G E U S

# Extreme sea-level events in the Danish Wadden Sea

## Sedimentological and morphological impacts caused by the Storegga tsunami and the 1634 AD storm

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**GEOLOGI NÅR DET GÅR STÆRKT**

Årsmøde i Dansk Geologisk Forening
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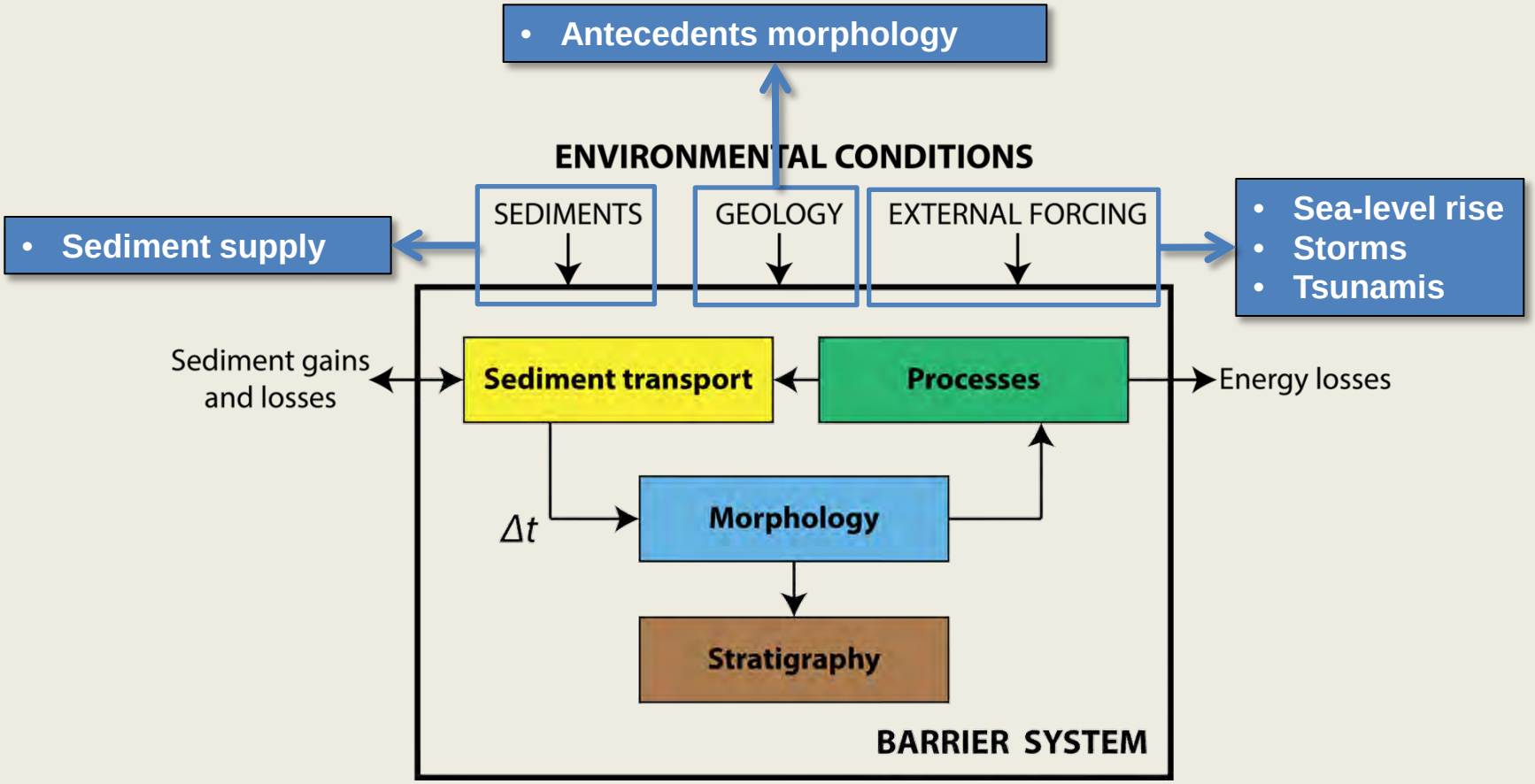
# Barrier coast distribution

