Invertebrate fauna of the Albian–Lower Cenomanian deposits in the Fars and Isfahan provinces (Firuzabad and Fasakhod sections), Zagros Basin, Central Iran

Fauna de invertebrados de los depósitos del Albiano-Cenomaniano Inferior en las provincias de Fars e Isfahan (secciones Firuzabad y Fasakhod), Cuenca de Zagros, Irán Central

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ABSTRACT

The Albian- Cenomanian deposits of the Kazhdumi Formation at Zagros Basin (Firuzabad section and Central Iran (Fasakhod section), represents a carbonate sedimentary succession and contain rich and diverse invertebrate macro fauna. Detailed studies on about 200 specimens of invertebrate macro fauna revealed from two stratigraphic intervals led to recognition of 5 species of gastropods; (*Liopeplum*? sp., *Columbellina* sp., *Cryptaulax*? sp., *Turritella*? sp., *Pleurotomaria* sp.), 3 species of ammonites; (*Knemiceras duberterti*, *Sphenodiscus* sp., *Knemiceras persicum*), 10 species of bivalves assemblages; (*Ceratostreon flabellatum, Cardium?* sp., *Exogyra (Costagyra) olisiponensis*, *Neithea (Neithea) quinquecostata*, *Trigonia* sp., *Buchia*? sp., *Cardium*? sp., *Pseudogyra* sp., *Ontaria*? sp., *Nucula*? sp., *Pleuromia*? sp., 1 species of echinoids; *Dorocidaris taouzensis* with a prolific horizon of *Notopocorystes xizangensis* of raninoid crabs. The absence of large gastropods and bivalves fauna and abundance of suspension-feeders indicated instability of the substrate, shallow marine paleoenvironment.and a medium energy condition.

Keywords: Cretaceous, Albian-Cenomanian, Kazhdumi Formation, fossil content, Iran.

RESUMEN

Los depósitos del Albiano-Cenomaniano de la Formación en la Cuenca de Zagros (sección Firuzabad e Irán Central (sección Fasakhod), representan una sucesión carbonatada sedimentaria que contiene una diversa y rica macrofauna de invertebrados. Estudios detallados de 200 muestras de macrofauna de invertebrados, colectados en dos intervalos estratigrádicos , llevaron al reconocimiento de 5 especies de gasterópodos; (Liopeplum? sp., Columbellina sp., Cryptaulax.? sp., Turritella? sp., Pleurotomaria sp.), 3 especies de ammonites; (Knemiceras duberterti, Sphenodiscus sp., Knemiceras persicum), 10 especies de composiciones de bivalvos (Ceratostreon flabellatum, Cardium.? sp., Exogyra (Costagyra) olisiponensis, Neithea (Neithea) quinquecostata, Trigonia sp., Buchia? sp., Cardium? sp., Pseudogyra sp., Ontaria? sp., Nucula? sp., Pleuromia? sp., una especies de echinoideo; Dorocidaris taouzensis, con un prolífico horizonte de cangrejos raninoides Notopocorystes xizangensis. La ausencias de gandes gasterópodos y bivalvos y la abundancia de alimentadores por suspensión, indican inestabilidad del substrato, un paleoambiente marino somero y condiciones de energía media.

Palabras clave: Cretácico, Albiano-Cenomaniano, Formación Kazhdumi, contenido fósil, Irán.

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1. Introduction

The Iranian Plate, a major segment of the Cimmerian micro-continent, had detached from northeastern Gondwana by the end of Permian and collided with the Turan Plate (part of Eurasia) towards the end of the Triassic (Sengore, 1990; Stampfli *et al.*, 1991; Saidi *et al.*, 1997; Mirnejad *et al.*, 2013). From the Early Jurassic to Senonian, the young Neo-Tethyan oceanic basin was reduced in extent by its subduction under the Iranian continental plate. The final closure of the Neo-Tethys, marked by the collision between the Iranian and Arabian plates, took place during the Neogene (Berberian *et al.*, 1982; Shahabpour, 2005; Ahmadi-Khalaji *et al.*, 2007). The Iranian plateau is divided into several zones from SW to NE (Figure 1): Zagros fold-thrust belt, Sanandaj-Sirjan metamorphic zone, Urumieh-Dokhtar volcanic belt, central Iran zone, Alborz zone, Kopeh Dagh zone, and Eastern Iran zone (Falcon, 1967; Stocklin, 1968; Dewey *et al.*, 1973; Stocklin and Nabavi, 1973; Jackson and McKenzie, 1984; Sengore, 1984; Byrne *et al.*, 1992; McCall, 2002; Blanc *et al.*, 2003; Alavi, 2004; Walker and Jackson, 2004; Barber *et al.*, 2018; Ghorbani, 2019; Ghassemi *et al.*, 2023). Among rock units studied in the Zagros basin, the Kazhdumi Formation (Albian-lower Cenomanian) is significant for its characteristics as a petroleum source rock, being part of the Bangestan Group which consists of the Kazhdumi, Sarvak, Surgah, and Ilam formations. In general, the lithological aspect of the Kazhdumi Formation is comprised of dark bituminous shale, fossiliferous marl and limestone intercalations (James and Wynd, 1965; Afghah *et al.*, 2007; Soleimani, 2009). The surrounding strata, Dariyan (Aptian) is the underlying formation, while Sarvak is known as the overlying formation (upper Cenomanian) (Afghah *et al.*, 2020; Arampour *et al.*, 2021). These strata are

