# Palynofacies and paleoenvironment of the Early Cretaceous deposits in the Koppeh-Dagh Basin, Iran

## *Palinofacies y paleoambiente de los depósitos del Cretácico temprano en la Cuenca de Koppeh-Dagh, Irán*

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## ABSTRACT

We used the palynomorphs from the Early Cretaceous deposits in the Koppeh-Dagh Basin in the Neo-Tethyan province of northeastern Iran to investigate the site's paleoenvironmental conditions and depositional settings. The AOM–Phytoclast–Palynomorph (APP) ternary diagram highlighted three distinct palynofacies: Type I, II, and IVa. We can accordingly conclude that the depositional environments of the basin included a highly proximal shelf, a marginal basin, and a shelf-to-basin transition. Palynofacies analysis of the Sarcheshmeh and Sanganeh formations of the Koppeh-Dagh Basin revealed that the two formations were deposited in a shallow marine setting characterized by conspicuous input of plant material from nearby land. By comparing these results with those from adjacent sections, two paleoenvironmental trends are present in the Koppeh-Dagh Basin: the eastern side was more turbulent, and the western side was quieter. A previous calcareous nannofossil analysis from the section has been used to date the studied interval of the Sarcheshmeh and Sanganeh Formations, indicating a Late Barremian to Late Albian age.

**Keywords: palynofacies, Cretaceous, Koppeh-Dagh Basin, Sarcheshmeh Formation, Sanganeh Formation, Iran.**

## *RESUMEN*

*Utilizamos los palinomorfos de los depósitos del Cretácico inferior en la cuenca de Koppeh-Dagh, situada en la provincia neotetiana del noreste de Irán, para investigar las condiciones paleoambientales y los entornos de depósito del sitio. El diagrama ternario AOM–Fitoclastos–Palinomorfos (APP) destacó tres palinofacies distintas: Tipo I, II y IVa. En consecuencia, podemos concluir que los ambientes depositacionales de la cuenca incluyeron una plataforma altamente proximal, una cuenca marginal y una transición entre plataforma y cuenca. El análisis de palinofacies de las formaciones Sarcheshmeh y Sanganeh de la cuenca de Koppeh-Dagh reveló que ambas formaciones fueron depositadas en un entorno marino somero caracterizado por una notable entrada de material vegetal procedente de tierras cercanas. Al comparar estos resultados con los de secciones adyacentes, se identificaron dos tendencias paleoambientales en la cuenca de Koppeh-Dagh: el sector oriental era más turbulento, mientras que el occidental era más tranquilo. Un análisis previo de nanofósiles calcáreos en la sección se utilizó para fechar el intervalo estudiado de las formaciones Sarcheshmeh y Sanganeh, indicando una edad que va desde el Barremiense tardío hasta el Albiense tardío.*

***Palabras clave: palinofacies, Cretácico, cuenca de Koppeh-Dagh, formación Sarcheshmeh, formación Sanganeh, Irán.***

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## 1. Introduction

Palynofacies analysis represents an interdisciplinary approach to reconstructing paleoenvironments. Instead of confining the investigation solely to palynomorphs in palynological residue, the focus is on examining the entire organic content. Particulate organic matter is considered a sedimentary component that provides insights into the original conditions of the source area and the depositional environment (Tyson, 1995). The composition and proportion of sedimentary organic matter in marine paleoenvironments are directly correlated with sea level (*e.g.*, Gorin and Steffen, 1991; Tyson, 1995; Bombardiere and Gorin, 1998; Maleki et al., 2020; Farmani et al., 2020).

As the final and most prolonged phase of the Mesozoic Era, the Cretaceous is distinguished by its prevalence of warm and humid climates (Kauffman and Johnson, 2009). It is marked by substantial rifts, colossal volcanic eruptions that fragmented massive supercontinents into smaller land masses, elevated sea levels, and caused the proliferation of low-oxygen conditions in oceanic basins (Steuber et al., 2005; Tejada et al., 2009; Keller et al., 2011). These climatic and geological features would have been globally distributed, affecting various parts of the Earth. However, specific manifestations of these features may have varied depending on regional geological settings and local environmental conditions.

Situated between Iran, Afghanistan, and Turkmenistan (Figure 1A), the Koppeh-Dagh Basin is recognized as a component of the northern Tethyan realm (Glennie, 2000). Known for its substantial hydrocarbon potential and gas reservoirs, the basin has attracted attention in geological studies (Kavoosi et al., 2010; Sharifi et al., 2018). The Koppeh-Dagh Basin has become a focal point for paleontologists, primarily due to its abundant Cretaceous deposits. Extensive palynological investigations of various rock units within this basin have been conducted in recent years (*e.g.*, Maleki et al., 2020). The Sanganeh and Sarcheshmeh formations, which make up the lower Cretaceous (Barremian-Albian) strata of the basin, have been subjects of considerable interest in palynology studies (Sharifi et al., 2018, 2019). Although the paleoenvironment of these formations has been extensively studied—particularly in the eastern part of the basin—what distinguishes the present study from previous works is its specific focus on the western part of the basin, a region that has received comparatively less attention. The aim of the present study is to investigate the paleoenvironments in the western part of the basin and their changes during the deposition of the Sarcheshmeh and Sanganeh formations.

