Georgian National Academy of
Sciences, Department of Earth
Sciences, Tbilisi, Georgia

2-9 October 2016

INTERNATIONAL GEOSCIENCE PROGRAMME

Proceedings of the Fourth Plenary Conference

IGCP 610 “From the Caspian to Mediterranean:
Environmental Change and Human Response during the
Quaternary” (2013 - 2017)

http://www.avalon-institute.org/IGCP610
IGCP 610 Fourth Plenary Conference and Field Trip, Tbilisi, Georgia, 2-9 October 2016

PROCEEDINGS

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PROCEEDINGS

IGCP 610 Fourth Plenary Conference and Field Trip

“From the Caspian to Mediterranean: Environmental Change and Human Response during the Quaternary”

http://www.avalon-institute.org/IGCP610

Tbilisi ◆ Georgian National Academy of Sciences ◆ 2016
ISSN 978-9941-0-9178-0

Printed in Georgia, Georgian National Academy of Sciences, Tbilisi

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PEDOGENETIC RESPONSE TO CLIMATIC FLUCTUATIONS
WITHIN THE LAST GLACIAL-INTERGLACIAL CYCLE IN THE
LOWER VOLGA BASIN

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Keywords: paleosol, loess, marine clays, paleoenvironmental reconstruction

Introduction

Soils form under the direct influence of climatic parameters, and they retain environmental
information in their features (soil memory: Targulian and Goryachkin, 2008). Thus, buried
soils provide an excellent opportunity to reconstruct paleoenvironments preceding burial. The
area of the lower Volga basin experienced considerable changes due to fluctuations in
Caspian Sea level together with other responses to glacial-interglacial cycling in the
Quaternary. Numerous horizons of buried soils have been recorded in sedimentary sequences,
and they have been used for stratigraphic correlations and paleogeomorphic reconstructions in
the area (Konstantinov et al., 2016). But the study of paleosols as a paleoenvironmental proxy
has not been performed until now.

The study of the 20 m exposure on the terrace in the middle stream of the Akhtuba River
provides a unique opportunity to reveal the complex interplay among several factors: Caspian
Sea level cycling, related fluctuations in fluvial activity, continental (aeolian) sedimentation,
the local environment of the Akhtuba River valley, and the pedogenetic response to
environmental and geomorphic changes.

Study area and methodology

The site is situated on the terrace of the Akhtuba River with an elevation of 21 m asl and 20
km from Volzhskiy city. The exposure was thoroughly examined in the field. The stratigraphy
includes a designation of loess layers separated by marine clays and fluvial deposits. Six
pedogenetic levels (Fig. 1a) were examined morphologically according to the FAO
Guidelines for Soil Description (IUSS, 2006: 109) and classified according to the WRB
(2014). Soil samples for hierarchical morphological (mesomorphology, micromorphology,
SEM) and analytical studies were taken from all horizons. OSL dating (described in the paper
of Yanina et al., this volume) allows us to bracket the pedogenetic events to various stages
within the last interglacial-glacial cycle.
Figure 1. The Lower Akhtuba soil sedimentary sequence. a. General view; b. The upper MIS 3 paleosol in the Atel-Akhtuba strata with a truncated humus horizon; c. The middle MIS 3 paleosol of the Atel-Akhtuba strata with 30-40 cm deep sand cracks, forming a regular network; d. The lower MIS 3 paleosol of the Atel-Akhtuba strata with cryogenic deformations; e. The upper soil of the Mezin pedocomplex (MIS 5) with a network of frost wedges - Gleyic Phaeozem; f. The middle soil of the Mezin pedocomplex (MIS 5) - Gleyic Chernozem; g. The lower soil of the Mezin pedocomplex (MIS 5e) - Mollic Calcic Gleysol.

Results

The 20 m high exposure is capped by a 120 cm upper (MIS2) loess layer with modern surface soil (Kastanozem) typical for dry steppe areas. The loess is underlain by marine clays 120-520 cm. OSL dates for the middle (13,000±500) and lower parts (15,000±1000 yrs) characterizes marine clays of the Early Khvalynian transgression of the Caspian Sea (Arslanov et al., 2013). The clays consist of fine plates with a typical chocolate hue. The clay strata are slightly touched by pedogenesis down to 110±20 cm (230±20 cm from the day surface); vertical cracks and sub-angular structural units are covered by weakly developed clay cutans with overlying carbonate coatings.

Marine clays are underlain by a soil-sedimentary sequence formed during the Atel-Akhtuba regression of the Caspian Sea (MIS 3) with three pedogenetic levels developed in loess and corresponding to MIS 3 interstadial paleosols. The humus horizon of the upper well-developed soil (520-600 cm) is truncated to the AhB horizon (Fig. 1b). The remaining profile could be preliminarily attributed to a Relictigleyic Luvic Chernozem with Bt horizons showing well-developed clay-humus cutans covered by carbonate films. The profile is underlain by fluvial sand (600-770 cm), showing a gradual transition to silty loess loam downward. Sand merges laterally into the 10-20 cm loess layer with large gypsum crystals, confirming an arid environment at the time of loess sedimentation.

The second pedogenetic level (770-800 cm) is presented by loess strata with weakly developed soil without clear horizonation. Pedogenetic features include platy and angular structural units, clay cutans, rhizoliths, manganese mottling, carbonate concretions, and gypsum crystals. Dark spots indicate the remains of displaced humus horizons. The upper surface of the pedogenetic level is complicated by a regular network of sand cracks, indicating severe seasonal frost and possible permafrost (Fig. 1c).

