

Agriopleura Morphotypes of the Lower Aptian Shu'aiba Formation of Saudi Arabia

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Abstract

The Shu'aiba Formation of the Arabian Platform consists of Aptian carbonates in which rudists are important biocomponents. It is an important hydrocarbon reservoir. Semi quantitative micropalaeontology and macropalaeontological observations from cores have enabled three-dimensional interpretation of biofacies and lithofacies that have guided optimal reservoir exploitation.

In addition to the presence of *Offneria murgensis* MASSE, *O. cf. nicolinae* (MAINELLI), *Glossomyophorus costatus* MASSE et al., *Oedomyophorus shaybahensis* SKELTON, and *Horiopleura cf. distefanoi* BOEHM the Shu'aiba Formation contains *Agriopleura cf. blumenbachi* (STUDER) and *A. cf. marticensis* (d'ORBIGNY). Although species of *Agriopleura* are locally present over short sections below the *Glossomyophorus costatus* accumulations of the middle part of the formation, they are very well represented in its upper part, where they are typically associated with the moderately deep marine benthonic foraminifera *Praechrysalidina infracretacea*, *Vercorsella arenata*, *Debarina hahounerensis* and *Palorbitolina lenticularis*.

Agriopleura cf. blumenbachi and *A. cf. marticensis* display contrasting morphologies. *Agriopleura cf. marticensis* is cone-shaped, with a fixed valve expansion angle of 30–35°, and with average right valve dimensions of 3.5 cm length and 2.5 cm maximum diameter. A recently observed "clinger" form is, however, 70 cm long. *A. cf. blumenbachi* is elongate, almost tube-like, with a very low rate of fixed valve diameter increase, of less than 10° with average right valve dimensions of 6.5 cm length and 2.2 cm maximum diameter.

The two forms are present in distinct biofacies. Both *Agriopleura* facies are considered to compose a single depositional cycle, and it is possible that the elongate shape of *Agriopleura cf. blumenbachi* is better adapted to the slightly higher rate of sedimentation associated with the relatively rapid sea level rise at the base of each new depositional cycle. The cone-shape of *A. cf. marticensis* is possibly adapted to lower rates of sedimentation during the relatively slower rate of sea level rise, and ultimate fall of the upper part of each depositional cycle.

1. INTRODUCTION

The Shu'aiba Formation consists of carbonates that are extensively present in the Arabian subsurface where they provide a significant hydrocarbon reservoir, in the Shaybah Field of southern Saudi Arabia. The carbonates were deposited in a variety of environments (Fig. 1; HUGHES, 1998, 1999, 2000, 2001) on an extensive shallow marine platform that occupied much of the Arabian platform in which a number of intra-shelf basins were present. The basin flanks provided suitable conditions for rudist colonization and development of rudist bank complexes during the Early to possibly Late Aptian (WITT & GÖKDAG, 1994).

A variety of rudists are present of which, within the uppermost part especially of the Shu'aiba Formation, species of the elevator rudist *Agriopleura* display two distinctive morphologies (Fig. 2). Their vertical succession provides a refined depositional layering scheme of possible application for an improved reservoir layer model.

A need to understand the depositional environment and cyclicity is important for the optimal exploitation of the hydrocarbon reserves of the field. The inability of existing seismic data to resolve intra-reservoir facies variations justifies the ongoing detailed micropalaeontological and macropalaeontological analysis to which this paper is a contribution.

2. PREVIOUS WORK

The Shu'aiba Formation has been studied extensively in Oman and the Emirates (PITTET et al., 2002; VAN BUCHEM et al., 2002; MASSE et al., 1998), but mainly for sedimentological and sequence stratigraphic aspects. Studies in Saudi Arabia have been limited to relatively recent investigations of the Shaybah Field but have involved an integration of semi-quantitative micropalaeontological analysis of closely-spaced core samples with macropalaeontology (HUGHES, 1998, 2000, 2001, 2002). A variety of rudists have been identified from the Shu'aiba Formation in Saudi Arabia (SKELTON et al., 1998; HUGHES, 2000; SKELTON & MASSE, 2000), and have led to the development of a three dimensional depositional model (AKTAS et

