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Dynamic sedimentary environments of an Arctic glacier-fed river estuary (Adventfjorden, Svalbard). I. Flux, deposition, and sediment dynamics

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Abstract

The spatial patterns of the transport, settling, and deposition of sediments were studied in a small Arctic glacier-fed river estuary (Adventfjorden, west Spitsbergen, Svalbard). Salinity and temperature, suspended solids concentration, and particle fluxes in the water column were measured at seven stations situated on the tidal flat formed at the river mouth, the delta slope, and along the fjord axis down to the fjord mouth. Turbidity currents were measured *in situ* using a current meter combined with a turbidity meter. The sediments collected with a Niemisto gravity corer were x-rayed and analyzed for granulometric composition. The results of the major sampling campaign undertaken in July 2002 were supplemented with winter hydrological data from January 1996. Since the river is frozen in winter, no fresh water or fluvial sediment supply is observed in the fjord water column. A hypopycnal plume of brackish water (1.5 m thick) extends in summer as far as 0.8 km from the river mouth. The highest concentration (826 mg l^{-1}) and vertical flux (over 1000 g m^{-2} day^{-1}) of suspended solids were noted at the edge of the tidal flat and over the upper slope of the delta. Both concentrations and the solid particle flux decreased as distance from the river mouth increased. Local peaks of turbidity in the intermediate and deep water layers in the central fjord indicated the presence of hyperpycnal plumes. Tidal flat sediments are rhythmically laminated by the tidally controlled resuspension/redeposition cycles and occasionally eroded by catastrophic events such as intense storms or winter ice cover scouring. The steep inclination of the bottom of the slope (15–19°) promotes the gravity-driven processes of sediment transport (debris flows). Frequent resuspension and redeposition events can be traced on x-radiographs and in the granulometric composition of the sediment cores collected on the slope. Turbidity currents are observed throughout the fjord, although their intensity and frequency of occurrence change as distance from the river mouth increases. The near bottom hyperpycnal flows transport the finest sediment over the slope and into the low energy environment of the central basin of Adventfjorden. The current study shows that the patterns of sediment storage and sedimentary dynamics in a glacier-fed river estuary are driven by gravity flows and turbidity currents rather than by the patterns of the vertical sedimentation of suspensions in the water column.

Keywords: sedimentation; deposition; accumulation; sediment gravity flows; turbidity currents; fjord; Arctic; Svalbard; Spitsbergen; Adventfjorden

1. Introduction

Global climate changes are likely to be first perceived in the high latitude seas (ACIA, 2005). The freshwater and sediment supply to Arctic coastal waters may change dramatically in the global warming scenario. Notable climate warming during the last 100 years (Nordli et al., 1996) has caused the Svalbard glaciers to retreat significantly (Ziaja, 2001). The enhanced glacial activity results in the increased supply of terrigenous material to the fjords (Elverhoi et al., 1995; Svendsen et al., 2002; Zajaczkowski et al., 2004). According to Syvitski and Andrews (1994) and Syvitski (2002), further increases in sediment flux over the next 200 years are predicted.

Although large rivers are recognized as the main source of freshwater supply to the ocean, Milliman and Syvitski (1992) indicated the importance of small mountainous rivers in the

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global budget of terrigenous sediment discharges into the ocean. Arctic glacier-fed rivers that transport large quantities of mineral material eroded by glaciers are a special case. Turbid water plumes and significant vertical solids fluxes are characteristic features of near glacier or near glacier-fed river areas in high latitude fjords (Syvitski et al., 1985, 1987). Freshwater and terrigenous material inflows impact the functioning of coastal ecosystems, and the halocline may cause mass zooplankton mortalities due to osmotic shock (Zajaczkowski and Legezynska, 2001). High turbidity inhibits primary production (Keck et al., 1999), while high mineral sedimentation affects the composition and diversity of bottom-dwelling fauna (Syvitski et al., 1989; Wlodarska-Kowalczuk and Pearson, 2004; Wlodarska-Kowalczuk et al., 2005).

