Palynofacies-based sequence stratigraphy of the Upper Cretaceous strata (Abderaz Formation) in east of Koppeh-Dagh Basin, Northeast of Iran

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Abstract
The Upper Cretaceous strata were studied in a composite stratigraphic section named here Padeha-Baghak section in east of Koppeh-Dagh basin, north east of Iran. In this study, palynostratigraphy, palynofacies and depositional environment history of Abderaz Formation were integrated with sequence stratigraphy. Determination of sea level history and sequence units of the Abderaz Formation using sedimentology data is accompanied with many problems due to uniform deposition of this formation in moderately deep parts of the basin. Hence, using the fossil evidences together with sedimentology information, sequence units of this formation have been split up. For this purpose, 127 rock samples were collected and studied. Studies of planktonic foraminifera and dinoflagellate cysts suggested a late Turonian-early Campanian age for this formation. Palynofacies parameters such as frequency and diversity of dinoflagellate species and the ratio of continental to marine constituents (CONT/MAR ratio) have been used for interpretation of the sequence stratigraphy of the formation. The ratios of amorphous organic matter to Marine Palynomorphs (AOM/MP), and Chorate to Proximate, Proximochorate, Cavate (C/PPC) and peridinioid to gonyaulacoid dinocysts (P/G) reflect the changes in sea level throughout the studied section. According to these studies, five palynofacies have been recognized. The record of sea level changes in the shales and marls of this section shows seven third – order sequence with six sequence boundary (type II), The interpreted sea-level curve in the Koppeh-Dagh basin can be correlated with late Cretaceous global curves.

Keywords*: Koppeh-Dagh, Dinoflagellate, Palynofacies, Sequence Stratigraphy.*

Introduction

The Abderaz Fm. has previously been studied by many researchers in terms of foraminiferal and palynofacies–based stratigraphy (e.g. Vahidinia & Aryai, 1998, Moradian & Allameh 2010, Bakhshandeh and Khosro-Tehrani, 2009, Shafiee Ardestani *et al.,* 2012, 2013; Vahidinia *et al.,* 2014; Yousefi-moghadam *et al.,* 2015).

This manuscript is the first sequence stratigraphy study on the Abderaz Formation based on detailed palynological data coeval with sedimentological features to reconstruct the palaeoenvironment of deep marine hemipelgic platform along the east of Koppeh-Dagh basin.

Palynofacies is a significant and useful tool for paleoenvironmental reconstruction especially construction of sea-level curves (Habib & Miller, 1989; Gorin & Steffen, 1991, Tyson, 1993, 1995; Steffen and Gorin, 1993; Bombardiere & Gorin, 2000; Carvalho *et al.,* 2006). Sea level changes directly affect composition and quantity of palynofacies (Partridge, 1976; Goodman, 1979; Gorin & Steffen, 1991; Tyson, 1993; Carvalho *et al*., 2006). The main palynological parameters for reconstruction of sea level changes are: the ratio of marine to terrestrial palynomorphs, amount of recycled palynomorphs and depositional organic facies (Habib & Miller, 1989; Habib *et al.,* 1992; Moshkovitz & Habib, 1993).

The aim of this study is a better understanding of the depositional conditions of the upper cretaceous (upper Turonian –lower Campanian) successions in the Abderaz Formation. Sequence stratigraphy of this formation is specified based on palynofacies, microfacies and biostratigraphic data and compared with global sea level changes in the upper cretaceous.

Geological setting

The Koppeh-Dagh sedimentary basin is located in northeast of Iran and southern parts of Turkmenistan and north of Afghanistan. It has a WNW to ESE trend and the Iranian part of the basin is located between 35° 30' and 38° 15' N and 54° 00' and 61° 13' E. This tectono-sedimentary unit (Berberian & King, 1981) forms the northern end of the Iranian part of the Alpine-Himalayan orogeny and is formed after the closure of Palaeotethys Ocean (Late Triassic) when the Iranian Plate collided with Eurasia (Turan Plate) producing the Cimmerian Mountains chain (Sengör, 1990). From Jurassic through the Miocene time, relatively continuous sedimentation was recorded by five major transgressive – regressive sequences (Moussavi-Harami & Brenner 1992).

The Abderaz Formation that is made up of light gray to grayish white shale and marls with three chalky limestone beds, is one of the upper Cretaceous rock units in the basin that is following the glauconite-bearing sandstones and shales of the Aitamir Formaion. The Abderaz Formation is in turn overlain conformably and gradually by light and eroded marls and shales of the Abtalkh Formation.

The first layers of the Abderaz Formation containing light gray shales and marls have been sampled in the north of Baghak village with coordinate of N 36˚4' 42″ and E 60˚ 46' 6″ (Figure 1) where sampling continued to the end of the second Chalky limestone bed. The sampling was then shifted to a second locality, the Padeha section, some 4 km to the west of the Baghak where it was continued to the top of the formation. The formation at this composite section has a thickness of 359 m altogether and ranges from late Turonian to early Campanian.

Material and methods

Lithostratigraphical, biostratigraphical, and sedimentological investigations were carried out on Abderaz Formation. Fifty-five rock samples were selected for palynology and 126 for foraminiferal studies. The samples were prepared at the Department of Geology of the Ferdowsi University of Mashhad, Iran where the slides are also housed. Palynological preparation procedures followed those of Traverse (Traverse, 1988). Removal of carbonates and silicates with HCL and HF, sieving with 200µm and 20µm mesh (nylon sieve), was the first step taken for preparation of all palynology samples. The residues were then heavy- liquid separated using zinc chloride ($ZnCl_2$) (separation of organic material) and four or five slides were made from each sample. The prepared slides were scanned and their palynological contents were identified and counted. The identified specimens were grouped in dinoflagellate cysts and sporomorphs. Dinoflagellate cysts are the most abundant palynomorphs in most of the samples. For foraminiferal studies, samples from shaly and marly layers were selected and put in H_2O_2 10% for 24 hours. All samples were washed over a 63µm, dried and sieved into 63- 125 µm and 125- 250 µm. All specimens were picked, identified and housed in sample cells for a lasting record.

Thirty one thin sections from the Chalky limestone and limy marl have been prepared and studied by an optical microscope for the microfacies analysis of the late Turonian– early Campanian succession. The facies description (i.e., the types of allochems, composition, texture and rock types) has been documented based on carbonate classifications of Dunham (1962).

Palynofacies and sedimentary environment

Palynomorphs are one of the indices used for identifying the depositional environment and sedimentary origin and are important for zoning and interpreting depositional environments (Batten, 1996; Traverse, 2007).

