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Palynology of the Kılçak formation (Early Miocene) from Central Anatolia: Implications for palaeoclimate and palaeoenvironment

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Research Article

Keywords:
Palynology, palaeoclimate, early Miocene, Kılçak formation, Central Anatolia.

ABSTRACT

The palynological analysis of the early Miocene successions of the Kılçak formation (Central Anatoia, Turkey) was carried out in order to reconstruct the palaeovegetation. The pollen spectra indicate a flora dominated by Pinus, co-dominance of Cupressaceae in one of the investigated successions, and lower percentages of trees such as Taxodioideae within Cupressaceae, *Quercus* deciduous type, *Carya, Carpinus, Ulmus*, Engelhardioideae, *Salix, Alnus* and *Juglans*. Herbs are represented by minor amounts of Poaceae, Amaranthaceae/Chenopodiaceae and Asteraceae. This flora indicates the presence of a Taxodium topogenous mire with a nearby riparian vegetation and broadleaved deciduous mixed forests developed in the surrounding distant mountainous areas. δ^{13}C analysis shows that the vegetation was dominated by C3 plants. The Kılçak palynoflora reflects a humid, warm-temperate climate being compatible with the global warm conditions maintained during the early Miocene.

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1. Introduction

The Kılçak formation is the oldest Neogene unit in the Çankırı Basin (Central Anatolia) and exposed in a small area only around Kılçak village (Figures 1 and 2). The Kılçak locality is one of the well-known rodent-type sections in the Eastern Mediterranean and the age of the unit is tightly constrained by the rodent fauna (Bruijn and Saraç, 1992; Bruijn et al., 1993; Bruijn and Koenigswald, 1994; Ünay, 1994; Hoek Ostende, 1992, 1995*a* and *b*). However, the section from which fossils were collected, is at present completely covered by landslides (Kaymakçı, 2000).

The lens-shaped and thin (up to 30-cm- thick) coal lenses nearby Kılçak village were exploited by villagers but due to the low calorific value of the coal and due to landslides the mining actvities were stopped. The Kılçak fauna was originally described by a German team in the late 1960s from an open-pit lignite mine (Sickenberg et al., 1975). The deposits which yielded the Kılçak faunas have been included in different formations by different researchers. Şen et al. (1998), were the first to propose that the fossiliferous deposits at Kılçak must be distinguished as a different stratigraphic unit. Subsequently, Kaymakçı (2000) made the first formal definition of the Kıçak formation and outlined its lithological characteristics along a reference section located 1 km east of the Kılçak village (Figure 3). Rodent samples collected from this section, were studied by Hans de Bruijn and fitted to the MN-1 and the lower part of the MN-2 zones corresponding to the lower part of the early Miocene (Aquitanian) (Kaymakçı, 2000). Later, Özcan (2003) demonstrated that the Kılçak formation also crops out at a different site than the one originally described at the Kılçak village (Figure 2). From this outcrop Karadenizli et al. (2004) studied a stratigraphic section (Sülüklü Göl) and assigned an age of MN 1-3 (early Miocene) based on the following mammal fossils: *Galerix* sp., *Soricidae*

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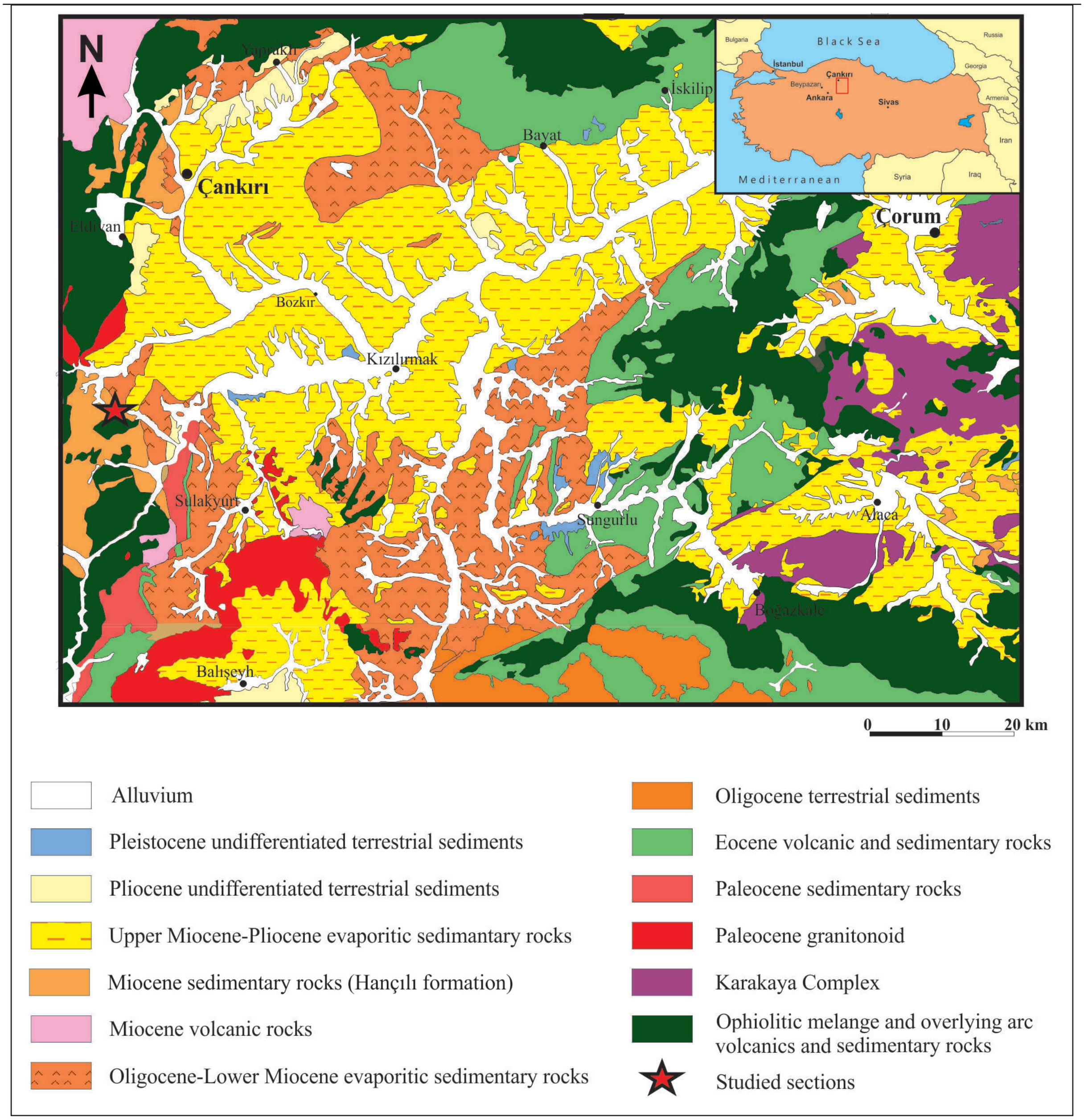

Figure 1- Geological map of the Çankırı-Çorum Basin (modified from MTA 2002).

indet., *Albertona* nov. sp., *Ctenodactylidae* indet., *Debruijnia* sp., *Spanocricetodon* sp., *Democricetodon* sp., *Megacricetodon* sp., and *Cricetodon versteegri* (identification by Gerçek Saraç).

