Accepted Manuscript

Palaeowind directions and sources of detrital material archived in the Roxolany loess section (southern Ukraine)

Jerzy Nawrocki, Petro Gozhik, Maria Łanczont, Magdalena Pańczyk, Maryna Komar, Andrej Bogucki, Ian S. Williams, Zbigniew Czupyt

PII: S0031-0182(17)30897-0

DOI: <https://doi.org/10.1016/j.palaeo.2018.01.028>

Reference: PALAEO 8637

To appear in: *Palaeogeography, Palaeoclimatology, Palaeoecology*

Received date: 27 August 2017

Revised date: 4 January 2018

Accepted date: 22 January 2018

Please cite this article as: Jerzy Nawrocki, Petro Gozhik, Maria Łanczont, Magdalena Pańczyk, Maryna Komar, Andrej Bogucki, Ian S. Williams, Zbigniew Czupyt , Palaeowind directions and sources of detrital material archived in the Roxolany loess section (southern Ukraine). The address for the corresponding author was captured as affiliation for all authors. Please check if appropriate. Palaeo(2017), <https://doi.org/10.1016/j.palaeo.2018.01.028>

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Palaeowind directions and sources of detrital material archived in the Roxolany loess section (southern Ukraine).

Jerzy Nawrocki^{ac,*}, Petro Gozhik^b, Maria Łanczont^c, Magdalena Pańczyk^a, Maryna Komar^{bd}, Andrej Bogucki^e, Ian S. Williams^f, Zbigniew Czupyt^a

^a Polish Geological Institute – NRI, Warszawa, Rakowiecka 4, 00-975, Poland

^b Institute of Geological Sciences, National Academy of Sciences of Ukraine, Kyiv, O. Gonchar 55-b, 01054, Ukraine

^c Maria Curie Skłodowska University, Faculty of Earth Sciences and Spatial Management, Lublin, Kraśnicka 2cd, 20-718, Poland

^d National Museum of Natural History, National Academy of Sciences of Ukraine, Kyiv, Bohdan Khmelnytsky 15, 01601, Ukraine

^e Faculty of Geography, Lviv University, Lviv, Petra Doroshenka 41, 79000, Ukraine

^f Research School of Earth Sciences, Australian National University, Canberra, ACT 2601, Australia

* jerzy.nawrocki@poczta.umcs.lublin.pl

Abstract

Measurements of the anisotropy of whole-rock magnetic susceptibility (AMS) and U-Pb ages of detrital zircons have been combined to define the palaeowind directions and sources of wind-blown dust in the loess-palaeosol key section at Roxolany (southern Ukraine). Zircon dating has also been used to determine the age and provenance of the interbedded Roxolany tephra. The distribution of AMS axes in the loess indicates that the prevailing wind during its accumulation blew from the north-west, the same as the mean present-day summer wind direction measured in the nearby city of Odessa. The U-Pb isotopic ages of the detrital zircons mostly range between 0.25 and 2 Ga, with clusters at 0.28, 0.32, 0.45, 0.58, 1.0 and 1.5 Ga. Single Neoproterozoic grains (ca. 2.7 Ga) were also found. These ages indicate that material from Carpathian and Podolian sources formed the Roxolany loess. This material initially was transported by the Dniester River, then was wind-blown from the Dniester liman and the lower Dniester valley, located NW of Roxolany. Most of the pyroclastic zircons from the Roxolany tephra gave ages of 470 – 840 ka, with a peak between 500 and 750 ka. This age range is consistent with their being derived from the Ciomadul volcano in Romania.

Keywords: magnetic susceptibility, anisotropy, zircon isotope ages, provenance, palaeogeography, loess

1. Introduction

Platy minerals in sediments and sedimentary rocks commonly are imbricated by wind or water currents. Because of this, the axes of minimum anisotropy of magnetic susceptibility (AMS) are tilted towards the flow direction. In a lower energy environment, elongated magnetic grains line up parallel to the current direction. Under the influence of stronger currents, prolate particles tend to become oriented perpendicular to the current (Tarling and Hrouda, 1993; Nawrocki et al., 2006). The magnetic lineation of loess is defined above all by magnetite and maghemite considered to be the principal carriers of magnetic susceptibility (Lagroix and Banerjee, 2002, 2004). AMS measurements are very useful for determining palaeowind velocity and direction during aeolian sedimentation of loess (e.g. Thistlewood and Sun, 1991). They also can provide valuable information about post-depositional displacement of loess deposits. Thus AMS can play a fundamental role in stratigraphic and palaeoenvironmental reconstructions of loess sedimentation (Lagroix and Banerjee, 2004). The most extensive AMS studies have been conducted on Chinese loess. Zhu et al. (2004) have demonstrated that long-term trends of magnetic foliation, degree of anisotropy and strengths of lineation match grain size variations in that loess. Wang and Løvlie (2010) suggested that foliation is acquired mainly during initial wetting of dry wind-deposited loess. Zhang et al. (2010) studied the AMS along W-E transect in the Chinese Loess Plateau and noted that the preferred orientation of the maximum susceptibility axis distribution represented the orientation of elongate magnetite grains, whilst the minimum susceptibility axis pattern was always contaminated by the distribution of the short dimension of oblate silicate mineral particles. For their palaeowind direction reconstruction, therefore, they preferred to use the peak orientation of maximum susceptibility axes from contour line plots. Finally they concluded that the loess material was brought to this area by the winter monsoon but the AMS was generated during the rainy summer monsoon when the AMS carriers were rearranged, settled, and fixed. Liu and Sun (2012) noticed that magnetic foliation and degree of anisotropy in the central Chinese Loess Plateau show upwards decreasing trend due to decreasing post-depositional compaction. Ge et al. (2014) indicated that the AMS of Chinese loess is determined mainly by the

patterns of regional surface wind flow that occurred during dust accumulation, rather than by the uniform pattern of large-scale atmospheric circulation.

Until now the AMS investigations of widespread loess patches in the Ukraine have been conducted in the westernmost areas, being restricted to the youngest unit correlated with the second marine isotope stage (MIS 2) (Nawrocki et al., 2006). The majority of the sections indicate a palaeowind orientation from WSW to ENE, with a mean azimuth of 258°. The AMS of the loess/palaeosol sequence in Roxolany has also been studied (Hus, 2003). Results from 62 loess and 29 soil samples taken from different horizons within the section showed an oblate fabric and strong deviation of some minimum magnetic susceptibility directions, explained by the author as the result of bioturbation.

The AMS investigations of the Roxolany loess section have been correlated with the marine isotope stages for better reference to global changes in palaeoclimate. It should be stressed, however, that the stratigraphy of this section remains equivocal because two different locations have been proposed for the Brunhes/Matuyama boundary (Tsatskin et al., 1998; Bakhmutov and Hlavatskyj, 2014; Bakhmutov et al., 2017). Here we have adopted the location identified by Bakhmutov and Hlavatskyj (2014) because it is consistent with the radiocarbon, TL and OSL dating of the youngest soils and loess (Fedorowicz et al. 2012; Wulf et al. 2016) and corresponds more closely with the general regional Quaternary stratigraphic framework (Gozhik et al. 1995).

The stratigraphic discrepancies mentioned above did not influence substantially the main tasks of our work. The aim of the present study was to reconstruct palaeowind directions, and to identify the sources of detrital material in the loess-palaeosol key section at Roxolany. AMS measurements were used to determine palaeowind directions, and the sources of the loess were investigated by U-Pb isotopic dating of detrital zircons. The dated zircons extracted not only from the loess, but also from tephra within the loess sequence. Geochemical comparison have established that this so-called “Roxolany Tephra” was derived from the Ciomadul volcano in the East Carpathians (Wulf et al. 2016). Both pyroclastic zircon and reworked detrital grains were expected to be present within the tephra layer. We aimed to check whether the volcanic zircons had an age spectrum comparable to the

duration of magmatic activity in the Ciomadul volcano, thereby indicating a westward direction of ash transport. We also compared the age spectra of reworked zircon grains from the tephra and the loess to test whether they come from the same source.

2. The Roxolany profile

2.1. *Present and past location*

The Pleistocene loess-soil sequence, which has been studied and discussed as the Roxolany profile (46°10'N, 30°27'E) for many years, forms the Pleistocene subaerial cover of the VII terrace of the Dniester River. Different fragments of these deposits, exposed on the high cliff of the left bank of the Dniester River liman (Fig. 1A) and on the steep, almost vertical walls of deep ravines dissecting the high bank, together form the complete profile of the Pleistocene cover. This is the mouth of the long liman, that cuts into the flat or slightly undulating Black Sea North Lowland. The liman is cut off by a bay-head bar from the Odessa Bay, which is a typical wide sea shelf within the Black Sea. The former Dniester River valley, once probably connected with the similar Dnieper River valley, is clearly visible in the relief of the bottom of this shallow sea. These palaeovalleys developed on a plain, that was exposed as a result of marine regression during the Last Glacial Maximum (LGM). During the Nepeuxinian phase (ca. 18 kyr BP), a shoreline was present at an absolute elevation of -90 to -110 m. Within the area of the present-day Odessa Bay the shore was then about 150 km south-east of its present-day position (Konikov, 2007). In contrast, during the preceding Karangatian phase of the Eemian interglacial, the sea-level was higher than the present day by 8-12 m, and the sea covered the lowlands in the coastal zone. Throughout the period 130-80 ka BP the sea in the region of the Dniester River valley reached almost the latitude of the Roxolany profile (Panin, 2007).

