

Calcareous algae, foraminifera and sequence stratigraphy of the Fahliyan Formation at Kuh-e-Surmeh (Zagros Basin, SW of Iran)



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Geologia Croatica

ABSTRACT

*Palaeontological, environmental and sequence stratigraphic studies were carried out on the shallow carbonate platform facies of the Berriasian to Hauterivian Fahliyan Formation and the lower part of the Gadvan Formation, at Kuh-e-Surmeh. The studies were based on calcareous green algae (mainly Dasycladales) and accompanying benthic foraminifera, focusing on revision of the considerable, pioneering work of GOLLESTANEH (1965, 1979), initially undertaken on behalf of the National Iranian Oil Company (NIOC). Thirty two species of calcareous green algae and thirty four species of benthic foraminifera were identified from the Fahliyan Formation and from the lower part of the Gadvan Formation. A number of the recognized calcareous green algae were previously given different names by other authors working in SW Iran. Additional taxa were also recorded for the first time in the Zagros basin, including *Clypeina dragastani*, *C. estevezii*, *C. solkani*, *C. parasolkani*, *Holosporella arabica*, *Otternstella lem-mensis*, *Salpingoporella circassa*, *S. istriana* and *S. katzeri*. *Salpingoporella circassa* is quite common and apparently recorded for the first time from Southern Tethys. Also *Salpingoporella? inopinata* n. sp., (originally named *Iranella inopinata* by GOLLESTANEH, a nomen nudum) appears to be quite common in the Fahliyan Formation, although apparently endemic to SW Iran. Three main depositional environments were recognized based on the faunal/floral association, lithological and sedimentological characteristics: inner ramp/restricted platform, mid ramp/margin to open platform, and outer ramp/platform slope, with water depths ranging from about 5m to 20m, rarely reaching 40m. Facies changes facilitated the recognition of three large scale sequences throughout the studied succession, bringing interesting relationships with the sequence bundles identified in the Arabian Plate.*

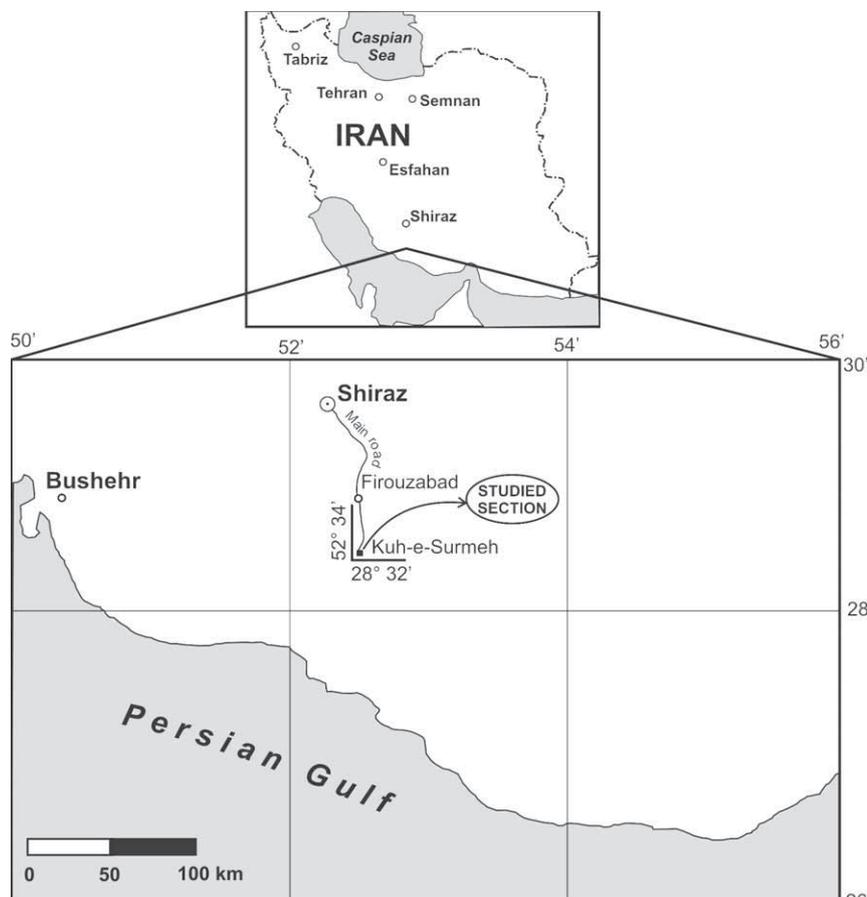
Keywords: Iran, Zagros Mountains, Fahliyan Formation, Gadvan Formation, Dasycladales, foraminifers, Cretaceous, stratigraphy

1. INTRODUCTION

This paper deals with the calcareous green algae (mainly Dasycladales) and foraminifera from the Zagros Basin (SW of Iran) which aims as a tool to recognize the depositional environments and to contribute to the understanding of algal palaeoecology. The section studied is located at 52° 34' longitude and 28° 32' latitude, in Kuh-e-Surmeh, south of the town of Firouzabad (Fig. 1). The exposed section is 212m thick and a total number of 254 thin-sections were prepared from the

collected samples. Systematic description of the whole microfossil assemblages is beyond the scope of this paper which focuses on sequence stratigraphy, benthic foraminifera and the newly identified dasycladalean algae.

The Fahliyan Formation has already been documented in previous articles and in several unpublished internal reports of the National Iranian Oil Company (NIOC), dealing with biostratigraphy and facies analysis. A preliminary report on this formation was carried out by Ali Gollestaneh in 1965



26 Figure 1: Location map of the studied section

(NIOC internal report no. 1056), as his PhD thesis, later published in London (GOLLESTANEH, 1965). It includes the systematic description of benthic foraminifera and calcareous green algae, along with a range chart distribution of the microfossils. Therefore, the present paper is a partial revision of Gollestaneh's report, focusing on the calcareous green algae. Most of the internal reports of the NIOC also centre on biostratigraphy and age determination, following the zonation scheme introduced by WYND (1965) for the exploration/production agreement area. The Cretaceous rock units (such as the Fahliyan and Gadvan formations) have been analyzed for microfossils and age determination by several geologists (GOLLESTANEH, 1974; SETUDEHNNIA, 1978; WYND, 1965¹; WELLS, 1965²; KHERADPIR, 1975³). However, additional, new, detailed palaeoecological and palaeobathymetric studies are essential for comprehension of the Fahliyan Formation and other Lower Cretaceous successions in the Zagros Basin, in order to ensure better correlations and improve our understanding of the regional geology.

¹ WYND, J.G. (1965): Biofacies of the Iranian consortium-agreement area. – NIOC report no. 1082, unpublished

² WELLS, A.J. (1965): Illustrated comments on the lithofacies/biofacies and sedimentary structures. – NIOC report no. 1068, unpublished

³ KHERADPIR, A. (1975): Stratigraphy of the Khami Group in southwest Iran. – NIOC report no. 1235, unpublished

2. TAXONOMIC DESCRIPTION

Among many known dasycladalean algae, the Fahliyan Formation yielded a new species, herein tentatively assigned to the genus *Salpingoporella* PIA. The species was first described and properly illustrated by GOLLESTANEH (1965), in his unpublished PhD thesis, under the name of *Iranella inopinata* gen. and sp. nov. Yet, adequately combining new observations on the present material with illustrations provided by GOLLESTANEH remains a difficult task. Hypothetically, more than one species may be present and certainly, additional material must be identified and investigated. Nevertheless, this opportunity is taken to formally introduce and provisionally describe the new species dedicated to Dr. Ali Gollestaneh.

Genus: *Salpingoporella* PIA in TRAUTH, 1918

Salpingoporella? inopinata GOLLESTANEH n. sp.

(Pl. 1, Figs. J–M, T; Pl. 2, Figs. N–P; Pl. 3, Fig. F; Pl. 4, Figs. D, L–P)

1965 *Iranella inopinata* gen. and sp. nov. – GOLLESTANEH, p. 250, Pls. 68–69

Material and stratum typicum: Up to 24 specimens, from different localities (Kuh-e-Surmeh), all from the Zagros fold belt, Iran. The specimen illustrated in Pl. 1, Fig. L is the holotype, an oblique section from sample JHT 1353 in the upper, Valanginian part of the section. Type location is at Kuh-e-Surmeh, 50 km south of Kazerun city, SW Iran (Fig. 1).

Depository: Materials (rock samples and thin-sections) are housed in the department of Geological and Geochemical

studies and researches of the Exploration Directorate of the National Iranian Oil Company (NIOC), A. Gollestaneh's collection.

Range: Berriasian – Valanginian, as confirmed by foraminifera and dasycladalean algae.

Diagnosis: Thallus and axial cavity cylindrical to slightly club-shaped. Laterals horizontal, forming quincunxes, four to five per verticil, connected to the main axis by a short and narrow pore (peduncle). Laterals then abruptly widen out, first elliptical, horizontally elongated, then circular in tangential section, where they are loosely adjacent to each other. Weak imprints of cysts, whenever present, are located in the lower part of the laterals (cladospory), or at the periphery of the axial cavity (endospory). Calcareous coat colourless, made of interlocking calcite crystals (originally aragonite), solid around the axial cavity, weak, forming a pellicle at the calcified periphery of the laterals.

Dimensions:

Outer diameter (D)	150–507 μm
Inner diameter (axial cavity, d)	63–202 μm
d / D	0.3–0.7
Verticils spacing (h)	54–67 μm
Laterals per verticil (w)	4–5
Proximal width of the connecting pore	11–22 μm
Cysts imprint diameter	approx. 40 μm

Comparisons and remarks: The closest species to *Salpingoporella? inopinata* is the Kimmeridgian – Aptian *Salpingoporella hispanica* CONRAD & GRÄBNER 1975, also with 4–5 laterals per verticil. In *S. hispanica*, (CARRAS et al., 2006, pl. V, fig. 1–5), the laterals are first rectangular in section, then hexagonal, horizontally elongated. The proximal pores (peduncles) of *S. hispanica* are eccentrically located, laterally to the axis of the corresponding laterals. In certain sections (Pl. 4, Fig. P), the laterals show the presence of questionable “holes”, possibly corresponding to eccentrically located proximal pores. In other sections, on the other hand (Pl. 1, Fig. L; Pl. 4, Fig. D), the pore is clearly located on the axis of the lateral. Based on a single tangential section (Pl. 4, Fig. O), the laterals of the new species are not adjoined beyond the calcareous coat. In other words, they do not or do not always form the distal, continuous assimilatory cortex typical of *Salpingoporella*. So far, the questionable endospory is based on a single oblique section (Pl. 3, Fig. F). Cladospory (e.g. in *Salpingoporella genevensis* CONRAD et al.) is part of the definition of the genus *Salpingoporella*. Also in *Salpingoporella turgida* RADOIČIĆ the axial cavity and the thallus may be slightly club-shaped. One section, of *S.? inopinata* (GOLLESTANEH, 1965, pl. 68, fig. 3) not illustrated here, suggests the possible presence of a much wider, possibly aberrant “head” of thallus.

