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TILMEN HÖYÜK: CLIMATE, SOIL, HYDROLOGY, AND VEGETATION

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1. INTRODUCTION

Tilmen Höyük is located in the southeastern part of Anatolia, within the so-called Anatolian corridor. The Amanus mountains to the West of the site form a natural barrier between the Mediterranean basin and the dry plateaus of inner western Asia. Climate, soil, and vegetation have been monitored and indexed over a two-year period, both to analyze the biological and climactic conditions at the site over time, and to begin to formulate a long-term management plan for the conservation of the cultural and natural heritage.

2. THE PAST CLIMATE

The climatic dynamics of an archaeological site are important not only to understand the evolution of climate through time, but also to monitor present time conditions of the archaeological remains. Several authors (Tainter 1990; Weiss 2000b; Weiss *et al*. 1993; Manzanilla 1997; Eastwood *et al*. 2006) investigated the relationships between climate change and early civilizations' collapse. Moreover the International Geosphere-Biosphere Programme proposed a project for the reconstruction of a climatic and environmental history of the Pleistocene-Holocene and of the last 2000 years (Eddy 1992). A large group of researchers reported major climatic changes in Anatolia during the EBA, which coincided with a sever shift toward a drier climatic area.

Frahm and Feinberg (2013) noted that during EB III several societies in the area failed to respond successfully to climatic desiccation. Indeed the abrupt desertification of northern Mesopotamia during the EB IV is well documented by Weiss (2000b), Weiss *et al.* (1993), and Weiss and Bradley (2001). In particular, Weiss suggested that the late Pleistocene and earliest Holocene abrupt climatic changes occurred at 12,800, 8200, 5200 and 4200 BP (Weiss 2000a). These authors argued that a considerable increase in aridity determined the collapse of Akkadian dry farming, as well as weakening subsequent Ur III intensive agricultural activities. The dry climatic period extended until 3000 BP (1000 BC), encompassing the period of the Tilmen Höyük flourishing, i.e. the MB II period.

Recent isotopes studies in the Gölhisar Lake in Turkey, performed with oxygen and carbon isotopes (Eastwood *et al*. 2006), confirmed the previous findings. These studies showed that until the end of the Pleistocene (10,600 to 8900 yr BP), the climate was more humid, while from the mid-Holocene (8900 to 3000 yr BP) until today, conditions became drier. In particular, a shift toward more positive ^{13}C and ^{18}O values indicated a pronounced shift toward increased climatic aridity in the last 1300 years. Overall, the past climate of Tilmen Höyük was wetter and more humid than today. These climatic conditions probably facilitated different plant species and crop aerial distribution.

3. THE PRESENT CLIMATE

Today, the climate at Tilmen Höyük is of continental type, with hot summers and cold winters, as indicated by the Bagnouls and Gaussen diagram (Bagnouls, Gaussen 1957), which shows the occurrence of dry periods (when precipitation in mm is less or equal to twice the temperature in Celsius degrees). Fig. 4 depicts the Bagnouls and Gaussen diagram for Tilmen Höyük. The intersection of the rainfall and temperature curves defines the extent of the dry period, which is typically comprised between May and September. Annual rainfall is 900 mm and mean annual air temperature is 16 °C. Low average temperatures during the winter months indicate that in such months freezing temperatures are very common. Therefore, a monitoring weather station was installed, thanks to a cooperation with Ecosearch Ltd., to investigate the annual dynamics of weather variables. The following variables were measured: precipitation, air temperature, wind speed, wind direction, atmospheric pressure, global solar radiation and relative humidity, as well as soil water content and the stability of buildings. Table 1 lists the main measured variables, the units and the instrumentation employed. Measurements were automatically performed by automated stations. Data were collected by a datalogger (Campbell Scientific CR1000) of a primary station and then sent to secondary stations through a radio-transmitter (Campbell Scientific RF416). Secondary stations were also equipped with a datalogger (Campbell CR216), connected to the primary station with an integrated radio receiver. In order to provide detailed time series, measurements were performed every fifteen minutes. Thus, to obtain daily values of the measured variables, the data were postprocessed through the computation of cumulative daily precipitation, average air temperature, average wind speed, trigonometric average wind direction, average global radiation and relative humidity. Additional measurements were aimed at observing the stability of the ancient buildings and to monitor potential occurring of failures. Moreover, soil water content was measured in order to control soil water dynamics and its effect on the stability of the structures at the site.

Fig. 2 depicts daily precipitation and average air temperature (a), together with average daily global solar radiation and relative humidity for the year 2007 (b). Cumulative precipitation is concentrated in the fall and winter seasons, while the precipitations are almost absent during the summer months. These features are typical of continental climate, characterized by cold and wet winters and by hot and dry summers. Average daily temperature depicts cold winters with an average temperature below the zero for few days during December and January, and hot summers with average temperatures often above 30 °C. This trend also affects relative humidity at the site, which is very dry during the summer months.

VARIABLE	UNIT	INSTRUMENTATION
Precipitation	mm	Environmental Measurements ARG100
Air temperature	°C	Campbell Sci. CS215
Wind velocity	$m\ s^{-1}$	Environmental Measurements WSS2
Wind direction	Degree	Environmental Measurements WSS2
Atmospheric pressure	Pa	Campbell Sci. CS215
Solar radiation	$W\ m^{-2}$	Apogee PYR-S
Relative humidity	Unitless	Campbell Sci. CS215
Stability	Pa	Sisgeo 0S700TL10H00
Soil water content	$m^3\ m^{-3}$	Sentek EasyAG50

Table 1 Weather, soil, and stability variables, units and instrumentation employed at the site.

