RECORD OF 700.000 YEARS VEGETATIONAL HISTORY IN EASTERN MACEDONIA (Greece)*

Por T. A. WIJMSTRA, M. C. GROENHART

Hugo de Vries-Laboratorium, Universiteit van Amsterdam,
Sarphatistraat 221, 1018 BX Amsterdam, The Netherlands

SUMMARY

In this paper the results of a palynological study of 134 meters of peat and lake sediments are reported. This sequence is part of a 280 meters core drilled in the Tenaghi Phillippon (Eastern Macedonia, Greece). Paleomagnetic studies revealed the presence of the Brunhes Matuyama boundary in the core at a depth of 134 meters. With the available ^{14}C - datings and the age of the Brunhes Matuyama boundary a time-depth relation could be established. This relation is used as time-base for a time series analysis. The analysed data demonstrate the presence of a 23,000 year, 28,000 year, 43,000 year and 95,000 year period. The arid assemblage present during the glacials could be split up into three subassemblages; comparable to a grass steppe, an *Artemisia-Chenopodiaceae* steppe and a forest steppe.

INTRODUCTION

In the eastern part of Macedonia between Drama and Kavalla a basin is found. In this basin extensive peat and clay layers are accumulated for at least 900,000 years. All the sediments contained a fair amount of pollen, and consequently a record of the vegetational histoyr for at least a greater part of the Pleistocene can be studied in this area. Previous results from a drill hole made in 1963 were reported for the upper 30 meters and the interval 30-78 meters (*Wijmstra*, 1969 and *Wijmstra et. al*, 1976, respectively).

In 1977 a new boring was made and 280 meters of peat and clay were sampled for pollen analysis. From 200 meters to 280 meters sand layers are found intercalated in the clay and peaty clays. The upper part consists of peat. This new drill hole was sampled for paleomagnetic studies at the same time. The samples were taken and analysed by Prof. Opdyke of Lamont Doherty. From these analyses it appears that the Brunhes Matuyama boundary was situated at 134 meters.

VEGETATIONAL HISTORY

In this paper only the general outlines of the forest vegetation history are reported, while special attention will be given to the development of the steppe vegetation during the various glacial periods. A comparison with deep-sea records is made.

The different steppe and forest phases and their corresponding pollen zones are indicated by numbers for easier comparison and description, in contrary to the more formal stratigraphical zonation introduced in *Wijmstra* (1969) and *Wijmstra et al.* (1976), see table I. A short description of the vegetation present during a particular pollen zone is given in this table and it appears that during the interval under discussion the following vegetation types may be recognised, *viz.*, forest vegetation and steppe vegetation.

The forest vegetation period, principally dominated by oak and pine, alternate with steppe vegetation mainly consisting of *Artemisia* and *Chenopodiaceae*.

These periods show a slight difference in hydro- and hygrophytic vegetation. During the steppe period elements like *Menyanthes, Nymphaea, Typa angustifolia* and *Salix* accompanied by *Sygnemataceae* express a relative dominance. In the forest phases *Alnus, Cyperaceae* and *Utricularia* are frequently found.

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*It is with great pleasure that the authors dedicate this paper to Prof. dr. Thomas Van der Hammen, whose work already contributed so much to the knowledge of the Pleistocene vegetation history in South America and Europe.

deep-sea stages	zone	pollen zone	character of vegetation
1	1	Z_{1-5}	oak forest differentiated in: *Ulmus Tilia* zone, a *Corylus*, a Fraxinua and an Ostry zone
	2	Y_3	open grass *Artemisia* steppe with some *Chenopodiaceae*.
	3	Y_2	open oak forest with *Pistacia, Juniperus, Ulmus*.
2	4	$Y_5 Y_1$	*Artemisia Chenopodiaceae* steppe
	5	X_4	open pine forest with patches of steppe vegetation
	6	$X_{1\,2,3}$	*Artemisia Chenopodiaceae* steppe. Occasional some pine. In lower part *Compositae*
3	7	P_{1-7}	*Artemisia Chenopodiaceae* steppe with grasses and *Compositae* and *Centaurea soltitiales* type pollen. In three intervals more trees in the steppe
4	8	V_{1-3}	steppe vegetation with *Artemisia* and *Chenopodiaceae* in the lower part, increasing influence of pine stands
a	9	U_{1-3}	oak forest with at the transition to next zone pine stands. In oak forest *Carpinus, Tilia* and *Ulmus*
b 5	10	T	steppe vegetation of *Artemisia, Chenopodiaceae, Plantago* and *Compositae*.
c	11	S_{1-4}	oak forest with at first an *Ulmus Tilia* zone followed by a *Carpinus Fagus* zone, at the transition to zone 10 a pine forest with some *Abies*.
d	12	R_{1-3}	grass steppe with *Artemisia* and *Chenopodiaceae*. In middle phase some oak pine shrubs with *Cistaceae*.
e	13	O_{1-2} Q_{1-3}	oak forest with at first an *Ulmus Tilia* zone, in the middle part an *Abies Rhododendron Carpinus* zone with *Ilex* and evergreen oaks, terminated by a pine zone
6	14	L_{1-5} M_1 K H_3	steppe vegetation with *Artemisia* and *Chenopodiaceae*, lower half some forest steppe with pine
	15	H_{12}	oak forest with evergreen and deciduous oaks with a well-developed *Carpinus* and *Abies* zone. In the beginning and *Ulmus Tilia* zone
7	16	G	open oak forest with in the lake floating mats of *Cyperaceae* and grass vegetation; shore vegetation *Chenopodiaceae* and *Artemisia*.
7	17	F	deciduous oak forest with *Quercus cerris*, stand of pine
8	18	D,E	*Artemisia Chenopodiaceae* steppe, in the middle part an open oak forest steppe with *Artemisia* and *Chenopodiaceae*
9	19	C	deciduous oak forest with *Quercus cerris*.
	20	B	forest steppe of oak and pine in a *Pistacia Artemisia Chenopodiaceae* association with much *Compositae*.
	21	A	mainly deciduous oak forest with some pine
	22	ZZ	forest steppe with oaks, pine; on slopes *Abies* and *Erica arborea* vegetation
	23	YY	deciduous Mediterranean oak forest with *Buxus* and *Pistacia;* in upper part *Quercus cerris, Q. suber, Erica arborea* vegetation
10	24	XX	open steppe vegetation, in lower part a pine forest steppe
11	25	PP	oak forest with evergreen oaks in middle part; here also a zone with *Ericaceae* vegetation
12	26		*Artemisia Chenopodiaceae* steppe. In middle part of this zone lower lake levels and forest steppe conditions
13	27		oak forest with *Ulmus* and *Carpinus*. Regular occurrence of *Acer, Taxus*. In middle part presence of evergreen oak
14	28		open pine oak forest with *Artemisia* and *Chenopodiaceae*
	29		oak forest with *Ulmus Taxus, Acer, Ostrya, Celtis*
	30		forest steppe with *Artemisia* and *Chenopodiaceae*
15	31		oak forest with *Zelkova, Fagus, Castanea, Hedera, Fraxinus* cf.
16	32		*Artemisia Chenopodiaceae* steppe with in the lower part some forest steppe with oak and pine
17	33		oak forest with *Zelkova, Fagus, Hedera, Taxus, Viscum, Ilex*
18	34		open grass steppe with *Artemisia* and *Chenopodiaceae*, in middle part some forest steppe

