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Platform-Basin Transect of a Middle to Late Jurassic Large-Scale Carbonate Platform System (Shotori Mountains, Tabas Area, East-Central Iran)

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SUMMARY

Following a phase of predominantly siliciclastic sedimentation in the Early and Middle Jurassic, a large-scale, low-latitude carbonate depositional system was established in the northern part of the Tabas Block, part of the central-east Iranian microplate, during the Callovian and persisted until the latest Oxfordian/Early Kimmeridgian. Running parallel to the present eastern block margin, a NNW/SSE-trending carbonate platform developed in an area characterized by reduced subsidence rates (Shotori Swell). The growth of this rimmed, flat-topped barrier platform strongly influenced the Upper Jurassic facies pattern and sedimentary history of the Tabas Block. The platform sediments, represented by the predominantly fine-grained carbonates of the Esfandiar Limestone Formation, pass eastward into slope to basin sediments of the Qal'eh Dokhtar Limestone Formation (platform-derived allochthonites, microbialites, and peri-platform muds). Towards the west, they interfinger with bedded limestones and marlstones (Kamar-e-Mehdi Formation), which were deposited in an extensive shelf lagoon. In a N-S direction, the Esfandiar Platform can be traced for about 170 km, in an E-W direction, the platform extended for at least 35-40 km. The width of the eastern slope of the platform is estimated at 10-15 km, the width of the western shelf lagoon varied considerably (>20-80 km). During the Late Callovian to Middle Oxfordian, the Esfandiar Platform flourished under arid climatic conditions and supplied the slope and basinal areas with large amounts of carbonates (suspended peri-platform muds and gravitational sediments). Export pulses of platform material, e.g. ooids and aggregate grains, into the slope and basinal system are interpreted as highstand shedding related to relative sea-level variations. The high-productivity phase was terminated in the Late Oxfordian when the eastern platform areas drowned and homogeneous deep water marls of the Upper Oxfordian to Kimmeridgian Korond Formation onlapped both the Qal'eh Dokhtar Limestone Formation and the drowned Esfandiar Limestone Formation. Tectonic instability, probably caused by faulting at the margins of the Tabas Block in connection with rotational movements of the east-central Iranian block assemblage, was responsible for the partial drowning of the eastern platform areas. In some areas, relicts of the platform persisted to produce shallow-water sediments into the Kimmeridgian.

1 INTRODUCTION

Jurassic rocks are widely distributed and superbly exposed in the Shotori Range (Tabas area) of east-central Iran (Fig. 1). The Lower and large parts of the Middle Jurassic are characterized by thick siliciclastic sequences, whereas the Callovian to Upper Jurassic rocks show a predominance of carbonates (Esfandiar Subgroup, Wilmsen et al., 2003). Three of the lithostratigraphic units of the subgroup, the Qal'eh Dokhtar Limestone Formation, the Esfandiar Limestone Formation, and the Korond Formation, are the scope of this paper.

Previous studies (e.g., Stöcklin et al., 1965; Ruttner et al., 1968) of Jurassic strata of the Shotori Range were mainly concerned with mapping. These authors broadly characterized the Esfandiar Limestone Formation as a "reefal limestone" and the Qal'eh Dokhtar Limestone Formation as "back reef" sediments. In a recent paper, Schairer et al. (2000) provided important data on ammonite biostratigraphy and sedimentary facies of the type section of the formation west of Boshrouyeh. They showed that the Qal'eh Dohktar Limestone Formation was not deposited in a "back reef" setting but in a basinal area in front of a carbonate platform represented by the Esfandiar Limestone Formation. Until now, lateral facies relationships are still poorly understood and detailed sedimentological studies of the Middle to Upper Jurassic rocks of the Shotori Range are missing.

The aim of this study is to analyse a cross-section through the "reefal" Esfandiar Limestone Formation and the associated slope rocks of the Qal'eh Dokhtar Limestone Formation

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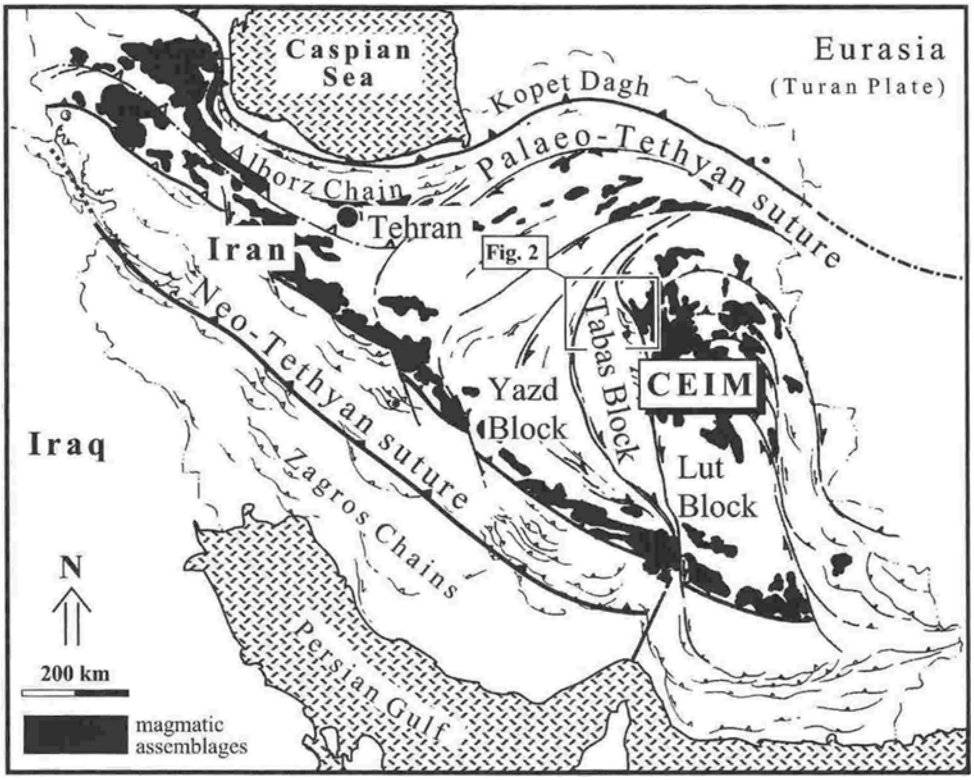


Fig. 1. Simplified map of Iran showing the main structures and lineaments (modified from Alavi et al., 1997; CEIM = Central-East Iranian Microcontinent). Note the dextral intracontinental transfer faults bounding the Tabas Block. The map area of Fig. 2 is indicated by the small rectangle in the northern part of the Tabas Block.

in order to document their microfacies variability, stratigraphic architecture and depositional environments. Four sections representing a 30 km long W-E transect were measured bed-by-bed using a modified Jacob Staff (Sdzuy and Monninger, 1985). The rocks were described in the field, sampled for microfacies analysis and classified according to depositional texture (Dunham, 1962; Embry and Klovan, 1972) combined with the classification of Folk (1959). Macrofaunal occurrences and ichnological observations as well as sedimentary structures were integrated into the stratigraphic logs.

2 GEOLOGICAL SETTING

The depositional history of Triassic/Jurassic sedimentary basins of central Iran was largely governed by differential subsidence of, and rotational movements between, three structural blocks, the Lut, Tabas, and Yazd blocks, which form part of the Central-East Iranian Microplate (CEIM, Fig. 1). These blocks, now adjoined from east (Lut Block) to west (Yazd Block), formed parts of the Cimmerian microplate assemblage (Sengör et al., 1988; Sengör 1990) that collided with the Eurasian (Turan) Plate in the Late Triassic, either at the Ladinian-Carnian boundary (Saidi et al., 1997) or around the Carnian-Norian boundary (Seyed-Emami, 1971a, b; Sengör, 1990; Alavi et al., 1997). The investigated sections are situated at the eastern margin of the Tabas Block and at the transition to the Lut Block. However, the lateral relationships of the three blocks during the Jurassic Period are still largely unknown since the CEIM rotated anticlockwise for about 135° since the Triassic (e.g., Soffel et al., 1975; Davoudzadeh et al., 1981; Wensink, 1982; Soffel and Förster, 1984). These rotational movements resulted in the formation of large (rotation-related) dextral intracontinental transfer faults at the block boundaries associated with strike-slip and thrust faulting (Alavi et al., 1997; cf. Fig. 1). This complex tectonic pattern largely governed Jurassic sedimentation in the working area (Fürsich et al., 2003; Seyed-Emami et al., submitted).

The Tabas block was submerged by the sea during most the Jurassic. Differential subsidence, strongly varying in time and space, created a complex facies mosaic with considerable lateral thickness changes, especially at the block margins. The so-called mid-Cimmerian tectonic movements in the Late Bajocian caused uplift and widespread erosion of the Tabas Block (e.g., Seyed-Emami and Alavi-Naini, 1990; Seyed-Emami et al., submitted). This tectonic event was followed, in the Bathonian to Callovian, by rapid subsidence and the deposition of a thick (up to 1,500 m), widespread, and uniform silty to sandy shelf sequence of the Baghamshah Formation (Fig. 3). Renewed tectonic activity in the (?Early) Callovian caused uplift and erosion of parts of the eastern Tabas Block and concomitant N/NE-ward progradation of fluvio-deltaic sediments of the Kuh-e-Neygu Member of the Sikhor Formation into the Baghamshah shelf system (Fürsich et al., 2003). Decreasing terrigenous input due to denudation of the source areas and/or sea-level rise initiated the predominantly calcareous depositional episode of the latest Middle and Late Jurassic (Majd Member of the Sikhor Formation and Esfandiar Subgroup, Fig. 3; Wilmsen et al., 2003).

In an east-west direction (Fig. 3), the Bathonian/Callovian siliciclastics (Baghamshah Formation and Kuh-e-Neygu Member of the Sikhor Formation) of the Shotori Mountains are overlain by four different calcareous units, i.e. the mixed siliciclastic-carbonate Majd Member of the Sikhor Forma-

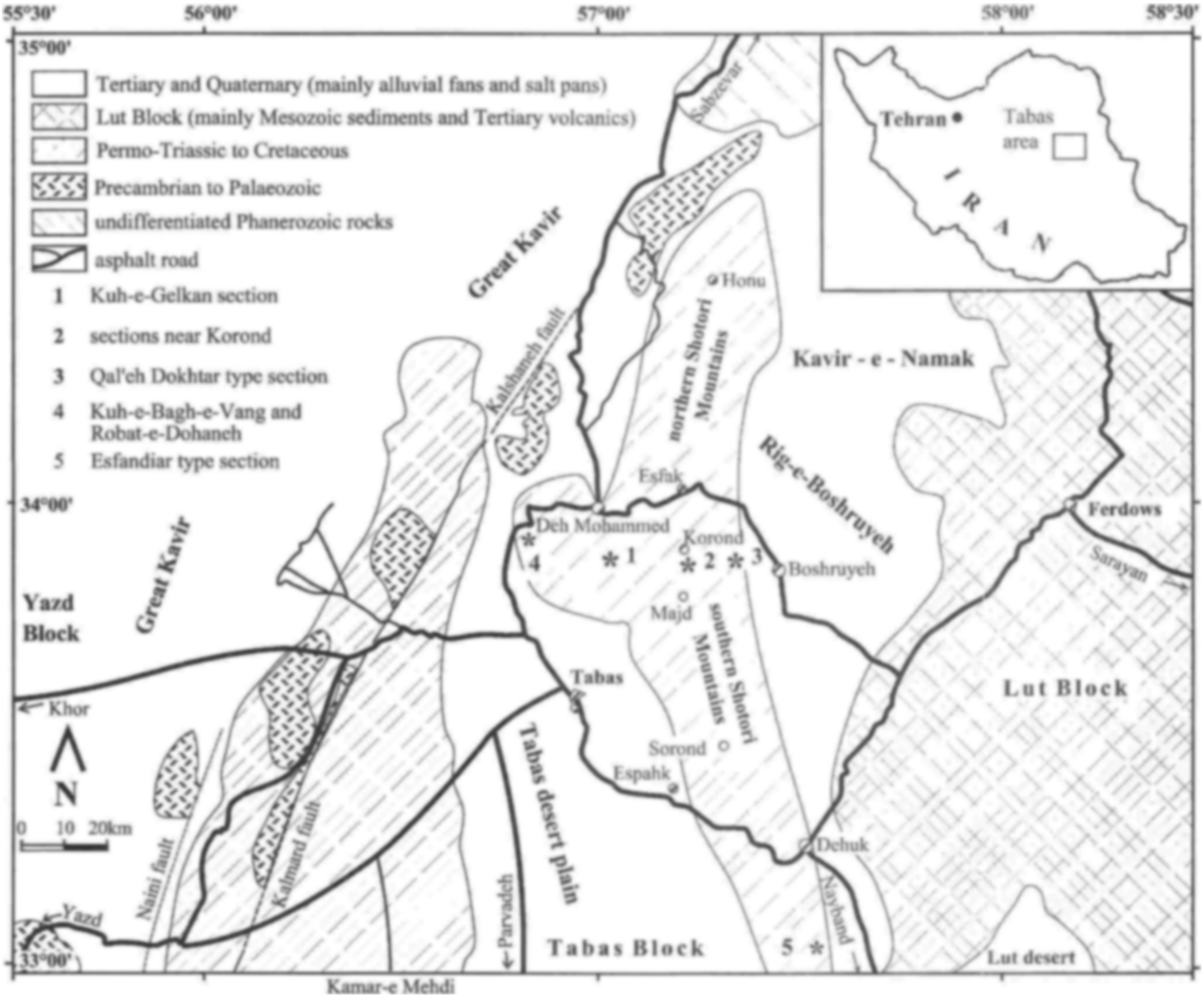


Fig. 2. Generalized map of the Tabas area, east-central Iran, with indication of the measured sections (no. 1-3) and additional localities mentioned in the text (4, 5). The boundary between the Tabas and Lut blocks runs parallel to the eastern margin of the Shotori Mountains; the boundary to the Yazd Block is represented by the Naini and Kalmard/Kalshaneh fault complex.

tion, the Qal'eh Dokhtar Limestone Formation, the Esfandiar Limestone Formation and the Kamar-e-Mehdi Formation (formerly known as "Pecten Limestone"). The latter formation is characterized by a basal Echellon Limestone Member and a capping Nar Limestone Member. These carbonate units run more or less parallel to the eastern margin of the Tabas Block for more than 150 km. The Kamar-e-Mehdi Formation can be traced for an even much greater distance, being widespread also in the Ravar-Kerman area, approximately 400 km to the south. The three limestone units are overlain either by the marly Korond Formation (Schairer et al., 2003), the Garedu Red Beds/Magu Gypsum formations (Fig. 3) or, with an hiatus, by Upper Cretaceous rocks of different lithology (e.g., the "Kerman conglomerate" of Huckriede et al., 1962).

