

Computerized Tomography Reveals Aptian Rudist Species and Taphonomy

Geraint W. HUGHES¹, Shameem SIDDIQUI² and Roy K. SADLER³

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Abstract

Computerized tomographic (CT) scans of cored carbonates from the Lower Aptian Shu'aiba Formation reveal clearly defined rudist profiles. Formation MicroImager (FMI) logs from the equivalent cored wellbore also display images related to the rudist content. Various rudist species can be identified in the cores and provide a key to the identification of the CT and FMI rudist images. As certain rudist species preferentially occupied different environments during the Early Aptian deposition of the Shu'aiba Formation carbonates, their recognition in the cores, CT and FMI images can be used to assist determination of palaeoenvironments, lithofacies and reservoir facies. This new ability to identify rudist images in FMI logs in uncored development wells can be used to extend depositional facies models into uncored parts of the hydrocarbon reservoir models.

1. INTRODUCTION

Core-based information on the rudist species has significantly assisted the development of a three-dimensional depositional model for the Shaybah field, and is currently impacting its development strategy. As horizontal development wells are drilled, however, additional depositional facies control is required, and this necessitates more detailed studies on the environmentally-indicative biocomponents. Cores collected during the exploration and development phases of carbonate reservoirs provide very important palaeontological, sedimentological, petrographic, diagenetic and petrophysical information. As plugging and slabbing often damage the cores, the original rudist fabric is often obscured and may cause inaccurate interpretations of the depositional environment. Rudist fossils characterise much of the Shu'aiba, and the distribution of various species is directly associated with

the depositional environment. In an attempt to assist the delineation of various reservoir facies of Fullbore Formation MicroImager™ (FMI) logs in uncored horizontal development wells, the macrobiofacies of vertical cores have been calibrated with Computerised Tomography (CT) scans and FMI logs (HUGHES et al., 2002).

The hydrocarbon-rich Shu'aiba Formation reservoir of the Shaybah Field is of Lower Aptian age. The Formation consists entirely of carbonates that were deposited as an extensive blanket on the Arabian Platform (SHARLAND et al., 2001, fig. 3.31). The rudist facies that form the focus of this contribution developed on the southern flank of an intra-shelf basin and were responsible for the lateral differentiation of an earlier open platform facies into lagoon, rudist bank complex and open marine regimes (HUGHES, 2000, 2001). Comprehensive palaeontological and sedimentological studies of the intensively cored field have revealed a depositional history that is associated with the initiation and subsequent development of a rudist-rimmed platform.

2. COMPUTERISED TOMOGRAPHY (CT)

A CT-scanner measures the attenuation coefficient of a material. The attenuation of the energy in the X-ray beams is related to the electron density and atomic number of the materials present in the object being scanned. At relatively high X-ray energies the attenuation coefficient becomes mainly a function of the electron density and the latter is a function of the core bulk density (porosity, grain density, and fluid saturation) and lithology. In this study a test slice thickness of 1 cm was used and image slices were stacked to generate a full 3-dimensional image of the core using software such as *AVS-Express* or *OpenDX*. CT-scanning offers the advantage that the data are stored for any future use unlike the cores, which become difficult to use after slabbing and plugging. CT-scanning is increasingly applied for non-destructive core characterization using core description, core quality assessment, lithology identification and for quantifying lithological heterogeneity. CT-scanning is also used to address reservoir scale-up issues, matching of conventional core analysis and log analysis data

¹ Saudi Aramco, Box 10646, Dhahran 31311, Saudi Arabia; e-mail: geraint.hughes@aramco.com.sa

² Saudi Aramco Research & Development Center, Box 62, Dhahran 31311, Saudi Arabia; e-mail: shameem.siddiqui@aramco.com

³ Saudi Aramco Reservoir Characterization Department, Box 1825, Dhahran 31311, Saudi Arabia; e-mail: sadlerrk@aramco.com

