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Soil forming processes of ancient man-made soils (cultural layers) by the example of sites in humid (Dunino) and arid (Ar-Dolong) regions of Russia: A first approach

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ABSTRACT

The specificity of cultural layer transformation by soil forming processes was examined in humid (Moscow region) and arid (Kalmykia) zones of Russia. The objects studied in the two regions are the Dunino and Ar-Dolong settlements. The former is attributed to the Early Iron Age and the latter to the Bronze Age. Archaeological excavations in both places revealed numerous ancient artifacts occurring in situ which prove the sites having been inhabited in the past. Though located in different natural zones, the investigated objects have two features in common: sandy parent material and the leading role of the anthropogenic factor in the past.

Morphological examination was supplemented with analysis of chemical properties (organic and inorganic matter, total phosphorus, pH). At the arid site, humic acids extracted from the organic matter in the ancient cultural layer have been dated by radiocarbon. Simultaneously, the background soils were also studied.

Though both ancient settlements were abandoned for a long time, the cultural layers have not been buried under later sediments. They stayed exposed and subjected to transformations by soil-forming processes. The duration of the latter was different at the two sites, not exceeding 2 ky in the humid zone and about 3.0–3.5 ky in the arid zone. After people had left the settlements, younger soils developed in the course of pedogenesis, their morphology being similar to the zonal soils. Integrated analyses of soils enable determination of how far the natural processes have gone in the cultural layer transformation. The determination of the total phosphorous provides a means for cultural layer diagnosis with confidence, long after the settlement had been abandoned. It is possible to determine the trends for human-made soil development in different climate zones, from Arenosol to Podzol and Arenosol to Andosol in humid and arid zones respectively.

In the course of time, the cultural layers of ancient settlements are being transformed into zonal soils, no matter the geographical location of the region. However, the rate of transformation, both of individual soil features and of the entire soil profiles is variable. Transformation rate of ancient non-buried cultural layers is higher in the humid environment than in the arid environment.

1. Introduction

In the process of settlement, humans exert a profound and occasionally irreversible effect on the environments, such as deforestation, tilling virgin lands, and in some cases replacing the original vegetation with newly introduced plants. The most drastic changes occur within the limits of a human settlement itself. In the course of constructing and repairing their dwellings and other household activities, specific deposits are formed, known as cultural layers (Sedov et al., 1999; Marfenina et al., 2008; Sycheva et al., 2008; Engovatova and Golyeva, 2012). The layers are diversified in composition depending, in particular, on the kind of the construction material (stone, wood, or adobe) (Alexandrovskiy et al., 2012). At the same time, different cultural layers have much in common, such as alkaline reaction of solutions, high concentration of total phosphorus, organic carbon, carbonates, amorphous silica (Chandler, 1987; Lima et al., 2002; Angelucci, 2003; Schaefer et al.,

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Table 1
Geographical and historical characteristics of studied sites.

Characteristics	Ar-Dolong	Dunino
Location	47°42′50″ N; 44°48′24″ E	55°43′20.7″ N; 36°55′35.1″ E
MAT, °C	11.1	3.4
MAP, mm yr^{-1}	150–200	550–600
Nature zone	Semi-desert	Southern taiga
Vegetation	Sparse dry steppe	Coniferous and broad-leaved forest
Parent material	Sand	Sand
Age of the site	Bronze Age	Early Iron Age
Age of modern soil, years	3000–3500	1500–2000

2004; Richter, 2007; He and Zhang, 2009; Certini and Scalenghe, 2011; Sanchez et al., 2013 and many others). The phosphorus comes into soil with domestic waste and household garbage, and form extremely stable organic-mineral compounds with organic matter and ash. Apart from the phosphorus, cultural layers of human settlements are often enriched in limestone, gypsum, and other mineral salts, specially brought in and used for constructing walls, floors, ceilings, and so on (Trinkaus et al., 2000; Mandel and Bettis, 2001; Meijboom et al., 2004). The appearance of the horizons bearing traces of human presence (cultural layers) depends directly on the land use type and intensity (Macphail et al., 2003; Davidson et al., 2006). The most stable and morphologically significant elements (most suitable for the subsequent analysis using methods of natural sciences) develop in places of productive activity and dwellings, while in the streets, lanes between huts, yards etc. a cultural layer is of small thickness and has limited information.