In the eastern part, the 300-400 m thick Qal'eh Dokhtar Limestone Formation borders the eastern margin of the Tabas Block. It consists of alternations of coarse, platform-derived limestones, microbialites, and calcareous, in part marly mudstones containing ammonites. The Esfandiar Limestone Formation, occurring slightly further to the west, reaches a thickness of up to 800 m and is characterized by shallow-water limestones indicating a carbonate platform setting. The well-bedded Kamar-e-Mehdi Formation, which is not considered here, is found in the central and western parts of the Tabas Block (see Aghanabati, 1977). It consists of stacked, metre-scale cycles of silty marl and fine-grained limestones, reaches up to 1,200 m in thickness, and was deposited in an extensive shelf-lagoon. The age of the three units, which clearly interfinger in an east-west direction, is Callovian to Early Kimmeridgian. Palaeogeographic reconstructions for the Late Jurassic (e.g., Enay et al., 1993) place the Tabas Block at a palaeo-latitude of approximately 20-30° N. Late Jurassic climate conditions were probably more arid than today (Valdes and Sellwood, 1992).

3 SECTIONS

Several sections of the Qal'eh Dokhtar Limestone and Esfandiar Limestone formations were measured, four of

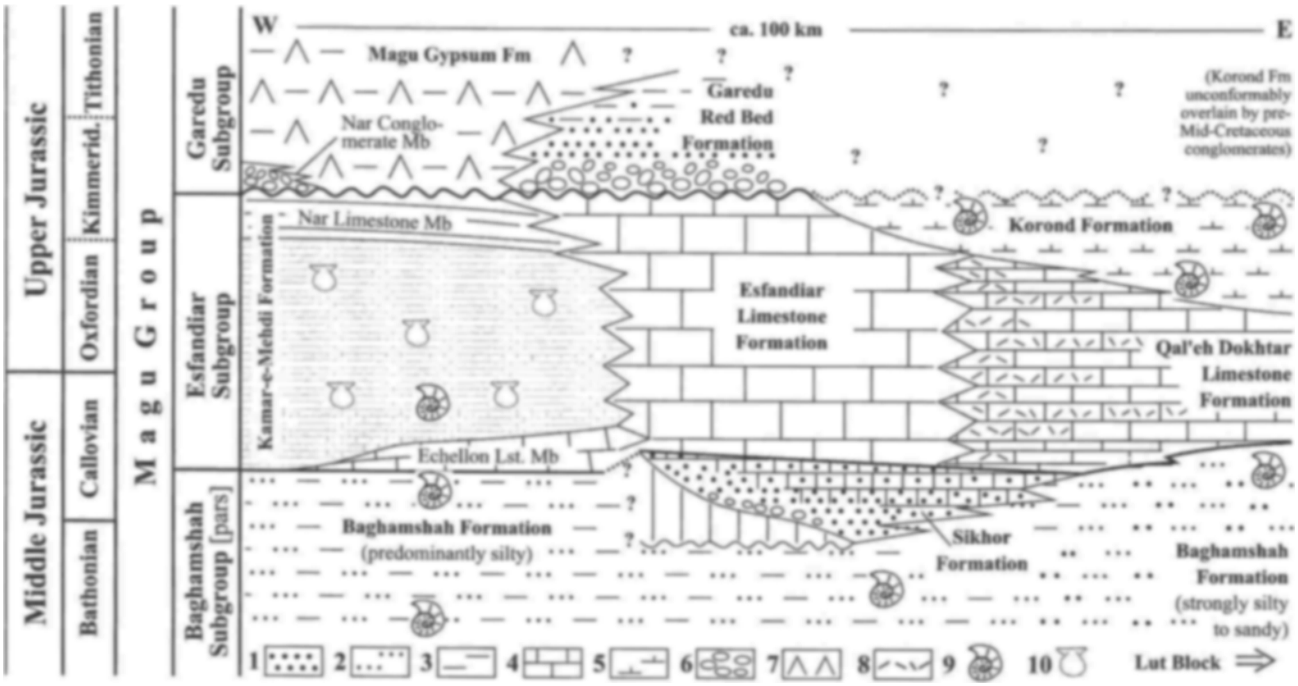


Fig. 3. Lithostratigraphic framework of the Middle/Upper Jurassic Magu Group, northern Tabas Block, east-central Iran (modified from Wilmsen et al., 2003). The Esfandiar Limestone Formation, the Qal'eh Dokhtar Limestone Formation and the Korond Formation are the scope of this paper. Key: 1. Sandstone; 2. Siltstone; 3. Clay; 4. Limestone; 5. Marl; 6. Conglomerate; 7. Gypsum; 8. Bioclasts; 9. Ammonites; 10. Bivalves).

which are described below in detail. They form a cross-section through the eastern margin of a rimmed, flat-topped carbonate platform and associated slope to basin system. In the steep limestone massifs formed by the Esfandiar Limestone Formation (reaching nearly 3000 m altitude), logging of complete sections is almost impossible due to the alpine relief and an associated complex fault pattern.

In order to characterize the Esfandiar Limestone, we re-measured the type section of the Esfandiar Limestone Formation (Stöcklin et al., 1965) located at Kuh-e-Esfandiar south of the Shotori Mountains (co-ordinates: N 33°10'51", E 57°27'35"; see Fig. 2). The type section has a thickness of approximately 760 m and is unconformably overlain by the Kerman Conglomerate of Late Cretaceous age (Huckriede et al., 1962). Apart from high-energy coral/chaetetid "bioconglomerates" at the base, the section shows a predominance of bedded, fine-grained ("muddy") carbonates (mudstones, biowackestones) indicating a low energy environment with few, thin intercalations of bio- and/or intraclastic grainstones and oolites. Macrofossils (sponges, bivalves, gastropods, corals) are generally rare; some diceratids were observed occurring in floatstones (Pl. 32/4). *Thalassinoides* burrows are recorded in the uppermost part of the section. The facies of the Esfandiar Limestone at the type section indicates a sheltered interior platform setting. The age of the formation at the type section is given as late Middle to Late Jurassic (Callovian to Kimmeridgian) by Stöcklin et al. (1965). We cannot determine the age more precisely.

The type section of the Qal'eh Dokhtar Limestone Formation was recently described by Schairer et al. (2000) and is treated in section 3.4. Schairer et al. (2000) indicate a platform slope to basin environment and a Middle Callovian to Late Oxfordian age for the formation.

3.1 Kuh-e-Gelkan (N 56°58'35", E 33°53'36", Fig. 4)

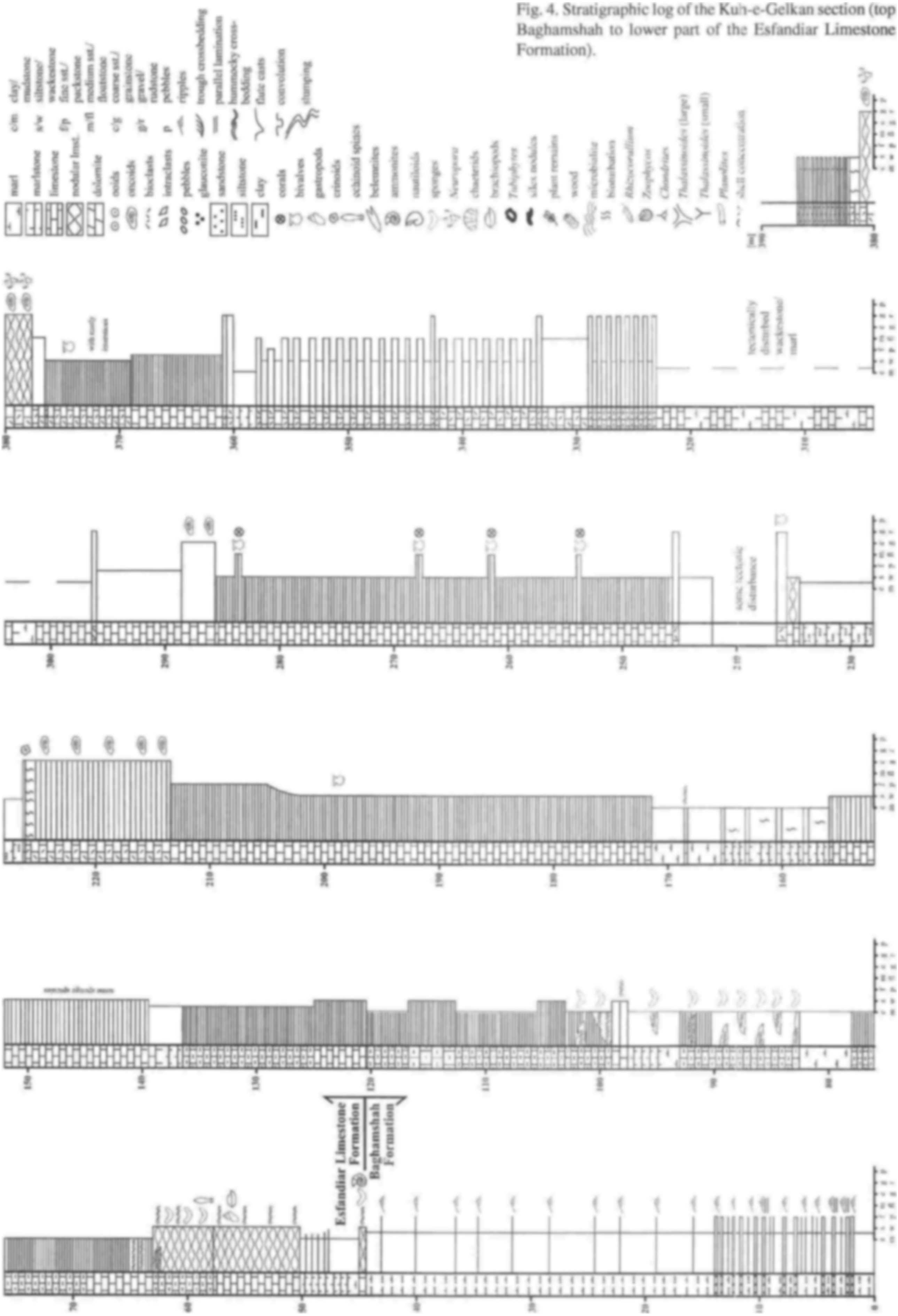
The approximately 340 m thick Kuh-e-Gelkan section was measured at the western slope of the Kuh-e-Gelkan (Fig. 2). It represents the lower part of the Esfandiar Limestone Formation and is underlain by a thick marly sequence of the Baghamshah Formation. The transition into the Esfandiar Limestone Formation is placed at a level of microbial limestones (at 44 m, Fig. 4) where the occurrence of the ammonite genus *Macrocephalites* indicates an Early Callovian age.

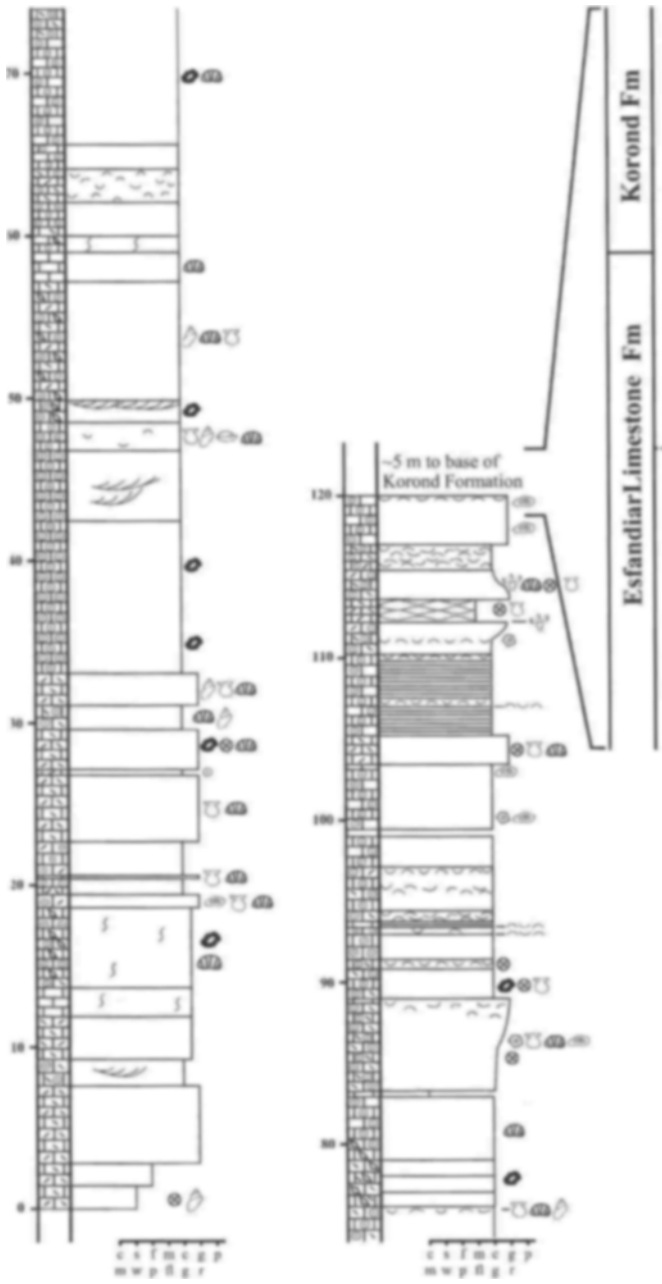
The Esfandiar Limestone Formation at Kuh-e-Gelkan is characterized by muddy fabrics. The lower parts are dominated by thin-bedded, argillaceous mudstone and nodular biowackestone with interspersed, up to 1 m thick and 4-5 m wide sponge-microbialite mounds (Pl. 32/3) and occasional marly intervals. Up-section, oncolite float- and rudstones (around 220 m), *Neuropora*-oncoid rudstones (at 380 m) as well as bioclastic grain- to rudstones (between 320 and 360 m) are intercalated. Macrofossil occurrences are extremely rare and consist of sponges (mainly the delicate arborescent sclerosponge *Neuropora*), corals, and bivalves.

3.2 Korond (N 33°55'02", E 57°09'20", Fig. 5)

The section at Korond exposes the upper part of the Esfandiar Limestone Formation and its transition into the overlying Korond Formation (e.g., Pl. 32/1-2). It was mea-

Fig. 4. Stratigraphic log of the Kuh-e-Gelkan section (top Baghamshah to lower part of the Esfandiar Limestone Formation).





