Palynology and sequence stratigraphy of the Albian-Cenomanian strata from the Koppeh-Dagh Basin, northeastern Iran

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(*received: 22/10/2019 ; accepted: 05/02/2020*)

Abstract
The Albian-Cenomanian strata of the Koppeh-Dagh Basin were investigated for their marine palynomorphs and palynofacies contents and used for palaeoclimatic, palaeoenvironmental and sequence stratigraphical purposes. Various palynofacies criteria such as Palynological Marine Index (PMI), chorate/proximate, proximochorate and cavate ratio (C/PPC) and outer neritic/inner neritic index (ON/IN) were applied as alternative indicators to monitor the proximal-distal trends. Higher values of the former proxies versus low continental/marine ratio (CONT/MAR) were documented during periods of relative rise of sea-level. Increasing values of the marine palynological proxies such as the PMI, C/PPC and ON/IN were consistent with maximum flooding surfaces (MFS). A relatively diverse dinoflagellate cyst assemblage was reported at MFS, whereas, during the periods of relative sea-level fall, the dinocyst diversity decreased and coincided with those above-mentioned marine palynological ratios that reinforced terrestrial conditions. Palaeovegetation reconstruction showed the predominance of the pteridophyte spores. This palynoflora indicates a humid and warm climate during the Albian-Cenomanian time. Three deducted depositional sequences correspond with those suggested in previous studies based on surface and subsurface geological data. Sea-level changes correspond well with those reported from other parts of the Tethys.

Keywords: *Palynology, Sequence Stratigraphy, Albian-Cenomanian, Tethys, Koppeh-Dagh Basin.*

Introduction

The Albian-Cenomanian strata of the Koppeh-Dagh Basin (Aitamir Formation) are deposited in a relatively shallow marine environment, and are exposed in outcrops of northeastern Iran. Several studies have been conducted on the dinoflagellate cyst assemblages of this succession (Soleymannori & Allameh, 2010; Allameh & Sardar, 2015) while, some studies have focused on the sequence stratigraphic models of these strata based on lithostratigraphic evidences, their fossil contents and subsurface data (Ghasemi-Noghabi *et al.,* 2008; Sharafi *et al.,* 2010, 2011, 2012, 2013). Palynological investigations on the Albian-Cenomanian strata in different basins demonstrated presence of abundant marine and terrestrial palynomorphs (e.g. Horikx *et al*., 2016; Barrón *et al*., 2015).

The scope of the present study is to establish a detailed sequence stratigraphic framework for the study succession based on palynomorphs contents of the rock units. The constructed depositional sequences will also be correlated with lithostratigraphic-based depositional sequences from adjacent areas. Statistical calculations and relative abundances of important palynological components are used as monitoring criteria to determine the transgressive versus regressive trends. Biostratigraphic studies on the Albian-Cenomanian Aitamir succession of the Koppeh-Dagh Basin have been focused on ammonites (Mosavinia *et al*., 2014). Foraminiferal contents of the rock unit have also been studied (e.g. Kalantari, 1969; Motamedalshariati *et al*., 2012) whereas, their nannofossil contents were addressed by Notghi-Moghadam *et al*. (2013) and Moheghy *et al*. (2014).

The first palynological study of the Aitamir Formation was carried out by Soleymannori & Allameh (2010). Subsequently, Allameh & Sardar (2015) studied this formation based on dinoflagellate cyst content and suggested a neritic low oxygen environment. Due to the lack of a thorough palynological study, it is necessary to carry out an integrated analysis based on both terrestrial and marine palynomorphs to better reconstructions of the depositional paleoenvironment and their sequence stratigraphic framework.

Geological setting

The Koppeh-Dagh Basin that stretches over nearly 700 km from the NE of Iran to the north of Afghanistan and a large part of Turkmenistan formed after the closure of the Palaeotethys by the convergence of the Iranian and Turanian plates (e.g.

Stöcklin, 1974). The Basin preserves thick (5-8 km), folded Middle Jurassic to Miocene deposits (Afshar-Harb, 1994). Deposition in the Cretaceous basin begins in the Neocomian with the Shurijeh Formation and ends in the late cretaceous with deposition of the Kalat Formation.

The Aitamir Formation extends laterally in the northern parts of the Basin. Due to the active faulting during sedimentation, each fault block of the formation has different thicknesses (Afshar-Harb, 1994). The Formation reaches a thickness of 1000 m at both the type section and the Khartoot section studied here. The Formation has been divided into lower greenish glauconitic sandstone and upper green shale at the type locality in the northeast of Gonbad-e Kavous (Afashar-Harb, 1994).

The studied section is located in the central Koppeh-Dagh Basin in northwest of Bojnourd City, with coordinates N 37° 87' 00" and E 56° 50' 00" (Figure 1). Generally, shales, marls, siltstones, and sandstones of the Aitamir Formation conformably overlie the siltstones of the Sanganeh Formation and are unconformably overlain by the chalky limestones of the Abderaz Formation. Foraminiferal analysis showed that the erosional unconformity at the upper boundary of the formation represents a hiatus from the latest Cenomanian to the early middle Turonian (Sadeghi & Foroughi, 2004). For the Aitamir Formation, most biostratigraphic studies have given an age ranging from the Albian to the Cenomanian (e.g. Kalanat *et al*., 2016; Motamedalshariati *et al*., 2017).

Material and method

The Khartoot section (Figure 1A) is located at N 37° 87' 00" and E 56° 50' 00", approximately 80 km northwest of Bojnourd and 4 km southwest of Amanly village. This section is composed of shale, sandstone, and marl. A total of 50 rock samples were collected from the section under study (Figure 1). All samples were processed for palynological studies by following standard maceration techniques (e.g. Traverse, 2007). After cleaning, 15 g of sediments was treated with 10%–50% HCl to remove carbonates. The residue was then washed to neutrality and the remaining inorganic matter was dissolved in 40% HF. The fluoride precipitate formed during this step was removed using 50% hot HCl, and the residue was washed for neutralization. The organic matter was sieved using a 20-µm mesh. At least two permanent strew slides were made per sample by using the organic residue. The slides were mounted using Canada balsam. Residue samples with a fraction of less than 20 µm were also examined by mounting a single slide and using ×40 and ×100 objectives under a Leitz Wetzlar light microscope. When possible, a minimum of 200 palynomorphs were counted for each slide. All strew slides used in this investigation were deposited in the Palynology Collection at the Department of Geology, College of Science, University of Tehran. The organic particles were carefully identified, and their proportions were calculated.