## 2. Geological Setting

One of the tecto-sedimentary units of the Iranian Plate is the Koppeh–Dagh Basin (also called the Kopet–Dagh Basin), a tectonic and sedimentary unit in northeastern Iran, south of Turkmenistan, and northwest of Afghanistan (Afshar–Harab, 1979; Berberian and King, 1981; Figure 1C). The Koppeh–Dagh sedimentary basin was formed after the Middle Triassic orogeny in northeastern Iran. It began to sink along major faults aligned approximately at NW–SE. Four of these major active basement faults were identified in the central and western parts of the basin. The blocks north of these basement faults subsided faster than the blocks in the south (Afshar–Harab, 1979; Berberian and King, 1981). In the eastern part of the basin, where five major transgressive-regressive sequences have been identified (Afshar-Harb, 1979). The basin contains over 6000 m thick of nearly continuous shallow marine to continental deposits, ranging in age from the Middle Jurassic to the Miocene, with no significant sedimentary hiatuses or volcanic activity (Afshar-Harb, 1994). Its southeastern boundary corresponds to the Paleo–Tethyan suture, while its northern boundary coincides with the Turan Plate and the main Koppeh–Dagh Fault (Robert et al., 2014). The Koppeh–Dagh

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Basin is the result of the southeastern extension of the South Caspian Basin by neo–Tethys back–arc rifting following the conclusion of the Paleo–Tethys and early Cimmerian Orogenies (Golonka, 2004; Wilmsen et al., 2009; Figures 1A and 1B).

There is no proof of significant tectonic movements in this region. All formations are conformable, except for some disconformities in the Cretaceous succession (*e.g.*, Raisossadat and Moussavi-Harami, 2000). The deposition of the Cretaceous sequence (several kilometers thick) began with the non-marine Shurijeh Formation of Neocomian (Berriasian to Hauterivian), followed upwards by the shallow shelf carbonates of the Tirgan Formation of Barremian-early Aptian age (Afshar-Harb, 1994). The lower Cretaceous continues with the deposition of the Sarchemeh and Sanganeh Formations, followed by the Aitamir Formation, which lies atop the Sanganeh Formation (Aghanabati, 2004).

The Sarcheshmeh Formation underlies the

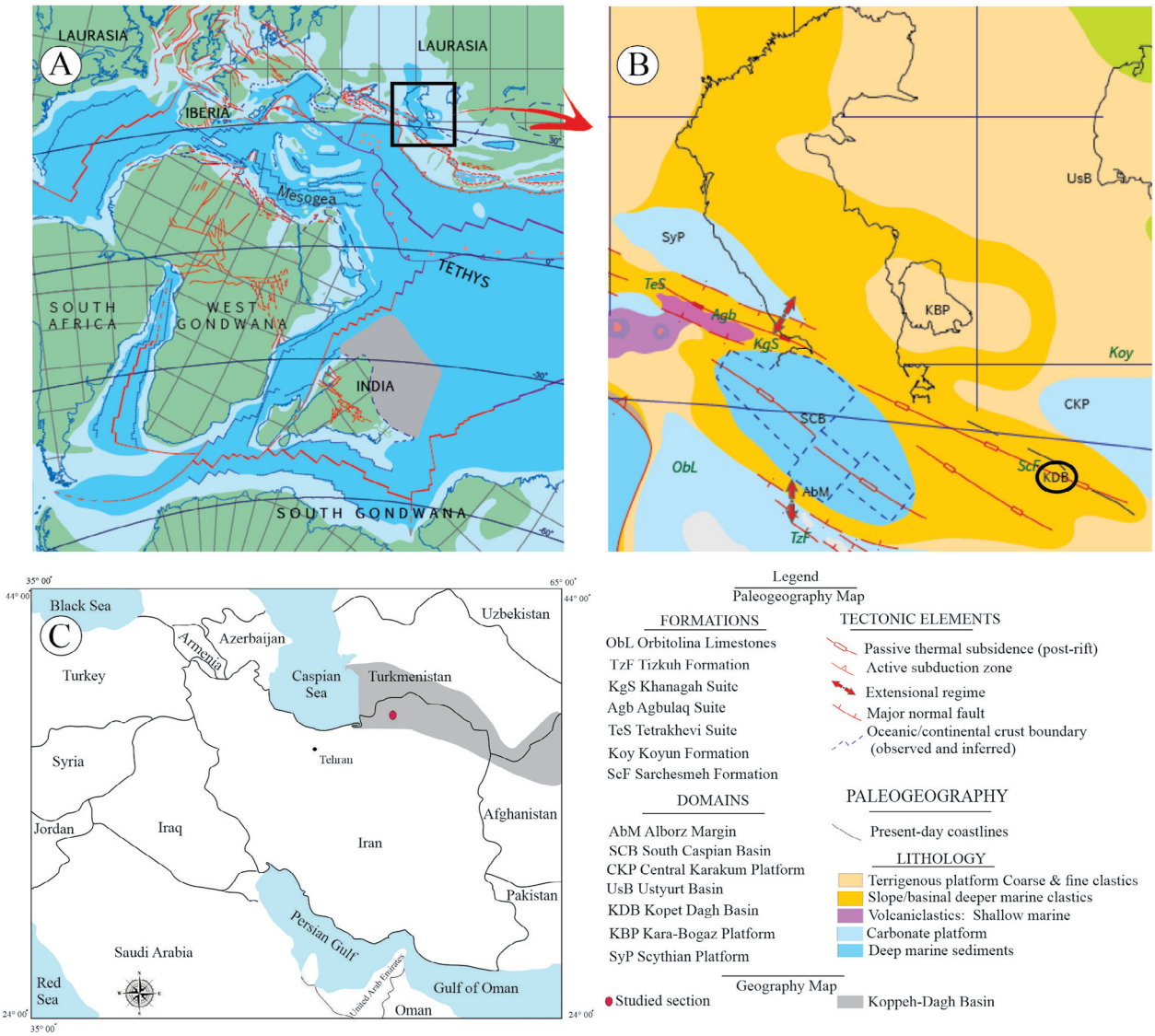


**Figure 1** A) Paleogeographic map of the studied area (modified from Barrier et al., 2018), B) Magnified paleogeographic map of the studied area, C) Geographic map of the studied area in the Koppeh–Dagh Basin.