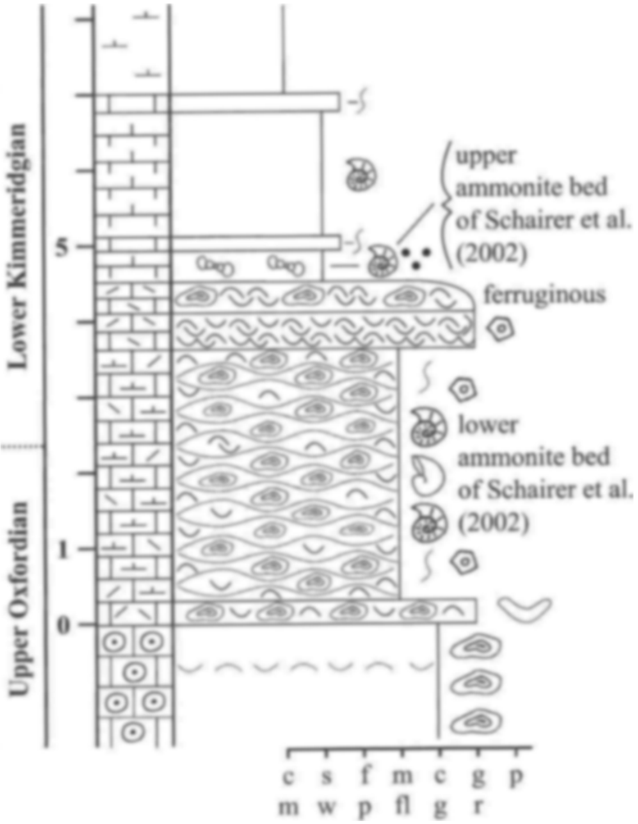


Fig. 5. Stratigraphic log of the Korond section (top of the Esfandiar Limestone Formation). For key of symbols see Fig. 4.

sured approximately 800 m south of the village of Korond at the eastern slope of the Shotori Mountains and has a thickness of 120 m.

The limestones of the Esfandiar Limestone Formation at this locality are dominated by sparitic, grain-supported fabrics (aggregate grainstone, bioclastic ooid-grainstone, ooid-grainstone, bioclastic rudstone). They are massive to thick-bedded and exhibit, at least partly, large-scale trough cross-bedding. Bioconglomeratic layers with chaetetid debris up to 20 cm in diameter and, especially in the upper part, shell beds are intercalated. Apart from chaetetids, crinoids, gastropods, corals, bivalves, *Tubiphytes* and *Neuropora* were recorded.

The transition into the overlying marls of the Korond Formation is relatively sharp (Fig. 5, Pl. 32/2). The top beds of the Esfandiar Limestone Formation consist of oolitic and/or bioclastic oncolites which become increasingly ferruginous and marly up-section, and yield a rich cephalopod fauna (nautiloids and ammonites). A marl bed with encrusted, glauconitized and partly corroded (fragments of) internal moulds of ammonites forms the top of the Esfandiar Limestone Formation. The rich ammonite assemblage (phylloceratids, perisphinctids, aspidoceratids, including *Orthosphinctes (O.) tiziani*, *Subnebrodites* cf. *planula*, *S.* cf. *proteron*, and *Sowerbyceras silenum*) indicates a Late Oxfordian to Early Kimmeridgian age for the strongly condensed top of the Esfandiar Limestone Formation at Korond (Schairer et al., 2003). The overlying Korond Formation is characterized by greenish, monotonous marls (Pl. 32/2); it is poorly fossiliferous, yielding rare ammonites, bivalves, and irregular echinoids at a few levels. Its base is Early Kimmeridgian in age at Korond.

3.3 Hill range east of Korond

(N 33°54'47", E 57°10'10", Fig. 6)

Southeast of the village of Korond, across a north/south trending hill range, a section through the Majd Member of the Sikhor Formation and the Qal'eh Dokhtar Limestone Formation into the lower Korond Formation was measured. The strata are nearly vertical to slightly overturned (Pl. 32/7). This section is situated only 1.5 km to the east of section 3.2 and shows a thickness of about 320 m.

The sediments of the Majd Member of the Sikhor Formation and the Qal'eh Dokhtar Limestone Formation overlie a thick succession of trough-crossbedded deltafront sandstones of the Kuh-e-Neygu Member of the Sikhor Formation, which attain a thickness of about 250 m. The base of the

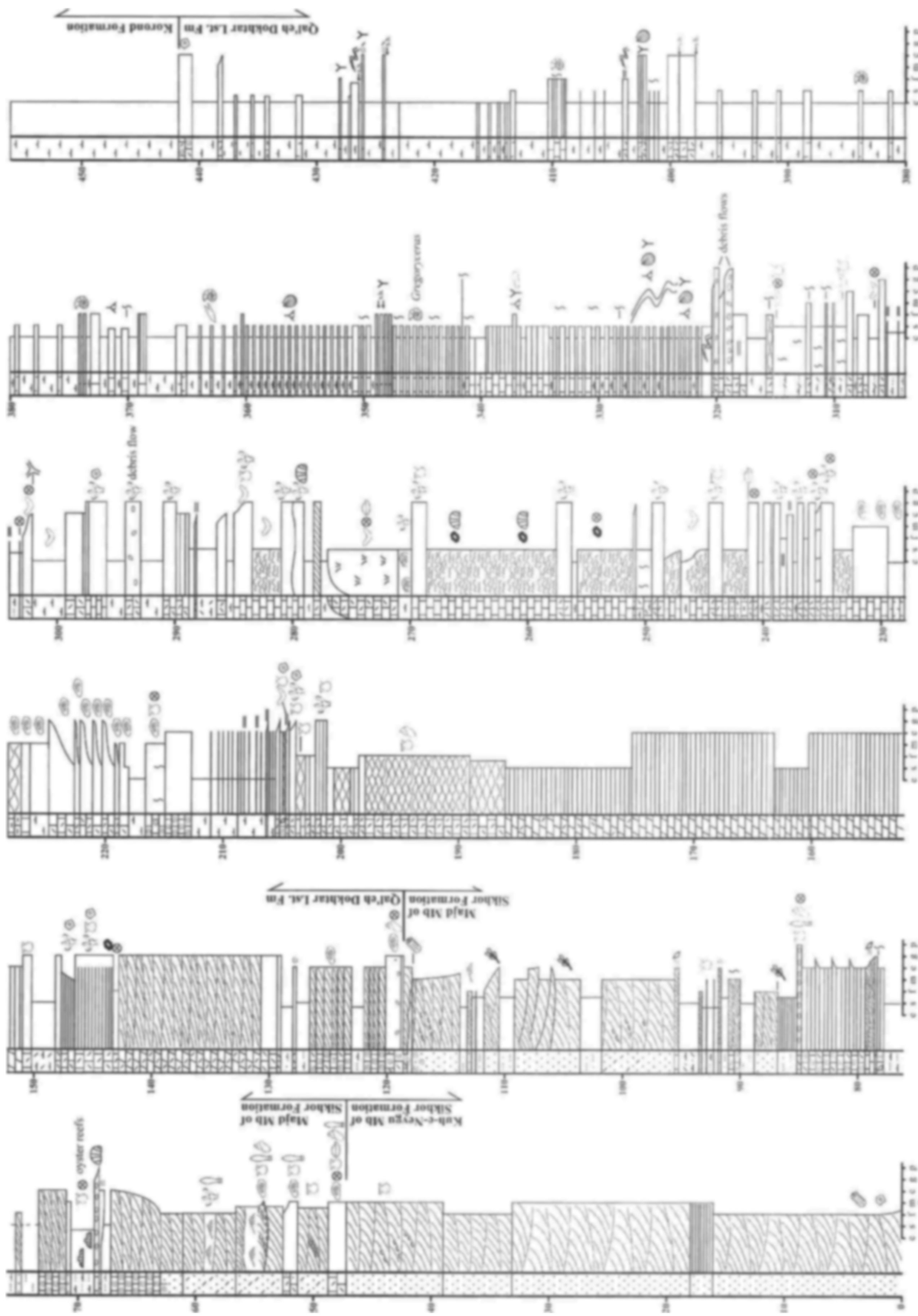


Fig. 6. Stratigraphic log of the section east of Korond (top Sikhor Formation, Qal'eh Dokhtar Limestone Formation and lower part of Korond Formation). For key of symbols see Fig. 4.

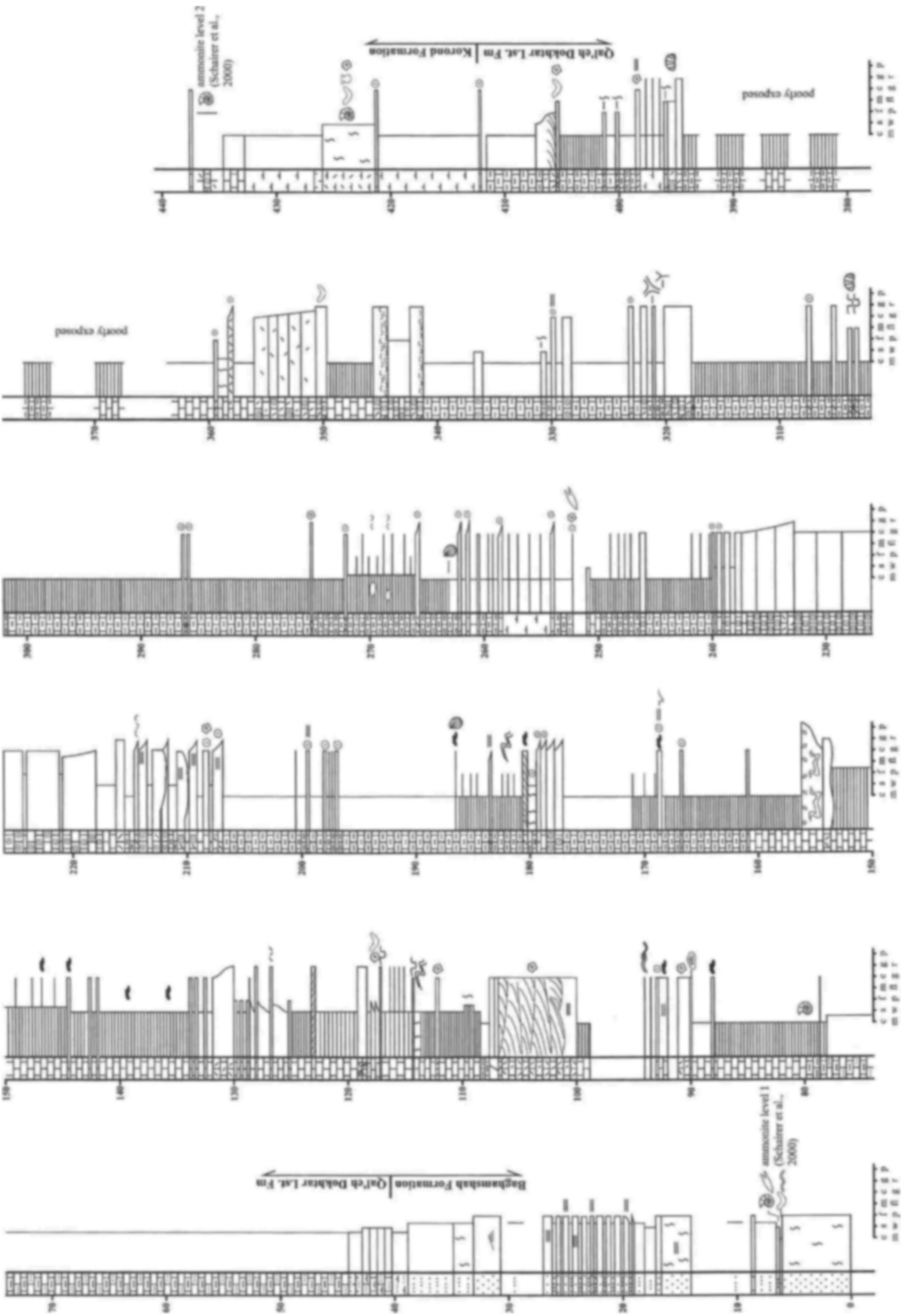


Fig. 7. Stratigraphic log of the Qal'eh Dokhtar Limestone Formation at the Qal'eh Dokhtar type section (redrawn after Schairer et al., 2000). For key of symbols see Fig. 4.

Majd Member of the Sikhor Formation is placed at a level were the sandstones turn increasingly bioclastic (oysters, echinoid spines, crinoid debris) and carbonates start to predominate (at about 47 m, Fig. 6). The Majd Member consists of a mixed sequence of plant-bearing sandstone, cross-bedded bioclastic sandstone, and oolitic/bioclastic limestone with fragments of brachiopods, crinoids, echinoids, bivalves, gastropods, and corals indicating a nearshore environment. The base of the Qal'ch Dokhtar Limestone Formation is placed at 118 m. Between 150 to 185 m, the rocks are strongly dolomitized. Up-section, the succession is characterized by alternations of well-bedded mudstones/ fine wackestones, sharp-based, graded biodetrital rud-/grainstones exhibiting cross-bedding and/or parallel lamination, conglomeratic layers with limestone clasts and chaetetid/ coral debris up to 30 cm in diameter, and interspersed sponge-microbialite buildups, often associated with *Tubiphytes*, brachiopods and oncoids (Pl. 32/7). Occasionally, individual beds or bedsets - except for the microbialites - show slumping structures (e.g., between 320 and 330 m and at 404 m). In the upper part of the section, the fine-grained limestones turn more marly, ammonites and belemnites occur and bioturbation (*Thalassinoides, Chondrites, Zoophycos*) increases. Shallow-water elements are confined to the graded and conglomeratic beds (e.g., chaetetids and ooids). The base of the Korond Formation is placed at 442 m, at the top of the last thick biodetrital limestone; from there onwards, marl predominates. The ammonite assemblage collected from this interval includes *Perisphinctes* (*Dichotomosphinctes*) aff. *marnesiae* (upper Middle Oxfordian *transversarium* Zone) and *Gregoryceras* (*G.*) cf. *fouquei* (*transversarium* to lower Upper Oxfordian *bifurcatus* Zone). These data indicate a late Middle to early Late Oxfordian age for the top of the Qal'eh Dokhtar Limestone Formation at this locality.

3.4 Qal'eh Dokhtar Limestone Formation, type section
(N 33°55'40", E 57°17'47", Fig. 7)

The Qal'eh Dokhtar Limestone Formation at the type section has a thickness of about 370 m and overlies the strongly silty Baghamshah Formation (Fig. 3, formerly known as the Siltstone Member of the Qal'eh Dokhtar Formation). It was measured approximately 10 km east of section 3.3 at the eastern slope of a north/south trending hill range at the western margin of the Rig-e-Boshrouyeh (Fig. 2; Pl. 32/5).

Lithologically, the Qal'eh Dokhtar Limestone Formation at the type locality is very similar to the section east of Korond (section 3.2) being mainly composed of marly mudstones, spiculitic wackestone and sharp-based biodetrital and oolitic limestone. However, graded bioclastic beds are thinner at this locality and in part replaced by sharp-based bioclastic ooid-grain- and packstones, sometimes showing flute casts at their base. Moreover, microbialites are much less common and conglomeratic layers are largely missing. The ichnofauna is basically the same as in the previous section and small-scale sediment deformation features due to slumping (at 114 m and 182 m) also occur (Pl. 32/6). At 154 m of the section (Fig. 6), convolute bedding is developed, capped by an intraformational conglomerate. Shallow-water elements are recorded only from the coarser beds, whereas the finer sediments yielded rare ammonites and belemnites. Near the top of the section (from 412 m onwards), marl predominates. It is here that the base of the Korond Formation is placed.