3. MICROPALAEONTOLOGICAL ASSEMBLAGES

The total thickness of the studied succession is 212m. The Fahliyan Formation is 150m thick and the remainder belongs to the Gadvan Formation which overlies the Fahliyan Formation in this area. Based upon the micropalaeontological data, the following three geological age intervals can be separated.

Berriasian: The first (lower) interval is about 93m thick. Lithologically, it is essentially composed of limestone (bioclastic wackestone to packstone with micritization, bioturbated mudstone-wackestones (Pl. 7, Fig. A), peloidal bioclastic grainstones (Pl. 7, Fig. C), peloidal-fenestrated grainstones (Pl. 7, Fig. B), mollusc floatstones (Pl. 7, Fig. G), spongiferous (spicules) packstones (Pl. 7, Fig. E), argillaceous wackestones with dissolved gastropod shells (Pl. 7, Fig. H), *Lithocodium/Bacinella* bindstones and rare non-fossiliferous dolomitic mudstones (Pl. 7, Fig. D). The calcareous green algae encountered in this interval are: *Salpingoporella istriana* (GUŠIĆ), *S. pygmaea* (GÜMBEL), *Clypeina* sp., *Salpingoporella circassa* FARINACCI & RADOIČIĆ, *Otternstella lemmensis* (BERNIER), *Cylindroporella?* sp., *Salpingoporella? inopinata* n. sp., *Zergabriella embergeri* (BOUROULLEC & DELOFFRE), *Otternstella sudgeni* ELLIOTT, *Rajkaella* sp., *Salpingoporella annulata* CAROZZI, *Holosporella* sp., *Salpingoporella katzeri* CONRAD & RADOIČIĆ, *Actinoporella podolica* (ALTH), *Salpingoporella* aff. *piriniae* CARRAS & RADOIČIĆ, *Terquemella* sp., *Clypeina* cf. *onogosti* RADOIČIĆ, *Clypeina* aff. *nigra* CONRAD & PEYBERNÈS, *Clypeina dragastani* DIENI & RADOIČIĆ, *Clypeina estevezii* GRANIER, *Anisoporella* sp., *Praturlonella* sp., *Holosporella arabica* GRANIER & BRUN, *Clypeina* gr. *solkani* CONRAD & RADOIČIĆ, *Clypeina parasolkani* FARINACCI & RADOIČIĆ. These are associated with *Thaumatoporella parvovesiculifera* RAINERI, *Permocalculus inopinatus* ELLIOTT, *Cladocoropsis mirabilis* FELIX, *Lithocodium aggregatum* ELLIOTT and *Bacinella irregularis* RADOIČIĆ.

The accompanying foraminifera are essentially represented by: *Trocholina chouberti* HOTTINGER, *T. gigantea* GORBATCHIK, *T. alpina* LEUPOLD, *T. elongata* LEUPOLD, *T. sagittaria* ARNAUD-VANNEAU et al, orbitolinids, *T. molesta* GORBATCHIK, *Pseudocyclammina lituus* YOKOYAMA, *Pseudochrysalidina arabica* HENSON, *Praechrysalidina infracretacea* LUPERTO SINNI, *Trocholina campanella* ARNAUD-VANNEAU et al, *Everticyclammina hedbergi* MAYNC, *Rumanoloculina pseudominima* BARTENSTEIN & KOVATCHEVA, *Nautiloculina oolithica* MOHLER, *Trocholina delphinensis* ARNAUD-VANNEAU et al, *Haplophragmoides* sp., *Trocholina cherchiai* ARNAUD-VANNEAU et al, *Dukhanina conica* HENSON, *Nezzazata* sp., *Montsalevia salevensis* CHAROLLAIS et al, *Vercorsella halleinensis* SCHLAGINTWEIT, *Protopenneroplis ultragranulata* GORBATCHIK and *Scythiloculina bancilai* NEAGU, associating with *Aeolisacus inconstans* RADOIČIĆ, echinoid remains, mollusc fragments, sponge spicules and ammonite shells.

Valanginian: The second interval has a thickness of 57m. It is dominated by *Lithocodium/Bacinella* bindstones (Pl. 7, Fig. I), bioclastic wackestones to packstones with dissolved gastropod shells (Pl. 7, Fig. M), bioclastic wackestones to packstones containing aptychi and the calcareous opercula of ammonites (Pl. 7, Fig. J), peloidal-fenestral grainstones (Pl. 7, Fig. K), serpulid limestone (Pl. 7, Fig. L), bioclastic packstone-grainstones, peloidal-fenestral grainstones with coated grains (Pl. 7, Fig. N) and argillaceous wackestones with evidence of subaerial exposure (Pl. 7, Fig. O).

PLATE 1

Dasycladalean algae of the Kuh-e-Surmeh section

- A** *Zergabriella embergeri* BOUROULLEC & DELOFFRE, Berriasian, sample JHT 1298.
B *Salpingoporella annulata* CAROZZI, Berriasian, sample JHT 1298.
C *Actinoporella?* cf. *podolica* (ALTH), Berriasian, sample JHT 1303.
D *Salpingoporella* sp. aff. *piriniae* CARRAS & RADOIČIĆ, Berriasian, sample JHT 1307.
E *Salpingoporella annulata* CAROZZI, Berriasian, sample JHT 1307.
F *Clypeina* cf. *solkani* CONRAD & RADOIČIĆ, Berriasian, sample JHT 1307.
G *Otterstella* cf. *sudgeni* ELLIOTT, Berriasian, sample JHT 1308.
H *Salpingoporella* sp. aff. *piriniae* CARRAS & RADOIČIĆ, Berriasian, sample JHT 1313.
I *Salpingoporella* cf. *circassa* FARINACCI & RADOIČIĆ, Berriasian, sample JHT 1316.
J–M *Salpingoporella?* *inopinata* GOLLESTANEH, n.sp. (section L is the holotype), Berriasian, sample JHT 1317.
N, O *Cylindroporella?* sp. (basal, sterile portion of the thallus), Berriasian, sample JHT 1319.
P *Holosporella arabica* GRANIER & BRUN, Berriasian, sample JHT 1319.
Q, S *Actinoporella podolica* (ALTH), Berriasian, sample JHT 1319.
R *Terquemella* sp., Berriasian, sample JHT 1319.
T *Salpingoporella* cf. *inopinata* GOLLESTANEH, n. sp., Berriasian, sample JHT 1320.

Scale: Figs. A, C, I = 150 µm; Figs. E, F, G, J, K, N, O, P, Q, S = 100 µm; Figs. B, D, H, L, M, R, T = 50 µm.

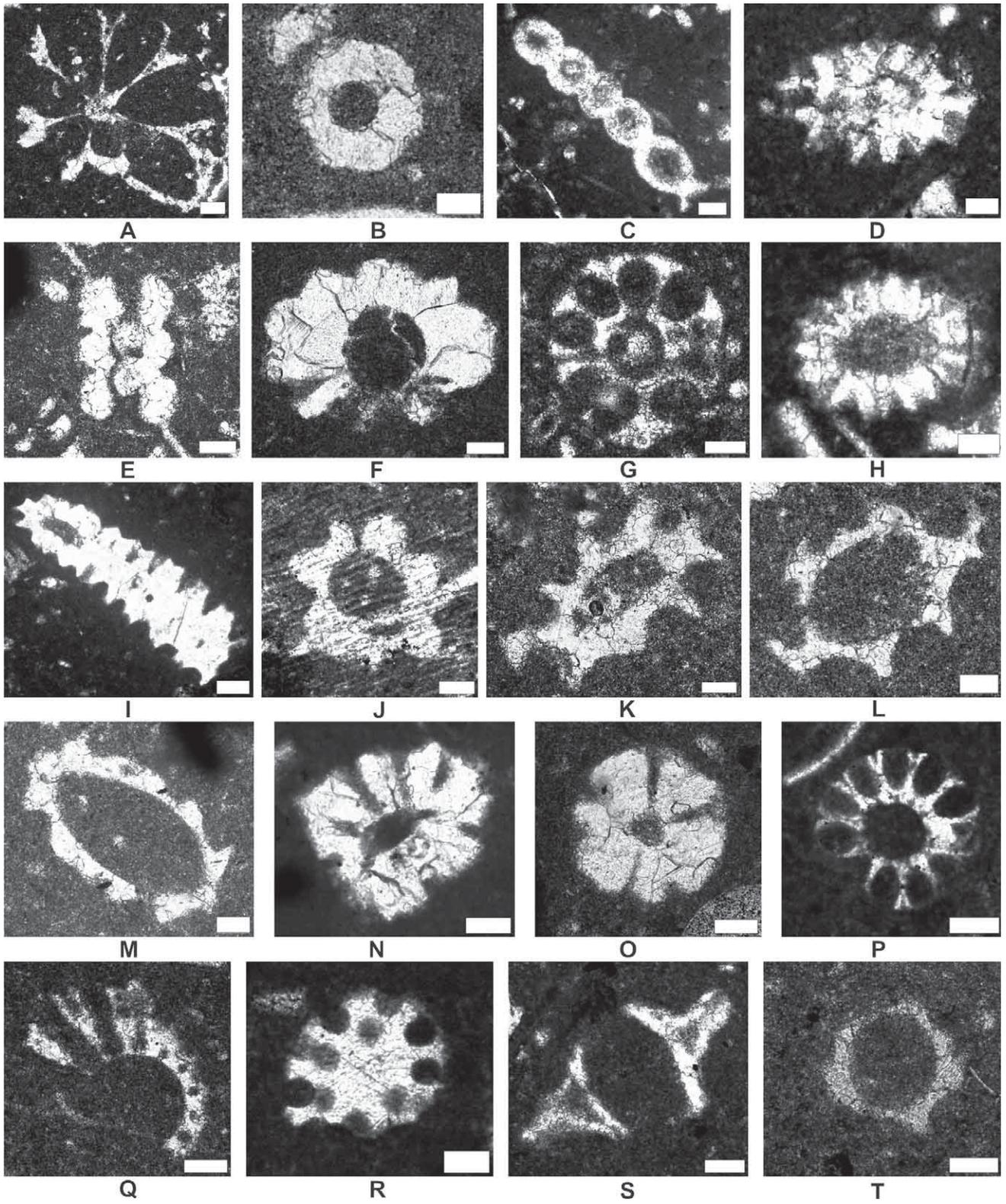


PLATE 2

Dasycladales of the Kuh-e-Surmeh section

A *Salpingoporella circassa* FARINACCI & RADOIČIĆ, Berriasian, sample JHT 1320.

B *Neomizzia?* sp., Berriasian, sample JHT 1321.

C *Salpingoporella circassa* FARINACCI & RADOIČIĆ, Berriasian, sample JHT 1324.