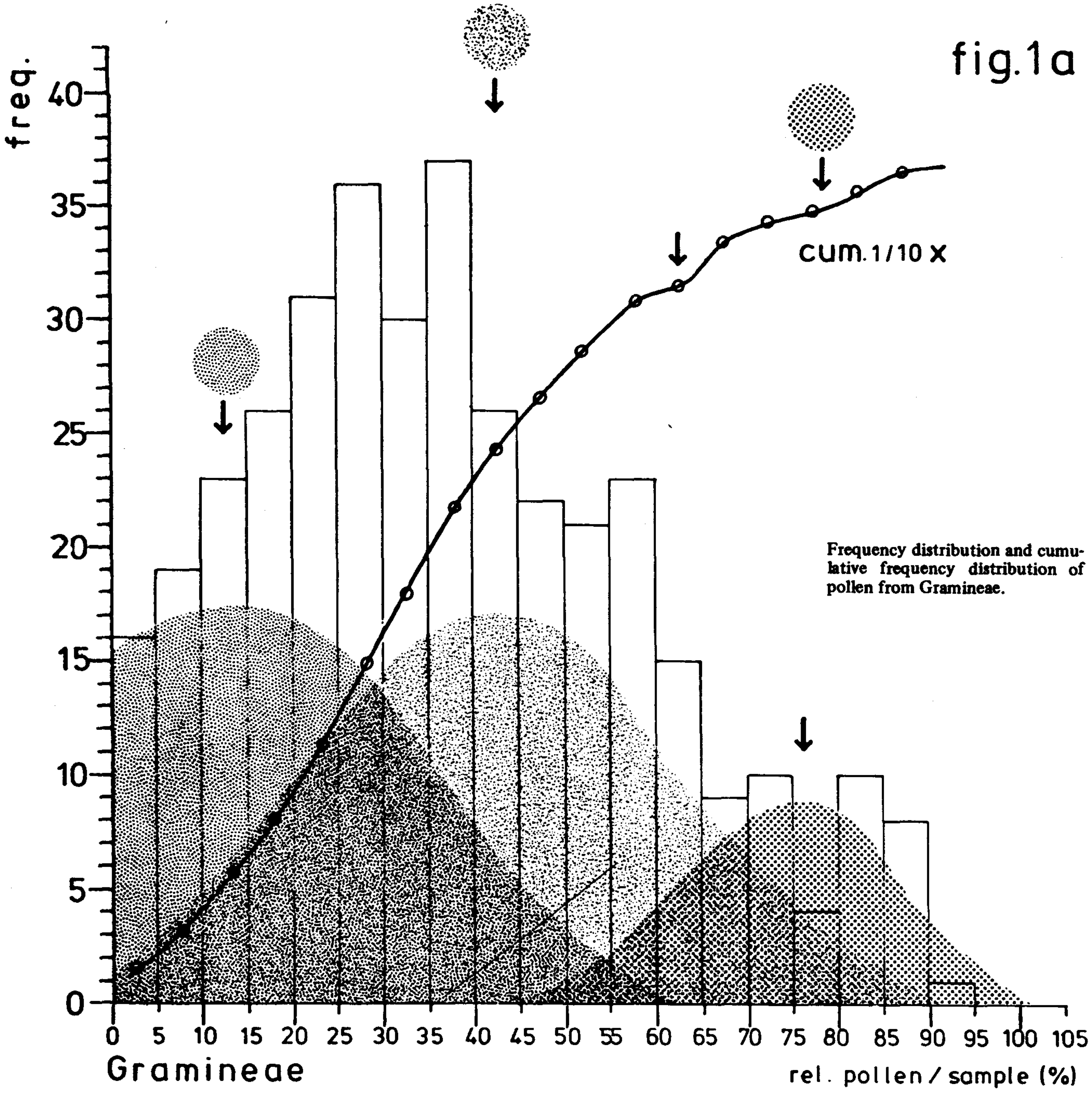
Table I. Pollen zonation and vegetation history of the Tenaghi Phillippon area.

In the forest phases several vegetation sequences may be recognised. There are sequences with a marked development of evergreen vegetation in the middle part of the series. Usually this is accompanied by an *Abies* zone in the pollen diagram. This is considered as a reflexion of an *Abies* forest zonation preceded by an evergreen forest belt on the hill slopes. At the start of this sequence a vegetation of *Cistaceae* with patches of *Tilia, Ulmus* and *Pistacia* is often observed. The zones 1, 13, 15, 25 and 27 are characterized by this type of vegetation sequence.

An other forest sequence is composed of a deciduous oak vegetation only. Here usually *Carpinus* is present, accompanied by *Fraxinus* and *Corylus*, This forest sequence existed during zones 9, 11, 17, 19, 21, 29, 31, and 33.

In the pollen zones 15, 23, 25, 27, 29, 31 and 33, trees like *Pterocarya, Zelkova, Acer, Celtis* and *Fagus* occurred regularly and *Parrotia* is present too. These forests resemble the forest nowadays present along the borders of the Caspian Sea (*Zohary*, 1973; *Walter*, 1968, 1974), belonging to the Hyrcanian and Sub-Hyrcanian mesic forest.

The fluctuations of percentages of *Artemisia, Chenopodiaceae* and *Poaceae* within the assemblages dominated by these elements suggest the presence of subassemblages representing different vegetation types. In order to make a more extensive analysis of the quantitative differentiation of the elements of these vegetation types the data of the previous taxa were grouped into frequency distributions and cumulative frequency distributions (fig. 1a, b, c). In the frequency distribution of the grasses (fig. 1a) a three modal shape may be recognised and consequently two points of inflexion in the cumulative frequency distribution. Possibly the underlying frequency distributions may explain the observed vegetation differentiation (fig. 1a).



Frequency distribution and cumulative frequency distribution of pollen from Gramineae.

1b. Frequency distribution of pollen from Artemisia.

1c. Frequency distribution of pollen from Chenopodiaceae.