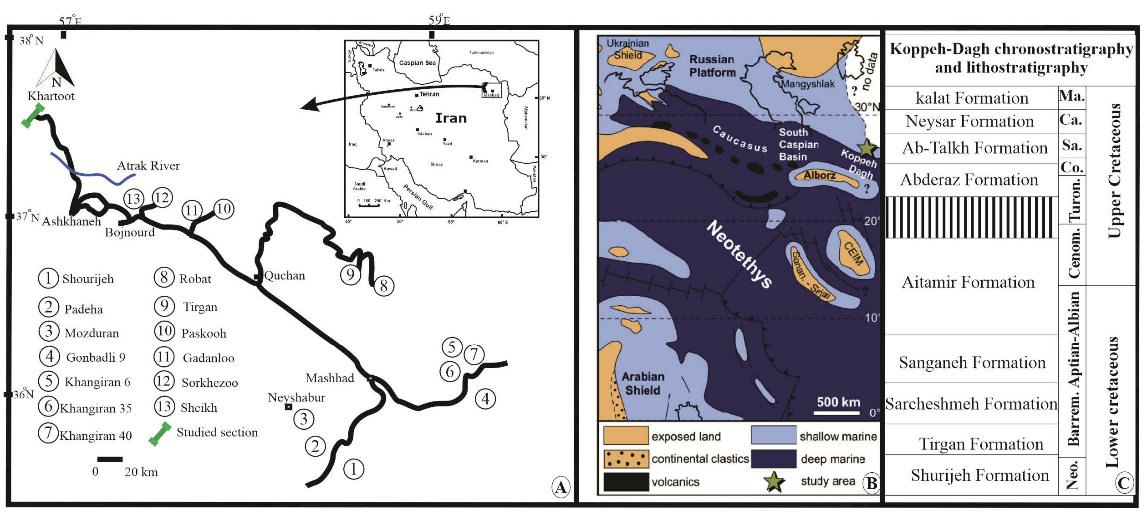

Figure 1. A. Location map of the section studied and those used for comparison and correlation. B, Palaeogeographic setting of the study area (map modified after Philip & Floquet, 2000; Mosavinia *et al*., 2014). C. Lithostratigraphy of the Cretaceous System in the Koppeh-Dagh (northeast Iran).

Various palynological parameters, including the percentage of palynomorphs, phytoclasts, and amorphous organic matter (AOM) were plotted on the AOM-palynomorph-phytoclast (APP) ternary plot of Tyson (1993). Moreover, several palynofacies criteria, such as PMI, C/PPC, and ON/IN, were applied for interpreting the palaeoenvironmental conditions. For further reliable and consistent interpretations, the SEG method (Abbink, 1998) was used.

Results and discussion

Biostratigraphy

Ammonite studies have given an age of Albian-Cenomanian (Mosavinia *et al*., 2007; Mosavinia & Wilmsen, 2011; Moradi-Salimi *et al*., 2012) to the formation. This age was confirmed by planktonic foraminiferal studies based on which three biozones of *Rotalipora appenninica* Interval Zone, *Rotalipora globotruncanoides* (*Rotalipora brotzeni*) interval Zone and *Whiteinella aumalensis – Dicarinella canaliculata* assemblage Zone were established (Kalanat *et al*., 2016; Motamedalshariati *et al*., 2017) (Table 1).

Table 1: The existing Foraminifera and Ammonites biozones for the Aitamir Formation

	(Kalanat *et al.*, 2016) (Motamedalshariati *et al.*, 2012, 2017)	**(Moradi-Salimi *et al.*, 2012)**
	Foraminifera	**Ammonites**
Cenomanian	*Whiteinella aumalensis* - *Dicarinella canaliculata* assemblage zone	*Mantelliceras dixoni* Interval Zone *Mantelliceras mantelli* Interval Zone *Rotalipora brotzeni*
Albian	*Rotalipora appenninica* Interval Zone	*Stonliczkaia dispar* Interval Zone *Hysteroceras varicosum* Interval Zone *Diploceras cristatum* Interval Zone

Palynological investigation of the Aitamir Formation has yielded 18 species of dinoflagellate cysts (belonging to 12 genera), 25 species of spores (belonging to 21 genera), 9 species of pollen grains (belonging to four genera), foraminiferal test linings and a few acritarchs (Plate I-III). Stratigraphic ranges of the palynomorphs recorded are presented in Figure 2.

As presented in Plate I, dinocyst assemblages are moderately well preserved. The chorate group is represented by abundant *Achomosphaera, Florentinia, Spiniferites, Hystrichosphaeridium, Hystrichodinium, Coronifera, Kiokansium*, *Kleithriasphaeridium, Hystrichosphaerina* and *Oligosphaeridium* genera. However, the proximate dinocyst *Cribroperidinium* is very abundant and constitute the main component of the studied samples. Furthermore, Albian samples contain just a few *Odontochitina* cavate cysts.

Palynofacies analysis and applications

Palynofacies analyses are used in palaeoenvironmental interpretation, source rock evaluation, and sequence stratigraphic studies (e.g. Batten & Stead, 2005). Various palynofacies criteria (e.g. C/PPC, ON/IN, CONT/MAR) are associated with vertical oscillation of relative sea level. Thus, they are commonly used to trace successive systems tracts and their stratigraphic bounding surfaces (e.g. Tyson, 1995; Batten & Stead, 2005).

The ratio of continental to marine particles (CONT/MAR) is a parameter that can be used for the analysis of sea level fluctuations. This ratio decreases basin-ward (Tyson, 1995; Wood & Gorin, 1998; Götz *et al*., 2008). Helenes *et al*. (1998) suggested the *Palynological Marine Index* (PMI) as PMI= (Rm/Rt+1)100 based on the richness of marine (Rm) and terrestrial palynomorphs (Rt). The PMI value is 100 when the samples have no marine palynomorphs. This index is related to transgressive and regressive events. The highest values of this index can be seen in maximum flooding surfaces (MFSs) (Carvalho, 2004). Opaque phytoclasts are carbonized particles (Lorente *et al*., 2014) which are mainly developed by oxidation of translucent phytoclasts (Götz *et al*., 2008). The ratio of opaque to transparent phytoclasts (OP/TR ratio) increases basin-ward (Summerhayes, 1987; Tyson, 1993; Pittet & Gorin, 1997; Bombardiere & Gorin 1998; Götz *et al*., 2008). However, oxidation at the seafloor in high-energy shelf areas may cause a reverse trend (decrease basin-ward) for this ratio (Batten, 1982; Boulter & Riddick, 1986; Bustin, 1988; Tyson, 1993; Götz *et al*., 2008).