D *Clypeina* cf. *solkani* CONRAD & RADOIČIĆ, Berriasian, sample JHT 1324.

E *Salpingoporella annulata* CAROZZI, Berriasian, sample JHT 1324.

F *Salpingoporella* sp. aff. *piriniae* CARRAS & RADOIČIĆ, Berriasian, sample JHT 1324.

G, H *Salpingoporella annulata* CAROZZI, Berriasian, sample JHT 1324.

I, J *Neomizzia?* sp., Berriasian, sample JHT 1324.

K *Clypeina parasolkani* FARINACCI & RADOIČIĆ, Berriasian, sample JHT 1324.

L Dasycladalean alga, gen. & sp. indet. Berriasian, sample JHT 1325.

M *Clypeina?* cf. *dragastani* DIENI & RADOIČIĆ, Berriasian, sample JHT 1326.

N-P *Salpingoporella?* *inopinata* GOLLESTANEH, n. sp., Berriasian, sample JHT 1327.

Q, R *Neomizzia?* sp., Berriasian, sample JHT 1327.

S *Salpingoporella katzeri* CONRAD & RADOIČIĆ, Berriasian, sample JHT 1327.

T *Clypeina* cf. *solkani* CONRAD & RADOIČIĆ, Berriasian, sample JHT 1327.

Scale: Figs. H, I, S = 150 μ m; Figs. A, B, C, D, E, G, J, M, N, Q, R, T = 100 μ m; Figs. F, K, L, O, P = 50 μ m.

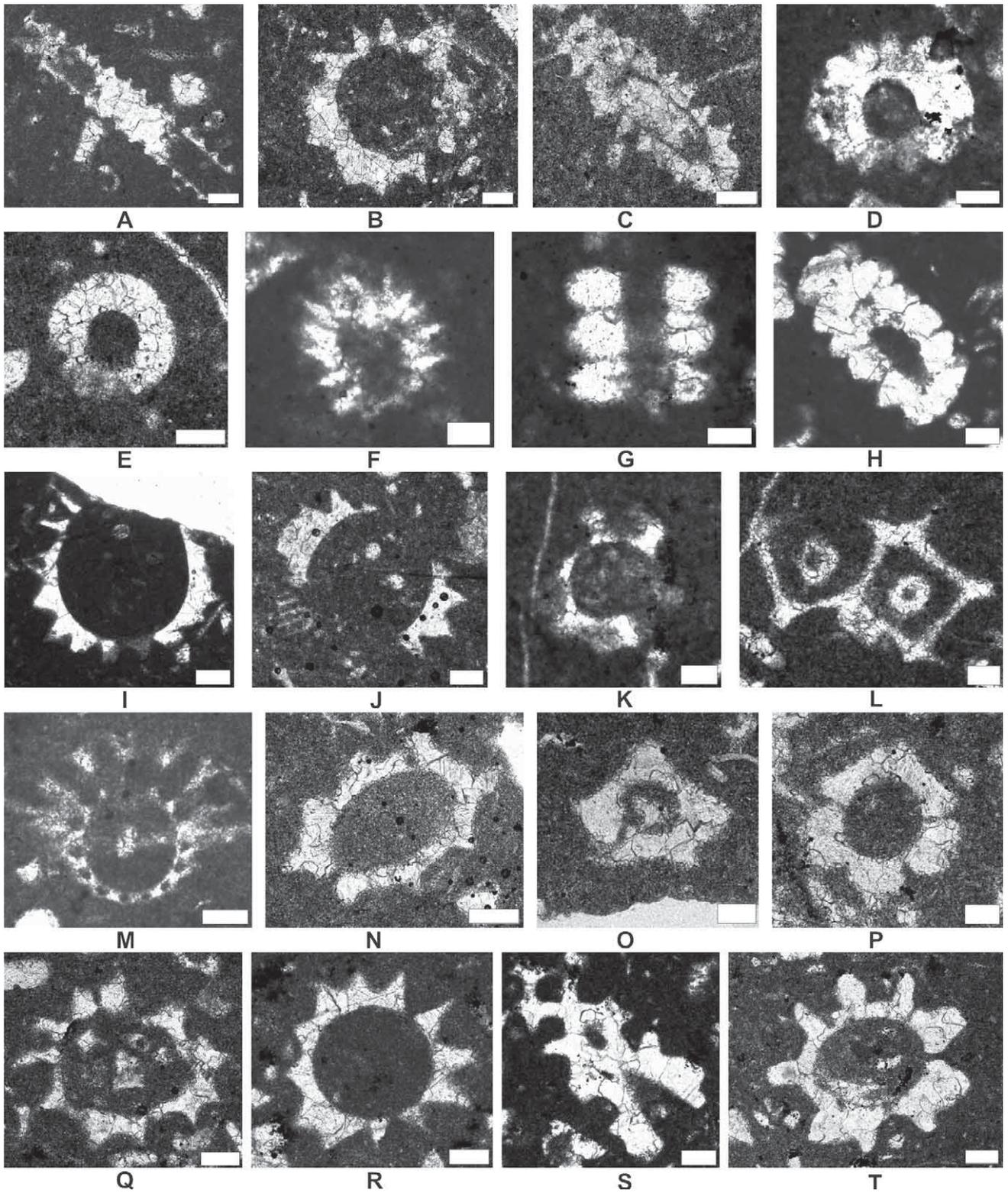


PLATE 3

Calcareous algae of the Kuh-e-Surmeh section

- A** *Clypeina parasolkani* FARINACCI & RADOIČIĆ, Berriasian, sample JHT 1327.
- B-E** *Actinoporella podolica* (ALTH), Berriasian, sample JHT 1328.
- F** *Salpingoporella? inopinata* GOLLESTANEH, n. sp., Berriasian, sample JHT 1328.
- G** *Otternstella lemmensis* (BERNIER), Berriasian, sample JHT 1328.
- H** *Salpingoporella pygmaea* (GÜMBEL), Valanginian, sample JHT 1330.
- I** *Bacinella irregularis* RADOIČIĆ, Valanginian, sample JHT 1330.
- J, K** *Actinoporella* cf. *jaffrezoii* GRANIER, Valanginian, J: sample JHT 1339 & K: sample JHT 1340.
- L** *Clypeina* cf. *estevezii* GRANIER, Valanginian, sample JHT 1340.
- M-P** *Terquemella* sp., Valanginian, M: sample JHT 1340 & N-P: sample JHT 1346.
- Q** *Clypeina* cf. *estevezii* GRANIER, Valanginian, sample JHT 1346.
- R-T** Second order laterals of *Selliporella neocomiensis* (RADOIČIĆ), Valanginian, sample JHT 1349.
- Scale: Fig. H = 300 µm; Fig. I = 200 µm; Figs. A, B, C, D, E, F, G, J, K, L, Q, R, S = 100 µm; Figs. M, O, P, T = 50 µm; Fig. N = 30 µm.

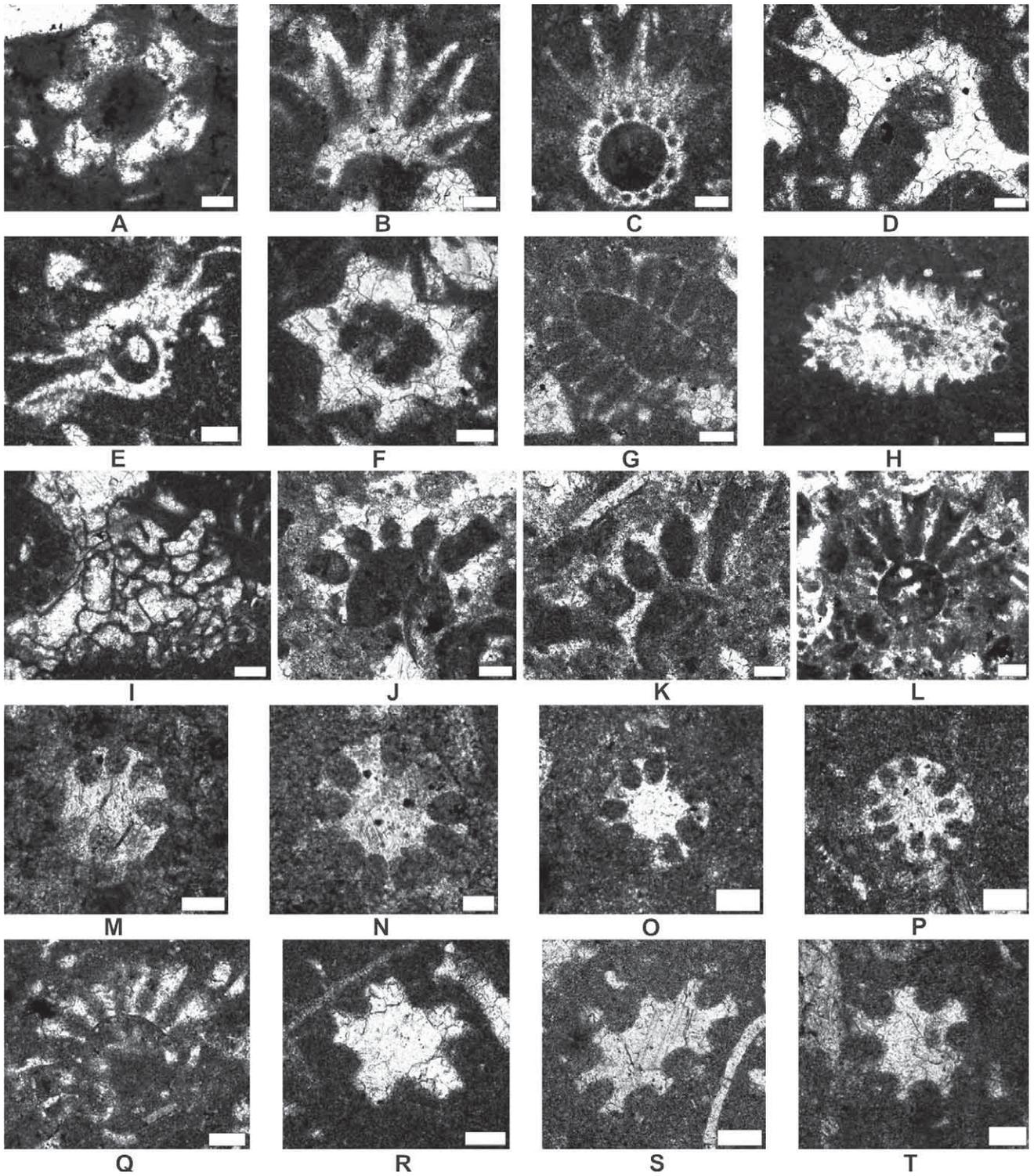


PLATE 4

Calcareous algae of the Kuh-e-Surmeh section

- A, B** *Zergabriella?* cf. *embergeri* (BOUROULLEC & DELOFFRE), Valanginian, sample JHT 1349.
- C** Oncoïd of *Bacinella irregularis* RADOIČIĆ and *Lithocodium aggregatum* ELLIOTT, Valanginian, sample JHT 1351.
- D** *Salpingoporella?* *inopinata* GOLLESTANEH., n. sp., Valanginian, sample JHT 1353.
- E-H** *Salpingoporella circassa* FARINACCI & RADOIČIĆ, Valanginian, sample JHT 1353.
- I** Dasycladalean alga, gen. & sp. indet., Valanginian, sample JHT 1356.
- J** *Salpingoporella?* cf. *annulata* CAROZZI, Valanginian, sample JHT 1356.
- K** *Salpingoporella dinarica* RADOIČIĆ, Hauterivian -Barremian, sample JHT 1358.
- L-P** *Salpingoporella?* *inopinata* n. sp., in GOLLESTANEH, 1965, pls. 68 & 69, × 150.
- Scale: Fig. C = 300 μm; Fig. F, G, H, I, J, L, M, N, O, P = 100 μm; Figs. A, B, D, E, K = 50 μm.