2.2 *Significance of the Roxolany profile*

The Roxolany site was first mentioned by Chepalyga (1967) in his description of molluscan fauna in alluvia, although the loess profile was not described. The whole profile, including the loess-soil series, was featured at the 8th Loess Symposium in the Ukraine in 1976 (Putievoditel 1976), and since then multidisciplinary research has been conducted at the site by several Ukrainian and international

teams (Tsatskin et al., 1998, 2001; Sartori, 2000; Simakova, 2002; Evans and Heller, 2003; Gendler et al., 2006; Dodonov et al., 2006; Gozhik et al., 1995, 2006, 2007; Pilipenko et al., 2007; Faustov et al., 2009; Gozhik, 2013; Bakhmutov and Hlavatskyi, 2014; Lanczont et al., 2015). The results were also presented in the field (Guidebook, 1982, 1984; Putivnyk, 2000; Bogucki et al. (eds.), 2013). The profile is popular with researches because it is one of the most complete and comprehensively studied loess profiles in the whole of southern Ukraine. It is unique due to the following features: i/ the large thickness (up to 50 m) of the loess-paleosol sequence; ii/ the atypical structure of the loess cover, the upper part of which (0 - 40 m; to the Dnieper loess of MIS 8) consists of extremely thick, almost horizontal loess beds, which are separated by interstadial and interglacial soils. In particular the Bug loess (bg) is one of the thickest loess beds in the territory of the Ukraine. Furthermore no other section in the Ukraine contains such a thick loess mass corresponding to the Uday loess (ud). Ukrainian researchers consider the upper part of the Roxolany profile to be the key profile of loess deposits in southern Ukraine. Below the Zavadiivka pedocomplex (zv) (MIS 12) the proportions of loess and fossil soils are more equal but compacted paleosols and loess layers of lesser thickness are characterized by spatial variability of occurrence and thickness (Putivnyk, 2000; Gozhik, 2013); iii/ striking physiognomic resemblance between reddish-brown paleosols of different stratigraphic rank, which represent steppe soil with an A-Bk profile, affected by rubification processes, with well-developed horizon of illuvial concentration of carbonates; iv/ the presence of a thin (20 – 30 mm), but clearly visible, layer of volcanic ash (the Roxolany Tephra) in the upper loess bed.

The international importance of the Roxolany loess profile results from its key role in the regional and interregional correlation of European loess deposits, as well as the correlation of those deposits with the loess in China. The Roxolany loess deposits are also a source of information about palaeoecological and palaeoclimatic transformations in the steppe area on the north side of the Black Sea during the whole Pleistocene, and especially the Late Pleistocene. As mentioned above, the magnetostratigraphy of the Roxolany profile is a matter of debate. Tsatskin et al. (1998) positioned the Brunhes/Matuyama boundary in the middle part of the section (Fig. 1B). As a consequence and the main portion of the loess deposit above this boundary was assigned to the middle Pleistocene. This

location for the Brunhes/Matuyama transition is not in agreement with previous work (see Gozhik et al., 1995) or the results of recent studies by Bakhmutov and Hlavatskyi (2014) and Bakhmutov et al. (2017), who positioned this boundary in the bottom part of the section (Fig. 1B). The lower position of the Brunhes/Matuyama boundary corresponds well with the regional scheme of Quaternary development in the Black Sea region (Gozhik et al., 1995, 2006, 2007). The stratigraphy of the Roxolany profile by Tsatskin et al. (1998) and Gendler et al. (2006) is not consistent with the results of radiocarbon, TL and OSL dating of soils and loess from the upper part of the section (Fedorowicz et al., 2012; Wulf et al., 2016) (Fig. 1B).

2.3 Structure of the Roxolany profile

The structure of the Roxolany profile, based on the work by Gozhik et al. (2006, 2007) and by a Polish-Ukrainian team (2011-2013), with later supplements (Bogucki et al. (eds.), 2013; Łanczont et al., 2015) is shown in Table 1 and Figure 1B. This subdivision is in agreement with the position of the Brunhes/Matuyama boundary determined by Bakhmutov and Hlavatskyi (2014), but only partly fits the stratigraphic schemes of Dodonov et al. (2006) and Gendler et al. (2006). Loess-soil units have been labelled according to the so-called “Chinese” loess nomenclature, using appropriate symbols for loess (L) and soil (S) units, as proposed by Liu et al. (1985). The stratigraphic terminology used is in accord with the Stratigraphical Framework of the Pleistocene of the Ukraine (Veklich et al., 1993).

2.4. Source material, wind directions, origin and age of tephra

Dodonov et al. (2006), in their discussion of loess alimentation at Roxolany, assumed that the main source of loess material was regional, namely that it was silt transported in large quantities by the Dniester palaeoriver, that subsequently was blown by wind and accumulated in neighboring areas. The environment in which loess accumulated at the mouth of the Dniester palaeoriver was extremely unstable, so this process was sensitive to changes in the location of the river delta, either the thickness of the loess layers increased, or erosion by water and intensified deflation reduced the soil thickness. Different authors have used different methods to reconstruct the wind directions for the Vistulian period, producing different results. Bokhorst et al. (2011) inferred the wind directions in Central and

Eastern Europe from loess grain-size records, concluding that the winds varied from predominantly westerly during the Early and Middle Plenivistulian, to north or northwesterly during the Late Plenivistulian. Chlebowski et al. (2003 a, b), concluded from the predominance of garnet, biotite, chlorite, muscovite and glauconite in the heavy mineral assemblages from the Bug Loess at Roxolany that silt forming that loess had been transported from the Crimean Peninsula. This fact, as well as the occurrence of salts from the Caspian area, might indicate that local winds, both southerly and southeasterly, contributed to the accumulation of the Bug Loess.

Another question is the age and origin of the tephra in the Roxolany profile. Minerals from this volcanic ash have been dated by different researchers using different methods with the following results: Fission track – > 12 Ma (Gozhik, 2013), K-Ar – 12.3 ± 0.15 Ma, 11.9 ± 0.15 Ma, 14.5 ± 0.15 Ma (Fedorowicz et al., 2012), and Ar-Ar – 50 ± 3 Ma (Sartori, 2000). Gozhik (2013) argued that material so old and varied was not the product of volcanic eruption. He proposed that material weathered from old igneous rocks from Asia Minor had been transported to the Roxolany area by a major dust storm. Subsequently the petrography and chemical composition of the tephra were studied by Wulf et al. (2016). Their results indicated that the tephra consisted of pyroclastic material most likely sourced from the Ciomadul volcano in the Romanian Eastern Carpathians. Radiocarbon ages measured on sediments enclosing the Roxolany tephra (Wulf et al., 2016) are consistent with its having been deposited during the last eruption of this volcano constrained to be ca. 29.6 ka BP by radiocarbon dating of bulk sediment, charcoal and organic matter from lacustrine sediments recovered from craters (Karátson et al., 2016).

3. Material and methods

One inch in diameter and 22 mm long 241 loess samples for the AMS measurements were taken from fresh walls of the outcrops using a steel cylindrical sampler. Most of the samples (135) were collected from the Bug loess (MIS2). The vertical sampling interval was here 100 mm, except in the middle part of the section, where it was 50 mm. The rest of the samples were taken from the loess assigned to MIS6, 8, 10 and 12 (Fig. 1B). The length of the samples was always the same as the length of the holes in the wall of the outcrop, meaning that there was no compaction of the samples

during extraction. The axial trend and plunge of the stainless steel tube for every sample was recorded. The magnetic susceptibility and its anisotropy were measured by means of a MKF1-FB Kappabridge (Agico Ltd., Brno) and resulting AMS parameters (Jelinek, 1981) were computed using the ANISOFT software. The AMS measurements were performed in the Geophysical Laboratory of the Polish Geological Institute – NRI. The tensor defining the susceptibility anisotropy of a sample can be illustrated by means of an ellipsoid with three orthogonal axes that correspond to the maximum, intermediate and minimum principal axes. These principal axes of the AMS ellipsoid are herein labeled K_{max} , K_{int} and K_{min} , respectively. The orientation of the axes in space can be defined in the polar coordinates of declination and inclination. The 95% confidence uncertainty ellipses were determined using the linear perturbation analysis described by Jelinek (1978). The semi axis of the uncertainty ellipse ε was labelled by the numbers 1, 2 and 3 assigned to K_{max} , K_{int} and K_{min} , respectively. Measurements with statistical parameters $\varepsilon_{12} < 22.5^\circ$ and $F_{12} > 4$ were regarded as recording statistically significant magnetic lineations (see Lagroix and Banerjee, 2004). Statistically significant magnetic foliation was defined in the samples with $F_{23} > 10$ and $\varepsilon_{23} < 30^\circ$. Magnetic mineralogy of the loess and palaeosols from Roxolany was investigated and described by Tsatskin et al. (1998) and Evans and Heller (2003). They demonstrated that magnetite is the main magnetic carrier. However, a subordinate admixture of hematite was also noted.

Two samples for the U-Pb isotope studies of zircon grains were collected from the loess correlated, according to the assumed stratigraphic scheme (Table 1), with marine isotope stages (MIS) 2 and 10. Another sample was taken from the Roxolany Tephra. Zircons were separated using mechanical panning techniques (watch-glass) as the first step. Next the concentrate of heavy minerals was cleaned up using conventional heavy liquid and magnetic techniques. Hand-picked zircons from the studied samples, and several grains of the TEMORA II (radiogenic $^{206}\text{Pb}/^{238}\text{U} = 0.06683$) (Black et al., 2003) and two grains of the 91500 ($\text{U} = 80 \mu\text{g/g}$) zircon standards were cast into an epoxy mount. The zircons from the MIS 10 loess were subdivided into two mounts according to crystal size. These were polished, documented using optical (reflected and transmitted light) microscopy, and then imaged by cathodoluminescence (CL) using a Hitachi SU3500 scanning electron microscope. The CL images

were used to characterize the zircon grains and select locations for the isotopic analyses. All samples were analysed using the SHRIMP IIe/MC ion microprobe in the Micro-area Analysis Laboratory of the Polish Geological Institute – NRI. The applied analytical procedure was based on those described by Williams and Claesson (1987) and Williams (1998).

The analytical conditions were as follows: 3 nA negative O_2^- primary ion beam focused to ca. 25 μm diameter spot; mass resolution ca. 5500; isotope ratio measurement by single multidynode electron multiplier and cyclic peak stepping. Each analysis consisted of seven scans through the isotopic species of interest: $^{196}Zr_2O$, ^{204}Pb , ^{206}Pb , ^{207}Pb , ^{208}Pb , ^{238}U , ^{248}ThO , ^{254}UO . A baseline was measured 0.06 amu up mass of ^{204}Pb . The TEMORA II standard was measured every three spots.