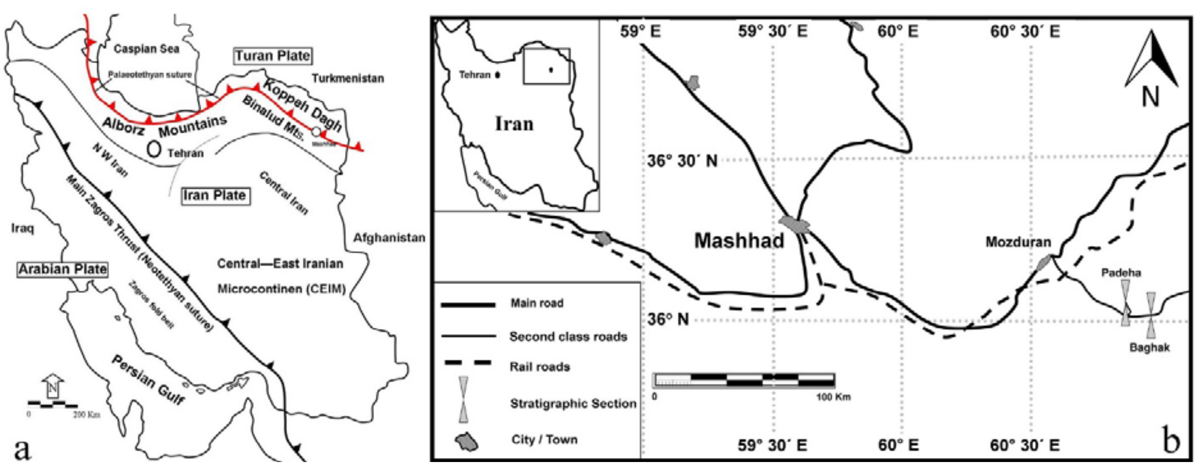

Figure 1. Location map of the studied section.

Due to the morphology and diversity of these organisms, they are being used as index fossils in interpretation of the transgressive and regressive sequences and relative sea-level changes (Schioler, 1992; Habib & Miller, 1989; Gorin & Steffen, 1991). Marine dinoflagellates are reliable proxies for identifying the proximal–distal trends (Ghasemi-Nejad, 2001; Scull *et al.,* 1966; Vozzhennikova, 1965; Carvalho, 2004). In terms of morphology, dinocysts are classified into four different groups: Proximate, Proximochorate, Chorate and Cavate (Sarjeant, 1974). Frequency changes between different forms of dinoflagellate cysts are especially used for identification of relative sea-level changes. Accordingly, cysts with long processes (Chorate) are index for offshore and low-energy environments and their abundance show open marine conditions (Mahmoud and Moawad 2000, Ghasemi-Nejad *et al.,* 1999), and forms with short or no processes (Proximate) indicate shore or costal environments.

Relative frequency of Proximate, Proximochorate and Cavate forms in some parts of the studied section indicate high energy and coastal environment while, relative increase in Chorate forms show deeper sedimentary basin in different intervals.

Chorate cysts in this formation:
Achomosphaera, Coronifera, Cleistosphaeridium, Exochosphaeridium, Florentinia, Heterosphaeridium, Hystrichosphaeridium, Oligosphaeridium, Pterodinium, Raetiaedinium, Pervosphaeridium, Spiniferites, Surculosphaeridium,…

Proximate, proximochorate cysts in this formation:
Apteodinium, Canningia, Circulodinium, Cyclonephelium, Cribroperidinium, Gonyaulacysta, Kallosphaeridium, Senoniasphaera, Trichodinium…

Cavate cysts in this formation:
Alterbidinium, Deflandrea, Eurydinium, Trithyrodinium, Odontochitina, Subtilisphaera, Spinidinium, Isabelidinium, Chatangiella

Palynofacies
Palynological contents of the slides were used for environmental interpretations. These include three main organic groups: Marine Palynomorphs (MP), Amorphous Organic Matter (AOM) and palynomacerals or Phytoclasts (PH). Palynofacies are related to the composition and state of preservation of organic content of a rock unit or loose sediments (Batten, 1996). Each palynological facies or palynofacies is characterized by its organic material content (Traverse, 2007). Palynofacies are used to determine inshore-offshore trends and to evaluate hydrocarbon potential of the source rocks. Amounts of amorphous organic matters correlate directly with marine palynomorphs and inversely with phytoclasts. The ratio between the different groups of organic elements can show relative proximity or distant of sedimentary basin to coastal area. Two hundred and seventy palynological slides were studied for their organic matter contents allowing differentiation of five palynofacies based on Tyson (1993), (Figures 2, 3 and Table 1).

Palynofacies type II
Most particles in this palynofacies are dark macerals forming over 70% of the particles content. In this palynofacies, dinoflagellates are rare and the amount of AOM is low. Generally, high proportion of continental to marine components and existence of spore and pollen grains in the samples reflect a depositional environment close to the origin. This palynofacies represents the marginal environment with low oxygen (Marginal dysoxic–anoxic basin) (Figure 3, A).

Palynofacies type VI
In this palynofacies, dinoflagellate cysts form less than 10% of the palynological elements in the slides. Amorphous organic matters count for 35% to 60% and phytoclasts vary from 40% to 65%. This facie shows a shelfal environment close to the origin with low oxygen content. (Figure 3, B).

Palynofacies type IV
*Palynomaceral*s are about 20-50% in this palynofacies; the amount of AOM has a decreasing trend and are about 20-30% and the *marine palynomorphs* are about 10-3%. Compared to palynofacies II and IV, diversity and abundance of dinocysts has increased. It shows a more appropriate condition for which diversity and preservation of dinocysts increased. This palynofacies represents a shallow to deep intermediate paleoenvironment with low oxygen content.

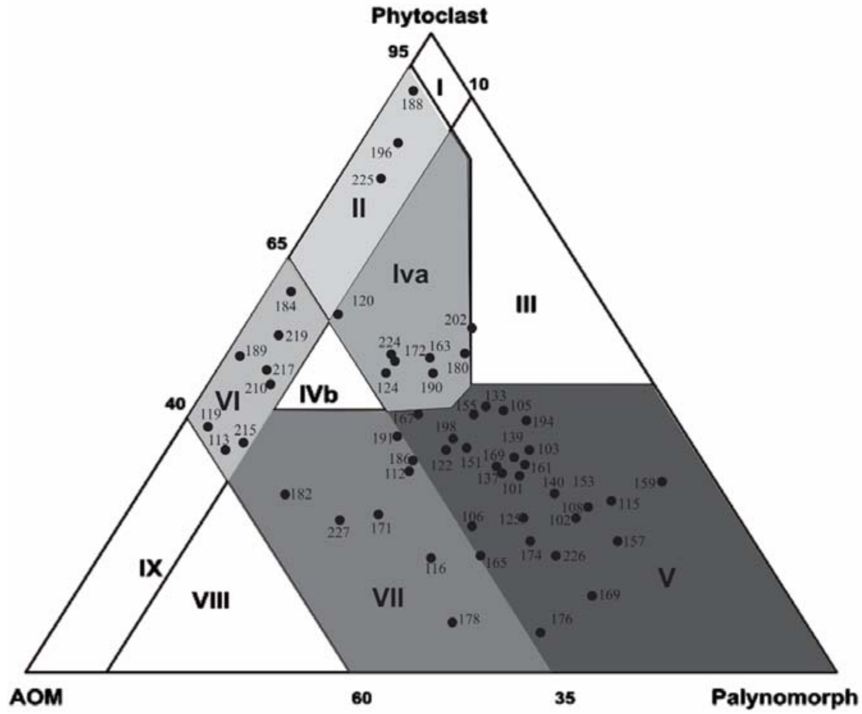

Figure 2. Palynofacies data (AOM-Phytoclast-Palynomorph) presented based on Tyson (1993) diagram.

