High-Resolution 3D Stratigraphic Modeling: From Digital Outcrop Modeling to Carbonate Sedimentary System Characterization - Example of the Gresse-En-Vercors Lower Cretaceous Carbonate Platform (South-East France)*

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Abstract

Typical ancient carbonates reservoirs are characterized by imbricated stratigraphic architecture and facies at various spatial dimensions, thus resulting in a wide range of heterogeneities at different scales. More specifically, the accurate characterization of the spatial relationships between stratigraphic architecture, sedimentary geometries and facies is fundamental to understand the parameters and processes registered in these carbonate systems, and to predict sub-surface rock properties repartition and the flow-units connectivity. This is also critical for 3D modeling of hydrocarbon carbonate reservoirs properties.

A possible large part of the misconception of ancient carbonates is rooted in the difficulty to obtain high-resolution data set over carbonate systems (modern and ancient) that typically cover areas of at least several hundreds of km^2. Platform-to-basin transition or ramp that form gentle slope over several kilometers - and are associated to various facies mosaic - can propagate through time in complex prograding systems with. Such strata forms are very critical in sub-surface as they can result in non-layer cake reservoir architecture more challenging to predict and model. On outcrop models, such carbonate systems are characterized by high resolution (cm-dm) and low uncertainty in the “vertical” direction (perpendicular to strata) and variable (low-high) resolution and uncertainty in the “lateral” directions (conform to strata). This is the consequence of the poor horizontal continuity of outcrops compared to the great lateral dimensions of the platform systems. In this case, the spatial gap is filled by stratigraphic interpolation and correlation between observations that is not constrained by data. Concepts and knowledge used in this correlation process are based on recent carbonate depositional environments, seismic or outcrop analogue.

Introduction

The aim of this study is to realize a high-resolution 3D stratigraphic model of a lower Cretaceous carbonate platform from a continuous cliff of 500 m high and 20 km long in the Vercors, SE France. One of the main purposes is to quantify the geometry of the abundant clinoforms located at the transition between the Urgonian platform and the Vocontian basin. This study integrates a traditional outcrop stratigraphic and sedimentological correlation of distant logged sections combined with stratigraphic interpretations and interpolation from high-resolution numerical support obtained from helicopter LIDAR survey (LIght Detection And Ranging survey) on the Gresse-en-Vercors cliff (Figure 1). This particular carbonate outcrop is an analogue to Middle East carbonate reservoir and consists in a continuous seismic scale object with a large spectrum of facies (from shallow platform carbonate to slope deposits) and a Barremian age (Richet et al., 2011). The study addresses specifically the regional implications about the Vercors carbonate platform development during the early Barremian.

Discussion

Fieldwork and field data provide the fundamental stratigraphical and sedimentological framework; new numerical tools and digital dataset give us an indirect access to previously inaccessible parts of the outcrop. They allow the integration and the visualization of outcrop observations in 3D virtual space, avoiding the classical distortion due to the projection of 3D geobodies (surface and volume) on 2D flat surface (Viseur et al., 2007).

The working method was divided in three steps. The first step consisted of 1) environmental interpretation based on bedding pattern and macro-facies/micro-facies (fauna, microfauna and lithology) analysis; and 2) a sequence stratigraphic interpretation with a special focus on the identification of discontinuity surfaces with a significant stratigraphic correlation potential and critical environmental meaning and sequence correlation over the study area.

The second step consist of 1) high-resolution stratigraphic mapping on the digital data (using the Solid Image technique i.e. an image analysis applied to helicopters high-resolution ortho-photographs; Bornaz and Dequal, 2004) and accurate correlations of the mapped stratigraphic lines, and, 2) a 3D facies digital mapping by photo-interpretation on the high-resolution helicopter ortho-photograph. This interpretation is calibrated with the field observation, precisely located on the high-resolution DEM, and established stratigraphic architecture (Richet et al., 2011). The resulting digital outcrop model (DOM) – i.e. a high-resolution DEM on which georeferenced geological data of variable resolution are posted - is used to generate and visualize a coherent model of the apparent outcrop geology (Figure 2).

The volumic model was constructed in the third step, with the aim of integrating the facies geological attributes within the 3D space, populated from the DOM previously established. 3D stratigraphic grids are created using the Gocad integrated workflow (Figure 3). The realization of a 3D stratigraphic model allows the quantification and the interpretation of critical parameters of this carbonate platform-basin system (size, shape, orientation and sediment composition) in terms of paleo-sea bottom topography, facies partitioning and geometry of geobodies such as clinoforms, particularly well exposed in this cliff.

