SOIL-LITOLOGICAL FEATURES OF ANCIENT GREEK VINEYARDS ON THE HERAKLEIAN PENINSULA, SOUTH-WEST CRIMEA

Prof. Dr. Fedor Lisetskii[1]
PhD student Arseniy Poletaev[2]
PhD student Evgeniya Zelenskaya[2]

[1] Belgorod State National Research University, Federal-regional centre of aerospace and surface monitoring of the objects and natural resources, **Russian Federation**

[2] Belgorod State National Research University, Institute of Earth Sciences, **Russian Federation**

ABSTRACT

The period of Greek colonisation and economic land development in the northern Black Sea coast stimulated an active transfer of agricultural technologies of subtropical farming from Asia Minor to the sub-Mediterranean region of the South-West of Crimea starting in late 5 c. BC. This determined the formation of the original land management system, the practice of soul cultivation for perennial plantations, and adaptive crop production within the area of about 10 thousand ha, which largely characterises Tauric Chersonesos and its rural district (chora) as one of the best multi-period archaeological sites preserved elsewhere in Europe. This study aims to analyse the biogeochemical differences of the vineyard soils and parent rocks in ancient agricultural zones as one (along with the climate) of the key causes of differences in the quality of grapes and the role of wine trade among ancient states in Crimea and Asia Minor. The geochemical prerequisites of these differences, which are determined by the characteristics of the parent rock and vineyard soil of Tauric Chersonesos on the Herakleian Peninsula in comparison with the more southern region of Asia Minor (Eastern Mediterranean), were considered. We determined the concentrations of 22 macroelements and trace elements in soils and parent rocks in order to compare virgin forest ecosystems and agro-economic zones, which were located in the territory of the ancient states Lycia and Tauric Chersonesos with different bio-climatic conditions. Lithological and geochemical differences of parent rock (for 15 elements), as well as contrast content in soils seven trace elements (Co, Cu, Ni, Cr, Zn, V, Al) in the areas of ancient Eastern Mediterranean Eastern farming and within 880 km to the North (South-West of Crimea) could become one of the substantive reasons for the development of the taste specific features of wines produced in these regions.

Keywords: soil geochemistry, vineyard soil, antique vineyards, Crimea, Eastern Mediterranean

INTRODUCTION

The natural conditions of the region (the landscape, climate, physical, chemical, and biological components of the soil and rock) comprise a major part of "terroir". According to the concept of terroir, the soil in which grapes are grown plays a key role

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in the vine behaviour, the grape quality, and the wine sensory characteristics [1]. If to establish a correspondence among the chemical composition of grape, the geochemistry of vineyard soil and the geolithological features of cultivation zone, and determine the provenance of the grapes by means of their chemical fingerprints [2]. Thus based on the comparison of different geographical areas of viticulture with the use of biogeochemical analysis of the vineyard soil and parent rock in the context of local climatic conditions we can hypothesise about natural prerequisites of diverse specialisation of arable farming in ancient times, which makes it possible to verify the archaeological and historical presumptions using the potential of Earth sciences. Pedoarchaeology has certain capabilities for the analysis of the period and the role of the anthropogenic factor in agropedogenesis of the steppe soils [3]. The purpose was to establish a biogeochemical difference of the soils and parent rocks in ancient agricultural zones as one of the key reasons for differences in the quality of grapes and the role of the wine trade among ancient states in Crimea and Asia Minor.

DATA AND METHODS

Description of the study area. The studies were conducted in two regions: 1) Asia Minor (Eastern Mediterranean) and 2) South-West of Crimea with Sub-Mediterranean climate, which were associated with migrations and movements of goods in the ancient epoch. The East coast of the Mediterranean Sea, the Gulf of Antalya (5 km from Kemer). This is an agricultural area to grow grapes, olives and figs, and the Göynük plain is known for its orangeries and pomegranate gardens. In 4th to 3rd centuries BC the agricultural history of this region was connected with the ancient Greek state of Lycia. We compared soil and their parent rock in native forest and horticulture (plots T1 and T2). calcaric Cambisols on light red limestone talus deposits (T1) has been sampled on the second coastal terrace, 600 m away from the shore, under the mature subtropical forest (*Pinus. Arbutus*, xerophytic shrubs) with underlays of 4 cm thick. The alluvial deposit soil of greyish brown colour with some grey limestone pebbles (T2) has been sampled in an almond and fig garden (*Prunus dulcis* and *Ficus cárica*) on the plain Göynük (7 m a.s.l., 420 m from the sea). The boundaries of the second study area cover the Herakleian Peninsula, which corresponds to the boundary of Tauric Chersonesos in this area at the turn of 4th–3rd centuries BC. The total area of the Herakleian Peninsula is estimated at 12.6 thousand ha (Figure).

