
The paleoecology and depositional model of the Oligo-Miocene coral reefs in the Mohammad Abad Area, the West of Baft, SW Kerman, Iran

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| A B S T R A C T |

This paper deals with the Oligo-Miocene coral reefs in the Mohammadabad Area, W Baft, SW Kerman. The studied coral reefs include 11 families, 25 genera and 33 species of the scleractinian corals. The coral reef successions have been deposited in three cycles on a mixed siliciclastic-carbonate platform. To understand the paleoecology, reef architecture and depositional model of the studied reefal successions, statistical analyses based on the coral niches, sedimentology analyses based on the grain size of the marly strata and microfacies analyses on limestone strata have been used. Based on the statistical analyses, the coral community includes eight ecotypes. The distribution of these ecotypes indicates that, despite of various thicknesses, and in all three coral reef successions, the branching and fast growth ecotypes are present in the basal parts and the massive, placoid and meandroid colonies are recorded in the slope, crest and distal parts of the reefs. The main disruptive phenomenon that stopped reef development and affected the reef architecture has been the addition of clastic deposits to the carbonate system. This sediment load increase is recorded as marly strata. By the addition of clastic sediment load to the system, the carbonate content of the system has been diluted, the salinity, water transparency and photic level are decreased, the favorable attachment hard substrate for coral polyps is limited, the nutrient and oxygen flux is disrupted and the coral reefs are suffocated.

KEYWORDS | Coral reef; Paleoecology; Oligo-Miocene; Baft; Kerman.

INTRODUCTION

The geological history of the Iranian plateau mainly was affected by the collision of the Arabian and the Central Iran plates that resulted in the closure of the Neo-Tethys Ocean during the Cenozoic (Berberian and King, 1981; Berra *et al.*, 2014; Ghasemi and Talbot, 2006; Golonka, 2004; Jafarzadeh and Hosseini-Barzi, 2007; Leturmy and Robin, 2010; McCall, 1997; Stocklin, 1968). During the Oligo-Miocene, a moderately shallow sea has born in

the near volcanic arc depressions that was a part of the marine passage which connected the Mediterranean and Indo-Pacific realms during the Oligo-Miocene (Reuter *et al.*, 2009; Zamani *et al.*, 2010). The deposits of this sea have been named as the Qom Formation. These deposits are mainly carbonaceous with minor proportions of siliciclastic and evaporate deposits (Aghanabati, 2004). On the basis of their position relative to the Volcanic Arc, these deposits are divided into the Qom-Kashan back-arc and Isfahan-Sirjan fore-arc deposits (Reuter *et al.*, 2009). The carbonaceous deposits of the Isfahan-Sirjan Fore-arc basin

crop out as disjunct mountains in the Sirjan-Baft area, SE Iran. These deposits consist of thick-bedded marls, medium to thick bedded fossiliferous limestone and various sized coral reef strata. The biostratigraphy of these deposits was studied by many researchers (Amirshahkarami and Nadimi, 2016; Hamad *et al.*, 2015; Hassani, 2012; Hassani and Vaziri, 2011; Hassani *et al.*, 2007; Hosseinipour, 2004; Hosseinipour and Hassani, 2015; Hosseinipour *et al.*, 2010; Mohammadi, 2014; Mohammadi and Ameri, 2015; Mohammadi *et al.*, 2012; Mohammadi *et al.*, 2013), but the reefal strata did not receive enough attentions. These deposits were studied in Vartun section (Rahiminejad *et al.*, 2016), Dizlu (Yazdi *et al.*, 2012), Khavich (Hassani *et al.*, 2006) and Abadeh (Schuster, 2002; Schuster and Wielandt, 1999) areas. There are some coral reefs strata with various volume and thickness in the Qom formation deposits in the Sirjan-Baft area. In some cases, the coral reef layers are very thick and show complete reefal bioherms. The lower contact of the Qom Formation in the Sirjan-Baft area is sharp and the underlying units include Metamorphic rocks of the Sanandaj-Sirjan Metamorphic Belt (SSMB), volcanic units of the Urumieh-Dokhtar Volcanic Belt (UDVB) and the clastic deposits of the Lower Red Formation (LRF) respectively. The Upper contact is mostly eroded; but in the studied section, is gradually covered with the Upper Red Formation (URF) clastic deposits. The reefal strata of the Qom formation in the oil fields near the Qom area are the main reservoirs and in the Sirjan-Baft depression contain ground water. These layers also play a fundamental role in the evolution of ecosystem during the deposition of the Qom formation deposits. This paper is the first report of coral reef strata from the Sirjan-Baft area and is aimed at studying the architecture and paleoecological history of these layers.

GEOLOGICAL AND GEOGRAPHICAL SETTINGS

The studied section locates on the SW of the Kerman Province (Fig. 1A). This area is a part of the Central Iran Structural Zone between the UDVB to the E-NE and SSMB to the S-SW. The Central Iran forms a triangle region with a complex structure. Here, rocks of all ages, from the Precambrian to the Quaternary, and several episodes of orogeny, metamorphism, and magmatism can be recognized (Ghorbani, 2013). There is not a consensus regarding the boundaries of Central Iran. According to Stocklin (1968), Central Iran is bordered by the Alborz Mountains in the north, the Lut Block in the east, and Sanandaj-Sirjan in the south-southwest, whereas Nabavi (1976) considers the northern part of the Lut Block as a part of Central Iran. Nogol-e-Sadat (1993) extends the frontiers to the northeast as well as Eastern Iran and presents new subzones in his classification. In this area, the most popular outcrops

include the recent alluvial deposits and the oldest unit include the purple Eocene-Oligocene clastic deposits (time equivalents to the LRF) (Fig. 1B). The studied section is located 55km E of Sirjan and 41km W of Baft, near the Mohammadabad Village at 56° 10' 46.29" E and 29° 18' 29.57" N (Fig. 1C). At this location, the Qom formation strata crop out as light cream layers in an anticline structure (Fig. 1D, E). The stratigraphic succession of this part of the Sirjan-Baft- Khabr depression is similar to northern realms of the Qom basin, where the Qom Formation is sandwiched between the continental clastic deposits of the LRF at the base and URF at the top.

MATERIALS AND METHODS

The total thickness of studied section is 176m (Fig. 2), that includes a 1m thick conglomerate layer at the base, which is followed by three distinct cycles of marine carbonaceous strata. Each cycle starts with marl and marly strata succession and topped by reefal layers and fossiliferous limestone intercalations. The first cycle includes 16m loose marly strata at the base and 6m hard reefal limestone layers at the top. The second cycle starts with 30m marl/marly limestone strata and ends with 8m reefal limestone strata. The final cycle includes 50m loose marly strata at the base and 54m hard fossiliferous limestone and reefal limestone layers at the top. The final marine strata in the measured section include 8m of mainly marl and silty deposits with Mollusca debris.

In the study area, the Qom Formation overlays the clastic deposits of the LRF non conformably (Fig. 3A). The upper contact is non conformable too and is covered by the terrigenous sediments of the URF (Fig. 3B). To determine the age of the section 35 hard and 33 loose samples of marly and marly limestone strata have collected. The total of 63 in situ samples of coral colonies (Fig. 3C-D) were collected from the measured section and know housed in the Payamenoor University of Kerman. The Cluster analysis method and SPSS statistics software was used to differentiate ecotypes. A data matrix, including all morphological and ecological characters of each genera, was used to cluster the identified fauna (Table 1). To find the mean grain size of the marly deposits, 300gr of 23 selected layers were analyzed by the Hydrometric Method in the soil mechanic laboratory of the Payamenoor University.

RESULTS AND DISCUSSION

Paleoecology

Field observations confirm that the reefal deposits in the studied section form continuous layers. The faunal

