Stratigraphy of the Upper Jurassic shallow marine carbonates of the Moghan area (NW Iran), with paleobiogeography implication on *Alveosepta jaccardi* (Schrodt, 1894)

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Abstract
A micropaleontological study has been carried out on the samples collected from the Sarv Abad section, the oldest and only known Jurassic sedimentary rocks cropping out in the Moghan area. Studied sequence consists of carbonates bounded at both base and top by clastic deposits. Studied carbonate deposits provide an assemblage of benthic foraminifera as well as calcareous algae. The stratigraphic distribution of the larger benthic foraminifera, particularly, almost consistent present of *Alveosepta jaccardi* allowed us to propose an age of Late Oxfordian to Early Kimmeridgian for the studied succession. At this time, Paratethys Basin was at very beginning of its opening. Larger benthic foraminifera and inhabited fauna at this basin are in close similarity with Tethyan Realm association. Data provided by larger foraminifera, calcareous algae, and microfacies analysis may suggest an environment of warm shallow water with low to medium energy regime.

Keywords: *Paratethys, Moghan, Late Jurassic, Stratigraphy, Larger benthic foraminifera, Alveosepta jaccardi*

Introduction

The Caspian Basin and Paratethys host many hydrocarbon reserves in post-Soviet states of Central Asia. These reserves have been in production or exploration stages since the Soviet era. Consequently, geology of the area was widely studied during evaluation and development of hydrocarbon fields (e. g., Abrams & Narimanov, 1997; Jones & Simmons, 1998; Guliyev *et al.*, 2003; Sachsenhofer & Schulz, 2006). In recent decades, Iranian oil companies revealed interest in exploration of hydrocarbon in Iranian sector of Paratethys known as Moghan and south Caspian Basin as well, that resulted in exploration of some hydrocarbon fields such as Sardar-e Jangal and Moghan fields. Principal reservoir units in the Moghan area are Cenozoic rock units (Amini, 2006). Astara, Ghara Aghaj, Shekarlu, Salm Aghaji, Ojaghgeshlagh, Ziveh, Turtonian, Akchagil and Apsheron formations are main introduced rock units in Cenozoic of the Moghan area (Aghanabati, 2004; Amini, 2006). However, due to very limited exposures and lack of drilling in exploration/appraisal wells, Mesozoic stratigraphy of the Moghan area is still not fully erected.

Some studies proposed Cretaceous rock units as the oldest sedimentary deposits of the Moghan area (Rahimzadeh, 1994; Zavarehi & Maghfuri Moghadam, 2000) and put the older units in volcanic series. However, scrutinizing geological maps and available outcrops together with exploration wells reveal the presence of Jurassic sedimentary deposits as appeared on 1/100000 scale geological map of the Razi sheet prepared by geological survey of Iran (Khalatbari-Jafari, 2005). Consequently, these deposits could be regarded as the oldest sedimentary rock units of the Moghan area, which were developed at very beginning stages of the Paratethys development. Jurassic carbonates are widespread in different structural units of Iran such as Dalichai and Lar formations in Alborz, Mozduran and Chaman Bid formations in Koppeh Dagh, Surmeh and Neyriz formations in Zagros and Esfandiar, Qaleh Dokhtar and Parvadeh formations in Central Iran (Aghanabati, 2004). This study with focus on a single outcrop of Jurassic strata (Sarv Abad section) in the Moghan area, strives to shed more light on stratigraphy, age dating and paleoenvironmental condition of Jurassic carbonate deposits in the Moghan area. In the studied section of Sarv Abad, an assemblage of larger benthic foraminifera characterized by abundant *Alveosepta jaccardi* (Schrodt) was observed in carbonate sequence. Calcareous algae, bivalves and ostracods also were found. In addition to age dating and paleoenvironmental interpretations, obtained data from micropaleontology and sedimentary petrography have been used for paleogeographical purpose and connectivity of the Moghan area and Paratethys with other parts of Iran during depositional time.