The surface of the Herakleian Peninsula is wavy with a maximum to the altitude of 230 m a.s.l. with cinnamonic mountainous gravelly soils. This Peninsula in the west ends with Chersonesos cape with a height of 30 m a.s.l., which is composed of Neogene limestones and covered with xerophytic vegetation. The modern climate is characterized by the following thermal parameters: the average July temperature is 22.1 °C; the frost-free period lasts 239 days. The climate of Eastern Mediterranean is warmer and wetter than on Herakleian Peninsula (average annual temperature is 18.8 and 12.2 °C, annual precipitation 1005 and 379 mm, respectively). This explains why soil genesis and pedogenic mineral weathering processes are so different in intensity.

Figure. The location of soil genetic research objects in the system of ancient land surveying of Tauric Chersonesos (boundaries of land surveying according to [4], numbering of plots according to [5]. 1 – Points of selection of soil samples; 2 – Land boundaries.

METHODS

A wavelength-dispersion X-ray fluorescence spectrometer (Spectroscan Max-GV) was used to determine the contents of chemical elements. The concentrations of macroelements and trace elements in soils (22 metals and oxides) were determined by measuring the fractions of metal mass and oxides in powdered samples. Molar ratios were determined by the formulas: $SiO_2/(RO+R_2O) = SiO_2/(CaO+MgO+K_2O+Na_2O)$ and $SiO_2/(10*R_2O_3) = SiO_2/(10*(Al_2O_3+Fe_2O_3+MnO)$. The accumulation coefficient of trace elements (Ni, Zn, Mn, Pb, Cu, Co) and biophilic elements (Si, P, K) was calculated from the values of soil content (S_n) and parent rock (P_n) by the formula: $K_S= (S_1/P_1* S_2/P_2*...*S_n/P_n)^{1/9}$. The determination of Corg in the soil was performed by oxidation of the organic substance with a solution $K_2Cr_2O_7$ in sulfuric acid until the formation of carbon dioxide. By multiplying the values of organic matter by a coefficient of 0.579, conversion to organic carbon was performed (Corg). The colour of soil samples (in dry condition) was determined by Munsell color Charts, 2000 [6]. The Munsell optical system uses cylindrical coordinates, which makes it difficult to use the system for statistical calculations. The soil colour values have been converted using a formula by Munsell Charts to the RCIE redness index in the CIE-L*a*b* system that uses a universal colour space in Cartesian coordinates [7; 8].

RESULTS AND DISCUSSION

Cambisols (cinnamonic forest soils), which were formed on eluvium and deluvium of bedrock under dry forests and shrubs, occupy on the Crimean Peninsula only 5.9 % of the area [9], but widely represented on the Herakleian Peninsula. Here calcaric Cambisols are marked by a lighter A horizon, carbonates at 20–50 cm depth, gleysation and biochemical recovery of Fe, Mn and so on [10]. calcaric Cambisols and especially their subsoils are fractured, they cannot hold enough moisture and, therefore, soil drought is quite often to occur, thus reducing yields. However, for a grapevine with its deep root system they are quite suitable, especially on carbonate soils grape does not suffer from harmful phylloxera. Grape pollen (*Vitis*) in stratigraphic profiles on the Herakleian Peninsula is recorded from the beginning of Greek viticulture in 4th c. BC [11]. It is believed that the Chersonesos people themselves [12] consumed the local wine from the Herakleian Peninsula but it is also argued that the Tauric Chersonesos was the largest centre of ancient viticulture and wine-making in the Northern Black Sea region, and wine was the main export of this Greek city [13]. The particular feature of the modern horticulture in the Crimean foothills is that fruit crops are confined mainly to the terraces of river valleys containing lighter non-carbonate rocks and meadow-Chernozem soils, because gardens tend to have negative reaction to soil and terrain carbonation. Herakleian Peninsula has an erosion network density 0.94 km km^{-2}. For the development of horticulture, the wide bottoms of the small flat-bottom valleys (balka) offer the favourable conditions with meadow chernozem light clay soils being prevailed. This is due to the fact that the humus-accumulative horizon in the balkas has been augmented by agrogenic talus deposits during the centuries-old development of the water-catchment areas. It can be assumed that such ecotopes, which did not require any plantation ploughing, were primarily involved in gardening. Within Yukharina Balka, where in the stratigraphic section AA on depth 25–20 cm, AMS radiocarbon age (ash) was determined, which amounted to 2907 ± 30 yr BP [14, p. 270], we selected samples of deluvial soil for geochemical analysis in 2018. The agrarian history of this region is very long (about 800 years). In the Yukharina balkas the agrogenic talus deposits that are genetically related to the ancient arable farming on plains differ from calcaric Cambisols by higher concentrations (in a decreasing array): $Co>Zr>>TiO_2>SiO_2>Ba>Rb>K_2O>MnO>V>Cr>Al_2O_3>Cu$ at a significantly lower content of calcium oxide. The upper part of the talus deposits (up to 20 cm) in the balka bottom is more enriched as compared to the underlying layers (in a decreasing ordered series): $P_2O_5>As>Cu>V>Sr>Cr>Al_2O_3>Ni>Ba$, with a slight decrease in the concentration of Zr and Pb. The mineralogy of both soil and their parent rock in objects T1 and T2 is significantly different, as evidenced by differences in the content of a number of trace elements, and especially Cu, Rb, Zr (Table 1).

