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# Detecting baffle mudstones using microfossils: an integrated working example from the Cardamom Field, Block 427 Garden Banks, Gulf of Mexico

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ABSTRACT

Sedimentological observations, planktonic microfossil data, terrigenous index proxy data, benthic morphogroup analyses, pressure analyses and geochemical fingerprinting were integrated in order to assess the nature of mudstones in the Cardamom Field in the Auger salt withdrawal minibasin (Gulf of Mexico). Both ponded and slope accommodation have occurred through the salt basin's history resulting in complex stratigraphic architecture of stacked submarine lobes and channels. Continuous core (164 ft) from the Messinian reservoir unit enabled this study to assess the depositional nature of the mud-rich intervals. Four mudstone facies (Mudstones 1–4) and respective depositional settings were interpreted. A modified benthic foraminifera microfacies model, in conjunction with variations recorded in planktonic flora and fauna abundances and reworking, serves as the key reference for the paleoecological interpretations. Of particular interest is the potential of a 41 ft thick (below seismic resolution) intra-reservoir mudstone (Mudstone 3) to act as a baffle/barrier to fluid flow between the lower U Sand and the upper U Sand. Mudstone 3 shows a hemipelagic character containing a diverse benthic community, high abundances of autochthonous planktonic flora and fauna, reduced terrigenous input and extensive bioturbation. Downhole formation pressure data and fluid fingerprinting from the reservoir pay sands (upper and lower U Sands) show significant differences in the calculated pressure gradients and fluid composition. This suggests that most likely the two reservoir pay sands are not in vertical communication. Mudstone 3 paleoenvironmental analyses suggest the lateral extension of a possible baffle/barrier to vertical fluid flow. These results show that benthic morphogroup analyses in mudstones can be a robust method to assess reservoir compartmentalization and consequently, impact field development planning and reservoir modeling.


## 1. Introduction

### 1.1. Field background

The Cardamom oil and gas field is located 362 km south-west of New Orleans, Louisiana within the Auger salt withdrawal minibasin in the Gulf of Mexico, in water depths of 2,720 ft (800 m). The basin is approximately 150sq mi (400sq km) in area and is bounded by salt-cored ridges on its outboard margins (Booth et al., 2000, 2003) (Fig. 1). The basin developed in the early Miocene and has undergone many episodes of accommodation creation and destruction due to salt withdrawal and sediment infilling. Both ponded and slope accommodation (*sensu* Prather et al., 1998) have occurred through the basin's history, resulting in a complex stacking arrangement of submarine lobate and channelized depositional architectures. The Auger basin contains an active petroleum system; hydrocarbons are sourced from a Jurassic marine marl and are trapped predominantly by turbidite lobe pinchouts along the basin margin. Seafloor pockmarks and seeps indicate that there is active present-day expulsion and migration (Dixon, 2007).

The Cardamom Field (Fig. 1) is an oil and gas discovery located 1.7 mi (2.8 km) east of the Auger tension leg platform. The field contains stacked Miocene and Pliocene turbidite reservoirs onlapping a salt diapir. Vertically stacked reservoir targets range from Messinian to Gelasian in age and are chronologically named from 'U' (oldest) to 'F' (youngest). The field was discovered in 2010 and is expected to produce from three highly productive reservoirs.

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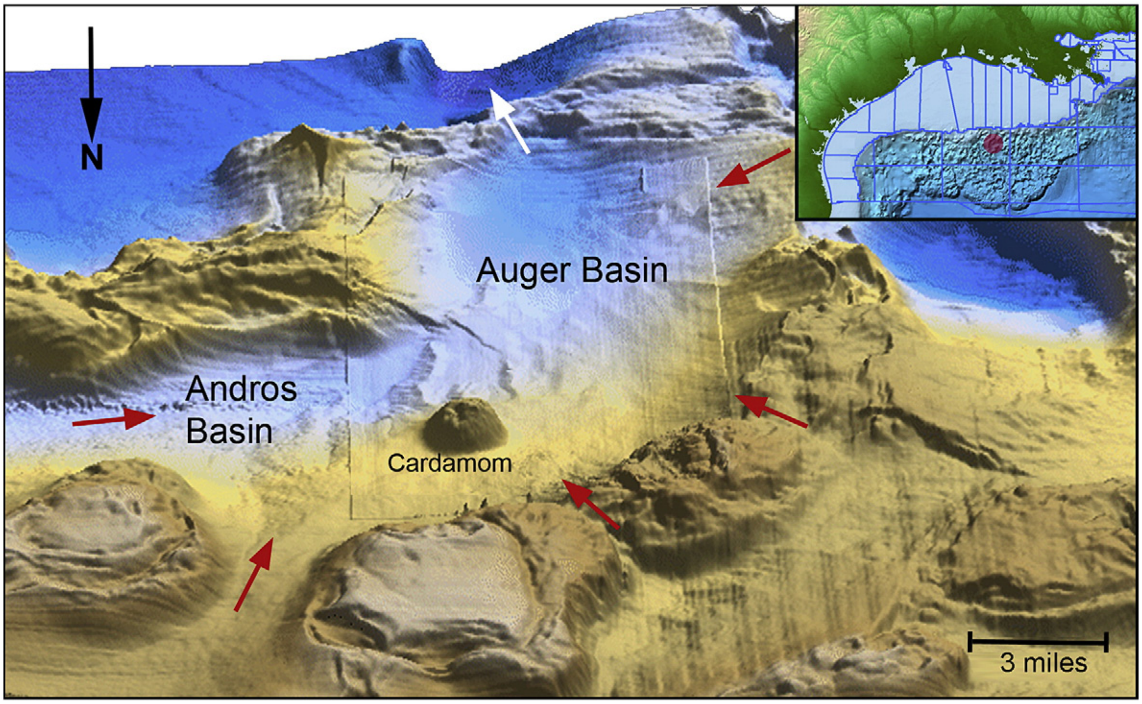