fig. 1b

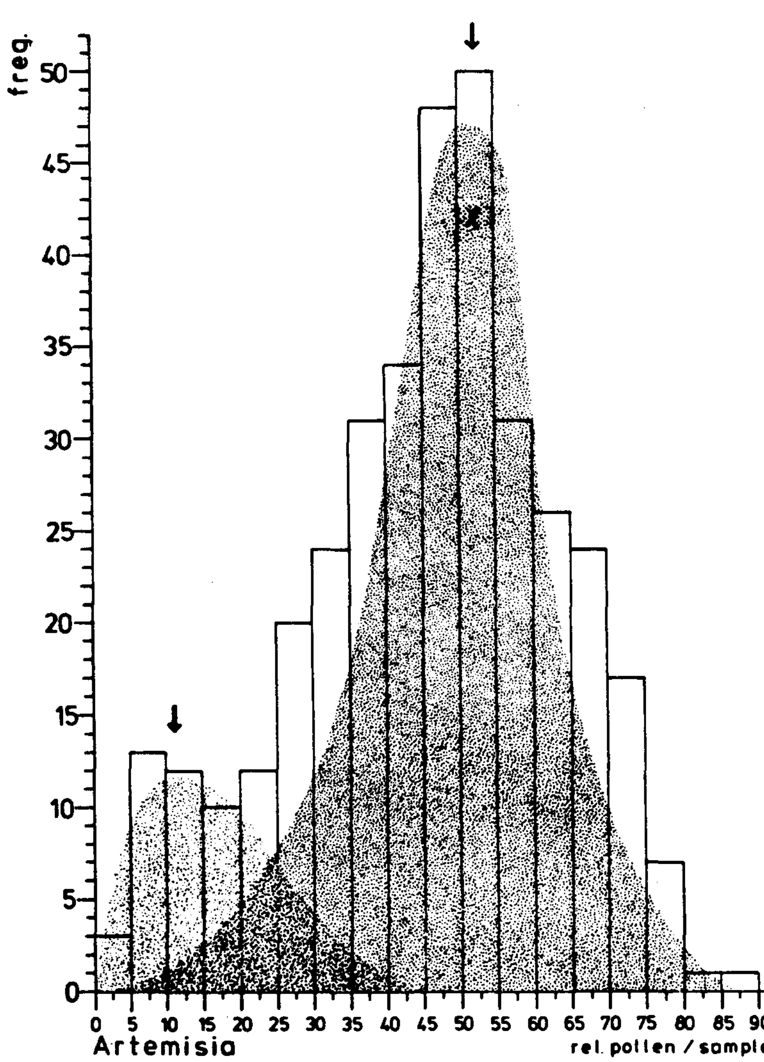
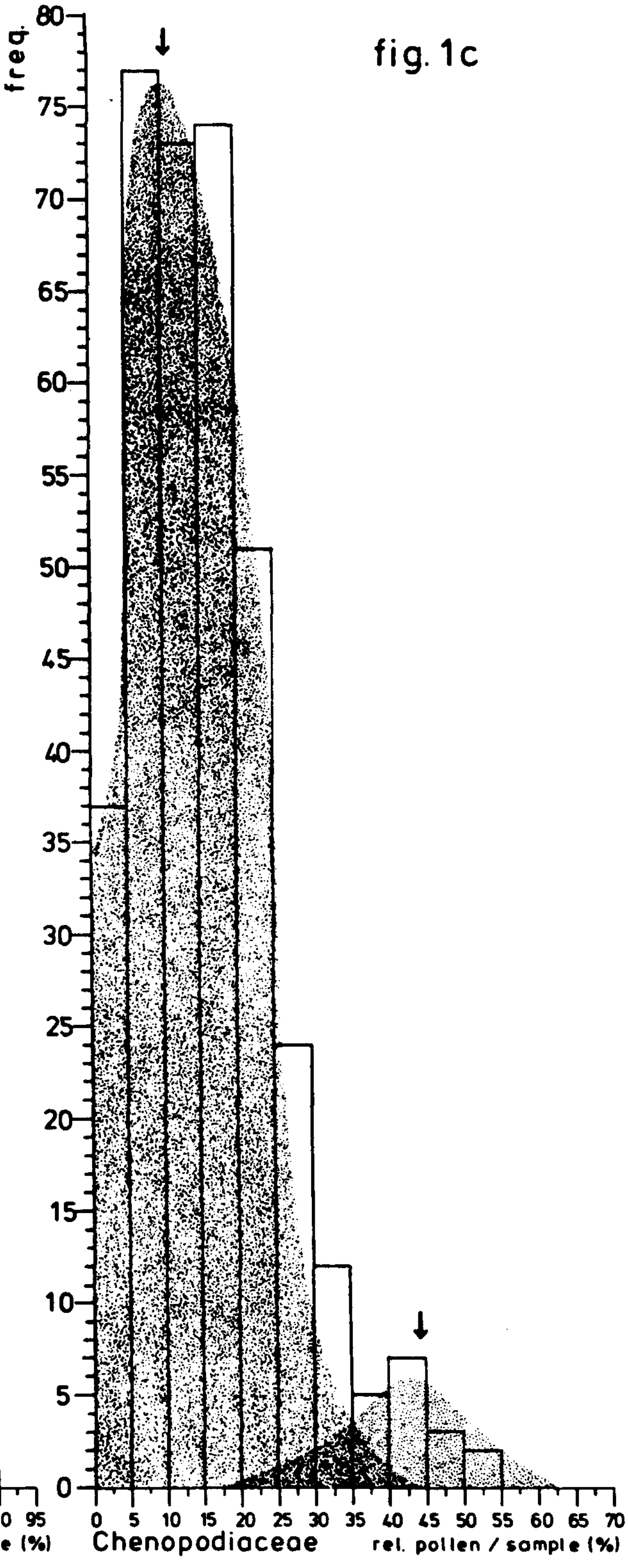


fig. 1c



The histograms for *Artemisia* (fig. 1b) and *Chenopodiaceae* (fig. 1c) show both two maxima indicating two separate underlying distributions for these taxa. These results indicate a possible split up of the grass–*Artemisia-Chenopodiaceae* assemblages into at least three subassemblages. In order to explore this possibility further, a cluster analysis of the scores of the three species was made. For this analysis a cluster program, called *Micka*, developed by *McRae* (1970), was used. This program clusters the data into numbers of clusters as defined beforehand by the user. We finally used a weighed Euclidian distance as distance measure in order to account for scale differences among the variables; and the data were standarized.

