Core Examples from Modern Estuarine Tidal Bars, Tillamook Bay, Oregon, USA*

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Abstract

Tidal sand bars are ideal estuarine morphologic features to use as modern analogues in understanding the complex sediment distribution of ancient estuarine environments, many of which host large hydrocarbon resources (e.g. McMurray Formation in Alberta). Tidal bars may accrete both laterally and vertically, resulting in complex stratal geometries and sediment distributions. Heterolithic Stratification and Inclined Heterolithic Stratification (Thomas et. al, 1987) are common characteristics of inner and middle estuary tidal bars at Tillamook Bay. Due to changes in sediment source, and the interplay between tidal and fluvial currents and sediment reworking, large variations appear in the sedimentological and ichnological character of Inclined Heterolithic Stratification (IHS). At Tillamook Bay, IHS is observed in the inner and middle estuary, being the most prominent in the middle estuary bars. In the outer estuary bars, IHS is largely absent and not recognized.

Study Area

Tillamook Bay is located on the coastline of the state of Oregon, United States, approximately 100 km west of the city of Portland (Figure 1). It is a restricted bay, separated from the Pacific Ocean by the 5 km long Bayocean Peninsula. The bay is approximately 10 km long in a northwest-southeast direction and 3.4 km wide, but averages only 2 meters depth over a 34 km^2 area. It is a mesotidal estuary, with a mean tidal range of 1.7 m and a diurnal range of 2.3 m. Five major rivers, comprising a watershed of 1,546 km^2, deliver sediment to Tillamook Bay. Four of the rivers enter the bay at the southeast part and deliver the vast majority of mud and sand found within the inner and middle estuary. The outer estuary consists of clean, well-sorted sands, both of marine and terrestrial origin (Komar, 1997, and Komar et. al. 2004).

The inner estuary is characterized by dominantly muddy channel fills and alternating layers of medium sand and mud at the river mouths. More complex sediment distributions are characteristic of the middle estuary mixed sand and mud IHS; the middle estuary deposits are also the most intensely bioturbated. The clean, well-sorted sands of the outer estuary are sparsely bioturbated.

Methods

Twenty-four cores were collected in the summer of 2011. Core locations are indicated in Figure 2, with the exception of three cores, which were collected further upstream in the inner estuary river channels, and lie outside of the map area. Nine cores were selected as examples for this core presentation, and their locations are indicated in Figure 2. Seven of the nine cores were selected from locations in the inner and middle estuary, due to the complexity of deposits found there, and therefore the higher amount of information that can be discussed. Cores were collected through vibracoring using 3-meter long, 8 cm inside diameter, aluminum pipes. Recovery ranged from as much as 2.5 meters in the middle estuary, to as little as one meter in the outer estuary. In the university lab, the pipes were cut longitudinally in half; the sediment in one half was x-rayed and sampled for grain size and total organic carbon (TOC) analyses, and the sediment in the other half was photographed and described. Sandmud ratios were calculated, and sedimentological and neoichnological characteristics were observed and described. Neoichnological characteristics and related bioturbation intensity were assigned a bioturbation index (BI) ranging from 0-6, as suggested by Reineck (1963) and modified by Taylor and Goldring (1993).

Examples

The inner estuary channels in the southeastern part of the bay are mud-dominated and lack bioturbation. At the river mouths of the inner estuary, poorly sorted, coarse and medium-grained sands mixed with mud (Figure 3) are observed locally in the form of inclined heterolithic stratification (IHS). In this portion, bioturbation diversity and intensity are low, and appear mostly in the form of *Thallasinoides* and *Arenicolites*. The grain size decreases gradually and the sands become better sorted in the inner to middle estuary transition zone.

The middle estuary is characterized by dominantly mixed fine sand and mud (Figure 4). Bioturbation intensity in the IHS deposits increases away from tidal channels and upwards into current and wave-rippled, bioturbated tidal flat deposits. Middle estuary bioturbation consists of a high-diversity, high-abundance suite of *Skolithos*, *Thallasinoides*, *Arenicolites*, *Planolites*, *Paleophycos*, and *Siphonichnus*. Bioturbation intensity is moderate to high in the middle estuary, with a bioturbation index (BI) commonly ranging from two to five in this portion.

