Flamborough head's Upper Cretaceous Chalk: insights into a mixed deep-sea sedimentation system

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FLAMBOROUGH HEAD'S UPPER CRETACEOUS CHALK: INSIGHTS INTO A MIXED DEEP-SEA SEDIMENTATION SYSTEM

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Abstract: The outcrops of the Flamborough Head promontory in Yorkshire, UK, including sea cliffs and inland quarries, provide an exceptional view of the Upper Cretaceous sedimentation. These exposures reveal chalks uplifted during the Tertiary inversion. A detailed sedimentological study of the Turonian to Campanian sections, incorporating both macroscopic and microscopic observations, reveals well-preserved sedimentary features consistent with depositional processes in a deep marine environment. The study identified three main types of facies: contourites, turbidites, and hemipelagites. Contourites, influenced by bottom currents, are composed of fine-grained chalk and exhibit thinly laminated beds with planar and undulating laminations, as well as current ripples. These beds, which can reach a total thickness of several dozen meters, exhibit internal organization with topographic compensation. That suggests deposition within larger contourite drifts – as observed in nearby offshore seismic profiles. Turbidites are characterized by massive beds with sharp bases fining upward, laminated deposits, and minimal bioturbation. Hemipelagites, in contrast, are intensely bioturbated mudstones with sparse fauna and show no evidence of current reworking. These deposits in Flamborough Head provides a valuable analogue for the North Sea deposits, offering insights into the dynamics of chalk deposition along the paleo-slope influenced by bottom currents. The identification of these contouritic facies in chalk across the Flamborough Head promontory highlights periods of increased bottom current activity, with hemipelagite-dominated intervals in between. The outcrop presents a unique combination of stylolitization from burial diagenesis and differential weathering, which highlight its sedimentary features. This provides insights into sedimentary processes that are usually hardly observable in chalk from cores. Although contourites geometries are widely reported through seismic data, facies observations are rare. This study not only provides a valuable analogue for North Sea Chalk deposits but also enhances our understanding of the sedimentology and current dynamics within the Chalk bassin.

Keywords: chalk facies, contourite, sedimentology, Northern Province, bottom-current

1 INTRODUCTION

Recent studies have demonstrated that the Upper Cretaceous chalk deposits in the North Sea and Danish Basins were significantly shaped by contour currents, challenging the traditional perception of chalk as a flat-lying pelagic sediment. Seismic data reveal extensive contourite systems characterized by drifts, moats, and sediment waves, indicating the presence of energetic bottom currents flowing parallel to bathymetric contours, according to Esmerode et al. (2007). Distinguishing contourites from turbidites and hemipelagites is challenging in all sediment types (Hüneke et al., 2020), but it is particularly difficult in fine-grained deposits such as chalk. Previous research on contourite chalk identified through seismic data has shown that it is difficult to differentiate from pelagic chalk based solely on facies analysis (Rasmussen & Surlyk, 2012). The lack of access to contourite facies represents a missing link in understanding the variations in reservoir properties and the internal organization of structures recognized in seismic data. The Flamborough outcrops, ranging from the Turonian to Campanian, provide a unique opportunity to study chalk deposits analogous to those in the subsurface of the North Sea. These outcrops feature deep-sea sediments with alternating contouritic facies, turbidites, and hemipelagites.

2 GEOLOGICAL SETTINGS

Flamborough Head, located on the Yorkshire coast in northern England, is a prominent chalk promontory that extends into the North Sea. The cliffs at Flamborough Head provide a continuous section from the base of the Upper Cretaceous Series to the lower part of the Lower Campanian succession (Mortimore, 1986). The deposits of interest in this study correspond to the Burnham and Flamborough formations, as defined by the lithostratigraphy of the Northern Province Chalk in the UK. The Flamborough Chalk Formation is characterized by the absence of flint and the presence of numerous marl layers. This formation is divided into three members: South Landing, Danes Dyke, and Sewerby Steps (Whitham, 1993). Underlying the Flamborough Chalk is the Burnham Chalk Formation, which contains flint and is well-exposed in the cliffs from North Landing to South Landing (Mortimore, 1986).

3 RESULTS AND DISCUSSION

3.1 Seismic scale

A seismic line acquired 70 km north of Flamborough Head has been analyzed, revealing kilometer-wide architectures typical of contourites, characterized by a topography of ridges and valleys (Fig. 1). The study uncovered various mounded and drift structures, including large erosive formations filled with sediment waves. Some mounded structures show truncation on one flank, while smooth draping occurs on the other side. Additionally, a large channel is inferred, with an erosive structure to the south that is filled by the lateral development of sediment waves.

