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Fluctuations of sea water temperature based on nannofloral changes during the Middle to Late Miocene, Adana Basin, Turkey

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Abstract: Some nannoplankton species are sensitive to water temperatures. While *Coccolithus pelagicus* and *Reticulofenestra gelida* indicate cooler water conditions, the genera *Discoaster* and *Sphenolithus* and *Calcidiscus leptoporus* are indicative of warmer water environments. This paper focuses on relative fluctuation of sea water temperatures during the Middle and Late Miocene, emphasised by cold and warm nannofossil changes in abundance in 2 wells. At the A-1 well in the Middle Miocene, the total abundance of cooler water species is 45%, while that of the warmer species is 3%. During the Late Miocene, the total abundance for cooler water species decreases to 34%; in contrast, the total abundance of warmer species increases up to 7%. Thus, the cooler sea water temperature during the Middle Miocene becomes warmer in the Late Miocene. From the A-2 well, the total abundance of Middle Miocene cooler water species is 46%, but that of the warmer species is 11%. The total abundance of cooler water species decreases to 41%, and the total abundance of warmer species increases to 18% in the Late Miocene. Based on nannofloral fluctuation, we may thus deduce that water surface temperature increased from the Middle to the Late Miocene. Data on nannofossil abundance from the Miocene Adana Basin show that sea water temperature was cooler in the Middle Miocene, and water temperatures increased in the Late Miocene.

Key Words: Adana Basin, Miocene, Calcareous Nannofloral fluctuation, well log, Turkey

1. Introduction

The Adana Basin, bounded by the Ecemiş Fault Zone to the west, the Tauride Mountains to the north and the Amanos Mountains to the east, and extending to Cyprus in the south, is located in the Eastern Mediterranean (Figure 1). Although this basin and its adjacent regions were the subject of various geological studies, a detailed biostratigraphic framework is still missing. In addition to the data for fluctuations of sea water temperatures, the present study also provides some age data for the marine Miocene deposits.

Various types of geological studies were carried out in the study area and its surroundings by Ternek 1957; Özer *et al.* 1974; Görür 1977; Yalçın 1982; Yetiş & Demirkol 1986; Ünlügenç 1993; Kozlu 1987, 1991; Yetiş 1988; Demir 1992; Toker 1985; Toker *et al.* 1996; Aksu *et al.* 2005; Avşar *et al.* 2006; Demircan & Yıldız 2007; and Sınacı & Toker 2010.

2. Setting

Late Cretaceous-Holocene tectonic evolution in the Eastern Mediterranean has been very complex. Rapid convergence of the Asian and African Plates caused basin formation in the Late Cretaceous. At the beginning of the Cenozoic, African northward movement caused a collision of the Arabian Plate with the Anatolian Plate. The recent tectonism is between the Asian and African Plates and the Aegean, Anatolian and Arabian Microplates. The final collision between the Arabian and Asian Microplates took place in the Late Miocene. All of these events formed the Eastern Mediterranean Region, including the Antalya, Adana and İskenderun Basins and Cyprus, into their present shape (Rögl 1999; Aksu *et al.* 2005).

Palaeogene-Neogene units crop out in the Adana Basin, while Quaternary units are located in the South (Ternek 1953, 1957; Özer *et al.* 1974; Görür 1977). Cenozoic units covering large areas of the Adana Basin unconformably overlie Palaeozoic and Mesozoic rocks (Ternek 1957; Özer *et al.* 1974; Görür 1977; Yetiş & Demirkol 1986). The study area is in the eastern Tauride part of the Tauride Belt. A compressional tectonic regime was active in the Eastern Taurides during the Middle-Late Miocene (Yetiş & Demirkol 1986). The Adana Miocene Basin is bounded by the Kozan and Göksu Fault zones (Kozlu 1987).

The Gildirli Formation, composed of conglomerates, sandstones, siltstones and mudstones, is the lowest unit of the Miocene succession in the study area. It is overlain by the Karaisalı Formation, which consists of conglomerates,

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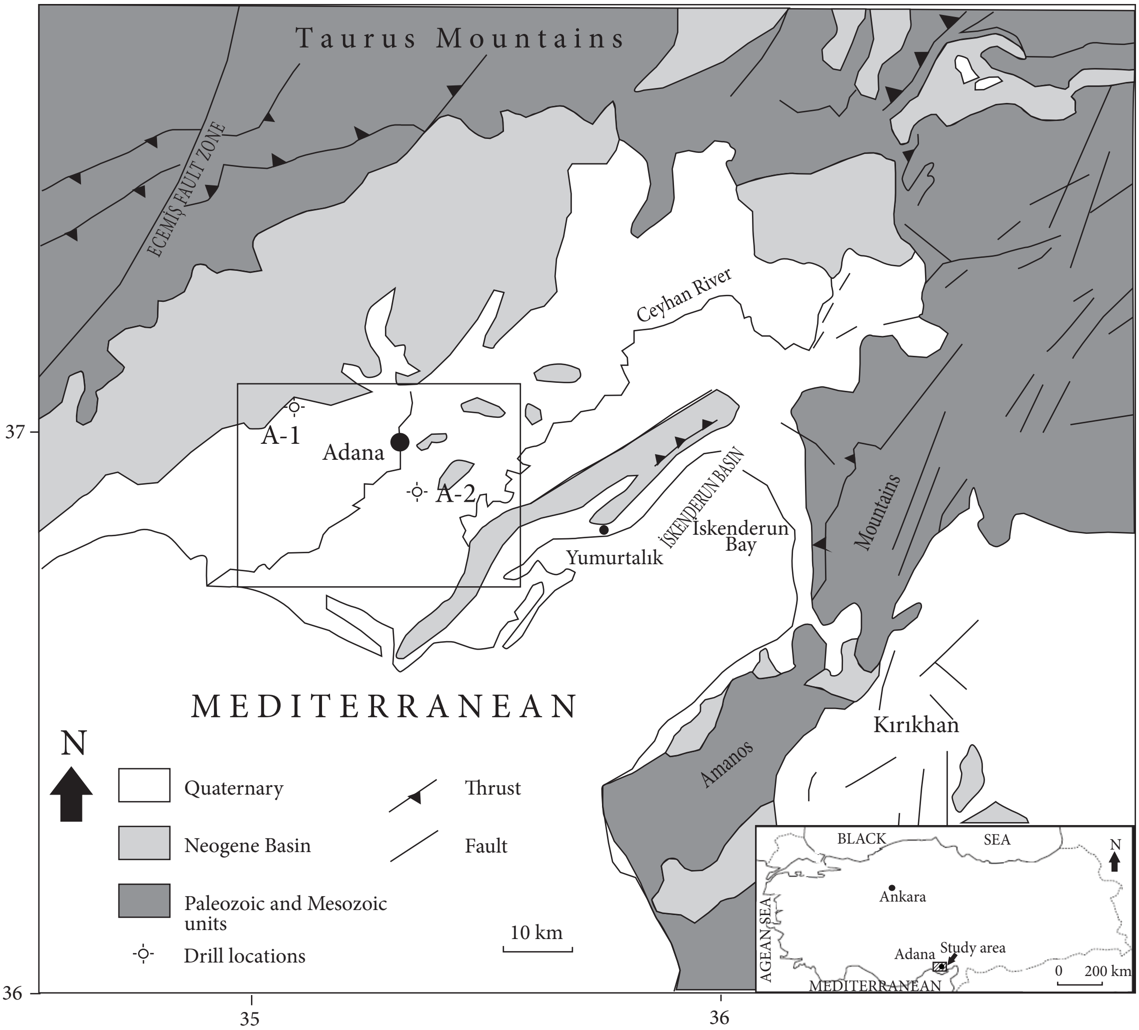


Figure 1. Location map of the study area and wells (adopted from Gürbüz 1999, with some modifications).

sandstones and limestones. This formation is succeeded in turn by the Köpekli Formation, composed of shales, marls and sandstones, and above the Cingöz Formation, comprising sandstone-shale intercalations, conglomerates and claystones. The Köpekli Formation is overlain by the Kuzgun Formation, composed of conglomerates, sandstones, siltstones, mudstones and tuffs. The Handere Formation overlies the Kuzgun Formation and it consists of evaporites, conglomerates, sandstones, siltstones and claystones. This formation is overlain by the Kuranşa Formation, composed of conglomerates, sandstones, claystones and siltstones (Yalçın 1982; Yetiş 1988; Kozlu 1991). The Kuzgun Formation is subdivided into Kuzgun, Salbaş and Memişli Members (Ünlügenç 1993); the Handere Formation is subdivided into the Gökkuyu Member (Yetiş & Demirkol 1986) and the Cingöz Formation is subdivided into the Ayva, Eğner, Topallı and Güvenç Members (Kozlu 1991; Demir 1992) (Figure 2).

