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Sediment dynamics and hydrographic conditions during storm passage, Waquoit Bay, Massachusetts

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ABSTRACT

The impact of storm events on the sediment dynamics of the shallow groundwater fed estuaries of Cape Cod, Massachusetts, USA is little understood. To address this, the objectives of this study are to assess sediment dynamics during storm passage and determine whether shallow back-barrier lagoons like Waquoit Bay have the preservation potential for a sedimentary archive of hurricanes. When setting out in this study, it was unclear whether paleotempestological methods could be applied successfully to cores collected from the landward reaches of shallow estuaries of southern New England. Water level and bottom current data using Arm-and-Float tide gauges and SeaHorse Tilt Current Meters was collected during Tropical Storm Irene (2011) and coupled with storm surge modeling projections to better elucidate storm-induced sediment transport mechanisms. Three sediment cores were collected at the head of Waquoit Bay, located 2.8 km from the barrier beach. Grain size analysis of sediment cores was conducted with a laser particle size analyzer at 1 cm increments in order to identify coarse grain anomalies, which can act as a storm event proxy. Bayesian statistics were applied to develop age models of two of the cores based on three Pb pollution chronomarkers and 21 continuous flow ^{14}C AMS ages. The results yield variable sediment accumulation rates between 2 mm/yr to 10 mm/yr, with significantly higher rates occurring in the upper 1 m of sediments. Grain size results are highly variable, and contain numerous large amplitude, short duration fluctuations suggesting that during storm passage coarse sand is deposited in the coring site. The sensitivity of the site to both tropical and extratropical storm events, uncertainties in the age model, and the multiple sediment sources and transport pathways limits the utility of using the Waquoit sediments to determine long-term hurricane frequencies. Results nonetheless provide insights into how extreme storm events impact coastal lagoons.

1. Introduction

1.1. Background

For millennia extreme storm events have impacted the New England coastline resulting in catastrophic alterations of coastal systems with significant loss of life and resources (Ludlum, 1963; Boose et al., 2001; Donnelly et al., 2001; Emanuel, 2005; Boldt et al., 2010; Maio et al., 2014, 2015). The dramatic rise in coastal populations during the 20th century (Kelley et al., 1989), coupled with increasing rates of sea-level rise (SLR) (Pachauri et al., 2014; FitzGerald et al., 2008; Kemp et al., 2009), is resulting in increasing vulnerability of millions of people and critical infrastructure along the U.S. northeast coast to future storm events (Kirshen et al., 2007; Woodruff et al., 2013; Brandon et al., 2014). Due to these factors it is important to gain a better understanding of how storm events impact sediment and hydrographic conditions within lagoon systems along populated coastlines.

The environmental role of episodic storm events can only be understood by assessing their individual and collective impacts over centennial to millennial temporal scales and at both local and regional spatial extents. This can be achieved by examining the sedimentary records and incorporating hydrographic measurements and storm surge modeling. A short instrumental and incomplete historical record make understanding long-term trends in storminess difficult, and necessitates the development of paleo-proxy records based on sedimentary data that identify prehistoric storm induced coarse grain event beds (Liu and

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Fearn, 2000; Donnelly et al., 2001, 2015; Buynevich et al., 2004; Boldt et al., 2010; Lane et al., 2011; Brandon et al., 2014). The study of prehistoric tropical cyclones based on geologic proxies and historical records, known as "paleotempestology," provides methods to address this gap in knowledge by elucidating local sediment dynamics during storm passage and providing late Holocene chronologies of hurricane events (Emanuel, 1988; Nott, 2004; Nott et al., 2007; Woodruff et al., 2008: Wallace et al., 2014). Previous paleotempestological studies have shown that sedimentary archives of past hurricane events have been well preserved in some back-barrier environments as coarse grain horizons interbedded with finer sediments (peat, mud, and silt) (Emery, 1969; Liu and Fearn, 1993; Donnelly et al., 2001, 2015; Donnelly and Woodruff, 2007; Scileppi and Donnelly, 2007; Woodruff et al., 2008; Brandon et al., 2014). However, not all locations are suitable for storm reconstructions and therefore efforts to identify viable study sites is an important component to advancing the science (Wallace et al., 2014).

An important component for determining the feasibility of applying paleotempestological methods to the shallow groundwater fed estuaries of Cape Cod is developing a better understanding of the sediment dynamics operating during storm passage. This study will address three questions in regard to the Waquoit Bay lagoon system including:

1) During extreme storm events what are the hydrographic conditions impacting sediment transport pathways?

2) What are the sediment sources and transport pathways that contribute to coarse sand deposition within the north basin?

3) Do the sediments in the north basin archive a record of past storm events that can be used to calculate long-term hurricane frequencies?

