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An evaluation of the climatic conditions during the Late Quaternary in northern Greece by means of multivariate analysis of palynological data and comparison with recent phytosociological and climatic data

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Abstract

An analysis of the different interglacial forest phases and glacial steppe phases in the vegetation history of northern Greece, as recorded in the first 86 metres of the Tenagi Philippon core, resulted in the distinction of three forest vegetations and one steppe vegetation. From the comparison of those vegetation data with the present day occurrence of the various forest and steppe vegetations and the corresponding climatic data, an estimation of climatic conditions (temperature and precipitation) during the Late Quaternary was made.

Typically, in the beginning of the interglacials an open forest vegetation characterized by *Pistacia* was found, indicative for warm conditions and wet summers and winters. Relatively soon summers became drier, forcing an evergreen oak forest to develop. During the second half of the interglacials deciduous forests and cool, wet conditions prevailed. At the glacial maxima a dry continental climate with cold winters accompanied a steppe vegetation.

The results suggest that winter conditions are more important in determining the nature of the vegetation in the Mediterranean and that the maquis and garrigue are purely man made vegetations, as its elements occurred in different periods in the past.

Introduction

Between 1969 and 1987 several pollen diagrams have been published that describe the vegetation history of northern Greece, as recorded in sediment cores from the Tenagi Philippon area (Wijmstra 1969, Wijmstra & Smit 1976 and Van der Wiel & Wijmstra 1987a and b). Wijmstra's (1969) pollen diagram was the first description of the whole Weichselian based on one uninterrupted sequence. Palynological analyses, dating and correlation with north-western European stratigraphy of the 120 m deep section Tenagi Philippon II and the 280 m deep section Tenagi Philippon III (see the above mentioned authors and Wijmstra & Groenhart (1983)), showed that the two sections describe a period of ± 960,000 years of vegetation history.

The Tenagi Philippon pollen diagrams showed the persistent alternation of forest and steppe phases in the vegetation history of northern Greece. Numerous pollen zones were distinguished, all of which were indicative of one of several forest, forest steppe, or steppe vegetation types, prevailing during the periods concerned. Also in other (short-

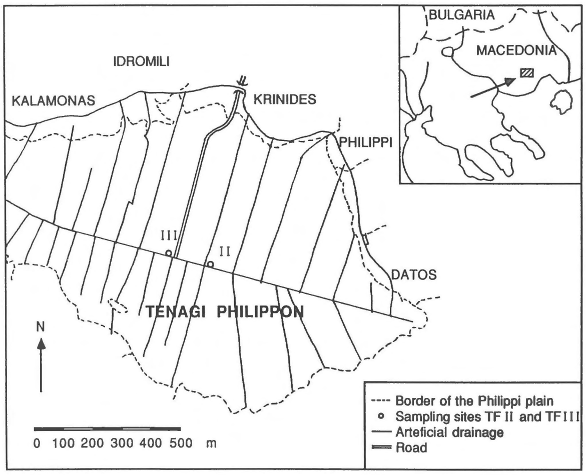


Fig. 1. Location of the borings TF II and TF III on the Philippi Plain, Macedonia, Greece.

er) sections from the northern part of the Mediterranean region (Van Zeist 1967, Niklevski & Van Zeist 1970, and Bottema 1974) steppe zones occur. This implies that the European vegetation belts (see Van der Hammen et al. 1971) did not simply migrate north or southward with the climatic changes from glacial to interglacial and vice versa, otherwise the Mediterranean area would have been covered by boreal forests or tundra during the ice ages. Instead, during glacials the area was covered by a steppe vegetation as occurs in the more continental Near East and the Soviet Union nowadays.

A good correlation of the Tenagi Philippon data with north-western European stratigraphy (based on isotope dating, magneto-stratigraphy, fluctuations in the arboreal pollen sum and on the introduction or extinction of certain taxa) was possible. Most of the important changes in the vegetations of north-western and southern Europe appear to have occurred at the same time and show the same trends. While for instance the vegetation in north-western Europe at the decline of a glacial developed from an polar desert via tundra towards mixed forest, the vegetation in southern Europe developed from steppe via forest steppe towards evergreen forest. The same appeared to be true for the correlation between the reconstruction of climate from the pollen data from Tenagi Philippon and the climatic reconstruction by means of deep sea cores (Shackleton & Opdyke 1976). This indicates the global nature of climatic fluctuations.