Geological setting

Studied section is located south of the Caspian Sea in the Moghan area. This region covers some 6300 km^2 in northwestern Iran (including parts of Ardabil and Eastern Azarbaijan provinces) in vicinity of the Iran-Azarbaijan boundary (Fig. 1). The Moghan area as a part of the south Caspian basin is located in northwestern corner of Iran and bounded towards the north by southeastern part of the Kura through and towards the south by the northern flank of the Talysh-Lesser Caucasus orogenic belt (Amini, 2006). From tectonic setting point of view, the Moghan area together with the Kura Basin are considered to have a back-arc setting which were subjected to rapid siliciclastic sedimentation during Late Mesozoic Paleogene time due to a high sediment supply from neighboring rising mountains (Brunet *et al.,* 2003; Amini, 2006). In other word, the region is located in eastern Paratethys domain extending from Central Europe to Aral Lake in Kazakhstan including the present day Black Sea and Caspian Sea basins (e. g., Rögl, 1998). The Paratethys Sea was formed during the Oxfordian stage of the Late Jurassic as an extension of the rift that formed the Central Atlantic Ocean and was isolated during the Oligocene epoch (about 34 million years ago). It was separated from the Tethys Ocean to the south by the formation of the Alps, Carpathians, Dinarides, Taurus and Alborz Mountains. During its long existence, the Paratethys was at times reconnected with the Tethys or its successors, the Mediterranean Sea or Indian Ocean (Rögl, 1998; Schulz *et al.,* 2005).

Sarv Abad section

The section is measured and sampled in vicinity of Sarv Abad village, several kilometers north of the city Namin, in an area consisting of some NW-SW trending minor folds and thrust sheets.

The sedimentary succession in this area is composed of three main units including pre-Jurassic, Jurassic and Cretaceous deposits (Fig. 1).

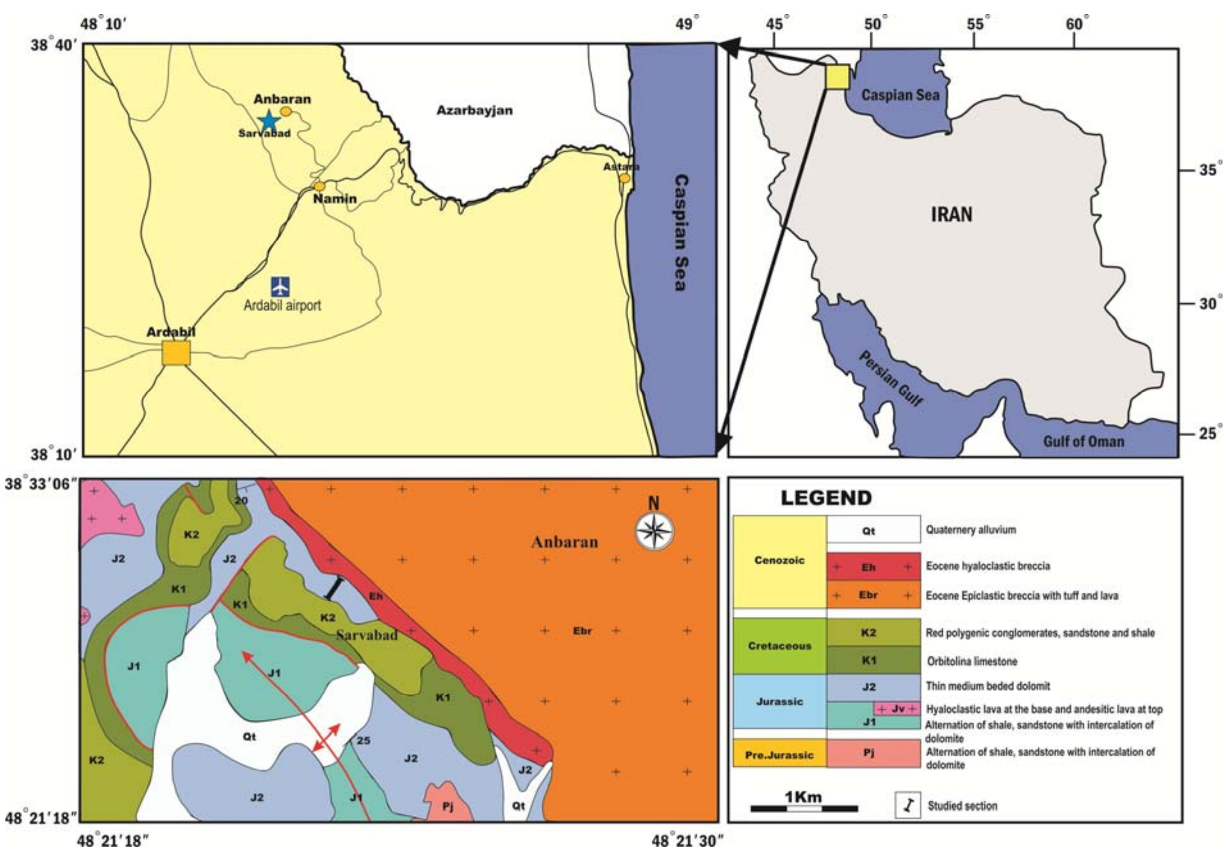

Figure 1. Location and geological map of the studied section in the Moghan area, geological map is modified after Khalatbari-Jafari (2005)