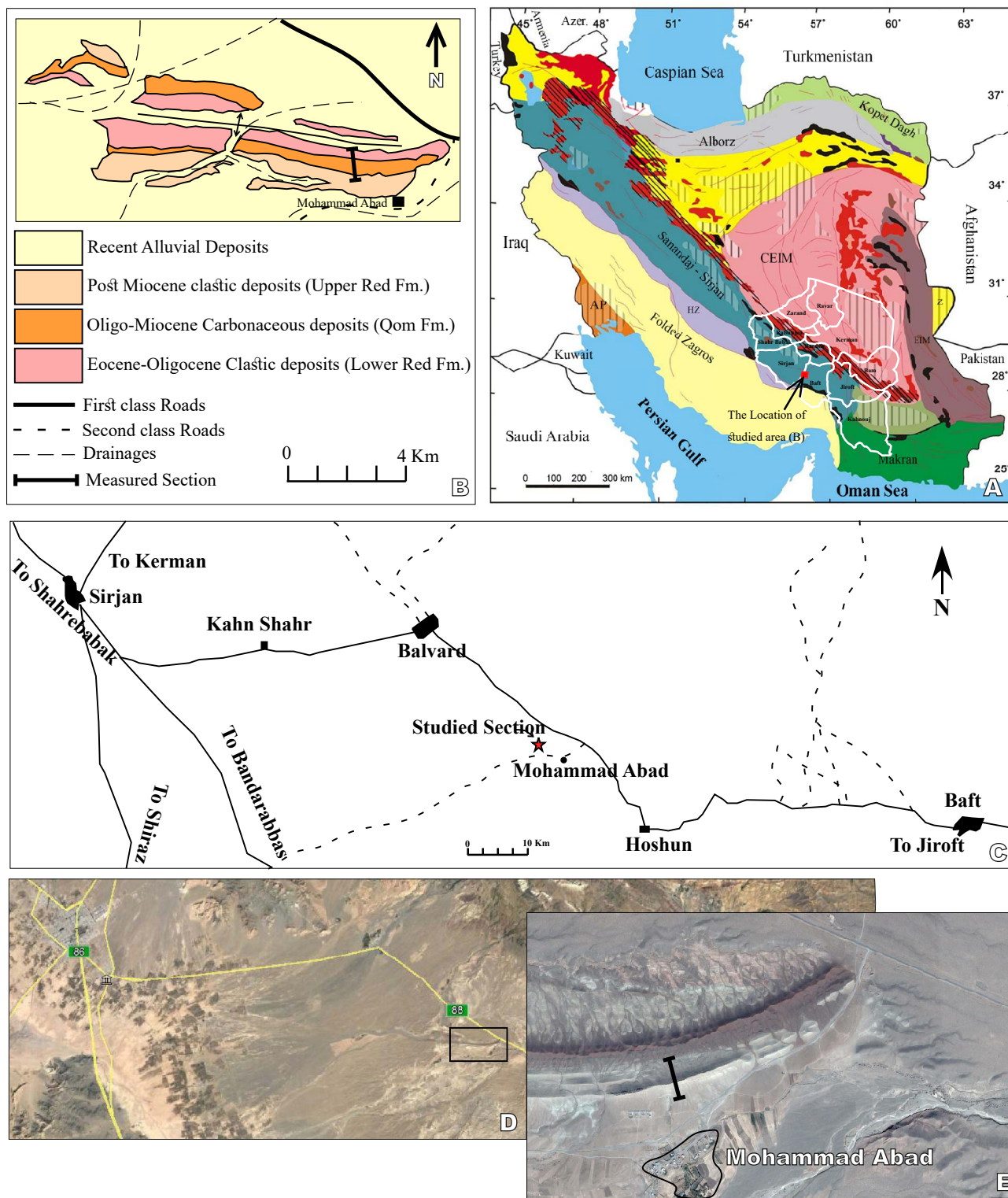


FIGURE 1. A) Structural zones of Iran (after Aghanabati, 2004) and location of the Kerman province; B) Simplified geological map of the studied area; C) Access map to the studied section; D) Satellite image of the studied area (from Google Earth); E) Satellite image of the studied section (from Google Earth).

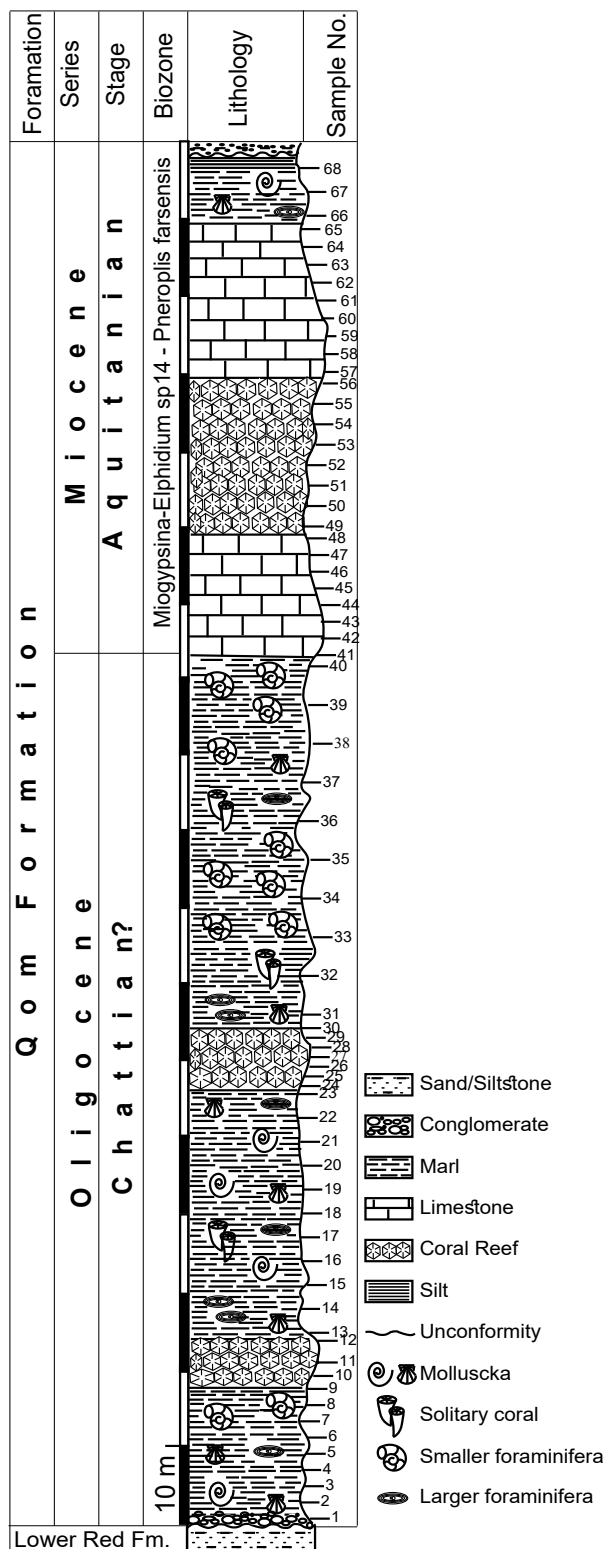


FIGURE 2. The simplified stratigraphic column of the studied section.

diversity is high and includes 11 family, 25 genus and 33 species of the scleractinian corals (Table 2). The identified coral community includes fauna of both low and high energy waters, various depth, various colony forms and also solitary individuals. Clustering the identified corals based on these characters (Table 3) indicates that eight ecotypes could be distinguish in the coral community (Fig. 4).

The first ecotype includes species of *Agathiphyllia*, *Placocoenia*, *Septastrea*, *Leptastrea*, *Ceriosmilia*, *Platycoenia*, *Antiguastrea*, *Simplastrea* and *Oulastrea*. These faunas are mainly zoxantellate symbiotic and live in the euphotic zone. These are hermatypic, massive and mainly placoid colonies and prefer to live in mainly agitate waters near the reef crest and core (Moore, 1981; Pomar and Hallock, 2007) (Fig. 5).

The species of *Acropora* and *Stylophora* are included in the second ecotype. These branching and mainly placoid forms can be found in the moderately deep parts of the basin and basal parts of the reef body (Moore, 1981; Wallace and Bosellini, 2014; Wallace and Rosen, 2006) (Fig. 5).

The ecotype three includes the non-reef building and solitary genus, *Ilariosmilia*. This genus includes only one species in the studied coral community. These fauna are dominant in the bottom of the deep waters and rarely found in the main reef body (Moore, 1981; Wilson et al., 2017) (Fig. 5).

The fourth ecotype includes *Favia* and *Astreopora*. These massive, placoid and dome-shaped colonies are present in the basal and near the base of the coral reefs, in moderate depths in the low energy parts of reef body (Moore, 1981; Wilson et al., 2017) (Fig. 5).

The fifth ecotype includes massive, mainly cerioid, dome-shaped to hemispherical colonies of *Favites*, *Goniastrea* and *Tarbellastrea*. These fauna are the most common ones and found in the main reef body (core reef and reef crest) (Moore, 1981; Pomar and Hallock, 2007) (Fig. 5).

The species of the genus *Caulastrea* and *Astrocoenia* are assigned to the sixth ecotype. These massive, dome-shaped and pedunculate fauna are adapted to live in the shallow and high energy parts of the reef body such as reef slope and reef front (Moore, 1981; Wilson et al., 2017) (Fig. 5).

The seventh ecotype includes *Alveopora* species. These are mainly branching, massive and cerioid corals and dominant on the reef slope in turbid waters (Moore, 1981; Wilson et al., 2017) (Fig. 5).

TABLE 1. Data used for clustering the coral genera in distinct ecotypes

Coral genera	Main form		Growth Form												Colony Type								Climat				Depth				Water energy		
	Colony	Solitary	Branching	Nodular	Emerging	Mushroom	Dom-shaped	Pillar shape	Funiform	Hemispheric	Platy	Massive	Circular	Pedunculate	Sub-cylindrical	Phaceloid	Cerroid	Placoid	Meandroid	Hydnophorid	Warm	Temperate	Tropical	Nontropical	Deep	Moderate	Shallow	Low	Medium	High			
<i>Favites</i>	1	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0	0	0	1	1	1	0	0	0	1	0	1	0			
<i>Caulastrea</i>	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1	1	0	0	0	1	0	1	0			
<i>Hydrophyllia</i>	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	1	1	1	0	0	0	1	1	1	1			
<i>Goniastrea</i>	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	1	1	1	0	0	1	0	1	1	1			
<i>Leptoria</i>	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1	1	0	1	1	0	1	1	0			
<i>Hydrophora</i>	1	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	1	0	0	1	1	1	1	0			
<i>Favia</i>	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	0	1	1			
<i>Aniguastrea</i>	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	0	1	1			
<i>Ceriosmilia</i>	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	0	1	1			
<i>Tarbellastrea</i>	1	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	1	1			
<i>Simplastrea</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	1	1			
<i>Leptoseris</i>	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	1	0	0	1	1	1	1	0			
<i>Cyathoseris</i>	1	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	1	0	1	1	1	0	0	1	1	1	1	0			
<i>Playcoenia</i>	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	0	1	1			
<i>Astrocoenia</i>	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	1	1			
<i>Asreopora</i>	1	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	0	1	1			
<i>Acropora</i>	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	0	1	1			
<i>Alveopora</i>	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	0	1	1			
<i>Ilariosmilia</i>	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	1	1	1			
<i>Septastrea</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	1	1	1			
<i>Oulastrea</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	1	1	1			
<i>Leptastrea</i>	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	1	1	1			
<i>Sylophora</i>	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	1	0	1	1	1	1	1	1			
<i>Agathiphyllia</i>	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	1	1	0	1	1	1	1	1	1			
<i>Placocoenia</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	1	1	1	1	1	1			

