

Palaeontological evidence and sedimentary facies in a lower Miocene (Aquitanian) succession from the Bingöl minibasin (Sivas Basin), Central Anatolia

Mehmet Serkan AKKİRAZ^{1*}, Özgen KANGAL², Nazire ÖZGEN ERDEM², Yeşim BÜYÜKMERİÇ³, Cihan DOĞRUÖZ⁴

¹Department of Geological Engineering, Faculty of Engineering, Dumlupınar University, Kütahya, Turkey

²Department of Geological Engineering, Faculty of Engineering, Cumhuriyet University, Sivas, Turkey

³Department of Geological Engineering, Faculty of Engineering, Bülent Ecevit University, Zonguldak, Turkey

⁴Department of Mining Engineering, Faculty of Engineering, Dumlupınar University, Kütahya, Turkey

Received: 25.10.2017 • Accepted/Published Online: 13.05.2018 • Final Version: 28.09.2018

Abstract: The results of palaeontological (palynological and mollusc) and sedimentological analyses of the lower Miocene deposits from the Bingöl minibasin, a part of the Sivas Basin, are exhibited to define the vertical shifts in sedimentation environments and plant covers, linking to eustasy. The presence of index species *Corbulomya (Lentidium) aquitanica* suggests an Aquitanian age for the studied succession, which can be divided into three informal units: a lower unit, a middle unit, and an upper unit. Fine-grained sediments of the lower unit were deposited in a low sea-level setting due to high quantities of terrestrial palynomorphs. This unit is overlain by the middle unit, coralline limestone, which marks the first initiation of Aquitanian transgression. Continuing shallow marine settings in the upper unit gave rise to deposition of coarse to fine-grained sediments. Palynological data were recovered from the fine-grained sediments of the lower and upper units. A total of 35 spore and pollen taxa were recorded, including 2 spores from ferns, 5 gymnosperms, 26 angiosperms, 1 group of undifferentiated dinoflagellate cysts, and 1 fresh water alga of *Botryococcus* sp. The pollen spectrum is dominated by coniferous forest, mainly undifferentiated Pinaceae, and herbaceous communities including high quantities of Poaceae and Chenopodiaceae-Amaranthaceae, with minor contributions of *Ephedra* sp., Caryophyllaceae, and Asteraceae subf. Asteroidae. High sea-level conditions, which started with sedimentation of the middle unit, survived during the deposition of the upper unit due to being overwhelmingly dominated by dinocysts. Thermophile plants including *Avicennia* sp., *Engelhardia* sp., *Myrica* sp., Sapotaceae, Cyrillaceae-Clethraceae, and *Revesia* sp. along with relatively high quantities of xerophytes and the quantitative palaeoclimate values imply a subtropical and dry palaeoclimate.

Key words: Sivas Basin, Miocene, palaeoecology, Central Anatolia, palynology, Mollusca

1. Introduction

The Miocene is an epoch in earth history before the development of the Northern Hemisphere ice sheet. It was characterised by transgression-regression events leading to the opening and closing of seawater in Europe (Rögl, 1998; Zachos et al., 2001; Meulenkamp and Sissingh, 2003). The early Miocene, which is the main subject of this study, is a critical period between Oligocene mainly “icehouse” climates and the middle Miocene climatic optimum (MMCO) (Flower and Kennet, 1994). Some authors indicated that relatively warm and ice-free conditions persisted during the early Miocene (Zachos et al., 1997; Mosbrugger et al., 2005). Conversely, other authors claimed that this warm period was stopped by several cooling and glaciation events, especially for the high latitudes (Miller et al., 1991; Zachos et al., 1997; Larsson et al., 2006, 2010). Alpine tectonics leading to

the uplift of Anatolia were active during this time and resulted in sea corridors and significant climate and vegetation changes. During the early Miocene, there was a pronounced connection between the Mediterranean and the Indo-Pacific Ocean (Figure 1). The Mediterranean area was wide, covering East Anatolia and the Taurides. Moreover, the Paratethys was a wide-open connection with the Indo-Pacific Ocean (Figure 1) (Rögl, 1998, 1999). Although there exist many geological studies in Central Anatolia, the Cenozoic deposits were poorly studied in terms of palaeobotany and palaeoecology, especially focusing on the gypsum-bearing deposits (e.g., Altunsoy and Özçelik, 1998; Akgün et al., 2000; Doğan and Özel, 2005; Sancay et al., 2006; Yılmaz and Yılmaz, 2006; Kayseri and Akgün, 2008; Ribes et al., 2015; Poisson et al., 2016; Ocağolu et al., 2018). Most of the information associated with the Cenozoic palaeofloras originates from the

* Correspondence: sakkiraz73@gmail.com

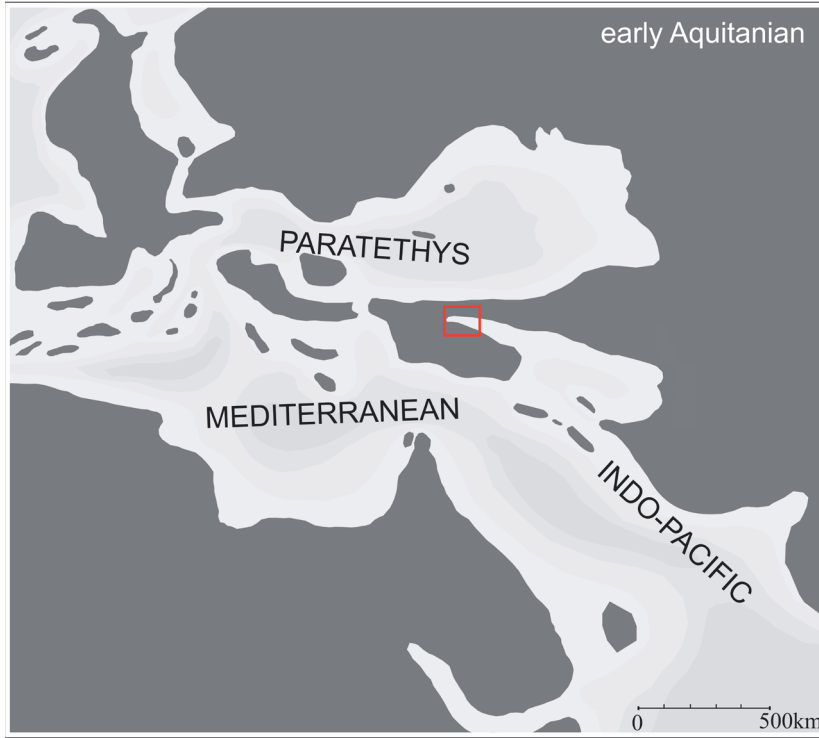


Figure 1. Palaeogeographic scheme of the Mediterranean, Indo-Pacific and Paratethys realms in the Aquitanian showing seaways (from Rögl, 1998, 1999). The studied area is marked by a rectangle.

Western Anatolian basins, which have a wide range of age from early to middle Miocene (e.g., Thrace, Manisa-Soma, Aydın-Şahinalı, Kütahya (Seyitömer and Tunçbilek); e.g., Akgün and Akyol, 1987; Ediger, 1990; Akgün and Akyol, 1999; Akgün et al., 2007, 2013; Kayseri and Akgün, 2008; Akkiraz, 2011; Çelik et al., 2017). To date, only a few palynological studies have focused on the sediments of coastal environments (Akgün and Sözbilir, 2001; Akkiraz and Akgün, 2005; Akkiraz et al., 2006, 2008, 2009, 2011a; Sancay et al., 2006; Akgün et al., 2013; Kayseri-Özer, 2013; Kayseri-Özer et al., 2014; Ocakoğlu et al., 2018). This paper attempts to answer the question of how the vegetation and climate were during the Aquitanian prior to the MMCO. For this, we selected the Sivas Basin, which is located at the point of junction of the Indo-Pacific and Mediterranean seas, recessing to the north-west (Figure 1). In this area, sedimentation took place in shelf and marginal marine environments. Shelf environments were filled by coralline limestones and associated clastics. Since the studied succession represents a well-dated record and includes marine and terrestrial fossils, it is possible to interpret more clearly the palaeoecological inferences. Using all data obtained, the aims of this paper can be listed as follows: 1) revealing the palaeontological and sedimentological aspects of the Aquitanian (lower Miocene) deposits

from the Karacaören Formation (Bingöl minibasin; Sivas Basin), 2) reconstructing palaeoecological characteristics according to palaeontological data, and 3) elucidating a visible marine invasion during the Aquitanian.

2. Geological setting

In Central Anatolia, during the Cenozoic such basins as the Çankırı-Çorum, Ulukışla, Haymana-Polatlı, and Tuz Gölü accumulated (Görür et al., 1984, 1998; Göncüoğlu et al., 1991; Clark and Robertson, 2002, 2005). The Sivas Basin, situated at the eastern side of Central Anatolia and filled by a thick Cenozoic succession, is another basin and developed after closure of the northern branch of the Neotethys as a result of collision between the Eurasian and African continents (Şengör and Yılmaz, 1981; Görür et al., 1984). This basin is a NE-SW trending basin, constrained by the Pontides to the north, the Taurides to the south, and the Kırşehir Massif to the west (Guezou et al., 1996; Poisson et al., 1996; Görür et al., 1998; Yılmaz and Yılmaz 2006) (Figure 2). Different views were suggested for the development of the basin, including posttectonic (Yılmaz, 1994; Yılmaz and Yılmaz, 2006) and syn- to posttectonic (Cater et al., 1991; Poisson et al., 1992, 1996, 2016). However, the main tectonic regime around the early Cenozoic was compressional and resulted in a north-south

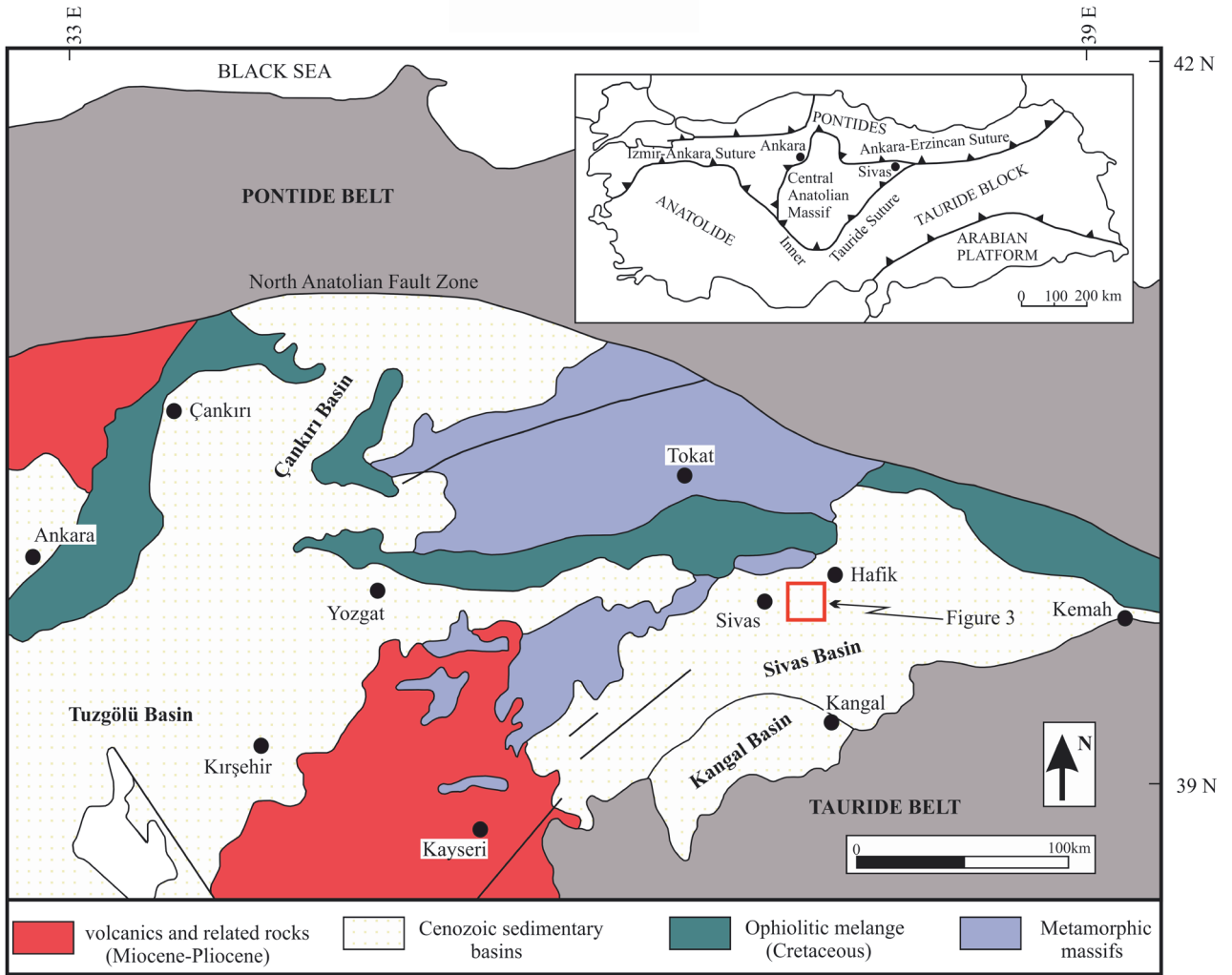


Figure 2. Simplified geological and tectonic maps of Sivas and its surrounding (from Bingöl 1989; Okay and Tüysüz, 1999).