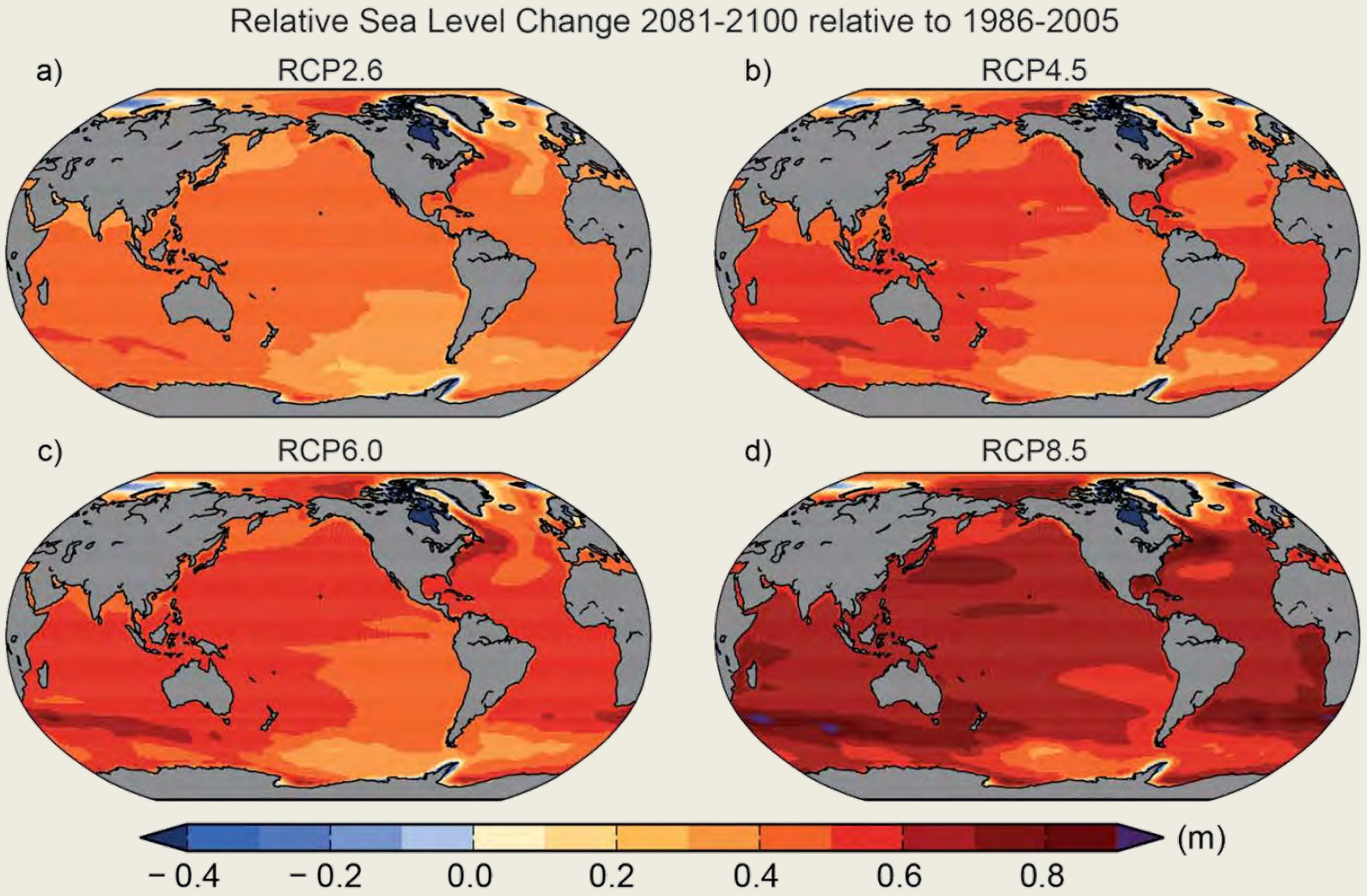

- About 13% of the world's ocean coastlines
- Often densely populated and urbanized
- Important economic value and recreational areas

