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CHALK MARL SEAMS: NOT QUITE WHAT THEY SEEM …

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Abstract: The origin of wispy marl seams and nodular chalk has long been debated, particularly regarding their sedimentary versus diagenetic origins. Through scanning electron microscope (SEM) observations of thin sections from the Chalk of Southern England (UK), we gain new insights into the microtexture of nodular chalk, specifically the Lower Turonian Holywell Nodular Chalk and Upper Turonian–Coniacian Lewes Nodular Chalk formations, and marl seams from the Turonian New Pit Chalk Formation. In nodular chalks, microscale observations reveal evidence of pressure dissolution, either overprinting early diagenetic nodules or generating a stylonodular fabric. The darker seams, visible to the naked eye between the nodules, are lower porosity zones with bioclast concentration due to the preferential dissolution of the micritic matrix, cementation, and/or mechanical compaction. Surprisingly, despite their darker colour due to porosity loss, they often contain very little clay. The latter are concentrated in the insoluble residue coating the nodules. Interestingly, in the New Pit Chalk Formation, marl seams do not consist of marl, instead, they are primarily related to the mechanical compaction and pore reduction of the micritic matrix. Low-field nuclear magnetic resonance (NMR) T_2 analysis provides insight into the porous network, where T_2 is a proxy for pore size. Results reveal the T_2 logarithmic mean (T_2lm) equals 34−41ms in white chalk from the New Pit Chalk Formation, while marl seams samples average 18−24 ms, which does not correspond to the signal of typical argillaceous–marly chalk where T_2lm<10 ms. These findings challenge the view that nodular chalk results solely from sedimentary and early diagenetic processes and provide a new perspective on the formation of thin, wispy so-called marl seams. *Marl seams* are likely not of sedimentary origin nor strict dissolution seams but rather correspond to compaction bands or hybrid compaction-dissolution bands. These observations may have important implications for future stratigraphical correlations and fluid flow within the Chalk.

Keywords: Nodular chalk, pressure dissolution, microtexture, diagenesis, compaction bands, marl seams

1 INTRODUCTION

Marl is defined as a sedimentary rock composed of a mixture of clay (35-65%) and calcium carbonate (65-35%) (Tucker, 2003). In the context of chalk, the term *marl seam* traditionally refers to concentrations of clay that form conspicuous seams within the chalk, a terminology dating back to William Smith, the father of UK geology in the 18th century. These marl seams, observed in cliffs and core samples, appear brown to dark grey and range from a few millimetres to a few centimetres thick in the Anglo-Paris Basin. The origin of marl seams in chalk is still a subject of debate. Mortimore (2011) emphasizes this ongoing controversy: are marl seams the result of pressure dissolution, or are they primary sedimentary structures? Wray and Jeans (2014) argue, based on XRD analysis, that marl seams are sedimentary in origin, as the insoluble residue mineralogical content differs from the white chalk. Conversely, Garrison and Kennedy (1977) describe wispy marl seams as flaser chalk or solution seams, attributing their formation solely to pressure dissolution. Understanding and characterizing marl seams is essential for delineating compartments in chalk reservoirs. These layers may act as mechanical interfaces within groundwater reservoirs and contribute to karst development. Therefore, comprehending their formation processes is crucial for predicting their geographical and stratigraphical distribution.

2 GEOLOGICAL CONTEXT AND METHODS

Chalk samples from the Holywell, New Pit and Lewes Chalk formations ranging from Turonian to Coniacian in age, were studied. Samples were collected from a borehole located a borehole on Salisbury Plain, Wiltshire, at the border, at the border between the Southern and Transitional Chalk Provinces, as defined by Mortimore et al. (2001). Twenty standard thin sections (30 mm thick) were prepared. Backscattered electron (BSE) analysis, using a Quanta 600 SEM, at magnifications of 200 to 5,000 times, was used to observe the microtexture, identify non-carbonate minerals and microporosity. NMR transverse relaxation time (T_2) of chalk plugs was measured using a low-field (0.196 T; 8.33 MHz) Halbach-based rock core analyzer at the Sakellariou NMR lab, KU Leuven. NMR T_2 distributions were obtained using the Carr-Purcell-Meiboom-Gill

(CPMG) method and provide a proxy for pore size (see Khajooie et al., 2024). Parallelly, also water-saturation porosity was measured on the plug-samples.