The Tenagi Philippon area forms a part of the Drama Basin (location 41° 10′ N and 24° 20′ E, see Fig. 1) and is separated from the Aegaean Sea to the south by the low Symvolon mountains and to the west and east by the Pageon and Ori Lekanis mountains. In the north the Falakron mountains are found. In this basin deposition of clay and marl took place. The basin originated in the Late Miocene by tectonic downwarping in the metamorphic sediments of the Rila-Rhodope Massifs. In a separate part of the basin, the Tenagi Philippon area, a 200 m thick peat deposit is found.

In the past, climatic interpretation of palynological data was usually confined to an evaluation of temperature fluctuations in time. The general preoccupation with temperature seems to reflect the opinion of most authors that temperature is the only, or at least by far the most important, climatic factor causing changes in the vegetation of a specific area. In our opinion precipitation is at least as important as temperature in determining the nature of the vegetation. This idea is strongly supported by the fact that the distribution and form of present-day vegetation provinces or areas in which certain taxa occur are a reflection not only of global temperature patterns but also of differences in the quantity and distribution of precipitation over the year.

Another shortcoming of most climatic interpretations of palynological data is the fact that single variables are considered to be a measure for the temperature in a certain period. The most important variable used in this way is the percentage of tree pollen found in a certain set of spectra or period. The use of this variable does not take into account the fact that different forest taxa may have different preferences for climatic conditions.

Sometimes the first appearance or disappearance of pollen of individual taxa within a stratigraphical sequence is taken as an indication of an important change in climate (e.g., temperature). However, one should realize that boundaries are not only established by temperature patterns but also by competition between species as well as by chance.

A more reliable approach to reconstruct environmental conditions in the past, would be to regard a whole vegetation unit with its optimum temperature and precipitation characteristics. As a vegetation contains many taxa its occurrence is less susceptible to chance processes than the occurrence of individual taxa, and the ecological range in which it occurs is more restricted. In order to make a reliable reconstruction of the climatic developments in the past, only the optimum ecological conditions for a vegetation type are considered. After the definition of the climatic conditions during certain periods, the direction of climatic changes can be deduced.

The first aim of this research was to reconstruct the climatic conditions in the past, discriminating between temperature and precipitation as the two most important climatic factors regulating the floristic and phytosociological composition of the plant cover in a certain area.

The second aim was to evaluate the usefulness of numerical, particularly multivariate, techniques on palynological data for the achievement of this goal.

One of the most suitable sediment cores that can be used for a climatic description of the past originates from the Tenagi Philippon area. It is one of the longest continuous records, well described geologically and palynologically. The present paper concentrates on the first 86 m of this core.

Methods

The 0.6 to 86.0 m interval of the Tenagi Philippon core was analyzed palynologically. This interval comprises the period from more than 445,000 years ago until a few thousand years ago (Wijmstra & Groenhart 1983).

The raw palynological data were entered and stored in a database application. Taxa occurring in less than 4 spectra (less than 1%) were thought to be too rare to reveal any interpretable pattern and were removed from the data set. Since some plants show long distance dispersal, frequency distributions were made for these taxa to define the lower limit beneath which pollen counts were thought to be too small to imply regionally present plants. Thus counts less than 20 pollen grains per spectrum of *Pinus* and *Artemisia* were ignored. A raw data file containing all spectra and taxa in the 0.6 to 86.0 m interval was exported for further processing. This file was analyzed with the classification program TWINSPAN. The analysis permitted a major division of the material in forest and steppe spectra and taxa. Based on this classification an overall diagram was drawn. Also based on this classification separate forest and steppe files were created by the selection of all forest spectra and all steppe spectra in the database respectively. In the forest and steppe percentage files the scores of all taxa were expressed as percentages of the sum of the scores of all forest taxa and the sum of the scores of all steppe taxa respectively. The percentage files and raw data files were converted to input files for the TWINSPAN and DECORANA programs (Hill 1979a and b).