Conclusions

This accurate 3D model provides a suitable tool to test forward modeling software, and allows capturing statistical information about facies repartition and lateral extend in 3D. 3D modeling is also very critical for sequence stratigraphic characterization in comparison to 2D modeling: this work have shown that apparent low stand wedge or distal onlapping lobes in 2D appeared to belong in 3D to prograding high stand system in different directions. This is typical of non-cylindrical platform-slope transition system where the depositional lobes can diverge or converge by lateral stacking during a single high stand.

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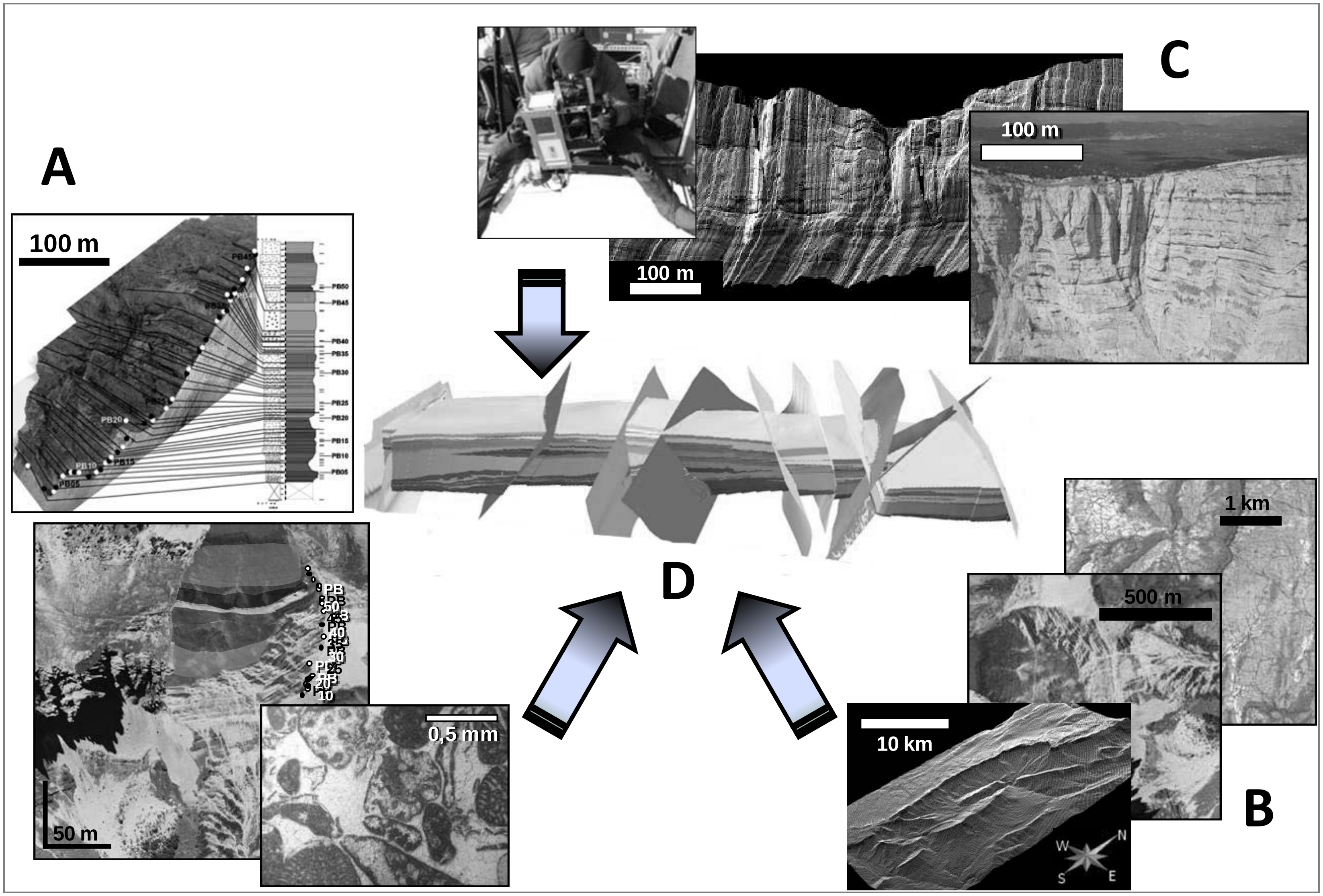