After people had left the habitable site, the constructions were destroyed, the surface overgrown with grass and herbs, and the processes of soil formation commenced and formed new soils. We do not want to discuss the problem of classification of these new soils. It is a real problem (see Golyeva et al., 2014). In our opinion the best name would be Archeoanthrosol according to the nomenclature of Kämpf et al. (2003). However, we named our new soil as an Arenosol because it is the nearest name according to WRB (2014). The anthropic horizons were symbolized by adding the letter ‘u’ to differentiate it from natural soil horizons.

Various problems directly related to the cultural layers of settlements, their specific features and the rates of development have been comprehensively covered in the modern soil literature (Aleksandroskiy et al., 1998; Sedov et al., 1999; Macphail et al., 2003; Golyeva, 2004, 2006; Kaidanova, 2006; Sycheva et al., 2008; and many others). However, problems of post-settlement landscape transformation as a result of the subsequent soil-forming processes, as well as trend of new soils development, are still much less known (Macphail et al., 2003; Correa et al., 2013; Golyeva et al., 2014; Spohn et al., 2015). Taking into account that sizeable areas of coastal terraces and even of watersheds were populated in the past (Graves et al., 2009), it seems to be of present interest to know more about the trends and rates of the cultural layer transformation.

With regard to all the above, the principal purpose of the work is to determine trend and degree of the transformation of ancient settlement sites by soil forming processes. In this connection, it is also important to estimate the climatic influence on the rate of cultural layer transformation and to find whether the process intensity measured in a certain zone may be extrapolated to other landscape zones.

2. Objects of study

The specificity of cultural layers transformation by the soil forming processes was examined in humid (Moscow region) and arid (Kalmykia) regions (Fig. 1, Tables 1 and 2). Table 1 shows that

Table 2
Chemical properties of all soils and particle-size distribution of background soils in both climate zones.

Depth, cm	Horizon	pH	Corg., %	P_2O_5tot., %	CO_2, %	Sand, % 1–0.05 mm	Silt, % 0.05–0.001 mm	Clay, % less 0.001 mm
Humid region Dunino-4 Background soil. Entic Podzol								
0–10	AO	5.5	3.49	0.12	0	78.95	15.3	5.75
10–20	AE	5.1	1.05	0.14	0	85.83	10.71	3.46
20–30	B	5.3	0.75	0.13	0	85.3	10.13	4.51
30–40	B	5.6	0.29	0.11	0	87.09	8.63	4.28
40–50	BC	5.7	0.14	0.11	0	93.17	3.49	3.34
Humid region Dunino-4 Iron age site. Arenosol on household pit								
0–2	AO	5.5	3.5	0.13	0			
2–12	AEu	5.4	1.85	0.12	0			
12–22	Au	5.8	1.91	0.14	0			
22–32	Au	5.8	1.66	0.12	0			
32–42	Au	6.2	1.3	0.11	0			
42–52	Au	6.2	1.09	0.12	0			
Humid region Dunino-4 Iron age site. Arenosol on cultural layer								
0–2	AO	5.7	4.4	0.14	0			
2–12	AEu	5.2	1.53	0.14	0			
12–22	Bu	5.3	0.85	0.12	0			
22–32	Bu	5.4	0.25	0.1	0			
32–42	B	5.5	0.27	0.09	0			
42–52	BC	5.7	0.16	0.07	0			
Arid region Ar-Dolong. Background soil. Andosol								
0–5	A	7.8	1.2	0.15	0.1	94.38	1.89	3.73
5–15	B	8.5	0.5	0.14	0	94.99	0.84	4.17
15–25	B	8.6	0.4	0.13	0.3	94.75	1.2	4.05
25–35	B_{Ca}	8.4	0.3	0.13	4.5	95.99	0.76	3.25
35–45	BC	8.4	0.1	0.13	2.2	94.91	1.24	3.61
Arid region Ar-Dolong Bronze age site. Arenosol on cultural layer								
0–10	Au	8.5	1.22	0.16	0.04			
10–23	Bu	8.6	0.43	0.2	0			
23–39	Bu	8.2	0.43	0.24	0.05			
39–66	B_{Ca}u	9.5	0.36	0.31	3.27			
66–100	BC	8.8	0.15	0.13	1.73			

