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Assessment of the historical trace metal contamination of sediments in the Elizabeth River, Virginia

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Abstract

Two sediment cores (Southern Branch, PC-1, and Western Branch, WB-2) were taken from the highly industrialized Elizabeth River, Virginia. The concentrations of trace metals cadmium, cobalt, chromium, copper, nickel, lead and zinc, major elements iron, manganese and aluminum, organic carbon content and the specific surface area of the sediments were determined in each of the cores. Down-core variations in metals varied significantly in each core with maximum contamination events occurring at different times in different portions of the river. In PC-1, maximum metal concentrations were seen after the appearance of ^{137}Cs. In contrast, the highest levels in WB-2 occurred well before the appearance of ^{137}Cs. Although stricter environmental regulations have caused a decrease in metal concentrations since the 1980s, the concentrations in the surface sediments of many trace metals were elevated to levels 2–5 times higher than the levels at the bottom of the cores in both the Southern and Western Branches of the river.

Keywords: Elizabeth River; Enrichment factor; Geochronology; Metals; Sediments

1. Introduction

The contamination of coastal systems through human activities has increased over the past years as population density has increased. Significant monitoring and restoration efforts of these impacted systems have been developed to provide managers with the scientific information needed to implement effective controls for remediation. To fully understand the anthropogenic impact on an ecosystem, long-term data from chemical, physical and biological indicators are needed. Carefully dated sediment cores can provide chronologies of contaminant concentrations and a record of the changes in concentrations of chemical indicators in the environment over time (Schropp et al., 1990; Hornberger et al., 1999). Because metals strongly associate with the surface of particles, their transport and deposition in estuarine and coastal systems are often closely related to the transport and deposition of fine-grained sediments (Olsen et al., 1982; Dzombak and Morel, 1987; Davis and Hem, 1989; Scheidigger et al., 1997; Bertsch and Seaman, 1999). In the absence of significant changes in sediment texture, trace metal accumulation rates in sediment cores can reflect variations in metal inputs in a given system over long periods of time.

The commonly observed historical pattern of trace metals in sediments distant from major sources of contamination is the initial occurrence of increased heavy metal concentrations in sediments beginning in the early 1800s followed by a larger increase in the 1900s. A sharp increase in metal concentrations is often seen between 1940 and 1970 followed by decreasing metal concentrations in subsequent decades (Owens and Cornwell, 1995; Ravichandran et al., 1995). This pattern reflects the onset and then steady increase in industrialization, with the recent decline reflecting the implementation of environmental laws such as the prohibition of lead as a gasoline additive. In the vicinity of direct sources of contamination, the historical variation

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in metals concentrations may be markedly different, reflecting the local influence of pollution sources.

The Elizabeth River is a tributary of the James River located in the southern portion of the Chesapeake Bay whose watershed includes the cities of Chesapeake, Norfolk, Portsmouth and Virginia Beach (Fig. 1). It is a highly industrialized estuary with an estimated 600,000 people inhabiting the 777 km^2 watershed. The entire river is subject to tidal forcings with a gradient of decreasing salinity as distance upstream (away from the Chesapeake Bay) increases. Salinity is generally lowest in the surface waters and increases with depth with the highest values in the near-bottom waters (Ewing et al., 1990). The morphology of the river has been greatly altered over the years. Originally a broad shallow estuary, the river channels have been dredged to 12–15 m, twice its normal depth, and its width has been decreased by 75% due to development of its shores. Over 50% of the adjacent wetland areas have been lost since WWII.

The Elizabeth River is the major deep-water port for the Hampton Roads Area and one of the largest naval bases in the United States. The most impacted section of the river is Paradise Creek which is located in the Southern Branch and drains 7.6 km^2 of the central portion of the City of Portsmouth (Johnson and Villa, 1976; Conrad and Chisholm-Brause, 2004). Land use along the shores of this region is primarily industrial and includes oil terminals, shipyard installations, coal transloading facilities, petroleum distribution and shipment operations, and wood treatment facilities (Fig. 1). US Naval operations began in this portion of the river in 1787 and dredging began in 1900 (Fig. 2). This portion of the river is also more confined than other branches of the river leading to increased residence times of contaminants in this region (Ewing et al., 1990). In contrast, the Western Branch is primarily a residential area that is readily flushed with little industrial activity resulting in lower levels of both organic and metal contaminants in its waters and sediments.