directed shortening (Özçelik and Altunsoy, 1996; Temiz, 1996; Gürsoy et al., 1997; Altunsoy and Özçelik, 1998). The Sivas Basin was formed above the allochthonous ophiolites and ophiolite-related rocks well exposed on the northern and southern flanks of the basin (Poisson et al., 1996; Okay et al., 2006) (Figure 3). The metamorphic basement of the Kırşehir Massif to the north and rocks of the Mesozoic carbonate platform to the south underlie these ophiolites (Poisson et al., 1996, 2016). Deposition in the Sivas Basin starts with upper Cretaceous (Maastrichtian)-Palaeocene shallow-marine carbonates of Tecer Dağı (Kurtman, 1973; Cater et al., 1991) (Figure 3). The Eocene sequence is characterised by the Bozbel Formation, consisting mainly of deep-marine turbiditic and clastic deposits and calcareous mudstones (Kurtman, 1973). Evaporate-bearing deposits including an alternation of gypsum and anhydrite occur at the top of this Eocene succession and

indicate the base of the salt-controlled Sivas Basin in the strict sense (Ribes et al., 2015). The overlying Oligocene Selimiye Formation includes reddish to greenish sandstone-shale and thick massive gypsum, deposited in fluvial, playa, and lake settings (Kurtman, 1973; Poisson et al., 1996; Çiner et al., 2002; Ribes et al., 2015) (Figures 3 and 4). The Karayün Formation, assigned a Chattian age according to assemblages of benthic and planktonic foraminifera, was deposited in fluvial, lacustrine, playa, and lake environments indicating an inception of salt tectonism, which gave rise to the formation of at least 20 minibasins such as Eğribucak, Emirhan, Bingöl, and Eskiboğazkesen (Ringebach et al., 2013; Callot et al., 2014; Ribes et al., 2015; Kangal et al., 2016; Kergaravat et al., 2016; Pichat et al., 2016). According to Callot et al. (2014), these minibasins register a typical model of wall and basin structures for the development of a

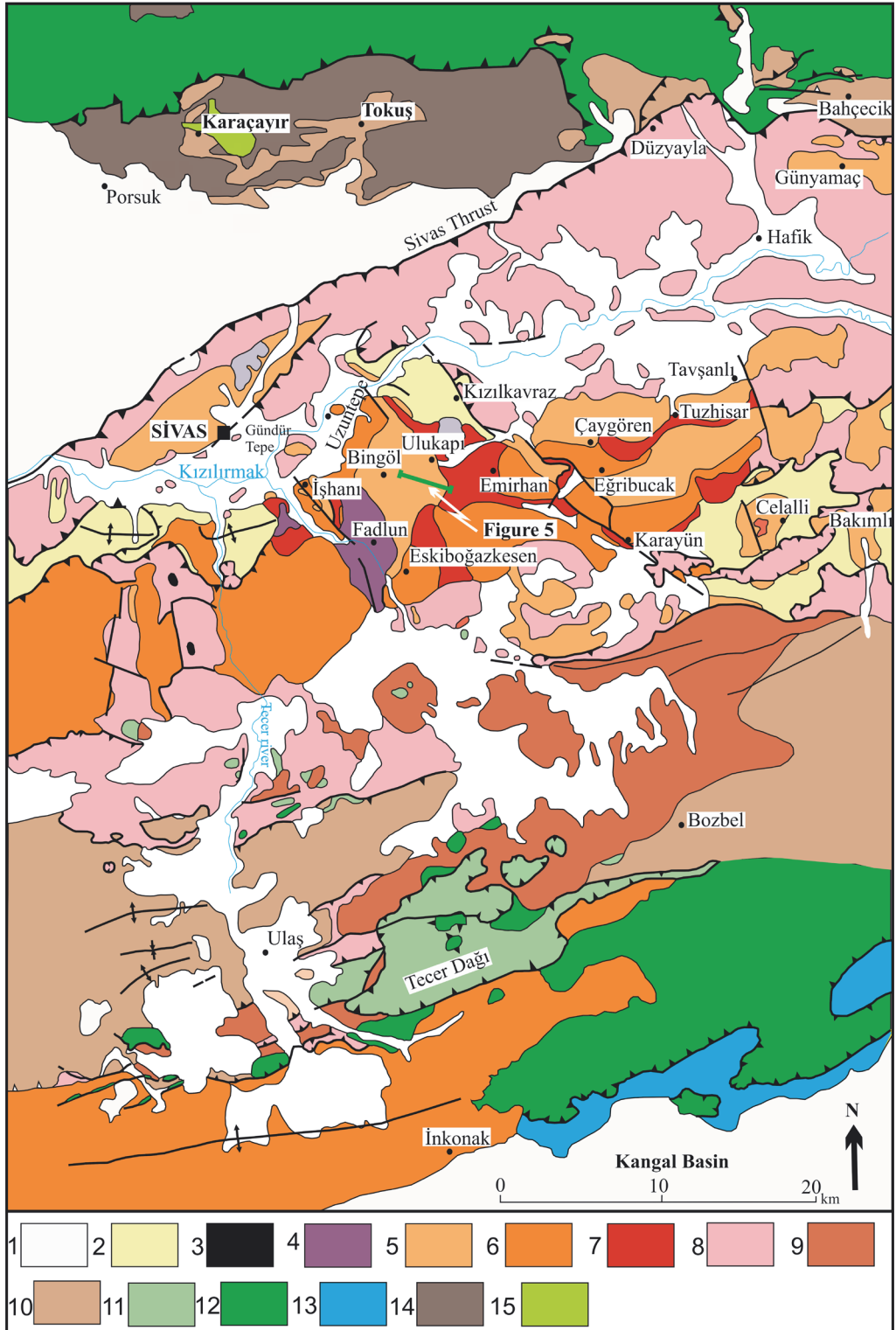


Figure 3. Geological map of the Sivas Basin (redrawn from Poisson et. al., 1996; 2016). 1. Miocene-Quaternary units; 2. Benlikaya Formation (early to middle (?) Miocene); 3. basalts (middle Miocene); 4. Fadlun Formation (early to middle (?) Miocene); 5. Mini-basins such as Egribucak, Bingöl and Karayün (early Miocene); 6. Karayün Formation (middle-late Oligocene); 7. gypsum diapirs; 8. Hafik Formation (early Oligocene); 9. Selimiye Formation (Oligocene); 10. Bozbel Formation (Eocene); 11. Shallow marine limestones of Tecer Dağı (Maastrichtian-Palaeocene); 12. Ophiolitic nappes and ophiolitic mélangé (late Cretaceous); 13. Taurus Carbonate Platform (Mesozoic); 14. Kırşehir Massif; 15. Karaçayır Intrusive syenite (100 ma).

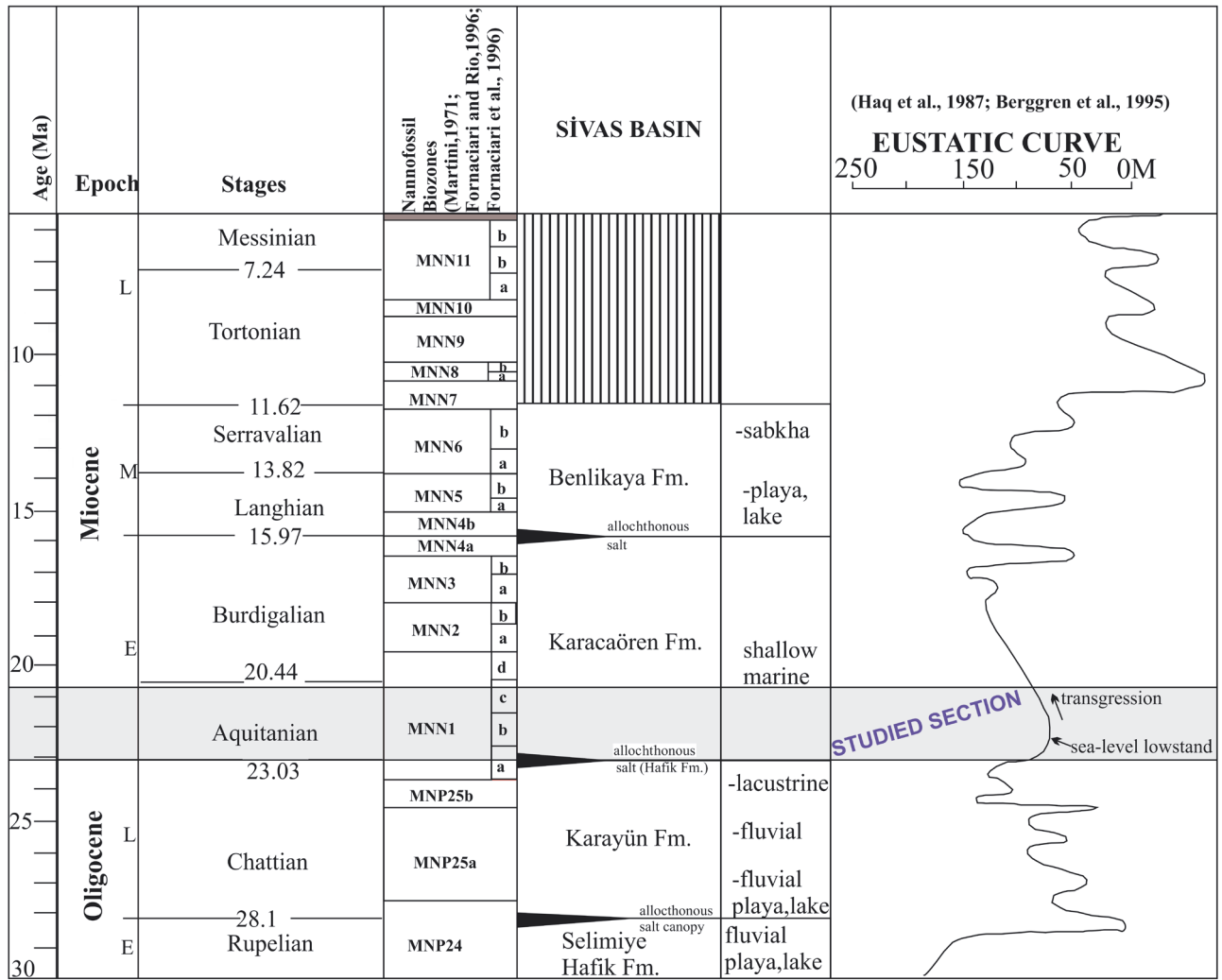


Figure 4. Generalised stratigraphic column of the Sivas Basin (Yılmaz and Yılmaz, 2006; Poisson et al., 1996; 2016; Ribes et al., 2015, Ocakoğlu et al., 2018).

minibasin. Above the Karayün Formation, deposition of the Karacaören Formation, named by Kurtman (1973), underwent regional transgression during the early Miocene (Kurtman, 1973; Cater et al., 1991; Özcan et al., 2009; Sirel et al., 2013; Ribes et al., 2015; Poisson et al., 2016) (Figures 3 and 4). The Karacaören Formation, which constitutes the main subject of this study, consists of shallow marine deposits including sandstones, marls, gypsums, coralgall limestones, and locally conglomerates (Figures 4 and 5). According to Poisson et al. (2016), the formation was divided into five members involving the Sivas marls, the reefs and algal limestones, the Ulukapı clastics, the Bingöl marls and sandstones, and the Fadlun resedimented gypsum (Figure 3). Terrestrial deposits of the lower-middle Miocene Benlikaya Formation overlie the previous units and are made up of conglomerates

and sandstones with mudstone interbeds accumulated in the sabkha-playa and lake environments (Ocakoğlu, 2001; Poisson et al., 2010; Ribes et al., 2015). There are several allochthonous salt diapirs as well (Ribes et al., 2015). The studied succession includes terrestrial and marine sediments of the Karacaören Formation and may informally be divided into three parts as the lower side of the coralgall limestone (lower unit), coralgall limestone (middle unit), and the upper side of the coralgall limestone (upper unit) (Figure 5).