Sanganeh Formation, and outcrops of both formations are observed throughout the Koppeh–Dagh Basin, with thickness varying across different sections (Afshar-Harb, 1994). The studied sequence, the Aghband section, is located west of the Koppeh–Dagh Basin (Figure 1C). The geographic coordinates for the studied stratigraphic section are 37° 47' 01" N and 55° 12' 1.8" E.

## 3. Previous paleontological studies

Previous paleontological studies of the Sanganeh and Sarcheshmeh formations focused on four main categories: age dating, paleoenvironmental conditions, hydrocarbon potential, and the effect of OAE 1a on micro and macro-organisms in the Koppeh–Dagh Basin.

The present study uses the results of a previously detailed investigation in age dating based on calcareous nannofossils (Foroughi et al., 2023). The studied assemblage in the Aghband section belongs to a part of NC5 (E–D), NC6, NC7, NC8, and a part of NC9 of the Tethyan zones. This zonation was based on proposed zones of Roth (1978), modified by Bralower et al. (1993, 1995). Accordingly, a late Barremian age is suggested for the Sarcheshmeh Formation, while an Aptian to late Albian age is proposed for the Sanganeh Formation.

Based on the ammonite assemblage, the Sarcheshmeh and Sanganeh formations belonged to the late Barremian and early Aptian (Raisossadat and Shokri, 2011). Additionally, Seyed-Emami (1980) identified ammonites dating from the late Aptian to the early Albian within the Sanganeh Formation. Ammonites have been extensively documented within the Sarcheshmeh and Sanganeh Formations (*e.g.*, Seyed-Emami, 1980; Raisossadat and Shokri, 2011). Paleontological research conducted in the basin has revealed an interval with a lack of ammonites (Mahanipour et al., 2011, 2012). However, analysis of calcareous nannofossils has confirmed an early Aptian age for this interval in the Sanganeh Formation, which is consistent with the Nannoconids crisis and is interpreted as the effect of the OEA1a (*e.g.*, Mahanipour et al., 2011; Gholami Fard et al., 2019). Furthermore, analyses of oxygen and carbon isotopes have demonstrated the occurrence of this event in the early Aptian deposits of the Sanganeh Formation (Raisossadat and Mahboubi, 2011). It is important to note that a similar analysis of oxygen and carbon isotopes has not been conducted in the currently studied section.

According to the stratigraphic distribution of the recorded foraminiferal assemblage, Kalantari (1968) suggested an Albian age for the Sanganeh Formation, whereas Motamedalshariati et al. (2010) reported a late Aptian foraminifera assemblage from the Sanganeh Formation. Nannofossil biozones of NC5, NC6, and NC7 were recorded in the basin, suggesting an age of late Barremian to early Aptian for the Sarcheshmeh Formation and early Aptian to late Aptian for the Sanganeh Formation (Mahanipour et al., 2011). Khodadadi and Hadavi (2013) reported on the transition from the Tirgan Formation to the overlying Sarcheshmeh Formation, which occurred within an interval dated to the early Aptian.

The first palynological investigation in the Koppeh-Dagh basin was initiated under the leadership of Ebrahim Ghasemi-Nejad (Maleki, 2023). Two palynozones, DZ1 and DZ2, were identified at the Sanganeh and Gharasoo sections, confirming an age of late Aptian to early Albian (Shokri et al., 2015) for the Sanganeh Formation. Dinoflagellate cyst assemblages have also been used in different sections to investigate environmental changes during the early Cretaceous in both the Sarcheshmeh and Sanganeh formations (*e.g.*, Allameh et al., 2011, 2014; Allameh, 2019; Sharifi et al., 2019).

## 4. Systematic paleontology

### 4.1. LABORATORY

Palynofacies analysis were carried out on a total of 42 samples from the early Cretaceous Sarcheshmeh and Sanganeh formations in the west of the Koppeh Dagh Basin in Iran (Figure 1C

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and Figure 2). These are the same samples used for the palynological study. Five slides were processed and prepared from each sample in the palynology laboratory of the Department of Geology at Tehran University, using the extraction technique proposed by Traverse (2007). Cold hydrochloric acid (20%) and hydrofluoric acid (50%) were used to dissolve carbonate and silicate minerals. No oxidants or alkalis were used. The residue was neutralized and centrifuged in an aqueous solution of $ZnCl_2$ (specific gravity 1.9 g/cm$^3$) and then sieved at 15 µm via a nylon mesh and mounted on microscope slides using liquid Canada balsam. The prepared palynological slides were examined thoroughly under 40X and 100X objective to check for the presence of any palynomorphs. Observations were made under an Olympus BX51 (E330–ADU1.2X) transmitted light microscope. All microscope slides and residues, cataloged under collection number SAR 2323, are housed in the Department of Geology laboratory at the College of Sciences, University of Tehran.

