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Miocene sedimentary sequences of the Sardinian Graben System as possible analogue for the Upper Jurassic Rogn Formation of the Norwegian Continental Shelf

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1. INTRODUCTION

The Rogn Fm is an Oxfordian to Volgian (Late Jurassic) sand-rich interval recognised in the offshore subsurface of the Norwegian Continental Shelf (Gjelberg et al., 1987, Dalland et al., 1988). In its type well the formation is up to 60 m thick and exhibits a coarsening-upward trend (Provan 1992) (Fig. 1). The Rogn Fm, which has found encased in shelf fines or adjacent to the flanks of structural highs, consists of well-sorted coarse-grained sandstones, made up of sub-angular clasts, diffusely cross laminated, and also including siltstones and shales (e.g., Elliott et al., 2015) (Fig. 1). The Rogn Fm has become even more renowned thanks to its good reservoir properties (P=29%; K=8 Darcy; N/G=0.7) and because it provided promising oil discoveries in the last twenty years.

The more accepted interpretation on the depositional genesis of the Rogn Fm is the derivation from the erosion of several hundred of meters of pre-Permian to Upper Jurassic successions from the uplifted Frøya High, and the subsequent accumulation in sheltered coastal zones and/or in more distal 'shelf' environments, tectonically shaped into narrow-elongate depocenters (Provan 1992). The recurrent motif of cross-bedding observable in the Rogn sandstones point out towards a general control exerted by tractional flows, whose strength was possibly influenced by lateral constrictions, generating a series of current-influenced subaqueous bedforms (i.e. in the southern-east Frøan Basin) or transported towards further to north on the Halten Terrace.

However, a number of uncertainties related to the sub-seismic depositional architectures or lateral facies changes of the Rogn Fm call for evaluable outcrop-analogue studies, useful to constrain or revise preliminary interpretations and, thus, to increase the exploitation potential of the Rogn Fm.

The tectonic evolution and the type of sedimentation that characterised the Norwegian Continental Shelf during the Late Jurassic seems well matching the geological history of the Sardinian Graben System (SGS) in the western Mediterranean, during the Miocene. For this reason, a field-based study was promoted focused on two main representative outcrop areas belonging to this extensional basin.

2. THE SARDINIAN GRABEN SYSTEM AND THE ROGN FM OUTCROP-ANALOGUE AREAS

The Sardinian Graben System (SGS) was an N-S-striking elongate basin, developed in a back-arc setting from the Late Oligocene onwards (Cherchi et al., 2008). The SGS was progressively filled by continental and marine extra-basinal clastics and intra-basinal carbonates during at least three main complete cycles of relative sea-level changes (Casula et al., 2001; Oggiano et al., 2009). The field study, based on a detailed facies analysis, logging of stratigraphic sections, grain size lab analyses and mineralogical tests, has been focused on two main areas (Fig. 2) belonging to the SGS: (i) an Early Miocene ca. 10-km-wide palaeo-embayment, whose deposits are presently exposed in the center of the island, and (ii) an Early-Middle Miocene, 10-km-wide and 20-km-long half-graben, namely the Logudoro Basin located in the northern Sardinia. Both these areas resemble the two end-member settings invoked for the deposition of the Rogn Fm (i.e., embayment vs. confined shelf) and point out towards a general control on the sedimentation exerted by a specific oceanographic circulation deriving from the amplification of bottom (tidal currents) flowing across epicontinental restrictions (i.e., seaways and straits) (Chiarella et al., 2012, 2016; Longhitano, 2013; Longhitano et al., 2012, 2014).

