A sedimentological model of the Callovian oolite reservoir of the Villeperdue oil field, Paris Basin (France)

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ABSTRACT: The Villeperdue oil field is a composite stratigraphic and structural trap. The study focuses on the stratigraphic control, i.e. the relationship between stratigraphy and sedimentology, and a sedimentological model constrained by core data, outcrop analogues, and thorough petrographic analyses. The Callovian oolite limestones are subdivided into three stratigraphic units each with its own oolitic shoal facies; the upper two units form two separate complex reservoirs with porosity zones which are hard to correlate though they are probably interconnected.

KEYWORDS: Dogger, ooid, early lithification, parasequence

INTRODUCTION
The Villeperdue oil field is located 100 km east of Paris. The first well (MT 2) was drilled in 1959 by RAP and tested some oil from the Lower Callovian limestones but was non-commercial at the time. Development activity was resumed by TOTAL and TRITON in 1981. Today, the concession is jointly held by COPAREX and TRITON. With about 100 × 10^6 barrels reserves, it is one of the two largest fields discovered in the Paris Basin, the other being Chaunoy (Fig. 1A). About 150 wells have now been drilled: 120 are producing, and 20 are used for water injection; in recent years, horizontal wells have been interpreted as an isolated oolitic shoal developed on a submerged relative high, surrounded by open-marine depositional environments (Arbin and Euriat 1989; Duval and Arbin 1990; Comité des Techniciens 1991; Coudeyre et al. 1991; Cosse 1993).

The purpose of this paper is to present the sedimentological model which has helped to (re-)define reservoirs and so predict their trends, correctly map them and determine the most favourable orientations for horizontal drilling.

CORE STUDIES
Most of the internal heterogeneities match with sedimentary discontinuities, either hardgrounds or gravel and pebble layers (Fig. 5F). Such hardgrounds, oolite gravels, and oolite pebbles give evidence of early (synsedimentary) lithification; they are commonly bored by pholadids (Fig. 5E), worms (Trypanites) or clionids (Fig. 3H), and encrusted by oysters, bryozoans, serpulids, foraminifers (Nubecularids,...) or algae (Girvanella structures). Hardgrounds, oolite gravels, and oolite pebbles form in the same manner as most of the Jurassic submarine hardgrounds described by Fürsch (1979). Following sedimentation, they result from the complex interplay of bioturbation, cementation (biological and/or chemical), colonization, omission, erosion (biological, chemical and/or mechanical), reworking and burial. One major discontinuity coincides with the top of the 'Dalle Nacree' Formation (Fig. 3A,B). Another is located within the tight zone between R1 and R2 (Fig. 3C).

In addition, core slabs show unidirectional oblique stratification within the oolite facies (Fig. 3G). This is related...

to the occurrence of bioclast, grapestone, or oncoid laminae. Such laminae are cemented due to their high contents of echinoderm remains which commonly show overgrowths. Dual Dipmeter (SHDT) tool and core measurements indicate a general migration trend towards the east-southeast.

OUTCROP ANALOGUE STUDIES

Analogues of the same stratigraphic interval are found in Burgundy, near Dijon (Pierre de Dijon–Corton and Pierre de Ladoix Formations: Laville et al. 1989). Several quarries have been investigated there. The oolite bodies consist of stacked large sand waves (Fig. 4A,B), about one metre thick and with wavelengths of some tens of metres (Laville et al. 1989). Oblique stratification is easy to identify due to weathering (in former distension joints). Such outcrop studies have helped us to understand the geometric pattern of the oolite sand waves and particularly of their bounding (bottom and top) surfaces. Most of the latter correspond to hardgrounds (Purser 1969) (Fig. 4C,D) or to erosional surfaces associated with gravel (Fig. 4E,F) and pebble lag-deposits which may pass laterally from one to the other (Fig. 5A,B). Such discontinuities may also diverge, stack or even cut one another. Therefore, the number of discontinuities observed on vertical sections may vary.

Fig. 1. (A) Location map. Legend: 1 Villeperdue and Chaunoy oil fields; 2 Middle Jurassic outcrops in Burgundy and in the southeastern part of the Paris Basin. (B) Structure map on the top of the Lower Callovian oolite limestones. Depths in metres (after Comité des Techniques 1991).

Fig. 2. (A) An early reservoir correlation of five Villeperdue wells showing two main reservoir zones (R1, R2). The FDC and CNL logs are in reversed displays in order to emphasize reservoir features: the more these curves are separated from the GR the more porous the layer is. (B) Stratigraphic correlations of five Villeperdue wells based on changes in the ooid texture. The result is quite different from the previous, log-based interpretation. (C) Isopach map of the concentric (middle) ooid unit. Thickness in metres. (D) Isopach map of the micritic (upper) ooid unit. (E) Combined isopach map of the middle and upper ooid units.

