Marine and Petroleum Geology 81 (2017) 169–195

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Research paper

Linking early diagenesis and sedimentary facies to sequence stratigraphy on a prograding oolitic wedge: The Bathonian of western France (Aquitaine Basin)

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ARTICLE INFO

Article history:
Received 15 September 2016
Received in revised form
22 November 2016
Accepted 10 January 2017
Available online 11 January 2017

Keywords:
Infralittoral prograding oolitic wedge
Carbonate platform
Depositional model
Early diagenesis
Facies
Sequence stratigraphy
Jurassic

ABSTRACT

To improve the understanding of the distribution of reservoir properties along carbonate platform margins, the connection between facies, sequence stratigraphy, and early diagenesis of discontinuities along the Bathonian prograding oolitic wedge of the northeastern Aquitaine platform was investigated. Eight facies are distributed along a 50 km-outcropping transect in (1) toe-of-slope, (2) infralittoral prograding oolitic wedge, (3) platform margin (shoal), (4) open marine platform interior, (5) foreshore, and (6) terrestrial settings. The transition from shallow platform to toe-of-slope facies is marked in the field by clinoforms hundred of meters long. Carbonate production was confined to the shallow platform but carbonates were exported basinward toward the breakpoint where they cascaded down a 20–25° slope. Ooid to intraclast grainstones to rudstones pass into alternating marl-limestone deposits at an estimated paleodepth of 40–75 m. Three sea-level falls of about 10 m caused the formation of discontinuities corresponding to sequence boundaries. Along these discontinuities, erosional marine hardgrounds formed in a high-hydrodynamic environment at a water depth of less than 10 m, displaying isopachous fibrous cements and meniscus-type cements. The cements pass landward into meniscus and microstalactitic forms along the same discontinuities, which are characteristic of subaerial exposure. During the deposition of transgressive systems tracts, carbonate accumulation remained located mostly on the shallow platform. Energy level increased and carbonates were exported during the deposition of highstand systems tracts forming the infralittoral prograding oolitic wedge. During the deposition of lowstand systems tracts, carbonate production fell to near zero and intraclast strata, derived from the erosion of hardgrounds on the shallow platform, prograded basinward. Early diagenetic cements are related exclusively to discontinuities that are not found within the prograding wedge because of the continuous high sedimentation rate under lower hydrodynamic conditions. This absence of early cementation within the infralittoral prograding oolitic wedge was conducive to porosity conservation, making such features good targets for carbonate reservoir exploration. This study proposes a novel sequence stratigraphy model for oolitic platform wedges, including facies and early diagenesis features.

1. Introduction

Numerous studies undertaken since the early 2000s have shown the infralittoral prograding wedge (ILPW) model to be useful for understanding depositional processes on many Mesozoic to Cenozoic carbonate platform edges (e.g. Pomar et al., 2015; Pomar and Haq, 2016). The ILPW model describes a progradational platform-margin slope with elongated wedges formed by the export of sediments from the shallow platform to the toe-of-slope area, within which topsets, foresets, and bottomsets can be recognized (Hernández-Molina et al., 2000; Pomar et al., 2015). Studies have been conducted to constrain ILPW dynamics within a sequence stratigraphic framework (Pomar and Tropeano, 2001; Mateu-Vicens et al., 2008; Pierre et al., 2010; Amour et al., 2013) but the relationship between sequence stratigraphy and early diagenesis in platform margins has come in for less study and is not fully understood (e.g. Loreau and Durlet, 1999; Morad et al., 2012; Coffey, 2012). Nevertheless, this relationship is of major relevance

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http://dx.doi.org/10.1016/j.marpetgeo.2017.01.005
0264-8172/

in predicting the spatial and temporal distribution of reservoir properties (Morad et al., 2000; Moore, 2004; Caron et al., 2005).

Discontinuities are widely used to constrain sequence stratigraphy models and then for correlation at basin scale and beyond (Durlet and Loreau, 1996; Loreau and Durlet, 1999; Christ et al., 2015). However, the lateral changes in discontinuities and the factors controlling their formation (eustasy, tectonics, sedimentation rate, environmental conditions) are old problems that are still not fully understood despite recent studies (Christ et al., 2012, 2015; Hamon et al., 2016). Marine hardgrounds generally developed above the fair-weather wave-base under high hydrodynamic conditions, but it is difficult to define the precise paleobathymetry of their formation (Christ et al., 2012, 2015). Moreover, examples of hardgrounds forming in upper offshore environments and related to storm-induced waves and currents are also documented (Kennedy and Juignet, 1974; Kennedy and Garrison, 1975; Kim and Lee, 1996; Lasseur et al., 2009; Reolid et al., 2010). Early diagenesis is sensitive to relative sea-level changes and displays high variability along sequence boundaries (subaerial exposure, erosional or non-erosional marine hardground, firmground, etc.) and between different systems tracts (Caron et al., 2012; Morad et al., 2012; Ritter and Goldstein, 2012). This variability as well as the formation and lateral evolution of discontinuities needs to be better constrained via new sequence stratigraphy models combining facies analyses, discontinuity characterization, and early diagenesis.

A shallow wave-dominated to tidally-influenced carbonate platform margin surrounded by offshore environments developed in the northeastern Aquitaine Basin during the Bathonian. It featured various environments ranging from terrestrial to toe-of-slope, whose detailed architecture can be studied from numerous high quality outcrops in quarries and boreholes (Foucher, 1986). The biostratigraphic framework is ascertained from brachiopod, ammonite, foraminifer, and ostracod fauna at the sub-stage scale (Foucher, 1986).