The data for the detrital zircons were reduced in a manner similar to that described by Williams (1998, and references therein), using the SQUID Excel Macro of Ludwig (2000). Probability density distribution plots of SHRIMP results for each sample were prepared using ISOPLOT/EX (Ludwig 2003). Ages were calculated using the constants recommended by the IUGS Subcommittee on Geochronology (Steiger and Jäger, 1977).

The first results from dating zircons from the Roxolany tephra indicated ages less than 1 Ma, so for those grains a more extensive analytical procedure was used. The analyses were repeated for selected, pyroclastic-origin zircons with different analytical condition: 7 scans for each analysed spot point and a longer counting time for ^{206}Pb (20 s). The ages of zircons younger than 2 Ma were calculated separately for each spot using a first-principles correction for U-series disequilibrium and initial ^{230}Th based on the equations of Bateman (1910), as described by Williams et al. (2016) and Li et al. (2017).

Results

3.1. Anisotropy of magnetic susceptibility

The anisotropy factors of magnetic susceptibility measured in the loess from Roxolany (Table 2) are several times lower than in the periglacial loess of the Western Ukraine and Poland (Nawrocki et al., 2006). An oblate magnetic fabric is prevalent in all the horizons of Roxolany loess studied (Figs. 2A and 2B). Such a feature is characteristic of loess sediments (Hus, 2003; Lacroix and Banerjee, 2004). The value of anisotropy P is proportional to the foliation parameter F , indicating a subordinate role of lineation. There is an inverse relationship between half-angular uncertainty in the direction of

maximum susceptibility (ϵ_{12}) and the magnetic lineation parameter L , and between half-angular uncertainty in the direction of minimum susceptibility (ϵ_{23}) and the magnetic foliation parameter F caused by increased measurement errors for weak lineations (foliations) (Fig. 2C). On the other hand, the absence of correlation between ϵ_{12} and foliation indicates that the lineation and foliation sub fabric are probably defined by the orientation distribution of separate minerals. Only some of the samples had statistically significant magnetic lineations, with $F_{12} > 4$ and $\epsilon_{12} < 22.5^\circ$ (Fig. 2D).

Figure 3A illustrates the geographic orientation of the principal axes of magnetic susceptibility calculated for all samples from Roxolany. The magnetic susceptibility axes obtained for samples from only the Bug loess are presented in Fig. 3B. The moderate or even shallow dip of K_{min} axes in ca. 15% of the sample population is mainly due to a very weak anisotropy causing large measurement errors. The data from samples for which $F_{23} > 10$, $\epsilon_{23} < 30^\circ$ and a dip of K_{min} greater than 70° (see Zhu et al., 2004) were selected for further evaluation (Figs. 3C, D). Most of the minimum susceptibility axes constrained in this way for the Bug loess are imbricated to the first or second quadrant of the hemisphere with mean values of azimuth and dip of $110.1^\circ E$ and 82.2° , respectively (Fig. 3C; Table 3). The maximum susceptibility axes are stretched mainly in the fourth and third quadrants of the hemisphere. The minimum susceptibility axes determined in the samples from older loess horizons also are imbricated mainly towards the first and second quadrant of the hemisphere but to a lesser degree than in the Bug loess, having a mean value of azimuth and dip of $128.8^\circ E$ and 86.4° , respectively (Fig. 3D; Table 3).

Contour lines and rose diagrams showing the distribution of K_{max} and K_{min} directions for the AMS data from Roxolany are illustrated in Figure 4. In this evaluation the inclination of K_{min} was not delimited by the value of 70° , but statistical parameters of K_{max} were delimited by values of $F_{12} > 4$ and $\epsilon_{12} < 22.5^\circ$. The maximum susceptibility axes for the Bug loess obtained in this way are grouped in several hemisphere areas with the largest densities in two regions within fourth quadrant. A third cluster with maximum susceptibility axes from this loess horizon corresponds to the NNE-SSW direction (Fig. 4A). K_{max} in most of the samples from this group is perpendicular to the direction of imbrication of K_{min} in the same sample. The maximum densities of distribution of K_{min}

characteristic of the Bug loess correspond to the azimuths of ca. 130° E and 80° E (Fig. 4C). It should be stressed that in the rose diagrams the most significant direction of imbrication of K_{min} (ca. 130°E) is almost opposite to the most significant direction of K_{max} (ca. 320°E). In older horizons of loess the maximum susceptibility axes fulfilling the statistical criteria mentioned above are relatively rare (Figs. 4E, F). Most of them have an azimuth of K_{max} enclosed between 240°E and 353°E. The minimum susceptibility axes presented in the density and rose diagrams have their maximas of occurrence mostly located in the second quadrant of the hemisphere.

The degree of AMS and the shape parameter change cyclically along the Bug loess profile (Fig. 5). Samples with the azimuth of K_{max} perpendicular to the azimuth of imbrication occur in different places within this profile. Their most frequent occurrence, however, is observed especially in the bottom part of the Bug loess where a higher content of larger sediment grains was noted. On the other hand they occur only occasionally between 6.5 and 10 m of the profile, where the loess material is finer. The volume magnetic susceptibility displays significantly elevated values in the samples from the soils limiting the Bug loess and in two samples inside this loess. One of them was located just above the Roxolany tephra and another in a thin layer of sediment with red spots ca. 2 m above the Vytachiv soil (Fig. 5). The scanning electron microscope analyze indicates that this horizon with fragments of siliceous pumice most probably contains reworked and weathered tephra.

4.2. U-Pb isotope ages of detrital zircons from the loess

The detrital zircons separated from the Bug loess are small, typically 30 - 50 μm in length, rarely ranging up to 100 μm (Fig. 6A). Most of them are strongly rounded zircon fragments. They are fine-grained and more rounded than the zircons from the Orel loess. There are no sharply euhedral prismatic crystals in the sample. The Orel loess correlated with the MIS 10, in contrast, contains zircons of a range of sizes, shapes and types. They range from 30 μm up to even 300 μm in length (Figs. 6B, C). Most of them are only slightly rounded. Zoning textures range from typical concentric growth to pronounced sector zoning. Some of grains are elongated, prismatic crystals. Metamorphic grains with evidence of partial dissolution are also common in this sediment.

The zircon from the Bug loess is mostly of late Neoproterozoic to early Palaeozoic age (Fig. 7A, Table 4). Some groups of older grains (early Neoproterozoic to Mesoproterozoic and early

Palaeoproterozoic) are also present, as well as single grains with Neoproterozoic (ca. 2.7 Ga) and Palaeozoic ages younger than Ordovician. The isotopic ages of both small and large grains of zircon extracted from the sample of the older loess are similar, and in turn comparable to those of zircon from the Bug loess (Fig. 7B, Table 4). The only difference between the two loess horizons is a higher content of Variscan (380–300 Ma) zircons in the loess deposited during MIS10. Neither studied loess sample contained zircon grains older than 2.7 Ga.

4.3. U-Pb isotope ages of detrital zircons from the Roxolany Tephra

The population of zircons recovered from the Roxolany Tephra is not homogeneous. It contains crystals and fragments of crystals from the ash fall and from reworked material (Fig. 8A). The zircons of pyroclastic origin range from 80 to 130 μm in length and 40 up to 60 μm in width, with an average aspect ratio of about 3-3.5. These magmatic zircons are relatively uniform, pale-coloured, doubly-terminated prismatic crystals or fragments of such. Only a few zircons contain inherited cores. Almost all crystals are characterized by the presence of well-developed concentric growth zoning. The reworked detrital zircon crystals and fragments of crystals from the tephra are smaller and range from 35 to 80 μm in length. Most of them are strongly rounded. They include zoned crystals, crystals with inherited cores, and metamorphic grains with evidence of dissolution.

The pyroclastic zircons provided ages from 0.39 to 4.95 Ma (Fig. 7B; Table 5). Most of them, however, gave ages in the range 470-840 ka, with a cluster between 500 and 750 ka. Only seven zircon grains were older than 1 Ma. The youngest population consists of three zircon grains with ages 0.39, 0.41 and 0.42 Ma. The population of smaller and rounded grains from the Roxolany tephra gave ages similar to those obtained from the loess samples (Fig. 7C).

5. Discussion

5.3. Wind strength and directions of aeolian transport

Despite the very weak anisotropy of magnetic susceptibility, i.e. almost 5 times weaker than noted in the periglacial loess of Western Ukraine and Poland (Table 2), and comparable to that noted in the Chinese loess (e.g. Zhang et al., 2010), nearly all samples from Roxolany provided well-defined axes of minimum susceptibility. In the Bug loess they are imbricated predominantly to the SE, indicating a

prevailing wind direction from the NW. The aeolian transport of particles forming the Bug loess by a NW wind can also be inferred from the distribution of maximum susceptibility axes. They are grouped predominantly in the fourth quadrant of the hemisphere. Some maximum susceptibility axes deviate and are even perpendicular in a NW direction. Many of them are perpendicular to the direction of imbrication of K_{min} measured in the same sample. This might reflect strongly blowing wind during sedimentation of particular portions of the loess. The wind intensity seems to have changed from dominantly strong winds in the lowest part of the Bug loess towards more variable wind in its middle and upper parts. Migration of the K_{max} axes due to variable wind strength limit their usefulness for the determination of aeolian transport directions. They may not be used alone for this purpose, but may support the information obtained from the imbrication directions of the K_{min} axes.

The SE imbrication of K_{min} axes is not so distinct in the older loess horizons from Roxolany, probably because of compaction, the older horizons are covered by ca. 30 m of younger loess. Nevertheless in this case also, the distribution of magnetic susceptibility axes points to prevailing westerly or north-westerly wind directions.

The NW direction of the wind that brought the aeolian dust to Roxolany in the past is entirely consistent with the mean direction of present-day summer wind measured in the city of Odesa located 50 km NE of the studied section (Fig. 9). The complete lack of influence of winter winds on loess sedimentation is understandable because during glacial winters the source areas would have been covered by snow.