As the multivariate analysis of the raw data files gave better results than the analysis of the percentage files, the raw data were used for further evaluation. The classification of the spectra and taxa in the raw data file containing both forest and steppe spectra was easier to interpret than the classification of the data in the files containing only forest or steppe spectra.

After some final arrangement by hand the analysis resulted in the classification of spectra and taxa into 6 different vegetation types. By evaluating the historical order in which those 6 types occurred, it appeared that types 2 and 3 occurred alternately in many periods in history. This fact and the great phytosociological similarity between those types was the reason that these types were taken together as the Mediterranean type (II). For the same reasons types 4 and 5 were combined into the warm temperate type (III). Comparing the 4 remaining vegetation types with present-day vegetation data in the literature (Rikli 1948, Walter 1968, Zohary 1973) resulted in 4 corresponding phytogeographical provinces in Europe and the Middle East. Climatic data for several stations within those 4 provinces were gathered (Müller 1982). Averaging those climatic data gives some insight in the temperature and the amount and distribution over the year of the precipitation that is characteristic for the different forest and steppe vegetations. A so-called Walter diagram (see Walter & Lieth 1967) is one of the best ways to facilitate the evaluation of the several phytogeographically important climatic parameters simultaneously.

Mean winter and summer temperatures (the av-

Table 1. Summarized phytosociological table of palynological data from the Tenagi Philippon core in northern Greece (X: occurrence frequent or more frequent than in other vegetation types; r: occurrence rare)

plant taxon \ vegetation type	1	2	3	4	5	6	
Poterium	r	r					forest taxa
Ilex	r	r	r				
Rhus	r	r	r				
Buxus	r	r	r	r			
Primulaceae	r	r	r	r			
Fagus	r	r	r	r	r		
Zelkova	X						
Vitis	X						
Phillyrea	X						
Castanea	X						
Sanguisorba	X						
Pistacia	X						
Tilia	X	X	X	r	r		
Ulmus	X	X	X	r	r		
Corylus	X	X	X	r	r		
Fraxinus / Olea	X	X	X	r	r		
Abies		X	X	r	r		
Ericaceae		X	X	r	r		
Carpinus		X	X	r	r		
Ostrya		X	X	r	r		
Hedera			X				
Picea			X	X	X		
Pinus	r	r	X	X	X	r	
Cornus	X	X	X	X	X	X	
Acer	X	X	X	X	X	X	
Rhamnaceae	X	X	X	X	X	X	
Centaurea cyanus	X	X	X	X	X	X	
Taxus	X	X	X	X	X	X	
Alnus	X	X	X	X	X	X	
Quercus	X	X	X	X	X	X	
Poaceae	X	X	X	X	X	X	steppe taxa
Chenopodiaceae	X	X	X	X	X	X	
Asteraceae tubuliflorae	X	X	X	X	X	X	
Betula	X	X	X	X	X	X	
Juniperus	X	X	X	X	X	X	
Plantago	X	X	X	X	X	X	
Asteraceae liguliflorae	X	X	X	X	X	X	
Brassicaceae	X	X	X	X	X	X	
Salix	X	X	X	X	X	X	
Centaurea solstitialis	X	X	X	X	X	X	
Daphne	X	X	X	X	X	X	
Thalictrum	X	X	X	X	X	X	
Artemisia	r	r	r	r	X	X	
Polygonum viviparum					X	X	
Caryophyllaceae					X	X	
Ephedra					X	X	
Xanthium					X	X	
Cistaceae					X	X	
Climate	I warm wet	II warm winter rain		III cool moist		IV cold dry	
	forest types					steppe type	