The “lability index” (ratio of brown to opaque palynodebris) corresponds to proximal-distal trends (Van Waveren & Visscher, 1994; Bombardiere & Gorin, 2000). Brown palynodebris indicate a mixture of labile and resistant material, whereas opaque palynodebris may partially represent reworked organic matter (Van Waveren and Visscher, 1994).

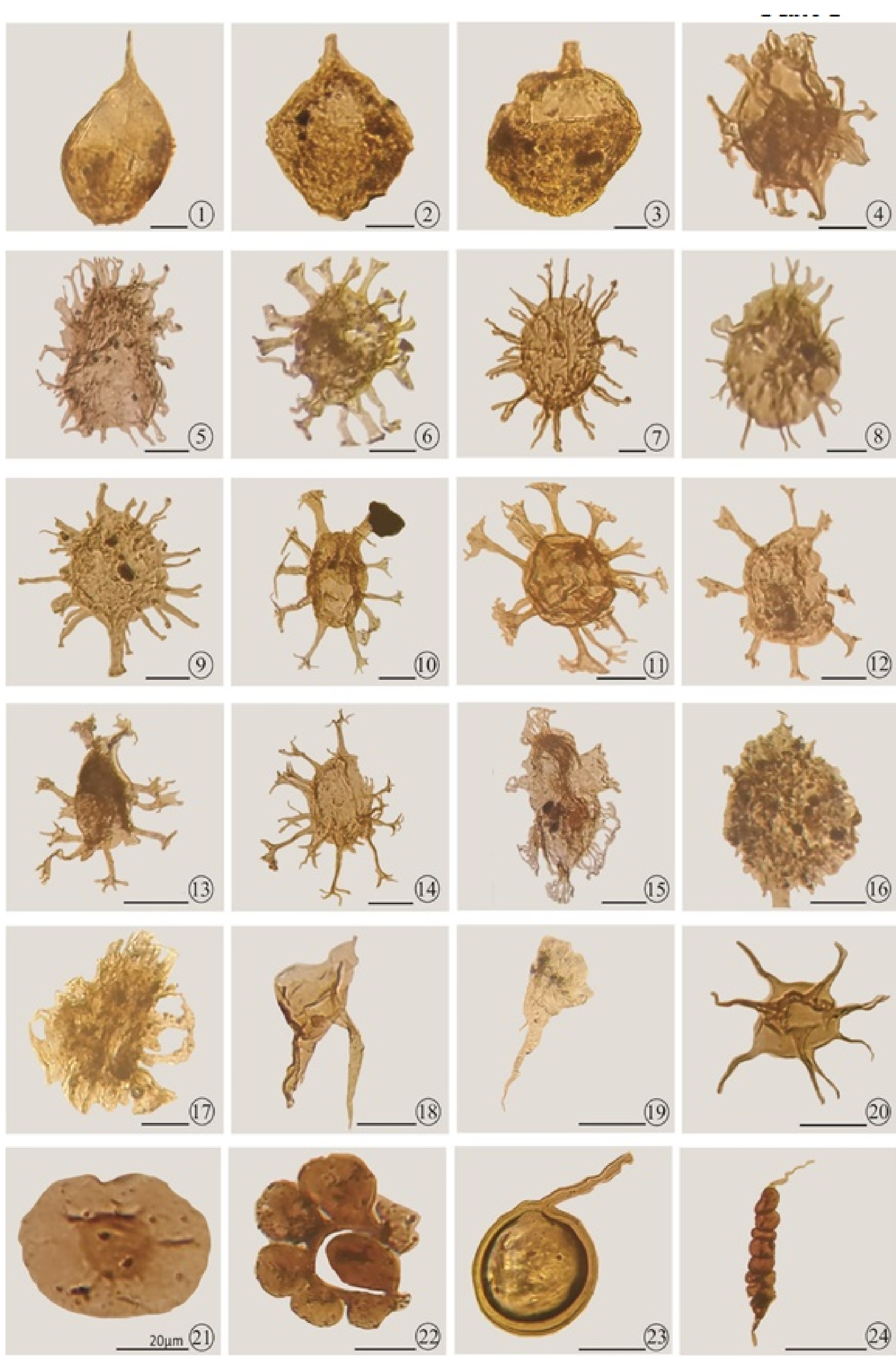

Plate 1. 1. *Cribroperidinium orthoceras* Davey, 1969, 2. *Cribroperidinium edwarsii* Cookson & Eisenack, 1958, 3. *Cribroperidinium* sp., 4. *Spiniferites ramosus* Lentin & Williams, 1973, 5. *Achomosphaera sagena* Davey & Williams, 1966, 6. *Kleithriasphaeridium tubulosum* Stover & Evitt, 1978, 7. *Kiokansium polypes* Below, 1982, 8. *Hystrichodinium pulchrum* Deflandre, 1935, 9. *Florentinia cooksoniae* Singh, 1971, 10. *Oligosphaeridium abacalum* Davey, 1979, 11. *Oligosphaeridium pulcherrimum* Davey & Williams, 1966, 12. *Oligosphaeridium albertense* Davey & Williams, 1969, 13, 14. *Oligosphaeridium complex* Davey & Williams, 1966, 15. *Hystrichosphaerina schindewolfii* Alberti, 1961, 16. *Coronifera oceanica* Cookson & Eisenack, 1958, 17. *Hystrichosphaeridium anthophorum* Cookson & Eisenack, 1958, 18. *Odontochitina operculata* Deflandre & Cookson, 1955, 19. *Odontochitina singhii* Morgan, 1980, 20. *Michrystridium* sp., 21. *Pterospermella* sp.*,* 22. Foraminiferal test lining, 23. *Glomus* sp., 24. Fungal spore.

