Rivista Italiana di Paleontologia e Stratigrafia | volume 110 | no. 1 | pp. 173-179 | April 2004

MIDDLE TO LATE JURASSIC BIOFACIES OF SAUDI ARABIA

GERAINT W. HUGHES

Received January 13, 2003 ; accepted October 8, 2003

Keywords: Jurassic, Saudi Arabia, Foraminifera, stratigraphy, palaeoenvironments.

Abstract. Saudi Arabian Jurassic carbonate hydrocarbon reservoirs were first examined stratigraphically using microfauna. Current microfaunal studies concentrate on the identification and constraint of palaeoenvironmental variations and determination of high-resolution depositional cyclicity of the reservoir carbonates. It is apparent that the environmental sensitivity of benthonic foraminifera provides a potentially valuable technique for the determining subtle variations in the depositional environment and also providing a proxy for sea-level fluctuations.

Riassunto. Il presente lavoro tratta lo studio stratigrafico di reservoirs carbonatici dell'Arabia Saudita utilizzando associazioni a foraminiferi bentonici. Gli studi microfaunistici sono stati utilizzati anche per la determinazione delle variazioni paleoambientali e della ciclicità deposizionale ad alta risoluzione. La dipendenza delle associazioni microfaunistiche bentoniche dalle caratteristiche ambientali, ha fornito importanti informazioni sulle caratteristiche degli ambienti deposizionali e sulle fluttuazioni del livello marino.

Introduction

Recent work has assisted in improving the benthonic foraminiferal stratigraphic and palaeoenvironmental ranges of the Middle to Late Jurassic carbonate reservoirs of Saudi Arabia (Fig.1). The entire carbonate Jurassic succession includes the Dhruma, Tuwaiq Mountain, Hanifa, Jubaila and Arab Formations that terminate with a succession of evaporites, the final, thickest unit of which is called the Hith Formation (Fig. 2). The Sulaiy Formation forms a new depositional cycle that commences in the latest Jurassic, but is not considered in this paper.

A succession of deep to shallow marine foraminiferal assemblages has been determined for these formations that have been used to distinguish both long term and high-frequency palaeobathymetric variations. The *Lenticulina-Nodosaria*-spicule dominated assemblage characterises the deepest mud-dominated successions, although the consistent presence of *Kurnubia* and *Nautiloculina* species suggests only moderately deep conditions, considered to be below fair-weather wave base. A foraminiferally-depleted succession then follows that is characterised by encrusting stromatoporoids. This assemblage is followed by one in which fragments of the branched stromatoporoid *Cladocoropsis mirabilis* Felix dominates, together with *Kurnubia* and *Nautiloculina* species and a variety of indeterminate simple miliolids. *Pseudocyclammina* and *Redmondoides* species are present within this assemblage. A slightly shallower, possibly lagoon influenced assemblage then follows that includes *Cladocoropsis mirabilis, Kurnubia* and *Nautiloculina* species and the dasyclad algae *Clypeina jurassica* Favre and *Heteroporella jafferezoi.* Complex, alveolar-walled agglutinating foraminifera such as *Alveosepta* spp. are also present within this assemblage. A further shallower assemblage is characterised by the presence of *Mangashtia viennoti* Henson, *Clypeina jurassica* Favre and *Cladocoroposis mirabilis.* This assemblage is supplemented by *Pfenderina salernitana* Sartoni & Crescenti and is interpreted as slightly shallower conditions. A very shallow assemblage is characterised by the presence of *Trocholina alpina,* which is then followed by an intertidal assemblage of cerithid gastropods and felted calcareous algae in which foraminifera are typically absent.

Geological Technical Support Division, Saudi Aramco, Box 10646, Dhahran 31311, Saudi Arabia. E-mail: geraint.hughes@aramco.com.sa

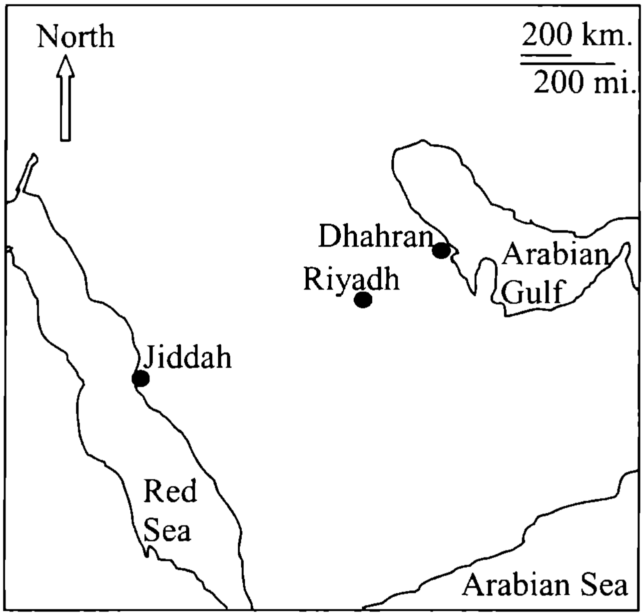

Fig. 1 - The Arabian peninsula showing Saudi Arabian localities mentioned in the text.

