Catena 149 (2017) 1–18

Contents lists available at ScienceDirect

Catena

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

The impact of natural and anthropogenic processes on the evolution of closed depressions in loess areas. A multi-proxy case study from Nałęczów Plateau, Eastern Poland

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ARTICLE INFO

Article history:
Received 6 November 2015
Received in revised form 22 May 2016
Accepted 20 July 2016
Available online xxxx

Keywords:
Closed depression
Loess
Palaeosol
Colluvium
Holocene
Late Vistulian

ABSTRACT

Closed depressions are reported in loess landscapes in various parts of Europe. The anthropogenic and natural origin of closed depressions is highly debated in literature. Closed depressions are an important component of the landscape in loess areas of the Lublin Upland. Furthermore, they perform the role of local closed sediment basins, creating unique conditions for the preservation of soils and colluvial sediments, along with the record of the evolution of the Holocene landscape, occurring under the influence of climate changes and human activity.

The study objective was to evaluate the contribution of natural and anthropogenic processes influencing the origin and evolution of closed depressions. The Nałęczów Plateau is composed of loess, whose thickness varies from a few meters to >30 m. 1761 closed depressions have been documented within the Nałęczów Plateau (493 km^2). A detailed investigation was conducted within selected closed depression, dissected by a deep and long road trench. The studied form was 40 m long, 26 m wide and 0.7 m deep. The analyzed exposure; 20 m long and 7 m high, presents a cross-section of the closed depression. Fieldwork and subsequent laboratory analyses were conducted: morphological, micromorphological, microstructural, geochemical, physico-chemical, OSL and ^{14}C dating. Archaeological and historical correlations were also performed.

The primary bottom and slopes of the studied depression are composed of loess in situ, overlain by Late Glacial-Holocene fossil soil. Periglacial structures, such as deformed ice-wedge pseudomorphs, cracks and lenses macrostructures were documented in the loess and palaeosol at the bottom of the closed depression. The depression is filled with Neoholocene soil-sediment sequences consisting of 2 layers of colluvial sediments, separated by Neoholocene subfossil soil. They constitute a record of the two stages of CD infillings in the Holocene, connected with human agricultural activity, lasting from the Neolithic up to modern times.

A detailed analysis of the loess, Late Glacial-Holocene fossil soil and Holocene colluvial sediments made it possible to distinguish the stages of evolution of closed depression influenced by changing environmental conditions and human activity, during the Late Glacial and Holocene.

1. Introduction

Loess–paleosoil sequence imply an important record of former climatic conditions and provides informations about landscape evolution in the Pleistocene (Vancampenhout et al., 2013, Meszner et al., 2013).

Periglacial structures documented in loess are of key importance for palaeoenvironmental reconstructions (Vandenberghe, 2001, 2004; Van Vliet-Lanoë et al., 2004; Jary, 2009, 2010).

Most authors indicated the Late Glacial-Middle Holocene as the period of soil formation on the top of the loess cover (Kuhn, 2003; Dreibrodt and Bork, 2005; Reiß et al., 2009). They are polygenetical soils often formed from chernozem evolution. On European loess cover, chernozem soils, from the Early Holocene, have been documented (Czerny, 1965; Rau, 1968; Roeschmann et al., 1982). The problem of the Holocene evolution of Chernozems, due to illuviation in central Europe has been extensively described by Eckmeier et al. (2007) and in eastern Europe by Alexandrovsky and Chichagova (1998). These

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http://dx.doi.org/10.1016/j.catena.2016.07.029
0341-8162/

authors suggest that the transformation of Chernozems occurred in the Atlantic period or in the Late Holocene.

Thanks to long-lasting agricultural use, which started in the Neolithic, several phases of human impact, recorded in the colluvial sediments, have been documented in the loess areas of Europe, during the Holocene (Rommens et al., 2005; Dotterweich, 2008; Dotterweich et al., 2012). Various methods are used in the investigation of loess–palaeosol sequences and colluvial sediments: physico-chemical, micromorphological, microstructural, geochemical, palynological and absolute dating, as well as archaeological and historical correlation (Kalis et al., 2003; Vanwalleghem et al., 2006; Reiß et al., 2009).

Closed depressions are a landform feature, characteristic of loess covers in Europe. Investigations of these forms, in the western and central parts of the European loess belt, indicate that both natural and anthropogenic processes lead to their formation (Gillijns et al., 2005; Vanwalleghem et al., 2007; Etienne et al., 2011). In Poland's loess plateaus, closed depressions form a characteristic microrelief, with distinctive morphometric properties and distribution, suggesting the natural origin of these forms (Maruszczak, 1954, 1958; Kołodyńska-Gawrysiak and Chabudziński, 2012). Given the special character of closed local sedimentation basins, these forms create unique conditions, enabling the preservation of colluvial sediments, along with a record of Holocene landscape evolution, occurring under the influence of climate change and human activity.