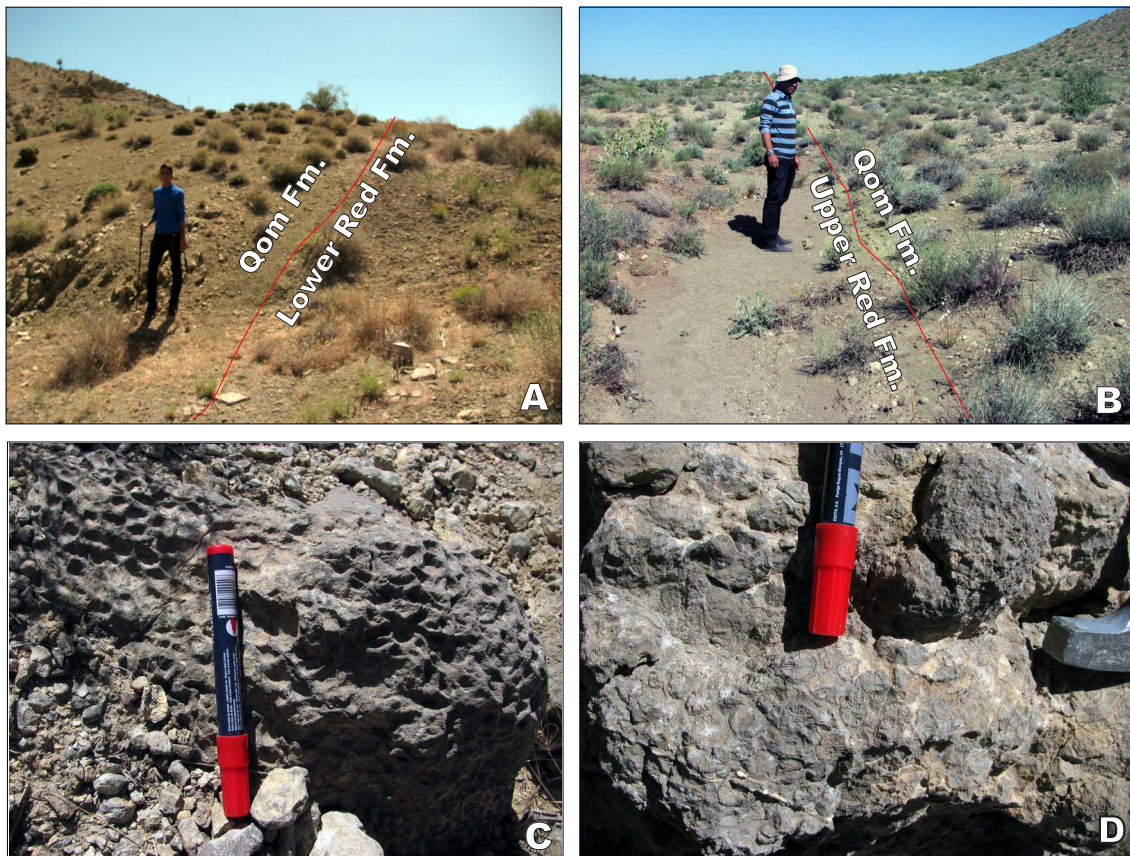


FIGURE 3. A) Lower contact of the studied section; B) Upper contact of the studied section; C, D) In-situ exposures of the coral colonies.

All species of the *Leptoseria*, *Leptoria*, *Cyathoseris*, *Hydnophyllia* and branching *Hydnophora* species with elongated monticles are included in the eighth ecotype. These fauna are mainly meandroid and hydnochoroid and adapted to live in various depth and light levels. In the studied reef deposits, these fauna mainly found in the protected shallow parts of the reef body (Moore, 1981; Wilson *et al.*, 2017) (Fig. 5).

Although almost all of the identified corals are hermatypic scleractinian corals, but the distribution of them in the three studied reefal bodies is different. The differences may result from different ecological conditions in each reefal succession.

The first reefal succession in the studied section is a 6m continuous layer. From the base to the top, ecotypes 2, 7+8, 1+5 and 6+8 are seen in this succession. Based on the present ecotypes, the reef body includes thin basal and core parts, while the distal (back reef) part is well developed. In this part of the section, there are some coral debris in the underlying and overlying marly strata that indicates the occurrence of moderately strong submarine currents and erosion of the reef body (Fig. 6).

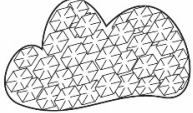


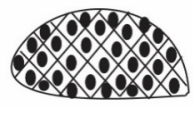
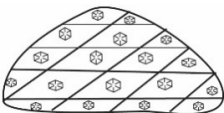
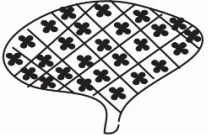


The second coral reef succession is thicker and more complex than the first one; having an average thickness of 8. Ecotypes 2+7, 7, 6+7, 6, 1+5 and 4+8 are present in this succession from the base to the top. The basal horizons of this reefal succession are not well developed and form less than the 30% of the whole thickness. About half of the succession is colonized by the reef core and crest ecotypes. It is topped by a moderately thick and homogeneous horizon of mainly back reef coral colonies. The top of the unit presents evidences of erosion (Fig. 7).

The third reefal succession is the thickest and most complete. Its average thickness is 16m and is sandwiched between two fossiliferous limestone intervals. From the base to the top, ecotypes 3, 2+4, 6+7, 2+4, 6+7, 6, 1+5, 6, 4+8 and 8 are represented. This coral reef succession can be divided into three distinct parts. The basal part include deep, slope and reef front colonies, the middle part include reef core and crest colonies and the upper part include shallow and back reef colonies. The basal part is the thickest part and includes the half thickness of the whole succession. The middle and upper parts have same thickness (Fig. 8). Although there are no obvious evidences of erosion on the basal and upper contacts of the reefal

TABLE 2. Identified coral species

Family	Genus	Species
Merulinidae		<i>Favites</i> sp.
		<i>Favites neglecta</i>
	<i>Favites</i>	<i>Caulastrea Pseudoflabellum</i>
	<i>Caulastrea</i>	<i>Hydnophyllia stellate</i>
	<i>Hydnophyllia</i>	<i>Hydnophyllia</i> cf. <i>fimbriata</i>
	<i>Goniastrea</i>	<i>Goniastrea</i> sp.
	<i>Leptoria</i>	<i>Leptoria phrygia</i>
	<i>Hydnophora</i>	<i>Hydnophora scripta</i>
		<i>Hydnophora rudis</i>
		<i>Hydnophora sativa</i>
	<i>Hydnophora elongate</i>	
Faviidae	<i>Favia</i>	<i>Favia cylindracea</i>
	<i>Antiguastrea</i>	<i>Antiguastrea</i> sp.
	<i>Ceriosmilia</i>	<i>Antiguastrea lucasiana</i>
	<i>Tarbellastrea</i>	<i>Ceriosmilia iranica</i>
	<i>Simplastrea</i>	<i>Tarbellastrea carryensis</i>
		<i>Simplastrea</i> cf. <i>leytensis</i>
Agariciidae		<i>Leptoseris alternans</i>
	<i>Leptoseris</i>	<i>Leptoseris irregularis</i>
	<i>Cyathoseris</i>	<i>Cyathoseris</i> sp1. <i>Cyathoseris</i> sp2.
Astrocoeniidae	<i>Platycoenia</i>	<i>Platycoenia iranica</i>
	<i>Astrocoenia</i>	<i>Astrocoenia nana</i>
Acroporidae	<i>Astreopora</i>	<i>Astreopora meneghiana</i>
	<i>Acropora</i>	<i>Acropora</i> sp.
	<i>Alveopora</i>	<i>Alveopora</i> sp.
Rhizangiidae	<i>Septastrea</i>	<i>Septastrea</i> sp.
Oulastreidae	<i>Oulastrea</i>	<i>Oulastrea</i> sp.
Incertae Sedis	<i>Leptastrea</i>	<i>Leptastrea</i> sp.
Pocilloporidae	<i>Stylophora</i>	<i>Stylophora thirsiformis</i>
Agathiphyllidae	<i>Agathiphyllia</i>	<i>Agathiphyllia gregaria</i>
Placocoeniidae	<i>Placocoenia</i>	<i>Placocoenia</i> sp.
Smilotrochiidae	<i>Ilariosmilia</i>	<i>Ilariosmilia subcurvata</i>

TABLE 3. Distinguished ecotypes, their taxa, colony form, ecology and symbol

Ecotype No.	Fauna	Colony Form	Ecosystem	Symbol
1	<i>Agathiphyllia, Placocoenia, Septastrea, Leptastrea, Ceriosmilia, Platycoenia, Antiguastrea, Simplastrea, Oulastrea</i>	Massive, Hermatypic, mainly Placoid	Euphotic zone in the reef crest and core	
2	<i>Acropora, Stylophora</i>	Branching Hermatypic mainly placoid	Euphotic zone in the reef base at the deeper waters	
3	<i>Ilariosmilia</i>	Solitary a-hermatypic	Deep waters Rare in the main reef body	
4	<i>Favia, Astreopora</i>	massive, placoid Hermatypic dome-shaped	Euphotic zone in the low energy and non agitated waters	
5	<i>Favites, Goniastrea, Tarbellastrea</i>	Hermatypic massive, mainly cerioid, dome-shaped to hemispherical	Common in the various reef ecosystems	
6	<i>Caulastrea, Astrocoenia</i>	Massive dome-shaped pedunculate Hermatypic	Euphotic zone Shallow and high energy parts in the reef front and reef slope	
7	<i>Alveopora</i>	Hermatypic Branching-massive Cerioid	Euphotic zone At the turbid waters on the reef slope	
8	<i>Leptoseris, Leptoria, Cyathoseris, Hydnohyllia</i>	Massive, Hermatypic meandroide and hydnohyllide	Euphotic zone protected low energy and shallow parts of the reef	

