Continental Shelf Research 74 (2014) 11–24

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

Late Holocene sedimentation in a high Arctic coastal setting: Simpson Lagoon and Colville Delta, Alaska

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ARTICLE INFO

Article history:
Received 23 May 2013
Received in revised form
23 September 2013
Accepted 25 November 2013
Available online 17 December 2013

Keywords:
Colville River
Radioisotope geochronology
CHIRP
Inner Beaufort Sea
Late Holocene transgression
Back-barrier sedimentation

ABSTRACT

Arctic coastal environments near major river outfalls, like Simpson Lagoon, Alaska and the adjacent Colville River Delta, potentially contain high-resolution sediment records useful in elucidating late Holocene Arctic sediment transport pathways and coupled terrestrial-ocean evidence of paleoclimate variability. This study utilizes a multi-tracer geochronology approach (^{137}Cs, $^{239,240}Pu$, and ^{14}C) tailored for high-latitude environments to determine the age models for cores collected from Simpson Lagoon, and to date seismic boundaries in shallow acoustic reflection data (CHIRP) to examine late Holocene infill patterns. Modern ($\sim$100 y) sediment accumulation rates range from <0.02 to 0.46 ± 0.04 cm y^{-1}, with a primary depocenter in western Simpson Lagoon adjacent to the Colville Delta and a secondary depocenter in eastern Simpson Lagoon. CHIRP reflectors, age-constrained by ^{14}C analysis, reveal rapid late Holocene (0–3500 y BP) transgression consistent with high modern shoreline retreat rates. The western depocenter contains >5 m of late Holocene interbedded sediments, likely derived primarily from the Colville River, with onset of accumulation occurring prior to $\sim$3500 y BP. A paleo-high in central Simpson Lagoon, separating the two depocenters, was subaerially exposed prior to $\sim$600 y BP. The millimeters-per-year sedimentation rates across the lagoon, coupled with the undisturbed, interbedded sediment record, indicate that these settings hold great potential to develop new Arctic paleoenvironmental records.

1. Introduction

The inner continental shelf, particularly near large riverine point sources, is potentially an important repository for large amounts of terrigenous sediment, often preserving higher-resolution sediment records than deep sea or continental repositories (lakes, river floodplains, etc.). Terrigenous shelf records are valuable for elucidating variability in climate on an annual to centennial scale (e.g., Dallimore et al., 2005; Gomez et al., 2004; Kennedy and Brassell, 1992; Schilman et al., 2001), but are complicated by spatial and temporal variabilities in sediment burial rates deriving from issues like river mouth switching, wave-current resuspension, and in the Arctic, by ice reworking processes (e.g., Brooks et al., 1995; Hill et al., 1991). Inner shelf sediments contain a record of both continental and oceanic fluctuations unlike other paleoenvironmental archives (e.g., ice cores, lakes, tree rings). Developing high-resolution sediment archives to understand high-frequency climate fluctuations on historical and late Holocene timescales is particularly important in Arctic regions, which are predicted to be the most sensitive to future climate change (Overpeck et al., 1997; and references therein), and which have instrument records dating back only 50–75 y. However, Arctic rivers generally have low sediment discharge and account for only 1% of the sediment reaching the global ocean (Gordeev, 2006; Hasholt et al., 2006), effectively limiting archive temporal resolution and the size of the coastal depocenter (Walsh and Nittrouer, 2009).

Between 90 and 95% of the fluvially derived sediment input to the Arctic Ocean is trapped within nearshore estuarine environments (Gordeev, 2006). Coastal environments, like the back-barrier lagoons found along the Alaskan Beaufort Sea coastline (Fig. 1), are also the primary repositories for sediment eroded from the shoreline, with coastal erosion contributing up to seven times more sediment than rivers on the Beaufort Shelf (Rachold et al., 2000; Reimnitz et al., 1988). These lagoons likely offer protection from

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http://dx.doi.org/10.1016/j.csr.2013.11.026