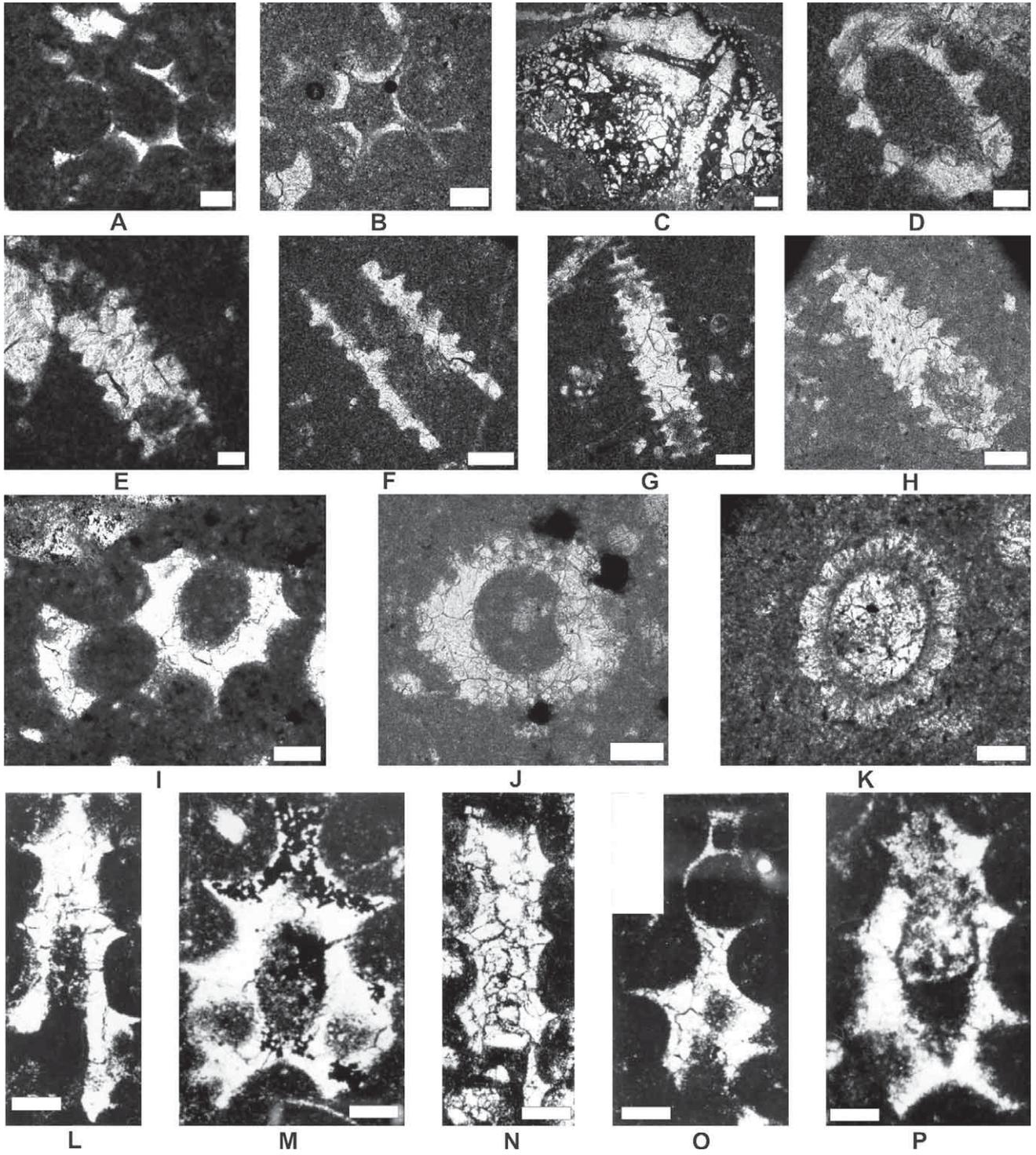


PLATE 5

Benthic foraminifera of the Kuh-e-Surmeh section

- A** *Trocholina* sp., Berriasian, sample JHT 1298.
- B** *Trocholina* sp., Berriasian, sample JHT 1298.
- C** ?*Mayncina* sp., Berriasian, sample JHT 1298.
- D** *Glomospira* sp., Berriasian, sample JHT 1302.
- E** *Trocholina sagittaria* ARNAUD-VANNEAU et al., Berriasian, sample JHT 1304.
- F** *Charentia* cf. *cuvillieri* NEUMANN, Berriasian, sample JHT 1305.
- G** *Trocholina* cf. *chouberti* HOTTINGER, Berriasian, sample JHT 1305.
- H** *Trocholina delphinensis* ARNAUD-VANNEAU et al., Berriasian, sample JHT1309.
- I** *Trocholina* cf. *chouberti* HOTTINGER, Berriasian, sample JHT1309.
- J** *Trocholina* cf. *gigantea* GORBATCHIK, Berriasian, sample JHT1312.
- K** *Trocholina delphinensis* ARNAUD-VANNEAU et al., Berriasian, sample JHT 1312.
- L** *Trocholina* cf. *elongata* LEUPOLD, Berriasian, sample JHT1314.
- M** *Trocholina campanella* ARNAUD-VANNEAU et al., Berriasian, sample JHT 1315.
- N** *Trocholina* sp., Berriasian, sample JHT 1316.
- O** *Pseudocyclammina lituus* YOKOYAMA Berriasian,, sample JHT 1317.
- P** ?*Vercorsella halleinensis* SCHLAGINTWEIT, Berriasian, sample JHT 1317.

Scale: Fig. O = 200 μ m; Figs. A, B, C, D, E, F, G, H, I, J, K, L, M, N, P = 100 μ m.

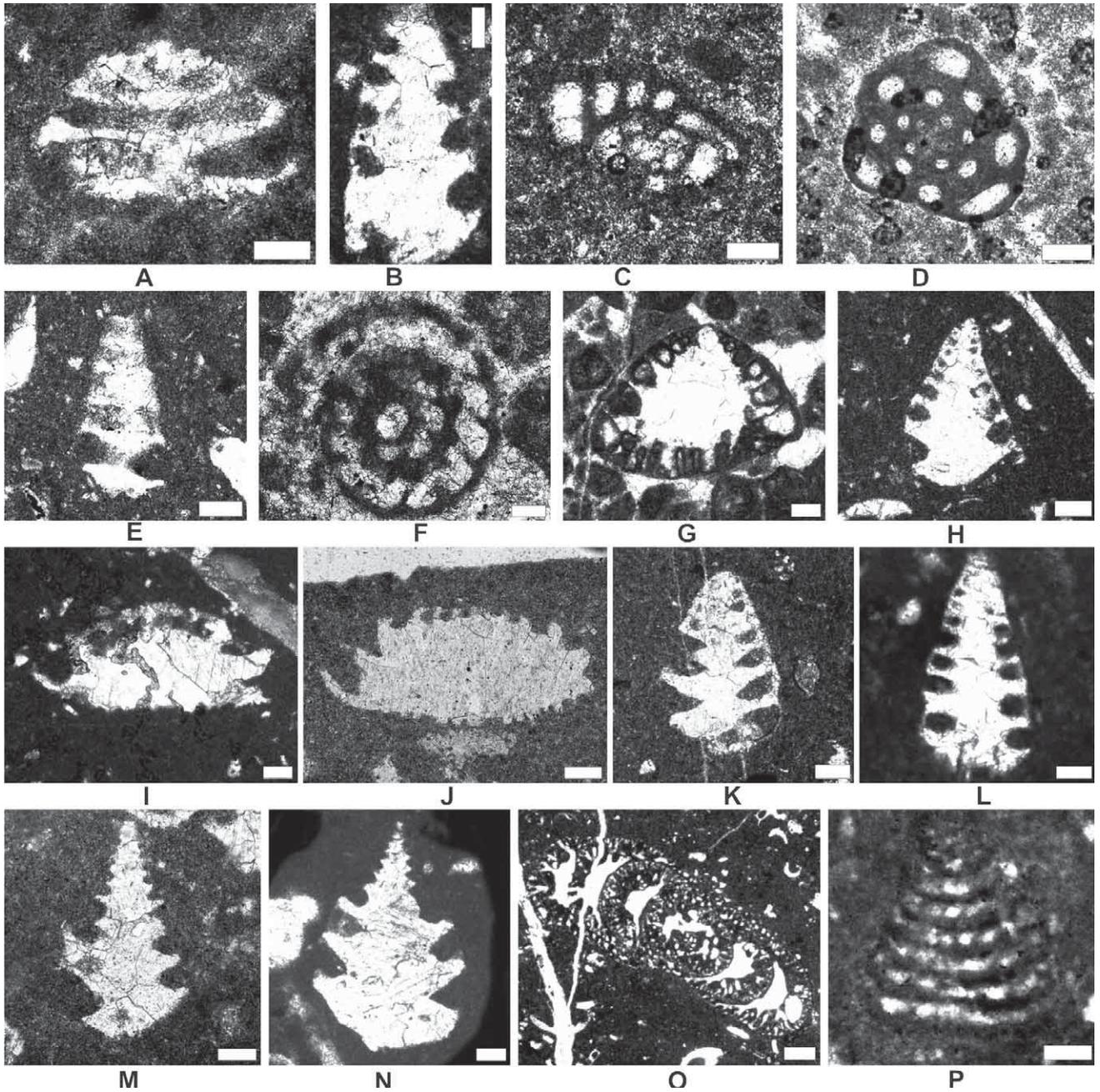


PLATE 6

Microfossils of the Kuh-e-Surmeh section

- A** Lituolid foraminifera, Berriasian, sample JHT 1324.
- B** *Mayncina* sp., Berriasian, sample JHT 1326.
- C** *Praechrysalidina infracretacea* LUPERTO SINNI, Valanginian, sample JHT 1331.
- D** *Pseudochrysalidina arabica* HENSON, Valanginian, sample JHT 1336.
- E** *Trocholina sagittaria* ARNAUD-VANNEAU et al., Valanginian, sample JHT 1337.
- F** *Rectocyclammina* sp., Valanginian, sample JHT 1339.
- G** *Redmondoides* cf. *lugeoni* (SEPTFONTAINE), sample JHT 1340.
- H** *Vercorsella* sp., sample JHT 1343.
- I** ?*Deabarina hahounerensis* FOURCADE et al., Valanginian, sample JHT 1343.
- J** *Aeolisaccus inconstans* RADOIČIĆ, Valanginian, sample JHT 1343.
- K** *Nautiloculina* cf. *broennimanni* ARNAUD-VANNEAU & PEYBERNÉS, Valanginian, sample JHT 1352.
- L** *Aulotortus* sp., Hauterivian-Barremian, sample JHT 1358.
- M** *Palorbitolina lenticularis* BLUMENBACH, Hauterivian-Barremian, sample JHT 1358.
- N** *Novalesia distorta* ARNAUD-VANNEAU, Hauterivian-Barremian, sample JHT 1359.
- O** *Tintinnopsella carpathica* MURG & FILIP, Berriasian, sample JHT 1320.