3. Materials and methods

A total of 152 samples derived from the A-1 and A-2 wells drilled by TPAO have been studied. The stratigraphic intervals are 10 m from shales and marly levels, although large gaps exist (given in parentheses) between samples A11-12 (750 m); A32-33 (78 m); A33-34 (34 m); A34-35 (186 m); A 35-36 (164 m); A36-37 (988 m); K1-11, K25-26 and K 39-43 (20 m); K23-24 (50 m); K38-39 (170 m) and K43-44 (190 m). These gaps mainly correspond to coarse-grained sediments such as sandstones and conglomerates (Meşhur *et al.* 1994; Sınacı & Toker 2010). Slides were prepared from the samples by using the stripping method. Nannoplankton were determined and counted in 200 areas per slide under the microscope, and their percentages were computed.

4. Litho- and biostratigraphy of studied wells

Seventy-three samples have been taken from the A-1 drill hole, which is 3980 m deep and penetrated shales,

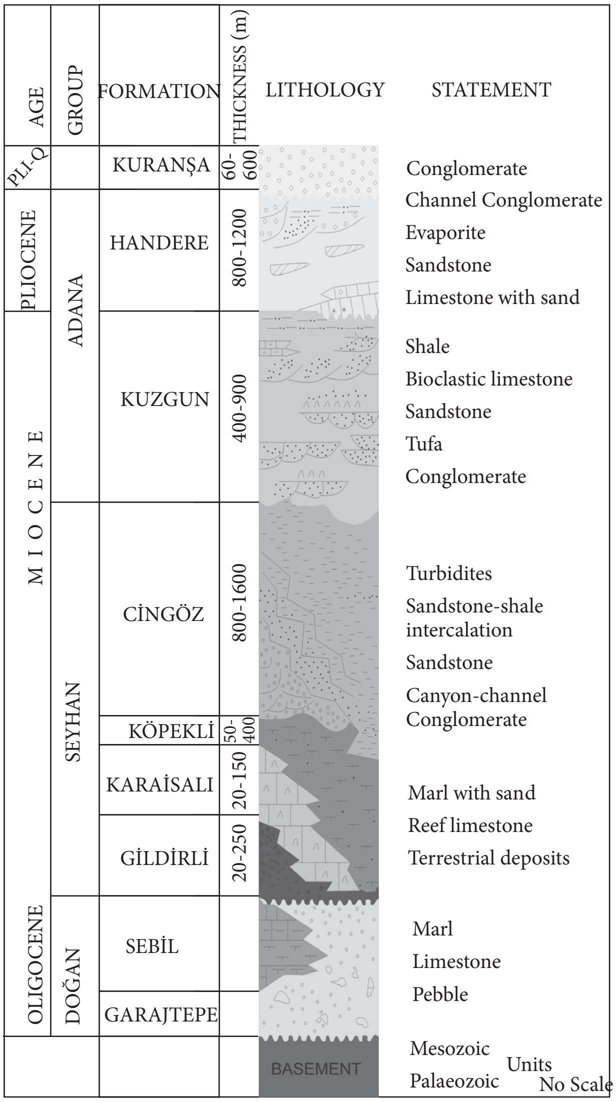


Figure 2. General lithostratigraphy of the Adana Neogene basin (Kozlu 1991).

sandstones and limestones in the first 204 m; shales and anhydrite between 204 and 285 m; and shales, siltstones, sandstones and conglomerates between 285 and 3980 m (Figure 3). In this core, we identified the *Sphenolithus heteromorphus* zone between 3820 and 3950 m, the *Discoaster exilis* zone between 2980 and 3820 m, the *Discoaster kugleri* zone between 1428 and 2980 m and the *Discoaster quinqueramus* zone between 1150 and 1320 m (Sınacı & Toker 2010).

The A-2 drill hole, 2305 m deep, is composed of conglomerates, sandstones, claystones and siltstones in the first 208 m; sandstones and claystones between 208 and 426 m; claystones, siltstones, shales, sandstones and conglomerates between 426 and 952 m; scarce conglomerates, sandstones, claystones and shales between 952 and 1495 m; siltstones, claystones and marls between 1495 and 1836 m; and marls, shales and claystones between 1836 and 2305 m. From this core we took 79 samples (Figure 4). We identified the *Discoaster exilis* zone between 1820 and 1830 m, the *Discoaster kugleri* zone between 1530 and 1820 m, the *Catinaster coalitus* zone between 1290 and 1530 m, the *Discoaster hamatus* zone between 1280 and 1290 m, the *Discoaster calcaris* zone between 1190 and 1280 m and finally the *Discoaster quinqueramus* zone between 1000 and 1190 m (Sınacı & Toker 2010).

5. Calcareous nannoplankton fluctuations and sea-level temperature changes

Nannoplankton show different palaeobiogeographic distribution features, which result from temperature changes in the ocean surface water, which is the main factor controlling climate changes. For instance, while *Discoaster* prefers tropical zones, *Coccolithus* characterises cool water environments (Haq *et al.* 1976; Bukry 1978; Raffi & Rio 1981). Perch-Nielsen (1985), Pujos (1987), Spaulding (1991) and Bakrač *et al.* (2009) describe *Reticulofenestra pseudoumbilica* as a warm water type; seemingly they assess *Reticulofenestra gelida* and *Reticulofenestra pseudoumbilica* as cool water forms. *Reticulofenestra pseudoumbilica* is a cosmopolitan form according to Krammer (2005), as is *Reticulofenestra haqii*. Therefore, *Reticulofenestra pseudoumbilica* and *Reticulofenestra haqii* are not used in the present study in assessing the sea water temperature fluctuations. The genera *Discoaster* and *Sphenolithus* were used, with the species *Calcidiscus leptoporus* (warm water species), *Coccolithus pelagicus* and *Reticulofenestra gelida* (cool water species). However, *Cyclicargolithus floridanus* was not used due to its scarcity in the studied samples (Table 1).

Haq *et al.* (1976) considered *Dictyococcites minutus* to be a warm water form and *Coccolithus pelagicus* a cool water form; Toker *et al.* (1996) considered *Coccolithus pelagicus* and *Reticulofenestra* species to characterise cool water while *Cyclicargolithus floridanus* and *Dictyococcites bisectus* and genera *Discoaster*, *Sphenolithus* and *Helicosphaera* are warm water forms. *Dictyococcites* and *Coccolithus pelagicus* were considered as cold and genera *Discoaster* and *Sphenolithus* as warm water forms by Kameo and Sato (2000); *Coccolithus pelagicus* and *Reticulofenestra* species were considered to be cool while genera *Discoaster*, *Sphenolithus* and *Helicosphaera* are warm water forms according to Demircan and Yıldız (2007). Demircan and Yıldız (2007) studied not only nannoplankton, but also foraminifera and trace fossils. Rio *et al.* (1990) studied palaeontology and isotopes and classified *Discoaster* as warm water and *Coccolithus pelagicus* as cool water forms. Authors supported their studies with foraminiferal data. Haq (1980) studied nannoplanktons, supported the study by isotope data and suggested that genera *Discoaster*