5.4. Sources of detrital material

The loess samples from Roxolany contain no zircons of Meso- to Palaeoarchean age (3.0-3.6 Ga), which are characteristic of the Ukrainian Shield (e.g. Claesson et al., 2006). The source area must lie elsewhere. The most common Proterozoic zircons, with ages of ca. 1.5 Ga, were most probably derived from the anorogenic granites that are widely distributed in the Fennoscandian portion of the Baltica palaeocontinent (e.g. Lahtinen et al., 2005; Johansson et al., 2006; Bogdanova et al., 2008). Detritus from the Fennoscandian crystalline basement filled Phanerozoic sedimentary basins that were

developed on the SW edge of Baltica (e.g. Nawrocki and Poprawa, 2006). Part of this zone, including early Devonian “old red” type clastic rocks, is exposed in the Podolia Upland of SW Ukraine. The late Neoproterozoic and early Palaeozoic zircons found in the loess are common in the Carpathian domain (Kohut et al., 2008; Vozarova et al., 2013; Balintoni et al., 2014). A comparison with isotopic ages of detrital zircons from the core parts of the Carpathians in Slovakia and Romania (Fig. 7B) leads to the conclusion that zircons like those in the loess samples that are from the early to middle stages of the Variscan orogeny (380–340 Ma) or as old as ca. 2.7 Ga are found only in Slovakia. The isotopic ages of the detrital zircons therefore suggest that the main sources of detrital material forming the Roxolany loess cover are Carpathian and Podolia. This material was eroded by the Dniester River and its tributaries, and deposited in the area of the Dniester River valley and liman (Fig. 9). This interpretation is in full agreement with the AMS data showing NW to W palaeowind directions, i.e. blowing from these source areas. Large and rounded grains of zircons that were found in the sample of older loess point to a relatively short distance of aeolian transport.

The age spectrum for the zircon grains from the Roxolany tephra fits very well to the history of the Ciomadul volcano in the Romanian Eastern Carpathians as inferred mainly from K-Ar ages (e.g. Szakács et al., 2015). The source for the Roxolany tephra was also postulated by Wulf et al. (2016) on the basis of its geochemical features. A set of K-Ar age data indicate that most of the volcano was built 650–400 ka ago when volcanic activity reached its peak (Szakács et al., 2015). The oldest K-Ar ages (1.02 and 0.85 Ma) were obtained on peripheral lava domes (Pécskay et al., 1995). The youngest eruption of the Ciomadul volcano was in the late Pleistocene, ca. 29 ka ago according to radiocarbon dating on lacustrine sediments from craters (Karátson et al., 2016; Wulf et al., 2016), but it most probably did not produce zircons of this age. The particles of volcanic ash from the Ciomadul volcano were transported in the upper part of atmosphere then deposited on the surface of the loess at Roxolany. Loess was being deposited at the same time, so zircon from the volcanic ash fall became mixed with detrital zircon that had isotopic ages characteristic of the loess.

The sediment with red spots and fragments of siliceous pumice that is exposed ca. 2 m above the Vytachiv soil of Roxolany section (Fig. 5) forms most probably a horizon of reworked tephra not

described up till now. The activity of Ciomadul volcano dated at ca. 29 ka (Wulf et al., 2016) should be linked rather with this layer. Its linkage with the so called “Roxolany Tephra” (Wulf et al., 2016) that occurs in the uppermost part of the Bug loess implies the deposition of the main portion of the Bug loess not in the cold climate of MIS2 but during warming of MIS3. Clearly, more data is needed to solve this stratigraphic problem.

6. Conclusions

Our main conclusions are:

1. The AMS ellipsoid axes indicate that prevailing winds during accumulation of loess in Roxolany were blowing from the NW. This direction is in full agreement with the mean present-day summer wind measured in the city of Odessa.
2. The isotopic ages of detrital zircons point to the main sources of aeolian material to form the thick cover of loess in Roxolany being Carpathian and Podolian. The detritus was transported from these areas by the Dniester River and its tributaries.
3. The dust was blown from the end part of the valley of Dniester and its liman that are located to the NW of the deposition area in Roxolany.
4. The age spectrum of zircon grains from the Roxolany Tephra confirms their derivation from the Ciomadul volcano in Romania.

Acknowledgments

The analytical research and field works were founded by the National Science Centre of Poland (project No: UMO-2014/15/B/ST10/03695). The lithostratigraphy of the Roxolany section was determined as part of projects No, 691–N/2010/0 and No. NN306 474138 supported by the Polish Ministry of Science and Higher Education. We are grateful to Olena Tomeniuk and Sergiey Prylypko for assistance during field works. Two anonymous reviewers are thanked for their helpful comments and suggestions.

References

- Bakhmutov, V.G., Hlavatskyi, D.V., 2014. Identification of the Matuyama-Brunhes boundary by paleomagnetic studies of the Roxolany profile (Western Black Sea region). *Dopov. Nac. akad. nauk Ukr.* 10, 92-98 (in Russian).
- Bakhmutov, V.G., Kazanskii, A.Yu., Matasova, G.G., Glavatskii, D.V., 2017. Rock Magnetism and Magnetostratigraphy of the Loess-Sol series of Ukraine (Roxolany, Boyanychi, and Korshev Sections). *Izvestiya, Physics of the Solid Earth*, 53 (6), 65-86.

- Balintoni, I., Balica, C., Ducea, M., Hann, H.P., 2014. Peri-Gondwanian terranes in the Romanian Carpathians: A review of their spatial distribution, origin, provenance and evolution. *Geosc. Front.*, 5, 395-411.
- Bateman, H., 1910. The solution of a system of differential equations occurring in the theory of radioactive transformations. *Proceedings of the Cambridge Philosophical Society*, 15, 423–7.
- Black, L.P., Kamo, S.L., Allen, C. M., Aleinikoff, J.N., Davis, D. W., Korsch, R.J., Foudoulis, C., 2003. TEMORA 1: a new zircon standard for Phanerozoic U-Pb geochronology. *Chem. Geol.* 200, 155-170.
- Bogdanova, S.V, Bingen, B., Gorbatshev, R., Kheraskova, T.N., Kozlov, V.I., Puchkov, V.N., Volozh, Y. A., 2008. The East European Craton (Baltica) before and during the assembly of Rodinia. *Prec. Res.* 160, 23-45.
- Bogucki, A., Gozhik, P., Łanczont, M., Madejska, T., Yeovicheva, J. (Eds.), 2013. *Proceeding of the XVIII Ukr.-pol. workshop 8–13 Sept. 2013 p. Lublin: KARTPOL s. c. Lublin, 267 p. (in Polish and Ukrainian with English summary)*
- Bokhorst, M.P., Vandenbergh, J., Sümegi, P., Łanczont, M., Gerasimenko, M.P., Matviishina, Z.N., Marković, S.B., Frechen, M., 2011. Atmospheric circulation patterns in Central and Eastern Europe during the Weichselian Pleniglacial inferred from loess grain-size records. *Quat. Inter.* 234, 62-74.
- Chepalyga, A. P., 1967. *Antropogenovye presnovodnyye molljuskijuga Russkoy ravniny I ikh stratigraphicheskiye znachenije. Nauka, 222 p..*
- Chlebowski, R., Lindner, L., Barczuk, A., Bogutsky, A., Gozhik, P., Łanczont, M., Wojtanowicz, J., 2003a. Accumulation conditions of the younger upper less of Sandomierz Basin, Mid-Carpathian Foreland and Podolian Upland (border between SE Poland and NW Ukraine) on the basis of the geological and mineralogical studies. *Annales UMCS, sect. B, Lublin*, 7-64.
- Chlebowski, R., Gozhik, P., Lindner, L., Łanczont, M., Wojtanowicz, J., 2003b. Stratigraphy and sedimentology of the Bug loess (Pleistocene: Upper Vistulian) between Kiev and Odessa (Ukraine). *Geol. Quart.* 47, 3, 261-268.
- Claesson, S., Bibikova, E., Bogdanova, S., Skobelev, V., 2006. Archean terranes, Paleoproterozoic reworking, and accretion in the Ukrainian Shield, East European Craton. In: *European Lithosphere Dynamics* (Gee, D.G., Stephenson, R.A. eds.), Geological Society London, Memoirs, 32, 645-654.
- Comprehensive Atlas of Ukraine, 2004. DNVP “Kartografiya”, Kyiv.
- Dodonov, A. E., Zhou, L.P., Markova, A.K., Tchepalyga, A.L., Trubikin, V. M., Aleksandrowski, A. L., Simakova, A.N., 2006. Middle-Upper Pleistocene bio-climatic and magnetic records of the Northern Black Sea Coastal Area. *Quat. Inter.* 149, 44-54.
- Ehlers, J., Gibbard P.L., 2011. *Quaternary Glaciations – Extent and Chronology. I, Europe*, Elsevier, 488 pp.
- Evans, M., Heller, F. 2003. *Environmental magnetism. Principles and applications of Enviromagnetics.* Academic Press, Elsevier Science, 295 pp.