Table 1. Basic chemical indicators of soil and parent rock in the region of the ancient Greek state Lycia (Eastern Mediterranean)

Objects	Horizon, cm	Munsell colour		CaO	SiO_2	Na_2O	Cu	Rb	Zr
		Moist	Dry	%			ppm		
T1	A, 5-15	10YR 3/3	10YR 3/3	6.21	16.66	2.40	97.29	60.68	143.17
	C, >100	2.5Y 6/6	2.5Y 7/6	12.67	25.54	2.37	74.36	55.62	141.64
T2	A, 0-15	10YR 3/2	10YR 4/3	6.19	40.69	1.53	146.15	13.23	64.83
	C, >70	10YR 5/2	10YR 5/3	13.58	35.59	1.97	931.26	1.67	49.83

When comparing the examined objects by the average ratio of 17 elements preferentially accumulated in the soil to the parent rock (Table 2), we can make out the richest soils with the S/P value equal to 1.8 (post-antique long-term fallow land and forest soil on Herakleian Peninsula), they are somewhat inferior to the garden soil of Eastern Mediterranean. Thus, long-term processes of agro-pedogenesis, as well as natural soil formation in rarefied forest ecosystems of the sub-Mediterranean region, stimulate the enrichment of soil accumulation horizons in comparison with parent rock elements such as Co>V>TiO_2>SiO_2>MnO>Pb>K_2O>Rb>As>Zr>Al_2O_3>Fe>Zn. When analysing the differences of objects by the average ratio of five elements preferentially dispersed in the soil to the parent rock, we have to admit that the most impoverished soil is that under subtropical forest, especially for Ni and Cr, those elements that, on the contrary, accumulate in the forest soils of Herakleian Peninsula. In the balkas of this peninsula, the present-day talus deposits in layers of 0-5 cm and below 20 cm are almost identical in terms of dispersed elements, whereas buried deluvium has lower S/P ratios for Na_2O, MgO, CaO, which reflects a more humid climatic situation during the formation of the deluvium.

Table 2. The ratio of the content of chemical elements in the soil in relation to its parent rock (S/P) for the territory of Herakleian Peninsula and Eastern Mediterranean

