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Cosmogenic, anthropogenic, and airborne radionuclides for tracing the mobile soil particles in a tile-drained heavy clay soil

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Abstract

The atmospherically-derived cosmogenic (^7Be), anthropogenic (^{137}Cs), and airborne radionuclides ($^{210}\text{Pb}_{\text{xs}}$) were used to investigate the origin and travel time of the mobile soil particles discharged from the tile drain in a heavy clay soil. These radionuclides were accumulated mainly in the surface layer of the soil profile; nevertheless, they were detected with high activities in all the mobile soil particle samples collected from the tile drainage water in a rainfall event. This indicates that the major origin of the mobile soil particles discharged from the tile drain is the mobile soil particles in the uppermost surface soil. The average travel time of the mobile soil particles moving from the uppermost surface soil to the tile drain is estimated as about 35 d based on the difference in the activity ratio ($^7\text{Be}/^{210}\text{Pb}_{\text{xs}}$) of the mobile soil particles between in the surface runoff and in the tile drainage waters.

Key Words

^7Be , ^{210}Pb , ^{137}Cs , half life, travel time.

Introduction

The mobile soil particle is important as a carrier of environmental pollutants of poor water solubility or strong adsorptivity such as phosphorus, heavy metals, etc (Kretzschmar *et al.* 1999; Suzuki *et al.* 2005). This study tried to determine the origin and travel time of the mobile soil particles discharged from the tile drain in a heavy clay soil under field conditions. We applied an environmental radioisotope tracer technique using the atmospherically-derived cosmogenic (^7Be), anthropogenic (^{137}Cs), and airborne radionuclides ($^{210}\text{Pb}_{\text{xs}}$) that has been developed for determining the watershed-scale transit time of sediments in surface water systems (Bonniwell *et al.* 1999; Matisoff *et al.* 2005).

Methods

Study site

The study was conducted in a soybean field (100 × 30 m) of the Hokuriku Research Center, Niigata prefecture, Japan. The soil is a smectitic heavy clay soil classified as a fine-textured Mottled Gley Lowland soil (Cultivated Soil Classification Committee 1995). The tile drains are installed at a depth of 65 cm.

Radionuclide activity in bulk soil

The soil to a depth of 20 cm was sampled with depth increments of 1–5 cm by using a scraper plate (15 × 30 cm) (Loughran *et al.* 2002) and that between the depths of 20 and 100 cm was taken with a depth increment of 10 cm by using a soil auger with a diameter of about 6.5 cm. The soil samples were air-dried and the activity of bulk soil radionuclides (^7Be , ^{137}Cs , ^{210}Pb) was measured by gamma spectrometry.

Radionuclide activity in mobile soil particles in surface runoff and tile drainage waters

The surface runoff and tile drainage waters (~20 L) were collected with a peristaltic pump with a time interval of several hours during and just after a rainfall event. The water samples were filtered with a membrane filter with a pore size of 0.025 μm to collect the mobile soil particles.

Results

The atmospherically-derived cosmogenic (^7Be), anthropogenic (^{137}Cs), and airborne radionuclides ($^{210}\text{Pb}_{\text{xs}}$ = total ^{210}Pb – supported ^{210}Pb ; see Figure 1) were accumulated mainly in the surface layer of the soil profile (Figure 1). The short-lived (half life = 53.1 d) radionuclide, ^7Be , as well as the long-lived radionuclides, ^{137}Cs and $^{210}\text{Pb}_{\text{xs}}$, were detected in all the mobile soil particle samples collected from the tile drainage water (Table 1) and their activities were higher than those of the bulk soil (Figure 1). These results indicate that the major origin of the mobile soil particles discharged from the tile drain was the mobile soil particles in the uppermost surface soil and that the ^7Be -bearing mobile soil particles moved quickly through some preferential flow paths such as the large cracks frequently observed in the heavy clay soil. The average travel time of the mobile soil particles moving from the uppermost surface soil to the tile drain is estimated as about 35 d (Figure 2) based on the difference in the activity ratio ($^7\text{Be}/^{210}\text{Pb}_{\text{xs}}$) of the mobile soil particles between in the surface runoff and in the tile drainage waters.

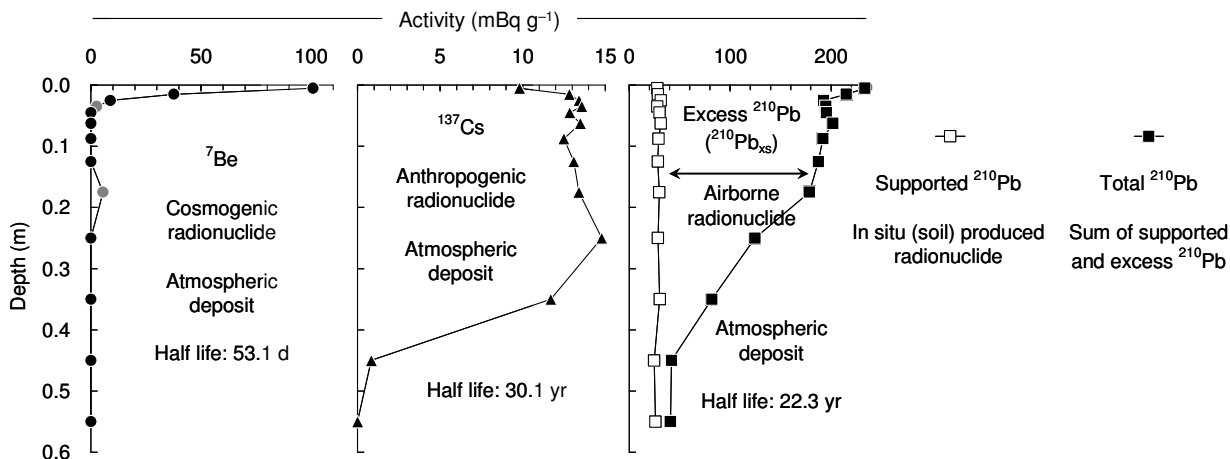


Figure 1. Vertical profiles of the bulk soil ^7Be , ^{137}Cs , and ^{210}Pb activities in the heavy clay soil. The gray plot for ^7Be indicates that the detected value was below the quantitation limit.

Table 1. Activity of atmospherically-derived radionuclides (^7Be , ^{137}Cs , $^{210}\text{Pb}_{\text{xs}}$) in mobile soil particle samples collected from the surface runoff and tile drainage waters in a rainfall event on 21–22 November 2008. Numerals in parentheses are standard deviations ($n = 4$ for surface runoff; $n = 5$ for tile drainage).

	^7Be (mBq g ⁻¹)	^{137}Cs (mBq g ⁻¹)	$^{210}\text{Pb}_{\text{xs}}$ (mBq g ⁻¹)	Activity ratio $^7\text{Be}/^{210}\text{Pb}_{\text{xs}}$
Surface runoff	1126 (±72)	16.7 (±1.5)	483 (±42)	2.26 (±0.30)
Tile drainage	555 (±86)	20.3 (±0.8)	371 (±73)	1.45 (±0.17)

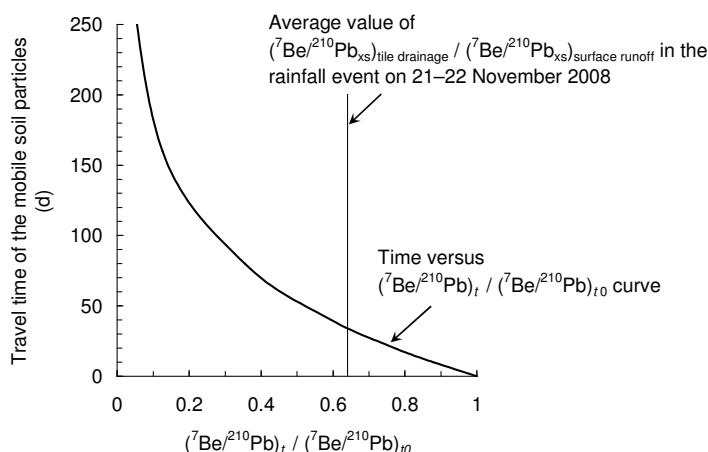


Figure 2. Estimation of the travel time of the mobile soil particles moving from the soil surface to the tile drain based on the difference in the activity ratio ($^7\text{Be}/^{210}\text{Pb}_{\text{xs}}$) of the mobile soil particles between in the surface runoff, ($^7\text{Be}/^{210}\text{Pb}_{\text{xs}}$)_{surface runoff} and in the tile drainage waters ($^7\text{Be}/^{210}\text{Pb}_{\text{xs}}$)_{tile drainage}.

Conclusion

The high activities of the atmospherically-derived cosmogenic (^7Be), anthropogenic (^{137}Cs), and airborne radionuclides ($^{210}\text{Pb}_{\text{xs}}$) of the mobile soil particles in tile drainage water indicate that the major origin of the mobile soil particles discharged from the tile drain is the mobile soil particles in the uppermost surface soil. The average travel time of the mobile soil particles moving from the uppermost surface soil to the tile drain is estimated as about 35 d based on the difference in the activity ratio ($^7\text{Be}/^{210}\text{Pb}_{\text{xs}}$) of the mobile soil particles between in the surface runoff and in the tile drainage waters.

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Development of soil properties in a riverine floodplain with time – results from a chronosequence study in the National Park Donau-Auen in Austria

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Abstract

Recently, we established a chronological framework for fluvial deposits along a soil sequence at the Danube River near Vienna, Austria, using optically stimulated luminescence (OSL) dating. We identified fluvial deposits from different time periods ranging from the early last millennium BC to the 18th century AD. We bridged the gap from the 18th century AD to the present with fallout ¹³⁷Cs dating, and developed a chronofunction model relating Fe oxide crystallinity (Fe_o/Fe_d) to deposition age along the studied soil sequence model relating Fe oxide crystallinity (Fe_o/Fe_d) to deposition age. This model allows age estimation of soil layers using routinely measured pedological characteristics (Fe_o/Fe_d). We examined specifically the build-up of soil organic matter, the redistribution of phosphorus among biogeochemical pools and the retention of pollutants related to soil development. We found rapid C accumulation during the initial 100 years of soil formation, with rates exceeding those in northern peatlands by an order of magnitude. We showed that floodplain land use strongly affects soil C sequestration and pool allocation, and found that the distribution of different C pools reaches a steady state within less than a century. Our results demonstrate that continually rejuvenated soils on riverine floodplains are strong C sinks, but also show that intensive cultivation severely compromises their high C sequestration potential. The youngest soils were dominated by calcium-associated phosphorus (CAP), in less than 100 yrs of pedogenesis, CAP markedly decreased and organic phosphorus (OP) increased, and in less than 180 yrs, OP reached CAP levels. Adsorption properties of the floodplain soils changed, governed specifically by OC accumulation and Fe-oxide and hydroxide accumulation with time. The soil retention capacity for Cd and Cu increased with increasing soil age.

Key Words

Chronosequence, floodplain soils, phosphorus, pollutant retention, soil organic matter.

Introduction

Ecosystems progressively evolve through the actions of biogeochemical processes over time. Soil studies across substrate age gradients (chronosequences) have enhanced our understanding of directions and rates of biogeochemical processes under different environmental conditions (Huggett 1998). On riverine floodplains, most chronosequence studies have covered thousands to millions of years and quantified long-term pedogenic changes, such as clay accumulation and translocation, the formation of pedogenic carbonate and silica, as well as increases in Fe oxide contents and crystallinity. By contrast, biogeochemical processes acting at shorter time scales, such as organic matter (OM) dynamics, remain poorly understood in floodplain soils, and short-term rates of change have rarely been quantified. However, in light of global change, a better understanding of C dynamics is essential for an improved assessment of the role of riverine floodplains in the global C cycle and biogeochemical cycle of elements in general. The objective of our study was, therefore, to bridge this knowledge gap and quantify the rates of organic C accumulation, changes of C pools, dissolution of primary mineral phosphorus and changes in contaminant retention properties in a riverine floodplain in Central Europe that have experienced different land use history.

Methods

Study area

The study area is located east of Vienna, Austria, in the National Park “Donau-Auen” (Figure 1). The area is situated in the tectonically active Vienna basin, which was formed in the Miocene when a subsidence of the basin occurred (Decker *et al.* 2005). Later, the basin inverted and more than 200 m of surface uplift occurred. During the Alpine glaciations, the Danube River continuously incised into the uplifted Tertiary basin fill and accumulated melt-water terraces. The floodplain is morphologically subdivided into two terraces called

“Younger part of today’s valley floor” (= alluvium) and “Higher and older part of today’s valley floor” (= Marchfeld fluvial terrace). We selected eleven representative sites at different geomorphic positions. Sites 4 and 11 are located on the older Marchfeld fluvial terrace, sites 5-10 on the younger alluvium and sites 1-3 on islands in the Danube River (Figure 1). The present main channel of the Danube River was created by a river regulation starting in 1870 and was at that time free of any islands. Thus, the studied island sites have evolved within the past 130 years (Fiebig and Preusser 2007). From 1882 to 1905, a dike was constructed to protect the area north of the Danube River from recurrent flood events and disconnected sites 7-11 from the river for the past 100 years (Figure 1). The recent floodplain consists of up to 20 m gravel and at many places several meters of fine sediments on top. The river regulation induced a higher flow velocity in the main channel and led to the deposition of predominantly silt- and fine sand-sized particles on the islands (sites 1-3). By contrast, the soils in the floodplain (sites 4-11) have considerably finer textures (Lair *et al.* 2007). The deposited sediments are dominated by dolomite and show medium to low amounts of quartz, plagioclase, K-feldspar, chlorite, kaolinite and mica (Haslinger *et al.* 2006). Most of the soils classify as Fluvisols and show progressing development with age towards the Chernozem group (IUSS Working Group WRB 2006; Lair *et al.* 2007). The study area experiences a continental climate with hot summers and cold winters (mean annual temperature ~ 9°C, C, mean annual precipitation ~ 550 mm).

Analyses

At each study site (Figure 1), we took three soil samples at the corners of an equilateral 15-m triangle using an 80-mm core drill. The samples were divided into the depth layers 0-5, 5-10 and 10-20 cm. At ploughed sites (sites 4, 8, 11), we took composite 0-20 cm cores. Suspended sediments from the 20 highest flood events between 1990 and 2006 were retrieved from a sediment trap located in the Danube’s main channel upstream of the studied floodplain. Depth profiles of fallout ¹³⁷Cs were used to assess short-term sedimentation, and optically stimulated luminescence (OSL) dating was used to attribute sediment deposits to time periods between the early last millennium BC and the 18th century AD. Total C was quantified by dry combustion, and carbonate C was measured gas-volumetrically. Organic C was calculated as the difference of total and carbonate C. Phosphorus fractionation was performed in duplicate according to the SMT protocol (Pardo *et al.* 2003). Sequential extraction was used to fractionate copper and cadmium in original and spiked soils in order to study the long-term and short-term behaviour of copper and cadmium retention (Vanek *et al.* 2005).

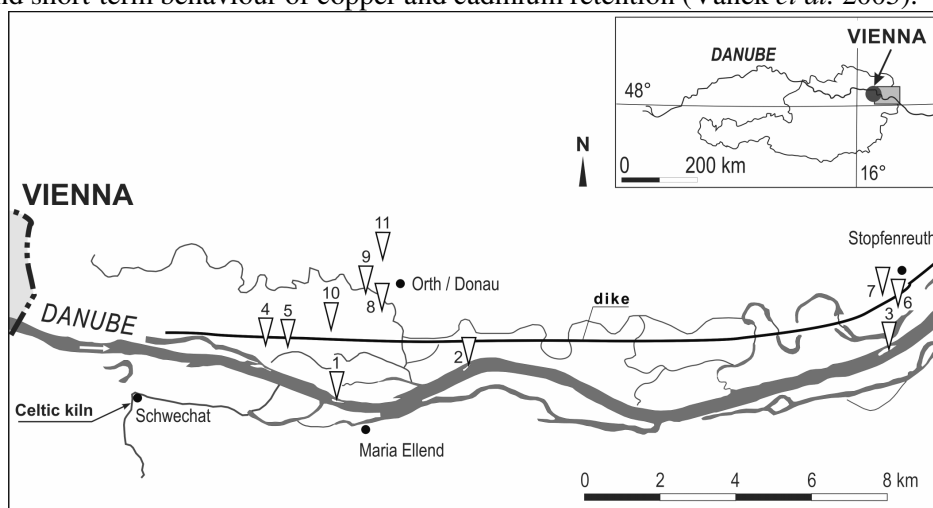


Figure 1. Map of the study area in the Danube floodplain with locations of sampling sites (▽) and an archaeological find near Schwechat. Sampling sites numbered 1 to 11 (elevation: 145-150 m a.s.l.). The chronofunction was further validated by dating a soil profile near the studied chronosequence that contained an archaeological find dated to the La Tène period (5th to 1st century BC) (Lair *et al.* 2009).

