Facies (2016) 62:2
DOI 10.1007/s10347-015-0452-6

ORIGINAL ARTICLE

Biofacies, taphonomy, and paleobiogeography of the Kamar-e-Mehdi Formation of east-central Iran, a Middle to Upper Jurassic shelf lagoon deposit

Franz T. Fürsich[1] · **Yanhong Pan**[2] · **Markus Wilmsen**[3] · **Mahmoud R. Majidifard**[4]

Received: 26 May 2015 / Accepted: 11 November 2015 / Published online: 27 November 2015
© Springer-Verlag Berlin Heidelberg 2015

Abstract The Callovian–Lower Kimmeridgian Kamar-e-Mehdi Formation of the western Tabas Block, part of the Central-East Iranian Microcontinent, represents the fill of an extensive carbonate shelf lagoon situated between a barrier carbonate platform in the east and the uplifted Yazd Block in the west. In the course of its development, the shelf lagoon experienced increasing isolation which, together with a climatic change to more arid conditions, led to deposition of evaporites and severe restriction of the benthic fauna. Sedimentation in the predominantly low-energy lagoon was controlled by an influx of fine-grained carbonate from the neighboring platform, biogenic carbonate production within the lagoon and episodic influx of siliciclastic material by high-density currents from the uplifted western margin. Much of the succession is composed of meter-scale asymmetric cycles that record decreasing terrigenous input as well as increasing shelliness and substrate firmness due to a decreasing sedimentation rate. They are interpreted as small-scale climatic cycles recording changes in humidity. Larger-scale cycles, comprising 250–400 m in thickness, document changes in terrigenous influx and may also be climate-controlled, although a tectonic origin cannot be excluded. The shelf lagoon was populated by several level-bottom communities and small patch reefs. The latter are of low diversity, composed of calcareous sponges, corals, or oysters, and are usually associated with thick microbial crusts. The level-bottom assemblages are dominated by bivalves, and rarely also by gastropods or brachiopods. Fossils occur scattered or concentrated in pavements and beds. Shell concentrations are autochthonous to allochthonous, most commonly parautochthonous. Concentrating agents were storm-induced flows and low sedimentation rates, less commonly also storm-waves. Within the small-scale cycles, infaunal assemblages prevail but are replaced by epifaunal assemblages at their top. The latter are commonly dominated by the bivalves *Pseudopecten tipperi* and *Camptonectes* (*Grandinectes*) *teres*, the two most characteristic faunal elements of the shelf lagoon. Diversity values of the benthic fauna were low to moderate. Environmental stress was mainly produced by elevated salinity values, at times possibly intensified by lowered oxygen values and soft substrate conditions. Paleobiogeographically, the benthic macrofauna exhibits a close relationship to that of European shelf seas but contains some immigrants from the southern shores of the Tethys and the northwestern Pacific. The degree of endemism was low (two taxa).

Keywords Shelf lagoon · Jurassic · East-central Iran · Taphonomy · Paleoecology · Paleobiogeography

Introduction

Shelf lagoons are extensive depressed areas of carbonate platforms, which are commonly protected from the open sea by barriers such as reef belts. Whereas the facies

---

✉ Franz T. Fürsich
franz.fuersich@fau.de

[1] FG Paläoumwelt, GeoZentrum Nordbayern der Friedrich-August-Universität Erlangen-Nürnberg, Loewenichstrasse 28, 91054 Erlangen, Germany

[2] Key Laboratory of Economic Stratigraphy and Palaeogeography, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 21008, China

[3] Senckenberg Naturhistorische Sammlungen Dresden, Museum für Mineralogie und Geologie, Königsbrücker Landstr. 159, 01109 Dresden, Germany

[4] Geological Survey of Iran, Box 131851-1494, Tehran, Iran

patterns of shelf lagoons have been thoroughly studied in modern (e.g., Hopley 1982; Tudhope and Scoffin 1984; Hamilton 2001; Purdy and Gischler 2003; Purdy et al. 2003) and to some detail in fossil examples (e.g., Jones and Desrochers 1992; Wilmsen et al. 2010), little information is available on the biota that populated shelf lagoons in the geological record. The Jurassic Kamar-e-Mehdi Formation of central Iran, characterized by excellent exposures, a cyclic sedimentation pattern, and an abundant benthic macrofauna, offers a unique opportunity to study in detail the biofacies, community relicts, and shell concentrations of a Mesozoic shelf lagoon. In this paper, we describe these features, analyze the sedimentary cycles, and discuss the sedimentological, biological, and taphonomic processes responsible for the observed patterns. The study thus greatly enhances our knowledge about the biota and processes of fossil shelf lagoonal environments.

Geological framework

The Cimmerian Plate in Iran is composed of the Alborz Mountains and central Iran, including the Central-East-Iranian Microcontinent (CEIM). It collided with Eurasia towards the end of the Triassic period thereby closing the Paleotethys Ocean in the area (e.g., Wilmsen et al. 2009a and references therein). Concomitant onset of subduction of the Neotethys in the south led to extensional tectonics and influenced the sedimentation pattern on central Iran during much of the Jurassic. The crustal fragment of the CEIM consists of three major blocks (from east to west the Lut, Tabas, and the Yazd Block; Fig. 1), which differed in their subsidence history during the Jurassic. Whereas sediments were deposited on the Tabas Block and the western Lut Block throughout the Jurassic, no Middle to lower Upper Jurassic sediments are known from the Yazd Block in the west, which was obviously an uplifted area and acted as a sediment source for the neighboring Tabas Block (Wilmsen et al. 2010; Salehi et al. 2014a, b). Fürsich et al. (2003a, b) and Wilmsen et al. (2009b, 2010) assumed the three blocks to represent tilted fault blocks during the Jurassic with corresponding pronounced lateral facies changes normal to the faults delimiting the blocks (see also Salehi et al. 2014a, b).

During the Early and early Middle Jurassic, siliciclastic sedimentation, partly marine and partly non-marine, prevailed on the Tabas Block (Salehi et al. 2014a, b). A conspicuous tectonic event, the so-called Mid-Cimmerian tectonic event, affected the area at the end of the Early Bajocian, resulting in uplift and local erosion and was followed by renewed transgression in the Late Bajocian (Seyed-Emami and Alavi-Naini 1990; Wilmsen et al. 2003; Seyed-Emami et al. 2004; Fürsich et al. 2009). From the Callovian onwards, the sedimentation pattern changed and siliciclastic sediments were replaced by carbonates. On the northern Tabas Block, this resulted in the establishment of the large-scale carbonate system of the Esfandiar Subgroup (Wilmsen et al. 2003, Fig. 2). It consisted of a carbonate platform situated on the crest of the tilted fault block in the east (Shotori Swell) and is represented by the Esfandiar Limestone Formation (Fig. 3). Towards the east, this carbonate platform produced allodapic limestones on the slope and in the adjacent basin (the Qal-eh-Dokhtar Formation), whereas towards the west a wide shelf lagoon developed between the carbonate platform and the emergent Yazd Block (Fürsich et al. 2003b; Wilmsen et al. 2010; Fig. 3). It reaches up to 100 km in width and can be traced for a N–S distance of approximately 500 km (Wilmsen et al. 2010; Zamani-Pedram 2011). The sediments deposited in this shelf lagoon are represented by the Kamar-e-Mehdi Formation (Fig. 2b), which is at the center of the present investigations. At the type section, it reaches a thickness of 1250 m but thins both towards the north and the south. Towards the south it interfingers with the partly siliciclastic Bidou Formation (Huckriede et al. 1962; Wilmsen et al. 2009b; Zamani-Pedram 2011). Due to increasing restriction within the shelf lagoon and increasing aridity, the predominantly fine-grained carbonates were partly replaced by gypsum in the upper part of the formation. The overlying Magu Gypsum Formation consists, as the name implies, mainly of gypsum and fine-grained red bed intercalations. Most of the Kamar-e-Mehdi Formation is, however, characterized by well-bedded, fine-grained carbonate mudstones, marlstones, and marl with minor, generally thin, intercalations of fine-grained sandstones. Locally, the basal part of the formation is characterized by abundant microbial-coral patch reefs, and this part has been singled out as the Echellon Limestone Member (Wilmsen et al. 2003; Fig. 2a). The uppermost unit of the formation is characterized by a relatively monotonous package of carbonate mudstones and has been termed Nar Limestone Member (Wilmsen et al. 2003; Fig. 2a).

The base of the Kamar-e-Mehdi Formation is Early Callovian in age, as is documented by the ammonite *Macrocephalites* occurring at the top of the underlying Baghamshah Formation (Seyed-Emami et al. 1997). Within the Kamar-e-Mehdi Formation ammonites are extremely scarce. Some reineckeiids indicate a Middle Callovian age (Seyed-Emami et al. 2002), whereas several fragments of perisphinctids were too poorly preserved to provide useful biostratigraphic information. The upper boundary of the formation can be dated as being late Oxfordian/early Kimmeridgian in age, based on agglutinated foraminifera found in the top part of the Nar Limestone (Wilmsen et al. 2010).

Wilmsen et al. (2010) documented in detail sections and microfacies of the Kamar-e-Mehdi Formation and characterized the various subenvironments of the shelf lagoon.

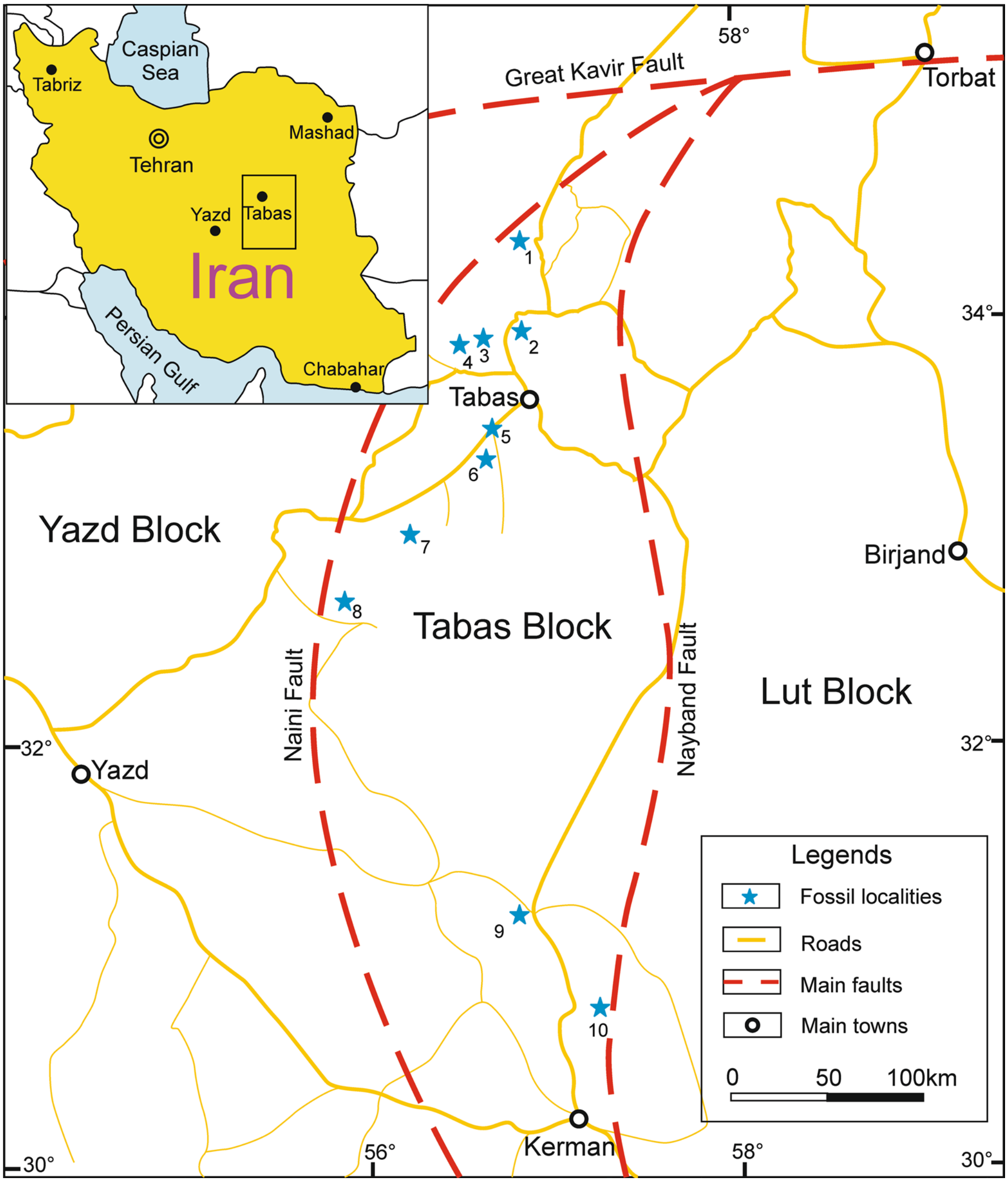


Fig. 1 Localities of the Kamar-e-Mehdi Formation investigated in detail. The three blocks Yazd, Tabas, and Lut form the so-called Central-East Iranian Microcontinent (CEIM). For GPS data of localities see Table 1

The benthic macrofauna, in contrast, was only cursorily dealt with. The present contribution therefore uses the macrofauna, its ecology, and taphonomic history as a tool to characterize the shelf lagoon and the paleobiogeographic relationships of its macrofauna.