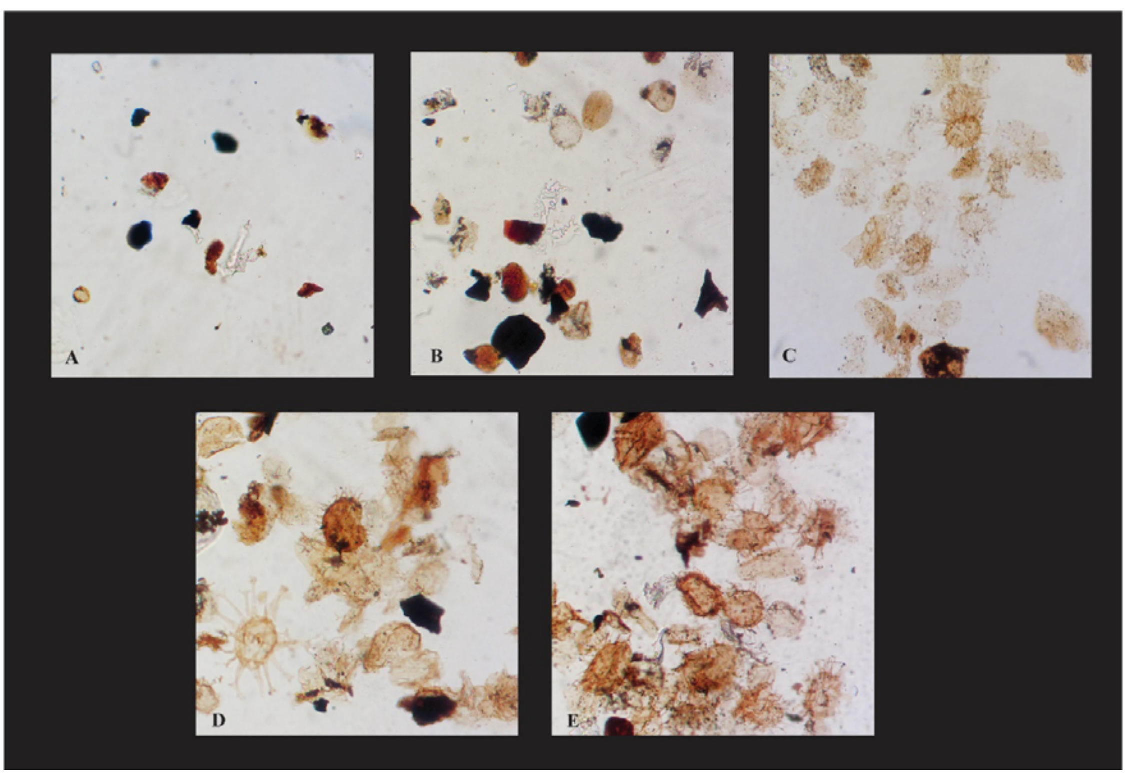

Figure 3. Palynofacies types differentiated for the Abderaz Formation; A. Palynofacies type II: Marginal dysoxic-anoxic basin (Sample NO. 196); B: Palynofacies type VI: Proximal suboxic-anoxic shelf (Sample NO. 119); C. Palynofacies type IV: Shelf to basin transition (Sample NO. 120); D. Palynofacies type V: Mud-dominated oxic shelf (distal shelf) (Sample NO. 116); E. Palynofaceis type VII distal dysoxic-anoxic shelf (Sample NO. 125)

This type of palynofacies is a transition zone from the areas near the origin towards the deep basin areas (Tyson, 1993) (Figure 3, C).

Palynofacies type V

Palynomacerals are about 10-35% in this palynofacies, marine Palynomorphs counts for 40–70% and the amount of AOM which are mainly clear is low (about 0-30%). Majority of the samples studied are falling in this palynofacies. Marine palynomorphs show good preservation and high diversity and abundance.This palynofacies shows a semi-aerobic condition with low energy and represents an open marine environment. In such an environment the lands inputs are decreased and the marine elements are increased (Tyson, 1993) (Figure 3, D).

Palynofacies type VII

In this palynofacies the amount of AOM reaches 35–65%, marine palynomorphs are 15–45% and Phytoclasts which are mainly opaque type are about 10-30%. This palynofacies shows a shallow open marine environment and indicates a distal dysoxic-anoxic shelf (Tyson, 1993).

Preservation of organic matter factors

Base on their color, palynomacerals (P) and amorphous organic materials (AOM) are divided into two groups of transparent and opaque. For estimating the amount of oxygen during accumulation of sediments, preservation factors of organic materials must be evaluated. To evaluate preservation of organic matters in this study, four factors have been evaluated (Table 2).

Brown to Opaque palynomacerals (BP/OP)

Brown palynomacerals are derived from terrestrial plants and represent an environment close to the shore or coast (Waveren & Visscher 1994; Schioler *et al*., 2002). Opaque palynomacerals represent the semi-aerobic and offshore environment and their amount usually increases in offshore areas. To increase confidence and accuracy, this factor must be considered along with other factors. Increase brown to opaque palynomacerals with increase in abundance and diversity of marine palynomorphs and reduction of AOM represent the high preservation of organic materials.

Review of brown to opaque palynomacerals in the studied samples show that the amount of brown palynomacerals is lower than opaque particles. Low levels of this factor represent the semi-oxic, offshore environment. In review of equidimensional opaque palynomacerals (P1) to blade–shape opaque palynomacerals (P2) diagram, the high proportion of blade–shape forms is an indication of offshore environments (Table 2).

Transparent AOM to Opaque AOM

One of the factors that indicate the amount of oxygen of depositional environment is the ratio of transparent AOM (anoxic conditions) to opaque AOM (oxygenated conditions) (Tyson, 1993). Transparent AOM is created due to performance of anaerobic bacteria in an anoxic environment slightly below the sediment surface. In such environment due to reduction conditions, organic material are broke down to nitrate and sulfate by bacteria and nitrogen, carbon dioxide, water and methane are produced (Tyson, 1993; Waveren & Visscher, 1994). Aerobic bacteria along with dissolved oxygen breaks down organic materials and create opaque AOM. Preservation of marine palynomorphs is highly dependent on the amount of oxygen and sedimentation rate. The highest degree for marine palynomorph preservation (especially dinoflagellate cysts) shows anaerobic conditions with high sedimentation rate. Lower rate of sedimentation increases the amount of oxygen diffusion in the sediments and breaks down the organic-walled dinoflagellate. Low oxygen levels and sedimentation rates led to low preservation of palynomorphs and convert them into transparent AOM and in high oxygen levels and low sedimentation rate; marine palynomorphs are transformed to opaque AOM (Tyson, 1993; Waveren & Visscher, 1994; Bombardiere & Gorin, 2000). Transparent to opaque AOM values of more than 1 means anoxic conditions while, values of less than 1 indicate oxygenated conditions (Bombardiere & Gorin, 2000). Calculating this factor for the Abderaz Formation shows that the ratio of the transparent to opaque AOM throughout the stratigraphic column is more than 1 which represents low-oxygen conditions during the deposition of the formation.

The ratio of AOM to marine palynomorphs

This factor is considered as a complementary factor to measure oxygen content and sedimentation rate. Increase in ratio of transparent AOM to marine palynomorphs represents anoxic conditions and low sedimentation rate. Increase in this ratio represents an oxygenated condition. Increase in marine palynomorphs represents anoxic conditions and high sedimentation rate. In this section, the ratio of transparent AOM to marine palynomorph is less than 1 that represents anoxic conditions and high sedimentation rate. Only in the areas where the depth has been reduced, this ratio is more than 1 that indicates low-oxygen conditions and low sedimentation rate. The ratio of opaque AOM to marine palynomorph is measured less than 1 that shows low- oxygen conditions and high sedimentation rate.