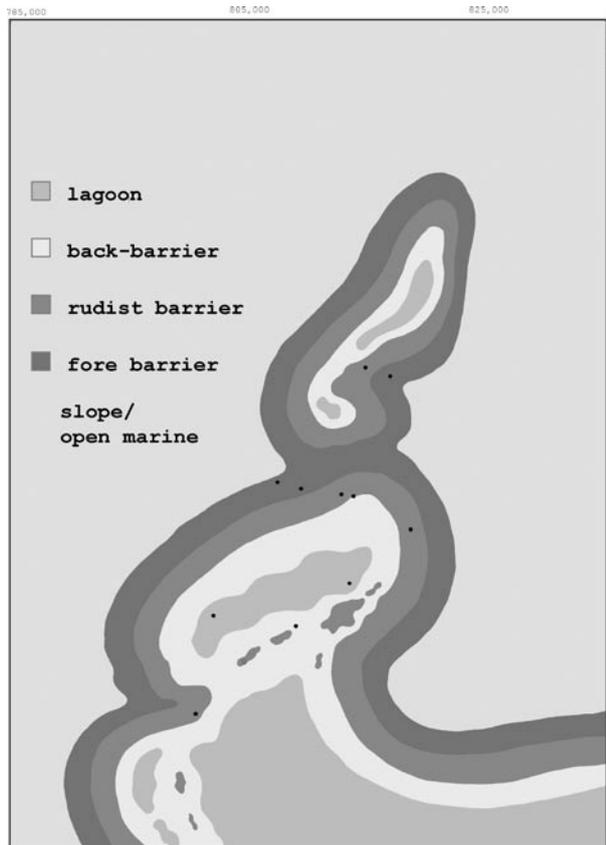


Fig. 1 Depositional regimes of the Shaybah Field, Saudi Arabia.

al., 1999) that had guided recent development of the Shaybah Field.

3. RUDISTS OF THE SHU'AIBA FORMATION

With the assistance of Dr. Peter Skelton, seven rudist species have been identified in the Shu'aiba Formation of Saudi Arabia (SKELTON & MASSE, 2000; HUGHES, 2000). They are represented by *Agriopleura* cf. *blumenbachi* (STUDER), *A.* cf. *marticensis* (d'ORBIGNY), *Glossomyophorus costatus* MASSE et al., *Oedomyophorus shaybahensis* SKELTON, *Offneria* cf. *nicolinae* (MAINELLI), *O. murgensis* MASSE and *Horiopleura* cf. *distefanoi* BOEHM. The preferred palaeoenvironment of each species has been deduced from stacking arrangements and the palaeoenvironmental information provided by the associated biocomponents (Fig. 2). Within the informal three-layered model of the formation (HUGHES, 2000), rudists are absent from the basal, lowermost and regionally extensive layer representing a deep open marine, orbitolinid and planktonic foraminiferal-bearing carbonate platform. The overlying, compound, highly differentiated layer represents rudist bank complex, lagoon and fore-bank environments. The upper layer is characterized by deposits indicating predominantly moderately deep, open platform conditions with

extensive areas with common *Agriopleura* rudists and sparsely distributed shallow rudist banks.

Agriopleura species

Two morphotypes of *Agriopleura* have been recognized, by Dr. Peter Skelton, from the Shu'aiba Formation of Saudi Arabia – *Agriopleura* cf. *marticensis* and *Agriopleura* cf. *blumenbachi* – and they are easily distinguished by their clearly different morphology. Both, however, display the typical elevator growth orientation.

Agriopleura cf. *blumenbachi* (Fig. 2) is typically thin, elongate and cylindrical resulting from a low expansion rate of the fixed, or right, valve with an apical angle less than 10°. The right valve typically has a very low degree of curvature, which when present is mostly the result of geniculate growth following disturbance and slight tilting during early growth history. It displays a maximum length of 6.5 cm and 2.2 cm diameter. The outer margin of the right valve is typically smooth, but some specimens display small extensions to the growth lamellae, most of which are irregular in length. This species has only been found in an elevator position, unlike *A.* cf. *marticensis*, as described below. It has only been found within the upper layer of the Shu'aiba Formation at Shaybah. It is typically found in association with the foraminiferal species *Praechrysalidina infracretacea* LUPERTO SINNI, *Debarina hahounerensis* FOURCADE, RAOLT & VILA, *Vercorsella arenata* ARNAUD-VANNEAU, *Bolivina* sp., *Rotalia* sp. and *Palorbitolina lenticularis* (BLUMENBACH) together with *Lithocodium aggregatum* ELLIOTT (Fig. 2). Rare specimens of the planktonic foraminiferal species *Hedbergella delrioensis* (CARSEY) are also present within this association.