Materials and methods

Altogether, ten sections of the Kamar-e-Mehdi Formation have been investigated and completely or partially measured on the Tabas Block. They range from Kalshaneh in the north to Kuh-Payeh (north of Kerman) in the south (Fig. 1; Table 1). Several of these sections, among them the type section between Kamar-e-Mehdi and Kuh-e-Qoleh Nar, have been documented in Wilmsen et al. (2010). Even though only limited observations of individual beds could be made due to the great thickness of the formation (>1200 m at the type locality), taphonomic and paleoecological observations were made in the field wherever possible and slabs were collected for further study in the laboratory. Except at a few levels, the benthic macrofauna was not sampled quantitatively bed-by-bed, but relative abundances were noted, and abundant material was brought back to the

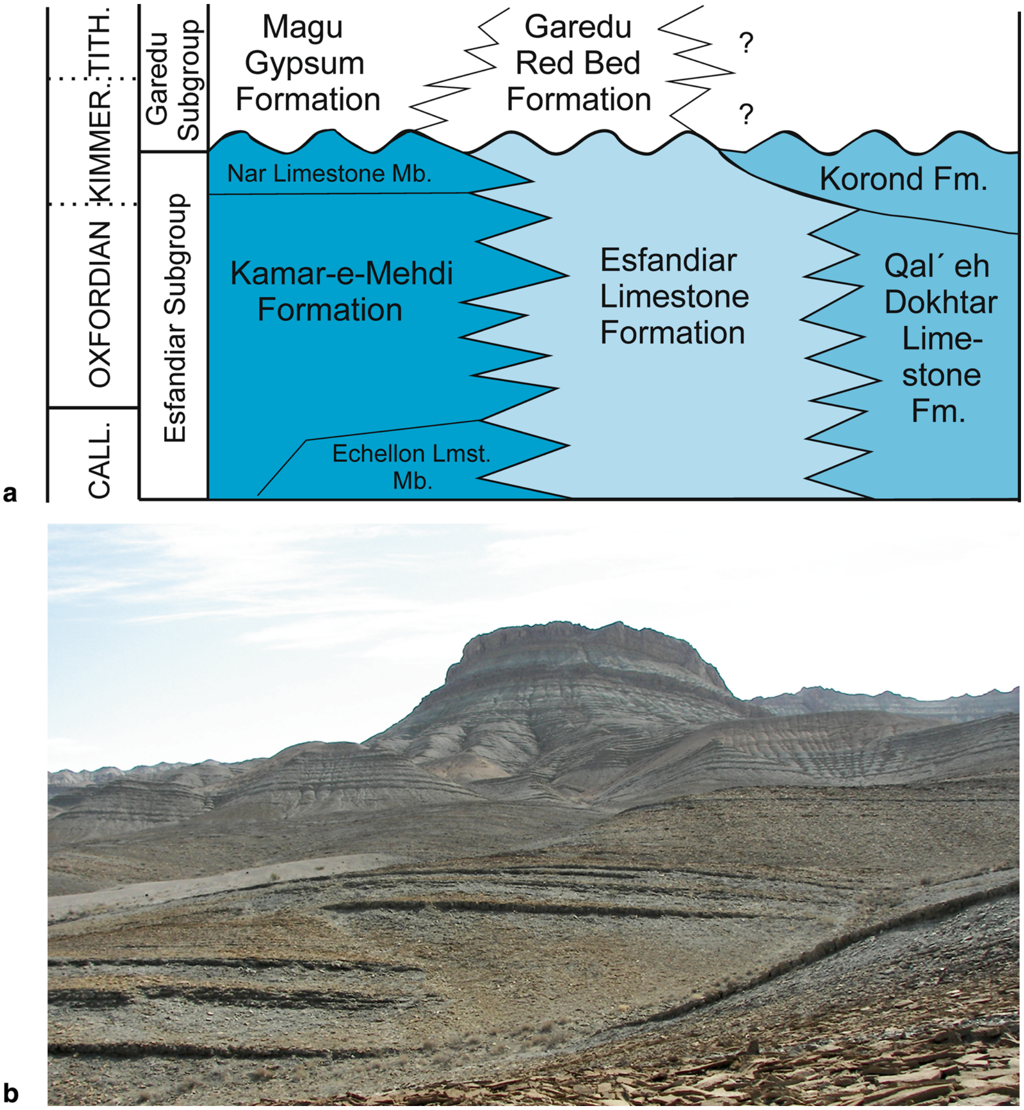


Fig. 2 **a** Stratigraphic framework of the Esfandiar Subgroup (*in blue*, modified from Wilmsen et al. 2003, 2010). **b** View across the Kamar-e-Mehdi Formation at the type area. The top of the hill is formed by the Nar Limestone Member

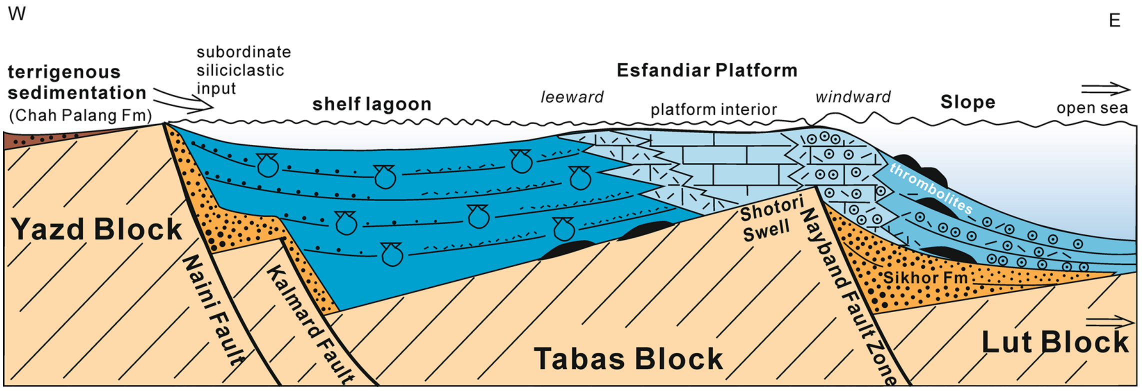


Fig. 3 West–east cross section through the carbonate system of the Esfandiar Subgroup (from Wilmsen et al. 2010). The Esfandiar carbonate platform originated on the crest of the tilted Tabas fault block. The shelf lagoon represented by the Kamar-e-Mehdi Formation extended between the platform and the raised Yazd Block in the west

Table 1 Localities of the Kamar-e-Mehdi Formation investigated

	Locality	Co-ordinates
1	N of Kalshaneh	N 34°07, E 56°49′
2	S of Kuh-e Bag-e Vang	N 33°56′54″, E 56°47′05″
3	Kuh-e Nakhlak	N 33°49′28″, E 56°36′34″
4	Kuh-e-Echellon area	N 33°47′, E 56°30′
5	SW of Tabas	N 33°21′, E 56°36′
6	Slopes 45 km SW of Tabas	N 33°19′, E 56°32′
7	Kamar-e Mehdi area	N 33°02′, E 56°26′
8	Kuh-e Dowshakh	N 33°08′32″, E 56°18′53″
9	Chorand Valley, W of Ravar	N 31°10′, E 56°53′
10	SE Tizi (Kuh Payeh)	N 30°25′31.6″, E 57°18′15.3″

laboratory. Of the hitherto virtually unknown macrofauna (only a few taxa had been described before from the unit by Cox 1936) the highly abundant bivalves, consisting of 70 taxa and accounting for nearly 90 % of all taxa, were recently monographed by Fürsich and Pan (2014) and the much rarer corals by Pandey and Fürsich (2003).

In order to understand the paleobiogeographic relationship of the bivalve fauna from the Kamar-e-Mehdi Formation, the occurrence of species elsewhere in the late Middle and early Late Jurassic was documented using the Jurassic bivalve catalogue housed in the GeoZentrum of Erlangen University. The following regions were considered: (1) Tabas Block (Iran), (2) western Europe, (3) Kachchh (India), and (4) Qiangtang Block (northern Tibet). In contrast to most paleobiogeographic analyses, which have been carried out at the generic level, the present analysis is based on species occurrences, this way allowing a higher resolution of the data.

Facies

Carbonate facies

As the microfacies has been discussed in detail by Wilmsen et al. (2010: Table 1), only a brief summary is given here. Segments characteristic of the Kamar-e-Mehdi Formation are shown in Fig. 4. Wilmsen et al. (2010) recognized 26 facies types. Of these, nine were characteristic of the Echellon Limestone Member at the base of the formation and signify somewhat deeper environments. They include microbialites, often developed as patch reefs, and oncoid float- and rudstones. In general, the member appears to characterize shelf environments below the storm wave-base.

In the Nar Limestone Member at the top of the formation, seven facies types have been recognized. All of them are fine-grained and consist mainly of mudstones (partly with gypsum/anhydrate needles) and peloidal wacke- to packstones (Wilmsen et al. 2010). The bulk of the remaining formation is composed of marl, marlstones, mudstones, bio-wackestones, and bio-floatstones, which may contain a certain admixture of silt. Gypsum beds and small-scale alternations of thinly bedded mudstones, gypsum, and dolostones are characteristic of the upper third of the formation in the type area. Most of these facies indicate low-energy conditions below the fair-weather wave-base but rare intercalations of grain- and rudstones containing components such as coral debris and ooids are related to brief high-energy events and a sediment source from the Esfandiar carbonate platform in the east. Numerous shell pavements and shell beds also indicate episodes of increased water energy (see below).

Siliciclastic facies

Repeated intercalations of thin sandstone beds, generally 2–15 cm, rarely up to 50 cm in thickness, are a characteristic feature of the formation in the central part of the Tabas Block, specifically in the type area (Fig. 4a). Invariably, these beds have a sharp erosional base, occasionally display flute casts, commonly are graded, and exhibit sedimentary structures such as parallel lamination (Fig. 5b), ripple lamination, and occasionally hummocky cross-stratification. Often, parallel-lamination in the lower part of a bed is replaced upwards by ripple-lamination and oscillation ripple surfaces, producing typical couplets, which record decreasing water energy during deposition of the bed. A rare phenomenon is parallel-crested megaripples with a wave length of 40–50 cm (Fig. 5a). Convolute bedding and ball-and-pillow-structures in sandstones are common in the lower part of the section (Fig. 5c). All these features point to rapid deposition of the sand by storm processes. As has been already argued by Wilmsen et al. (2010), the siliciclastic material must have been introduced from the emerged Yazd Block in the west and transported into the shelf lagoon possibly by storm-induced flows producing high-density currents. The erosional power of these currents is demonstrated by numerous shell fragments and complete shells that have been reworked from the carbonate mud and now form scattered pavements on top of the sandstone beds.

Clay and silt material in some carbonate beds also must have been derived from the Yazd Block but were transported in suspension. Coarser silt and fine sand was likely also transported by bed load processes and

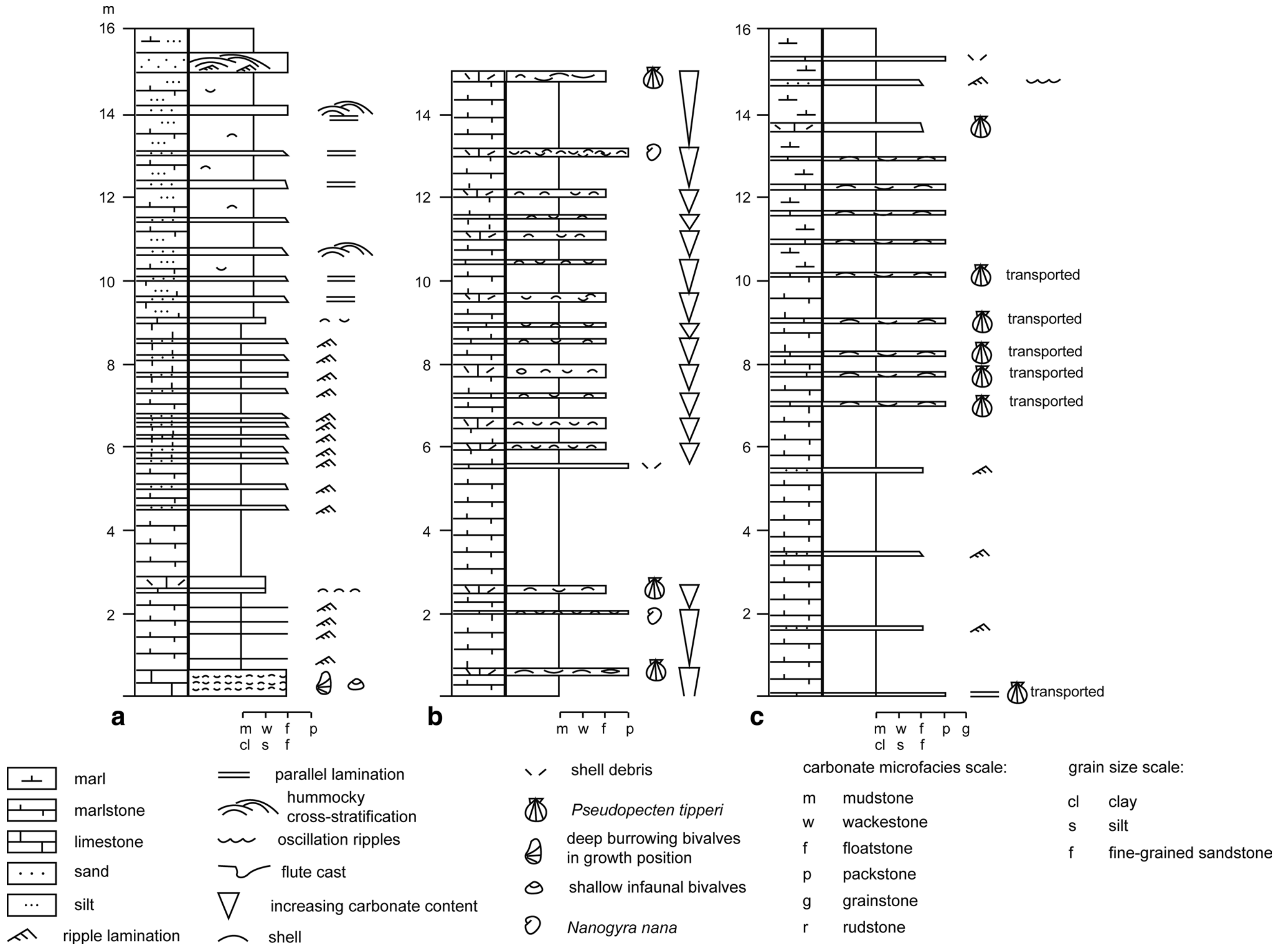


Fig. 4 Details of segments of the type section of the Kamar-e-Mehdi Formation depicting characteristic facies associations. **a** Background sedimentation of marlstone to silty marlstone punctuated by 5- to 20-cm-thick, commonly graded sandstone intercalations with sharp erosional base and cm-thick shell beds and shell pavements. Sedimentary structures include parallel and ripple lamination and hummocky cross-stratification (type section at 1243.5–1262 m; Wilmsen et al. 2010, fig. 6). **b** High-frequency cycles characterized by increasing carbonate content and shell concentrations with a floatstone matrix at the top (type section at 1129–1143.5 m). **c** Background sedimentation of marl and marlstone with thin intercalations of ripple- or parallel-laminated sandstone beds and shell concentrations with a packstone matrix. The shells consists mainly of large pectinid bivalves that exhibit signs of transport (type section at 1492.5–1508.5 m)

originally formed thin layers in the carbonate mud but subsequent pervasive bioturbation lead to complete mixing of the sediment. In an attempt to document the waning influence of siliciclastic sedimentation throughout the depositional history of the formation, the percentage of siltstones and sandstones has been calculated per 50 m of rock for the type section up to the base of the Nar Limestone Member (Fig. 6a). The percentage figures vary between close to zero and 15 % and exhibit a rough cyclic pattern. In the upper third of the section, hardly any sandstones are present. This is also illustrated in the second part of the diagram, in which the percentages of pure carbonates versus mixed carbonate-siliciclastics are depicted (Fig. 6b)