The analysis of proportions between different taxa and morphotypes of dinocysts in defined assemblages revealed certain patterns in their distribution (Lebedeva, 2010).

Table 1. Quantitative palynological data from the Baghak–Padeh section

Sample Number	SOM%	P%	MP%	Diversity	Abundance	AOM/MP	Con/Mar	C/PPC	G/P	G	P
101	25.52	31.16	43.32	33.33	25.53	0.82	1.39	0.86	5.337	89.47	10.53
102	20	24	56	15	23.4	0.36	0.43	0.76	3.89	79.55	20.45
103	20.6	34.55	44.85	25	22.34	0.46	0.77	0.96	3.96	79.83	20.17
105	20.47	40.95	38.58	20.83	30.43	0.53	1.06	1.92	7.67	88.46	11.54
106	33.43	22.66	43.91	37.5	47.87	0.76	0.52	1.82	7.7	88.5	11.5
108	17.6	25.75	56.65	29.17	37.45	0.31	0.45	1.32	7.04	87.56	12.44
112	36.84	31.58	31.58	10	10.64	1.17	1	0.58	9.4	90.36	9.64
113	58.1	34.9	7	0.84	1.06	8.31	5	0	0	0	100
115	14.2	26.77	59.03	60	92.34	0.24	0.45	1.05	6.7	86.96	13.04
116	41.24	17.52	41.24	20.83	16.38	1	0.43	1.44	11. 7	92.1	7.9
119	58.4	38.55	3.05	2.5	1.06	19.12	10.88	0	0.33	25	75
120	33.33	56.29	10.38	8.33	5.95	3.21	5.42	0.73	5.25	84	16
122	30.68	34.76	34.56	18.33	17.02	0.86	1.006	0.86	4.7	82.28	17.72
124	32.02	46.91	21.07	18.33	22.76	0.53	0.49	0.94	7.5	88.23	11.77
125	26.44	24.1	49.46	18.33	22.76	0.53	0.49	0.94	11.9	92.23	7.77
133	22.42	41.5	36.08	21.66	22.76	0.62	1.15	3	9	90	10
137	25.83	31.95	42.22	35	66.6	0.61	0.76	3.12	10	90.9	9.1
139	22.86	33.71	43.43	33.33	100	0.53	0.78	2.13	3.9	79.29	20.71
140	23.62	30.73	45.65	37.5	97.87	0.52	0.67	2	4.6	81.35	18.65
151	27.93	35.2	36.87	20.83	26.17	0.76	0.95	0.41	4.6	81.3	18.7
153	20.74	27.84	51.42	31.66	23.83	0.41	0.54	0.37	7.8	88.18	11.82
155	24.56	40.35	35.09	35	34.04	0.7	1.15	0.51	4.1	80.13	19.87
157	16.66	20.44	62.89	27.5	29.79	0.26	0.325	1.17	6.8	87.25	12.75
159	6.38	29.79	63.83	11.66	9.36	0.1	0.47	3.33	5.75	85.2	14.8
161	22.03	32.49	45.48	14.17	16.81	0.48	0.71	2.29	3.2	76.25	23.75
163	25.39	49.21	25.4	8.33	3.62	1	1.94	1.8	6.3	86.36	13.64
165	34.93	18.21	47.16	8.33	7.87	0.74	0.39	2.45	5.17	83.78	16.22
167	31.3	40.43	28.27	8.33	7.02	1.12	1.43	1.33	6.4	86.49	13.51
169	24.04	11.78	64.18	13.33	14.04	0.37	0.18	3	5.7	84.42	15.58
171	44.19	24.58	31.23	10.83	4.25	1.42	0.79	0.69	3.9	79.54	20.46
172	29.96	49.37	20.67	1.67	1.49	1.45	2.39	0.33	2.7	72.73	27.27
174	27.48	20.47	52.05	10	3.62	0.53	0.39	0.54	0.77	43.48	56.52
176	33.46	6.02	60.52	21.67	15.96	0.55	0.1	1.25	2.3	70	30
178	43.51	7.72	48.77	16.66	12.77	0.9	0.16	0.4	1.8	64.7	35.3

180	20.67	50.28	29.05	16.66	16.38	0.71	1.73	1.37	9.4	90.36	9.64
182	54.25	27.66	18.09	8.33	3.83	3	1.53	0.22	2	66.66	33.34
184	37.32	59.86	2.82	4.17	2.13	13.25	21.25	0	1	50	50
186	35.59	33.05	31.36	10.83	9.36	1.13	1.05	0.26	1.5	60.53	39.47
188	6.38	91.49	2.13	0.83	0.4	2	28.66	0	0	0	100
189	48.92	49.35	1.73	0.83	0.4	28.25	28.5	0	1.7	53.85	46.15
190	26.21	46.9	26.89	12.5	8.72	0.97	1.74	0.55	1.2	53.66	46.34
191	35.61	36.99	27.4	8.33	6.38	1.3	1.35	0.88	4	80	20
194	18.33	39.44	42.23	20.83	11.7	0.43	0.93	0.96	2.2	68.96	31.04
196	12.5	83.33	4.17	1.67	0.4	3	20	0	0	0	100
198	28.93	36.55	34.52	10.83	7.45	0.83	1.05	0.63	7.5	88.24	11.76
202	18	54	28	8.33	5.96	0.64	1.93	1.25	5.5	84.61	15.39
210	47.31	45.16	7.53	2.5	1.06	6.28	6	1	2.5	71.43	28.57
215	55.1	36.05	8.85	3.33	1.06	6.23	4.07	0.2	1	50	50
217	46.61	47.46	5.93	5	2.34	7.86	8	0.4	0.75	42.86	57.14
219	42.45	52.83	4.72	2.5	0.86	9	11.2	0	0	0	100
224	29.89	49.11	20.99	26.66	0.64	1.42	2.34	0.85	2.9	74.07	25.93
225	17.28	77.78	4.94	1.67	0.4	3.5	15.75	0	0	0	100
226	25.49	18.14	56.37	15	9.36	0.45	0.32	1.32	2.73	73.17	26.83
227	49.46	23.66	26.88	8.33	4.89	1.84	0.88	2.38	6.8	87.18	12.82

Table 2. Quantitative palynological data from the Baghak–Padeh section

Sample Number	SOM%	P%	MP%	Lablity	AOM$_T$/ MP	AOM$_{OP}$/ MP	AOM$_T$/AOM$_{OP}$	P$_1$/P^2
101	25.52	31.16	43.32	0	0.44	0.151	2.91	0.29
102	20	24	56	0	0.33	0.031	10.7	0.171
103	20.6	34.55	44.85	0	0.39	0.07	5.8	0.06
105	20.47	40.95	38.58	0	0.48	0.049	9.75	0.15
106	33.43	22.66	43.91	0	0.71	0.052	13.75	0.013
108	17.6	25.75	56.65	0	0.28	0.03	9.25	0.03
112	36.84	31.58	31.58	0	1.16	0	∞	0.09
113	58.1	34.9	7	0	8.1	0.03	35	0.08
115	14.2	26.77	59.03	0	0.23	0.01	21	0.064
116	41.24	17.52	41.24	0	1	0	∞	0.13
119	58.4	38.55	3.05	0.02	16.37	2.75	5.95	0.13
120	33.33	56.29	10.38	0	2.67	0.56	4.9	1.32
122	30.68	34.76	34.56	0.08	0.85	0.04	21.57	1.37
124	32.02	46.91	21.07	0	1.15	0.37	3.07	1.17
125	26.44	24.1	49.46	0	0.54	0	∞	0.59
133	22.42	41.5	36.08	0	0.59	0.028	20.75	0.36
137	25.83	31.95	42.22	0	0.59	0.02	30.2	0.27
139	22.86	33.71	43.43	0	0.46	0.065	7.18	0.53
140	23.62	30.73	45.65	0	0.51	0.0064	80.5	0.28
151	27.93	35.2	36.87	0	0.61	0.15	4	0.53