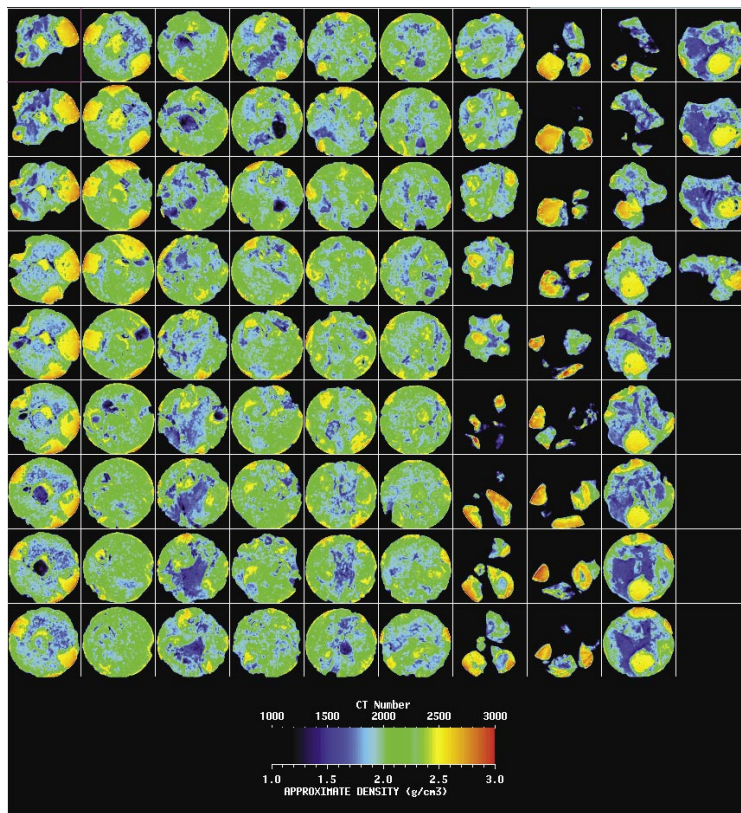


Fig. 1 CT images of a 85.34 cm (2.8 ft) section of core, together with a density calibration scale in which higher densities are displayed in "warm" colours, and low densities as "cool" colours. The circular images represent CT slices through the core. Images are arranged in rows in descending order down the core, commencing in the top left corner and terminating at the bottom right corner. The dense, calcite-filled rudists are displayed as orange/yellow shapes, such as in the lowermost right circle. Rudists with unfilled right valves are displayed as black shapes, such as in the circle above that in the lower left corner.

(mostly bulk density and porosity) and broad mineral classifications.

The particular applications of CT as a reservoir characterization tool include classification of heterogeneity; identification of lithology and broad mineralogy, sand–shale sequences, vugs, fractures and high-density mineral inclusions; measurement of bulk density and porosity; core-to-log depth correlation; visualization of mud invasion; evaluation of damage in unconsolidated cores, etc. Apart from core characterization, CT is used extensively to visualize and quantify hydrocarbon fluid displacement in cores in simulated laboratory experiments to determine residual oil saturation, to evaluate trapped porosities, to visualize and quantify gravity and viscous effects, etc. Detailed reviews of the application of CT in various coreflood experiments can be found in the literature (KANTZAS, 1990; SIDDIQUI, 2001). Application of CT technology towards palaeontological use is limited, but examples already include investigations into vertebrate morphology (ROWE et al., 2001) and algae (TORRES et al., 2003).

Rudists are extinct bivalves that form palaeoenvironmentally and stratigraphically important components of the Shu'aiba carbonates. As rudists are made of denser materials than the main ingredients of the rock, a high-density threshold was applied to the CT-derived data that resulted in Figs. 1 and 2). To illustrate the use of CT, a 85.34 cm (2.8 foot) cored section containing large elevator rudists has been scanned and

photographed. A series of transverse CT scan images were generated at 7.62 cm (3 inch) spacing (Fig. 1), in which low density areas are illustrated in cool colours black to blue, indicating densities up to 2 g/cm³. These slices are arranged in order down the core, in columns commencing at top left and terminating at bottom right. Higher density parts of the core, between 2.0 and 2.65 g/cm³, are displayed as warm colours ranging from green through yellow, orange to red. As most of the core consists of packstones and wackestones, the average density varies between 1.7 to 2.2 g/cm³. These slices were used to generate a synthetic vertical section through the core (Fig. 2). The large rudist at the base of the core in Fig. 2 consists of a yellow core with a green margin, depicting a moderately dense rudist wall enclosing the rudist chamber filled with denser calcite. In the upper core, the slice at seven positions below the top of the section displays a dark blue area in the centre, surrounded by a thin yellow rim, and represents another elevator rudist with an unfilled chamber.