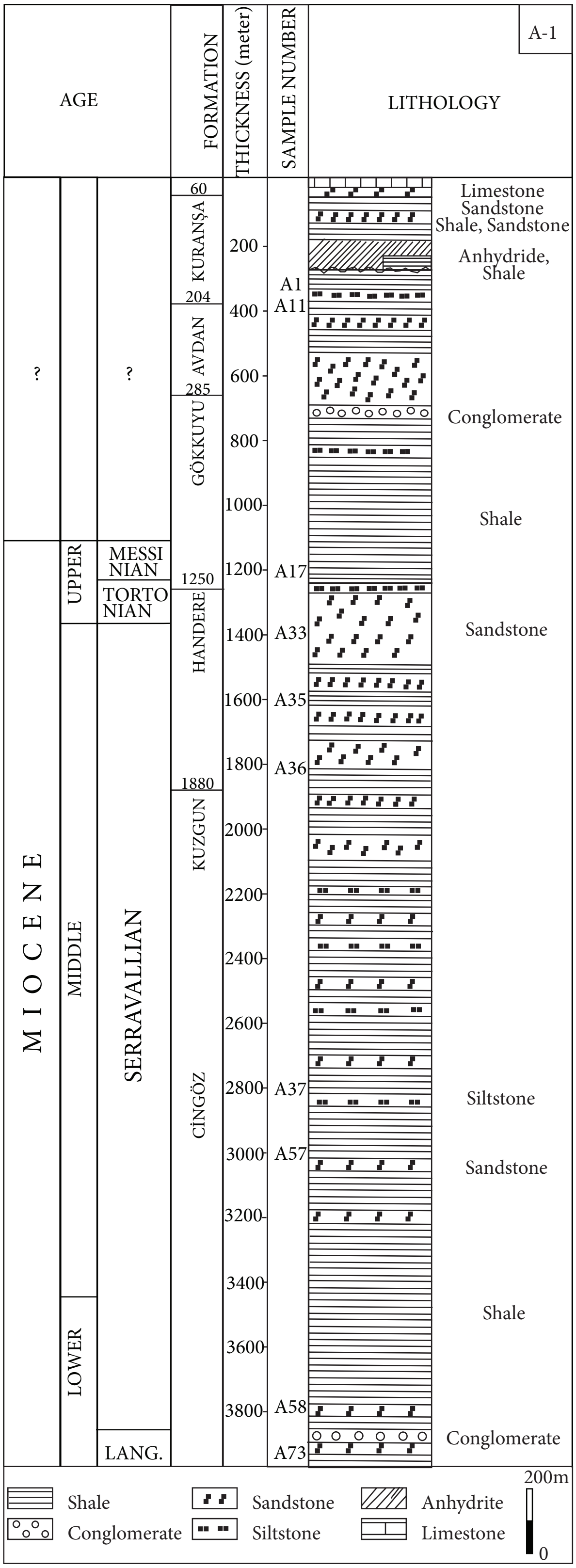


Figure 3. Lithology and sampling levels in the A-1 log (adopted from Meşhur *et al.* 1994, with some modifications).

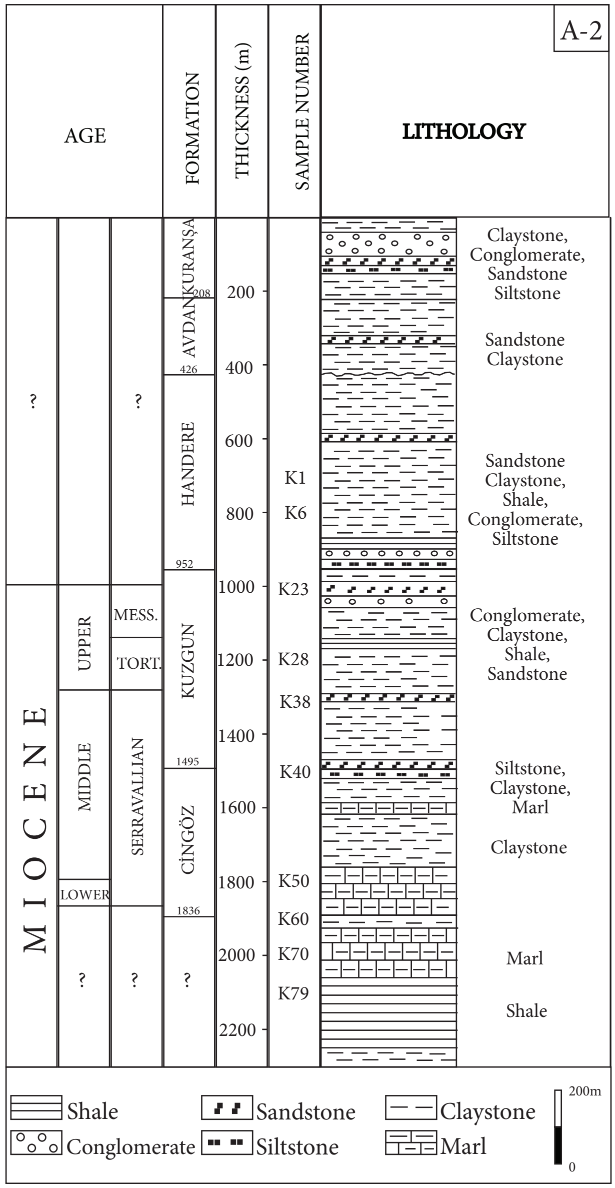


Figure 4. Lithology and sampling levels in the A-2 log (adopted from Meşhur *et al.* 1994, with some modifications).

and *Sphenolithus*, *Reticulofenestra pseudoumbilica* and *Reticulofenestra haqii* should be described as warm water forms and *Coccolithus pelagicus* as a cool water form. As in those studies, *Coccolithus pelagicus* and *Reticulofenestra gelida* are also determined as cool and genera *Discoaster* and *Sphenolithus* as warm water forms in this study in the Adana Basin, but *Reticulofenestra pseudoumbilica* was taken as a cosmopolitan form and thus not evaluated.

To evaluate the relative sea water temperature fluctuations between the Langhian and Messinian stages, the percentage of nannoplankton species abundance (Tables 2 and 3) was calculated and temperature tables were developed by semiquantitative analysis with

Table 1. Warm and cool water nannoplankton species.

Warm water types	Cool water types
Discoaster (Bukry 1973, 1975; Driever 1988; Siesser & Haq 1987; Wei & Wise 1990a, 1990b; Krammer 2005; Villa *et al.* 2008)	*C. pelagicus* (McIntyre & Bé 1967; McIntyre *et al.* 1970; Haq & Lohmann 1976; Haq *et al.* 1976; Bukry 1978; Okada & McIntyre 1979; Raffi & Rio 1981; Applegate & Wise 1987; Wei & Wise 1990a, 1990b; Winter *et al.* 1994; Wells & Okada 1996, 1997; Cachao & Moita, 2000; Krammer 2005; Villa *et al.* 2005)
Sphenolithus (Wei & Wise 1989; Krammer 2005)	*R. gelida* (Backman 1980; Perch-Nielsen 1985; Pujos 1987; Rio *et al.* 1990; Spaulding 1991; Bakrać et al. 2009)
C. leptoporus (Flores *et al.* 1999; Krammer 2005)	*C. floridanus* (Spaulding 1991; Aubry 1992a, 1992b)

nannoplankton species that are cool and warm water indicators (Figures 5 and 6).

In the A-1 log, the dominant form is *Coccolithus pelagicus*, which is a cool water form, its percentage ranging between 10.52% and 71.42%. The other cool water form, *Reticulofenestra gelida*, has percentage ranges between 3.23% and 27.37. The total abundance of *Discoaster* (0.97%–17.25%), *Calcidiscus leptoporus* (1.16%–9.09%), and *Sphenolithus* (1.33%–4.55%), which are warm water species, is a relatively low percentage.

While the total abundance of cooler water species was around 45%, that of the warmer species was around 3% during the Middle Miocene. During the Late Miocene the total abundance of cooler water species decreased to 34%, whereas the total abundance of warmer species increased to 7%. These results show that in the Adana Basin the sea water temperature was cooler during the Middle Miocene (during the *Sphenolithus heteromorphus*, *Discoaster exilis* and *Discoaster kugleri* zones), and it became warmer during the Late Miocene in the *Discoaster quinqueramus* zone (Figure 5, Table 2).

In the A-2 log, the percentages of nannoplankton species are as follows. The dominant form is the cool water type *Coccolithus pelagicus*, ranging between 9.09% and 73.33%. The other cool water type is *Reticulofenestra gelida* (between 4% and 50%). The warm water species percentages are *Discoaster*, 0.71%-100%; *Calcidiscus leptoporus*, 5.26%-31.82%; and *Sphenolithus*, 1.14%-12.5%.

In the A-2 log, the total abundance of cooler water species was around 46%, but the total abundance of warmer water species was around 11% during the Middle Miocene. During the Late Miocene the total abundance of cooler water species decreased to 41%, whereas the total abundance of warmer water species increased to 18%. Hence, cooler sea water temperatures during the Middle Miocene, indicated here by the *Discoaster kugleri*, *Catinaster coalitus* and *Discoaster hamatus* zones, became warmer during the Late Miocene, indicated by the *Discoaster hamatus*, *Discoaster calcaris* and *Discoaster quinqueramus* zones in the A-2 log (Figure 6, Table 3).

