New Petrophysical Approach in the Study of Cenozoic Coral Carbonate Rocks as Reservoirs: Example of Pleistocene Platforms, Guadeloupe, French West Indies*

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Abstract

The aim of our study is both to characterise Cenozoic coral carbonate rock reservoirs and to develop a new petrophysical approach based on step by step measurements of P-waves propagation within rocks, at outcrop and sample scales. The Cenozoic era was chosen because scleractinian corals are a major component of subtropical to tropical sedimentary rocks and play a predominant role in carbonate anisotropy and porosity, whatever the scale. By their reef building activity, corals (1) modify their environment and thus both the sedimentary architecture and the nature of sediments, (2) create huge sedimentary architectures up to hundreds of metres in thickness and are widespread over a thousand kilometres, (3) display a high diversity of colony shapes and dimensions, and of complicated reef-frameworks, and (4) act on both internal fluid flows and diagenesis of carbonate sediments and rocks. Coral skeletal voids and moldic pores produced by aragonite skeletal dissolution in the meteoric realm have high porosity. This porosity following the coral reef-frame can facilitate water circulation in carbonate rocks.

Geological Setting

The Grande Terre Island of the Guadeloupe archipelago offers a good example of carbonate rocks, and especially coral carbonates, for reservoir study (Figure 1). The sedimentary succession, late Pliocene to early Pleistocene in age, represents a vertical stacking of four different carbonate systems represented by two rhodalgal ramps and two coral platforms (Cornée et al., in press). The carbonate systems exhibit lateral facies change along a 40 km-long, eastward platform-basin-profile. Deposits up to 100 m thick crop out over several tens of kilometres and are well exposed along sea cliffs 50 m high on average (Figure 1). Deposits underwent no burial diagenesis, but late meteoric diagenesis with karstification of the whole Plio-Pleistocene succession. This succession is subdivided into four carbonate units (Figure 2; Cornée et al., in press; Vernhet and Conesa, 2012). The “Lower Red Algal Limestones” Unit 1, 50 m thick, consists of recurrent coarseningupward sequences of poor-cemented, red algal calcarenites and well-cemented, red algal-molluscan calcarenites to calcirudites. In the eastern part of the island, only the 10 m thick upper section crops out, with chalky, planktonic-rich calcarenites. A few metre thick volcano-sedimentary level erodes the top of the whole unit (Garabé, 1983). The "Upper Red Algal Limestones" Unit 2 thickens eastward from 15 to 25 m. It contains red algal sequences like Unit 1 and additional, thick lamellar *Montastraea* corals. In the eastern part of the island, the unit shows trough cross-bedded, foraminiferal, bioclastic calcarenites and calcirudites. The "Lower Coral Limestones" Unit 3 thickens eastward from 10 to 20 m. Coral assemblages consist of thin-lamellar *Agaricia,* lamellar to massive *Montastraea* and *Diploria*, and thin lamellar and branching *Porites.* Corals occur in the form of scattered colonies in bioclastic calcarenites, coral breccia or buildups. The unit is topped and locally incised down to a depth of 15 m by an erosional surface, as in the Delair quarry (Cornée et al., in press). The "Upper Coral Limestones" Unit 4, 25 m thick, is composed of bioclastic calcarenites and buildups with predominant *Acropora* and common *Montastraea,* and *Diploria*.

Material and Method

Two portable tools of the brands "Pundit7" and "Boviar", based on the ultrasonic-pulse method, were used on rocks to generate and record P-waves propagation between two electrodes. Different carbonate facies representative of the Plio-Pleistocene succession of Grande Terre Island were selected (Figure 1): (1) planktonic foraminiferal limestones, (2) bioclastic limestones, (3) rhodolitic limestones, (4) *Agaricia* micritic limestones, (5) *Porites* limestones, (6) *Porites-Montastraea limestones*, and (7) *Acropora* limestones. Each facies was sampled for thin section analysis, helium porosity analysis, and P-waves propagation measurements in the laboratory. P-waves propagation was also measured in the field, along 2D metre square grids, traced on outcrops with a 10 cm-long average step. Special attention was devoted to coral facies anisotropy. Thus P-waves propagation measurements with one cm-long step along parallel sliced sections were conducted on a 10 cm-sized sample of *Acropora* limestone. All the measurements were compared to petrography (grains, cements, and pores), internal spatial organisation of biological components, peculiarly rhodolites and corals with red algal crusts, and sedimentary environments. Multivariate analyses (components analyses and cluster analyses) and the geo-modeller gOcad software were used for the coral sample in order to relate selected P-waves parameters (amplitude, time) to the coral frame.