The current study presents the first palynological and stable isotope ($\delta^{13}C$) analyses carried out on samples collected from organic-rich layers along the measured sections, from which rodent samples had earlier been collected and identified. A main aim of this study is to discuss environmental and climatic conditions during the early Miocene deposition of the Kılçak formation.

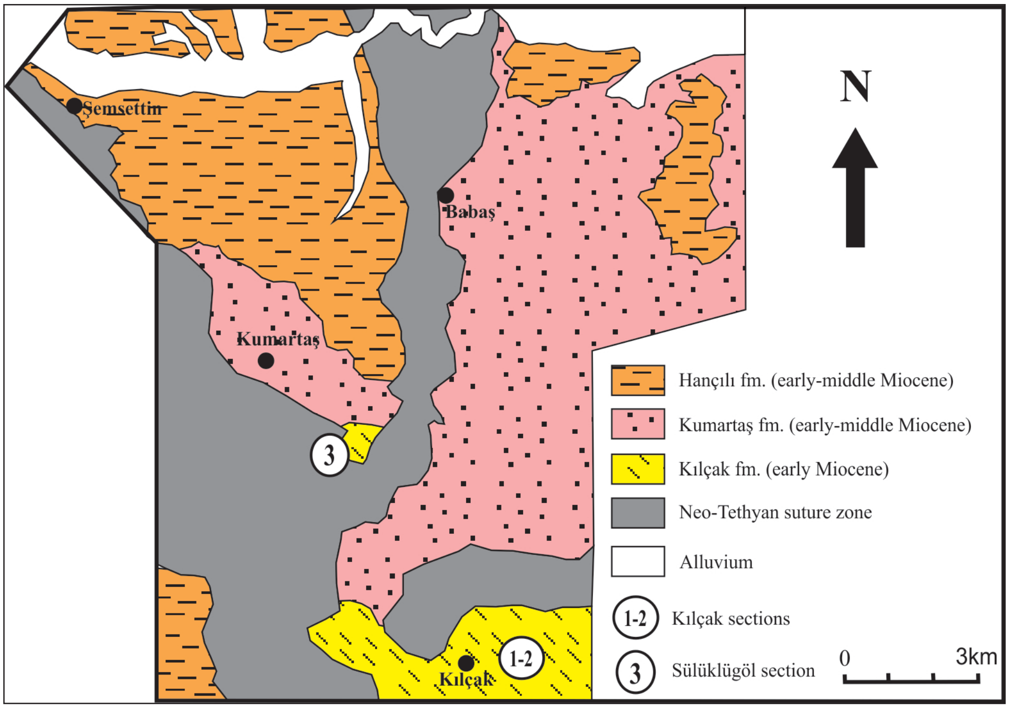

Figure 2- The distribution of the Kılçak Formation (Karadenizli et al., 2004).

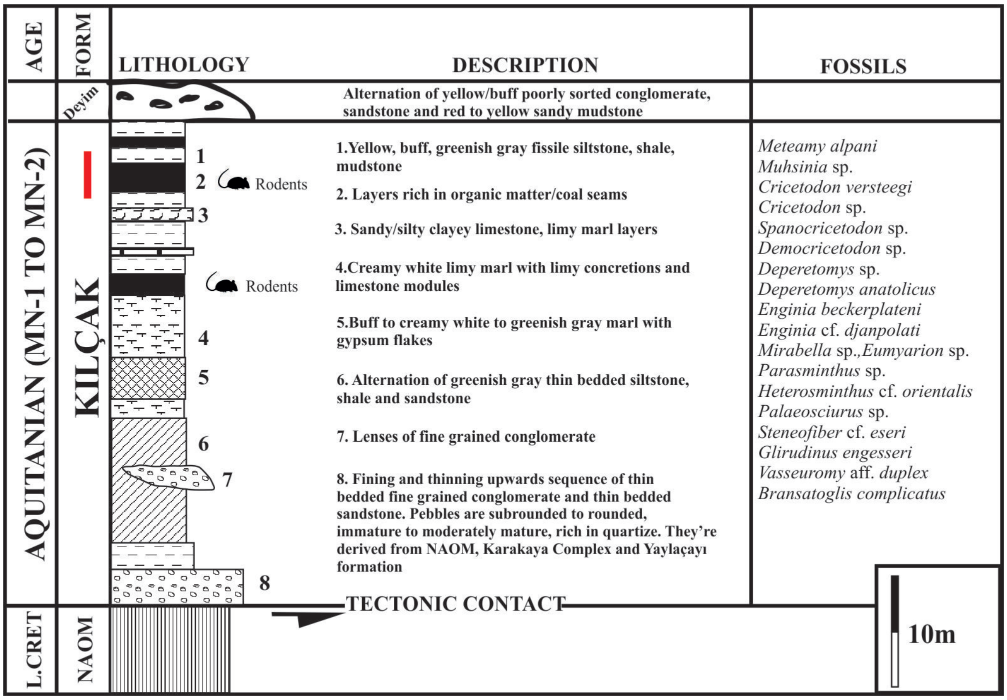

Figure 3- Generalized section of the Kılçak Formation (Kaymakcı, 2000). Red line indicates tentative corelation of Kılçak sections.

2. Geological Setting

The Çankırı Basin lies within the İzmir-Ankara-Erzincan suture which demarcates the former position of the northern branch of the Neo-Tethyan Ocean (Kaymakçı, 2000). The Çankırı fore-arc basin was formed by northward subduction of the Neo-Tethyan Ocean floor beneath the Sakarya continent (Figure 4). During the Late Palaeocene-Early Eocene it was covered by a transgressive sea. Beginning in