Outer estuary bioturbation diversity is moderate, appearing mainly in the form of Skolithos and Siphonichnus. The BI ranges from 0 to 3. The sand bars in the outer estuary are smaller in total volume due to a larger tidal prism in this portion, relative to the inner and middle estuary bars. However, both tides and waves influence the outer estuary bars and, as a result, the bars contain clean, well-sorted medium-grained sands (Figure 4) with very low mud content, observed as low-relief dunes and low-relief megaripples.

Reservoir Analog

Complex stratal geometries of Inclined Heterolithic Stratification are observed in the inner and middle estuary part of Tillamook Bay, but not in the outer estuary. In the inner estuary, poorly sorted, medium and coarse-grained sands mixed with mud, would have reduced permeability and porosity in an ancient, subsurface reservoir. Bars of the inner estuary would be the most likely to be preserved during a transgression, because of their location. Compared to middle estuary bars, inner estuary bars would provide a reservoir with better properties, but smaller overall volume.

The fine-grained, well-sorted sands mixed with mud that characterize the IHS deposits of the middle estuary, would have more greatly reduced porosity and permeability, due to a high percentage of mud present. The reduction in reservoir quality would be counterbalanced by the total volume of middle estuary bars, which is significantly greater than the volume of both inner and outer estuary bars.

The outer estuary at Tillamook Bay lacks IHS. The clean, well-sorted, medium sands of the outer estuary bars would be ideal hydrocarbon reservoirs. However, due to the high tidal prism in this part of the estuary, the total volume of the sand bars is greatly restricted. In addition, the outer estuary bars would be most susceptible to erosion during a transgression, and while characterized by high quality reservoir properties, could become uneconomical to exploit if their volume is greatly reduced.

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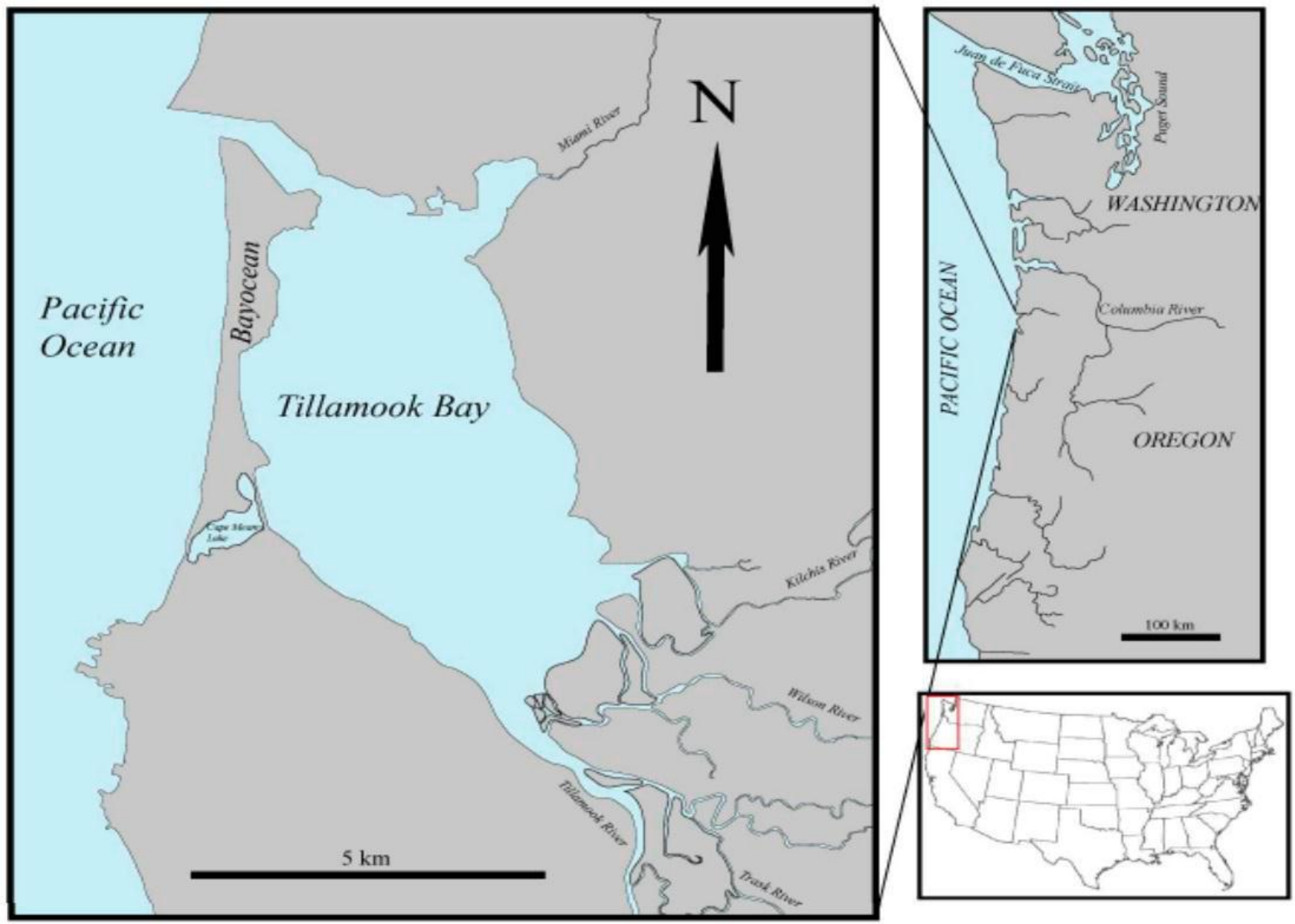