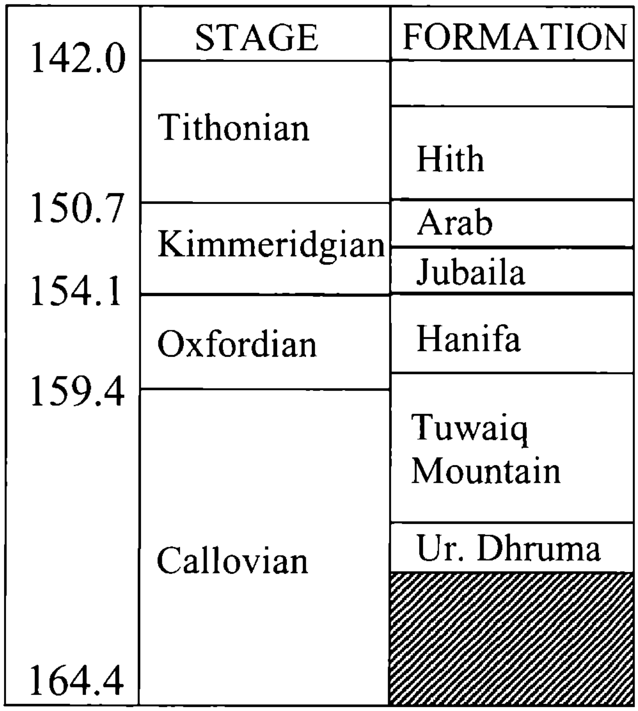

Fig. 2 - Chronostratigraphy of the Middle to Late Jurassic Saudi Arabian carbonates, after International Commission on stratigraphy (2003).

Previous works

Taxonomy

The taxonomy of the warm water Jurassic benthonic foraminifera of the Middle East is poorly established, although the most commonly encountered species are moderately well understood and documented. Saudi Arabian agglutinated species have been described by Redmond (1964, 1965), Banner (1970) and Maync (1965). The most recent taxonomic assessments of the shallow marine species of the region, but excluding Saudi Arabia, include Banner & Highton (1990), Banner & Whittaker (1991), Banner et al. (1991), Whittaker et al. (1998) and Clark & Boudagher-Fadel (2001).

Biostratigraphy

The stratigraphic ranges of the Middle East benthonic foraminiferal species is also relatively poorly established, although Whittaker et al. (1998), Tasli (2001) and Clark & Boudagher-Fadel (2001) have provided much useful refinement to previously published ranges. Hughes (1996) suggested three biofacies and 16 bioevents for the Kimmeridgian to Tithonian Arab-D Reservoir, comprising the upper part of the Jubaila Formation and the lower part of the Arab Formation in Saudi Arabia. Non-foraminiferal biostratigraphic works of significance include Enay et. al. (1987) for ammonites, Tintant (1987) for nautiloids, Almeras (1987) for brachiopods, Depeche et al. (1987) for ostracods, Fischer et al. (2001) for gastropods and Manivit (1987) and Varol (2001) for calcareous nannofossils.

Lithostratigraphy

The Middle to Upper Jurassic Formations include the Dhruma, Tuwaiq Mountain, Hanifa, Jubaila, Arab and Hith. In addition to the pioneering publications of Steineke & Bramkamp (1952) and Powers (1962, 1968), the most recent reviews of the Jurassic stratigraphy include Al-Husseini (1997) and Sharland et al. (2001).

Palaeoenvironment

The palaeoenvironmental significance of the Middle East benthonic foraminifera is the least well known, although individual species have received attention in the Mediterranean region (Derin & Reiss 1966; Pelisse & Peybernes 1983). The palaeoenvironment of various complex-walled agglutinated species is briefly considered by Banner & Highton (1990), *Alveosepta* species by Banner & Whittaker (1991) and *Trocholina* species by Mancinelli & Coccia (1999). More detailed information on Saudi Arabian foraminiferal assemblages has been presented by Hughes (1996, 1998, 2000, 2001, 2002a,b,c), Meyer et al. (2000) and Al-Dhubeeb (2001, 2002a, 2002b) based on detailed studies of the vertical successive appearance of the various species, in samples from cored oil well and exposed sections, and their relationship to the host carbonate fabrics.