Benthic macrofauna

Faunal composition

The Kamar-e-Mehdi Formation contains a rich, moderately diverse macrofauna dominated by bivalves (recently monographed by Fürsich and Pan 2014), which in terms of taxa (70 species) account for about 70 % of the total fauna, in terms of individuals more than 90 %. Other faunal groups are gastropods (at least ten taxa, e.g., nerineids, *Globularia*), corals (15 species, mainly as reef components, rarely isolated; Pandey and Fürsich 2003), brachiopods (terebratulids and, less common, rhynchonellids, often as elements of patch reefs; Mukherjee and Fürsich 2014), calcisponges (as components

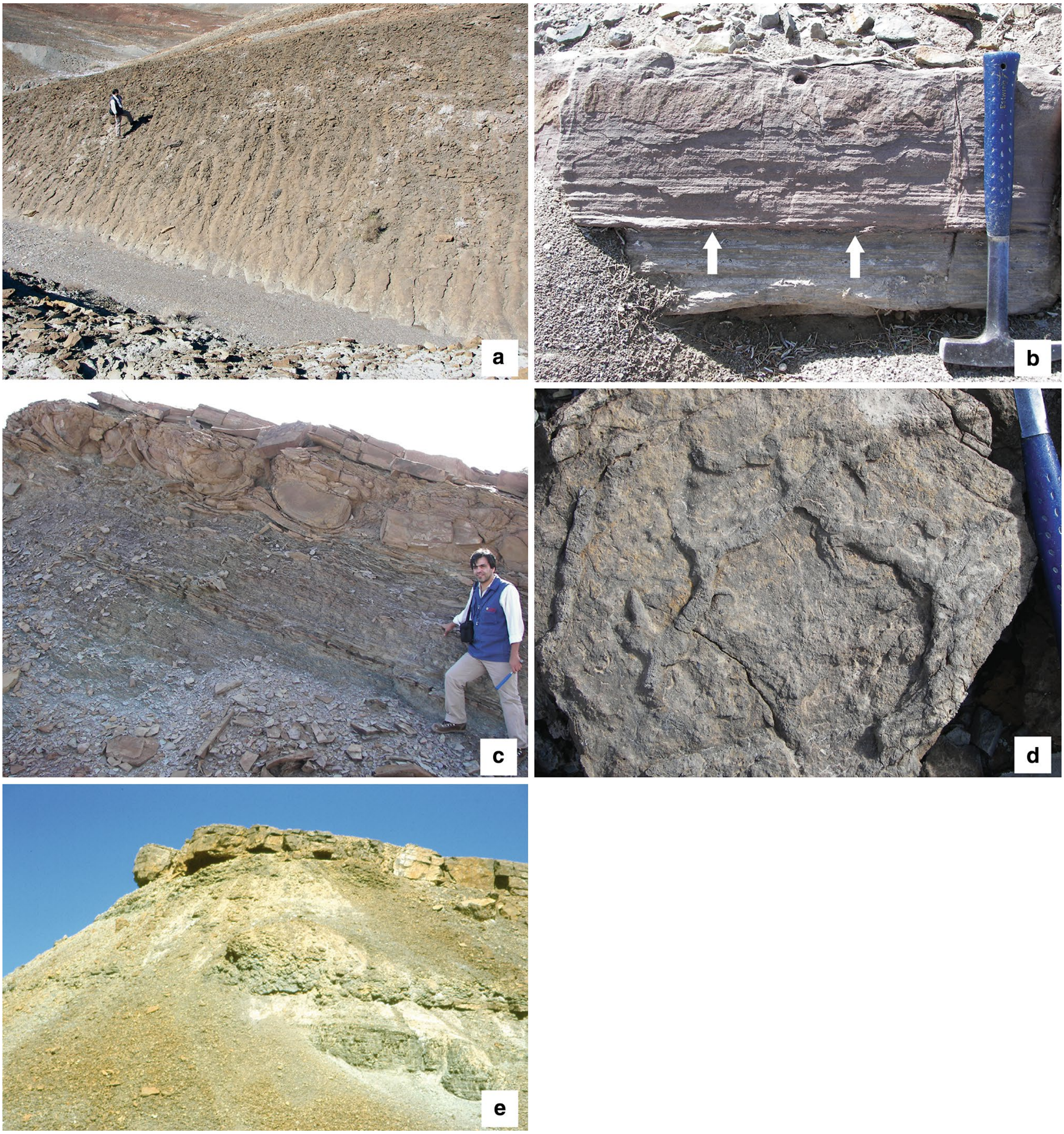


Fig. 5 Field photographs of the Kamar-e-Mehdi Formation, Kamar-e-Mehdi type area (**a**–**d**). **a** Parallel-crested megaripples in oograinstones, lower part of the formation. **b** Sharp-based sandstone (*arrowed*) consisting of a lower parallel-laminated part and an upper ripple-bedded part, both forming a tempestite couplet. **c** Basal calcareous sandstone with ball-and-pillow structures. **d** The trace fossil *Thalassinoides suevicus*. **e** Coral-microbialite patch reef within the Esfandiar Limestone Member, 45 km SW of Tabas

of patch reefs), serpulids, crinoids (rare), echinoids (rare), and *Tubiphytes*. The ichnofauna is greatly impoverished. Although much of the sediment appears to have been thoroughly bioturbated, only few discrete trace fossils have been recorded, usually tied to sandstones. They consist of small and large *Thalassinoides suevicus* (Fig. 5d), *Rhizocorallium irregulare*, *Chondrites* isp., and *Planolites* isp.

The most conspicuous elements of the bivalve fauna are two large epibyssate pectinid taxa, *Camptonectes* (*Grandinectes*) *teres* (Fig. 7a) and *Pseudopecten tipperi* (Figs. 7g, 8),

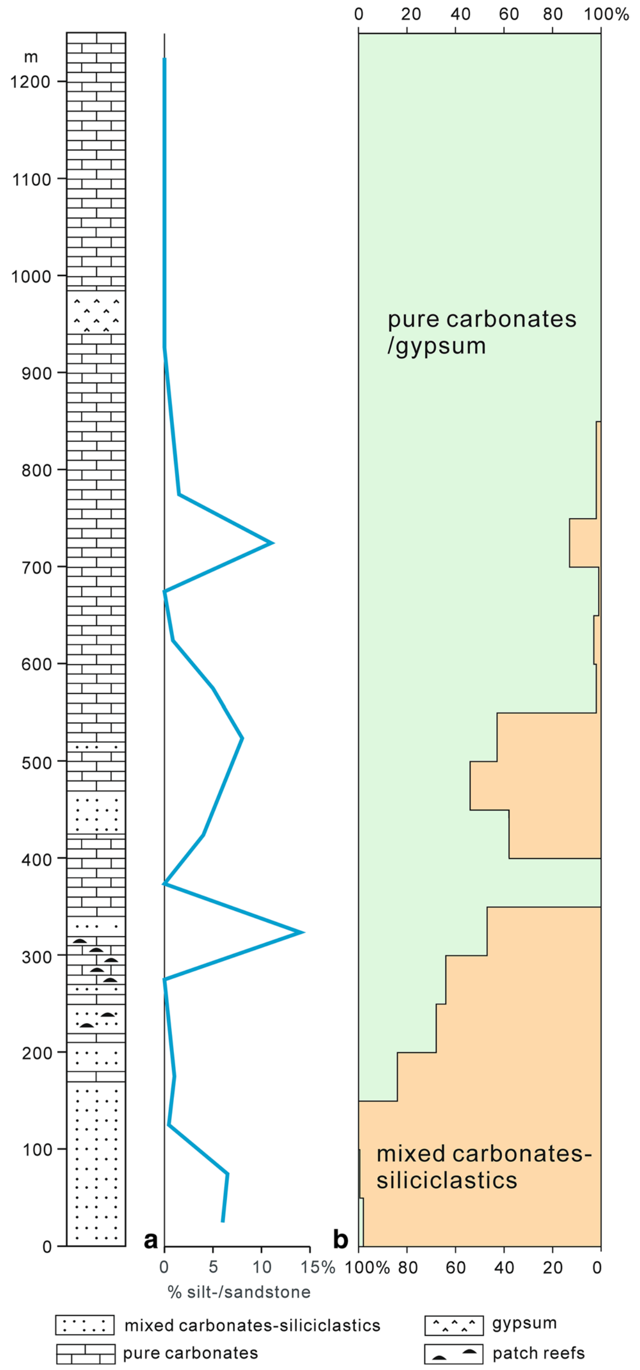


Fig. 6 Schematic section through the Kamar-e-Mehdi Formation (type section). Note the decreasing influence of siliciclastic (silt, sand) material up-section (**a**) and the decrease of mixed carbonates-siliciclastic sediments in the same direction (**b**). Note the large-scale rhythmic alternations of carbonates and mixed carbonates–siliciclastic sediments

which form persistent, diagnostic elements of the formation. Both species occur scattered and concentrated in pavements and shell beds and gave the formation its original informal name, "Pectinidenkalk" (=Pecten Limestone, Huckriede et al. 1962; Aghanabati 1977). Other common bivalves are the epibyssate *Eligmus*, *Plagiostoma*, and *Grammatodon,* the endobyssate *Arcomytilus* and *Gervillella,* the cementing oysters *Actinostreon* and *Nanogyra*, the shallow-burrowing *Corbulomima*, *Protocardia,* and *Nicaniella*, and the deep-burrowing *Ceratomya* and *Homomya* (Fig. 7).

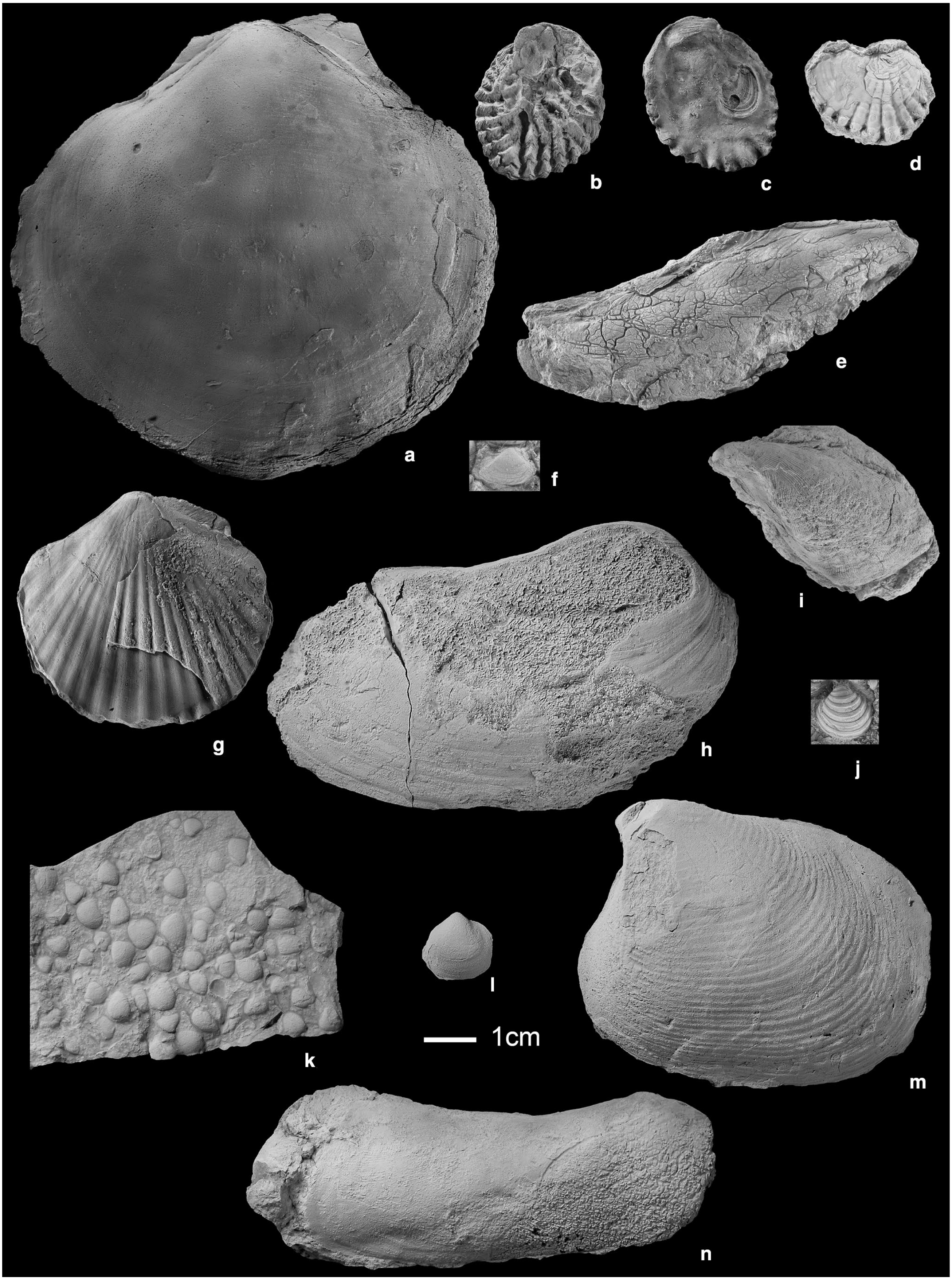
Fig. 7 Characteristic elements of the benthic macrofauna of the ▶ Kamar-e-Mehdi Formation (all bivalves). **a** *Camptonectes* (*Grandinectes*) *teres* Fürsich and Pan, 2014. **b**, **c** *A. gregareum* (J. Sowerby, 1815). **d** *E. rollandi* Douvillé, 1907. **e** *Gervillella lanceolata* (Münster, 1833). **f** *Grammatodon* (*Grammatodon*) sp. **g** *Pseudopecten* (*Pseudopecten*) *tipperi* (Cox, 1936). **h** *Homomya vezelayi* (d'Archiac, 1843). **i** *Arcomytilus laitmairensis* (de Loriol, 1883). **j** *Nicaniella* (*Nicaniella*) *extensa* (Phillips, 1829). **k** Pavement of *Corbulomima* cf. *obscura* (J. de C. Sowerby, 1827). **l** *Protocardia* (*Protocardia*) *striatula* (J. de C. Sowerby, 1829). **m** *Ceratomya concentrica* (J. de C. Sowerby, 1825). **n** *Agrawalimya tubularis* Fürsich and Pan, 2014

Level bottom assemblages (Table 2)

Only a few quantitative samples are available, but based on field observations it is possible to distinguish different assemblages, some of which are autochthonous, more or less undisturbed relicts of former communities, others are winnowed relicts, and yet others underwent limited transport and suffered differing degrees of sorting. However, even though undergoing some transport, nearly all these faunas are at least parautochthonous, that is they stayed within their environment. In contrast, there are some rare assemblages, usually occurring in cross-bedded bio-oo-grainstones or -packstones that have been introduced into the shelf lagoon from neighboring environments (e.g., the Esfandiar carbonate platform situated in the east) and are clearly allochthonous. The assemblages indicate that the benthic communities populating the shelf lagoon were not as uniform as the comparatively uniform succession of facies may suggest. In the following text, these assemblages are briefly described and evaluated with respect to their ecology and their degree of autochthony and distortion.