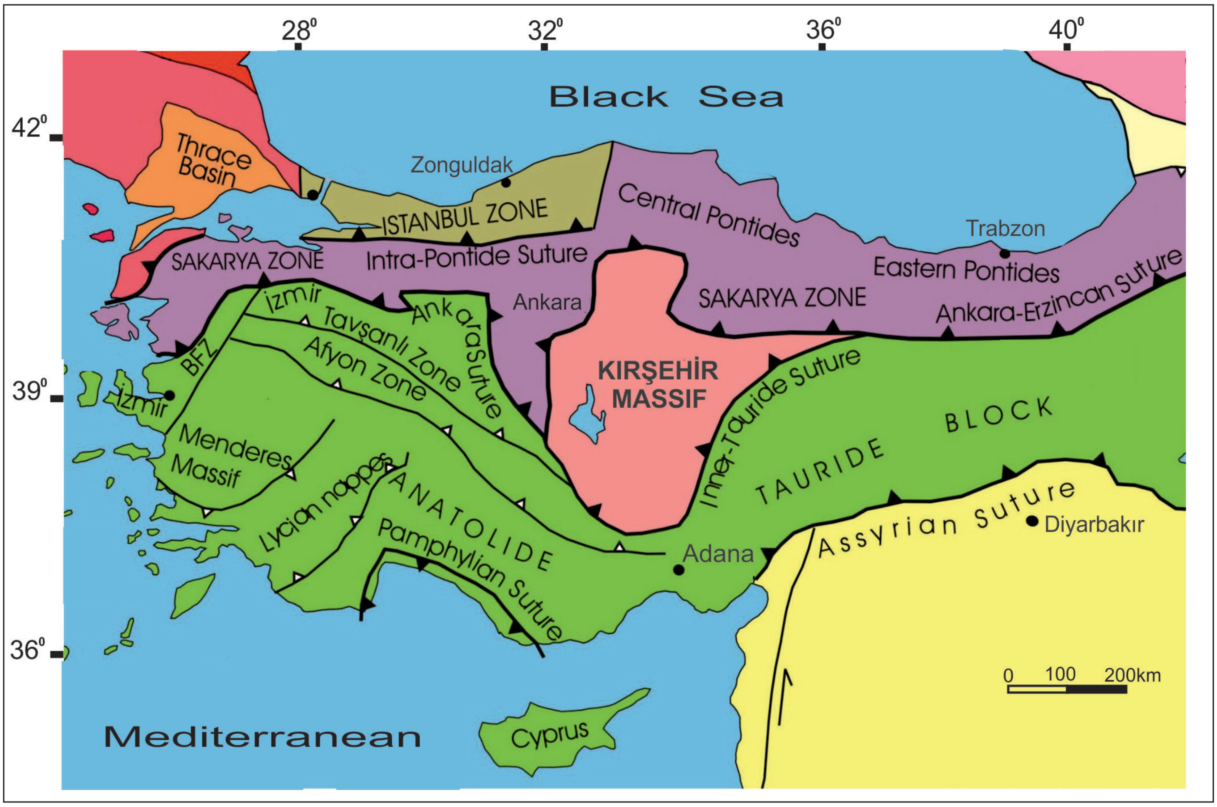

Figure 4- Tectonic map of Turkey and the surrounding areas (Okay and Tüysüz, 1999). The omega shape of the Ankara-Erzican Suture, confining the upper boundry of the Kırşehir Massif, defines the approximate boundary of the Çankırı Basin.

the Middle Eocene, mainly south-vergent thrusts developed around the Çankırı Basin. Due to the compressional regime older units surrounding the basin thrusted over younger in-fills, the basin rose, shallowed up and became a continental intermontane basin. During the Late Eocene-Oligocene terrestrial deposits and evaporites were deposited. It was characterized by alluvial fans during Oligocene while evaporitic lake deposits were formed during the Late Miocene-Pliocene (Tüysüz and Dellaloğlu, 1994) (Figure 4).

The Early Tertiary lithologies of the Çankırı Basin include units formed and deposited in various tectonic/depositional settings, ranging from accretionary wedge, fore-arc, to inter-arc to collisional settings. The collision and indentation of the Kırşehir Block with Sakarya Continent in the Late Paleocene to Oligocene gave rise to an anticlockwise rotation of the western rim and a clockwise rotation of the eastern rim, which subsequently resulted in the Ω-shape of the Çankırı Basin (Kaymakçı, 2000) (Figure 4).

The oldest Neogene unit in the Çankırı Basin is the Kılçak formation of Aquitanian age. It is followed in order of younging, by the Altıntaş formation of Burdigalian age, the Hançılı formation of Burdigalian to Langhian age, the Çandır formation of Burdigalian (?) to Serravalian age, the Bayındır formation of Tortonian age, the Kızılırmak formation of Messinian to Pliocene age, the Bozkır formation of early Pliocene age and the Değim formation of early Quaternary age (Kaymakçı, 2000).

The Kılçak formation, the focus of this study, was deposited during a phase of compressive deformation which terminated synchronous with the end of Kılçak deposition. The Kılçak formation unconformably overlies the pre-Neogene units and is tectonically overlain by the North Anatolian Ophiolitic Melange (Kaymakçı, 2000).

3. Materials and Methods

Since landslides are very common in the Kılçak area, great caution is needed to collect *in situ* samples. A total of thirty three samples from two undisturbed sections very close to the faunal level of Kaymakcı (2000) and sixteen samples close to the mammal locality of Karadenizli et al. (2004) were collected (Figure 5, 6A, B). The number of palynologically

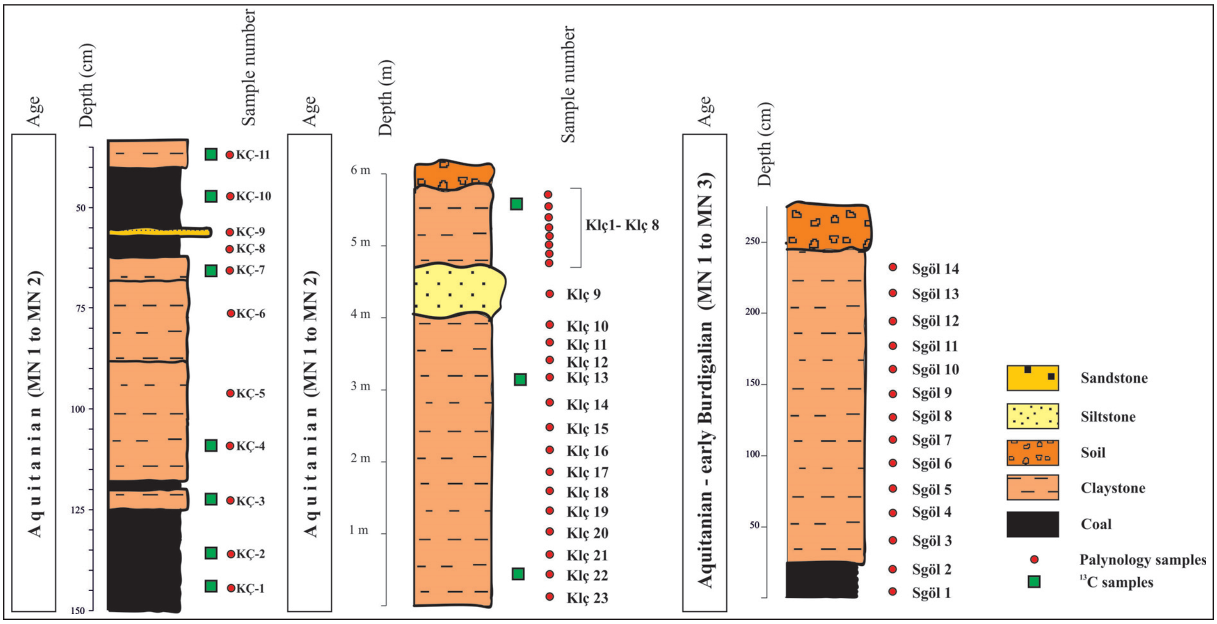

Figure 5- Kılçak-1, Kılçak-2 and Sülüklügöl stratigraphic sections.

Figure 6- A) Close up view of Kılçak-1 section. B) Close up view of Kılçak-2.

productive samples are nine out of eleven from the Kılçak-1 section (X:534282, Y:4451640), four out of twenty three from the Kılçak-2 section (X:533438, Y:4451831), and nine out of fourteen from the Sülüklügöl section (X:533800, Y:4456649).

Samples for pollen analysis were prepared using standard palynological techniques, in the Palynology Laboratory of the General Directorate of Mineral Research and Exploration. This included successive treatment with HCl, HF and KOH. After each acid treatment, the samples were washed with distilled water. Separation between organic and inorganic fractions was achieved using a $ZnCl_2$ solution of a density of 2.10 g/cm^3. The residue was sieved at 10 μm using a nylon mesh, mixed with glycerine, and mounted on microscope slides. Counting was performed at 400× magnification to a minimum pollen sum of 200 pollen grains with a Nikon Eclipse-Ni transmitted light microscope. The identification of pollen grains was accomplished to the lowest taxonomic level possible by comparing the fossils with their present-day relatives using pollen atlases and the keys of Faegri and Iversen (1989) and Moore et al. (1991). Detailed pollen diagrams (Figures 7, 8 and 9) using the programmes TILIA and TILIA GRAPH (Grimm, 2005) and a synthetic pollen diagram (Suc, 1984) taking into account ecological and climatic requirements of plants were constructed (Figure 10). In the synthetic pollen diagram taxa were grouped according to their ecological properties following Fauquette et al. (2006) and Jimenez-Moreno (2006).