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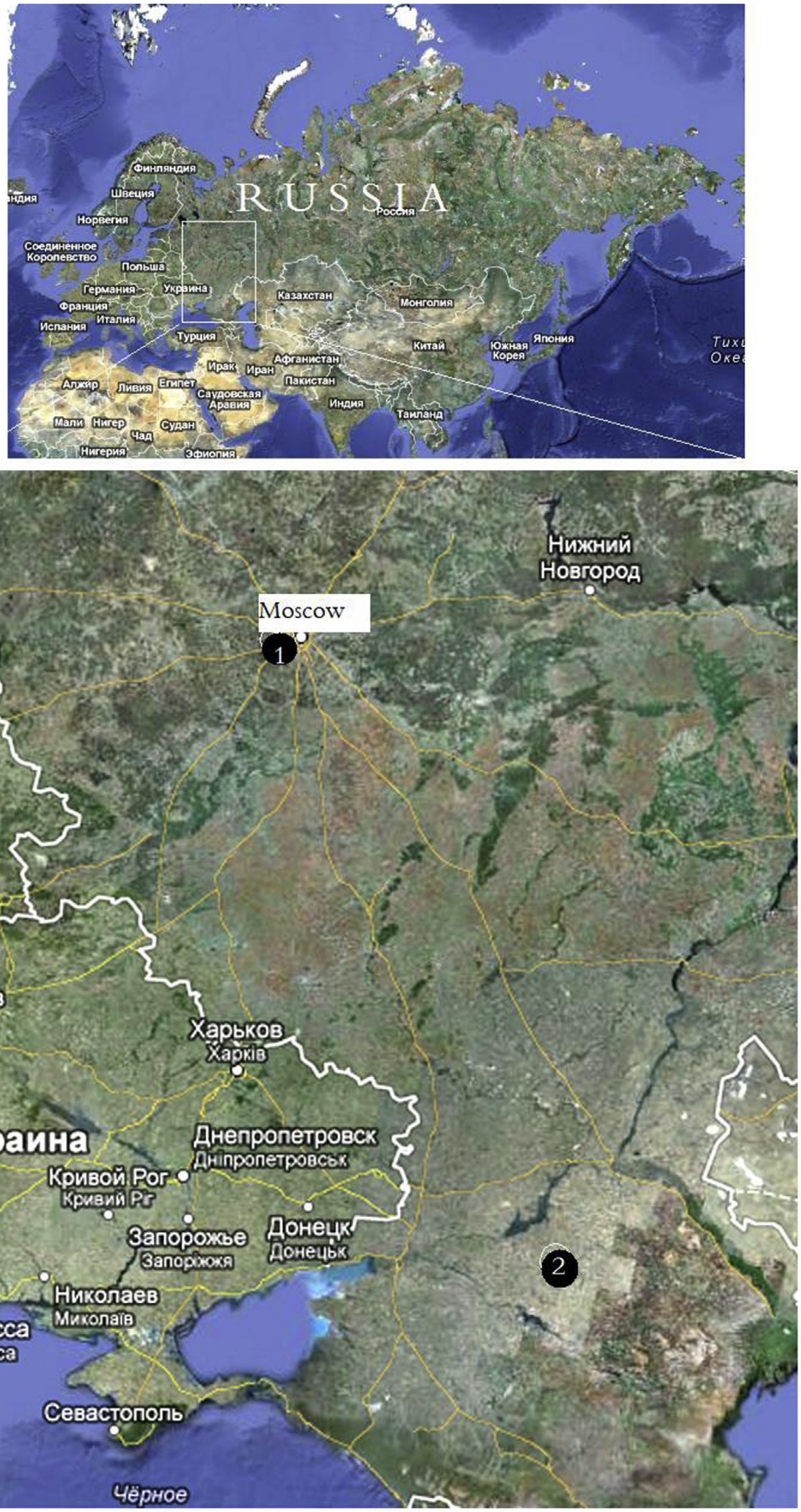

Picture 1. Study sites location: 1 – Dunino in humid climate zone; 2 – Ar-Golong in arid climate zone.

the investigated objects share two features: sandy parent material and a leading role of the anthropogenic factor in the past.

The humid region is represented by the settlement of the Early Iron Age "Dunino" (excavated by archeologist A.A. Alekseev), and the arid region by settlement of the Bronze Age "Ar-Dolong" (archeologist P.M. Kol'tsov). Archaeological excavations revealed in both regions the presence of ancient artifacts occurring in situ at a depth of 35 cm in the first site, and up to 66 cm in the second one. Simultaneously, background soils were studied at both sites.