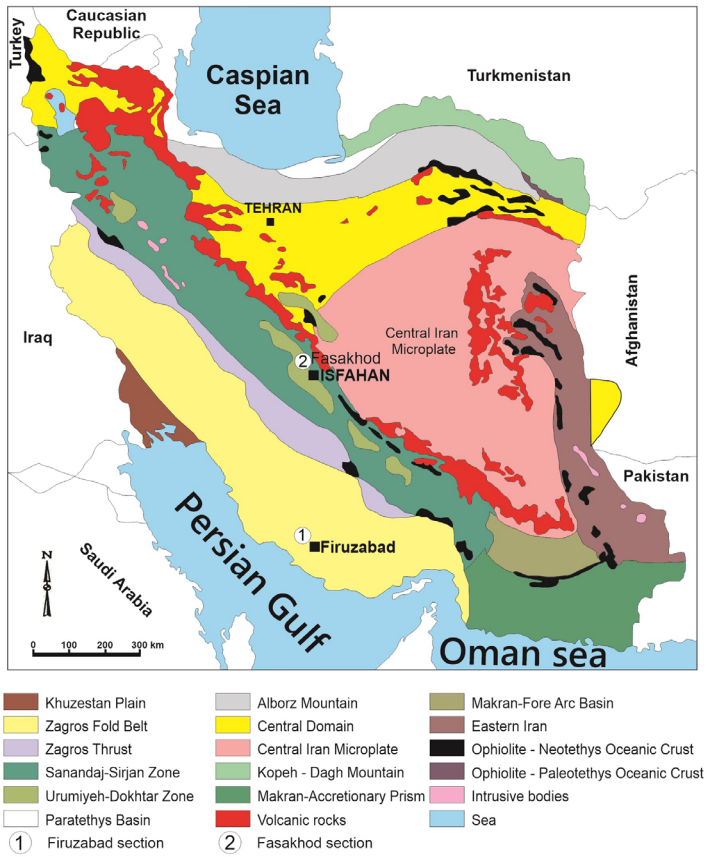


Figure 1 Structural and sedimentary zones of Iran (after Sahandi *et al.*, 2002; Richards *et al.* 2006).

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well exposed in many parts along the Zagros mountain ranges (Figure 2).

The lithostratigraphic contact between the Dariyan and Kazhdumi formations is marked by an oxidized iron nodule zone (James and Wynd, 1965; Motiei, 1992; Afghah and Shabanpour Haghighi, 2014; Soleimani *et al.*, 2014). The Sarvak Formation (gray well-bedded limestone) covers the marl of Kazhdumi Formation. Sarvak Formation reveals various lower biostratigraphic limits covering the continuous sedimentation of the Kazhdumi and Sarvak formations during the Albian-Cenomanian. Kalantari (1976) studied the Kazhdumi marls in the southeastern Shiraz with continuous sedimentation between the Dariyan and the Kazhdumi formations.

In Central Iran domain (Isfahan province), following the late Cimmerian orogeny, the Early Cretaceous sea advanced onto the small continent of Central Iran. The transgression began in the late Barremian and continued to the early Albian. A sequence of thick sediments eroded by this uplift included several lithologies such as red conglomerate, sandstones and limestones, *Orbitolina* gray limestones with marl intercalations into the late Aptian. Shales with intercalations of limestone contain ammonites and green to gray marly limestone with small turritellid gastropods, bivalves, ammonites can be found throughout the unit which indicate an Albian age for this sequence (Seyedemami *et al.*, 1971; Kalantari, 1981; Amirshahkarami, 1998; Amirshahkarami and Vaziri-Moghadam, 2000; Salehi and Tadayon, 2019). Thick, micritic Cenomanian-Turonian limestones unconformable overlie the Albian deposits.

The present contribution indicates invertebrate macro fauna of the Albian-lower Cenomanian deposits of south and central Iran to better interpret the depositional condition during the time interval.

