Global and Planetary Change 68 (2009) 58–72

Contents lists available at ScienceDirect

Global and Planetary Change

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

# The role of currents and sea ice in both slowly deposited central Arctic and rapidly deposited Chukchi–Alaskan margin sediments

D.A. Darby [a,*], J. Ortiz [b,1], L. Polyak [c,2], S. Lund [d], M. Jakobsson [e], R.A. Woodgate [f]

[a] Department of Ocean, Earth, and Atmospheric Sciences, Old Dominion University, Norfolk, VA 23529, USA
[b] Department of Geology, Kent State University, Kent, OH 44242, USA
[c] Byrd Polar Research Center, Ohio State University, 1090 Carmack Road, Columbus, OH 43210, USA
[d] Department of Earth Sciences, University of Southern California, Los Angeles, CA 90089-0740, USA
[e] Department of Geology and Geochemistry, Stockholm University106 91 Stockholm, Sweden
[f] Applied Physics Laboratory, University of Washington, Seattle, WA 98105-6698, USA

ARTICLE INFO

*Article history:*
Accepted 18 February 2009
Available online 19 March 2009

*Keywords:*
Arctic Ocean
sedimentation rates
sedimentology
sea ice
drift deposits

ABSTRACT

A study of three long cores from the outer shelf and continental slope north of Alaska in the Arctic Ocean indicate that localized drift deposits occur here with sedimentation rates of more than 1.5 m/kyr during the Holocene. Currents in this area average about 5–20 cm/s but can reach 100 cm/s and these velocities transport the sediment found in these cores primarily as intermittent suspended load. These high accumulation sediments form levee-like deposits associated with margins of canyons cutting across the shelf and slope. Unlike most textural investigations of Arctic sediment that focus on the coarser ice-rafted detritus (IRD), this paper focuses on the >95% of the sediment, which is finer than 45 µm. The mean size of this fraction varies between 6 and 15 µm in Holocene sediments from the Chukchi–Alaskan shelf and slope with the higher values closer to shore. Analysis of detailed size distributions of these Holocene deposits are compared to 34 sediment samples collected from sea ice across the Arctic Ocean and to Holocene sediment from central Arctic Ocean cores and indicate that similar textural parameters occur in all of these sediments. Principal components of these size distributions indicate that sea ice is an important link between the shelves and the central Arctic. Factor scores indicate nearly identical components in the clay and fine silt size fractions but very different components in the coarse silt for sea ice sediment and central Arctic ridge sediments compared to shelf and continental slope deposits. Sea ice must contribute to sedimentation in both of these Arctic regions, but bottom currents dominate in the slope region, forming drift deposits.


## 1. Introduction

The paleoclimate history of the western Arctic is still elusive due to the lack of high-resolution sedimentary records. Leg 1 of the Healy–Oden Trans-Arctic Expedition (HOTRAX) of 2005 recovered eight piston cores with accompanying trigger gravity cores and six multi-core stations nearby each piston core from which seven core tubes and one water sample were recovered (Darby et al., 2005). This new material along with a 20 m long piston core recovered in 2002 immediately east of these HOTRAX cores (Keigwin et al., 2006), promises to provide new insights into the paleoenvironment and paleoclimate of the Beaufort Sea region of the Arctic Ocean. This paper investigates the sedimentologic characteristics, primarily sediment texture, of three of these cores with the longest Holocene records and compares them to size parameters of five central Arctic Holocene sections from across the Arctic.

Sea ice is a dominant transport agent in the Arctic Ocean especially for areas of lower sedimentation (Eicken et al., 1997; Darby et al., 2006). Its role in depositing sediment on the shelf and slope is thought to be important but uncertain (Bischof and Darby, 1999; Darby and Bischof, 2004). Slope and shelf regions with very high sedimentation rates exist off northern Alaska and the depositional processes responsible for these high rates are unknown but essential to the proper interpretation of the paleoceanographic record in these areas (Darby and Bischof, 2004). Here we provide analysis of new sedimentary records to elucidate the factors controlling sedimentation in these regions.

## 2. Regional setting

The Chukchi shelf northwest of Barrow, Alaska receives a considerable amount of sediment from the Yukon River and smaller rivers in this part of Alaska, especially when sea level was lower in the early Holocene and even today (McManus et al., 1969; Nelson and

* Corresponding author. Tel.: +1 757 683 4701.
*E-mail addresses:* ddarby@odu.edu (D.A. Darby), jortiz@kent.edu (J. Ortiz), polyak.1@osu.edu (L. Polyak), slund@usc.edu (S. Lund), martin.jakobsson@geo.su.se (M. Jakobsson), woodgate@apl.washington.edu (R.A. Woodgate).
[1] Tel.: +1 330 672 2225.
[2] Tel.: +1 614 292 2602.