3. Materials and methods

3.1. Materials

The Bingöl minibasin is located on the western side of the central Sivas Basin (Figure 3). A cross-section from the eastern side of the city of Bingöl, which is situated

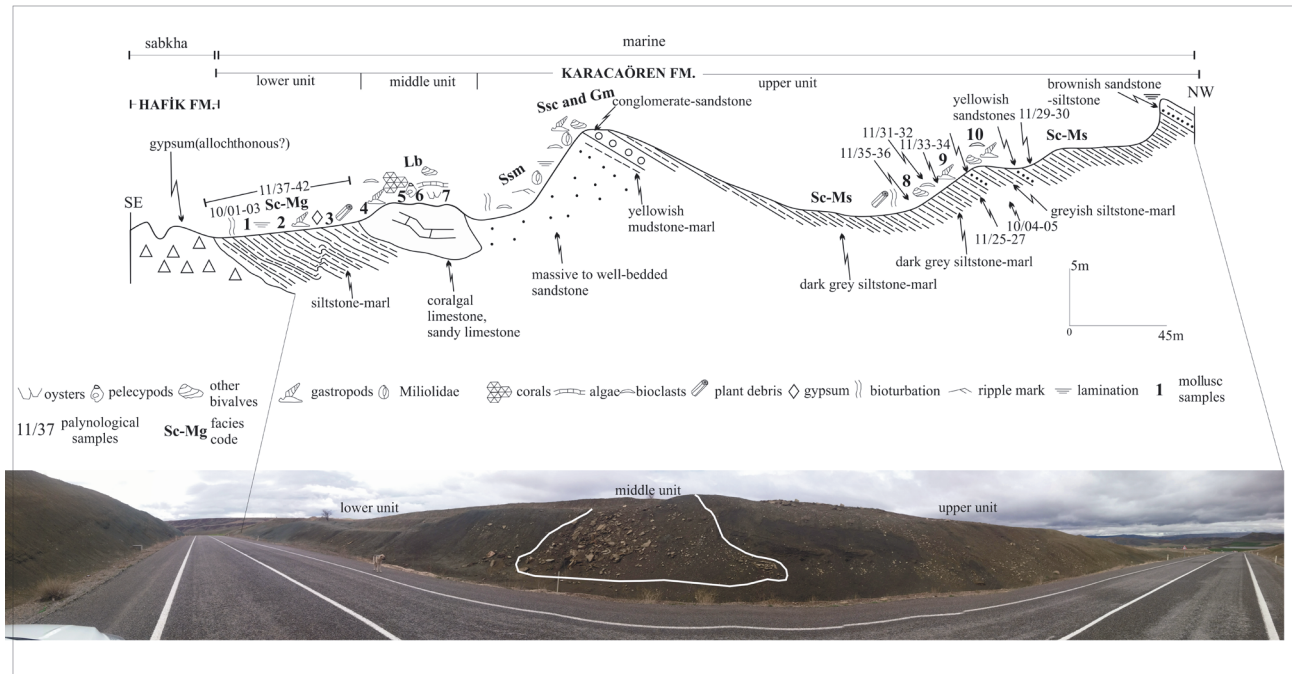


Figure 5. Geological cross-section showing the sample numbers and lithological properties of the Karacaören Formation in the Bingöl mini-basin (See table 1 for the explanations of facies codes).

about 8 km south-east of Sivas, was taken and sampled for palaeontological examinations (Figure 5). Macrofossils are common along the succession. A total of 10 samples for the investigation of macrofauna were collected, of which 3 samples were from the lower unit (Sc-Mg) and 7 samples from the middle unit (Lb) and the upper unit (Sc-Ms) (4 samples from Lb and Ssm, 3 samples from Sc-Ms) (Table 1). Additionally, 23 samples from grey-greenish clays with gypsums and mudrocks were collected for pollen studies, of which 9 were from the lower unit (Sc-Mg) and 14 from the upper unit (Sc-Ms) (Figure 5). Since the lithologies of the middle unit were not suitable for palynological examinations, we did not collect samples from the field.

3.2. Methods

Facies definitions for the siliciclastic rocks were based on lithology, grain size, sorting, sedimentary structures, and fossil content (Table 1). The Dunham (1962) classification was used for description of the carbonate rocks. For the examination of palynomorphs, HCl, HF, $\text{HNO}_3 + \text{KClO}_3$, and KOH were applied to the samples. A mesh screen (8 μm) was used to eliminate organic materials. One to 3 slides for per sample were prepared. According to the frequency of taxa, between 52 and 230 pollen grains for each sample were counted and converted to percentages. Selected photomicrographs for palynomorphs were taken using a Leica DM 2500 microscope and Leica DFC295 camera (Figure 6). Selected molluscs were also photographed

(Figure 7). The TILIA and TILIGRAPH software developed by Grimm (1994) was utilised for preparation of pollen diagrams. A coexistence approach method was used for quantitative palaeoclimate estimates (Mosbrugger and Utescher, 1997; Utescher et al., 2014). CLIMSTAT software and the Palaeoflora database were used for application of the coexistence approach (www.palaeoflora.de). In this study, the following palaeoclimate parameters were considered: mean annual temperature (MAT), temperature of the coldest month (CMT), temperature of the warmest month (WMT), and mean annual precipitation (MAP).

4. Modern climate and vegetation

The city of Sivas and its immediate surroundings (around 1300 to 1600 m a.s.l.) are located in the Central Anatolian Region, which has hot and dry summers and cold and snowy winters. According to the Köppen climate type, the region is affected by a continental steppe climate, coded as Dsc. The MAT varies from 7.2 to 8.9 °C. The average temperature for the coldest month is about -3.3 °C. July is the warmest month of the year with an average temperature of 19 °C. The area receives low annual rainfall of between 400 and 600 mm per year (Kadioğlu, 2000; <https://mgm.gov.tr/en-US/forecast-5days.aspx>). The savannah system is dominantly constituted by herbaceous plants due to harsh and dry conditions. However, in some places, there exist small amounts of scotch fir and oak forests.

Table 1. Summary of facies descriptions and their interpretations.

Fm.	Facies type	Facies code	Description	Fossil content	Interpretation
Karacaören Formation	Siltstone and marl	Sc-Mg	Alternation of greyish to brownish siltstone and marl with thin gypsum levels and disseminated gypsum crystals; exhibits parallel lamination	Scarce to abundant gastropods and plant debris	Brackish water (lagoon) with low hydrodynamic regime
	Bioclastic packstone	Lb	Greyish to whitish corallgal limestone, sandy limestone; displays lenticular geometry	Rich and diverse macroinvertebrates, bivalves, oysters, gastropods, and stony coral	Lagoon to shallow marine settings
	Fine to medium-grained sandstone	Ssm	Brownish to dark grey, fine to medium-grained sandstone, poorly sorted, with granules and pebbles of quartz, feldspar, chert, epidote, and pyroxene; displays cross-lamination and ripple marks	Scarce marine benthic foraminifera remains	Tidal flat-intertidal lagoon
	Medium to coarse-grained sandstone	Ssc	Greyish sandstone, poorly sorted, medium to coarse grain size, and dispersed pebbles; exhibits lobe geometry, massive to well bedded	Scarce fragmented bivalve and benthic foraminifera remains	Delta front
	Clast-supported conglomerate	Gm	Greyish conglomerate, normally graded, moderately sorted with sand matrix	-	
	Siltstone and marl	Sc-Ms	Alternation of dark to pale grey siltstone and marl with sandstone beds, which display parallel lamination and ripple marks	Scarce to abundant gastropod, bivalve and plant debris	Shallow marine

5. Results

5.1. Lithology and facies of the Karacaören Formation

The entire succession (39°43'20.17"N, 37°06'24.96"E; 1367 m a.s.l.) reaches a thickness of about 400 m in total (Figure 5). The sediments start with massive gypsums, probably belonging to the allochthonous Hafik Formation, which were covered by an alternation of folded mudstone and marl with gypsum interlayers and mollusc assemblage (Figure 5). Reefal limestones with small-scaled reef crest including abundant coral and algae occur towards the upper levels. The succession continues with massive sandstones attaining a thickness of about 70 m. There are yellowish mudstones and marl with molluscs in the top of the massive sandstones. The rest of the sequence involves conglomerates, dark grey mudstones, and marls with sandstone interlayers with an assemblage of mollusc

fauna (Figure 5). According to changes in the lithologies, the following facies may be distinguished.

5.1.1. Siltstone and marl (Sc-Mg)

The sediments of the Sc-Mg form the lowest side of the sequence and are represented by an alternation of grey-green siltstone and marl involving intense bioturbation (Figure 5; Table 1). The thickness of sediments ranges from a few centimetres to 15–20 m. The sediments include the following mollusc assemblage: *Crassostrea gryphoides*, *Corbulomya (Lentidium) aquitanica*, *Terebralia bidentata*, and *Turritella (Turritella) gradate* (Figure 8a). Thin laminae of lignites with carbonised plant debris and levels of gypsum take place in the fine-grained clastics as well. These data together with *Crassostrea gryphoides* indicate that the sediments of the Sc-Mg were deposited in a low sea-level condition, probably in brackish to lagoonal palaeoenvironments (i.e. restricted marine).

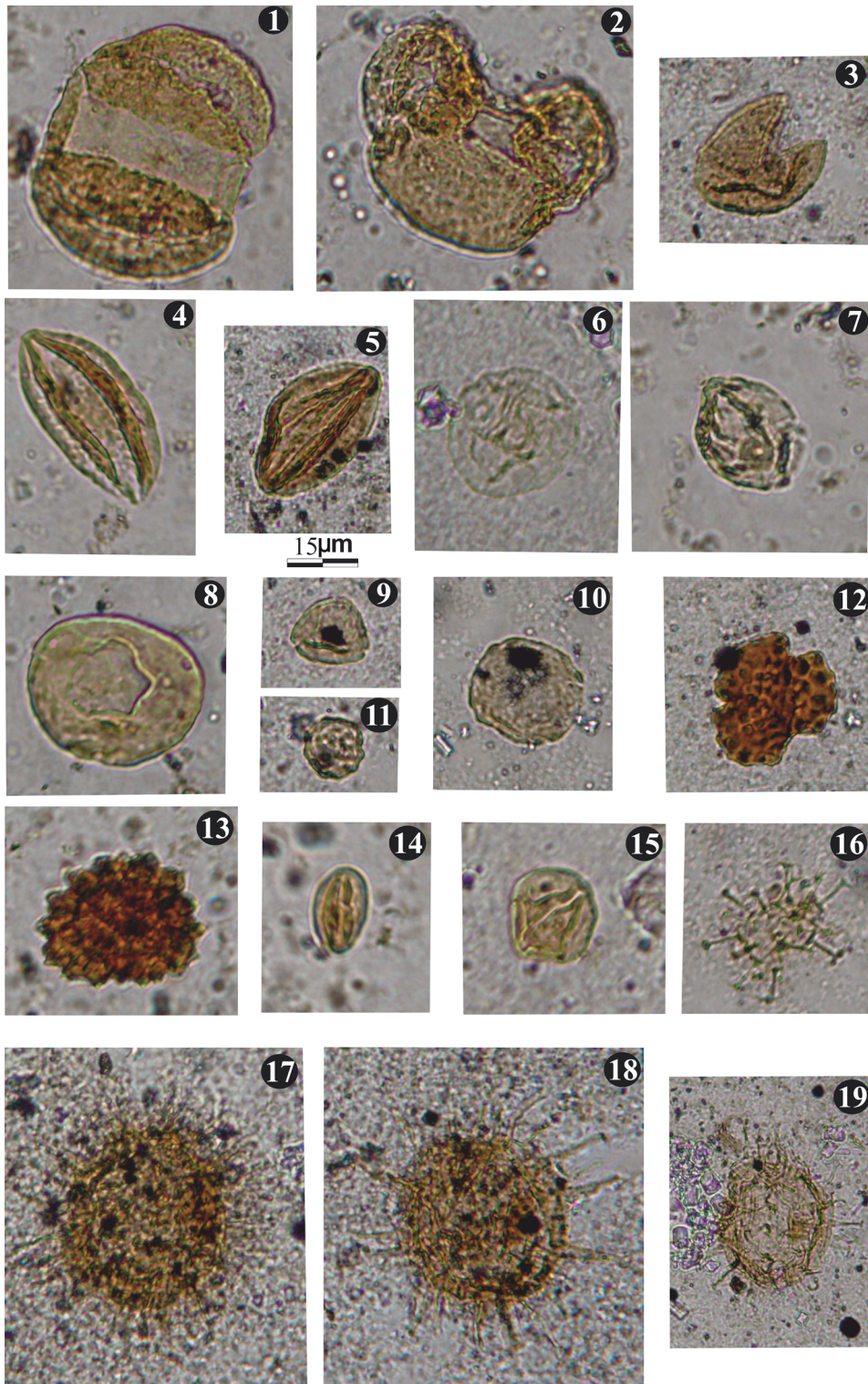


Figure 6. Selected palynomorphs from the cross-section showing the sample numbers. **1, 2.** undifferentiated Pinaceae sample 11/40; **3.** Cupressaceae, sample 10/05; **4, 5.** *Ephedra* sp., (4) sample 11/40; (5) 11/38; **6, 7.** Poaceae, (6) sample 11/37; (7) sample 10/01; **8.** *Carya* sp., sample 10/02; **9.** *Engelhardia* sp., sample 11/42; **10.** *Ulmus* sp., sample 11/40; **11.** Chenopodiaceae-Amaranthaceae, sample 11/41; **12, 13.** Asteraceae-Asteroidae, (12) sample 10/01; (13) sample 10/03; **14.** *Castanea-Castanopsis* sp., sample 11/35; **15.** Cyrillaceae-Clethraceae, sample 11/37; **16-19.** undifferentiated dinoflagellate cysts, (16) sample 11/35; (17,18) sample 10/04; (19) sample 11/36. Photomicrographs are the same scale (see 15µm bar).