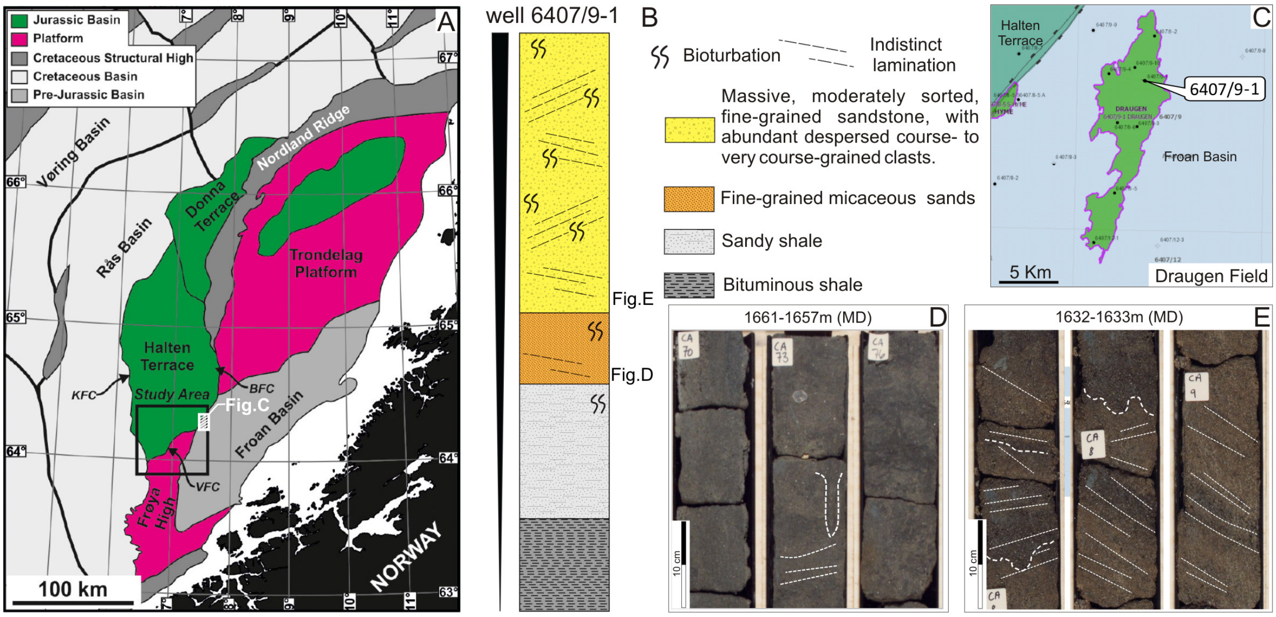

Fig. 1 - A) Structural elements of the mid-Norwegian Shelf and location of the Draugen Field (modified, after Elliott et al. 2015); B) Synthetic lithological column of the Rogn Fm in the well 6407/9-1; C) The Draugen Field and location of the well 6407/9-1; D), E) Core pictures of the Rogn reservoir in the Draugen Field.

3. RESULTS

3.1. First study area

The first succession is exposed in the central SGS, east of Oristano. It is Aquitanian-Burdigalian in age and includes three sandstone-rich stratal units, unconformably lying on the southern flank of a Palaeozoic basement block. These units are separated by major discontinuities and record transitions from continental, to shallow-marine to open-sea settings. Sedimentary facies include a variety of lithologies; however, sandstones showing a clear tidal signature (Fig. 3) represent the most volumetrically important deposit. The area was interpreted as a coastal embayment, in which the most important transport agent were tidal currents, generated because of the presence of a larger coastal area capable to damp an incoming tidal wave. The tidal influence occurred because of the peripheral position of the study area respect to a larger seaway (namely the Sardinian Seaway) (Longhitano et al., 2017). This area shows strong analogies with some of the prospects investigated along the eastern margin of the Frøya High in the Norwegian Sea, where seismic-imaged reconstructions indicate the filling of marginal coastal areas in very shallow-marine conditions.

3.2. Second study area

The second area is the Miocene Logudoro Basin, located in the northern SGB. This basin was a half-graben depression, whose Aquitanian-to-Serravallian basin-fill succession includes two of the three, regional-scale sedimentary cycles of Sardinia. A sand-rich Serravallian interval, namely the Florinas Sandstones (FS) (Funedda et al., 2000, in press), exhibits textural features comparable to those observed in the Rogn sandstone. The FS (Fig. 4) have been interpreted as deposited in a shallow-marine setting, due to delta-fed sand discharge, associated with minor recycling of older substrate units.

The Logudoro Basin is thought to be part of the larger Sardinian Seaway, crossed by alongshore (tidal) currents, capable to rework large volumes of sand in the delta-front sectors of marginal river deltas and forming extensive bedform fields in axial sector of the conduits. Large-scale architectural elements, as well as facies-scale features, suggest that these dispersal motifs can be considered as a potential candidate process for the interpretation of the depositional mechanism that was responsible of the deposition of the Rogn sandstone during the Late Jurassic in the Norwegian Continental Shelf.

4. CONCLUSIONS

The deposition of the Upper Jurassic Rogn sandstone (Norwegian Continental Shelf) suggests two main depositional scenarios: (i) one immediately adjacent to structural highs with consequent sublittoral setting; (ii) one localised along the axis of laterally-confined basins, in a general 'shelf' setting. Possibly, both are affected by a tidal amplification due to the coastal sheltering and the lateral confinement.

Based on the morpho-structural similarities and the equal condition of sedimentation (i.e., a major marine transgression during an extensional phase) two areas belonging to the SGS have been investigated, as outcrop analogues of these two depositional settings of the Rogn Fm, in order to improve the current knowledge about such promising target for the oil exploration in the mid-Norwegian Shelf.