0921-8181/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.gloplacha.2009.02.007

Creager, 1977; Naidu and Mowatt, 1983; Keigwin et al., 2006; Ortiz et al., 2009-this issue). Sediment supply to the shelf north of Alaska and Canada is dominated by the Mackenzie River, which provides $1.25 \times 10^8$ t $a^{-1}$ of mostly fine-grained sediment and other rivers, which provide another $1.5 \times 10^6$ t $a^{-1}$, and the erosion of coastal bluffs supplies $5.62 \times 10^6$ t $a^{-1}$ (Hill et al., 1991). The net transport of the Mackenzie plume is generally eastward away from Alaska and then northward into the Canada Basin (Macdonald and Carmack, 1991; Hwang et al., 2008).

The shelf and slope north of Alaska is at the apex of several currents that can transport and deposit sediment under favorable conditions (Weingartner et al., 1998, 2005; Woodgate et al., 2005a). The Alaskan Coastal Current moves north along the western coast of Alaska (Fig. 1). Although some of this current mixes with waters in the central Chukchi Sea, a significant part of the flow turns east near Pt. Barrow with near bottom mean velocities of about 5–15 cm/s and maximum velocities of 50 cm/s, with a tidal constituent of around 10 cm/s near the head of the Barrow Canyon (Woodgate et al., 2005a; Weingartner et al., 2005). Within the canyon, flows are generally stronger with means of 23 cm/s and up to 95 cm/s episodically (Weingartner et al., 2005). Also there can be strong up-canyon flows or upwelling flows (Mountain et al., 1976; Aagaard and Roach, 1990) and there is evidence of the upper layers of the Atlantic Water being advected up Barrow (and other) canyons, to mix on the Chukchi shelf before returning to their density layer in the Arctic Ocean (Woodgate et al., 2005b).

The current structure east of Pt. Barrow is not entirely clear. There is a generally eastward coastal "shelf break" jet (Aagaard, 1984; Pickart et al., 2005), which is variable, but of comparable strength to the Alaskan Coastal Current in the Chukchi Sea, and is fed at least in part by the Alaskan Coastal Current (Fig. 1A). Beyond about the 50 m contour on the shelf and extending to the base of the continental slope the dominant flow appears to be the eastward Beaufort Undercurrent, which is ~10 cm/s becoming stronger apparently with depth (Aagaard, 1984). The relationship between these currents is unclear. The coastal/shelf break jet is variable, strongly influenced by the local wind, and shows significant seasonal variability (Pickart, 2004). The Beaufort Undercurrent is less documented – the upper portions likely are strongly influenced by wind, while the deeper portion may be part of a basin-wide circulation and thus not locally driven (Aagaard, 1984). Both of these currents flow generally in the opposite direction to the surface Beaufort Gyre circulation, which is primarily anticyclonic but variable and strongly wind-influenced (Proshutinsky and Johnson, 1997). West of Barrow, the flow structure is likely similar. The shallower part of the flow is fed by Pacific waters from Herald Canyon, while the deeper part of the flow is likely part of the basin-wide circulation of Atlantic Water. The behavior of these typically contour-following currents in the vicinity of canyons is not well known.

All along the Chukchi slope eddies spin off the eastward flowing coastal current and move offshore into the Canada Basin (Aagaard et al., 1985; D'Asaro, 1988; Plueddemann et al., 1998; Pickart, 2004). These as well as brine enriched density flows from sea ice formation can move sediment offshore (Weingartner et al., 2005) and especially the density flows can transport sediment down the slope (Williams et al., 2008). There is also likely turbulent mixing (probably wind-driven) associated with the upwelling of upper Atlantic water up canyons onto the shelf (Woodgate et al., 2005b). While this can introduce coastal sediment from the east to the Barrow Canyon area, this longshore current does not directly impact on the core sites in this study, which are much farther offshore.

The winter coastal or longshore drift is generally negligible along the northern Alaska coast (Aagaard, 1984; Reimnitz et al., 1988). During summer storms, this longshore drift can increase to 50 cm/s in a westward direction building spits to the west (Short et al., 1974; Hill and Nadeau, 1989).