Eligmus rollandi assemblage

The malleid bivalve *Eligmus* (Fig. 7d) is a characteristic faunal element of the tropical belt during the Middle Jurassic. In Iran, it occurs only in the Echellon Limestone Member, where it forms several shell beds, accounting for more than 90 % of the individuals. Additional taxa are *Radulopecten*, *Chlamys textoria*, *P. tipperi*, *Costigervillia crassicosta*, calcisponges, echinoid spines, and bryozoans. The species diversity is low. Many *Eligmus* are articulated and despite a relatively high packing density, there is no evidence of current or wave activity that might have concentrated the shells. The marlstone matrix also points to low-energy conditions. The assemblage occurs in several beds across a vertical distance of 12 m at the top of the Echellon Limestone Member


a
b
c
d
e
f
g
h
i
j
k
l
1cm
m
n

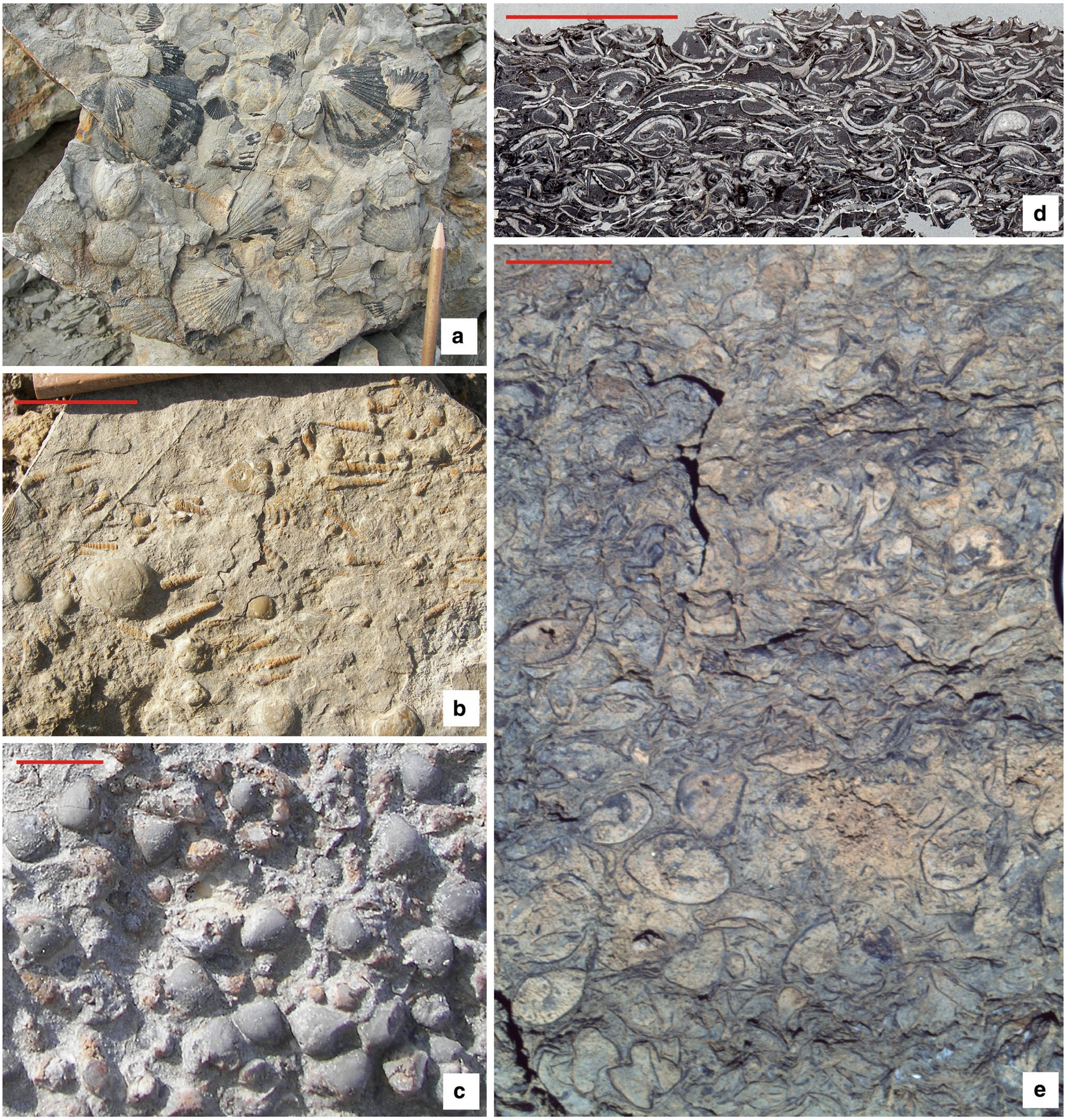


Fig. 8 **a** Shell pavement dominated by *P. tipperi*. The bivalves are overwhelmingly convex-up oriented documenting the influence of currents. Diameter of *pen* 8 mm. **b** Thin sandstone slab with scattered turriform gastropods exhibiting a preferred plan-view orientation. *Scale* 2 cm. **c** Pavement of disarticulated convex-up oriented *Corbulomima* valves. *Scale* 1 cm. **d** Cross section through a densely packed shell bed composed of small disarticulated bivalves. Note sheltered porosities and occasional nesting. At the top, most shells are concave-up oriented, which suggests settling out of suspension. Thin-section, *scale* 1 cm. **e** Segment of the cross section through a 1.5-m-thick monospecific shell bed composed of the brachiopod *Dorsoplicathyris dorsoplicata*. The more densely packed horizons indicate phases of more pronounced reworking. Overall, the shell bed is thought to have accumulated in situ and suffered only minor disturbance by physical processes and bioturbation. Field photograph, *scale* 2 cm. **a**–**d** Kamar-e-Mehdi area; **e** syncline N of Kalshaneh (loc. 1), 38.5 m above base of the Echellon Limestone Member

Table 2 Level-bottom assemblages in the Kamar-e-Mehdi Formation

Assemblage	Main taxa	Main features
Eligmus	*Eligmus rollandi*	Monospecific; % articulation high, microbial crusts abundant; autochthonous
Actinostreon	*Actinostreon gregareum*	Paucispecific; autochthonous
Softground	*Nicaniella extensa*, *Corbulomima* cf. *obscura*, *Protocardia striatula*, *Isocyprina cyreniformis*, *Mesosaccella morrisii*	Moderately diverse; small taxa dominant
Nicaniella	*Nicaniella extensa*, small gastropods	Paucispecific; small taxa dominant
Protocardia	*Protocardia striatula*	Paucispecific; dominated by small, shallow-infaunal bivalves; winnowed
Arcomytilus–Ceratomya–Homomya	*Arcomytilus laitmairensis, Ceratomya concentrica*, *Homoya vezelayi*	Diverse, percentage of articulation high; autochthonous
Grandinectes	*Camptonectes* (*Grandinectes*) *teres*	Mono- to paucispecific, some specimens articulated
Pseudopecten	*Pseudopecten tipperi*	Mono- to paucispecific, some specimens articulated
gastropod	High-spired gastropods	Paucispecific, unimodal plan-view orientation
Terebratulid	*Dorsoplicathyris*	1.5-m-thick shell bed; high percentage of articulated shells; monospecific
Rhynchonellid	Rhynchonellid brachiopod	Up to 1-m-thick shell beds; monospecific; most shells disarticulated
Moderately diverse brachiopod	Rhynchonellids, *Actinostreon*, *Chlamys*, *Acesta*	Moderately diverse

near Kuh-e-Echellon (Wilmsen et al. 2010, fig. 5). It is interpreted as an in situ biogenic concentration sensu Fürsich and Oschmann (1993), produced by prolific growth of the epibyssate bivalve, most likely initiated by large larval swarms and optimal conditions for growth. A first generation colonizing the lagoonal floor must have found sufficient hard substrates such as skeletal fragments for anchorage. Subsequent generations could have settled on top of earlier ones.

Actinostreon gregareum assemblage

The oyster *Actinostreon* (Fig. 7b, c) forms several-cm-thick near-monospecific patches and beds (thin biostromes) with individuals commonly encrusting shells of the same species. The assemblage is clearly autochthonous. The species diversity is moderate (up to 18 species) except in biostromes where it is low. The latter might be due to the sea floor being more or less completely covered of by the oyster, which prevented infaunal organisms from entering the substrate. The oyster rarely also forms larger patch reefs (see below).

Softground assemblage

The softground assemblage is dominated by small, shallow-infaunal bivalves, especially *Protocardia striatula* (Fig. 7l) and *Nicaniella extensa* (Fig. 7j), but also *Corbulomima* cf. *obscura*, *Isocyprina* cf. *cyreniformis*, and the rare nuculid bivalve *Mesosaccella morrisii* may be present. Other characteristic species, although much rarer, are the endobyssate *Gervillella aviculoides*, *Modiolus imbricatus*, and *Grammatodon* sp. In a few samples, gastropods constitute a considerable part (up to 10 %) of the fauna. Cementing or byssate epifauna is rare, as are large deep-burrowing bivalves such as *Ceratomya*. Species diversity is low to moderate. The individuals occur scattered in the sediment (usually marlstone or mud- to wackestone) or may form loosely packed concentrations. Although winnowing may have concentrated shells to some extent, there is little evidence of transport or sorting, and the softground assemblage appears to represent the autochthonous relict of a former community.

Nicaniella extensa assemblage

The small bivalve *N. extensa* (Fig. 7j) strongly dominates some thin (up to 5-cm-thick) shell concentrations where it co-occurs with small gastropods and occasionally other small, shallow-burrowing bivalves. The shells are disarticulated, convex-up oriented, and clearly record small-scale in situ reworking, winnowing by gentle currents, and possibly some short transport. The assemblage is interpreted as the mechanically sorted relict of the softground association described above.

Protocardia striatula assemblage

The low-diversity assemblage is dominated by shallow-infaunal bivalves, mainly *Protocardia striatula*, while

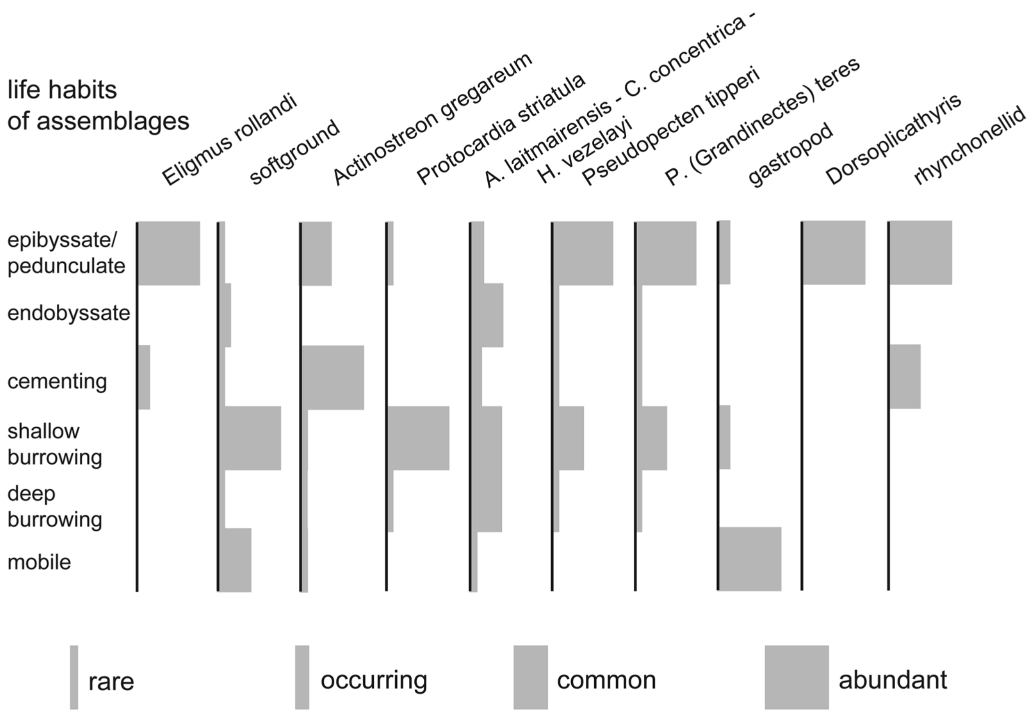


Fig. 9 Life habits of assemblages

deep-burrowing and epibyssate bivalves (e.g., *P. tipperi*) are rare. The assemblage occurs as pavements in thin-bedded mudstones. It is the autochthonous to parautochthonous winnowed relict of a former community.

Arcomytilus laitmairensis/Ceratomya concentrica/Homomya vezelayi assemblage

This assemblage is characterized by the name-giving taxa and occurs in high density in wackestone. The diversity is high (up to 28 taxa). It is dominated by endobyssate bivalves, but a wide variety of life habits are present (Fig. 9). A high percentage of the bivalves are articulated, even epifaunal taxa, many of which are encrusted by the small oyster *Nanogyra*. Most taphonomic data suggest a concentration undisturbed by waves or currents during a phase of slow sedimentation. This is, however, contradicted by the common articulated epifaunal bivalves which indicate that the final burial was a short event and affected organisms that were still alive.

The assemblage occurs also in biopackstone where it is clearly winnowed, forming a pavement of disarticulated, convex-up-oriented valves.