The A-1 and A-2 drill holes are in the same geographic region and provided similar results. Water temperature fluctuation was indicated by the increase and decrease in the total number of warm and cool water nannoplankton species. Sea water temperature was cooler during the Middle Miocene period, since the total number of cool water species was much greater than the total number of warm water species. As the total number of cool water species decreased in the Late Miocene, the water became warmer.

The Middle Miocene is considered to have been a tectonically very active period in the eastern Mediterranean, and it consequently had a changing and complicated palaeogeography (Rögl 1999). During this period the Mediterranean was connected to the Atlantic Ocean due to its geographic position. According to Rögl (1999), the Mediterranean-Indian Ocean seaway reopened in the Langhian (Figure 7). The Mediterranean-Indian (Atlantic-Indian) Ocean seaway became definitely closed in the early Serravallian, which caused the accumulation of evaporites, gypsum and halite in the closed sedimentary basins (Figure 8). The area was uplifted during the Tortonian because of the collision between the Afro-Arabian and Eurasian Plates (Figure 9). During the Messinian, there was a salinity crisis linked with a strong marine regression, heat increase and evaporation in the Mediterranean (Rögl 1999).

Barnosky & Carrasco (2002) and Herold (2009) showed that the general temperature of the world seas was warm in the Langhian. Rögl (1999) mentioned in his Mediterranean study that the climate was tropical in the Langhian. Toker (1985) and Özgüner & Varol (2009)

Table 2. The percentage value (%) of nannoplankton species abundance in A-1 log.

A-1																																		
Depth (m)	Epoch		Age	Nannoplankton zones	Sample number	Reticulofenestra pseudoumbilica	Coccolithus pelagicus	Reticulofenestra haqii	Helicosphaera kamptneri	Reticulofenestra gelida	Cronocyclus nitescens	Pontosphaera multipora	Sphenolithus heteromorphus	Discoaster variabilis	Helicosphaera sellii	Calcidiscus leptoporus	Discoaster deflandrei	Discoaster brouweri	Braarudosphaera bigelowii	Discoaster aulakos	Discoaster exilis	Dictyococcites antarticus	Discoaster kugleri	Calcidiscus macintyrei	Sphenolithus compactus	Discoaster challengeri	Reticulofenestra placomorpha	Helicosphaera minuta	Discoaster calcaris	Discoaster surculus	Discoaster quinqueramus	Discoaster distinctus	Discoaster pansus	TOTAL
300				?	A1		71.42		14.28	7.14		7.14																						100
310					A2		60			26.67	13.33																							100
320					A3	16.67	58.33		8.33		8.33					8.33																		100
330					A4	25	37.5		25	12.5																								100
340					A5	8.33	50		8.33	8.33	8.33					8.33								8.33										100
350					A6	25	56.25		6.25	6.25		6.25																						100
360					A7	25.64	46.15	7.69	7.69	10.26					2.56																			100
370					A8	19.44	30.55	36.11	11.11										2.78															100
380					A9	26.66	36.17	23.4	8.51					2.12			2.12																	100
390					A10		47.05	23.52	17.65		5.88	5.88																						100
400					A11	32.25	25.8	22.58	9.68	9.68																								100
1150					A12	22.85	42.86	11.43	2.86	11.43	2.86										2.86			2.86										100
1160	MIOCENE	UPPER	MESSINIAN	Discoaster quinqueramus zone	A13	17.5	37.5	12.5	7.5	12.5		2.5					2.5							5							2.5			100
1170					A14	48	28	8		8							4																4	100
1180					A15	26.31	21.05	5.26	10.52	15.79				10.52	5.26																5.26			100
1190					A16	25.93	25.93	29.63	7.4	3.7		7.4																						100
1200					A17	34.65	34.65	16.33	12.32																						2.04			100
1210					A18	24.39	39.02	17.07		9.76		2.44	2.44	2.44												2.44								100
1220					A19	14.81	44.44	18.52	14.81	3.7							3.7																	100
1230					A20	18.18	18.18	18.18	18.18		9.09	9.09												9.09										100
1240					A21	11.11	33.33	22.22	11.11	7.4		11.11																				3.7		100
1250			TORTONIAN		A22	36.84	10.52	15.79	21.05	5.26		5.26					5.26																	100
1260					A23	14.29	28.57	35.71	7.14	7.14						7.14																		100
1270					A24	22.23	22.23	31.81	4.55	13.64										4.55														100
1280					A25	13.79	20.68	6.9	20.68	20.68							6.9	6.9													3.45			100
1290					A26	45.45	27.27	9.09				9.09				9.09																		100
1300					A27	21.74	34.78	17.39	4.7			8.35				8.69													4.35					100
1310					A28	21.43	35.71	17.85	7.14		3.57	3.57								7.14									3.57					100
1320					A29	23.64	23.64	23.64	10.9	10.9		3.64																		1.82	1.82			100
1330		MIDDLE	SERRAVALLIAN	?	A30	29.33	22.67	10.67	8	16							2.67					5.33						2.67	2.67					100
1340					A31	29.41	41.18	11.76		11.76																	5.88							100
1350					A32	20.83	20.83	12.5	8.33	29.17						4.17				4.17														100
1428					A33	23.52	41.18		17.65	11.76	5.88																							100
1462				Discoaster kugleri zone	A34	19.04	57.14	4.76	4.76	4.76													4.76				4.76							100
1648					A35	62.5	25																			12.5								100
1812					A36	33.33	33.33		33.33																									100
2800					A37	32.56	20.93	9.3	6.98	25.58		3.49				1.16																		100
2810					A38	51.06	21.27		8.51	12.76		2.13				2.13									2.13									100
2820					A39	48.48	24.24	3.03	12.12	12.12																								100
2830					A40	27.27	27.27		18.18	27.27																								100
2840					A41	47.05	47.05																5.88											100
2850					A42	38.89	31.48	3.7	7.4	16.67		1.85																						100
2860					A43	28.57	35.71	14.29	7.14	7.14						7.14																		100
2870					A44	42.46	24.65	2.74	9.59	19.17						1.37																		100
2880					A45	48.57	15.71	5.71	8.57	21.43																								100
2890					A46	38.89	36.11	5.55	5.55	8.33						5.55																		100
2900					A47	36.84	28.95	1.32	6.58	18.42	1.31	1.31		1.31		1.31		1.31						1.31										100
2910					A48	47.05	11.76		17.65	23.53																								100
2920					A49	29.09	30.9	5.45	12.73	18.18						3.63																		100
2930					A50	33.68	23.16	1.05	8.42	27.37	1.05	3.16		1.05		1.05																		100
2940					A51	45.83	25		12.5	12.5	4.17																							100
2950					A52	39.66	25.86	8.62	10.34	12.06		1.72				1.72																		100
2960					A53	17.48	29.13	11.65	15.53	21.36									3.88				0.97											100
2970					A54	42.72	36.89	1.94	9.7	3.88		0.97		1.94		1.94																		100
2980					A55	38.3	29.79	2.12	8.51	12.77	2.12	2.12				2.12							2.12											100
2990				Discoaster exilis zone	A56	35.77	19.51	6.5	9.75	21.13		3.25		1.63			1.63				0.81													100
3000					A57	13.79	48.28	17.24	3.45	3.45	3.45	3.45					3.45					3.45												100
3800					A58	24.52	42.58	3.87	12.9	12.9		1.29					1.29				0.64													100
3810					A59	24	53.33		8	5.33				8							1.33													100
3820					A60	41.93	38.7		9.68	3.23							3.23			3.23														100
3830				Sphenolithus heteromorphus zone	A61	43.33	36.67		6.66	10			3.33																					100
3840					A62	42.3	26.92	1.92	15.38	7.69		3.86	1.92																					100
3850					A63	33.33	30.77	2.56	20.51	7.69		2.56							2.56															100
3860			LANGHIAN		A64	26.76	32.39	4.23	18.31	16.9		1.4																						100
3870					A65	27.02	37.83	5.4	8.1	13.51			1.35	2.7			2.7	1.35																100
3880					A66	34.67	34.67	4	12	8		4	1.33	1.33																				100
3890					A67	27.27	40.9	9.09	4.55				4.55	13.63																				100
3900					A68	21.38	41.62	0.58	7.51	24.85	0.58	0.58		2.89																				100
3910					A69	23.25	58.13		6.98	11.63																								100
3920					A70	20.75	47.16	1.88	15.09	5.66		5.66			1.89	1.89																		100
3930					A71	41.38	34.48		6.89	6.89			3.45	6.89																				100
3940					A72	9.61	63.46	3.85	9.61	9.61	1.92	1.92																						100
3950					A73	37.75	37.75	2.5	17.5	5																								100

Table 3. The percentage value (%) of nannoplankton species abundance in A-2 log.