Results

In our soils the ratio of oxalate to dithionite-extractable iron (Fe_o/Fe_d), which indicates the degree of iron oxide crystallinity and can be a reliable indicator of soil maturity (e.g. McFadden and Hendricks 1985) progressively decreased from ratios greater than 0.5 to values less than 0.2 with increasing soil age (Figure 2A). We linked the observed Fe_o/Fe_d ratios to the radiometric and OSL ages in a chronofunction (Figure 2A), which allows to approximately date soil layers that lack an independent age control. The soil ages calculated with this chronofunction accurately reflected their geomorphological position, resulted in consistent age trends with depth and highlighted the active morphodynamics of the studied floodplain.

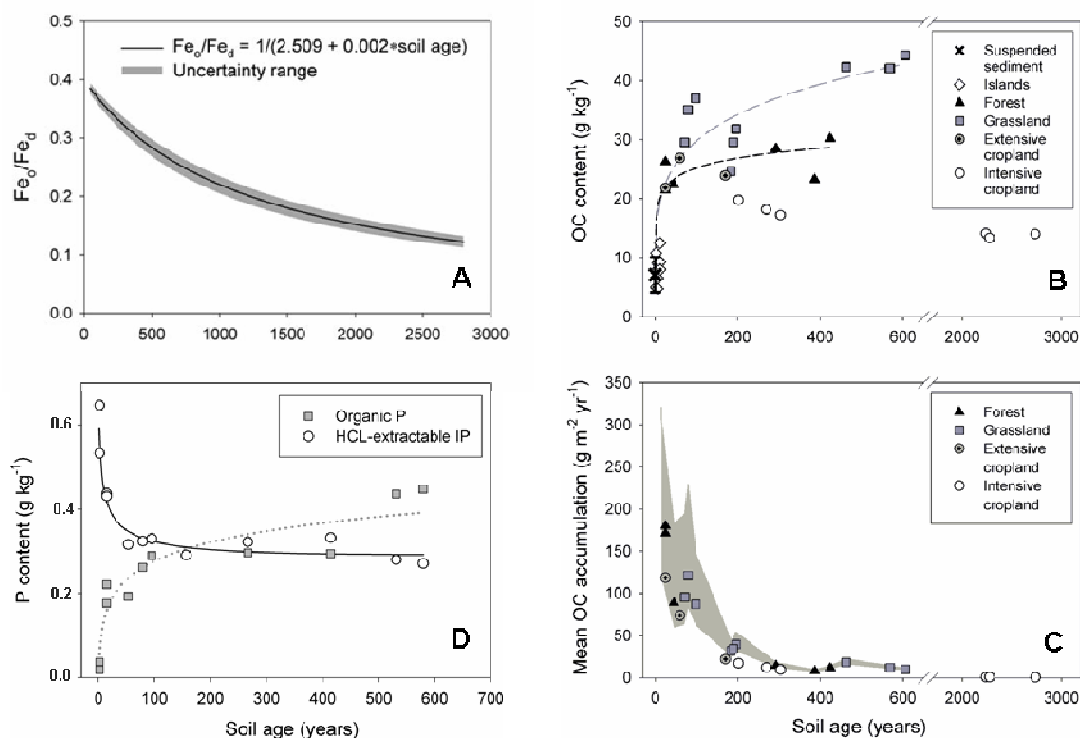


Figure 2. (A) Chronofunction model relating iron oxide crystallinity (Fe_o/Fe_d) to soil age measured with ^{137}Cs and optically stimulated luminescence in the Danube floodplain (Lair *et al.* 2009); Fe_o =oxalate-extractable Fe; Fe_d =dithionite-extractable Fe. (B) OC contents (weighted means of 0-20 cm depth); non-linear trend lines were fitted to forest and grassland soils, respectively, and forced through the mean of 20 suspended flood sediment samples. (C) Mean OC accumulation rates to 20 cm depth; shaded area indicates uncertainty of calculated accumulation rates in forest and grassland soils due to uncertainties in age estimation (Zehetner *et al.* 2009a). (D) Distribution of phosphorus among biogeochemical pools along the floodplain soil chronosequence (0–10 cm depth); P extraction according to Pardo *et al.* (2003); IP=inorganic phosphorus (Zehetner *et al.* 2009b)

Organic C contents and accumulation rates across the studied soil age gradient showed distinct trends (Figure 2B and C). The suspended river sediments and young island soils contained relatively little OC. However, within 50 to 100 years of soil formation, the topsoil OC contents at forest and grassland sites showed a steep increase, which continuously levelled off during the following 300 to 500 years. The grassland topsoils accumulated higher amounts of OC than the forest topsoils. The OM in young (<5-yr-old) sediment deposits contained almost no hydrolyzable components and relatively little humic acids, but already a sizeable fraction of microbial biomass C and comparatively high proportions of DOC and non-oxidizable OM (Zehetner *et al.* 2009a). After a few decades of soil formation, OM composition changed dramatically. The fraction of microbial biomass C remained more or less constant, but humic acids and hydrolyzable OM significantly increased ($p < 0.01$; Scheffé's test) while DOC and non-oxidizable OM became less dominant (data not shown). This rapidly established pool distribution remained essentially unchanged throughout the studied soil chronosequence.

Total phosphorus (TP) averaged 732 mg/kg, and biogeochemical fractionation yielded important primary mineral contributions (CAP ~80% of TP). The TP concentrations of the floodplain soils were in the range of the Danube sediments and showed little variation along the chronosequence (Zehetner *et al.* 2008). However, the distribution of P among biogeochemical fractions changed considerably in less than 600 yrs of soil development (Figure 2D). The youngest soils (<20 yrs) were dominated by CAP, as was observed for the Danube sediments. In less than 100 yrs of pedogenesis, CAP markedly decreased and OP increased, and in less than 200 yrs, OP reached CAP levels. This shows that while P biogeochemistry in very young floodplain soils is strongly related to the river sediments, significant transformations can occur in less than 200 yrs of soil development in the dry and temperate climate of Central Europe (Zehetner *et al.* 2009). Copper partitioning among defined geochemical fractions was mainly determined by soil pH and the contents of carbonates, organic matter and Fe-/Mn-oxides and hydroxides. Copper retained in original soils was found in more strongly bound fractions, whereas sorption of freshly added copper was primarily influenced by the presence of carbonates. Beyond the effect of progressing soil formation, variations in organic carbon contents due to different land use history affected the

copper retention capacity of the investigated soils (Graf *et al.* 2007). Cadmium remained in weakly bound fractions in both original and spiked soils, representing an entirely different behaviour than observed for copper. Correlation analysis revealed the involvement of different sorption surfaces in soil, with no single soil constituent determining cadmium retention behaviour. Nevertheless, in the calcareous soils of the Danube floodplain, we found increased cadmium retention and decreased portions of readily desorbable cadmium with progressing soil development (Lair *et al.* 2008).

Conclusion

Our analyses show that the floodplain development towards a terrestrial ecosystem in the National Park Donau-Auen is accompanied by considerable changes in the soil environment, such as increasing organic matter content, changes in nutrient content and Fe-oxide crystallinity as well as a general increase in the retention capacity for (cationic) pollutants. In the studied floodplain, OC accumulation rates seem to be larger than in most other soil ecosystems. Other soil properties like phosphorus forms and heavy metal retention properties undergo quite rapid changes as well and are partly linked to the observed OC dynamics.

Acknowledgement

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Investigating processes of pedogenesis in the Werrikimbe National Park, NSW, Australia

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Abstract

The significance in analysing pedogenesis quantitatively has become apparent as a response to increasing environmental problems. Recently there has been a movement of interest towards quantifying the rate of soil formation in situ to better understand the dynamics of soil systems. Work on quantifying the processes that form a soil profile is still minimal in soil science, but with laboratory techniques available now to address this demand, this research aim is achievable. Therefore, we conducted a field study along three principal toposequences in the Werrikimbe National Park situated in northeastern NSW, Australia. To investigate soil formation processes we used terrestrial cosmogenic nuclides (TCN) to derive production rates of soil (SPR) in mm/kyr and optically stimulated luminescence (OSL) to examine vertical mixing rates of soil and also to estimate relative dates of soil horizons. SPR calculated at Werrikimbe National Park are relatively low ranging between 3 and 18 mm/kyr underneath soil depths of 40 to 120 cm. Looking at each toposequence individually, the SPR has the tendency to decrease with increasing soil thickness, which supports the concept of exponential decrease of soil production with increasing soil depth. Results of our study in a warm-temperate to subtropical environment with high annual rainfall show the lowest TCN-derived SPR so far when compared to published SPR of different climate regimes. However, with a value for a potential weathering rate, P_0 , of 10 ± 4 mm/kyr, our data fit very well within those previously derived data.

Key Words

Pedogenesis, soil production rate (SPR), soil mixing rates, dating, terrestrial cosmogenic nuclides, optically stimulated luminescence.

Introduction

Quantifying soil formation is important to understand the dynamics of soil systems. The significance to investigate pedogenesis quantitatively has become apparent as a response to increasing environmental problems (Hoosbeek and Bryant 1992). In pedology the focus has been directed towards the prediction of soil properties from landscape attributes at specific sites based on empirical quantitative relationships (McBratney *et al.* 2003). However, recently there has been a movement of interest towards quantifying the rate of soil formation and improving the understanding of pedogenesis (Minasny, McBratney *et al.* 2008). With laboratory techniques available now to address this demand, this research aim can be achieved and is necessary since work on quantifying the processes that form a soil profile is still minimal in soil science (Bockheim and Gennadiyev 2009).

This paper aims to present the application and findings of using terrestrial cosmogenic nuclides (TCN) and optically stimulated luminescence (OSL) to investigate soil formation processes.

Methods

Study site

We conducted a field study in a subcatchment with significant relief of the Werrikimbe National Park in northeastern NSW, Australia. The National Park belongs to the warm-temperate to sub-tropical climate zone with an annual rainfall of up to 2000 mm. Werrikimbe National Park lies within the New England Fold Belt of Eastern Australia. Parent materials of the sampling sites at Spokes Mountain, Plateau Beech and Mount Boss comprise of sedimentary and metamorphic rocks of Devonian, Carboniferous and Permian age, consisting of mudstones, siltstones and fine lithic sandstones (Atkinson 1999).

Within Werrikimbe National Park we ensured to choose sampling sites with minimal disturbance by human activities. Hence, sampling took place in old growth forest areas along three principal toposequences, following

a sampling scheme by Odgers *et al.* (2008). This sampling scheme combines the concepts of catenas, random sampling and stream order.

Three soil profiles along each toposequence were dug to the soil-bedrock or soil-saprolite interface with soil pits varying between 40 and 120 cm in depth. A total of nine soil pits were located at the top, midslope and the base of the hillslope. Each horizon of the soil profiles has been fully analysed in terms of physical and chemical properties including bulk density, particle size distribution, organic carbon content and mineralogy suite of the soil.

TCN Analysis

About 1500 g of parent material, sampled beneath different soil depths, was analysed for concentrations of the TCN ^{10}Be via Accelerator Mass Spectrometry (AMS), a very mass-sensitive, precise technique that can detect radioisotope atoms as low as 10^6 for ^{10}Be . TCN preparations and TCN laboratory analysis was carried out at the ANTARES AMS facility at the Australian Nuclear Science and Technology Organisation (ANSTO) in Sydney, Australia (Child, Elliott *et al.* 2000). TCN are formed via the interaction of secondary cosmic rays with earth materials. The higher the measured concentration of TCN in the sample, the longer the exposure to cosmic rays has been. Concentrations of ^{10}Be in parent materials of soils were used to derive soil production rates (SPR) following equations in Nishiizumi *et al.* (1991) and Heimsath *et al.* (1997). SPR were normalized to sea level and high latitude (Stone 2000), and corrected for shielding, slope and depth below the soil surface (Dunne, Elmore *et al.* 1999; Granger and Muzikar 2001). Here, SPR are defined as the conversion from parent material to soil combining the effect of physical and chemical processes whereas the physical conversion of the parent material is the dominant process in thickening the soil profile.

OSL Analysis

Undisturbed soil samples were taken with soil cores of 26 cm in length and 5 cm in diameter to ensure that the soil in the middle part of the soil core was not exposed to daylight at any time during sampling. This sampling procedure was necessary, because the OSL dating technique is based on the exposure of mineral grains to daylight. Hence, all sample preparations and analysis was carried out in the darkroom environment. OSL samples were analysed at CSIRO Land and Water in Canberra, Australia, using the single-aliquot regenerative-dose (SAR) protocol of Olley, Pietsch *et al.* (2004). The OSL dating technique uses a beam of light to release a luminescence signal within a particular mineral grain (quartz), which is measured by a photomultiplier. The measured OSL signal (dose, D_e in Gy) is proportional to the time elapsed since individual mineral grains were last exposed to daylight. However, to estimate a burial age for individual quartz grains, we also need to know the annual radiation dose (Gy/yr) the grains received over time. Therefore, the annual radiation dose rate has been calculated in using high resolution gamma spectrometry measurements of the radionuclide content of the samples. Burial ages of quartz grains have been calculated using the following equation:

$$\text{Burial age (yr)} = \frac{\text{Dose (Gy)}}{\text{Annual radiation dose (Gy/yr)}} \quad (1)$$

Results

Physical and chemical soil properties

The vegetation at the field sites consists of cool temperate rainforest, wet sclerophyll forest and dry sclerophyll forest. At our sampling sites at Werrikimbe National Park soil types belong to the soil group of Kandosols under the Australian soil taxonomy nomenclature (belonging to Acrisols and Luvisols under the FAO-Unesco World Reference Base). Topsoils are characterized by stony silty loams to silty clay loams whereas subsoils are characterised by silty loams, silty clay loams and silty clays with a significant amount of stones. For all sampling sites, the clay contents were moderate to high (>40 %) throughout the soil profile. The organic carbon content of the forest soils was approximately 10% in the topsoils, decreasing to 1 % with depth.

Results of the soil mineralogy suite, obtained from X-Ray diffraction spectroscopy are shown in Figure 1. At all three toposequences, the clay mineral Kaolinite (basal spacing (d) =0.718 nm) and the aluminium-oxide Gibbsite (d =0.356 nm) were found. The iron-oxide Goethite was also present in each horizon of the nine soil profiles. Chlorite (d =1.408 nm) was present in two of the three toposequences (at Spokes Mountain and Plateau Beech). Kaolinite, Gibbsite and Chlorite are all indicators of extensive soil weathering.

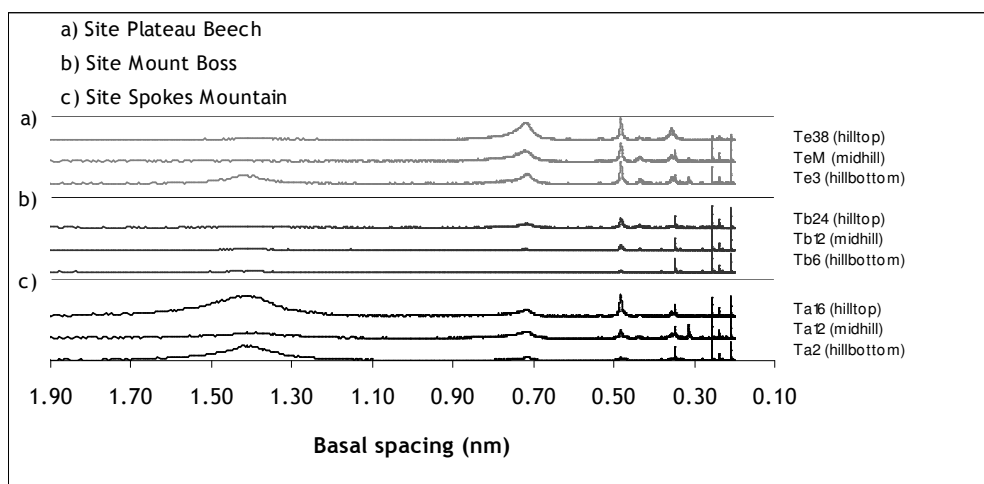


Figure 1. Diffractograms obtained from clay tile preparations, from 10-20 cm depths, for all study sites at Werrikimbe National Park

TCN-derived SPR

Normalized concentrations of ^{10}Be , analysed from parent materials below different soil depths and one outcrop sample, range between 0.103 to 0.450×10^6 atoms/g-quartz and are shown in Figure 2.

At Werrikimbe National Park, calculated soil production rates vary between 3 and 18 mm/kyr, with a maximum of soil production occurring between 0 and 50 cm of soil depth. The SPR of each individual toposequence tends to decrease with increasing soil depth. Hence, under steady-state conditions, the production of soil (SPR) follows an exponential decline of the weathering of bedrock with increasing soil thickness:

$SPR = P_0 \exp(-bh)$ where P_0 is the potential physical and chemical weathering rate of the parent material at depth $h=0$, and b is an empirical constant (Minasny and McBratney 1999). With a value of 10 ± 4 mm/kyr ($b=0.125 \pm 0.617$), the potential weathering rate (P_0) is relatively low for this warm-temperate to subtropical environment.