3 RESULTS AND DISCUSSION

3.1 Nodular chalks

SEM observations of nodular chalk reveal its microtexture, highlighting the nodules and seams, which appear very dense (white) compared to the surrounding chalk (Fig. 1).

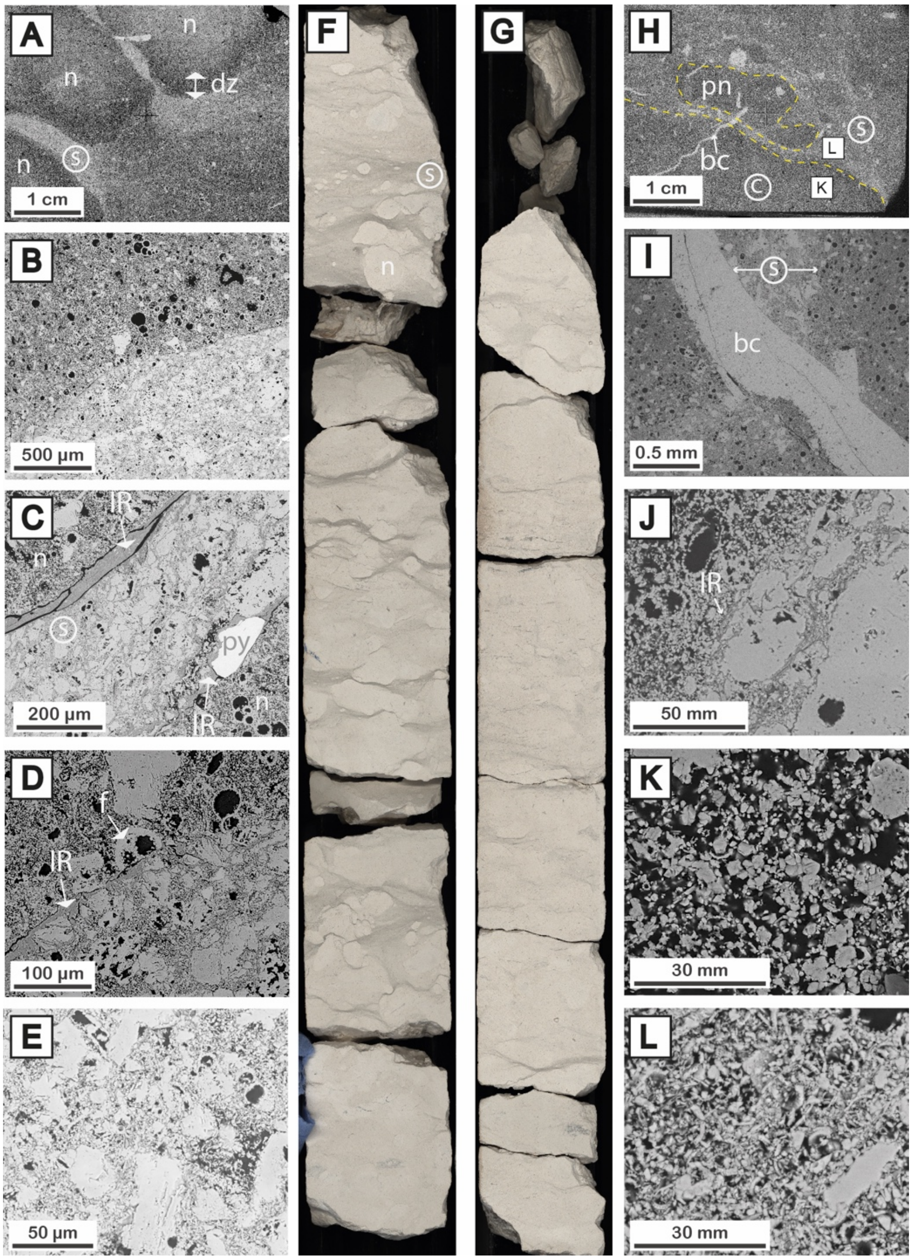

Figure 1. (A) SEM observation of a thin section from Lewes Chalk showing eogenetic nodules and solution seams. Colour contrast (white seams, dark grey nodules) due to porosity loss in seams. Pressure dissolution indicated by a porous dissolution zone. (B) Close-up view emphasizing the colour contrast between the seams (white) and nodules (dark grey). (C) Detailed image of a solution seam in Lewes Chalk, with insoluble residue concentration, and truncated foraminifera. (D) Interface between a nodule and a seam in Lewes Chalk. (E) Microtexture of a seam showing mechanical compaction and loss of interparticle porosity. (F) Core image of Holywell Chalk with nodular texture. (G) Core image of Holywell Chalk showing coarse facies and nodular texture. (H) SEM observation of a thin section from Holywell Chalk with a diagenetic pseudo-nodule indicated by a bioclast crosscutting both the chalk, seam and nodule. (I) Close-up of the bioclast cross-cutting the seam. (J) Interface between solution seam and nodule in Holywell Chalk, marked by insoluble residue concentration. (K) Microtexture of the chalk matrix in Holywell Chalk, showing primary textural characteristics. (L) Microtexture of a solution seam in Holywell Chalk, showing mechanical compaction and reduced interparticle porosity. Abbreviations: bc – Bioclast, c – Chalk matrix, dz – Dissolution zone, f – Foraminifera, IR – Insoluble residue concentration, n – Nodule, pn – Pseudo-nodule, py – Pyrite, s – Solution seam.