153	20.74	27.84	51.42	0	0.35	0.05	7.1	0.48
155	24.56	40.35	35.09	0.23	0.6	0.1	6	0.16
157	16.66	20.44	62.89	0	0.25	0.011	24	0.076
159	6.38	29.79	63.83	0	0.1	0	∞	0.01
161	22.03	32.49	45.48	0	0.48	0.006	77	0.031
163	25.39	49.21	25.4	0	0.99	0		0
165	34.93	18.21	47.16	0	0.75	0	∞	0
167	31.3	40.43	28.27	0	1.05	0.06	17	0.14
169	24.04	11.78	64.18	0	0.35	0.02	15.67	0.38
171	44.19	24.58	31.23	0	1.29	0.13	10.08	0.075
172	29.96	49.37	20.67	0	1.45	0	∞	0.25
174	27.48	20.47	52.05	0	0.51	0.022	22.5	0.029
176	33.46	6.02	60.52	0	0.55	0.0062	88.5	0
178	43.51	7.72	48.77	0.063	0.89	0	∞	0
180	20.67	50.28	29.05	0.022	0.71	0	∞	0.11
182	54.25	27.66	18.09	0.04	3	0	51	0
184	37.32	59.86	2.82	0	11.75	1.5	7.83	0
186	35.59	33.05	31.36	0	0.92	0.22	4.25	0.09
188	6.38	91.49	2.13	0	3	0	∞	0.21
189	48.92	49.35	1.73	0	27.75	0.5	55.5	0.18
190	26.21	46.9	26.89	0	0.87	0.1	8.5	0.08
191	35.61	36.99	27.4	0	1.25	0.05	25	0
194	18.33	39.44	42.23	0	0.42	0	∞	0.076
196	12.5	83.33	4.17	0	3	0	∞	0.11
198	28.93	36.55	34.52	0	0.84	0	∞	0.094
202	18	54	28	0	0.64	0	∞	0.08
210	47.31	45.16	7.53	0	5.29	1	5.29	0.11
215	55.1	36.05	8.85	0	5.38	0.85	6.36	0.024
217	46.61	47.46	5.93	0.018	7.71	0.14	54	0
219	42.45	52.83	4.72	0	9	0	∞	0.11
224	29.89	49.11	20.99	0	1.42	0	∞	0.13
225	17.28	77.78	4.94	0	3.5	0	14	0
226	25.49	18.14	56.37	0	0.45	0	52	0
227	49.46	23.66	26.88	0	1.84	0	46	0

Proportions between peridinioid and gonyaulacoid dinocysts represent one of the important characteristics of assemblages (Lebedeva, 2010). The dominance of gonyaulacoid cysts in the Abderaz Formation is specific of Palynofacies type V (open marine environment).

Conclusions made from percentage of three main groups of palynological elements as well as studying the preservation factor of organic materials, the ratio of transparent to opaque AOM, the ratio of transparent and opaque AOM to marine palynomorph that display low–oxygen conditions prevailed for a long time during the deposition of the Formation.

Sedimentary facies

The Abderaz Formation in the Koppeh-Dagh basin dominantly consists silisiclastic sediments (shale and marl) and carbonate rocks (marl-chalky limestones).

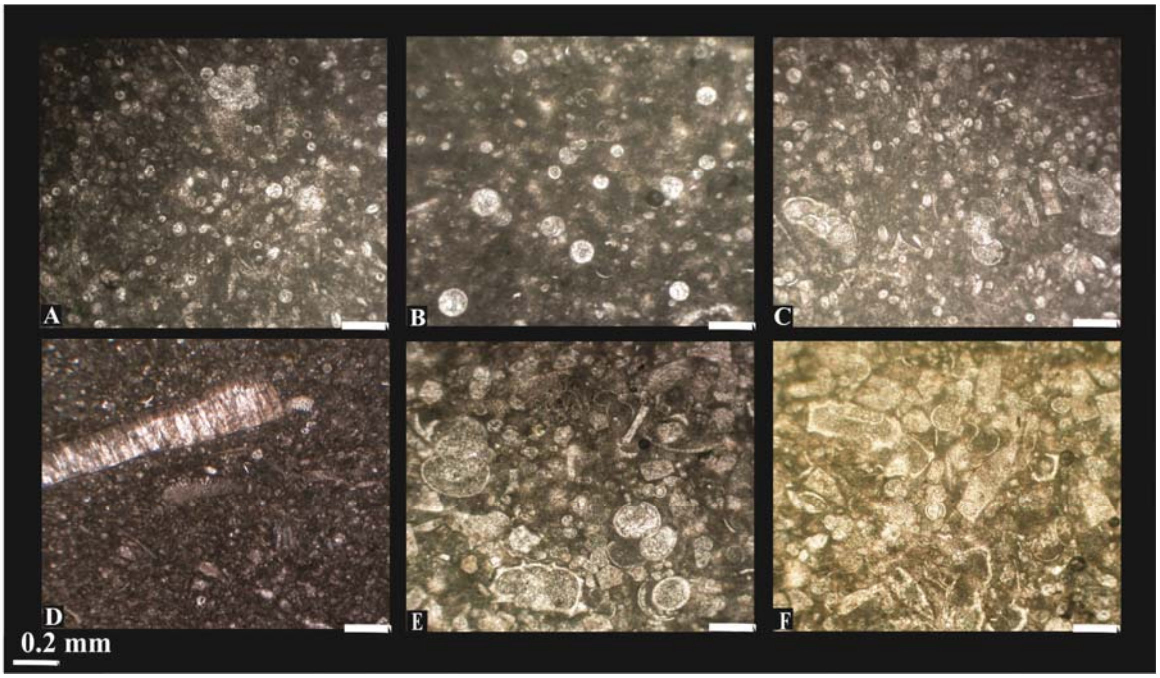

Figure 4. A, Oligosteginide biomicrite/ Oligosteginide wackestone -packstone with abundant calcispheres, B, C, Oligosteginide biomicrite/ Oligosteginide wackestone -packstone. D, Inoceramid biomicrite / Inoceramid packstone. E, F, Globotruncanide biomicrite/ Globotruncanide wackestone.

Three main carbonate facies were identified (Fig. 4) based on the microscopic studies of three interbedded chalky limestones in the formation, which are located in the thicknesses of 12-21, 100-125, and 325-359 from the base of the section. These facies are composed of:

1: Inoceramid biomicrite/ Inoceramid Packstone: that includes numerous inoceramid prisms; foraminifers, echinoid fragment and calcispheres are also visible (Figure 4B).

2: Oligosteginid biomicrite/ Oligosteginid wackestone-packstone: that includes numerous Calcisphere- rich, Pithonell (Figure 4B)

3: Globotruncanide biomicrite/ Globotruncanide wackestone: that includes numerous planktonic foraminifers.

According to facies variation, chalky limestones beds have been deposited in relatively open marine environment (shallower than other part of this formation).