Depth (m)	Epoch	Age	Nannoplankton zones	Sample number	Coccolithus pelagicus	Reticulofenestra pseudoumbilica	Reticulofenestra haqii	Reticulofenestra gelida	Helicosphaera kamptneri	Dictyococcites antarticus	Pontosphaera multipora	Discoaster neorectus	Discoaster variabilis	Sphenolithus abies	Discoaster exilis	Reticulofenestra placomorpha	Helicosphaera sellii	Discoaster brouweri	Discoaster pansus	Discoaster mendomobensis	Triquetrorhabdulus rugosus	Calcidiscus leptoporus	Discoaster kugleri	Cyclicargolithus luminis	Braarudosphaera bigelowii	Discoaster bollii	Pontosphaera japonica	Calcidiscus macintyrei	Discoaster challengeri	Discoaster hamatus	Cronocylus nitescens	Discoaster calcaris	Discoaster surculus	Discoaster quinqueramus	Pontosphaera indooceanica	Scyphosphaera amphora	Discoaster intercalaris	Rhabdosphaera tenuis	TOTAL
700				K1	3108	1486		2838	9.46	27	1.35					9.46												27											100
720				K2	3813	5.75	1367	2158	1.44	3.59	0.72					7.91	2.88										1.65	1.74										0.91	100
740				K3	352	3.2	176	24	128		3.2																	3.2									0.8		100
760				K4	40			20			20					20																							100
780				K5																																			0
800				K6																																			0
820				K7																																			0
840				K8	2857	3333	1429	1905	4.76																														100
860				K9	50	3333	1667																																100
880				K10	1667		1667	3332					1667			1667																							100
900				K11	30	10							30									20							10										100
910			?	K12	7143	2857																																	100
920				K13	50	10							20															10	10										100
922				K14	2727	1818		1818	9.09	9.09	1818																												100
930				K15	2857	7.15		2143	3571																												7.15		100
940				K16	57.14	1428																1428						1428											100
942				K17		1429		7142																												1429			100
950				K18	7333				6.67				6.67									6.67													6.67				100
960				K19	2308	3077		7.69	1538									7.69				1538																	100
970				K20	3182	9.09			2273									4.55				3182																	100
980				K21	50	1667		1667														1667																	100
990				K22	35	30		15	15				5																										100
1000				K23	40	10		10	6.67				6.67				3.33		3.33			6.67						10	3.33										100
1150	UPPER MIOCENE	MES.	Discoaster quinqueramus zone	K24	2188	125			6.25									2813				125			3.13				6.25					9.38					100
1160				K25		5.4		27.03	5.4	5.4	5.4		1082					2.7				2163			5.4			108											100
1180		TORTONIAN		K26	3809	1904				9.52				9.52		9.52		4.76																9.52					100
1190				K27	2727	1818			1818								9.09														9.09		9.09	9.09					100
1200			Discoaster calcaris zone	K28	36	8		4	4	28	4							4			4							8											100
1210				K29	7273														1818													9.09							100
1220				K30	1724	3448		17.24	3.45	1234								3.45		4.45								4.45	3.45										100
1230				K31	17.64	17.64			1176	1176		5.88	1176			5.88										5.88		1176											100
1240				K32	3014			1644	8.22	1096		2.74	2.74			8.22	2.74	2.74			2.74	5.47									5.47	1.37							100
1250				K33	50	30		10	10																												100
1260				K34	2631	2631		3157	5.26												5.26					5.26												100
1270				K35	3182	159		1818	4.54	1817							4.54								4.54	2.27													100
1280				K36	3461	1538		1154	1623								3.85					1254								4.85								100
1290			Discoaster hamatus zone	K37	3243	2432	5.4	1891	2.7												5.4	+							2.7	8.1								100

Table 3. (continued).

Sample number	K38	K39	K40	K41	K42	K43	K44	K45	K46	K47	K48	K49	K50	K51	K52	K53	K54	K55	K56	K57	K58
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Rhabdosphaera tenuis																					
Discoaster intercalaris																					
Scyphosphaera amphora																					
Pontosphaera indooceanica																					
Discoaster quinqueramus																					
Discoaster surculus																					
Discoaster calcaris																					
Cronocylus nitescens																					
Discoaster hamatus																					
Discoaster challengeri	29																				
Calcidiscus macintyrei					25																
Pontosphaera japonica	1.45						4.54														
Discoaster bollii									1333												
Braarudosphaera bigelowii															3.92						
Cyclicargolithus luminis	29							9.52							3.92						
Discoaster kugleri						1.54		4.76				9.09			3.92						
Calcidiscus leptoporus							9.09	9.52				1818		5.88		6.25					
Triquetrorhabdulus rugosus											3333						1.81				
Discoaster mendomobensis																					
Discoaster pansus			8.33				4.54	9.52								6.25					
Discoaster brouweri							4.54		6.67												
Helicosphaera sellii							4.54										3.63			1111	
Reticulofenestra placomorpha		3.12																	2.78	5.55	4.17
Discoaster exilis									2667							3.12					
Sphenolithus abies													125								
Discoaster variabilis		3.12					4.54			7.69						125		8.88	2.78	5.55	4.17
Discoaster neorectus																					
Pontosphaera multipora															7.84	6.25	3.63				
Dictyococcites antarticus		3.12																8.88	1111	5.55	
Helicosphaera kamptneri	5.79		8.33			3.08	9.09	9.52		7.69				5.88	1569	3125		4.44	5.55	5.55	4.17
Reticulofenestra gelida	1159	1562	1667	25		1231												2667	1944	3333	8.33
Reticulofenestra haqii	29	125		25		3077	1364		40	3076		1818	125	2941	3333		40	6.66	2.77		2083
Reticulofenestra pseudoumbilica	1739	3.12	8.33		25	2154	2727	4762	1333	1538	3333			5.88				8.89	2778	5.55	1667
Coccolithus pelagicus	5507	5937	5833	50	50	3077	1818	9.52		3846	3333	5454	75	5294	3137	3437	509	3555	2778	2777	4166
A-2 Nannoplankton zones	Catinaster coalitus zone					Discoaster kugleri zone										?					
A-2 Age	SERRAVALLIAN																				
A-2 Epoch	MIDDLE																				
Depth (m)	1300	1470	1490	1510	1530	1550	1740	1750	1760	1770	1780	1790	1800	1810	1820	1830	1840	1850	1860	1870	1880

Sample number	K59	K60	K61	K62	K63	K64	K65	K66	K67	K68	K69	K70	K71	K72	K73	K74	K75	K76	K77	K78	K79
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	0	100	100	100	100	100	100	100
Rhabdosphaera tenuis																					
Discoaster intercalaris																					
Scyphosphaera amphora																					
Pontosphaera indooceanica																					
Discoaster quinqueramus																					
Discoaster surculus																					
Discoaster calcaris																					
Cronocylus nitescens																					
Discoaster hamatus																					
Discoaster challengeri																					
Calcidiscus macintyrei																					
Pontosphaera japonica																					
Discoaster bollii																					
Braarudosphaera bigelowii																					
Cyclicargolithus luminis																					
Discoaster kugleri																					
Calcidiscus leptoporus																					
Triquetrorhabdulus rugosus																					
Discoaster mendomobensis	4.35																				
Discoaster pansus		2.38																			
Discoaster brouweri			4.76																		
Helicosphaera sellii									1052												
Reticulofenestra placomorpha	8.69	3095	9.52	1428		125		40		2222											
Discoaster exilis									5.26			1.14									
Sphenolithus abies												1.14									
Discoaster variabilis	4.35	7.14									100		2222								
Discoaster neorectus	4.35			7.14					1052			1.14					8.33				
Pontosphaera multipora												3.42					8.33	9.09			
Dictyococcites antarticus												5.68						9.09			
Helicosphaera kamptneri			4.76	7.14	1667	25				1111		4.55	2222							1118	
Reticulofenestra gelida	8.69	119	1904	2857	50		20			2222		1023	2222		40	25	3333	9.09		2018	3636
Reticulofenestra haqii	8.69	4.76	9.52			125		40	2105			4.55			20	50	25	3636		1109	9.09
Reticulofenestra pseudoumbilica	2609	2619	1429	1428			60		1053	2222		1136	2222		20	25	8.33	2727	3333	1918	1818
Coccolithus pelagicus	3478	1666	3809	2857	3333	50	20	20	421	2222		5682	1111		20		1667	9.09	6667	4745	3636
A-2 Nannoplankton zones	?																				
A-2 Age																					
A-2 Epoch																					
Depth (m)	1890	1900	1910	1920	1930	1942	1950	1960	1970	1980	1990	2000	2010	2020	2030	2040	2050	2070	2080	2090	2100