# Barrier coast morphology

# Barrier coast evolution



# Sea levels and future barrier coast evolution



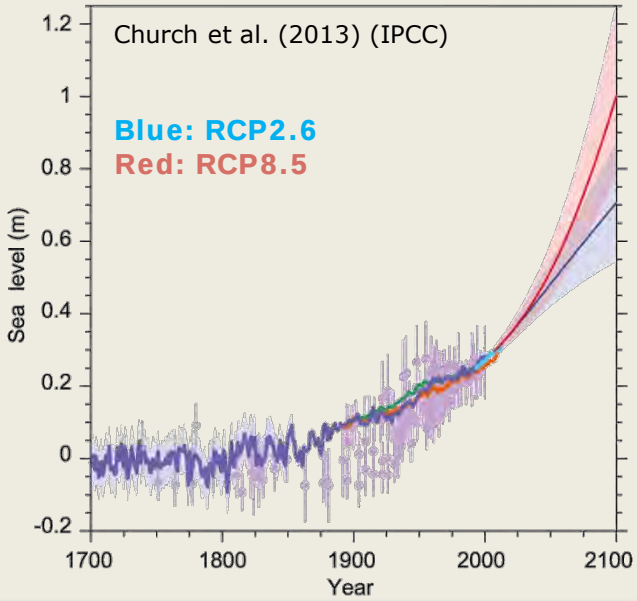

Stocker et al. 2013 (IPCC)

# Sea levels and future barrier coast evolution

*"In the future it is very likely that there will be a significant increase in the occurrence of sea level extremes…"*

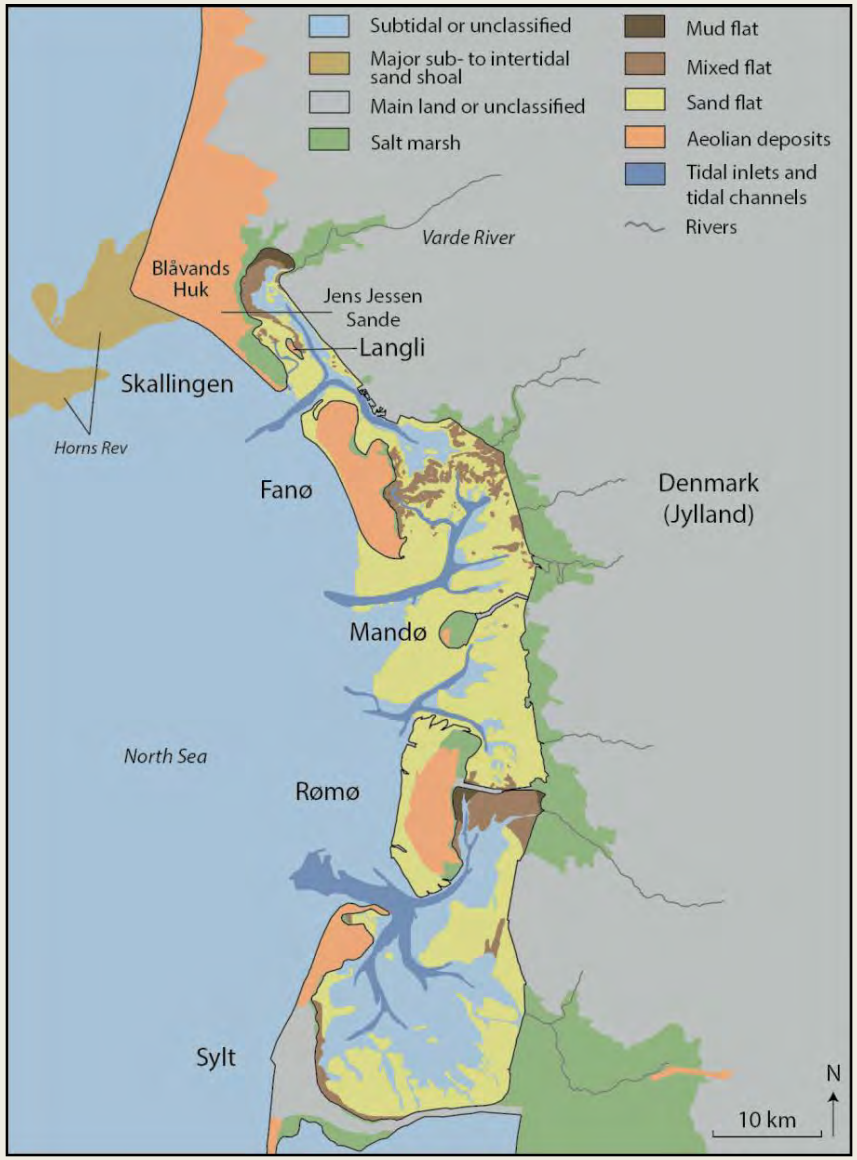
*"…this increase will primarily be the result of an increase in mean sea level."*