The first study area, whose volcano-sedimentary

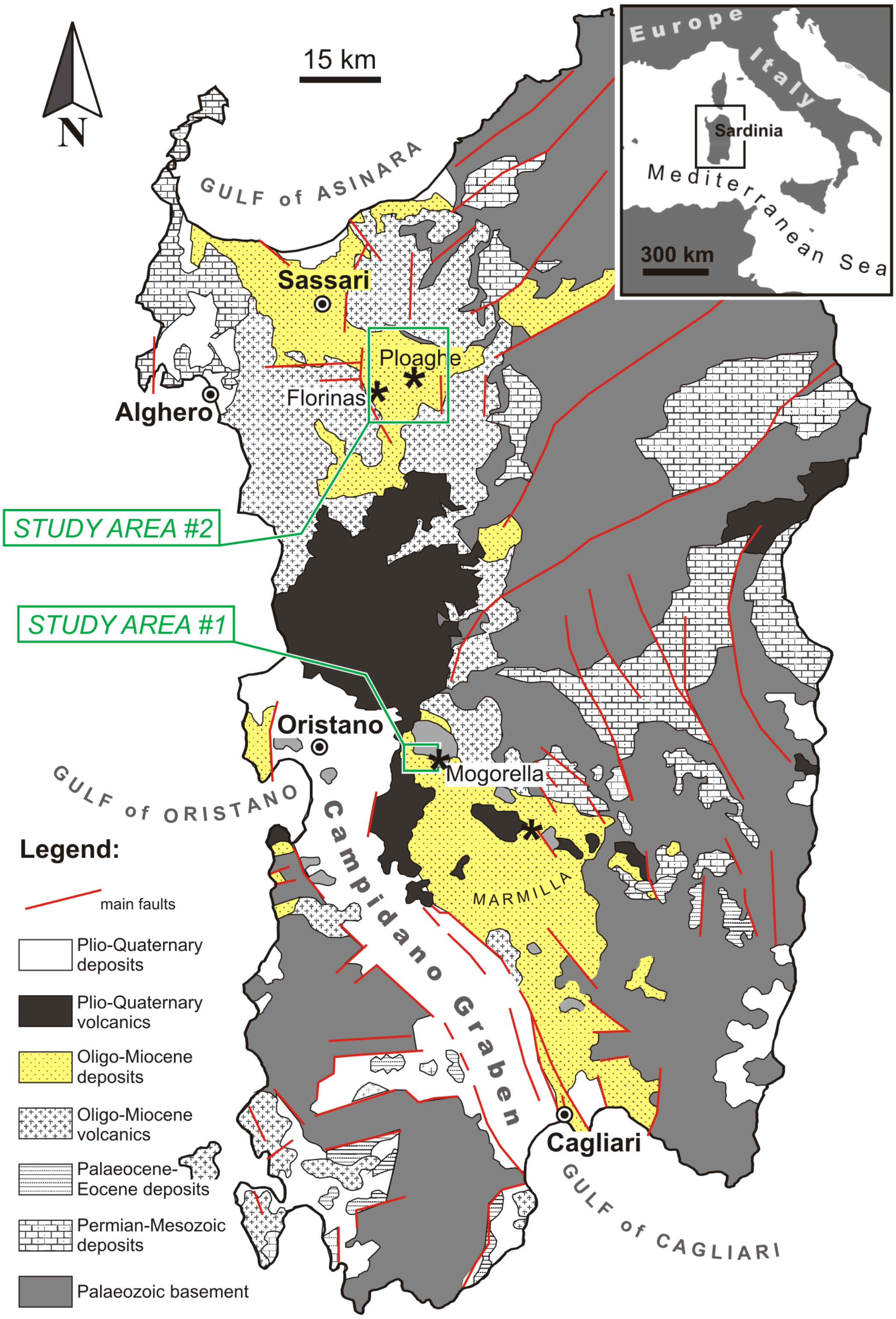

Fig. 2 - Geological sketch of Sardinia and location of study areas (modified, after Funedda et al., in press)

succession lapping against a tectonic horst, represents the analogue for the first setting (i.e., the sublittoral setting). Continental-to-transitional tide-influenced deposits are transgressively overlain by tidal flat heterolithics and, in turn, by beach-barrier sands.

The second study area reveals depositional analogies with the second setting (i.e., laterally confined 'shelf' setting). The marine deposits of the Serravallian FS record a generalised phase of marine transgression controlled by the strong tectonic subsidence. A tidal signature was recognised near the basin margins, as well as near the basin axis.

Both study areas indicate the episodic dominance of tidal dynamics, possibly developed during the stages of

Fig. 3 - Heterolithic foresets forming a herringbone architecture (arrows indicate the main directions of lateral accretion) and including tidal bundles and reactivation surfaces.

Fig. 4 - Cross-stratified, heterolithic medium- to coarse-grained sandstones and siltstones to fine-grained sandstones, characterised by tidal bundles and reactivation surfaces. These sandstones erosionally pass upwards to low-angle cross-stratified biocalcarenites.

marine inundation and consequent oceanic connections.

The present work, thus, can be considered as an important geological evidence in supporting the existence of the Sardinian Seaway, a N-S-elongated tide-dominated passageway responsible for a significant amplification of tidal currents from the early to the late Miocene and provides two examples of sedimentary succession deposited during extensional tectonics associated with a marine transgression.

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