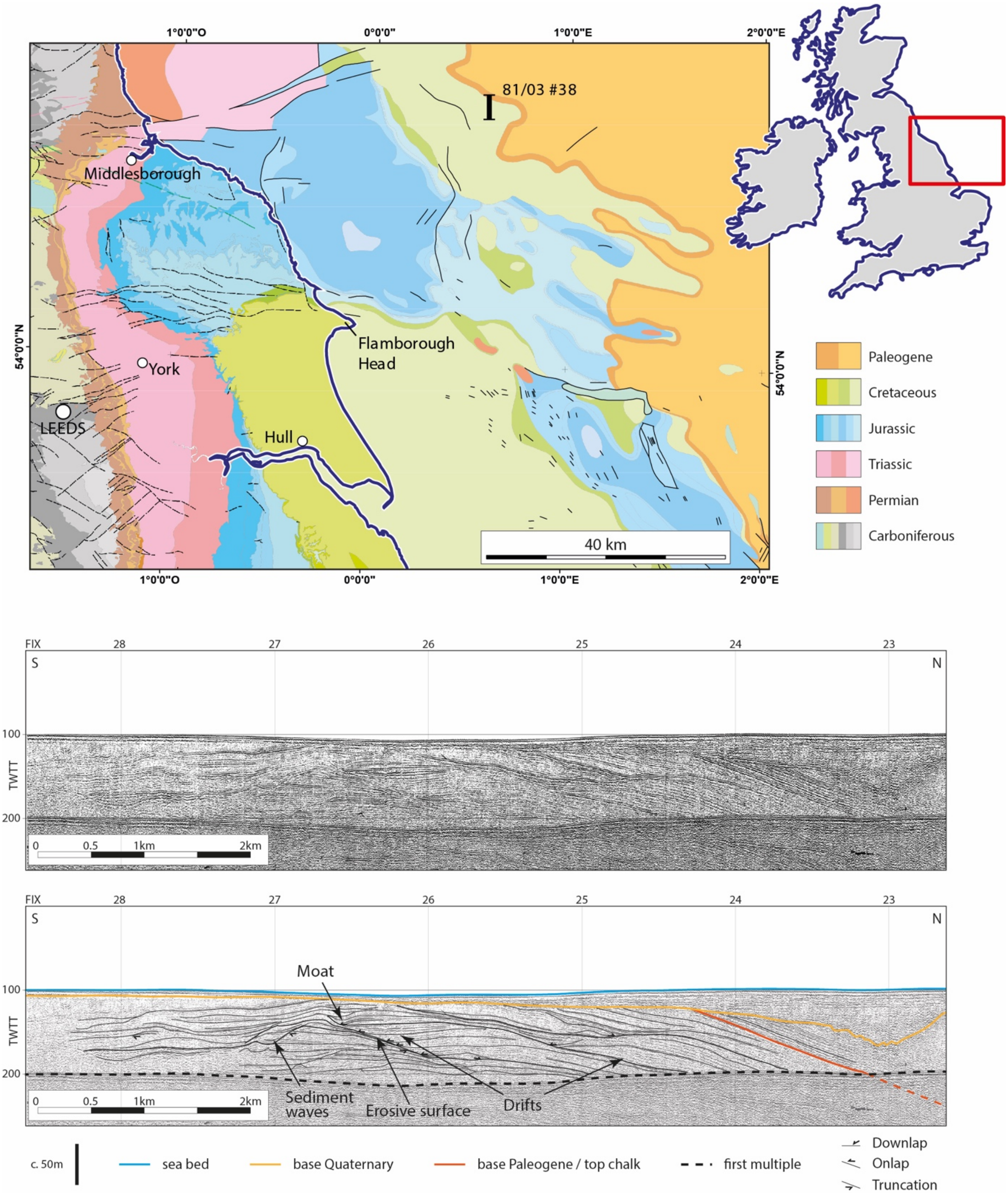

Figure 1. Raw and interpreted seismic section and its location offshore Flamborough Head, UK [modified from BGS geological maps (© UKRI) and EMODnet Geology (2021)]

3.2 Outcrop scale

A total of 250 meters were logged in detail, with the deposits classified as biomicrite according to Folk's classification. Three facies were identified as follows (Fig. 2):

- Hemipelagite facies are characterized by fine-grained sediments deposited by slow settling in deep marine environments. These deposits typically exhibit homogeneous intervals with in-situ fall-out fossils, such as sponges and inoceramids, which are almost intact (Fig. 2A).