Scale: Fig. C = 200 μ m; Fig. H, I, J = 75 μ m; Figs. A, B, D, E, F, G, K, M = 100 μ m; Figs. L, N, O = 50 μ m.

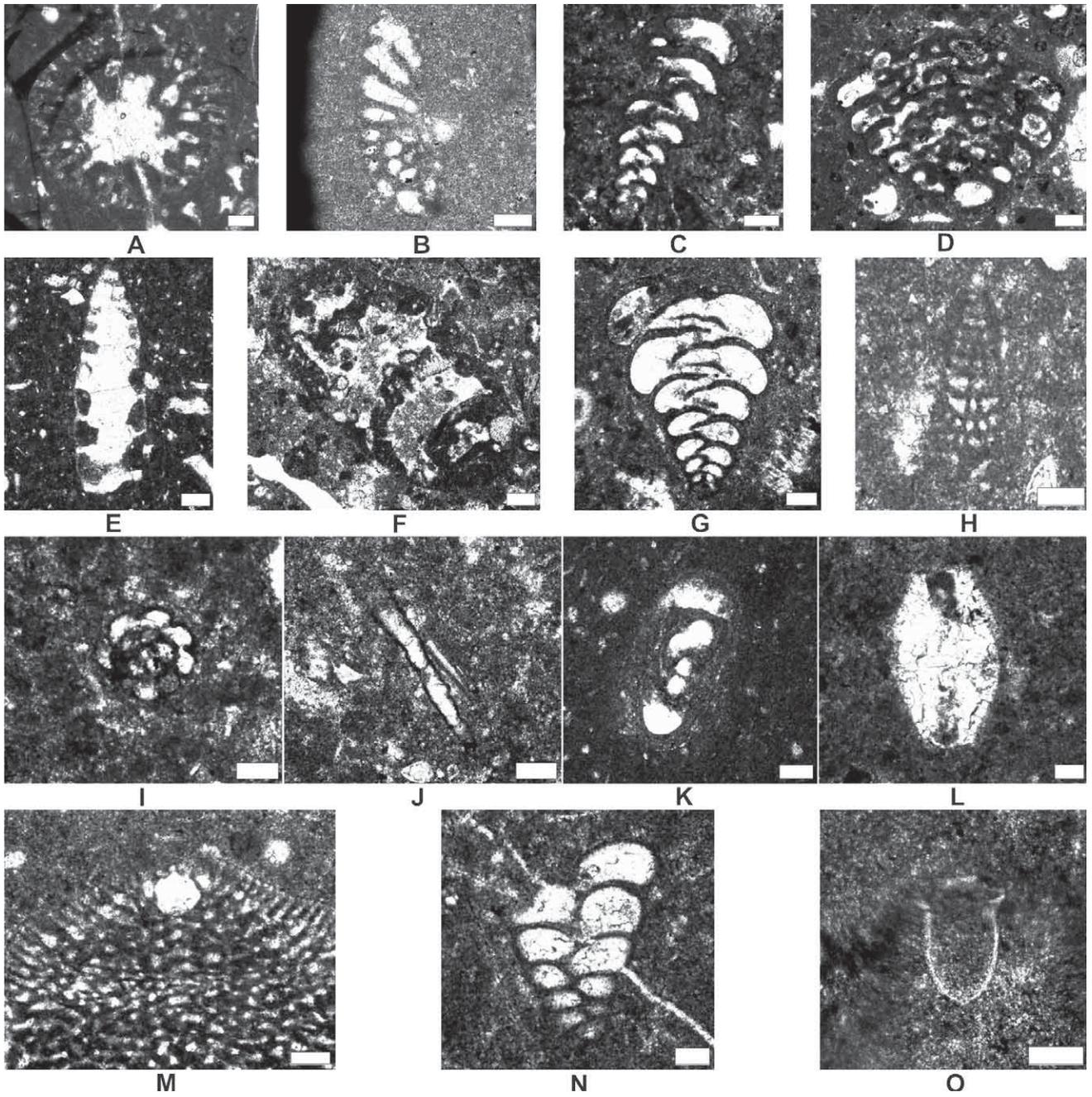
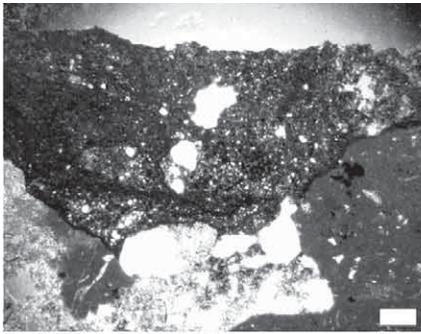


PLATE 7

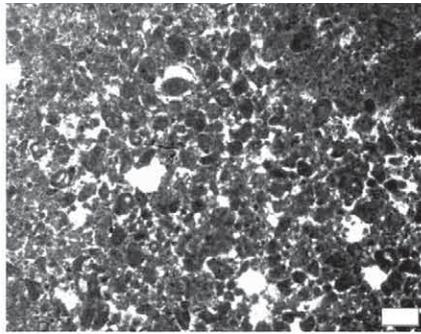
Carbonate facies types

- A** Bioturbated dolomitic mudstone, shallow subtidal deposits; sequence A, sample JHT 1299.
- B** Bioclastic, pelletal and fenestral grainstone; inner ramp, transgressive deposits of sequence A, sample JHT 1302.
- C** Bioclastic grainstone with *Trocholina cf. chouberti* and other common benthic foraminifera; inner/mid ramp, transgressive deposits of sequence A, sample JHT 1305.
- D** Non-fossiliferous mudstone; inner/mid ramp, transgressive deposits (before the maximum flooding surface) of sequence A, sample JHT 1306.
- E** Spongiferous (spicules) packstone; outer ramp, maximum flooding surface of sequence A, sample JHT 1308.
- F** Bioclastic packstone with abundant *Trocholina* spp.; inner/mid ramp, highstand deposits of sequence A, sample JHT 1315.
- G** Mollusc floatstone; inner/mid ramp, highstand deposits of sequence A, sample JHT 1316.
- H** Argillaceous wackestone with dissolved gastropod shells; inner/mid ramp, highstand deposits of sequence A, sample JHT 1320.
- I** *Lithocodium/Bacinell* bindstone; inner ramp, highstand deposits of sequence A, sample JHT 1333.
- J** Bioclastic packstone with aptychi (calcareous opercula of ammonites); inner ramp, highstand deposits of sequence A, sample JHT 1337.
- K** Peloidal, fenestral grainstone; inner/mid ramp, transgressive deposits of sequence B, sample JHT 1339.
- L** Serpulid limestone; inner ramp, shallow subtidal deposits of sequence B, sample JHT 1345.
- M** Bioclastic wackestone with dissolved gastropod shells; inner ramp, shallow subtidal deposits of sequence B, sample JHT 1347.
- N** Peloidal grainstone and coated grains; inner/mid ramp, shallow subtidal deposits of sequence B, sample JHT 1348.
- O** Subaerial exposure facies with pelecypod shell floatstone, dissolved shells and iron oxides; upper sequence boundary of sequence B, sample JHT 1356.

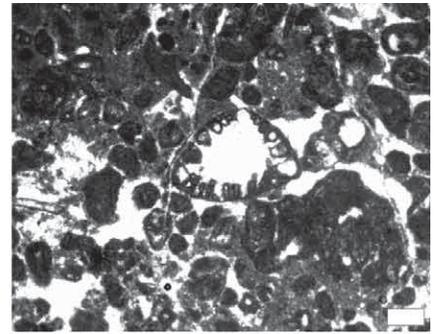
Scale: Fig. A, B, C, D, E, F, G, I, J, K, L, N, O = 300 μ m; Fig. H, M = 200 μ mm.



