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Meandering channel dynamics in highly cohesive sediment on an intertidal mud flat in the Westerschelde estuary, the Netherlands

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ABSTRACT

Small meandering channels of about 1 m wide on an intertidal mudflat in the Westerschelde estuary the Netherlands) were studied with the aim to improve understanding of the effect of highly cohesive bed and bank sediment on channel inception and meander geometry and dynamics. The study is supported by experiments and modelling. The estuarine meandering channels are less dynamical than alluvial meandering rivers, and the dynamics are more localised. Moreover, the high thresholds for bed sediment erosion and for bank failure lead to two processes, uncommon in larger rivers, that cause most of the morphological change. First, the beds of the channels are eroded by backward migrating steps under hydraulic jumps, while the remainder of the bed surface along the channel is hardly eroded. Second, channel banks erode i) where eroding steps locally cause undercutting of otherwise stable channel banks and ii) in very sharp bends where the flow separates from the inner-bend channel boundary and impinges directly on the bank on the opposite side of the channel. Further morphological change is probably induced by rainfall splash erosion and by storm waves that weaken the mud, and by large mud fluxes from the estuary. The steps were successfully reproduced in laboratory flume experiments. An existing model for step migration predicted celerities consistent with field and laboratory observations and demonstrated a strong dependence on the threshold for erosion. Bank stability models confirm that banks and steps only fail when undercut and weakened by waves, rain or excess pore pressure in agreement with observations. The effects of a high threshold for bank erosion was implemented in an existing meander simulation model that reproduced the observed locations of bank erosion somewhat better than without the threshold, but flow separation and its effect on meander bends remains poorly understood.

1. Introduction

Unvegetated intertidal mudflats and vegetated tidal salt marshes commonly have small meandering channels (e.g., Bridges and Leeder, 1976; Gabet, 1998; Fagherazzi and Furbish, 2001; Temmerman et al., 2003b). Sediment on mudflats is generally very strong compared to the bank and bed sediment of terrestrial rivers even where the banks of the latter consist of cohesive sediment and are vegetated. Friedkin (1945) and Ferguson (1987) argued that the width–depth ratio and therefore channel pattern strongly depend on the strength of the banks. It is therefore insightful to compare meandering channels on mudflats to terrestrial rivers with weaker banks and noncohesive bed sediments.

Various combinations of factors and processes have been put forward to explain the patterns and dynamics of channels on intertidal mudflats. The most important, detailed below, are i) the high strength and high threshold for erosion of the sediment, more so when salt marsh vegetation is abundant; ii) the shape and size of the drainage area; and iii) the action of rain or waves on the intertidal flat between the channels.

The strength of intertidal mud depends on the water content and compaction of the mud and on the presence of salt marsh vegetation (van Eerdt, 1985; Gabet, 1998; Winterwerp and van Kesteren, 2004, chapters 2 and 8). The critical threshold for erosion and deposition determines the width and depth of the channels as demonstrated in a model for the cross-sectional shape of salt marsh channels (Fagherazzi and Furbish, 2001). The critical shear stress for erosion of mud from a channel boundary increases with depth because the mud consolidated under its own weight during sedimentation. Since the discharge increases in the downstream direction of tidal channel networks, both width and depth are expected to increase as well. However, the critical shear stress also increases with depth so that erosion increasingly takes place at the banks in downstream direction. Hence the width–depth ratio of tidal channels increases as discharge increases in downstream direction. Fagherazzi et al. (2004) demonstrated the effect of bank material strength under bidirectional bend flow on the shape of the meanders in the San Francisco Bay. They found that slump blocks correlated well with locations of the highest velocities near the banks predicted by a meander simulation model applied to

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both flood and ebb flow. Typical migration rates of bends were of the order of 1×10^{-2} m/y, which, given widths of meters, is slow compared to terrestrial meandering rivers (see data of Van de Wiel in Kummu et al., 2008, Fig. 11). Thus, the high cohesion of the sediment and the salt marsh vegetation strengthen the banks, which renders the meander dynamics very slow.

The large-scale shape and size of the tidal flat determine the flow capacity that causes morphological change in the channels, and are therefore important boundary conditions (the channels barely affect the large-scale morphology). Mudflat cross-shore profile shape and overall gradient are influenced by the hydrodynamics (tides, longshore current) and mud supply of the surrounding estuary, as well as by exposure of the site to waves (Roberts et al., 2000). Hence, the overall morphology of the flat is the result of the tidal water level variation as well as the bidirectional flow properties. However, the current may be focussed through the channels when the estuarine stage is at the level of the mudflat. For very low-gradient flats the flow surges toward land (flood current) when the flat is just inundated and surges toward the estuary (ebb current) when the flat just emerges. Most of the morphological change of channels will take place during these surges only. The surges are delayed as time is needed for the flow to travel between shallow onshore areas and the mouth in either direction. The ebb surge is commonly stronger than the flood surge as the outflow of the upstream drainage area will be concentrated in the channels whereas the inflow takes place through the channels and over the entire mudflat (Fagherazzi et al., 2008).