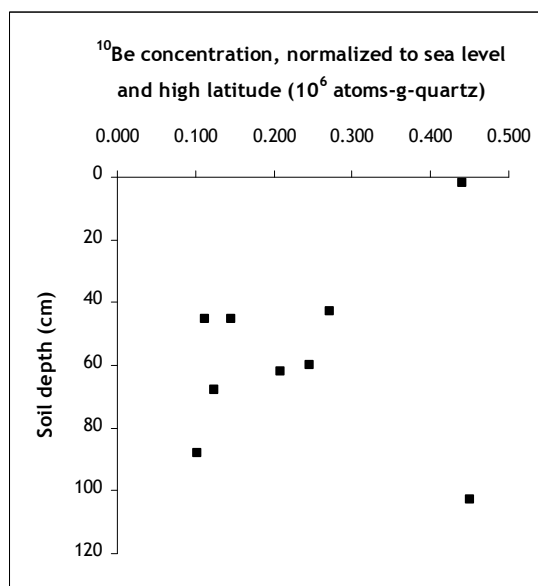


Figure 2. In situ produced ^{10}Be concentrations versus measured soil depths, normalized to sea level and high latitude (Stone 2000)

OSL

Results show that the amount of quartz grains responsive to the OSL dating technique decreases down the soil profile. Median ages of quartz grains range between 100 and 5000 years, calculated using dose (in Gy) and annual dose rate (in Gy/yr) values, following equation (1). For the toposequence at Mount Boss, median ages of quartz grains are generally younger (up to 500 years) in the top 15 cm of the soil profile than quartz grains deeper down the profile (with median ages of up to 1500 years). This tendency is also present in the data from

the topo-sequence at Plateau Beech, but here median ages are significantly higher, with up to 1500 years in the top 15 cm of the soil profile and up to 5000 years deeper down the profile. However a few younger grains can also be found deeper down the profile and older grains near the soil surface.

Conclusions

Interpreting the results of the semi-quantitative analysis of clay minerals and oxides implies that the soils at our field site of Werrikimbe National Park are highly weathered.

TCN-derived SPR at our study site are the lowest so far compared to previously published data with a P_0 value of 10 ± 4 mm/kyr. SPR at Werrikimbe National Park follow an exponential decline with increasing soil thickness, and therefore support the conceptual work of an exponential decrease of soil formation with increasing soil thickness (Ahnert 1977).

Results of the OSL data show that grains near the surface of the soil profile are younger and are getting much older down the profile. However a few younger grains can also be found deeper down the profile and older grains near the soil surface. These results imply some kind of mixing in the first 50 cm of the soil profiles. TCN and OSL data will be used to refine parameters of a quantitative model to simulate soil profile development in the landscape and to predict the function and the response of the soil to a changing environment. This work is ongoing...

Acknowledgments

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Pedo-geomorphic response to Late Glacial/Holocene climate fluctuations and human impact: A case study of combined micromorphology and luminescence dating

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Abstract

Combined application of micromorphology and luminescence dating allows us to distinguish pedogenic processes and phases of sediment accumulation. Near Frankfurt/M., Germany, a section provides an exceptional pedosequence from the termination of the Last Glacial Maximum to the youngest Holocene period in Middle Europe. The distinct sequence of buried soil horizons and colluvial deposits is a key sequence for the comprehension of pedogenic response to climate fluctuations and anthropogenically induced formation of colluvial deposits as they are typical for Middle Europe. Besides we also get a better understanding of the evolution of surface soils in loess landscapes and have herewith the possibility of predicting soil evolution against the background of climate change. The pedosedimentary reconstruction is based on both OSL-dating, using different irradiation techniques, and the vertical occurrence of pedogenic micromorphological features such as microstructure, secondary carbonate precipitation and clay coatings. Lateglacial and Holocene pedogenic processes can be separated, as there were decalcification and distinct clay illuviation in the Lateglacial followed by Chernozem and Luvisol formation until 7.5 to 6.5 ka. Interrupted by two events of colluvial deposition Luvisol formation went on until the Subboreal/Subatlantic period. Renewed colluvial deposition of calcareous material on top of the sequence led to secondary calcification of the upper part of the pedosequence.

Key Words

Soil formation, luminescence dating, micromorphology, loess, soil evolution.

Introduction

For a reconstruction of the pedo-geomorphic response to climate fluctuations and human impact precise information about the age of sediment deposition as well as exact information about occurring pedogenic processes and their succession are necessary. Such data are obtainable by combined micromorphology and luminescence dating methods. Thus we get a better understanding of soil formation rates and soil evolution through time. Only some investigations with combined micromorphology and luminescence dating methods were carried out so far (Hülle *et al.*, 2009; Kadereit *et al.*, 2009; Kaiser *et al.*, 2009; Kemp *et al.*, 1996; 2003; Suchodoletz *et al.*, 2009).

Since more than three decades luminescence dating methods provide an independent dating tool for the determination of deposition ages of aeolian sediments (e.g. Hilgers, 2007; Huntley *et al.*, 1985; Lai *et al.*, 2009; Lian and Roberts, 2006; Singhvi *et al.*, 1982; Wintle and Huntley, 1979; Zöller *et al.*, 1988). Aeolian sediments such as loess or dune sands are particularly suitable for the application of luminescence dating methods, which reveal the time since feldspar and quartz grains were exposed to heat or sunlight. This technique was further developed and applied to the dating of colluvial sediments (e.g. Kadereit *et al.*, 2009; Lang 2003) and recently of periglacial slope deposits in Middle Europe (Hülle *et al.*, 2009; Völkel and Mahr, 1997).

Micromorphology is an excellent tool to analyse results of *in situ*-pedogenic processes (e.g. Stoops *in press*). It gives information about the intensity and succession of soil forming processes and allows to distinguish between pedosediment and sediment. When combined properly both methods provide therefore essential information that lead to an improved understanding of soil evolution and landscape genesis. Here we present results of combined micromorphology and OSL-dating studies and the pedosedimentary reconstruction of a unique Lateglacial/Holocene pedosequence in Middle Europe which formed on loess, periglacial and colluvial deposits.

Methods

Luminescence measurements were carried out on polymineral fine grain samples (0.1 - 0.2 mm) following the multiple aliquot regenerative-dose protocol. To calculate the annual dose derived from the decay of lithogenic radionuclides in the sediment, the concentration of uranium, thorium, and potassium was determined by neutron

activation analysis (analysed by Becquerel Laboratories, Sydney, Australia). In addition, for some samples radionuclide contents have been determined by gamma-spectrometry. Soil description followed FAO Guidelines (FAO, 2006). Particle size distributions of fine earth (< 2 mm) were determined by sieving and analysing the <63 µm fractions by pipette using Na₄P₂O₇ as a dispersant. Those samples containing appreciable amounts of humus or carbonate were pre-treated with H₂O₂ and HCl, respectively. For micromorphological analysis, undisturbed samples were collected with tin boxes (4.5 x 2.5 x 2.5 cm and 10 x 6 x 3 cm) at depths shown in Figure 1. The blocks were air dried, impregnated with Oldopal P80-21 and sliced into 4.0 x 2.4 and 9.0 x 6.0 cm thin sections. Thin sections were described at 25 - 400 magnification under a petrological microscope mainly using the terminology of Stoops (2003).

Results

Study area

In Tertiary limestone, situated in the area south of the mountainous ranges of the Taunus, numerous karst depressions contain sediment fillings, which are excellent archives of soil and landscape history. The pedosequences have been developed since the older Pliocene, but they are particularly well documented during the Late Pleistocene and Holocene (Hilgers *et al.*, 2003; Semmel, 1995). The investigated pedosequence (Dyckerhoff outcrop) is situated in the loess covered and gentle rolling southern Taunus foreland around 40 km west of Frankfurt/M (Germany).

OSL-Dating

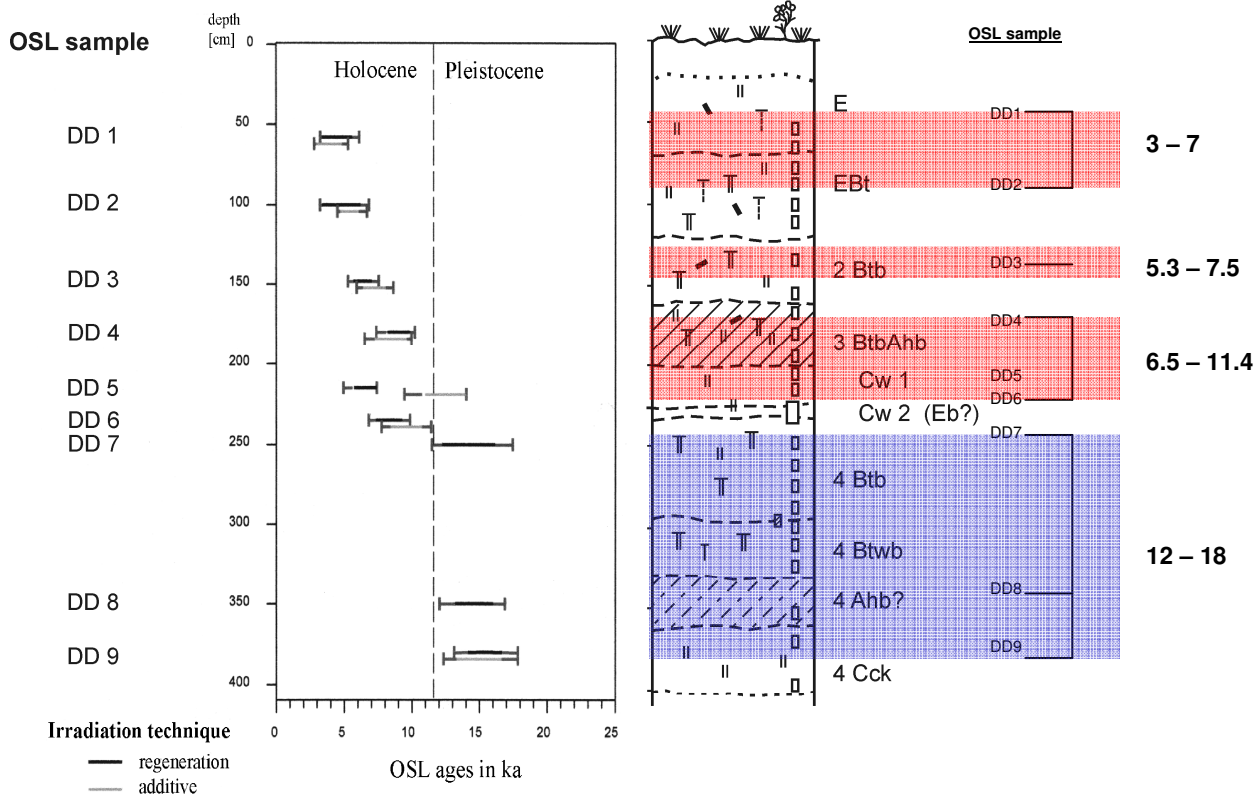


Figure 1. OSL-dating results of polymineral fine grain samples (multiple-aliquot method). Rectangles on the right hand side of the profile sketch indicate micromorphology samples.

Micromorphology

Table 1. Selected micromorphological features of the Dyckerhoff pedosequence. The micromorphological property is shown by the presence (cross) or absence (no cross).

Horizon (sample depth cm)	Groundmass						Pedofeatures										
	Micromass ^a						Redoximorphic features ^b			Translocation features ^c							
	b-fabric						nodule			hypocoating		clay coating					
	u	ms	ss	gs	s	c	t	n	a	gm	cc	vd	d	l	s-c	f	li-f
E (56)			X					X				X				X	X
E (67)			X					X						(x)		(x)	
E (78)	X			X				X		X			(x)			X	
EBt (89)			X					X					X			(x)	
EBt (103)			X		X			X					X	X			
EBt (113)			X		(x) ^d			X					X			X	X
2 MBt (134)			X					X	X	X			X	X			X
MBt (154)			X					X		X			X	X			X
3 Ahb (169)			X					X					X				X
Ahb (181)			X					X		X			X				X
Ahb (195)			X					X					X				X
Cw1 (210)			X					X	X					(x)			X
Cw2 (fE?) (216)			X						X			X	X	(x)		X	X
Cw2/Btb (224-235)			X	(x)				X		X		X	X	X		X	(x)
4 Btb (248)			X					X	X	X	X		X	X	X	X	X
Btb (258)		X	X				X		X	X	X		X	X		X	X
Btb (273)			X		X				X	X			(x)	X		X	X
Btb (287)			X					X	X	X			X	X			
Btwb (300)			X					X	X	X			X	X			
Btwb (314)			X		X			X	X	X			X			(x)	
Btwb (325)			X					X	X	X			X				
Ahb (?) (355)			X					X					X				
Cc (370)						X							X				
Cc (393)						X							X				

Pedosedimentary reconstruction

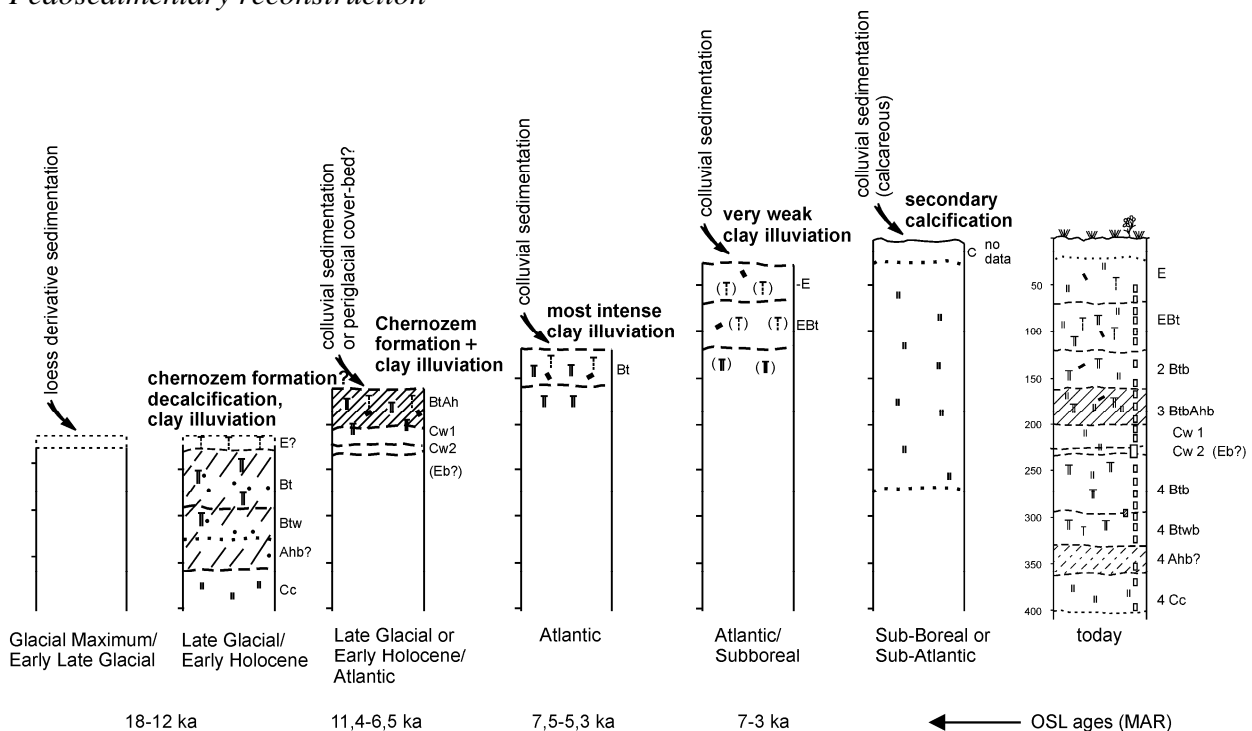


Figure 2. Pedosedimentary reconstruction of the pedosequence in the Dyckerhoff outcrop near Frankfurt, Germany. Colluvial sedimentation is anthropogenically induced.

Conclusion

Combined application of micromorphology and luminescence dating on the Dyckerhoff pedosequence reveals a distinct sequence of buried soil horizons and colluvial deposits from the termination of the LGM to the youngest period in the Holocene. Pedogenesis responds to Lateglacial interstadial climate with Luvisol formation, with Chernozem formation to Early Holocene climate conditions and again with Luvisol formation from the beginning of the Atlantic period. Many surface soils of loess landscapes of Middle Europe have experienced the same evolution (Luvisol – Chernozem – Luvisol) that is often completely masked by the last phase of soil formation. Human impact on soils and relief in form of forest clearances and agriculture led to soil erosion and formation of colluvial deposits since around 7.5–6.5 ka, which is also characteristic for loess landscapes with early human occupation.

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Problems of degradation of Soils of dry Subtropics of Southern Caucasus

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Abstract

A map of degradation of soils of dry subtropics of Southern Caucasus using an example of Miles-Karabakh steppe has been made. On the basis of the map various actions directed to restoration of the broken lands are offered. In particular ways of conducting supported agriculture are offered. Based on the form and degree of degradation of the soils are options are offered for carrying out of concrete actions, intended to restore degraded lands.

