HISTORICAL EVOLUTION OF THE COLUMBIA RIVER LITTORAL CELL BARRIERS

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INTRODUCTION

This abstract is based on Kaminsky *et al.*, 1999. It summarizes a synthesis of geological observations, morphodynamic changes, and processes modeling to explain the historical coastal evolution of the Columbia River littoral cell. The synthesis draws from analyses of historical shoreline and bathymetric changes, and subsurface stratigraphy. The spatial and temporal scales of change caused by both natural and human influences are quantified and compared. The results indicate that the Columbia River littoral cell is a highly dynamic coastal system that naturally evolves in response to large magnitude episodic events as well as frequent high energy forcing conditions. Human impacts, and particularly the installation of jetties at the entrances to the Columbia River and Grays Harbor during the early 1900s, have dramatically influenced the evolution of the littoral cell. The integration of diverse data sets and the synthesis of their analyses enable the development of conceptual models and predictive capabilities of the coastal evolution of the Columbia River littoral cell.

HISTORICAL EVOLUTION OF THE CRLC

The U.S. Coast & Geodetic Survey topographic surveys (NOS T-Sheets) of 1868 mark the beginning of the historical period for reliable data in the Columbia River littoral cell. Previous maps and topographic surveys since the late 1700s lack adequate control for use in quantitative change analysis. However, through geological investigations, a well-constrained 1700 shoreline position (erosion scarp) from an earthquake-induced subsidence event has been mapped (Woxell, 1998; Peterson *et al.*, 1999). This time line allows for the comparison of change over the historical period with the recent prehistoric period to obtain a quantitative assessment of coastal evolution. Over the historical period, shoreline progradation rates are typically an order of magnitude greater, and are up to two orders of magnitude greater along reaches adjacent to the estuary entrances. In addition, the historical shoreline change rates have much larger alongshore gradients over the length of the sub-cells.

In each of the sub-cells, the coastal plains accreted rapidly within a few decades of jetty construction at the entrances to the Columbia River and Grays Harbor in the early 1900s. Clatsop Spit accreted over 7 km^2 of land within 5 km of the Columbia River South Jetty, and shoreline progradation rates typically jumped from 0.5 m/yr to 5m/yr or more along the Clatsop Plains sub-cell. North of the Columbia River, a pocket beach quickly developed, accreting nearly 4 km^2 of land between the Columbia River North Jetty and North Head, 3.5 km to the north. In stark contrast to the shoreline progradation rates of 0.1 m/yr or less between 1700 and the 1870s, the southern half of Long Beach Peninsula experienced a major accretionary period, prograding at rates of 4-6 m/yr. Along the

Grayland Plains, shoreline progradation rates jumped from 1.2 m/yr to 5 m/yr. The North Beach sub-cell prograded rapidly along its southern end, accreting approximately 8 km^2 of land within 6 km of the Grays Harbor North Jetty, with decreasing rates of accretion over tens of kilometers toward Point Grenville.

The sediment accumulation rates over the historical period along the littoral cell reveal higher accumulation rates during the early historical period compared to the period since the 1950s. The largest differences in accumulation rates between the periods are generally closest to the estuary entrances. Prior to the jetty installation, ebb-tidal currents are assumed to have been in equilibrium with existing wave forcing and sediment budget, resulting in broad, shallow ebb-tidal deltas extending on the order of 5 km seaward from the shoreline of the estuary entrances. The jetties at both the Columbia River and Grays Harbor were built on these shallow delta plains to constrict the inlet flow and scour the entrance channel for navigation purposes. Over the course of several decades, the increased ebb-tidal flows pushed the center of the deltas farther offshore, and waves forced large volumes of sediment onshore from the flanks of the ebb-tidal deltas, where tidal inlet currents were no longer present.