The age of the Qal'eh Dokhtar Limestone Formation at the type locality is biostratigraphically well constrained (Schairer et al., 2000). In the uppermost part of the underlying Baghamshah Formation, an ammonite assemblage of reineckeiid ammonites indicates a Middle Callovian age (Seyed-Emami et al., 2002). The ammonite level in the basal Korond Formation (level 2 of Schairer et al., 2000) contains *Orthosphinctes, Subdiscosphinctes, Larcheria, Aspidoceras,* and *Amoebopeltoceras* aff. *alberti*, and has been dated as Middle to Late Oxfordian. Thus, the base of the Korond Formation is here considerably older than at Korond, further west (section 3.2).

Based on macrofacies, sedimentary structures, macrofossil content and structural position, the four sections can be arranged along a platform-basin transect. The sections of the Esfandiar Limestone Formation at Kuh-e-Gelkan and at Korond represent the carbonate platform (called Esfandiar Platform), whereas the Qal'eh Dokhtar Limestone Formation east of Korond and at the type locality were deposited in a slope to basin setting. Accordingly, the various types of microfacies of the different environmental units (platform, slope, basin) are separately described below.

4 FACIES ANALYSIS

The facies analysis is primarily based on the study of rock specimens in the field and of thin-sections. It has been supplemented by observations in the field of features such as bedding, sedimentary structures, and fossil content.

4.1 Platform

Mudstones: Light-grey to white mudstones with minor amounts of microbioclasts occurring in well-bedded or massive units. This facies constitutes large parts of the Esfandiar Limestone Formation deposited in low-energy inner platform settings. The carbonate mud was at least partly derived from disintegration of peloids (Pl. 33/2) and green algae, but was possibly also from (mechanical and biological) erosion of biogenic hard parts or from microbial whitings (see discussion below).

Biowackestones: Grey, often thinly to medium-bedded, in part marly wackestones with variable amounts of microbioclasts (echinoderm and bivalve debris, sponge spicules), rare foraminifera (small textulariids and nodosariids) and peloids; this facies type often forms the matrix of floatstones (Pl. 33/3).

Peloid pack- to grainstones: Densely packed peloid pack-/grainstones with less than 10% microbioclasts and small textulariids (Pl. 33/1), often grading laterally and vertically into mudstone (Pl. 33/2). They were deposited in a (semi-) protected inner platform setting subject to episodic weak current/wave action. The transition from peloid packstone to mudstone suggests that part of the carbonate mud observed in thin-sections originated from the compaction and disintegration of soft peloids of faecal pellet origin.

Neuropora floatstones: Thick (0.3-2 m) beds of *Neuropora* floatstones are interspersed within the succession. The *Neuropora* fragments are usually less than one centimetre long and commonly show branching. Often, they are coated with a thin microbial layer and float within a fine-grained bioclastic wackestone matrix (Pl. 33/3) containing coral and brachiopod fragments as well as small *Tubiphytes* and peloids. Some of the larger bioclasts show micritized rims.

The large amounts of carbonate mud indicate a low-energy environment. However, episodic high-energy events may be indicated by the fragmentation of *Neuropora*, corals and brachiopods. A semi-protected setting within the inner platform area is inferred.

Onco-float- to rudstones: This facies occurs in distinct, laterally persisting, ~0.1 m to 2 m thick beds. The well-sorted oncoids reach diameters of up to 4 cm but are usually between 1 and 2 cm in size and contain skeletal nuclei (*Neuropora*, bivalves, gastropods). Spherical to weakly ovoid forms predominate. The coating consists of relatively dense microbial laminae with subordinate foraminifera (Pl. 33/5). The matrix between oncoids, if present, is a fine-bioclastic, sometimes marly wacke- to packstone. The bases of the oncoid float-/rudstones are usually sharp, whereas the tops often appear gradual.

This facies type was deposited in a shallow, lagoonal environment subject to intermittent current activity and relatively low accumulation rates. The oncolitic beds may represent transgressive episodes (Peryt, 1981) or wide, shallow channels on the platform.

Bioclastic rudstones: This facies type forms relatively rare intercalations, usually not exceeding one or two metres in thickness. It consists of poorly to medium-sorted debris of *Neuropora*, crinoids, (mainly punctate) brachiopods and *Tubiphytes* as well as rare corals and lithoclasts (Pl. 33/4). The pore space is usually filled with matrix (peloid-bearing, microbioclastic wacke- or packstone), rarely with sparry calcite. Crossbedding was not observed.

Bioclastic rudstone beds in platform setting are inferred to indicate short-term *in-situ* reworking of the platform sediments during high-energy events (i.e., storms) with limited lateral transport. This interpretation is corroborated by the poorly-sorted fabric of the rock, the presence of mud in pore spaces, and the absence of sedimentary structures such as grading or crossbedding, which indicates lack of hydrodynamic sorting. The component spectrum corresponds to that of the platform facies types.

Aggregate grainstones: They consist of usually well-sorted and rounded aggregate grains (mainly lumps) with a diameter of 1-2 mm and may contain variable amounts of ooids, micritized bioclasts and bahamite peloids (Pl. 33/7-8). The aggregate grainstones have been deposited in a shallow subtidal to intertidal environment with low accumulation rates and high, but varying water energy. Depending on the amount of bahamite peloids, this facies type grades into aggregate grain-bearing peloid grainstone (Pl. 33/6). The poorer sorting of this facies type suggests somewhat reduced energy levels. This facies type is found in the vicinity of the platform margin.

Diceratid floatstones: Large shells of diceratid bivalves (up to 0.1 m in height) float within a matrix of bioclastic

Plate 32 Field aspects of the Jurassic platform-basin transect, east-central Iran

Fig. 1. Massive to thickly-bedded limestones dipping to the east (top part of the Esfandiar Limestone Formation approximately 800 m south of Korond; persons [arrow] for scale).

Fig. 2. Top beds of the Esfandiar Limestone Formation (left) overlain by onlapping basinal marls of the Korond Formation. The transition between both formations (arrow) represents a drowning sequence (approximately 800 m south of Korond, see Fig. 5; exposed thickness approximately 50 m).

Fig. 3. Small sponge-microbialite patch intercalated between marly limestones (basal part of the Esfandiar Limestone Formation at Kuh-e-Gelkan; hammer for scale).

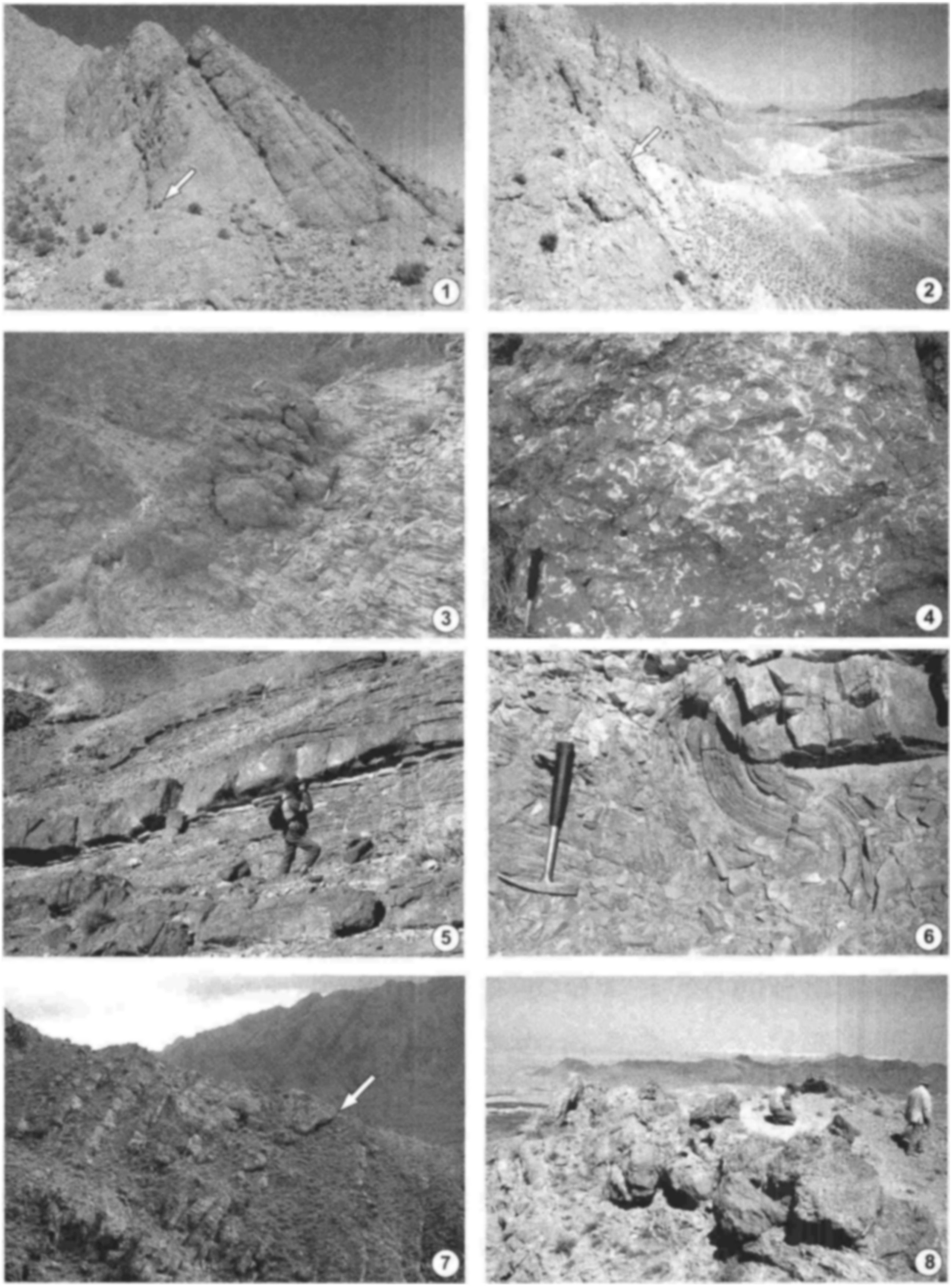
Fig. 4. Patch of diceratid shells on a bedding plane (type locality of the Esfandiar Limestone Formation at Kuh-e-Esfandiar in the southern part of the study area).

Fig. 5. Thickly-bedded allodapic limestones intercalated into thinly-bedded peri-platform mudstones at the type locality of the Qal'eh Dokhtar Limestone Formation.

Fig. 6. Slump fold involving a parallel-laminated allodapic limestone in the uppermost part of the Qal'eh Dokhtar Limestone Formation at the type locality.

Fig. 7. Qal'eh Dokhtar Limestone Formation east of Korond; the beds are overturned and dip to the east. Note convex-up structure (arrow) corresponding to a sponge-microbial buildup and lateral interfingering with bedded rocks (exposed thickness approximately 50 m; the mountains in the background are formed by the Esfandiar Limestone Formation).

Fig. 8. Olistostrome with olistoliths up to 2 m in diameter (Qal'eh Dokhtar Limestone Formation near Majd, approximately 10 km south of Korond; see Fig. 8)



wacke- to packstone with peloids. The shells are commonly articulated, commonly bored, and are usually heavily recrystallized (Pl. 32/4, Pl. 34/2). In part, they are geopetally infilled with red sediment, which can also replace the (dissolved) shell material. Occurrences of this facies type are laterally and vertically very restricted (patch-like, e.g., Pl. 32/4).

Diceratid floatstones were deposited in inner platform settings where the bivalves probably lived in patches as recliners on a soft substrate. Disintegration of shells might be due to reworking by episodic current/wave action or by bioerosion.

Coral/chaetetid rudstones ("bioconglomerates"): In this facies type, large fragments of (rare) corals and hemispherical chaetetids (Pl. 34/1) up to 20 cm in diameter "float" in a matrix of bioclastic or aggregate grain-bearing bioclastic grain- and rudstone. In addition, large, recrystallized shells of bivalves may occur. The internal fabric of these beds, which attain a thickness of up to one metre, is often chaotic. The chaetetids are commonly bored, mainly by bivalves.

Bioconglomeratic layers indicate, similar to bioclastic rudstones, *in-situ* reworking by storms of the platform sediments. The predominance of large chaetetids may reflect particularly heavy storm events or the proximity to the platform margin (see below).

Ooid grainstones: This facies type occurs in thick beds or massive units (Pl. 32/1). In some cases, trough crossbedding and erosive bases can be observed. The radial ooids are generally well-sorted and display numerous concentric laminae (Pl. 34/3). Their nuclei often consist of small bioclasts. Minor constituents of this facies type are bioclasts, which commonly show micritized rims, aggregate grains, and well-rounded bahamite peloids. Pore space is cemented by isopachous rim cement (A) and blocky calcite (B) (Pl. 34/3); in some cases, a first generation of meniscus cement followed by cement A and/or B is developed (Pl. 34/4).

Ooid grainstones predominantly occurred in the platform-margin area in thick-bedded to massive units, partly showing large-scale trough crossbedding. They are interpreted to represent ooid shoals at the high-energy margin of the Esfandiar Platform protecting the extensive platform interior from the open sea. The shoals were deposited in very shallow water and some of them were subject to episodic emersion as is indicated by early diagenetic vadose cements. The ooid shoals developed in close association with bioconglomerates and shell beds.

Shell beds: In the upper part of the Esfandiar Limestone Formation at Korond, densely packed shell beds up to 2 m in thickness occur which become more numerous up-section. The shell beds consist of single valves in predominantly convex-up orientation. Two types of shells can be recognized: a larger, thicker one (size around 10 cm and thickness up to 1 cm), which is usually strongly recrystallized and possibly represents diceratid bivalves, and a dark, thin, foliated type most likely representing oysters (size 3-5 cm and thickness several mm, Pl. 34/5). The matrix is a bioclastic and/or oolitic grainstone with aggregate grains.

The shell beds are interpreted as high-energy deposits in the area of the platform margin. They possibly formed in inter-shoal areas connecting the platform interior with the open sea.

Oolitic/bioclastic ferruginous oncolites: This facies type occurs only right at the top of the Esfandiar Limestone, at the transition to the Korond Formation (Pl. 32/2). It is characterized by oolitic and/or bioclastic oncoid rudstones/floatstones with a brownish colour (Pl. 34/6-7). Within the uppermost five metres of the Esfandiar Limestone Formation, some distinct trends can be recognized from base to top:

i) the oncoids get larger and their shape changes from nearly sub-spherical to lobate;

ii) the contribution of serpulids, foraminifera and *Tubiphytes* to oncoid growth increases;

Plate 33 Microfacies of the Jurassic Esfandiar Limestone Formation, east-central Iran.

Fig. 1. Peloid packstone (note relicts of sparitic rims around some of the peloids); upper Esfandiar Limestone Formation at Kuh-e-Bagh-e-Vang, width of field of view is 10 mm.

Fig. 2. Peloid packstone (right part of picture) grading into mudstone (left); upper Esfandiar Limestone Formation at Kuh-e-Bagh-e-Vang, width of field of view is 2 mm. This observation suggests that parts of the mudstone formed by peloid disintegration.

Fig. 3. *Neuropora* fragments (arrows) floating in a matrix of fine-bioclastic wackestone; note thin microbial coating around *Neuropora*. Lower Esfandiar Limestone Formation at Kuh-e-Gelkan, width of field of view is 10 mm.

