At the Castle Creek study area in B.C., Canada, levee deposits of the Neoproterozoic Windermere Supergroup are vertically dipping and exceptionally well exposed due to glacial polishing, allowing for detailed observations to be made at scales ranging from millimeters to hundreds of meters vertically and along strike. This makes comprehensive examination and description of lateral and vertical lithological variation and stratal geometries possible, which is critical to understanding and modelling depositional processes and reservoir geometry and continuity. In addition, mudstone samples can be used for various geochemical analyses, including total organic carbon (TOC), elemental geochemistry, and stable isotope analysis.

Results and Observations

TOC ranges from 0.04 – 1.7% in levee deposits at Castle Creek. These values are uncorrected for the effects of greenschist metamorphism, which is estimated to have resulted in the loss of 50 – 75% of the original organic material (Smith, 2009; Hayes et al., 1983), indicating that depositional values may initially have been as high as almost 7%. High TOC was recorded in both mud-rich and sand-rich facies (Figure 1) but is less common in sand-rich strata. Sand beds with elevated TOC are usually carbonate-cemented Tbcde turbidites with distinctive black interlaminae. Analysis of these strata using a scanning electron microscope (SEM) shows that carbon occurs in three main forms: (i) discrete sand-sized amorphous particles; (ii) sand-sized organomineralic aggregates; and (iii) nano-scale carbon coatings on clay grains. The amorphous carbon particles and organomineralic aggregates are interpreted to be detrital grains sourced from disaggregated bacterial mats that grew on the continental shelf before being remobilized downslope by turbidity currents. However, carbon in these coarser-grained forms is relatively uncommon; they are absent in mudstones and only occur as very dispersed particles in sand-rich strata. Additionally, the black interlaminae, where organic matter is intuitively assumed to be concentrated, are instead composed principally of clay minerals with abundant dispersed silt and sand-sized quartz grains. Many of the clay minerals in these bands, in addition to those that comprise other organic-rich levee mudstones in the study area, are surrounded by nanometer-scale black rims related to adsorbed carbon-rich films on clay mineral surfaces, and therein the primary occurrence of organic carbon in these rocks (Figure 2). This organic material is interpreted to have originated as freely suspended micro- and nano-scale organic compounds and extracellular polymeric substances (EPS) that made up part of the dissolved organic carbon pool in the upper water column over the continental shelf and further offshore. These particles then became physically adhered and/or chemically adsorbed onto the surface of clay minerals and subsequently were resedimented by suspension settling and active transport into the deep sea. Accumulation by suspension settling would have been slow and also more or less uniform across the seafloor. However in the case of active transport, due to their low density, organic material and fine-grained clay minerals would be preferentially transported in the upper portion of turbidity currents, and hence be more likely to overspill the channel margin and become concentrated in the levees, where because of high sedimentation rates become rapidly buried and therefore protected from extensive oxidative and microbial degradation (Figure 3).

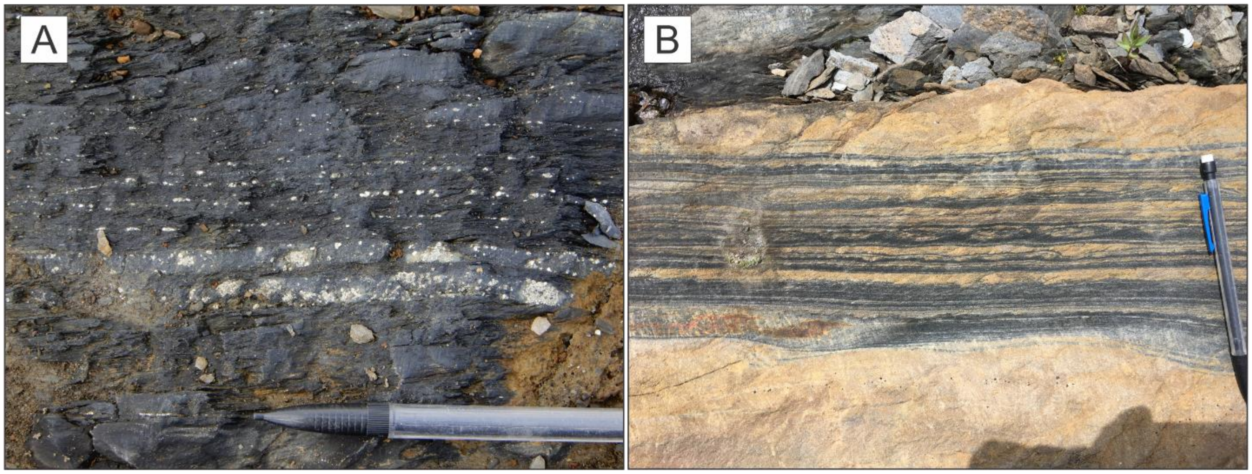

Figure 1. A) Outcrop photo of an organic-rich levee mudstone with abundant framboidal pyrite. B) Outcrop photo of an organic-rich sandstone – organic carbon is concentrated within the black laminae and is closely associated with clay minerals.