Results

Using P-wave velocity measurements and wave amplitude analyses, we demonstrate a relationship between petrophysical properties, petrography, and facies distribution according to environmental setting (Figure 3). We also visualized and discriminated from the sediment matrix the spatial distribution of biological components such as corals, red algal crusts, and rhodolites (Figure 4). Nevertheless, P-wave measurements in the field will need a better resolution than 10 cm to get in precision. Both porosity and cementation types act on the P-waves velocity and amplitude. The lowest values of P-wave velocity and related amplitude occur either in dissolved corals or in micritic facies, including basinal planktonic facies and *Agaricia* micritic facies of inner platform setting. The highest P-waves velocity and amplitude values characterize the platform facies of predominant packstone-grainstone texture "red algal limestones", "bioclastic limestones", and "mud-poor coral limestones" characterised by *Porites*, *Montastraea*, or A*cropora* colonies; in these facies cementation tends to seal intergranular and skeletal porosities. The mud-poor coral limestones exhibit the highest values despite high moldic macroporosity of the coral colonies as waves propagation follows the well-cemented sediment matrix. Thus, for Pliocene to Pleistocene carbonate of Grande Terre

Island the P-wave velocities and related amplitudes are driven by cementation, abundance in micrite content, and selective dissolution.

Conclusion

This petrophysical study is a preliminary approach in estimating initial sedimentary fabric of Cenozoic carbonate rock reservoirs and their diagenetic transformation, using electronic pulse method. Resolution of the P-wave analysis needs to be improved for a better visualization of the petrographical and petrophysical properties. A scale change from metres to hundreds of metres will be investigated in order to extend the study to sedimentary bodies and to compare the result to seismic data. Coral assemblages and building patterns of Grande Terre Island appear of major interest in this study as they are common in the Caribbean region within Pliocene-Pleistocene series, and some of them are widespread in the word, such as *Porites*.