Fig. 3. ‘Dalle Nacrée’ Formation, Villeperdue oil field. (A) Bored hardground at the top of the R1 reservoir, top of the ‘Dalle Nacrée’ Formation (core slab). Scale bar = 5 cm. (B) As above, close up on a Pholadid boring (thin section). Scale bar = 5 mm. (C) Bored hardground in the tight zone between the R1 and R2 reservoirs (core slab). (D) Discontinuity, i.e. bored and encrusted hardground (core slab), corresponding to the boundary between the concentric ooid unit (below) and the micritic ooid unit (above). (E) Pholadid boring on a hardground (thin section). Scale bar = 5 mm. (F) Bored and encrusted oolite pebbles (core slab). (G) Oblique stratification (core slab). (H) Clionid boring on a hardground (thin section). Scale bar = 1 mm. (I) Close up of a Pholadid boring (thin section) infilled with micritic ooids (same as in Fig. 3D): Discontinuity, i.e. bored and encrusted hardground, corresponding to the boundary between the concentric ooid unit (below) and the micritic ooid unit (above). Scale bar = 5 mm. (J) As above, close up of the border of the Pholadid boring (thin section). Scale bar = 2 mm.
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Legend

1. coral pebbles; 2. oolite pebbles; 3. hardground at top of the 'Comblanchien' limestones; 4. hardgrounds within the oolite facies.

Fig. 5. (A) Hard-grounds, erosional surfaces and gravel or pebble layers observed in the Pierre de Dijon-Corton Formation at the face of Les Buis quarry, North of Ladoix-Serrigny (after C. Gilli, unpublished). Legend: 1, coral pebbles; 2, oolite pebbles; 3, hardground at top of the 'Comblanchien' limestones; 4, hardgrounds within the oolite facies. (B) Field sketches illustrating the lateral relationships between hardgrounds, erosional surfaces and gravel or pebble layers. Legend: 5, ooids; 6, oolite (early lithification); 7, bioclasts; 8, borings.

PETROGRAPHIC ANALYSES OF CORES

Detailed petrographic analyses revealed systematic changes in the ooid texture from the base to the top of the 'Dalle Nacrée' Formation: radial ooids (Fig. 4H), concentric ooids (Fig. 4I) and then micritic ooids (Fig. 4J). At first sight (i.e. if we take a sample every metre), the changes from radial to concentric and from concentric to micritic textures seem to be rather progressive (Fig. 6A). This gradual process is marked within the ooid cortex by a thickness decrease of the radial layers and by an increase of the number of radial and micritic layers. The micritic layers correspond to breaks in the growth of the ooids, often marked by the occurrence of encrusting foraminifera (*Nubecularia reicheli* Rat., *Tolypammina* sp., *Placopsilina* sp., ...): they do not appear in radial ooids, are common in concentric ooids and abundant in micritic ooids. In addition, with respect to ooid structures, hemiooids are common among the radial ooids, rare among the concentric ooids, and absent among the micritic ooids (Granier 1993).

In a similar way to the Purbeck ooids described by Strasser (1986) from the Jura Mountains, all these points can be explained as sedimentary records of the gradual changes in the biological, physical, and chemical states of the environment (Fig. 6A).

DEPOSITIONAL HISTORY

These environmental changes are related to a relative sea-level rise (transgression) which was supposedly continuous, as shown by:

- the lack of evidence of subaerial exposure (except at the top of the underlying 'Comblanchien' muddy facies, i.e. the Upper Bathonian);
- the common occurrence of algae in the 'Comblanchien' facies (the green alga *Coniporella micromera* De Saporta) and in the lower part of the 'Dalle Nacrée' Formation (the green alga *Holosporella siamensis* Pia and the red alga *Permocalculus* sp.);
- the absence of algae in the upper part of this formation,
- the distribution of echinoderm remains (Ferre and Granier, in prep.), etc.

More detailed studies (i.e. if we take a sample every ten centimetres or if we focus on discontinuities) have shown that changes from one ooid texture to another are not gradual. There are at least two main breaks within the sedimentary record (which lead us to define three units). Each of these breaks coincides with a discontinuity (Fig. 3J) corresponding

The changes in the ooid textures are evidence that the relative sea-level rise was not continuous; there were pulses. The upper two units have been mapped, first as a whole (Fig. 2E) then separately (Fig. 2C–D). They show a rapid thinning toward the ESE, i.e. in a downcurrent direction with respect to current directions seen on cores or measured with the Dual Dipmeter (SHDT) tool. This thinning out is interpreted as the distal end of ‘backstepping’ oolitic sandwave complexes. The upper unit often migrates farther downcurrent than the middle unit. At the same time, it appears that they show thickness compensation: the thick trends in the middle unit coincide with the thin trends of the upper one. The limit between the two units is interpreted to represent ‘forestpping’ in an upcurrent direction (Granier 1994); it is ascribed to a rupture of the equilibrium profile possibly related to a positive sea-level pulse.

CONCLUSIONS

The suggested hierarchy of discontinuities based on changes in the ooid texture leads us to subdivide the ‘Dalle Nacrée’ Formation into at least three parasequences (Fig. 6B). As a more practical result, our correlative lines cross-cut some of the reservoir layers based on well logs; this earliest reservoir layering is therefore inconsistent with geological data (Fig. 2B). The two main reservoir units corresponding to the upper two parasequences can be divided into thinner porosity zones. Outcrop analogues suggest that, though these reservoir subunits still remain extremely difficult to correlate, they are probably connected within the same reservoir unit.

I am pleased to acknowledge the contributions of many persons in TOTAL, particularly P. Poulée, G. Goy, C. Gilli, P. Imbert and R. Boichard. Finally, I would like to thank TOTAL (TEP/FEO/TOTALEX), COPAREX, and TRITON FRANCE for their kind permission to publish.

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