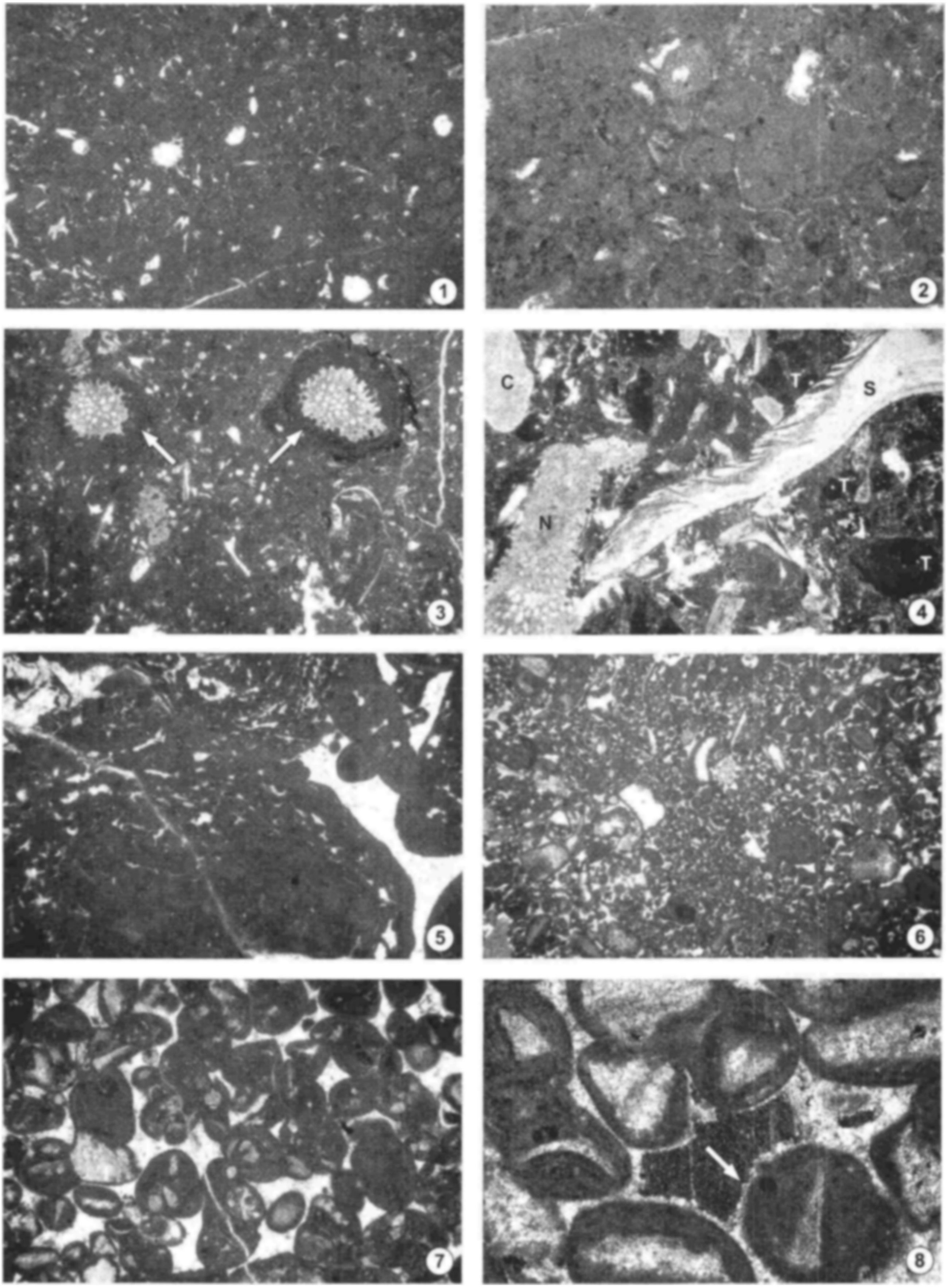
Fig. 4. Poorly sorted bioclastic rudstone with large shell fragment (S), crinoids (C), *Neuropora* (N) and *Tubiphytes* (T); Esfandiar Limestone Formation at Kuh-e-Gelkan, width of field of view is 10 mm.

Fig. 5. Oncoid rudstone; upper Esfandiar Limestone Formation at Kuh-e-Bagh-e-Vang, width of field of view is 10 mm.

Fig. 6. Moderately sorted, bioclastic peloid grainstone with some aggregate grains; some of the peloids display sparitic internal fabrics suggesting that they originated via micritization from bioclasts (bahamite peloids, cf. Pl. 33/8); upper Esfandiar Limestone Formation at Korond, width of field of view is 10 mm.

Fig. 7. Well-winnowed aggregate grainstone (lumps) with some bahamite peloids and ooids; upper Esfandiar Limestone Formation at Korond, width of field of view is 10 mm.

Fig. 8. Close-up of Pl. 33/7. Pore space between bahamite peloids and ooids is filled with cement showing a vadose fabric; note stubby fibrous rim cement (arrow). Upper Esfandiar Limestone Formation at Korond, width of field of view is 2 mm (crossed nicols).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iii) the percentage of ooids decreases;

iv) the matrix between oncoids changes from mainly sparite to marly bioclastic pack- and wackestone.

The oncoids in the lower part are smaller than 1 cm and commonly have ooids or small bioclasts as nuclei; the larger ones further up grew around larger bioclasts such as shells and sponges (*Neuropora*, calcareous sponges) and reach a maximum size of approximately 30 mm. The iron hydroxide occurs as impregnations of bioclasts and oncoids, as individual laminae in oncoids, or as finely disseminated oxidized framboids of pyrite. The most important bioclastic components are crinoids followed by shells of bivalves and brachiopods; sponges are also common. More marly layers of this rock type yield abundant cephalopods (nautiloids, ammonites) and are eventually overlain by marls of the Korond Formation (Pl. 32/2).

The oolitic/bioclastic oncolites and the observed vertical trends are inferred to reflect decreasing accumulation rates (beginning condensation, e.g., Peryt, 1977) and a rapid deepening at the top of the Esfandiar Limestone at Korond. This drowning, culminating in the spreading of the basinal Korond Formation over areas formerly characterized by shallow-water conditions, occurred, according to ammonite data, in the Late Oxfordian to Early Kimmeridgian. The contact between the Esfandiar Limestone and the Korond formations corresponds to a drowning sequence in the sense of Ehrlich et al. (1990).

Additional facies types recorded from other sections of the Esfandiar Limestone Formation, e.g. the type section of the Esfandiar Limestone Formation, a section near Robat-e-Dahaneh (N 33°56'57" - E 56°49'18"), and a section south of Kuh-e-Bagh-e-Vang (N 33°56'54" - E 56°47'05") both WNW of Kuh-e-Gelkan (see Fig. 2) include *Cladocoropsis* floatstones (*Cladocoropsis* probably also represents a branched sponge taxon, e.g., Termier et al., 1985) and *Cayeuxia* bindstones with gastropods and *Tubiphytes*. *Cladocoropsis* floatstones are similar in fabric and origin to *Neuropora* floatstones. *Cayeuxia* bindstones were deposited in sheltered lagoonal settings.

4.2 Slope

Sponge-microbialites: This facies type occurs as rather thick, stratiform units or as laterally restricted metre- to decametre-scale buildups with distinct convex-up shape (Pl. 32/7). It is characterized by irregular microbialites with a "clotted" fabric and laminar to digitate growth. Siliceous sponges (lithistids and hexactinellids) as well as *Tubiphytes*, some of them branched, serpulids and, in some cases, microsolenid corals are important constituents (Pl. 35/4). Internally, numerous irregularly-shaped growth cavities are (often geopetally) filled with microbial peloids (Pl. 35/4). The microbialites are commonly bored by bivalves and encrusted by serpulids and *Tubiphytes*); crinoids and terebratulid brachiopods occur as associated faunal elements. Laterally, this facies type may grade into oncolitic float- to rudstones and crinoid-bearing *Tubiphytes* wacke- to packstones.

Sponge-microbialites occurred abundantly in upper to middle slope settings of the Esfandiar Platform. Borings and encrusters testify their *in-situ* synsedimentary lithification. In the field, they can be shown to grade laterally into bedded facies types (Pl. 32/7). Commonly, they are overlain by

Plate 34 Microfacies of the Jurassic platform-basin transect (Esfandiar Limestone and Qal'eh Dokhtar Limestone formations), east-central Iran.

Fig. 1. Segment of a hemispherical chaetetid from the upper part of the Esfandiar Limestone Formation at Korond, width of field of view is 10 mm.

Fig. 2. Diceratid limestone. Diceratid shells (D) were subjected to early diagenetic dissolution and the voids were in part filled with red internal sediment (R) prior to recrystallization; upper Esfandiar Limestone Formation north of Korond.

Fig. 3. Ooid grainstone with isopachous rim cement (A, arrowed) followed by blocky sparite (B); upper Esfandiar Limestone Formation at Korond, width of field of view is 2.5 mm (crossed nicols).

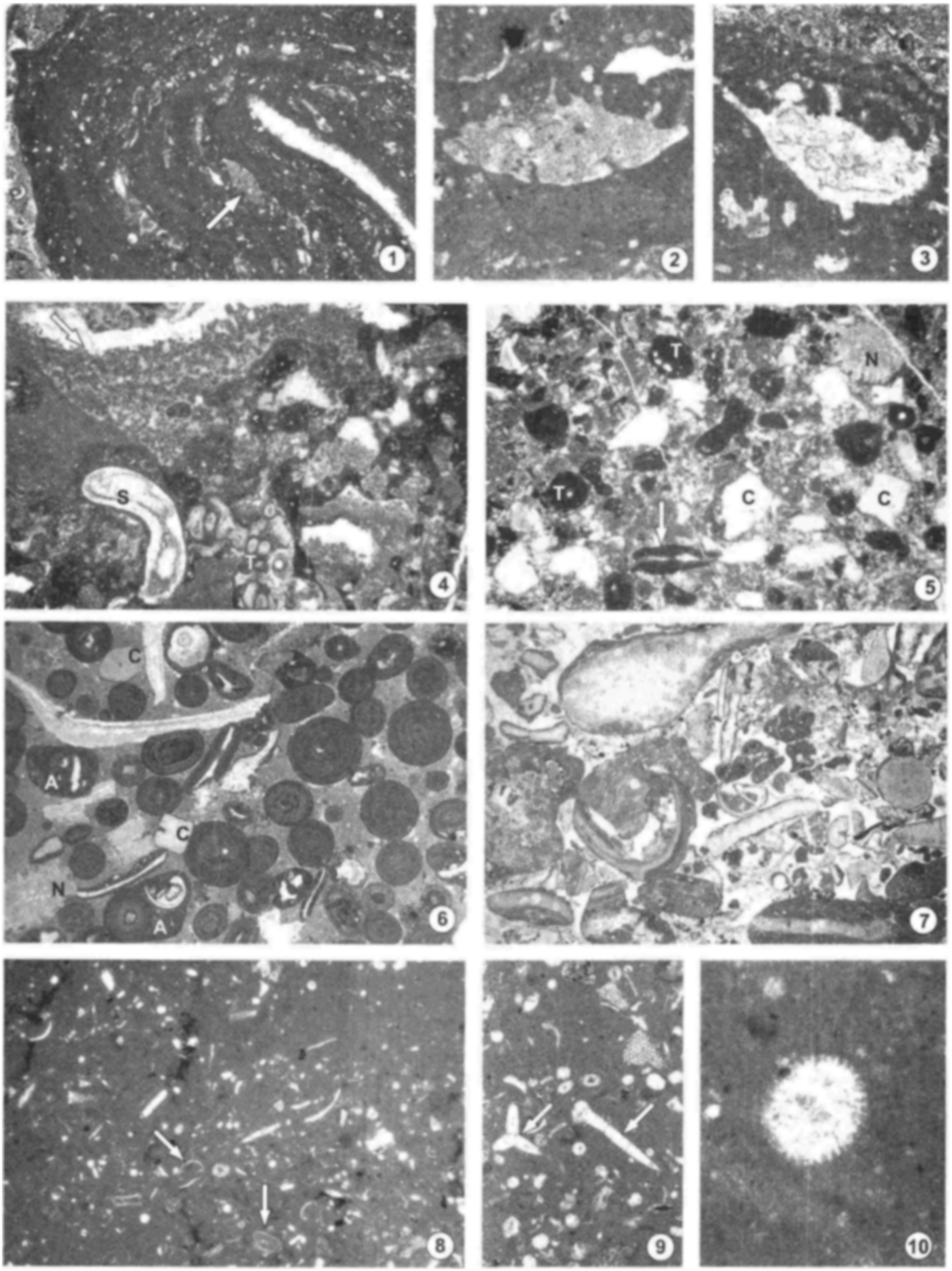
Fig. 4. Ooid grainstone cemented with (inferred) primarily aragonitic meniscus-type cements (M) followed by blocky calcite; upper Esfandiar Limestone Formation near Honu, northern Shotori Montains, width of field of view is 2.5 mm (crossed nicols).

Fig. 5. Oyster shells floating in a matrix of peloids and aggregate grains. This microfacies is characteristic of shell beds occurring near the top of the Esfandiar limestone Formation at Korond (see Fig. 5), width of field of view is 10 mm

Fig. 6. Oolitic and bioclastic oncolites from the uppermost Esfandiar Limestone Formation at Korond, width of field of view is 10 mm.

Fig. 7. Outer parts of two large, lobate ferruginous oncoids within bioclastic packstone matrix from the uppermost bed of the Esfandiar Limestone Formation at Korond (width of field of view is 10 mm); note the contribution of *Tubiphytes* (T) to final oncoid accretion.

Fig. 8. Oncoid floatstone from the Qal'eh Dokhtar Limestone Formation east of Korond; note larger rounded (arrows) and smaller incipient oncoids around shells.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corals, partly also articulated crinoid stems, cidaroid spines, gastropods, and bivalves) floating in a matrix of (in part marly) bioclastic wacke- to packstone. The skeletal elements in these deposits are usually very well preserved. Neither preferred orientation of components nor grading or sedimentary structures can be observed.

This facies type represents high-viscosity mud-flow deposits as is indicated by the internal fabric of the beds (e.g., Cook and Mullins, 1983). The mud flow deposits are usually intercalated between lower slope deposits (e.g., mudstones, wackestones, graded distal turbidites). The unusually good preservation of the enclosed platform biota can be attributed to the high-viscosity transport process. The lack of large limestone cobbles might indicate limited erosional and/or restricted transport capacity of the mud flows.

Bioclastic (Neuropora-rich) rud-/grainstones: This facies type occurs in sharp-based, rarely also erosional beds ranging from 5 cm up to >1 m in thickness (Pl. 32/5). The most abundant components are debris of *Neuropora*, crinoids, bivalves, brachiopods, *Tubiphytes*, gastropods and corals as well as fragments of oncoids and intraclasts (e.g., spiculitic wackestone; Pl. 35/7). Bioclasts are usually poorly sorted and are often coated with a thin layer of microbial micrite or are bored and micritized. Individual beds sometimes show normal grading from a poorly-sorted rudstone at the base to a better sorted grainstone, rarely also packstone, at the top. Pore space is usually filled with a thin isopachous rim of a fibrous cement A around all components followed by a blocky cement B completely closing primary porosity.