Selected References

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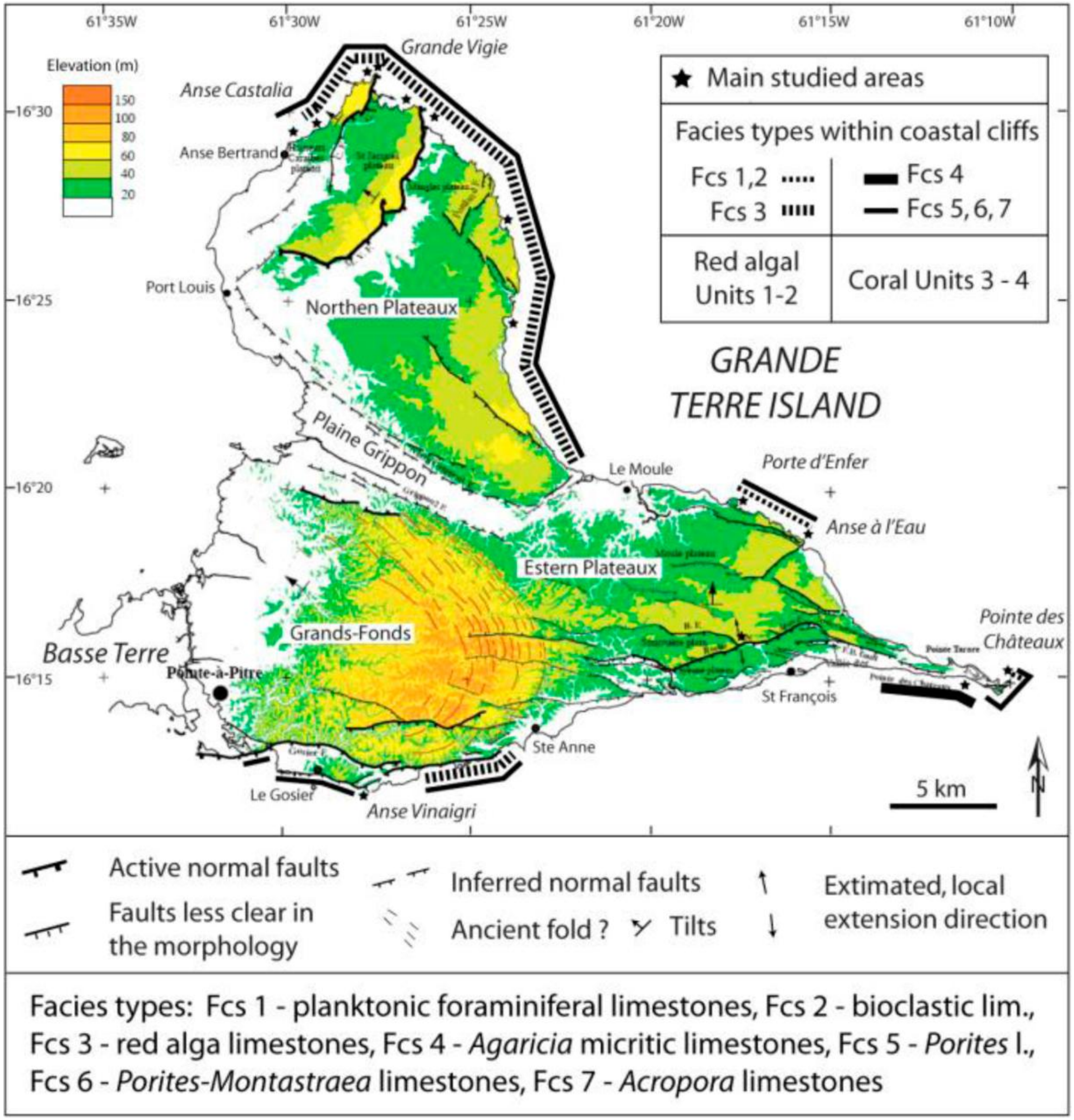


Figure 1. Spatial repartition of Plio-Pleistocene carbonate facies along sea cliffs. Structural map of Feuillet, et al., 2001.