**Fig. 1.** Perspective view from the north of the present-day seafloor in the Auger Basin and the Cardamom salt diapir. Sediment entry (red) and exit (white) points are indicated. Comparison to subsurface data indicates that the present-day basin configuration is a good analogue for the late Miocene basin configuration and sediment delivery pathways (modified from Booth et al., 2003). Inset map shows the location of the Cardamom field within the Gulf of Mexico protraction areas (red dot).

### *1.2. Reservoir background and microfossils*

The U Sand is the main reservoir interval in the Cardamom Field. It is a turbidite sandstone package deposited in a middle bathyal setting that displays convergent baselapping seismic facies (*sensu* Prather et al., 1998) against a salt-cored basin margin (Fig. 1). The reservoir is of late Messinian age, below the last occurrence of *Globigerinoides mitra* and *Discoaster berggrenii* within planktonic foraminifera standard zone M14 (Berggren et al., 1995) and nannofossil standard zone NN11 (Martini, 1971). Biostratigraphy has been a critical stratigraphic tool in developing this field, including to calibrate the velocity model and to avoid penetrating an underlying overpressured mid-Miocene formation.

Seismic and well data indicate that the U Sand package thins rapidly onto the basin margin, likely indicating that the sediment gravity flows were ponded (Prather et al., 1998; Lamb et al., 2006). Four well penetrations in the field show that the U Sand interval contains two sand-rich units. The upper and lower U Sand packages are separated by a mud-rich interval of varying thickness (Figs. 2 and 3). There is particular interest in the lateral extent of this mud-rich interval and its potential to form baffles to vertical fluid flow and to compartmentalize the U Sand reservoir.

The U Sand interval was cored (Figs. 2 and 3) in 2011 to delineate the depositional environment and age of the reservoir, as well as to define completion procedures. The core recovered 164 ft (50 m) of the U Sand interval, including the upper part of the lower U Sand, the intervening mud-rich interval, and the lower part of the upper U Sand (Fig. 3). The 41 ft (12.5 m) thick intra-reservoir mud-rich interval is below seismic resolution (Fig. 2). Detailed core description, high resolution microfossil work, pressure calculations and fluid fingerprinting in the U Sand interval have been obtained in order to understand the nature of these deposits and the potential of this intra-reservoir mud-rich interval to form a baffle to fluid flow. Calcareous nannofossils and foraminifera are generally abundant, diverse and well-preserved, permitting detailed biostratigraphic analysis.

This project presents biostratigraphy as a key component of integrated reservoir description which, in conjunction with sedimentology, geochemistry and petrophysics, can answer reservoir connectivity questions.

## **2. Materials and methods**

### *2.1. Microfossil sample processing*

A total of 44 samples were prepared for quantitative foraminiferal and calcareous nannofossil analyses. Thirty-three core plugs were obtained from the intra-reservoir and underlying mud-rich units. An additional 11 ditch cutting samples were acquired at 30 ft intervals throughout the study section to capture data from the overlying mud-rich interval. Core plug samples were selected according to sedimentary characteristics from the mud-rich horizons. To determine the coarse silt/sand content, samples were dry weighed prior to, and after disaggregation and washing (over a 44 μm sieve) to estimate the weight of fine silt and clay.

The following procedure was applied for the foraminiferal analysis: samples were (1) soaked in distilled water and detergent; (2) washed through a 44 μm sieve; and (3) dried in an oven at 50 °C. Foraminiferal census data were obtained by running residues through a stack of 150 μm, 125 μm, and 106 μm dry sieves, from which a minimum of 300 specimens were counted when recovery allowed. The 44–106 μm size fraction was also analyzed in order to quantify the abundances of planktonic juveniles and small benthic foraminifera that are overlooked in routine analyses. Particularly large samples, or those with rich fauna, were split once using a microsplitter, and counts were scaled and normalized accordingly.

Simple smear slides for calcareous nannofossil analysis were prepared from the same sample intervals as microfossil samples using industry standard methods (Bown, 1998). Approximately 300 field of views (FOVs) at 100× magnification (radius of 100× FOV = 1100 μm