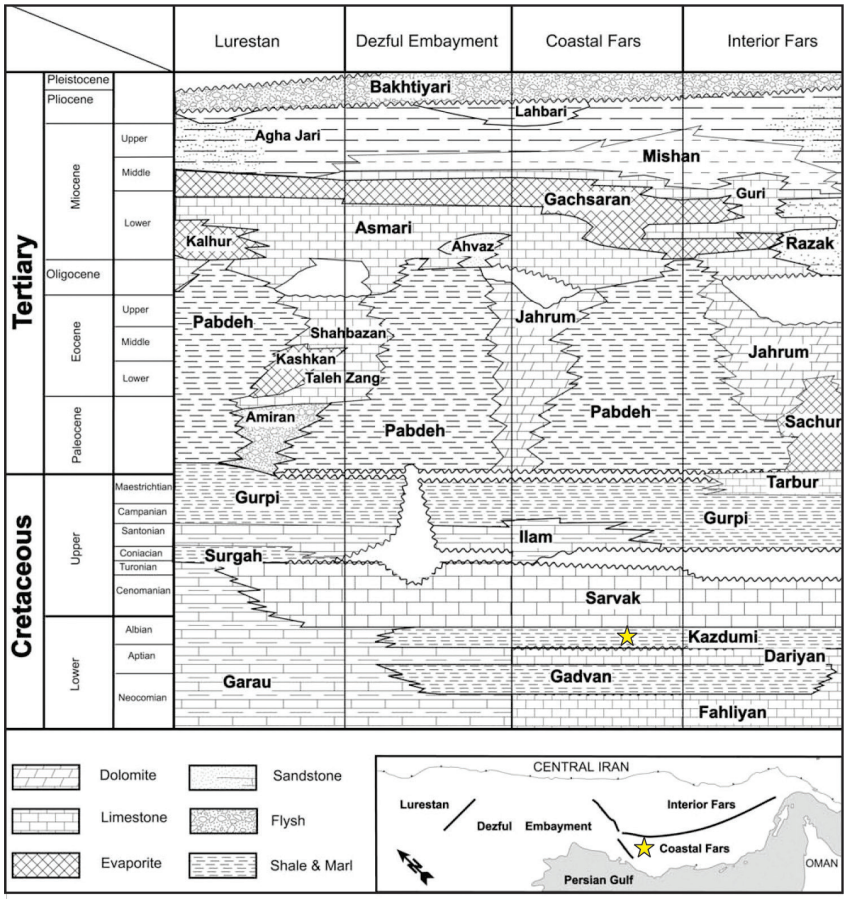


Figure 2 Expansion and stratigraphic correlation chart of Iranian sector of the Zagros (adapted from James and Wynd, 1965; Motiei, 1993).

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2. Geological setting

2.1. FIRUZABAD SECTION

The Firuzabad section is located 45 km southwest of Firuzabad city in Fars province, southwest Iran. The geographic coordinates for the base are E: 52°24′35″, N: 28° 35′49″and the top of the section E: 52°24′32″, N: 28° 35′59″, with 2423 m above the sea level. The studied section is part of the southern flank of the Khartu anticline with a northwest-southeast trend and somehow crushed between the kuh-e-Gach and kuh-e-Jehani Salt domes of the late Precambrian-Cambrian Hormoz Series (Figure 3).

The studied Cretaceous interval outcrop is assigned to Aptian through Cenomanian successions (Dariyan, Kazhdumi and Sarvak formations). The Dariyan Formation (Aptian) is well exposed and mainly composed of gray thick bedded to massive orbitolinid sandy limestone. The Kazhdumi shale, marl and marly limestone formation covers the Dariyan Formation and the white gray massive limestone of the Sarvak Formation (Cenomanian), which overlies the Kazhdumi Formation as a gradational contact.

The thickness of the studied deposits of the Kazhdumi Formation is approximately 60 m. From top to bottom, the succession is as follows (Figure 4):

Top - white gray massive sandy nodular limestone containing crushed rudists fragments (Sarvak Formation).

- Alternation of cream to light brown limestone and red marls with very tiny sandstone sub minors including scattered ammonites, bivalves and echinoderms (5 m).
- Alternation of green marls with loose clay

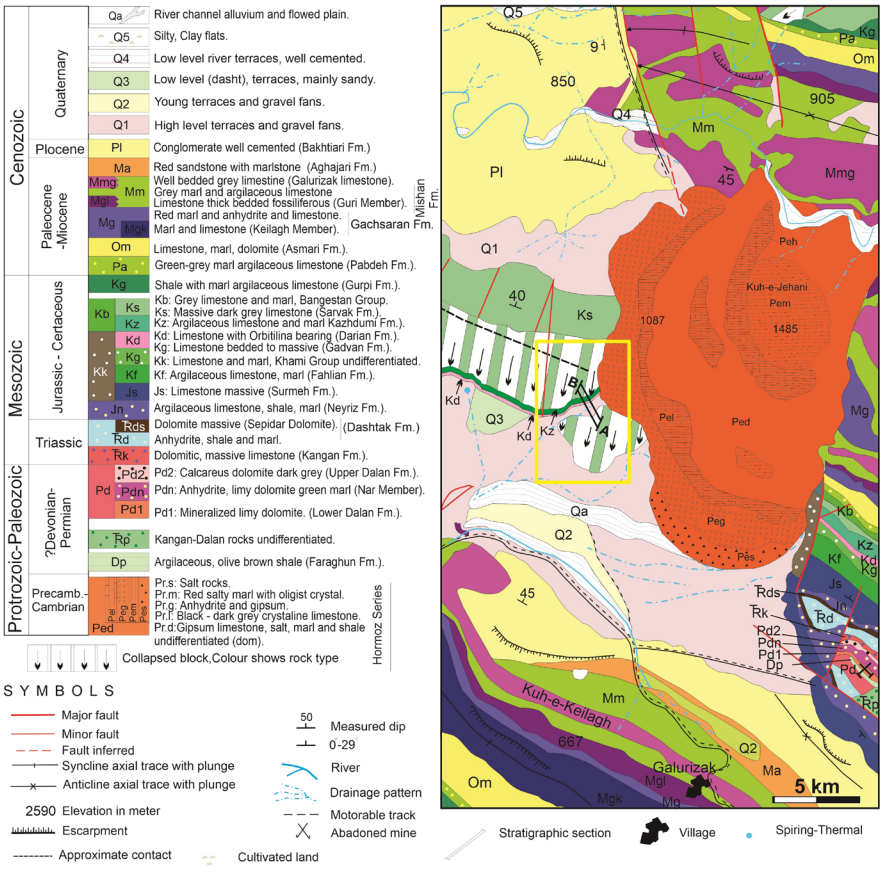


Figure 3 Simplified geological map of the Khartu anticline and Kuk-e-Jehani Salt Dome, showing the location of the study exposure (adapted from Sedaghat and Dabaghian Nejad, 1996, Farrashband Geological map, Series Sheet No 6447).