- Faustov, S.S., Virina, E.I., Tsatskin, A., Gendler, T.S., Heller, F. 2009. The Matuyama/Brunhes boundary in loess sections in the south of the East European Plain and their correlation on the basis of palaeomagnetic and palaeopedonic data. *Quat. Inter.* 201, 60-66.
- Fedorowicz, S., Woźniak, P. P., Hałas, S., Łanczont, M., Paszkowski, M., Wójtowicz, A., 2012. Challenging K-Ar dating of the Quaternary tephra from Roxolany, Ukraine. *Mineralogia, Special Papers*, 39, 102-105.
- Ge, J., Guo, Z., Zhao, D., Zhang, Y., Wang, T., Yi, L., Deng, Ch., 2014. Spatial variations in paleowind direction during the last glacial period in north China reconstructed from variations in the anisotropy of magnetic susceptibility of loess deposits. *Tectonophysics*, 629, 353-361.
- Gendler, T.S., Heller, F., Tsatskin, A., Spassov, S., Du Pasquier, J., Faustov, S.S., 2006. Roxolany and Novaya Etuliya - key sections in the western Black Sea loess area: Magnetostratigraphy, rock magnetism, and paleopedology. *Quat. Inter.* 152-153, 78-93.
- Gozhik, P. 2013. Loess cover of the Northern Black Sea. In: Bogucki, A. et al. (Eds.), *Proceeding of the XVIII Ukr.-pol. workshop 8-13 Sept. 2013. KARTPOL s. c. Lublin*, 17-33 (in Ukrainian with English summary).
- Gozhik, P., Komar, M., Krokhmal, O., Prylypko, S., Kovaliukh, M., 2006. The Pleistocene stratigraphy and palaeogeography of the Roksolany, Odessa Region, Ukraine. *Danube Loess Symposium INQUA Loess Subcommittee, Novi Sad, Serbia*, 11-12.
- Gozhik, P., Komar, M., Krokhmal, O., Shovkoplyas, V., Khrystoforova, T., Dykan, N., Prylypko, S., 2007. The key section of Neopleistocene subaerial deposits near Roxolany village (Odessa region), Institute of Geological Sciences of NAS of Ukraine, "Problemy serednoplejstocenogo interglacialu". *Lviv, Vid. Centr LNU im. I. Franka*, 109-128 (in Ukrainian with English summary).
- Gozhik, P., Shvokoplyas, V., Khristoforova, T., 1995. Development stages of loessial and facial formation in Ukraine (Stratigraphy of loess in Ukraine). *Lublin. Annales Universitatis Mariae Curie-Sklodowska. Sec. B*, 50, 65-74.
- Guidebook for Excursions A-7, C-7, 1982. *Moldova and the Odessa Region, XI Congress INQUA, Moscow*, 45 p.
- Haase, D., Fink, J., Haase, G., Ruske, R., Pécsi, M., Richter, H., Altermann, M., Jäger, K.D., 2007. Loess in Europe – its spatial distribution based on a European Loess Map, scale 1:2 500 000. *Quat. Sci. Rev.* 26, 1301-1312.
- Hus, J. J., 2003. The magnetic fabric of some loess/palaeosol deposits. *Phys. Chem. Earth*, 28, 689-699.
- Jelinek, V., 1978. Statistical processing of magnetic susceptibility measured in groups of specimens. *Stud. Geoph. Geodet.* 22, 50-62.
- Jelinek, V., 1981. Characterization of magnetic fabrics of rocks. *Tectonophysics*, 79, 63-67.
- Johansson, A., Bogdanova, S., Cecys, A., 2006. A revised geochronology for the Blekinge Province, southern Sweden. *GFF*, 128 (4), 287-302.
- Karátson, D., Wulf, S., Veres, D., Magyari, E.K., Gertisser, R., Timar-Gabor, A., Novothny, Á.,

- Telbisz, T., Szalai, Z., Anechitei-Deacu, V., Appelt, O., Bormann, M., Jánosi, C., Hubay, K., Schäbitz, F., 2016. The latest explosive eruptions of Ciomadul (Csomád) volcano, East Carpathians - a tephrostratigraphic approach for the 52-29 ka BP time interval. *J. Volc. Geot. Res.* 319, 29-51.
- Kohut, M., Poller, U., Gurk, C., Todt, W., 2008. Geochemistry and U-Pb detrital zircon ages of metasedimentary rocks of the Lower Unit, Western Tatra Mountains (Slovakia). *Acta Geol. Pol.* 58, 371-384.
- Konikov, G. K., 2007. Sea-level fluctuations and coastline migration in the northwestern Black Sea area over the last 18 ka based on high-resolution lithological-genetic analysis of sediment architecture. In: Yanko-Hombach, V., Gilbert, A. S., Panin N., Dolukhanov, P. M. (Eds.), *The Black Sea Flood Questions*. Springer, Dordrecht, 405-436.
- Lahtinen, R., Korja, A., Nironen, M., 2005. Paleoproterozoic tectonic evolution. In: *Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield*. Elsevier, Amsterdam, pp. 481-532.
- Langroix, F., Banerjee, S.K., 2002. Paleowind directions from the magnetic fabric of loess profiles in central Alaska. *Earth Planet. Sci. Lett.* 195, 99-112.
- Langroix, F., Banerjee, S.K., 2004. The regional and temporal significance of primary aeolian magnetic fabrics preserved in Alaskan loess. *Earth Planet. Sci. Lett.* 225, 379-395.
- Li, L., Shi, Y., Williams, I.S., Lawford Anderson, J., Wu, Z., Wang, S., 2017. Geochemical and zircon isotopic evidence for extensive high level crustal contamination in Miocene to mid-Pleistocene intraplate volcanic rocks from the Tengchong field, western Yunnan, China. *Lithos*, 286-287, 227-240.
- Liu, T.S. et al., 1985. *Loess and the Environment*. Beijing: China Ocean Press. 251 pp.
- Liu, W.M., Sun, J.M., 2012. High-resolution anisotropy of magnetic susceptibility record in the central Chinese Loess Plateau and its paleoenvironment implications. *Science China, Earth Sciences*, 55, 488-494.
- Ludwig, K.R., 2000. *SQUID 1.00, A User's Manual*. Berkeley Geochronology Center Special Publication. No. 2, 2455 Ridge Road, Berkeley, CA 94709, USA.
- Ludwig, K.R., 2003. User's manual for a geochronological toolkit for Microsoft Excel (Isoplot/Ex version 3.0). Berkeley Geochronology Center Special Publication, 1-70.
- Łanczont, M., Madeyska, T. (Eds.). *Paleolithic oecumene of peri- and meta-Carpathian zone (in Polish with Ukrainian summary)*. Maria Curie-Skłodowska University Press, Lublin, 968 pp.
- Łanczont, M., Madeyska, T., Bogucki, A., Mroczek, P., Hołub, B., Łacka, B., Federowicz, S., Nawrocki, J., Frankowski, Z., Standzikowski, K., 2015. Abiotic environment of the Palaeolithic oecumene in the peri- and meta-Carpathian zone In: M. Łanczont, T. Madeyska (eds) *Palaeolithic oecumene in the peri- and meta-Carpathian zone*, Wydawnictwo UMCS, Lublin, 55–457 (in Polish with Ukrainian summary).
- Nawrocki, J., Poprawa, P., 2006. Development of Trans-European Suture Zone in Poland: from Ediacaran rifting to Early Palaeozoic accretion. *Geol. Quart.* 50, 59-76.

- Nawrocki, J., Polechońska, O., Boguckij, A. and Łanczont, M., 2006. Palaeowind directions recorded in the youngest less in Poland and western Ukraine as derived from anisotropy of magnetic susceptibility measurements. *Boreas*, 35, 266-271.
- Panin, N., 2007. The Black Sea – geology, environment and archaeology. In: G. Oaie, M. Diaconescu, D. Ioane (Eds.): *Hazard natural: Evenimente tsunami in Marea Neagra*, Bukareszt, 3-10. (<http://www.profet.ro/Panin.pdf> (15.12.2009)).
- Pécskay, Z., Edelstein, O., Seghedi, I., Szakács, A., Kovats, M., Crihan, M., Bernad, A., 1995. K-Ar datings of the Neogene-Quaternary calc-alkaline volcanic rocks in Romania. In: H. Downes, H. and Vaselli, O. (Eds.), *Neogene and related volcanism in the Carpatho-Pannonian Region*. *Acta Vulcanologia*, 7, 53-63.
- Pilipenko, O.V., Sharonova, Z.V., Trubikhin, V.M. 2007. Direction and relative paleointensity of the geomagnetic field in the middle and later Pleistocene from paleomagnetic data of the Roxolany section (Ukraine). *Izv., Phys. Solid Earth* 43, 430 p.
- Putievoditel VIII mezhdunarodnogo symozjuma po lessovym porodam Kiev-Odessa, 1976, Naukova Dumka, 72 p. (in Ukrainian).
- Putivnyk X polsko-ukrainskoho seminaru “Korelaciya lesiv i lodowykovykh vidkladiv Polshi i Ukrainy, 2000. ING NAN Ukrainy, Kiev, 36 p. (in Ukrainian).
- Sartori, M., 2000. The Quaternary climate in loess sediments: Evidence from rock and mineral magnetic and geochemical analysis. PhD Thesis, Swiss Federal Institute of Technology, Zurich, Switzerland, 231 pp.
- Simakova, A., 2002. New pollen records from the key section Roxolany (Southwestern Russian Plain) and its correlation with Central Asia data. In: *Upper Pliocene and Pleistocene of the Southern Urals region INQUA-SEQS 2002 Conference*, volume of Abstracts, Ufa.
- Steiger, H., Jäger, E., 1977. Subcommittee on geochronology: convention on the use of decay constants in geo- and cosmochemistry. *Earth Planet. Sci. Lett.* 36, 359-362.
- Szakács, A., Seghedi, I., Pécskay, Z., Mirea, V., 2015. Eruptive history of a low frequency and low-output rate Pleistocene volcano, Ciomadul, South Harghita Mts., Romania. *Bull. Volc.* 77:12, 1-19.
- Tarling, D.H., Hrouda, F., 1993. *The magnetic anisotropy of rocks*. 217 pp. Chapman & Hall Eds., London.
- Thistlewood, L., Sun, J., 1991. A palaeomagnetic and mineral magnetic study of the loess sequence at Liujiapo, Xian, China. *J. Quat. Sci.* 6, 13-26.
- Tsatskin, A., Heller, F., Hailwood, E.A., Gendler, T.S., Hus, J., Montgomery, P., Sartori, M., Virina, E. I., 1998. Pedosedimentary division, rock magnetism and chronology of the loess/palaesol sequence at Roxolany (Ukraine). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 143, 111-133.
- Tsatskin, A., Heller, F., Gendler, T.S., Virina, E. I., Spassov, S., Du Pasquier, J., Hus, J., Hailwood, E. A., Bagin, V.I., Faustov, S.S., 2001. A new scheme of terrestrial paleoclimate evolution during the last 1.5 Ma in the western Black Sea region: integration of soil studies and loess magmatism. *Phys. Chem. Earth*, 26, 911-916.

