Deciphering sedimentological building blocks: Predicting sediment partitioning and its influence on CO$_2$ storage and migration based on clinoform geometries

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Abstract

Clinoforms develop on varying scales in a vast variety of settings, and form the basic building blocks of prograding sedimentary systems. They are common features in both reservoirs and overburden, and sediment dispersal and preservation in these systems is integral to understanding CO$_2$ storage, migration pathways, secondary storage, and local baffles and seals. Clinoform complexes are associated with significant lateral as well as vertical changes, which can be difficult to assess based on wells and seismic data alone. Improved predictability models based on data from geometric parameters could significantly improve and de-risk assessment of CO$_2$ sites and storage.

The study categorizes clinothems using their slope curvature together with internal characteristics to discuss the fundamental drivers controlling the shape, dimensions and geometries of different kinds of clinoforms. The study is approached using data from a wealth of different study areas, including the targeted Smeaheia CO$_2$ storage site offshore western Norway. Understanding how factors such as accommodation, relative sea-level, tectonism, sediment influx rate and type, and sediment remobilization, depositional environment, and depositional processes influence sediment partitioning provides a basis for predicting a host of sedimentary characteristics potentially including sediment type, lateral connectivity, porosity and permeability.

Studies of clinoform slope geometries suggest that there are three basic curvatures: sigmoidal (Gaussian), tangential and linear. Further subdivision can be done based on internal characteristics such as sediment distribution (symmetrical, top or bottom-heavy) or divergence of reflectors and chaotic or non-chaotic internal traits. The typical, and also most common, sigmoidal geometry, is generally associated with periods of increasing accommodation. It is also observed that sediment distribution in sigmoidal clinothems allow greater detail in quantification compared to other geometries, i.e. that several parameters show a close relationship with potential for prediction. However, detailed sedimentological study in the Ainsa Basin, Spain, indicates that the geometry can develop in both high-energy and low-energy environments within both dominantly mud-prone and increasingly sand-dominated clinothems.

Indications from several studied systems suggest that linear slopes are commonly associated with asymmetric sediment distribution, with increased sediment volumes along the slope and toe, as a result of shelf bypass. Interestingly these clinothems are typified by high-angle to retrograding trajectories, suggesting a complex development rather than simply limited accommodation or base-level fall. Sediment bypass and increased slope and basin floor accumulation would typically be associated with increased sand-influx but detailed data from the Ainsa Basin do not indicate increased amounts of sand delivery within the lowstand succession.

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Accommodation is suggested to exert a higher degree of control than sedimentation rate on foreset steepness, whereby the steepest clinoforms develop in the deepest waters and form significantly lower angles upon prograding into shallower areas/across structural highs. In basins without significant change in accommodation, clinoforms associated with limited sedimentation are inferred to create steeper clinoforms. Steeper slopes are also associated with high advance of the toe, which is also seen in the more chaotic clinothems, indicating both are associated with processes promoting basin floor accumulation. Otherwise it was found that in undegraded clinothems, toe-advance and amount of sediment in the clinothem are closely related, a link which was unrelated to the trajectory, which is controlled to greater extent by accommodation.

There are many indications that suggest that the geometric characteristics of clinoforms can provide important sedimentological information. However, it is also apparent that many preconceived assumptions related to trajectory and clinoform shape can be misleading. Further detailed study of sediment partitioning in clinoform systems and how this affects size, shape and dimensions has the potential to be a valuable contribution to furthering our understanding of safe geological CO₂ storage.