The base of pre-Jurassic unit (PJ), the oldest rocks exposed in the study area, is covered by alluvium and consists of alteration of red micaceous shales and sandstones interbedded with grey cherty dolomite at the upper part.

No micro- or macrofossils have been reported from these strata and they are assigned to the Infracambrian or lower Paleozoic based on geological map of the Razi, scale: 1:100,000.

The pre-Jurassic rocks are unconformably followed by a relatively thick succession of lower Jurassic shales and sandstones (J1) which in turn are topped by upper Jurassic thin to medium bedded limestones and dolomitic limestones (J2). The shale and sandstone strata were palynologically barren (PPZ, 2013) and also devoid of any micro or macro-fauna. These strata, based on their stratigraphic position, have been ascribed to the Early Jurassic age on the geological map.

The top limestone beds (J2) contain Late Jurassic benthic foraminifera (including *Alveosepta jaccardi*). These strata have some 92 m. thickness and are of considerable importance because they are representatives of the Paratethys Basin at very beginning time. Cenozoic strata are main reservoirs of the Moghan area. Consequently, no exploration well is hitherto drilled in Jurassic aged rocks. According to available data, Sarv Abad section is the only known outcrop in the Moghan area in which, Jurassic aged strata are cropped out. In order to characterize general stratigraphy of Late Jurassic strata in the Moghan area, in this study, these deposits have been subjected to micropaleontological and microfacies analysis.

The Cretaceous succession is characterized by lithological diversity allowing further subdivision into three units (K1, K2 and K3).

The K1 unit is composed of bioclastic orbitolinid bearing limestones resting disconformably on the upper Jurassic limestone beds (J2). The K2 unit comprises clastic rocks including polygenetic conglomerate, sandstone and shale. This unit disconformably overlies the K1 unit. The K3 unit consists mainly of thin to medium bedded limestone containing Pelecypoda shells. The boundary between the K2 and K3 units is also disconformable.

Material and methods

Late Jurassic deposits of the Sarv Abad section have been measured and systematically sampled. Overall some 31 rock samples from carbonates of the Late Jurassic were collected. In order to investigate micropaleontological content and microfacies analysis, thin sections have been prepared for all collected samples using conventional methodology. Available thin sections were thoroughly studied under microscope and photographed with a mounted camera on microscope. For classification and texture descriptions, the classification scheme of Dunham (1962) is adopted and detailed petrographic analysis was carried out.

Result and discussion

Microfacies analysis

Detailed petrographic observation of collected samples revealed low variation in microfacies types with diversified skeletal and non-skeletal elements such as benthic foraminifera, calcareous algae, bivalves, ostracods and pelloids. Some two main microfacies have been recognized in Late Jurassic carbonate deposits of the Moghan area.

MF 1) Mudstone

This microfacies type has been differentiated based upon presence of light to grey carbonate mudstone with dominant micritic matrix and minor occurrence of pelloids, green algae and larger benthic foraminifera such as *Alveosepta jaccardi*. In some samples of this microfacies partial dolomitization took place and rhombic dolomite crystals are developed. This microfacies indicates low energy condition during depositional time.

MF 2) Bioclastic wackestone to packstone

This microfacies type is frequently recorded and contains a variety of skeletal elements such as larger benthic foraminifera, calcareous algae, bivalves, ostracods and non-skeletal elements such as pelloids and crustacean coprolites (*Favreina*). The skeletal components are generally well preserved and show no abrasion. Presence of larger benthic foraminifera and calcareous algae such as *Alveosepta jaccardi, Pseudocyclammina* aff. *lituus, Everticyclammina* sp., *?Haurania* sp., *Thaumatoporella parvovesiculifera* and ?*Clypeina sulcata* reveals deposition of this microfacies type in shallow marine condition under low to medium energy.