### 4.2. DATA ANALYSIS

The palynofacies classification system proposed by Tyson (1993, 1995) was used in this study.

The percentages of the three primary groups of palynological elements—amorphous organic matter (AOM), terrestrial elements (phytoclasts), and marine palynomorphs, were calculated for all samples, with 500 particles counted per sample.

The data obtained were plotted on a Tyson, type ternary diagram (Tyson, 1989). Interpretation of the paleoenvironment is based on the nature of the palynomorph assemblages and the integration of palynofacies analysis.

In the present study, different morphotypes of dinoflagellate cysts have also been employed in interpreting sedimentary environments (Table 1). Several previous studies investigated the palynofacies of the Sarchemeh and Sanganeh formations, allowing for comparisons with the results of the present study. The outcomes of these comparisons are discussed in detail in the section comparison and correlation.

## 5. Discussion

### 5.1. PALYNOFACIES AND PALEOENVIRONMENT

Palynology has a wide range of applications in geological studies, including biostratigraphy (Dehbozorgi and Maleki, 2023), paleoecology (Maleki, 2024), and paleoenvironmental reconstruction (Abbasi et al., 2025). Tyson's APP ternary diagram (AOM–phytoclast–palynomorph; *e.g.*, Tyson, 1995) is helpful for deciphering differences in relative proximity to the sediment source. Terrestrial organic matter also accumulated within a fluvio-lacustrine system (Atta-Peters et al., 2013) developed in proximity to an estuarine–deltaic environment. The presence of these environments is plausible near a coastline. However, it is also possible that turbidity currents deposited such phytoclasts at depth (Habib, 1982). The high percentage of palynomorphs associated with structured phytoclasts indicates proximity to the depositional source (Batten and Stead, 2005; Aggarwal, 2022).

The samples plotted in the AOM–Phytoclast–Palynomorph (APP) ternary diagram (Tyson, 1995) showed the palynofacies types I, II, and IVa for the studied samples (Figures 2 and 3; Table 2). Palynofacies type I was identified solely in samples 7, 8, and 10 among the samples studied, which indicates a highly proximal shelf (Tyson, 1995). Phytoclasts were the main constituents of these palynofacies (92-94.4%), and dinoflagellate cysts were rarely observed. Palynofacies type IVa was observed in only two samples, numbered 15 and 20, from the studied interval, which indicates the transition from a shelf to a basin (Tyson, 1995). All other studied samples belonged to palynofacies type II (Figures 2 and 3).

The studied section had rich dinoflagellate cyst assemblages and almost poor spore and pollen grains, with moderate preservation (Plate 1). The identified dinoflagellate cysts were categorized into four main morphotypes: proximate, chorate, proximochorate, and cavate (Table 1). Of these morphotypes, high percentages of the proximate and chorate groups were observed in the studied interval.

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Palynofacies I is characterized by a higher proportion of structured phytoclasts that may have been deposited in a proximal environment with short transport (Figure 3).

Two of the main components of palynofacies II are chorate and proximochorate dinoflagellate cysts. Spores of *Cicatricosisporites* sp., *Cyathidites* sp., and pollen grains of *Cycadopites* sp. were also found in this palynofacies. However, the presence of structured organic matter and well–preserved palynomorphs in the palynofacies II suggests oxic or suboxic conditions in the depositional environment. Therefore, the palynofacies II may have been deposited in a proximal environment. Palynofacies IV were encountered only at the Albian deposits and NC 8 calcareous nannofossil zone.