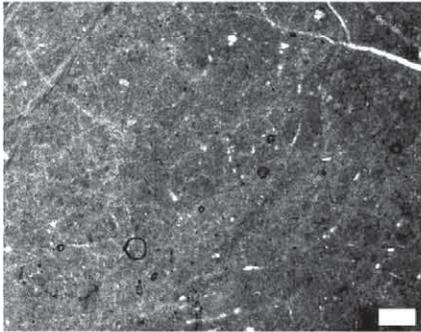
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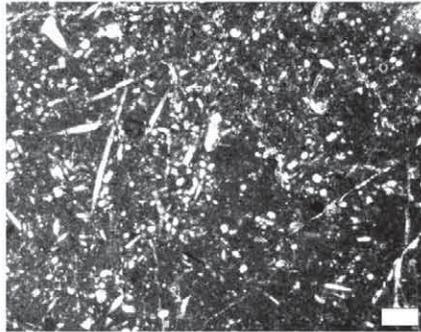
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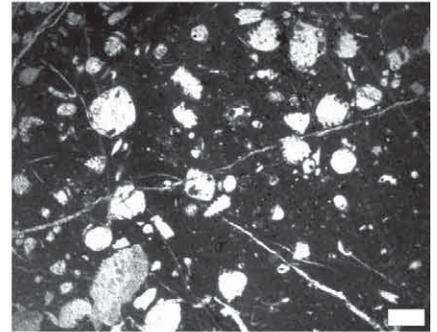
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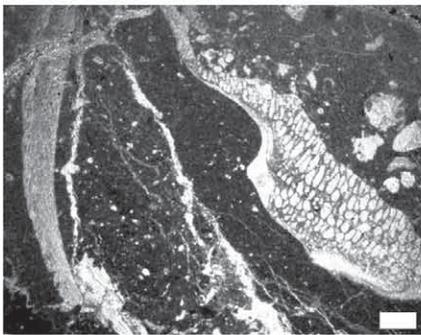
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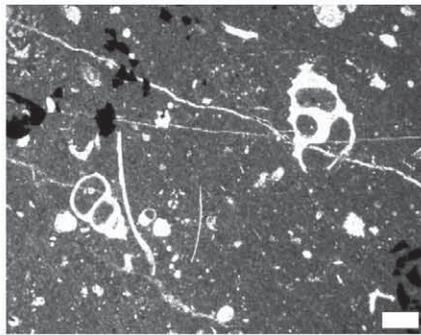
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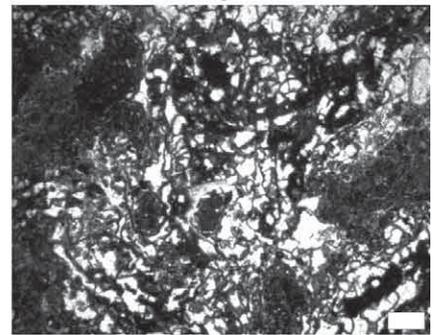
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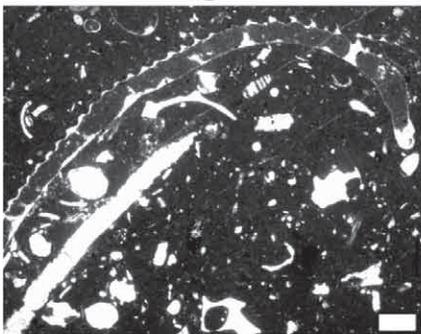
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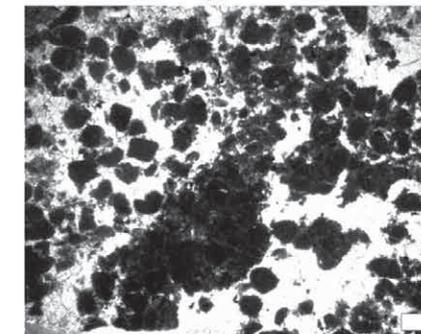
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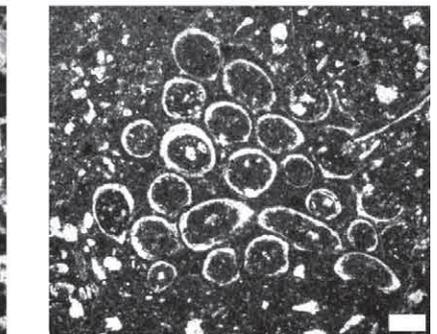
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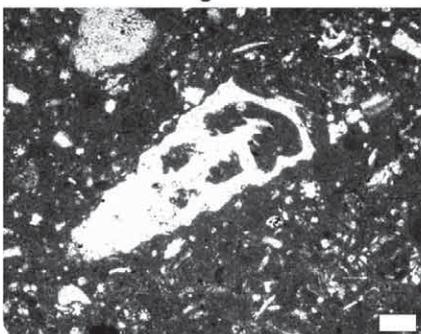
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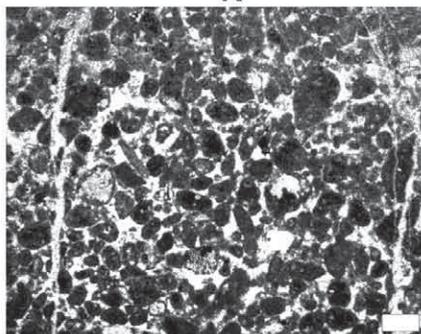
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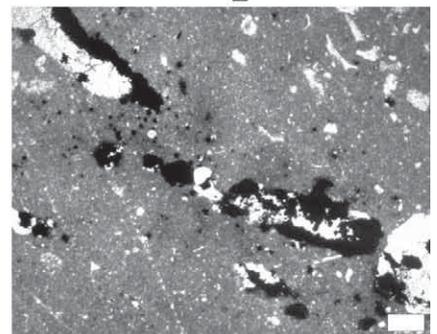
L



M



N



O

As shown by the range chart distribution (Fig. 2), most of the benthic foraminifera and calcareous green algae found in the Berriasian interval are also present in the Valanginian. The main difference is the first occurrence of some benthic foraminifera and dasycladalean algae such as: *Choffatella* sp., *Debarina hahoumerensis* FOURCADE & al, *Redmondoides* cf. *lugeoni* (SEPTFONTAINE), *Nautiloculina broemmimanni* ARNAUD VANNEAU & PEYBERNÈS, *Cuneolina laurenti* SARTONI & CRESCENTI, *Vercorsella* sp. *Falsogaudrynella tealbyensis* BARTENSTEIN, *Conicospirillina basiliensis* MOHLER, *Selliporella neocomiensis* (RADOIČIĆ) and *Actinoporella jaffrezoi* GRANIER. It is also worth mentioning that the following important calcareous green algae found in the previous (Berriasian) interval are absent from the Valanginian: *Clypeina dragastani* DIENI & RADOIČIĆ, *Otternstella lemmensis* (BERNIER), *O. sudgeni* ELLIOTT, *Salpingoporella istriana* (GUŠIĆ) and *Holosporella arabica* GRANIER & BRUN. Among the benthic foraminifera, *Trocholina gigantea* GORBATCHIK, *Charentia cuvillieri* NEUMANN and *Trocholina chouberti* HOTTINGER are also missing from the interval. Based on the faunal and floral content, a Valanginian (possibly Early Valanginian,) age can be assigned to this interval.

Hauterivian-Barremian: The third, 62m thick interval of the studied surface section belongs to the lower part of the Gadvan Formation. This formation mainly comprises marl and some thin to medium size intercalations of clean limestone (bioclastic packstone). Most of the Gadvan Formation (the shaly portions) is covered by vegetation so that no samples could be taken. Only two surface samples were prepared from the limestone horizons of this formation which are dominated by: *Palorbitolina lenticularis* BLUMENBACH, *Salpingoporella dinarica* RADOIČIĆ, *Debarina hahoumerensis* FOURCADE et al., *Choffatella decipiens* SCHLUMBERGER, *Trocholina sagittaria* ARNAUD-VANNEAU et al, *T. odukpaniensis* DESSAUVAGIE, *Aulotortus* sp., *Novalesia distorta* ARNAUD-VANNEAU, *Dukhania* sp., *Falsogaudrynella tealbyensis* BARTENSTEIN, *Dukhnia conica* HENSON and oncooids of *Lithocodium aggregatum* ELLIOTT with *Bacinella irregularis* RADOIČIĆ, associated with echinoid remains, mollusc fragments and corals. Based upon the aforementioned microfossils, an Hauterivian – Barremian age is assigned to this part of the Gadvan Formation in this area.

4. DEPOSITIONAL ENVIRONMENTS

Based on the analysis of the faunal and floral content of 254 thin-sections, and also on standard facies analysis criteria (texture, grain types and sedimentary features), three main depositional environments have been identified (Fig. 3).

Inner ramp/restricted platform: The inner ramp (shallow subtidal) depositional environments generally include the open lagoon, inner shoal and restricted lagoon. In the studied section, most of the deposits belong to the inner ramp environment, especially the open lagoon and inner shoal, which are characterized by the presence of bioclastic wackestone-packstones and bioturbated wackestone-packstones (Pl. 7, Fig.

A). Peloidal-bioclastic fenestral packstones to grainstones are also observed, indicative of the upper subtidal environments (Pl. 7, Figs. B–C). Most of the deposits are dominated by *Lithocodium/Bacinella* bindstones which are interpreted as typical shallow subtidal deposits (Pl. 7, Fig. I). The inner ramp deposits are represented by a highly diversified fauna and flora (Fig. 4) such as: calcareous green algae (*Salpingoporella*, *Actinoporella*, *Clypeina*, *Otternstella*, *Zergabriella* and rare *Selliporella*, associating with *Lithocodium/Bacinella*). Among the large benthic foraminifera, *Pseudocyclammina*, *Choffatella*, *Cuneolina*, *Trocholina* and miliolids are common, while *Dukhania* and orbitolinids are rarely observed. These are associated with abundant mollusc fragments, dissolved gastropods, corals and rare echinoid remains. The calcareous green algae dominate and prevail over benthic foraminifera in this environment. The serpulid limestone is also present in some parts, marking a transition from carbonate ramp stage to a platform stage (Pl. 7, Fig. L). The occasional presence of tintinnids (*Tintinnopsella carpathica* MURG & FILIP) and echinoids (*Saccocoma*) indicates a temporally limited connection to open platform environments. The miliolid–ostracod carbonates which indicate restricted lagoonal environments are extremely rare. They occur in the middle part of the section and are mainly mud supported, with wackestones. Based upon the abundant calcareous green algae, it is suggested that the water depth varies from 5m to 10m in this environment.

Mid ramp/margin to open platform: This depositional environment is characterized by the presence of abundant large benthic foraminifera associated with calcareous green algae. The texture of these deposits varies from bioclastic wackestones (low energy) to peloidal-bioclastic packstone–grainstones indicative of high energy conditions. The main faunal content of this depositional environment includes benthic foraminifera such as *Pseudocyclammina*, *Cuneolina*, *Trocholina*, orbitolinids and *Dukhania*, associated with abundant echinoid remains, ammonite shells and rare sponge spicules. Among the dasycladalean algae, *Salpingoporella pygmaea*, *Salpingoporella katzeri*, *Salpingoporella? inopinata* n. sp., *Salpingoporella istriana* and *Selliporella neocomiensis* are rather common, whereas other species of *Salpingoporella* as well as *Clypeina*, *Actinoporella*, *Otternstella* and *Lithocodium/Bacinella* are rarely present. In our opinion, a water depth of 10–20m is estimated for this depositional environment.