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and thin bedded limestone rich in vertebrate micro-remains, crustacean remains, as well as gastropods and bivalves (7-10 m).

- Alternation of brown marl with thin bedded limestone including large scale echinoids and ammonites (4-5 m).
- Red muddy clay and marls with scattered ammonites and isolated orbitolinids (10 m).
- Alternation of thin bedded argillaceous limestone with olive-green marls including isolated orbitolinids and tube worms (5 m).
- Yellow marls rich in macro-fauna: bivalves, echinoids and gastropods (3 m).
- Cream to light thin bedded limestone and marly limestone (20 m).
- Alternation of yellow muddy bituminous clay and marls with orbitolinids (2 m).
- Oxidized iron nodule and bauxitic levels (1.5-2 m).

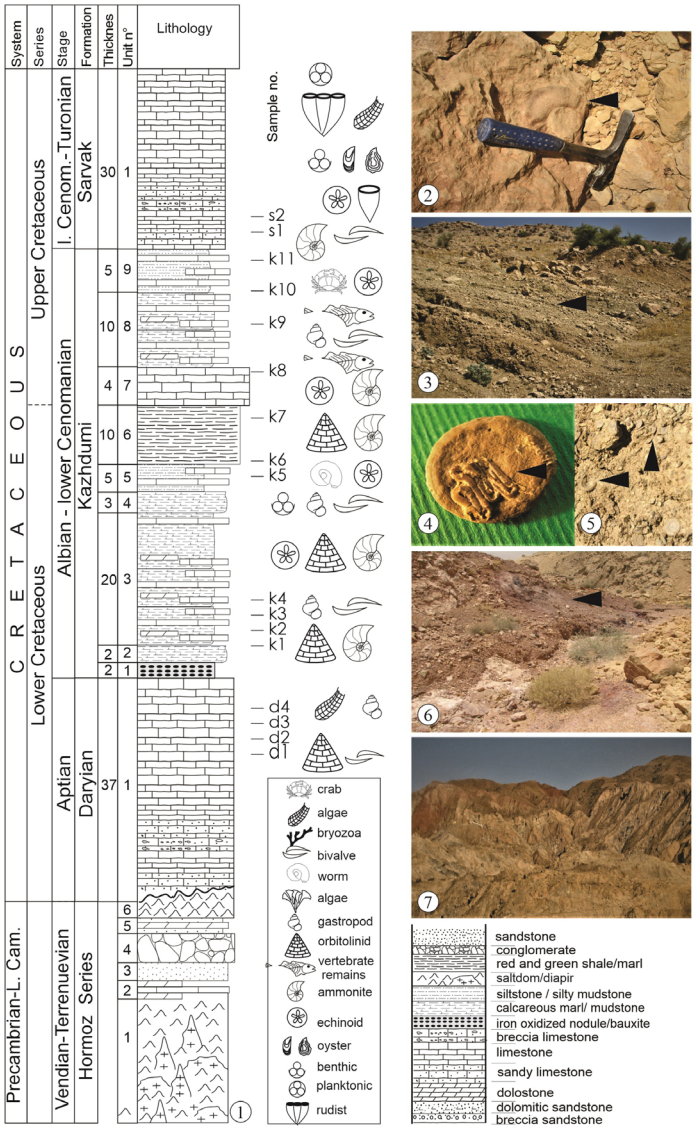


Figure 4 (1) Lithostratigraphical column of the studied exposure of the Firuzabad section showing the distribution of the main collected macrofossils and the assigned levels, (2) black arrow shows the rudist fragments of the Sarvak Formation, 3- panoramic view of the Kazhdumi Formation in the studied exposure with indication to the fossiliferous horizons, 4- isolated orbitolinid from the marls of the unit 5 with encrusted tube worms, 5- isolated orbitolinids from the unit 6, 6- iron oxidized nodule (unit 1) at the base of the Kazhdumi Formation in contact to the underlying Darian Formation, and 7- panoramic view of the Kuh-e-Jehani Salt Dom of the Precambrian-Cambrian Hormoz Series.

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Base: Cream to light medium to thick bedded limestone, breccia limestone and sandy limestone (Darian Formation).

2.2. FASAKHOD SECTION

The most complete Cretaceous sections in Central Iran domain are found in the Isfahan province. The rocks consist of marine shale, marl, limestone and sandstone, reaches a thickness of more than 800 m and seems to represent all major parts of the Lower to Upper Cretaceous strata (Seyedemami et al., 1971; Mannani and Yazdi, 2009; Salehi and Tadayon, 2019). However, the marine sequences are frequently interrupted by conglomerates, red beds, sedimentary gaps and unconformities and the sections vary in detail over short distances, reflecting the unstable conditions of the sedimentary environment during the initial phases of the Alpine orogeny. This and considerable disagreement between interpretations of different authors regarding the stratigraphic significance of the faunas, has so far made reliable correlation over any greater distance difficult and a consistent stratigraphic subdivision of the Cretaceous has yet to be established. The Stratigraphic Terminological