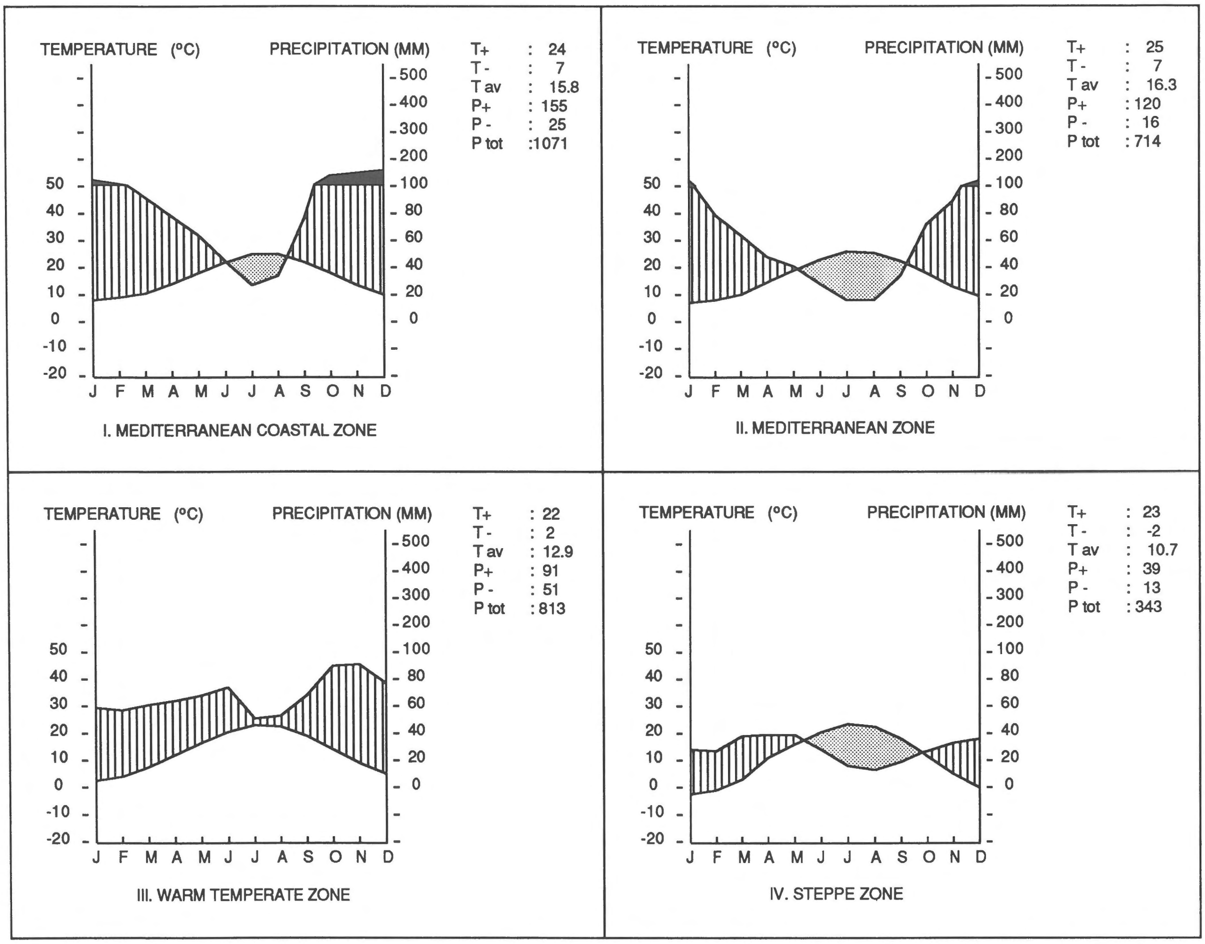
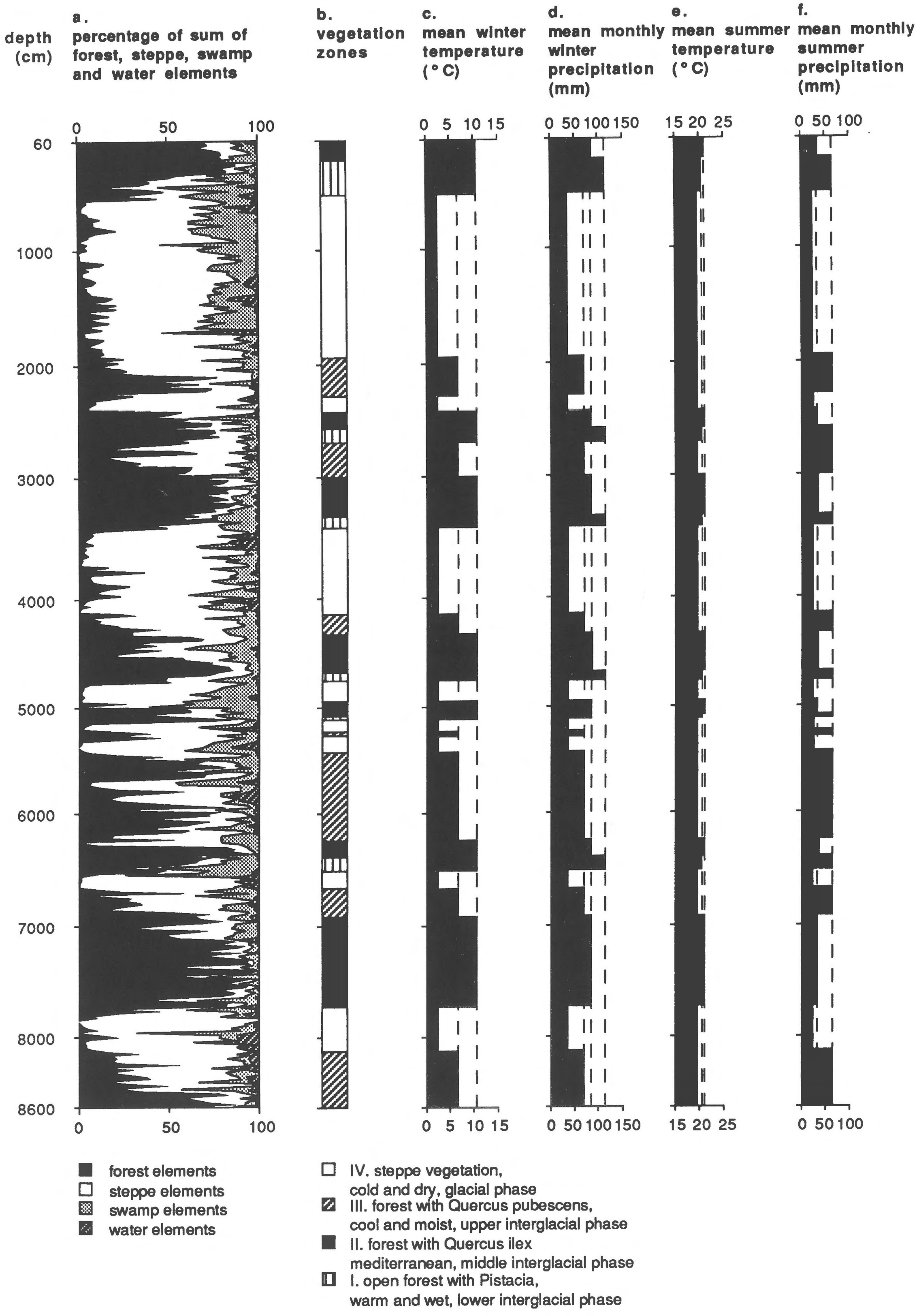