Analyte	Unit	S1/P1	S2/P2	S3/P3	S4/P4	S5/P5	S6/P6
Elements of preferential accumulation in the soil							
Co	ppm	1.00	9.66	0.92	0.96	0.49	2.03
Rb	ppm	2.07	1.28	0.92	1.02	2.97	1.09
As	ppm	1.77	1.52	1.18	1.03	2.39	1.08
Sr	ppm	1.30	0.76	1.19	0.89	3.68	0.91
Al_2O_3	%	1.89	1.26	1.05	0.99	2.37	0.99
TiO_2	%	2.22	1.47	0.94	1.04	1.50	1.28
P_2O_5	%	1.19	1.15	1.21	1.12	1.87	1.92
V	ppm	2.47	1.43	1.09	1.06	1.19	1.17
MnO	ppm	2.03	1.61	0.90	1.03	1.29	1.49
Pb	ppm	1.78	1.62	0.71	1.08	1.89	1.12
K_2O	%	2.07	1.29	1.04	0.96	2.11	0.95
Ba	ppm	1.56	1.26	0.98	1.03	1.69	1.30
Zn	ppm	1.72	1.23	0.99	0.98	1.48	1.18
Fe	%	2.10	1.34	0.99	1.00	0.91	1.18
Zr	ppm	1.73	1.43	0.78	0.91	1.30	1.02
Cu	ppm	1.04	1.40	1.00	1.16	0.16	1.27
SiO_2	%	1.98	1.70	0.99	0.95	0.65	1.14
Elements of predominant dispersion in the soil							
Ni	ppm	1.27	1.16	0.97	1.05	0.15	1.30
Cr	ppm	1.53	1.22	1.04	1.03	0.25	0.64
Na_2O	%	0.53	0.65	1.05	0.91	0.96	0.78
MgO	%	0.36	0.59	1.04	0.88	0.38	0.65
CaO	%	0.19	0.51	1.19	0.76	0.49	0.46

S/P is the ratio of the chemical element in the soil (S) to its parent rock (P): 1 – Herakleian Peninsula, calcaric Cambisols, native forest; 2 – In the same place, post-

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antique long-term fallow land; 3 – Herakleian Peninsula, a modern deluvium in the balka; 4 – There, buried deluvium in the balka; 5 – Turkey, native forest (T1); 6 – Ibid., Garden (T2). Chemical elements are arranged from top to bottom as the average S/P ratio decreases.

It is known that in addition on the Herakleian Peninsula to the vineyards there were also gardens that were provided with plantation ploughing of the calcaric Cambisols was carried out. It is natural that the geochemical properties of such soils significantly differed from the meadow Chernozem soils in the balka bottoms. This is shown by ranked decreasing series of quantities S/P>1.1: Co>SiO_2>Pb>MnO>As>TiO_2>V=Zr>Cu>Fe>K_2O>Rb>Al_2O_3=Ba>Zn>Cr>Ni>P_2O_5 (post-antique fallow land on the calcaric Cambisols); P_2O_5>Sr>CaO>As>V (a modern deluvium in the balka); Cu>P_2O_5>Pb>V (buried deluvium).

This data shows that the long-term agropedogenesis and subsequent renaturation on the ploughed calcaric Cambisols resulted in the soils having more significant biogeochemical diversity as compared to the geochemical properties of the parent rock. The geochemical stratification of the profile of meadow Chernozem soils is less contrasting. On the talus deposits of the Göynük plain (T2) the garden soil has lower content of such chemical elements as Co, Mn, Cr, Ni, Cu (more than 1.5 times), as well Na, Fe, V, Pb, Mg, Sr, but higher content (in an ordered series) of Rb, K, P, Si, Zr, As, Ba, Ti, Zn, Al as compared to the brown soil on the second coastal terrace under the subtropical forest (T1). Given the initial differences in the geochemical properties of the parent rock, we can assume an important role of long-term arable farming in the formation of significant biogeochemical differences between undeveloped and agro-transformed soils. The lower content of Fe, Ni, Cu, Mg in the arable layer can be explained by biological removal as a result. A comparison of the geochemical soil characteristics for the minor landscapes (on the Göynük (S6) plain and in the balka bottom of the Herakleian Peninsula (S3)) has shown that the Eastern Mediterranean soils are richer in the composition of plant nutrients and, in particular, by the sum of macroelements (K, Mg, Ca, P) by 2.8 times and by the sum of trace elements (Mn, Fe, Ni, Cu, Zn) by 59.1 times, mainly due to the higher content of Ni, Cu and Zn. The parent rock under the garden on the Göynük plain (T2) differs significantly in its chemical composition from limestone talus deposits of the Herakleian Peninsula (Table 2), primarily in its accumulation elements. The lithological features of alluvial deposits in Eastern Mediterranean determine a higher content of Co (13 times), Cr>Cu>SiO_2 (2-3 times), TiO_2>Ni>V (1.5-2 times), Zr>MnO>Pb>Al_2O_3>P_2O_5>Fe>Zn>K_2O (1.3-1.5 times). The greatest deficit in the garden soil on the Göynük plain is shown by the following increasing ordered series of elements: CaO<Na<As<Ba<Sr<MgO. Soil under the garden on the Göynük plain (T2) compared to allotment deposits Tauric Chersonesos has a higher content of Co (2.7 times), P_2O_5>Cu (2-2.3 times), Ni>Cr>TiO_2 (1.5-2 times), (SiO_2=MnO)>Zn>V>Fe (1.2- 1.5 times), Al_2O_3 (1.1 times).