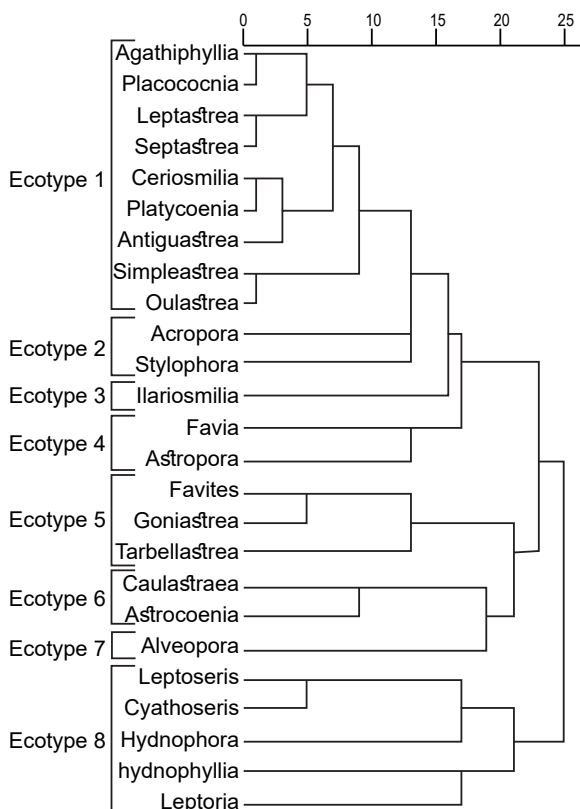


FIGURE 4. Dendrogram of the eight ecotypes.

succession, the presence of coral floatstone microfacies in the adjacent limestone strata points to the abrasion of some marginal layers of the main reef body.

Microfacies and sedimentary analysis

Two limestone intervals are present below and above the third reefal succession and include the following microfacies. The most common allochemical particles include peloids, benthic foraminifera (*Rotalia*, *Nephrolepidina*, *Ammunia*, *Elphidium*, *Miogypsinidae* and *Textularids*) and ostracods tests, molluscan (mainly *Bivalvia*) debris, bryozoans, algae and coral particles. The texture of the limestone microfacies varies from wackestone to condensed packestone grainstone, floatstone, rudstone and framestone. Based on the allochemical particles present and texture six microfacies have been distinguished (Fig. 9) and summarized in the Table 4.

The marly deposits of the studied section are divided into three types based on their faunal content and mean grain size. The first marl type mainly deposited in the basal and final layers of the section. The faunal content of these deposits includes *Elphidium* spp. rare biserial agglutinate foraminifera and extremely rare miliolidae. This faunal content reflects that these layers are deposited in near shore and brackish waters (BouDagher-Fadel and Lokier, 2005; BouDagher-Fadel, 2008). The mean grain size of these deposits is 1.0-0.30mm that covers the coarse to fine grain sand size.

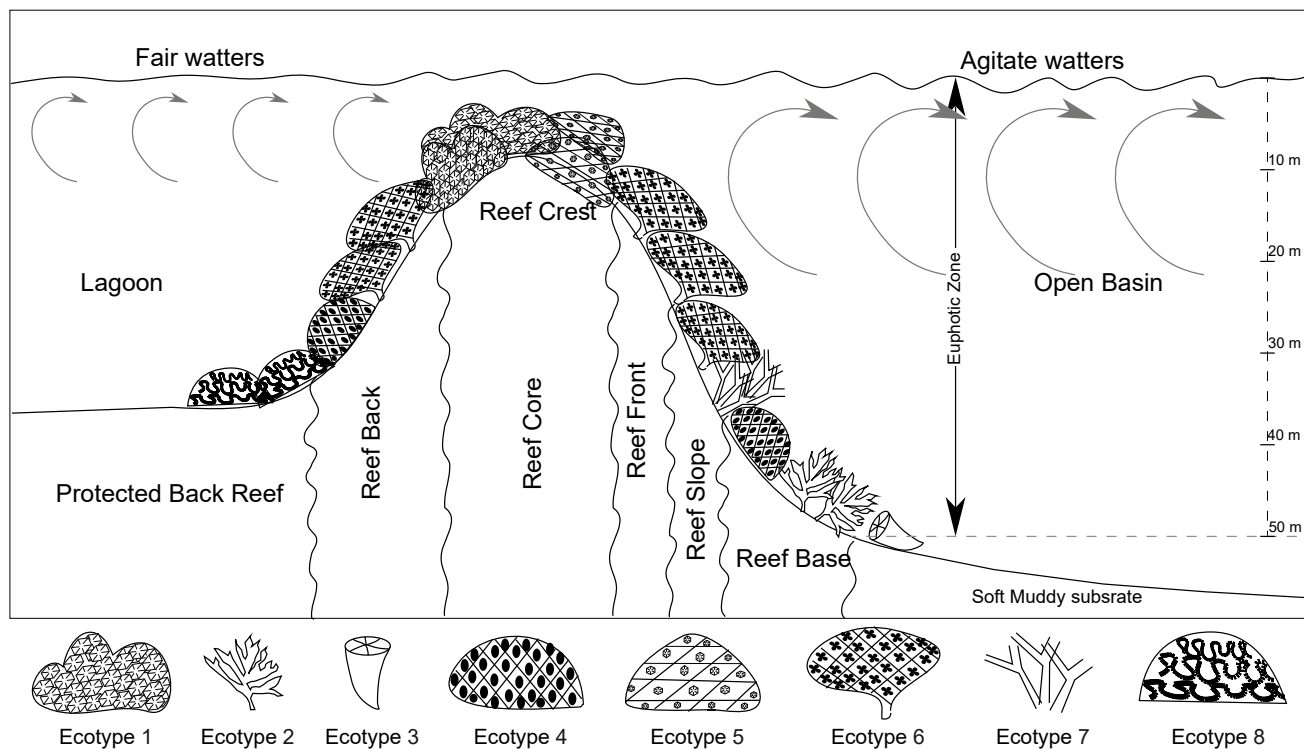


FIGURE 5. Ecological and architectural position of the distinguished ecotypes.

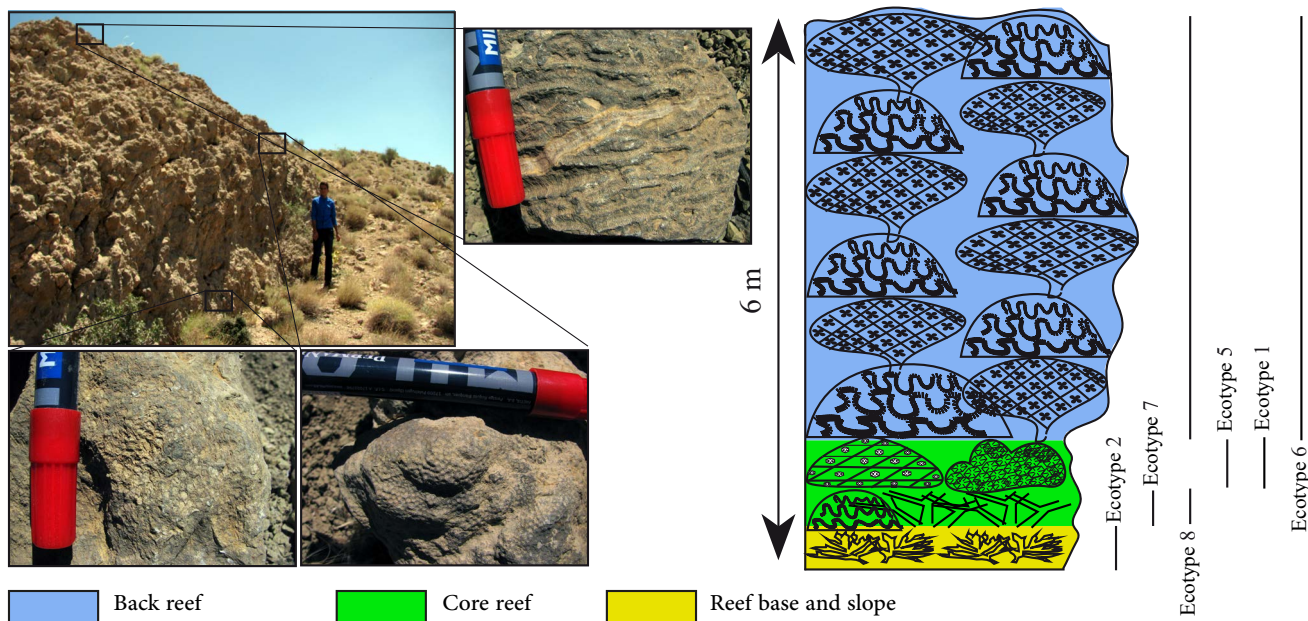


FIGURE 6. Outcrop of the first coral succession (left) and distribution of present ecotypes (right). See Table 3 for legend of symbols.