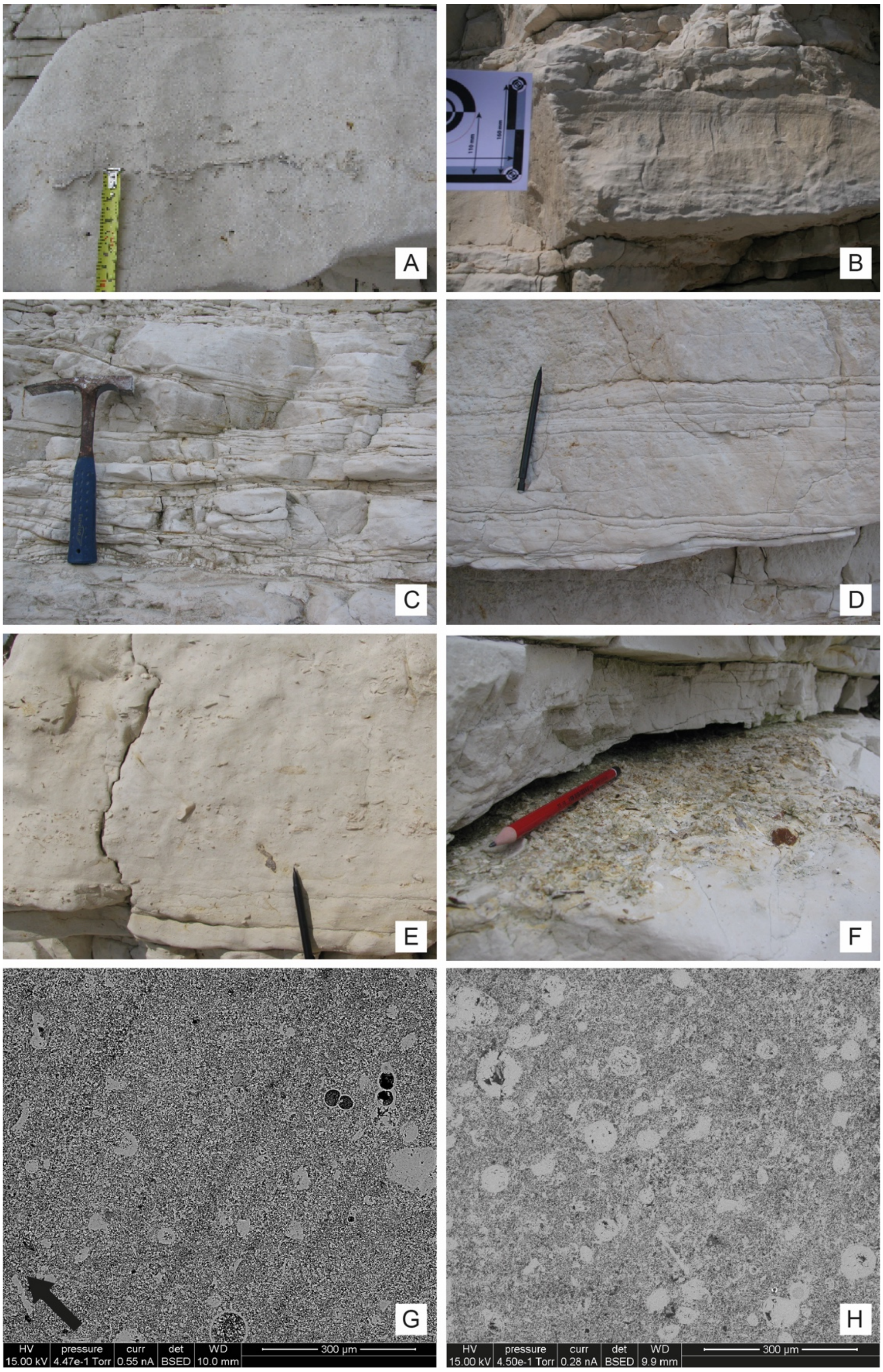

Figure 2. (A) Hemipelagites, displaying non fragmented large bioclasts only perturbed by compaction; (B) Turbidites, with sharp base and normal grading; (C) Superimposed 3D dunes with some preserved traction features, and little to no erosion between bedforms; (D) Wavy lamination (HCS like features); (E) Bedforms displaying successive levels of abundances (growing and lowering) of fragmented bioclasts interpreted as the effect of acceleration decelerating bottom currents; (F) Bioclastic lag associated with more energetic bottom currents; C to F are interpreted as contourites deposits; (G) Microfacies of a contourite, with the black arrow indicating the stratigraphic upward direction (H) Microfacies of a turbidite.