The Duino settlement (55°43′20.7″ N, 36°55′35.1″ E) is located in a temperate continental area, with mean annual temperature of +3°, and annual precipitation about 550–600 mm. Geologically it is Late Pleistocene fluvial sandy deposits (Krivtsov, 2012). It belongs to the natural zone of southern taiga; dominant vegetation is pine forest with some small-leaved species and shrubs in the undergrowth. The grass and herb layer is well-developed, rich in species composition, and includes a number of plants typical of nemoral flora (*Aconítum*, *Convallaria majalis*, *Lamium album*, *Veronica*, *Paris quadrifolia*, *Aegopodium podagraria*). Two areas were studied within the site limits, one on the cultural layer itself, and another one at the place of an ancient household pit. The parent material is coarse and medium-grained coherent sand. The zonal soil is rzhavozem in the Russian classification (Shishov et al., 2004) or Entic Podzol (WRB, 2014). Geomorphologically, both areas are identical: they are located on the 1st terrace composed of ancient fluvial deposits.

The Ar-Dolong settlement (47°42′50″ N, 44°48′24″ E), studied by archeologist P.M. Koltsov, is situated in the dry steppe zone. The climate is extremely continental, with mean annual temperature +11.1° and total annual precipitation 150–200 mm. The vegetation is wormwood steppe, with rarified plant cover. Background soils are mostly brown semidesert ones by the Russian classification (Shishov et al., 2004) or Andosol by WRB (2014). The studied site lies within the limits of a sandy marine depositional plain resulting from the Late Khvalynian transgression (Late Pleistocene) of the Caspian Sea (Yanina, 2012; Tudryn et al., 2013). The plain is composed of marine fine grained well-sorted sands with an admixture of clay particles. Its surface is rather smooth, very gently sloping (0.5–1.5°) towards the Caspian Sea, flat areas alternating with undulating ones.

Both ancient settlements were abandoned long ago. The ancient cultural layers, however, have not been overlain with younger sediments, so they were exposed to soil-forming processes and as a result have been essentially transformed. The duration of soil formation was different in the two zones, not exceeding 2 ky in the humid zone, and about 3.0–3.5 ky in the arid one. As a result of pedogenesis, new soils developed in both sites, the newly-formed soil being similar morphologically to the zonal soils. In this way we can compare the degree of the zonal soil characteristics' recovery depending on: 1) climate and environments; 2) duration of the postanthropogenic period; and 3) intensity of the initial landscape transformation by human activities (dug-up holes or "ordinary" cultural layers).

3. Methods of study

The studies consisted of describing morphological characteristics of the studied profiles and chemical analyses of samples in laboratory. Particle-size analyses were done in both background soils. The latter included standard chemical analyses usually performed in the course of archeological soil studies (Mandel and Bettis, 2001; Golyeva, 2004; Engovatova and Golyeva, 2012). Chemical properties of samples were determined using conventional procedures (Arinushkina, 1970; Vorobiova, 1998, 2006).

pH was determined by potentiometry in a suspension at a soil to water) ratio of 1:2.5 (or 1 M KCl and single shaking followed by settling for 30 min (pH_{H_2O}) or 18–20 h with periodical mixing (pH_{KCl}) (Arinushkina, 1970). Organic carbon was determined by the Tyurin method which included the wet digestion of organic substance in a mixture of 0.4 N $K_2Cr_2O_7$ and conc. H_2SO_4 (1:1) under heating to 150 °C for 20 min. Measurements were performed by photometry on a SPECOL 211 spectrometer at 590 nm (Arinushkina, 1970).

Carbonates in the sample were determined by alkalimetry using the Kozlovskii procedure. A soil sample was treated with 2 M HCl; the released CO_2 was absorbed by a 0.4 M NaOH solution. Then a saturated $BaCl_2$ solution was added to the tube with NaOH, and the excess of alkali was titrated with 0.2 M HCl (Vorobiova, 1998, 2006).

Total Phosphorus procedure includes a burn sample with concentrated sulphuric acid on the heater. Phosphate in the extract is determined colorimetrically employing spectrophotometer SPECOL 211 using the blue ammonium molybdate method with ascorbic acid as a reducing agent (Vorobiova, 1998, 2006).

Particle-size analysis was performed for particles <1 mm. After pretreatment with a dispersing agent (4% Na pyrophosphate), the fraction 1–0.25 mm was separated by wet sieving. The content of silty and clay particles (<0.05 mm) was determined by sedimentation (pipette method).

The age of humus from the lower part of the cultural layer (B_{Ca}u horizon, 39–66 cm) in Ar-Dolong was determined by radiocarbon dating of the humic acids extracted from the sediment (Table 3). Material pre-treatment included acid washing. Conventional radiocarbon ages were calibrated using CALIB Rev 5.0.1 (CALIB 5.0 Website; Stuvier and Reimer, 1993) on the IntCal 04 calibration dataset (Reimer et al., 2004). The aim of this investigation was to compare the radiocarbon dating of organic matter with the archaeological dating based on the artifact analysis.