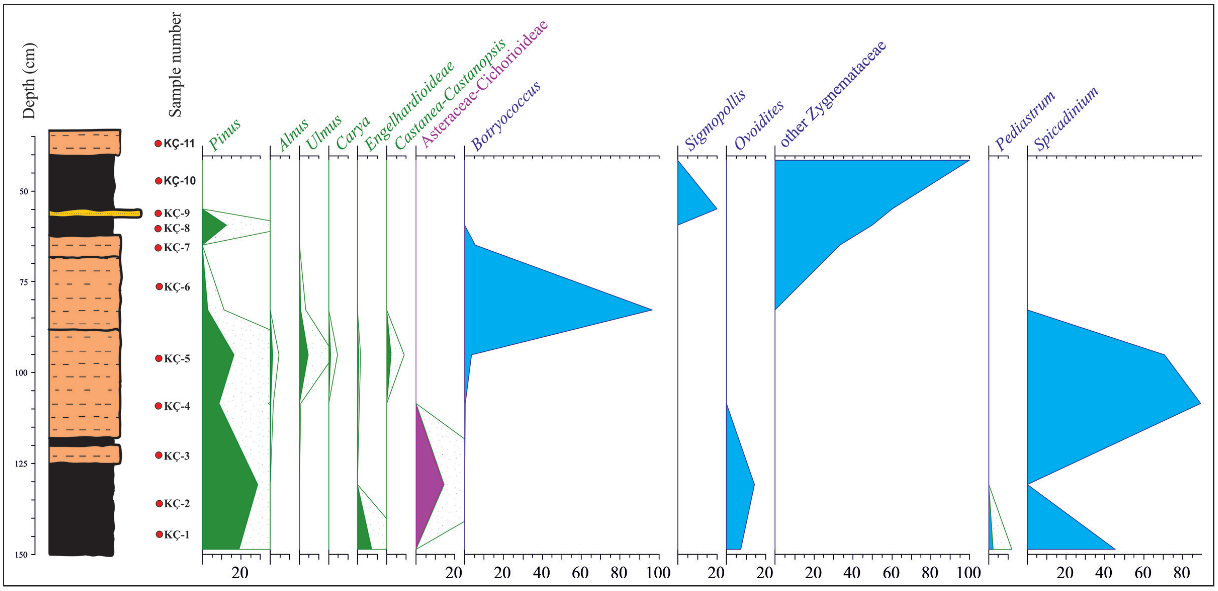

Figure 7- Palynological diagram of Kılçak-1 stratigraphic section.

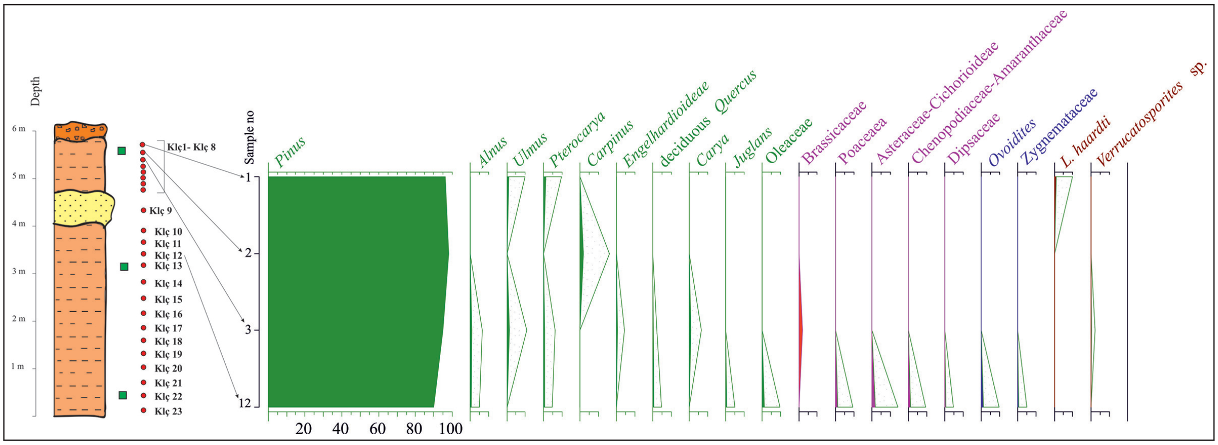

Figure 8- Palynological diagram of Kılçak-2 stratigraphic section.

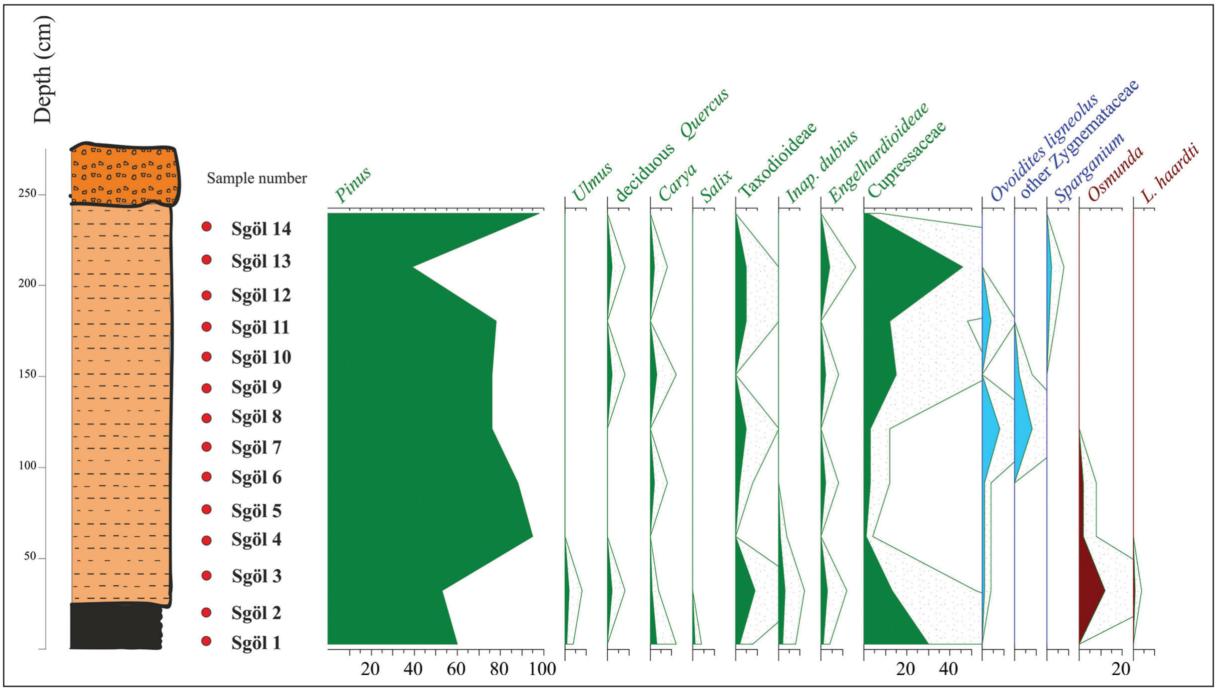

Figure 9- Palynological diagram of Sülüklügöl stratigraphic section.