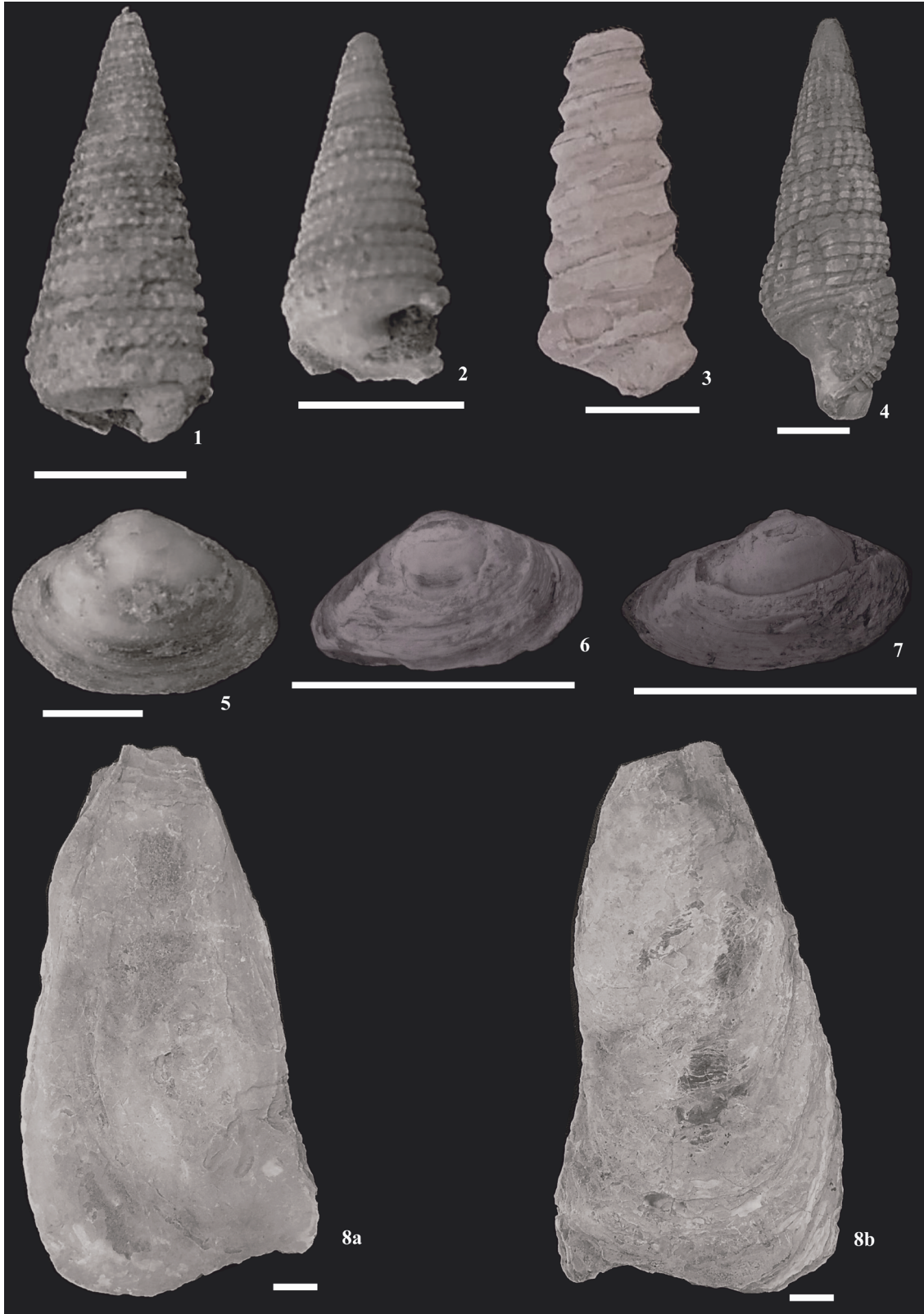


Figure 7. Selected gastropods and bivalves from the cross-section showing the sample numbers. **1, 2.** *Tympanotonos margaritaceus* (1) sample 2; (2) sample 10; **3.** *Turritella* (*Turritella*) *gradata* sample 3; **4.** *Terebralia bidentata* sample 9; **5.** *Mactra substriatella* sample 7; **6,7.** *Corbulomya* (*Lentidium*) *aquitana* (6) sample 5 (7) sample 8; **8a,b.** *Crassostrea gryphoides* sample 6. Scale bar is 1 cm.

5.1.2. Bioclastic packstone (Lb)

This facies is distinguished in the middle unit (Figure 8b; Table 1). A limited organic carbonate aggregate in the lower Miocene Karacaören Formation as well as a small patch reef are referred to here as Lb (Figures 5 and 8b). Lateral continuity of the aggregate with *Ostrea* sp. does not exceed a few dozen meters. The main aspect of this facies is the presence of disseminated molluscan fossils (e.g., *Anadara diluvii*, *Lucina* sp., and *Oliva* sp.), coral colonies mainly in the growth position (e.g., *Echinopora* sp. and *Goniastrea* sp.), and bryozoa *Stomatopora* sp., indicating variable salinity. Undoubtedly, a marine environment is explicit owing to the presence of corals and *Ostrea* sp., whereas a lagoon-estuarine depositional setting including brackish water conditions is depicted by the occurrence of *Crassostrea* (Curry et al., 1969; Dickinson et al., 1972). Considering the facies zone (modified Wilson Standard Facies Zones, SZ-7/8; Flugel, 2004), it may be interpreted as an open or restricted shallow marine environment.



(a)



(b)

Figure 8. a) Field photo indicating siltstone-marl with plant debris and mollusc fauna (Sc-Mg). b) Field photo indicating coralline limestones (Lb) (arrows show the hermatypic coral colonies).

5.1.3. Fine to medium sandstone (Ssm)

This lithofacies, distinguished in the upper unit, consists of grey, fine to medium-grained, massive to well-bedded, and densely bioturbated sandstone changing between 30 and 40 cm in thickness. Some parts of the sandstone display ripple marks and cross-laminations. Sandstone classified as litharenite was poorly cemented with calcite and their constituents were enriched by quartz, alkali feldspar, chert, and some heavy minerals including epidote and pyroxene (Folk, 1962). The sandstone, which includes an association of undifferentiated benthic foraminifera, was derived from the ophiolite source area and deposited in intertidal, lagoon-tidal flat palaeoenvironments according to broken shells and bioturbation structures (Reineck, 1972; Reineck and Singh, 1980; Weimer et al., 1982).

5.1.4. Medium to coarse sandstone (Ssc)

This lithofacies (upper unit) is made up of grey, medium to coarse-grained, pebbly and massive to well-bedded sandstone with rare bivalves (Table 1). There is mostly calcite cement in the pore-fillings of the poorly sorted pebbles. The cross-bedding structures display a dip at an angle of about 30°. This facies exhibits a delta lobe reaching approximately 1–2 mm in thickness. Some places register cross-bedded sets attaining a thickness of 1 m, forming a foreset of the Gilbert-type deltas developed by a meandering system, which fed into shallow water (Collinson, 1969; Flores, 1990; Kazancı, 1990; Kazancı and Varol, 1990; Postma, 1990; Reading, 1996; Kangal and Varol, 1999).

5.1.5. Clast-supported conglomerate (Gm)

This lithofacies (upper unit) includes grey, massive, normal graded, and clast-supported conglomerate. The thickness of bedding is about 50 cm. Pebbles, 1 to 5 cm in diameter, are moderately sorted with polygenic traits (mainly metamorphic and rare components of volcanic and sedimentary rocks). There is a close relationship with Ssc. This lithofacies together with Ssc indicates a foreset of a coarse-grained delta progradation towards the shallow water environment (Kazancı, 1990; Postma, 1990; Kangal and Varol, 1999).

5.1.6. Siltstone and marl (Sc-Ms)

This lithofacies, determined in the upper unit, includes an alternation of dark and pale grey to green siltstone and marl with sandstone beds, which are common lithologies for the Karacaören Formation. The main discrepancy of this facies from the Sc-Mg is that thin laminae of gypsum levels are missing here. The sandstone beds, ranging in thickness from 15 to 20 cm, exhibit a clear lateral continuity and also include dense bioturbation traces. The main sedimentary structures of these sandstone beds are parallel lamination and ripple marks. The thickness of sediments is variable and may reach from a few centimetres to 15–20 m. The

existence of marine fossils, including gastropods and bivalves, and thin lignite levels with plant debris indicate a coastal palaeoenvironment with limited water circulation.

5.2. Palaeontological data and age

Assemblages of the coralline limestone (Lb) contain copious fragments of molluscs, corals, and algae (Figure 5). The following bivalve taxa were determined: *Anadara diluvii*, *Nucula* (*Nucula*) *nucleus*, *Crassostrea gryphoides*, *Macra substriatella*, *Corbulomya* (*Lentidium*) *aquitana*. *Tympanotonos margaritaceus*, *Terebralia bidentata*, and *Turritella* (*Turritella*) *gradata*, which characterise gastropod taxa. Some corals including *Echinopora* sp., *Goniastrea* sp., and *Stomatopora* sp. were described as well. The assemblages of thin sections from the sandstones (Ssm and Ssc; Table 1) in the upper unit reveal the dominance of bivalves and corals, and minor amounts of Miliolidae. Previous studies on the Karacaören Formation suggested an early-middle Miocene age on the basis of various fossil groups (i.e. foraminifera and nannoplankton) (Altunsoy and Özçelik, 1998; Callot et al., 2014; Ribes et al., 2015; Poisson et al., 2016). However, Sirel et al. (2013) studied the planktonic and benthic foraminiferal biostratigraphy from the same basin and suggested an Aquitanian age, referring to SBZ 24 from the İshani section (Figure 3). The following taxa were determined: *Miogypsina gunteri*, *Miogypsina* sp., *Miogypsinoidea* sp., *Operculina complanata*, *Nephrolepidina morgana*, *Amphistegina* sp., *Rotalia* sp., and *Elphidium* sp. As a result, although the age of the Karacaören Formation has a wide range of early Miocene (Aquitanian-Burdigalian), the age in the studied succession is considered to be Aquitanian according to *Corbulomya* (*Lentidium*) *aquitana*.

5.3. Palynology

Samples including marine and terrestrial palynomorphs (samples 11/35-10/05) have been used for correlation

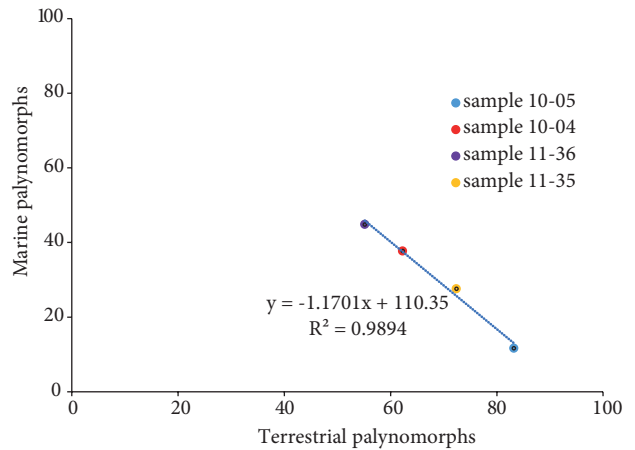


Figure 9. Relationship between terrestrial and marine palynomorphs.

coefficient analyses, which indicate a very good relationship. According to results of pollen groups from Sc-Ms, the terrestrial and marine pollen data are compared with an R^2 value of $R^2 = 0.9894$ (Figure 9). This indicates that marine palynomorphs represented by undifferentiated dinocysts did not come from afar to the site of fossilisation. Thirteen samples were productive with respect to palynomorph counting because of the low recovery in other samples (Figure 10).

