Catena 74 (2008) 58–64

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Reconstructing the paleotopography beneath the loess cover with the aid of an electromagnetic induction sensor

Timothy Saey [a,*], David Simpson [a], Udayakantha W.A. Vitharana [a], Hans Vermeersch [a], Jan Vermang [b], Marc Van Meirvenne [a]

[a] Research Group Soil Spatial Inventory Techniques, Department of Soil Management and Soil Care, Faculty of Bioscience Engineering, Ghent University, Coupure 653, B-9000 Gent, Belgium
[b] Laboratory of Soil Physics, Department of Soil Management and Soil Care, Faculty of Bioscience Engineering, Ghent University, Coupure 653, B-9000 Gent, Belgium

ARTICLE INFO

Article history:
Received 31 October 2007
Received in revised form 26 February 2008
Accepted 17 March 2008

Keywords:
EM38DD
Apparent electrical conductivity
Paleolandscape
Tertiary substrate
Quaternary loess cover
Erosion patterns

ABSTRACT

During the last glacial period (Weichselian), wind-blown loess was deposited over the undulating landscape of central Belgium, which had been formed in surfacing Tertiary marine sediments. Since valleys were filled up with a thicker loess layer than hill tops, the present topography is much smoother. This smoothing was enhanced by subsequent erosion processes. Reconstructing the paleolandscape at a detailed scale is almost impossible by conventional procedures based on soil augerings. Therefore, the use of the electromagnetic induction sensor, EM38DD, was evaluated as an alternative for mapping the depth to the Tertiary clay substrate. On our 2.7 ha study site, located in the loess belt of central Belgium, a strong non-linear relationship (R^2=0.86) was found between the apparent electrical conductivity (ECa), measured by the vertical dipole orientation of the EM38DD and the depth to a Tertiary clay substrate. These predictions were validated by independent observations of the depth to the Tertiary clay and a correlation coefficient of 0.83, with an average error of 0.22 m, was found. So, our dense ECa measurements (2 by 2 m resolution) allowed us to build a three-dimensionall surface of the depth to the Tertiary substrate, reconstructing the paleotopography beneath the loess cover. This paleotopography revealed distinct erosion patterns on the surface of the Tertiary clay. The continuity of these was confirmed by an analysis of surface flow patterns conducted on the reconstructed paleotopography. The non-invasive, time- and cost-effective electromagnetic induction sensor was found to offer new perspectives to reconstruct and analyse in detail the Quaternary paleotopography beneath the loess cover.

1. Introduction

The loess belt of Central Europe extends from the Atlantic coast, through central Belgium, to Eastern Europe. During the last glacial period (Weichselian), the periglacial undulating landscape of central Belgium had been formed in surfacing Tertiary marine sands and clays. This paleolandscape was covered by niveo-aeolian loess, with a thickness ranging from only a few decimeters on hill tops up to several tens of meters in valleys (Gillijns et al., 2005). As a consequence, the paleotopography was strongly smoothened and since slope processes have modified the thickness of the loess layer further, the paleotopography cannot be reconstructed on the basis of the present topography. The world's major loess deposits have correctly been linked to glacial processes or to cold weathering processes (Iriondo and Kröhling, 2007). Yet, a precise and accurate representation of landforms and niveo-aeolian loess sediments offers fundamental information about Pleistocene periglacial environments (Smith et al., 2006).

Geomorphological mapping, particularly at large scales (1:10 000 or greater) is one of the most important techniques in Quaternary research with the aim at analyzing glacial landscapes, including those resulting from the passage of the last ice sheets and particularly from more recent phases of glacier activity (Lowe and Walker, 1997). However, traditional geomorphological mapping needs to adapt to challenges for greater precision and objectivity within a GIS environment (Gustavsson et al., 2006). Leverington et al. (2002) digitally reconstructed late Quaternary landscapes by using a GIS method that subtracted interpolated isobase values from modern elevations. These maps served for the reconstruction of the Quaternary landscape on a large scale and with a limited accuracy. Therefore, quantifications of the subtle changes in paleotopography could not be made.