The factors controlling turbid water plumes in high latitude fjords were described by McClimans (1978), Dowdeswell and Cromack (1991), Cowan et al. (1999), O'Cofaigh et al. (2001), and Blanton et al. (2003). Three major environmental zones were defined: (1) proximal (near the glacier front/river mouth) where plume energy controls the flux of particles; (2) prodelta, shelf area offshore river mouths that is characterized by significant mud deposition below storm wave base; (3) distal (far from the glacial and glacio-fluvial source) where other factors like tides, wind, and waves determine plume behaviour. In the proximal zone, the annual net sediment accumulation rate can reach tens of centimetres per year (Gorlich et al., 1987; Cowan et al., 1999); although, seasonal sedimentation records may be much higher as most terrigenous matter is delivered in the short summer season. The sediments supplied by an Arctic glacier-fed river and deposited at the river mouth can form an extensive tidal mudflat. As fjords are typically deep and narrow, the shallow mud flats at the river mouth quickly progress into a steep, unstable slope. High sediment flux to the bottom, the steepness of the slope, and the high hydrodynamic energy of the shallow proximal zone can cause numerous sediment gravity flows (Ren et al., 1996). Prior et al. (1981), working with the first side-scan images of Arctic glacial fjord sediments (Adventfjorden, Spitsbergen), identified numerous landslide chutes on the submarine slopes of a glacier-fed river tidal flat, and these suggested that the chutes are produced by sediment instability. The current paper presents the first extensive study of sediment fluxes in and the fate of the fjord visited by Prior. Direct measurements of turbidity currents are accompanied by an extensive survey of the hydrological and sedimentological settings of Adventfjorden. The aim of the current study was to describe the transport and fate of the mineral material, the processes of sediment storage, and spatial patterns of sea-bed disturbances in an Arctic glacier-fed river estuary.

In the proglacial areas of active glaciers sediment storage can be highly variable and driven mostly by temporal patterns of terrigenous material supply (Hodgkins et al., 2003). Discrete episodes of enhanced meltwater discharge from active glaciers induce sediment evacuation and thus influence sediment storage in proglacial areas (Hodgkins et al., 2003). Similar processes may take place in glacio-fluvial estuaries. In the present paper, it is shown that gravity flows of sediment in the proximal zone and the turbidity currents in the distal zone determine sediment storage in a small glacier-fed river estuary in an Arctic fjord.

2. Study area

Adventfjorden is one of the southern arms of Isfjorden, the biggest fjord system on the west coast of Spitsbergen. This marine inlet is 8.3 km long, 3.4 km wide, and oriented from the SE to the NW. The depth of most of Adventfjorden exceeds 50 m, while those in the outer part exceed 100 m (Fig. 1).

The tidal flat is formed at the mouths of two braided rivers, the Adventelva and the Longyearelva, situated in the innermost part of Adventfjorden. The tidal flat is 0.9 km wide during the ebb, and the bottom inclination does not exceed 0.1°. The prodelta slope reaches an inclination 15–19° and terminates at a depth of 30 m. Depth in the central part of the fjord varies from 60 to 80 m and the seaward inclination is from 1 to 3°.

Adventelva and Longyearelva transport meltwater from the glaciers, which have retreated several kilometres from the seashore. Meltwater transport is restricted to 122 days of the melting season (Weslawski et al., 1999). During the melting period, the Adventelva flows at an average rate of 3.6 $m^3\ s^{-1}$, and the mean concentration of suspended solids in river waters reaches 309 ± 177 mg l^{-1} (6 samples in July 2002). Although Longyearelva transports less water (2.04 $m^3\ s^{-1}$, on average), the mean summer concentration of suspended solids is usually higher (471 ± 221 mg l^{-1}) (8 samples in July 2002) (Zajaczkowski, unpublished data). In winter, the rivers are frozen, the supply of terrigenous material to the fjord ceases, and the surface of the fjord is covered by fast ice about

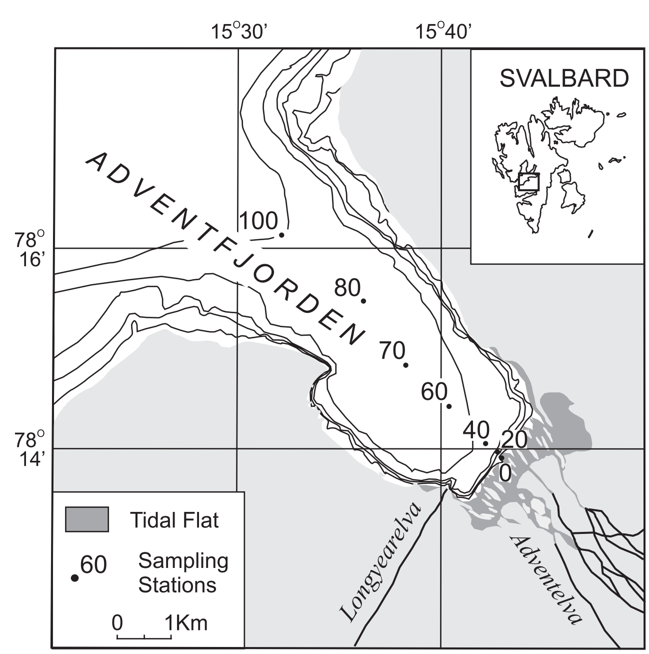

Fig. 1. Location of sampling stations in Adventfjorden. Stations are named according to depth.