Using the palynological data, in the Aquitanian of the Karacaören Formation, no attempt has been made yet to elucidate variations in a coastal environment. The samples of the lower (Sc-Mg) and upper (Sc-Ms) units yielded pollen data. Since the other samples contained only a few grains of spores and pollen taxa, they were not suitable for counting. The prominent and visible features of the pollen diagram display a discrepancy between the assemblages

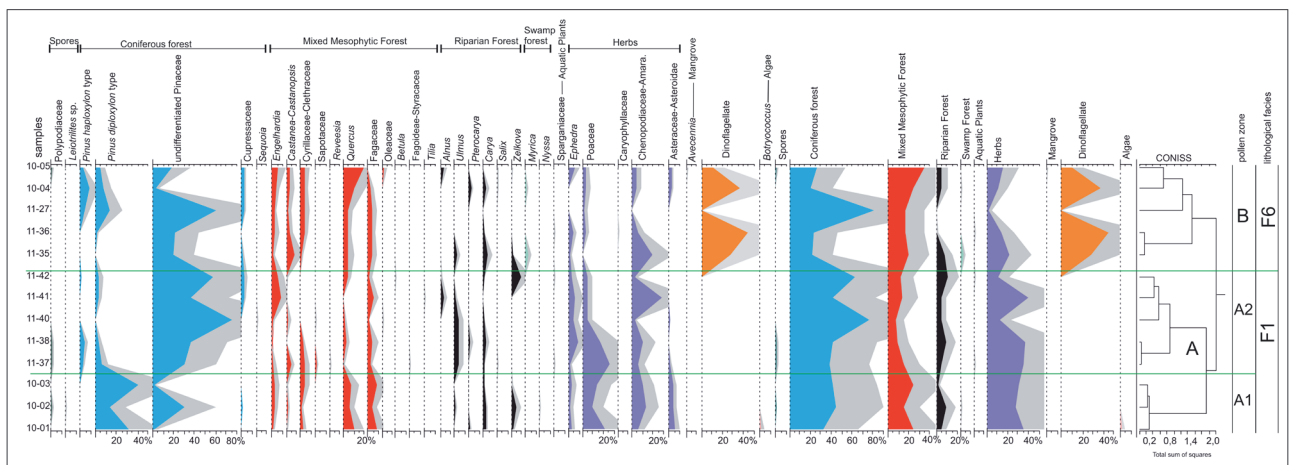


Figure 10. Simplified pollen diagram of the samples from the Bingöl mini-basin (Sivas Basin). Shaded area: 3 times exaggerated

of the lower and upper units (Figure 10). Table 2 summarises pollen characteristics of both assemblages. These discrepancies are more remarkable since the sediments of Sc-Mg and Sc-Ms were accumulated in more or less comparable environments, probably on low-lying coastal plains.

5.3.1. Palynology of the lower unit

Eight of nine samples were productive for palynology. Thirty taxa were reported in total. The plant groups are represented by large quantities of coniferous forest and herbaceous plants, and minor quantities of mixed mesophytic and riparian plants. Two pollen zones (coded as A and B) with subzones (coded as A1 and A2) were recognised by cluster analysis according to changes in the abundance of palynomorphs (Figure 10).

5.3.1.1. Zone A (sample numbers 10/01-11/42)

This zone is dominated by undifferentiated Pinaceae (range: 5.1% to 76.2%), *Pinus diploxylon* type (range: 2% to 40%), and nonarboreal plants such as Poaceae (range: 4.8% to 25.2%), *Ephedra* (range: 2.1% to 7.8%), and Chenopodiaceae-Amaranthaceae (range: 5.1% to 29.8%). This also includes minor amounts of *Ulmus* sp. and *Carya* sp. with a constant fluctuation.

5.3.1.1.1. Subzone A1 (sample numbers 10/01-03)

The lowermost samples within this subzone involve high percentages of *Pinus diploxylon* type (range: 13.8% to 40%), Poaceae (range: 9.8% to 25.8%), *Quercus* sp. (range: 5.1% to 10.8%), Fagaceae (range: 4.8% to 89.6%), and Chenopodiaceae-Amaranthaceae (range: 6.2% to 11.8%) and minor quantities of *Engelhardia* sp. (average: 2%), *Ephedra* sp. (average: 1.8%), and Asteraceae-Asteroidae (average: 4.8%). A freshwater alga of *Botryococcus* sp. and a marker of a marsh environment, *Nyssa* sp., which do not occur in other zones, are found in minor percentages as well (Table 2). The curve of undifferentiated Pinaceae peaks at around 29.8% for sample 10/02.

5.3.1.1.2. Subzone A2 (sample numbers 11/37-42)

This includes large amounts of undifferentiated Pinaceae (exceeding 75% in sample 11-40), Chenopodiaceae-Amaranthaceae (range: 4.8% to 28.1%), and *Ephedra* sp. (range: 4.7% to 8.3%). Compared to zone A1, the percentages of *Ulmus* sp. (average 5%) and *Ephedra* sp. (average 5%) are augmented, whereas the amounts of *Pinus diploxylon* type, *Zelkova* sp., Poaceae, *Quercus* sp., Fagaceae, Asteraceae-Asteroidae, and *Botryococcus* sp. are decreased. Some other pollens such as *Tilia* sp., Fagoideae-Styracacea (morphospecies *Tricolporopollenites pseudocingulum*), *Betula* sp., *Reveesia* sp., Sapotaceae, and *Salix* sp. are present in low amounts.

5.3.2. Palynology of upper unit

Five of 14 samples were productive for counting. Palynological data indicate that undifferentiated dinocysts, which are lacking in other zones, and coniferous plants and mixed mesophytic forest communities predominated at the time of deposition. In total, 21 taxa were recorded, assigned to 18 families. The elements of riparian plants and herbs decreased notably in comparison to pollen zone A.

5.3.2.1. Zone B (sample numbers 11/35-10/05)

This zone starts with a peak occurrence of undifferentiated dinocysts (range: 0% to 44.8%). It also contains high percentages of undifferentiated Pinaceae (range: 3.9% to 59.8%) and *Quercus* sp. (range: 5% to 19.8%). An augmentation in the abundance of dinocysts and the minor presence of *Avicennia* sp. are the basis for separating zone B from subzone A2 (Figure 10; Table 2). Only single grains of *Avicennia* sp. (mangrove element) were found in sample 10-05. The curves of *Pinus diploxylon* type and *Pinus haploxylon* type reached the highest percentages at about 11.3% in sample 11-27 and 9.7% in sample 10-04, respectively. Also noteworthy is the low representation of Poaceae (range: 0% to 3.8%) in this zone (Table 2), whereas it peaks at 25.8% in sample 11/37 (subzone A2). The representation of Chenopodiaceae-Amaranthaceae

Table 2. Conflicting palynological data of the lower and upper units from the Bingöl minibasin.

Karacaören Formation	
Lower unit (pollen zone A)	Upper unit (pollen zone B)
Dinoflagellate assemblage absent	Dinoflagellate assemblage important
Mangrove plant <i>Avicennia</i> absent	Mangrove plant <i>Avicennia</i> rare
Green alga <i>Botryococcus</i> rare	Green alga <i>Botryococcus</i> absent
Amaranthaceae-Chenopodiaceae abundant	Amaranthaceae-Chenopodiaceae reduced
Poaceae abundant	Poaceae reduced
<i>Ephedra</i> constantly existed	<i>Ephedra</i> locally appeared
Relatively high pollen diversification	Low pollen diversification

prominently increases at the beginning of this zone and tends to decrease upwards. Unlike in pollen zone A2, other herbs including *Ephedra* sp. are diminished.

6. Discussion

6.1. Vegetation dynamics

The study of palynofloras from the Karacaören Formation can be useful in order to reveal the Aquitanian palaeoenvironment and gain knowledge of the pollen flora of the Bingöl minibasin. During the whole period, coniferous forest (mainly undifferentiated Pinaceae) and herbaceous plants (*Ephedra* sp., Poaceae, and Chenopodiaceae-Amaranthaceae) were dominant. Nonconiferous plants such as mixed mesophytic and riparian forests were present in minor quantities and consisted of *Engelhardia* sp., *Castanea-Castanopsis* sp., Cyrillaceae-Clethraceae, *Quercus* sp., Fagaceae, *Ulmus* sp., and *Carya* sp. Swamp and aquatic plants were in minor quantities, as well (Figure 10). If we exclude undifferentiated dinocysts, which are common in Sc-Ms, a homogeneous vegetation cover existed during the whole period. However, there are some discrepancies between pollen zones A and B. The sediments of pollen zone A, consisting mainly of coniferous forest, mostly undifferentiated Pinaceae, mixed mesophytic forest (*Engelhardia* sp., *Castanea-Castanopsis* sp., Cyrillaceae-Clethraceae, *Quercus* sp., and Fagaceae) and herbs (Poaceae, *Ephedra* sp., and Chenopodiaceae-Amaranthaceae), were deposited more proximally in the palaeoenvironment such as in brackish and/or freshwater settings than the sediments of zone B, deposited in more distal areas due to the presence of dinocysts. Thus, the pollen flora in zone A implies a low sea-level condition and an open palaeoenvironment rich in herbaceous taxa, growing under a dry palaeoclimate that resulted in the accumulation of gypsum levels.

Moreover, there are small excursions distinguishing subzones between A1 and A2. Subzone A1 includes high quantities of *Pinus diploxylon* type, which was recorded with minor percentages in subzone A2. The green alga *Botryococcus* sp., indicating a more freshwater setting, is recorded as single grains in sample 10-01 (lowermost side of the sequence) and does not exist in subzone A2. Hygrophilous plants of Sparganiaceae occur in subzone A2, but in minor quantities. Additionally, it can be said that an alternation of mudstone and marl with gypsum may imply low water energy. After sea drawdown, appearance of coralgall limestone (Lb) here represents an onset of Aquitanian transgression (Figures 4 and 5).

The continued influence of the marine setting in the upper unit corresponding to the upper side of the Aquitanian resulted in the assemblage of pollen zone B. The most notable aspect of this zone is an abrupt surge in the abundance of undifferentiated dinocysts, concerning

the high sea-level condition, with smaller proportions of terrestrial palynomorphs except for undifferentiated Pinaceae derived from long distance transport. As a result, marine conditions prevailed during the depositions of the middle (Lb) and upper units (Ssm, Scs, Gm, and Sc-Ms). According to Poisson et al. (2016), a marine palaeoenvironment existed during the deposition of the Karacaören Formation, documented by nannoplankton taxa including *Cyclicargolithus floridanus*, *C. abisectus*, *Sphenolithus moriformis*, *Helicosphaera euphratis*, *H. carteri*, *Cocolithus pelagicus*, *Cyclococolithus formosus*, and *Discoaster deflandrei*. The authors also recorded a marine transgression during the Aquitanian that was globally observed (Figure 4). Pollen and sedimentological data displayed by this study confirm that transgression. A detailed study of the Karaman Gypsum Member, the overlying part of the studied succession in the Karacaören Formation, has shown that marine conditions persisted at least until the end of the middle Burdigalian (Ocakoglu et al., 2018). The authors recorded peak occurrences of dinocysts (around 60%) and foraminiferal test linings (around 10%) at the lower part, and their amounts (around 10% for dinocysts and 1% for foraminiferal test linings) decreased upwards, related to sea-level falls.

An impoverished *Avicennia* sp. mangrove and low amounts of pollen producers, together with halophytes of Chenopodiaceae-Amaranthaceae, indicate a coastal marine (mangrove) palaeoenvironment as well. No indication of a mangrove palaeoenvironment has been published for the Sivas Basin to date. Around the late Oligocene and Miocene, an *Avicennia* mangrove system developed in the Mediterranean region (Jimenez-Moreno, 2005). Biletekin et al. (2015) reported single grains of *Avicennia* sp. from the Miocene and Pliocene sediments of Anatolia as well.

As a result, the palynological associations imply that the Aquitanian sediments of the Karacaören Formation were first deposited in low sea-level conditions (pollen zone A), probably swamp and/or ponding environments (Sc-Mg) (Figure 4). Subsequent persistence of sea-level rise resulted in the development of bioclastic packstone (Lb). Shallow marine settings then persisted upwards and induced the deposition of coarse to fine-grained clastics (Ssm, Scs, Gm, and Sc-Ms), including large quantities of dinocysts and minor amounts of mangrove plant *Avicennia* sp. (pollen zone B). Since no tectonic obstacle was exposed in the eastern part of Anatolia, the water from the Indian Ocean could easily invade the Sivas Basin (Figure 1).

