# Reconstruction of differential formation and phasing of crevasses in the fluvial-tidal realm of the Old Rhine

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## Introduction

Crevasses splay complexes can be found in many different river systems around the world, both in the purely fluvial as well as the tidal-fluvial (estuarine) realm. They originate at a breakthrough in the natural levee during peak discharges, forming a lobate landform with multiple interconnected shallow channels proximal to the river channel belt. In some cases crevasses extend several kilometres into the distal floodplain as a single deeper channel (e.g. the crevasse channels branching of the channel belt of the Old Rhine in Figure 1).

Combined field and modelling studies (e.g. Kleinhans et al. 2012; Millard et al., 2017) found that these extensive crevasses can evolve from the small proximal ones during a prolonged period of frequent peak discharge events when sufficient (i.e. not too much) supply of coarse silt to fine sand suspended sediment from the parent river channel is available. Too coarse and too much suspended sediment increases crevasse channel bed aggradation, which leads to healing, whereas coarse silts and fine sands promote levee build-up during overbank sedimentation, causing flow confinement, incision and progradation. However, the influence of tidal and other marine processes on crevasse formation, evolution and persistence has not been studied on a river scale yet. For example, both above mentioned studies did not include these in their models or analysis.

The Old Rhine provides an excellent area to study the interplay between tidal and fluvial processes and how they affect the formation and evolution of extensive single-channel crevasses, since many of these are well preserved (see Figure 1). Moreover, sufficient literature has been published about the spatio-temporal development of the system and its boundary conditions (affecting the tidal and fluvial processes) (cf. De Haas et al., 2018).

We hypothesize that extensive crevasses within the tidal-fluvial realm of a river system have different phases of activity and various origins of formation under continuously changing boundary conditions. The aim of this study is to test whether this hypothesis is true for the crevasses of the Old Rhine.

## Methods

We gathered hand-augered borehole data of four single-channel crevasse splay complexes of the Old Rhine during a field campaign in early September 2018 (see Figure 1 for locations). The corings were performed along transects perpendicular to the crevasse channel belts, at roughly similar distances along each crevasse from the Old Rhine channel belt to enable fair comparison between crevasses. Sedimentary characteristics were logged, based on which lithological cross-sections were made. Additionally, we will obtain $^{14}$C-dates of the formation and abandonment phases of the crevasses from peat samples.

## Results and preliminary conclusions

Figure 2 and Figure 3 show the lithological cross-sections of the Zwiet crevasse and a crevasse South of present-day Alphen aan den Rijn (henceforward Alphen crevasse) respectively.

For the Zwiet crevasse, at least three different phases can be distinguished: an early purely tidal creek phase, and two younger tidal-fluvial crevasse phases. The three phases can be distinguished from each other through intermittent peat layers. We argue that the crevasse adopted the pre-existing course of the older tidal creek, which we infer from the depth of channel deposits and the presence of laminated silty clay deposits directly underneath crevasse levee deposits (Figure 2).

On the other hand, for the Alphen crevasse only one crevasse phase could be recognized, which dates after the first peat had formed here on top of older tidal deposits (see Figure 3). This crevasse did not take on the course of an earlier tidal creek (like the Zwiet), but progradated into the floodplain as a novel channel.

We presume that, pending $^{14}$C-dates, the Alphen crevasse formed between roughly 3000 to 2000 years BP and that during this period also the initiation of the 1$^{st}$ tidal-fluvial crevasse phase of the Zwiet took place. This period is characterized by an increase in suspended sediment load, due to

anthropogenic deforestation upstream since the Bronze Age (Erkens and Cohen, 2009), a relatively high frequency of intense storms in North-Western Europe from 3350 to 1550 BP (Pierik et al., 2017), and the occurrence of relatively many large flood events (especially around ca. 3300 years BP) between 4000 and 3000 BP compared to 3000 and 1500 BP (Cohen et al., 2016). The combined effects of the relatively high frequency of storm surges and large floods in this period led to a breach in the natural levee of the Old Rhine, initiating the formation of the Alphen crevasse. The contemporaneous increase in suspended sediment load facilitated the Alphen crevasse to extend far into the floodplains, and the Zwiet to build up relatively high natural levees along its already existing course.