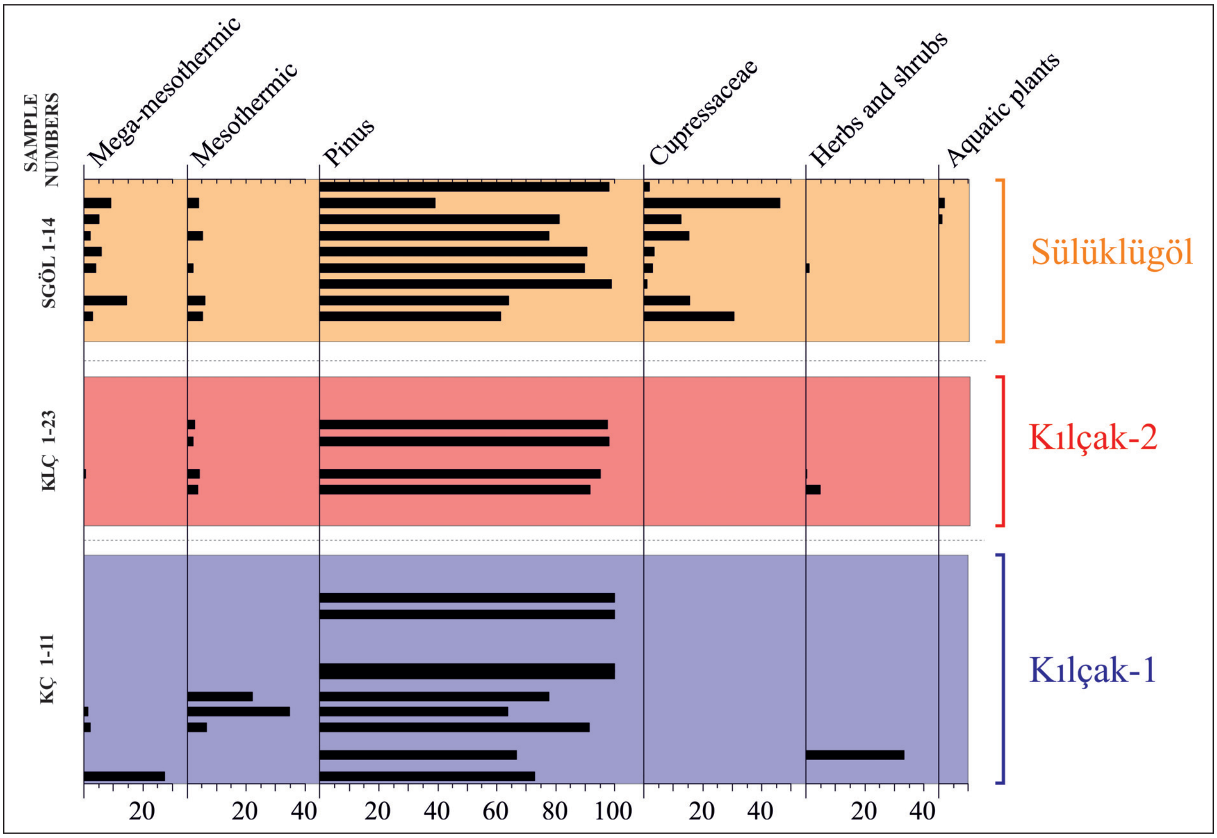

Figure 10- Synthetic pollen diagram of Kılçak-1, Kılçak-2 and Sülüklügöl stratigrahic sections.1. Mega-mesothermic (=subtropical) elements (Taxodioideae, Engelhardioideae, *Carya*); 2. Mesothermic (=warm-temperate) elements (deciduous *Quercus, Pterocarya, Carpinus, Juglans, Ulmus, Alnus, Salix*, Oleaceae, *Castanea–Castanopsis* type); 3. *Pinus* and poorly preserved Pinaceae; 4. Cupressaceae; 5. Herbs and shrubs (Poaceae, Asteraceae/Cichorioideae, Brassicaceae, Chenopodiaceae/Amaranthaceae, Dipsacaceae); 6. Aquatic plants (*Sparganium*).

Microphotographs of selected palynomorphs are given in plate 1.

Seven samples from the Kılçak-1 section and three samples from the Kılçak-2 section were selected for stable isotope analysis (Figure 5). $\delta^{13}C$ determinations were carried out on a continuous-flow gas-ratio mass spectrometer (Finnigan Delta PlusXL) coupled to an elemental analyzer at the Enviromental Isotope Laboratory in University of Arizona. Analytical precision was better than ±0.08‰. Calibration to the VPDB standard was performed by repeated measurements of international reference standards NBS-19 and NBS-18.

Mosbrugger and Utescher (1997) proposed a method, the Coexistence Approach (CA), for quantitative reconstructions of Tertiary terrestrial palaeoclimate data using plant fossils. This method widely accepted in the scientific community and numerous palaeoclimate reconstructions are done especially in European countries since the day of its publication. The method is based on the assumption that Tertiary plant taxa have similar climatic requirements to their nearest living relatives. The aim of the coexistence approach is to find for a given fossil flora and a given climate parameter the climatic interval in which all nearest living relatives of the fossil flora can coexist. According to the method, at least 10 taxa contributing climate data are required to obtain significant results. With respect to the low diversity of the palynomorphs, the CA was applicable on a summary record of Kılçak-2 (e.g. on a flora list combined from all Kılçak-2 samples). Data were calculated for mean annual temperature (MAT), cold and warm month means (CMT, WMT), mean annual precipitation (MAP), as well as monthly precipitation data for the wettest, driest and warmest months (MPwet, MPdry, MPwarm). All climate data calculated are given in table 1. With 19 taxa contributing with climate data and 100 % overlapping for each variable the analysis deliveres reliable results.

4. Results and Discussion

4.1.Palynoflora

Pinus fluctuates between 3 and 28% in the Kılçak-1 pollen diagram (Figure 7). Pollen of *Alnus, Ulmus, Carya,* Engelhardioideae and *Castanea-Castanopsis* participate with frequencies below 7% while that of Asteraceae-Cichorioideae by 14%. *Spicadinium* exist in the lower parts of the the Kılçak-1 section with a maximum of 89%. Zygnemataceae is present in the upper part reaching 100% at the very top of the section. *Ovoidites* and *Sigmopollis* are represented by lower percentages (7–20%). *Botryococcus* has its maximum (96%) in the middle part of the section. *Pediastrum* is present only at the bottom of the section (2%).

The Kılçak-2 pollen diagram is characterized by predominance of *Pinus* ranging from 90 to 98% (Figure 8). *Alnus, Ulmus, Pterocarya, Carpinus,* Engelhardioideae, deciduous *Quercus, Carya, Juglans*, Oleaceae are represented by low percentages (<2%). Brassicacaeae, Poaceaea, Asteraceae-Cichorioideae, Chenopodiaceae - Amaranthaceae and Dipsacaceae are present in the lower part of the section with low percentages (0-2%). Zygnemataceae and *Ovoidites* occur in trace amounts. Spores are represented by low percentages of *Laevigatosporites haardti* (Polypodiaceae) (<2%) and *Verrucatosporites* sp. (Polypodiaceae) (<1%).