In recent years, Miocene marine pollen data including dinocysts, foraminifer test linings, and mangrove plants from the east and south of Anatolia have been described by several researchers. For instance, an Aquitanian palynoflora with dinocysts and coastal lepidocaryoid palm

Longapertites retipiliatus was recovered from the Kavak Formation, Burdur area, South-west Anatolia (Akkiraz et al., 2009). Deposits for the lower Miocene from the northern Adana Basin (south-east Anatolia), situated on southern side of the Sivas Basin, were established by Gürbüz (1999), who suggested a major marine transgression from the early mid-Burdigalian leading to the development of a reef complex, Karaisali Formation. Moreover, a recent study from the Adana Basin emphasised that the overlying Köpekli Formation, assigned as late Burdigalian-Langhian (early-middle Miocene), includes well-preserved dinoflagellates, foraminifera, and nannofossils (Türkecan et al., 2018). A short-lived marine incursion during the Aquitanian was noted from the northern Mut and Karsanti basins located on the southern side of the Sivas Basin (Ünlügenç et al., 1993; Şafak et al., 2005). Rich and diverse palynofloras were described in the Oligocene-Miocene marine sediments from the Ebulbahar and Keleşdere sections of the Muş Basin, East Anatolia (Sancay et al., 2006). Durak and Akkiraz (2016) highlighted a sea-level highstand in the Aquitanian (Bengiler succession) according to pollen data from the nonmarine Kalkım-Gönen Basin (West Anatolia).

Another controversial question is when the herbaceous vegetation indicating open environments expanded, because palaeobotanical studies carried out in other parts of Turkey, mostly in western areas, recorded dense arboreal plant taxa during the early and middle Miocene lato sensu (e.g., Benda, 1971; Akgün and Akyol, 1999; Akgün et al., 2000, 2007; Sancay et al., 2006; Kayseri and

Akgün, 2008; Yavuz-Işık, 2008; Akkiraz, 2011; Akkiraz et al., 2011b, 2012; Biltekin, 2018). To date, an abrupt surge in the herbaceous plant cover has only been known from the Tortonian (late Miocene) (Akgün et al., 2000; Yavuz et al., 2017). However, pollen records defined in this study have indicated an opposing view and are in accordance with the conclusion of Strömberg et al. (2007), who recognised herbaceous vegetation from the early Miocene onwards in Central Anatolia. Thus, the question remains of whether herbaceous plants were common or not in Anatolia during the early Miocene. It may be a plausible explanation that the dominance of woody vegetation decreased from west to east and was replaced by herbaceous plants. Then the change in the vegetation cover of the Aquitanian should be related to spatial variation. Sancay et al. (2006) and Ocağolu et al. (2018) unveiled a similar picture and recorded minor amounts of herbs in the lower Miocene deposits of Central and East Anatolia.

6.2. Palaeoclimatic inferences

Since the samples were limited with respect to diversity of spores and pollen, unfavourable for quantitative palaeoclimate estimates, all samples were combined into a sample including 33 taxa. However, 19 taxa with known nearest living relatives were considered for the quantitative palaeoclimate estimations (Figure 11). The coexistence interval for the MAT ranges from 17.2 to 22.2 °C, delimited by *Avicennia* sp. (left border) and *Tilia* sp. (right border). According to *Avicennia* sp. (left border) and *Nyssa* sp. (right border), the estimated interval for the CMT changes between 12.6 and 15 °C. The WMT interval was between

Sivas Basin (Bingöl mini-basin), palynoflora of Karacaören

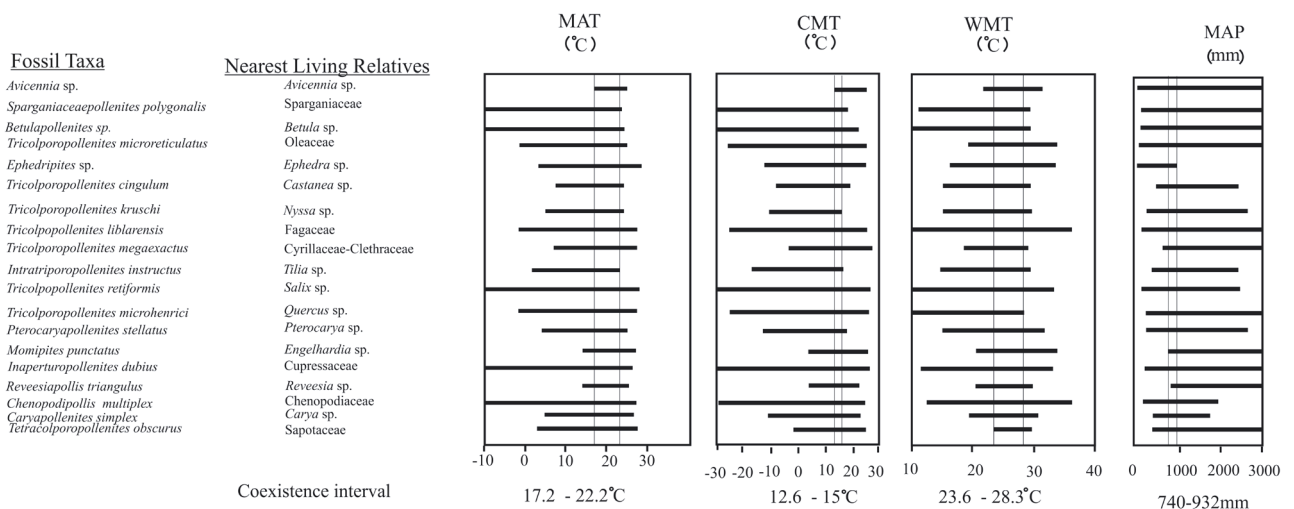


Figure 11. Quantitative palaeoclimate data from the samples of the Bingöl mini-basin. The shaded boxes indicate the climatic requirements of the taxa, the vertical lines delimit the widths of the coexistence intervals (MAT: mean annual temperature, CMT: mean temperature of the coldest month, WMT: mean temperature of warmest month, MAP: mean annual precipitation).

23.6 and 28.3 °C, determined by Sapotaceae (left border) and *Quercus* sp. (right border). The MAP calculated by the coexistence approach resulted in an interval of 740 to 932 mm based on *Engelhardia* sp. (left border) and *Ephedra* sp. (right border). The interval for the annual rainfall (MAP) implies dry conditions leading to the development of an open vegetation including high quantities of xerophytes such as Chenopodiaceae-Amaranthaceae, Poaceae, and *Ephedra* sp., and minor contributions of Caryophyllaceae and Asteraceae-Asteroidae (Figure 12). The genus *Ephedra* is especially common in semiarid to arid areas of the world (Stanley et al., 2001). According to Mosbrugger et al. (2005), palaeoclimate evolution is mainly expressed by changes in winter temperatures rather than other parameters calculated. The estimated intervals for the CMT (winter temperature) indicate a warm palaeoclimate, proved by pollen data including the megathermic taxon *Avicennia* sp. and mega-mesothermic taxa *Engelhardia* sp., *Myrica* sp., Sapotaceae, Cyrillaceae-Clethraceae, and *Reevesia* sp. as well (Figure 12). Relatively uniform

palynofloras from Sc-Mg and Sc-Ms indicate that stable palaeoclimate conditions probably existed at the time of deposition.

The early-middle Miocene vegetation was mainly dominated by arboreal taxa and the calculated palaeoclimate values of Anatolia marked a warm, humid climate and high annual rainfall (e.g., Ediger, 1990; Akgün and Akyol, 1999; Akgün et al., 2007; Yavuz-Işık, 2007, 2008; Kayseri and Akgün, 2008; Akkiraz et al., 2012; Kayseri et al., 2014; Durak and Akkiraz, 2016; Biltekin, 2018). The calculated early Miocene climate of Turkey, mostly for the western Anatolian basins, is characterised as warm-temperate (16.5–20.8 °C for the MAT, 5.5–13.3 °C for the CMT, 27.3–28.1 °C for the WMT, and 1122–1520 mm for the MAP) (Akgün et al., 2007). Kayseri et al. (2014) provided quantitative palaeoclimate data for the lower-middle Miocene sediments of the Muğla-Ören area (West Anatolia) and suggested similar values with MAT of 15.7–21.3 °C, CMT of 6.2–13.3 °C, WMT of 26.5–28.1 °C, and MAP of 1122–1520 mm. According to Durak and

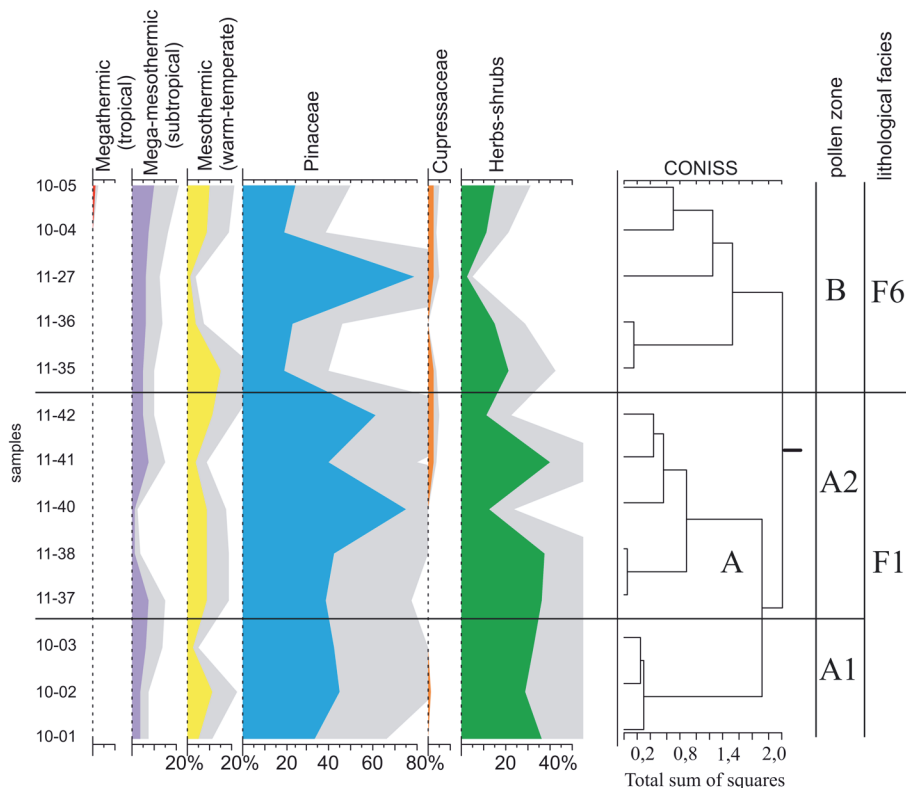


Figure 12. Synthetic pollen diagrams. Pollen taxa have been grouped on the basis of ecological criteria (according to Suc 1984, Ivanov et al., 2002; Jimenez-Moreno et al., 2005): Megathermic element (tropical): *Avicennia* sp.; Mega-mesothermic elements (subtropical): *Engelhardia* sp., *Myrica* sp., Sapotaceae, *Castanea-Castanopsis* sp., Cyrillaceae-Clethraceae, *Reevesia* sp.; Mesothermic elements (warm temperate): *Sequoia* sp., *Carya* sp., *Alnus* sp., *Betula* sp., *Pterocarya* sp., Oleaceae, *Zelkova* sp., *Ulmus* sp., Tiliaceae, *Salix* sp., and *Nyssa* sp.; Pinaceae: *Pinus haploxylon* type, *Pinus diploxylon* type and undifferentiated Pinaceae; Cupressaceae; Herbs-shrubs: Poaceae, Chenopodiaceae-Amaranthaceae, *Ephedra* sp. Shaded area: 3 times exaggerated.

Akkiraz (2016), the values from the Kalkım-Gönen Basin (Aquitanian), North-west Anatolia, also represented a warm climate with high rainfall (15.7 to 20.5 °C for MAT, 9.6 to 13.3 °C for CMT, 23.6 to 28.3 °C for WMT, and 1096 to 1356 mm for MAP). The calculated intervals defined in this study are mostly consistent with previous calculations. However, the lower boundary of intervals for the MAT increases due to the presence of thermophilic element *Avicennia* sp., whereas MAP shows a clear decrease. In conclusion, a warm and dry palaeoclimate existed during the early Miocene, or at least the Aquitanian, with the recessing of the warm Indian Ocean (Rögl, 1999). Slight warming and drying in comparison to preceding studies may be linked to the increasing of herbaceous taxa. Since tree covers decreased to the eastward, enhanced aridity led to relatively low amounts and diversity of trees and/or the presence of glades, and high quantities of xerophytes. Akkiraz et al. (2011b) validated this assumption and provided several precipitation maps showing longitudinal precipitation gradients rather than latitudinal precipitation gradients. Compared to modern climate values, the Aquitanian was warmer and relatively humid.

7. Conclusions

The following results may be stated at the end of this study:

1) A part of the lower Miocene marine sequence (Karacaören Formation) from the Bingöl minibasin (Sivas Basin) is informally divided into lower (Sc-Mg), middle (Lb), and upper (Ssm, Ssc, Gm and Sc-Ms) units. Pollen zone A corresponding to sediments of Sc-Mg includes high quantities of herbs (Poaceae, Chenopodiaceae-Amaranthaceae, and *Ephedra* sp.) and conifers (mainly undifferentiated Pinaceae), and minor occurrences of aquatics (Sparganiaceae) and freshwater

algae (*Botryococcus* sp.) indicating a low sea-level setting (=regressive event).