The Middle and Upper Jurassic carbonates of Saudi Arabia were deposited on a very extensive submarine platform that extended over most of the Arabian Peninsula. Although a moderately shallow environment is generally assumed, there is evidence that the platform was also the site of several deeper intra-shelf basins (Murris 1980; Al-Husseini 1997).

Six palaeoenvironmental regimes have been defined in the present study, including the open marine/intra-shelf basin, transitional basin – shoal, shoal complex, deep lagoon, shallow lagoon and shore – intertidal. These categories are used in the following discussion of the palaeoenvironmentally significant biofacies distribution.

Facies of the Middle and Upper Jurassic Formations

Upper Dhruma Formation

Stratigraphy

The upper Dhruma Formation has been subdivided by Powers et al. (1968) into the lower yellow-brown limestone of the Atash Member, and upper yellow-brown shales of the Hisyan Member. The Atash Member is correlated with the Lower Fadhili reservoir of eastern Saudi Arabia.

Age

The Upper Dhruma is of Middle Jurassic, Middle Callovian age.

Biofacies

The Upper Dhruma carbonates contain a moderately diverse foraminiferal assemblage that includes the localized distribution of *Everticyclammina virguliana* (Koechlin), *Kurnubia palastiniensis* Henson, *Praekurnubia crusei* Redmond, *Pfenderina trochoidea* Smout & Sugden, *Pseudomarssonella* spp., *Redmondoides lugeoni* (Septfontaine), *Redmondoides rotundatus* (Redmond), *Riyadhella* spp., *Trocholina alpina* (Leupold), *Trocholina elongata* Weynschenk and the ubiquitous presence of *Nautiloculina oolithica* Mohler. Dasyclad algae are also locally present and are dominated by *Salpingoporella annulata* Carozzi. The sclerosponge *Cladocoropsis mirabilis* Felix is locally present, as are sponge spicules.

Palaeoenvironment

An undifferentiated subtidal depositional environment for the Upper Dhruma was suggested by Enay et al. (1987) and Enay (1987). Recent work within Saudi Aramco has been able to refine this interpretation, based mostly on the foraminiferal assemblages. The foraminiferal, dasyclad and stromatoporoid distribution suggests a moderately shallow, lagoonal environment in which localized shoals of branched stromatoporoids were present, between which deeper parts of the lagoon became dominated by spicule-secreting sponges during times of elevated sea level.

Upper Tuwaiq Mountain Formation

Stratigraphy

The Tuwaiq Mountain Formation was first defined by Steineke et al. (1958), as a cliff-forming, resistant, coral and stromatoporoid-bearing limestone overlying a softer, less resistant shale-dominated upper Dhruma Formation.

Age

According to Enay et al. (1987), the Tuwaiq Mountain Formation is of Middle Callovian age, based on superposition over the Upper Dhruma age diagnostic species; species of *Pachyerymnoceras* are common and define equivalence with the NW European "carinatum" ammonite zone. Upper Fadhili Reservoir (upper Tuwaiq Mountain Formation).

Biofacies

Benthonic foraminifera include undifferentiated nodosarids, *Lenticulina* spp., *Bolivina* spp., *Trocholina elongata* (Leupold), *Kurnubia palastiniensis* Henson, *Kurnubia wellings* (Henson), *Nautiloculina oolithica* Mohler, *Valvulineria* sp., *Redmondoides lugeoni* (Septfontaine), *Praekurnubia* sp., *Pfenderina trochoida* Smout and Sugden, *Meyendorffina bathonica* Auroze and Bizon and *Trochamijiella gollesstanehi* Athersuch et al.. Stromatoporoids include the branched species *Cladocoropsis mirabilis* Felix together with stratified forms. Monaxon and tetraxon sponge spicules are locally present, as are valves of *Bositra buchi* (Roemer) and juvenile brachiopods.

Palaeoenvironment

The uppermost T3 unit of the Tuwaiq Mountain Formation (Enay et al. 1987) has previously been concluded to represent a back reef depositional environment. Recent work by Saudi Aramco has revealed a variety of depositional environments, based mostly on an interpretation of the foraminiferal and associated fossil and microfossil assemblages.