The Sülüklügöl pollen diagram is dominated by *Pinus* that fluctuates between 39 to 98% with an average of 74% (Figure 9). Cupressaceae ranging from 1 to 46% are well represented and increase towards the top of the section. Taxodioideae fluctuates between 0 and 9%. *Ulmus* and *Salix* are present in the lower part of the section at low percentages (<2%). *Carya*, deciduous *Quercus* and Engelhardioideae have more uniform distributions ranging from 0 to 4%. Zygnemataceae and *Ovoidites ligneolus* reach their maximum (8%) in the middle part of the section. *Sparganium* is present only in the upper part (1 to 2%). *Osmunda* is well represented at the base of the section with a maximum of 12% while *Laevigatosporites haardti* (Polypodiaceae) occurs at very low amounts (1%).

4.2. $\delta^{13}C$ Analysis

The stable carbon isotope ratio difference for a sample relative to the PDB (Pee Dee Belemnite) standard is given as :

$$\delta^{13}C(‰)=[(R_{sample}-R_{PDB})/R_{PDB}]x1000$$

where R is the isotope ratio $^{13}C/^{12}C$. The Pee Dee Belemnite (PDB) being established as a standart for ^{13}C analysis, is based on a Cretaceous marine fossil (*Belemnitella americana*) found within the Pee Dee Formation in South Carolina. This material displays an anomalously high $^{13}C/^{12}C$ ratio (0.0112372); higher than nearly all other natural carbon-based substances.

Table 1- Coexistence Approach results of Kılçak-2 samples (Summary).

Fossil taxon	**Reference taxon**	MATmin	MATmax	CMTmin	CMTmax	WMTmin	WMTmax	MAPmin	MAPmax	MPWETmin	MPWETmax	MPDRYmin	MPDRYmax	MPWARMmin	MPWARMmax
dimension		°C	°C	°C	°C	°C	°C	mm	mm	mm	mm	mm	mm	mm	mm
Alnus sp.	*Alnus* sp.	-13,3	27,4	-40,9	25,6	4,9	38,6	160	2730	25	353	0	135	0	533
Asteraceae-Cichorioideae															
Brassiacaceae															
Carpinus cf. *betulus*	*Carpinus betulus*	5,3	17,6	-7,5	9,7	17,4	26,4	471	1958	56	236	1	85	6	219
Carpinus cf. *orientalis*	*Carpinus orientalis*	7,7	18,3	-5,3	10,9	18,6	27,6	402	1548	71	191	3	82	3	122
Carya sp.	*Carya* sp.	4,4	26,6	-11,5	22,2	19,3	30,6	373	1724	68	434	8	93	45	258
Castanea , *Castanopsis*	*Castanea* , *Castanopsis*	6,9	27,7	-8,2	27	14,5	28,9	473	10798	70	2446	2	165	1	1100
Chenopodiaceae, Amaranthaceae															
Cupressaceae	Cupressaceae	-15,6	26,5	-48,9	26,1	11,2	32,9	184	4486	22	409	0	326	0	378
Dipsacaceae	Dipsacaceae	-1,7	24,6	-25,4	23,6	16,2	29,4	24	1828	8	343	0	85	0	239
Engelhardioideae	Engelhardioideae	13,8	27	3,1	25	20,6	33,6	740	10798	150	2446	5	152	79	1100
Juglans sp.	*Juglans* sp.	0	27,5	-22,7	25	9,5	31,2	210	2617	28	582	1	114	2	189
Laevigatosporites haardtii															
Myriophyllum sp.	*Myriophyllum verticillatum*	-0,4	17	-21,7	10,3	13,9	26,3	422	2648	68	369	9	108	26	344
Oleaceae	Oleaceae	-1,1	27,7	-25,8	27	19,6	33,1	37	3293	8	985	0	165	0	320
Osmunda sp.	*Osmunda* sp.	0,2	27,4	-16,6	25,6	13,9	30,6	206	4150	34	914	0	89	2	228
Pinus sp.	*Pinus* sp.	-9,2	25,5	-36,8	21,4	7,1	32,9	180	10798	28	2446	0	94	0	1100
Poaceae															
Pterocarya sp.	*Pterocarya* sp.	3,9	24,2	-12,8	17	15,3	31,6	246	2648	46	424	1	64	2	424
Quercus sp. (deciduous)	*Quercus* sp. (deciduous)	-1,4	27	-25,1	25,9	8,4	28,3	201	10798	33	2446	0	180	5	1100
Quercus sp. (evergreen)	*Quercus* (evergreen)	11,7	19,5	0,4	13,3	18,8	26,1	224	1800	48	159	0	72	0	116
Salix sp.	*Salix* sp.	-17	27,7	-50,1	26,5	7,6	32,9	122	2399	22	448	0	108	0	252
Taxodioideae	Taxodioideae	3,8	25	-9,4	19,8	13,7	31,2	290	2615	60	448	0	114	3	431
Ulmus sp.	*Ulmus* sp.	-4,9	26,6	-25,8	26,1	16	29,4	201	3285	33	569	0	100	0	239
Verrucatosporites sp.															
CA results															
no. of taxa with climate data	19														
CA intervals															
min		13,8		3,1		20,6		740		150		9		79	
max		17		9,7		26,1		1548		159		64		116	
taxa coexisting (%)		100		100		100		100		100		100		100	

Therefore, for convenience, it is assigned a δ^{13}C value of zero, giving almost all other naturally-occurring samples negative delta values (http://siel.uga.edu/stable-isotope-overview).

The δ^{13}C values of the fine-grained and organic rich sediments of Kılçak formation are presented in table 2. The δ^{13}C values of the Kılçak-1 samples range between -24.6‰ and -25.8‰ with a mean of -25.1‰ while that of the Kılçak-2 samples range between -26.4‰ and -27.0‰ with a mean of -26.7‰. The δ^{13}C values of both Kılçak-1 and Kılçak-2 samples show minor fluctuations with very close mean values pointing to the persistence of C3 vegetation during the studied time-span.

Table 2- δ^{13}C values of bulk organic sediment samples from Kılçak, Central Anatolia. [a]Sample number assigned at Enviromental Isotope Laboratory, University of Arizona.

Lab. number[a]	**δ^{13}C (%)**
KC-11	-25.0
KC-10	-24.6
KC-07	-25.7
KC-04	-24.9
KC-03	-25.0
KC-02	-25.0
KC-01	-25.8
KLC-22	-26.7
KLC-13	-26.4
KLC-02	-27.0

The ^{13}C/^{12}C ratio in organic lake sediments depends on various factors (such as temperature, CO$_2$ supply, latitude effect, change in terrestrial vegetation, change in organic productivity etc.) affecting the ^{13}C content of the samples. The differences in ^{13}C/^{12}C ratio in terrestrial plants is the result of differences in the metabolic pathways during the synthesis of the plant material. The C3 metabolic pathway (the Calvin cycle) generally results in lower ^{13}C/^{12}C ratio than the C4 metabolic pathway (Håkansson, 1985). The range in δ^{13}C for C3 plants is from -33 to -22‰ and for C4 plants from -20 to -10‰ (Bender, 1971). The δ^{13}C values of the Kılçak samples indicate that vegetation was dominated by C3 plants during deposition.