Key Words

Reclamation of disturbed soils

Introduction

In last 60-70 years soil resources under anthropogenic influence have been changed. For protection and reconstruction of the natural resources of soils it is necessary to examine them in the evolutionary order, to analyze their contemporary situation, to prognosticate changes and management option.

The problem of soil degradation and soil exhaustion of Southern Caucasus dry subtropics zone has reached an alarming scale (Aliyev 1983). These problems are closely connected with the process of active social development. The main types of soil degradation are the loss of the organic matter, weakening of biological activity, physical degradation, irrigated erosion, salinization, lack of nutrients, lack of moisture, anthropogenic and chemical pollution, acidity increase, etc. (Babayev 1984, 2006; Gerayzade 1989; Mamedov 1980, 2007; Mamedov 1989). The intensive use of soil for monoculture can be considered the beginning of soil degradation (Salayev 1991). In this case the violation of technical measures also led to the loss of soil organic matter in an area of more than 1.5 million hectare, and reduced biological activity by 1.5-2.0 times.

Methods and Results

The influence of the human on a physical condition of soil has been verified. Agricultural affects density and porosity of soils. The physical degradation of soil as the result of the influence of heavy agricultural technique, leads to structural violation, concentrating the soil layer under tillage, decreasing its porosity, in some occasions to the loss of upper layers, and occupies an area 0.5 million ha. The mountainous territories of the arid zone are characterized by appreciable amplitudes of height and strong relief. Consequently about 41.8 % of soils (3.61 million ha) are exposed to the erosion of different degree. The most widespread types of erosion area: windy, water and irrigation. Here the influence of the natural factors is more aggravated by violations of the zonal agrotechnics. The salted soils are mainly in Kura-Araks lowland and Apsheron peninsula. Their area is 1.5 million ha. The nature of salts is soda, chloride, sulfate, sulfate-chlorite, chloride-sulfate. 500 thousand ha of these salted soils are irrigated. In these regions the irrigation-drainage network is out of order everywhere. This fact and violation of the irrigation regime lead to repeated soil salinity, forming an saline-alkali stain. The incomplete restitution of elevated crops of nutrients, the insufficient use of organic fertilizers, the erroneous use of crop rotations or their complete absence has led to loss of nutrients from an area of 1.5-2.0 million ha.

The chemical polluted soils mainly contain the following substances -the remnants of pesticides, herbicides, radioactive elements, heavy metals, etc. Losses of the fertile soils which have been taken away under building of megacities and their communications has also occurred.

The complex maps indicating different kinds of degradation (erosion, salting and others) have been composed. The composition of the soil degradation maps is based on exact soil maps. In this work revealing the natural and anthropogenous factors influencing soil cover have an important meaning. As an example we can present the map of the soil cover degradation of the Mil-Karabakh plain. Mil-Karabakh plain which is 772 thousand hectares of the dry subtropics zone and is widely used for agricultural production (40% of the general area).

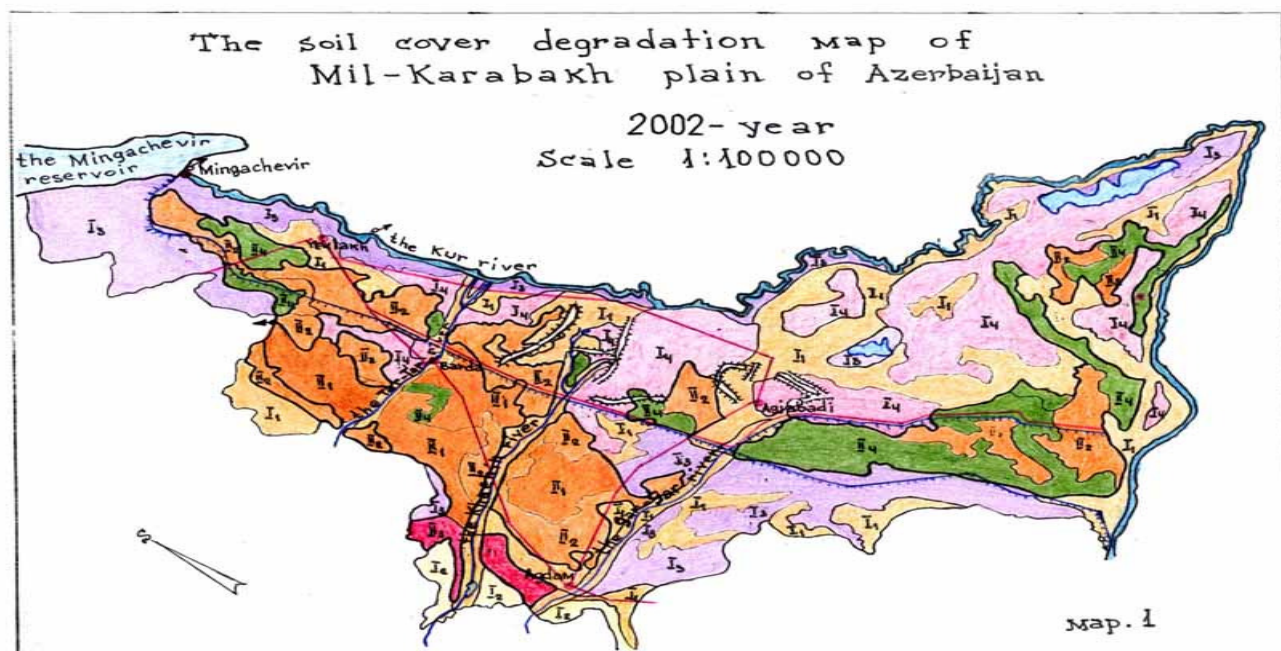


Figure 1. Fragment of the map showing degradation degree of the dry subtropics soils of Southern Caucasus.

Legend to Figure 1.

- I₁- Normal soils: Virgin, greyish-brown (chestnut), meadow. An even surface, ground water level 3-5 m, humus layer 30-50 cm, it is provided with N, P, K optimally. Regulating pasturage, grass sowing, afforestation, planing surface, irrigation-drainage system, agriculture direction-forage preparation, crop rotation, mineral organic and local fertilizer. Cattle breeding, cultivated grasses, watering, technical and cereals, gardening and sericulture.
- I₂- Soil erosion: Brown Soil exposed to erosion. Strongly destroyed surface (sharply changing) concentrating, carbonate, little thickness, stony. Unfit for irrigation, afforestation, grass sowing, cattle breeding, gardening, viticulture.
- I₃- Salinity, concentrating. Salting, greyish-brown serozem, meadow and meadow-swampy virgin soils. Weak destroyed surface, surface good for irrigation, carbonate, develops on loess forming salinity. Thick layer of fine soil, provides elements of nutrition. Complex of ameliorative measures: right irrigation, improvement of collector – drainage system, planing of surface, deep ploughing, sowing of bean fodder crops. Cereals and technical cultures, viticulture, grass of high crop capacity, stock-breeding.
- I₄- Salinity-solonetz garden and repeated salting soils. Garden-saline meadow - marl soils. An even surface, exists weak slope, under ground water level 1,0-2,5 m, strong salinity, solonetz, clayey. Planing of surface, drainage, use of ameliorant on clayey soils. Cotton, cereals, vegetables, melon, grain-bean, cultural pasturage.

The soil-climatological conditions of Mil-Karabakh plain are favorable for cultivating valuable agricultural plants (cereals, bean, grape, pomegranate, cotton, etc.). On the basis of the having soil map of Mil-Karabakh plain (scale 1:200000) the map of the soil degradation of this zone had been composed (map 1). On the map have found the reflection the kinds of the soil cover degradation of Mil-Karabakh plain, and found their geographical reflection

In this connection the condition of the soils of on dry-steppe zone of Southern Caucasus has been studied, changes of physical characteristics of soils are established, the various maps and the schemes characterizing various types and level of degradation of soils have been made. In Figure 1 part of a map of degradation of soils of dry-steppe zone of Southern Caucasus, covering Miles-Karabakh plain is presented. In a legend to the map of the degraded soils actions are presented which are necessary for soils according to their degree of degradation.

In the legend of the map of soil cover degradation every kind of degradation of types and subtypes of soils are shown, they show area, agro-industrial character, limiting factors and agromeliorative measures.

The maps of the soil cover degradation identify separate regions. In accordance with the appreciation of the expertise a choice of measures directed to the prophylactic and the removal of negative processes is suggested.

The given stage of work including methodical recommendations on conducting complex appreciation of soil degradation in the Southern Caucasus is prepared and on the basis a computer expert system of soil degradation expertise is composed.

So, we use these technologies to solve the problems of soil degradation and desertification, we do not try to fight with the nature, on the dry steppe we aspire to restore the natural ecological balance.

Conclusion

For the fight with the processes of degradation we use technologies promoting optimization of the natural environment situation, stable management of degraded soils enabling restoration. For the creation of these technologies it is necessary to consider traditional methods that are acceptable for the conditions of the regions. The technologies include agro and phytomelioration measures, restoration of soil biological activity and vegetation of the degraded pastures and Tugay ecosystems.

Considering the zonal soil-climatic conditions we have used the complex of ameliorative and agrotechnical methods of soil protection from erosion (soil-protective crop rotation, anti-deflation forestry zones, link sowing, soil-protective technology of soil cultivation including non-moldboard friability with root remnants, minimalization method). The irrigated system must include progressive methods of surface watering (discrete watering on furrow, automatization of watering and etc.) also technology of dropping irrigation, providing economic use of irrigated water. For preventing excessive evaporation of the deficient moisture and microelement improvement it is offered mulching. With the use of the vegetative remnants, silt of river water, zeolite, turf, waste of fish and wine-making industries, silk science, etc. The ameliorative measures must be directed to using in crop rotation with salt-stable plants which are stable under extreme environments.

Reffereces

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Reconstruction of past environments based on pedological, micromorphological and phytolith analyses

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Abstract

Kurgans are significant cultural and ecological values of the Carpathian Basin and Hungary. These formations were primarily built in order to serve sacral-burial purposes. By the erection of these mounds, the ancient soil surface has been covered and isolated. Due to the protection of law, kurgans in Hungary can only be examined by drillings. Due to a special and unconventional occasion the Lyukas-halom kurgan could have been excavated. The mound is situated on the Great Hungarian Plain in the Carpathian Basin. The surrounding landscape dominated by agricultural production. Together with archaeological experts transverse section of the kurgan has been prepared as a result of the excavation. It reveals the kurgan is 40 meters length and 8 meters height. Not only the stages of the erection of the mound were easily detectable, but the buried soil profile could be easily identified. According to the morphology (crumbly structure, dun colour, typical lime and humus dynamics) and to the results of the laboratory analyses (TOC, loamy texture, balanced water regime) the 5500 B.P. aged soil (C^{14} calibration) can be classified as a Chernozem, which is interesting data in the light of former theories. Formerly, research on the vegetation development of the inner basin territories underlined the existence and dominance of forest cover on the Great Hungarian Plain. Additional soil analyses, such as micromorphological investigations and geochemical examinations support the same as no signs of Luvisol evolution processes, such as lessivage, clay migration nor forms of clay coatings were found. In addition, paleobotanical results (phytolith analysis) of the palaeo [A]-horizon refer to steppe-dominated vegetation mosaics.

Key Words

Palaeoecology, paleopedology, kurgan, soil micromorphology, phytolith analysis

Introduction

The geomorphological, pedological and paleontological examination of ancient environment became more and more popular with the extension studies focusing on burial mounds and tells of the Eurasian steppe zone. As a pioneering forerunner of these tendencies, Sümegi *et al.* (1998) has undertaken the geoarcheological research of a Bronze Age tell, the so called Test-mound located near Szakáld. By implementing geological drillings, Sümegi's (2003) researches resulted in formative and new findings when he conflated data of soil resistance and magnetic anomaly measures from the Neolith Csósz-mound, the Bronze-aged Ásothalom and Kenderföld tells, Kovács-mound and the Gara-mound. Similar geomorphological and stratigraphical investigations of the Büte-mound and other kurgans rising on the southern plain territories of Hortobágy National Park have been carried out by Tóth (1998). Füleký (2001) has reconstructed the original soil profile buried under a Bronze Age tell near Százhalombatta through pedological examinations. According to the morphological results the profile buried under a 1.5 meter thick cultural layer, turned out to be a Luvisol, with typical reddish, leached [B] horizon.

Our research team has started the pedological studies of kurgans and the paleoenvironmental reconstruction of their surroundings in 1999 (Barczy *et al.* 2003; 2004; Molnár *et al.* 2004). Our aim was to examine buried paleosoils underneath kurgans located at various territories of the Hungarian Great Plains and to detect geochemical processes. As all kurgans are protected by law in Hungary (*Law for the protection and conservation of nature, 1996. LIII.*) we could only undertake our researches by implementing drillings. The multidisciplinary excavation of the Lyukas-halom kurgan (Hajdúnánás, Hungary) was lead by the Department of Landscape Ecology from the Szent István University (Gödöllő, Hungary) in 2004. It was a special and unique occasion that we could collect all relevant permissions for the excavation. The cross-section wall of the – 5 meters high and approximately 42 meters in diameter wide – kurgan was prepared aiming detailed environmental and archaeological studies. The buried soil profiles under these 5000 to 6000 years old (B.C.) burial mounds are the messengers of ancient landscape forming factors and soil generation processes (Alexandrovskiy *et al.* 1999). There are contradictory theories on the Holocene landscape evolution of the

Carpathian Basin. One of them describes the Holocene environment with closed forest vegetation, forest-steppe mosaics and claims the non-existence of sodic, alkaline soils in the early Holocene. In contrast to the first theory, the second one denies the dominance of closed, extended forest vegetation and the secondary, anthropogenic evolution of the sodic, alkaline soil area.

Main aims of preparing a cross-section wall were to clarify the circumstances of the kurgan's construction, to describe recent soil development, to study the buried soil profile and to reconstruct the one-time environment with the tools of paleoecology. The Lyukas-mound is situated in the Hajdúhát mesoregion of the Hungarian Great Plain, between Nyírség and Hortobágy mesoregions, near the town of Hajdúnánás (Figure 1a.). The area is a one-time silt-cone plain covered with loess and loessy silt. Its small relative relief is corrugated by 5-7 m high shifting sand accumulations and mounds covered by loessy sand. Climate of the microregion is moderately warm and dry, annual average precipitation is 550 mm. Its water regime is characterised by dryness, thin runoff and water shortage. Average depth of the groundwater is 2-4 m; its amount is not significant, with a calcium-magnesium-hydrocarbonate character. Potential vegetation of the area is oak-ash-elm grove forests, tartar maple steppe oak woods and loess steppes. The landscape is used by agriculture. The dominant soil type is Chernozem. Basic space of the designated kurgan is relatively great. Soil tillage is typical for the surroundings however; the kurgan itself has not been ploughed. Despite this fact, the body of the kurgan is not covered by natural vegetation, but by modern vegetation dominated by young locust woods. Thorough fox hollow system can be seen in the cross-section, ruining the upper layers of the kurgan. There is a dirt road on the northern and western sides of the kurgan, almost giving a kind of fence around these sides and compacting and cutting the original layers. Human influence could be detected in the upper (the highest) part in form of deep holes used for robbing in the body of the kurgan (Figure 1b.). The USLE soil erosion model was applied to show the erosion processes on the mound (Centeri *et al.* 2007).

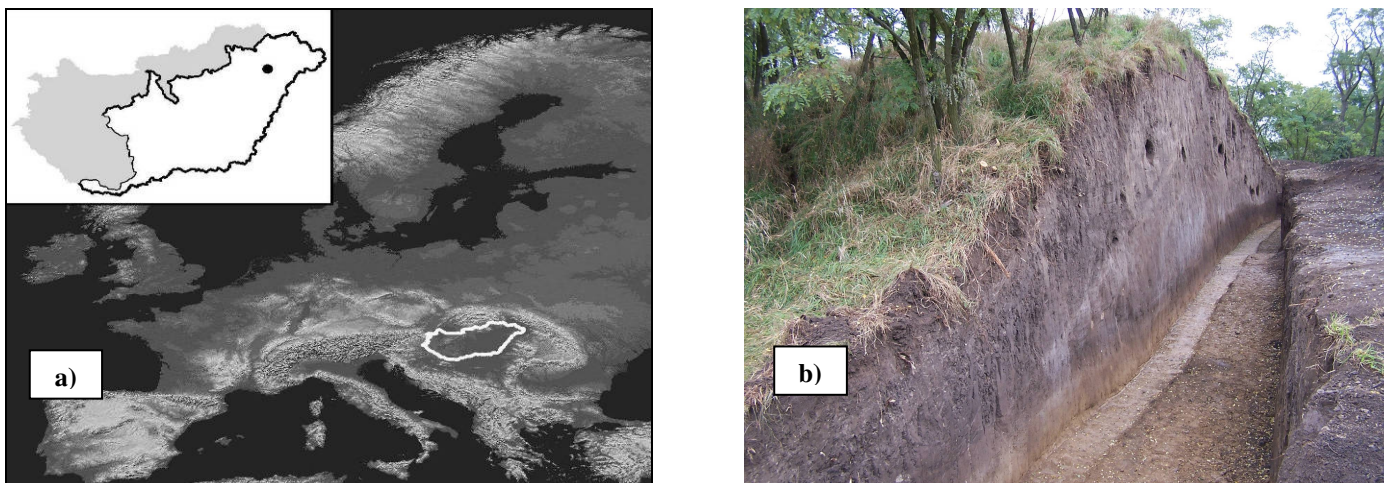


Figure 1. Location (a) and the prepared cross-section (b) of the Lyukas-mound, Hajdúnánás, Hungary.