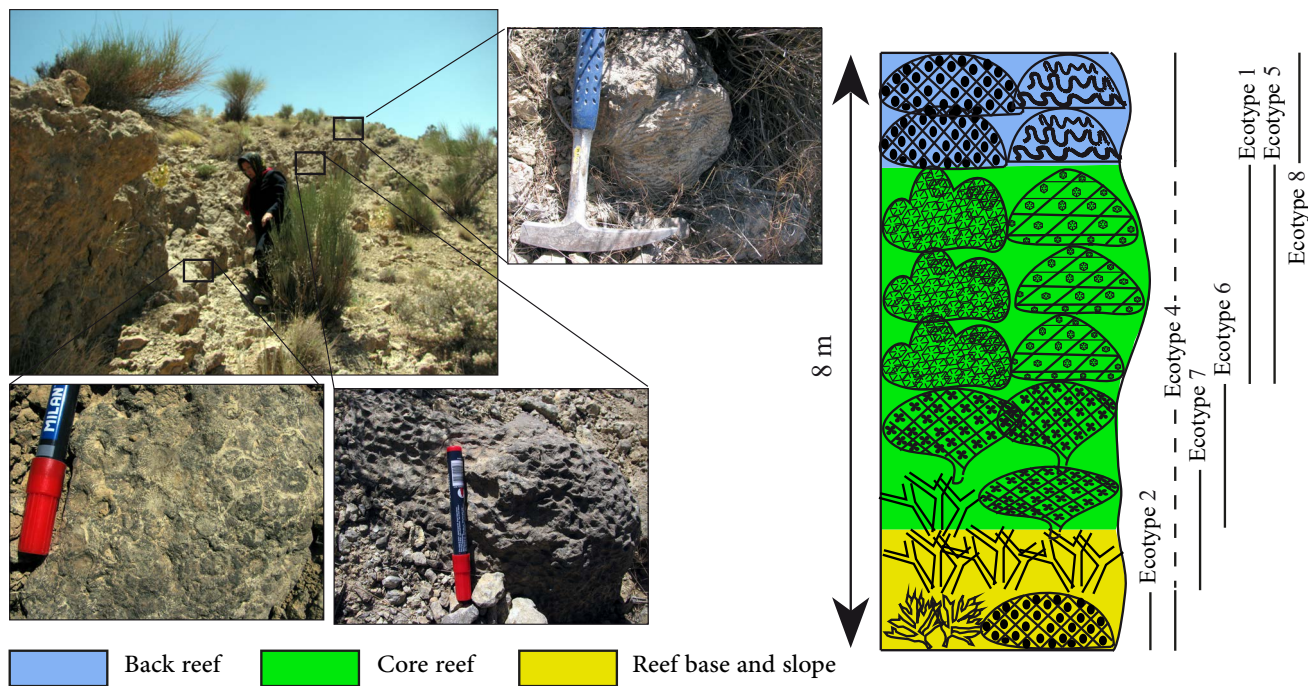


FIGURE 7. Outcrop of the second coral succession on the field (left) and distribution of present ecotypes (right). See Table 3 for legend of symbols.

TABLE 4. Identified carbonate microfacies in the studied section

Lithology	Microfacies cod	Microfacies name	Allochemicals, structures, SMF (Flügel, 2010)	Facies belt (Flügel, 2010)
limestone	L1	Bioclast wack/packstone	Ostracoda and smaller foraminifera tests, SMF No.2	deep parts of the basin
	L2	Bioclast Miogypsina wackstone	Miogypsinae, foraminifera and molluscan shell debris, SMF No.8-9	moderately deep shelf below the wave effected depth
	L3	Coral rudstone/floatstone	coral debris, SMF No.5 - 6	fore slope of the marginal reef setting
	L4	Coral boundstone	Various coral frameworks, SMF7	marginal reef
	L5	Algal bryozoan rudstone/grainstone	large bryozoan (<i>Tubucellaria</i>) and algae (<i>Archaeo-lithothamnium</i>) debris, SMF5	marginal back reef and sand shoals
	L6	Fossiliferous peloid wackstone/packstone	Benthonic foraminifera (<i>Miliolidae</i> , <i>Alveolinidae</i> , <i>Rotalia</i> , <i>Nephrolepidina</i> , <i>Ammunia</i> , <i>Elphidium</i> and <i>Textularids</i>) tests, peloid Mollusca and echinoderm debris, SMF No.10	non-restricted to restricted lagoon

The second marl type contains mainly miliolidae, biserial agglutinate benthic foraminifera and rare *Borelis* tests. These layers are light green to cream in color and mainly present in the upper part of the section. The grain size range of these deposits indicates that these deposits consist of fine sand to silt (0.25 to 0.0075mm) grains

The third type includes dark green to gray deposits with smaller and moderately deep benthonic foraminifera such as *Cibicidoides* and *Bolivina*. These layers also contain smooth and no ornamented ostracoda and echinoderm spines. The grain size is 0.0085 to 0.0030mm, falling within the clay size range.

The main mineralogy of the marly strata includes quartz, mica, rare feldspars, heavy minerals and clay. This mineral content is very similar to the main mineralogy of the Sanandaj Sirjan Metamorphic Belt and Uromieh-Dokhtar Volcanic Belt rocks, which means that these zones were the source of the siliciclastic fraction of these sediments.

In general, the main lithology of the studied succession suggests a mixed carbonate-siliciclastic marginal shelf

setting. The grain size analysis and faunal content of the marly strata indicate that a significant clastic supply contributed to the carbonate environment during at least four major phases and corresponding to the marly units (Fig. 10). In fact, the carbonate sediments of the environment have diluted by the addition of these sediments. In a brief context, deposition of the marly strata on the carbonaceous platforms would be a result of the extraordinary increase in activity of rivers in response to the climatic changes or increasing the sediment supply by continental uplifting (Einsele, 1982; Miall, 1984; Miall and Tyler, 1991; Pomar *et al.*, 2002; Westphal, 2006; Westphal and Munnecke, 2003). Beside the deposition of marly strata, because of the extraordinary addition of freshwater, the salinity of sea water has decrease. The addition of the fine grained load decrease the transparency and light level, diluted the sedimentary carbonate content and the standard marine condition has interrupted (Wilson *et al.*, 2017).

In fact, corals are very sensitive creatures (Mewis and Kiessling, 2012). The juvenile forms of corals could not be preserved and growth in harsh environments and the large and continuous coral reefs are developed in clear, warm and

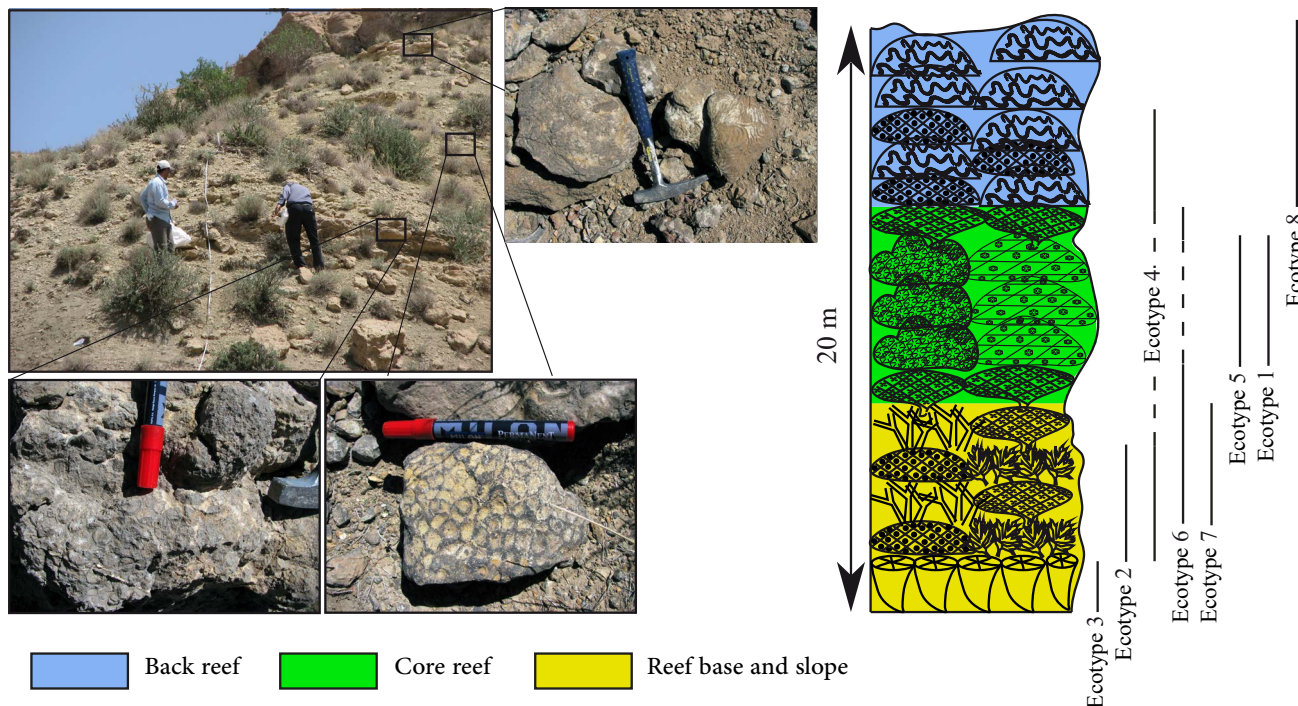


FIGURE 8. Outcrop of the third coral succession on the field (left) and distribution of present ecotypes (right). See Table 3 for legend of symbols.