Porosity loss in the seams may be a combination of dissolution of the micritic matrix, cementation and reorganization of the grains by mechanical compaction. The origin of the nodules varies between samples, including both synsedimentary, early diagenetic, and late burial nodules. In all cases, the nodules are characterized by pressure dissolution on their outer edges. Early diagenetic nodules, as described by Garrison and Kennedy (1977), appear dense (light grey, Fig. 1A-C) due to porosity reduction caused by cementation. Around the nodules, the insoluble residue ranges from 10 to 100 µm thick. Considering an averaged insoluble residue of 2% in white chalk (Wray and Jeans, 2014), it would imply that 0.5 mm of chalk must have dissolved to accumulate 10 µm of insoluble residue, or 5 mm for a 100 µm-thick residue. This nodular facies is predominantly encountered in the Lewes Nodular Chalk, particularly near hardgrounds. The rheological contrast between eogenetic nodules and the surrounding chalk concentrates pressure dissolution, sometimes forming microstylolites between nodules. In the Holywell Nodular Chalk, intraclasts are observed, likely related to early sediment remobilization, and concentrate pressure dissolution at their interfaces as well. Microscopic observations reveal that some nodules are strictly diagenetic. In figure 1 (H-I), bioclasts crosscut both the seam and the nodule, indicating the diagenetic origin of the nodule. The micritic matrix has been preferentially compacted both mechanically and by pressure dissolution in the seam (Fig. 1, J-L). Similar facies were described in limestone (Kahsnitz and Willems, 2019) as stylonodular.

Interestingly, nodular chalk formations occur at rheological and mechanical interfaces. The base of the Holywell Nodular Chalk Formation is the Plenus Marls, a global anoxic event. It forms atop the argillaceous Zig Zag Chalk and shows a decrease in nodulation upward. Similarly, the Lewes Nodular Chalk forms atop hardgrounds, with nodulation also decreasing upward. It can be argued that due to the rheological interface and the different mechanical behaviours of the formations, there is a concentration of stress and intensification of pressure, leading to increased mechanical and chemical compaction at these interfaces.