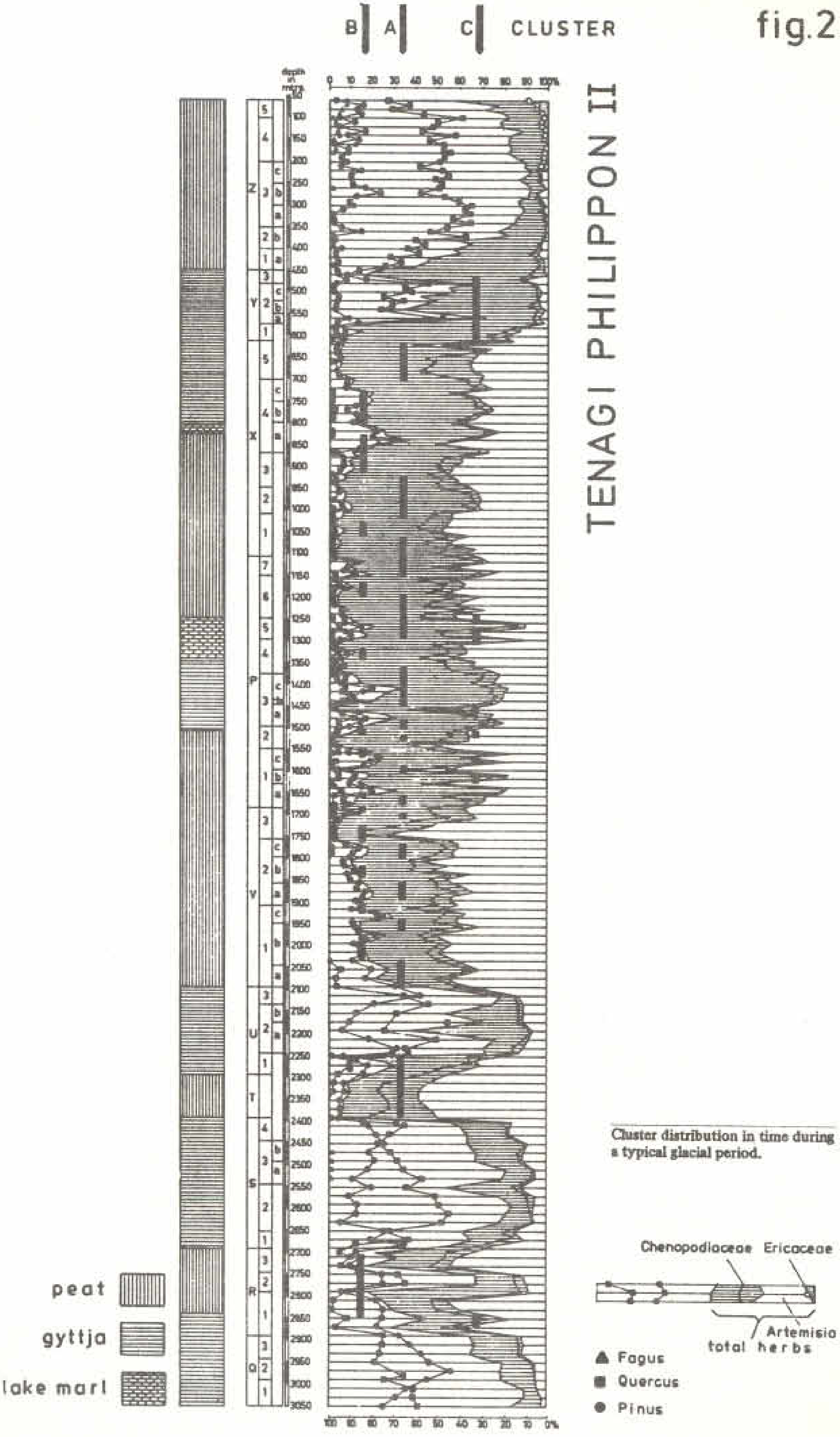
The results of this analysis are shown in table II. In this table the centroid of the subassemblages are shown, first for all data, and then for the various pollen zones from table I. From this table II it is evident that the various biozones cluster in the same way, although there are individual differences in the places of the various centroids in the variable spaces. Those differences are caused by a slight variation in ecological conditions within the subassemblages. Looking at the distribution of the clusters in the various pollen zones we see that

		Output cluster analysis, Mikca; Standarized; Weighed Euclidian distance			Output transformed to Relative values		
		Cluster Centroids (absolute)			Cluster Centroids (Relative) o/o		
Biozone		*Artemisia*	*Chenopodiaceae*	*Gramineae*	Art.	Chen.	Gram.
Total	1	15.262	5.133	4.444	61	21	18
	2	10.379	3.394	9.015	46	15	40
	3	3.733	1.873	14.075	19	10	72
480 t/m 2100	1	12.251	3.124	8.287	52	13	35
	2	7.768	1.507	10.739	39	8	54
2 t/m 8	3	1.527	909	5.800	19	11	70
2260 t/m 2400	1						
10	2						
	3						
2710 t/m 2880	1	12.950	2.450	7.425	57	11	33
	2	2.750	1.150	4.150	34	14	52
12	3	8.350	2.175	11.100	39	10	51
3400 t/m 4240	1	14.208	4.063	5.058	61	17	22
	2	9.384	3.905	12.337	37	15	48
14	3	7.200	4.100	23.150	21	12	67
4780 t/m 4940	1	15.167	6.667	4.700	57	25	18
	2	10.567	6.400	9.100	41	24	35
16	3	4.733	4.767	16.600	18	18	64
5160 t/m 5520	1	11.150	3.650	11.030	43	14	43
	2	5.000	1.225	7.975	35	9	56
18	3	5.000	3.300	45.000	9	6	84
6210 t/m 6280	1						
	2						
22	3						
5760 t/m 5940	1	11.000	5.275	8.175	45	22	33
	2	8.200	3.467	11.700	35	15	50
20	3	3.500	1.250	22.200	13	5	82
6560 t/m 6860	1	10.425	2.875	3.750	61	17	22
	2	6.129	3.457	12.100	28	16	56
24	3	4.067	5.867	38.867	8	12	80
7780 t/m 8440	1	14.840	3.810	2.760	69	18	12
	2	9.292	5.292	6.223	45	25	30
26	3	2.829	1.400	34.286	7	4	89
9480 t/m 9650	1	12.875	5.225	4.875	56	23	21
	2	9.650	5.500	7.950	42	24	34
28	3	4.075	1.900	6.275	33	16	51
9900 t/m	1	9.079	3.600	3.643	56	22	22
10,250	2	4.700	3.100	24.900	14	9	76
30	3	1.200	4.000	32.000	3	11	86
10,580 t/m	1	15.891	5.364	3.273	65	22	13
11,370	2	12.962	9.631	1.362	54	40	6
32	3	10.755	3.918	7.918	48	17	35
11,970 t/m	1	11.133	4.000	2.167	64	23	13
12,770	2	13.925	7.875	2.875	56	32	12
34	3	2.833	2.583	5.833	25	23	52

Table II. Cluster centroids of the total subassemblages and the subassemblages of the biozones for *Artemisia Chenopodiaceae* and *Gramineae*. The lack of centroids in biozones 2 and 8 is caused by singularity.

type C clusters are concentrated in the last part of the sequence dominated by open vegetation types; the type A clusters reflecting the most extreme conditions of this sequence, and the type B clusters occurring when isolated patches of forest exist (see fig. 2). In this figure the distribution of clusters is shown throughout a typical ice age, for instance the Weichselian.

fig.2



Cluster distribution in time during a typical glacial period.

This pattern is also found in other intervals corresponding to periods of probable ice extension in the northern hemisphere (for correlation steppe vegetation and ice extension, see *Wijmstra,* 1969, 1976).

If our cluster analysis is a meaningful tool in recongnizing vegetation types, then it is probable that the accompanying species of the pollen zone dominated by *Artemisia, Chenopodiaceae* and *Gramineae* show a meaningful different preference for the three vegetation types/pollen subassemblages under discussion. In order to explore this possibility two tables were made, III and IV, respectively, and a cumulative frequence distribution for the three subassemblages (figs. 3 and 4).