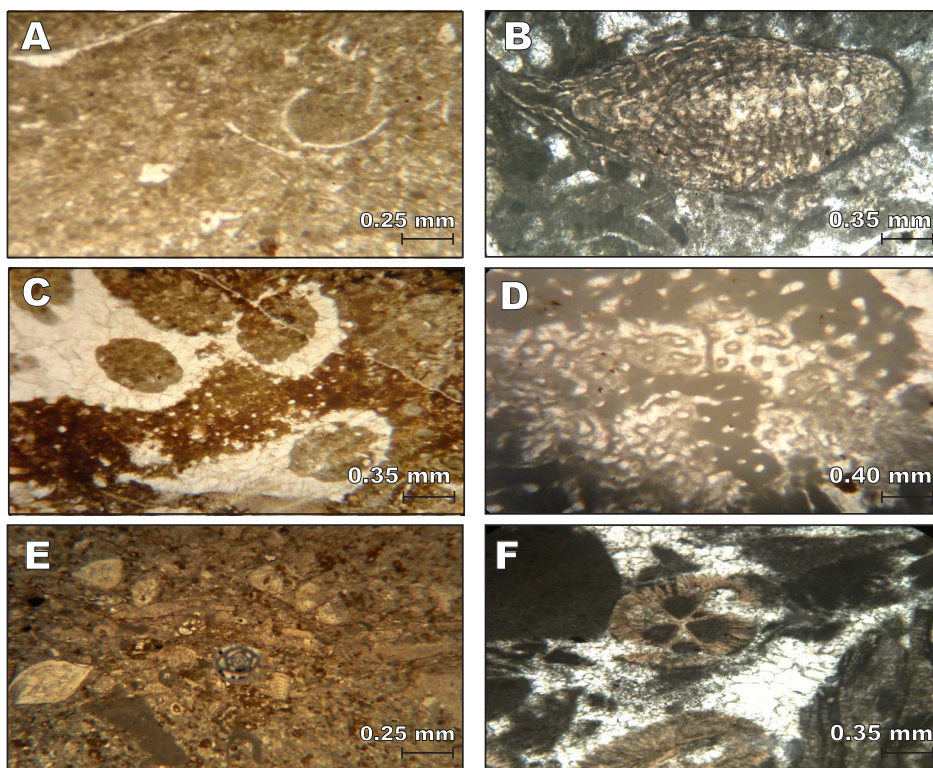


FIGURE 9. Microphotographs of the identified microfacies; A) Bioclast wack/packstone (L1); B) Bioclast Miogypsina wackstone (L2); C) Coral rudstone/floatstone (L3); D) Coral Boundstone (L4); E) Algal bryozoan rudstone/grainstone (L5); F) Fossiliferous Pelloid Wackstone/Packstone (L6).

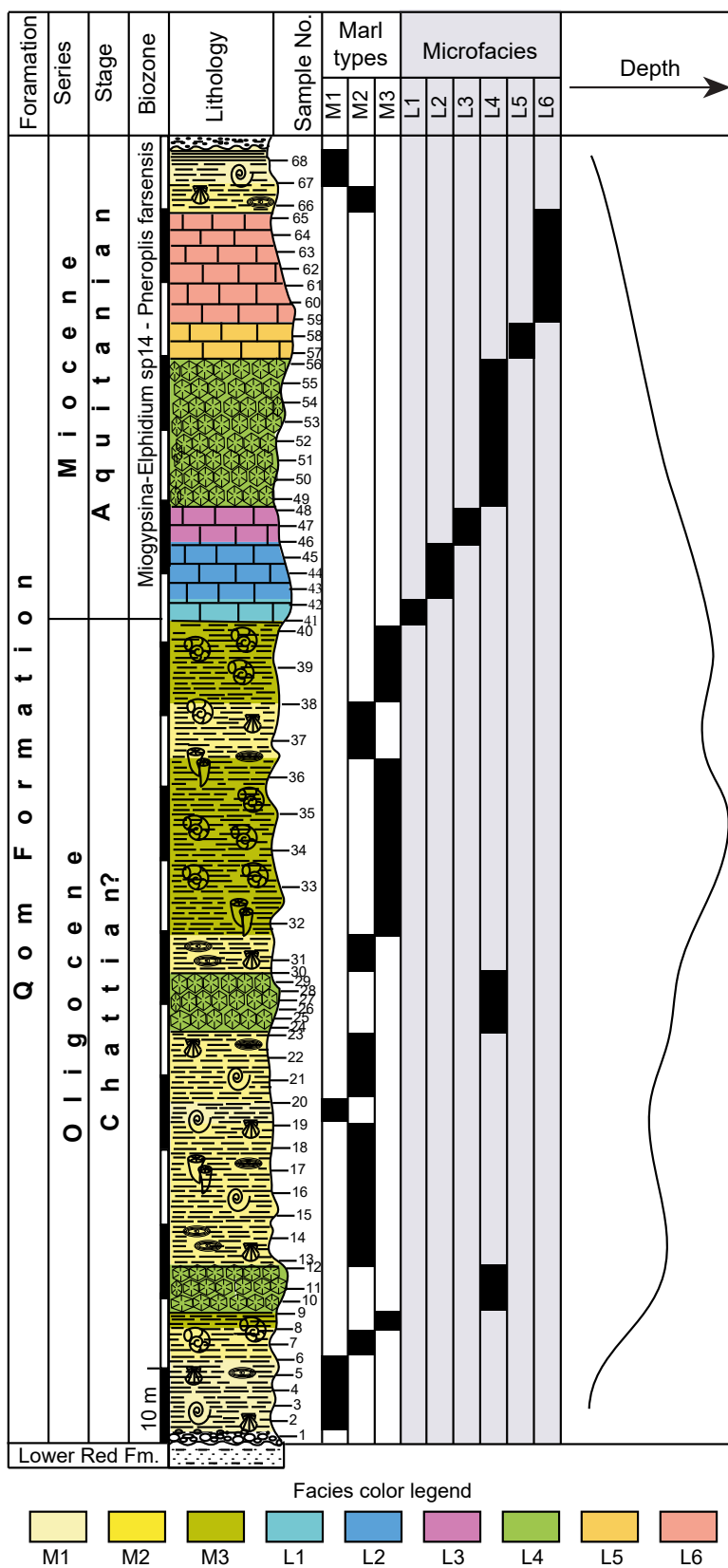


FIGURE 10. Distribution patterns of the marl types and microfacies along the stratigraphic column of the studied section.

normal saline waters in the euphotic zone on stable platforms (Hoogenboom and Connolly, 2009; Mewis and Kiessling, 2012; Wilson *et al.*, 2017). Because of the importance of symbiotic algae in the coral reef development, the high light level and water clarity are vital factors for reef colonies.

The taphonomic preservation of the corals in geological records depends on some intrinsic and extrinsic factors. The main intrinsic factors include growth rate and colony form and size (Greenstein, 2007; Hoogenboom and Connolly, 2009) and the main extrinsic factors are water energy and agitation, nutrient and oxygen supply, light level, salinity and temperature (Greenstein, 2007). The branching corals are more sensitive to water energy and light but their regeneration and growth rate is higher than the massive ones (Greenstein, 2007). In comparison to branching corals, the agitation and water energy tolerance of massive colonies is higher but their growth and regeneration rate is lower (Greenstein, 2007). Therefore, in almost all typical reefal deposits, the base of the reef body consists of branching colonies that means the prevalence of favorable ecological factors (Greenstein, 2007). Also, in the studied reefal deposits, the base of all three coral reef successions was made of branching colonies (ecotypes 2 and 7). This solid framework was the basis for the development of the different parts of reef body (slope, core and crest and back reef) by increasing the stable attach area for the coral polyps (Greenstein, 2007). In the first and second reefal succession punctuated stability episodes allowed the reef development, but the ecosystem stability was not long enough to develop thick reefal and limestone layers. In the case of the studied area, the main cause of ecosystem instability has been the addition of the clastic input to the carbonate system. By the addition of this clastic sediment input, the salinity and water transparency are reduced, the euphotic zone narrows, the hard attachment basements are buried and nutrient/oxygen flux is disturbed. In fact, the first and second coral reefs are suffocated under the marly strata. In comparison to the first and second coral reefs, the third one has deposited during a moderately longer period of ecosystem stability. The lower 15m of limestones, the following 20m of reef strata and the upper 19m of limestones indicate that carbonate system was not aborted by the influx of clastic sediments. The reef architecture in the third reef succession starts with the basal branching ecotypes and follows by other massive colonies. The reef base, slope, crest, core and back reef of this coral reef are well developed. The facies changes in this part of the section suggests the gradual sea level fall and upward shallowing of the whole system (Fig. 10).

CONCLUSION

The coral reefs in the Mohammad Abad section (176m, Qom Formation, Oligo-Miocene), W Baft, SW Kerman,

are deposited in three cycles. The coral reef community includes 11 Families, 25 genus and 33 species. Based on the ecological studies, the coral community includes eight ecotypes. The distribution of these ecotypes in three coral cycle shows that each cycle has started by the branching corals, which are faster in regeneration and growth, as the hard basis for the overlaying massive corals. Each coral reef cycle includes distinct proximal, crest, core and distal parts with special adopted ecotypes. The lithological state of the coral reef cycles in the studied area indicated that the main ecological distortions factor, which aborted the coral's favorable ecosystem, was the increase of fluvial discharge and clastic sediment supply to the carbonate system. This activation of continental runoff changed the salinity to brackish waters, diluted the carbonate content, decreased the transparency and light level, limited the hard attach basements for coral polyps and suffocated the young coral colonies. The sedimentological expression of this increase of sediment flux is the thick marly strata with similar mineralogy to the SSMB and UDVB units. When the deposition of marly strata stopped, the coral growth resumed and the reef ecosystem developed. This favorable carbonate system is stronger in the final phase of the basins evolution that resulted to the deposition of moderately thick limestone and coral reef succession. Based on the presence of hermatypic scleractinian corals in the studied area, the main ecosystem located in a shallow, warm and non-agitated sea.