With regards to the average of daily global solar radiation, it is possible to observe that on the one hand these data reflect the average of incoming radiation at these latitudes (with a maximum of about 300 W m^{-2} in July), and on the other hand the solar radiation displays marked oscillations during the winter, due to the overcast sky, and small oscillations during the summer due to the clear sky (indeed confirmed by the rare precipitation events in the summer). Wind direction was computed as a trigonometric daily average of fifteen minutes measurements, therefore providing a detailed characterization of wind dynamics at the site (Fig. 3). 360° (or 0°) corresponds to wind blowing from the exact North, while 45° corresponds to wind blowing from North-East, 90° to wind blowing from East and so forth. The arrows indicate the peaks of the wind speed and the corresponding wind direction.

Overall, the wind's speed at the site – during 2007 – was relatively low with a maximum speed of 6.18 m s^{-1} on 3rd February, and average annual speed of 2.34 m s^{-1}. The dominant direction for the average wind speed was 360° (from North); however, the dominant direction changed when the wind speed increased, with a direction from North-East (45°), as shown by the arrows. In some cases, the increased wind direction corresponded to precipitation events, such as weather fronts which were arriving from the North-East Anatolian region. Indeed, Tilmen Höyük is located in the Anatolian corridor, which at this latitude and longitude, displays a North-East bending determined by the geographic settings of the Amanus and Taurus ranges. This geographical setting is very likely responsible for the observed trends in wind direction.

4. THE SOIL AND THE HYDROLOGY

The aim of soil analysis, within an archaeological excavation, is to provide information which can help to reconstruct the history of the site. Often, chemical composition of soil is an indication of specific processes, such as water stagnation, human or animal bone decomposition, dietary indication and so forth, which occurred at the site. Many archaeometric techniques – including soil, mineralogical and depositional analyses – are available to investigate these aspects. At Tilmen Höyük the investigation of soil properties was performed through drilling, core sampling and collection of disturbed and undisturbed soil samples.[1]

In order to obtain a complete characterization of soil properties, numerous physical and chemical properties were measured (Table 2). The samples were: (a) collected at the location displayed on the site map (Fig. 1), (b) georeferenced using a portable Global Positioning System (GPS), (c) numbered in order to assign them an identification number (ID), and (d), finally, integrated into a Geographical Information System (GIS).

ID	Sand (%)	Silt (%)	Clay (%)	$CACO_3$ (%)	P_2O_5 (ppm)	N (%)	SAL (mS/cm)	CEC (meq/100g)	K (ppm)	pH (-)	C/N (-)	OM (%)	K_2O (ppm)
1	-	-	-	1.2	270	3.8	0.13	24	1182	6.58	12.3	8.1	1424
2	-	-	-	1.3	255	1	0.06	23.1	922	6.9	10.8	1.86	1111
3	32	48	20	1.4	298	0.7	0.06	21.5	1137	7.01	9.5	1.05	1370
4	32	49	19	1.3	249	2.6	0.08	23	695	6.44	12.5	5.68	837
5	32	50	18	1.4	267	4.4	0.11	27.8	1067	6.63	12.1	9.22	1286
6	-	-	-	1.6	276	0.3	0.04	21	2553	7.04	10.1	0.54	3075
7	-	-	-	1.6	322	0.7	0.06	20.8	1688	7.1	6.9	0.78	2033
8	22	48	30	1.8	81.1	1.7	0.34	18.3	220	7.75	10.6	3.18	265
9	-	-	-	1.2	145	1.7	0.12	18.7	1223	7.3	10.4	3.06	1473
10	-	-	-	0.9	237	3.3	0.32	20.2	1431	7.08	10	5.69	1724

Table 2 Soil properties at the site: identification number (ID); percentage of sand, silt and clay; total calcium carbonate (CaCO3); plant available phosphorous (P2O5); total nitrogen (N); salinity (SAL); cation exchange capacity (CEC); total potassium (K); pH (pH); carbon nitrogen ratio (C/N); organic matter content (OM); plant available potassium (K2O).

Soil textural compositions revealed that the dominant textural classes are loam, silty-loam and clay-loam. Considering that bedrock is a coherent basalt deposit, and that the area is small, such variations in textural composition may also be due to human activity over the years, as well as to natural phenomena such as soil-water erosion and weathering. Moreover, the soil presents a relatively high content of nutrients and organic matter, facilitating the growth of many plant species and indicating the presence of grazing. Soils at Tilmen Höyük are naturally fertile but vulnerable to erosion and damage, because of the shallowness of the soil over basalt bedrock, as indicated by the bedrock outcrops around the area, and also by the soil survey.

