Marine and Petroleum Geology 76 (2016) 329–343

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Evaluation of pinnacle reef distribution at shallow subsurface using integrated geophysical methods: A case study from the upper Kimmeridgian (Spain)

Ó. Pueyo Anchuela [a,*], G. San Miguel [b], B. Bádenas [a], M. Aurell [a]

[a] Departamento de Ciencia de la Tierra, Universidad de Zaragoza, C/Pedro Cerbuna 12, 50009 Zaragoza, Spain
[b] Total E&P, Technology Centre, CSTJF, Avenue Larribau, 64018 Pau Cedex, France

ARTICLE INFO

Article history:
Received 21 January 2016
Received in revised form
27 April 2016
Accepted 20 May 2016
Available online 24 May 2016

Keywords:
Magnetometry
Electromagnetic multifrequency
Ground-penetrating radar
Shallow-marine carbonates
Pinnacle reefs
Kimmeridgian
Iberian chain

ABSTRACT

The well exposed outcrops of the upper Kimmeridgian shallow-marine carbonates at Jabaloyas (Iberian Chain, NE Spain) permit the evaluation of geophysical methods for the identification of sedimentary facies. Direct measurement of magnetic susceptibility in facies and detailed grids of magnetometry, electromagnetic multifrequency and ground-penetrating radar (50–500 MHz antennas) have been performed in two study areas where the upper Kimmeridgian rocks are nearly horizontal. Magnetometry indicates negative anomalies in residual magnetic field and vertical magnetic gradient related to reef pinnacles and faults. Electromagnetic data reveal that positive anomalies of apparent conductivity correlate with non-reefal facies. The areal distribution of magnetometry and EM data does not permit the unequivocal identification of pinnacles and faults at the studied area. By contrast, ground penetrating radar profiles and maps of relative reflectivity in two way travel time slices are useful for the identification of faults (hyperbolic anomalies) and reefal and non-reefal facies (radar facies A and B, respectively). The integration of geophysical data, mainly ground penetrating radar, has permitted the 3D reconstruction of reef pinnacles and its tectonic framework.

1. Introduction

Limited well data and low resolution of seismic surveys are often the origin of uncertainties at subsurface at different phases in the hydrocarbon field analysis. Modern and ancient sedimentary models facilitate the understanding of sedimentological data, being crucial to better define reservoir heterogeneities (e.g. Asprion and Aigner, 2000; Mancini et al., 2004; Borgomano et al., 2008). These models provide for multi-scale sedimentary heterogeneities that together with diagenetic porosity-enhancing processes can predict the permeability distribution (van Koppen et al., 2015).

The well exposed outcrops of the Upper Jurassic at Jabaloyas in the Sierra de Albarracín (Iberian Chain, NE Spain; Fig. 1a) allow identification of the detailed facies architecture of the upper Kimmeridgian shallow-marine pinnacle reefs and related non-reefal facies which are potential outcrop analogue of carbonate reservoirs in the Middle East and Gulf of Mexico (Mancini et al., 2004; Bádenas and Aurell, 2010; Alnazghah et al., 2013; Pomar et al., 2015; San Miguel et al., 2013). Well exposed outcrop conditions of the Kimmeridgian rocks, especially in the Jabaloyas area, also provide the opportunity for integrated sedimentary and geophysical analyses, including ground-penetrating radar, to evaluate the presence of geophysical contrasts between sedimentological facies.

The application of ground-penetrating radar (GPR) in the characterization of carbonate rocks has been especially focused on tufa deposits (Pedley, 1993; Hill et al., 1998: Brusi et al., 1998; Pedley et al., 2000; Pedley and Hill, 2003; Pedley, 2009; McBride et al., 2012), but also on shallow-marine carbonates (e.g. Pratt and Miall, 1993; Sigurdsson and Overgaard, 1998; Dagallier et al., 2000; Grasmueck and Weger, 2002: Asprion et al., 2009; Jorry and Biévrem, 2011), some of them including carbonate buildups (Asprion and Aigner, 2000; Mukherjee et al., 2012; Nielsen et al., 2004). These works have showed the high resolution of GPR analyses to evaluate the architecture of carbonate rocks, especially for those formed in highly heterogeneous shallow environments where lateral facies changes are usually present. In addition, the

* Corresponding author.
E-mail addresses: opueyo@unizar.es (Ó. Pueyo Anchuela), galo.sanmiguel@total.com (G. San Miguel), bbadenas@unizar.es (B. Bádenas), maurell@unizar.es (M. Aurell).