Agriopleura cf. *marticensis* is cone-shaped (Figs. 2 and 3) and displays a relatively high rate of expansion of the fixed valve and an apical angle of between 30–35°. It displays a maximum length of 3.5 cm length and 2.5 cm diameter. The outer margin of the right valve displays characteristic extensions to the growth lamellae, most of which are rather irregular in the degree of their extension. These extensions typically radiate out from the right valve and suggest a possible stabilizing function within poorly consolidated sediments. One recently discovered specimen, however, displays a horizontal, clinger growth habit, as the lateral growth lamellae are only developed on the lowermost side where it was in contact with the sediment (Fig. 3a). It is well represented in the upper layer of the Shu'aiba Formation, in addition to forming the basal unit of the *Glossomyophorus costatus*–*Offneria murgensis* associations in the middle layer. It is typically found in association with the foraminiferal species *Palorbitolina lenticularis* (BLUMENBACH), and simple *Quinqueloculina* and biserial agglutinated species, and with the dasyclad algae *Salpingoporella*

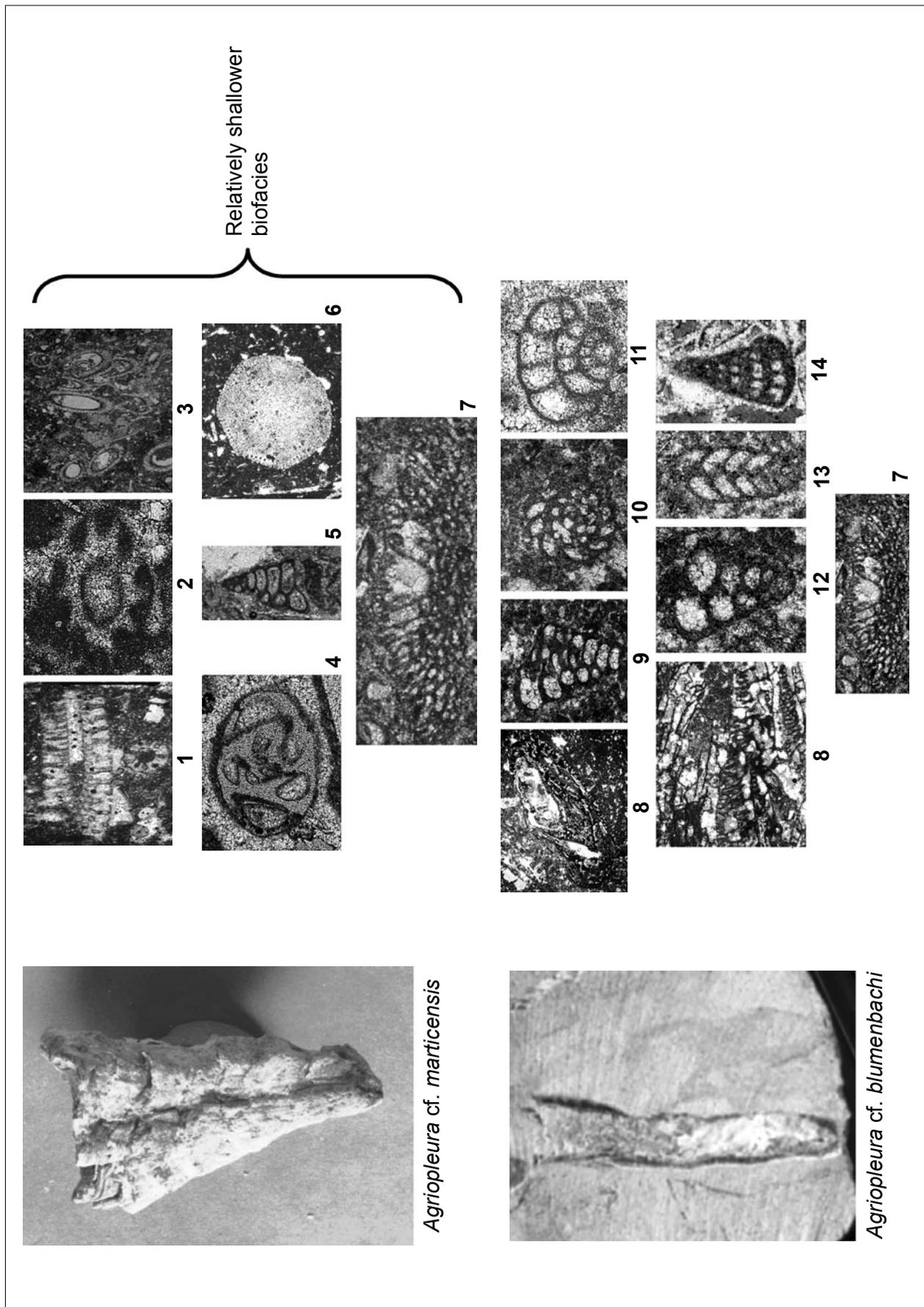


Fig. 2 *Agriopleura* species and their microfossil association. 