Micropaleontology and age dating

Most studied samples of the Sarv Abad section yielded an assemblage of benthic foraminifera and calcareous algae. Index recorded larger benthic

foraminifera in this study were *Alveosepta jaccardi, Pseudocyclammina* aff. *lituus, Everticyclammina* sp.*,* and ?*Haurania* sp., whereas *Thaumatoporella parvovesiculifera,* ?*Clypeina sulcata* and *Rivularia piae* were main recorded calcareous algae. Incidentally, some smaller benthic foraminifera such as miliolids, valvulinids and textulariids were detected as well including *Gaudryina* sp., *Reophax* sp. and *Siphovalvulina* sp. Among recorded microfossil groups, larger benthic foraminifera were of comparatively more use for age dating. Particularly *Alveosepta jaccardi* has an immense practical use for age dating and biostratigraphy and indicates an age of Late Oxfordian to Early Kimmeridgian (Bassoullet, 1997; Bucur and Sasaran, 2005) (Fig. 2). The taxon has been detected in many parts of the world and is widely recorded in the Tethys and neighboring areas (e. g., Hottinger, 1967; Tasli, 1993; Simmons & Al-Thour, 1994; Hughes, 2000). According to total range of this species, *Alveosepta jaccardi* biozone has been erected and used as well (Simmons & Al-Thour, 1994; Simmons, 1998; Al-Wosabi, 2005).
Based upon detected microfossils and particularly total range of *Alveosepta jaccardi* an age of Late Oxfordian to Early Kimmeridgian is constrained for studied deposits of the Sarv Abad section. Moreover, the studied section could be quoted to the *Alveosepta jaccardi* biozone.

Paleoenvironmental interpretation

Late Jurassic carbonates of the Sarv Abad section are characterized by a low to medium energy depositional regime and predominance of mudstone to bioclastic wacke to packstone. Recorded fauna were mostly agglutinated larger benthic foraminifera, miliolids and calcareous algae.