Methods

Differences between colour, structure, lime content, moisture content and compactness were observed in the cross-section wall. Situation of visible concretions and morphological parameters (root systems in the soil, animal tubes, iron, lime and silica concretions, bones etc.) were recorded. The prepared soil column of the kurgan was separated into layers based on their morphological features (Figure 2.) (Stefanovits 1963). Layers were separated according to our observations and were sampled to conduct pedological, micromorphological and biomorphic laboratory analysis. Samples for pedological survey were taken from each layer and basic laboratory analysis was done: pH (KCl), CaCO₃ % (Scheibler method), organic matter % (Total Organic Carbon), humus % (Tyurin's method), total salt %, mechanical analysis %, total phosphorus (mg/kg) (Buzás 1988). Samples for phytolith analysis were taken from the upper 1-2 centimeters of each soil horizon buried under the kurgan. The preparation of soil samples for the biomorphic analysis was done in several discrete steps according to Piperno (1988) Golyeva (1997), Golyeva (2001a) and Golyeva & Khokhlova (2003). After the separation method was completed, a drop (0.5 mL) of each specimen mixed with the same amount of additional glycerin was examined under optical microscope. A magnification ranging from 350x to 700x was applied. Classification system used in the analysis was developed by Golyeva (2001b). It includes identification classes for plant residues indicating typical association types of a given biome and of significant climatic conditions. For micromorphological analysis, oriented samples were collected with modified Kubiena tins (Kubiena 1938).

The preparation method was done in two discrete steps. After air drying at the temperature of 30°C the blocks were impregnated with Oldopal P80-21, cut and polished to 6.0 x 9.0 cm slices, with a thickness of 10 µm after the procedure of Beckmann (1997). Diamond emery- and cutting-wheel was used to prepare the samples. The micromorphological description was carried out according to Stoops (2003).

Results and Conclusion

With regard to the pedological survey the parent material of the examined paleosoil underneath the Lyukas-mound is bright, loessy sediment with high lime content. Its organic matter content is low, shows typical values for parent materials (Table 1.).

Table 1. Basic laboratory data of the paleosoil horizons.

Code*	pH (KCl)	humus %	TOC %	CaCO ₃ %	P _{total} ppm	Total salt %	Mechanical analysis %		
							clay	silt	sand
Ly3	7.69	1.54	4.43	0.37	1198	0.16	9	49	42
Ly2	7.91	0.61	5.84	6.05	1325	0.13	15	49	36
Ly1	7.96	0.51	3.83	10.52	1105	0.07	17	45	38

see Figure 2.

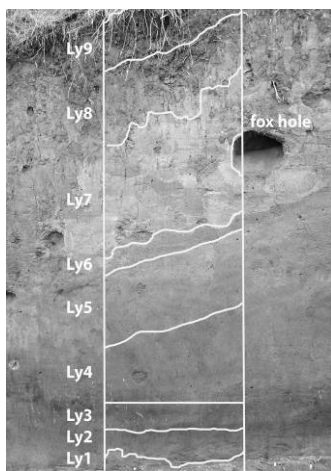


Figure 2. Layers and soil horizons of the Lyukas-mound.

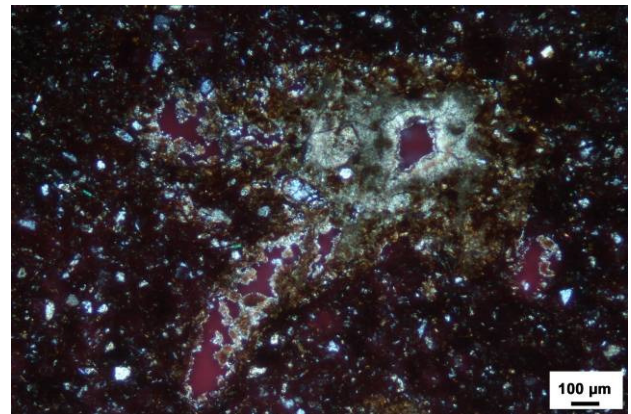


Figure 3. Carbonate precipitations in a kurgan.

During the biomorphic analysis of sample Ly1/2 - deriving from the interface of the parent material and the paleo [B]-horizon we found indicator forms (diatoms and sponge spicules) typical for water-effected surfaces. So water could have played a significant role in the evolution of the parent material. There are possible theories to support this idea. Either the sedimentation of airborne dust on a water-effected surface, or the effect of regular flowing water may have resulted in the generation of this parent material. The existence of the needle-formed carbonate precipitations (Figure 3.) that are visible in the thin section prepared from this layer confirms this theory, as the generation process of these forms is done through a relative fast down evaporation of calcium- and magnesium-ions dominated solutions. These results let us conclude, that the evolution of the parent material was predominated by water to a certain extent. The occurrence of strongly corroded coniferous phytolith forms are an effect of hydrochlor dispersion. These give us a broader view and additional information on the mound's wider paleoenvironment. The micromorphological analysis proved the existence of *Mollusc* species. Further malacological analysis is preferable to extend our knowledge in terms of the paleoenvironmental factors and the ancient flora and fauna that inhabited the surroundings.

The biomorphic analysis of sample Ly2/3 deriving from the interface of paleo [B]- and [A]-horizons shows indicate grass biomass production to a greater extent and the closeness of a once-existed surface. Corroded phytoliths mark their ancient matter and reflect the first stages of soil development.

The paleo [A]-horizon still preserves its well-developed crumbly structure. Its micromorphology is characterised by definite microaggregation and a higher organic matter content. Lime content is typical for Chernozem [A]-horizons. The high amount of phytoliths proves that this has been a surface once and collates with the pedological and macromorphological observations according to that of the location of the paleosoil. Among the biomorphs single particles of sponge spicules appear as a heritage of the parent material. The amount of arboreal detritus correlated to the total biomorph content refers to an one-time grove, a grassland vegetation with discrete tree species. The macro- and micromorphological and biomorphic analysis together with chemical and physical

soil qualities clearly show a Chernozem-type soil development. The texture is loamy and the mechanical analysis refers to water effects. All undertaken analyses prove the complex, water-effected evolution of the parent material. According to the results of the total phosphorus content, we did not find any traces of significant human impact, such as ploughing nor any form of human-related erosion. We did not find the micro- nor macromorphological traces of clay leivage, clay formation nor intensive weathering and leaching processes. The extent of leaching, the dispersion of the carbonate is characteristic of Chernozem soils. This statement is also supported by the vertical distribution patterns of the humus and the animal soil activity, which played a significant role in its structure development. The biomorphic analysis of the pale [A]-horizon proves that this has been a surface in ancient times and describes the vegetational patterns of the surrounding environment. According to the results we assume that the primary vegetation was predominated by steppe flora in addition with discrete tree species forming a grove type habitat. Mosaic-like habitat patches of wetter, muddy areas may have occurred within this predominantly dry environment.

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Reconstruction of the Ecological Condition of Bronze Age Civilization to the Border of Europe and Asia, Russia

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Abstract

In 1987 in the Chelyabinsk region Russia a fortified settlement of the Bronze Age was found, called the Arcaim. Nowadays near it 22 ancient settlements and thousands of archaeological monuments were opened along the Ural Mountains. This suggests that an ancient civilization was on the border between Europe and Asia at the turn of III and II Millennia BC. New radiocarbon dating of paleosols humus was received. On the base of our investigation we can distinguish stages of soil formation in the Trans-Uralian region during the last 4000 years. Research of paleosols buried under bank-walls and mounds showed that the soils have the more shallow profile, greater carbonate horizon thickness, less humus content, more pronounced features of solonchecity and salinity degree than modern background soils. These features indicate a more arid climate 3900-3000 years ago compared to today's environmental conditions. The stage of 3000-2400 years ago characterized by progressive climate humidification.

Key Words

Paleosols, steppe, ecological condition, climate reconstruction

Introduction

Authors of several articles during 20 years are conducting a comprehensive scientific work in the Arcaim Reserve and nearby area. In 2009 for the continuation of this work scientists from five universities of Japan were invited. Results of these studies will be published in materials of this congress.

The climate of the region is continental with a dry hot summer and little snow and cold winters. There mainly ordinary chernozems and soloncheks, rarely southern chernozems have formed. Soils often have salinity and alkalinity signs. The objects of study were paleosols buried under the walls and mounds. Field work was conducted in Bredinskiy and Kizil'skiy areas of Chelyabinsk region. Three sites were studied (52° N, 58-60° E) (Figure 1).

1. Paleosols of Arcaim settlement of Bronze Age under the inner and outer walls, constructed 3700 years ago were objects of study. The city diameter makes up 165 m. Bypass ditch and two rings of defensive wooden walls of 7 m height with towers and advanced fortification are well distinguished (Arcaim, 1995; Zdanovich, Batanina, 2007). It is located at the confluence of the Big Karaganka and Utyaganka rivers. Height of the earthen walls is 0.7 and 1.4 m.
2. Paleosols of four mounds which were built 3900, 3500, 3000, 2300 years ago near the Aleksandrovskii village in the Big Karaganka river valley were investigated.
3. Big Syntashta mound, which is part of the historical complex, localized at 4 km from the village Rymnitskiy on the first floodplain terrace of the Syntashta river was studied. The mound was excavated in 1971-76 (Gening *et al.*, 1992). From previous excavations two walls remained.

Methods

Soil properties were determined by standard methods: particle size distribution - pyrophosphate method, the content of humus - by Tyurin method, carbonates - acidimetric method, gypsum - gravimetric method, content and composition of easily soluble soils - by Arinushkina method and exchangeable cations content - by Pfeiffer method (Arinushkina, 1970). Reconstruction of environmental conditions of past eras is done through a comparison of the properties of buried paleosols and modern background soils.

The contact between the mound and the buried soil is very distinctive. It is marked by a bleached layer that developed at the place of the former sod (AO) horizon. Diagenetic changes in the upper horizon of buried soils are manifested by a certain decrease in the humus content because of its mineralization and the absence the input of fresh plant residuals. It has been shown earlier that the humus horizon of the soils buried 2000-4000 years ago retains about 40% of the initial amount of humus (Ivanov, 1992).

Radiocarbon dating of humus from the upper 5 cm layer of paleosols were done in the Kyiv Radiocarbon laboratory. For determination of the radiocarbon dating of paleosol humus for data of mounds building and soil

burring respectively we used the approach (Chichagova, 1985; Alexandrovskiy *et al.*, 1996). According this method "own" age of humus of upper 5 cm of stepper chernozems varies from 300 to 500 radiocarbon years. Thus age of humus of paleosols equals radiocarbon age determined with the help of ^{14}C analysis minus 500 years.

Results

Arcaim

The thickness of humus horizon (A + AB) of buried paleosols is less on few cm than in the background-modern day soils. Carbonate horizon was greater in the ancient soils than in background ones. Reconstructed humus content in profile of paleosols is less than the background-modern soils. Alkalinity degree is more pronounced in paleosols and it is accompanied by a higher content of water soluble salts and gypsum. Amount and form of humous tongues in paleosols and background soils do not differ. Nowadays ground water level is near 4 m. Modern soils in the BC horizon have rusty spots of iron oxides. In paleosols these signs are absent suggesting that in ancient time ground water was deeper than at present.

Modern soil is chernozem, weakly alkalized and with moderate thickness and the residue of the recent short stage of shallow ground water table. Paleosols characterized as chernozem ordinarily with thin thickness and high and moderate alkalinity and salinity features.

Arcaim paleosols have features that suggest greater aridity of the climate compared with today. Atmospheric moisture in the Arcaim era was smaller than at present.



Figure 1. Settlement Arcaim of the Bronze Age from the sky.
(photo of Arcaim Reserve archives).



Figure 2. Reconstructed ancient mound.

Syntashta

The height of the Syntashta mound was 4.5 m and diameter - 95 m. Unusually for this mound is the presence of a horizontal layer with thickness of 40 cm. This layer was constructed on the surface of paleosol. This horizontal layer was created from an obliquely arranged soil blocks.

It was as a kind of "step", on top of which different sections of the embankment were created. The embankment of the mound has a complicated construction and consists from alternating layers of soil, sand, wood, bark, etc. On archaeological evidence its date is by boundary of II and III millennium BC.

Parent material has a light loam texture. In the investigated soils at a depth of 1-1.2 m is a plate of cemented sandstone (Mesozoic-Cenozoic basement rocks), relatively solid, and slightly disintegrated.

The morphology and properties of soils at the mound edges and inside are different.

Determining the paleosols age by the radiocarbon method showed that the soil in the central part of the mound was more ancient than at the periphery (Table 1). The older soil compared with younger one has less humus at 6-16 cm, worse structure, more pronounced humus tongues and signs of waterlogging in the form of manganese neoformations in the upper horizons, and the presence of bluish and brown shades in the lower profile. The older paleosol is meadow chernozemic with signs of overmoistening.

Younger soil, overlying the edge of the mound contains more humus than the more ancient soil. Humus tongues in AB horizon are less pronounced and have a thick base. In the younger paleosol waterlogging signs in the upper horizons are absent, they remain only in the lower horizons, the carbonate horizon had less thickness with more pronounced CaCO_3 accumulation in the form of white spots. The soil is a meadow chernozemic.

The thickness of humus horizon in background soils is greater than in paleosols and ranges from 45 to 60 cm. Modern soils have more humus than the reconstructed humus content of paleosols. The modern background soil is a meadow chernozemic.

Differences of paleosol age under the one Syntashta mound can be explained by two phases of burial monument construction (Khokhlova *et al.*, 2008) or the spread of the mound after its construction.

Paleoclimatic conditions of the time of development of both paleosols are characterized by contrast: alternation of humid and dry periods occurred. Arid intervals were expressed more clearly than now. The present time is relatively more humid than at the time of paleosol formation.

Table 1. Radiocarbon dating of Syntashta mound.

Profile	Location	Laboratory number	Soil humus age on the base of ^{14}C	
			BP	BC/AD
P. 4-C-II-09	End of mound	Ki – 16132	3210 ± 70	1σ 1530-1400 BC 2σ 1690-1310 BC
P. C1π/06-2	End of mound	Ki – 13828	3540 ± 90	1σ 1980-1740 BC 2σ 2150-1600 BC
P. 5-C-II-09	Inside of mound	Ki – 13827	4170 ± 140	1σ 2910-2570 BC 2σ 3100-2300 BC
P. C1π/06-1	Inside of mound	Ki – 16134	4110 ± 90	1σ 2870-2800 BC 2σ 2890-2460 BC

Alexandrovskii

On the base of our investigation we can distinguish the following stages of soil formation in the Trans-Uralian region during the last 4000 years (Ivanov, Chernyansky, 1996). In the soil buried 3900-3000 years ago the humus profile thickness and reconstructed humus content in the upper horizon was slightly lower than in the modern soils (by 5 cm and 0.8-1% respectively). Paleosol contains a low CaCO_3 amount (1.3% in the layer 0-1 m). At this period environmental conditions ranged from more arid and continental to those close to the present ones. Aridization developed very gradually and had a cyclic character. The soils of this epoch can be classified as intergrades between ordinary and southern chernozems.

The stage of 3000-2400 years ago characterized by progressive climate humidification.

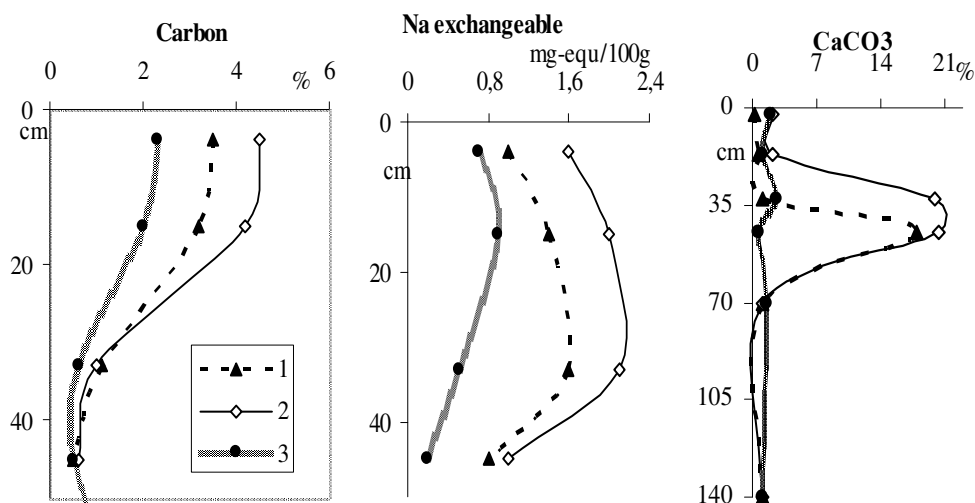


Figure 3. Soil properties of Alexandrovskii plots, 1 - modern soil, paleosols buried years ago: 2 - 2200, 3 - 3900.