The study objective was to evaluate the contribution of natural and anthropogenic processes, influencing the origin and evolution of closed depressions. For this purpose, interdisciplinary investigations of loess–palaeosoil and colluvial sequences have been conducted, in the representative closed depression. The morphological, physico-chemical, microstructural, micromorphological and geochemical properties, as well as the origin and age of palaeosol and soil-sediment sequence, infilling the closed depression, were examined. Thanks to identification of the processes involved in the formation and evolution of closed depressions, this research will contribute to the understanding of the main processes influencing the morphogenesis of loess cover in the post-glacial period. They will also enable an assessment of the morphogenetic effects of permafrost melting on the contemporary relief of the loess areas.

More research is needed to unravel the genesis and evolution of these depressions to better understand the importance of the Late Glacial and Holocene stages for the morphogenesis of the loess belt in Europe.

2. Study area

The investigation was conducted in the eastern part of the Nałęczów Plateau, a region of the Lublin Upland, in eastern Poland (Fig. 1). The bedrock of the study area is composed of Upper Cretaceous opokas and marls covered by glacigenic sediments (glacial tills, sands with gravels and clays) accumulated during Elsterian and Odranian Glaciation (Harasimiuk, 1987). Glacigenic sediments underlie loess cover, whose thickness ranges from several meters to >20 m (Harasimiuk and Henkiel, 1978). Loess cover was formed mainly during the last glaciation, and loess accumulation lasted until 15,000–12,000 BP (Maruszczak, 1976, 1980).

The undulating loess plateau; rising up to 210–250 m a.s.l., is the main landform in the study area. Numerous oval-shaped closed depressions occur on the plateau top (Fig. 1). Most of them have a diameter ranging from 25 m to 50 m (Kołodyńska-Gawrysiak and Chabudziński, 2012). The loess plateau is dissected by erosion-denudation valleys, forming multi-branched systems.

Detailed studies were conducted within a closed depression, dissected by a deep and long road trench. This closed depression is located in Jastków; a locality about 7 km NW of Lublin, on a loess plateau top, between the Ciemięga and Czechówka rivers, at 210 m a.s.l (Fig. 1). Georeferencing of the studied site is 51°17′33.43″, 22°25′41.58″. The studied form was 40 m long, 26 m wide and 0.7 m deep. The catchment of this form was about 1500 m^2. Due to its morphometric characteristics, the depression under study, belongs to the most common group of such forms, occurring in the loess areas of eastern Poland. Two profiles, J2 and J3, were selected for detailed investigation; in the centre and in the slope of the closed depression respectively.

3. Materials and methods

3.1. Field methods and sampling strategy

A large exposure 20 m in length and 6–7 m in height was investigated (Fig. 2A, B). The analyzed exposure constitutes a cross-section of the closed depression, formed in the loess cover. This allowed the conducting of direct geological, geomorphological, as well as palaeopedological observations and documentation of loess–palaeosoil and colluvial sequences in the closed depression.

After cleaning the exposure, soil horizons, colluvial layers, cracks and past permafrost structures were identified and documented in detail. The morphological properties of the layers and horizons were also documented and described, according to Guidelines for soil descriptions, FAO (2006) The exposure was documented in photographs and in a scale drawing.

Detailed studies of soil–sediment sequences in the exposure, were carried out, based on two profiles, located in the central part (J2) and on the SE fossil slope of the depression (J3) (Fig. 2B).

Samples for laboratory analysis were collected, directly from the wall of the exposure. Bulk samples of soils and sediments for physico-

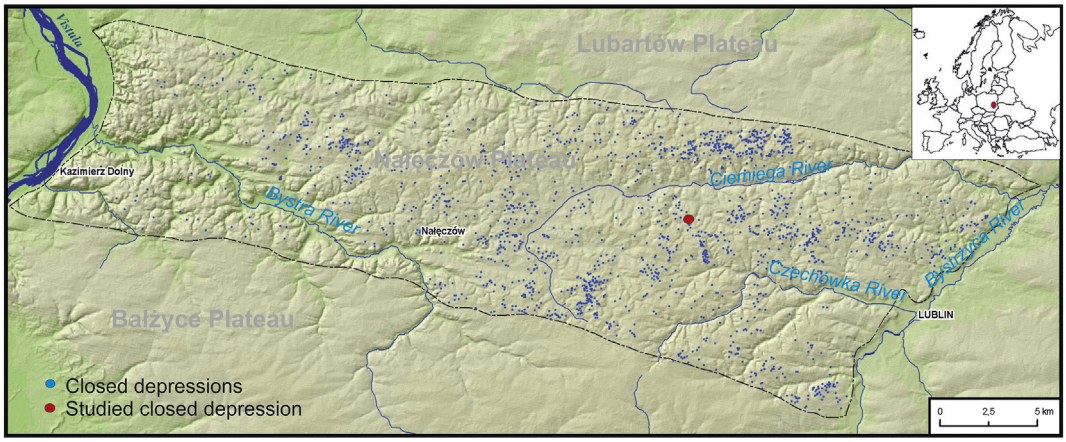

Fig. 1. Study location.