Stocker et al. 2013 (IPCC)

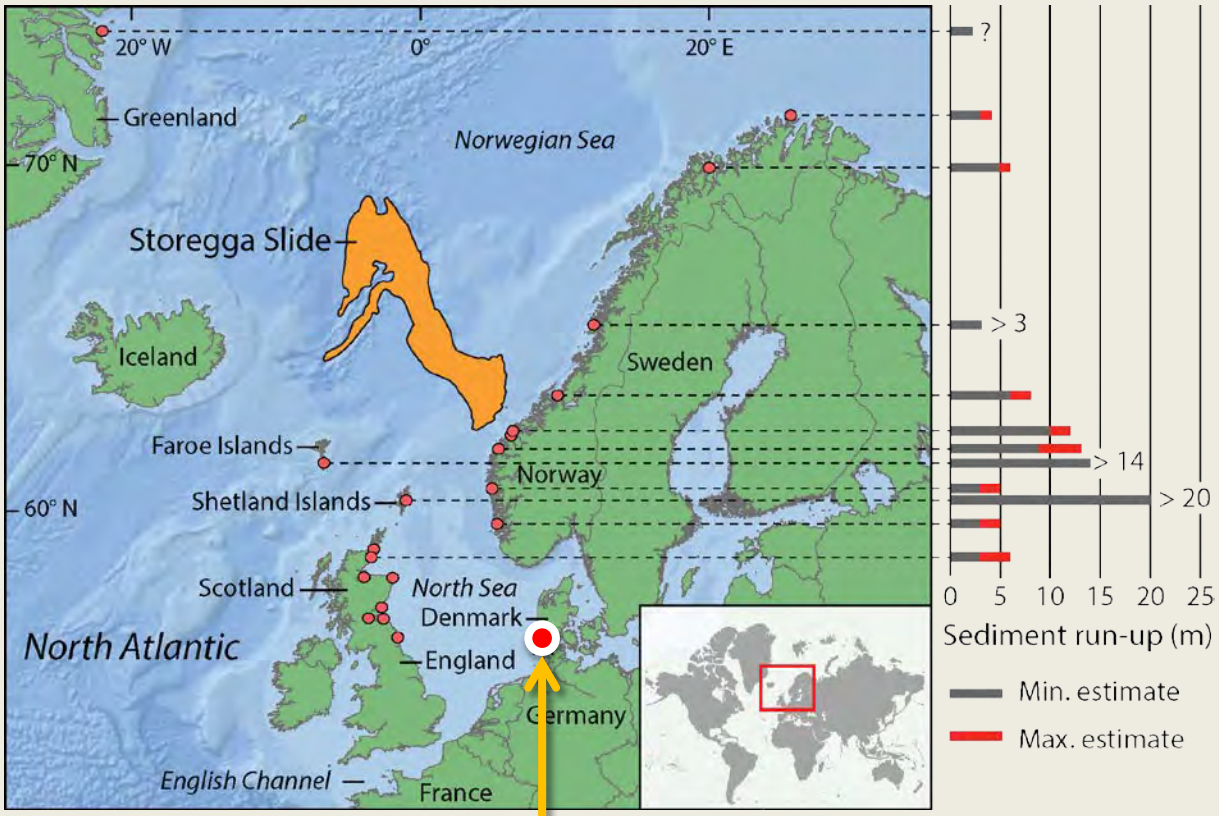



# The Wadden Sea





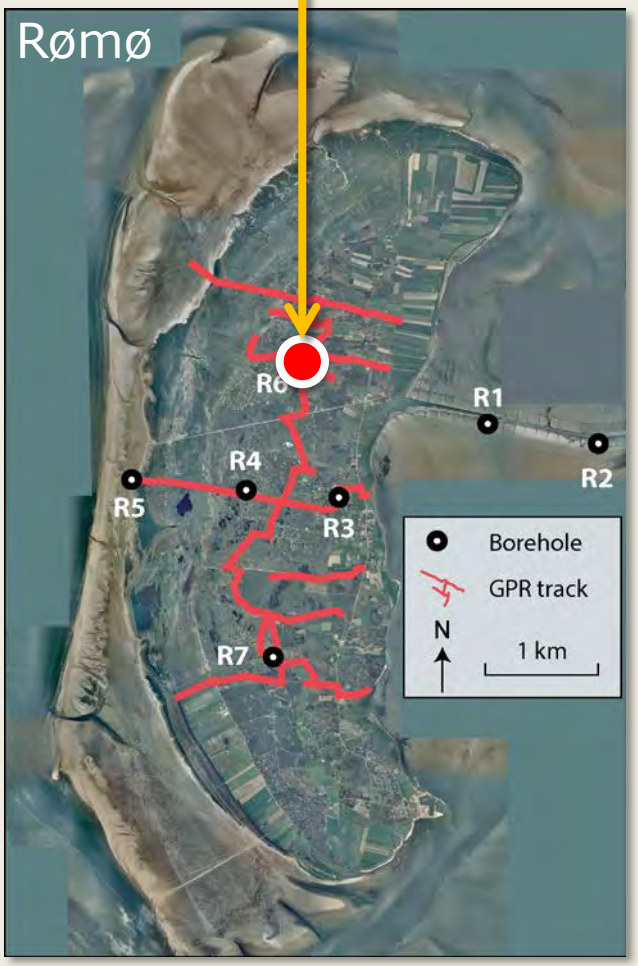