The post-jetty historical shoreline change rates show a highly dynamic shoreline with kilometer scale variability, nonlinear long-term trends, and trend reversals as shown in Figures 1 and 2. It is evident that the jetties have influenced accretion and possibly erosion patterns on the beaches over distances of tens of kilometers. It is also apparent that accretion rates along the entire littoral cell have generally slowed since the 1926 - 1950s period. During the most recent period, high erosion rates occur adjacent to the jetties, where the beaches had previously accreted most rapidly. Through time, all of these erosion sites have either increasing erosion rates or an expanding spatial scale of erosion along the shoreline or both.

These large scale coastal change patterns and the accumulation of sediment can not be explained by a simple model of longshore sediment transport accumulating against an imposed boundary. For example, along the southern Long Beach Peninsula, both geologic data and wave refraction modeling suggest a dominant net northward flux of sediment. The sediment accumulation adjacent to the jetties over the historical period does not merely represent the trapping of sediment by the jetties, but rather sediment transport from its ebb-tidal delta source. Preliminary modeling results in each sub-cell indicate that the areas near the jetties tend to have the highest sediment-transport rates.

Summary of Historical Observations

The changes in shoreline progradation rates that have occurred throughout the littoral cell are coupled with equally striking reversals in shoreline change trends. The installation of jetties resulted in sediment accumulation on the coastal plains supplied in part by erosion of the extensive tidal inlet shoals. Within the past few decades, the areas adjacent to the jetties have experienced chronic erosion conditions. Presently the ebb-tidal deltas of Grays Harbor and the Columbia River appear to be essentially decoupled from the littoral zone. The overall changes in shoreline orientation and inlet morphology, and the deepening of the adjacent shorefaces appears to have significantly affected the distribution of Columbia River sediment throughout the littoral cell. The modern sediment pathways, fluxes, and compartment volumes that comprise the littoral cell sediment budget may in fact be quite different from that of the late Holocene.

SHORELINE CHANGE MODELING

Among the most challenging tasks in the study is the development of a predictive capability of coastal change. It remains difficult to determine whether the estuary entrances, ebb-tidal deltas, and adjacent shorelines of Grays Harbor and the Columbia River are approaching an equilibrium condition from the jetty-induced perturbations of the early 1900s. In addition, the ongoing changes in Columbia River sediment supply and other factors such as climate change or relative sea-level change, may be independently influencing the behaviour of the shoreline. Since both the late prehistoric and early historical periods show shoreline behaviour patterns that differ significantly from the present trends, it is especially important to have an understanding of the mechanisms and influences driving coastal change. A simple extrapolation of historical shoreline change trends in this region could potentially be wrong in both magnitude and direction. A more detailed investigation of historical shoreline change and more sophisticated techniques for predicting future shoreline position are therefore warranted.

A major question to evaluate is whether recent regional-scale shoreline change rates indicate a long-term trend of slowing shoreline progradation that may manifest as a future erosion trend or if the shoreline is adjusting to a dynamically stable position. Various modeling tools are being applied to simulate the long-term morphologic change and quantitatively evaluate conceptual models. The initial efforts are derived from the model formulation and implementation process that allows testing of hypotheses and diagnosing trends, patterns and variability in the system response to different input conditions. The optimized output results may be preliminary, but they can be refined as additional data and knowledge are obtained and other approaches are applied.

SUMMARY

The Columbia River littoral cell functions as a large-scale morphodynamic system with controlling variables such as sediment supply, regional tectonics, climatic forcing, and especially human intervention. There are a number of significant results and observations that can be synthesized to present a coherent understanding of the behaviour of the Columbia River littoral cell. The diversity of data sets and the multi-scale systems approach taken in the study has enabled the development of a conceptual working model to be refined through continued data collection, analyses, integration, and modeling applications. The application and integration of modeling approaches including both top down geological-based models and bottom up process-based models should advance capabilities for predicting management scale coastal evolution.

