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Revisiting the utility of hummocky cross-stratification in paleo-environmental reconstruction of wave-dominated shelves

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Abstract

Sand beds deposited across wave-dominated shelves form some of the most prolific hydrocarbon reservoirs in the world. However, the processes responsible for transporting sands across ancient shelves, and concentrating and reworking them into quality reservoirs are poorly understood. Wave-dominated storm-influenced shelf sand deposits are often characterized by hummocky cross-stratification (HCS), which through the concepts of Airy-wave Theory, are shown to indicate the nature and magnitude of processes responsible for their deposition. Statistical data on these bedforms can be used to estimate the wave regime and water depths at which these bedforms deposited, allowing for a reconstruction of paleo-environments along ancient shelves.

Statistical data on crest spacing of hummocks and grain size distributions of deposits containing HCS were collected by comprehensive survey of previously reported HCS deposits across the world throughout different geological time scales. Two example localities were visited to analyze these deposits and collect additional data; Cape Sebastian Sandstone in southwestern Oregon and the Tocito Lentil of the Mancos Shale in the southeastern San Juan Basin, New Mexico. These localities are known to be the world-class outcrops for studying storm-influenced shelf systems. Field studies were done to quantify the architecture of HCS in these units. Statistical data was calibrated using field measurements from these two units. Measurements of hummock spacing were used to estimate the range of orbital diameters. Maximum and median grain sizes were used to estimate range of orbital velocities. Possible combinations of wave heights, orbital velocities and water depths were deduced using wave equations. Results suggest that paleo-wave regime and paleo-environments can be deduced by utilizing this quantitative approach enhancing the utility of HCS. Utilizing this approach, predictions can be made on the magnitude of processes prevailing on ancient shelves that can help in locating exploration targets in both shallow marine and deep-water sedimentary deposits in siliciclastic system. One must keep in mind that the applied equations only calculate approximations of the real hydraulic processes and their application requires certain assumptions. Other geological evidence can be used to further refine paleohydraulic interpretations.

Introduction

Sandy deposits on shallow marine shelves occur in a variety of geometries and deposits, and these deposits are known to commonly host a unique sedimentary structure known as hummocky cross-stratification. Hummocky cross-stratification (HCS) has been one of the most debated sedimentary structures in geological science over the past 30 years, with many models proposed to explain its origin and formation. Apart from a few deviations that might suggest differently, the model of oscillation-dominated combined flow associated with long-period surface gravity waves in a shelf setting has been mostly accepted to explain the formation of this structure. Outcrop studies have focused on the HCS sequences as a component of larger stratigraphic frameworks, but little has been done to assess what these deposit types imply about depositional conditions other than the commonly stated “storm conditions”. There still is scope to increase our understanding of the processes that move sediments onto and beyond the marine shelf, and to enhance the utility of these deposits for better understanding of these regions by both geoscientists and climatologists.

Methodology

Many authors have discussed the use of wave ripples for reconstruction of ancient wave conditions (Komar et al., 1974; Clifton & Dingler, 1984; Immenhauser, 2009). In this study, assuming an oscillation-dominated origin for nearly symmetrical HCS, concepts of linear Airy-wave theory (Komar, 1974; 1975) and threshold of sediment movement under oscillatory flow (Komar, 1973) along with relationships between wavelength and orbital diameter (Figure 1; Sherman and Greenwood, 1989; Arnott & Southard, 1990; Li & Amos, 1999; Dumas et al., 2005; Yang et al., 2006) have been applied to measurements of wavelengths of HCS and median grain size collected from field studies to comment on the wave conditions (time period, wavelength, wave height) and orbital velocities existing at the time of bedform formation. These measurements and observations are further used to give a range of water depths at which these bedforms formed.

Two example localities were visited to analyze these deposits and collect additional data; Cape Sebastian Sandstone in southwestern Oregon, USA and the Tocito Lentil of the Mancos Shale in the southeastern San Juan Basin, New Mexico, USA (Figure 2, Figure 3). These localities are known to be the world-class outcrops for studying storm-influenced shelf systems. Both of these deposits are marine transgressive deposits of Late Cretaceous age, giving us an opportunity to study the nature of these deposits and their depositional conditions during the greenhouse period of Cretaceous.

Field studies were done to quantify the architecture of HCS in these units. Statistical data was calibrated using field measurements from these two units. Measurements of hummock spacing were used to estimate the range of orbital diameters. Maximum and median grain sizes were used to estimate range of orbital velocities. Possible combinations of orbital velocities and water depths were deduced using wave equations.

Results and Conclusions

Probabilistic analysis using HCS show deeper water deposition for the TL compared to CSS. The deeper water setting at TL compared to the CSS is supported by higher percentage of mud and lesser dips preserved in the TL HCS. Results suggest that HCS at both locations are formed by long-period (10–30 sec) waves and orbital velocities ranging from 40 cm/sec to 140 cm/sec.