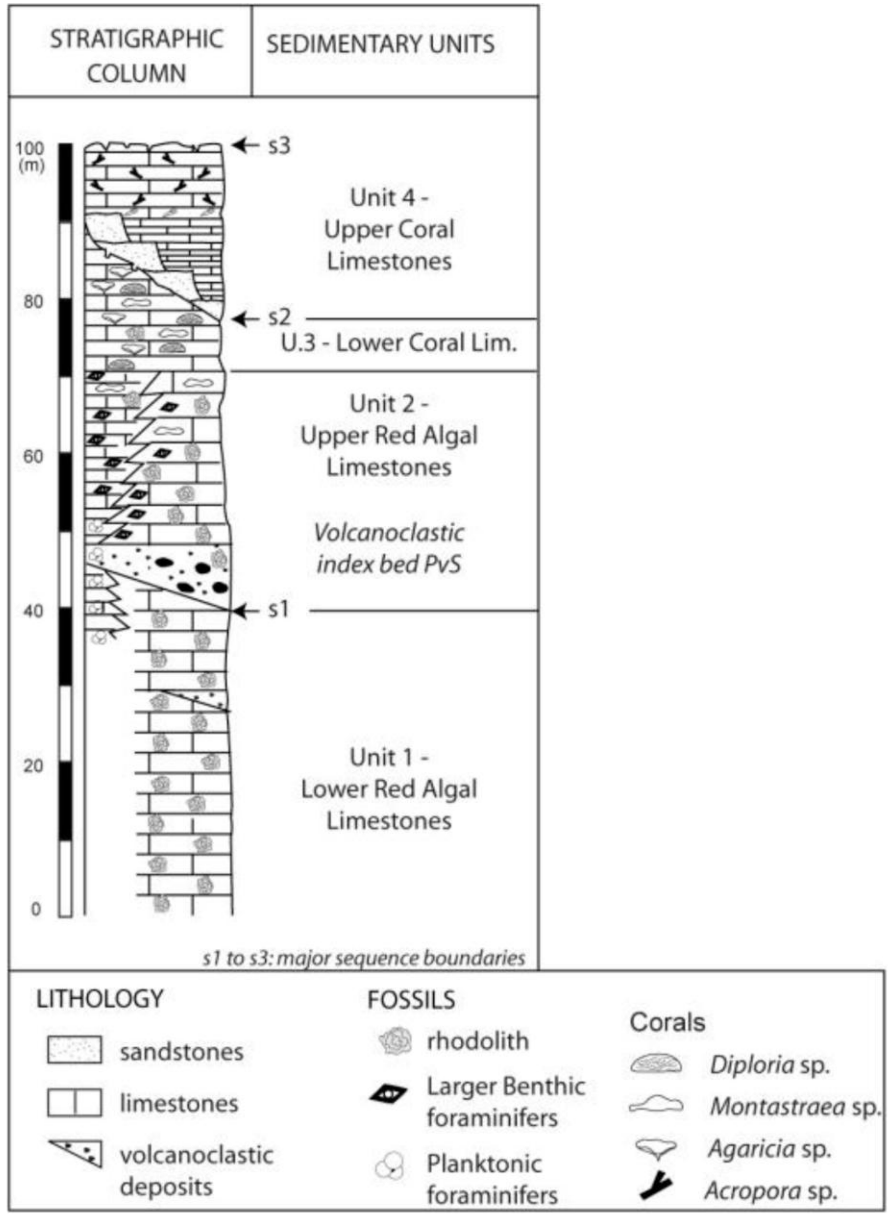
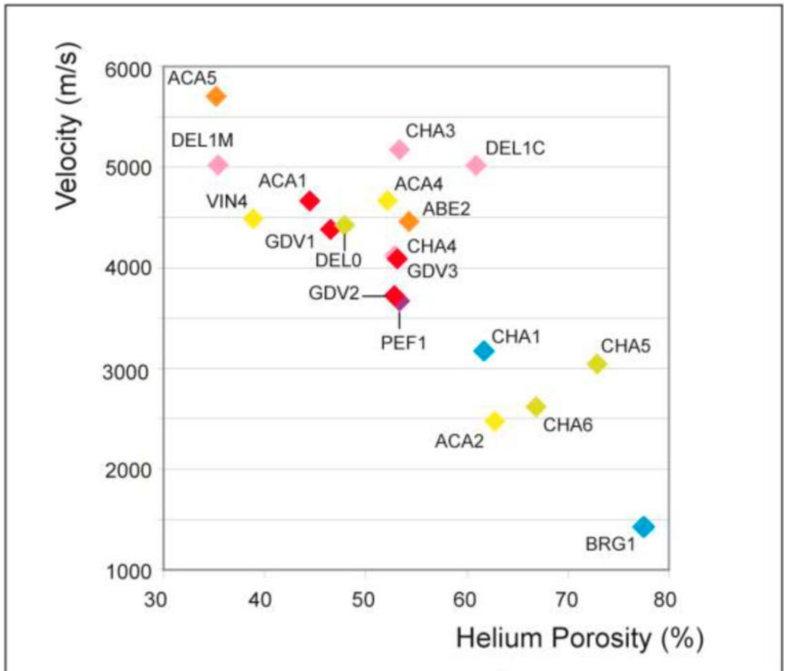


Figure 2. Plio-Early Pleistocene stratigraphic column of Grande Terre (modified from Garabbé, 1983; Léticée et al., 2005).



Sedimentary facies	Sedimentary Units
Fcs 1 - planktonic foraminiferal lim.	U2 - Upper red algal Limestones
Fcs 2 - planktonic bioclastic lim.	
Fc3 - Red algal limestones.	
Fcs 4 - *Agaricia* micritic lim.	U3 - Lower coral Limestones
Fcs 5 - *Porites* limestones	
Fcs 6 - *Porites-Montastraea* lim.	
Fcs 7 - *Acropora* limestones	U4 - Upper coral L.