Bioclastic rud-/grainstones represent debris flows or, when graded, proximal calcareous turbidites ("allodapic limestones" *sensu* Meischner, 1964) deposited from low-viscosity turbidity currents (e.g., Cook and Mullins, 1983). They usually lack platform top-derived components such as ooids and aggregate grains.

Spiculitic wackestones: This fine-grained, often thinly bedded sediment is characterized by spiculitic (rhaxes, monaxones, triaens) wackestone with some microbioclasts, thin-shelled ostracods (Pl. 35/8-9) and radiolarians (spherical, calcite-filled moulds with a diameter of 0.1-0.5 mm and an ill-defined boundary to the sediment; Pl. 35/10). The internal fabric of the sediment tends to be inhomogeneous due to bioturbation. In the field, *Zoophycos*, *Chondrites*, and small *Thalassinoides* burrows were observed. Occasionally, the well-bedded wackestones show slumping structures.

Spiculitic wackestone is interpreted as autochthonous slope sediment composed of peri-platform muds (allomicrites) and subordinately of hard parts of authochthonous benthic (sponges) and planktic (ostracods, radiolarians) organisms (e.g., Enos and Moore, 1983).

4.3 Basin

Ooid pack-/grainstones: This facies type occurs in well-defined, sharp-based beds with a thickness of a few centimetres to more than 1 m, intercalated between typical basinal sediments (mud-/wackestones and marly mudstones). Apart from the dominant ooids, some bioclasts (most notably crinoid ossicles), aggregate grains, and small oncoids can occur (Pl. 35/6). Commonly, faint parallel lamination (Pl. 32/6) and flute casts can be observed; the beds are often not or only faintly graded due to the good sorting of components. The matrix of the packstones is usually recrystallized (pseudosparitic), originating from a fine bioclastic wackestone (Pl. 35/8). In the case of grainstone, the pore space is filled with a single cement generation of blocky calcite spar. Gradual transitions from pack- to grainstone may occur within a single sample. With a higher amount of bioclasts, some beds may be classified as oolitic bio-grain/packstones. In the Qal'eh Dokhtar type section (Fig. 7), bioclastic ooid pack-/grainstones are often bundled into thicker bedsets (e.g., between 205 and 235 m).

Ooid pack-/grainstones in basinal setting are interpreted as distal calcareous turbidites shed from the Esfandiar Platform. Their allochthonous nature is indicated by shallow-water components such as ooids and by basal flute casts, the latter testifying turbulent flow. Their distal character is indicated by the thin nature of the beds, good sorting of components and the infiltration of suspended material (matrix) into pore space. The bundling into bedsets might indicate deposition within submarine channels cutting into underlying fine-grained carbonates (e.g. between 207-217 m in the Qal'eh Dokhtar type section) and/or turbidite bundling due to highstand shedding of the carbonate platform (e.g., Droxler and Schlager, 1985).

Mud-/wackestones: This sediment is very similar to spiculitic wackestones recognized in slope settings of the Esfandiar Platform (see Pl. 35/8-10). It is characterized by bedded, partly microbioclastic, spiculitic wacke- to mudstones forming thick packages. Furthermore, radiolaria and thin-shelled ostracods may occur. The sediment is commonly bioturbated; trace fossils include *Zoophycos* and *Thalassinoides*. Often, chert nodules are developed.

The mud- to wackestones represent fine-grained basinal background sedimentation under the influence of Esfandiar peri-platform muds.

Marly mudstones: This facies type is characterized by homogeneous marly mudstone with subordinate biogenic components (some spicules, microbioclasts, ostracods). It forms either thick packages or intercalations between distal turbidites. Macrofossils include ammonites and belemnites as well as rare bivalves. The sediment appears completely bioturbated; however, individual trace fossils such as *Zoophycos* and *Chondrites* are only recognizable at bed contacts.

Marly mudstone represents the fine-grained basinal background sedimentation largely beyond the influence of Esfandiar Platform muds; only distal turbidites reflect the existence of a distant platform. This facies type, which is the typical lithology of the Korond Formation, starts to predominate in the upper part of the Qal'eh Dokhtar Limestone Formation (Figs 5, 6), indicating the withdrawal of the platform. This change in depositional style is equivalent to the initial deepening and beginning condensation recorded at the top of the Esfandiar Platform at Korond (see facies type ferruginous oncolites and discussion below).

5 DISCUSSION

Based on field observation and microfacies analysis, the Esfandiar Limestone and Qal'eh Dokhtar Limestone formations in the Shotori Mountains are interpreted as flat-topped, rimmed carbonate platform and associated slope to basin system. This interpretation is in contrast to the original assumption of Stöcklin et al. (1965), who considered the entire Qal'eh Dokhtar Limestone Formation as "back reef" facies of the "reefal" Esfandiar Platform. However, as shown above and discussed below, a "back reef" setting of the Qal'eh Dokhtar Limestone Formation is highly unlikely.

5.1 The Esfandiar Platform

The limestones of the Esfandiar Limestone Formation were deposited on a shallow, flat-topped carbonate platform (Esfandiar Platform) that developed at the eastern margin of the Tabas Block in the Early Callovian. The Esfadiar Platform extended for at least 170 km in a NNW-SSE direction with a maximum width of 30-40 km. In a broad sense, the platform was structured into a high-energy margin facies and a platform interior facies. The extensive lagoonal platform interior was characterized by a low-energy depositional regime and thus fine-grained limestones (mudstones, fine bioclastic wackestones, peloid pack-/grainstones, *Neuropora* floatstones) predominate. In the vicinity of the platform margin, where energy levels were higher, an aggregate grain facies developed. Organismic density was probably very low because macrofossils are extremely rare; noteworthy are the occurrences of diceratids, sponges (chaetetids, *Neuropora*, *Cladocoropsis*), and rare calcareous algae. The diceratids lived as sediment recliners in loosely packed clusters. Dendroid *Neuropora* and *Cladocoropsis* probably formed meadows rather than solid structures; especially the sclerosponge *Neuropora* was very abundant. *Neuropora* is a common component of Upper Jurassic carbonate depositional systems and occupied a wide bathymetric and ecologic range, from shallow coral to deeper siliceous sponge facies (e.g., Leinfelder et al., 1993a; Nose, 1995). This agrees with our observations since *Neuropora* occurs ubiquitously in sediments of both, platform and slope settings. Hemispherical chaetetids reached up to 50 cm in diameter and formed meadows or grew as isolated patches on the platform, especially in the areas close to the protective marginal shoals characterized by firm substrates (aggregate grainstones) and moderate energy levels. Such substrate and water energy preferences of chaetetids have also been reported in the literature (e.g., Connolly et al., 1989; West and Kershaw, 1991). Chaetetids are usually inferred to indicate shallow subtidal environments, and even a symbiosis with zooxanthellate algae is discussed (Connolly et al., 1989). Both, diceratids and chaetetids are commonly bored by bivalves, thus supporting the shallow water interpretation (Leinfelder et al., 1993a; Schmid, 1995: fig. 143). In addition, this interpretation is corroborated by rare occurrences of calcareous algae (codiaceans), indicating deposition in very shallow, light-saturated water (upper euphotic zone, probably less than 20 m water depth; e.g., Liebau, 1984). The low-energy environment of the platform interior was episodically subjected to storms as is evidenced by chaotic and poorly sorted bioconglomeratic layers and bioclastic rudstones indicating *in-situ* reworking of the platform sediments. Laterally widespread oncolitic layers indicate reduced accumulation rates and somewhat increased energy levels; they might represent transgressive episodes (Peryt, 1981) or deposition in wide channels dissecting the platform top. Buchanan et al. (1972) reported Recent oncoids with a sub-spherical shape and a diameter of 1.5 to 3 cm completely covering the bottom of a roughly 2 m deep tidal channel on the Great Bahama Bank. Emersion of the Esfandiar Platform during low sea-level stands might be indicated by the early dissolution of diceratid shells followed by infilling of the voids with red internal sediment (Pl. 34/2). In contrast to many carbonate platforms described from the geological record (e.g., Fischer, 1964; Goldhammer et al., 1990; Strasser, 1988, 1991), the inner platform deposits of the Esfandiar Platform do not show a cyclic pattern such as stacked, high-frequency shallowing-upward cycles. Apparently, carbonate production generally was not sufficient to rapidly fill available accommodation space.

In contrast to the platform interior, the platform margin was characterized by high-energy environments. Characteristic sediments are ooid grainstones, bioconglomerates and shell beds. The ooids were piled up to form well-sorted and winnowed grainstone shoals with variable amounts of bioclasts; in part they show large-scale trough-crossbedding. The shoals were deposited in very shallow water, which is suggested by vadose fabrics of early cementation. However, the micritic meniscus-type cements shown in Pl. 34/4 may also have originated in a subtidal setting by initial microbial stabilization of carbonate sands (Hillgärtner et al., 2001). Inter-shoal areas were characterized by shell beds and some chaetetid bioconglomerates. The shoal facies fringes the eastern margin of the NNW/SSE-trending Esfandiar Platform and sheltered the platform interior from the open sea further east. The position of the platform margin was tectonically induced and is related to increasing fault-controlled subsidence at the eastern margin of the Tabas Block (Figs 1, 3). According to Fürsich et al. (2003), the eastern margin of the Tabas Block represents the footwall scarp of a west-dipping fault block. Therefore, eastward progradation of the platform was limited and the position of the margin was fixed by high rates of subsidence at the footwall scarp (see Leeder and Gawthorpe, 1987). On the NNW-SSE crest of the fault block ("Shotori Swell"), the Esfandiar Platform, and on the gently westward inclined hanging wall dip-slope the shelf lagoon of the Kamar-e-Mehdi Formation developed.

Although organismic diversity appears to have been slightly higher at the platform margin, in no case larger reef structures were observed (which is also true for the platform interior). Only locally, small patch reefs or reef meadows of corals and calcareous sponges existed. For example, NW of Esfak (Fig. 2), reefal elements occur abundantly in debris and mud flow deposits of middle to lower slope settings.

However, the Esfandiar Limestone Formation cannot be regarded as "reefal limestone" or as a barrier reef.

In many Recent and fossil carbonate platforms, their rims are stabilized by reef bodies (e.g., Read, 1985). In the case of the Esfandiar Platform, the rim was predominantly built of ooid shoals. Stabilization of this kind of platform margin may have been aided by microbial activity and/or early diagenetic cementation of the shoals. According to Schlager (1992), carbonate sand shoals are able to build stable barriers at platform margins. Parts of the margin of the Recent Bahama Platform also lack reefal support but are formed by ooid shoals or skeletal sands (e.g., Newell et al., 1959; Harris, 1983).

5.2 The slope

The sediments of the Qal'eh Dokhtar Limestone Formation were deposited on the eastward-dipping slope of the Esfandiar Platform and in the adjacent basin. They are composed of gravitationally transported sediments derived from the shallow-water platform areas, autochthonous microbialites and fines deposited from suspension.

The upper slope (section 3.3) shows a predominance of sponge-microbial buildups (Pl. 32/7, Pl. 35/4). These microbial reefs thrived along the slope of the Esfandiar Platform and are commonly associated with lithistid and hexactinellid sponges, microsolenid corals and *Tubiphytes*. The microbialites form cone-shaped patches up to 15 m in thickness (Pl. 32/7), and are characterized by clotted internal fabrics and growth cavities filled with internal sediment. Commonly, they are bored, mainly by bivalves and encrusted by serpulids and *Tubiphytes* pointing to syndepositional lithification of the structures. Laterally, microbial reefs may grade into oncolitic float- and rudstones or crinoid/ *Tubiphytes* packstones, which alternate with spiculitic mud-/wackestones and coarse, platform-derived allochthonites. Sponge-microbial buildups are thought to indicate a certain minimum water depth (generally deeper than 50 m, e.g. Reitner and Neuweiler, 1995) and reduced accumulation rates (Leinfelder et al., 1993b, 1994; Schmid, 1996). In slope settings, they are confined to areas and/or time intervals of reduced input of coarse platform material. Similar carbonate platform slope sequences were recorded, for example, from the Lias of Morocco (Kenter and Campbell, 1991; Scheibner and Reijmer, 1999). Schlagintweit and Ebli (1999) report a siliceous sponge/*Tubiphytes* facies from the middle slope of Late Jurassic/Early Cretaceous carbonate platforms of the Northern Calcareous Alps. Ellis et al. (1985) described thrombolitic mounds with siliceous sponges and *Tubiphytes* from the Upper Jurassic/Lower Cretaceous off Nova Scotia. According to the authors, the buildups thrived on slopes of carbonate ramps and steepened platform margins in deeper waters (several 10's to 100's of metres).

Types of mass transport (see Cook and Mullins, 1983) on the slope of the Esfandiar Platform include slides and sediment gravity flows. The sediment gravity flow deposits include turbiditic (allodapic) graded bioclastic grain-/ rudstones and ooid grainstones, debris flows, and mud flows. The allodapic limestones were deposited from low-viscosity turbidity currents flowing down the slope of the Esfandiar Platform. This interpretation is supported by the sharp, sometimes erosional bases, flute casts, normal grading of components, and the shallow-water components (e.g. bioclasts of platform biota, ooids). Occasional convoluted bedding suggests rapid deposition of the coarse beds. A proximal-distal trend can be shown from the section east of Korond (3.3) and the Qal'eh Dokhtar type section (3.4; upper/middle slope and lower slope to basin, respectively). The former section is characterized by thick, bioclastic beds (mainly *Neuropora*-rich rudstones, Pl. 35/7), whereas the latter shows thinner allodapic limestones, mainly well-sorted ooid and bioclastic (crinoid) pack-/grainstones (Pl. 35/6) bundled into thicker bedsets. The same proximal-distal trend holds true for the distribution of debris flow and mud flow deposits originating from high-viscosity gravity flows. These beds, which contain large shallow-water biota (coral heads, chaetetids) and lithified limestone clasts up to 30 cm in diameter (derived from eroded platform and slope deposits) and commonly show poorly organized to chaotic internal fabrics, are more common in the proximal section east of Korond and reflect deposition on the steeper mid-slope. These sediments could maintain steeper angles of repose because of their coarser grain size and poorer sorting (Kenter, 1990). In contrast, the better sorted, finer-grained allodapic limestones characterizing the distal Qal'eh Dokhtar type section were transported further down-slope to come to rest on the less steep lower slope due to their smaller angle of repose. Characteristically, these sediments occur in bedsets several metres in thickness, which represent short-term bundling of depositional events. An analogous situation was described by Blomeier and Reijmer (2002) for the Liassic Jebel Bou Dahar platform of Morocco.