Sequence stratigraphy

Sequence stratigraphy as a new method in the stratigraphic studies improves our understanding about sedimentation and preservation of deposits in sedimentary basins (Catuneanu, 2002). The changes in sequences take place based on the interaction of sedimentation, erosion and fluctuations of the basin floor (Embry, 2001). Analysis and studies of organic material in the sediments and sedimentary rocks are very useful tools for reconstructing the ancient environments (Pross *et al.,* 2006). Palynofacies are used in description of uniform sequences that cannot be described by sedimentology data (Carvalho, 2006).

Qualitative and quantitative studies of palynofacies and their compliance with sedimentology data help us in determining proximal–distal (offshore– onshore) trend of the environments and also designation of transgressive-regressive trends of relative sea levels in system tracts and sea level rises in environmental and sequence stratigraphic studies (Oboh *et al.,* 2005, Tyson 1993, Oboh and Villiers 2003, Pross and Schmiedl 2002, Pross *et al.,* 2006 , Stover 1996, Carvalho *et al.,* 2006, Moshkovitz and Habib 1993). Palynological changes during the system tracts and main surfaces of the depositional sequences are interpreted below (Figure 5, 6 and 7 and table 1, 2).

Transgressive system tract (TST)

In this systems tract sea level arises rapidly (Van wagoner *et al.,* 1988), pelagic sediments are largely formed and clastic deposits reduces (Robertson, 1993; Tyson, 1993). Diversity and abundance of marine palynomorphs increase during deposition of this systems tract (Carvalho *et al*., 2006).

Maximum Flooding Surface (MFS)

At this level, dinoflagellate cysts, amorphous organic matter and organic matter content (total organic carbon, TOC) are maximized and amount of phytoclasts are minimized (Carvalho, 2006). The highest diversity and abundance of marine palynomorphs have been observed at this surface.

Highstand system tract (HST)

The HST forms when the accumulation rates exceed the rate of accommodation during the late stage of relative see level rise. This system tract lies directly on the MFS and capped by the sequence boundary (Catuneanu *et al*., 2011). Towards the SB phytoclasts increase and AOM decrease in this system tract.

Sequence Boundary (SB)

At the sequence boundaries, due to the relative sea-level fall, the dominance of marine dinoflagellate and amorphous organic matter decreases. On the other hand, the amount of terrestrial plants such as spores, pollen and phytoclasts increases (Carvalho, 2006).

Considering the paleontology and the palynofacies data collected seven 3th-orders sequences with six sequence boundary of type II have been determined and differentiated in this study.

The 1st sequence (*late Turonian*)

The 1st sequence is about 40 m thick and composed of shale, marl, Limestone and marly limestone. This sequence commenced with a TST. The Presence of palynofacies V indicates that, this part of the section was deposited under a relatively deeper environment.

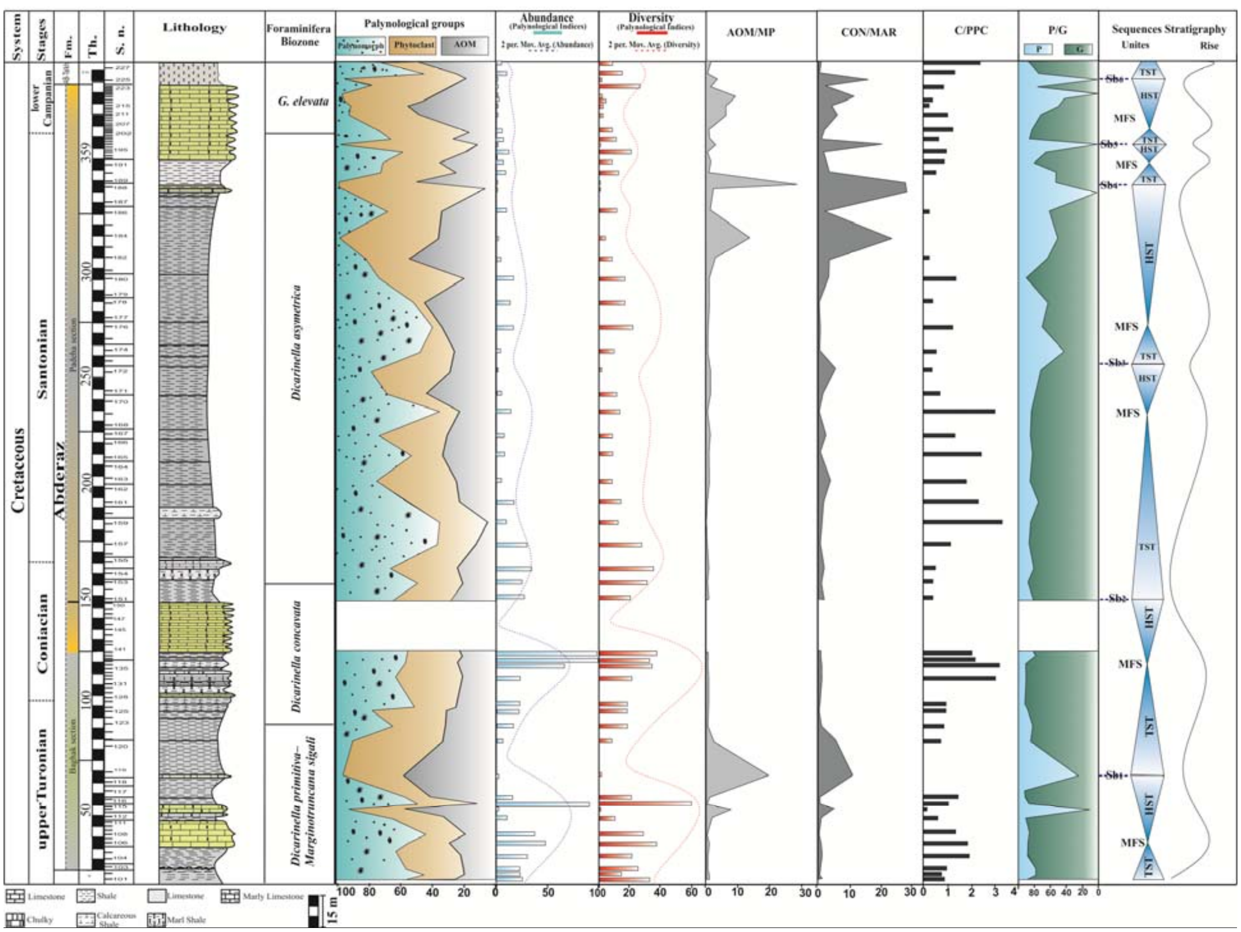

Figure 5. Relative changes in parameters used for sequence stratigraphy of the Abderaz Formation at Baghak- Padahe compound section in north of Koppeh-Dagh, eastern Iran.

The MFS is placed above the TST in sample number 106 and is characterized by minimum values of AOM/MP and CON/MAR and also maximum abundance and diversity of palynomorphs. The top boundary of this sequence (SB) is marked by palynofacies IV with maximum values of continental palynomorphs and phytoclasts (Figure 5). This sequence starts with TST that deposited in a low energy condition and represents an open deep marine environment. The lithofacies is shale and marl and crossing upward changes to shallower marine environment lithofacies (chalky limestone). HST is located in chalky limestones interval.

This SB at the end of Turonian is equivalent with global sequence boundary Tu4 (Hardenbol *et al.*, 1998; Ogg and Gradstein, 2008).