2) The presence of bivalves and accompanying gastropods in the whole succession suggests an Aquitanian age indicating an initiation time of marine transgression that resulted in the development of corallgal limestone (middle unit, Lb). Shallow marine conditions existed during the deposition of the upper unit (Ssm, Ssc, Gm, and Sc-Ms). An important increase of undifferentiated dinocysts, absent in Sc-Mg, and single grains of mangrove element *Avicennia* sp. in pollen zone B support this assumption.

3) On the basis of quantitative values and palynofloras from the lower and upper units, the palaeoclimate was warm and dry, confirmed by deposition of gypsum. Today's climate values of Sivas are cooler than the Aquitanian ones. Additionally, modern calculated values of annual rainfall indicate a drier condition than the fossil one.

4) During the early Miocene, or at least the Aquitanian, the western side of Anatolia was warm and humid, leading to the development of dense tree covers including highly diversified floras that resulted in economic coal seams. However, the eastern side was still warm, but drier, probably due to ingress of the Indian Ocean.

Acknowledgment

This study was supported by a research grant from the Scientific and Technological Research Council of Turkey (TÜBİTAK Grant No. 109Y041). The assistance provided by Mehmet Can Diyarbakırlı, who took part in the fieldwork, is acknowledged. The authors would like to thank Ali Gürel, two anonymous reviewers, and the manuscript editor, Ayşegül Yıldız, for their helpful comments.

References

- Akgün F, Akkiraz MS, Üçbaş SD, Bozcu M, Kapan Yeşilyurt S, Bozcu A (2013). Vegetation and climate characteristics of the Oligocene in north-west Turkey: data from the south-western part of the Thrace Basin, Northwest Turkey. *Turkish J Earth Sci* 22: 277-303.
- Akgün F, Akyol E (1987). Palynological investigations of Akhisar (Çitak) lignite. *Geol Soc Turkey Bull* 30: 35-50.
- Akgün F, Akyol E (1999). Palynostratigraphy of the coal-bearing Neogene deposits in Büyük Menderes Graben, Western Anatolia. *Geobios Lyon* 32: 367-383.
- Akgün F, Kaya T, Forsten A, Atalay Z (2000). Biostratigraphic data (Mammalia and Palynology) from the Upper Miocene İncesu Formation at Düzyayla (Hafik Sivas, Central Anatolia). *Turkish J Earth Sci* 9: 57-67.
- Akgün F, Kayseri MS, Akkiraz MS (2007). Palaeoclimatic evolution and vegetational changes during the Late Oligocene-Miocene period in Western and Central Anatolia (Turkey). *Palaeogeogr Palaeocl* 253: 56-90.
- Akgün F, Sözbilir H (2001). A palynostratigraphic approach to the SW Anatolian Molasse Basin. Kale-Tavas and Denizli Molasse. *Geodin Acta* 14: 71-93.
- Akkiraz MS (2011). Vegetation and climate in the Miocene strata of southern side of the Büyük Menderes Graben, Şahinalı well-2, SW Turkey. *B Geosci* 86: 859-878.
- Akkiraz MS, Akgün F (2005). Palynology and age of the Early Oligocene units in Çardak-Tokça basin, southwest Anatolia: paleoecological implications. *Geobios Lyon* 38: 283-299.

- Akkiraz MS, Akgün F, Örcen S (2009). Palynomorph and foraminifer content of the Lower Miocene (Aquitian) Kavak Formation outcropping in Burdur area. *Bulletin of the Turkish Association of Petroleum Geologists* 21: 31-53.
- Akkiraz MS, Akgün F, Örcen S (2011a). Stratigraphy and palaeoenvironment of the Lower-“middle” Oligocene units in the northern part of the Western Taurides (İncesu area, Isparta, Turkey). *J Asian Earth Sci* 40: 452-474.
- Akkiraz MS, Akgün F, Örcen S, Bruch AA, Mosbrugger V (2006). Stratigraphic and palaeoenvironmental significance of Bartonian-Priabonian (Middle-Late Eocene) microfossils from the Başçeşme Formation, Denizli Province, Western Anatolia. *Turkish J Earth Sci* 15: 155-180.
- Akkiraz MS, Akgün F, Utescher T, Bruch AA, Mosbrugger V (2011b). Precipitation gradients during the Miocene in Western and Central Turkey as quantified from pollen data. *Palaeogeogr Palaeoclimatol* 304: 276-290.
- Akkiraz MS, Akgün F, Utescher T, Wilde V, Bruch AA, Mosbrugger V, Üçbaş SD (2012). Palaeoflora and climate of lignite-bearing Lower-Middle Miocene sediments in the Setitömer and Tunçbilek Sub-basin, Kütahya Province, Northwest Turkey. *Turkish J Earth Sci* 21: 213-235.
- Akkiraz MS, Kayseri MS, Akgün F (2008). Palaeoecology of coal-bearing Eocene sediments in Central Anatolia (Turkey) based on quantitative palynological data. *Turkish J Earth Sci* 17: 317-360.
- Altunsoy M, Özçelik O (1998). Organic facies characteristics of the Sivas Tertiary Basin (Turkey). *J Petrol Sci Eng* 20: 73-85.
- Benda L (1971). Grundzüge einer pollenanalytischen Gliederung des türkischen Jungtertiärs (Känozoikum und Braunkohle der Türkei) 4. Beihefte zum Geologischen Jahrbuch 113: 1-46 (in German).
- Berggren WA, Kent DV, Flynn JJ, Van Couvering JJ (1995). Cenozoic geochronology. *Geol Soc Am Bull* 96: 1406-1418.
- Biltekin D (2018). Palynomorphs from a lacustrine sequence provide evidence for palaeoenvironmental changes during the early Miocene in Central Anatolia, Turkey. *Can J Earth Sci* 55: 1-9.
- Biltekin D, Popescu SM, Suc JP, Quézel P, Jiménez-Moreno G, Yavuz N, Çağatay MN (2015). Anatolia: A long-time plant refuge area documented by pollen records over the last 23 million years. *Rev Palaeobot Palynol* 215: 1-22.
- Bingöl E (1989). Geological Map of Turkey (1:2.000.000 Scale). Ankara, Turkey: Mineral Research and Exploration Institute of Turkey.
- Callot JP, Ribes C, Kergaravat C, Bonnel C, Temiz H, Poisson A, Vrielynck B, Salel JF, Ringenbach JC (2014). Salt tectonics in the Sivas Basin (Turkey): crossing salt walls and minibasins. *B Soc Geol Fr* 185: 33-42.
- Cater JML, Hanna SS, Ries AC, Turner P (1991). Tertiary evolution of the Sivas Basin, Central Turkey. *Tectonophysics* 195: 29-46.
- Çelik Y, Karayigit AI, Querol X, Oskay RG, Mastalerz M, Kayseri Özer MS (2017). Coal characteristics, palynology, and palaeoenvironmental interpretation of the Yeniköy coal of Late Oligocene age in the Thrace Basin (NW Turkey). *Int J Coal Geol* 181: 103-123.
- Çiner A, Kosun E, Deynoux M (2002). Fluvial, evaporitic and shallow-marine facies architecture, depositional evolution and cyclicity in the Sivas Basin (Lower to Middle Miocene), Central Turkey. *J Asian Earth Sci* 21: 147-165.
- Clark M, Robertson A (2002). The role of the Early Tertiary Ulukışla Basin, Southern Turkey, in Suturing of the Mesozoic Tethys Ocean. *J Geol Soc London* 159: 673-690.
- Clark M, Robertson A (2005). Uppermost Cretaceous–Lower Tertiary Ulukışla Basin, south-central Turkey: sedimentary evolution of part of a unified basin complex within an evolving Neotethyan suture zone. *Sediment Geol* 173: 15-51.
- Collinson JD (1969). The sedimentology of the Graind Shales and the Kinderscout Grit: a deltaic complex in the Namurian of northern England. *J Sediment Res* 39: 194-221.
- Curray JR, Emmel FJ, Crampton PJS (1969). Holocene history of a strand plain, lagoonal coast, Nayarit, Mexico. In: Castaneres AA, Phleger FB, editors. *Coastal Lagoons-A Symposium*, Universidad Nacional Autonoma, Mexico, pp. 63-100.
- Dickinson KA, Berryhill HL, Holmes CW (1972). Criteria for recognizing ancient barrier islands. In: Rigby JK, Hamblin WK, editors. *Recognition of Ancient Sedimentary Environments*. Tulsa, OK, USA: Society of Economic Paleontologists and Mineralogists Special Publications, pp. 192-214.
- Doğan U, Özel S (2005). Gypsum karst and its evolution east of Hafik (Sivas, Turkey). *Geomorphology* 71: 373-388.
- Durak SDÜ, Akkiraz MS (2016). Late Oligocene–Early Miocene palaeoecology based on pollen data from the Kalkım–Gönen Basin (Northwest Turkey). *Geodin Acta* 28: 295-310.
- Dunham RJ (1962). Classification of carbonate rocks according to depositional texture. *AAPG Bull* 1: 108-121.
- Ediger VS (1990). Paleopalynology of coal bearing Miocene sedimentary rocks associated with volcanics of the Biga Peninsula (NW Turkey) and the effect of volcanism on vegetation. *Neues Jahrb Geol P-A* 180: 259-277.
- Flores RM (1990). Transverse and longitudinal Gilbert-type deltas, Tertiary Coalmont Formation, north Park Basin, Colorado, USA. In: Colella A, Prior DB, editors. *Coarse Grained deltas*. Ghent, Belgium: International Association of Sedimentologists, pp. 223-233.
- Flower BP, Kennett JP (1994). The middle Miocene climatic transition: East Antarctic ice sheet development, deep ocean circulation and global carbon cycling. *Palaeogeogr Palaeoclimatol* 108: 537-555.
- Flügel E (2004). *Microfacies of Carbonate Rocks*. Berlin, Germany: Springer Verlag.
- Folk RL (1962). Spectral subdivision of limestones types. In: Ham WE, editor. *Classification of Carbonate Rocks*. Tulsa, OK, USA: American Association of Petroleum Geologists Memoirs, pp. 62-84.
- Fornaciari E, Di Stefano A, Rio D, Negri A (1996). Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. *Micropaleontology* 42: 37-63.