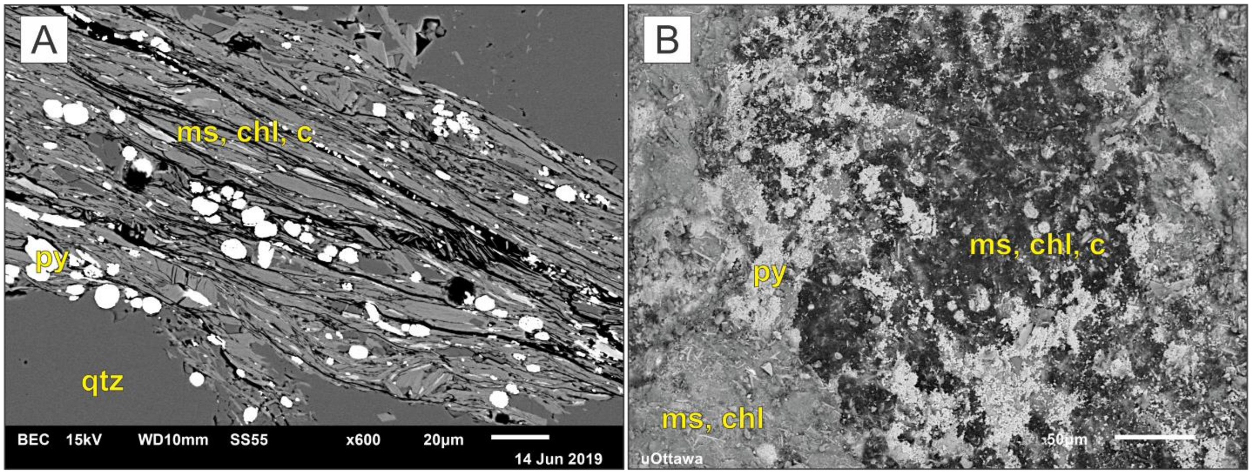

Figure 2. A) Backscattered electron micrograph of an organic-rich sandy claystone (perpendicular to bedding). Nano-scale rims of carbon (black) surround most of the clay particles (muscovite, chlorite). B) Backscattered electron micrograph of an organic-rich mudstone (parallel to bedding). Clay particles (dark grey, cloudy to needle-like in appearance) and framboidal pyrite (light grey) surrounded by organic carbon (black).

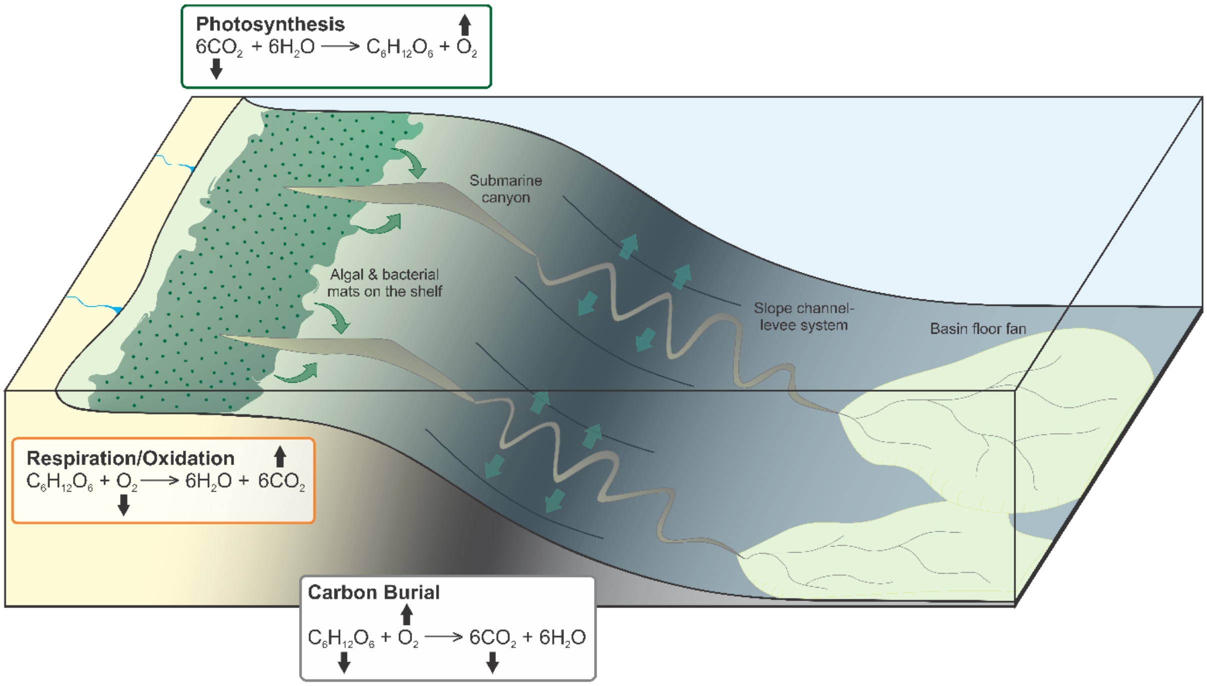

Figure 3. Depositional model showing the origin, transport, and deposition of organic material from the shelf to deep-marine leveed slope channels, and the relative impact of this process on the carbon budget (arrows indicate which products are consumed or released in each process).

Conclusions

Levees are major depocenters of organic material, which is sequestered in both mudstones and sandstones in a variety of forms, but which predominantly occurs as nano-scale carbon films adsorbed onto clay mineral surfaces. Depositional TOC values high enough to be of potential economic value have been measured throughout levee strata at Castle Creek, which, combined with the expansive area covered by levee deposits, represents a significant reservoir for organic carbon and potential hydrocarbon source rocks. The combination of high-quality outcrop data and advanced geochemical analyses will improve our understanding of carbon sequestration and cycling within these complex deep marine slope systems, and therein have important implications for assessing and quantifying hydrocarbon source rock potential.

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