Fig. 2. Walter diagrams of the climates prevailing in the 4 phytogeographical provinces in which the 4 vegetation types present in the Tenagi Philippon core in northern Greece (Table 1) still occur.

erages of the November to April temperatures and the averages of the May to October temperatures respectively) and mean monthly winter and summer precipitations (the averages of the monthly November to April precipitations and the averages of the monthly May to October precipitations respectively) were calculated.

Table 2. Aspects of climate in the 4 phytogeographical provinces in which the 4 vegetation types present in the Tenagi Philippon core in northern Greece (Table 1) still occur

		mean winter temp (°C)	mean monthly winter prec. (mm)	mean summer temp (°C)	mean monthly summer prec (mm)
I.	Med. coast:	10.4	116	21.2	63
II.	Mediterranean:	10.3	84	22.3	35
III.	Warm temperate:	6.7	68	19.2	67
IV.	Steppe:	2.5	34	18.8	24


depth (cm)
a. percentage of sum of forest, steppe, swamp and water elements
b. vegetation zones
c. mean winter temperature (° C)
d. mean monthly winter precipitation (mm)
e. mean summer temperature (° C)
f. mean monthly summer precipitation (mm)
0 50 100
0 5 10 15
0 50 100 150
15 20 25
0 50 100
60
1000
2000
3000
4000
5000
6000
7000
8000
8600
■ forest elements
□ steppe elements
▩ swamp elements
▨ water elements
□ IV. steppe vegetation, cold and dry, glacial phase
▨ III. forest with Quercus pubescens, cool and moist, upper interglacial phase
■ II. forest with Quercus ilex mediterranean, middle interglacial phase
◫ I. open forest with Pistacia, warm and wet, lower interglacial phase

Results and discussion

The outcome of the classification of the palynological data by TWINSPAN and further processing by hand is summarized in Table 1.