Pseudopecten tipperi/Camptonectes (Grandinectes) teres assemblages

The large pectinid bivalves *P. tipperi* and *Camptonectes* (*Grandinectes*) *teres* (Figs. 7a, g, 8a) dominate assemblages of low to moderate diversity, whereby either one of the taxa or both are present. Apart from these epibyssate suspension-feeding taxa, shallow infaunal suspension-feeders are common, the other life habits being rare (Fig. 9). The assemblages represent a wide variety of preservational modes, ranging from moderately diverse autochthonous relicts of former communities with predominantly articulated individuals in wackestones to allochthonous, sorted assemblages, which form pavements in sandstones that exhibit flute and groove casts at their base and thus underline currents as concentrating agents.

Gastropod assemblage

A small, high–spired gastropod forms pavements in mudstones, in which the individuals exhibit a distinct unimodal plane-view orientation (Fig. 8b). The gastropods co-occur with small disarticulated bivalves (*Protocardia*, *Gervillella*, and *Pteria*). Most likely the assemblage is the current-winnowed, sorted, parautochthonous relict of a former community dominated by mobile grazing epifaunal gastropods.

Brachiopod assemblages

Brachiopod assemblages occur as autochthonous monospecific concentrations of terebratulids or rhynchonellids in the Echellon Limestone Member. North of Kalshaneh, the terebratulid *Dorsoplicathyris dorsoplicata* forms a

Table 3 Patch reefs occurring in the Kamar-e-Mehdi Formation

Frame builders	Associated organisms	Diameter (m)	Height (m)	Stratigr. position
Actinostreon gregareum	*Grandinectes teres*, *Plagiostoma* sp.	5	0.5–1	Kam.-e-M.
Nanogyra nana	Monospecific	>5	0.1–0.2	Kamar-e-Mehdi Fm.
Nanogyra nana	Calcisponges, *Trichites* sp., *Camptonectes subulatus*	2–3	0.8	Kamar-e-Mehdi Fm.
Calcisponges-*Nanogyra nana*	Crinoid debris, *Trichites* sp.	1.5	0.5	Kam.-e-M.
Corals	Gastropods, bryozoans	0.3	0.3	Kam.-e-M.
Neuropora-corals	*Actinostreon gregareum*, microbial crusts, borers	3	1.5	Kamar-e-Mehdi Fm.
Microbialite-corals	*Ctenostreon* sp., *Nanogyra nana*, *Actinostreon gregareum*, *Trichites* sp.	1.5–2	0.5–0.6	Kamar-e-Mehdi Fm.
Microbialite-calcisponges	*Neuropora,* regular echinoids, *Tubiphytes* sp., *Spondylopecten* sp., *Radulopecten inequicostatus*, serpulid clusters, terebratulids	>10	6	Echellon Lmst. Mb.
Microbialite-calcisponges	Terebratulids	2–4	1.5–3	Echellon Lmst. Mb.
Corals	*Trichites* sp., microbial crusts, calcisponges, A*ctinostreon gregareum*	6	5	Echellon Lmst. Mb.
Corals	*Trichites* sp., microbial crusts, borings (*Gastrochaenolites*, *Entobia*)	>40	10–12	Echellon Lmst. Mb.
Corals	*Tubiphytes* sp., microbial crusts	2–3	1.3	Echellon Lmst. Mb.
Corals	Serpulids, borings (*Gastrochaenolites*, *Entobia*)	6	2.5	Echellon Lmst. Mb.

loosely to densely packed, 1.5-m-thick concentration composed of articulated and single valves that apparently accumulated in situ during a phase of reduced sedimentation (Fig. 8e). Another monospecific terebratulid concentration, composed of articulated and disarticulated shells in a rudstone matrix, occurs at Kuh-e-Bagh-e-Vang, at the eastern margin of the shelf lagoon. The 0.6-m-thick shell bed is lenticular and the shells clearly are reworked and underwent some transport. In a stratigraphically lower position of the same section, rhynchonellids form a 1-m-thick monospecific assemblage of varying packing density embedded in a bio-rudstone matrix. As most shells are disarticulated, the shells suffered some transport, most likely from marginal areas of the carbonate platform.

Brachiopods also form moderately diverse assemblages co-occurring with rare corals and the bivalves *Actinostreon*, *Chlamys*, and *Acesta*. These assemblages occur in cross-bedded oo-bio-packstone and most likely have been derived from the margin of the shelf lagoon. The dominant guild is a suspension-feeding, pedicle-attached or byssally attached mode of life.

Patch reefs (Table 3)

Patch reefs and biostromes are a common feature in the Echellon Limestone Member at the base of the formation but are rare in the remaining part of the succession where they are concentrated in the lower third in a segment of the section in the Kamar-e-Mehdi area with only few sandstone intercalations.

In the Echellon Limestone Member, the reefs reach a length of >40 m and a height of 6–8 m southwest of Tabas where they are composed largely of corals (Fig. 5e; Wilmsen et al. 2010, fig. 4h). The primary framework organisms are covered by a microbial crust and bored by a variety of organisms. Smaller patch reefs and biostromes consist mainly of microbialites usually associated with *Tubiphytes*, occasionally also with calcareous sponges. The reef-dwelling fauna is dominated by bivalves (*Plagiostoma*, pectinids, oysters, *Trichites*) and some terebratulids.

In more central areas of the shelf lagoon the reef structures are smaller (diameter 3–5 m, height 0.5–1.5 m). They are composed of either (1) branching corals, microbial organisms, and the sponge *Neuropora*, associated with the bivalves *Actinostreon*, *Ctenostreon*, *Nanogyra*, and *Trichites*, (2) *A. gregareum*, associated with the byssate bivalves *Plagiostoma* and *Grandinectes*, (3) *Nanogyra nana* (Fig. 10b), and (4) sponges, associated with *Nanogyra*, *Trichites* and crinoid debris.

Faunal distribution through time

The benthic macrofauna shows certain temporal trends. Where the Echellon Limestone Member is present, which invariably is at the base of the formation, the species diversity of the macrofauna is relatively high as is the number of guilds. Reefs, dominated by corals and microbial crusts, are locally widespread. They suggest more or less fully marine environments, even though their diversity is only moderate. In contrast, the upper part of the formation, in particular the Nar Limestone Member, are largely devoid of

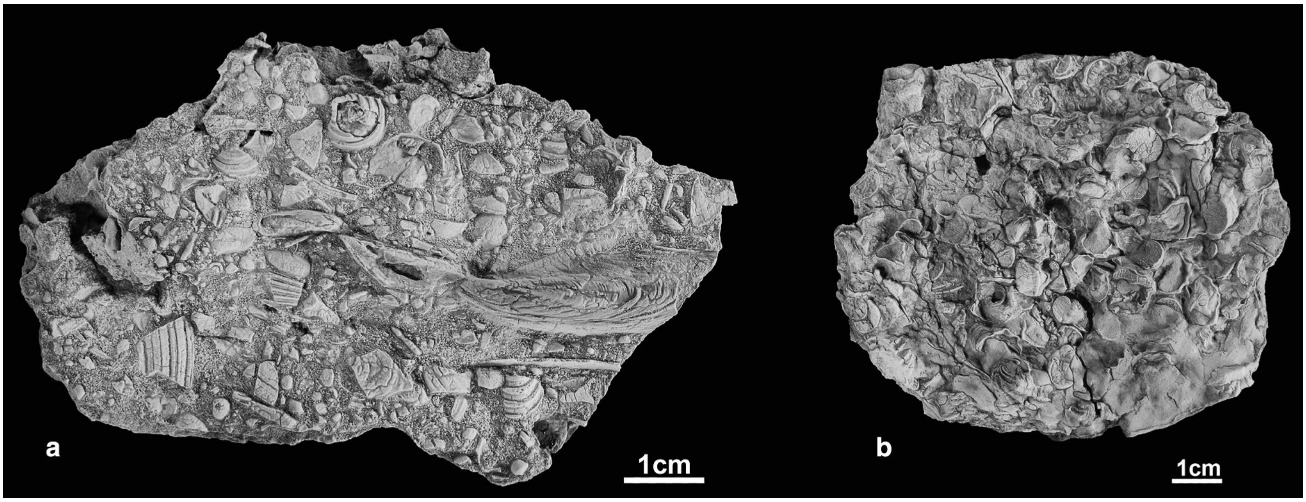


Fig. 10 Shell concentrations from the Kamar-e-Mehdi area. **a** Surface of thin sandstone slab with pavement of heavily fragmented bivalves indicating extensive reworking and transport. **b** Fragment of a small patch reef composed of the small oyster *Nanogyra nana*

any macrofauna, and where a benthic fauna is present it is of very low diversity.

The diagnostic taxa of the formation, large pectinid bivalves, also exhibit a characteristic distribution pattern: *P. tipperi* dominates the lower and upper part of the formation, whilst in the middle part *Camptonectes* (*Grandinectes*) *teres* prevails. Both species also co-occur in the same bed and apparently were able to live side by side. Their ecological requirements appears to have been very similar, both being suspension-feeding epibyssate recliners. The dominance of one of the two taxa may be related to slightly different physiological requirements such as adaptations to slightly different salinity values or water temperatures.

Shell concentrations (Table 4)

Biogenic hard parts occur in the Kamar-e-Mehdi Formation either dispersed or concentrated in shell beds and pavements. The shell-producing organisms all lived within the basin and generally suffered only a short-distance transport, an exception being those assemblages which occur in packstones and were swept off the leeward margin of the Esfandiar Platform in the east.

Autochthonous faunas are usually scattered but may also form concentrations. They are either biogenic in origin, being caused by optimal growth conditions and a gregarious settling behavior, often in combination with reduced sediment input (e.g., *Eligmus* shell beds, *Actinostreon* shell beds; *Dorsoplicathyris* concentration; Table 4). They are characterized by varying percentages of articulated shells, lack of a preferred plane- or side-view orientation pattern, very few fragmented shells, and by a micritic matrix.

Parautochthonous concentrations generally suffered winnowing by gentle currents or waves but did not undergo significant transport. They may, however, have become sorted [e.g., pavements of the large pectinids *Camptonectes* (*Grandinectes*) *teres* and *P. tipperi* (Fig. 8a), pavements of *Nicaniella* or *Corbulomima* (Fig. 8c); Table 4]. The diversity is generally low. Nearly all shells are disarticulated and fragmented shells are common. Turriform gastropods commonly exhibit a preferred orientation in plane-view (Fig. 8b), and shells of bivalves invariably are found in a convex-up orientation. Some of these shell beds are densely packed. In the example illustrated in Fig. 8d the convex-up oriented shells occasionally display sheltered porosities and are more common in the lower part of the bed, whereas at the top most shells are in a convex-down position and commonly exhibit nesting. This suggests that they settled out of suspension. The biofabric of this about 1.5-cm-thick shell bed thus points to storm waves which scoured the lagoonal floor and brought the sediment into suspension. While the finer sediment particles took a longer time to settle, shells became concentrated and were initially still affected by wave motion (hence common convex-up orientations in the lower part) before the last shells settled in a preferred convex-down position.

Allochthonous concentrations, despite having suffered more substantial transport, nearly exclusively have been reworked from within the shelf lagoon as can be judged from the taxa involved. These allochthonous concentrations occur as loosely packed pavements on top of thin sandstone beds, which are characterized by flute casts on their lower surfaces and parallel lamination followed by ripple lamination towards the top. In some cases, hummocky cross-stratification can be seen. All shells are disarticulated,

Table 4 Shell concentrations occurring in the Kamar-e-Mehdi Formation

Dominant taxa	Geometry	Matrix	Diversity	Degree of autochthony	Main concentrating agent	Position within cycles
Corbulomima	Pavement	Mudstone	Monospecific	Parautochthonous	Winnowing/sorting	Middle
Nicaniella	Pavement	Mudstone/wackestone	Paucispecific	Parautochthonous	Winnowing/sorting	Middle
Nicaniella	Pavement	Sandstone	Paucispecific	Allochthonous	Currents	Middle
Protocardia	Pavement	Mudstone	Paucispecific	Autochthonous/parautochthonous	Winnowing	Middle
Shallow-burrowing bivalves	Bed/dispersed	Mudstone/wackestone	Paucispecific	Autochthonous/parautochthonous	Winnowing	Middle–top
Turriform gastropods	pavement	Wackestone	Paucispecific	Parautochthonous	Currents	Top
Large pectinid bivalves	Bed/pavement	Wackestone	Paucispecific	Autochthonous/parautochthonous	Winnowing/sorting	Middle–top
Large pectinid bivalves	Pavement	Sandstone	Paucispecific	Allochthonous	Currents	Middle
Nanogyra	Bed	Wackestone	Monospecific	Parautochthonous	Currents	Middle
Actinostreon	Bed/cluster	Wackestone	Mono-/paucispecific	Autochthonous	Low sedimentation rate/high productivity	Top
Arcomytilus	Bed	Mudstone/wackestone	Polyspecific	Autochthonous	Low sedimentation rate/high productivity	Top
Eligmus	Bed	Mudstone/wackestone	Paucispecific	Autochthonous	High productivity	–
Dorsoplicathyris	Bed	Wackestone	Monospecific	Autochthonous	High productivity	–
Rhynchonellid	Bed	Rudstone	Monospecific	Allochthonous	Currents	–
Brachiopods	Pavement	Packstone	Paucispecific	Allochthonous	Currents	Middle
Mixed bivalves	Pavement	Sandstone	Paucispecific	Allochthonous	Currents	Middle

commonly fragmented, and consist of a mixture of infaunal and epifaunal elements (Fig. 10a). They were reworked by fairly strong currents with a high load of sand grains. The latter were initially carried in suspension but with waning flow velocities were transported as bed load. As noted already by Wilmsen et al. (2010), the source of the sand material was the uplifted Yazd Block in the west and the siliciclastic material has been stirred up by storms and subsequently transported into the shelf lagoon.

Also allochthonous, but experiencing more limited transport, are the monospecific rhynchonellid concentrations occurring in the area transitional between the Esfandiar carbonate platform and the shelf lagoon. In contrast to the autochthonous *Dorsoplicathyris* concentration, the shells occur in a rudstone matrix, are commonly disarticulated, and exhibit nesting.

Bivalve paleobiogeography

Little is known about the paleobiogeographic relationship of the bivalve fauna from the Kamar-e-Mehdi Formation. The following is a preliminary analysis to clarify the relationship of the Iranian fauna with that of Europe, northern Tibet and western India (Kachchh), the latter situated at the southern margin of the Tethyan Ocean. The approach differs from that of the multidimensional scaling-based analysis of Kiessling et al. (2011) who investigated several macroinvertebrate groups, including bivalves, at the generic level from a similar stratigraphic interval (Callovian–Kimmeridgian). We are aware that paleobiogeographic similarities may be influenced by variations in sample size between regions. Moreover, the restriction of our analysis to bivalves that occur in the Kamar-e-Mehdi Formation and the fact that they all come from carbonate-dominated facies additionally limits the significance of our findings. Still, the following analysis, carried out at the species level, helps to understand the biogeographic relationship of the Kamar-e-Mehdi bivalves during the later part of the Jurassic.

