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Virtual Worlds and Ancient Depositional Systems: The Use of Earth System Modelling to Understand the Geological Past

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Abstract

The extent to which modern depositional environments can be used as analogues for petroleum systems is limited by the extent to which ancient settings have modern counterparts. The most striking example of this challenge relates to epicontinental seas. The epicontinental seas of the geological past were vast, typically shallow and lack suitably scaled modern analogues (see Allison & Wells, 2006 for review). However, the vast majority of the accessible sedimentary archive of climate and environmental change and repository for hydrocarbons was deposited in shallow seas.

Computer models provide a virtual laboratory for evaluating the behaviour of non-uniformatarian systems like epicontinental seas (e.g. see Wells et al., 2007, Mitchell et al, 2010, 2011). A key question is the extent to which these water-bodies were stratified or mixed and how this has affected productivity and preservation. Modern coastal seas such as the North Sea become seasonally stratified in summer but are mixed at the coasts through the interaction of the tidal wave with the seabed. The stratified deeper water is separated from the mixed coastal shallows by a front. Modern fronts are associated with elevated productivity in the frontal region with potential for preservation in stratified areas.

Herein we use a range of modeling tools to evaluate the development of seasonal stratification, tidal mixing and tidal fronts in the Cretaceous Western Interior Seaway (WIS) of North America. The paleogeographies (supplied by Getech) are underpinned by extensive geological databases and based on an in-house plate model. Paleobathymetric reconstructions utilize geological observations (seismic, lithofacies, fossils) for the shelf and a combination of geological data and age-depth relationships for areas underpinned by oceanic crust. Fluidity-ICOM, an unstructured FE model was used to quantify the development of tidal mixing and tidal fronts. A low resolution coupled atmosphere-ocean general circulation model (HADCM3) was used to evaluate the development of seasonal stratification and GOTM, a 1D vertical ocean model was used to evaluate the impact of a suite of parameters (salinity, temperature, depth and atmospheric forcing) on water-body mixing.

A meshed representation of the bathymetry was created using the open source meshing tool QGIS-Meshing, https://github.com/adamcandy/QGIS-Meshing) and the tidal model was forced by the four principal tidal components, M2, S2, K1, and O1. Model output includes tidal range, tidal flow vectors and velocities and bed shear stress. An additional output is the Hunter-Simpson parameter, which is used to estimate the formation of tidal fronts. Tidal modelling is clearly dependent upon bathymetry and this was assessed through a series of sensitivity studies. However, the objective was not to predict the exact tidal range at a given point but rather to evaluate the broad impact of tides in the seaway. Tidal modelling results suggest the seaway was largely microtidal but that tidal bed-shear stress was elevated in embayments and over topographic highs. The results also show that tidal mixing in the seaway was limited to narrow coastal regions and the

ocean facing entrance to the seaway and had little influence in the seaway interior. HADCM3 results however, show that the seaway was predominantly seasonally stratified in summer when solar heating had increased and tended to be better mixed in winter. GOTM was used to evaluate a broad range of environmental parameters to determine the conditions that might lead to permanent stratification in epicontinental seas. Preliminary GOTM results suggest that permanent stratification is very difficult to establish in seaways less than 150m deep with seasonal stratification being the norm. Results suggest that there was nowhere in the seaway that was permanently stratified. Permanent water-body stratification has often been invoked to account for the formation of organic rich laminated black shales deposited in oxygen deficient settings. We note however that ancient black shales often contain evidence of brief oxygenation events (e.g. Wignall 1989) and that permanent seaway-wide stratification is likely to lead to nutrient depletion and reduced productivity. Seasonal mixing is important because it is an effective way of transporting nutrients to the productive upper layers of the water column. We argue that seasonal stratification was likely to have been the norm in ancient epicontinental seas.

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