- Veklich, M.F., Sirenko, N.A., Matviishina, Z.N., Gerasimenko, N.P., Perederij, V.I., Turlo, S.I., 1993. Stratigraphical schemes of the Quaternary deposits of Ukraine. Goskomgeologia of Ukraine, Kiev (Explanatory notes).
- Vozárová, A., Laurinc, D., Šarínová, K., Larionov, A., Presnyakov, S., Rodionov, N., Paderin, I., 2013. Pb ages of detrital zircons in relation to geodynamic evolution: Paleozoic of the Northern Gemericum (Western Carpathians, Slovakia). *J. Sed. Res.* 83, 915-927.
- Wang, R., Løvlie, R., 2010. Subaerial and subaqueous deposition of loess: Experimental assessment of detrital remanent magnetization in Chinese loess. *Earth Planet. Sci. Lett.* 298, 394-404.
- Williams, I.S., Claesson, S., 1987. Isotopic evidence for the Precambrian provenance and Caledonian metamorphism of high grade paragneisses from the Seve Nappes, Scandinavian Caledonides: II Ion microprobe zircon U-Th-Pb. *Contributions to Mineralogy and Petrology*, 97, 205-217.
- Williams, I.S., 1998. U-Th-Pb Geochronology by Ion Microprobe. In: M.A. McKibben, W.C. Shanks III, W.I. Ridley (eds), *Applications of microanalytical techniques to understanding mineralizing processes*. *Rev. Econ. Geol.* 7, 1-35.
- Williams, I.S., Rojas-Agramonte, Y. and Kröner, A., 2016. The deficiencies and excesses of the very young. Abstracts, VIII International SHRIMP Workshop, Granada, Spain, 86-87.
- Wulf, S., Fedorowicz, S., Veres, D., Łanczont, M., Karátson, D., Gertisser, R., Bormann, M., Magyari, E., Appelt, O., Hambach, U., Gozhik, P.F., 2016. The 'Roxolany Tephra' (Ukraine) – new evidence for an origin from Ciomadul volcano, East Carpathians. *J. Quat. Sci.* 31, 6, 565-576.
- Zhang, R., Krvchinsky, V., Zhu, R., Yue, L., 2010. Paleomonsoon route reconstruction along a W-E transect in the Chinese Loess Plateau using the anisotropy of magnetic susceptibility: Summer monsoon model. *Earth Planet. Sci. Lett.* 299, 436-446.
- Zhu, R., Liu, Q., Jackson, M.J., 2004. Paleoenvironmental significance of the magnetic fabrics in Chinese loess-paleosols since the last interglacial (<130 ka). *Earth Planet. Sci. Lett.* 221, 55-69.

Figure captions

Fig.1. (A) Location of the studied section on a shaded-relief map of Eastern Europe. Maximum extent of the Vistula Glaciation (after Ehlers and Gibbard, 2011) is marked. (B) Simplified lithological column of the Roxolany loess-palaeosol sequence with sampling sites marked in black color. Loess distribution is presented according to Haase et al. (2007). Relief model made by B. Holub was adopted from Łanczont and Madeyska (2015).

Fig.2. (A) Relationships between the AMS parameters T (shape parameter), P (anisotropy factor), L (lineation) and F (foliation) characteristic for the Bug loess in Roxolany. (B) Relationships between the same parameters characteristic for older horizons of loess in Roxolany. (C) Correlation between lineation/foliation and ε_{12} (half-angular uncertainty in the direction of Kmax), and between foliation and ε_{23} (half-angular uncertainty in the direction of Kmin) in the Bug loess from Roxolany. (D) Half-angular uncertainty in the direction of Kmax and parameter F_{12} (statistical significance of lineation) in the loess samples from Roxolany.

Fig. 3. (A) Equal-area projections of AMS principal axes of all samples from Roxolany. (B) Equal-area projections of AMS principal axes of samples from Bug loess only. The AMS axes of selected samples (according to criteria presented on top of the projections) from the Bug loess (C) and older horizons of loess from Roxolany (D).

Fig. 4. Contours and rose diagrams of K_{max} and K_{min} prepared for samples of Bug loess (MIS2) and older loess horizons (MIS 6, 8, 10 and 12) from Roxolany. Statistical constraints for selection of data for presentation are described in the text.

Fig. 5. Changes of normalized anisotropy factor, shape parameter, azimuth of imbrication of minimum susceptibility axes, content of larger grains (Łanczont et al., 2015) and volume magnetic susceptibility in the Bug loess from Roxolany.

Fig. 6. Representative CL images of representative zircon crystals from the Bug loess (A), and populations of large (B) and small (C) zircon crystals from the loess deposited during MIS10. Location of the analyzed spots and obtained isotope ages are also presented.

Fig. 7. (A) Probability density diagrams presenting results of U-Pb isotope studies of detrital zircons from the loess sampled in Roxolany. (B) Age spectrum of non-mafic rocks from Carpathians in Slovakia and Romania (Kohut et al., 2008; Vozarova et al., 2013; Balintoni et al., 2014).

Fig. 8. (A) Representative CL images of representative zircon crystals from the Roxolany tephra. Location of the analyzed spots and obtained isotope ages are also presented. (B) Density diagram presenting results of U-Pb isotope studies of magmatic zircons from the Roxolany tephra. (C) Probability density diagram with U-Pb isotope ages of magmatic and detrital zircon grains from the Roxolany tephra.

Fig. 9. Source areas and directions of transportation of material composing the loess and tephra from the Roxolany section. Directions of prevailing present-day summer and winter winds in the city of Odesa (Comprehensive Atlas of Ukraine, 2004) are also presented. Loess distribution is presented according to Haase et al. (2007). Relief model made by B. Hołub was adopted from Łanczont and Madeyska (2015).

Table 1.

The loess/palaeosol units and bedrocks in Roxolany.

Loess-soil units Major isotope stages	Litho- and pedostratigraphic units	Depth [m]	Litho- and pedological characteristics
S0/MIS 1	Holocene soil (hl)	0 - 1.85	Recent chernozem, silty-sandy, strongly carbonate, especially intensive in the upper part of Bk horizon, with numerous small tunnels (traces of pedofauna).
L1/MIS 2	Prichernomorsk loess (pr)	1.85 - 6.4	Two loess layers and separating them well-developed, 1.6 m thick paleosol. Loess is typical, homogenous, with black small Mn-Fe nodules and numerous carbonate pseudomycelia. The soil corresponds to the Late Glacial interstadial(s).
	Dofinivka pedocomplex (df)	6.4 - 8.35	Double silty-sandy compact palaeosols, a large amount of pseudomorphs of mole tunnels filled with loess and humus material, and black small Mn-Fe nodules.
	Bug loess (bg)	8.35 - 20.05	Typical homogenous carbonate loess, with numerous black Mn-Fe nodules. Light grey tephra occurs in this unit at a depth of 9.65 m in the form of lenses and 1-4 cm thick layers.
L1/MIS 3	Vitachiv paleosol (vt)	20.05 - 22.05	Well-developed interstadial soil with A-Bk profile, silty-sandy and silty-clayey, very compact, with numerous zoogenic biopores. Silty concentrations of carbonates in the Bk horizon.
L1/MIS 4	Uday loess (ud)	22.05 - 29.95	Silty-sandy loess, carbonate-rich (up to 20%), but in places - carbonate-free.
S1/MIS 5	Pryluky pedokomplex (pl)	29.95 - 33.05	Three paleosols separated by loess-like loam. Paleosols are similar but the Eemian soil at bottom is thicker and carbonate-rich (up to 25%) than the interstadial soils. Numerous secondary calcite forms

			occurs in this pedocomplex. Systems of small fissures, occurring in the top of individual soils, are filled with the loess material.
L2/MIS 6	Tyasmyn loess (ts)	33.05 - 34.05	Typical macroporous carbonate loess, with numerous black Mn-Fe nodules.
S2 /MIS 7	Kaydaky paleosol (kd)	34.05 - 35.45	Soil is silty-clayey and carbonate-rich (up to 30%) in the humus horizon, silty-sandy below, with numerous mole tunnels and small black Mn-Fe nodules.
L3 /MIS 8	Dnieper loess (dn)	35.45 - 40.45	Silty-sandy loess, carbonate-rich, gleyed at bottom, with numerous carbonate nodules, phytogenic bioturbations and mole tunnels filled with the loess and illuvial material of the Kaydaky soil. Vertical, narrow fissures run downwards from the surface of the loess horizon.
S3/MIS 9	Potagaylivka paleosol (pt)	40.45 - 41.05	Silty-sandy, carbonate-poor humus horizon with numerous, black Mn-Fe nodules, is disturbed by solifluction in the upper part. Bk horizon, with numerous mole tunnels, is lighter due to the occurrence of carbonates.
L4/MIS 10	Orel loess (or)	41.05 - 42.45	Silty-sandy loess, with numerous carbonate nodules, with numerous phytogenic biopores and mole tunnels.
S4/MIS 11	Zavadivka pedocomplex (zv)	42.45 - 44.0	Double paleosol, composed of sandy silt, very compact, with mole and worm tunnels filled with the loess and humus material, rich in carbonate silt and nodules, with vertical carbonate pseudomorphs of plant roots, with very numerous, small, black Mn-Fe nodules. Deep fissures, filled with the material of Orel loess, run downward from the uneven upper boundary of this unit.
L5/MIS 12	Tiligul loess (tl)	44.0 - 44.5	Loess silty-sandy, very compact, with carbonate pockets, and with mole tunnels.
S5/MIS 13?-15?	Lubny paleosol (lb)	44.5 - 45.0	Two-horizon silty-sandy soil, with silty concentrations of carbonates in the Bk horizon.

L6/MIS 16	Sula loess (sl)	45.0 - 46.3	Silty-sandy, very compact loess, with few mole tunnels filled with the material of the Lubny soil, with very numerous, large carbonate nodules.
S6-7/ MIS 17-19	Marthonosha paleosol (mr)	46.3 - 48.1	Soil with thick (1.1 m) humus horizon, silty-sandy, rich in different forms of carbonates.
L8/MIS 20	Pryazovsk loess (pr)	48.1 - 49.7	Sandy loess, carbonate rich in the bottom part, with numerous zoogenic biopores.
Early Pleistocene Dniester alluvial deposits		49.7 - 54.2	<p>The upper part of the alluvia consists of flood silts with two-horizon hydromorphic paleosol in the top. Molluscan shells of the Kitzkan fauna and mammalian remains of the Late Nogaisk fauna (the Tamanian faunistic complex) occur in the flood deposits (Dodonov et al. 2006, Gozhik 2013).</p> <p>The bottom part of the alluvia is composed of channel gravels with sand (cemented with calcium carbonate) and stratified sands.</p>
Bedrock of the terrace		54.2	Pontian organogenic limestone.