Most (91 %) of the 70 taxa of bivalves reported (Fürsich and Pan 2014) are also known from central and western Europe, whereas only 34 % are shared with northern Tibet and 43 % with Kachchh, western India (Fig. 11; Table 5). The data from northern Tibet are from the Qiangtang Block, which had become part of South China by the

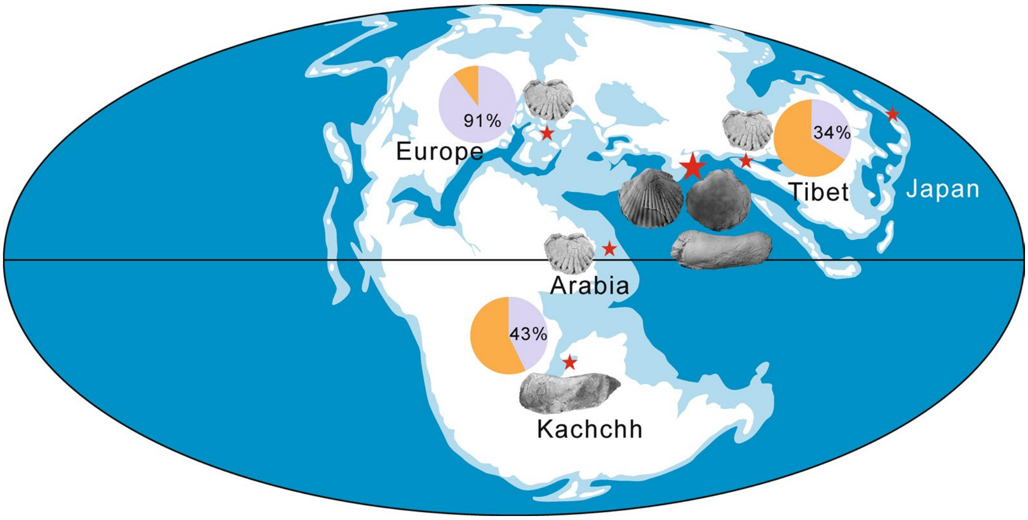


Fig. 11 Jurassic paleogeography and biogeographic relationship of the benthic macrofauna of the Kamar-e-Mehdi Formation with that of Europe, Kachchh (western India), and Tibet. Shown is also the distribution of the bivalves *Eligmus*, *Agrawalimya*, *Grandinectes*, and *P. tipperi*. The latter two are highly characteristic elements of the shelf lagoon, whereas the former two are typical elements of the southern margin of the Tethys (*Agrawalimya*) or have largely a tropical distribution (*Eligmus*). Arabia is shown in the figure because together with Jordan and the Sinai Peninsula it is the center of the distribution of *Eligmus*. Palaeogeography after Blakey (2011)

late Triassic (e.g., Li et al. 2003, 2009), whereas the Lhasa Block, situated further south, collided with the Qiangtang Block not before the end of the Jurassic–early Cretaceous (e.g., Yin and Harrison 2000; Guynn et al. 2006). As during the time interval under discussion the bivalve fauna of the Lhasa block still might have carried a signature of its previous position further south, data from this block have not been considered in the analysis.

Two species are endemic to east-central Iran: *Camptonectes* (*Grandinectes*) *teres* and *Agrawalimya tubularis*. The latter is very rare, whereas the former is abundant and, together with *P. tipperi*, constitutes the most characteristic element of the benthic fauna of the shelf lagoon. Apart from its occurrence in the lagoon, *P. tipperi* has also been recorded from Middle Jurassic strata of the northern Tibet Plateau (Wen 1979; Sha et al. 1998).

The rare anomalodesmatan *Neoburmesia iwakiensis* was until now only known from Japan. This deep-burrowing bivalve also occurs in the slightly younger (Kimmeridgian) Korond Formation of the easternmost Tabas Block (pers. observ.).

The byssate *Eligmus rollandi* is a typical element of Middle Jurassic tropical carbonate environments and has been regarded as a characteristic member of the Ethiopian Faunal Province (e.g., Hallam 1977; Heinze 1996). Its main distribution is along the southern margin of the Tethys including the Malagasy Gulf (Madagascar, Kachchh), but apart from its presence in France it has been also recorded from the Bathonian–Callovian Tuotuohe Formation of the Tanggula Mountains, northern Tibet Plateau (Yin and Fürsich 1991) and from the Namyau Group of Myanmar (Reed 1936), although the latter occurrence has not been substantiated. The restriction of the species to the base of the Echellon Limestone Member in the Kuh-e-Echellon area, where it occurs profusely, suggests successful colonization by a large larval swarm but failure to establish itself as a regular member of the benthic communities that populated the shelf lagoon.

The second south Tethyan element, the genus *Agrawalimya*, has so far been known only from Bathonian to Lower Callovian strata of the Kachchh Basin, where it is represented by two rare species (Pandey et al. 1996). The shallow burrower *Pterocardia buvignieri*, a characteristic member of the Submediterranean Province, is a rare component of the benthic fauna of the shelf lagoon. All other taxa are known from the epicontinental seas of Europe.

Cycles

Large parts of the Kamar-e-Mehdi Formation are composed of small-scale, commonly 2 to 4-m-thick cycles (Fig. 12a–c). A characteristic cycle is schematically depicted in Fig. 13. The cycles are strongly asymmetric and are characterized by an increase in carbonate content. The lower part consists of silty marl with occasional intercalations of thin, parallel-laminated and/or ripple-laminated sandstone beds. The tops of these sandstones occasionally exhibit shell pavements or scattered shells in convex-up orientation. Benthic macrofauna occurs scattered and in

Table 5 Paleobiogeographic distribution of bivalves from the Kamar-e-Mehdi Formation in selected areas (Western Europe, northern Tibet, and western India)

Bivalve taxa from the Kamar-e-Mehdi Formation	Europe	Northern Tibet	Kachchh
Mesosaccella morrisi	▨	▨	
Modiolus (*Modiolus*) *imbricatus*	▨	▨	▨
Arcomytilus laitmairensis	▨		▨
Inoperna perplicata	▨		
Pteria plana	▨	▨	
Bakevellia (*Bakevellia*) *waltoni*	▨	▨	▨
Costigervillia crassicosta	▨	▨	▨
Gervillella lanceolata	▨		▨
Isogonomon (*Rostroperna*) *thurmanni*	▨		▨
Eligmus rollandi	▨	▨	▨
Pinna lanceolata	▨		
Acesta (*Acesta*) *spectabilis*	▨		
Acesta (*Acesta*) *subantiquata*	▨		
Plagiostoma laeviusculum	▨		
Plagiostoma hersilia	▨		
Plagiostoma aff. *mutabile*	▨		
Plagiostoma aciculata	▨	▨	
Limea (*Pseudolimea*) *duplicata*	▨		
Liostrea sandalina	▨		▨
Nanogyra nana	▨		▨
Actinostreon gregareum	▨	▨	▨
Actinostreon erucum			▨
Camptonectes (*Camptonectes*) *laminatus*	▨	▨	▨
Camptonectes (*Camptonectes*) *virdunensis*	▨		▨
Camptonectes (*Camptonectes*) *subulatus*	▨	▨	
Camptonectes (*Grandinectes*) *teres* sp. nov.			
Camptonectes (*Camptochlamys*) *clathratus*	▨	▨	
Chlamys (*Chlamys*) *textoria*	▨	▨	▨
Eopecten velatus	▨		▨
Pseudopecten (*Pseudopecten*) *tipperi*		▨	
Radulopecten inequicostatus	▨		
Radulopecten fibrosus	▨	▨	
Radulopecten strictus	▨		
Spondylopecten (*Plesiopecten*) *subspinosus*	▨		▨
Trigonia (*Trigonia*) cf. *reticulata*	▨		
Corbulomima cf. *obscura*	▨		
Pterocardia buvignieri	▨		
Neocrassina (*Neocrassina*) *subdepressa*	▨		▨
Nicaniella (*Nicaniella*) *extensa*	▨	▨	▨
Protocardia (*Protocardia*) *striatula*	▨		▨
Protocardia (*Protocardia*) *intexta*	▨		▨
Integricardium (*Integricardium*) *bannesianum*	▨		▨
Quenstedtia laevigata	▨		▨
Quenstedtia bathonica	▨		
Anisocardia (*Anisocardia*) aff. *tenera*	▨		
Isocyprina cyreniformise	▨		
Eocallista tancrediformis	▨		▨
Agrawalimya tubularis sp. nov.			
Goniomya (*Goniomya*) *literata*	▨		
Homomya vezelayi	▨	▨	
Neoburmesia iwakiensis			
Pholadomya (*Pholadomya*) cf. *socialis*	▨	▨	
Pholadomya (*Bucardiomya*) *lirata*	▨		▨
Ceratomyopsis striata	▨		▨
Ceratomya concentrica	▨	▨	
Myopholas acuticostata	▨	▨	
Cercomya (*Capillimya*) *striata*	▨		

low abundance but generally articulated. Deep-burrowing bivalves such as *Homomya, Agrawalimya*, or *Pholadomya* and endobyssate taxa (e.g., *Inoperna*) are occasionally found in life position. The fauna is dominated by shallow- and deep-burrowing bivalves adapted to life in a soft substrate. Up-section the silty marl grades into silty marlstone. Finally, silt and clay percentages reach zero and carbonate mudstones and wackestones prevail. Intercalations of thin shell beds and shell pavements with winnowed elements of the softground fauna become more common, whereas sandstone intercalations are absent. The tops of the cycles are commonly formed by shell beds dominated by bivalves representing a wide range of guilds. The large pectinids *P. tipperi* and *Camptonectes* (*Grandinectes*) *teres* are the most conspicuous elements. Often, these bivalves exhibit a preferred convex-up orientation due to winnowing by currents, but in some cases the shells are randomly oriented, and not only infaunal elements but also epibyssate bivalves are articulated. The matrix of these shell beds is micrite (mud- to wackestone).

A higher order of cycles is seen in the lower 800 m of the type section (Fig. 6). These cycles are 250 to 300 m thick and characterized by units in which the silt/sand content alternates between high and low. Four such cycles can be recognized within the section. In each successive cycle, the amount of siliciclastics diminishes until, from around 850 m onwards, the sediments consist solely of pure carbonates and gypsum.

Discussion

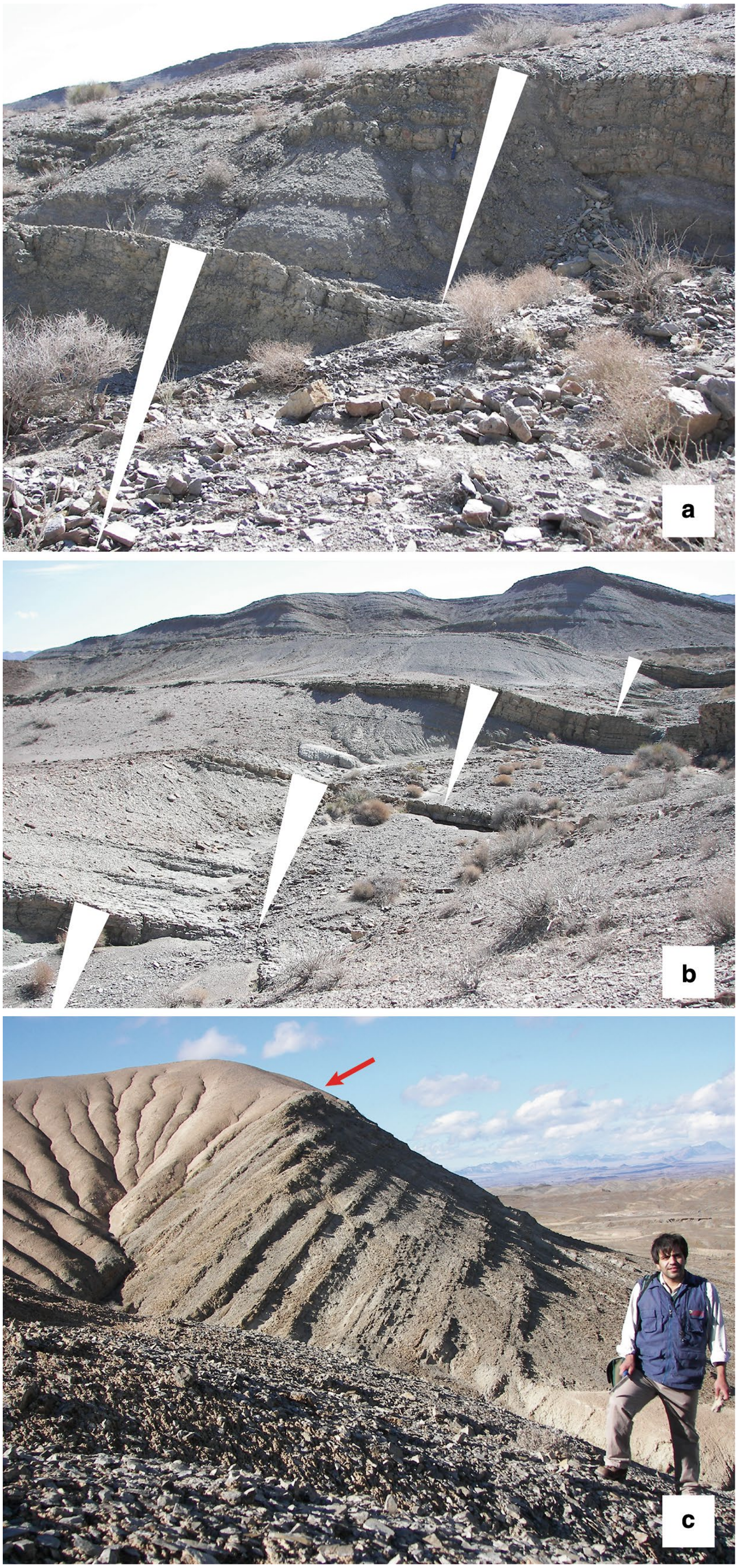
Cycles

Nature and origin of small-scale cycles

The small-scale cycles of the Kamar-e-Mehdi Formation are characterized by a decrease in the amount of clay and/or silt within the mixed siliciclastic–carbonate background sediment (Fig. 13). Originally, part of the silt fraction may have formed discrete laminae and mm-sized layers which subsequently were destroyed by bioturbation resulting in a homogenized sediment. As also the number of sandstone beds decreases within a cycle, it appears that the cyclic sedimentation pattern reflects short-term diminishing influx of siliciclastic material from the western margin of the shelf lagoon. Diagenetic overprinting of the observed pattern by carbonate migration appears to have played only a minor role as the carbonate-rich top beds lack undulating contacts, which are common where secondary segregation of carbonate and clay has taken place. The distribution of clay governed the degree of cementation processes within the cycles: Cementation of the top beds is a result of their low clay content, whereas the high clay content in the lower part of the cycles (silty marl) is responsible for their poor induration.