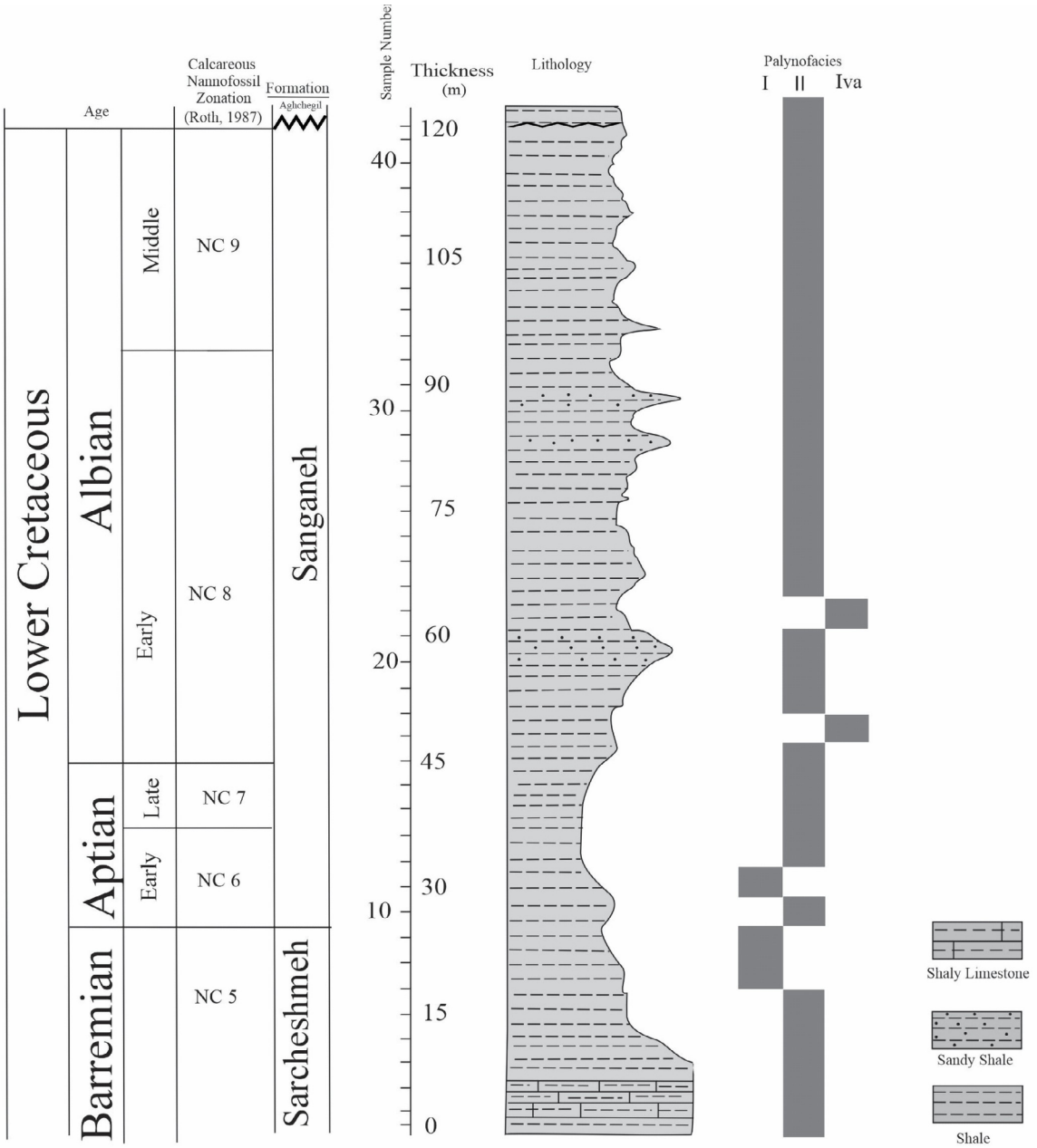


**Figure 2** Calcareous nannofossil zone, stratigraphic column, and recorded palynofacies within the Sarcheshmeh and Sanganeh formations in the Aghband section.

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**Table 1. Identified dinoflagellates from Sanganeh and Sarcheshmeh formations, Koppeh-Dagh Basin, and their morphotypes. The following dinoflagellate cysts have been recorded exclusively in samples from the Sanganeh Formation: *Odontochitina singhii*, *Florentinia abjuncta*, and *Subtilisphaera perlucida*, while others were identified in both the Sarcheshmeh and Sanganeh formations.**

| | | |
|---|---|---|
| **Morphotypes** | Proximate | *Cribroperidinium edwardsii*, *Cribroperidinium* sp. *Wrevittia- cassidata*, *Palaeoperidinium cretaceum* |
| | Chorate | *Callaiosphaeridium assymetricum*, *Coronifera oceanica*, *Cleistosphaeridium* sp., *Exochosphaeridium bifidum*, *Florentinia abjuncta*, *Hystrichodinium oligacanthum*, *Hystrichodinium pulchrum*, *Hystrichosphaerina schindewolfi*, *Kiokansium polypes*, *Kleithriasphaeridium eoinodes*, *Oligosphaeridium complex*, *Oligosphaeridium poculum*, *Oligosphaeridium pulcherrimum* |
| | Proximo–chorate | *Achomosphaera neptuni*, *Circulodinium distinctum*, *Spiniferites dentatus*, *Spiniferites ramosus*, *Prolixosphaeridium conulum*, *Prolixosphaeridium parvispinum* |
| | Cavate | *Odontochitina operculata*, *Odontochitina singhii*, *Pseudoceratium polymorphum*, *Subtilisphaera perlucida* |

AOM has been reported to decrease in shallow shelf sediments, whereas it tends to increase in deeper basins under suboxic–anoxic conditions (Bujak et al., 1977). Degraded plant debris and AOM indicate suboxic–anoxic conditions during deposition. Therefore, oxic–dysoxic and fluvio–deltaic conditions were assumed during palynofacies I–II formation. The ternary diagram APP (Tyson, 1995; Figure 2 and Figure 3) shows that the Sarcheshmeh and Sanganeh formations belonged mainly to PT II (palynofacies type II), *i.e.*, the marginal basin. Two other palynofacies in this section are PT I and PT IVa. All these three palynofacies confirm a generally shallow marine depositional environment. The geological features of the section allowed us to sample only part of