3. IMAGING WELL BORE WALLS – FMI LOGS

The Fullbore Formation MicroImager™ (FMI), records an array of microresistivity measurements from 192 receivers on eight pads mounted on four orthogonally placed caliper arms. The spacing and position of the pads provides 80% coverage of an 20.32 cm (8 inch) diameter hole and a resolution of 5 mm. The FMI yields a continuous, high-resolution electrical image of a

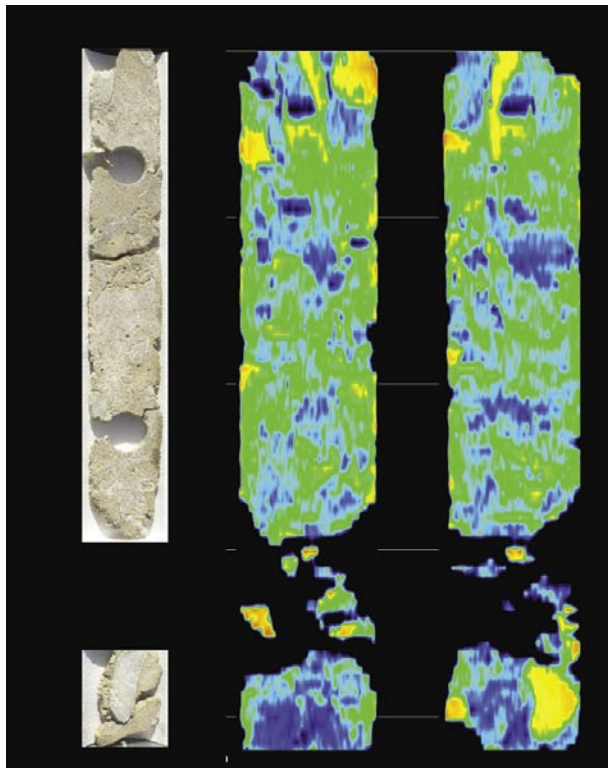


Fig. 2 Core photograph of Shu'aiba carbonates with the elevator form of the rudist *Offneria murgensis*, together with two synthetic vertical CT scan images of the same core. See density calibration scale in Fig. 1. The CT image on the right is in the same plane as the slabbled core; the CT image on the left represents a vertical slice normal to the slabbled plane, and has missed the rudist.

borehole, and therefore complements whole cores cut in the same well. If the image is of sufficient quality and calibrated against the core, it can provide a continuous survey of the formation in places where core was not cut, there was no core recovery, or when a core has been damaged through handling, transportation, or plugging. In the case of the subject of this paper, the FMI images provide a third perspective to the core and CT Scanned images of the vertical distribution of macrofossils in the Shu'aiba Formation.

4. RUDIST BIOFACIES AND PALAEO-ENVIRONMENTAL SIGNIFICANCE

Seven rudist species are known from the Shu'aiba Formation in Saudi Arabia based on analysis of cored wells over the Field. Each of these rudist species, and growth style, are clearly identifiable in side profile, and their preferred ecological preference in relation to the rudist bank complex has provided a useful method of determining sediment type, provenance and associated reservoir quality prediction. The rudist complex includes the recumbent species *Offneria murgensis* MASSE that is typically found on the crest of the bank, and represents adaptation to high-energy conditions with no ambient sediment deposition. The presence of pallial

canals in the wall of this caprinid species probably permitted rapid growth in a high energy environment with sediment bypass, and its later fragmentation into coarse, highly porous carbonate sediments has significantly contributed to the subsequent development of good reservoir facies within the Shaybah Field. *Oedomyophorus shaybahensis* SKELTON was adapted to the high rate of coarse sediment deposition on the lee side of the bank. The most extensive and well-developed rudist biofacies is that containing the elongate conical, caprotinid elevator species *Glossomyophorus costatus* MASSE et al. This species is smaller and less robust than *O. shaybahensis*, but developed in response to sediment accumulation in a moderately low energy environment at a greater distance lagoonwards from the *Offneria* bank. The sediment forming the supportive matrix of this species typically includes a high proportion of finely comminuted *Offneria* debris and provides high porosity and permeability in the reservoir. Rare specimens of the long, thin, pencil-like caprinid elevator species *Offneria nicolinae* SKELTON & MASSE are present in this biofacies. Forming a very narrow flank lagoonwards of the above biofacies is a fine-grained belt occupied by the stubby, conical, caprotinid elevator rudist *Agriopleura* sp. cf. *A. marticensis* SKELTON & MASSE. The left valve is not visible laterally because it lies countersunk within the flared open end of the right, or fixed, valve. This species displays an extensive distribution in the uppermost layer of the Shu'aiba Formation at Shaybah, where it alternates with the related, but elongate, form *Agriopleura* cf. *blumenbachi* (STUDER) (HUGHES, 2002, 2003). On the outer flank of the rudist complex lies the large, conical elevator rudist *Horiopleura* sp. cf. *H. distefanoi* (DOUVILLEI), that adapted to moderately high rates of sedimentation derived from the tidal backwash of sediment from the adjacent rudist bank complex. Recently, exceptionally large specimens of the rudist *Offneria murgensis* were discovered in the outer flank position, where they display a vertical, growth position indicating an elevator mode of life. Identification of the rudist species therefore provides an important guide to the palaeoenvironment.