1 – dasyclad alga; 2 – *Coptocampylodon lineolatus*; 3 – *Salpingoporella dinarica*; 4 – *Quinqueloculina* sp.; 5 – biserial agglutinated foraminifera; 6 – large echinoid spine; 7 – *Palorbitolina lenticularis*; 8 – *Lithocodium aggregatum*; 9 – *Praechrysalidina infracretacea*; 10 – *Debarina hahounerensis*; 11 – indeterminate rotaliid; 12 – textulariid; 13 – *Bolivina* sp.; 14 – *Vercorsella arenata*.

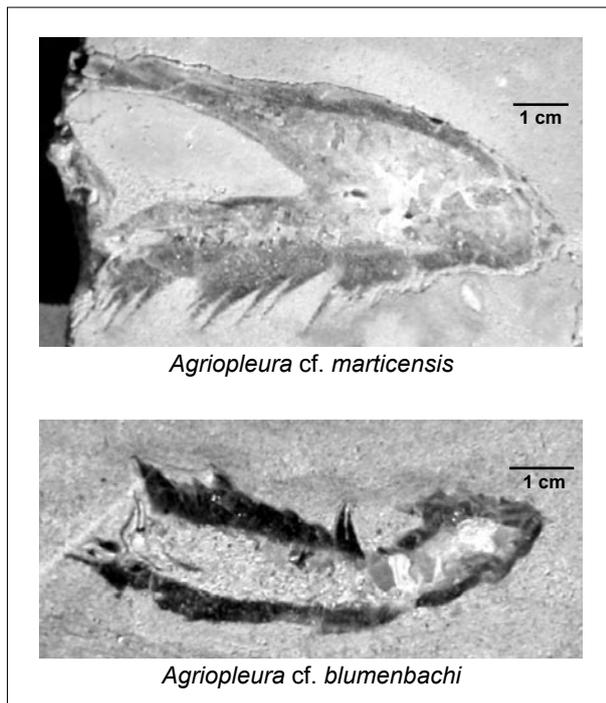


Fig. 3 (a) *Agriopleura* cf. *marticensis* in a horizontal position and preferential growth line extensions on the lowermost side. This is interpreted as a possible "clinger" life habitat of this particular specimen. (b) *Agriopleura* cf. *blumenbachi* also in a horizontal position, but here possibly the result of displacement from an elevator growth habit, based on the relatively similar growth lamellae on the lower and upper sides, together with an unusual, partial, irregular geopetal sediment infill.

dinarica RADOIČIĆ and *Coptocampylodon lineolatus* ELLIOTT (Fig. 3).

Palaeoenvironmental and stratigraphic interpretation

In the upper Shu'aiba, both *Agriopleura* species are present within wackestones and packstones, but form almost individually exclusive populations. *Agriopleura* cf. *blumenbachi* is most commonly present, and is often without the presence of *A. marticensis*. These associations are always developed with *Agriopleura* cf. *blumenbachi* forming the lower unit up to 97 cm thick, overlain by beds up to 83 cm thick containing *A. marticensis* and both typically display elevator growth habits confirming their position within an environment of net sedimentation.