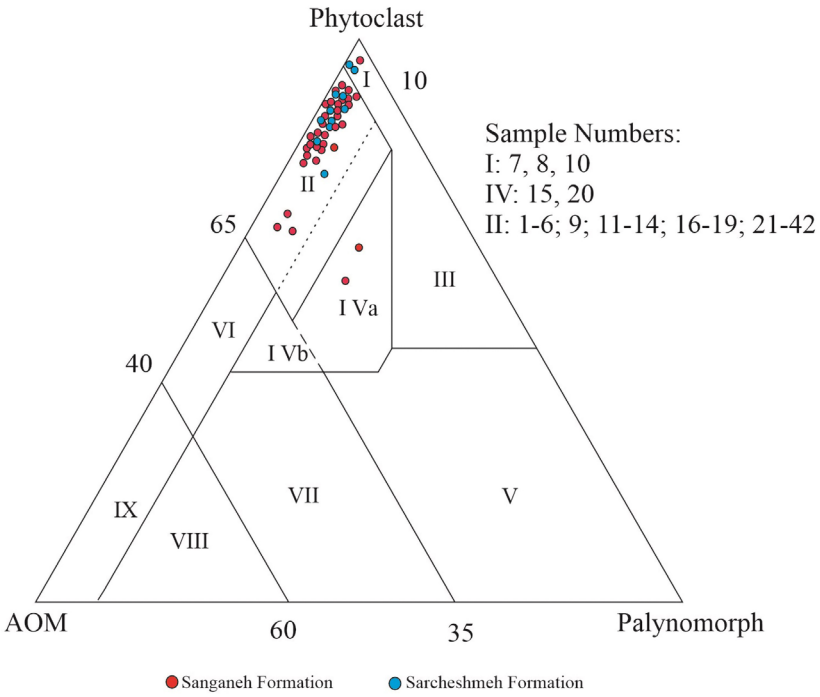


**Figure 3** APP ternary plots for the analyzed sediments from the Sarcheshmeh and Sanganeh formations at Aghband Section Koppeh-Dagh.

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Table 2. The AOM, Phytoclast, and Palynomorph percentages across different sample numbers, through the studied interval.

| Sample Number | AOM (%) | Phytoclast (%) | Palynomorph (%) | Palynofacies Type |
|---|---|---|---|---|
| 1 | 18 | 2 | 80 | II |
| 2 | 16 | 1 | 83 | II |
| 3 | 17 | 1 | 82 | II |
| 4 | 13 | 1 | 86 | II |
| 5 | 22 | 3 | 75 | II |
| 6 | 25 | 2 | 73 | II |
| 7 | 2 | 1 | 97 | I |
| 8 | 0.5 | 0.5 | 99 | I |
| 9 | 23 | 1 | 76 | II |
| 10 | 1 | 1 | 98 | I |
| 11 | 19 | 2 | 79 | II |
| 12 | 22 | 3 | 75 | II |
| 13 | 25 | 2 | 73 | II |
| 14 | 12 | 2 | 86 | II |
| 15 | 18 | 15 | 67 | IV |
| 16 | 11 | 2 | 87 | II |
| 17 | 41 | 1 | 85 | II |
| 18 | 12 | 2 | 86 | II |
| 19 | 15 | 2 | 83 | II |
| 20 | 20 | 17 | 63 | IV |
| 21 | 23 | 1 | 76 | II |
| 22 | 21 | 2 | 77 | II |
| 23 | 42 | 1 | 75 | II |
| 24 | 14 | 1 | 85 | II |
| 25 | 20 | 2 | 78 | II |
| 26 | 20 | 1 | 79 | II |
| 27 | 25 | 2 | 73 | II |
| 28 | 11 | 3 | 86 | II |
| 29 | 14 | 1 | 85 | II |
| 30 | 8 | 3 | 89 | II |
| 31 | 24 | 3 | 73 | II |
| 32 | 22 | 3 | 75 | II |
| 33 | 21 | 3 | 76 | II |
| 34 | 18 | 3 | 79 | II |
| 35 | 17 | 2 | 81 | II |
| 36 | 23 | 5 | 72 | II |
| 37 | 10 | 2 | 88 | II |
| 38 | 11 | 3 | 86 | II |
| 39 | 16 | 2 | 82 | II |
| 40 | 14 | 3 | 83 | II |
| 41 | 13 | 2 | 85 | II |
| 42 | 21 | 2 | 77 | II |

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the Sarcheshmeh Formation. The upper part of this formation, recorded in our samples, belongs to the late Barremian age and is part of the NC 5 calcareous nannofossil zone.

In the Tyson APP plot (Tyson, 1995) the upper part of the Sarcheshmeh Formation in the Aghband stratigraphic section plots in the depositional environment II. The II environment is a long–lasting palynofacies recorded in all nannofossil zones from NC5 to NC 9 which represent a marginal basin. Environment II contains a higher proportion of phytoclasts and