Figure 3. Direct P-Waves velocity (m/s) versus helium porosity (%) measured on representative samples of the main sedimentary facies of the Plio-Pleistocene of Grande Terre.

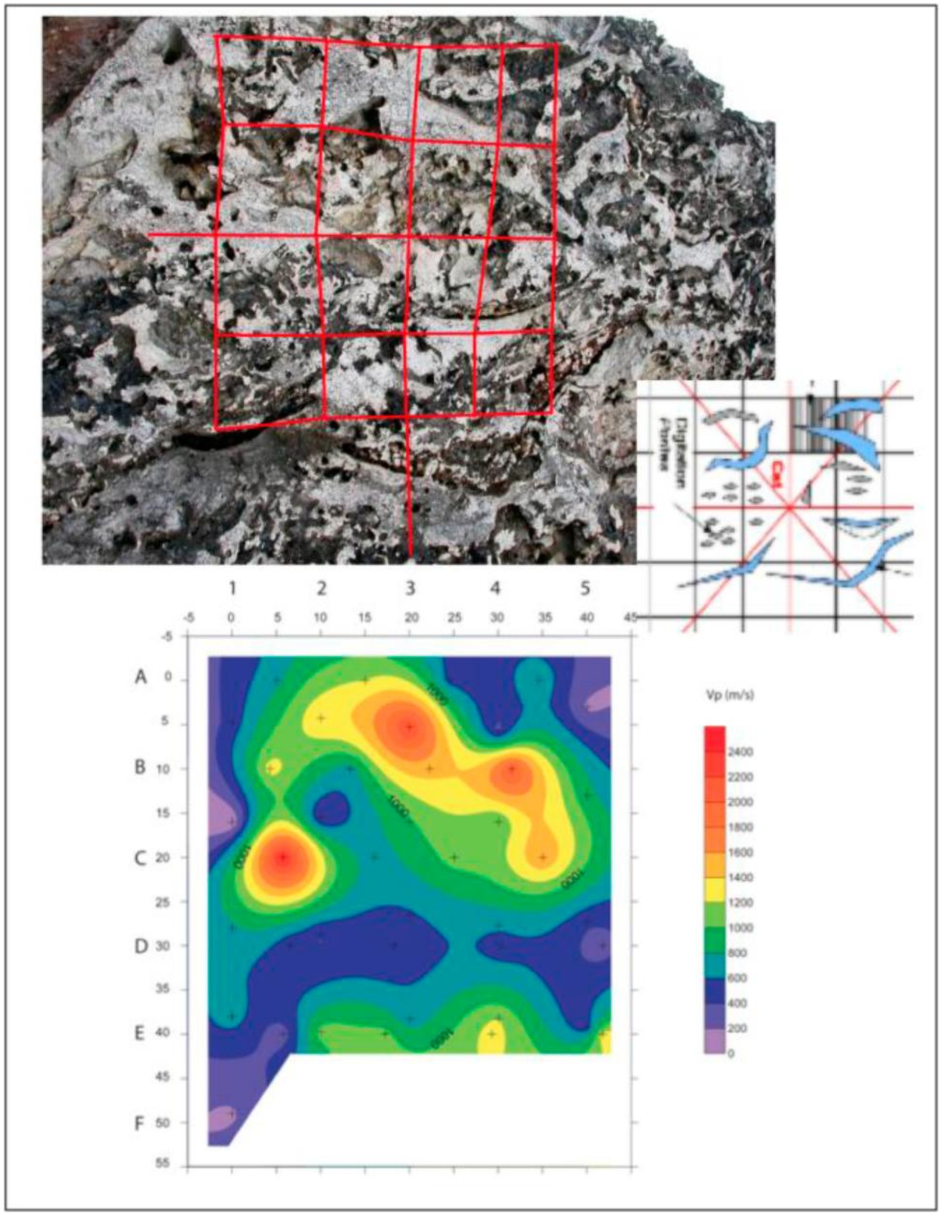


Figure 4. Interpoled map of indirect P-Waves velocity (m/s) measured along a 40 cm square grid traced on a *Montastraea-Porites* coral limestone. The lowest velocities in blue color coincide with the incurved lamellar *Montastraea* colonies, the highest ones in red with the cemented matrix.