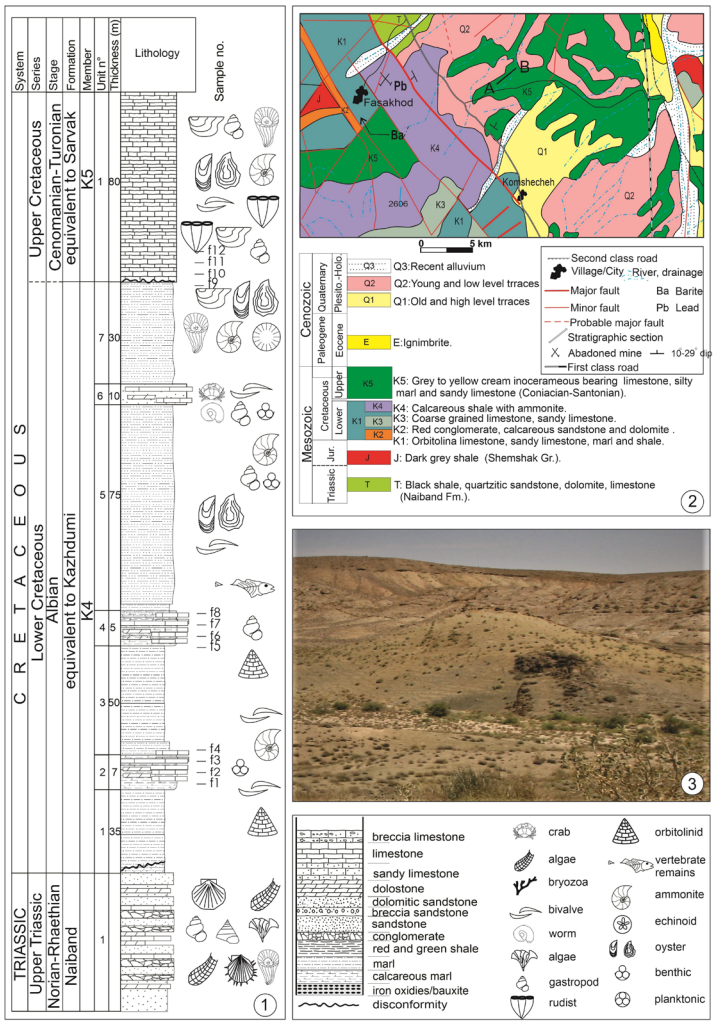


Figure 5 (1) lithostratigraphical column of the studied exposure of the Fasakhod section showing the distribution of the main collected macrofossils and the assigned levels, (2) simplified geological map of the Fasakhod area showing the location of the study exposure (adapted from Radfar, 1998, Geological map of Ardestan 1:100000, (3) panoramic view of the studied section, lower part indicates the Albian green shales and the upper cliff-making Cenomanian-Turonian limestone.

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Committee (STC) of Iran has recommended not introducing any formal stratigraphic names for the Cretaceous strata of the Central Iran until more regional information becomes available to clarify the situation, in compliance with this recommendation (Stocklin and Setudehnia, 1991; Ghasemi and Talbot, 2006). The Fasakhod section is situated in the NW-SE striking at approximately 5 km southeast of Fasakhod village (Ardestan area, 75 km north Isfahan city), and is accessible by the Isfahan-Ardestan road (Figure 5). The section is 210 m thick and is composed of 7 lithological associations, marls and limestones, which were deposited alternatively (Figure 5). The section from the lower to the upper part is as follows:

Top: massive cliff making limestone (Cenomanian-Turonian; equivalent to Sarvak Formation).

- Disconformity.
- Shale and light green marl with gastropods, bivalves, scattered solitary corals, ammonites (30 m).
- Gray, thin-bedded sandy limestone with gastropods, bivalves tube worms, crustacean remains (10 m).
- Light green marls with ammonites and shell fragments (75 m).
- Gray sandy limestone with intercalation of marls including scattered ammonites and shell fragments (5 m).
- Green to olive marl (50 m).
- Brown sandy limestone (7 m).
- Green marls (35 m).
- Angular unconformity.
- Purple to brown sandstone, conglomerate, dolomitic limestone and shale, with thin bedded limestone including plants remains, bivalves, colonial and solitary corals, gastropods (Upper Triassic Naiband Formation).

3. Materials and methods

Two well-exposed stratigraphic sections of the Cretaceous deposits (Kazhdumi Formation and its lithologic equivalents) in southwest and central Iran were selected in order to study the frame of the biostratigraphy and fossil fauna. The lower and upper lithostratigraphic limits were determined by detailed field observations. In addition, the material includes a large proportion of crushed, distorted, imperfect, or weathered individuals. Well-preserved specimens were cleaned by means of a mild detergent, and whenever necessary, an ultrasonic vibrator and a preparation needle. Finally, a light bionocular microscope was used, where it was necessary. 35 samples were collected from the studied profile in Fashakhod section (12 rock samples and 23 washing samples), 170 m from the base of the profile there is 10 m of thin bedded limestone prolific in crustacean remains here reported. From the deposits of the Kazhdumi Formation at Firuzabad section, 17 rock samples and about 200 individual fossils (gastropods, ammonites, bivalves, crustaceans and echinoids) with morphological structures preserved were collected and prepared for further studies. At 27 m from the base of the studied exposure at Firuzabad section there is also a level of small crustaceans, with abundant microscopic crushed fragments of carapace and claws. All the studied samples are housed in the Department of Geology, Faculty of Sciences, University of Isfahan under the IUMC.