The third pedogenetic level is concise with shallow loess patches (880-910 cm), merging laterally and covered by a fluvial sand interlayer (800-880 cm, Fig. 1d). Pedogenetic features are recorded in clay cutans and biopores. Remains of a carbonate horizon are visible in the
upper 7 cm of loess. The third pedogenetic level is disturbed by cryogenesis (Fig. 1d). The lower part of the loess is intermixed with sandy lenses.

The study of the MIS 3 soil-sedimentary complex confirms that the soils formed in a cold, arid environment during short periods of mesomorphic pedogenesis coinciding with loess sedimentation and interrupted by an increase in fluvial activity. A cold environment and possible permafrost are indicated by frost wedges and involutions disturbing the soil horizons. Gley mottling contradicting the aridity features could be the result of waterlogging owing to long-seasonal overflooding of the terrace surface. The lower part of the Atel-Akhtuba strata (910-1530 cm) is represented by a carbonate loess without noticeable pedogenetic transformation.

The Mesin pedocomplex (MIS 5a-e, 1530-1680 cm) is attributed to the Late Khazarian transgressive epoch and includes three distinct soils formed in loess. The age of the upper soil (MIS 5a-d) is characterized by OSL as 68,000 ± yrs. The Gleyic Phaeozem has an accretionary humus horizon (about 1 m) owing to synsedimentary pedogenesis at the onset of loess sedimentation. The soil surface is disturbed by a network of frost wedges 40-50 cm apart with a broad part going down to 40 cm and narrow fissures much lower than the soil profile (Fig. 1e). The wedges start in the overlying Atel-Akhtuba loess layer, indicating the beginning of the last glacial cycle (MIS 4). Krotovinas, mostly expressed at 20-30 cm from the buried surface, show a steppe environment, and gleyic features indicate seasonal overflooding. Lower horizons (1650-1670 cm) are developed in loess and interlayered with fine sandy layers owing to contrasting sedimentation. The soil profile gradually merges into the middle soil of the Mesin pedocomplex (1670-1790 cm, Fig. 1f).

The upper 5 cm of the humus horizon of the middle soil (Gleyic Chernozem) are intermixed with the Bg horizon of the upper soil (welded paleosol). Carbonates in the upper layer are most probably diagenetic; in the Bg horizon, the complex assemblage of carbonate neoformations is a result of steppe pedogenesis. Gleyic features are due to seasonal overflooding. Narrow endings of frost fissures penetrate from the Atel-Akhtuba loess down to the middle part of the profile.

The lower soil of the Mezin pedocomplex (MIS 5e) is separated from the middle soil by a transportic layer (1790-1800 cm) and represented by a Mollic Calcic Gleysol (1790-1860 cm, Fig. 1g) formed in loess sediments accumulated during the penultimate glaciation (MIS 6).

The presence of the Mezin pedocomplex formed in loess confirms that the area was beyond the Late Khazarian transgression of the Caspian Sea. Nevertheless, the high stand of the Akhtuba River caused long-term seasonal overflooding resulting in gleyic features. Three soils of the Mezin pedocomplex have common features: well-developed humus horizons and a complex assemblage of carbonate neoformations formed in a steppe environment; gleyic features owing to long-term seasonal overflooding; welded and/or synlithogenic profiles owing to contrasting sedimentation on the river terrace.

The lower part of the sequence is represented by interlayering of loess and clay bands without clear pedogenetic influence that indicates quick sedimentation with contrasting changes in the water level of the Akhtuba River. However, carbonate pseudomicellia indicate at least primitive pedogenesis in clays on the river terrace or dried firth surface.

Conclusions

The soil sedimentary sequence is formed in loess layers intermixed with marine and fluvial sediments. The upper loess (MIS 2) is underlain by marine chocolate clays. Such a unique feature allows setting a reliable correlation for Caspian marine and lower Volga loess stratigraphic patterns. Loess sedimentation on the river terrace frequently changed to fluvial
sedimentation according to fluctuations of the Caspian Sea level. Various loess units are divided by stream sands and terrace clays. Six pedogenetic levels are linked to periods of loess sedimentation between MIS 5 and MIS 1. The longer interval of geomorphic stability after loess sedimentation results in better developed loess profiles. All soils were formed in an arid environment that is indicated by a complex assemblage of carbonate neoformations and krotovinas. Nevertheless, all soils except the modern one show hydromorphic features (gley mottling, iron and manganese concretions). Such a mutually exclusive combination of soil features indicates polygenesis caused by river influence: long-term seasonal overflooding. There are three levels of interstadial paleosols (MIS 3). They formed in a cold and arid environment. This is especially obvious in the upper pedogenetic level that was influenced by deep seasonal freezing during the LGM. Interglacial soils (MIS 5a-d and especially MIS 5e) are much better developed. In contrast to the last interglacial soils of the center of the East European Plain (Mikulino) and Western Europe (Eemian), they are represented by steppe soils with gleyic features—Gleyic Chernozems and Mollic Calcic Gleysols. Soils are partly synlithogenic, their upper horizons formed simultaneously with loess sedimentation. The Mezin pedocomplex is represented by welded profiles. The upper horizons of some profiles are truncated. Interlayering and a gradual transition between loess and sand layers, contrasting pedogenetic features (humus accumulation and clay cutans, a complex assemblage of carbonate neoformations, gypsum crystals and gleyic features) indicate contrasting sedimentation and pedogenetic environments.

Pedogenetic horizons serve as good stratigraphic markers that will help correlate late Pleistocene soil-sedimentary sequences of the whole Caspian-Azov-Black Sea region of the East European Plain and link it with global stratigraphic schemes.

Detailed analytical and further field studies are required to reveal further pedogenetic responses to environmental changes in the area.

This research was supported by Russian Science Foundation, project 14-17-00705.

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