Specimens of the pelagic bivalve *Bositra buchi* (Roemer) have been recovered in abundance within certain parts of the Upper Tuwaiq Mountain Formation, and have been used to deduce a deep, open marine depositional environment in which a low sedimentation rate prevailed. These thin bivalve beds are accompanied by monaxon and tetraxon sponge spicules and dwarf, or juvenile, costate brachiopods. Open marine biofacies, deposited below wave-base, include species of *Lenticulina*, *Nodosaria* and *Bolivina*. The shoal complex includes both laminated and branched stromatoporoids , of which the laminated form is interpreted as being typical of the distal, higher energy regime of the shoal, probably above wave base. The branched stromatoporoid *Cladocoropsis mirabilis* Felix is typically found above the laminated form, and concluded to have prograded out from the lagoonal shoal flank, above wave base. The deep lagoon biofacies displays the highest species diversity, and includes *Meyendorfina bathonica* (Auroze & Bizon), *Trochamijiella gollesstanhi* Athersuch, *Redmondoides lugeoni* (Septfontaine), *Kurnubia wellingsi* (Henson), *Praekurnubia* sp., *Pfenderina trochoidea* Smout & Sugden, *Valvulineria* sp., *Trocholina elongata* Weynschenk and *Nautiloculina oolithica* Mohler. Fragments of stromatoporoids are often associated with this biofacies at locations close to shoals. A shallow lagoon environment is concluded for the sparse biofacies in which *Nautiloculina oolithica* Mohler, branched coral, large, robust echinoid spines and the alga *Arabicodium aegagrapiloides* Elliott are typical components.

Hanifa Formation

Stratigraphy

The Hanifa Formation (Bramkamp & Steineke 1952; Powers et al. 1966; Powers 1968) is divided into a lower unit termed the Hawtah Member and an upper unit termed the Ulayyah Member (Vaslet et al. 1983; Enay et al. 1987).

Age

An Oxfordian age is assigned to the Hanifa Formation based on the presence of the ammonite *Euaspidoceras* cf. *catena perarimatum* (Sowerby) (Enay et al. 1987; Fischer et al. 2001), and defines the "plicatilis" ammonite zone.

Biofacies

The Hanifa Formation displays a moderately low foraminiferal species diversity that includes undifferentiated nodosarids, *Lenticulina* spp., *Kurnubia palastiniensis* Henson, *Nautiloculina oolithica* Mohler, *Pseudomarsonella sp.*, *Alveosepta jaccardi* (Schrodt), *Pseudocyclammina lituus* (Yokoyama), undifferentiated miliolids and biserial agglutinated forms. Stromatoporoids include the branched species *Cladocoropsis mirabilis* Felix together with stratified forms. Monaxon and tetraxon sponge spicules are locally present, as are valves of juvenile brachiopods. Dasyclad algae are well represented by *Clypeina jurassica* Favre.

Palaeoenvironment

An upwards transition from inner lagoon, back reef to reef palaeoenvironmental trend is suggested by Enay et al. (1987). Deep, open marine conditions below wave base are typified by the presence of *Lenticulina* spp., *Nodosaria* spp., *Kurnubia palastiniensis* Henson, *Nautiloculina oolithica* Mohler, *Pseudomarsonella* sp., juvenile costate brachiopods and sponge spicules. Open marine, moderately deep marine conditions are typified by agglutinated foraminifera that include *Alveosepta powersi* (Redmond) (Redmond 1964), *Pseudocyclammina lituus* (Yokoyama), *Kurnubia palastiniensis* Henson and *Nautiloculina oolithica* Mohler. The shoal complex includes both laminated and branched stromatoporoids, of which the laminated form is interpreted as being typical of the distal, higher energy regime of the shoal, probably above wave base. The branched stromatoporoid *Cladocoropsis mirabilis* Felix is typically found above the laminated form, and concluded to have prograded out from the lagoonal shoal flank, above wave base. In Khurais Field, there is good evidence to support the existence of a series of southerly-prograding stromatoporoid bank complex. A deep lagoon environment is interpreted for the *Kurnubia palastiniensis* Henson and *Nautiloculina oolithica* Mohler -dominated assemblage, in conjunction with the well-represented dasyclad alga *Clypeina jurassica* Favre and the encrusting alga *Thaumatoporella parvovesiculifera* (Raineri). In the studied sections, no shallow marine, miliolid-dominated sediments have yet been encountered.