Table 2.

Magnetic susceptibility and its anisotropy in the loess from Roxolany, Poland and W Ukraine.

Roxolany

Age	K ($\times 10^{-6}$ SI u.)	Pj	L	F	T	N
MIS2-12*	172	1.008	1.001	1.006	0.668	241
L1-L9**	191	1.008	1.001	1.007	0.824	62
Poland and Western Ukraine						
MIS2***	198	1.037	1.007	1.028	0.573	123

K – magnetic susceptibility, Pj – normalized anisotropy factor, L – lineation

parameter, F – foliation parameter, T – shape parameter, N – number of samples.

Data from: * - this paper, ** - Hus (2003), *** - Nawrocki et al. (2006). The correlation of loess units from Roxolany with marine isotope stages according to stratigraphy by Gozhik et al. (2006, 2007).

Table 3.

Mean directions of minimum magnetic susceptibility axes (K_{min}) in the loess from Roxolany.

Age	N	D	I	E_1	E_2
MIS 2	94	110.1	82.2	9.0	8.6
MIS 6,8,10 and 12	36	128.8	86.4	8.7	5.2

N- number of samples, D – declination, I – inclination, E_1/E_2 – confidence angles. Statistics according to Jelinek (1981). Data with inclination greater than 70° , $\varepsilon_{23} < 30^\circ$, $F_{23} > 10$ were taken into consideration only. The correlation of loess units with marine isotope stages according to stratigraphy by Gozhik et al. (2006, 2007).

Table 4.

Summary of the U-Pb isotope data from detrital zircons found in the Roxolany tephra (30 grains) and loess (104 grains).

Grain . Spot	U (ppm)	Th (ppm)	Th/U	²⁰⁶ Pb* (ppm)	²⁰⁴ Pb / ²⁰⁶ Pb ±%	% ²⁰⁶ Pb _c	(1) ²⁰⁶ Pb/ ²³⁸ U Age (Ma)
Roxolany Tephra - detrital zircons							
7.1	72	54	0.74946	3	-2.1E-3 29	--	353 ±9
11.1	561	131	0.23309	42	-3.1E-4 18	--	541 ±12
5.1	185	240	1.30075	16	-4.3E-4 29	--	612 ±14
13.1	711	234	0.32868	65	-2.7E-5 54	--	655 ±15
1.1	413	113	0.27260	41	2.2E-5 95	0.04	700 ±16
6.1	559	336	0.60053	56	-1.4E-5 113	--	710 ±20
4.1	95	56	0.59144	16	-1.3E-3 26	--	1129 ±28
3.1	208	75	0.36077	38	-8.2E-5 44	--	1243 ±33
39.1	341	162	0.47514	13.07	-6.6E-5 80	--	282 ±7
31.1	80	42	0.52269	3.20	-1.1E-3 41	--	293 ±8
35.1	196	59	0.30332	12.64	1.9E-3 30	3.43	467 ±12
30.1	623	158	0.25398	43.86	1.1E-4 35	0.20	508 ±12
15.1	135	75	0.55490	29.50	-9.1E-5 50	--	1460 ±33
53.1	1012	135	0.13302	20	7.3E-5 106	0.13	145 ±6
62.1	154	65	0.41892	6	-3.2E-4 44	--	298 ±14
71.1	393	84	0.21433	24	9.6E-4 19	1.76	437 ±17
67.1	183	71	0.38900	11	6.5E-5 83	0.12	454 ±18
75.1	464	24	0.05224	33	1.5E-4 34	0.28	518 ±21
60.1	130	63	0.48398	11	-2.7E-4 41	--	614 ±24
61.1	57	31	0.54163	5	1.1E-3 30	1.98	623 ±27
49.1	336	414	1.23303	30	-4.9E-5 49	--	635 ±25
64.1	257	154	0.59996	24	1.4E-4 33	0.26	668 ±26
68.1	155	40	0.25998	15	-1.9E-4 35	--	698 ±31
73.1	379	14	0.03708	38	5.1E-5 100	0.09	703 ±29
48.1	133	30	0.22605	17	-1.9E-4 35	--	901 ±35
57.1	55	49	0.89731	9	5.6E-4 34	1.02	1083 ±45
47.1	62	15	0.24875	10	-2.8E-4 35	--	1138 ±43
77.1	147	45	0.30871	26	-1.2E-4 34	--	1195 ±47
72.1	130	60	0.45922	24	-1.0E-4 38	--	1255 ±48
44.1	158	70	0.44002	40	3.9E-5 50	0.07	1648 ±60
Loess MIS2							
3.1	1054	754	0.71520	2	5.3E-4 45	0.96	17.3 0.7
11.1	340	212	0.62447	12	1.3E-4 45	0.23	254 ±7
1.1	553	265	0.47995	27	--- ---	0.00	358 ±6

5.1	212	99	0.46727	12	9.9E-5	50	0.18	414 ±6
6.1	595	392	0.65781	34	1.6E-5	75	0.03	415 ±6
7.1	265	178	0.66990	15	7.5E-5	50	0.14	419 ±6
9.1	481	161	0.33543	35	-4.3E-5	45	--	520 ±7
8.1	76	40	0.51771	6	1.3E-4	71	0.24	577 ±18
12.1	155	44	0.28448	24	2.9E-4	26	0.54	1057 ±15
10.1	152	74	0.48926	26	2.3E-5	71	0.04	1169 ±17
4.1	225	89	0.39726	43	3.7E-5	45	0.07	1294 ±16
2.1	79	52	0.66288	15	-4.1E-5	71	--	1315 ±22
13.1	81	69	0.85976	35	1.1E-4	28	0.21	2638 ±40
17.1	90	52	0.57386	4	8.0E-4	28	1.47	306 ±8
14.1	158	61	0.38708	10	3.3E-4	27	0.59	465 ±11
15.1	38	4	0.11324	2	6.8E-5	113	0.12	469 ±10
18.1	76	23	0.29953	6	-1.5E-4	50	--	531 ±10
19.1	125	65	0.52081	10	1.5E-4	41	0.27	580 ±12
16.1	207	54	0.26341	26	4.6E-5	45	0.08	876 ±13
46.1	367	260	0.70996	13	3.3E-4	29	0.60	259 ±5
51.1	898	492	0.54794	35	1.5E-4	29	0.28	284 ±4
47.1	532	139	0.26112	21	8.4E-5	43	0.15	290 ±4
53.1	203	55	0.27151	11	5.1E-4	22	0.92	406 ±6
48.1	383	73	0.19104	24	1.1E-4	35	0.21	463 ±8
49.1	150	35	0.23149	10	-3.1E-5	100	--	463 ±7
44.1	864	296	0.34295	128	9.7E-5	29	0.18	1026 ±19
45.1	62	0	0.00681	12	2.3E-4	38	0.41	1295 ±24
54.1	134	56	0.42078	29	5.2E-5	50	0.09	1446 ±22
55.1	170	49	0.28834	39	-5.0E-5	45	--	1516 ±23
50.1	233	170	0.73032	57	-4.1E-5	38	--	1624 ±23
52.1	148	70	0.47570	40	3.5E-5	50	0.06	1761 ±26
43.1	481	87	0.18041	18.4	-6.0E-5	43	--	281 ±4
27.1	589	161	0.27374	26.6	-4.6E-5	40	--	331 ±5
41.1	209	47	0.22562	10.0	-9.5E-5	45	--	350 ±7
21.1	407	213	0.52182	25.4	1.9E-4	23	0.35	452 ±3
32.1	471	71	0.15191	30.7	-2.3E-5	52	--	472 ±6
36.1	241	12	0.05126	16.3	1.7E-4	28	0.30	489 ±6
40.1	243	77	0.31768	16.8	-3.2E-5	58	--	500 ±4
39.1	633	149	0.23483	48.2	7.4E-4	8	1.35	548 ±8
33.1	109	64	0.58342	8.4	-4.6E-5	71	--	553 ±6
20.1	108	46	0.42897	8.3	-2.2E-4	41	--	556 ±7
24.1	396	373	0.94184	32.4	1.2E-4	25	0.22	587 ±11
22.1	116	45	0.39032	9.6	2.6E-4	32	0.47	588 ±6
26.1	143	88	0.61470	16.5	1.2E-4	34	0.22	810 ±16
28.1	33	14	0.42307	4.0	-1.9E-4	58	--	851 ±15
25.1	19	2	0.07978	3.5	1.5E-4	50	0.28	1220 ±12
37.1	390	177	0.45265	83.6	1.0E-5	50	0.02	1435 ±37
38.1	378	53	0.13934	85.3	-1.2E-5	45	--	1501 ±46
29.1	184	54	0.29590	42.3	3.7E-5	39	0.07	1531 ±11
31.1	79	26	0.33160	20.4	-1.0E-5	100	--	1698 ±19
23.1	61	17	0.28229	16.1	3.1E-5	71	0.06	1718 ±22
30.1	141	70	0.49500	38.2	3.2E-5	45	0.06	1771 ±12
42.1	75	123	1.63146	22.6	1.5E-4	24	0.28	1933 ±21
35.1	31	43	1.37964	14.4	3.7E-5	58	0.07	2756 ±39