http://dx.doi.org/10.1016/j.marpetgeo.2016.05.027
0264-8172/

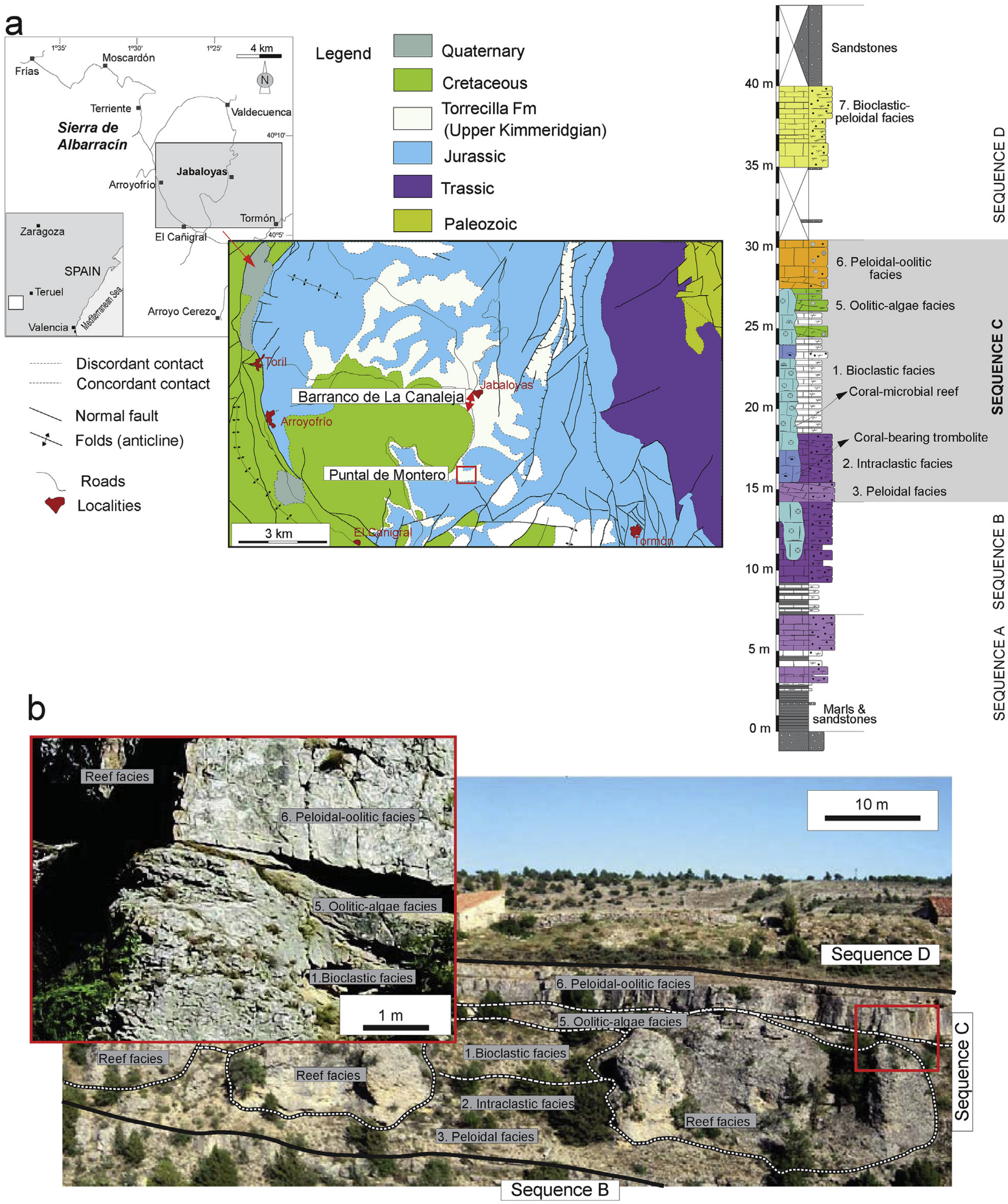

Fig. 1. (a) Geological map and location of the upper Kimmeridgian rocks in the two studied sectors, Barranco de la Canaleja and Puntal del Montero, close to Jabaloyas (Teruel province, NE Spain) A simplified log of the geological series from the studied zone is included. (b) Overview of the reef pinnacles and related non-reefal facies in the cliff of Barranco de la Canaleja close to Jabaloyas. These facies belongs to a deepening-shallowing high-order sequence (sequence C in Aurell and Bádenas, 2004; Bádenas and Aurell, 2010; San Miguel et al., 2013). Inset a detail from the facies changes in the upper part of the reefs is included.

combined analysis of GPR analysis and diagenetic and tectonic structures can be suitable for deciphering controls on porosity systems and lateral changes of permeability. Good results have been obtained in the evaluation of carbonate rocks, especially where changes in porosity and internal structure between reefal and related non-reefal facies are present (e.g. Asprion and Aigner, 2000; Mukherjee et al., 2012). GPR quantitative characterization in outcropping sedimentological units is also a future promising field (e.g. Grasmueck et al., 2005; Takayama et al., 2008: Forte et al., 2012).