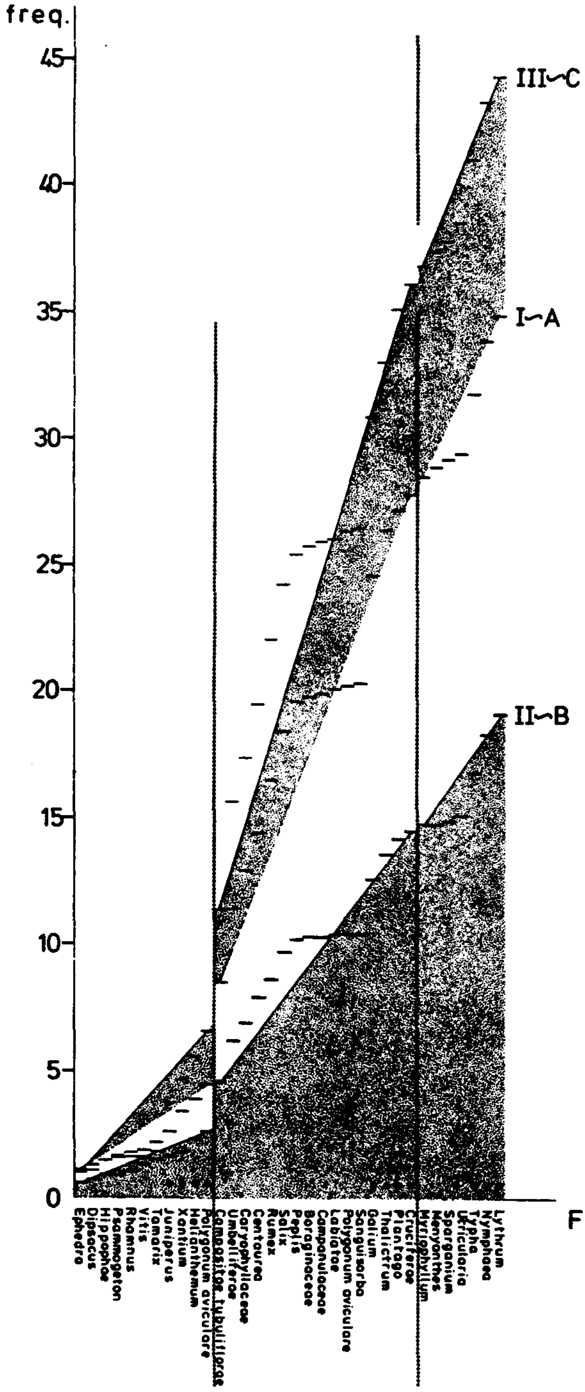
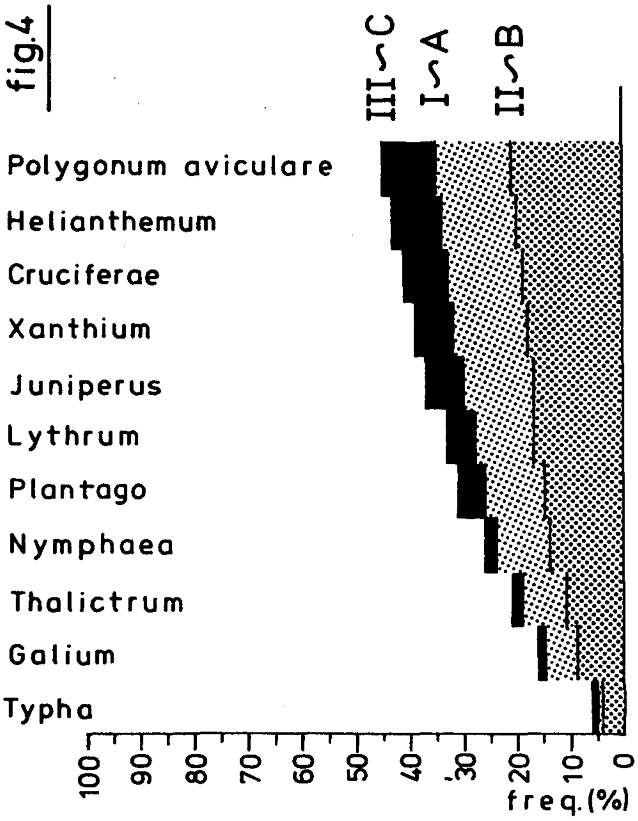


Fig. 3

Cumulative frequency distribution for the additional species in the three clusters.



Cumulative frequency distribution for the differential species in the three clusters.

Table III is a kind of synoptic table based on all core samples considered as a vegetation sample within the three subassemblages differentiated by their composition in *Artemisia, Chenopodiaceae* and *Gramineae.* The presence figures are classified in relative presence classes. The classes are indicated by a Roman numeral preceded by a point to distinguish them from the traditional customary tables in plan sociology. According to similarity in presence classes the species are rearranged to the final structure of table III.

The differentiating species were arranged in the same way in table IV. The cummulative frequency distribution show the overall differences between the clusters.The differences were tested by ordinary statistical procedures. All the results point into one direction, namely that the three subassemblages are accompanied by different species combinations, respectively, and they show to be independent from the original cluster analysis. We can consider this result a test on the reliability of the analysis.

When we try to translate our subassemblages into vegetation types some difficulties arise. We could say that in the biozones dominated by subassemblages (C) a grass steeppe with *Artemisia* was the main vegetation type. In subassemblages (A) *Eurotia ceratoides* is found present beside *Artemisia herba-alba* pollen types. This pollen type is produced by the specis *A. austriaca, A. herba-alba, A. scoparia, A. persica, A. maritima* and *A. fragrans.*

Vegetation types comparable to this pollen association are found nowadays in the high pla-

Centroids													
Dominant species	Cluster C			Cluster A			Cluster B						
Artemisia	3.733 19			15.261 61			10.379 46			Relative Freq. (N=2961)			
Chenopodiaceae	1.873 10			5.133 21			3.394 15						
Gramineae	14.075 72			4.444 18			9.015 40						
Additional species	Pres. fig.	Rel.Pres. % fig.	Pres. Class Modif.	Pres. fig.	Rel.Pres. % fig.	Pres. Class Modif.	Pres. fig.	Rel.Pres. % fig.	Pres. Class Modif.		I	II	III
in common:													
1.Compositae tubuliflorae	145	10.9	.VI	120	11.3	.VI	66	11.3	.VI	331	4.0	2.2	4.8
2.Umbelliferae	128	9,6	.V	87	8.1	.V	48	8.2	.V	263	2.9	1.6	4.3
3.Caryophyllaceae	50	3.7	.III	46	4.3	.III	21	3.6	.III	117	1.5	0.7	1.7
4.Centaurea	62	4.6	.III	46	4.3	.III	31	5.3	.III	139	1.5	1.0	2.1
5.Rumex	79	5.9	.III	63	5.9	.III	22	3.7	.III	164	2.1	0.7	2.6
6.Salix	65	4.9	.III	59	5.5	.III	34	5.8	.III	158	1.9	1.1	2.2
7.Ephedra	32	2.4	.II	34	3.2	.II	19	3.2	.II	85	1.1	0.6	1.0
8.Peplis	37	2.7	.II	36	3.3	.II	14	2.4	.II	87	1.2	0.5	1.2
9.Myriophyllum	23	1.7	.I	21	1.9	.I	9	1.5	.I	53	0.7	0,3	0.7
10.Boraginaceae	10	0.7	.I	7	0.6	.I	2	0.3	.I	19	0.2	0.1	0.3
11.Campanulaceae	6	0.4	.I	2	0.1	.I	0	0.0	.I	8	0.1	0.0	0.2
12.Dipsacus	2	0.1	.I	8	0.7	.I	2	0.3	.I	12	0.2	0.1	0.1
13.Hyppophaea	11	0.8	.I	7	0.6	.I	6	1.0	.I	24	0.2	0.2	0.4
14.Labiatae	4	0.3	.I	6	0.5	.I	4	0.6	.I	14	0.2	0.1	0.1
15.Menyanthes	17	1.2	.I	14	1.3	.I	0	0.0	.I	31	0.4	0.0	0.6
16.Psammogeton	7	0.5	.I	3	0.2	.I	0	0.0	.I	10	0.1	0.0	0.2
17.Polygoum viviparum	9	0.6	.I	4	0.3	.I	0	0.0	.I	13	0.1	0.0	0.3
18.Rhamnus	3	0.2	.I	0	0.0	.I	2	0.3	.I	5	0.0	0.1	0.1
19.Sanguisorba	3	0.2	.I	2	0.1	.I	1	0.1	.I	6	0.1	0.0	0.1
20.Sparganium	11	0.8	.I	10	0.9	.I	3	0.5	.I	24	0.3	0.1	0.4
21.Utricularia	20	1.5	.I	6	0.5	.I	6	1.0	.I	32	0.2	0.2	0.7
22.Vitis	3	0.2	.I	1	0.1	.I	8	1.3	.I	12	0.0	0.3	0.1
23.Tamarix	8	0.6	.I	5	0.4	.I	5	0.8	.I	18	0.2	0.2	0.3
differential:													
24.Polygonum aviculare	30	2.2	.II	17	1.6	.I	9	1.5	.I	56	0.6	0.3	1.0
25.Cruciferae	31	2.3	.II	19	1.7	.I	9	1.5	.I	59	0.6	0.3	1.0
26.Plantago	61	4.6	.III	26	2.4	.II	17	2.9	.II	104	0.8	0.6	2.1
27.Galium	130	9.8	.V	128	12.0	.VI	68	11.7	.VI	326	4.3	2.2	4.4
28.Typha	74	5.5	.III	73	6.8	.IV	53	9.1	.V	200	2.4	1.7	2.5
29.Thalictrum	65	4.9	.III	55	5.1	.III	30	5.1	.VI	150	1.8	1.0	2.2
30.NymphaXa	67	5.0	.III	61	5.7	.III	45	7.7	.IV	173	2.1	1.5	2.3
31.Lythrum	29	2.1	.II	30	2.8	.II	24	4.1	.III	83	1.0	0.8	1.0
32.Juniperus	48	3.6	.II	25	2.3	.II	3	0.5	.I	76	0.8	0.1	1.6
33.Xanthium	28	2.1	.II	25	2.3	.II	6	1.0	.I	59	0.8	0.2	0.9
34.Helianthemum	27	2.0	.I	15	1.4	.I	14	2.4	.II	56	0.5	0.5	0.9
Total frequency	1325	(98.6) =100%		1061	(98.2) =100%		581	(98.7) =100%		2961	(37.9)	(19.3)	(44.4)(98.6)