Outer ramp/platform slope: In the Kuh-e-Surmeh section, the deposits containing pelagic organisms (sponge spicules, *Saccocoma*, ammonite shells and abundant echinoid remains), rare in situ benthic foraminifera (*Dukhania* and small *Valvulinids*) and very rare *Salpingoporella? inopinata* n. sp., *Salpingoporella pygmaea*, *S. katzeri* and *S. istriana* have been assigned to the outer ramp to platform slope depositional environment. Other benthic foraminifera in this environment including species of *Trocholina*, *Falsogaudrynella*, *Choffatella*, *Cyclamminids*, *Praechrysalidina*, *Debarina*, *Rummanolucina*, *Nautiloculina*, *Cuneolina* and calcareous green algae such as other species of *Salpingoporella* and *Clypeina* (Fig. 3), were probably brought in by storms and are not in situ. The lithology of these deposits is marked by mud supported car-

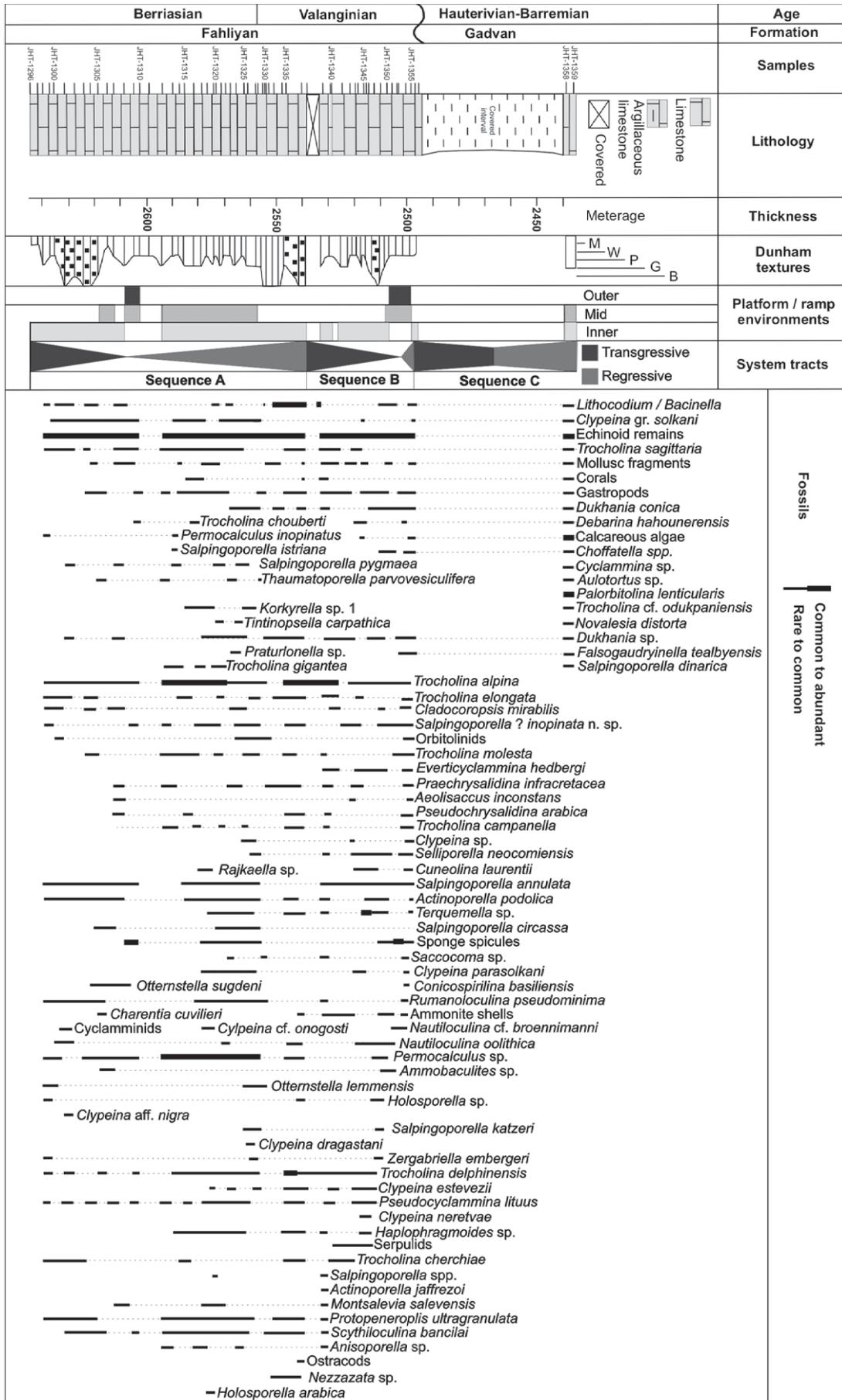


Figure 2: Biostratigraphy, sedimentology and sequence stratigraphy of the Fahliyan and Gadvan Formations in Kuh-e-Surmeh.

bonates, commonly with wackestones and packstones (Pl. 7, Fig. E). Based on the faunal composition, it is expected that the water depth ranges from 20m to some 40m.

5. SEQUENCE STRATIGRAPHY

The presented sequence stratigraphic model is based on the definition of VAIL et al. (1991). Herein we have amalgamated possibly low stand and transgressive system tracts as transgressive deposits. Three 2nd and 3rd order sequences have been recognized throughout the studied section, ranging from about 2 to 8 MY (Fig. 2 and Fig. 4). Each sequence is shown by two triangles or polygons, differently coloured. If A/S > 1 (Accommodation more than Sediment supply), this indicates the transgressive trend, and if A/S < 1, the regressive trend is represented. As for the sequence boundaries, two inferred categories are shown in Fig. 2 and Fig. 4: SB I, corresponding to the Type I with evidence of exposure; SB II, corresponding to the Type II with a shallowing upward trend. Fig. 4 shows the benthic foraminiferal diversity increases during the transgressive phases, reaching a maximum value before the maximum flooding surfaces, and decreases or remains constant during the regressive stages, finally reaching the minimum at the sequence boundaries. Instead, the maximum diversity of calcareous algae occurs in the first phase of transgression as well as in the last phase of highstand, when the sea level is intermediate. Conversely, their lowest diversity occurs in or close to the maximum flooding surface (mfs), since during the sea level rise, the environmental conditions (light, temperature, salinity and substrate) were not suitable for floral productivity (Fig. 4).

Sequence A: The thickness of this sequence is 106m. The lower sequence boundary is a regional discontinuity located between the Hith Anhydrite and the Fahliyan Formation (Late Jurassic–Early Cretaceous) in the Zagros basin as well as in the Arabian Plate (SHARLAND et al. 2001, 2004). Tentatively this sequence boundary is placed in Type I, corresponding to an exposure. The sequence represents a deepening–shallowing trend, with shallow subtidal (inner ramp), inner to mid ramp and outer ramp environments. The maximum flooding surface (mfs) is marked by the presence of abundant sponge spicules and echinoid remains, with rare benthic foraminifera and calcareous green algae; it is assigned to the mid to outer ramp environments. The highstand deposits show a seaward stepping and regressive cycle, with a decreasing diversity of the benthic foraminifera and an increasing diversity of the calcareous green algae (Fig. 4). The sequence is assigned a Berriasian – Lower Valanginian age, quite comparable with the Arabian Plate sequence stratigraphy scheme of SHARLAND et al. (2001, 2004).

Sequence B: The second partly covered sequence of the Fahliyan Formation has a thickness of about 44m. It includes deepening and shallowing upward deposits, with inner ramp/lagoonal to mid ramp and also outer ramp deposits. The transgressive trend begins with bindstone mats overlain by high energy and low energy deposits denoting mid ramp environments. The maximum flooding surface is dominated by sponge spicules, ammonite shells, *Saccocoma* and echinoid remains.

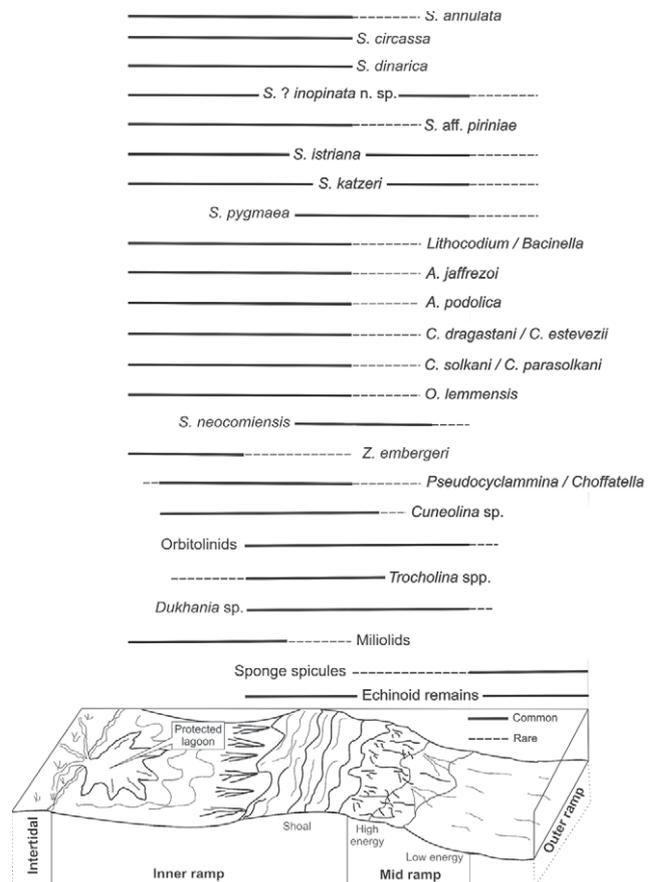


Figure 3: Environmental distribution of the main calcareous green algae (especially dasycladalean), some benthic foraminifera and other biota (sponge spicules and echinoids) in the studied succession.

The highstand deposits are marked by seaward stepping with the presence of inner ramp deposits. The lower sequence boundary is normal (SB II, or Type II), whereas the upper sequence boundary is of Type I, with evidence of subaerial exposure (iron oxide-rich, karstification and hard ground) illustrated in Pl. 7, Fig. O. This sequence is given an Early Valanginian age, again showing an interesting relationship with the sequence bundle identified in the Arabian Plate (SHARLAND et al., 2001, 2004).

Sequence C: This 62m thick sequence belongs to the lower part of the Gadvan Formation. As mentioned above, most parts of the Gadvan Formation are covered. The soft materials in the basal part of the Gadvan Formation are interpreted as being transgressive deposits with a deepening upward trend. In the mid part of the Gadvan Formation, at the top of the sampled section, some thin to medium sized, clean limestone beds occur indicating inner to mid ramp depositional environments. This interval is formally called the Khalij Member. It can be traced over the whole of the Zagros basin as well as in the Arabian Plate. By similarity with the sequence stratigraphic model for the Arabian Plate (SHARLAND et al., 2004), the upper sequence boundary is placed at top of the limestone horizon of this member. At present, there is no data, in the studied section, to document the transgressive trend and the maximum flooding surface.

