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Climate shift at 4400 years BP: Evidence from high-resolution diatom stratigraphy, Effingham Inlet, British Columbia, Canada

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Abstract

Diatom paleoecology and climatic interpretations were assessed from a 15-cm long laminated sediment slab extracted from an anoxic fjord in southwest British Columbia. The slab spans at least 62 years of deposition, determined from counting varves, and is dated at approximately 4400 years BP. The slab shows a sedimentation pattern where thick diatom-rich varves at the bottom become thinner and more silty toward the top. Thin section analysis reveals that the thicker varves contain a distinct succession of diatoms, representing seasonal deposition throughout each year. Annual-scale subsampling shows that the abundance of coastal marine diatoms, namely a weakly silicified form of *Skeletonema costatum*, decreased over the 62-year period, while benthic and brackish water diatoms, such as *Planothidium delicatulum* and *Achnanthes minutissima*, increased with the concomitant increase in silt. The increase in such benthic species and silt, along with the presence of ~1 cm thick nonlaminated intervals, is interpreted to represent deposition during progressively increasing precipitation over time. These sedimentation patterns and changes in diatom assemblages may signify a change in the relative intensities of the Aleutian Low (AL) and North Pacific High (NPH) atmospheric pressure systems. Thicker diatomaceous varves at the bottom of the slab reflect a stronger NPH system with associated coastal upwelling and enhanced diatom production. The thinner silty varves at the top of the slab suggest that the AL system was prevalent, resulting in greater amounts of precipitation and reduced upwelling. The findings of this study show that significant natural environmental change can occur within a twenty-year time frame, and can provide a basis for the study of modern change in the ocean–atmosphere system over the northeast Pacific Ocean.

Keywords: Diatoms; Laminated sediments; Paleoecology; Stratigraphy; Climate change; Oceanography; Holocene; Northeast Pacific

1. Introduction

Assessing modern climate and environmental change is of utmost importance as society becomes increasingly aware of the sensitive balance in natural systems. In the 21st century, understanding the

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causal factors involved in rapid (decadal to bidecadal) change can be challenging because anthropogenic and natural signals need to be differentiated. Although instrumental records exist for the last ~150 years and can be compared to contemporary sediments to determine the relationship between climate, primary production and depositional patterns, these modern sediment records can be tainted from the effects of industrialization. Hence, older sediments from the pre-industrial era must be used to provide a natural baseline.

Large-scale ocean–atmosphere oscillations such as the El Niño-Southern Oscillation, the Pacific Decadal Oscillation (Mantua et al., 1997) and the 50–70 year oscillation (Minobe, 1999) can have a profound influence on climate over the northeast Pacific Ocean and biological production off the coast of British Columbia. For 20th century records, primary production and fish migratory patterns were observed to oscillate between warm and cool climate phases in the northern Pacific (Mantua et al., 1997; Chavez et al., 2003). These shifts in production have a major impact on coastal communities that rely on the commercial harvesting of economic fish species. It is therefore important to understand the causes and timing of these productivity cycles. One way to investigate this issue is to determine whether such changes have occurred previously, or are recurring phenomena, by looking into the sediment record. Recent studies of finely laminated sediments in the fjords of Vancouver Island, British Columbia, have utilized high-resolution imaging and/or statistical techniques in order to resolve late Holocene depositional and climate patterns (e.g., Dean et al., 2001; Chang et al., 2003; Dean and Kemp, 2004; Patterson et al., 2004a). These studies reveal that there are a multitude of climate cycles that have left an imprint within the sediments for at least the last 4500 years.

In this paper, we examine a high-resolution laminated sediment record and primary production proxy from Effingham Inlet, southwest Vancouver Island, by determining diatom abundance and assemblages and measuring changes in lamina thickness. Thin sections and successive annual samples were extracted from a 15-cm long sediment slab that encompasses at least 62 years of deposition and was dated at approximately 4400 years BP (Chang et al., 2003). The objectives of this study are to (1) describe the seasonal components of the sediments from thin section analysis, (2) present quantitative results from the enumeration of diatoms, and (3) interpret past climatic and oceanographic trends derived from the sedimentation patterns and diatom assemblages. The results of this study should be able to provide a foundation for comparison to modern sediments from similar depositional environments.

2. Regional climate and oceanography today

The modern coastal climate of southwest Vancouver Island is cool-temperate and precipitation can reach up to 250 cm annually (Ryder, 1989). Winters are relatively cool and rainy, and the coastal region is affected by a succession of frontal systems associated with cyclonic storms. Coastal air temperatures are mild, ranging from 1 to 5 °C. Summers are relatively warmer and drier, and the coastal region is influenced by large anticyclonic systems. Air temperatures can reach up to 20 °C.

The dominant surface currents seaward of the continental slope of North America are the northward-flowing Alaska Current and the southward-flowing California Current (Thomson, 1981). Over the continental slope and outer shelf of Vancouver Island, the surface currents are seasonally variable in response to the prevailing winds (Fig. 1A). In the winter, the Northeast Pacific Coastal Current flows northwestward in response to winds associated with the counterclockwise circulation of the Aleutian Low (AL) atmospheric pressure system (Thomson, 1981; Thomson and Gower, 1998). In the summer, the current flows southeastward as the “shelf-break current” in response to winds associated with the clockwise circulation of the North Pacific High (NPH) pressure system (Thomson and Gower, 1998). Flow over the inner shelf is dominated by the buoyancy-driven Vancouver Island Coast Current (Thomson et al., 1989). This current is driven primarily by brackish water outflow from Juan de Fuca Strait and flows to the northwest throughout the year (Fig. 1B).

Wind-induced annual upwelling along the west coast of Vancouver Island is most prevalent from May through August. The upwelling extends seaward of the 200-m shelf break, with subsequent transport of deeper (>150 m) oxygenated and nutrient-rich slope waters onto the outer shelf (Thomson et al., 1989).