Table 3
Comparison of archaeological age and radiocarbon dating of organic matter from cultural layers, Ar-Dolong site.

Index IGAN	Sample, depth, cm	Archaeological age (approximate)	Conventional radiocarbon date, humic acids	1σ confidence interval: [start: end] relative area
2807	Ar-Dolong, 39–66 cm	Bronze Age	1600 ± 160 yrs BP	Cal AD 256 (439) 635 Cal BP 1694 (1511) 1315

4. Results and discussion

The results of studies are presented in Tables 2 and 3.

4.1. The humid natural zone

4.1.1. Dunino 1: Arenosol on the household pit dated to the Early Iron Age, southern wall

The pit wall was excavated to a depth of 60 cm. The Au horizon is composed of a relatively homogeneous dark-gray humified material, becoming darker with depth up to black. The dark color of the total thick horizon is due to anthropogenic influence, which includes abundant charred organic matter. Numerous small charcoals are visible in the lowermost part of the pit.

In the distribution of soil acidity over the profile, there is a slightly higher acidity recorded directly under leaf litter in the AEu horizon, gradually decreasing downwards. The organic matter content is high and very high all over the profile, not typical for sandy soils in the taiga zone. The total phosphorus content agrees with natural standards in practically all samples, although the distribution of the element along the profile differs from that in natural soil profiles. The phosphorus distribution over the profile is rather uniform, without noticeable decrease with depth, slightly higher values being found at depths 12–22 cm and 52–62 cm. Maximum content of phosphorus in this profile have been recorded in the lowermost part of Au horizon, which may be attributed to the anthropogenic origin of the entire series.

4.1.2. The eastern wall. Arenosol on the cultural layer

The cultural layer has been completely transformed by the soil-forming processes and cannot be identified in the field as a separate unit. The soil is more acid – the pH values are lower than those in the samples taken on the southern wall, though the acidity distribution over the section is similar to the latter (the highest acidity is confined to the AEu horizon directly underlying the leaf litter and gradually decreases downwards). The organic content is high in the uppermost organic horizon and decreases drastically with depth. Phosphorus is relatively abundant in the upper organic horizons, unlike the mineral B soil horizons. A distinguishing feature is a continuously high proportion of total phosphorus in the upper 12 cm which is not typical of taiga soils on sands.

One may safely conclude that in place of typical cultural layers, ordinary soddy soils are present. It is only due to abundance of archeological objects (occupational debris) in the soils that the studied soil horizons may be considered as cultural layers of settlements.

It seems evident that after the inhabitants had left the settlement, the entire mass of deposits was completely transformed by the soil forming processes; the latter smoothed sharp boundaries between the layers – one of the most reliable diagnostic characteristic of cultural layers in soil science. In most of the studied objects, the basic chemical properties (such as soil solution acidity, proportion and distribution of organic carbon) correspond to those of soddy soils. That strongly suggests a deep restructuring of the profile. Thus, the distribution of organic matter in the cultural layer profile is accumulative, maximum in the leaf litter and gradual decrease with depth: such a distribution is typical of recent soddy soils. A higher acidity in the horizons indirectly underlying leaf litter in the soils suggests the beginning of acid hydrolysis, that is, podzolization (Sauer et al., 2007). In this case, it is safe to say that those soils would develop into typical podzols in the future. So at present we have recorded initial stages of the intrazonal soddy soil transition into zonal podzols.

The only characteristic persisting since the ancient time of the human inhabitance is the total phosphorus distribution over the profile. It is the even distribution of the element that points unambiguously to the anthropogenic factor influence in past stages of the sites and supports the suggestion about the soils having gone through the stage of cultural layers. Only those objects where human activities were exceedingly intensive (pits used for domestic purposes) maintained some specific characteristics of cultural layers, namely, high contents of humus and total phosphorus all over the studied deposits, although the process of acid hydrolysis is already well detectable.

4.2. The arid natural zone

4.2.1. Ar-Dolong. Arenosol on the Bronze Age cultural layer

The new soil of the arid zone is characterized by the presence of a horizon of carbonate accumulation (39–66 cm), and by low humus content and its gradual decrease with depth, which is completely similar to the background semidesert soil. The only important difference is the character of total phosphorus distribution. Phosphorus is a biophile element, and its accumulation in sediments indicates an input of organic matter. The concentration of total phosphorus in soils decreases with depth. Its maximal concentration in surface horizons of natural soils of the region does not exceed 0.17%. The total phosphorus content in the upper 10-cm layer of the new soil corresponds to its amount in natural soils. That may be attributed to reworking of the element stored in the root layer by the vegetation. However, at a depth greater than 10 cm, higher-than-average concentration of total phosphorus is preserved, which permits identification of the ancient cultural layer. A comparison of thickness and morphology of profiles between typical zonal soils and the horizons identified within cultural layers during the archeological excavations revealed their complete conformity.