The objective of this work is (1) to propose a dynamic depositional model within a sequence stratigraphic framework for the northeastern Aquitaine Bathonian platform (50 km-long cross-section), locating and describing the different facies (including their sedimentological and diagenetic features) and surfaces (subaerial exposure, hardgrounds, etc.), and (2) to define the lateral evolution of early diagenetic processes across the platform. The facies are described and classified in such a way as to identify their depositional and eogenetic environments. A paragenetic sequence is proposed, and the diagenetic changes within the various facies are compared.

2. Palaeogeographic and stratigraphic setting

The Aquitaine Basin is an intracontinental basin in southwestern France where Triassic to Quaternary sedimentary cover overlies the crystalline Variscan basement (Biteau et al., 2006). The study area lies in the northeastern part of this basin, close to Angoulême (Fig. 1A–B). From Bajocian to Callovian times, western France formed a shallow epicontinental sea at subtropical latitudes (20–30°N) bordered to the northwest by the Armorican Massif and to the east by the present-day Massif Central, which was probably a paleohigh covered by shallow marine deposits (Fig. 2A; Ziegler, 1988; Thierry and Barrier, 2000). The sediments are predominantly shallow marine carbonates deposited on a vast platform, which was open to the Atlantic, Tethys, and Artic oceans (Fig. 2A; Enay and Mangold, 1980; Thierry and Barrier, 2000). The northern Aquitaine platform is separated into a shallow carbonate platform area southeastward and a deeper platform with offshore carbonate to clayey deposits toward the north and west (Fig. 2B; Foucher, 1986). In the study area, the environments vary from terrestrial southeastward to platform interior (foreshore, open marine), platform margin (shoal), platform slope (infralittoral prograding wedge) and then toe-of-slope northwestward (Fig. 2C; Foucher, 1986). In the study area the strike of the shallow platform edge resembles a capital gamma (Γ) (Fig. 2C; Foucher, 1986).

Foucher (1986) studied the ammonite, brachiopod, and foraminifera fauna of the Middle Jurassic outcrops and boreholes of the northeastern Aquitaine platform and defined a reliable lithostratigraphic framework for the Bathonian to the mid Callovian (Fig. 3).

The Bajocian deposits in the southeast of the study area are lagoonal dolomite and dolomitic limestones (*Dolomies de Montbron* Formation) overlain by shallow platform granular ooid facies (*Calcaires de Combe Brune*, *Calcaires de Vilhonneur* and *Calcaires de Saint-Martial* Formations; Fig. 3). These proximal deposits pass laterally northwestward into offshore mudstone to wackestone alternating with marly layers (*Calcaires de Nanteuil-en-Vallée* Formation). The thickness of the Bathonian units, in the proximal as in the distal domains, is about 50 m. The base of the *Calcaires de Saint Martial* Formation is dated as early Bajocian (*Sonninia propiquans* to *Stephanoceras humphriesianum* Zones) by the brachiopod *Parvirhynchia parvula* and the top of the *Calcaires de Nanteuil-en-Vallée* Formation is dated to the *Parkinsonia parkinsoni* Zone of the late Bajocian by the ammonite *Parkinsonia* sp (Fig. 3; Alméras and Lathuilière, 1984; Foucher, 1986; Fauré et al., 2015). The Bathonian/Callovian boundary represents an exposure surface located on top of the *Calcaires de Saint-Martial*, *Calcaires de Vilhonneur*, and *Calcaires de Combe Brune* Formations, which are dated by ostracods (*Fabanella bathonica*) and brachiopods (*Burmirhynchia semiglobosa*, mid to late Bathonian; *Burmirhynchia thierachensis* and *Burmirhynchia elegantula*, late Bathonian; Fig. 3; Foucher, 1986; Garcia et al., 1996). A specimen of *Trocholina gigantea* has been found at the top of the *Calcaires de Combe Brune* Formation. These proximal deposits pass northwestward into mudstone to wackestone alternating with marly layers (*Calcaires de la Rochefoucault* Formation; Fig. 3; Foucher, 1986). The early Callovian is characterized by a sedimentary hiatus above the *Calcaires de Combe Brune* and the *Calcaires de Vilhonneur* Formations. The base of the *Calcaires crayeux de Montbron* Formation, which is made up of lagoonal mudstones to wackestones, is dated as mid Callovian by the brachiopod *Aulcacothyris pala* (Fig. 3; Foucher, 1986; Garcia et al., 1996). Northwestward, the Callovian deposits are distal clayey limestones dated at their base from the *Macrocephalites macrocephalus* Zone (early Callovian) by the ammonite *Macrocephalitidae* (Fig. 3; Foucher, 1986).

3. Material and methods

3.1. Sedimentology

This study is based on the detailed examination of five outcrop sections (Combe Brune, Vilhonneur, Cosses Noires, Chez Trape and Javerlhac) between La Rochefoucault and Nontron supplemented by previous descriptions of three outcrop sections (one around Saint-Sauveur and two around Saint-Martial) and one borehole (Montignac; Foucher, 1986, Fig. 2). The transect extends for 50 km from Montignac in the northwest to Nontron in the southeast. The outcrop sections were logged in detail: lithology, texture, allochem content, and sedimentary structures have all been characterized. Facies were determined on the basis of visual characterization of components (skeletal and non-skeletal grains), textures, sedimentary structures, sorting, and grain size on 37 thin-sections. The porosity types grain contacts, and cements of each facies were analyzed. Porosity was computed for granular grainstone facies with Jmicrovision software by measuring the blue proportion (color of the resin injected into the porosity) on the 37 thin-section scans.