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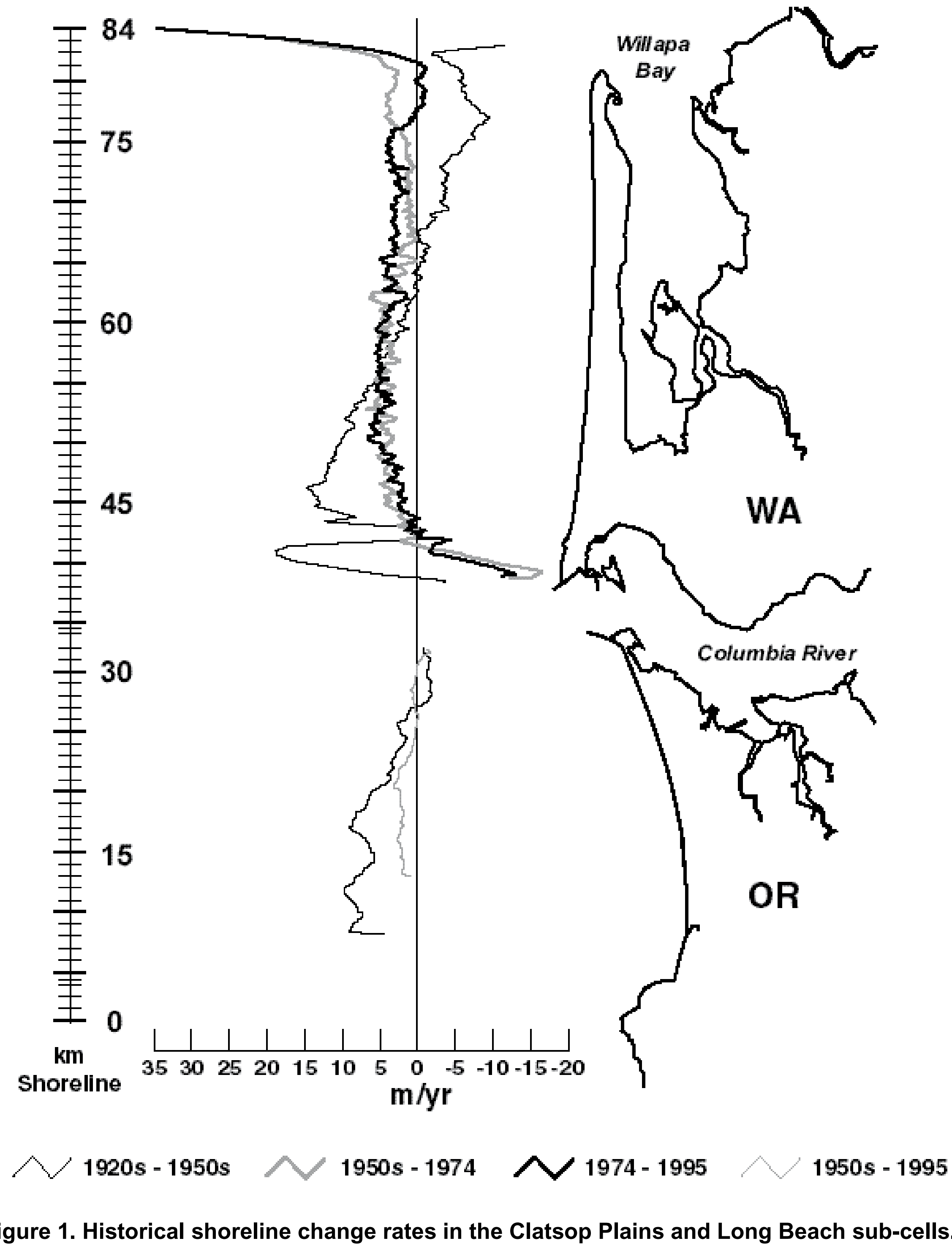

Figure 1. Historical shoreline change rates in the Clatsop Plains and Long Beach sub-cells.