The increase in shelliness and the occurrence of bio-rudstones towards the top of the cycles can be interpreted as being due to a lower rate of net sedimentation. The change from infaunal- to epifaunal-dominated benthic assemblages probably reflects increased substrate firmness.

Fig. 12 **a**–**c** Carbonate cycles in the Kamar-e-Mehdi Formation at the type area. The meter-scale cycles start with marl and turn into marlstone and carbonate mudstones. Towards the top, the percentage of bioclasts increases (wackestones, floatstones) and the top bed(s) commonly are shell concentrations, either pavements or beds. The *arrow* in **c** marks the boundary to the overlying Magu Gypsum Formation



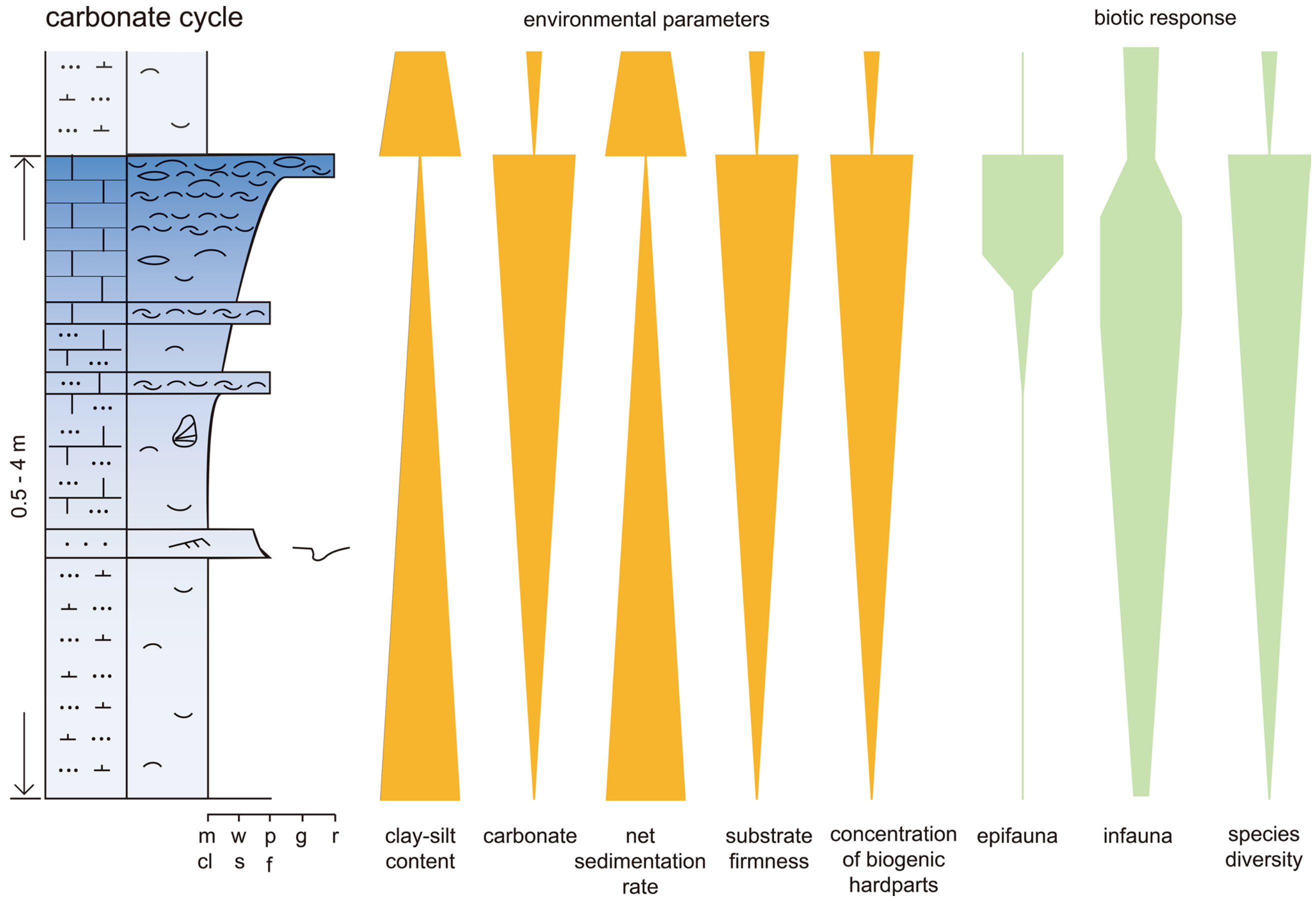


Fig. 13 Schematic carbonate cycle in the Kamar-e-Mehdi Formation. For key of symbols see Fig. 4. Note that the top of the cycles may consist of packstone, floatstone, or rudstone, depending on the degree of shelliness and packing density

Based on these features, the small-scale cycles in the Kamar-e-Mehdi Formation are interpreted as climate-controlled, reflecting a change from humid to more arid conditions and a corresponding decrease in terrigenous influx. The apparent increase in water energy towards the top and the ensuing winnowing produced shell beds/pavements and changed the nature of the substrate. This led to a change in the composition of the benthic communities from a dominance of infaunal to epifaunal taxa. When the general accumulation rates of the Kamar-e-Mehdi Formation are considered (up to 150 m/myr; Wilmsen et al. 2010), the temporal framework of the small-scale cycles may be in the range of precession (~20 kyr) and/or obliquity (~40 kyr) of the Milankovitch Band.

Alternatively, the observed features could also be explained by an increase in water energy due to shallowing or a more open water circulation. Shallowing, however, does not explain the decrease in siliciclastic material, which can be expected to increase under such conditions, and high-frequency relative sea-level changes in the precession/obliquity band would be typically in the range of a few meters at most, insufficient to explain the observed facies changes in the relatively deep parts of the shelf lagoon. Furthermore, on the Esfandiar Platform, representing the shallow-marine barrier of the Kamar-e-Mehdi lagoon and being much more prone to record high-frequency relative sea-level changes, small-scale cycles are largely lacking (see Fürsich et al. 2003b). Thus, the increased shelliness is not interpreted as a result of shallowing but due to the distinct lowering of the sedimentation rate. Throughout the cyclic succession, the water depth was below the fair-weather wave-base but above the storm wave base. Consequently, a lower sedimentation rate means that a certain package of sediment represents a longer period of time and was more often affected by storm processes than a package of the same thickness deposited by a higher rate of sedimentation. Consequently, reworking processes and winnowing affected the lower parts of the cycles less so compared to the upper parts. Moreover, the decreasing rate of sedimentation increased the ratio between biogenic hard parts and abiogenic sediment particles and contributed to the increased shelliness.

Nature and origin of large-scale cycles

The large-scale cycles (Fig. 6b), which represent long-term (2–3 myr) changes in the input of sand-sized siliciclastic material, are less well defined, but as in the case of the small-scale cycles they document alternations in the amount of terrigenous material introduced into the shelf lagoon. They can be interpreted in a similar way as climate controlled, reflecting alternations of wet and dry periods. A tectonic origin cannot, however, be excluded with certainty. In the fault-block-controlled setting of the Central-East Iranian Microcontinent the observed pattern could also be explained by phases of increased uplift of the crest of the tilted Yazd Block in the west (Wilmsen et al. 2010; Salehi et al. 2014a, b) and corresponding higher rates of erosion and transport of sediment into the shelf lagoon. It is noteworthy that the large-scale cycles obviously do not show any correlation to the nine third-order depositional sequences recognized for the Esfandiar Platform based on the analysis of the windward eastern margin and slope (Fürsich et al. 2003b) and the western leeward margin (section at Kuh-e-Bagh-e-Vang; Wilmsen et al. 2010). This observation may in fact point to a tectonic rather than a climatic control.

Trends within the Kamar-e-Mehdi Formation

Apart from the two orders of cycles discussed above, the Kamar-e-Mehdi Formation exhibits some clear trends. Overall, the proportion of sand and silt decreases up-section so that the upper third of the sedimentary succession is devoid of siliciclastic material. Assuming a tectonic origin, this pattern could be explained by a decrease in tectonic activity and a corresponding leveling of the hinterland (Yazd Block). Tectonic pulses documented by siliciclastic material in the lower and middle part of the succession would give way to a period of tectonic quiescence documented by the lack of terrigenous material in the upper part. A climatic origin of this trend in the form of increasing aridity is, however, more likely. This is corroborated by the intercalations of gypsum beds, carbonate mudstones with scattered gypsum/anhydrate needles, and rare rauwacke beds in the upper third of the type section and the fact that the Kamar-e-Mehdi Formation is followed by evaporites of the Magu Gypsum Formation (Wilmsen et al. 2010; Zamani-Pedram 2011). Mattei et al. (2014, 2015) relate this climate trend to plate tectonic-induced latitudinal shifts of the larger area. Accordingly, this facies pattern is not only known from Iran but is widespread in Central Asia, testifying its supra-regional forcing. For example, in the Afghan-Tajik Basin of present-day southern Uzbekistan, Callovian-Oxfordian carbonate platform sediments (Kugitang Formation) are followed by Kimmeridgian-Tithonian evaporites (Gaurdak Formation) (Fürsich et al. 2015).

Paleoecological and paleobiogeographic aspects

The benthic macrofauna of the Kamar-e-Mehdi Formation is largely autochthonous to parautochthonous. Reworking took place by storm processes but no large-scale transport appears to have taken place. Burrowing taxa such as *Homomya*, *Agrawalimya*, *Ceratomya*, *Quenstedtia*, and the semi-infaunal *Inoperna* are occasionally encountered in growth position (i.e., with their anterior-posterior axis vertical to slightly inclined), especially in the lower part of the high-frequency cycles and further testify that, at least there, reworking was limited. An exception is shells that became excavated and transported by the high-density currents that introduced sandy material from the western margin.

At most horizons, the benthic fauna is impoverished, with diversity values ranging from very low to moderate. In settings protected from the open sea, one may expect salinity values to deviate from fully marine. Indeed, stenohaline organisms such as echinoderms, brachiopods, ammonites, and belemnites are rare to absent, and bivalves and, to a lesser extent, gastropods are the prevailing taxa. Many species of the latter groups are euryhaline, but none of the assemblages occurring in the shelf lagoon resembles brackish associations known from Jurassic environments elsewhere (e.g., Fürsich and Werner 1986; Fürsich et al. 1995). Communities living in weakly-to-moderately hypersaline environments usually do not exhibit particular morphological traits, and their most diagnostic feature may be the low species diversity. However, low diversity is a result of stress conditions, which can be created by a number of environmental parameters. For example, confined environments are prone to lowered oxygen values. Although there are no indications of anoxic conditions in the shelf lagoon, slight reductions in the oxygen availability may have depressed species diversity at times. Another parameter limiting species diversity in the lower part of the small-scale cycles may have been a soft substrate, which excluded most epifaunal organisms from colonizing the sea floor.

The degree of environmental stress within the shelf lagoon clearly changed through time and space. In areas close to the eastern margin of the lagoon, next to the carbonate platform of the Esfandiar Limestone Formation but locally also in more central parts of the lagoon (e.g., southwest of Tabas), the lower part of the formation is represented by the Echellon Limestone Member. This member is characterized by up to 6- to 8-m-thick patch reefs composed of corals or sponges associated with abundant microbial crusts, *Tubiphytes*, and a moderately diverse reef-dwelling fauna of bivalves and brachiopods. The biota record fully marine conditions. In the upper part of the formation in contrast, environmental stress, caused by strongly hypersaline conditions, must have been high, as is evidenced by the very low diversity benthic fauna or lack of any macrofauna. Levels dominated by the pectinid bivalves *Camptonectes* (*Grandinectes*) *teres* and *P. tipperi* intercalated between unfossiliferous gypsiferous carbonate mudstones point to occasional amelioration of living conditions. This suggests that the two dominant bivalve species of the shelf lagoon were able to cope with slightly to moderately raised salinity values and appear to have flourished under these conditions. The conspicuous absence of the deep-burrowing bivalve *Pleuromya uniformis*, a very common element of Jurassic benthic faunas of the shelf seas along the northern margin of the Tethys (e.g., Fürsich 1977) and also common in strata underlying the Kamar-e-Mehdi Formation, may indicate that this taxon could not tolerate raised salinity values.

The long persistence of the shelf lagoon (ca. 10 myr according to the GTS 2012; Gradstein et al. 2012) with environmental conditions that did not fluctuate strongly but changed rather gradually, produced the endemic bivalve *Camptonectes* (*Grandinectes*) *teres*, which most likely evolved from related *Camptonectes* species populating the area such as *Camptonectes* (*Camptochlamys*) *clathratus*. Together with the pectinid *P. tipperi*, it was highly successful in colonizing the lagoonal floor, probably due to its ability to tolerate raised salinity conditions. The second endemic species, *Agrawalimya tubularis*, must have evolved from an ancestor that successfully crossed the Tethys in a northward direction, because so far the genus was only known from Bathonian–Callovian strata of the Kachchh Basin, situated at the margin of the Malagasy Gulf.

The fact that more than 90 % of the bivalves occurring in the shelf lagoon also populated the epicontinental shelf seas of western Europe indicates free larval dispersal along the northern margin of the Tethyan Ocean. The high faunal similarity between the two areas has also been documented repeatedly for ammonites (e.g., Seyed-Emami et al. 1991, 2001). Surprising is the low similarity of the bivalve fauna with that of the Qiangtang Block (34 %), which is even lower than the figure from Kachchh situated on the southern margin of the Tethys (43 %; Table 5). The most likely reason for this anomaly is the very limited data available from the area. Thus, the percentage figure from northern Tibet should be regarded as an artefact and illustrates the limits of this kind of paleobiogeographic analysis.