The radiocarbon dates (Table 3) confirmed our assumptions about the transformation of the initially uniform cultural layer by the processes of modern soil formation. The radiocarbon dates on humic acids from 39 to 66 cm depth of the cultural layer of the Bronze Age were significantly younger. That may be attributed to an input of younger organic matter from above.

5. Discussion and conclusion

Thus, the cultural layers of the ancient settlements transform with time into zonal soils regardless of their geographical location. But, we should bear in mind that the transformation rates of individual soil features and entire soil profiles may vary over wide limits. According to our data, the rejuvenation of the organic matter is a relatively fast process: the “young” humus is found incorporated into the soil at a depth about 0.5 m even in semidesert zone with small amount of precipitation and sparse vegetation. The “normal” type of the organic profile has been formed in both new soils. The typical carbonate profile has been found in the soil of the arid zone.

The main difference between the studied sites appears to be the content and distribution of total phosphorus over the soil profile. The “older” new soil at Ar Dolong where pedogenesis duration is estimated at 3.0–3.5 ky shows a higher content and an increase of total phosphorus below the depth of 10 cm, completely different from its distribution in the zonal soil. At the same time, in the “younger” new soil of Dunino (the duration of soil formation is 1.5–2.0 ky), the total phosphorus concentration does not exceed the reference values all along the former cultural layer. The only explanation for this is the difference in mean annual precipitation between these regions. The rate of transformation of ancient non-buried cultural layers in the humid environment is higher than in the arid environment. In the latter, only the upper 10 cm of the profile are comparable to the zonal soil in all characteristics.

Over the past 1500 years, the soil-forming processes in the humid zone blurred and obliterated previously sharp transitions between individual horizons in cultural layers, except in the objects affected by the most active human interference (such as the household pit). The latter maintain the characteristic properties of cultural layers, such as high content of humus and total phosphorus, all over the studied unit, even after 1500 years.

The information is better preserved in deeper layers. The thicker is the artificial horizon, the richer is information persisting in its

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lower part, the more diversified and complete it is. From this point of view, the less persistent are soils where human activities affected only the surface, or at most the upper 5 cm of the soil. The most stable are cultural layers with thickness up to a meter or more, such as household pits.

The cultural layers related to ancient settlements noticeably differ in the degree of preservation. In the course of time, soil forming processes transform the cultural layers into an intrazonal soil distinguished only by the presence of artifacts. It may be seen that the development of human-induced horizons under ancient human settlement has a reversible character, and on removal of anthropogenic load some natural properties of the soil may be restored. The time interval necessary for a complete landscape restoration at the place of an abandoned settlement depends on natural environments, the settlement function, and domestic and economic activities of the inhabitants.

Integrated analyses of soils enable determination of how far the natural processes have gone in the cultural layer transformation. The determination of the total phosphorous provides a means for the cultural layer diagnosis with confidence long after the settlement had been abandoned. Even in dry steppe and semi-desert environments, the cultural layer transformation by soil-forming processes does not exert any noticeable effect on the content and distribution of phosphorus over the profile.

It is possible to determine the trends for human-made soils development in different climate zones from Arenosol to Podzol and Arenosol to Andosol, in humid and arid zones respectively. The results of the studies not only made possible to identify various different in trend and rate soil-forming processes which take part in soil development, but also open new opportunities for the future development of those soils.

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References

Aleksandroskiy, A.L., Boytsov, I.A., Krenke, N.A., et al., 1998. Excavations in the yard of the Moscow State University: an integrated approach to study of the urban cultural layer. In: Methods of Natural Sciences in the Field Archeology. Issue 2. Institute of Archeology, Moscow, pp. 3–13 (In Russian).

Alexandrovskiy, A.L., Dolgikh, A.V., Alexandrovskaya, E.I., 2012. Pedogenetic features of habitation deposits in ancient towns of European Russia and their alteration under different natural conditions. Boletin de la Sociedad Geologica Mexicana 64 (1), 71–77.