Presence Classes: .I = 0 -2.0% .IV = 6.1- 8.0%
.II = 2.1-4.0% .V = 8.1-10.0%
.III = 4.1-6.0% .VI =10.1-12.0%

Total X^2 (marginal prerequisites) = 120.93 $\{$ df = 2x33=66
Total G (test acceptable) =-160.52 p>.001

Differential species:
$X^2 = 20.2$
df = (2-1)(11-1)=10
$\chi^2_{10;.05} = 18.307 < X^2 = 20.2 < \chi^2_{10;.025} = 20.483$

Table III. Distribution of the presence of the additional species in the three clusters.

	Clauster C			Clauster A			Clauster B			
	Pres. fig.	Rel. Pres. (N=590)	Rel. Pres. (N=1342)	Pres. fig.	Rel. Pres. (N=474)	Rel. Pres. (N=1342)	Pres. fig.	Rel.Pres. (N=278)	Rel. Pres. (N=1342)	Total
Polygonum aviculare	30	5.1	2.2	17	3.6	1.3	9	3.2	0.7	56
Cruciferae	31	5.3	2.3	19	4.0	1.4	9	3.2	0.7	59
Plantago	61	10.3	4.6	26	5.5	1.9	17	6.1	1.3	104
Galium	130	22.0	9.7	128	27.0	9.5	68	24.5	5.1	326
Typha	74	12.5	5.5	73	15.4	5.4	53	19.1	4.0	200
Thalictrum	65	11.0	4.8	55	14.6	4.1	30	10.8	2.2	150
Nymphea	67	11.2	5.0	61	12.9	4.6	45	16.2	3.4	173
Lythrum	29	4.9	2.2	30	6.3	2.2	24	8.6	1.8	83
Juniperus	48	8.1	3.6	25	5.3	1.9	3	1.1	0.2	76
Xanthium	28	4.6	2.1	25	5.3	1.9	6	2.2	0.5	59
Helianthemum	27	4.6	2.0	15	3.2	1.1	14	5.0	1.1	56
	590	99.6	44.0	474	100.1	35.3	278	100.0	21.0	1342

Table IV. Clusterdifferentiation within the set of differential species.

teaus and mountains of northeasthern Anatolia, an area covered by steppe associations, and the steppe areas in the Soviet Union (*Walter*, 1974).

In the subassemblages B and C *Typha*, *Lythrum*, *Peplis* and *Menyanthes* are frequently found and they are accompanied by *Equisetum* and *Phragmites* (macro-remains). This assemblage is a characteristic for the alkalitrophic swamps and bogs in he Ukraine and Dnjepr area (*Walter*, 1974). These bogs and swamps are found in the forest-steppe and steppe zones. In our opinion a forest-steppe may be postulated from elements available in subasemblabe B. Whereas during the periods when subassemblage A appear the vegetation ressembles a grass-steppe.

In order to get an impression of the climatological implications we propose the following model. In our opinion we may compare our vegetation reconstruction with a transect in Turkey running from the Black Sea border to the inner Anatolia plateau (*Zohary*, 1973). (See the previous comparison of the interglacial vegetation with the Hyrcanian and Sub-Hyrcanian mesic forest). This implies that the climate for the interglacial forests may have a mean annual temperatura of 14° C (extreme max. of 39° C, and extreme minimum of–9° C). The rainfall is scattered over the year between 760 and 1260 mm.

The intermediate steppe and steppe-forest climate of zone B may be reflected by the climatological data of Ankara (*Walter et al.*, 1975; mean annual temperature 11.7° C, extreme mean of –24.9° C and rainfall of 341 mm concentrated in winter).

The climatical condition for the steppe vegetation comparable to pollen subassemblage A, may be postulated as follows: mean annual rainfall between 200-300 mm; extreme minimum temperature of about –26°C, mean January temperature of ca. –4.5° C. For the boundary steppe-forest/steppe we may use the isohyete of 450 mm rainfall (*Schmidt*, 1969).

DATING AND CORRELATION OF THE SECTION

In this part we will discuss the absolute dating of the section, the correlation with the deep-sea stratigraphy, and with the Northwestern European sequence.

The age of the Brunhes Matuyama boundary at 134 meters, the base of the Pangaion interstadial (pollen zone 13) at 120,000 years and the available ^{14}C-datings provide the points for the construction of a regression line showing sedimentation rate as a function of time. The result of the calculation is

$$y = -25{,}000 + 1090\ X \quad (R = 0.98)$$

Here y represents the age in years, x the depth of the section.

From this calculation and the coefficient of determination R, we can conclude that there exists a linear relation between depth and time.

With the calculated time-depth regression line it is possible to determine the age of the boundaries of the various pollenassemblages and also the age of the pollenspectra. After the establishment of the age of the various sample points it is possible to determine by interpolation the value of the total tree pollen content at an equidistant sample distance of ca. 2000 years. These sample values were used as an input for the time series analysis (see below).