Arab-D Reservoir (Jubaila Formation)

Stratigraphy

The Jubaila Formation (Bramkamp & Steineke 1952; Powers et al. 1966; Powers 1968; Manivit et al. 1985) is divided into a lower Ju1 unit termed the Ju1 and an upper Ju2 unit (Enay et al. 1987). It disconformably overlies the Hanifa Formation (Meyer & Hughes 2000; Meyer et al. 2000) and is approximately 130 m thick (D. Vaslet, oral communication 2002).

Age

A Kimmeridgian age is assigned to the Jubaila Formation based on the presence of the ammonite species *Perisphinctes jubailensis* Arkell in the lower part of the Formation (Enay et al. 1987) and the nautiloids *Paracenoceras wepferi* (Loesch) and *P.* gr. *moreausum* (Tintant 1987).

Biofacies

In recent Saudi Aramco investigations of surface sections at Wadi Laban, Wadi Nisah and in the Khurais and Ghawar subsurface, Jubaila Formation displays a moderately low foraminiferal species diversity that includes undifferentiated nodosarids, *Lenticulina* spp., *Kurnubia palastiniensis* Henson, *Nautiloculina oolithica* Mohler, *Alveosepta jaccardi* (Schrodt) undifferentiated miliolids and biserial agglutinated forms. Allochthonous stromatoporoids include the branched species *Cladocoropsis mirabilis* Felix together with stratified forms. Monaxon and tetraxon sponge spicules are locally present, as are valves of juvenile brachiopods.

Palaeoenvironment

A lagoon palaeoenvironment is suggested by Enay et al. (1987) for the Jubaila Formation. Foraminiferal assemblages from the outcrop in the Tuwaiq Mountain escarpment, west of Riyadh and in the subsurface of the Ghawar and Khurais fields of Saudi Arabia provide evidence for a variety of sub-environments. Open marine, normal salinity, moderately deep marine conditions, below normal fairweather wavebase are typified by the presence of *Lenticulina* spp., *Nodosaria* spp., *Dentalina* spp., *Pseudomarsonella* spp., monaxon and tetraxon sponge spicules, juvenile costate brachiopods. The presence of *Kurnubia palastiniensis* Henson and *Nautiloculina oolithica* Mohler is of limited palaeoenvironmental significance, as they are presence in most of the Jubaila environments. Fragments of *Cladocoropsis mirabilis* Felix and layered stromatoporoids are locally present and attributed to storm-triggered transportation from a shallower setting. As with the Hanifa Formation, the shallower part of the open marine regime is characterized by the presence of alveolar walled agglutinated *Alveosepta powersi* (Redmond). The ubiquitous species *Kurnubia palastiniensis* Henson and *Nautiloculina oolithica* Mohler are also present. The shallowest depositional facies in the Jubaila Formation includes *Kurnubia palastiniensis* Henson, *Nautiloculina oolithica* Mohler, *Clypeina jurassica* Favre, miliolids and scattered fragments of laminated and branched stromatoporoids and corals and suggests proximity to a shoal complex.

Arab Formation

Stratigraphy

The Arab Formation consists of four members (Steineke & Bramkamp 1952; Powers et al. 1966; Powers 1968), named in vertical succession as D, C, B and A. Each member consists of a lower carbonate and an upper evaporitic section, although the anomalously thick evaporate associated with the Arab A member is called the Hith Formation. The Arab-D reservoir spans the upper part of the Jubaila Formation, and the carbonates of the Arab-D Member.

Age

Neither ammonites nor calcareous nannofossils have been recovered from the D Member of the Arab Formation, and the age is based on benthonic foraminifera. The presence of *Alveosepta jaccardi* (Schrodt), *Kurnubia palastiniensis* Henson, *Mangashtia viennoti* Henson, *Trocholina alpina* (Leupold), *Everticyclammina virguliana* (Koechlin) and *Pfenderina salernitana* Sartoni & Crescenti provide an undifferentiated Kimmeridgian age.

Biofacies

Benthonic foraminifera recovered from the Arab-D Member include *Nautiloculina oolithica* Mohler, *Kurnubia palastiniensis* Henson, *Pfenderina salernitana* Sartori and Crescenti, *Trocholina alpina* (Leupold), *Mangashtia viennoti* Henson, undifferentiated miliolids and undifferentiated biserial agglutinated species. A variety of dasyclad algae include *Clypeina jurassica* Favre. Stromatoporoids include the branched species *Cladocoropsis mirabilis* Felix and undifferentiated layered forms.