Angelucci, D.E., 2003. Geoarchaeology and micromorphology of Abric de la Cativera (Catalonia, Spain). Catena 54 (3), 573–601.

Arinushkina, E.V., 1970. Guide on the Chemical Analysis of Soils. Moscow State University Publishing House, Moscow, pp. 1–487 (in Russian).

CALIB 5.0 Website. 2006. http://calib.qub.ac.uk/.

Certini, G., Scalenghe, R., 2011. Anthropogenic soils are the golden spikes for the Anthropocene. The Holocene 2, 1269–1274.

Chandler, T., 1987. Four Thousand Years of Urban Growth. An Historical Census. The Edwin Mellow Press, Lewiston, NY, pp. 1–676.

Correa, G.R., Schaefer, C.E., Gilkes, R.J., 2013. Phosphate location and reaction in an archaeoanthrosol on shell-mound in the Lakes region, Rio de Janeiro State, Brazil. Quaternary International 315, 16–23.

Davidson, D.A., Dercon, G., Stewart, M., Watson, F., 2006. The legacy of past urban waste disposal on local soils. Journal of Archaeological Science 33 (6), 778–783.

Engovatova, A., Golyeva, A., 2012. Anthropogenic soils in Yaroslavl (Central Russia): history, development, and landscape reconstruction. Quaternary International 265, 54–62.

Golyeva, A.A., 2004. Integrated natural-scientific studies on the Rostislavl' Ryazansky gord (fortified settlement). In: Engovatova, A.V., Koval, V.Ju., Kuzina, I.N., Scorobogatova, T.V. (Eds.), Archeology of the Moscow Region. Proceedings of the Scientific Seminar. Moscow, pp. 24–34 (In Russian).

Golyeva, A.A., 2006. Soil studies on te Myakinino archeological monuments. In: Engovatova, A.V., Koval, V.Ju., Kuzina, I.N., Scorobogatova, T.V. (Eds.), Archeology of the Moscow Region. Proceedings of the Scientific Seminar. Issue 3. Institute of Archeology RAS, Moscow, pp. 85–111 (In Russian).

Golyeva, A., Zazovskaia, E., Turova, I., 2014. Properties of ancient deeply transformed man-made soils (cultural layers) and their advances to classification by the example of Early Iron Age sites in Moscow Region. Catena. http://dx.doi.org/10.1016/j.catena.2014.12.030.

Graves, I.V., Galkin, Yu.S., Nizovtsev, V.A., 2009. The landscape analysis of the settlement structure in the Moscow Region Archeology of the Moscow Region. In: Proceedings of the Scientific Seminar. Issue 5. Institute of Archeology RAS, Moscow, pp. 43–55 (In Russian).

He, Y., Zhang, G.-L., 2009. Historical record of black carbon in urban soils and its environmental implications. Environmental Pollution 157 (10), 2684–2688.

Kaidanova, O.V., 2006. Geochemical methods of cultural layer studies of ancient towns. In: Cultural Layers of Archeological Monuments. Theory, Methods, and Practice of the Studies. Proceedings of the Scientific Conference. Institute of Geography RAS, Institute of Archeology RAS, National Information Agency (NIA), Priroda, Moscow, pp. 270–280 (In Russian).

Kämpf, N., Woods, W.I., Sombroek, W., Kern, D.C., Cunha, T.J.F., 2003. Classification of Amazonian Dark Earths and Other Ancient Anthropic Soils. In: Lehmann, J., Kern, D.C., Glaser, B., Wodos, W.I. (Eds.), Amazonian Dark Earths: Origin Properties Management. Kluwer Academic Publishers, Printed in the Netherlands, pp. 77–102. http://dx.doi.org/10.1007/1-4020-2597-1_5.

Krivtsov, V.A., 2012. The peculiarities of the Oka flood structure and development in the limits of Ryazan region. Bulletin of the Ryazan State University Named After S.A. Esenin 11, 1–9.

Lima, H.N., Schaefer, C.E.R., Mello, J.W.V., Gilkes, R.J., Ker, J.C., 2002. Pedogenesis and pre-Colombian land use of “Terra Preta Anthrosols” ("Indian black earth") of Western Amazonia. Geoderma 110 (1–2), 1–17.

Macphail, R.I., Galinie, H., Verhaeghe, F., 2003. A future for Dark Earth? Antiquity 77 (296), 349–358.

Mandel, R.D., Bettis III, E.A., 2001. Use and analysis of soils by archaeologists and geoscientists. In: Goldberg, P., Holliday, V.T., Ferring, C.R. (Eds.), Earth Sciences and Archaeology. Kluwer Academic/Plenum Publishers. Springer, US, pp. 173–204.