Figure 2 displays a section of slabbled core containing the elevator rudist *Offneria murgensis* together with its CT scan images in transverse slices and vertical composite. The large rudists present in the study core were first interpreted from the CT scan, as the core tube was not open at that time, but enclosed in a plastic sleeve. Their large size and elevator attitude suggested that identification as *Oedomyophorus shaybahensis* and a back-barrier palaeoenvironment was supposed. When the core was opened and slabbled, the larger right valves of the rudists were seen to bear thin sub-horizontal platform structures called tabulae, and the identification was corrected to *Offneria murgensis*. This was a significant discovery, as *O. murgensis* had not been seen in an elevator growth form in any previously examined cores. According to Dr. P.W.

SKELTON of the Open University, United Kingdom (pers. comm.), it is not unusual for certain species to adopt an elevator growth form instead of recumbent, whenever environmental conditions are appropriate. At the location of the study core, a high rate of sediment deposition is interpreted on the fore-slope of a rudist bank in which only the rapid growth capability of *O. murgensis* enabled survival. Whereas most of the Lower Aptian rudists display sufficiently different profiles to enable their identification in CT scans and FM images, it must be admitted that differentiation between *O. murgensis* and *O. shaybahensis* cannot be established with confidence.

5. CONCLUSIONS

Rudists appear as high-density bodies scattered through the CT scan and FMI images of the core, and can be used for species identification, taphonomy and therefore palaeoenvironmental interpretation. The elongate high-density (from CT) and high resistivity (from FMI) shapes represent an elevator rudist (Fig. 2). The dimensions originally suggest that the specimens could represent the robust back-bank species *Oedomyphorus shaybahensis*, but it was difficult to explain the very low density of the inner part of the left valve. On examination of the core, it was found that the images were, in fact, of a new elevator growth habit of the robust caprinid *Offneria murgensis*, and that a fore-bank depositional setting is represented with its associated high rate of sedimentation. Further examination revealed that the low-density internal character results from the absence of infill material owing to the baffle compartmentalization created by the transverse septulae.

The vertical orientation of the rudists in the core further indicates that the cored assemblage represents an undisturbed assemblage. The three-dimensional vertical interpretation of the succession of horizontal CT scan images further reveals the torsional aspect of the rudist valves, this being an aspect of elevator-mode *Offneria murgensis* that has, until now, never been observed in this species. The inclination of the rudist valves has the potential for revealing the direction of predominant water current direction, as flume tank experiments have revealed (GILI & LABARBERA, 1998). Elevator rudists would be, as part of an optimal filter-feeding strategy, preferentially inclined away from the predominant direction of water flow.

One important advantage of the use of CT scans is that a three-dimensional view of the rudists is available for study, as this primary fabric is often destroyed when friable cores from the Shu'aiba are slabbed for internal description. The three dimensional aspect also has the advantage of revealing rudists that would never be visible in unexposed core surfaces, and thereby enable a taphonomic and palaeoenvironmental interpretation to

be made on a higher number of rudist individuals than would normally be visible for study. The advantage of the present approach lies in the ability to (1) calibrate the CT scan images with the core, and (2) calibrate the FMI images with the CT scan interpretation, thus enabling interpretation of the depositional environment, depositional and potential reservoir facies from FMI logs of vertical and horizontal development of non-cored wells. Further work is required to define all other Shu'aiba rudist species in terms of their CT and FMI profiles.

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