4. Invertebrate fauna

4.1. MOLLUSKS

The gastropods are represented mainly by internal molds (Figure 6.1-6.10), and thus their taxonomic position is hard to precise: *Liopeplum*? sp. (Figure 6.1, 6.2), *Columbellina* sp. (Figure 6.3-6.5), *Cryptaulax*? sp. (Figure 6.6, 6.7), *Turritella*? sp. (Figure 6.8), *Pleurotomaria* sp. (6.9, 6.10). Although incomplete, some specimens of ammonites were able to be identified as *Knemiceras duberterti* Basse, 1940 (Figure 6.11), *Sphenodiscus* sp. (Figure 6.12), *K. persicum* Collignon, 1983 (Figure 6.13-6.16). The bivalves include *Ceratostreon flabellatum* (Figure 7.1-7.3, 7.5,

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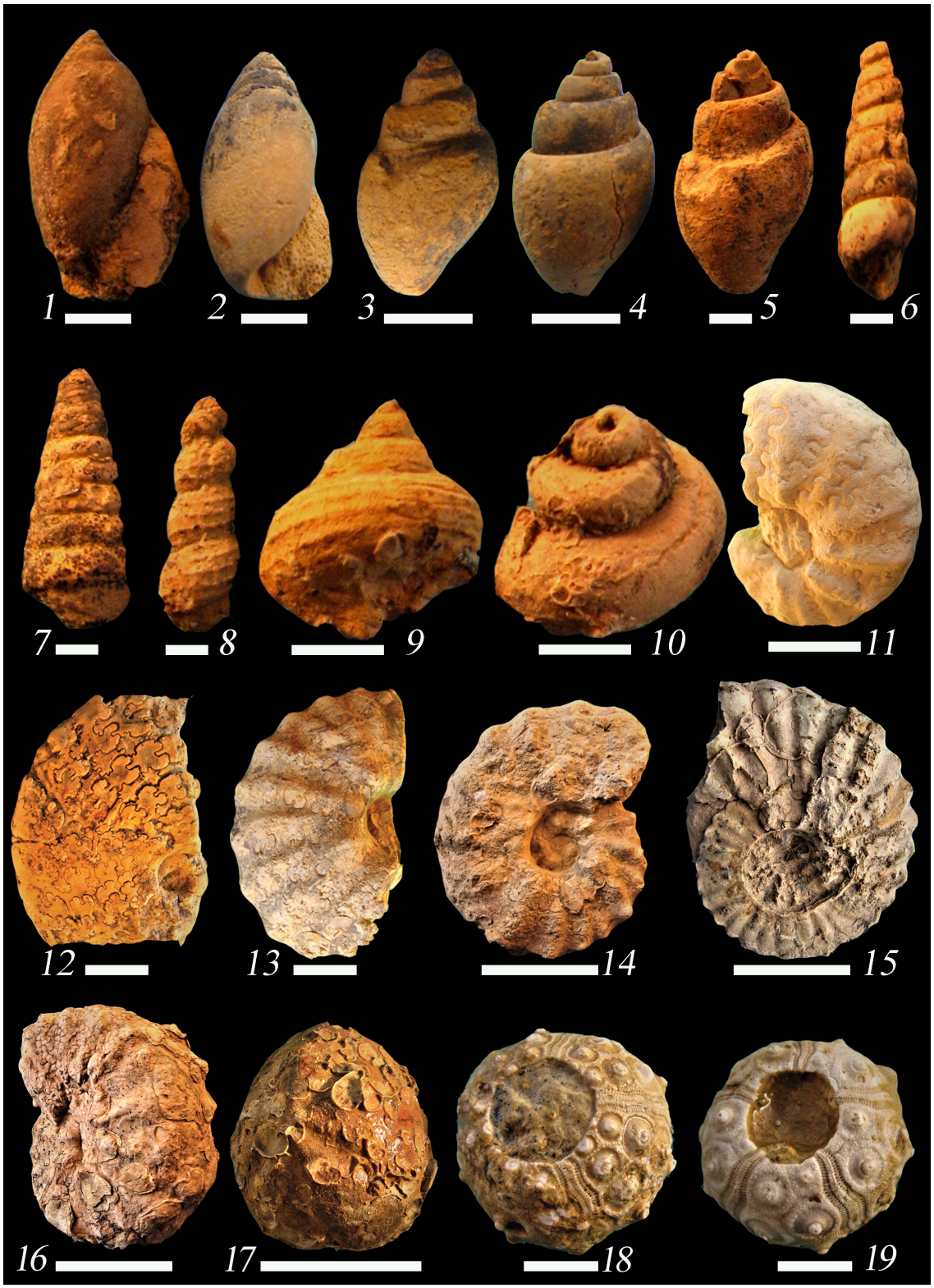


Figure 6 Gastropods, cephalopods and echinoids. 1, 2, *Liopeplum?* sp.; 3-5, *Columbellina* sp.; 6, 7, *Cryptaulax?* sp.; 8, *Turritella?* sp.; 9, 10, *Pleurotomaria* sp.; 11, *Knemiceras duberterti*; 12, *Sphenodiscus* sp.; 13-16, *Knemiceras persicum*; 17, Serpulid polychaete worms and osteroids attached to the echinoid; 18, 19, *Dorocidaris taouzensis*. Scale bars = 1 cm.