The 2nd sequence (*Coniacian*)

The 2nd sequence is generally consists of alternation of shale, marl, Chalky Limestone and marly limestone and is about 81 m thick.

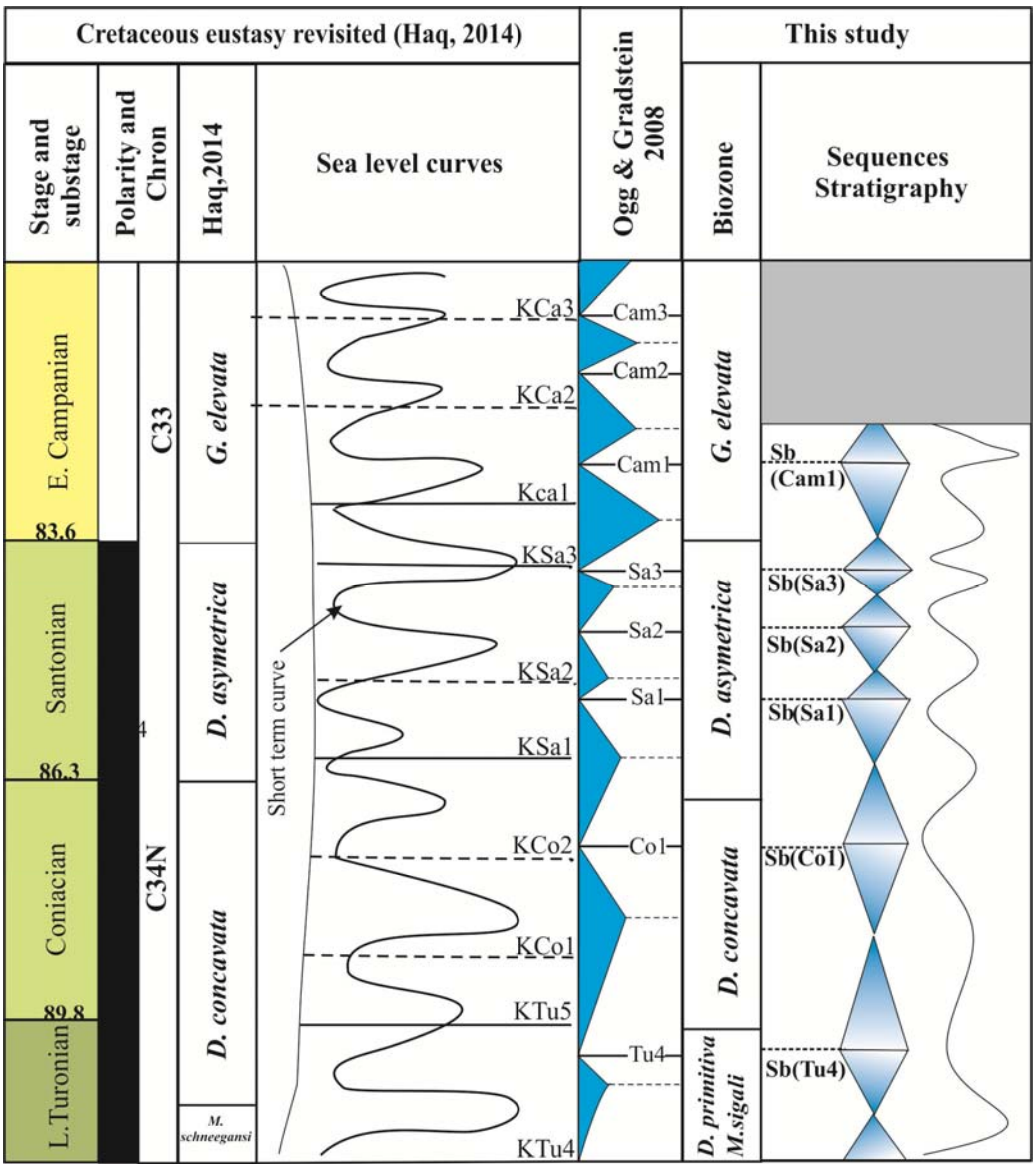

Figure 6. Correlation of sequence boundaries of the Abderaz Formation and global Cretaceous sea-level changes of Haq (2014); Ogg and Gradstein (2008)