The slope interpretation of large parts of the Qal'eh Dokhtar Limestone Formation is also supported by slump structures due to sliding (Pl. 32/6). The slope of the Esfandiar Platform in the described transect may best be characterized as a depositional slope (e.g., Enos and Moore, 1983) with a low to medium angle. This is suggested by the enormous lateral extent of the slope towards the east (at least 10 km): Assuming an average slope angle of 6°, the bathymetric difference between platform margin and toe-of-slope would have been approximately 1,300 m, a very high value for the adjacent basin. This interpretation is corroborated by the lack of olistoliths, rare debris flow deposits and only small-scale slumping. However, the slope angle of the platform varied laterally: at Majd (co-ordinates N 33°46'34", E 57°15'01"), less than ten kilometres to the south of the described transect, olistostromes (with olistoliths up to 4 m in diameter) and debris flow deposits constitute a large part of the slope sediments of the Esfandiar Platform (Fig. 8, Pl. 32/8), indicating a steeper slope angle and repeated submarine gravity sliding and/or large-scale slumping at this locality. Olistoliths of lithified platform sediment (e.g. diceratid and coral limestone) most likely indicate subaerial exposure accompanied by substantial erosion of the adjacent platform.

5.3 The basin

The toe-of-slope and basin show a predominance of (marly) mudstones and spiculitic wackestones and thin, mainly sharp-based ooid and bioclastic pack-/grainstones. The latter beds are interpreted as distal allodapic limestones (see above). The fine-grained, often thinly-bedded limestones are interpreted as autochthonous peri-platform muds that settled from suspension (background sedimention). In part they are rich in sponge spicules (Pl. 35/8-9) and contain an open marine nektic fauna of belemnites and ammonites as well as planktic organisms such as radiolaria and thin-shelled ostracods (Pl. 35/8, 10). The interbedded allochthonous and autochthonous sediments supported a moderately diverse ichnofauna of infaunal deposit-feeders such as *Zoophycos* and *Rhizocorallium*. Similar lithofacies associations have been reported from lower slope to basin transitions of Jurassic carbonate platforms elsewhere (e.g., Blomeier and Reijmer, 2002).

Basinal areas largely beyond the influence of Esfandiar peri-platform muds are characterized by deposition of monotonous greenish marls (sediments of the Korond Formation).

5.4 Growth and disintegration of the Platform

The development of the Esfandiar Platform commenced in the Early Callovian after a phase of strong siliciclastic input (Sikhor Formation) following the asymmetric uplift of the eastern margin of the Tabas Block (Figs 3, 9; Fürsich et al., 2003). The crest of this NNW-SSE trending fault block ("Shotori Swell") served as the nucleus for platform growth. According to Fürsich et al. (2003) and Seyed-Emami et al. (submitted), the southwestern parts of the Shotori Mountains were repeatedly sites of tectonic uplift and erosion during the Jurassic. In this area, the Baghamshah Formation is strongly reduced and the Sikhor Formation, if present, is developed in partly conglomeratic, fluvial facies. At some localities, the Sikhor Formation is completely missing and the Esfandiar Limestone Formation transgressed across eroded silty marls of the Baghamshah Formation.

Carbonate deposition started at the eastern margin of the Tabas Block in areas sheltered from siliciclastic input of the Sikhor Formation ("clastic shadows", e.g. Kuh-e-Gelkan), and later, with decreasing terrigenous supply, spread into areas characterized earlier on by deltaic deposits and onto formerly emergent areas. There, initially mixed and/or interbedded siliciclastic-carbonate shallow-water sediments accumulated (Majd Member of the Sikhor Formation, e.g., section east of Korond). The early developmental stages of the Esfandiar Platform are represented by ramp-deposits (Fürsich et al., 2003). The gradual transition from the basinal sediments of the Baghamshah Formation to the Esfandiar Limestone Formation at Kuh-e-Gelkan (Fig. 4) likewise suggests a ramp geometry without steep slopes. This initial ramp stage cannot be dated precisely, but most likely is of Early to Middle Callovian age.

During the Late Callovian to Early Oxfordian, the

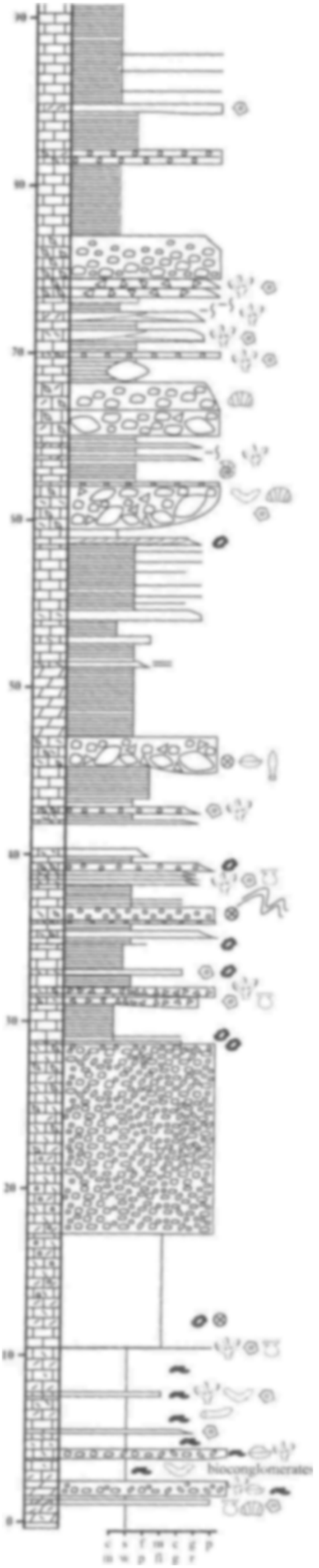

Fig. 8. Part of the section near Majd showing abundant debris flow deposits and olistostromes of the Qal'eh Dokhtar Limestone Formation (compare with Pl. 32/8). For key of symbols see Fig. 4.

Esfandiar Platform developed into a flat-topped, rimmed barrier platform fringing the eastern margin of the Tabas Block for more than 150 km. It supplied large amounts of carbonates to the slope and basinal areas (suspended peri-platform muds and gravitational sediments). There are three factors that may have influenced the observed transgressive development and the general change of the depositional regime from siliciclastics to carbonates in the Callovian:

(1) There was a northward expansion of the arid zones into southern Eurasia around the Middle to Late Jurassic boundary with arid conditions prevailing troughout the Late Jurassic (e.g., Hallam, 1984; Valdes and Sellwood, 1992). Increasing aridity would have decreased the influx of terrigenous sediments and favoured deposition of carbonates.

(2) Starting in the Early Callovian, global sea-level steadily rose to reach a Jurassic maximum in the Tithonian (e.g. Hallam, 1992; Hardenbol et al., 1998); the Middle Callovian represents one of the most important transgressive/deepening events in the whole Jurassic that is also well-documented in the Alborz Chain (pers. obs. K.S.-E.), in the Salt Range of Pakistan, and in the Himalayas (Hallam, 2001).

(3) After rapid denudation of the source areas (causing progradation of the Sikhor deltas), the regional Early Callovian uplift phase might have been followed by increased tectonic subsidence.

The high-productivity phase of the Esfandiar Platform was abruptly terminated in the Late Oxfordian when large parts of the platform drowned and were covered with basinal sediments of the Korond Formation (Fig. 9, Pl. 32/2). The demise was initiated at the eastern platform margin with the appearance of ferruginous, bioclastic, oncolitic rudstones and bioclastic marls with corroded and glauconitized ammonites overlying ooid shoal deposits, indicating deepening and condensation. Contemporaneously, the debris signal of the platform was strongly reduced and eventually switched off on the slope and in the basin so that homogeneous deep water marls (Korond Formation) accumulated on top of the Qal'eh Dokhtar Limestone Formation. Available ammonite evidence suggests a late Middle to early Late Oxfordian age (*transversarium* to *bifurcatus* zones) for the withdrawal and a Late Oxfordian to Early Kimmeridgian age for the drowning sequence at Korond (*bimammatum* to *platynota* zones; Fig. 9). Further to the west, relicts of the Esfandiar Platform continued to grow and shallow-water deposits probably persisted into the Kimmeridgian. Although there is strong evidence for global 3rd order transgressions and concomitant deposition of C_{org}-rich sediments in the *transversarium* and *bimammatum* zones (e.g., Leinfelder, 1993; Weissert and Mohr, 1996), we think that block faulting was responsible for the partial drowning of the eastern platform areas because of the strong evidence for regional tectonic movements (Seyed-Emami et al., submitted).

5.5 Carbonate factory and sequence stratigraphy

Despite a palaeolatitudinal position favourable for reef growth, reef structures are nearly absent from the Esfandiar Platform. Instead, the Esfandiar Platform was mud-dominated. The origin of the enormous amount of carbonate mud is somewhat problematic. Green algae, which are commonly accepted as important primary producers of carbonate mud in shallow-water settings, are not well represented in the sediments of the Esfandiar Platform (the preservation potential of green algae is usually low). Soft peloids originating as faecal pellets, which either disintegrated or were compacted, possibly were an additional source for mudstones formation. A certain amount of the carbonate mud was probably related to bio- and mechanical erosion of hart parts of organisms. As recent studies have shown (e.g., Thompson, 2000), microbial whitings might be of considerable importance for the formation of carbonate muds on shallow carbonate platforms. However, the complex processes involved are not yet fully understood.

A simple division of the thickness of the platform succession (600-800 m) by the time interval in question (7.5 my; Middle Callovian to Late Oxfordian, cf. Gradstein et al., 1994; Pálfy et al., 2000) results in an accumulation rate of about 80-100 m/my which, according to Bosscher and Schlager (1993), is an average value (mean values for longer time intervals usually range between 100 and 200 m/my). However, the platform also exported large amounts of sediment into the eastern slope and basinal areas (suspended carbonate mud and allochthonites) as well as into the western areas represented by the extensive shelf lagoon of the Kamar-e-Mehdi Formation. The bundling of allodapic limestones in certain stratigraphic intervals of the lower slope and basinal area (e.g. Qal'eh Dokhtar type section between 205 and 240 m) is inferred to indicate "export pulses" of the platform (Fig. 9) (Mullins, 1983; Droxler and Schlager, 1985; Haak and Schlager, 1989). They should correspond to a productive carbonate factory flourishing on the flooded platform top ("turbidite bundling" *sensu* Droxler and Schlager, 1985; "highstand shedding" *sensu* Schlager et al., 1994). Highstand shedding is common in productive low-latitude platforms and the interpretation is supported by the composition of the exported sediment, which is rich in non-skeletal grains such as ooids and aggregates usually developing on flooded platform areas during sea-level rise and highstand (e.g., Reijmer et al., 1991, 1994). These well sorted and relatively fine-grained sediments bypassed the steep middle slope. The bypassing of sediment favoured the development of microbialites in upper and mid-slope settings. During lowstands of sea-level, the productive area of the platform was strongly reduced in size and shifted towards the outer margin where a "lowstand factory" characterized by production of predominantly skeletal material (e.g., Haak and Schlager, 1988; Reijmer et al., 1991, 1994) became established. Sediment export of the latter is documented by packages of skeletal grain-/rudstones and debris flow deposits that accumulated on the steeper middle slope. On the lower slope and in the basin, in contrast, deposition of fine background sediments prevailed. A similar relationship between highstand and lowstand allochthonites was observed in carbonate platforms systems from both the Recent and the geological record (e.g., Crevello and Schlager, 1980; Whalen et al., 2000; Blomeier and Reijmer, 2002).

The development of microbialites in upper to mid-slope settings corresponds to phases of low net-accumulation rates. Commonly, those phases are thought to be linked to transgressive pulses of sea-level (e.g., Leinfelder et al., 1993b; Schmid, 1996). In the case of the Esfandiar Platform, times of low-net accumulation coincided with transgressive and highstand conditions, when sediment produced on the flooded platform top bypassed the steeper segments of the slope (Fig. 9).

Based on the stratigraphic and sedimentological data presented above and based on the dynamics of carbonate platform systems in response to sea-level variations (e.g., Schlager, 1992), a tentative sequence stratigraphic platform-basin correlation can be carried out (Fig. 9). Approximately 9 to 10 depositional sequences (DS) were recognized from the Middle Callovian to (early?) Late Oxfordian. The sequence boundaries were placed on the slope at the base of bioclastic rudstones and debris flow deposits interpreted as lowstand wedges (cf. Whalen et al, 2000; Blomeier and Reijmer, 2002). The lowstand deposits reach their greatest thickness on the middle slope and thin both in a basinward and up-slope direction. On the lower slope and in the basin, the lowstand interval is documented by few allochthonites interspersed between fine-grained background sediment (marls, marly mudstones). On the platform, the lowstand intervals are represented by gaps and the succession is composed of trangressive (TST) and highstand (HST) systems tracts (stacked TST/HST sequences). The oncolite layers on the platform are interpreted as early transgressive deposits (cf. Peryt, 1981), and their bases represent fused sequence boundaries and transgressive surfaces. On the slope, the TST/HST intervals are characterized by microbialites (middle slope) and by bundled calciturbidites with abundant platform top components such as ooids and aggregate grains (lower slope). These allochthonites bypassed the steeper middle slope and document highstand shedding of the flourishing carbonate factory (cf. Droxler and Schlager, 1985; Schlager et al., 1994; Blomeier and Reijmer, 2002). From the late Middle Oxfordian *transversarium* Zone onwards, a decrease in shedding documents a general retrogradational development of the platform culminating in the drowning sequence and the onlap of the basinal sediments observed at Korond.

5.6 Palaeogeography and palaeo-oceanography

The Esfandiar Platform carbonate factory probably thrived in an arid setting. Palaeogeographic reconstructions place the Tabas Block during the Callovian between 20 and 30°N (Enay et al., 1993). In the Early Kimmeridgian, it was situated around 20°N (Cecca et al., 1993). A low latitude position of the Esfandiar Platform is also indicated by the production of large amounts of carbonate mud, aggregates and ooids and the tendency to highstand shedding, which is typical of tropical warm water carbonates (e.g., Nelson, 1988; Schlager et al., 1994). Climatic indicators such as rare intercalations of thin red beds and the development of gypsum in the shelf lagoon facies of the Kamar-e-Mehdi Formation further to the west support arid conditions which are in accordance with the distribution of climatically significant rocks for the Late Jurassic (e.g., Hallam, 1984) and numerical global circulation models (GCM) for the Kimmeridgian (Valdes and Sellwood, 1992).