In addition, melt-out from sea ice contributes an unknown volume of sediment to the nearshore and as far offshore as the summer ice front, several hundred kilometers seaward. Occasional storm waves and associated currents during ice-free intervals can also move sediment offshore. To summarize, typical local current activity is likely in the range of 5–20 cm/s and on rare occasions during storm events or in focused currents can reach values as high as 50–100 cm/s. Flows of this magnitude are capable of transporting sediment in the clay through sand sizes and into the gravel sizes, while most of these currents should be capable of initiating sediment transport in even cohesive silt and sand size sediments typical of the mid to outer shelf areas.

The sediments of the Chukchi–Alaskan shelf are sandy muds to muddy sands with spotty occurrences of sand and gravel (Barnes and Reimnitz, 1974; Reimnitz et al., 1998). The nearshore (<30 m isobath) is highly variable with mean sizes between 16 and 250 µm that are moderately to well sorted. The central shelf and slope north of Alaska contain fairly well-sorted, fine-grained silt (4–45 µm) but the outer shelf is poorly sorted with patchy gravelly-mud to muddy gravel (Barnes and Reimnitz, 1974). The coarse nature of these patches of sediment here are either palimpsest deposits from a time of lower sea level or due to localized currents that sweep the fines sediments away. The continental slope consists primarily of silty muds except in the channel axes of canyons where coarser sediments often occur.

## 3. Materials and methods

The HOTRAX cores studied in this paper are designated HLY0501-JPC5, -JPC8 (Darby et al., 2005), and HLY0203-JPC16 (Keigwin et al., 2006) herein referred to as JPC5, 8, and 16, respectively (Fig. 1). All of these cores are missing sediment in the core tops due to bypassing near the surface during core barrel entry. Trigger cores for JPC5 and 8 (TC5 & 8) or a multi-core (MC14) for JPC16 are used to obtain the uppermost sediment sections. These surface sediments are correlated to the piston cores using radiocarbon dates, core logs (such as density and reflectance logs), and mineral abundance peaks. The estimated offset is 51 cm in JPC8 and TC8, 75 cm in JPC5 and TC5, and 25 cm in JPC16 and MC14 (Table 1). The Holocene sediment of these cores is compared to the Holocene in several box-cores obtained during the Arctic Ocean Section expedition (AOS94) (Darby et al., 1997; Poore et al., 1999). Two cores are from the Mendeleev Ridge (94BC12 and 94BC19, henceforth BC12 and BC19, Fig. 1). One is from the Podvodniko Basin (BC21; formerly Wrangel Abyssal Plain) between the two major ridge systems in the Amerasian half of the Arctic; and two cores (BC25 and BC28) are from the Lomonosov Ridge. An added tube from the same box core as BC28 (BC28-B) is included for replication. In order to assess the role of sea ice, 34 sediment samples collected from modern sea ice sampled at 24 locations across the Arctic were analyzed (Fig. 1). In 2005, twenty-nine samples were collected during the HOTRAX expedition, including 15 from north of Alaska (Fig. 1a). In 2007, 16 samples were collected in the central Arctic mostly near the North Pole, 12 samples at six sites between Fram Strait and the North Pole during the Lomonosov Ridge off Greenland expedition (LOMROG), and four samples at two sites from the mouth of M'Clure Strait in 2007 (Fig. 1).

Radiocarbon age dating by Accelerator Mass Spectrometry (AMS) was performed on shell material, mostly mollusks and benthic foraminifers from cores JPC 5, 8, and 16 (Table 1). The ages were corrected for marine reservoir effects and stable carbon isotope fluctuations with CALIB5.0.2 (Stuiver et al., 2005) using $\Delta R$ values of 0 and 460 for comparison because the magnitude of the Arctic Ocean reservoir effect is poorly constrained (Dyke et al., 1996; Bauch et al., 2001a,b). The higher $\Delta R$ is favored by studies of mollusks from the near shore or coastal environment near Barrow, Alaska (McNeely et al., 2006) but there is no consensus on samples from farther off shore in the Amerasian half of the Arctic Ocean (Barletta et al., 2008). Several dates in the lower several meters of JPC16 were close to 40 ka and possibly transported offshore from older deposits (Table 1). No lithologic change is observed above this anomalously old interval and the texture also remains unchanged, leading us to suspect the old ages here as transported probably by ice-rafting during the waning stages of the last deglaciation. Only the uppermost unit composed of soft,