Palaeoenvironment

A sabkha palaeoenvironment is suggested by Enay et al. (1987) for the Arab Formation. Foraminiferal assemblages from the outcrop in the Tuwaiq Mountain escarpment, west of Riyadh and in the subsurface of the Ghawar and Khurais fields of Saudi Arabia provide evidence for a variety of sub-environments. The deepest biofacies of the Arab-D member represents a deep lagoon, normal salinity settling and includes *Kurnubia palastiniensis* Henson, *Nautiloculina oolitica* Mohler, laminated stromatoporoids, *Cladocoropsis mirabilis* Felix, *Clypeina jurassica* Favre and *Thaumatoporella parvovesiculifera* (Raineri). A slightly shallower lagoon subtidal setting includes *Pfenderina salernitana* Sartoni & Crescenti, *Mangashtia viennoti* Henson, *Trocholina alpina* (Leupold) and undifferentiated simple miliolids. A hypersaline, shallow lagoon to intertidal environment is characterized by undifferentiated simple miliolids, costate, cerithid-like gastropods, bivalve and brachiopod debris and algal laminae.

Conclusions

The following conclusions are based on observations made on the reservoir-associated sections of the Middle and Upper Jurassic formations encountered during industrially-applied micropalaeontological studies. It is conceivable that the trends observed may require modification after more extensive studies of closely sampled measured sections from the outcrop belt – currently in progress. Stacking order of the respective species and their associations, together with limited sedimentological information, have enabled palaeoenvironmental interpretations to be deduced, using peculiarities of foraminiferal wall structure and comparisons to modern genetical analogues where possible.

The deepest part of each of the depositional cycles represented by the Tuwaiq Mountain, Hanifa and Jubaila formations display a similar microbiofacies that consists of monaxon and tetraxon spicules, species of *Lenticulina* and *Nodosaria*, with occasional *Dentalina*, together with juvenile costate brachiopods. The pelagic bivalve *Bositra buchi* (Roemer) is only present within this biofacies of the Tuwaiq Mountain Formation. These species are often found in association with species that are typically found within the lagoon setting, such as *Kurnubia palastiniensis* Henson and *Nautiloculina oolithica* Mohler and may either have a very wide palaeoenvirinmental tolerance, or their presence may be attributed to an allochthonous, tidal or storm derived cause. Of these, the former is considered more likely because of their ubiquitous presence. The assemblage here considered to typify the moderately deep regime probably represents episodes of marine transgression when the most open marine, normal salinity and unrestricted environmental conditions persisted. Episodic events characterized by concentrations of spicules and *Bositra buchi* (Roemer) suggest low carbonate production rates and the resulting concentration of pelagic elements and of those that did not secrete a continuous shell or test, and may represent condensed beds related either to rapid transgression and a "catch-up" carbonate setting, or the acme of a cycle-scale transgression. In the Tuwaiq Mountain Formation, these events are repeated and have been integrated with the sedimentology to deduce depositional cycles from which reservoir layers have been suggested. This association provides evidence to support the concept that *B. bucchi* was not restricted to shallow marine conditions, but was more representative of low energy conditions at water depths below wave base.

A relatively shallower environment within the open marine, unrestricted regime, but deeper than the stromatoporoid shoals, below fair-weather wavebase but within the carbonate factory contains a depleted equivalent of the assemblage described above, in the presence of *Alveosepta jaccardi* (Schrodt), *A. powersi* (Redmond), *Pseudocyclammina lituus* (Yokoyama) and *Everticyclammina* spp. The reason for the predominance of large, complex-walled agglutinated species is questionable, but may be explained by the need for rapid colonization of an environment in which input of storm and tide-derived bioclastic debris was common.

The shoal complex within the studied sections is always represented by the presence of stromatoporoids (Wood 1987), minor corals and few microbiocomponents. Stratigraphically, in core samples, the laminated, encrusting stromatoporoids underlie the branched forms assigned to *Cladocoropsis mirabilis* Felix. Interpretation of the depositional environments of both extinct stromatoporoid types can be assisted by using their morphological similarity to domal and branched corals (James 1983; fig 59). The domal forms would represent a shoal crest or flank, with moderate to high wave energy and low rates of sedimentation would prevail, above fairweather wave base. The branched *Cladocoropsis mirabilis* Felix would be expected to occupy lower energy conditions with high rates of sedimentation such as on the lee side of a stromatoporoid shoal. The vertical succession represented in cores may, therefore, represent progradation of a lee or lagoonal *Cladocoropsis mirabilis* Felix facies over the encrusting and dome-shaped stromatoporoids of the shoal crest. Swan and Kershaw (1994) suggest that stromatoporoid morphology is strongly influenced by the pattern of sedimentation and this is upheld in the present study.