The historical industrial and commercial development along the river has lead to increased contaminant loads to the sediments (Fig. 2). Dangerous levels of metal and organic contaminants in the sediments of the Elizabeth River have lead to its designation as a toxic hot spot by the Environmental Protection Agency. Metals concentrations in surface sediments from the Elizabeth River have been studied extensively over the years and have been documented to be up to 10 times higher than baseline levels for the lower Chesapeake Bay area (Sinex and Helz, 1981; Rule, 1986; Conrad and Chisholm-Brause, 2004). Specifically, Cu, Pb and Zn are all found at elevated levels within most portions of the Mainstem and Southern Branch of the river. However, the historical levels of contamination in the river are not well known, and few studies have been carried out in shallow estuaries that are highly industrialized

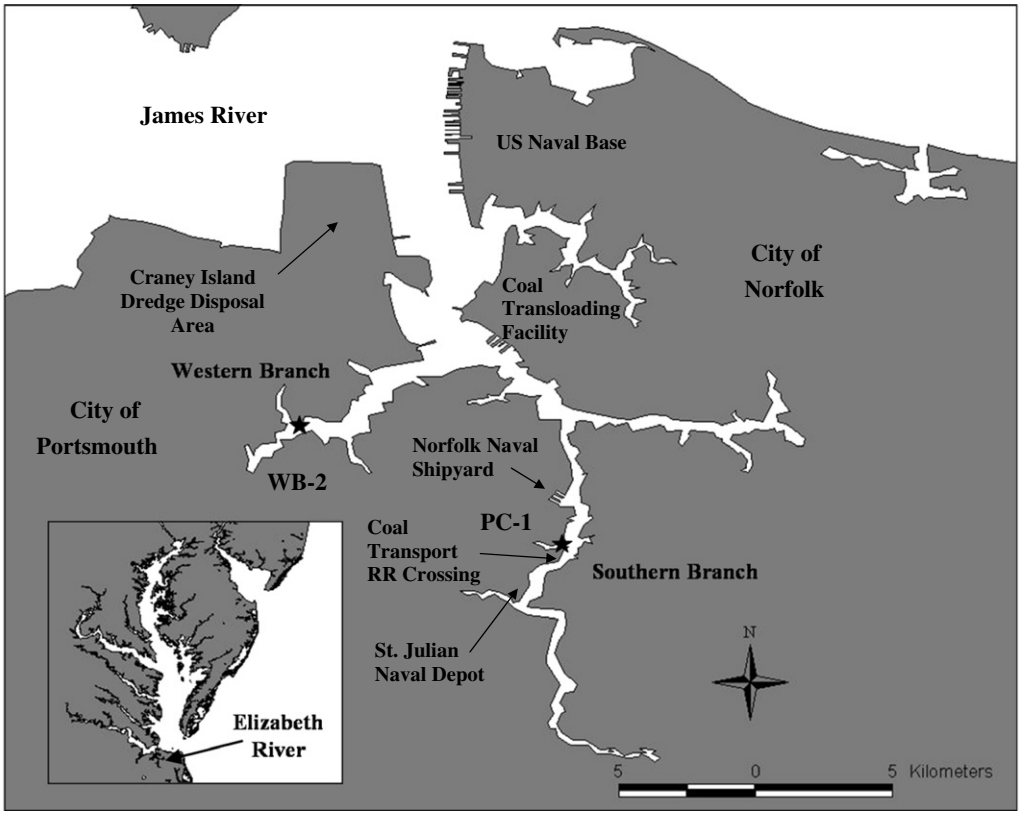

Fig. 1. Map of the Elizabeth River subestuary system located in the Southern Chesapeake Bay on the East coast of Mid-Atlantic United States. The locations of the two sediment cores, PC-1 and WB-2, are starred on the map. Other important sites throughout the system are also detailed.