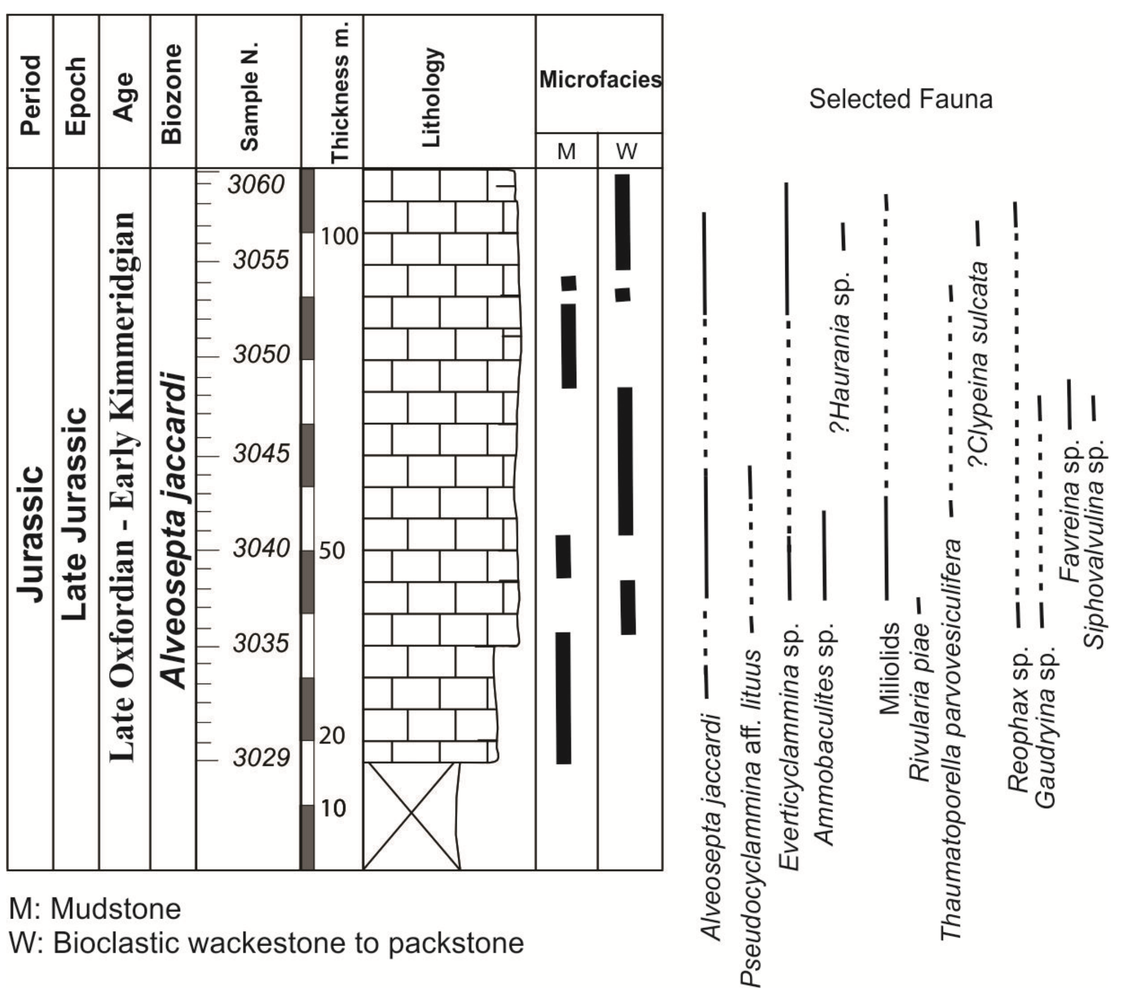

Figure 2. Stratigraphic column of the carbonate Late Jurassic strata in the Sarv Abad section and distribution of index microfossils

Studied samples revealed almost consistent presence of *Alveosepta jaccardi* that towards up-section coexisted with an assemblage of calcareous algae such as *Thaumatoporella parvovesiculifera* and ?*Clypeina sulcata*. Occurrence of these microfossils indicates a shallow depositional setting with well oxygenated condition above the photic zone.

Alveosepta jaccardi could thrive in deposits below fair-weather wave base (Pélissié *et al.,* 1984; Hughes, 2000; Betzler *et al.,* 2007). Regarding to obtained microfacies and recorded microfossils, low energy regime and detected fauna are indicating a semi-restricted inner platform setting. Though, due to lack of exposure, high energy facies of Late Jurassic carbonates of the Moghan area are not yet detected but new studies and drilling of exploration wells could shed more light on paleoenvironmental conditions of these deposits.

Paleobiogeography and bioprovinces correlation

Constrained age of Late Oxfordian to Early Kimmeridgian coincides with early stages of Paratethys development. During depositional time, Paratethys was still in connection with neighboring areas such as western Tethys and Mediterranean realm. Late Jurassic deposits are widely distributed in Iran and have been recorded from different structural units such as Central Iran, Koppeh Dagh, Zagros and Alborz. In this study larger benthic foraminifera and particularly *Alveosepta jaccardi* is used for correlation and proof of Paratethys connection and extension.

As a cosmopolitan taxon, *Alveosepta jaccardi* is widely recorded from Tethys and beyond, consequently this foraminifer is of considerable practical use for the purpose of correlation (Bucur & Sasaran, 2005). This species was first described as *Cyclammina jaccardi* from the upper Oxfordian of Switzerland (Schrodt, 1894) and was also reported from Tethys in France (Hottinger, 1967; Pélissié and Peybernès, 1982; Pélissié et al., 1984), Morocco (Hottinger, 1967; Bouaouda et al., 2004), Tunisia (Bismuth *et al.,* 1967), Romania (Bucur & Sasaran, 2005) and Germany (Betzler *et al.,* 2007). Elsewhere in the Middle East, it was recorded from Saudi Arabia (Redmond, 1964; Hughes, 2000; Hughes, 2004), Yemen (Simmons & Al-Thour, 1994), Lebanon (Clark and Boudagher-Fadel, 2001), Turkey (Tasli, 1993) and Iran (Gollesstaneh, 1965; Bagi *et al.,* 2006) (Fig. 3).

In Iran, this species has been recorded from Surmeh Formation in Zagros (Gollesstaneh, 1965), Esfandiar Formation in Central Iran (Bagi *et al.,* 2006) and Mozduran Formation in Koppeh Dagh (Zaman, 2014).