The foraminiferal associations present with both species indicate normal salinity conditions. The association of complex walled agglutinated foraminiferal species and rare planktonic foraminifera with *A. cf. blumenbachi* suggests that this species occupied moderately deep marine conditions with open marine influence (Fig. 2). The shallower foraminiferal associations found with *A. cf. marticensis* suggest relatively shallower conditions, and that both species may respectively represent the lower, deeper and upper, shallower part of a depositional cycle.

In general, the tendency of *A. cf. blumenbachi* to display near vertical orientation in the studied cores would suggest limited disturbance by wave action. This enables a depth range of below fair-weather wave base to be estimated, to the shallowest planktonic foraminiferal depth. BANNER & SIMMONS (1994) suggest 150 feet as the shallowest planktonic foraminiferal range, but this is considered to be too deep for the Shu'aiba platform. Although individual beds may reach 4.5 m in thickness, the palaeobathymetry represented by this single cycle would be in excess of this, but the generally disturbed orientation of *A. cf. marticensis* suggests that the upper and shallowest part of the depositional cycle was probably above fair weather wave base.

One large specimen of *A. cf. marticensis* has been found displaying a clinger life habitat (Fig. 3a), with preferential development of lateral growth lamellae on the ventral side in a presumed adaptation for additional stability. Unlike the predominant elevator lifestyle of the specimens encountered, where conditions of net sedimentation prevailed, the clinger specimen testifies to an adaptation to shallower, higher energy conditions in an area of sediment bypass.

Controls on *Agriopleura* morphology

In view of the overall morphological similarity of the two species of *Agriopleura*, and the lack of statistical data to demonstrate that intermediate forms exist, it is possible that both forms represent two distinct species, here compared with *Agriopleura marticensis* (d'ORBIGNY, 1850) and *Agriopleura blumenbachi* (STUDER, 1834). This interpretation does not conform to the interpretation of such similar morphology contrasts of *Praeradiolites* species described by FLOQUET (1998), and further biometrics are recommended before a convincing decision is achieved for the two morphological variants here assigned to species of *Agriopleura*.

Regardless of the taxonomic arguments, there must be some environmental control on the adaptive nature of the conical right valve shape of *A. cf. marticensis* over the slender, cylindrical right valve of *A. cf. blumenbachi*. It is possible that the elongate cylindrical shape of *A. cf. blumenbachi* is an adaptation to the relatively high rate of ambient sediment accumulation during the lower part of the depositional cycle, when the ability to maintain the commissure above the sediment would be vital for survival. The conical form of *A. cf. marticensis* may preferentially be adapted to lower rates of sediment accumulation during the upper part of a depositional cycle, when the need for increased stability in a relatively higher energy regime was achieved by greater width and lamellar extensions were critical adaptations. The adaptation of a clinger lifestyle, with the associated preferential development of accentuated ventral growth lamellae further testifies to the morphological plasticity of *Agriopleura*.

4. CONCLUSIONS

In the uppermost depositional layer of the Lower Aptian carbonates of the Shu'aiba Formation in Shaybah Field, Saudi Arabia, the elevator rudist genus *Agriopleura* displays a common and regionally extensive distribution. Two morphotypes are distinguished, of which the slender cylindrical form is assigned to *A. cf. blumenbachi* and the squat, conical form to *A. cf. marticensis*.

A. cf. blumenbachi is typically present within the lower part of a depositional cycle, or parasequence, and associated with relatively deep marine foraminifera, including rare planktonics. Shallower, lower diversity foraminiferal assemblages are found within the upper part of the depositional cycle where *A. cf. marticensis* is well represented. There is no overlap in the distribution of both morphotypes, and they are tentatively assigned to the two species of *Agriopleura*. In both cases, the energy levels are considered to have been relatively low, but sufficiently high to introduce sediment for support of the elevator life-style. Of note is the single observation of *A. cf. marticensis* adapting to a clinger mode of life, and is considered to represent localized higher energy conditions in areas of net sediment bypass.

The distribution of the morphotypes are concluded to have been controlled by palaeobathymetric variations linked to the transgressive "catch-up" and regressive "keep-up" parts of a single depositional cycle. These cycles, up to 4.5 m thick, are repeated through this upper layer of the Shu'aiba Formation.

During hydrocarbon exploitation of the uppermost part of the Shu'aiba reservoir at Shaybah Field, the contribution of both *Agriopleura* species lies in providing a fine-scaled stratigraphy and units of inter-well correlation that lead to an improved model for reservoir characterisation.

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