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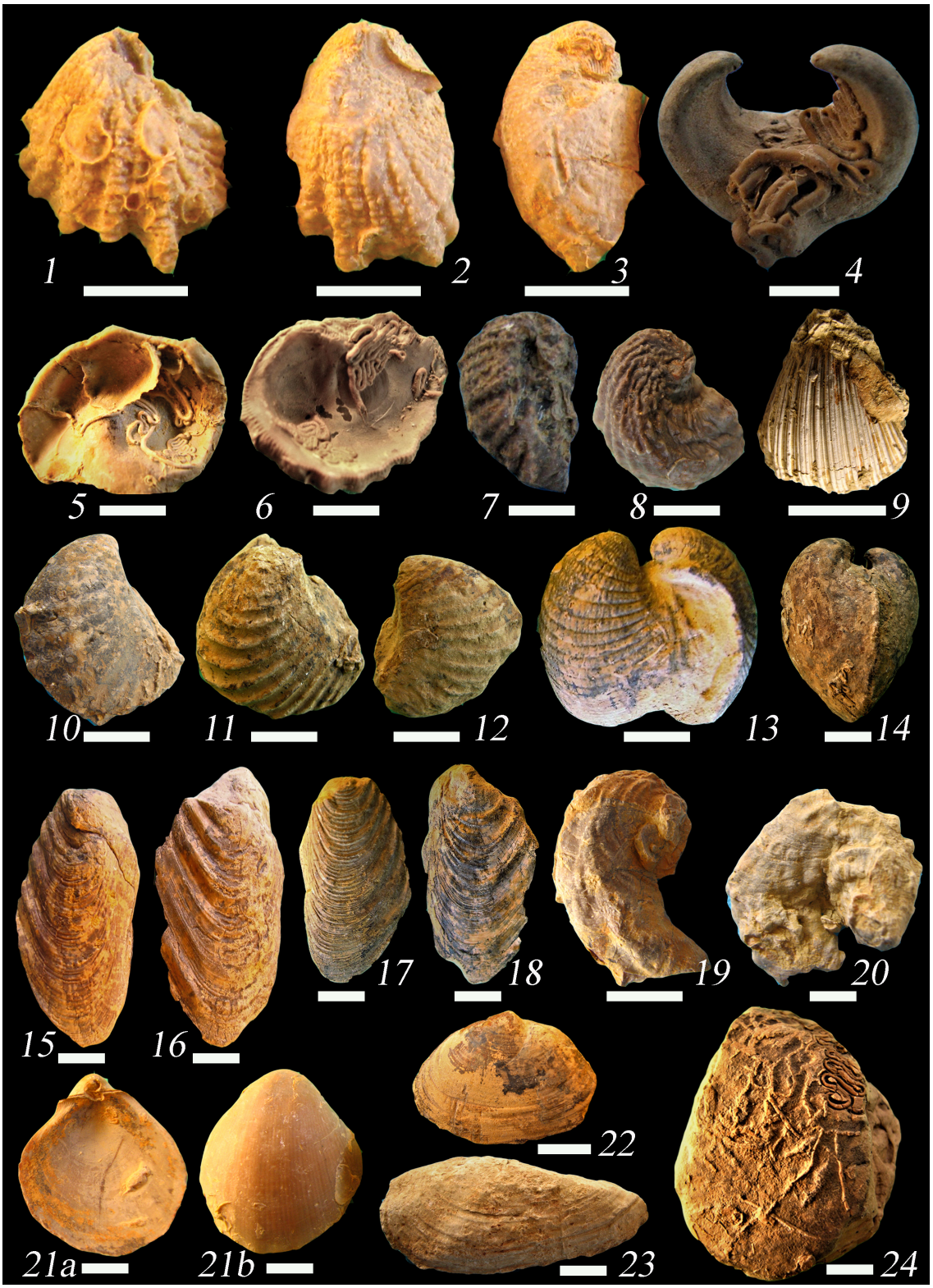


Figure 7 Bivalves. 1-3, 5, 6, *Ceratostreon flabellatum*; 4, *Cardium?* sp., 7, 8, *Exogyra (Costagyra) olisiponensis*; 9, *Neithea (Neithea) quinquecostata*; 10-12, *Trigonia* sp.; 13, *Buchia?* sp.; 14, *Cardium?* sp.; 15-18, *Inoceramus* sp.; 19, 20, *Pseudogyra* sp.; 21a, 21b, *Ontaria?* sp.; 22, *Nucula?* sp.; 23, *Pleuromia?* sp., 24, Bivalvia. Scale bars = 1 cm.

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7.6), *Cardium*? sp. (Figure 7.4), *Exogyra* (*Costagyra*) *olisiponensis* (Figure 7.7, 7.8), *Neithea (Neithea) quinquecostata* (Figure 7.9), *Trigonia* sp. (Figure 7.10-7.12), *Buchia*? sp. (Figure 7.13), *Cardium*? sp. (Figure 7.14), Inoceramidae (Figure 7.15-7.18), *Pseudogyra* sp. (Figure 7.19, 7.20), *Ontaria*? sp. (Figure 7.21a, 7.21b), *Nucula*? sp. (Figure 7.22), *Pleuromia*? sp. (Figure 7.23), Bivalvia (Figure 7.24).