Furthermore, we argue that ebb and flood flows flowed through the Zwiet on a daily basis, whereas the Alphen crevasse seems to have been active infrequently, i.e. only during peak discharge events. We base this on the fact that the Zwiet's natural levee deposits show very regular laminations, and that abundant smaller-sized tidal creeks branch off from its main channel, as identified on AHN imagery. Contrastingly, the natural levees of the Alphen crevasse lack laminations and its more distal floodplain deposits are more humic. Apparently tidal flows did not reach this far upstream, despite the estimation that the tidal backwater effect reached up to ca. 30 km inland from the apex of the estuary (Van Dinter, 2013). This might have to do with the shape of the course of the Old Rhine, effectively blocking the tidal wave at some point.

Our comparison of two crevasses at different locations from the Old Rhine mouth thus shows that tidal processes can play an important role in determining the course, extent, planform shape and sedimentary characteristics of extensive crevasse channels. This can be used to further refine theories about crevasse formation and evolution.

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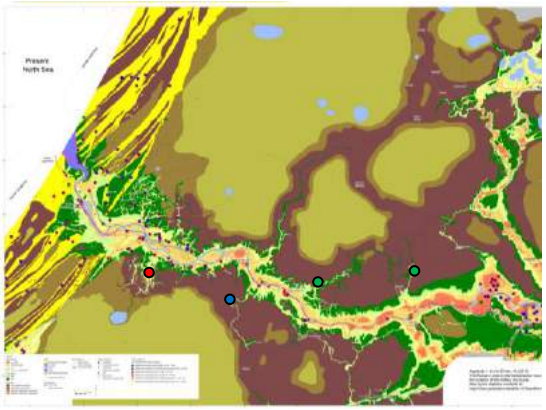

*Figure 1 Palaeogeographic map of the Old Rhine in Roman times. Blue dot indicates the location of Zwiet lithological cross-section in figure 2, red dot indicates the location of that in figure 3, and green dots indicate locations of other coring locations. Modified after Appendix 1 of Van Dinter (2013).*

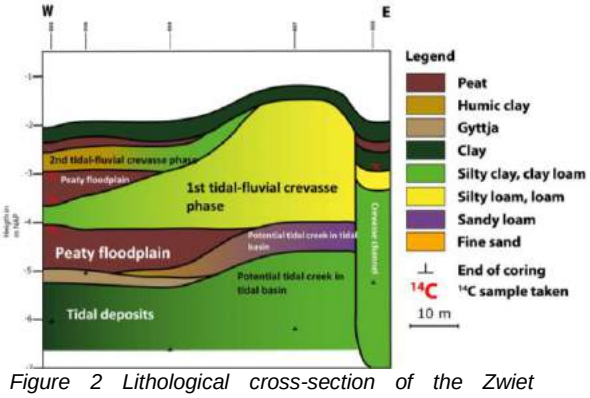


*Figure 2 Lithological cross-section of the Zwiet crevasse with annotations on the lithogenesis and different phases of the Zwiet.*

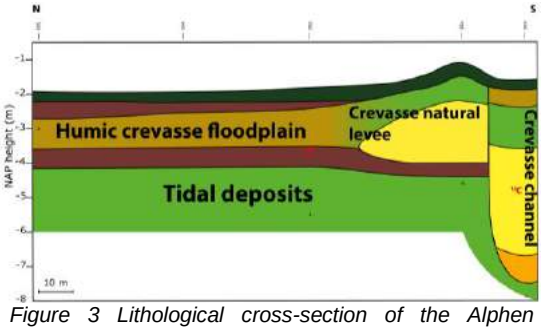


*Figure 3 Lithological cross-section of the Alphen crevasse with annotations on the lithogenesis. Legend as in figure 2.*