If we use the age of the stage boundaries as defined by *Shackleton* and *Opdyke* (1976; see table V) and we compare these with the calculate age of the pollen zones as defined in table I, we can compare events in the Tenaghi Phillippon section with those in the deep-sea (see table VI). As shown in the table there is apparently a good agreement between the calculated age of the pollen zone boundaries and the deep-sea stage boundaries.

The maximum observed difference does not exceed 30,000 years at pollen zone boundaries 31-32.

Analysing the vegetation history we may conclude that all deep-sea stage boundaries can be matched with a change from steppe vegetation to forest vegetation and vice versa. The transition

Boundary	Depth in core (cm)	Age (B.P.)
1-2	25	13,000
2-3	45	32,000
3-4	72	64,000
4-5	82	75,000
5-6	127	128,000
6-7	190	195,000
7-8	235	251,000
8-9	275	297,000
9-10	320	347,000
10-11	345	367,000
11-12	377	440,000
12-13	430	472,000
13-14	462	502,000
14-15	500	542,000
15-16	567	592,000
16-17	635	627,000
17-18	660	647,000
18-19	715	688,000
19-20	725	
20-21	750	
21-22	777	
22-23	825	

Table V. Stage boundaries in core V28-239 (after Shackleton & Opdyke, 1976: 455).

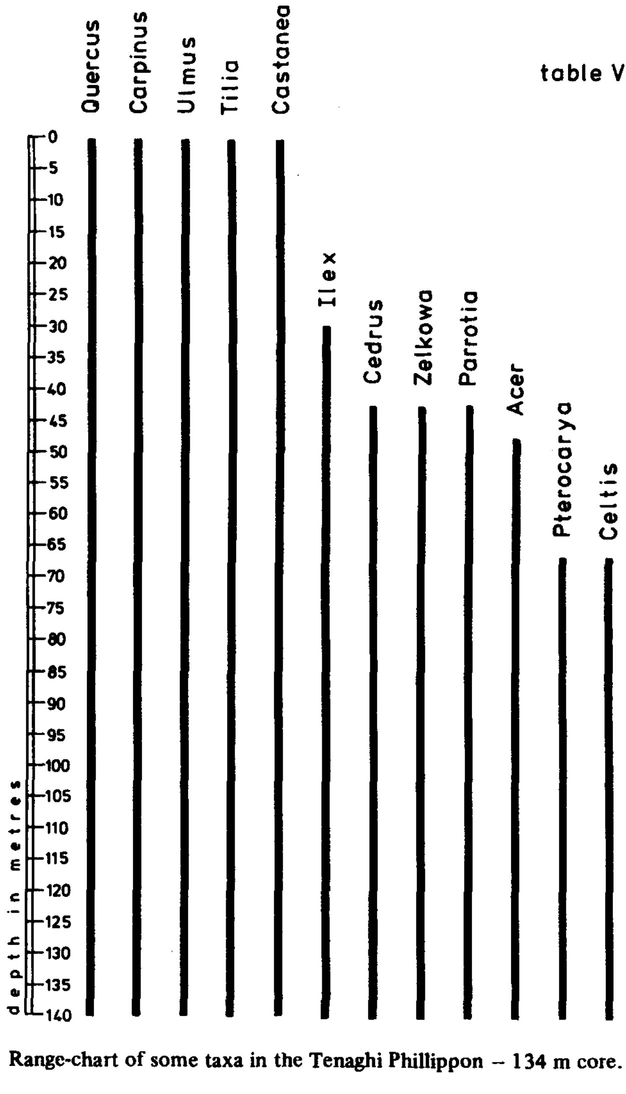
Pollen zone	Age	Depth Tenaghi Phillippon	Stage boundary	Age V28-239
3-4	13,500	5.70	1-2	13,000
6-7	28,000	11.20	2-3	32,000
7-8	54,000	17.00	3-4	64,000
8-9	64,000	21.00	4-5	75,000
13-14	125,000	34.80	5-6	128,000
14-15	200,000	43.00	6-7	195,000
17-18	246,000	51.10	7-8	251,000
20-21	294,000	59.50	8-9	297,000
23-24	330,000	65.90	9-10	347,000
24-25	348,000	68.80	10-11	367,000
25-26	400,000	78.10	11-12	440,000
26-27	445,000	85.90	12-13	472,000
27-28	497,000	95.00	13-14	502,000
30-31	536,000	101.90	14-15	542,000
31-32	562,000	106.00	15-16	592,000
32-33	621,000	116.80	16-17	627,000
33-34	649,000	121.80	17-18	647,000
34-35	701,000	131.00	18-19	688,000

Macedonia sequence

Deep-sea sequence

Table VI. Calculated age of pollen zone boundaries compared with the age of the deep-sea stage boundaries from core V28-239.

table VII



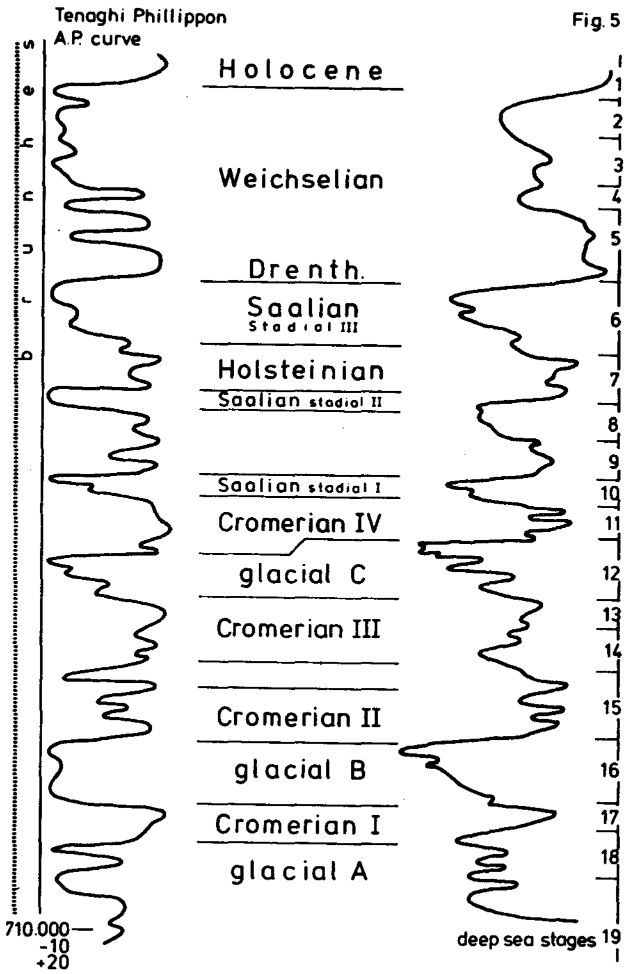
Range-chart of some taxa in the Tenaghi Phillippon – 134 m core.

at glacial stages 2, 6, 10, 12, 16 and the pollen zones 3-4, 13-14, 23-24, 25-26 and 31-32 took place very rapidly. Stages 4, 8, 14 and 18 do not show such a rapid change and neither do the vegetation changes.

For a correlation with N.W.-Europe table VII is of importance. In this table the range of some important forest elements is put out. From this table it may be noticed that *Parrotia, Zelkova* and *Celtis* can be found up to pollen zone 15. Pollen of the *Quercus robur/pubescens* type is present throughout the whole section. This is also the case for *Ulmus, Carpinus betulus, Tilia, Castanea* and *Fagus. Rhododendron* is restricted to pollen zone 13 (29-35 m), while *Ilex* is found for the last time in this zone.