The absence of larger coral reef structures from the Esfandiar Platform, despite a palaeogeographical position favouring reef growth, and the abundance of microbialites is striking and requires an explanation. Reef-building scleractinian corals are highly adapted to nutrient-deficient environments and the growth of modern and fossil coral reefs is strongly reduced by nutrient excess (e.g., Hallock and Schlager, 1986; Limmon, 1996). Apart from a reduced background sedimentation, fluctuating oxygen and nutrient levels are held to be responsible for the extensive development of Upper Jurassic siliceous sponge-rich microbialites (especially with thrombolitic fabric; Leinfelder, 1993; Leinfelder et al., 1993b). The widespread occurrence of thrombolites along the northern Tethyan margin during the Late Jurassic was attributed by Weissert and Mohr (1996) to widespread eutrophication of Oxfordian to Kimmeridgian coastal water-masses. Increased nutrient transfer from the hinterland in response to accelerated weathering and erosion would have resulted in widespread development of low-oxygen water masses. In the case of the Esfandiar Platform, the scarcity of coral reefs and the abundance of microbial communities (such as oncoids, siliceous sponge-microbialite buildups), especially on the upper slope, and the abundance of shell concentrations of suspension-feeding bivalves could be related to meso- or eutrophic conditions (e.g., Brasier, 1995) and concomitant low-oxygen deeper water masses. However, nutrient input from the hinterland of the Esfandiar Platform (Yazd Block?) was probably low as is indicated by the low terrigenous (i.e., fluvial) input due to the dry climate. Therefore, we favour coastal upwelling of nutrient-rich and oxygen-poor waters along the slope of the platform to explain the lack of coral reefs and the abundance of siliceous sponge-rich microbialites. Plate tectonic reconstructions (Dercourt et al., 1986) suggest that, during the Jurassic, the CEIM occupied a pre-rotational position so that the (present-day) eastern margin of the Tabas Block was more or less E-W orientated and faced the Neothethys. The inferred upwelling system could have been triggered by offshore-blowing NE trade winds. Roberts and Phipps (1988) presented a Holocene example of coral reef growth limited by upwelling of nutrient-rich waters in the eastern Java Sea. However, further investigations are needed to test this hypothesis.

6 CONCLUSIONS

Following a phase of predominantly siliciclastic sedimentation in the Early and Middle Jurassic, a highly productive, low-latitude carbonate depositional system (Esfandiar Subgroup, Wilmsen et al., 2003) was established at the eastern margin of the Tabas Block in east-central Iran during the Callovian to Early Kimmeridgian. Running parallel to the eastern block margin, a NNW/SSE-trending flat-topped,

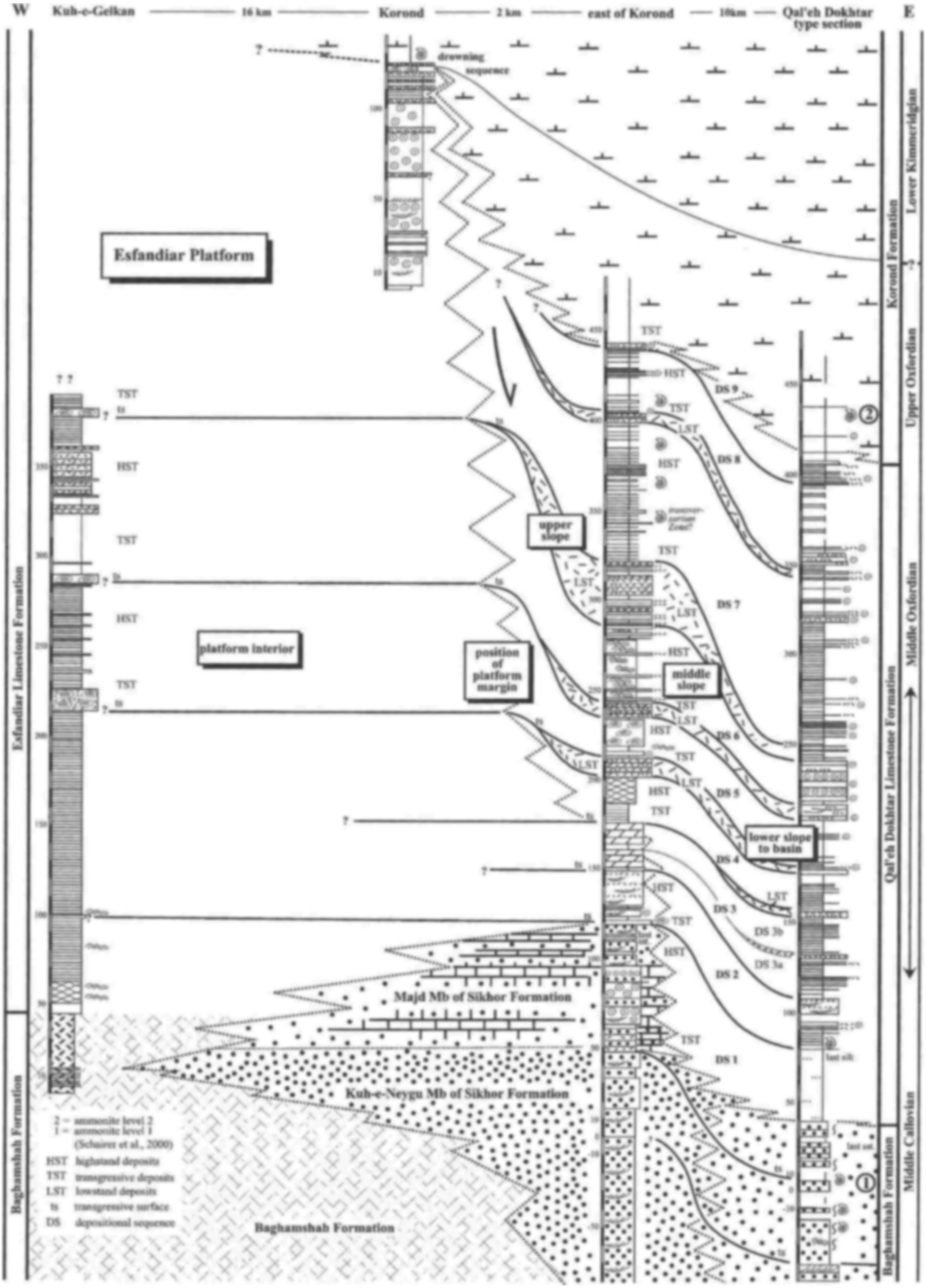

Fig. 9. Platform-basin correlation based on four sections (simplified after Figs 4-7). Note bioclastic lowstand wedges on the middle slope and the bundling of platform top-derived calciturbidites on the lower slope (interpreted as highstand shedding) as well as the spreading of the basinal Korond Formation over the platform top during the Late Oxfordian to Early Kimmeridgian (drowning). For key of symbols see Fig. 4.

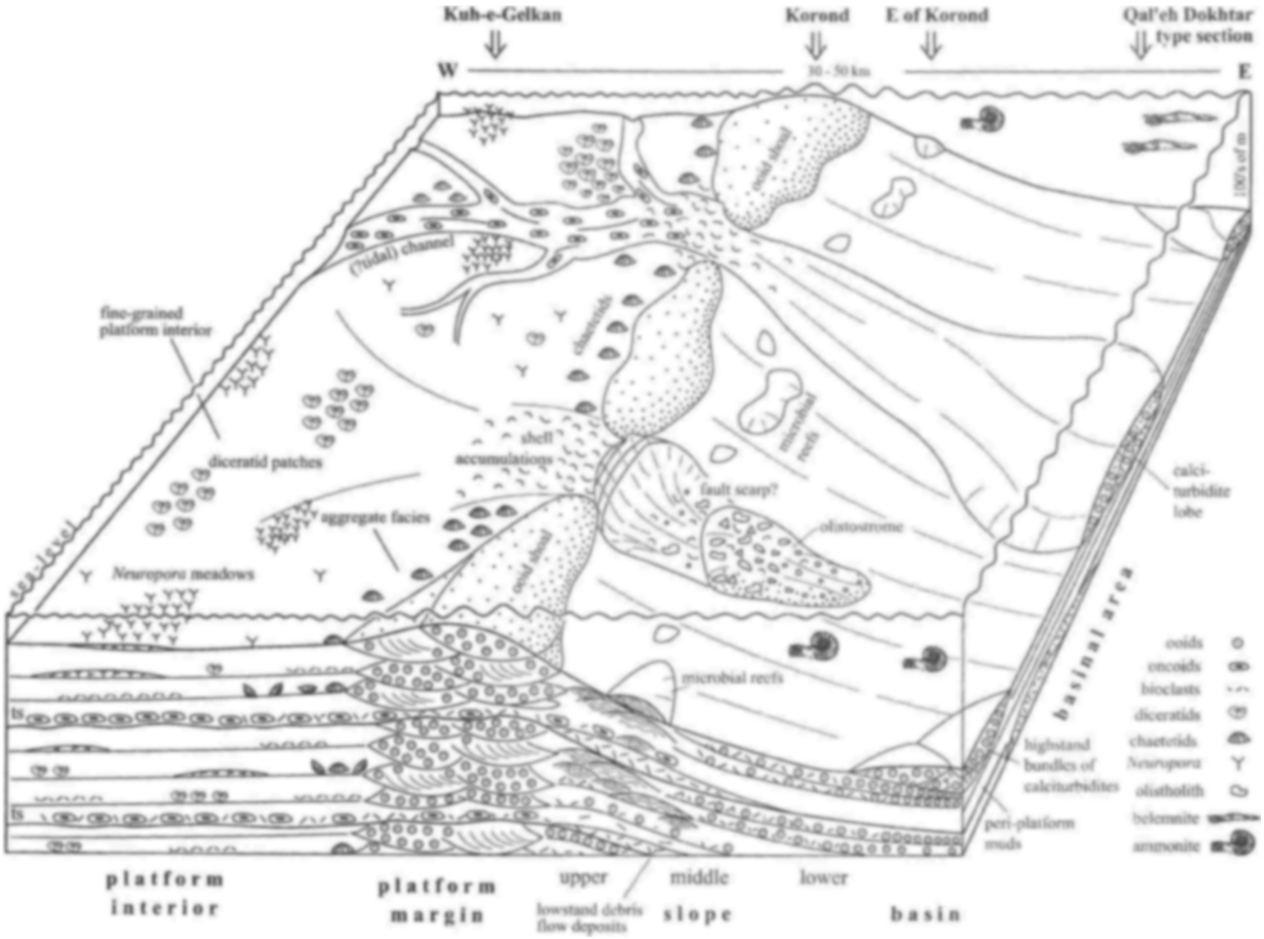

Fig. 10. Synoptic facies model of the eastern margin of the Esfandiar Platform based on sections between Esfak and Majd (see Fig. 2).

rimmed carbonate platform developed on the crest of a tilted fault block ("Shotori Swell"; see Fürsich et al., 2003). The growth of this platform strongly influenced the Upper Jurassic facies pattern and sedimentary history of the Tabas Block. The platform sediments, represented by the Esfandiar Limestone Formation, pass eastward into slope to basin sediments of the Qal'eh Dokhtar Limestone Formation. Towards the west, they interfinger with the bedded marly limestones of the Kamar-e-Mehdi Formation which were deposited in an extensive shelf lagoon bordered still further west by the emergent Yazd Block. Causes of the general change in depositional style in the late Middle Jurassic might include a climatic change towards more arid conditions in the Late Jurassic and the pronounced Middle Callovian sea-level rise (Valdes and Sellwood, 1992; Hallam, 2001).

The development of the Esfandiar Platform commenced in the Early Callovian after a phase of strong siliciclastic input (Kuh-e-Neygu Member of the Sikhor Formation) following a tectonic uplift of eastern parts of the Tabas Block. This activity may be related to extensional tectonics resulting in rejuvenation of a large westward-dipping tilt-block (Fürsich et al., 2003). Carbonate deposition started at the eastern margin of the Tabas Block in areas sheltered from Sikhor siliciclastics and subsequently spread into areas characterized by deltaic sedimentation (Majd Member of the Sikhor Formation) and, finally, extended to formerly emergent areas. This clearly diachronous transgression cannot be dated precisely, but apparently took place during the Early to Middle Callovian.

By the Late Callovian to Early Oxfordian, the Esfandiar Platform had developed into a NNW/SSE-trending rimmed barrier platform fringing the eastern margin of the Tabas Block for more than 170 km (Fig. 10). The low-energy environments of the platform interior had an E-W extension of tens of kilometres and are characterized by fine-grained limestones, often with muddy fabric and low organismic diversity (only the minute, arborescent sclerosponge *Neuropora* occurred abundantly). Calcareous algae are poorly represented in rocks of the Esfandiar Limestone Formation. At the high-energy platform margin, ooid shoals, now represented by massive ooid grainstone, protected the platform interior from the open sea to the east. Apparently, the eastern platform margin was stabilized by synsedimentary cementation of the shoals. Even where reef-building organisms such as corals and chaetetids occurred, they never formed larger reefal structures. Thus, the Esfandiar Limestone Formation should not be termed a "reef" or "reefal" as in the early reports by Stöcklin et al. (1965) and Ruttner et al. (1968). The scarcity of reef structures may be related to coastal upwelling of nutrient-rich water masses. Nevertheless, the carbonate factory of the Esfandiar Platform was moderately productive as is indicated by an accumulation rate of 80-100 m/my and the export of gravitational sediments and peri-platform muds into the eastern slope areas. The origin of the carbonate mud on the platform is not yet fully understood but possibly is related to microbial whitings (e.g., Thompson, 2000).

Slope to basin sediments of the Qal'eh Dokhtar Limestone Formation were characterized by autochthonous microbialites, often associated with siliceous sponges, *Neuropora* and *Tubiphytes*, gravitational sediments such as mud- and debris flows as well as allodapic limestones (oolitic and/or bioclastic calcareous turbidites), and mud- to fine-grained wackestones representing background sediments settling from suspension. The slope of the Esfandiar Platform extended for at least 10 km to the east and varied laterally from a low-angle depositional slope as in the described transect to steeper bypass slopes (e.g., near Majd). Upper and middle slope areas were characterized by sponge-microbial buildups, indicating reduced accumulation rates. Debris-flow deposits are largely confined to steeper mid-slope areas and were deposited during lowstands of sea-level. Allodapic limestones (graded bioclastic and oolitic grain-/packstones) interbedded with marly mud- and wackestones characterize the lower slope. Bundling of allodapic limestones (turbidite bundling *sensu* Droxler and Schlager, 1985) at certain stratigraphic intervals on the lower slope and their composition is inferred to indicate highstand shedding (Schlager et al., 1994) of the Esfandiar Platform.

During the Late Callovian to Middle Oxfordian, the Esfandiar Platform supplied the slope and basinal areas with large amounts of carbonates (suspended peri-platform muds and gravitational sediments). This high-productivity phase was terminated in the Late Oxfordian, when much of the platform drowned and was covered with basinal sediments of the Korond Formation. The demise was initiated at the platform margin with the deposition of condensed ferruginous oncolites overlying ooid shoal deposits, indicating a considerable deepening. More or less contemporaneously, the debris signal of the platform was strongly reduced and eventually switched off so that homogeneous deep water marls (Korond Formation) onlapped both the Qal'eh Dokhtar Limestone Formation and the drowned Esfandiar Limestone Formation. Ammonite data suggest a late Middle to Late Oxfordian age for the withdrawal and a Late Oxfordian to Early Kimmeridgian age for the drowning (Schairer et al., 2003). However, further to the west, parts of the Esfandiar Platform and thus shallow-water deposition probably persisted in the Early Kimmeridgian. Despite signs of global environmental changes during the Late Oxfordian to Kimmeridgian (e.g., Weissert and Mohr, 1996), we think that block faulting was responsible for the partial drowning of the platform areas because there is strong evidence for regional synsedimentary tectonics (Seyed-Emami et al., submitted).

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