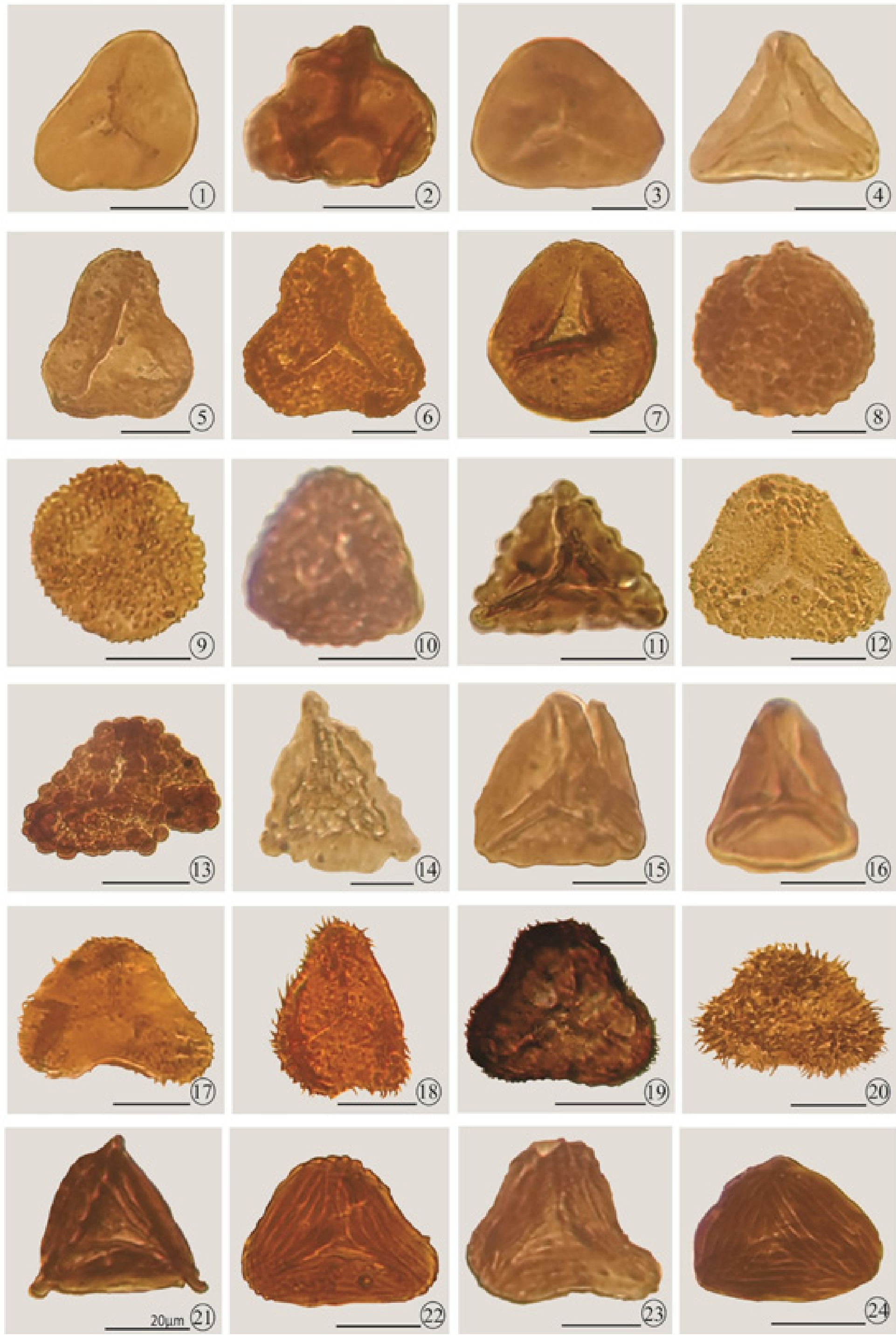

Plate 2. 1. *Cyathidites australis* Couper, 1953, 2. *Cibotiumspora juncta* Zhang, 1978, 3. *Dictyophyllidites harrisii* Couper, 1958, 4. *Dictyophyllidites mortonii* Playford & Dettmann, 1965, 5. *Concavissimisporites punctatus* Pocock, 1964, 6. *Concavissimisporites verrucosus* Delcourt & Sprumont, 1955, 7. *Converrucosisporites* sp., 8. *Verrucosisporites major* Burden & Hills, 1989, 9. *Verrucosisporites varians* Volkheimer, 1972, 10. *Klukisporites variegatus* Couper, 1958, 11. *Clavifera triplex* Bolkhovitina, 1966, 12. *Impardecispora apiverrucata* (Couper) Venkatachala, Kar & Raza, 1969, 13. *Impardecispora* sp., 14. *Ornamentifera* sp., 15. *Foveogleicheniidites confossus* Burger, 1975, 16. *Gleicheniidites senonicus* Ross, 1949, 17. *Pilosisporites notensis* Cookson & Dettmann, 1958, 18. *Pilosisporites ingramii* Backhouse, 1988, 19. *Pilosisporites grandis* Dettmann, 1963, 20. *Pilosisporites* sp., 21. *Appendicisporites* sp., 22. *Ruffordiaspora ludbrookiae* Dettmann & Clifford, 1992, 23. *Ruffordiaspora australiensisatus* (Cookson) Dettmann & Clifford, 1992, 24. *Cicatricosisporites* sp.,