The extent to which conventional invasive methods can be employed for the quantification of the small-scale soil variability is often limited by the availability of expertise and the expense and labour associated with obtaining soil samples by augering (Stroh et al., 2001). Non-invasive geophysical methods (like seismic, geo-electric and electromagnetic) have proven to be effective for investigating the stratigraphy over relatively large depths (20–80 m) (Bersezio et al., 2007; Sass, 2007; Sloan et al., 2007). While geophysical investigations

* Corresponding author. Fax: +32 9 264 62 47.
E-mail address: Timothy.Saey@UGent.be (T. Saey).

0341-8162/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.catena.2008.03.007

focus on the exploration of natural resources, hydrogeology or engineering purposes, knowledge about the applicability in shallow (<3 m) subsurface exploration for geomorphologic purposes is still incomplete (Sass, 2007). To investigate the soil constitution over shallower depths, soil-adapted geophysical sensors, like the EM38DD (Geonics Ltd., Mississauga, ON, Canada), have proved their functioning (Boll et al., 1996; Sudduth et al., 2003; Cockx et al., 2006; Cockx et al., 2007).

The objective of this study was to evaluate a methodology for mapping the paleotopography at shallow depths (<3 m) beneath the loess cover using the EM38DD electromagnetic induction (EMI) sensor. Therefore, a relationship between the paleotopography and the apparent electrical conductivity (ECa), measured by the EM38DD sensor, had to be found and validated. As a test case, a study site of 2.7 ha in central Belgium was used where the paleolandscape prior to the deposition of the loess cover was formed in Tertiary marine clay.

2. Materials and methods

2.1. Geology

The Belgian loess belt, which is part of the large European loess belt, is characterized by a gentle rolling landscape, where Tertiary marine sandy and clayey deposits were covered by a Quaternary loess layer (Vanwalleghem et al., 2005). Generally, the thickness of the loess cover varies with the position in the landscape. Thin loess deposits (sometimes as thin as a few decimetres) can be found on the ridges, while in depressions thick loess deposits (of several tens of meters) can occur. The main sedimentation phase of the Quaternary loess was in the Weichselian glacial stage of the Late Pleistocene (80 ka–10 ka) (Lowe and Walker, 1997).

The Tertiary material located directly below the Quaternary loess is composed of a range of marine depositions dating from the Early Eocene (54.8 Ma–49.0 Ma), generally with a clayey or sandy constitution. Within the study area this layer belongs to the clayey variant of the Ypresian (Maréchal and Laga, 1988).

2.2. Study site

The research site was located in Heestert (southeast of the province of West-Flanders, Belgium), situated in the Belgian loess belt (Fig. 1). It was situated on a southeast facing hillside with an average slope of 7% and an elevation ranging between 30 to 40 m above sea level (a.s.l.). The site consisted of two neighbouring fields. Field 1 was a 2 ha arable parcel (with central coordinates: 50°47′58"N, 3°24′41"E), planted to a sugar beet (*Beta vulgaris* L.)–winter wheat (*Triticum aestivum* L.) rotation. This field was used to calibrate and validate the relationship between ECa and the depth to the Tertiary substrate, observed after soil augering. Field 2 was a permanent pasture of 0.7 ha, located next to the eastern boundary of field 1 (with central coordinates: 50°47′01"N, 3°24′46"E). This field was added to reconstruct the paleotopography beyond the boundaries of the calibration field.

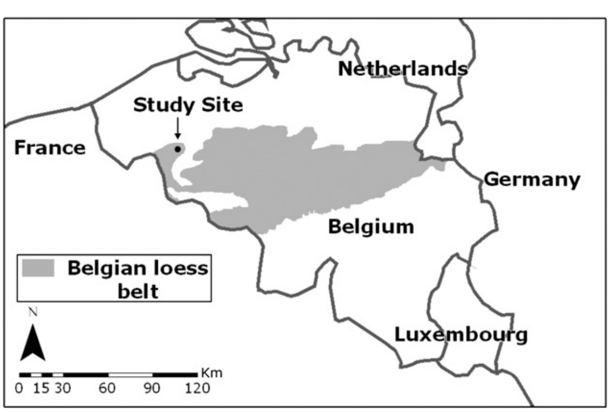

Fig. 1. Localization of the study site in the Belgian loess belt.