The paleosol buried under the mound 2300 years ago is characterized by contradictory properties, such as: high humus content and large alkalinity degree, large carbonate horizon thickness, well-defined humus tongues. These rather controversial soil properties, i.e., the combination of soil features that could develop in arid and in humid conditions within one profile. They can be explained by their nonsimultaneous, successive origin. High humus concentration could have formed prior to the development of arid pedogenesis, one or two centuries

earlier. Before being buried, this humus was still preserved in the soil profile; there was not enough time for it to mineralize in the more arid environment. Judging from the integrity of features one can classify this soil as an ordinary chernozem, intergrading to a southern one.

Conclusion

Nowadays 22 ancient settlements and thousands of archaeological monuments have been opened on the steppe area stretching along the eastern slopes of the Ural Mountains for 300 km. Research on paleosols buried under bank-walls and mounds for few archaeological monuments was carried out. New data on the reconstruction of environmental conditions of the Bronze Age civilization of this area were received. Radiocarbon dating of paleosols humus for mounds and buried soils was done. On the base of our investigation we can distinguish a few stages of soil formation in the Trans-Uralian region during the last 4000 years. Soil features indicate a more arid climate 3900-3000 years ago compared to present environmental conditions. The stage of 3000-2400 years ago is characterized by progressive climate humidification. In the Arcaim Reserve scientists of many specialties work together and, the ancient technologies are studied. On its territory a museum was built, ancient burial mound "Temyr" and Neolithic settlements were reconstructed (Figure 2). 20 thousand tourists visit the Museum-Reserve annually.

Acknowledgements

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Relationship between ^{14}C age and structural property of humic acids

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Abstract

To understand the relationship between residence time and structural property of soil humic acids (HAs), a HA sample obtained from the A horizon of a Haplic Andosol at a depth of 35-40 cm (247 ± 33 years before present (yBP)) was fractionated to 8 sub-fractions having different degrees of humification, and their ^{14}C age, molecular size distribution (high performance size exclusion chromatography (HPSEC)), C composition (ramp cross polarization/magic angle spinning (CPMAS) ^{13}C nuclear magnetic resonance (NMR) spectroscopy), and N composition (X-ray photoelectron spectroscopy (XPS)) were measured. Condensed aromatic components were investigated by ruthenium tetroxide oxidation (RTO) method and based on 11 band profile analysis in X-ray diffraction (XRD) spectra. With increasing ^{14}C age, aromatic C and N contents as well as molecular size became larger. RTO yielded degradation products derived from naphthalene to coronene nuclei, and XRD analyses suggested the presence of carbon-layer planes corresponding to 4-37 ring condensed aromatic structures in the HAs. Contents of condensed aromatic components having 5-37 rings increased with increasing ^{14}C age, suggesting their contribution to the longer residence time of darker-coloured HAs with larger aromaticity.

Key Words

^{14}C age, condensed aromatic structure, humification, humic acids, X-ray diffraction profile.

Introduction

Humic acids are synthesized secondarily from biomass constituents or their metabolites biochemically and/or chemically in the environment. It is considered that initial HAs lose relatively easier decomposable components while condensation-polymerization and oxidation proceed, which result in more refractory structure. Partial degradation and oxidation of charred plant materials might be another production mechanism of refractory HAs, although their contribution to the whole HAs is unknown. Concentration of aromatic C with increasing soil age was suggested by the comparison of ^{13}C NMR spectra of HAs obtained from the surface and several buried A horizons in a soil profile (Watanabe and Takada 2006). The presence of various condensed aromatic components in HAs was suggested by Kramer *et al.* (2004) using Fourier transform-ion cyclotron resonance mass spectrometry. Although condensed aromatic components may be more recalcitrant than benzene derivatives, it is difficult to estimate their content and structure using ^{13}C NMR. The purpose of the present study is to find components or structural moieties that contribute to the longer residence time of refractory HAs. For this purpose, HAs prepared from a soil layer were fractionated into sub-fractions with different degrees of humification, and the relationship between ^{14}C age and structural property of the sub-fractions was analyzed.

Methods

Preparation of sub-fractions of humic acids

Soil sample used was collected from the A horizon of a Haplic Andosol at a depth of 35-40 cm (247 ± 33 yBP) in Miyazaki, Japan. After plant residues were removed using ZnCl_2 solution (density, 1.6), HAs were prepared according to the NAGOYA method (Kuwatsuka *et al.* 1992). The HA sample was fractionated by successive precipitation method with 0.01 M NaOH—acetone solutions. Seven fractions precipitated at acetone mixing ratios of 20% (designated 20P), 30% (30P), ..., and 80% (80P), and a fraction soluble at the mixing ratio of 80% (80S) were obtained as powder samples after removal of acetone and sodium ion.

^{14}C age of humic acid sub-fractions

Each sample of the sub-fractions was combusted with CuO, and CO_2 produced was purified and then transformed into graphite by heating with reduced iron under H_2 atmosphere. ^{14}C concentration in graphite samples was determined using an accelerator mass spectroscopy system, and ^{14}C age was calculated.

Structural analysis of humic acid sub-fractions

Degree of humification of the sub-fractions was evaluated using two variables of A_{600}/C and $\log(A_{400}/A_{600})$, in which A_{600} , A_{400} , and C are absorbances at 400 and 600 nm and C concentration of HAs dissolved in 0.1 M NaOH. Molecular size distribution was measured by HPSEC, and weight average molecular weight (M_w) was calculated from the calibration curve made with several sodium polystyrene sulfonate samples. Composition of C functional groups was estimated from ramp CPMAS ^{13}C NMR spectra (Dria *et al.* 2002). Composition of N functional groups was estimated using XPS (Abe and Watanabe 2004). RTO followed by gas chromatography (GC) was conducted for 4 sub-fractions according to Ikeya *et al.* (2007). Briefly, HAs were reacted with $\text{RuCl}_3 \cdot n\text{H}_2\text{O}$ and NaIO_4 at 25°C , and water-soluble products were methylated. Methyl esters of benzenepolycarboxylic acids (BPCAs) with 2 to 6 carboxyl groups derived from naphthalene to coronene structures were determined by GC using internal standard method. XRD spectra were recorded in the scan range of $2\theta = 5\text{-}100^\circ$. A silicon folder was used. The 11 band profile was analyzed to estimate the composition of carbon-layer planes on a weight basis. A mixture of two series of carbon-layer plane models starting from benzene/coronene and pyrene (Fujimoto 2003) was adopted for calculating the theoretical scattering intensities. Total amount of carbon-layer planes in arbitrary units (A.U.) per mg of sample was evaluated from the intensity of 11 band (base-line method).

Results

In the fractional precipitation, HAs with higher degrees of humification precipitated at lower acetone concentrations. The ^{14}C age was older in the sub-fractions precipitated at lower acetone concentrations and ranged from 104 to 530 yBP. The ^{14}C age correlated positively with A_{600}/C ($r^2 = 0.93$; $P < 0.005$) and negatively with $\log(A_{400}/A_{600})$ ($r^2 = 0.97$; $P < 0.005$). The relationship between ^{14}C age and A_{600}/C was expressed as follows:

$$^{14}\text{C age} = 29.4 A_{600}/C + 78.8 \quad (1)$$

Since the sub-fraction samples for structural analysis were prepared separately from the samples used for ^{14}C age analysis, their ^{14}C age was estimated using equation 1.

The M_w value estimated by HPSEC was larger in an older fraction. The proportion of aromatic C in total C (37-51%) showed a positive correlation to ^{14}C age ($r^2 = 0.93$; $P < 0.005$). Positive correlation was also observed between the proportion of aromatic N in total N (7-19%) and ^{14}C age ($r^2 = 0.88$; $P < 0.05$), while the proportion of peptide/amide N in total N decreased with increasing ^{14}C age ($r^2 = 0.92$; $P < 0.05$).

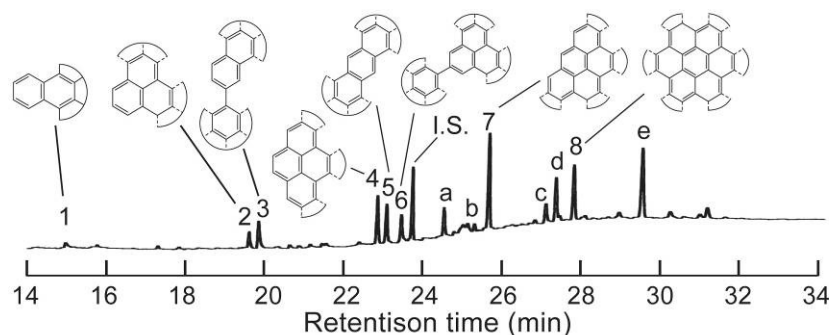


Figure 1. GC chromatogram of degradation products from sub-fraction (50P) of Miyazaki humic acids by RuO_4 oxidation. I.S., Internal standard (nonadecanoic acid methyl ester). Peaks 1, 2-3, 4-6, 7, and 8 were assigned to benzene-di-, tri-, tetra-, penta-, and hexa-carboxylic acids methyl esters. Their representative condensed aromatic nuclei origins are shown above peak Nos. Peaks a-e were assigned to benzenepolycarboxylic acids having other side chains than carboxyl groups.

Table 1. Yields of degradation products derived from condensed aromatic structures from the sub-fractions of Miyazaki humic acids with different ^{14}C age by RuO_4 oxidation (mg/g).

Number of aromatic rings in original structure	Estimated ^{14}C age of sub-fraction (yBP)			
	530	325	223	147
2 (Peaks 1 and 3 in Figure 1)	6.0	3.8	6.4	5.6
3 (Peaks 2, 5, and 6)	15	9.8	15	11
4 (Peak 4)	7.9	5.9	7.0	5.0
5-7 (Peaks 7 and 8)	35	21	17	8.7
Unknown (Peaks a-e)	47	27	18	14
Total	111	68	63	44

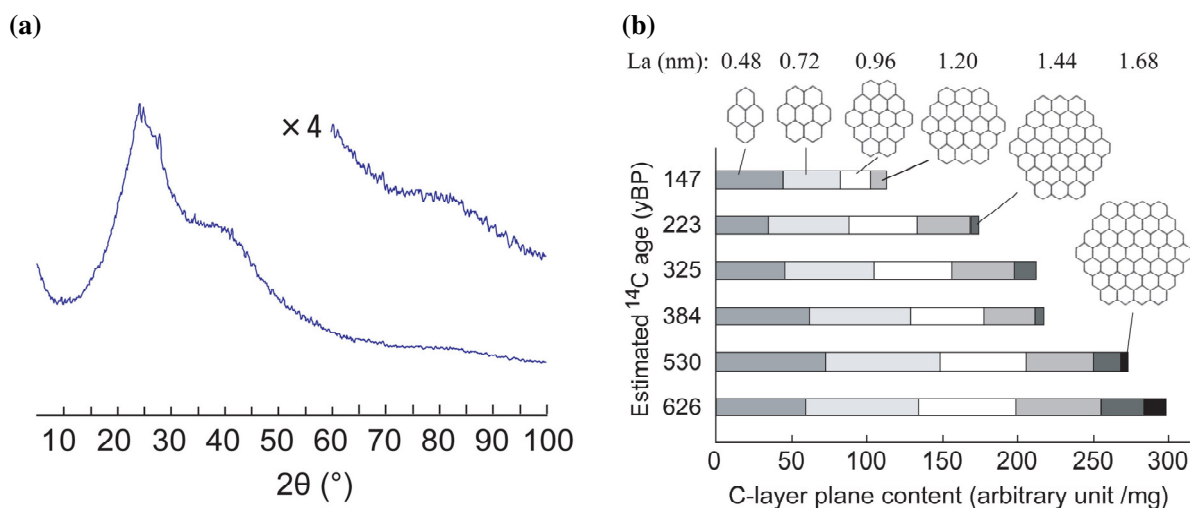


Figure 2. X-ray diffraction profile of sub-fraction 50P (a) and relative content of various sizes of carbon-layer planes in the sub-fractions of Miyazaki humic acids (b). L_a indicates the size of carbon-layer plane.

Figure 1 shows an example of the GC chromatogram of RTO products. In RTO, condensed aromatic components are degraded mainly into BPCAs. In Table 1, the estimated ^{14}C age of each fraction is shown instead of fraction name. Sum of the yield of BPCAs was largest and smallest in the oldest and youngest fractions, respectively. Difference among the fractions was more conspicuous in the yield of BPCAs derived from 5- to 7-ring condensed aromatic structures than in those from 2- to 4-ring condensed aromatic structures (Table 1). Figure 2a shows the representative XRD profile of Miyazaki HAs (50P). The 002 band ($2\theta = 24^\circ$) was most prominent, followed by 01 band at around $2\theta = 40^\circ$. The 11 band with maximum at around $2\theta = 80^\circ$ was weak but clearly observed in all the fractions. The 11 band analysis indicated the occurrence of multiple sizes of carbon-layer planes from 0.48 to 1.20 nm, corresponding to condensed aromatic structures consisting of 4 to 19 rings, in the youngest fraction (Figure 2b). Larger carbon-layer planes up to 1.68 nm corresponding to 37-ring condensed aromatic structures were observed in the older fractions. Total amount of condensed aromatic structures based on the intensity of 11 band was larger in the older samples and positively correlated to the proportion of aromatic C in total C ($r^2 = 0.985$).

Conclusion

Sub-fractions of HAs having different ^{14}C age in a soil layer showed different structural properties. Aromatic C and N became more abundant with increasing ^{14}C age. RTO and XRD analyses showed that the contents of condensed aromatic components that have 5-37 rings were greater in the older fractions. These results were not contradictory to the larger M_w in older than younger fractions. It was therefore concluded that aromatic components with a larger degree of condensation contributed to the longer residence time of highly-aromatic and darker-coloured HAs.

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Soilscape of the west-central Taiwan — the footprints on soil pedogenesis and geomorphic environment

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Abstract

There are five different types of soils including Entisols, Inceptisols, Arfisols, Ultisols, and Oxisols, distributed in west-central Taiwan. They cover the surfaces belonging to three major geologic terrains namely the Pleistocene anticline, the Holocene coastal plain, and the modern alluvial fan. This study demonstrates the mosaic pattern of the soil distribution may help to identify the extents and boundaries between geologic terrains, and to resolve the environmental changes due to complex fluvial migration. The informative soil mapping is achieved by properly grouping certain soil units based on genetic relationship between soil properties and the geomorphic environment. Moreover, the chronological data from archaeological and geological studies in the area is used as time constraints to envisage the progressive development in soil pedogenesis through time.

Key Words

Entisols, Inceptisols, Arfisols, Ultisols, Oxisols.

Introduction

Soil is earth material subject to the formation processes that involves the factors of climate, organism, topography, parent material, and time (Jenny 1941), which leads to a wide variety of compound in composition and structure from place to place. Among the total of 12 soil orders in *Soil Taxonomy*, the island of Taiwan contains 11 of them distributed on the surfaces of various landforms developed by active tectonics since Plio-Pleistocene. The wide diversities on both soil and landform in Taiwan provide an excellent environment and opportunity to the inter-discipline study of pedology and geomorphology (eg., Tsai *et al.* 2006, 2007a, b, c, 2008; Hseu *et al.* 2007). The goals of this study is to (i) establish an up to date soil database, (ii) identify the extent and boundary in each terrain, (iii) reconstruct the fluvial environment on the Choshui alluvial fan, and (iv) envisage the progressive development of pedogenesis.

Geology and soil distribution

There are five soil types, including Entisols, Inceptisols, Arfisols, Ultisols, and Oxisols, developed in west-central Taiwan. They cover the surfaces belonging to three geologic terrains namely Pleistocene anticlines, Holocene coastal plain and modern alluvial fan (Lin 1957; Ho 1986; CGS 2004) (Figure 1). The alluvial fan was developed on the coastal plain with frequently floods and river migration resulting in ambiguous terrain boundaries (Chang 1983,1985). Moreover, there are river terraces developed on these anticlines, where surface soils forms a typical post-incisive type of soil chronosequence.

Geomorphic expression and time constraints

The fundamental unit of the soil database in this study was based on taxonomic class of soil series, which allows different levels of map units in soil mapping. However, the soils mapped with the unit of low hierarchical classes show detail fabrics in a very complex mosaic. With properly grouping of the soil units based on the genetic relationship between soil properties and geomorphic environments, the geomorphic expression for each grouped soil variety provides a useful tool to locate the position or landform of the environment. In this study, the pattern of the fabrics based on taxonomic class of great group is adequate in detail for the geomorphologic purpose, and is therefore used in our soil mapping. The geomorphic interpretation for the soil varieties distributed in the study area was based on Buol *et al.* (1997) (Table 1) (Figure 2). Moreover, there are chronological data in the geological and archaeological studies, which can be used as age or time constraints in studying both the pedogenic process during soil development and the geomorphic evolution.