1.2. Regional setting

Waquoit Bay is located on the south shore of Cape Cod within the towns of Falmouth and Mashpee, Massachusetts, approximately 90 km southeast of Boston (Fig. 1). The geologic framework of the lagoon consists of reworked glacial sediments. During the end of the Wisconsin Glacial Period, the Laurentide Ice Sheet reached its southern terminus at the islands of Nantucket and Martha's Vineyard approximately 23,000 ybp (Balco and Schaefer, 2006). The subsequent coastal evolution of southeast Massachusetts occurred in response to the melting and northward retreat of the ice sheet beginning approximately 18,000 ybp (Gutierrez et al., 2003; Oldale, 1992; Uchupi and Mulligan, 2006). Flow of meltwater resulted in the formation of a pitted outwash plain consisting mostly of sand, which became deposited around and above the stagnant ice blocks and ice contact debris (Uchupi and Mulligan, 2006). Groundwater seepage along the southern end of the outwash plain resulted in the formation of linear spring sapping valleys, which sometimes crossed the kettles and reworked the existing outwash deposits (Gutierrez et al., 2003). The relict glacial topography including the kettles and spring sapping valleys have been subsequently altered by fluvial, coastal, and aeolian processes and provides the geologic framework for the Waquoit system (Oldale and O'Hara, 1984; Gutierrez et al., 2003; Uchupi and Mulligan, 2006).

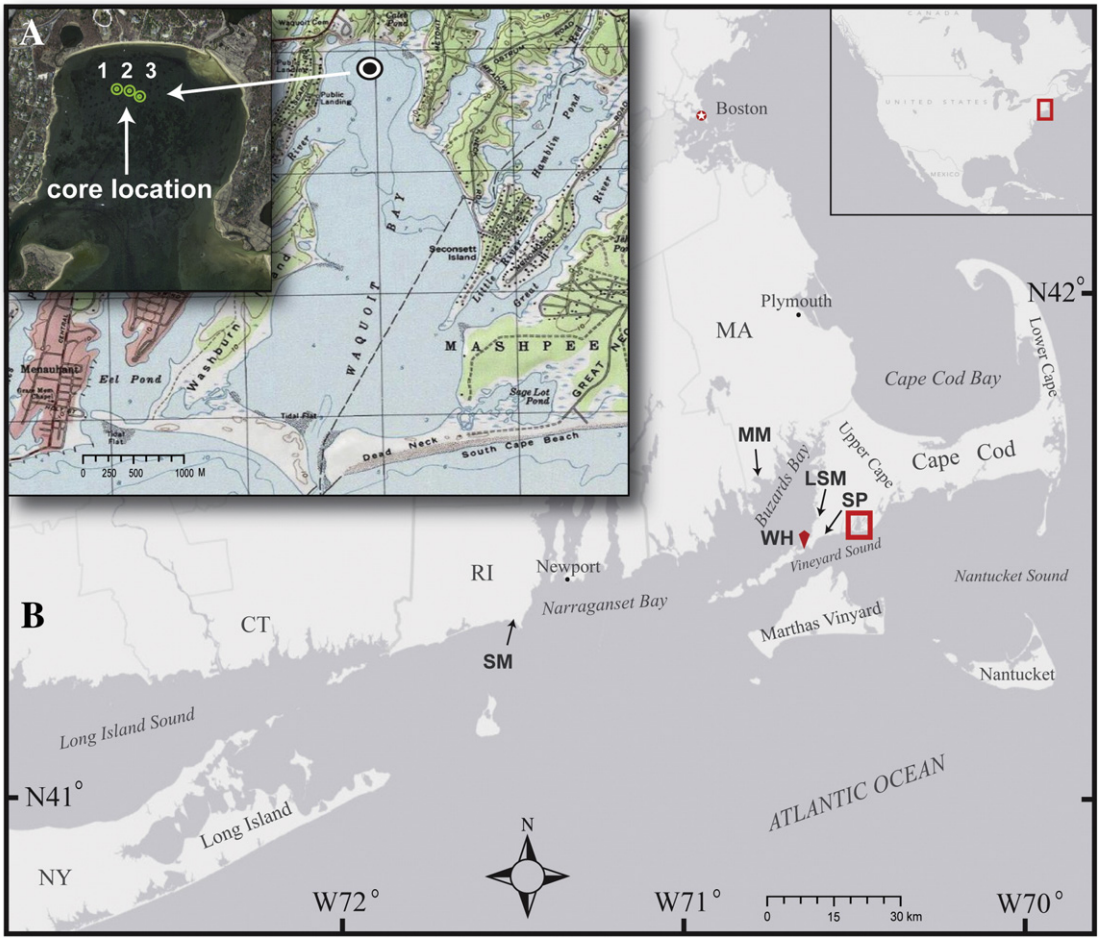

Fig. 1. The study site is located within Waquoit Bay, a shallow water estuary along the south shore of Cape Cod, Massachusetts, USA. A) The three sediment cores (WAQ1, WAQ2, and WAQ3) were collected in the north basin of the bay approximately 50 m apart. B) The lagoons position along the south side of Cape Cod, and its south to north orientation makes it particularly sensitive to storm surges resulting from northward tracking hurricanes. The Woods Hole (WH) tide gauge provides instrumental records of storm surges going back to 1932. The location of previous storm reconstructions carried out in the area (i.e. Donnelly et al., 2001; Madsen et al., 2009; Boldt et al., 2010; Donnelly et al., 2015) include Succotash Marsh (SM) Mattapoisett Marsh (MM), Little Sippewissett Marsh (LSM) and Salt Pond (SP) respectively.