The deep lagoon association includes the benthonic foraminifera *Trocholina elongata* (Leupold), *Redmondoides lugeoni* (Septfontaine), *Meyendorfina bathonica*, *Trochamijiella gollestanhi* Athersuch et al., *Pfenderina trochoidea* Smout & Sugden, *Kurnubia wellingsi* (Henson), *Praekurnubia* sp. and *Valvulineria* sp., *Kurnubia palastiniensis* Henson and *Nautiloculina oolithica* Mohler and sparse simple miliolids are also present within this association. Other biocomponents include *Clypeina jurassica* Favre and *Thaumatoporella parvovesiculifera* (Raineri).

The shallow lagoon assemblage is typified by undifferentiated simple miliolids, *Kurnubia palastiniensis* Henson, *Nautiloculina oolithica* Mohler, *Pfenderina salernitana* Sartori and Crescenti, *Pfenderina trochoidea* Smout and Sugden, *Mangashtia vienotti* Henson, undifferentiated biserial agglutinated forms and *Trocholina alpina* (Leupold) with common *Clypeina jurassica* Favre. Upwards within this succession, believed to represent gradually shallowing conditions, *M. vienotti* Henson becomes rare to absent, followed by *Pfenderina salernitana* Sartoni & Crescenti and finally by *Trocholina alpina* (Leupold). The uppermost biofacies typically contains rare undifferentiated simple miliolids, cerithid gastropods and felted algal laminae, and believed to represent intertidal, shoreline conditions.

Acknowledgements. I am grateful to R. Rettori and G. Parisi for their comment and suggestions.

REFERENCES

Al-Dhubeeb A. G. (2001) - Agglutinated foraminifera of the Upper Jurassic Jubaila and Arab-D Formations and their palaeoenvironmental significance. Sixth International Workshop on Agglutinated Foraminifera, September 2001, Abstract: 32, Prague.

Al-Dhubeeb A. G. (2002a) - Late Jurassic foraminifera and their palaeoenvironmental significance in the Arab-D reservoir of the Ghawar field, Saudi Arabia, *GeoArabia*, 7 (2):195, Bahrain.

Al-Dhubeeb A. G. (2002b) - Late Jurassic foraminifera and their palaeoenvironmental significance in the Arab-D reservoir of the Ghawar Field, Programme and Abstracts Joint Meeting of AASP-TMS-NAMS, 11-13 September, 2002, University College, London.

Al-Husseini M. I. (1997) - Jurassic sequence stratigraphy of the western and southern Arabian Gulf. *GeoArabia*, 2: 361-382, Bahrain.

Almeras Y. (1987) - Les brachiopods du Lias-Dogger: paleontology et biostratigraphie. In: Enay, R. (ed.), *Geobios, Mem. Spec.*, 9: 161-219, Lyon.

Banner F. H. T. & Whittaker J.E. (1991) - Redmond's "new lituolid foraminifera" from the Mesozoic of Saudi Arabia. *Micropaleontology*, 37: 41-59, New York.

Banner F. T. & Highton J. (1990) - On *Everticyclammina* Redmond (Foraminifera), especially *E. kelleri*. *Jour. Micropal.*, 9: 1-14, London.

Banner F. T. (1970) - A synopsis of the Spirocyclinidae. *Rev. Esp. Micropal.*, 2: 243-290, Madrid.

Banner F. T., Simmons M.D. & Whittaker J.E. (1991) - The Mesozoic Chrysalidinidae (Foraminifera, Textulariacea) of the Middle East: The Redmond (Aramco) taxa and their relatives. *Bull. British Museum (Nat. Hist.), (Geology)*, 47: 101-152, London.

Bramkamp R. A. & Steineke M. (1952) – The larger benthic foraminifera and stratigraphy of the Upper Jurassic/Lower Cretaceous of Central Lebanon. *Rev. Micropal.*, 44 (3): 215-232, Paris.

Clark G. N. & Boudagher-Fadel M.K. (2001) - The larger benthic foraminifera and stratigraphy of the Upper Jurassic / Lower Cretaceous of Central Lebanon. *Rev. Micropal.*, 44: 215-232, Paris.

Conti M. A. & Cresta S. (1982) - Considerazioni stratigrafiche e paleoecologiche sui "livelli a Posidonia" (Auct.) dell'Appennino Umbro-Marchigiano. *Paleont. strat. Evol.*, 2: 73-80, Roma.