During the soil survey at the site, high concentrations of phosphorus and potassium were found in respect of the average soil concentrations of these elements under natural conditions in similar environments. The phosphorus (P_2O_5) concentration ranged from 100 to 300 ppm, with an average of 219 ppm, while total potassium ranged from 220 to 2553 ppm with an average of 1105 ppm. High $CaCO_3$ was also detected at the site, indicating a possible accumulation of ash due to past burnings, since $CaCO_3$ is the dominant component of ash. The lack of strong alkaline conditions also indicates that the soil did not experience salt accumulation near the surface, which is usually due to

[1] We would like to thank the scientific staff of Gaziantep Museum and that of the General Directorate for Cultural Heritage and Museums in Ankara, for the possibility of analyzing the samples at the University of Bologna.

high evaporation rates fed by a shallow groundwater. This is explained by the deep level of groundwater in the upper part of the höyük, and by the good drainage properties of the soil. The neutrality – or close to neutrality – values of pH do not indicate anaerobic conditions at the site, which indeed is well drained and does not favor water stagnation.

Therefore the site was investigated from hydrological standpoint to identify the position of groundwater level, and the dynamics of soil water. The site itself is positioned at a higher altitude than the surrounding area, the soil is permeable and well drained, and groundwater level is determined by the small river and the water reservoir which surround the site. In order to identify the depth of groundwater, a geophysical prospection was performed in the South-East part of the site using a Ground Penetrating Radar. In particular, Pl. I: 1 depicts the water table level in front of Gateway K-6. The water table is shallow (130 cm ca), and it is determined by the presence of a small river surrounding the site in its northeastern part. However, the water table, because of the increased distance from the river, tends to become deeper while moving toward a southwestern direction.

5. The plant cover

The plant cover was subjected to a detailed analysis that allowed us to establish on the one hand the type and the number of plant species which are present in the Tilmen Höyük site (flora), and on the other hand to determine how they combine to form communities of species, in relation to the different environmental conditions (vegetation). The investigation regarded higher plants (vascular plants), as well as bryophytic component (mosses). Knowledge of the floristic and vegetational heritage is necessary both to assess the quality from a naturalistic point of view, and to prepare protocols for monitoring vegetation in the areas directly interested by the presence of archaeological remains. Both these aspects are important for the purposes of a sustainable management, with the aim of appreciating and protecting naturalistic peculiarities and biodiversity, as well as the archaeological patrimony and the historical value of the area. With regards to the study of the moss communities, we can point out that it is particularly interesting not only as a complement to the evaluation of the floristic patrimony of the area, but also on account of the significance of the moss species as bio-indicators of particular microclimatic and micro-environmental conditions.

The floristic and vegetational study was fulfilled in spring 2006-2007, by means of a series of field surveys (plant community *relevés*) carried out throughout the site together with our colleague H. Çakan from the University of Çukurova (Pl. I: 2). The *relevés* are representative samples of the different types of plant communities, recognized not only on the basis of the dominance of one or more species, but also on the greater or lesser complexity of the structural organization (herbaceous, shrub, tree, mixed communities). Each *relevé*, performed on surface areas ranging from 20 m^2 to 80 m^2, is composed of a list of species accompanied by a qualitative-quantitative estimation of the percentage cover of each species, with respect to the surface surveyed. Moreover, the *relevés* were geo-referenced and organized in a data base manageable through a GIS. A survey was also carried out with regards to the communities prevalently made up of mosses. These communities grow especially on piles of large basaltic rocks, on the stone surfaces of archaeological structures and on ground soil. In this case, the extension of the areas surveyed was considerably smaller, in the order of a few dm^2. The surveying method adopted is widely used throughout Europe for vegetation studies (Braun-Blanquet 1932; Westhoff, van der Maarel 1973). Higher plant species were identified on the basis provided by the *Flora of Turkey and the East Aegean Islands* (Davis 1965-1985; Davis *et al.*, 1988), the *Flora of Syria, Palestine and Sinai, from Taurus to Ras Muhammad and from Mediterranean Sea to the Syrian desert* (Post 1932), and the *Flora of Iraq* (Guest and Townsend 1968-1974). Whereas the moss species were identified following the works of Agnew and Vondráček (1975), Smith (1980), Nyholm (1981), Ireland (1982), and Frey and Kürschner (1991).

6. THE FLORA

A general floristic list, which covers the whole site of Tilmen Höyük, was made merging the floristic lists of thirty-three *relevés*. The higher plant flora of Tilmen Höyük is made up of 220 different plant *taxa*, at the rank of species, subspecies and varieties. The most widespread botanical families are the Asteraceae (34 species), the Fabaceae (34 species), and the Poaceae (25 species). These statistic data reflect the general situation of Turkey. Moreover it is worth noting that among the 34 species belonging to the Fabaceae family, at least 15 species belong to the single genus *Trifolium*, whose diversity is particularly rich at the site of Tilmen Höyük. Other genera present with various species are *Vicia* (5 species), and *Medicago* (4 species), both of the Fabaceae family, *Centaurea* (4 species) of the Asteraceae family, and *Bromus* (4 species) of the Poaceae family. With reference to the biological adaptations to the climate of the site, the annual herbaceous species are by far the most prevalent (104 *taxa*), followed by the perennial herbaceous hemicryptophytes (56 *taxa*), the perennial herbaceous geophytes (30 *taxa*), and the woody perennials, shrubs and trees (30 *taxa*). The clear prevalence of herbaceous annuals can be explained by the conditions of prolonged aridity (from May to September, see Fig. 4) that characterizes the site. The significant presence of hemicryptophytes, on the other hand, can be explained by the cold and wet climate which characterizes the winter season at Tilmen Höyük. The woody perennials are mostly broad-leaved deciduous species.