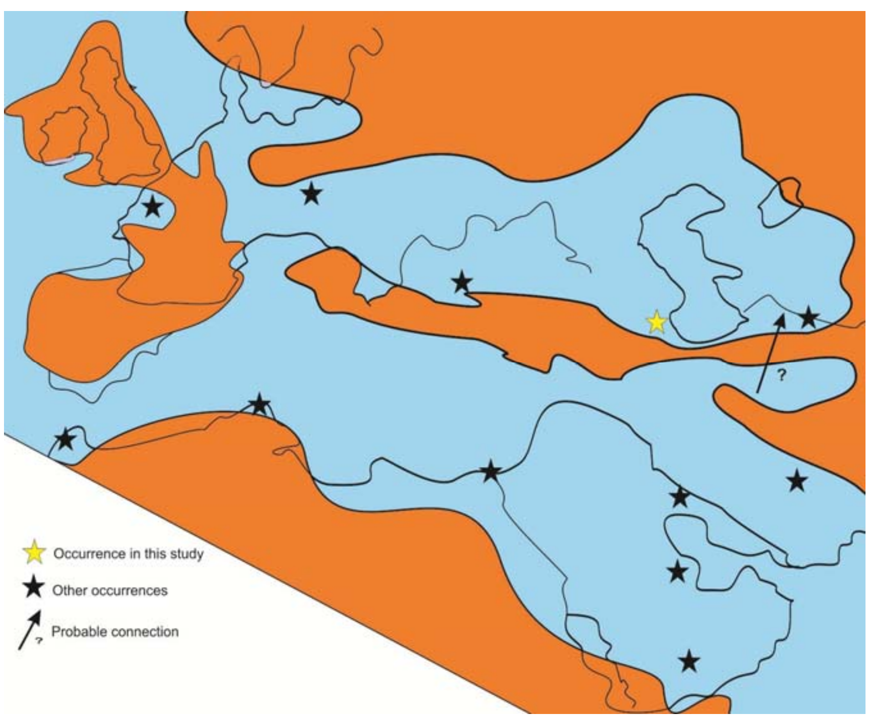

Figure 3. Schematic Late Jurassic paleogeography of the Tethys, approximate positions of the known occurrences of Alveosepta jaccardi are marked by asterisks