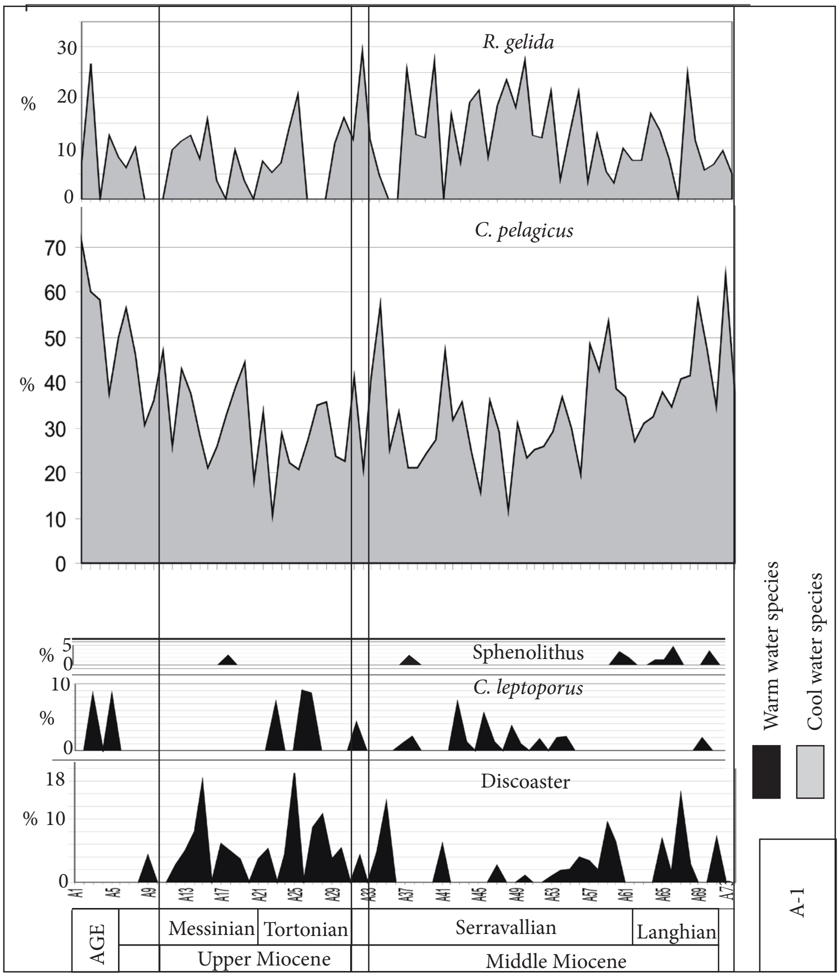


Figure 5. Semiquantitative analysis of warm and cool water species abundances in the A-1 log.

emphasised that warm conditions prevailed during the Langhian-Serravallian stages in the Antalya Basin. Sea water temperature was warm in Europe and in the Atlantic Ocean (as in the Mediterranean) during the Langhian stage (Haq *et al.* 1976; Haq 1980; Böhme 2003) (Table 4).

Toker *et al*. (1996) studied sea surface water temperature fluctuations in the Adana Basin using foraminifera-nannoplankton abundances; they found that the sea water temperature was cool during the Middle Miocene. Demircan & Yıldız (2007) identified the sea water temperature as cool during the Langhian and as warm based on planktonic foraminifers, calcareous nannofossils and trace fossils during the Serravallian in the same basin. The data from semiquantitative nannoplankton analyses in the present study show that cool water types are much more abundant than warm water types (Figures 5 and 6). The results of this study support both results from Toker *et al*. (1996) for the Langhian-Serravallian findings and results from Demircan & Yıldız (2007) in the Langhian. It is concluded that cool water conditions dominated during the Langhian-Serravallian stages in the Adana Basin. Investigations in the Malatya, Hatay and Antalya areas show that sea water temperature was warm at this time in the Mediterranean (Toker 1985; Toker *et al*. 1996; Rögl 1999; Özgüner & Varol 2009). The general sea temperature throughout the world was warm in the Langhian, while only in Adana Basin was the sea water cool (Toker *et al*. 1996; Demircan & Yıldız 2007; this study).

The occurrence of cool water temperatures in the Adana Basin during the Middle Miocene may be explained by:

1) A cool water current originating from outside the region;
2) The rise of cool, nutrient-rich (phosphorus) subsurface water to the sea surface, thus replacing warm nutrient-poor surface water (upwelling) (Özgüner & Varol 2009).

Since the Mediterranean-Indian Ocean seaway was open in the Langhian, a cool water current was assumed to have moved from the Atlantic and Indian Oceans into

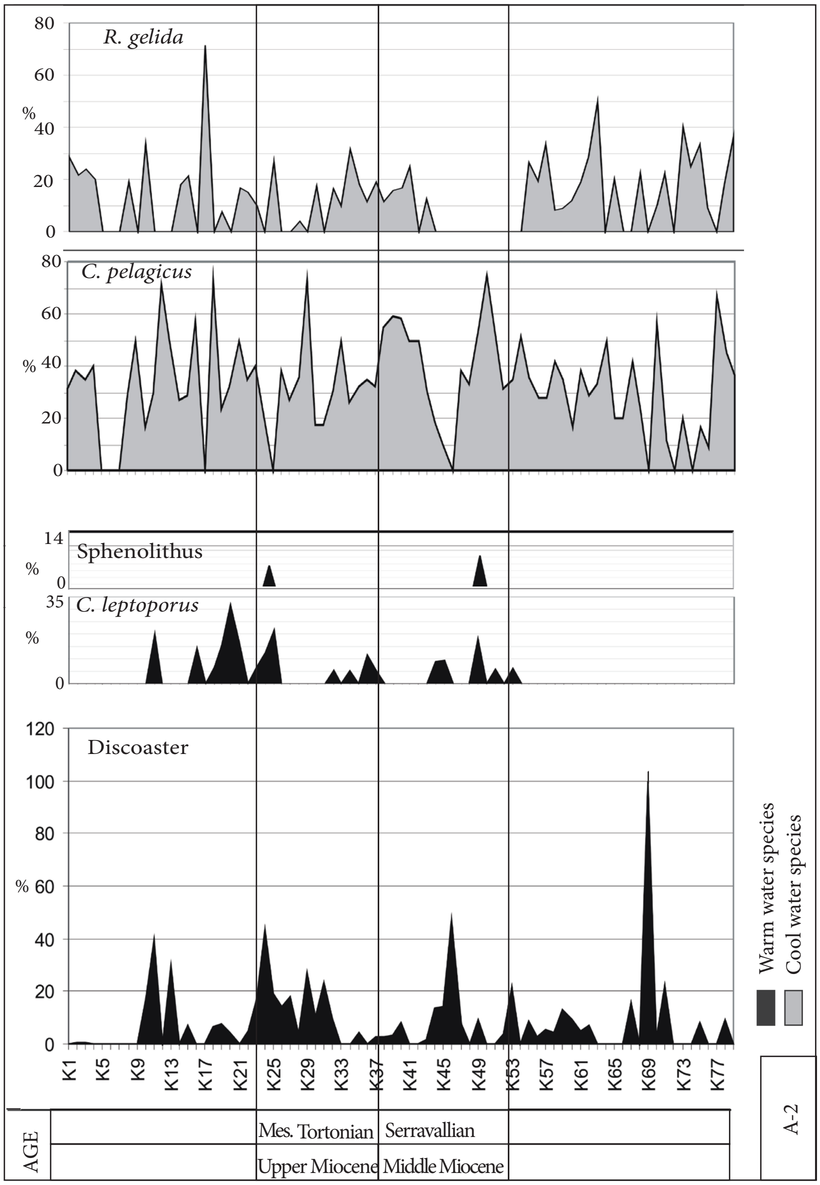


Figure 6. Semiquantitative analysis of warm and cool water species abundances in the A-2 log.

the Mediterranean. However, the Atlantic Ocean water was warm at that time (Haq *et al*. 1976; Haq 1980) and the Indian Ocean had tropical water in the region. Therefore, it was concluded that the possibility of a cool water current coming into the study area is low in the Langhian. In this case, the possibility of cool water caused by an upwelling current is higher.