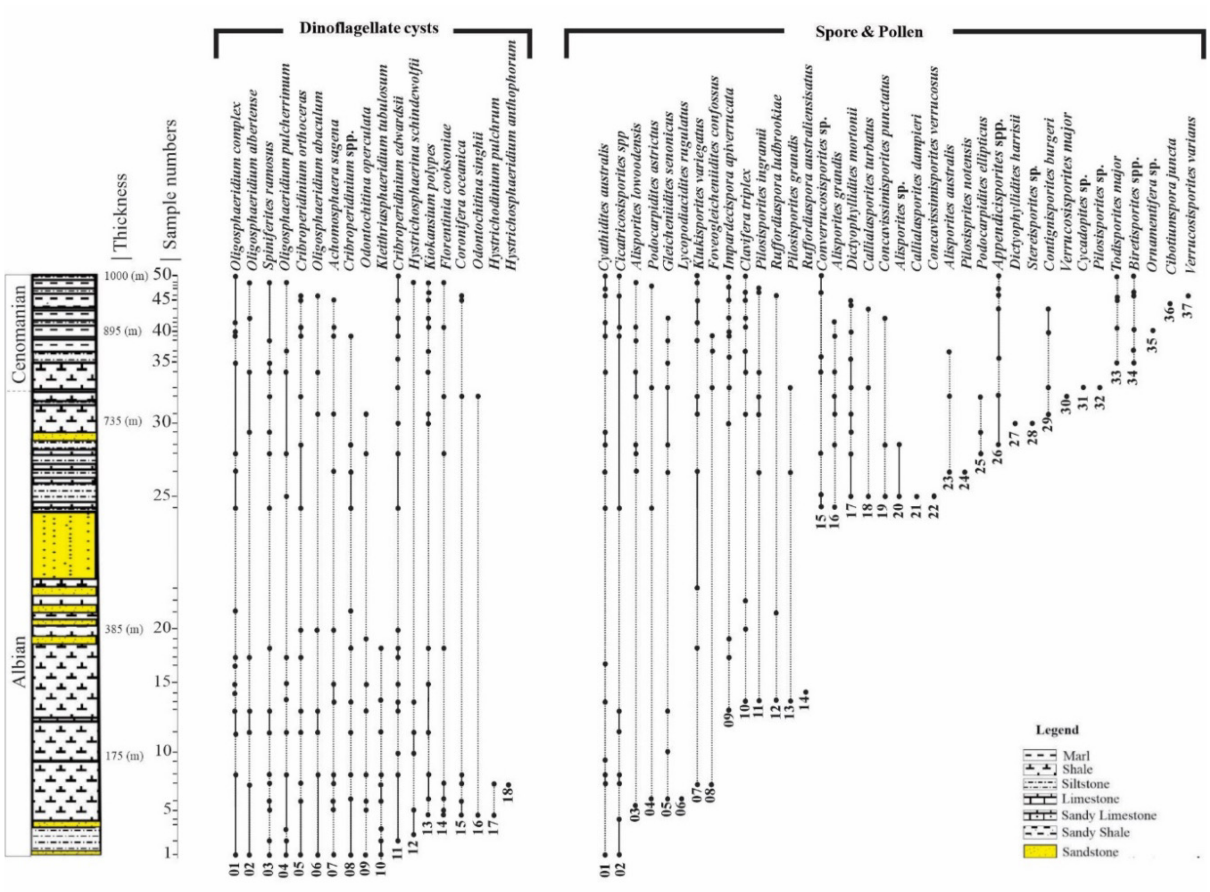

Figure 2. Stratigraphic ranges of the palynomorphs recorded in the Aitamir Formation.

The size and shape of opaque plant debris are used to decipher proximal-distal and transgressive-regressive trends. To minimize errors, equivalent particles were used as a factor for determining transgression and regression trends.

Species diversity of dinocysts is linked to the marine conditions of the water column and is related to marine transgression and regression (Götz *et al*., 2008; Habib & Miller, 1989). High dinocyst diversity values are related to a highstand system tract (HST) and show a stable condition in the water column (Peyrot *et al*., 2011).

The peridinioid/gonyaulacoid ratio introduced by Harland (1973) is also known as heterotrophic/ autotrophic ratio. After maximum flooding, the enrichment in nutrients causes a bloom of organic life usually expressed by the high P/G ratio (Jaminski, 1995). Based on the abundance of peridinioid dinocysts, absence of acritarchs and low content of terrestrial palynomorphs, Iakovleva (2011) consider an interval as HST.

Morphological differences in dinoflagellate cysts are affected by depositional environments and can help interpret palaeoenvironmental conditions (Tyson, 1995). Ghasemi-Nejad *et al*. (1999) coined a formula that uses dinocyst morphotypes (Table 2) to identify regression and transgression trends.

Table 2. Dinoflagellate morphotype Classification of the studied section.

Dinoflagellate type	Species
Chorate	*Oligosphaeridium, Hystrichodinium, Florentinia, Hystrichosphaeridium, Kleithriasphaeridium, Cribroperidinium, Kiokansium, Hystrichosphaerina*
Cavate	*Odontochitina*
Proximate and Proximochorate	*Coronifera, Achomosphaera, Cribroperidinium, Spiniferites*

[(chorate/proximochorate+proximate+cavate)]
Where the changes in ration of chorate forms to sum of proximochorate, proximate, and cavate forms indicate sea level changes.

Plate 3. 1, 2. *Cicatricosisporites* spp., 3. *Stereisporites* sp., 4. *Lycopodiacidites rugulatus* (Couper) Schultz, 1967, 5. *Biretisporites* sp., 6. *Contignisporites burgeri* Filatoff & Price, 1988, 7. *Todisporites major* Couper, 1953, 8. *Callialasporites dampieri* Sukh Dev, 1961, 9, 10. *Callialasporites turbatus* Schulz, 1967, 11. *Alisporites* sp., 12. *Alisporites grandis* Dettmann, 1963, 13. *Alisporites australis* De Jersey & Hamilton, 1967, 14. *Alisporites lowoodensis* De Jersey, 1963, 15. *Podocarpidites ellipticus* Cookson, 1947, 16. *Podocarpidites astrictus* Haskell, 1968, 17. *Cycadopites* sp.

Higher values of AOM may be related to a relative increase of distance to the shore (Tyson, 1995). A high proportion of black phytoclasts and AOM means an oxygenated depositional environment (Tyson, 1993, 1995; Götz *et al*., 2008). Generally, the ratio of opaque to transparent amorphous organic matter (OAOM/TAOM) increases basin ward (Tyson, 1993).

Abbink (1998) used the term Sporomorph EcoGroup (SEG) and introduced six SEGs (Table 3) for palaeoecological purposes (e.g. Birks & Birks, 1980; Huntley, 1990; Abbink *et al*., 2001). This parameter has been used in depositional sequence stratigraphy and palaeoecology for more than a decade (Abbink, 1998; Krupnik *et al*., 2014; Franz *et al*., 2014, 2015; Shivanna & Singh, 2016;

Li *et al*., 2016).

Table 3. Classification of Sporomorph EcoGroups (Abbink, 1998).