In general the vegetation types are sharply defined. The forest types 1 to 5 are characterized primarily by the dominance by most of the tree species, and particularly by the occurrence of *Tilia, Ulmus, Corylus* and *Fraxinus* or *Olea*. The steppe type is characterized by the combination of dominance of *Artemisia* and Chenopodiaceae, and the occurrence of *Polygonum viviparum*, Caryophyllaceae, *Ephedra, Xanthium* and Cistaceae, and negatively by low scores of *Pinus*. Type 5 showed a gradual transition from type 4 towards type 6 (which means a transition from forest towards steppe vegetation). The forest taxa *Tilia, Ulmus, Corylus, Fraxinus* or *Olea, Abies*, Ericaceae, *Carpinus* and *Ostrya* gradually disappear.

There are two groups of taxa that did not show enough affinity for forest or steppe to be considered characteristic for one or the other, but TWINSPAN classified them as forest or steppe taxa, respectively. The more or less indifferent forest taxa are *Cornus, Acer*, Rhamnaceae, *Taxus, Alnus* and *Quercus*. The relatively frequent occurrence of *Alnus* and *Quercus* in the steppe type IV might be explained by long distance dispersal (although for these taxa it was not possible to define a reasonable lower limit for regional appearance), or by the presence of forest steppes. The more or less indifferent steppe taxa are Poaceae, Chenopodiaceae, Asteraceae, *Betula, Juniperus, Plantago*, Brassicaceae, *Salix, Centaurea solstitialis, Daphne* and *Thalictrum*. These taxa might also be present in open spaces in the forest.

Since appearances of type 2 and 3 as well as of type 4 and 5 tended to alternate in history, they were taken together as (super) types II and III.

Type I is characterized by *Zelkova, Vitis, Phillyrea, Castanea, Pistacia, Tilia, Ulmus, Corylus*, and *Fraxinus* or *Olea*. All these taxa require a rather warm climate, while *Zelkova, Phillyrea, Castanea* and *Pistacia* require a rather great quantity of rain evenly distributed throughout the year. Therefore a warm, wet climate such as prevails nowadays in the Mediterranean coastal region is postulated for type I.

Type II is characterized by *Tilia, Ulmus, Corylus, Fraxinus* or *Olea, Abies*, Ericaceae, *Carpinus, Ostrya, Hedera, Picea* and *Pinus*. From the presence of *Tilia, Ulmus* and *Carpinus* it may be assumed that the vegetation was of a Mediterranean type. Since there are no Mediterranean taxa indicative for a high precipitation during the whole year, it is probable that the summer was dry as in the present Mediterranean region some distance from the coast. The *Quercus* found may have been *Q. ilex*. This may be concluded from the presence of several pollen grains of the *Q. ilex* type, as shown by Scanning Electron Microscopy analysis of the oak pollen (Wijmstra & Smit 1976).

Type III is characterized by *Picea, Pinus, Artemisia, Polygonum viviparum*, Caryophyllaceae, *Ephedra, Xanthium* and Cistaceae. Since in comparison with type II most Mediterranean taxa are less abundant, since *Pinus* and *Picea* are characteristic of this type and since the steppe taxa are present in part of the spectra, it is suggested that the climate corresponding with this type was cooler than the one corresponding with type II and that the precipitation was distributed more evenly over the year. This type of climate nowadays occurs in the southern part of the temperate zone where *Quercus pubescens* is found.