Figure 1. Location of Tillamook Bay, Oregon, United States.

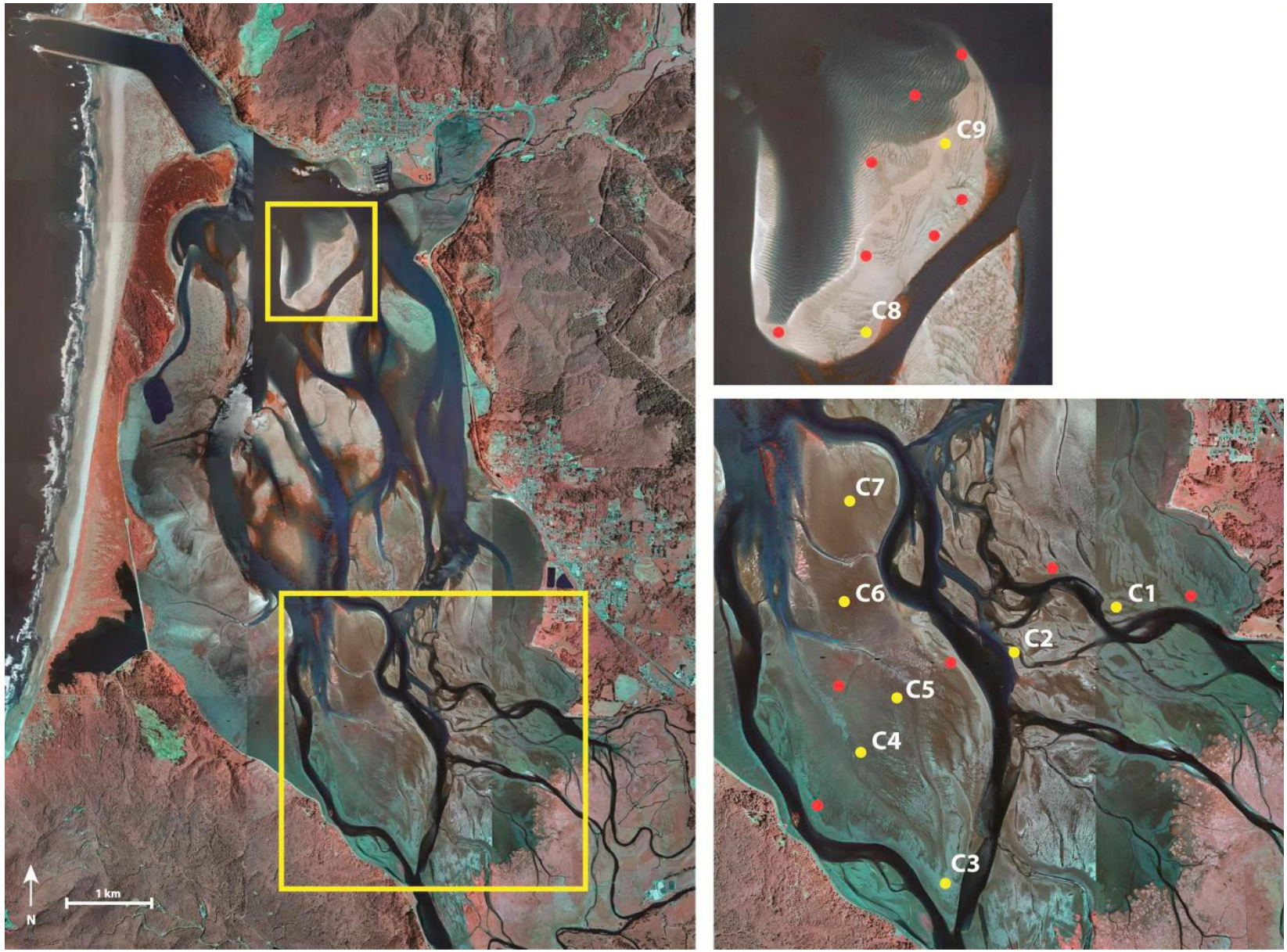

Figure 2. Locations of 21 cores collected at Tillamook Bay in summer 2011. The locations marked in yellow and labeled with a core location (e.g. C1 = Core 1) are included in this presentation. All other cores, which were collected but are not included in the presentation, are marked in red. Intertidal color infrared aerial mosaic courtesy of Oregon Department of Land Conservation and Development (DLCD).

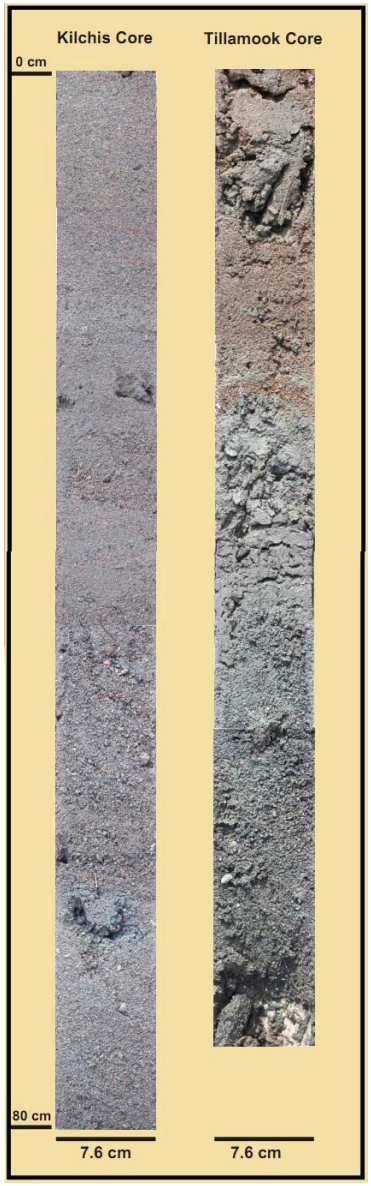

Figure 3. Inner estuary core examples from the river mouths of two rivers that flow into Tillamook Bay, Kilchis River and Tillamook River. Note the poor sorting of the sands, and relatively small percentage of mud present. Wood fragments can also be observed, especially in the core collected at the mouth of the Tillamook River. The Kilchis core was collected to the right of core C1 in Figure 2. The Tillamook core location lies south of the map view in Figure 2.

Figure 4. Middle estuary and outer estuary core examples. Note the complex Inclined Heterolithic Stratification observed in the core example from the middle estuary, and the high percentage of mud present. The relatively large features seen in this core are shell and wood fragments. The core example from the outer estuary shows the clean, well-sorted medium sands. The grey, anoxic layer is observed in the bottom half of this core.