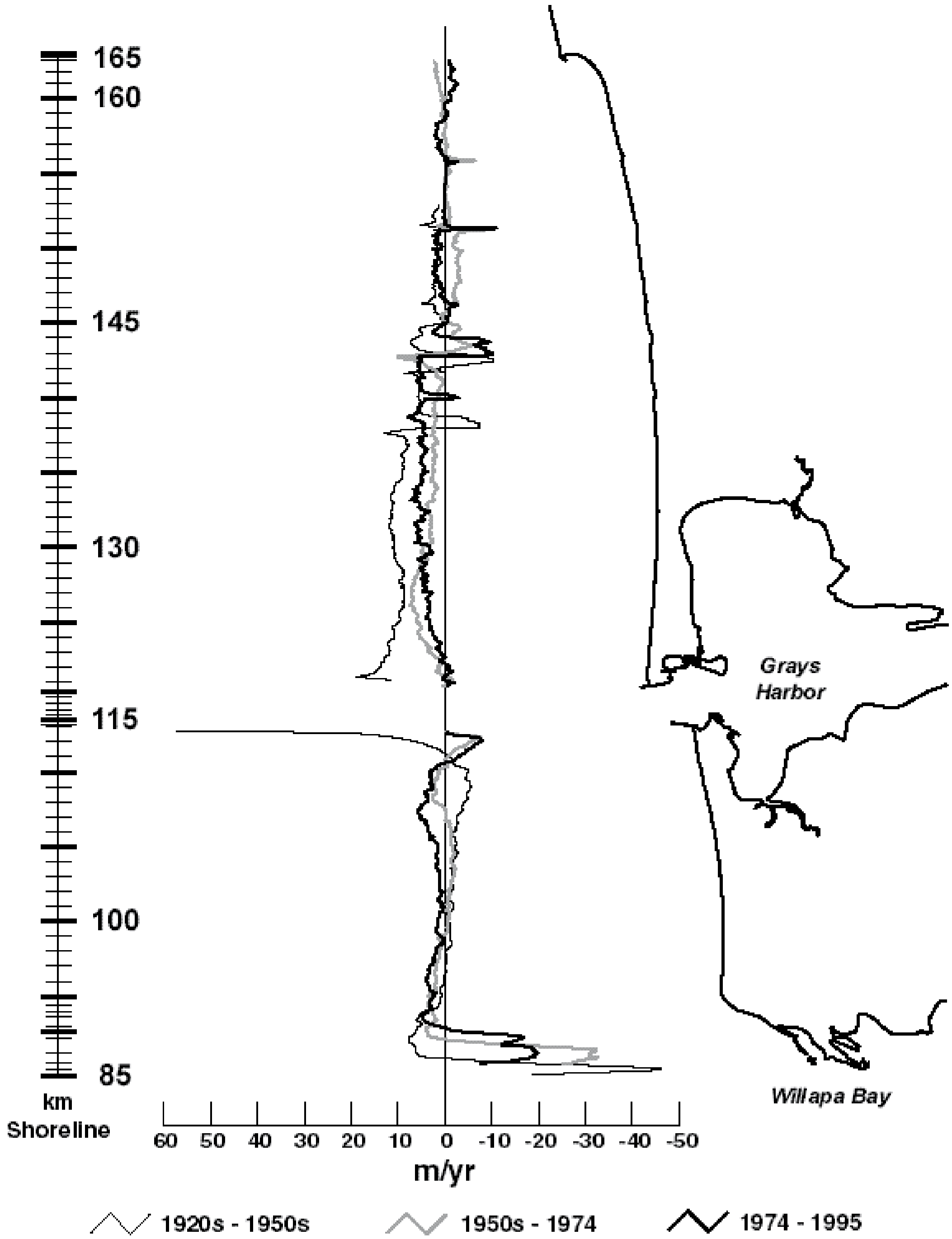

Figure 2. Historical shoreline change rates in the Grayland Plains and North Beach sub-cells.