Type IV is characterized by *Artemisia, Polygonum viviparum*, Caryophyllaceae, *Ephedra, Xanthium* and Cistaceae, most of which are steppe taxa. Hence a dry climate is postulated for this type. In the literature, for the periods in which this type of vegetation occurs a low temperature is assumed (Smit & Wijmstra 1970). Presently this type

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Fig. 3. Palynology, vegetation and climate in the Late Quaternary in northern Greece. a. overall diagram of palynological data from Tenagi Philippon; b. vegetation zones; c, d, e and f. assumed climatic conditions during different historical periods, each with a characteristically different vegetation type.

of climate is found in more continental areas in the Middle East and in the Soviet Union.

From several stations in the above mentioned phytogeographical provinces climatic data were gathered (Müller 1982) and average temperature and precipitation values were calculated for each province. These values are presented in Walter diagrams (see Fig. 2). The calculated mean winter and summer temperatures and mean monthly winter and summer precipitations in those 4 phytogeographical provinces are presented in Table 2.

The vegetational and climatic history of northern Greece is schematized in Fig. 3. In Fig. 3a the results of the palynological analyses are summarized. In order to visualize the alternation of forest and steppe phases simultaneously with the fluctuations in water level a pollen sum based on the sum of forest, steppe and aquatic elements was chosen. The bulk of the tree pollen is provided either by *Quercus* and *Pinus* together, or by one of them alone. In the periods of herbaceous pollen dominance the principal constituents of the pollen rain are Poaceae, *Artemisia* and Chenopodiaceae. For further discussion on the specific vegetational history, zonation and stratigraphy the reader is referred to Wijmstra (1969), Wijmstra & Smit (1976), and Van der Wiel & Wijmstra (1987a and b).

The vegetational zonation in Fig. 3b is based on the occurrence of spectra belonging to the different vegetation types (see Table 1) in the stratigraphical sequence. The temperature and precipitation values corresponding with these vegetations (see Table 2) are represented in Figs 3c, d, e and f.

A perusal of the overall diagram (Fig. 3a) shows in the first place that periods during which pollen of forest taxa dominates alternate with periods during which pollen grains of steppe taxa are more important. Forest pollen dominated periods represent interglacial phases, while steppe pollen dominated periods can be correlated with glacial periods. The higher water levels tend to occur during the glacial phases.

The described method of research appears to be promising and to yield interesting results. Although all climatic curves clearly correlate with the percentage of forest elements and the alternate persistence of glacials and interglacials, they are certainly not identical. There are also different tendencies in all four of them. This suggests that this method of climate reconstruction gives a much more multidimensional view on the climatic fluctuations in the past than the methods used so far.

Interglacial stages begin as warm, wet periods, during which open forests characterized by *Pistacia* develop. Relatively soon a Mediterranean climatic type with very dry summers and rainy winters takes over causing an evergreen *Quercus ilex* forest type to develop. During the second half of the interglacial phase the temperature drops sharply but the precipitation increases somewhat and is distributed more evenly over the year.

The maxima of the glacial phases are generally characterized by both a very low winter temperature and a very low winter and summer precipitation.

The climatic changes in the beginning of the interglacial seem to be much more abrupt (especially in the winter conditions) than the rather gradual changes during the transition from interglacial to glacial. The differences between the winter conditions in the four zones are much greater than those of the summer conditions. It may be assumed that the winter conditions have a greater influence on the type of vegetation that develops than the summer conditions have.

A comparison between past and present vegetations is hampered by the long duration of human influence in the area. When we compare the occurrence of elements of the present maquis and garrigue with their occurrence in the past it is remarkable that the evergreen oaks are found in the *Carpinus* zones. In other words the evergreen oaks occurred in the middle of the interglacials when a complete zonation of the forest along the slopes had developed and when summers were dry and winters rainy. On the other hand *Pistacia* is found generally at the beginning of the interglacials together with *Castanea, Zelkova* and *Phillyrea,* indicating a high precipitation with a more even distribution over the year. This suggests that it is necessary to re-evaluate the present maquis and garrigue vegetations, in which elements of open vegetations that prevailed during the beginning of interglacials are found together with elements of the evergreen forests, which occurred at the maxima of the interglacials. In our opinion the lack of competition provoked by human interference has played a great role in the grouping of the elements of the present-day Mediterranean vegetation.

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