Demircan & Yıldız (2007) stated that the sea water was warm during the Serravallian in the Adana Basin and argued that a warm water current could enter the Basin. However, this study supports the finding of Toker *et al*. (1996) that the sea water was cool in the Serravallian (depending on the semiquantitative analyses) (Figures 5 and 6). Normally, the sea surface water should have been warm at that time, but it appeared to be reduced for some reason. The Mediterranean and the Indian Ocean were disconnected at that time. Since sea water temperature was cool in the Atlantic during the Serravallian stage (Haq *et al*. 1976; Haq 1980; Westerhold *et al*. 2005), the possibility of movement of a cool water current from the Atlantic to the study area is hypothesised.

Sea water was cool in the Indian and Pacific Oceans in the Serravallian stage (Rio *et al*. 1990; Kameo & Sato 2000; Rai & Maurya 2009). While warm conditions prevailed in the Langhian (Böhme 2003) in Europe, the water was cool in the Langhian but warm in the Serravallian in East

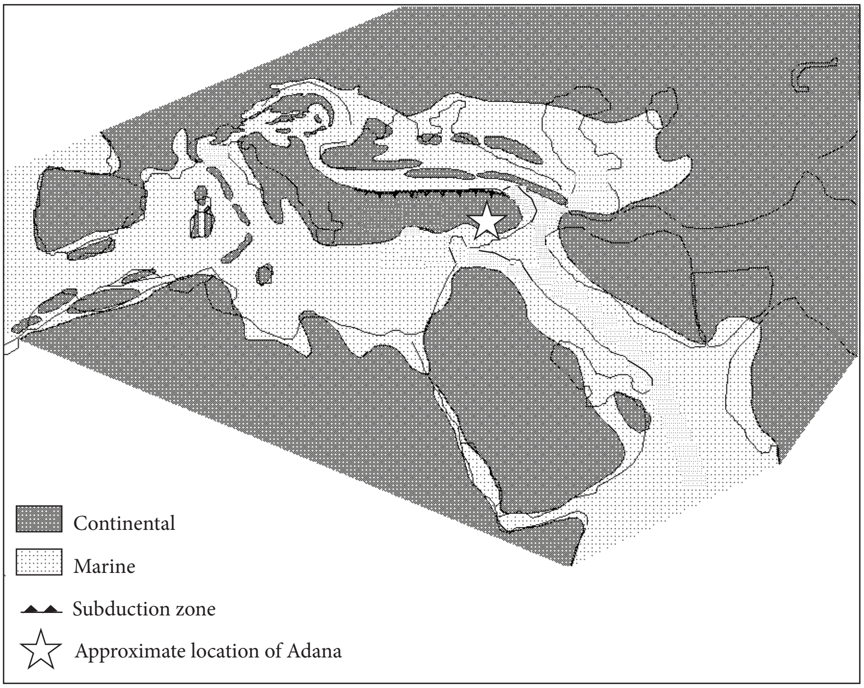


Figure 7. Mediterranean tectonic and palaeogeographic settings in the Langhian (Rögl, 1999).

Antarctica (Lewis *et al.* 2007). According to Ruddiman (2001), ice layers increased in Antarctica during the Langhian-Serravallian (up until 13 million years ago) (Table 4).

Due to general uplift in the Mediterranean realm (along the Alpine belt) during the Tortonian, the Mediterranean Sea became cut off during the Messinian, with increasing heat and intense evaporation, which resulted in the increase of warm water nannoplankton species. Atlantic Ocean water was warm at this time (Haq *et al.* 1976; Haq 1980). In this study, semiquantitative analyses of nannoplankton associations show that the sea surface water was warm during the Tortonian and Messinian stages.

All forms determined by the authors in the Antalya, Hatay and İskenderun basins, excepting *Amaurolithus delicatus*, which was found by İslamoğlu *et al.* (2009) in Hatay; *S. belemnos*, *D. druggii* and *T. carinatus* zones identified by Toker *et al.* (1996) in the Antalya Basin; and the *S. belemnos* zone determined by Toker *et al.* (1996) in the Hatay Basin, have also been recorded in the Adana Basin (Toker *et al.* 1996; Sınacı & Toker 2010; this study). *D. quinqueramus*, *D. calcaris*, *D. hamatus* and *C. coalitus* zones are restricted to the Adana Basin (Sınacı & Toker 2010; this study) and cannot be recognised in the basins of Antalya, Adana and İskenderun (Kaymakçı 1983; Toker & Yıldız 1989; Toker *et al.* 1996, İslamoğlu *et al.* 2009). *N. acostaensis*, *A. primus*, *A. delicatus*, *R. rotaria*, *H. stalis*, *H. orientalis*, *G. rotula* and *N. amplificus*, which were recognised by Morigi *et al.* (2007) and Kouwenhoven *et al.* (2006) in Cyprus, have not been detected in the Adana Basin (Toker *et al.* 1996; Sınacı & Toker 2010; this study).

The genus *Amaurolithus*, recognised in the eastern and western parts of the East Mediterranean region, the southern and western parts of Cyprus and the Dardanelles (Castradori 1998; Kouwenhoven *et al.* 2006; Morigi *et al.* 2007), has not been recognised in the west around Italy (Fornaciari *et al.* 1996). *Helicosphaera walbersdorfensis* (Fornaciari *et al.* 1996) and *Ceratolithus acutus* (Castradori 1998) have not been recognised in eastern Italy, either. All of these biostratigraphic events may be caused by the salinity and temperature changes in the Eastern Mediterranean (Figure 10, Tables 2 and 3).

6. Conclusion

Semiquantitative analyses of 152 samples derived from the A-1 and A-2 wells drilled by TPAO in the Adana Basin are presented here. Fluctuations in the temperature of the seawater were assessed based on cooler and warmer water nannoplankton species. The total abundance of Middle Miocene cooler water species is 45% in the A-1 well and 46% in the A-2 well. The abundance of these species decreases in the Late Miocene to 34% in the A-1 well and 41% in the A-2 well. The rate of warmer water species is 3% in the A-1 well and 11% in the A-2 well in the Middle Miocene. This rate increases in the Late Miocene to 7% in the A-1 well and 18% in the A-2 well. This nannofloral

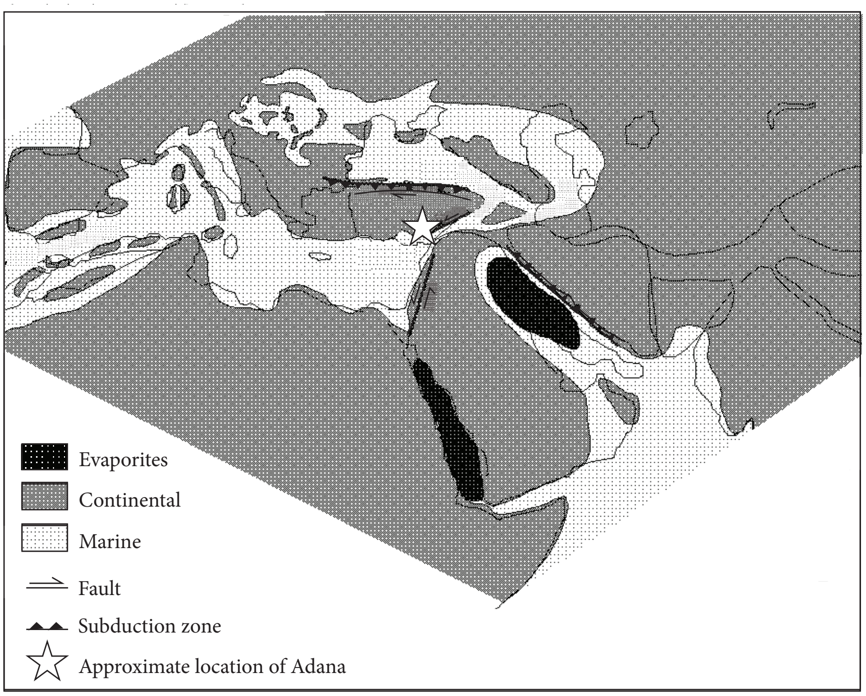


Figure 8. Tectonic and palaeogeographic settings of Mediterranean in the Serravallian (Rögl, 1999).