Regarding the characterisation of the flora in Tilmen Höyük from a phytogeographical point of view, 93 species (42% of the total flora) have a specific phytogeographical significance (38 Mediterranean species, 35 East Mediterranean species and 20 Irano-Turanian species). Whereas 54% of the total flora (120 species) has no specific phytogeographical significance, because it is characterized by a wide geographical distribution. Some endemic and rare species of the nearby Amanus mountains, with a restricted geographical distribution, such as *Cerasus microcarpa* subsp. *tortuosa*, *Salvia indica*, *Carduus rechingeranus*, *Onopordum boissieri*, *Trifolium aintabense*, *Erodium micropetalum*, *Alcea apterocarpa* and *Rumex amanus* are also present.

The flora of Tilmen Höyük is very interesting from an historical point of view, because it hosts a significant number of species considered as the wild relatives of important cultivated species. These include: *Hordeum spontaneum*, *Aegilops biuncialis*, *Pisum sativum* subsp. *elatius* var. *elatius*, *Ficus carica* subsp. *carica*, *Olea europaea* var. *sylvestris*, and *Vitis vinifera* subsp. *sylvestris*. The domestication in the Fertile Crescent area of *Hordeum spontaneum* gave rise to *Hordeum vulgare* (barley), the oldest cereal of Old World agriculture, dating back to 10,000 yr BP. Much more recent is the domestication of *Ficus carica* subsp. *carica*, *Olea europaea* var. *sylvestris*, *Vitis vinifera* subsp. s*ylvestris*, which started extensively in the EBA and developed in the MBA and LBA, coinciding with the most important period of the Tilmen Höyük civilisation. Other species of the Tilmen flora are used in popular medicine, such as *Althaea officinalis*, *Glycyrrhiza echinata*, *Silybum marianum*, *Tamus communis*, or for other human activities. *Taxa* used for ornamental purposes are present too. These include: *Salvia indica*, *Lonicera etrusca*, *Alcea apterocarpa*, *Rosa arvensis*, and *Hyacinthus orientalis* subsp. *chionophilus*.

The survey on the bryophytic flora revealed 45 different *taxa* of which 7 were liverworts and 38 mosses. Total bryophyte *taxa* in Tilmen Höyük belong to 28 genera and 20 families with different ecological adaptations. The xerophytic *taxa*, adapted to the summer drought of the Mediterranean climate, prevail. Moreover, the most widespread species on the rocks in the archaeological ruins are *Antitrichia californica*, *Grimmia laevigata*, *Grimmia pulvinata* and *Orthotrichum rupestre* var. *rupestre*. On the bare soils, *Rhynchostegium megapolitanum*, *Scorpiurium circinatum*, *Syntrichia ruralis* were recorded as the most common *taxa*, while *Leptodon smithii* and *Hedwigia ciliata* var. *leucophaea* are very rare *taxa*. During the field surveys of the present study, *Pyramidula tetragona* (Brid.) Brid. was recorded at Tilmen Höyük as a new species for the moss flora of Turkey.

The GIS and the link with floristic information stored inside it, allow us to locate throughout the site all the species recorded in the Tilmen Höyük area: an example is provided by Pl. II: 1.

7. The vegetation

The vegetation of Tilmen Höyük reflects, on the one hand, the long history of the anthropic presence in the area, and, on the other hand, the disturbance of human activities on the plant cover. Overgrazing, agriculture and clearing practices have shaped plant communities and their structure; more recently, excavation activities introduced a new type of disturbance on the vegetation of the archaeological site. The vegetation, like the flora, is also quite varied, and includes various types of plant communities, distinguishable by their different structure and floristic composition. The presence of water bodies and waterways represents an important element of environmental diversification, particularly appreciable during the dry summer period.

Six main vegetation types can be recognized, comparing the 33 plant community *relevés* through cluster analysis. A short description of each vegetation type follows.

Type 1) Herbaceous plant communities of the recently excavated areas, strongly dominated by annual species (*relevés* 18, 21, 27 in Pl. II: 2) – These plant communities develop on the excavated areas and are the most disturbed; the plant cover is very low, less than 25%. *Centaurea solstitialis*, *Lactuca serriola*, *Chondrilla juncea*, *Trifolium purpureum*, *Aegilops biuncialis*, *Aegilops triuncialis* are the most common species.

Type 2) Herbaceous plant communities of less recently excavated areas, dominated by annual and perennial herbaceous species (*relevés* 4, 6, 8, 9, 11, 19, 28, 29, 31 in Pl. II: 2) – These plant communities develop over a large area of the archaeological site and they are quite rich in species. *Vicia villosa* subsp. *eriocarpa*, *Hordeum spontaneum*, *Notobasis syriaca* are present with high cover values. Moreover the endemic species *Alcea apterocarpa* grow in these communities. Due to minor human disturbance, some woody species, such as *Styrax officinalis*, *Lonicera etrusca*, *Crataegus curvisepala*, *Paliurus spina-christi* are present.