Conclusions

Environmental summary

The vast carbonate shelf lagoon of the Callovian to Lower Kimmeridgian Kamar-e-Mehdi Formation of Central Iran received sediment from two sources: Carbonate material was derived from the large barrier carbonate platform, represented by the Esfandiar Limestone Formation, in the east in addition to its production within the lagoon, and siliciclastic material from the uplifted Yazd Block in the west. The lagoon appears to have had only limited connection to the open ocean but in the early stages of its ca. 10-myr-long life span conditions appears to have been more or less fully marine, even though nektonic groups such as ammonites and belemnites did not enter the area. Patch reefs developed particularly along the lagoon-facing leeward margin of the carbonate platform in the east. Small patch reefs formed also at several levels in more central areas of the lagoon. Most areas of the lagoon occupied a water depth close to the limit of the storm wave-base, because features such as hummocky cross-stratification are rare, whereas evidence of storm-induced currents such as erosional base, parallel-lamination followed by ripple-lamination is common (Wilmsen et al. 2010, Fig. 6). These high-energy events punctuated the prevailing low-energy conditions within the lagoon and contributed to the formation of shell concentrations. Climate-induced variations in sediment influx produced variations in substrate consistency (soft when sedimentation rates were high and firmer when they were low), which influenced the composition of the benthic macrofauna. Oxygen levels might have been slightly reduced at times considering the confined nature of the setting and produced some environmental stress. However, most of the sediment, especially in the lower two-thirds of the succession, is heavily bioturbated, which speaks against major reduction in oxygen availability.

In general, subsidence rates were high (up to 150 m/myr; Wilmsen et al. 2010) and stacking of meter-sized cycles, characterized by a decrease in terrigenous material and increased shelliness indicates a balance between subsidence and sediment accumulation. These small-scale cycles, which characterize much of the sedimentary succession, most likely have a climatic origin recording a change from humid to more arid conditions, which decreased the input of clay- to sand-sized siliciclastic material and hence led to a decrease in the rate of sedimentation. Due to the poor time-control and their not continuous development the high-frequency cycles cannot be firmly related to one of the cycles of the Milankovitch band.

The influx of siliciclastic material also fluctuated at a much larger scale, controlled again by climatic changes but possibly also by tectonic uplift. With time, conditions within the shelf lagoon became more and more restricted. This, in combination with increasing aridity, finally led to the deposition of the evaporitic Upper Jurassic Magu Gypsum Formation.

Paleoecological summary

The shelf lagoon was populated by a number of bivalve-dominated level bottom communities, some of them epibenthic, others endobenthic, as well as by patch reefs, the composition of which was dominated by corals or by calcisponges, *Nanogyra*, *Actinostreon*, or *Neuropora*. Microbial crusts invariably were an important element of these reefs. The most conspicuous faunal elements of the lagoon were two large pectinid bivalves, *Camptonectes* (*Grandinectes*) *teres* and *P. tipperi*. Faunal composition and density changed within the small-scale sedimentary cycles: The lower parts are characterized by shallow-burrowing bivalves in low density or reworked as shell pavements, whereas at the top epifaunal communities predominated commonly preserved as parautochthonous shell concentrations. This distribution pattern is interpreted to reflect increasing substrate firmness as a result of decreasing sedimentation rates. Compared to neighboring open-marine environments, faunal diversities within the lagoon were moderate to low, pointing to less-than-optimal living conditions. The main stress factor appears to have been raised salinity values, which increased towards the top of the formation as is corroborated by the sediment composition (gypsum and gypsiferous carbonate mudstones).

Nearly all bivalve species of the shelf lagoon are also known from western Europe. This demonstrates free larval dispersal of benthic macroinvertebrates along the northern shelf seas of the Tethys. The curious low percentage of bivalve species common with northern Tibet most likely is an artefact caused by the limited paleontological information about the latter area.

Acknowledgments We would like to thank K. Seyed-Emami (Tehran University) and M. Zamani-Pedram (GSI, Tehran) with whom part of the field work was carried out. Logistic support in the field by the Geological Survey of Iran (GSI) and the Tabas Coal Company is gratefully acknowledged. PYH acknowledges the support by grant 'Strategic Priority Research Programme (B)' of the Chinese Academy of Sciences (XDB03010101). Most of the fieldwork was financially supported by the National Geographic Society (Grant #5888-97). We would also like to thank Martin Aberhan, Berlin, and an anonymous reviewer for their constructive comments on the manuscript.

References

Aghanabati SA (1977) Etude géologique de la region de Kalmard (W. Tabas). Stratigraphie et tectonique. Geol Surv Iran Rep 35:1–230

Blakey R (2011) Global palaeogeography. http://jan.ucc.nau.edu/~rcb7/globaltext2.html

Cox LR (1936) Fossil Mollusca from southern Persia (Iran) and Bahrein Island. Mem Geol Surv India Palaeont Ind New Ser 22 Mem 2:1–69

Fürsich FT (1977) Corallian (Upper Jurassic) marine benthic associations from England and Normandy. Palaeontology 20:337–385

Fürsich, FT, Brunet M-F, Auxière J-L, Munsch H (2015) Lower and Middle Jurassic facies patterns in the northwestern Afghan-Tajik Basin of southern Uzbekistan and their geodynamic context. In: Brunet M-F, McCann T, Sobel ER (eds) Geological evolution of Central Asian basins and the western Tien Shan Range. Geol Soc Lond Spec Publ 427

Fürsich FT, Oschmann W (1993) Shell beds as tool in facies analysis: the Jurassic of Kachchh, western India. J Geol Soc Lond 150:169–185

Fürsich FT, Pan YH (2014) Callovian-Oxfordian (Jurassic) bivalves from the Kamar-e-Mehdi Formation of east-central Iran. Beringeria 44:3–50

Fürsich FT, Werner W (1986) Benthic associations and their environmental significance in the Lusitanian Basin (Upper Jurassic, Portugal). N Jb Geol Paläont Abh 172:271–329

Fürsich FT, Freytag S, Röhl J, Schmid A (1995) Palaeoecology of benthic associations in salinity-controlled marginal marine environments: examples from the Lower Bathonian (Jurassic) of the Causses (southern France). Palaeogeogr Palaeoclimatol Palaeoecol 113:135–172

Fürsich FT, Wilmsen M, Seyed-Emami K, Majidifard MR (2003a) Evidence of synsedimentary tectonics in the northern Tabas Block, east-central Iran: the Callovian (Middle Jurassic) Sikhor Formation. Facies 48:151–170

Fürsich FT, Wilmsen M, Seyed-Emami K, Schairer G, Majidifard MR (2003b) Platform/basin transect of a large-scale Middle-Late Jurassic carbonate platform system (Shotori Mountains, Tabas area, east-central Iran). Facies 48:171–198

Fürsich FT, Wilmsen M, Seyed-Emami K, Majidifard MR (2009) The Mid-Cimmerian tectonic event (Bajocian) in the Alborz Mountains, northern Iran: evidence of the break-up unconformity of the South Caspian Basin. In: Brunet M-F, Wilmsen M, Granath J (eds) South Caspian to Central Iran basins. Geol Soc Lond Spec Publ 312:189–203

Gradstein FM, Ogg JG, Schmitz MD, Ogg GM (eds) (2012) The Geologic Time Scale 2012. Elsevier, Amsterdam

Guynn JH, Kapp P, Pullen A, Heizler M, Gehrels G, Ding L (2006) Tibetan basement rocks near Ambo reveal "missing" Mesozoic tectonism along the Bangong suture, central Tibet. Geology 34:505–508

Hallam A (1977) Jurassic bivalve biogeography. Paleobiology 3:58–73

Hamilton LJ (2001) Cross-shelf colour zonation in northern Great Barrier Reef lagoon surficial sediments. Aust J Earth Sci 48:193–200

Heinze M (1996) Paläobiogeographie jurassischer Muschelfaunen: Beziehung zwischen Süd- und Nordrand der Tethys. Paläont Z 70:97–128

Hopley D (1982) The geomorphology of the Great Barrier Reef. Wiley, New York, p 453

Huckriede R, Kürsten M, Venzlaff H (1962) Zur Geologie des Gebietes zwischen Kerman und Sagand (Iran). Geol Jb Beih 51:1–197

Jones B, Desrochers A (1992) Shallow platform carbonates. In: Walker RG, James NP (eds) Facies models, response to sea level change. Geol Assoc Canada GeoText 1:277–301

Kiessling W, Pandey DK, Schemm-Gregory M, Aberhan M (2011) Marine benthic invertebrates from the Upper Jurassic of northern Ethiopia and their biogeographic affinities. J Afr Earth Sci 59:195–214

Li Y, Wang C-S, Yi H-S (2003) The late Triassic collision and sedimentary responses at western segment of Jinshjiang suture, Tibet. Acta Sediment Sin 21:191–197 **(in Chinese with English abstract)**

Li C, Zhai Q-G, Dong Y-S, Liu S, Xie C-M, Wu Y-W (2009) High-pressure eclogite-blueschist metamorphic belt and closure of Paleo-Tethys Ocean in central Qiangtang, Qinghai-Tibet Plateau. J Earth Sci 20:2009–20018

Mattei M, Muttoni G, Cifelli F (2014) A record of the Jurassic massive plate shift from the Garedu Formation of central Iran. Geology 42:555–558

Mattei M, Cifelli F, Muttoni G, Rashid H (2015) Post-Cimmerian (Jurassic–Cenozoic) palaeogeography and vertical axis tectonic rotations of Central Iran and the Alborz Mountains. J Asian Earth Sci 102:92–101

Mukherjee D, Fürsich FT (2014) Jurassic brachiopods from east-central Iran. Beringeria 44:107–127

Pandey DK, Fürsich FT (2003) Jurassic corals of east-central Iran. Beringeria 32:1–138

Pandey DK, Fürsich FT, Heinze M (1996) Contributions to the Jurassic of Kachchh, Western India. V. The bivalve fauna. Part II. Subclass Anomalodesmata. Beringeria 18:51–87

Purdy EG, Gischler E (2003) The Belize margin revisited. 1. Holocene marine facies. Int J Earth Sci (Geol Rundsch) 92:532–551

Purdy EG, Gischler E, Lomando AJ (2003) The Belize margin revisited. 2. Origin of Holocene antecedent topography. Int J Earth Sci (Geol Rundsch) 92:552–572

Reed FRC (1936) Jurassic lamellibranchs from the Namyau Series, northern Shan States. Ann Mag Nat Hist Ser 10(18):1–28

Salehi MA, Moussavi-Harami SR, Mahboubi A, Wilmsen M, Heubeck C (2014a) Tectonic and palaeogeographic implications of compositional variations within the siliciclastic Ab-Haji Formation (Lower Jurassic, east-central Iran). N Jb Geol Paläont Abh 271:21–48

Salehi MA, Moussavi-Harami R, Mahboubi A, Rahimi B (2014b) Palaeoenvironment and basin architecture of the Lower Jurassic Ab-Haji Formation, east-central Iran. Bol Inst Fisiogr Geol 84:29–44

Seyed-Emami K, Alavi-Naini M (1990) Bajocian stage in Iran. Mem Descr Carta Geol Ital 40:215–222

Seyed-Emami K, Schairer G, Aghanabati SA, Fazl M (1991) Ammoniten aus dem Bathon von Zentraliran (Tabas - Nayband region). Münchner Geowiss Abh A19:65–100

Seyed-Emami K, Schairer G, Aghanabati SA (1997) Ammoniten aus der Baghamshah Formation (Callov, Mittlerer Jura), NW Tabas (Zentraliran). Mitt Bayer Staatsslg Paläont Hist Geol 37:24–40

Seyed-Emami K, Fürsich FT, Schairer G (2001) Lithostratigraphy, ammonite faunas and palaeoenvironments of Middle Jurassic strata in north and central Iran. Newsl Stratigr 38:163–184

Seyed-Emami K, Schairer G, Fürsich FT, Wilmsen M, Majidifard MR (2002) Reineckeiidae (Ammonoidea) from the Callovian (Middle Jurassic) of the Shotori Range (East Central Iran). N Jb Geol Paläont Mh 2002:184–192

Seyed-Emami K, Fürsich FT, Wilmsen M (2004) Documentation and significance of tectonic events in the northern Tabas Block (east-central Iran) during the Middle and Late Jurassic. Riv Ital Paleont Stratigr 110:163–171

Sha J-G, Fürsich FT, Smith PL, Wang L (1998) Palaeotaxodonta, Pteriomorphia, and Isofilibranchia (Bivalvia) from the Jurassic of the main ridge of the Tanggula Mountains, China. Beringeria 21:3–55

Tudhope AW, Scoffin TP (1984) The effects of *Callianassa* bioturbation on the preservation of carbonate grains in Davies Reef Lagoon, Great Barrier Reef, Australia. J Sediment Petrol 54:1091–1096

Wen S-X (1979) Jurassic Bivalvia. In: The Nanjing Institute and Qinghai Institute of Geosciences (eds) Palaeontological atlas of northwestern China, Qinghai volume. Part 1. Geological Publishing House, Beijing, pp 218–314

Wilmsen M, Fürsich FT, Seyed-Emami K (2003) Revised lithostratigraphy of the Middle and Upper Jurassic Magu Group of the northern Tabas Block, east-central Iran. Newsl Stratigr 39:143–156

Wilmsen M, Fürsich FT, Seyed-Emami K, Majidifard MR, Taheri J (2009a) The Cimmerian orogeny in northern Iran: tectono-stratigraphic evidence from the foreland. Terra Nova 21:211–218

Wilmsen M, Fürsich FT, Seyed-Emami K, Majidifard MR (2009b) An overview of the lithostratigraphy and facies development of the Jurassic System on the Tabas Block, east-central Iran. In: Brunet M-F, Wilmsen M, Granath J (eds) South Caspian to Central Iran basins. Geol Soc Lond Spec Publ 312:323–344

Wilmsen M, Fürsich FT, Seyed-Emami K, Majidifard MR, Zamani-Pedram M (2010) Facies analysis of a large-scale Jurassic shelf-lagoon: the Kamar-e-Mehdi Formation of east central Iran. Facies 56:59–87

Yin J, Fürsich FT (1991) Middle and Upper Jurassic bivalves from the Tanggula Mountains, W-China. Beringeria 4:127–192

Yin A, Harrison TM (2000) Geologic evolution of the Himalayan-Tibetan orogen. Annu Rev Earth Planet Sci 20:211–280

Zamani-Pedram M (2011) Source, facies, and sedimentary environments of the Middle to Upper Jurassic strata in the Kerman and Tabas areas, east-central Iran. Doctoral thesis, Würzburg University, 212 p