- Fornaciari E, Rio D (1996). Latest Oligocene to early middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. *Micropaleontology* 42: 1-36.
- Göncüoğlu MC, Toprak V, Kuşcu İ, Erler A, Olgun E (1991). Geology of the Western Part of the Central Anatolian Massif, Part 1: Southern Section (Unpublished Report No: 2909, 140 p). Ankara, Turkey: Turkish Petroleum Company Report (in Turkish).
- Görür N, Oktay FY, Seymen İ, Şengör AMC (1984). Paleotectonic evolution of the Tuz Gölü Basin complex, central Turkey. In: Dixon JE, Robertson AHE, editors. *The Geological Evolution of the Eastern Mediterranean*. London, UK: Geological Society of London Special Publications, pp. 81-96.
- Görür N, Tüysüz O, Şengör AMC (1998). Tectonic evolution of the central Anatolian basins. *Int Geol Rev* 40: 831-850.
- Grimm E (1994). *TILIA and TILIAGRAPH Pollen Diagramming Program*. Springfield, IL, USA: Illinois State Museum.
- Guezou JC, Temiz H, Poisson A, Gürsöy H (1996). Tectonics of the Sivas Basin. The Neogene record of the Anatolian accretion along the Inner Tauride suture. *Int Geol Rev* 38: 901-925
- Gürbüz K (1999). Regional implications of structural and eustatic controls in the evolution of submarine fans: an example from the Miocene Adana Basin, southern Turkey. *Geol Mag* 136: 311-319.
- Gürsöy H, Piper JDA, Tatar O, Temiz H (1997). A paleomagnetic study of the Sivas Basin, central Turkey: crustal deformation during lateral extrusion of the Anatolian block. *Tectonophysics* 271: 89-105.
- Haq BU, Hardenbol J, Vail PR (1987). Chronology of fluctuating sea levels since the Triassic. *Science* 235: 1156-1167.
- Ivanov D, Ashraf AR, Mosbrugger V, Palamarev E (2002). Palynological evidence for Miocene climate change in the Forecarpathian Basin (Central Paratethys, NW Bulgaria). *Palaeogeogr Palaeoclimatol* 178: 19-37.
- Jiménez-Moreno G (2005). Utilización del análisis polínico para la reconstrucción de la vegetación, clima y paleoaltitudes a lo largo del arco alpino europeo durante el Mioceno (21- 8 Ma). PhD, Universidad de Granada, Granada, Spain (in Spanish).
- Jiménez-Moreno G, Rodríguez-Tovar FJ, Pardo-Iguzquiza E, Fauquette S, Suc JP, Müller P (2005). High-resolution palynological analysis in late early-middle Miocene core from the Pannonian Basin, Hungary: climatic changes, astronomical forcing and eustatic fluctuations in the Central Paratethys. *Palaeogeogr Palaeoclimatol* 216: 73-97.
- Kadıoğlu M (2000). Regional variability of seasonal precipitation over Turkey. *Int J Climatol* 20: 1743-1760.
- Kangal Ö, Erdem N, Varol B (2016). Depositional stages of the Eğribucak inner basin (terrestrial to marine evaporite and carbonate) from the Sivas Basin (Central Anatolia, Turkey). *Turkish J Earth Sci* 25: 1-20.
- Kangal Ö, Varol B (1999). Sivas havzası Alt Miyosen istifinde havza kenarı fasiyesleri. *Türkiye Petrol Jeologları Derneği Bülteni* 11: 31-53 (in Turkish).
- Kayseri MS, Akgün F (2008). Palynostratigraphic, palaeovegetational and palaeoclimatic investigations on the Miocene deposits in Central Anatolia (Çorum Region and Sivas Basin). *Turkish J Earth Sci* 17: 361-403.
- Kayseri Özer MS (2013). Spatial distribution of climatic conditions from the Middle Eocene to Late Miocene based on palynoflora in Central, Eastern and Western Anatolia. *Geodin Acta* 26: 122-157.
- Kayseri Özer MS, Akgün F, Mayda S, Kaya T (2014). Palynofloras and vertebrates from Muğla-Ören region (SW Turkey) and palaeoclimate of the Middle Burdigalian-Langhian period in Turkey. *Bull Geosci* 89: 137-162.
- Kazancı N (1990). Fan-delta sequences in the Pleistocene-Holocene Burdur Basin: the role of basin margin configuration in the sediment entrapment and differential facies development. In: Colella A, Prior DB, editors. *Coarse Grained Deltas*. Ghent, Belgium: International Association of Sedimentology, pp. 185-198.
- Kazancı N, Varol B (1990). The development of a mass flow dominated fan delta complex and associated carbonate reefs within a transgressive Paleocene succession, central Anatolia, Turkey. *Sediment Geol* 68: 261-278.
- Kergaravat C, Ribes C, Legeay E, Callot JP, Kavak KŞ, Ringenbach JC (2016). Minibasins and salt canopy in foreland fold-and-thrust belts: the central Sivas Basin, Turkey. *Tectonics* 35: 1342-1366.
- Kurtman F (1973). Geologic and tectonic structure of the Sivas-Hafik-Zara and İmranlı Region. *Bulletin of the Mineral Research and Exploration* 80: 1-32.
- Larsson LM, Vajda V, Dybkjær K (2010). Vegetation and climate in the latest Oligocene-earliest Miocene in Jylland, Denmark. *Rev Palaeobot Palyno* 159: 166-176.
- Larsson LM, Vajda V, Rasmussen ES (2006). Early Miocene pollen and spores from western Jylland, Denmark – environmental and climatic implications. *GFF* 128: 261-272.
- Martini E (1971). Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci A, editor. *Proceedings of the Second Planktonic Conference*, Rome, Italy, pp. 739-765.
- Meulenkamp JE, Sissingh W (2003). Tertiary palaeogeography and tectonostratigraphic evolution of the Northern and Southern Peri-Tethys platforms and the intermediate domains of the African-Eurasian convergent plate boundary zone. *Palaeogeogr Palaeoclimatol* 196: 209-228.
- Miller KG, Wright JD, Fairbanks RG (1991). Unlocking the ice house: Oligocene-Miocene oxygen isotopes, eustasy and margin erosion. *J Geophys Res* 96: 6829-6848.
- Mosbrugger V, Utescher T (1997). The coexistence approach - a method for quantitative reconstruction of Tertiary terrestrial palaeoclimate using plant fossils. *Palaeogeogr Palaeoclimatol* 134: 61-86.
- Mosbrugger V, Utescher T, Dilcher DL (2005). Cenozoic continental climatic evolution of Central Europe. *P Natl Acad Sci USA* 102: 14964-14969.

- Ocakoglu F (2001). Repetitive subtidal-to-coastal sabkha cycles from a Lower-Middle Miocene Marine Sequence, Eastern Sivas Basin. *Turkish J Earth Sci* 10: 17-34.
- Ocakoglu F, Yavuz N, Aydın A, Yılmaz İÖ (2018). Orbitally-driven Mid-Burdigalian Coastal Sabkha cycles from the Sivas Basin: Sedimentological, paleontological, and geochemical data. *Palaeogeogr Palaeocl* 490: 505-521.
- Okay Aİ, Tüysüz O (1999). Tethyan sutures of northern Turkey. *Geol Soc Spec Publ* 156: 475-515.
- Okay Aİ, Tüysüz O, Satır M, Özkan-Altınır S, Altınır D, Sherlock S, Eren RH (2006). Cretaceous and Triassic subduction-accretion, HP/LT metamorphism and continental growth in the Central Pontides, Turkey. *Geol Soc Am Bull* 118: 1247-1269.
- Özcan E, Less G, Baydoğan E (2009). Regional implications of biometric analysis of Lower Miocene larger foraminifera from central Turkey. *Micropaleontology* 55: 559-588.
- Özçelik O, Altunsoy M (1996). Clastic petrofacies, organic facies and source rocks characteristics of the Bozbel Formation (Lutetian) in the Eastern (Sivas Turkey). *Mar Petrol Geol* 13: 493-501.
- Pichat A, Hoareau G, Callot JP, Ringenbach JC (2016). Diagenesis of Oligocene continental sandstones in salt-walled mini-basins-Sivas Basin, Turkey. *Sediment Geol* 339: 13-31.
- Poisson A, Guezou JC, Öztürk A, İnan S, Temiz H, Gürsoy H, Kavak KŞ, Özden S (1996). Tectonic setting and evolution of the Sivas Basin, Central Anatolia, Turkey. *Int Geol Rev* 38: 838-853.
- Poisson A, Temiz H, Gürsoy H (1992). Pliocene thrust tectonics in the Sivas Basin near Hafik (Turkey): southward fore thrusts and associate northward back thrusts. *Bulletin of the Faculty of Engineering of Cumhuriyet University A-Earth Sciences* 9: 19-26 (in Turkish with abstract in English).
- Poisson A, Orszag-Sperber F, Temiz H (2010). DARIUS Annual Report 2010 – Proposal No Wd 09-11 Stratigraphic and Polyphased Tectonic Evolution of the Sivas Basin (Central Anatolia, Turkey). Paris, France: DARIUS.
- Poisson A, Vrielynck B, Wernli R, Negri A, Bassetti MA, Büyükeriç Y, Özer S, Guillou H, Kavak KŞ, Temiz H et al. (2016). Miocene transgression in the central and eastern parts of the Sivas Basin (Central Anatolia, Turkey) and the Cenozoic paleogeographical evolution. *Int Geol Rev* 105: 339-368.
- Postma G (1990). Depositional architecture and facies of river and fan deltas: a synthesis. In: Colella A, Prior DB, editors. *Coarse Grained Deltas*. Ghent, Belgium: International Association of Sedimentology, pp. 13-27.
- Reading HG (1996). *Sedimentary Environments: Processes, Facies and Stratigraphy*. 3rd ed. Oxford, UK: Blackwell Science.
- Reineck HE (1972). Tidal flats. In: Rigby JK, Hamblin WK, editors. *Recognition of Ancient Depositional Environments*. Tulsa, OK, USA: Society of Economic Paleontologists and Mineralogists, pp. 146-159.
- Reineck HE, Singh IB (1980). *Depositional Sedimentary Environments*. 2nd ed. Berlin, Germany: Springer Verlag.
- Ribes C, Kergaravat C, Bonnel C, Crumeyrolle P, Callot JP, Poisson A, Temiz H, Ringenbach JC (2015). Fluvial sedimentation in a salt-controlled mini-basin: stratal patterns and facies assemblages, Sivas Basin, Turkey. *Sedimentology* 62: 1513-1545.
- Ringenbach JC, Salel JF, Kergaravat C, Ribes C, Bonnel C, Callot JP (2013). Salt tectonics in the Sivas Basin, Turkey: outstanding seismic analogues from outcrops. *First Break* 31: 93-101.
- Rögl F (1998). Palaeogeographic considerations for Mediterranean and Paratethys Seaways (Oligocene to Miocene). *Annalen des Naturhistorischen Museums in Wien* 99: 279-310.
- Rögl F (1999). Mediterranean and Paratethys. Facts and hypotheses of an Oligocene To Miocene Palaeogeography (short overview). *Geol Carpath* 50: 339-349.
- Şafak Ü, Kelling G, Gökçen NS, Gürbüz K. (2005). The mid-Cenozoic succession and evolution of the Mut basin, southern Turkey, and its regional significance. *Sediment Geol* 173: 121-150.
- Sancay RH, Batı Z, Işık U, Kırıcı S, Akça N (2006). Palynomorph, foraminifera, and calcareous nannoplankton biostratigraphy of Oligo-Miocene sediments in the Muş basin, Eastern Anatolia, Turkey. *Turkish J Earth Sci* 15: 259-319.
- Şengör AMC, Yılmaz Y (1981). Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics* 75: 181-241.
- Sirel E, Özgen-Erdem N, Kangal Ö (2013). Systematics and biostratigraphy of Oligocene (Rupelian-Early Chattian) foraminifera from lagoonal-very shallow water limestone in the eastern Sivas Basin (central Turkey). *Geol Croat* 66: 83-110.
- Stanley C, Charlet DA, Freitag H, Maier-Stolte M, Starratt AN (2001). New observations on the secondary chemistry of world *Ephedra* (Ephedraceae). *Am J Bot* 88: 1199-1208.
- Strömberg CAE, Werdelin L, Friis EM, Saraç G (2007). The spread of grass-dominated habitats in Turkey and surrounding areas during the Cenozoic: phytolith evidence. *Palaeogeogr Palaeocl* 250: 18-49.
- Suc JP (1984). Origin and evolution of the Mediterranean vegetation and climate in Europe. *Nature* 307: 429-432.
- Temiz H (1996). Tectonostratigraphy and thrust tectonics of the central and eastern parts of the Sivas Tertiary Basin, Turkey. *Int Geol Rev* 38: 957-971.
- Türkecan AT, Munsterman D, Işık U, Altınır D, Pınar M, Çevik T, Alay Z (2018). Dinoflagellate cyst biostratigraphy of Miocene strata in the Adana Basin, Eastern Mediterranean, Turkey. *Palynology* 2: 1-24.
- Ünlügenç UC, Demirkol C, Şafak Ü (1993). Stratigraphical and sedimentological characteristics of the Karsanti Basin fill to the N-NE of the Adana Basin. In: *Proceedings of A. Suat Erk Geology Symposium*, Ankara, pp. 215-227 (in Turkish).
- Utescher T, Bruch AA, Erdei B, François L, Ivanov D, Jacques FMB, Kern AK, Liu YS, Mosbrugger V, Spicer RA (2014). The coexistence approach – Theoretical background and practical considerations of using plant fossils for climate quantification. *Palaeogeogr Palaeocl* 410: 58-73.

- Weimer RJ, Howard JD, Lindsay DR (1982). Tidal flats and associated tidal channels. In: Scholle PA, Spearing D, editors. *Sandstone Depositional Environments*. Tulsa, OK, USA: American Association Petroleum Geologists Memoirs, pp. 191-245.
- Yavuz N, Culha G, Demirer ŞS, Utescher T, Aydın A (2017). Pollen, ostracod and stable isotope records of palaeoenvironment and climate: Upper Miocene and Pliocene of the Çankırı Basin (Central Anatolia, Turkey). *Palaeogeogr Palaeoclimatol* 467:149-165.
- Yavuz-Işık N (2007). Pollen analysis of coal-bearing Miocene sedimentary rocks from the Seyitömer Basin (Kütahya), Western Anatolia. *Geobios Lyon* 40: 701-708.
- Yavuz-Işık N (2008). Vegetational and climatic investigations in the Early Miocene lacustrine deposits of the Güvem Basin (Galatean Volcanic Province), NW Central Anatolia, Turkey. *Rev Palaeobot Palynol* 150: 130-139.
- Yılmaz A (1994). An example of a post-collisional trough: Sivas Basin (Turkey). In: *Proceedings of the 10th Petroleum Congress of Turkey*, pp. 21-33.
- Yılmaz A, Yılmaz H (2006). Characteristic features and structural evolution of a post collisional basin: the Sivas Basin, Central Anatolia, Turkey. *J Asian Earth Sci* 27: 164-176.
- Zachos JC, Flower BP, Paul H (1997). Orbitally paced climate oscillations across the Oligocene/Miocene boundary. *Nature* 388: 567-570.
- Zachos J, Pagani M, Sloan L, Thomas E, Billups K (2001). Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science* 292: 686-693.