Marfenina, O.E., Ivanova, A.E., Kislova, E.E., Sacharov, D.S., 2008. The mycological properties of medieval culture layers as a form of soil ‘biological memory’ about urbanization. Journal of Soils and Sediments 8 (5), 340–348.

Meijboom, E., Hopman, A., Bijlsma, J., 2004. Historical soil. In: Deben, L., Salet, W., van Thoor, M.-T. (Eds.), Cultural Heritage and the Future of the Historic Inner City of Amsterdam. Aksant Acad.Pub., Amsterdam, pp. 161–172.

Reimer, P.J., Baillie, M.G.L., et al., 2004. INTCAL04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. Radiocarbon 46, 1029–1058.

Richter, D., deB, Jr., 2007. Humanity's transformation of earth's soil: pedology's new Frontier. Soil Science 172, 957–967.

Sanchez-Perez, S., Solleiro-Rebolledo, E., Sedov, S., McClung de Tapia, E., Golyeva, A., Prado, B., Ibarra-Morales, E., 2013. The black San Pablo Paleosol of the Teotihuacan Valley, Mexico: pedogenesis, fertility, and use in ancient agricultural and urban systems. Geoarchaeology 28, 249–267.

Sauer, D., Sponagel, H., Sommer, M., Glani, L., Jahn, R., Stahr, K., 2007. Podzol: soil of the year 2007. A review on its genesis, occurrence, and functions. Journal of Plant Nutrition and Soil Science 170, 581–597.

Schaefer, C.E.G.R., Lima, H.N., Gilkes, R.J., Mello, J.W.V., 2004. Micromorphology and electron microprobe analysis of phosphorus and potassium forms of an Indian Black Earth (IBE) Anthrosol from Western Amazonia. Australian Journal of Soil Research 42 (4), 401–409.

Sedov, S.N., Zazovskaya, E.P., Bronnikova, M.A., Kazdym, A.A., Rozov, S.Y., 1999. Late Holocene man-induced environmental change in Central Russian plain: paleopedological evidences from early-medieval archaeological site. Chinese Science Bulletin 44 (1 Suppl.), 159.

Shishov, L.L., Tonkonogov, V.D., Lebedeva, I.I., Gerasimova, M.I., 2004. Classification and Diagnostics of Soils of Russia. Ecumene, Smolensk, pp. 1–342 (in Russian).

Spohn, M., Novak, T.J., Incze, J., Giani, L., 2015. Dynamics of soil carbon, nitrogen, and phosphorous in calcareous soils after land-use abandonment – a chronosequence study. Plant and Soil. http://dx.doi.org/10.1007/sl1104-015-2513-6.

Stuiver, M., Reimer, P., 1993. Extended ^{14}C database and revised CALIB radiocarbon calibration program. Radiocarbon 35, 215–230.

Sycheva, S.A., Leonova, N.B., Pustovoytov, K.E., Sedov, S.N., Chichagova, O.A., 2008. Cultural layers as a storage of data on the anthropogenic soil formation and lithogenesis. In: Targulyan, V.O., Goryachkin, S.V. (Eds.), Soil Memory. Soil as a Storage of Data on the Biosphere-geosphere-anthroposphere Interactions. LKI Publishers, Moscow, pp. 651–675 (In Russian).

Trinkaus, E., Ranov, V.A., Lauklin, S., 2000. Middle Paleolithic human deciduous incisor from Khudji, Tajikistan. Journal of Human Evolution 38 (4), 575–583.

Tudryn, A., Chalié, F., Lavrushin, Yu.A., Antipov, M.P., Spiridonova, E.A., Lavrushin, V., Tucholka, P., Leroy, S.A.G., 2013. Late Quaternary Caspian sea environment: late Khazarian and early Khvalynian transgressions from the lower reaches of the Volga river. Quaternary International 292, 193–204.

Vorobiova, L.A., 1998. Chemical Analysis of Soils. Moscow State University Publishing House, Moscow, pp. 1–272 (In Russian).

Vorobiova, L.A., 2006. Theory and Practice of the Chemical Analysis of Soils. GEOS Publishers, Moscow, pp. 1–400 (in Russian).

World Reference base for soil resources, 2014. World Soil Resources Report 106. Rome, pp. 1–181.

Yanina, T.A., 2012. Correlation of the Late Pleistocene paleogeographical events of the Caspian Sea and Russian Plain. Quaternary International 271, 120–129.