Loess MIS 10								
45.1	365	107	0.29276	13.7	-8.3E-5	41	--	277 ±6
49.1	361	129	0.35609	14.1	1.8E-5	100	0.03	286 ±7
1.1	131	7	0.05297	5.4	4.6E-5	71	0.08	300 ±5
29.1	314	135	0.42987	13.0	-1.0E-5	150	--	303 ±7
6.1	186	57	0.30552	7.7	-1.3E-4	41	--	304 ±12
48.1	352	156	0.44329	14.8	1.3E-4	33	0.24	309 ±5
30.1	116	61	0.52915	4.9	-1.9E-4	51	--	310 ±5
46.1	161	50	0.31278	6.9	-9.5E-6	173	--	315 ±5
23.1	233	39	0.16578	10.2	-3.8E-5	71	--	320 ±5
40.1	242	44	0.18184	10.5	-1.2E-4	41	--	320 ±7
41.1	153	80	0.52320	6.7	-1.6E-5	134	--	322 ±5
24.1	78	24	0.31077	3.5	-1.7E-4	50	--	323 ±7
34.1	235	91	0.38536	10.4	1.5E-4	38	0.28	323 ±7
11.1	280	75	0.26883	12.7	-9.4E-5	38	--	332 ±6
2.1	326	110	0.33677	15.2	2.5E-4	23	0.45	341 ±6
56.1	298	98	0.33040	14.2	9.2E-5	38	0.17	347 ±7
10.1	314	189	0.60308	15.8	4.4E-5	58	0.08	368 ±8
58.1	264	109	0.41391	13.7	-2.1E-4	27	--	379 ±8
7.1	444	67	0.15126	24.0	-4.4E-5	45	--	394 ±15
16.1	391	41	0.10443	24.4	8.4E-5	31	0.15	452 ±10
9.1	444	17	0.03800	28.0	8.2E-6	106	0.01	456 ±7
33.1	233	66	0.28145	15.0	-1.9E-4	28	--	466 ±9
51.1	257	77	0.30044	18.7	5.2E-5	47	0.09	524 ±9
8.1	623	51	0.08226	45.3	-4.0E-6	90	--	525 ±17
50.1	804	48	0.05952	61.5	-6.8E-5	20	--	550 ±15
42.1	319	194	0.60723	24.9	-1.6E-5	71	--	560 ±9
61.1	410	67	0.16424	32.6	-1.0E-4	29	--	570 ±9
38.1	142	74	0.52054	11.5	-2.0E-4	32	--	580 ±13
35.1	389	104	0.26631	32.3	-5.9E-5	35	--	596 ±9
18.1	415	84	0.20290	34.6	4.6E-5	38	0.08	597 ±9
62.1	165	44	0.26526	14.1	-6.7E-5	50	--	612 ±21
39.1	245	68	0.27740	21.1	1.1E-4	29	0.20	615 ±12
57.1	89	50	0.56404	7.7	1.5E-4	45	0.27	615 ±15
63.1	61	23	0.37579	5.3	1.5E-4	61	0.28	618 ±71
44.1	157	186	1.18355	13.7	---	---	0.00	621 ±18
26.1	145	29	0.20130	12.9	3.7E-5	80	0.07	632 ±11
53.1	315	145	0.46110	31.2	-1.2E-5	75	--	704 ±11
60.1	255	160	0.62758	31.7	-3.0E-5	45	--	870 ±18
3.1	75	40	0.53318	10.4	-8.7E-5	50	--	956 ±22
36.1	229	49	0.21594	31.5	4.3E-5	35	0.08	957 ±15
59.1	72	17	0.23301	10.1	-2.1E-5	100	--	978 ±17
5.1	144	37	0.25602	20.5	1.8E-4	25	0.33	987 ±15
54.1	96	53	0.55831	14.0	-1.3E-4	33	--	1013 ±24
52.1	45	18	0.40633	6.7	2.6E-4	41	0.48	1035 ±36
21.1	201	96	0.47944	30.1	-3.8E-5	45	--	1036 ±19
32.1	50	54	1.06349	7.7	1.1E-4	58	0.20	1057 ±21
31.1	141	50	0.35131	23.1	8.4E-5	32	0.15	1125 ±18
12.1	91	45	0.49067	16.5	7.1E-5	50	0.13	1233 ±29
14.1	91	44	0.47833	19.0	-1.1E-4	32	--	1403 ±49
27.1	60	33	0.54486	13.3	1.7E-4	33	0.32	1487 ±39

37.1	129	54	0.42051	30.0	8.9E-6	100	0.02	1548 ±25
17.1	51	27	0.52128	12.0	6.4E-5	50	0.12	1551 ±24
55.1	115	62	0.54439	27.2	4.7E-5	38	0.09	1573 ±25
43.1	111	48	0.43251	26.8	-5.9E-5	38	--	1598 ±26
4.1	58	125	2.14846	15.7	7.3E-5	46	0.13	1764 ±32
19.1	89	58	0.64722	26.6	-7.6E-5	41	--	1924 ±33
47.1	75	46	0.60971	32.6	-6.5E-6	100	--	2639 ±36
33.1	601	131	0.21859	23.7	6.7E-5	31	0.12	289 ±2
30.1	747	386	0.51680	29.5	5.2E-5	39	0.10	289 ±2
15.1	108	42	0.39184	4.4	-4.2E-4	38	--	298 ±5
1.1	180	38	0.21203	8.0	2.3E-4	29	0.42	323 ±3
29.1	101	80	0.78441	4.6	-5.6E-4	30	--	330 ±3
13.1	307	113	0.36852	14.9	-2.4E-4	29	--	355 ±4
32.1	123	74	0.60717	6.4	-2.1E-4	41	--	382 ±6
16.1	211	110	0.52180	13.0	3.0E-4	24	0.54	447 ±4
25.1	339	54	0.16056	21.7	8.0E-5	34	0.14	463 ±3
24.1	290	153	0.52746	18.7	-1.5E-4	30	--	468 ±3
27.1	97	26	0.27131	6.5	-2.8E-4	34	--	484 ±5
3.1	169	58	0.34456	12.0	4.1E-4	22	0.73	514 ±4
35.1	47	8	0.17195	3.4	2.0E-4	58	0.35	519 ±4
6.1	334	85	0.25441	27.3	4.6E-5	35	0.08	586 ±4
8.1	243	195	0.79961	20.2	-1.3E-5	71	--	594 ±5
26.1	132	254	1.92100	11.3	-1.6E-4	35	--	609 ±4
4.1	254	210	0.82650	21.7	-1.1E-5	100	--	610 ±7
2.1	251	67	0.26726	21.8	1.0E-4	38	0.18	621 ±4
31.1	161	47	0.28964	15.5	8.1E-5	41	0.14	685 ±7
14.1	48	4	0.08241	4.7	---	---	0.00	705 ±7
34.1	165	9	0.05400	17.1	---	---	0.00	734 ±14
21.1	78	40	0.51574	8.2	-1.1E-4	51	--	746 ±8
10.1	276	12	0.04455	44.3	5.7E-5	28	0.10	1105 ±17
5.1	122	65	0.53600	23.0	6.6E-5	39	0.11	1283 ±11
19.1	110	88	0.79990	26.8	-1.1E-4	27	--	1614 ±12
11.1	80	14	0.17608	19.5	2.7E-5	56	0.04	1615 ±17
23.1	154	60	0.38803	38.6	1.1E-4	22	0.17	1650 ±12
12.1	596	180	0.30248	169.4	-1.0E-5	32	--	1844 ±13
20.1	107	99	0.91697	31.3	-7.5E-5	29	--	1884 ±17
18.1	95	39	0.41026	28.8	-7.6E-5	35	--	1948 ±13

Errors are 1-sigma; Pb_c and Pb* indicate the common and radiogenic portions, respectively.

Error in Standard calibration was 0.15 – 0.78% (not included in above errors but required when comparing data from different mounts).

(1) Common Pb corrected using measured 204Pb.

Table 5.

Results of isotope age estimations in magmatic zircons (37 grains) from the Roxolany Tephra.

Grain . Spot	Th/U	207 corr ²⁰⁶ Pb/ ²³⁸ U	±%	Uncorrected Age (Ma)	Disequilibrium Corrected Age (Ma)
9.1	1.00	4.734E-05	4.0	0.31	0.39
12.1	0.40	4.835E-05	2.8	0.31	0.41
22.1	0.49	4.957E-05	4.3	0.32	0.42
10.1	0.26	5.196E-05	2.0	0.33	0.44
32.1	0.46	5.828E-05	2.3	0.38	0.47
70.1	0.45	6.076E-05	2.9	0.39	0.49
37.1	0.56	6.225E-05	3.8	0.40	0.50
20.1	0.80	6.395E-05	4.6	0.41	0.50
36.1	0.48	6.700E-05	2.9	0.43	0.53
18.1	0.60	6.720E-05	1.2	0.43	0.53
2.1	1.20	7.000E-05	2.0	0.45	0.53
51.1	0.62	7.354E-05	2.4	0.47	0.57
69.1	0.77	7.491E-05	2.2	0.48	0.57
23.1	2.13	7.807E-05	1.0	0.50	0.56
45.1	0.74	7.860E-05	3.2	0.51	0.60
21.1	0.35	8.098E-05	7.6	0.52	0.62
59.1	0.43	8.345E-05	5.6	0.54	0.64
28.1	0.52	9.099E-05	19.7	0.59	0.68
58.1	0.55	9.649E-05	5.4	0.62	0.72
40.1	0.43	1.006E-04	10.5	0.65	0.75
43.1	0.33	1.015E-04	2.0	0.65	0.76
27.1	0.40	1.027E-04	1.4	0.66	0.76
29.1	0.71	1.058E-04	15.2	0.68	0.77
54.1	0.61	1.067E-04	5.2	0.69	0.78
19.1	0.95	1.154E-04	1.2	0.74	0.83
46.1	0.73	1.164E-04	5.1	0.75	0.84
34.1	0.44	1.307E-04	6.3	0.84	0.94

55.1	0.62	1.318E-04	13.7	0.85	0.94
25.1	0.29	1.333E-04	10.7	0.86	0.96
41.1	0.49	1.406E-04	3.7	0.91	1.00
56.1	0.22	1.585E-04	6.7	1.02	1.13
65.1	0.42	1.846E-04	18.0	1.19	1.29
24.1	0.39	1.977E-04	3.8	1.27	1.37
63.1	0.49	2.114E-04	6.4	1.36	1.46
52.1	0.36	2.625E-04	9.4	1.69	1.79
42.1	0.78	3.960E-04	13.6	2.55	2.64
66.1	0.40	7.525E-04	8.6	4.85	4.95

Highlights

Palaeowinds and sources of loess defined by magnetic susceptibility and zircon ages.

According to isotope data the Roxolany Tephra was provided by the Ciomadul volcano.

Loess in Roxolany section accumulated by the summer north-western winds.

Primary sources of loess from Roxolany in the Carpathians and the Podolia Upland.

Terminal sources of loess from Roxolany in the Dniester valley and liman.

A

B

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9