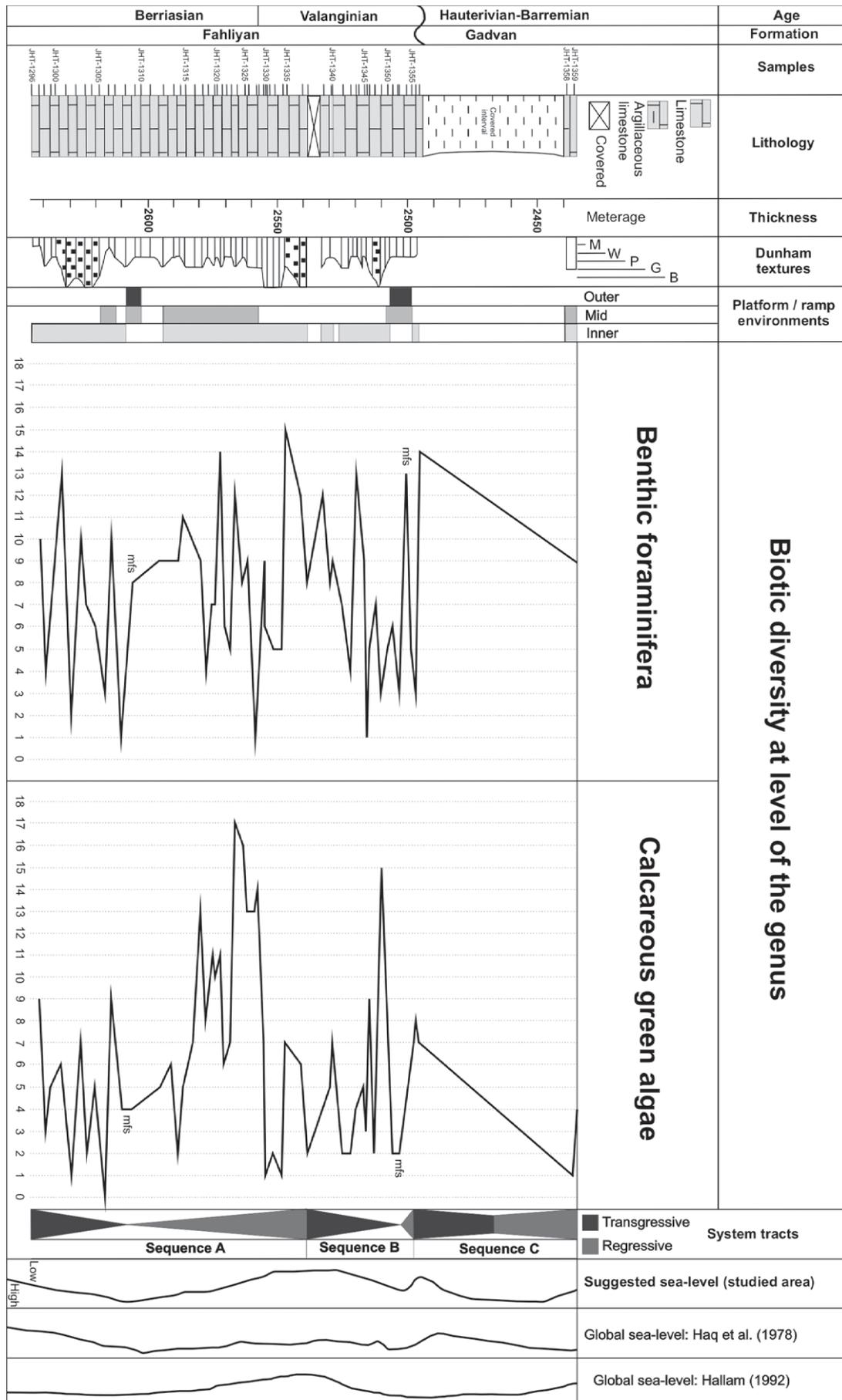


Figure 4: Biotic diversity of benthic foraminifera and calcareous green algae, at the generic level in the study section of Kuh-e-Surmeh.

6. PALAEOECOLOGY AND PALAEOBATHYMETRY

Environmental indicators used in this study are shown in Fig. 3. Concerning the dasycladalean algae, extant species usually live in normal (euhaline) waters, within the 20°C isocryme, in the infralittoral environment defined as corresponding to the habitat of the marine phanerogams. There are exceptions however, which were reviewed by BERGER & KAEVER (1992). The same applies to the fossil record. Most species identified in the Kuh-e-Surmeh section lived in the Inner Ramp environment, while three species deserve special interest. The first species, *Salpingoporella dinarica* RADOIČIĆ, was very tolerant, as shown by the fact that it flourished in low energy, restricted marine environments (for a review of the genus *Salpingoporella*, see CARRAS et al., 2006). The second species, *Salpingoporella pygmaea* (GÜMBEL), is typically found in open marine, high energy, reefal platform margins. In Abu Dhabi (AZIZ & EL-SATTAR, 1997) it is taken as a marker (*Salpingoporella pygmaea* Subzone) believed to indicate a Valanginian age in outer shelf areas. (Actually, the species, which has several synonyms, ranges from the Bathonian to the Aptian). The third species is *Zergabriella embergeri* (BOU-ROULLEC & DELOFFRE). Quoting BUCUR & SĂSĂRAN (2005), based on trace element analysis carried out by JAFREZO & RENARD (1979), when associated with charophytes, the species indicates a hypersaline environment, rather than a brackish one as would be suggested by biotic and facies data.

The benthic foraminifera and calcareous green algae diversity curves are shown in Fig. 4. The diversity index of benthic foraminifera ranges from 1 (minimum) to 15 (maximum), whereas this index varies from 0 (minimum) to 17 (maximum) for calcareous green algae. This study reveals that each depositional environment has a typical assemblage of benthic foraminifera and calcareous green algae. Concerning the benthic foraminiferal diversity, the maximum value is observed throughout the mixed sediments of the inner ramp to mid ramp environments (index from 4 to 15). The lowest diversity corresponds to the shallower subtidal and lagoonal environments, and, also to the outer ramp (index from 1 to 8). By comparison, the highest diversity values of calcareous green algae are found in open lagoon and shoals, with indexes ranging from 3 to 17, while the least values refer to the platform slope environments, with values ranging from 0 to 4. Among the calcareous green algae, the order Dasycladales is frequently represented. Some species of the family Dasycladaceae are reported for the first time from the Zagros Basin, e.g. *Zergabriella embergeri*, *Salpingoporella katzeri*, *S. istriana*, *S. pygmaea*, and *S. circassa*. The latter species is apparently reported for the first time from southern Tethys. The family *Acetabulariaceae* is also present, with the subfamily *Clypeineae* including species such as *Clypeina estevezi*, *C. solkani*, *C. parasolkani* and *C. dragastani*, which are reported for the first time from the Zagros Basin.

7. CONCLUSIONS

Based on micropalaeontological data from the Kuh-e-Surmeh section, the ages of the Fahliyan and Gadvan Formations have

been determined. The Fahliyan Formation is of Berriasian and Valanginian age, while a Hauterivian to Barremian age is assigned to the Gadvan Formation in the study area. Sequential interpretation reveals the presence of at least three sequences comprising several parasequences throughout the studied succession. Two sequence boundaries are considered to belong to the Type I, with subaerial exposures believed to correspond to regional discontinuities. One sequence boundary belongs to the Type II. Species of the Dasycladaceae and the subfamily *Clypeineae* are reported for the first time from the Zagros Basin and/or from southern Tethys. One new species of Dasycladalean algae, *Salpingoporella? inopinata* GOLLESTANEH, n. sp. is provisionally described, awaiting additional material. Palaeoecological and palaeobathymetric investigations indicate that the studied samples were deposited in shallow water, internal subtidal (open lagoon) to external subtidal (inner to mid ramp) and platform slope (outer ramp) environments, in water depths of 5m to 40m, with salinities ranging from normal marine to saturated (hypersaline).

ACKNOWLEDGEMENT

The authors wish to express their deep gratitude to the Exploration Manager of the National Iranian Oil Company (NIOC) for permission to publish this paper. Many thanks also for the assistance and technical support of Mr. Seyed Hassan Bahrani-Zadeh Sadjadi of the Department of Geological and Geochemical Researches and Studies of the NIOC. We are grateful to Prof. Rolf Schroeder (Frankfurt) for checking the benthic foraminifera and providing fruitful advice. We are also greatly indebted to Dr. Rajka RADOIČIĆ (Belgrade) and Dr. Nicolaos CARRAS (Athens) for their most helpful and critical review of the different species of Dasycladales.

REFERENCES

- AZIZ, S.K. & EL-SATTAR, M.M.A. (1997): Sequence stratigraphic modeling of the Lower Thamama Group, east onshore Abu Dhabi, United Arab Emirates. – *GeoArabia*, 2, 179–202.
- BERGER, S. & KAEVER, M.J. (1992): Dasycladales: An Illustrated Monograph of a Fascinating Algal Order. – Thieme, Stuttgart, 247 p.
- BUCUR, I.I. & SĂSĂRAN, E. (2005): Relationship between algae and environment: an Early Cretaceous case study, Trascau Mountains, Romania. – *Facies*, 51, 274–286.
- CARRAS, N., CONRAD, M.A. & RADOIČIĆ, R. (2006): *Salpingoporella*, a common genus of Mesozoic Dasycladales (calcareous green algae). – *Rev. de Paléobiol.*, 25, 457–517.
- CONRAD, M.A. & GRÁBNER, S. (1974): *Salpingoporella hispanica*, n. sp., une Dasycladale du Barrémien des Pyrénées espagnoles. – *C. R. Soc. Phys. Hist. Nat. Genève*, 9/1–3, 30–39.
- GOLLESTANEH, A. (1965): Micropalaeontological study of the Upper Jurassic and Lower Cretaceous of Southern Iran. – Unpubl. PhD Thesis, University College, London, 629 p.
- GOLLESTANEH, A. (1974): The biostratigraphy of the Khami Group and the Jurassic – Cretaceous boundary in Fars Province (Southern Iran). – *Bulletin du B.R.G.M. (Deuxieme série)*, section IV, 3, 165–179.
- GOLLESTANEH, A. (1979): The stratigraphic distribution of fossil calcareous algae in Southern Iran – In: 2nd International Symposium on Fossil Algae. *Bull. Cent. Rech. Explor. – Prod. Elf-Aquitaine*, 3, 619–624.

- JAFFREZO, M. & RENARD, M. (1979): Elements en traces de calcaires à dasycladales et charophytes. – Bull. Centr. Rech. Elf-Aquitaine Expl. – Product, Mém. 3, 639–649.
- SETUDEHNIA, A. (1978): The Mesozoic sequence in S.W. Iran and adjacent areas. – Journal of Petroleum Geology, 1, 3–42.
- SHARLAND, P.R., ARCHER, R., CASEY, D.M., DAVIS, R.B., HALL, S.H., HEWARD, A.P., HORBURY, A.D. & SIMMONS, M.D. (2001): Arabian plate sequence stratigraphy. – GeoArabia Special pub. 2, 371 p.
- SHARLAND, P.R., CASEY, D.M., DAVIS, R.B., SIMMONS, M.D. & SUTLIFFE, O.E. (2004): Arabian plate sequence stratigraphy. – GeoArabia, 9/1.
- VAIL, P.R., AUDEMARD, F., BOWMAN, S.A., EISNET, P.N. & PEREZ-CRUZ, C. (1991): Signatures of tectonics, eustasy and sedimentology – an overview. – In: EINSELE, G., RICKEN, W. & SEILACHER, A. (eds.): Cycles and Events in stratigraphy. Springer, Berlin, Heidelberg, New York, 617–659.

Manuscript received December 22, 2007
Revised manuscript accepted May 19, 2008