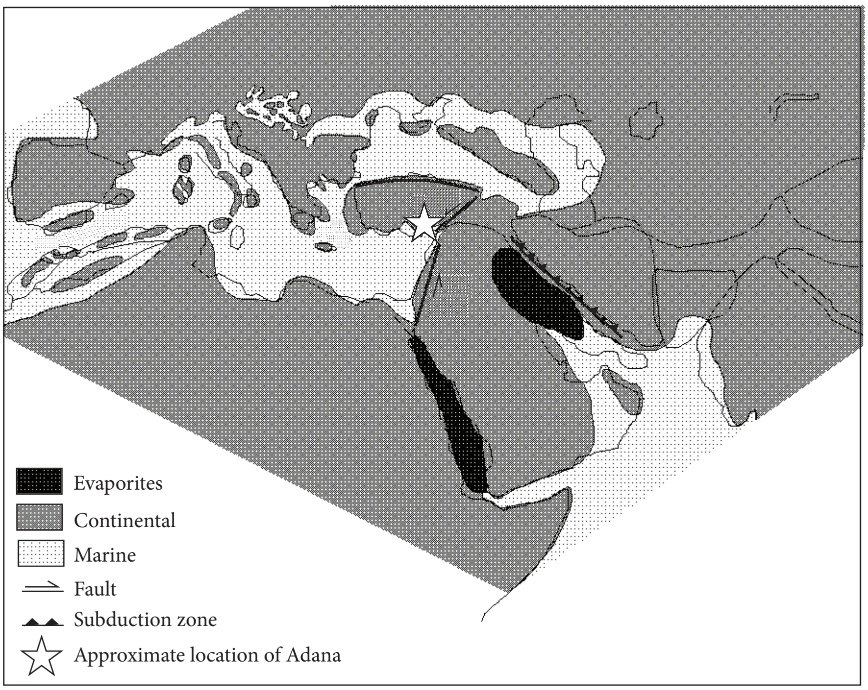
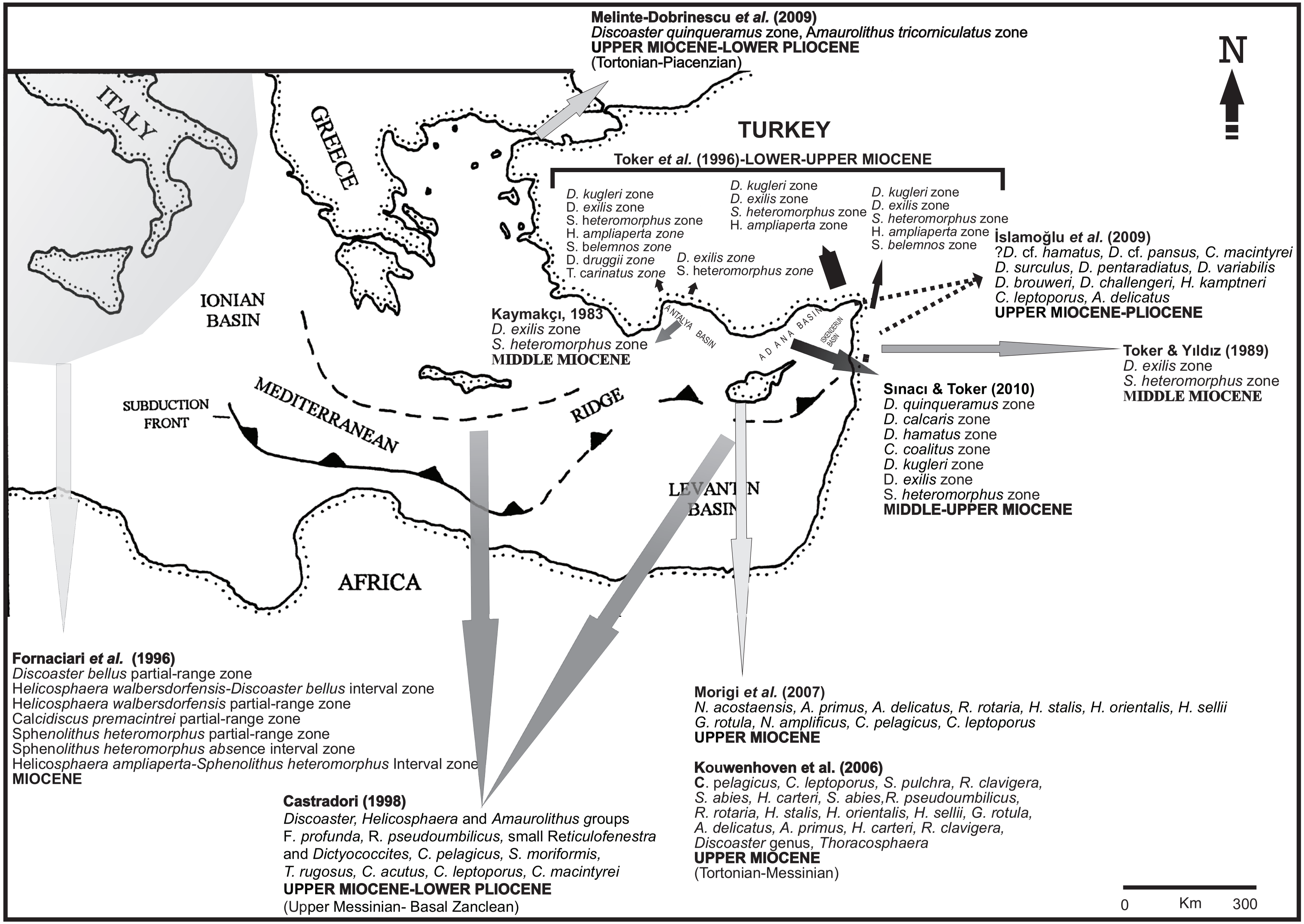


Figure 9. Tectonic and palaeogeographic settings of Mediterranean in the Tortonian (Rögl, 1999).

Table 4. Circumstance of the World seas water temperature in the Middle Miocene-Pleistocene.

Ma	Epoch	Age	This study (2012)	Demircan & Yıldız 2007	Toker *et al.* 1996		Toker 1985	Özgüner & Varol 2009	Rögl 1999	Kameo & Sato 2000	Rio *et al.* 1990	Rai & Maurya 2009	Böhme 2003	Haq *et al.* 1976	Haq 1980	Westerhold *et al.* 2005	Lewis *et al.* 2007	Barnosky & Carrasco 2002	Herold *et al.* 2009	Ruddiman 2001
			Turkey							Pacific Ocean	Indian Ocean	SE Indian Ocean		Atlantic Ocean			East Antarctica	General		
			Adana	Adana	Adana	Malatya-Hatay-Antalya	Antalya	Antalya	Mediterranean	Caribbean-E. Pacific	Indian Ocean		Central Europe	Falkland Plateau-Atlantic	N-S Atlantic	SE Atlantic	Transantarctic Mountains			
6.3	Miocene	Messinian	Warm							Warm (current)				Warm						Warm (Current) (America)
10.2		Tortonian						Warm		Cool (current)	Cool				Warm	Cool				
15.2		Serravallian		Warm						Cool	? Cool	Cool (Upwelling)	Cool	Cool	Cool		Warm			
16.2		Langhian	Cool	Cool	Cool	Warm	Warm		Warm				Warm	Warm	Warm		Cold	Warm	Warm	Cold (Antarctica)

Figure 10. Comparison of nannoplankton species and zones changes between Italy and eastern Turkey and the Mediterranean Ridge in the Eastern Mediterranean (map from Castradori, 1998).



change shows that the surface sea water was cool in the Middle Miocene but warmed in the Late Miocene.
The average temperature of the sea water was warm-hot in the Langhian-Serravallian (Toker 1985; Rögl 1999; Barnosky & Carrasco 2002; Herold 2009; Özgüner & Varol 2009), but only around Adana was the sea water temperature warm-cool in the Mediterranean (Toker *et al*. 1996 (Langhian-Serravalian); Demircan & Yıldız 2007 (Langhian); this study (Langhian-Serravalian)). A more interesting result of this paper is the possibility that the sea water temperature in the study area may have been cooled by an upwelling current in the Langhian stage and by a cool water inflow from the Atlantic in the Serravallian stage.

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