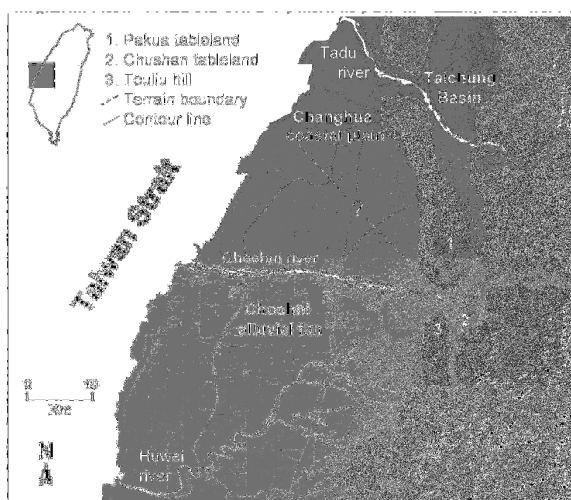


Figure 1. The shaded relief map of the study area.

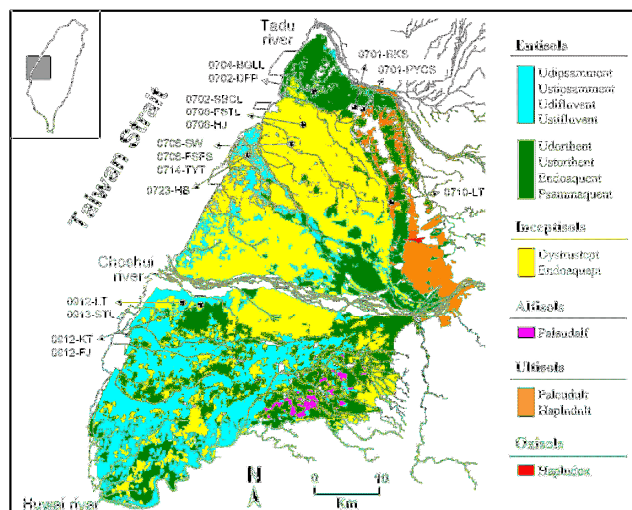


Figure 2 The soil map of the study area. The solid circles with arrow indicate the excavated archaeological sites.

Table 1. Taxonomic definition and corresponding geomorphic interpretation for the soils distributed in west-central Taiwan.

Soil taxa	Brief definition ^{*1}	Geomorphic interpretation ^{*2}
<i>Entisols</i>		
Udipsamment	Soils have textures of loamy fine sand or coarser and are better drained than Aquent.	The islands, bars and river banks positions in the floodplains of rivers.
Udifluvent	Soils are loamy and clayey (fine in texture than loamy fine sand) alluvial soils with very simple profiles. Irregularity of content of organic matter with depth is diagnostic.	The natural levee positions in the floodplains of rivers.
Ustifluvent	Stratification is common in alluvium and in soils derived from it.	
Udorthent	Soils are loamy and clayey Entisols with a regular decrease in content of organic matter with depth.	The higher dryland positions in the floodplains of rivers.
Ustorthent		
Endoaquent	Soils are permanently or seasonally wet (saturated) and even if artificially drained, which display bluish gray redoximorphic features.	The backwater lowland in the floodplains of rivers.
Psammaquent	Soils that have less 35% rock fragments and a texture of loamy fine sand or coarser are permanently or seasonally wet (saturated) and even if artificially drained, which display bluish gray redoximorphic features.	The backwater lowland in the floodplains of rivers.
<i>Inceptisols</i>		
Dystrudept	Soils have ochric epipedons.	The upland positions on young geomorphic surface.
Endoaquent	Soils have redoximorphic features and are saturated with water at some period in the year unless artificially drained.	The lowland positions on young geomorphic surface.
<i>Arfisol</i>		
Paleudalf	The depth of mineral soils with fine texture is greater than 150 cm, and soils have an argillic horizon with hue of 7.5YR or redder and chroma of 5 or more.	Landform surface was abandoned and has not been disturbed by fluvial processes for the past thousands of years.
<i>Ultisols</i>		
Hapludult	Soils with base saturation of less than 35% have argillic horizon.	Terrain of alluvial terraces in a steady state system of weathering, erosion, and isostatic uplift over a time span of ten or hundred thousand years.
Paleudult	Soils with base saturation of less than 35% have argillic horizon. And, relative clay content decreases less than 20% within 150 cm of the surface.	Terrain of alluvial terraces in a steady state system of weathering, erosion, and isostatic uplift over a time span of ten or hundred thousand years.
<i>Oxisols</i>		
Hapludox	A soil pedon with udic moisture regime contains 40% or more clay in the surface 18cm and CEC over clay is 16 cmol/kg or less.	Relatively stable upland summit positions, relict from a previous regional erosion surface, or on preserved remnants of an oldest alluvial terrace or pediment.

*1: based on Soil Survey Staff (2006)

*2: from Buol *et al.* (1997)

Progressive pedogenic development

The effective time interval for forming each soil in taxonomic class of soil is critical, information for estimating soil age. For instance, soil ages of ≥ 1300 and 19000 years for the Inceptisols distributed on the Changhua coastal plain and the Pakua tableland suggest the required time for development of Inceptisols. A longer period of time is required for Inceptisols to develop into Ultisols, and the soil age of more than 300 ka for Oxisols give a maximum time constraint for Ultisols. The minimum age of the Ultisols lies between 1.9 and 30 ka. As a result, the developmental sequence of soil pedogenesis based on time constraints is established for soils ranging through from Entisols, Inceptisols, Ultisols, to Oxisols (Figure 3).

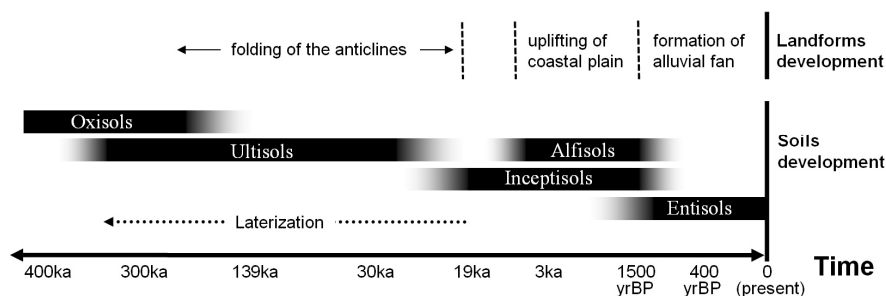


Figure 3. Soil development through time in Taiwan. Note that the timeline is not linearly indicated.

Concluding remarks

A landform with Inceptisols is expected to be older than that with Entisols formed during geomorphic evolution. The boundary between Inceptisols and Entisols observed in this study area distinguishes the geologic terrains between the Changhua coastal plain and the Choshui alluvial fan, which supports the idea that the alluvial fan was built on and above the coastal plain. The sediments discharged by the Choshui River covered most of the coastal area. However, this area may have been exposed by tides until its uplift in the middle Holocene. The coastal area received a massive deposition of alluvium from the Choshui River, which built a massive alluvial fan on the coastal plain. The pedogenic intensity of the reddish soils developed on the anticlines grades from Inceptisols, Ultisols, to Oxisols depending on the increasing altitude of the terrace surfaces on the anticlines. This study demonstrates soil varieties and their mosaic distribution may help to identify not only the extent of each geologic terrain but also the Paleo-environment of the west-central Taiwan. With chronological constraints, the genetic relationship between soils and landforms may reveal the progressive development of pedogenesis through time.

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Unravelling upbuilding pedogenesis in tephra and loess sequences in New Zealand using tephrochronology

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Abstract

The genesis of soils developed in either tephra or loess on stable sites differs markedly from that of soils developed on rock because classical topdown processes operate in conjunction with geological processes whereby material is added to the land surface so that the soils form by upbuilding pedogenesis. Understanding the genesis of such soils (typically Andisols and Alfisols, respectively) often requires a stratigraphic approach combined with an appreciation of buried soil horizons and polygenesis. In New Zealand, calendrically-dated tephtras provide an advantage for assessing rates of upbuilding through chronostratigraphy. Many Andisol profiles form by upbuilding pedogenesis as younger tephtra materials are deposited on top of older ones. The resultant profile character reflects interplay between the rate at which tephtras are added to the land surface and topdown processes that produce andic materials and horizons. In loess terrains, upbuilding pedogenesis since c. 25,000 years ago is associated with maximum rates of loess accumulation c. 3–10 mm per century, sufficiently slow for soil-forming processes to continue to operate as the land surface gradually rises. Thus, Alfisol subsoil features are only weakly developed and Bw or B(x) horizons typically are formed. In contrast, topdown pedogenesis is associated with minimal or zero loess accumulation, the land surface elevation remains essentially constant, and subsoil features become more strongly developed and Bg, Bt, or Bx horizons typically are formed.

Key Words

Soil-sediment, tephrochronology, chronostratigraphy, pedostratigraphy

Introduction

Most text books describe pedogenesis in terms of classical ‘topdown’ processes that progressively modify a stable, pre-existing parent material. Indeed, modelling of such processes in the context of explaining soil development in time and space is almost invariably restricted to soils formed on rock, that factor being ‘constant’ apart from change resulting from in situ weathering (e.g., Minasny *et al.*, 2008). However, in many landscapes, such as those of alluvial plains or where tephtras or loess have been deposited, aggrading parent materials are very common. The evolution of soils in such landscapes therefore has an additional complexity because the impact from topdown processes is modified by the rates at which new materials are added to the landsurface via geological processes. The resultant soils are formed by upbuilding pedogenesis instead of topdown pedogenesis (Johnson *et al.*, 1987; Almond and Tonkin, 1999; Schaetzl and Anderson, 2005). They may show distinctive layering and buried horizons, forming multisequal profiles. In this paper we use tephrochronology to examine the rates and processes involved in the evolution of late Quaternary soils via upbuilding pedogenesis from tephtras (typically forming Andisols) and from loess (typically forming Alfisols) in New Zealand. Such application has been enhanced by the development of new calibrated age models for tephtras erupted in the past c. 30,000 years (Lowe *et al.*, 2008a).

Upbuilding pedogenesis on tephtra

The accumulation at a particular site of numerous tephtra deposits from sequential eruptions from one or more volcanoes leads usually to the formation of Andisols with distinctive layered profiles and buried soil horizons. Such layered profiles, together with their andic soil properties and glass content, are key features of Andisols. Study of the layers and attaining ages for them (tephrostratigraphy) is an important aspect of understanding Andisol formation. During periods of quiescence between major eruptions, soil formation takes place, transforming the unmodified tephtra materials via normal topdown pedogenesis in a downward-moving front to form subsoil horizons. However, when new tephtras are added to the land surface, upbuilding pedogenesis takes place. The frequency and thickness of tephtra accumulation (and other factors) determine how much impact the topdown processes have on the ensuing profile character, and if ‘developmental’ or ‘retardant’ upbuilding, or both, will take place. Two contrasting scenarios can be considered. In *scenario 1*, successive thin tephtra deposits (ranging from millimetres to centimetres in thickness) accumulate

incrementally and relatively infrequently so that developmental upbuilding ensues. Such a situation occurs typically at distal sites. The thin materials deposited from each eruption become incorporated into the existing profile. Topdown pedogenesis continues as the tephras accumulate but its impacts are lessened because any one position in the sequence is not exposed to pedogenesis for long before it becomes buried too deeply for these processes to be effective as the land surface gently rises (Figure 1). This history thus leaves the tephra materials with a soil fabric inherited from when the tephra was part of the surface A horizon or subsurface Bw horizon (Lowe and Palmer, 2005; McDaniel *et al.*, in press). Each part of the profile has been an A horizon at one point, as illustrated in Figure 1.

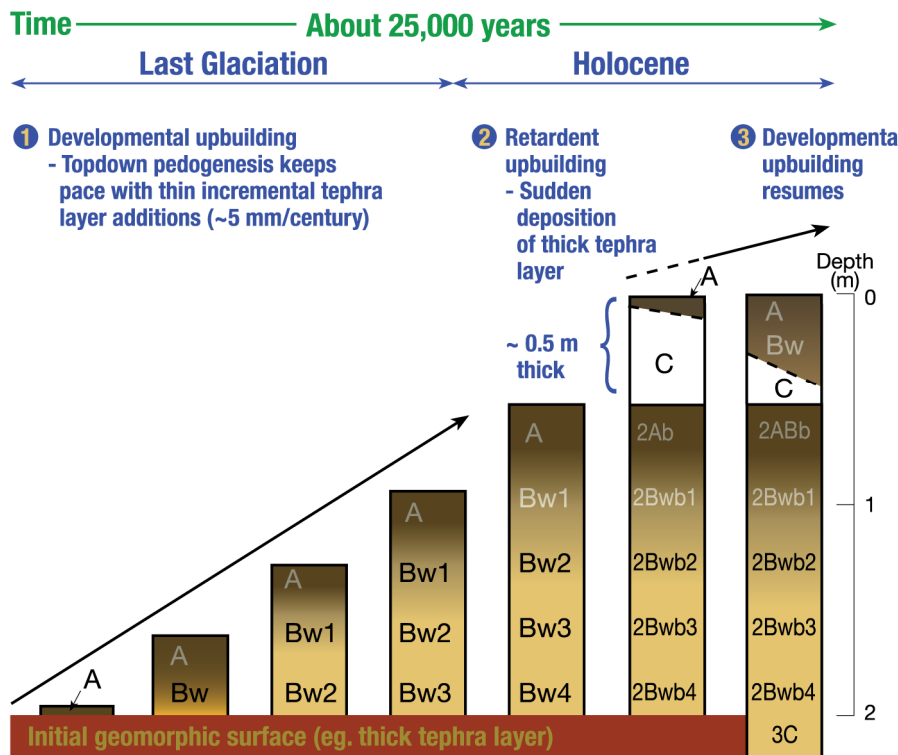


Figure 1. Model of upbuilding pedogenesis in tephra deposits and the formation of a multisequal Andisol over c. 25,000 years. In phase 1 (developmental upbuilding), thin, distal tephras accumulate slowly whilst topdown processes imprint weak horizonation features on them as the land surface gradually rises. In phase 2 (retardant upbuilding), the sudden deposition of a tephra layer ~0.5 m thick from a particularly powerful eruption buries the antecedent soil, isolating it from most surface processes so that topdown processes begin anew on the freshly deposited tephra. In phase 3, incremental tephra deposition on the new soil continues and developmental upbuilding resumes (after McDaniel *et al.*, in press).

In *scenario 2*, tephra accumulation is more rapid, as occurs in locations close to volcanoes or when a much thicker layer (more than a few tens of centimetres) is deposited from a powerful eruption. In the latter case, the antecedent soil is suddenly buried and isolated beyond the range of most soil-forming processes (i.e., it becomes a buried soil/buried soil horizons). A new soil will thus begin forming at the land surface in the freshly deposited material. This scenario typifies retardant upbuilding, which means that the development of the now-buried soil has been retarded or stopped, and the pedogenic 'clock' reset to time zero for weathering and soil formation to start afresh. An example of a multisequal Andisol profile formed via retardant upbuilding pedogenesis since c. 9500 years ago is shown in Figure 2. Each of five successive tephra deposits (named Rotoma, Whakatane, Taupo, Kaharoa, and Tarawera) shows the imprint of topdown pedogenesis, as depicted by their soil horizonation. But the sudden arrival of each new deposit buries and effectively isolates each of the weakly-developed 'mini' soil profiles as the land surface rises. The soil in Figure 2 (Rotomahana series) is an Udivitrant in North Island, New Zealand. Retardant and developmental upbuilding may both occur in the evolution of a single Andisol profile. For example, in Figure 1, topdown pedogenesis effectively keeps pace with incremental tephra additions (at c. 5 mm per century) until interrupted by deposition of a thick layer that overwhelms the pre-existing soil, leaving an abrupt, clear boundary.

Upbuilding pedogenesis in loess

As recognised c. 120 years ago by James Hardcastle in the South Island of New Zealand, loess deposits commonly comprise multiple sheets with buried soils, formed during phases of very slow or zero loess deposition, marking the boundaries between sheets. In some areas, the loess-buried soil horizon sequences have been considered to represent cold-warm climates, respectively, with the change from one to the other analogous to an on/off switch.