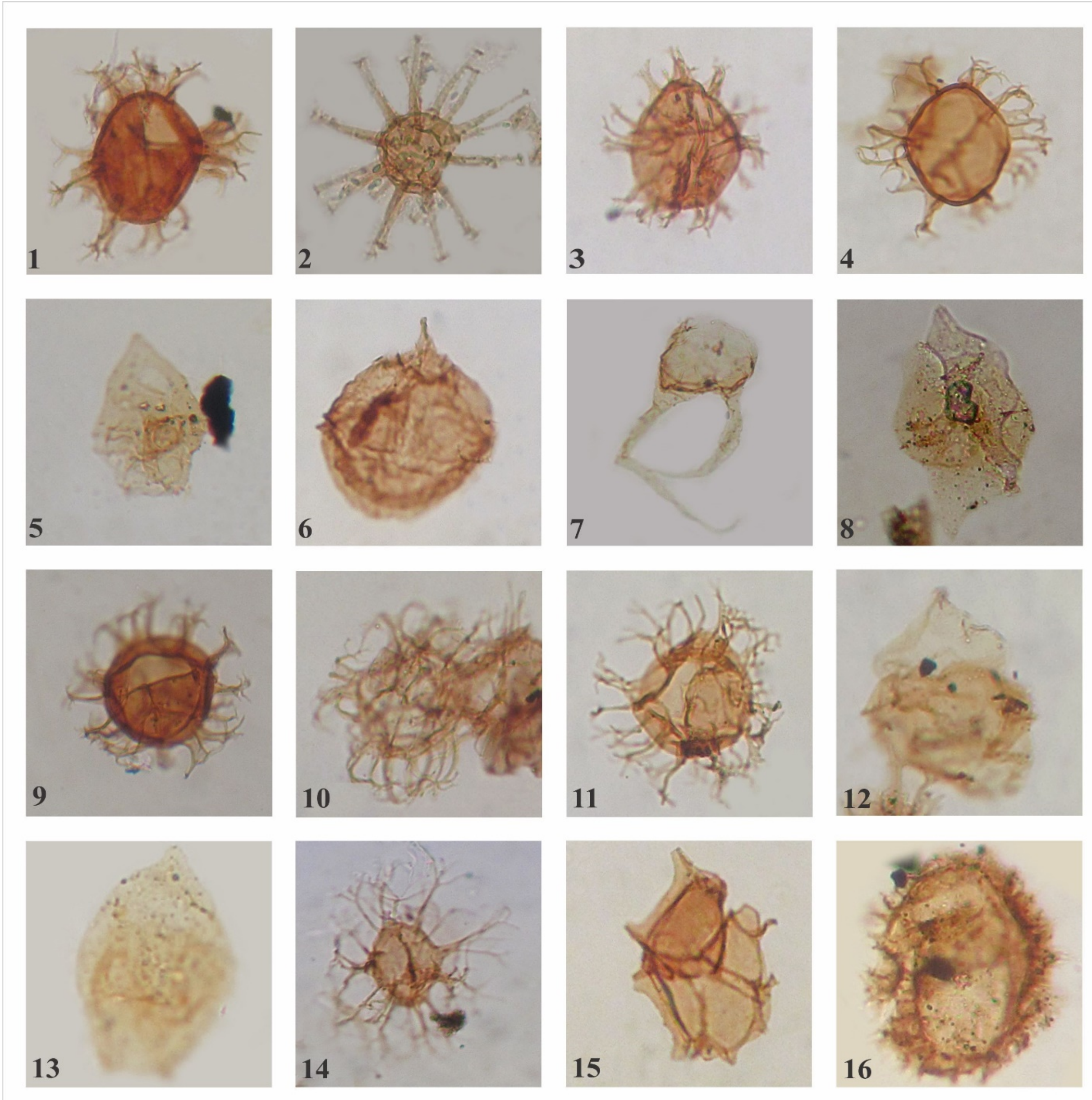

Figure7. Scale bar = 20 µm. 1, *Achomosphaera ramulifera,* (Deflandre, 1937) Evitt 1963; 2, *Cymososphaeridium benmorense* Schioler & Wilson 1966; 3, *Exochosphaeridium striolatum.* (Deflandre, 1937b) Davey, 1969a; 4, *Heterosphaeridium difficile (*Manum and Cookson, 1964); 5, *Chatangiella spectabilis* (Alberti) Lentin & Williams1976; 6, *Cribroperidinium orthoceras* (Eisenack, 1958a) Davey 1969a; 7, *Odontochitina operculata* (O. Wetzel 1933a) Deflandre and Cookson 1955; 8, *Chatangiella victoriense* Cookson & Manum, 1964; 9, *Achomosphaera sagena Davey and Williams, 1966a*; 10, *spiniferites ramosus* (Ehrenberg, 1838); 11, *Achomosphaera regiensis* Corradini, 1973; 12, *Chatangiella victoriense* Cookson & Manum, 1964; 13, *Isabelidinium cretaceum* (Cookson, 1956); 14, *Surculosphaeridium? longifurcatum* (Firtion 1952) Davey et al. 1966; 15, *Pterodinium cingulatum* (Wetzel, 1933b); 16, *Chlamydophorella ambigua* (Deflandre 1937) Stover & Helby 1987.

The Chalky limestone with 21.8 m thickness has no palynomorphs. The minimum diversity and abundance of palynomorphs at the base of this sequence increases gradually in the TST to reach a maximum value in the MFS (Sample 139). Other characteristic of the MFS contains minimum value of AOM/MP and CON/MAR and presence of palynofacies type V that indicates a distal shelf environment for this part of the sequence. After the MFS, phytoclasts increase and diversity and abundance of dinoflagellate cysts reduce in HST. A sequence boundary was placed at the top of the interval that is associated with dominance of phytoclasts and palynofacies IVa that suggest a shallow marine to transitional basin environment. The HST of 2nd sequence is located in the carbonate facies.

This SB is comparable with the global SB in the Coniacian (SB Co1) (Hardenbol *et al.,* 1998).

The 3rd sequence (*Santonian*)

The 3rd sequence is about 107 m thick and composed of shale, marl and marly limestone.

The MFS has been placed at about 210.35 m from the base of the section where the marine palynomorphs show relatively high abundance and the ratio of C/PPC is high. From this point upwards abundance and diversity of dinocysts decreases gradually and abundance of phytoclasts increases. This range has been attributed to the HST. Sample 172 at about 229.35 m from the base of the section marks the SB3.

This boundary is equivalent with global sequence boundary of Santonian (SB Sa1) (Hardenbol *et al.,* 1998).

The 4th sequence (*Santonian*)

The 4th sequence is about 80 m thick and composed of shale, marl to alternations of lime layers with intercalations of marly limestone.

The depositional condition changes at the beginning of the 4th sequence that suggests restart of the relative sea level rise. The ratio of AOM/MP slightly increases but then reduces upwards and reached its minimum at the thickness of 248.8 m, that marks the MFS. The strata located between the lower SB and the MFS represent the TST. The highstand systems tract is placed after the MFS boundary. Abundance and diversity of dinoflagellate cysts show a declining trend in this part of the section. The Palynofacies related to this part is of type V for MFS and types VII, VI and II for the HST that show a shallowing trend. The SB4 at the top of the HST is characterized by minimum abundance and diversity of dinocysts.

This boundary is equivalent with the global sequence boundary of Santonian (SB Sa2) (Hardenbol *et al.,* 1998).

The 5th sequence (*Santonian*)

The 5th sequence is about 16 m thick and composed of shale, marl and intercations of limestone with marly limestone. This sequence begins with a transgressive system tract that is marked by increasing diversity and abundance of marine dinoflagellate cysts. This system tract is overlain by the maximum flooding surface in sample NO. 194. An increase in continental palynomorphs was considered to represent the highstand systems tract. Another peak in the CON/MAR and occurrence of palynofacies type II was interpreted as the sequence boundary in this sequence.

This bundary is equivalent with the global sequence boundary of late Santonian (SB Sa3) (Hardenbol *et al.,* 1998).

The 6th sequence (*End of Late Santonian- Earliest Campanian)*

The 6th sequence is about 29 m thick. The dominant lithology in this sequence is limestone interbedded with thin marly limestone layers.

Depositional condition changes at the beginning of this sequence that indicate restart of a relative sea level rise. The ratio of AOM/MP shows a slight increasing trend at the beginning of this sequence but then reduces and reaches a minimum in MFS. The maximum abundance of dinocysts and the onset of palynofacies type V are the other characteristics of this surface.

The high stand systems tract (HST) is placed after the mfs where the diversity and abundance of dinocysts decline and the amount of CON/MAR and AOM/MP increase. In the HST, The dominant palynofacies is type VI that shows a shelf close to the margin with low oxygen values. The SB6 is located at the thickness of about 359 m. This boundary is equivalent with the global sequence boundary of Early Campanian (SB Cam 1) (Hardenbol *et al.,* 1998).

Lithologicaly this sequence is composed of interbedded marl-chalky limestones and chalky limestones, mainly consists of planktonic foraminifera and dinoflagellate that was deposited in an open marine setting (shallower than other part of this formation).

The 7th sequence (*Earliest Campanian)*

The 7th sequence is about 10 m thick and composed of limestone with intercalations of thin marly limestones, shale and marl. Overlying the 6th sequences, depositional sequence seven is characterized by the TST respectively and the other parts and the sequence boundary were not recognized. This system tract is associated with increase in diversity and abundance of dinocysts and decline of CON/MAR and AOM/MP ratios.

Conclusion

Palynological and microfacies studies of the late Turonian– early Campanian strata of the Abderaz Formation in east of Koppeh-Dagh Basin (Northeast of Iran) show rich dinoflagellate cyst and forminifera assemblages. Abundance and diversity of dinoflagellate cyst species, CONT/MAR ratio, AOM/MP, C/PPC and P/G is closely related to the changes in the sea level during depositional course of the formation. Abundance of marine palynomorphs increased at the lower and middle parts of the section where the abundance of phytoclasts and amorphous organic material decreased indicating together increase in depth during depositional period. The Phytoclasts and amorphous organic matter values increased and marine palynomorphs have no high frequency at the most top of the section indicating an intermediate sedimentary environment between shallow to deep areas with constant fluctuating nature.

Petrographical studies indicate that these strata may have been deposited in open marine environment (shallower than other part of this formation).

Seven sequences have been differentiated with six SB through the section studied ranging in age from late Turonian to early Campanian. The sequences shown to be well in accord with the globally recognized units recorded for the Tethyan Realm. Interpretation of sea level curve in this basin can be correlated with global curves during the Turonian to early Campanian.

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