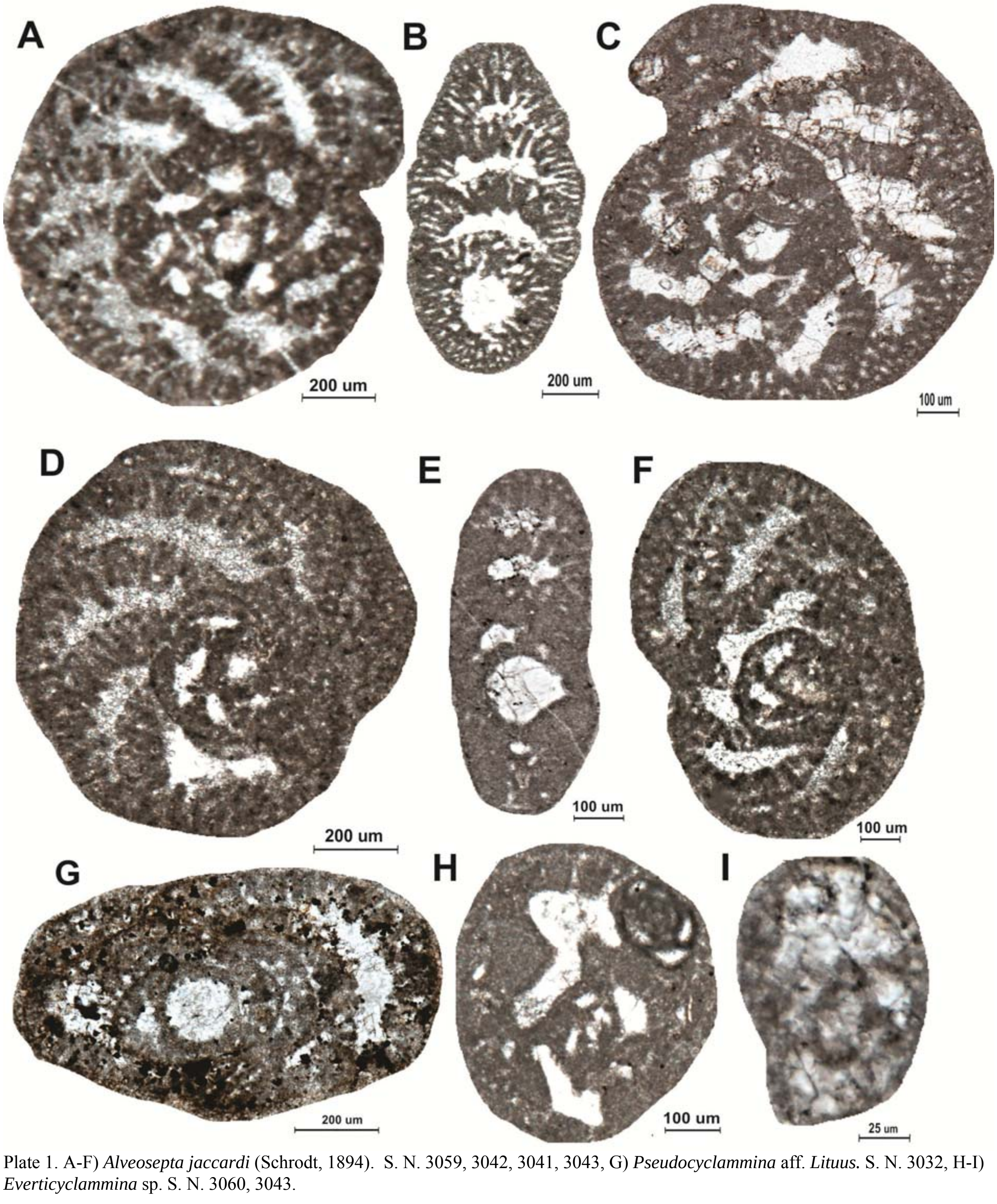

Plate 1. A-F) *Alveosepta jaccardi* (Schrodt, 1894). S. N. 3059, 3042, 3041, 3043, G) *Pseudocyclammina* aff. *Lituus.* S. N. 3032, H-I) *Everticyclammina* sp. S. N. 3060, 3043.