One of the main reasons of lower δ^{13}C values of samples is the abundant presence of halophyts which are salt-resistant or salt-tolerant plants that thrive and complete their life cycles in soils containing high salt concentrations. Valero-Garces et al. (2000) indicated that low δ^{13}C values (mean -23‰) of samples of Salada Medina playa lake (Spain) are due to the presence of high amounts of Chenopodiaceae which have a very high salt-tolerance. The sporadic presence of halophytic Chenopodiaceae in the Kılçak samples shows that the reason of low δ^{13}C values are not halophytes but the dominance of C3 plants within the vegetation (Figure 11).

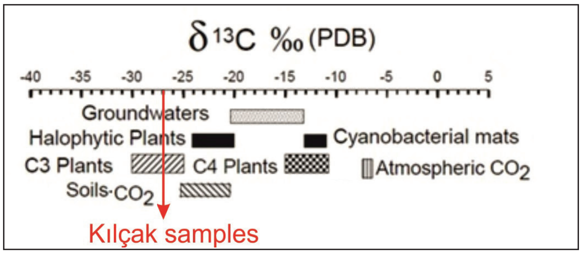

Figure 11- Sources of carbon in the Salada Mediana: C3 and C4 plants, halophytic plants, cyanobacterial mats, atmospheric CO$_2$ and soil CO$_2$. (Valero-Garces et al., 2000).

4.3.Paleoflora and Vegetation

The Kılçak-1 pollen diagram is dominated by freshwater algae. The identified algae are characteristic for stagnant (*Botryococcus* - Worobiec, 2010; *Ovoidites* - Rich et al., 1982; *Spicadinium* - Yi, 1997) or slowly flowing (*Sigmopollis* - Van Geel et al. 1983) shallow water. Zygnemataceae are among the most common algae in fresh waters. Most representatives of this cosmopolitan algal group occur in shallow, stagnant, clean, oxygen-rich waters (Worobiec, 2010). The Kılçak-1 pollen assemblage also has an arboreal component (*Pinus, Alnus, Ulmus, Carya,* Engelhardioideae*, Castanea-Castanopsis*) which must have constituted the surrounding vegetation of the freshwater lake/pond.

The Kılçak-2 pollen diagram records the presence of a tree association with the predominance of *Pinus* and a minor proportion of broadleaved trees (*Alnus, Ulmus, Pterocarya, Carpinus,* Engelhardioideae*,* deciduous *Quercus, Carya, Juglans*). Although *Pinus* is usually over represented in pollen diagrams because of its prolific pollen production and long distance transport (Denton and Karlen, 1973; Suc and Drivaliari, 1991; Traverse 2008), a mean value of 95 indicates the presence of an *in situ* pine forest. Minor amounts of Poaceae, Asteraceae-Cichorioideae and

Dipsacaceae probably reflect the understory within this forest. This mixed forest constituted the upland extention of the arboreal vegetation identified through the Kılçak-1 palynoflora.

The Sülüklügöl pollen flora is dominated by trees. *Pinus* dominates this flora with continuous presence of Cupressaceae and almost continuous presence of Taxodiaceae and Engelhardioideae. Cupressaceae pollen grains can not be identified to lower taxonomic levels. However, as frequency trends of Cupressaceae and Taxodioideae are similar, it is assumed that Cupressaceae were represented by taxa requiring warm and humid conditions, such as those (e.g., *Chamaecyparis*) living today in wetlands along the Gulf Coast of the United States (Mylecraine et al., 2004). The Sülüklügöl palynoflora indicates a topogenous mire vegetation.

The data obtained from this study indicates that during the early Miocene a *Taxodium* topogenous mire was developed in the Kılçak area near the lake shore. *Sparganium* represents a floral assemblage bordering the freshwater lake. Near the lake a riparian forest consisting of *Carya, Alnus*, *Salix* and *Pterocarya* was developed. This forest hosted some ferns characterized by the dominance of *Osmunda* and less *Laevigatosporites haardti* (Polypodiaceaea). The poor record of non-bisaccates of altogether (< 5 %) and the low diversity of arboreal taxa in general usually indicate the absence of local forest vegetation. However, there were tree associations composed dominantly of *Pinus* and broadleaved angiosperms (Engelhardioideae, *Carpinus*, *Castanea-Castanopsis*, deciduous *Quercus, Juglans* and *Ulmus*), and a herbaceous ground cover (Gramineae and Chenopodiaceae/Amaranthaceae).

Neogene swamp forest with Taxodioideae, alike Sülüklügöl, as main components and associated mainly with Cupressaceae, *Nyssa* and *Glyptostrobus* are identified from many European basins by palynological studies (Stach et. al., 1982; Nagy, 1992*a,b*; Kohlman-Adamska, 1993; Popescu, 2001; Yavuz-Işık, 2007; Yavuz-Işık and Demirci, 2009; Larsson et al., 2011; Ivanov and Worobiec, 2017; Biltekin, 2017). Kohlman-Adamska (1993) stated that pollen analysis of the Neogene deposits from the Wyrzysk region (north-western Polland) revealed the presence of a Taxodiaceae-Cupressaceae forest with *Taxodium, Nyssa, Glyptostrobus, Alnus, Salix, Betula, Palmae*, Polypodiaceae, Osmundaceae, Cyperaceae, Gramineae and *Typha* associated with a mixed deciduous-coniferous forest, a riparian forest, a mire and wetlands.

4.4. Palaeoclimate Implications

Wick (2000) showed that terrestrial plant ecosystems respond fairly well to environmental changes and minor climatic fluctuations are significantly more distinct in the pollen record than in other proxy data. Thus the consistent and continuous occurrence of mega-mesothermic and mesothermic plants within the Kılçak area (Figure 10) points to a subtropical to warm temperate climate.

Mega-mesothermic elements are rich in early Miocene coal-forming basins of Europe (Takahashi and Jux, 1991; Kohlman-Adamska, 1993; Kvacek, 1998; Kolcon and Sachsenhofer, 1999; Yavuz-Işık, 2007; Kayseri-Özer 2013; Bouchal et. al., 2016, 2017). *Taxodium* and *Glyptostrobus* are main components of these mire forests. Today *Taxodium distichum* is present in the coastal mires of northeastern America (Thompson et al., 1999) and *Glyptostrobus* grows in swampy lowlands within the evergreen broad-leaved forest in China (Chen and Chen, 1998).

Comprehensive palaeobotanical and palynological studies conducted on Miocene assemblages of Europe (Thomson and Pflug, 1953; Sadowska, 1997; Figueiral et al., 1999; Kolcon and Sachsenhofer, 1999; Magyar et al., 1999; Nagy, 1992*a*; Ivanov et al., 2002, 2011; Erdei et al., 2007; Bouchal et. al., 2016, 2017), show that generally a warm temperate vegetation prevailed, with a humid/semihumid character, influencing the changing floras during the Miocene. In wet areas, mire-forest associations thrived (Utescher et al., 2007) like that of the Kılçak area.

CA results reveal warm temperate, humid climate conditions, with MAT ranging from 13.8–17 °C, CMT from 3.1 to 9.7 °C and WMT from 20.6 to 26.1 °C, with Engelhardioideae in each case determining the lower CA interval limits (Table 1). The high MAP (740–1548 mm), MPwet (150–159 mm), and MPwarm (79–116 mm) values also relate to the presence of Engelhardioideae (Table 1). In the early Miocene, the Kılçak area experienced warm temperate (MAT ~14–20 °C), overall humid (MAP ~750–1500 mm) conditions of a C Koeppen climate type (Kottek et al., 2006).