Application of this methodology to storm deposits will help in improved understanding of paleo-processes active on the world's ancient shelves allowing us to built better depositional models of shelf sand movement and deposition that will enhance our ability to explore for and produce these reservoir facies, as well as model changes in storm and climate character along these ancient margins. An improved understanding of how these sands and muds distribute themselves in the shelf settings with varying physiographic and storm conditions will be extremely useful in limiting exploration and development risk in shelf sand reservoirs around the world.

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Figures

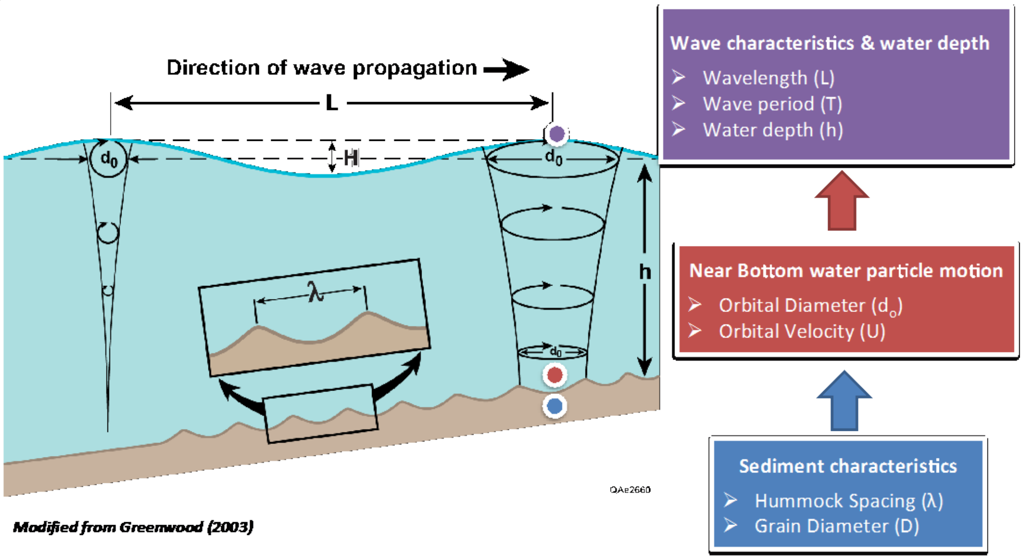

Figure 1. Methodology explained for utilizing sediment characteristics from hummocky cross-stratification deposits to infer paleo-wave parameters and water depths

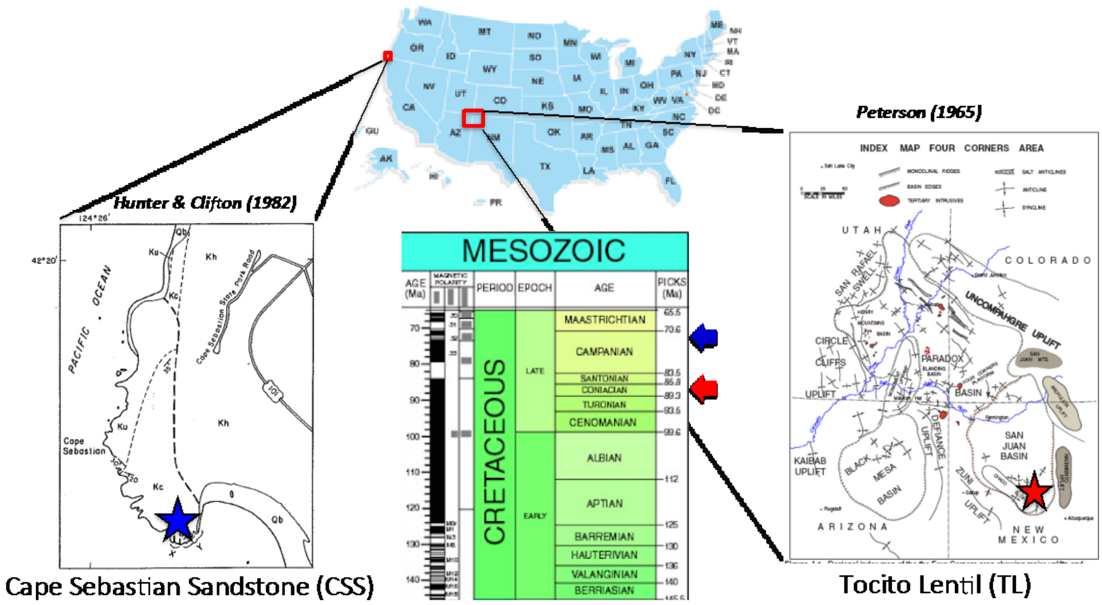

Figure 2. Field study areas highlighted on maps and geological time scale

Figure 3. Hummocky cross-stratification from Cape Sebastian Sandstone (CSS), Oregon and Tocito Lentil (TL), New Mexico