The greatest deficit in the garden soil on the Göynük plain is shown by the following increasing ordered series of elements: CaO<As<Na <Ba< (K_2O=Rb). Such differences could not but affect the characteristics of the cultivated crops that are most sensitive to the geochemical composition of the soil, parent and underlying rock. A comparison of the forest soils for the two regions by K_S coefficient values has shown a more significant accumulation of trace elements and biophilic elements in the soil relative to the parent rock for the Crimean conditions (1.61) than in the Eastern Mediterranean

(0.78) soil that is reported to have high content of copper and cobalt in the parent rock at the depths of more than 1 m, which makes the main reason for this difference. The advantage of the Crimea over the Eastern Mediterranean in terms of K_S coefficient (1.71 and 1.34) is preserved when comparing fallow soils in the Tauric Chersonesos allotments with the garden soil on the Göynük plain. The composition of macronutrient elements (Ca, Mg, Si, Mn, Fe, P, K) that reliably shape the wine taste qualities is much different between the upper accumulative horizons of calcaric Cambisols under the forest ecosystems near the Eastern periphery of the Herakleian Peninsula (51.2%) and on the coastal terrace of the Gulf of Antalya (32.2%). However, there are no significant differences when comparing the two regions (Göynük and Herakleian Peninsula plains) by the composition of macronutrient elements in the parent rock (58.0 and 56.3 %) and in the agrogenic soil horizons (55.1 and 53.2%). Therefore, the quality of wine from these geographical regions could more depend on the climate factor than on the geochemical features of the soil and parent rock in terms of the content of the main macronutrient elements. Another thing is the influence produced by rare dispersed elements that account for nuances of wine taste. If the calcaric Cambisols of the Herakleian Peninsula accumulated mostly Si, K, Fe, Al, P_2O_5, the grape soils of distant chora (Rendzina soils) differed by the predominance V, Pb, Rb, Cr. It is known [13; 15] that the Tauric Chersonesos supplied wine of non-export quality to its distant chora. This was presumably the case for vineyards on the Rendzina soils or in agroclimatically unfortunate years. A number of trace elements that made the Eastern Mediterranean soil different South-West of Crimea (Co, Cu, Ni, Cr, Zn, V, Al) from the Crimea soils could determine the specific qualities of the wines, which were commercially distributed.

CONCLUSIONS

The particular features of perennial crops grown on the land of the ancient states in the Crimea and Asia Minor were largely determined by biogeochemical differences of the soils and parent rocks. The obtained results showed that the soil under the garden on the Göynük plain, as compared to the vineyard soils in the Tauric Chersonesos allotments, was characterised by a higher content of a certain number of chemical elements ($Co>P_2O_5>Cu>Ni>Cr>TiO_2>(SiO_2=MnO)>Zn>V>Fe>Al_2O_3$) and a deficit of elements in an ordered series $CaO<As<Na<Ba<(K_2O=Rb)$. These differences formed the specific quality of the main product in those crops that were most sensitive to the geochemical composition of soil, parent and underlying rock. Agropedogenesis increased natural differences of cultivated soils in the subtropical zone (Eastern Mediterranean) and 880 km to the North on the periphery of the subtropics (South-West of Crimea). In the conditions of natural forest ecosystems, the composition of the macro-nutrient elements (Ca, Mg, Si, Mn, Fe, P, K) that reliably shape the wine taste qualities is significantly wider (1.6 times) in the accumulative calcaric Cambisols horizon of the Herakleian Peninsula as compared to the soil on the coastal terrace of the Gulf of Antalya. However, the quality of wine from these geographical regions could also depend on the content of rare trace elements that account for nuances of wine taste. The obtained list of trace elements (Co, Cu, Ni, Cr, Zn, V, Al) with their concentrations being the most distinctive factors for the two regions (Eastern Mediterranean and South-West of Crimea) could determine the specific qualities of wines that were part of commodity exchange of the ancient states of Lycia and the Tauric Chersonesos.

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