Depeche F., Le Nindre Y.-M., Manivit J. & Vaslet D. (1987) - Les ostracodes du Jurassique d'Arabie Saoudite centrale: systematique, repartition stratigraphique et paleogeographique. In: Enay, R. (ed.), *Geobios, Mem. Spec.*, 9: 221-275, Lyon.

Derin, B & E.Gerry (1966) – Jurassic biostratigraphy and environments of deposition in Israel. Proceedings of the 5[th] African Colloquium on Micropalaeontology, Addis Ababa, 1972. *Rev. Esp. Micropal.*, 7: 175 – 198, Madrid.

Enay R. (1987) - Le Jurassique d'Arabie Saoudite Centrale. *Geobios, Mem. Spec.*, 9: 1-314, Lyon.

Enay R., Le Nindre Y.-M., Mangold C., Manivit J. & Vaslet D. (1987) – Le Jurassique d'Arabie Saoudite Centrale: nouvelles donnes sur la lithostratigraphie, les paleoenvironnements, les faunes d'ammonites, les ages et les correlationes. In: Enay R. (ed.), *Geobios, Mem. Spec.* 9: 13-66, Lyon.

Fisher J.-C., Le Nindre Y.-M., Manivit J. & Vaslet D. (2001) - Jurassic gastropod faunas of Central Saudi Arabia. *GeoArabia*, 6: 63-100, Bahrain.

Hughes G. W. (1996) - A new bioevent stratigraphy of Late Jurassic Arab-D carbonates of Saudi Arabia. *GeoArabia*, 1: 417 – 434, Bahrain.

Hughes G. W. (1998) - Micropalaeontologically-derived palaeoenvironmental Variations within selected Saudi Arabian carbonates Proc. 4[th] Int. Conf. on the Geol. of the Middle East, 1998, Beirut, Abstract: 114–115, Beirut.

Hughes G. W. (2000) - Saudi Arabian Late Jurassic and Early Cretaceous agglutinated foraminiferal associations and their application for age, palaeoenvironmental interpretation, sequence stratigraphy and carbonate reservoir architecture. In: Hart, M.B., Kaminski, M.A. & Smart, C.W (eds.) - Proceedings of the Fifth International Workshop on Agglutinated Foraminifera, Abstract. *Grzybowski Foundation Spec. Publ.*, 7: 149–165, Krakòw.

Hughes G. W. (2001) - Palaeoenvironmental and sequence stratigraphic implications of *Pseudocyclammina lituus* events in the Upper Jurassic (Oxfordian), Hanifa Formation of Saudi Arabia. Sixth Int. Workshop on Agglutinated Foraminifera. Abstract: 45, Prague.

Hughes G. W. (2002) - The stratigraphic significance of microbiofacies to selected Saudi Arabian reservoirs, *GeoArabia*, 7: 248 – 250, Bahrain.

Hughes G. W. (2002b) - Palaeoenvironments of Middle to Upper Jurassic foraminifera of Saudi Arabia (abst), In L.Martire (Ed.) Abstracts and Program, 6th International Symposium on the Jurassic System, Mondello, Sicily, Italy: 92, Torino.

Hughes G.W. (2002c) - The stratigraphic significance of biofacies to selected Saudi Arabian reservoirs (abst.), Programme and Abstracts, Joint Meeting of AASP-TMS-NAMS, 11-13 September, 2002, University College, London.

James N.P. (1983) – Reef Environment, In carbonate Depositional Environments. In : Scolle P.A., Bbout D.G. & Moore C.H. (Eds.), *Amer. Ass. of Petroleum Geologists, Mem.* 33: 345-440, Tulsa.

Mancinelli A. & Coccia B. (1999) - Le Trocholine dei sedimenti mesozoici di piattaforma carbonatica dell'Appennino centro-meridionale (Abruzzo e Lazio). *Revue Paleobiol.*, 18: 147-171, Lausanne.

Manivit H. (1987) - Distribution des nannofossiles calcaires du Jurassique Moyen et Superieur en Arabie Saoudite centrale. In Enay, R. (ed.), *Geobios, Mem. Spec.*, 9: 277-291, Lyon.

Manivit J., Pellaton C., Vaslet D., Le Nindre Y.-M., Brosse J.-M. & Fourniquet J. (1985) – Geological map of the Wadi al Mulayh quadrangle sheet 22H, Kingdom of Saudi Arabia (with text). Saudi arabian Deputy Ministry Mineral Resources, *Geosciences Map* GM-92, scale 1/250000, Bahrain.