Table 1
Average textural composition of the Quaternary loess and Tertiary substrate based on samples taken along transect ABCD (*n*: number of samples, *m*: mean, *s*: standard deviation)

	n	Clay (%)		Silt (%)		Sand (%)	
		m	*s*	*m*	*s*	*m*	*s*
Quaternary loess	23	19.1	6.8	48.9	9.0	32.0	11.4
Tertiary substrate	17	40.2	8.0	53.3	7.2	6.5	5.6

On the national soil map (scale 1:20 000) one dominant soil series (uLdc) is indicated for both fields. These symbols represent: a shallow (<75 cm) clay substrate (u), a silt loam topsoil texture (L), moderately wet conditions (d) with a strongly degraded textural B-horizon (c). In the southern part of field 1 the shallow clay substrate was not indicated. This soil type corresponds to a Luvisol (WRB), which is characterized by an argic horizon ranging from 0.3–0.35 m up to 1.3–1.4 m in depth. Initially, the deposited loess was calcareous, but with time it decalcified, mostly down to a depth of 2–2.5 m (Hubert, 1976).

Across the study site, soil samples were taken from the Quaternary loess and the Tertiary clay substrate and analyzed for their textural composition according to the conventional sieve-pipette method. The mean clay-silt-sand fractions (with boundaries 2–50–2000 µm, respectively) of both the 23 Quaternary and the 17 Tertiary samples are given in Table 1, together with their standard deviations. On average, the loess layer has a larger sand content (32.0%) and a lower clay content (19.1%) than the Tertiary material (6.5% sand and 40.2% clay). Both layers show a relatively limited variability in soil texture, but the Tertiary clay layer is more homogeneous than the loess. These differences illustrate the relative easiness for an experienced soil scientist to distinguish between both layers in the field.

2.3. Mobile ECa-measurement equipment and temperature standardization procedure

An EM38DD sensor was mounted on a sled pulled by an all terrain vehicle (ATV), which drove with a speed of 6–10 km h^{-1} (Fig. 2(a) and (b)). The EM38DD is a dual dipole sensor and consists of two single EM38′s positioned perpendicular to each other, with one instrument oriented horizontally and the other vertically. The EM38DD simultaneously measures the ECa in the two dipole orientations: vertical (ECa_v) and horizontal (ECa_h). Every second, ECa_v and ECa_h measurements were recorded by a field computer. A Trimble AgGPS332, with Omnistar correction, was used to georeference the ECa measurements with a pass-to-pass accuracy of approximately 0.10 m. Measurements were taken along parallel lines with an in-between distance of 2 m, driving was supported by a Trimble Lightbar Guidance System. Additionally, at each ECa measurement point, the soil surface elevation was acquired with the Trimble AgGPS332 (accuracy ± 0.30 m). The ECa measurements on field 1 were taken on 27/04/2007; field 2 was surveyed on 19/06/2007. In both cases weather conditions were dry.

Since ECa measurements depend on the soil temperature, it is necessary to standardize them according to a reference temperature (Sheets and Hendrickx, 1995). Usually a reference temperature of 25 °C is taken (Slavich and Petterson, 1990):

$$ECa_{25} = ECa \cdot \left(0.447 + 1.4034 \cdot e^{-\frac{T}{26.815}}\right) \quad (1)$$

with ECa_{25} the standardized ECa at a temperature of 25 °C and *T* the soil temperature in °C. At the measurement dates, soil temperature was continuously measured at a depth of 0.20 m below soil surface, averaged and applied in Eq. (1). The ECa values presented in the