Type 3) Herbaceous plant communities of the non excavated areas, with a moderate or good presence of perennial woody species, shrubs and little trees (*relevés* 5, 10, 12, 13, 14, 15, 16, 17, 20, 22, 23, 24, 25 in Pl. II: 2) – The plant communities of this group are present in areas not disturbed by archaeological excavations, and therefore they show a good presence of woody species (shrubs and trees). Sometimes shrubs are dominant and their coverage reaches 60-70-80% of the area. The most frequent herbaceous species are: *Asphodelus aestivus*, *Vicia hybrida*, *Vicia villosa*, *Trifolium pilulare*, *Lathyrus annuus*, *Hordeum spontaneum*, *Hordeum bulbosum*. Some of the woody species are: *Paliurus spina-christi*, *Crataegus aronia* var. *aronia*, *Styrax officinalis*, *Prunus spinosa*, *Jasminum fruticans*, *Ulmus minor*.

Type 4) Overgrazed plant communities dominated by herbaceous perennial species (*relevés* 35, 36, 37, in Pl. II: 2) – These communities develop close either to the water of the small streams or to the artificial lake, and they are green even in summer, thanks to superficial groundwater level. *Cynodon dactylon* dominates these communities; the *Alhagi mannifera*, when present, indicates overgrazing and soil rich in nutrients.

Type 5) Hygrophilous plant communities along streams, small rivers, wetland areas (*relevés* 1, 2, 7, 30 in Pl. II: 2) – This group includes the plant communities which grow both on the banks of the system of small streams which surround Tilmen Höyük, and around the artificial lake situated North-East of the ancient city. Large wetland communities are dominated by *Phragmites australis*. The communities on the edge of the small streams host a more diversified flora, with *Typha domingensis*, *Lythrum salicaria*, *Lycopus europaeus*, *Cyperus longus*, *Cyperus serotinus*, *Schoenoplectus lacustris*, *Mentha aquatica*, *Salix acmophylla*.

Type 6) Shrublands and open woodlands (*relevés* 32, 33, 34 in Pl. II: 2) – This group includes most natural plant communities, localized in the eastern part of the site, at the feet of the Tilmen Höyük mound (outside the archaeological area). *Quercus* *coccifera* is very frequent, together with *Cianura erecta*, *Styrax officinalis*, *Quercus brantii*, *Rosa arvensis*. In more protected, less dry stations, *Ficus carica* subsp. *rupestris*, the wild fig tree, is present.

Concerning moss communities, they represent an important and interesting natural heritage of the area. Two main types of communities can be recognized, depending on the exposition of the basaltic rock surfaces – where the mosses grow – to the sun. On shady and less dry northern faces, *Antitrichia californica*, *Homalothecium sericeum* and *Orthotrichum rupestre* are the most frequent species. On sunny and very dry southern faces, *Grimmia laevigata* is the prevalent species.