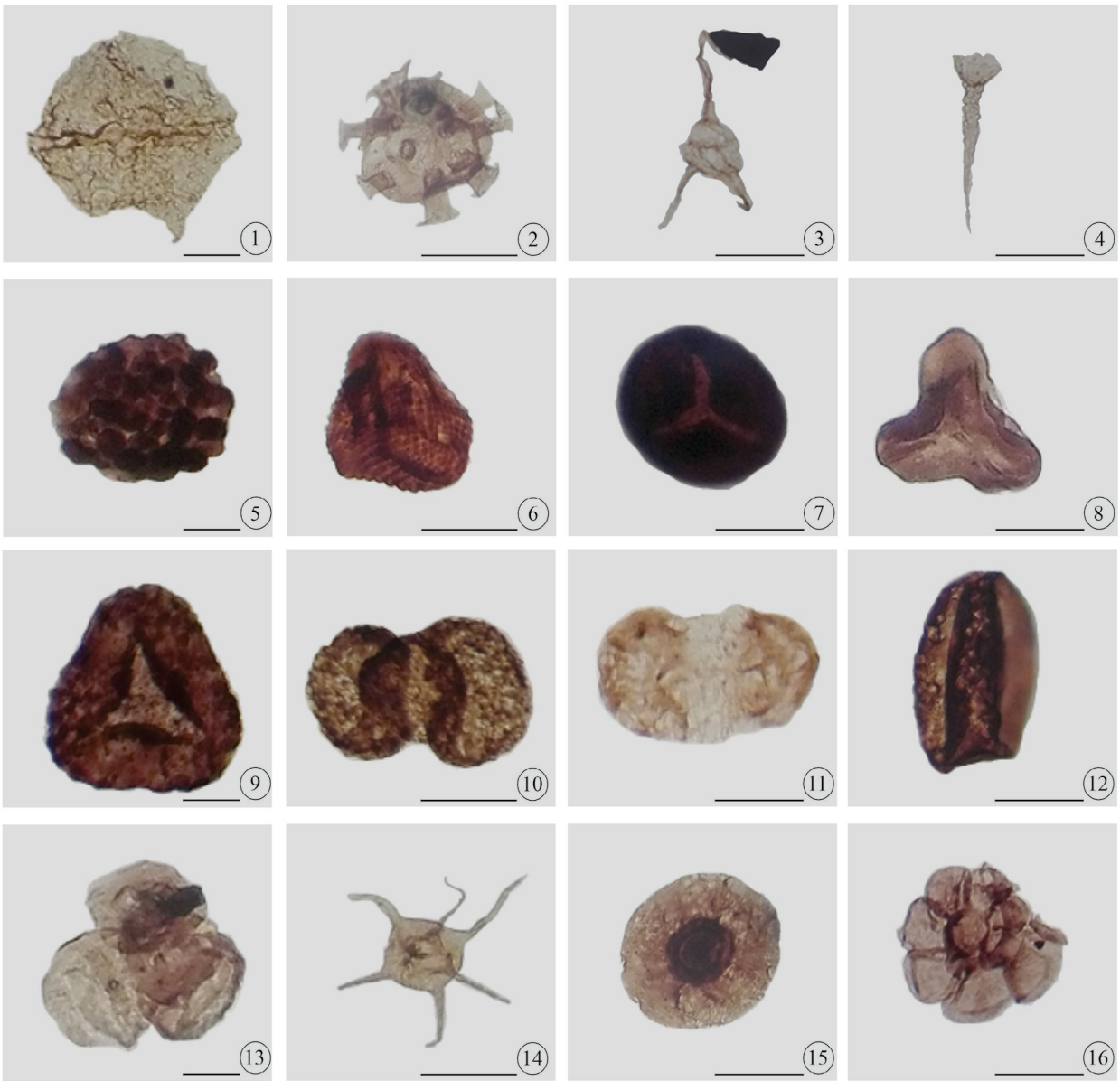


**Plate 1** Selected Recorded Palynomorphs. The scale bar is 20 µm. 1. *Palaeoperidinium cretaceum* (Pocock, 1962) Davey, 1970; 2. *Oligosphaeridium poculum* Jain, 1975; 3. *Odontochitina operculata* (Wetzel, 1933) Deflandre & Cookson, 1955; 4. *Odontochitina singhii* Morgan, 1980; 5. *Verrucosisporites* sp. Ibrahim, 1933; 6. *Cicatricosisporites* sp. Potonie, 1933; 7. *Todisporites* sp. Couper, 1958; 8. *Gleicheniidites* sp. Dettman, 1963; 9. *Impardecispora* sp. Venkatachala, 1969; 10. *Alisporites similis* Dettmann, 1963; 11. *Alisporites lowoodensis* de Jersey, 1963; 12. *Cycadopites* sp. Wodehouse, 1939; 13. Pollen in Tetrad; 14. *Michrystridium* sp.; 15. *Pterospermella* sp. Eisenack, 1972; 16. Foraminiferal organic linings

moderate AOM. Compared to the Sarcheshmeh Formation, the Sanganeh Formation record is complete, and the samples belong to the three palynofacies types.

### 5.2. COMPARISON AND CORRELATION

Previous palynology studies of the Sarcheshemh and Sanganeh formations were conducted mainly for paleoenvironmental purposes (*e.g.*, Ghasemi-Nejad et al., 2015; Shokri et al., 2015; Sharifi et al., 2019). The Sarcheshmeh Formation was studied for palynostratigraphy purposes at the Anjirbolagh section (Davtalab et al., 2011), belonging to the *Odontochitina operculata* zone. Paleoenvironment studies were mainly based on plotting samples in an APP ternary diagram (Tyson, 1995). Based on previous studies, the depositional environments of these formations vary from a highly proximal shelf to a distal shelf. Figure 4 illustrates the distribution of palynofacies frequencies across various sections of the Koppeh–Dagh Basin. The basin was previously believed to be deeper in the center (Shokri et al., 2022). A comparison of the results of this study with those of all the previous paleoenvironmental studies of the same age clearly showed that the environmental changes in the basin were more complex than previously thought. Even in close sections in the eastern part of the basin, the palynological factors changed significantly. Based on our new findings, the Koppeh–Dagh Basin during the late Barremian–late Albian age was divided into two parts: a more turbulent part in the east and a more stable part in the west. The basin in the eastern part faced more turbulent conditions, recording several palynofacies. For instance, palynofacies I, II, III, IV, V, VI, VII, and VIII were recorded in the Sanganeh stratigraphic section (Shokri et al., 2015). Recording diverse environments by plotting data in Tyson–type ternary diagrams has also been observed at the Ghale–No (Khosravi-Alghar, 2007) and Qarah–Su (Ghasemi-Nejad et al., 2015) stratigraphic sections. At the same time, in the western region, the situation was quieter, with only three palynofacies types (types I, II, and IV) recorded in the present study. The Sarcheshmeh Formation