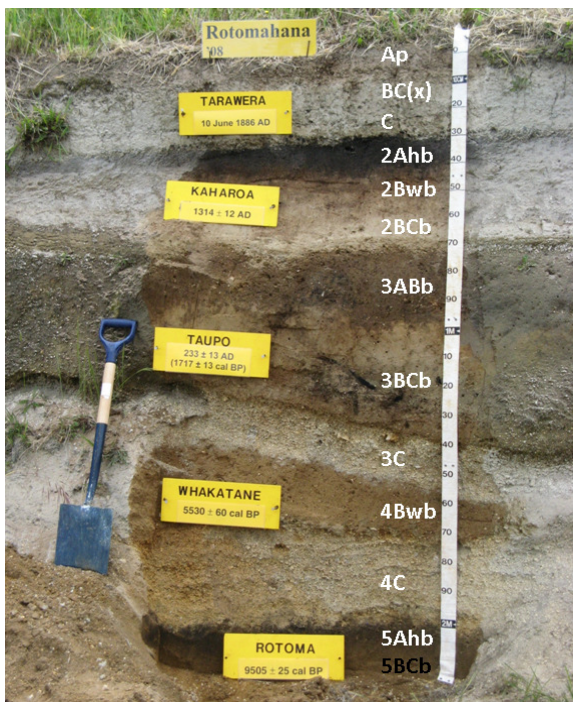


Figure 2. Example of a multi-layered Andisol formed through retardant upbuilding in New Zealand. After each tephra is deposited, soil begins to develop until it is buried by another tephra and topdown pedogenesis begins operating in the fresh deposit. The buried ‘mini’ soil profile on Whakatane tephra (4Bwb, 4C) reflects ~3800 years of pedogenesis, the amount of time it was at the land surface before burial by Taupo tephra; that on Taupo tephra (3ABb, 3BCb, 3C) reflects ~1100 years; that on Kaharoa tephra (2Ahb, 2Bwb, 2BCb) reflects ~570 years; and the topmost (surface) mini profile (Ap, BC(x), C) reflects ~125 years of pedogenesis on hydrothermally altered, mud-rich tephra deposited in AD 1886 by the Tarawera eruption. Some properties of the buried soil horizons may have been altered via diagenesis. The black 2Ahb horizon reflects a high content of type-A humic acids and charcoal following invasion by bracken fern and grasses after Polynesian deforestation and probably ongoing burning (after McDaniel *et al.*, in press). Photo: R. McEwan.

This model applied to the southern North Island area where cold climatic conditions (e.g., oxygen isotope stages [OIS] 2, 6, 8) corresponded to maximum loess accumulation and relatively slow pedogenesis, and warm climatic conditions (e.g., OIS 1, 5, 7) to relatively fast pedogenesis and no loess accumulation (Palmer and Pillans, 1996). Where loess accumulation is minimal or nil, soil development operates as a classical topdown process to form the distinctive subsoil (i.e. B horizon) features used to identify buried soils and to subdivide the loess column into sheets or soil stratigraphic units. But, as for distal tephra fallout sequences, most loess deposits have features indicative of continual pedogenesis. During periods when loess is accumulating, soil formation does not stop, but its effects are lessened as it eventually becomes buried too deeply for these topdown processes to be effective (Lowe *et al.*, 2008b). This upbuilding history leaves the loess deposit with a soil ‘vermiform’ fabric inherited from when the loess was at the land surface and represented by soil A horizons. These vermiform features include fragipans, the interiors of which have a soil fabric throughout comprising traces of faunal activity such as back-filled burrows and root traces. The latter are very obvious where secondary CaCO₃ in the loess has formed root pseudomorphs. (The vermiform fabric is one of the signatures used to distinguish loess from other silty sediments such as weathered siltstones.) Soil formation thus occurs simultaneously with slow loess accumulation, forming a ‘soil-sediment’ via upbuilding pedogenesis (Figure 3). In New Zealand, the average rates of net loess accumulation since deposition early in OIS 2 of the widespread marker bed the Kawakawa tephra c. 27,100 years ago, and before the Holocene, are only about 3 to 10 mm per century (Eden and Hammond, 2003; Lowe *et al.*, 2008a, 2008b). When loess accumulation slows further or ceases altogether, topdown soil formation takes over. The imprint of topdown pedogenesis is more marked in the long run, forming the distinctive buried soil features – not simply because of ‘improved’ climatic conditions but because the rate of loess accumulation is so reduced that pedogenic processes and weathering effectively operate for longer periods. This model of alternate upbuilding pedogenesis and topdown pedogenesis phases applies widely to loess sequences in the South Island and probably in most of southern North Island (Lowe *et al.*, 2008b).

In landscapes upwind from the main tephra sources in central North Island, the intermittent fallout of thin, distal tephra deposits at about 1 to 5 mm per century is at a rate comparable to slow loess accretion during glacial periods. Hence, for almost all of the time, upbuilding pedogenesis predominates in many distal-tephra-derived Andisol profiles because the accretion of tephra – together with tephric loess during glacials – is effectively continual. Typically, a few millimetres or centimetres of ash are deposited every few hundred years on the average, more frequently if cryptotephra (glass-shard concentrations not visible as layers in the field) are considered. The topdown-dominant phase only comes into play when a thicker tephra layer (approximately 20–30 cm or more) is emplaced so that the antecedent soil is effectively buried and sealed off. But in time, upbuilding pedogenesis will gradually resume as the ongoing eruptions of wind-borne (hence loess-like) tephra continue to ‘dust’ the imperceptibly rising land surface over thousands of years.

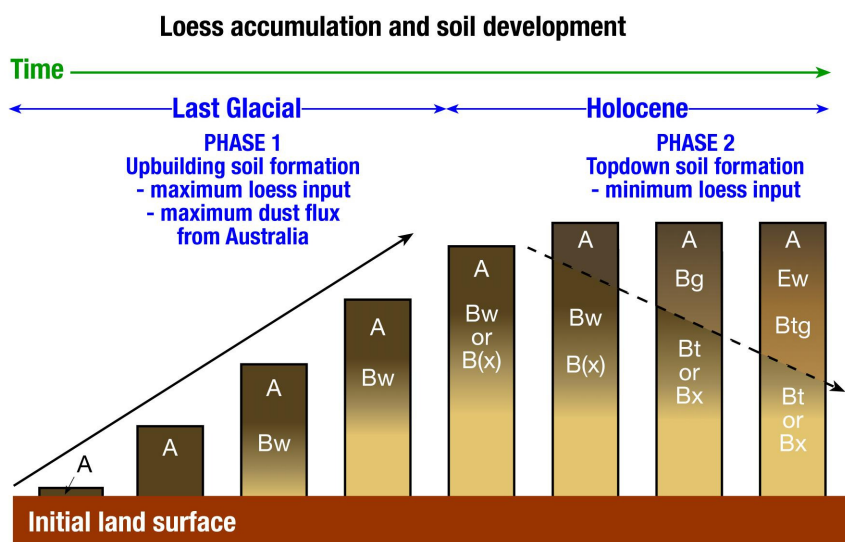


Figure 3. Model of soil development in loess since c. 25,000 years ago. The initial geomorphic surface approximates the Kawakawa tephra. Phase 1 depicts upbuilding pedogenesis during maximum (but slow) loess accretion (OIS 2); phase 2 depicts topdown pedogenesis with minimal or zero loess accretion (OIS 1). Soil horizons show that the maximum development of subsurface features occurs in phase 2 with more strongly developed horizons evident (after Lowe *et al.*, 2008b).

Conclusion

Andisol profiles commonly have distinctive layering and buried soil horizons and form by upbuilding pedogenesis as younger tephra materials are deposited on top of older ones. The resultant profile character is determined by the interplay between the rate at which tephra are added to the land surface and topdown processes that produce andic materials and horizons. Understanding Andisol genesis thus often requires a stratigraphic approach combined with an appreciation of buried soil horizons and polygenesis. In loess terrains, upbuilding pedogenesis is associated with maximum rates of loess accumulation (during cold climates) but these rates are sufficiently slow for soil-forming processes to continue to operate as the land surface gradually rises 'millimetre by millimetre'. Thus, subsoil features are only weakly developed and Bw or B(x) horizons are formed. In contrast, topdown pedogenesis is associated with minimal or zero loess accumulation (during warm climates), the land surface elevation remains essentially constant, and subsoil features become more strongly developed so that Bg, Bt, or Bx horizons are formed. Loess accumulation and soil formation may be envisaged as 'competing' processes (e.g., see Muhs *et al.*, 2004), but the former seldom exceeds the latter. Quantitative modelling of soil development should incorporate soils developed via upbuilding pedogenesis as well as those that evolve through topdown pedogenesis.

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U-series nuclides in weathering profiles: Rates of soil processes

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Abstract

The development of U-series nuclides for investigating weathering processes is quite recent, and was significantly stimulated by the analytical improvement made over the last decades in measuring the ^{238}U series nuclides with intermediate half-lives (i.e., ^{234}U - ^{230}Th - ^{226}Ra). Here it is proposed to review the recent results obtained with the analysis of U-series nuclides in weathering profiles to determine rates of soils processes as well as the age of minerals or concretions that the weathering profile can contain.

Key Words

U-series nuclides, rates of weathering processes, soil mineral dating

Introduction

The time parameter of processes that control the formation and evolution of soils and weathering profiles is a key information to be determined for many questions of the Earth Surface and Environmental Sciences. Such a determination is especially required for constraining and modelling the future evolution of soils and weathering profiles in response to external factors, including the impact of human activity. Radiochronological methods have a real potential for addressing this general issue (e.g., Vasconcelos, 1999; Chabaux *et al.*, 2008; Cornu *et al.*, 2009).

Here it is proposed to focus on the U-series nuclides, the potential of which for investigating weathering processes is recognized since the 1960s with for instance the works of Rosholt *et al.* (1966) and Hansen and Stout (1968). The development of this area of research is however quite recent, and was significantly stimulated by the analytical improvement made over the last decades in measuring the ^{238}U series nuclides with intermediate half-lives (i.e., ^{234}U - ^{230}Th - ^{226}Ra) using, first, thermal-ionisation mass spectrometric techniques, and, later, MC ICP-MS techniques. The interest of U-series nuclides as tracers and chronometers of weathering processes results from the dual property of the nuclides to be fractionated during water-rock interactions and to have radioactive periods of the same order of magnitude as the time constants of many weathering processes. Recent reviews of the application of U-series nuclides to the study of weathering and river transport can be found in Chabaux *et al.* (2003b; 2008). Here it is proposed to illustrate the interest of the analysis of U-series nuclides in weathering profiles to determine rates of soils processes as well as the age of minerals or concretion the weathering profile can bear.

Determination of regolith formation rates from analysis of U-series disequilibria in weathering profiles

Following the work by Hansen and Stout (1968) it was anticipated that the depth variation of U-series nuclides within a weathering profile could constitute a simple way to estimate the propagation rate of weathering fronts in regoliths. The subsequent studies in this topic (e.g., Boulad *et al.*, 1978; Mathieu *et al.*, 1995; Dequincey *et al.*, 2002) however demonstrated that U-series nuclides in soils and weathering profiles usually follow complex trends as a function of depth, which suggest the occurrence of complex history for U-Th-Ra fractionation in regoliths. These studies clearly show also that the recovery of time information on weathering processes from the analysis of U-series in soils requires a comprehensive understanding of the main processes leading to U-series fractionations in such weathering systems (Chabaux *et al.*, 2003a). As exemplified with the study of an African (Kaya) lateritic toposequence (Dequincey *et al.*, 2002; 2006; Chabaux *et al.*, 2003a), the combination of the study of U-series nuclides in soils with the study of major and trace element concentrations may constitute a simple method to bring important information on the origin of U-Th fractionation in weathering profiles. Such an approach, applied to the case of the Kaya toposequence, has shown that the main mechanisms that control U-Th distribution in the saprolite of this toposequence, is the breakdown of the upper ferruginous duricrusts that induces a downward vertical migration of U in the underlying pedological units. The comparison of the variations of ^{234}U - ^{238}U and ^{234}U - ^{230}Th disequilibria in the lateritic system, also suggests that both uranium gains and losses occur in each horizon of the profile. The mobility of U and Th isotopes in this system can be therefore modelled by the following equation:

$$\frac{dN_s^i}{dt} = Fi - kiN_s^i - \lambda_i N_s^i + \lambda_{i-1} N_s^{i-1}$$

where, the subscript s refers to soil, N^i represents the number of nuclides i in the soil phase, λ_i is the decay constant of nuclide i , k_i is a first-order constant describing the loss of nuclide i , and Fi is the input Flux of nuclide i gained by the soil. Using the Kaya data and the above modelling yields time information about chemical redistribution linked to the breakdown of the iron cap in this weathering profile (Chabaux *et al.*, 2003a). Similar approaches have been applied to other weathering profiles developed on different parent bedrocks, in Amazon (Chabaux *et al.*, 2006; Pelt, 2007) (Figure 1) and in Puerto Rico (Blaes *et al.*, 2009).

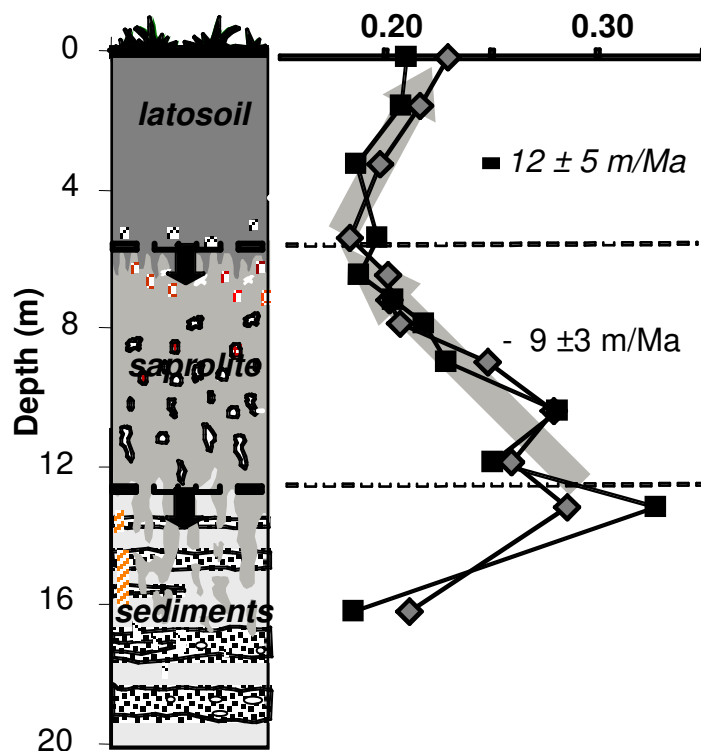


Figure 1 Propagation rate of a weathering front determined by ^{238}U - ^{234}U - ^{230}Th disequilibrium method in a lateritic profile developed on sediments (Manaus, Brazil) (in. Pelt, PhD Thesis, 2007). Black squares: $(^{230}\text{Th}/^{232}\text{Th})$ activity ratios; grey diamonds: $(^{238}\text{U}/^{232}\text{Th})$ activity ratios.

In both cases U-Th data allow to recover the propagation rates of the bedrock weathering front (Figure 1) and to discuss the steady-state situation of these weathering and erosion systems. Recently it was also shown that U-series isotopes can be successfully used to constrain the formation rate of a weathering rind developed on a basaltic clast in a sedimentary Costa Rican terrace (Pelt *et al.*, 2008). All these data clearly demonstrate now that analysis of U-series nuclides in weathering profile constitutes a powerful tool or approach to constrain the regolith production rate in weathering profiles (see also Dosseto *et al.*, 2008). The previous works and results should prompt new research in the field over the coming years.

U-Th Dating of soil minerals

Study of the mineralogical soil fractions can also constitute another means of getting time information on soil processes. U-series nuclides can be indeed used for dating soil minerals or concretions such as pedogenic calcite, pedogenic silica or soil ferruginous concretions and rinds (see review in Chabaux *et al.*, 2008). All these studies more or less rely on the hypothesis that soils and weathering profiles contain minerals and materials that have evolved in closed systems with respect to the U series chain. However the classical dating method used for pure carbonates (Kaufmann and Broecker, 1965) is rarely applicable for soil materials, even for soil carbonates, that usually contain detrital Th. Therefore, U-Th dating of soil minerals requires correction for initial detrital ^{230}Th , following classical methods reviewed for instance in Ludwig (2003). These methods rely on the assumption that soil concretions are mixtures of two isotopically homogeneous end-members, one of which does not contain initial Th. The aim of all the correction methods is to determine the $^{234}\text{U}/^{238}\text{U}$ and $^{234}\text{U}/^{230}\text{Th}$

ratios of the Th-free end-member to calculate its age. One approach to recover such ratios is to analyse a suite of coeval sub-samples from the same pedogenic horizon or the same soil samples. This approach has benefited from the analytical performances afforded by TIMS and MC-ICPMS techniques, especially due to the sample size reduction, (and hence sampling resolution), which enable the analysis of sufficiently small size samples to avoid the measurement of composite material with complex history. The more recent development of for *in situ* U and Th isotope analysis methods (e.g., Paces *et al.*, 2004; Bernal *et al.*, 2005; 2006) certainly constitutes a new and important step in the study and the dating of soil minerals, as already illustrated with accurate *in situ* U-Th isotope analysis of silicates glasses and iron oxides. These “*in situ*” studies are only at their initial stages. Their development could nevertheless rapidly renew the study of the weathering profiles and the determination of their formation ages and their history.

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