Ivanov et al. (2011) examined Miocene vegetation and climate dynamics in the Eastern and Central

Paratethys and stated that early Miocene climate was warm and humid with MAT values mainly above 16 °C and annual rainfalls over 1000 mm. Akkiraz et al. (2011) calculated palaeoprecipitation values, based on palynoflora, specifically for Turkey, and stated that MAP exceeded 1200 mm during the Aquitanian and early-middle Serravallian. The authors also calculated the precipitation of the driest month (LMP) and suggested values between 36 and 48 mm which indicates humid conditions in the Aquitanian. Akgün et al. (2007) stated that warm subtropical climatic conditions prevailed in western Anatolia during the Chattian and Aquitanian periods with MAT values between 16.5–21.3 °C. Additionally, Yavuz-Işık et al. (2011) stated that the MAP was between 1000 and 1100 mm and the MAT was between 14.6 and 16.6 °C in the early-middle Miocene by examining sedimentary sequences of Eskihisar lignite mine (Muğla, SW Anatolia). Kayseri-Özer (2013) calculated MAT values between 13.3–20.8 °C and MAP between 1122–1595 mm based on early Miocene palynoflora identified from Muş area (eastern Anatolia). The climatic conditions reflected by the early Miocene Kılçak palynoflora is in accordance with the aforementioned studies.

5. Conclusions

The palynological data of Kılçak and Sülüklügöl sections enabled the reconstruction of the vegetation and climate in the Kılçak area during the early Miocene.

The Kılçak-1 section was dominated by fresh water alga. The vegetation of this section has moderate amount of *Pinus* (max. 28%) and lesser amounts of deciduous trees and Asteraceae. The vegetation in the Kılçak-2 section was dominated by *Pinus* with minor occurrences of broadleaved trees (*Alnus, Ulmus, Pterocarya*, *Carpinus orientelis, C. betulus,* deciduous *Quercus*, evergreen *Quercus, Carya, Castanea, Juglans, Salix*, Oleaceae) and herbs (Brassicacaeae, Poaceaea, Asteraceae-Cichorioideae, Chenopodiaceae-Amaranthaceae, Dipsacaceae). The vegetation in the Sülüklügöl section was dominated by *Pinus* with moderate amount of Cupressaceae and lesser amounts of Taxodioideae, Engelhardioideae, *Ulmus, Salix, Carya* and deciduous *Quercus*.

All in all, the late Miocene Kılçak flora reflects presence of a freshwater body (with *Spicadinium*, Zygnemataceae, and *Botryococcus*) surrounded sparsely by Gramineae and Chenopodiaceae and associated with a riparian vegetation (*Carya, Alnus*, *Salix* and *Pterocarya*) and tree associations composed of *Pinus* and warmth-loving Angiosperms. Such vegetation suggests a humid, warm temperate climate for the Kılçak area as supported by the CA analysis (MAT ~14–20 °C and MAP ~750–1500 mm). The δ^{13}C values (between −24.6‰ and −27.0‰) indicate a predominance of C3 plants.

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PLATE

Plate

1. *Laevigatosporites haardti* (Sülüklügöl)

2. Trilete spore (Sülüklügöl)

3. *Osmunda* (Sülüklügöl)

4. *Pinus* (Sülüklügöl)

5. *Pinus* (Kılçak)

6. Taxodioideae (Sülüklügöl)

7. Cupressaceae (Sülüklügöl)

8. *Carya* (Sülüklügöl)

9. Engelhardioideae (Sülüklügöl)

10. *Ulmus* (Kılçak)

11. *Fagus* (Kılçak)

12. *Sparganium* (Sülüklügöl)

13. a,b) Dipsacaceae (Kılçak)

14. *Botryococcus* (Kılçak)

15. *Spicadinium* (Kılçak)

16. Zygnemataceae (Sülüklügöl)

17. *Spirogyra* (Sülüklügöl)


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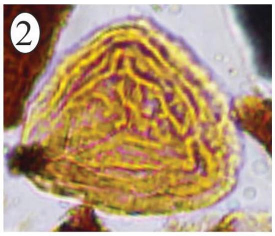
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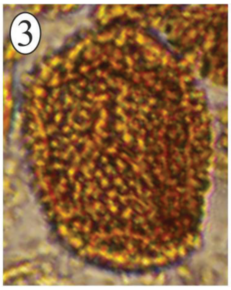
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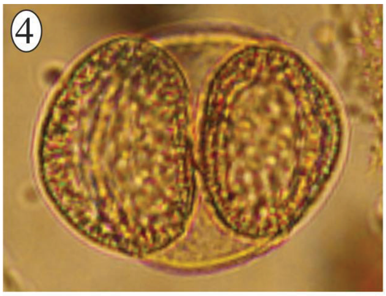
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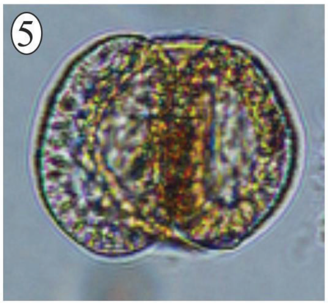
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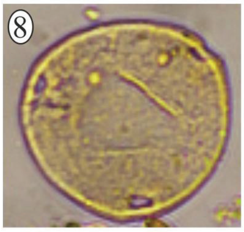
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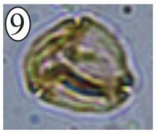
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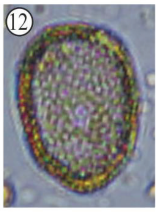
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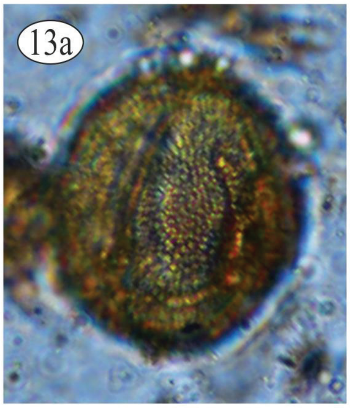
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13b


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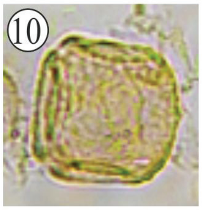
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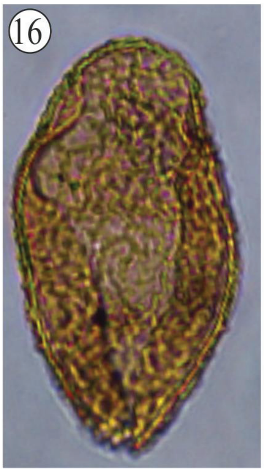
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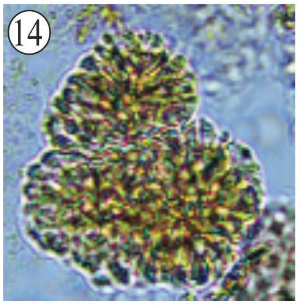
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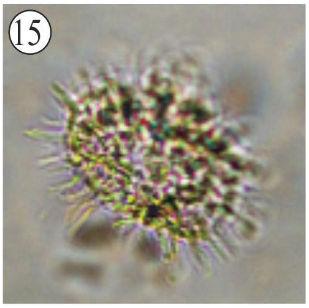
15