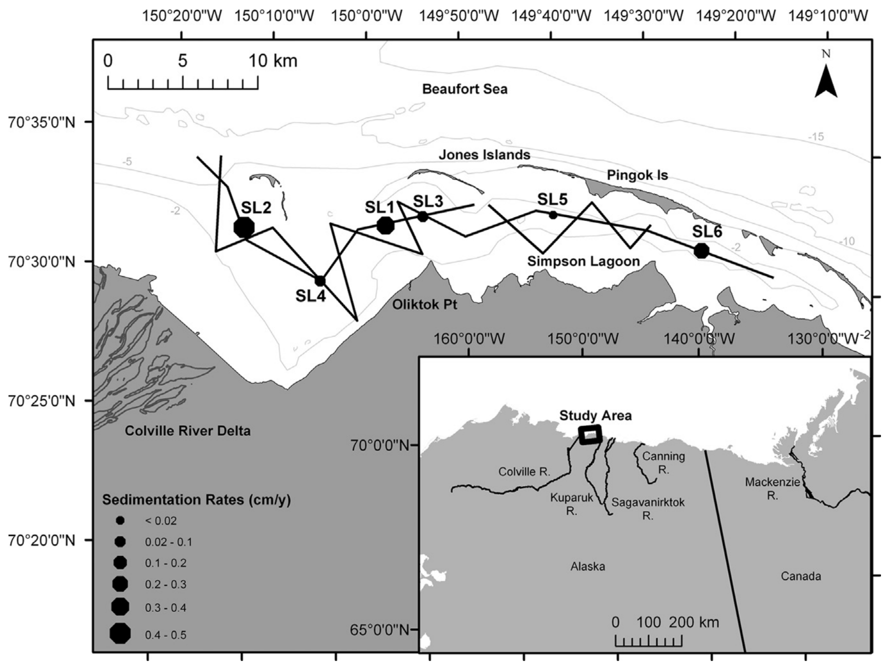

Fig. 1. Map of Simpson Lagoon, AK study area with locations and modern (~50 y) sediment accumulation rates of cores and CHIRP seismic lines collected during the August, 2010 field study.

storm induced wave-current winnowing (Hinzman et al., 2005) and the effects of ice reworking (Barnes et al., 1984) and therefore are high priority locations to seek out high quality, high-resolution coastal sediment records.

The primary objective of the present study is to investigate temporal and spatial changes in sedimentation within Simpson Lagoon, Alaska, a partially-enclosed, back-barrier lagoon on the inner shelf of the Beaufort Sea adjacent to the Colville River Delta (Fig. 1). Our initial goal is to establish a sediment geochronology, and thereby determine the suitability of Simpson Lagoon as a sediment repository for investigating Arctic paleoenvironment. Establishing sediment geochronology can be complicated in Arctic settings due to the low activities of many of the geochronological tracers typically utilized to develop age models in marine sediment cores (Baskaran, 2011; Naidu et al., 1999; Weiss and Naidu, 1986). In this study, we use a multi-radiotracer approach, in combination with measurement strategies tailored for low activity levels, to determine historical (using ^{137}Cs and ^{239,240}Pu) and millennial-scale (^{14}C) geochronologies for sediment cores collected from Simpson Lagoon. Acoustic reflectors in CHIRP seismic data, age-constrained with the radiocarbon dating, are utilized to extrapolate sedimentation patterns across the lagoon in space and time, and to determine the late Holocene transgressive history of this Arctic lagoon.

2. Regional setting

2.1. Colville River and Delta

Simpson Lagoon, located adjacent to the Colville River Delta (Fig. 1), was selected for this study due to the relatively large sediment flux from the adjacent Colville River and the sediment trapping potential afforded by the bordering barrier islands. The Colville River, located on the North Slope of Alaska, originates on the northern slope of the east–west trending Brooks Range at elevations of above 3000 m. After emerging from the highlands, the braided channels of the Colville River flow north for approximately 600 km, traversing the Arctic Foothills and the Arctic Coastal Plain (ACP) before terminating in a delta on the inner shelf of the Beaufort Sea (Payne, 1952) (Fig. 1). The Colville River catchment (53,000 km^2) is the largest on the North Slope, and is distinct in that the entire catchment is contained within the zone of continuous permafrost (Walker, 1998; Walker and Hudson, 2003). The low mean annual air temperature (-12 °C; Rember and Trefry, 2004; Telang et al., 1991) results in a duration of snow and ice cover in the catchment for 7–9 months of the year, during which the ice in the river reaches a thickness of >2 m and water discharge essentially ceases (Walker and Hudson, 2003). In late May to early June, break-up of ice and discharge of accumulated snowmelt takes place within weeks, making the Colville River particularly flood-prone with peak water discharges of ~6000 m^3 s^{-1} (Arnborg et al., 1967; Walker and Hudson, 2003). The break-up flood pulse is an effective erosional, transportational, and depositional agent which is estimated to carry 62% of the annual sediment load during only 4% of the year (Walker and Hudson, 2003). Glaciation within the Brooks Range is spatially limited with small valley and cirque glaciers covering only 520 km^2; the majority of which are located east of the Colville catchment (Geck et al., 2013). However, the central Brooks Range glaciers have experienced continuous retreat from 1970 to 2001 (Geck et al., 2013) and thus likely contribute additional water and sediment to the Colville River.

The Colville River catchment is underlain by Triassic to Cretaceous siliciclastics in the Brooks Range and Arctic Foothills, and Cretaceous to Quaternary marine and nonmarine deposits formed during a series of transgressions in the ACP (Moore et al., 1994; Payne, 1952). The fine-grained, highly erodible lithology combined with the annual break-up flood pulse contributes large amounts of suspended sediment to the Colville River, resulting in an annual suspended sediment flux to the coastal zone of 6×10^6 t y^{-1}; equivalent to a drainage basin sediment yield of 116 t km^{-2} y^{-1}(Arnborg et al., 1967; Walker and Hudson, 2003).

2.2. Simpson Lagoon

Simpson Lagoon is ~35 km long and 3–6 km wide, with water depths generally <2.5 m (Dunton et al., 2006). The Jones Islands barrier chain forms the northern border of the lagoon. To the east of Simpson Lagoon, smaller North Slope rivers (e.g., Kuparuk,