SEG	Description
Upland SEG	Reflects communities live on higher ground at a distance from the ocean, in this environment land never submerged by water and lack of nutrients and/or water can causes ecological stress
Lowland SEG	Access to nutrient and water are easy and the land can occasionally become flooded by water
River SEG	Vegetation on riverbanks which are periodically submerged
Pioneer SEG	Reflects vegetation submerged by the sea for a longer period
Coastal SEG	Vegetation growing immediately along the coast, never submerged by the sea but under a constant influence of salt spray
Tidally influenced SEG	Reflects vegetation influenced by daily tidal changes

The SEG method enhances the resolution of stratigraphic correlation of different sections by detecting changes in the environment and the climate especially for the Cenozoic and to a lesser degree for the late Mesozoic Era (Playford & Dettmann, 1996).

In the Aitamir Formation, a high ratio of transparent to opaque AOM (TAOM/OAOM) represents dysoxic–anoxic conditions associated with low-energy environments. Dominant opaque phytoclasts throughout the Formation represent a low sedimentation rate. The blade-shape/equidimensional opaque ratio has a value of less than 1 throughout the formation, indicating a shallow marine environment for the studied succession. This ratio is related to the transgressive-regressive trends and shows the highest amount in MFSs. The P/G ratio shows the highest amount in MFSs and reduces upward during HSTs in the studied succession. The proxy C/PPC shows high values in MFSs and low values in SBs.

Palaeoenvironment and sequence stratigraphy

Previous field-based and petrographic studies provided evidence for lagoon, barrier, shoreface and open marine palaeoenvironments for the Aitamir Formation in the eastern and southern parts of the basin (Ghasemi-Noghabi *et al*., 2008; Sharafi *et al*., 2010, 2011, 2012, 2013). These researchers have also differentiated sequences based on lithofacies, shell beds, and subsurface data and proposed up to six depositional sequences in different stratigraphic sections south and east of the basin. Evidence of such environments was also observed in our palynological slides. The lowstand system tract (LST) which is usually bounded by a sequence boundary (SB) below and a transgressive system tract above, is marked by poorly preserved spores and pollen grains and by large phytoclasts (e.g. Batten & Stead, 2005; Dalseg *et al*., 2016). These tracts (LSTs) are also recognized by low abundance and diversity of dinocysts (Revill *et al*., 1994; Batten & Stead, 2005; Carvalho *et al*., 2006), and by a reduction in the ratio of chorate to proximate, proximochorate, and cavate cysts (C/PPC) (Ghasemi-Nejad *et al*., 1999).

The Aitamir Formation contains depositional sequences in which deposits of the lowstand systems tract are not present (Sharafi *et al*., 2013). The transgressive system tract (TST) is bounded by the transgressive surface below and the maximum flooding surface (MFS) above. In this system tract, dinoflagellate cysts are more diverse and abundant, whereas spores, pollen grains, and phytoclasts are smaller and less abundant (e.g. Habib *et al*., 1992; Huan & Habib, 1996). The upper boundary of the TST represents the maximum water depth and is characterized by an abrupt decrease in phytoclasts and a great abundance of dinoflagellate cysts (Beiranvand *et al*., 2013). An increase in the variation of dinocysts species also reflects a maximum flooding surface (De Schepper *et al*., 2009). This surface is usually associated with a condensed section (CS) (Van Wagoner *et al*., 1988) that contains abundant fossil assemblages. The highstand system tract (HST) contains progradational deposits and lies above the MFS (Catuneanu *et al*., 2011). Dinoflagellate cysts are the most important and numerous components in this system tract (e.g. Steffen & Gorin, 1993; Helenes & Somoza, 1999). The uppermost HST which is bounded by the MFS below and the SB above shows a decrease in terrestrially derived debris (Brizuela *et al*., 2007).

A lagoonal environment was probably dominant in some parts of the rock unit where dinocysts are evident in minimal amounts and terrestrial palynomorphs, especially lowland sporomorph eco-groups (SEGs), are dominant. Terrestrial particles are also more abundant than marine forms, and ratios such as TAOM/OAOM and AOM/MP show the low oxygen and low energy conditions that are characteristic of a lagoonal environment. High percentages of dinocysts in some palynological slides and of ammonites observed in field studies are evidence of an open marine environment dominated during deposition of some parts of the formation. Palynofacies VI (Plate IV), the domination of dinoflagellate cysts and the variety of their species, and high values of palynological ratios PMI, ON/IN, and C/PPC (Figure 3) constitute further evidence of an open marine environment. The classified palynological data extracted from the rock samples show that the depositional sequences in the studied section are bounded by three type 2 and one type 1 sequence boundary. The base of the formation is marked by a sandstone layer that reflects the first SB. We used such proxies as high abundance of phytoclasts, relatively low abundance and diversity of dinocyst taxa, high inner neritic taxa, and low C/PPC ratios to identify the SBs. In the SBs, concentrations of dinocysts were low and lowland SEGs were dominant. The PMI and P/G ratios showed minimum values. Due to an unconformity between the Aitamir and the upper formation, the Abderaz Formation, this boundary is considered to be of a type 1 SB. In general, TSTs in the Aitamir Formation contain successions that show an increase in AOM content and a decrease in phytoclast content. The ON/IN ratio increases in TSTs. At the base of this system tract, dinocyst diversity and the C/PPC ratio show low values. The identified depositional sequences are presented in Figure 3. Correlation between the depositional sequences of the studied section and those of previous studies is illustrated in Figure 4. Although relative sea level fluctuations in eastern Tethys are controlled by tectonic events, regressive and transgressive oscillations in some parts of the Koppeh-Dagh Basin can be correlated with Eustatic sea level changes. Correlation of the sea-level fluctuations recorded on the basis of diversity and abundance of dinoflagellate cysts is plotted in Figure 3.

Discussion and results

Based on statistical analysis, three palynofacies were identified in the formation as follow:

Palynofacies type (I) shows more than 96% phytoclast, poor AOM and marine palynomorph content which indicate a highly proximal shelf. Palynofacies type (II) that is repeated periodically during deposition of the formation confirms a marginal anoxic basin while, Palynofacies type (VI) with more AOM and poor marine palynomorph content represents a proximal anoxic shelf. The three palynofacies distinguished in this study represent generally a shallow marine environment for the studied succession (Plate IV, Figure 5).