Splash erosion is the process where individual raindrops break down the cohesive structure of the (consolidated) clay during low

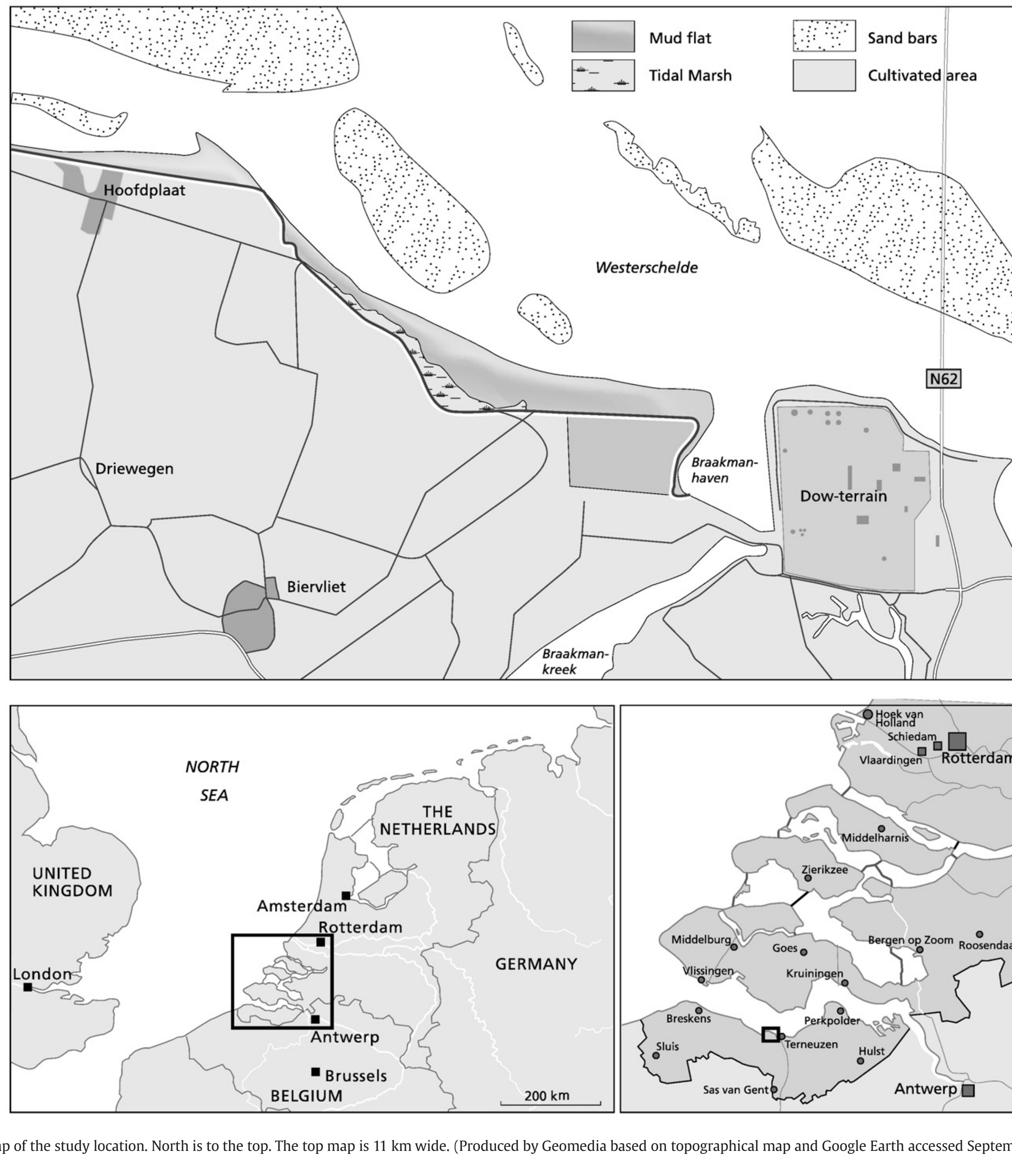

Fig. 1. Map of the study location. North is to the top. The top map is 11 km wide. (Produced by Geomedia based on topographical map and Google Earth accessed September 2008).