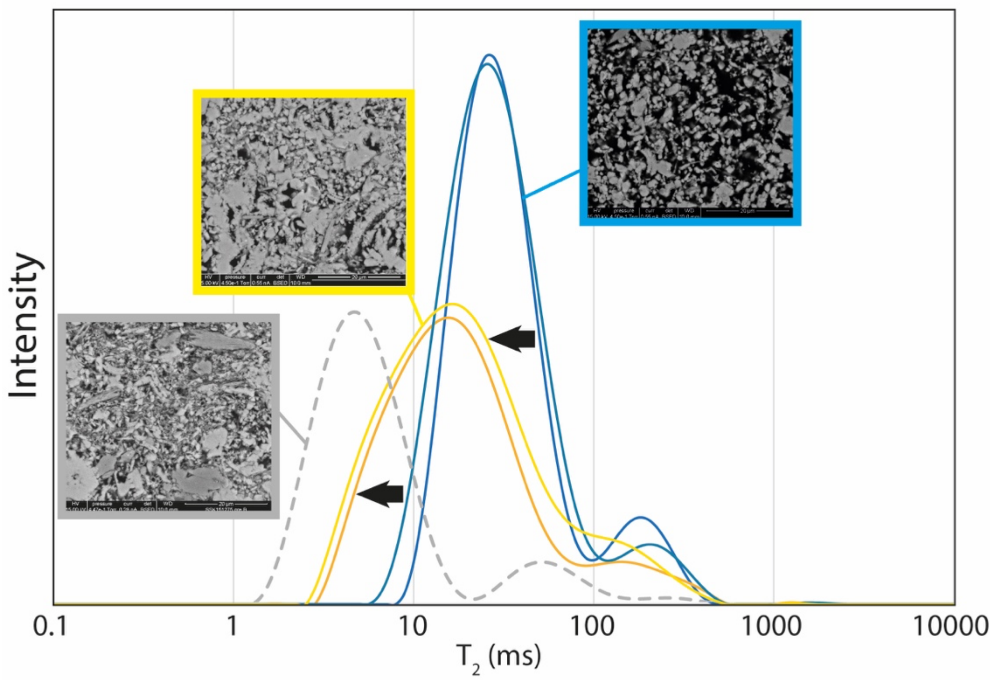

Figure 2. NMR T2 signal of marl seams (orange) and white chalk (blue) from the New Pit Formation. Lower T_2 values indicate a reduction in pore size due to mechanical compaction of the microtexture. For comparison, the typical T_2 signal and microtexture of a clay-rich chalk sample (Zig-Zag Chalk Formation) is shown in grey.

3.2 Marl seams

Linear structures darker than the host rock are observed on core surfaces. Their internal characteristics cannot be resolved by the naked eye, a hand lens, or even optical microscopy. SEM observations have revealed the intrinsic nature of marl seams. BSE images show that the seams are paler than the surrounding pure chalk due to higher density. Higher magnification reveals compaction of the microtexture and a loss of interparticle porosity (Fig. 2). The calcitic grains forming the microtexture display punctate contacts in the pure chalk but serrate to sometimes coalescent contacts in the marl seams. At the interface between the pure chalk and the compacted chalk, a thin layer of insoluble residue resulting from localized pressure dissolution is sometimes observed. Cements are occasionally seen in marl seam intervals as crystal overgrowths around bioclastic fragments. Porosity measurements reveal that the total sample porosity at the plug scale is reduced by about 8%. However, the average pore size (expressed by T_2) is halved in samples containing marl seams compared to pure chalk (Tab. 1).

The NMR signal from the marl seam samples also shows a distinct pattern compared to those of marly sedimentary origin (Fig. 2). The origin and mechanism behind the formation of marl seams remain to be fully understood. However, our microscale observations provide new evidence about their nature and suggest reconsidering the term “marl seams.” Previous studies (e.g., Wray and Jeans, 2014) have shown that many marl seams contain only 3-10% non-carbonate minerals, yet the term “marl” persists, further confusing the nature of these structures. They are hybrid compaction-pressure dissolution bands. Whether they overprint an initial signal remains to be determined.

Table 1. Petrophysical Properties of New Pit Chalk samples. Porosity, density, and T2lm range of values from pure chalk samples (3) and marl seam samples (3).

	Porosity (%)	Density (g/cm^3)	T_2lm (ms)
Pure chalk	41 - 43	1.57 - 1.61	34 - 41
Marl seams	35 - 38	1.72 - 1.75	18 - 24

4 CONCLUSION

Marl seams are more complex than they appear at first glance. For decades, geologists have been misled by the darker appearance of these intervals in the field, leading to the assumption that they are *marl*. However, our observations reveal that some of these seams do not contain more clay minerals than the surrounding white chalk. Instead, they all exhibit microtextural scale compaction features, and should be referred to as compaction bands or hybrid compaction-dissolution bands. Petrophysical characterization of these layers indicates lower porosity and, more importantly, smaller pore sizes, which significantly reduce permeability. These low-permeability intervals thus act as barriers to vertical fluid flow and may lead to the development of lateral fluid flow conduits and potential microkarstification atop the compaction bands (commonly known as marl seams) (Farrant et al., 2022). These findings underscore the importance of microscale observations in understanding basin-scale processes. Our research highlights the necessity of investigating the location and timing of compaction bands, as well as the role of early compaction within these intervals prior to rock consolidation. Future modelling efforts should build on our results to address these critical questions.

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