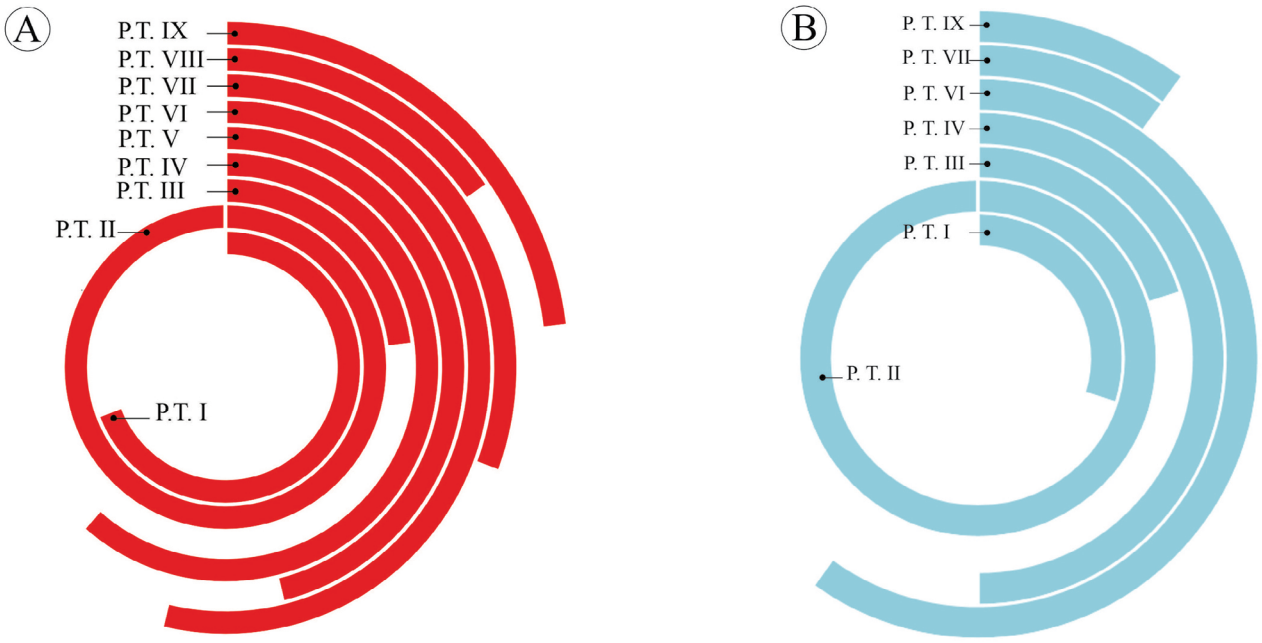


**Figure 4** Doughnut diagram showing the frequency of each palynofacies in different Koppeh–Dagh Basin sections. a) Sanganeh Formation; b) Sarcheshmeh Formation P. T. stands for palynofacies type.

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faced less diverse palynofacies than the Sanganeh Formation. Environment VII, an indicator of a distal shelf, has been recorded only in Borehole 1 (Sharifi et al., 2019). The location of this borehole is not far from that of the Khor syncline, in which an ichnofossil study was conducted in the Sarcheshmeh Formation. Based on recorded ichnofossils, including *Chondrites*, *Arthrophycus*, *Scolicia*, *Zoophycos*, *Paleodictyon*, *Paleodictyon maximum*, *Paleodyction strozzi*, and *Paleodictyon miocenicum*, an outer ramp environment with a low oxygen level has been suggested for the Sarcheshmeh Formation (Moussavi-Zadeh et al., 2011). In the present study, the only environment observed was in the upper Barremian deposits belonging to the upper part of the Sarcheshmeh Formation.

## 6. Conclusions

Palynofacies investigations were performed on 42 samples of the early Cretaceous Sarcheshmeh and Sanganeh formations observed in the Koppeh–Dagh Basin, Iran. To investigate environmental changes over time in the section, previously existing calcareous nannofossil data have been used. The AOM–Phytoclast–Palynomorph (APP) ternary diagram identified three distinct palynofacies types (I, II, and IVa), suggesting deposition in environments ranging from highly proximal shelf settings to marginal basins and shelf-to-basin transitions.

Palynofacies analysis of the Sarcheshmeh and Sanganeh Formations indicates that both units were deposited in shallow marine settings influenced by significant terrestrial input. However, the Sarcheshmeh Formation shows less palynofacies diversity, suggesting a more stable and uniform depositional environment compared to the Sanganeh Formation. Comparison with adjacent sections further reveals a basin-wide trend, with more turbulent conditions in the eastern part of the Koppeh-Dagh Basin and quieter, more stable settings toward the west.

## Contributions of authors

(1) Conceptualization: FF, SM; (2) Data analysis or acquisition: ELK, SB; (3) Methodological or technical development: ELK, SB; (4) Drafting of the original manuscript: FF, SM; (5) Graphic design: FF, SM; (6) Interpretation: FF, SM; (7) Other contributions (supervision, integration): EGN, FF, SM.

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## Conflict of interest

No potential conflict of interest was reported by the authors.

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