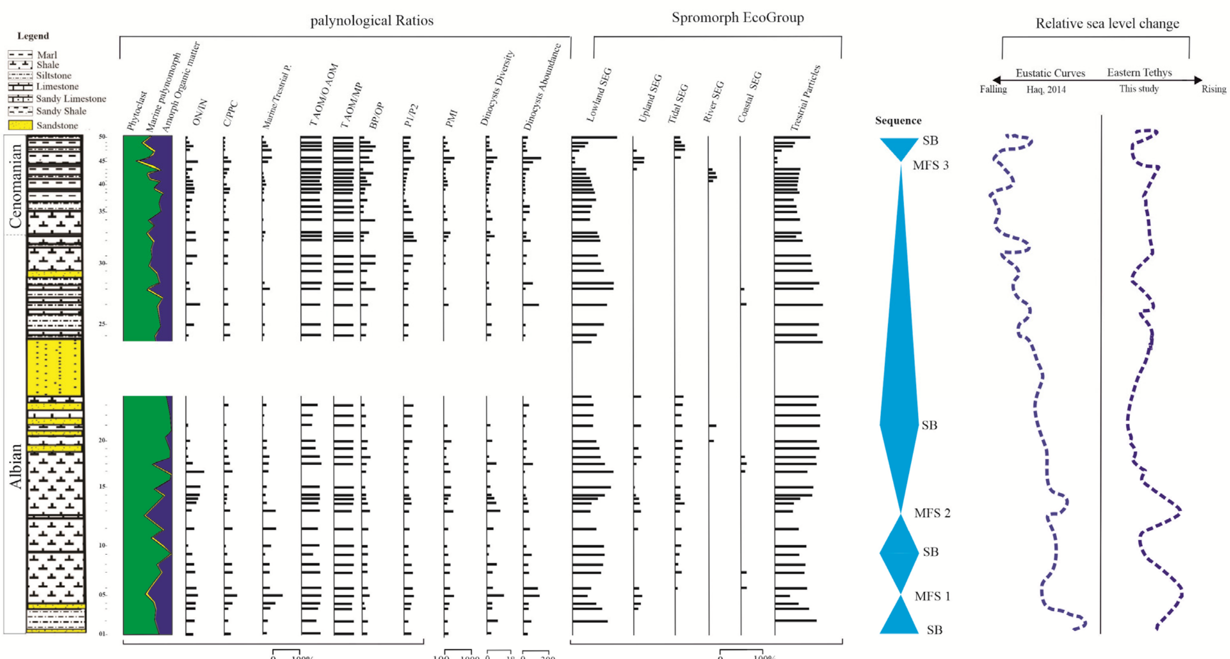

Figure 3. Changes in palynological parameters and relative abundances of the SEGs through the Aitamir Formation used for recognition of depositional sequences and correlation of the sea-level fluctuations recorded with Haq (2014) standard curve (right).

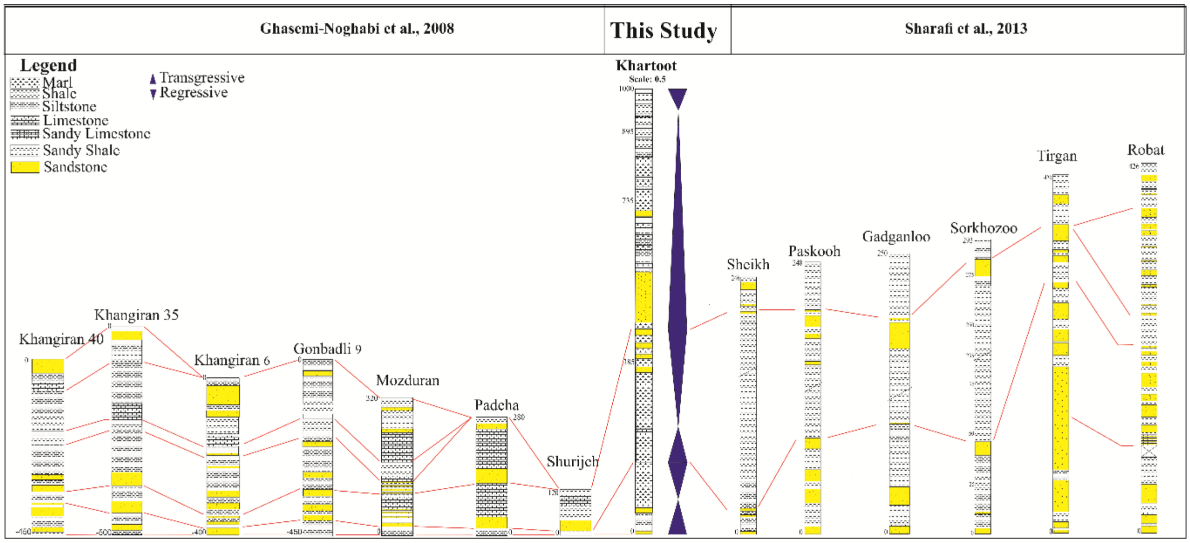

Figure 4. Correlation of stratigraphical sequences established for Albian – Cenomanian strata of the Aitamir Formation in this study with those erected previously.

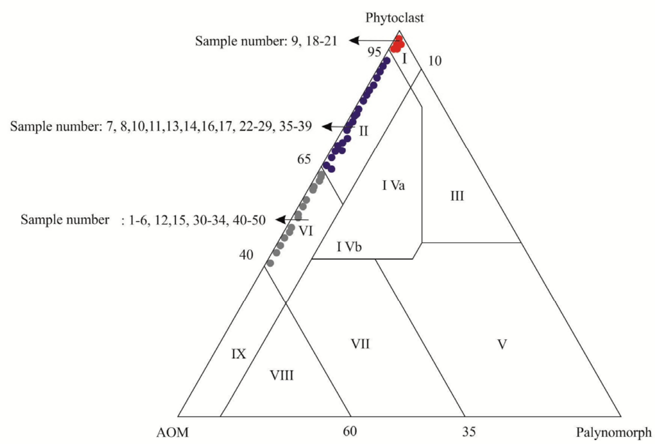

Figure 5. Plotting the samples studied on a Tyson-type diagram.