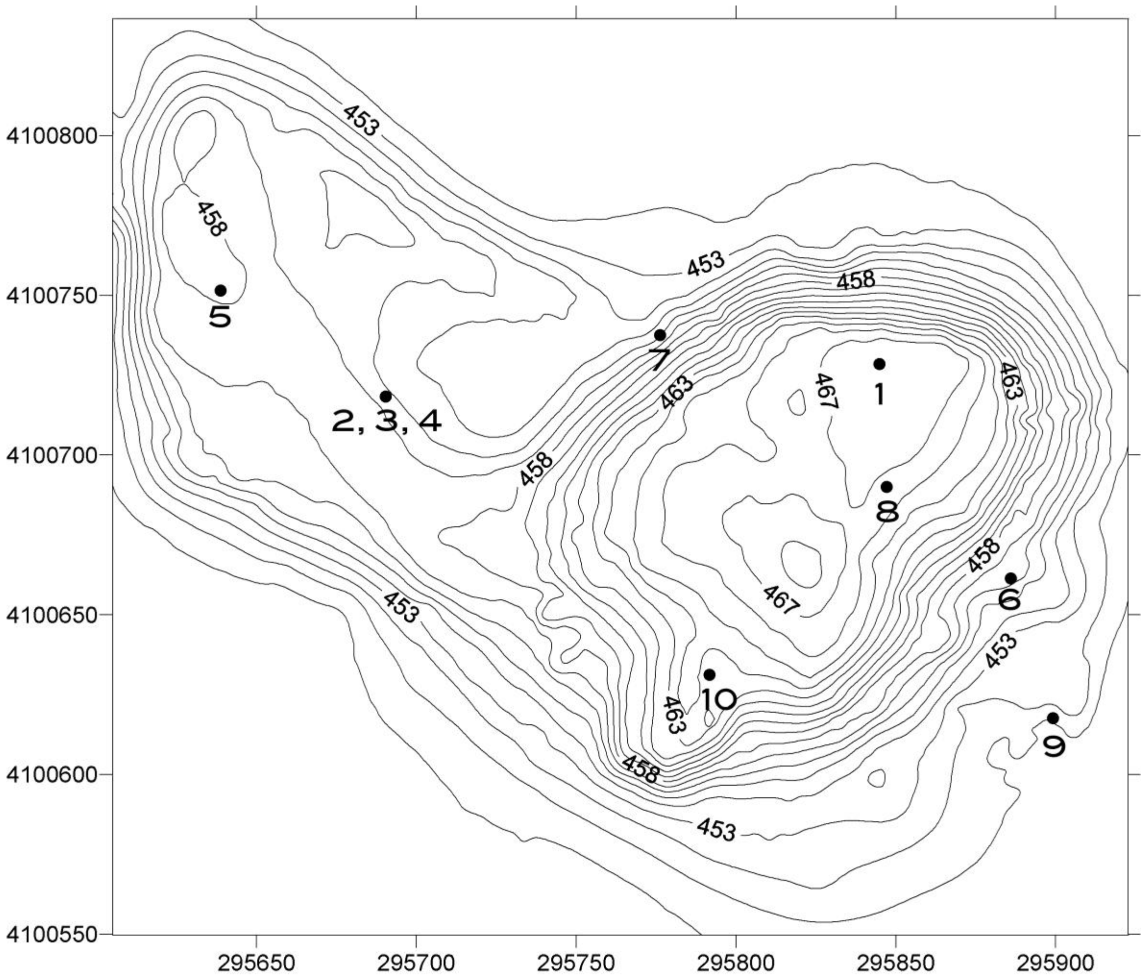

Fig. 1 Location on the site topographic map of the collecting spots of the analyzed samples.

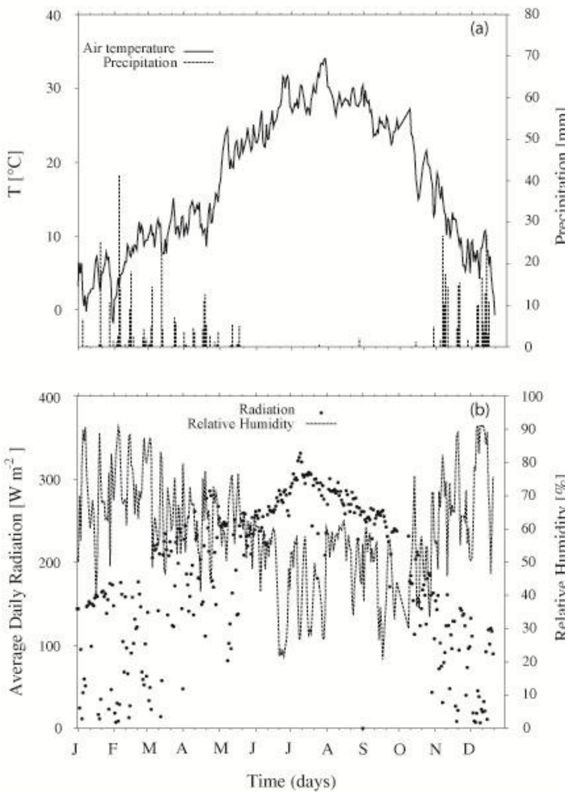

Fig. 2 Daily cumulative precipitation and average air temperature (a). Average daily global solar radiation and relative humidity (b).

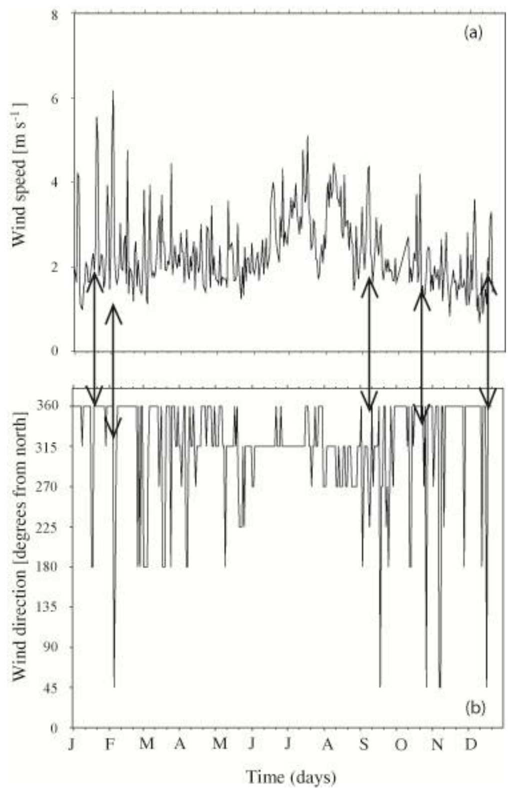

Fig. 3 Characterization of wind dynamics.

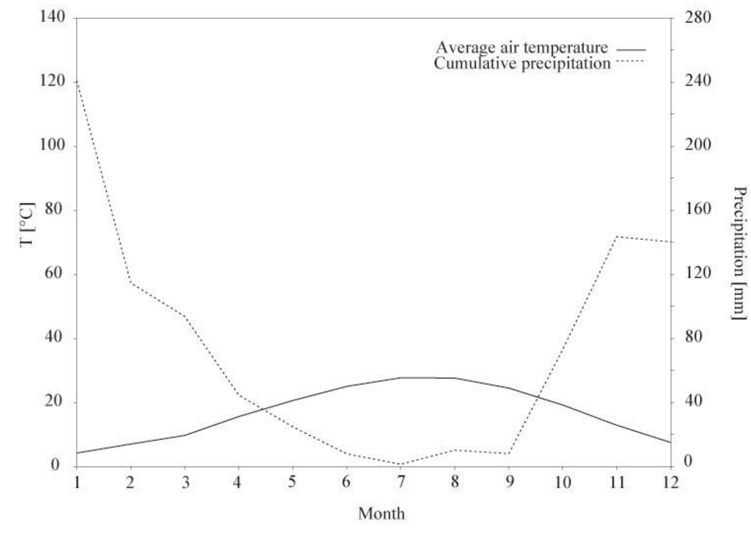

Fig. 4 Bagnouls and Gaussen diagram for Tilmen Höyük.

