the soil was used intensively or under a coniferous forest. An increased demand of wood caused a change of the tree composition during the 19th and the 20th centuries; namely coniferous trees were planted which changed and intensified soil formation processes: Podsols (with Ah-Ae-Bs/h and Cv horizons) started to develop.

In order to study recent processes in soils under different land-use system, a soil instability index was calculated. The results show that soil aggregates have a different behavior under different land-use systems. The soil instability index in agriculturally used areas was higher than in forest area as a result of the structural degradation at the soil surface; also the soil instability index in forest areas was higher with increasing depth under the soil surface. This change in the values of the instability index is related to a change of organic mater content with depths.

Human activities directly and indirectly effect the fertility of soils. Our investigations acknowledge that the change of soil management over long periods have had a significant impact on the soil fertility. Evidence in our investigation areas prove that the soil conditions have a significant relation with the decision-making in the past. This decision-making accelerated soil formation and increased chemical, physical and biological soil degradation.

Results also show that the change of the tree composition during the 19th and the 20th centuries have not had a significant effect on soil erosion as a external aspect of soil degradation but caused acidification which is one of the important aspects of the internal soil degradation.

Our study indicated that the use of an inter- and multidisciplinary approach with a historical perspective for different times and areas can help to reconstruct long-term natural and human-induced soil degradation.

This study also proves that colluvial sediments as an natural archive preserve several human effects in environment. Therefore soil erosion and sedimentation as visible parts of the soil degradation regarding the colluvial sediments provide a reliant indicator to study different aspects of the human-induced soil degradation.

In conclusion, it could be emphasised that the impact of human activities on soils is un-avoidable; in many cases negative effects will be multiplied by land mismanagement. The study of the effects of the past and current land-use changes prepare the part of the best solution to control soil degradation. Therefore having a good knowledge from the past and about current soil degradation helps to get a successful strategy against unwanted soil changes in order to achieve a sustainable management of the soils in the future.

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Statement

I explain that the present thesis, apart from the consultation of my supervisor in the six chapters, was made independently by myself and that it is my own work after form and contents. It was presented to no other place within the scope of an examination procedure. This is my only and doctorate procedure first up to now. The doctorate should occur in the field Physical Geography. Furthermore, I explain that I will admit listener with the Disputation.