For correlation of pollen zone 15 with the Holsteinian the presence of especially *Parrotia* and *Celtis* may be used. *Erd* (1966) pointed out that in N.W.-Europe *Celtis* was found for the last time in an interglacial of Holsteinian age. After pollen zone 15 we could not find *Celtis* and hence we suggested to correlate pollen zone 15 with the Holsteinian. The absence of *Pterocarya,* a species also to be expected in an interglacial of Holsteinian age, can be explained by the absence of a suitable biotope for the species. This correlation is corroborated by the expected age of the Holsteinian of ca. 200,000-220,000 years (*Evans,* 1977). According to our calculation, pollen zone 15 must fall between 195,000 and 220,000 years B.P.

As consequence of the previous correlation the two interstadials in zone 14 (L1 - L3; see table I)



Correlation of the continental forest-steppe vegetation phases and the deep-sea stages. In the middle part tentative correlation with the N.W. – European sequence.

are comparable to the interstadials of Bantega and Hoogeveen as defined by *Zagwijn* (1973).

Pollen zone 25 is the first pollen zone below the Holsteinian/Symvolon interglacial (pollen zone 15) which has also a characteristic interglacial character as may be deduced from its pollen content and vegetational reconstruction. This pollen zone 25 may be correlated with the 4th interglacial of the so-called Cromer complex (*Zagwijn*, 1975).

The steppe period of pollen zone 26 should then be correlated with the glacial C of Zagwijn. The next warm period consisting of pollen zones 27-31 is interrupted by two foreststeppe periods. This might be the equivalent of the so-called Cromer III interglacial in the sense of *Zagwijn* (1974). If the pollen zones 27 - 31 represent one single interglcial, this interglacial hence took some 100,000 years. This is the equivalent of a whole glacial cycle in the upper part (the Weichselian).

Pollen zone 32 has the characteristics of a full glacial cycle (the Weichselian) and can be correlated with the glacial B of the Netherlands (*Ruegg et al.* 1977).

Pollen zone 33 has an interglacial character and can be correlated with the so-called Cromer II of *Zagwijn* (1971).

With the previous data fig. 5 was constructed; this figure shows the correlation with the deep-sea stages and the Tenaghi section.

TIME SERIES ANALYSIS OF THE DATA

With the constructed time-base as explained in the previous section the time series was sampled at equidistant intervals. The estimates of the NAD/AP curve obtained in this way were used as input data. BMD provides a program for time series analysis (*Dixon*, 1976). The results of the analysis is shown in fig. 6. The presence of a 95.000, 43.000, 28.000 and 23.000 year period may be be noticed in this figure. When we compare these periods with the periods propose by *Hays et al.* (1976) we find a good correspondance at the 95.000 and 43.000 year period. The 28.000 and 23.000 year period shows some difference with the results of *Hays et al.* (1976). This slight dissimilarity can be explained by the difference in latitude. For the analysis of their data *Hays et al.* (1976) used the summer insolation curve for 60° N, while our site is situated at 41° N. Insolation curves for different latitudes are shown in *Imbrie et al.* (1980; fig. 3) and a clear shift of insolation minima can be noticed.

This is the first time that similar frequencies corresponding to variations in the earth's orbit are discovered as a response in a continental vegetation differentiation in time. It is known from *Hays et al.* (1976) that these frequencies are already recognised from deepsea records for some time. In our opinion the striking correlation between these two independent sets of data from the deep-sea and the continental Tenaghi cores, resulting in similar observed frequencies, support a better foundation of the astronomical theory of the Pleistocene Ice Ages. This theory implies that the earth's orbital variations influence climate by changing the seasonal and latitudinal distribution of the incoming solar radiation.

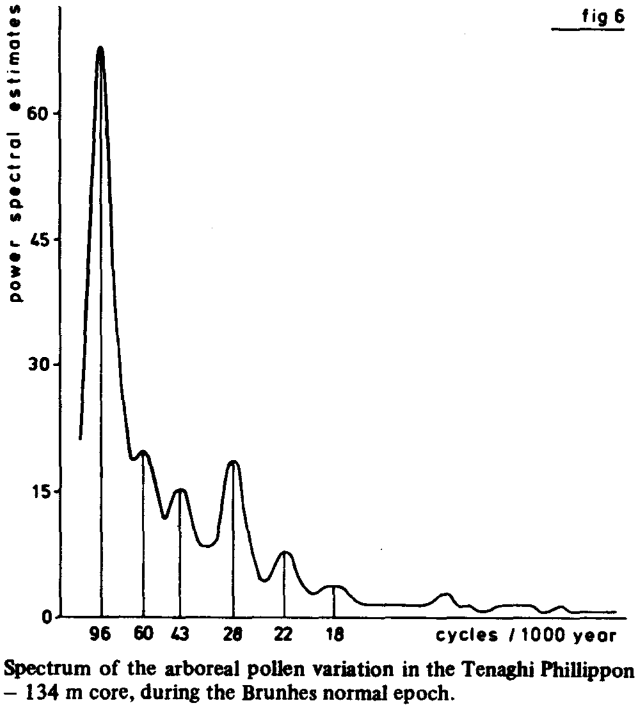


fig 6

Spectrum of the arboreal pollen variation in the Tenaghi Phillippon – 134 m core, during the Brunhes normal epoch.

CONCLUSIONS

A survey of the palynological data as put forward in this article resulted in a 730,000 years vegetation history of the eastern mediterrenean area. During this time-interval a regular alternation of steppe phase and forest phase could be demonstrated. During the time-interval in research at first a close accordance with the Hyrcanian mesic forest in the sense of *Zohary* (1973) could be demonstrated by the presence of *Parrotia, Zelkova, Pterocarya, Celtis,* etc. In the last and before the last interglacial this forest-type was replaced by a less luxurious oak forest. This might be due to the frequent interruption by steppe vegetation during the glacials, resulting in a gradual extermination of more demanding forest tree components.

In the steppe periods a sequence can be noticed from a grass steppe to an *Artemisia-Chenopodiaceae* steppe, indicating a decline in precipitation. In the Weichselian the periods with the severe decline in precipitation are dated between 20,000 and 14,000 and round about 70,000 14_{C} years ago.

The presence of the Brunhes Matuyama boundary at 134 meters in our section provided an approximate dating of the various biozones. This resulted in a good correlation with the deep-sea sequence.

A still tentative correlation with the N. W. –European sequence was also put forward in this article. This correlation is based on the approximate absolute datings of the various stratigraphic units, and the last appearance of *Celtis.* Still the most difficult problem is the correlation of the N.W. –European Lower Middle Pleistocene sequence with the Tenaghi-zonation. This is partly due to the fact that in N.W. –Europe the record is strongly influenced by the Saalian glaciation and partly by the fact that in the lower half of the Upper Pleistocene a long period without marked extension of the ice caps must be present.

The time series analysis of our data showed a good accordance with the deep-sea record periods as proved by *Hays et al.* (1976). The periods found in their study are also found present in the continental vegetation history of the Macedonian record. This points, in our opinion, to and extra terrestrial source, causing the correspondance in time of the major biological changes as observed on land and sea.

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