Figure 1. Overview of the datasets acquired and used to create the 3D volumetric model of the Vercors platform margin (D). (A) part of this figure show traditional field observation (facies mapping, logged sections, sampling); every observation were reported and linked on several field photograph support at different scales and resolution. (B) Part correspond to the low-resolution dataset (IGN data) used for this study; classic topographic map; orthorectified aerial photograph (pixel resolution = 50 cm^2); publicly available DEM (regular points spacing = 50 m). (C) Part show the high-resolution dataset acquired for this study; high-resolution georeferenced photograph (pixel resolution = 10 cm^2) and Lidar data (42*10^6 point, point density average = 10/ m^2). Booth the Lidar data and the photograph were captured by helicopter survey.

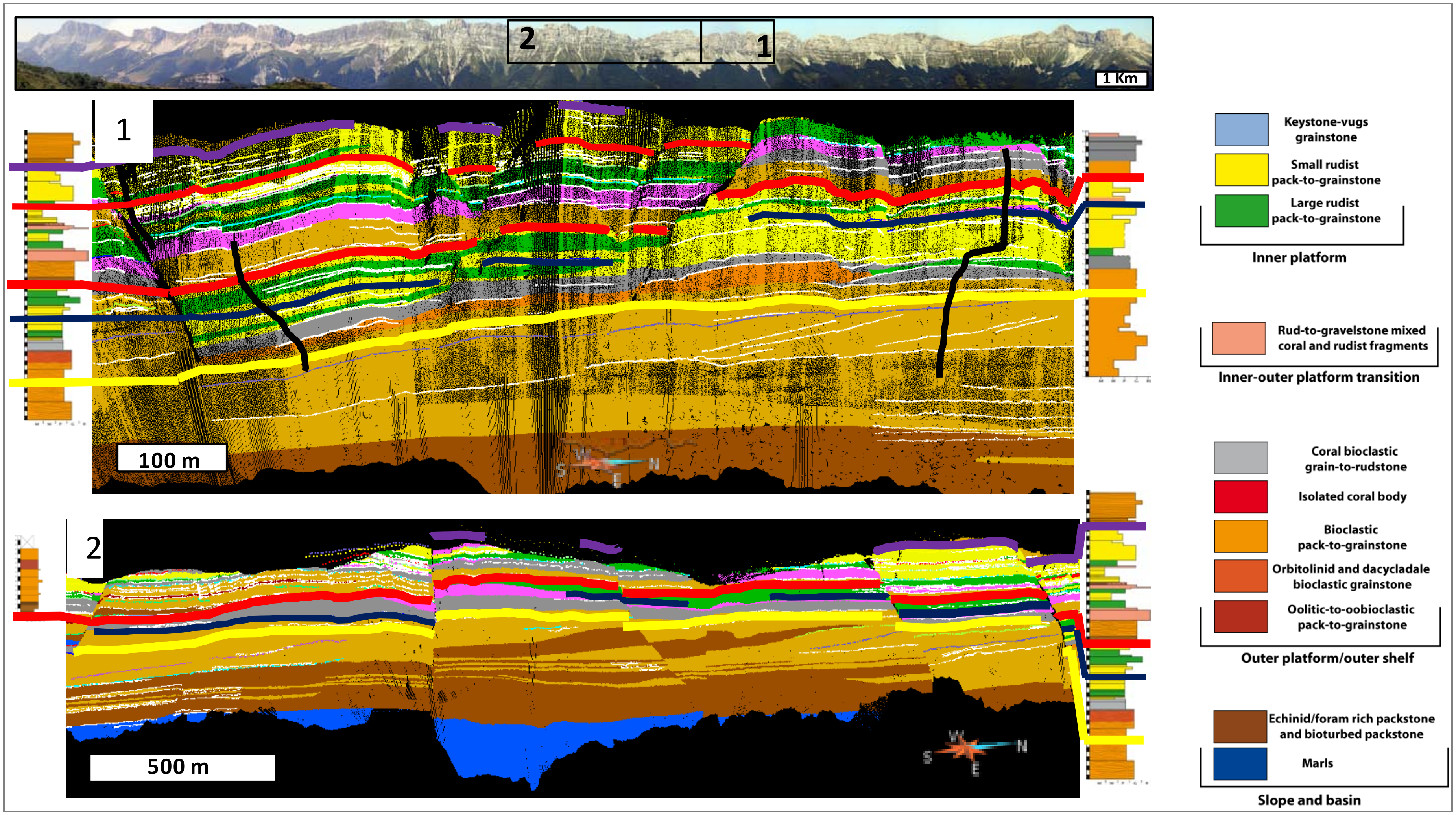

Figure 2. Examples of the resulting 3D facies mapping and interpolation on the high-resolution DOM obtained from LIDAR.