The mollusk fauna represents a shallow marine infaunal, epifaunal and pelagic species. The best-preserved mollusks are those epifaunal, filter-feeding ostreoids and suggest an environment rich in nutrients, possibly by influence of nearby fluvial source. However, some bivalves (Figure 7.4-7.6) show serpulid polychaete worms attached to the interior of the shells, suggesting that the ostreoids were dead and disarticulated or the shell was dissolved, leaving the steinkern to be colonized by the worms (Figure 7.4).

4.2. CRUSTACEA

Several, nearly complete carapaces of the raninoid crab *Notopocorystes xizangensis* (Figure 8) were collected from the study area, along with numerous small fragments of pereiopods of this species and callianassoid speecimens. *N. xizangensis* was first reported from Aptian–Albian beds of the Tackna Formation of the Lhsa region, Xizang, Tibet (Wang, 1981). The second report was from Albian strata of the Albian Kolah Qazi section-*Beudanticeras* shale, Central Iran (Yazdi *et al*., 2009). The here reported specimens show the same morphological features and small size, characteristic of this species of the genus *Notopocorystes*. In fact, the species seem to be more abundant in this new locality and specimes are more complete, showing mainly dorsal morphology, but some preserved also the venral región and coxae. Its abundance in Iran indicate favorable paleoecological conditions for the development and distribution of this species in the warm, shallow marine areas of the Albian in Central Iran.

4.3. ECHINOIDEA

Two specimens of regular echinoids belong to *Dorocidaris taouzensis* Lambert 1933 (Figure 6.17, 6.18). The test of the specimens is well-preserved, suggesting no significant transport from hard surfaces where these echinoids feed on algae and organic matter(Benyoucef *et al*., 2012; Gholamalian *et al*., 2016).

5. Discussion and Results

Bulot *et al*. (2010), Kennedy *et al*. (2009), Reboulet *et al*. (2011), Asadi *et al*. (2015, 2016) and Raisossadat *et al*. (2021) studied the ammonite species *Knemiceras dubertreti* and *K. persicum* from lower to upper Albian of Iran. Species *K. dubertreti* and *K. persicum* of Sample k3, k7 and k8, can be attributed to the Albian and corresponds to the zones 1-4 of Parvaneh-Nejad Shirazi *et al*., 2011). Maghfouri-Moghaddam *et al*. (2016) described assemblages of gastropods and bivalves of the Kazhdumi Formation in Naqsh-Rustam section N Fras province and attribiuted the assemblage to the upper Albian-lower Cenomanian, the bivalve species of their study *Ceratostreon flabellatum*, *Nucula* sp., *Inoceramus* sp., *Neithea* sp., are also presented at the Firuzabad and Fasakhod sections.

Benyoucef *et al*. (2012) present the echinoid species *Dorocidaris taouzensis* Lambert, 1933 from the Cenomanian of Algeria. Gholamalian *et al*. (2016) reported this species from the sample N10 of the Cenomanian interval at the upper part of the Kazhdumi Formation in Gurgen section of Fars province (SW Iran). *Dorocidaris taouzensis* belongs to the Sample k10 at the upper part of the Firuzabad section and indicates the Cenomanian age to unit 9 of the interval corresponding to the zones 5 of Parvaneh-Nejad Shirazi *et al*. (2011).
With respect to life habits of bivalves and gastropods, stationary epifauna organisms prevail, followed by epifaunal mobile, deep-infaunal is rare and there is no epifaunal cemented, this indicates the existence of soft substrate (Ayoub-Hannaa and

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Figure 8 Crustacea. 1-14, *Notopocorystes xizangensis*; 1, 2, dorsal and ventral views; 3-14, dorsal views. Sacel bars = 1 cm.

Fürsich, 2012). The absence of large and heavy gastropods and bivalves indicates instability of the substrate, according to feeding habits, suspension feeders dominate strongly the association followed by grazer. Deposits feeder is rare, this means that water energy was medium, low enough for organic matter, nutrients for deposit-feeders, to accumulate in the sediment, but sufficiently high for suspension-feeder. The studied taxa are similar to other assemblages of the western Tethys that show the existence of a possible passage which was open during this time interval Abdelhamid and El Qot, 2002 (Egypt).

6. Conclusion

Albian-Cenomaian gastropods, ammonites, bivalves, crustaceans and echinoids are reported for the first time in the Kazhdumi Formation of Firuzabad and (and equivalent deposits) Fasakhod sections. The co-occurrence of epifaunal mobile and shallow infaunal gastropods and bivalves indicates that the substrate was soft during this time. Also, the presence of deposit-feeders and suspension feeders in the association reflects a medium water energy. The water energy was low enough for organic matter, the food for deposit-feeders, to accumulate in the sediment, but sufficiently high for suspension feeder. The studied taxa are similar to other assemblages of the western Tethys that show the existence of a possible passage, which was open during this time interval.

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Contributions of authors

Babak Sedghi: fieldwork, basic stratigraphic data. Ali Bahrami: conceptualization, writing of original manuscript, figures design. Mehdi Yazdi: Fieldwork, data interpretation writing of original manuscript. Francisco J. Vega: partial paleontological identification and interpretation, correction and edition of the manuscript.

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Conflicts of interest

The authors declare no conflict of interest.

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