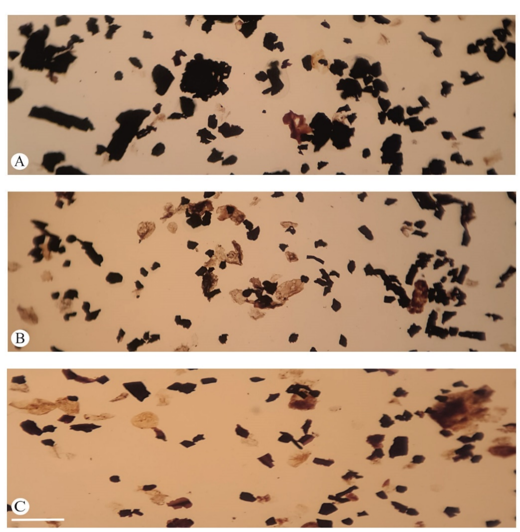

Plate 4. Palynofacies types recorded within the Aitamir Formation. (A) Palynofacies type 1, (B) Palynofacies type 2, (C) Palynofacies type 3. Scale bar represents 40 µm.

About 85% of all identified terrestrial palynomorphs were of Pteridophytes which had the greatest diversity and confirmed a warm and humid climate condition. Coniferophyta, Bryophytes, Lycophytes, Pteridospermophyta, and Cycadophyta were other groups represented by their terrestrial palynomorphs identified (Table 4). For the sequence stratigraphy of the formation, the palynomorphs recorded and identified were divided into five SEGs (Table 5 and Figure 3).

The lowland SEG reflects lowland communities. In this environment, access to nutrients and water is easy, while the upland SEG reflects communities living on higher ground with stress-tolerant strategy.

Table 4. Relative frequencies of the identified miospores. The numbers represent the group percentages of the respective taxon per sample. A. Abundant (>50%); C. Common (10–50%) and R. Rare (<10%).

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Pterophyta	*Cicatricosisporites*	A	A	A	A			A	A		C	A													A	C	A	C	A	C	C	C	A	C	C	C	A	C	C		A	C	C	C	C	C	C	C	C	C	C
	Klukisporites							R										A						A	R	R	R				R	R	R					R				R	C	R	R	R				R	R
	Impardecispora													A					A	A									R		R			R	R						R			R	R	R					R
	Converrucosisporites																								R	R		R							R	R										R	R	R	R	R	R
	Concavissimisporites																									R								R										R							
	Ornamentifera																																								R										
	Ruffordiaspora													C	A							A																							C						
	Appendicisporites																											C	C	C	C	R			C	C	C	C	C	A	C	C	C	C		R	R				R
	Cyathidites	R						C	C	A			C			A	A								C		R	R	R					R				R							R		R	C	C	C	C
	Dictyophyllidites																									C	R	R	R	R	R	R		R	R						R			C		R					
	Foveogleicheniidites							R																										R		R				R											
	Pilosisporites												C														C					R	C	R	R											R	C				
	Clavifera												C								A		A								R				R	R				R		R			R	R					R
	Cibotiumspora																																													R				
	Contignisporites																															R		R						R	R	R	R	R	R						
	Todisporites																																			R		R							R	C					C
	Verrucosisporites																															C															R				
	Gleicheniidites						R				C		R														R			R	C	R	R	R		R			R					R							
	Biretisporites																																		R	R		R		R					R	R					R
Bryophyta	*Stereisporites*																													R																					
Coniferophyta	*Callialasporites*																								R																										
	Podocarpidites						A								R										R			R	R					R																R	
Pteridespermophyta	*Alisporites*					A																				R	R	R	R			R		C	C	R	R				R								R		
Lycophyta	*Lycopodiacidites*						R																																												
Cycadophytes	*Cycadopites*																																R																		

Table 5. Botanical affinities of the sporomorphs recorded and links to Sporomorph EcoGroups (SEG).

SEG	Genus	AFFINITY
Lowland	*Cycadopites*	Cycadophytes, Gymnosperms
	Todisporites	Pterophytes, Filicopsida
	Contignisporites	Pterophytes, Filicopsida
	Biretisporites	Pterophytes, Filicopsida
	Gleicheniidites	Pterophytes, Filicopsida: Gleicheniaceae
	Verrucosisporites	Pterophytes, Filicopsida: Schizaeaceae
	Dictyophyllidites	Pterophytes, Filicopsida
	Cyathidites	Pterophytes, Filicopsida
	Concavissimisporites	Pterophytes, Filicopsida
	Klukisporites	Pterophytes, Filicopsida: Schizaeaceae
	Cibotiumspora	Pterophytes, Filicopsida
	Impardecispora	Pterophytes
	Cicatricosisporites	Pterophytes, Filicopsida: Schizaeaceae
	Appendicisporites	Pterophytes, Filicopsida: Schizaeaceae
	Ruffordiaspora	Pterophytes, Filicopsida: Schizaeaceae
	Pilosisporites	Pterophytes, Filicopsida
	Converrucosisporites	Pterophytes, Filicopsida, Dipteridaceae
	Clavifera	Pterophytes, Filicopsida, Gleicheniaceae
	Ornamentifera	Pterophytes, Filicopsida, Gleicheniaceae
	Foveogleicheniidites	Pterophytes, Filicopsida, Gleicheniaceae
Upland	*Podocarpidites*	Gymnosperms, Coniferophyta
River	*Steriosporites*	Bryophytes
	Lycopodiacidites	Lycophytes
Coastal	*Callialasporites*	Gymnosperms, Coniferophyta
Tidal	*Alisporites*	Gymnosperms, Pteridosphrmophyta

In this environment, the possible lack of nutrients and/or water can introduce ecological stress. Coastal and tidal SEGs reflect communities living adjacent to the ocean. They also have a stress-tolerant strategy affected by saltwater and salt sprays (Abbink, 1998).

Conclusion

Palynological analyses of the Albian-Cenomanian sedimentary succession of the Koppeh-Dagh Basin of northeastern Iran can help achieve a better understanding of its depositional sequences and environment.

The peaks in palynological parameters, such as the ratios of PMI, C/PPC, and ON/IN, are considered as indicators for palaeoenvironmental interpretation and MFSs. Palaeoenvironmentally, a shallow marine low-energy environment with a dysoxic-to-anoxic condition could be suggested such palynofacies signals. SEG modeling was also applied in a depositional sequence stratigraphy, and Lowland SEGs were dominant during periods of regression. Palynoflora with predominance of pteridophytes and some index dinocysts indicate a humid and warm climate during the depositional period. The abundance and frequency of dinoflagellate cysts show that the Albian-Cenomanian sea-level changes in eastern Tethys correspond partly with the eustatic curves of that age. Sequence-stratigraphic analyses carried out in the present study show a good correlation with depositional sequences presented by different proxies in previous studies.

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