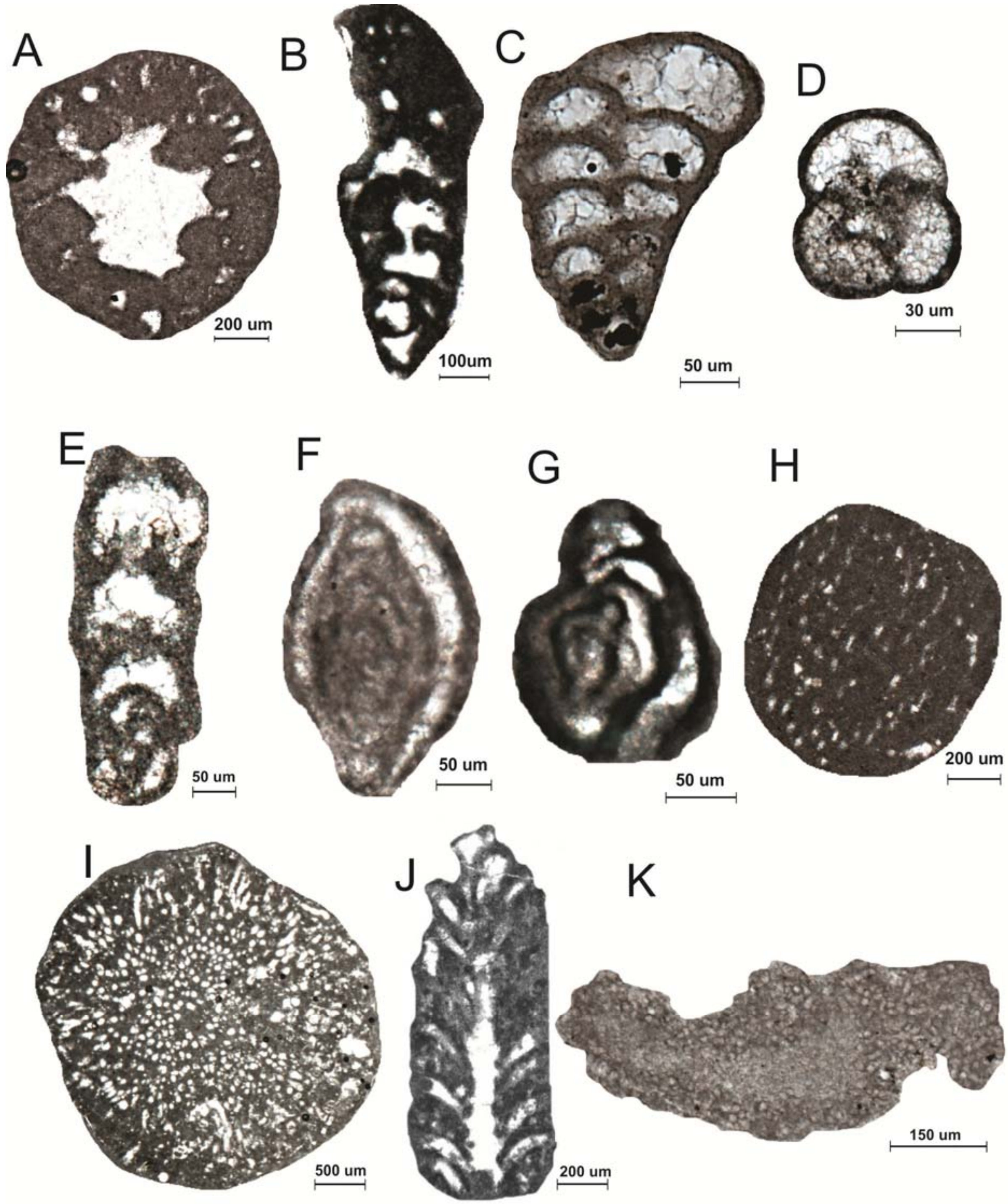

Plate 2. A) *Reophax* sp. S. N. 3037, B) ?*Haurania* sp. S. N. 3058, C) *Gaudryina* sp. S. N. 3058, D) *Siphovalvulina* sp. S. N. 3037, E) *Ammobaculites* sp. S. N. 3043, F-G) Miliolids. S. N. 3037, 3058, H) *Favreina* sp. S. N. 3058, I) *Rivularia piae* (Frollo, 1938) Dragastan, 1985. S. N. 3037, J) ?*Clypeina sulcata* (Alth, 1882). S. N. 3058, K) *Thaumatoporella parvovesiculifera* (Raineri, 1922). S. N. 3043.

Above mentioned occurrences prove connectivity between different geological sectors of Iran during Late Oxfordian to Early Kimmeridgian. Despite several micropaleontological and paleoenvironmental studies, so far *Alveosepta jaccardi* has not been known from Dalichai and Lar formations of northern Iran, Alborz Mountains. Even more, in contrast with other geological zones of Iran, larger benthic foraminifera rarely occur in these formations while smaller benthic foraminifera were successful to thrive and are usually found in high abundance (Aghaei *et al.,* 2013; Kochhann *et al.,* 2015). The dominance of r-selected strategists among benthic foraminifera suggests stressful paleoenvironmental conditions, probably related to bottom-water oxygen levels (Kochhann et al., 2015). The benthic foraminiferal fauna studied in these formations is similar to previously described ones attributed to the Boreal Realm. The absence of *Alveosepta jaccardi* and other larger benthic foraminifera might be due to lack of connection between the Alborz and other geological zones of Iran (including Moghan area) during Late Jurassic. This is in contrast to the Tethyan-Submediterranean paleozoogeographic affinity of the associated ammonites, belemnites and dinoflagellate fauna (Seyed-Emami & Schairer, 2011; Ghasemi-Nejad *et al.,* 2012; Parent *et al.,* 2013). All in all, during Late Jurassic different geological sectors of Iran reveal a very similar assemblage of foraminifera and calcareous algae except for Alborz Mountain that show some differences. This points to the fact that its paleobiogeography needs more investigation via different geochemical and paleontological proxies.

Conclusions

The studied section of Sarv Abad in the Moghan area contains an assemblage of larger agglutinated foraminifera and calcareous algae, which are recorded for the first time in the region. An age of Late Oxfordian to Early Kimmeridgian is constrained for the studied carbonates of the Sarv Abad section, based upon stratigraphic value of significant species of larger foraminifera, particularly *Alveosepta jaccardi*. This dating restricts the stratigraphic age of the Jurassic carbonate rocks in Moghan area as old as the Late Jurassic (Late Oxfordian-Early Kimmeridgian) and reveals that the formation of these sedimentary deposits has occurred during very early stages of Paratethys development.

An environment of shallow water, in a low to medium energy regime, is suggested, based on recorded benthic assemblages and the microfacies characteristics, which define a well oxygenated condition above the photic zone.

The species of larger foraminifera identified in the Late Jurassic of the Moghan area are tropical cosmopolitan forms, characteristic of the Tethyan Realm. Apart from Alborz Mountains, the recorded foraminiferal association shows high similarity with the known assemblages from the other geological sectors of Iran including Zagros, Central Iran and Koppeh Dagh.

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