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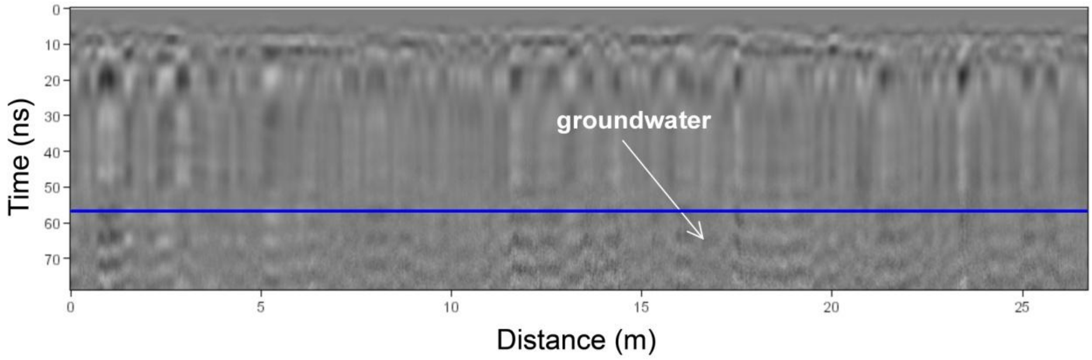
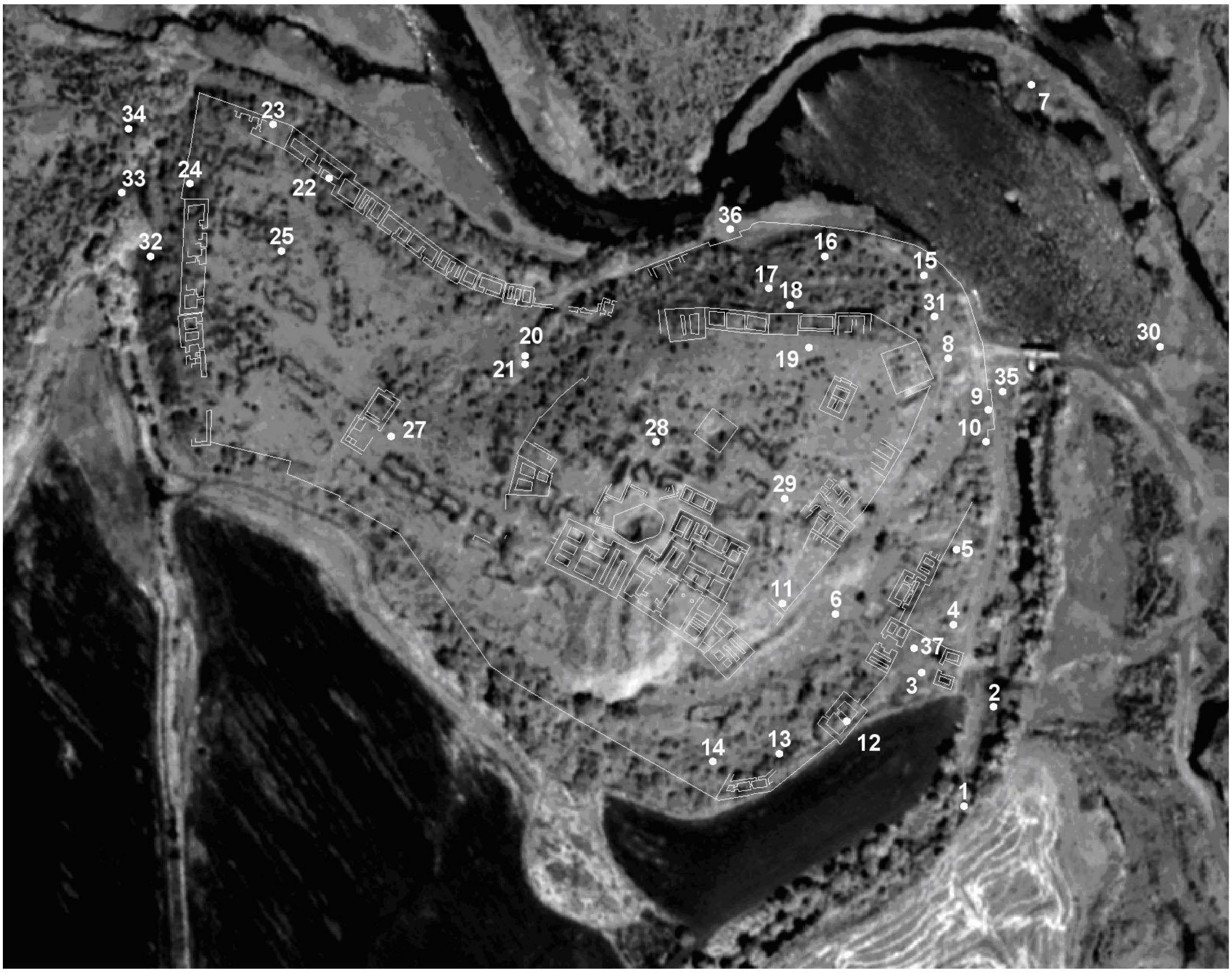
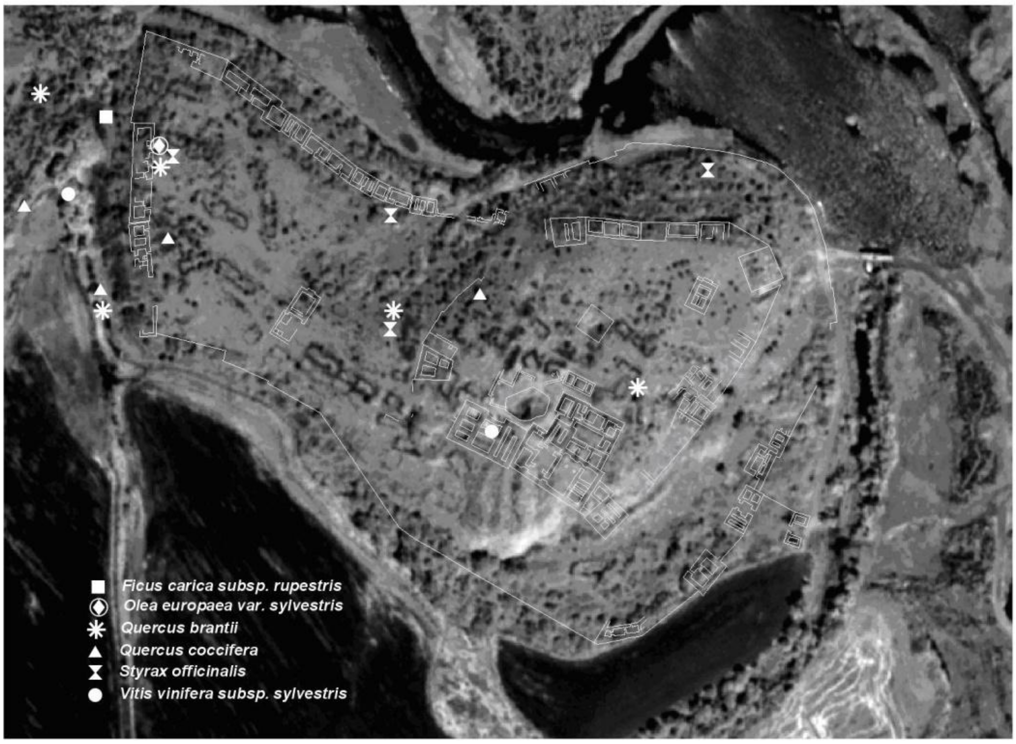