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APPENDIX I

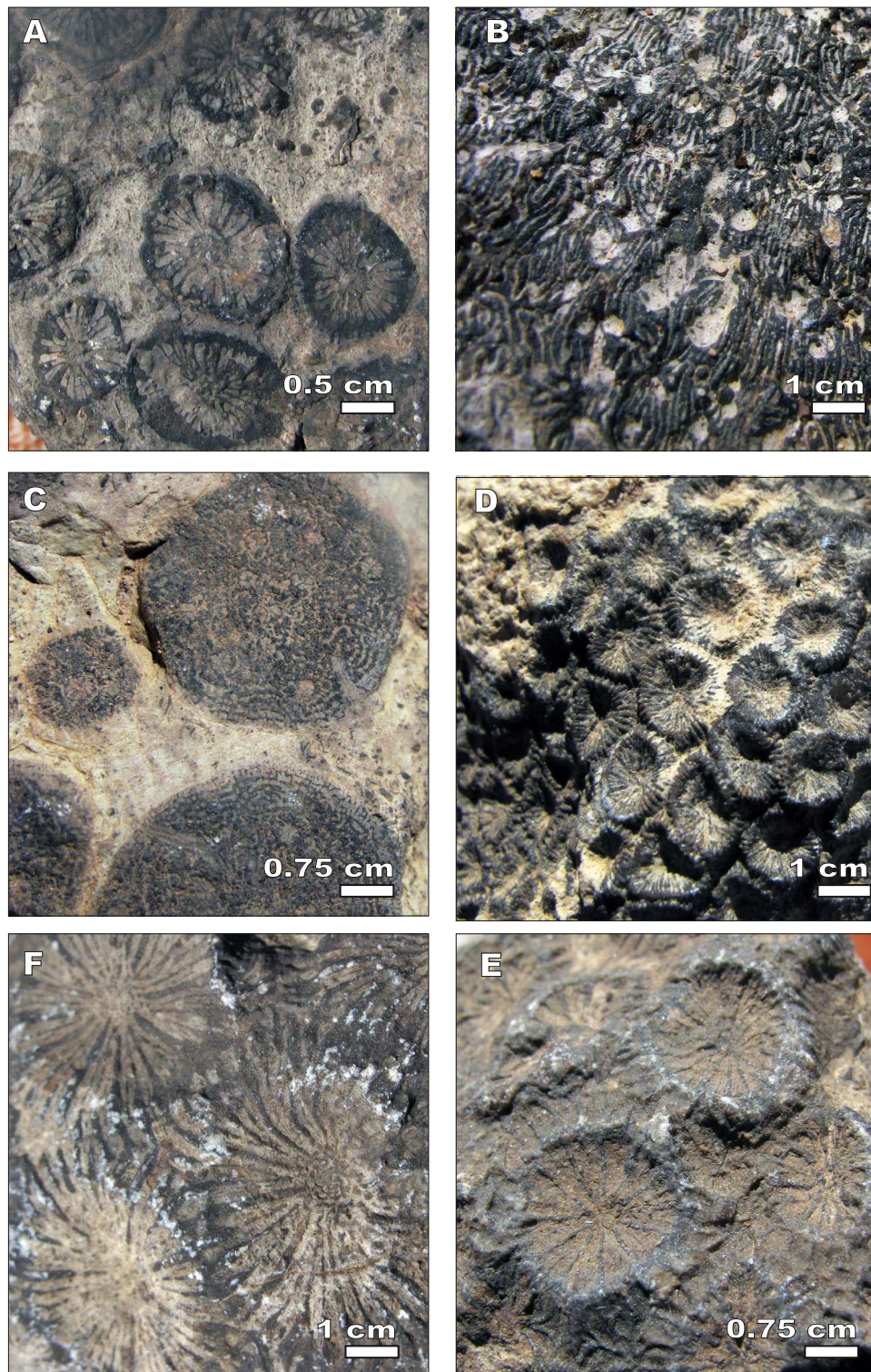


FIGURE I. Photograph of A) *Agathiphyllia sp.*; B) *Cyathoseris cf. radiata*; C) *Acropora sp.*; D) *Antiguastrea lucasiana*; E) *Favia cylindracea*; F) *Agathiphyllia gregaria*.

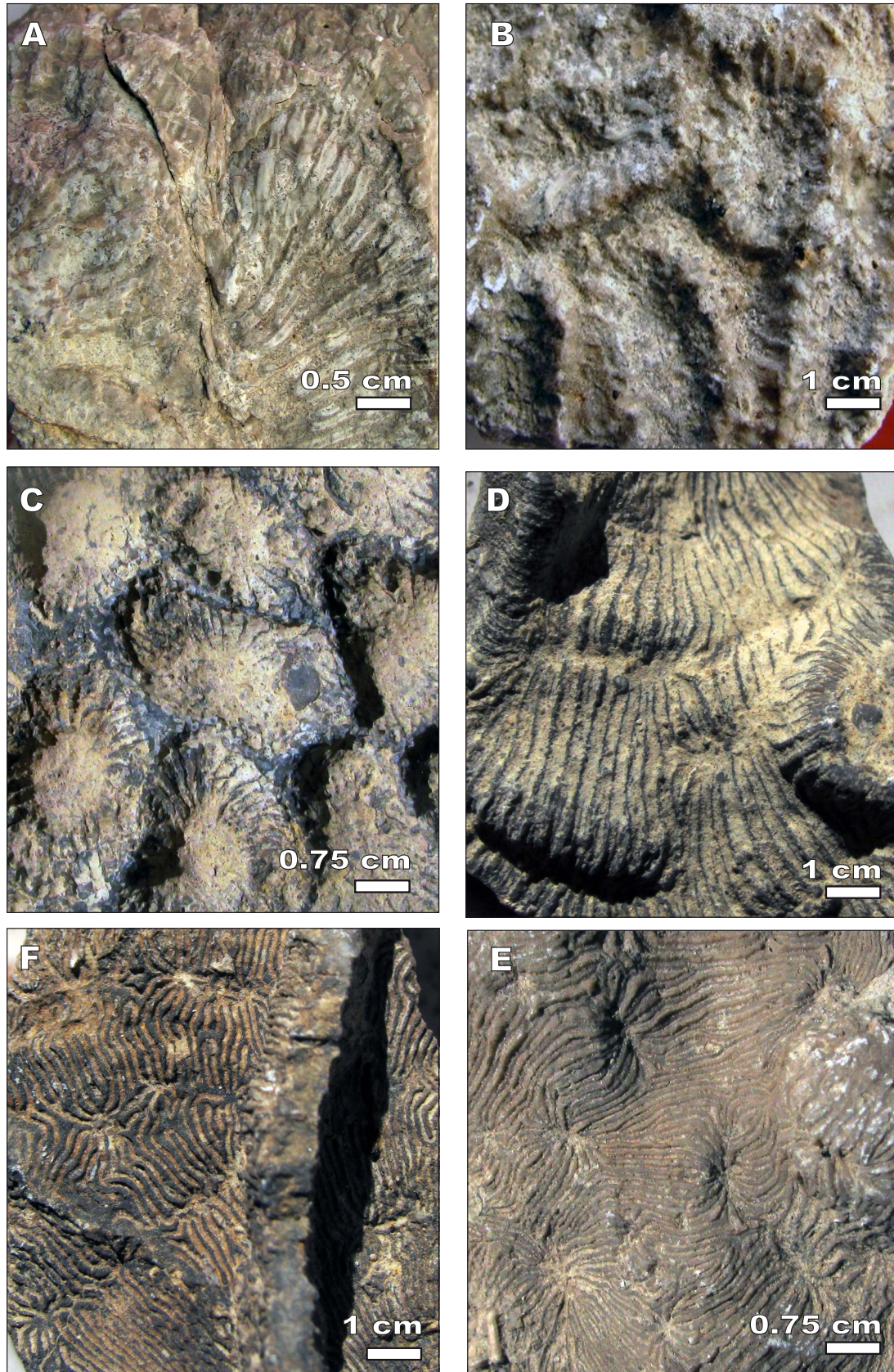


FIGURE II. Photograph of A) *Ceriosmilia iranica*; B) *Hydnophyllia stellate*; C) *Favites neglecta*; D) *Cyathoseris* sp1., E, F) *Cyathoseris* sp2.