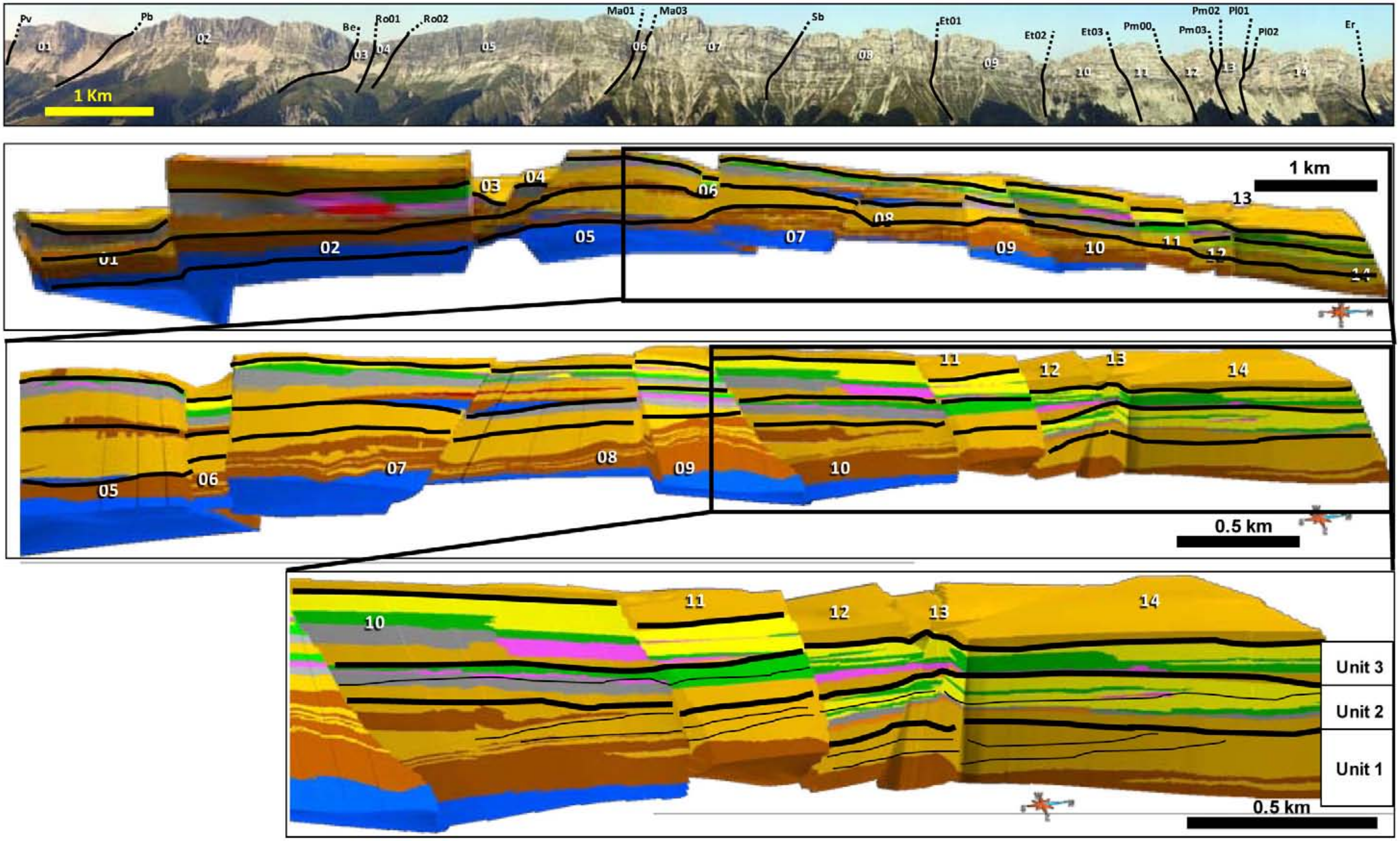

Figure 3. General view and details of the Gresse-en-Vercors cliff and 3D facies model in the present day structural situation (scale = 1x1). Color code is given in Figure 2.