1 The water table level in front of Gateway K-6.

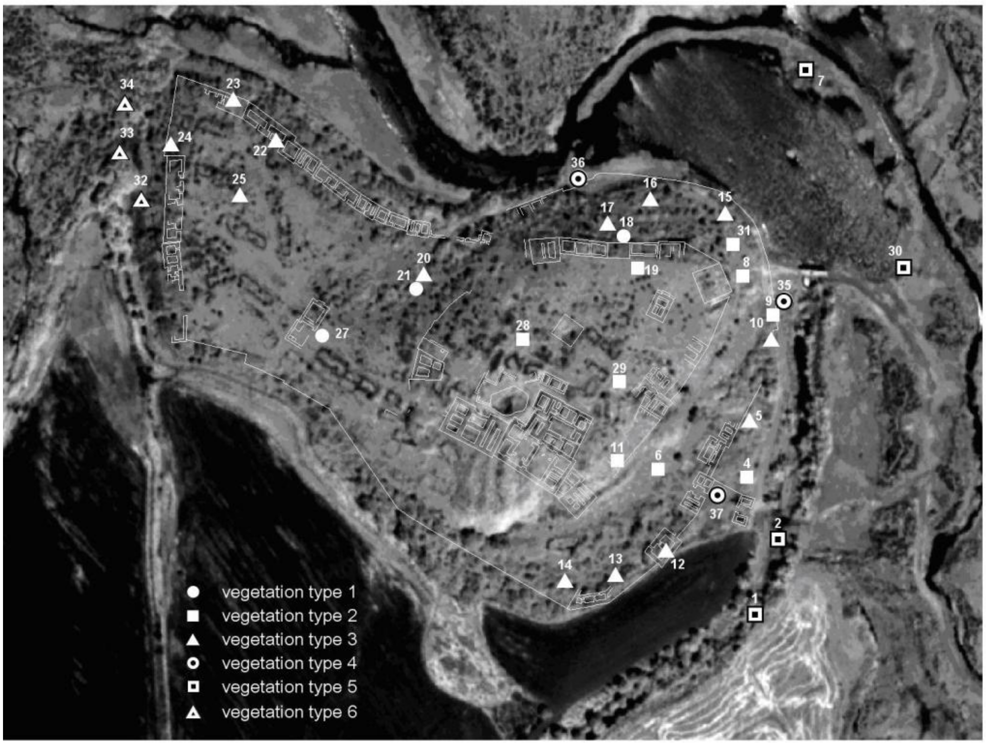


2 Distribution map of the field surveys across the area of the archaeological site.

Pl. II



1 Distribution map of some *taxa* of the Tilmen flora, obtained from the data base.



2 The field *rélevés* classified following the vegetation types recognised by cluster analysis.