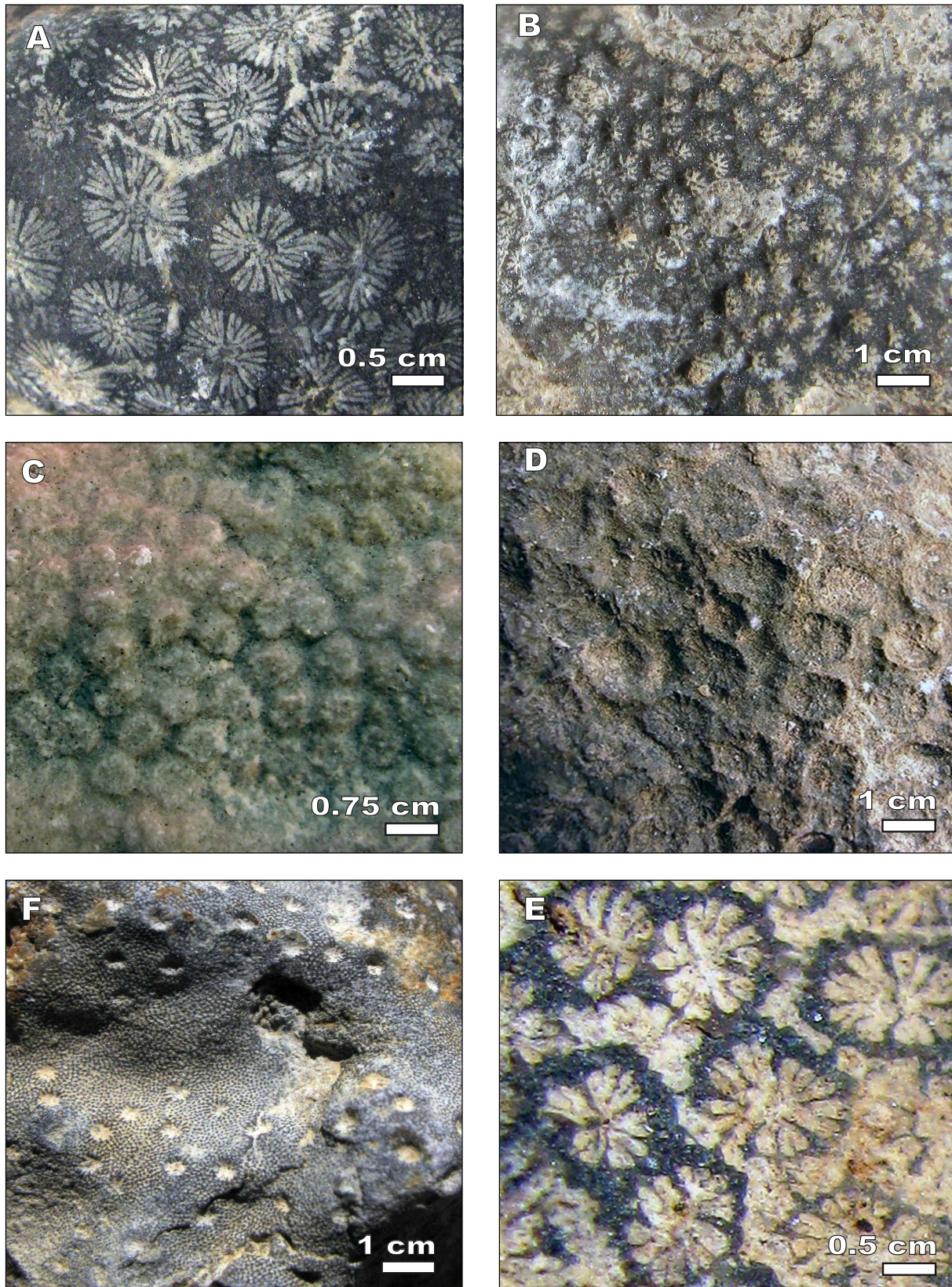


FIGURE III. Photograph of A) *Septastrea* sp.; B) *Platycoenia iranica*; C) *Lepastrea* sp.; D) *Simplastrea* sp.; E) *Stylophora thirsiformis*; F) *Tarbellastrea carryensis*.

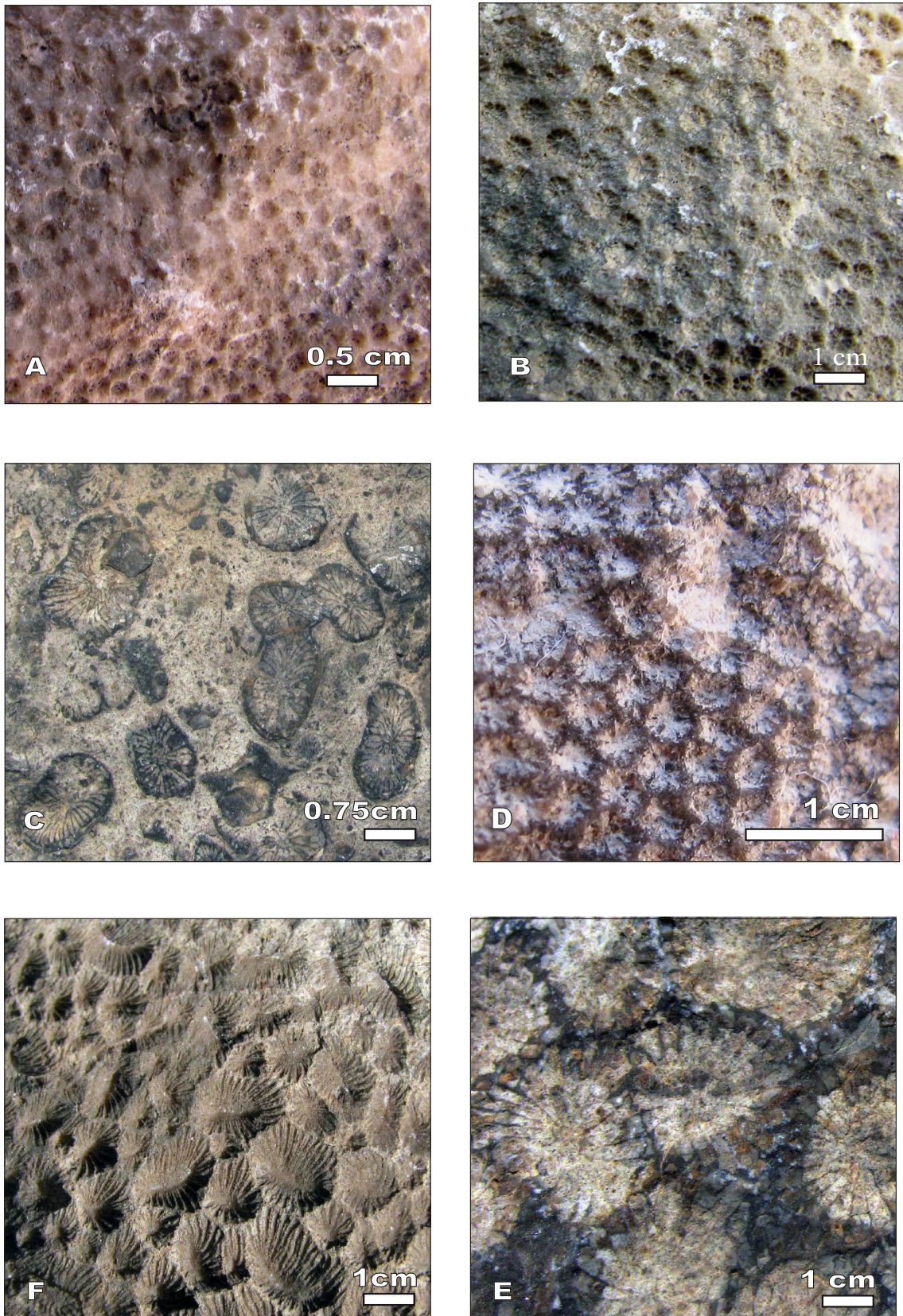


FIGURE IV. Photograph of A) *Goniastrea* sp.; B) *Astrocoenia nana*; C) *Caulastrea pseudoflabellum*; D) *Alveopora* SP.; E) *Hydnohpora rudis*; F) *Favites* sp.

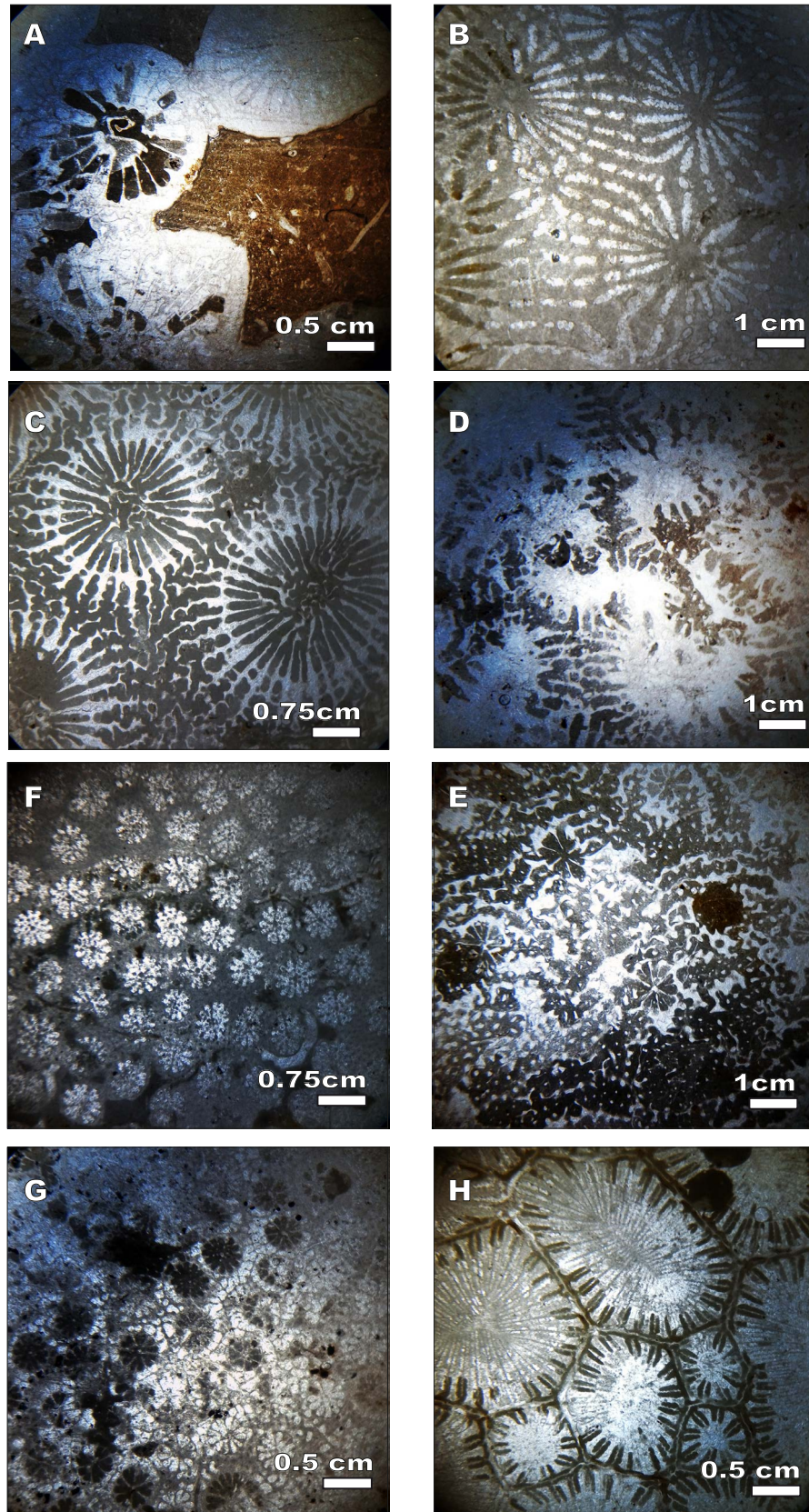


FIGURE V. Microphotograph of A) *Astrangia persica*; B) *Favia cylindracea*; C) *Agathiphyllia gregaria*; D) *Hydrophyllia stellate*; E) *Platycoenia iranica*; F) *Stylophora thirsiformis*; G) *Astrocoenia nana*; H) *Hydnothophora rudis*.