- Turbidites beds are 10 to 50cm thick. They are characterized by a sharp lower contact, suggesting a sudden deposition event. A normal grading indicates deposition by decelerating turbidity current. The sedimentary structures suggest that these facies are Ta and Tb terms of a Bouma sequence (Fig. 2B).

- Contourites display sedimentary structures, such, planar to undulating draping laminations, and winnowing features, such as HCS-like features organized as successive beds compensating each other (Fig. 2C-F). Although criteria are often lacking to precisely discriminate between contourites and turbidites, several sedimentary structures exhibit decimetre-thick layers with fragmented bioclasts (predominantly inoceramids) that show varying abundance, typically increasing and then decreasing. These layers are interpreted as records of progressively increasing and decreasing bottom current velocities, indicative of contourite deposition (Fig. 2E). Wavy geometries and laminations are frequently associated with these features, reflecting traction and suspension currents. Occasionally, lags with bioclastic drape are present, containing broken and reworked bioclasts with grain size varying from one lag to another. The largest lags contain pluricentimetric debris, while finer lags contain millimetric bioclasts. The presence of winnowing features suggests a sustained current with varying speeds, rather than a series of single events.

Although turbidites and contourites remain challenging to identify definitively, a trend is observed: contourites and turbidites dominate the South-Landing member at base of the sequence, while within the Sewerby Member, there is a transition from contourite/ turbidite-dominated to hemipelagite-dominated deposits.

3.3 Microscale

Optical microscopy does not allow discrimination between the three facies, as all are categorized as mudstone texture according to Dunham classification. However, the most significant findings come from SEM observations of thin sections of contourites using BSE imaging, which provide clear evidence of lamination. This marks the first microscale observation of laminations in chalk, showing a distinct alternation between very small grains (darker intervals) and slightly coarser grains (lighter intervals) belonging to the micarb fraction of the chalky matrix (Fig. 2G). Facies from the base of the turbidite, however, display a more abundant coarser fraction, including foraminifera, calcispheres, and bioclasts (Fig. 2H).

3.4 Discussion

The Flamborough Chalk has been buried to a maximum depth of 1200 meters. This burial diagenesis has resulted in the development of stylolites and the concentration of insoluble residues. Stylolites tend to form preferentially along sedimentary interfaces, thereby highlighting sedimentary features in both contourites and turbidites. This unique combination of deep burial stylolitization and outcrop weathering enhances the visibility of sedimentary structures and facilitates the identification of chalk facies. These deposits are typical of deep water and basinal environments, include some turbiditic events and hemipelagites, which have been reworked by more or less active contouritic currents. Mortimore (2019) described the structures within these deposits as resulting from intra-chalk tectonic movements. He suggests that the bedding corresponds to shear zones, which include internally laminated and deformed blocks that have been rotated, linking this deformation to a period before the chalk was fully consolidated. While we concur that synsedimentary faulting occurred in the Flamborough chalk outcrop (Faÿ-Gomord et al., 2017), our sedimentological analysis enables us to link the deposits to deep-sea sedimentation processes and subsequent burial diagenesis. Whitman (1993) had described the Sewerby Member as initially being a thin-bedded, stylolitic chalk that transitions to massive-bedded chalks higher in the succession. This is consistent with our interpretation of the lower part as laminated contouritic deposits, which transition to more homogeneous hemipelagic deposits in the upper part of the formation.

4 CONCLUSION

Seismic data and outcrop analyses in the vicinity of Flamborough Head promontory reveal complex deep-sea sedimentation system. Our study reveals the strong influence of bottom currents on deep sea chalk deposition from Turonian to Campanian. Although, end members of contourites from turbidites and pelagites can be identified their precise distinction remains challenging, the findings highlight the possibility of recognizing contourite facies, to better understand reservoir properties and the internal organization of chalk deposits. The Flamborough outcrop provides a valuable analogue for subsurface studies, showcasing alternating contouritic facies, turbidites, and hemipelagites. Future research should focus on improving methods for distinguishing between these deposits and studying outcrop analogues to enhance understanding of subsurface contourite systems and their impact on reservoir properties.

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