# The Storegga slide tsunami




Modified from Bondevik et al. 2012

Rømø

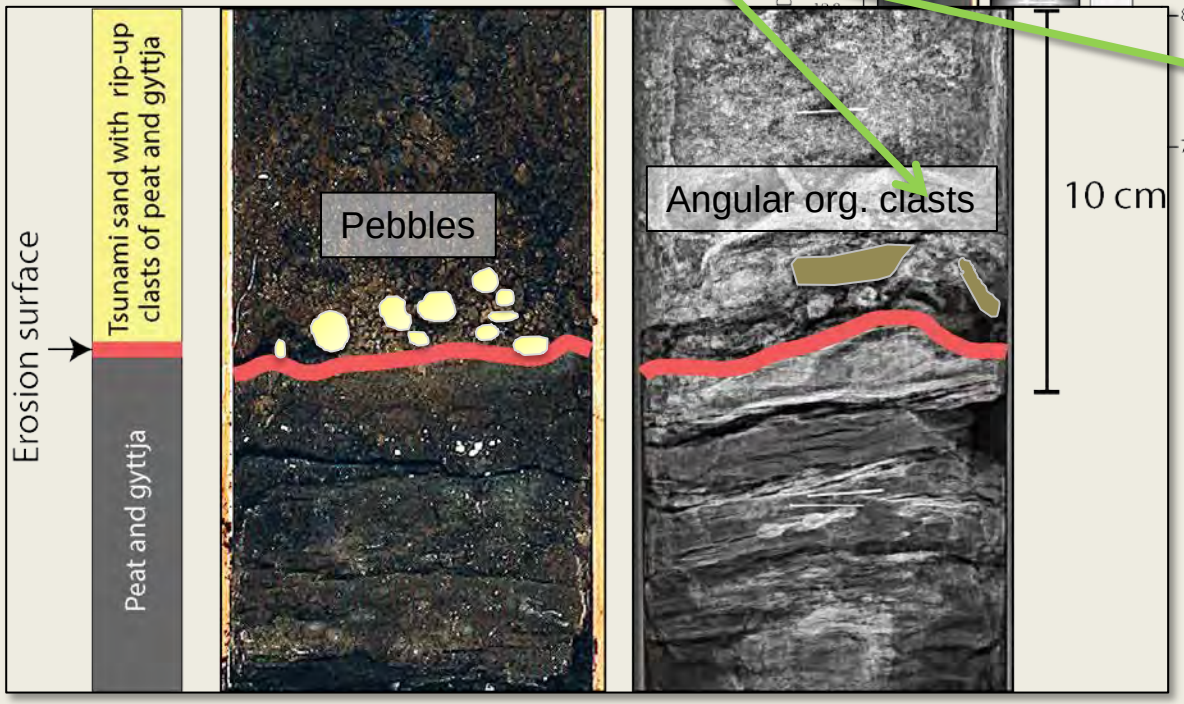
Core R6



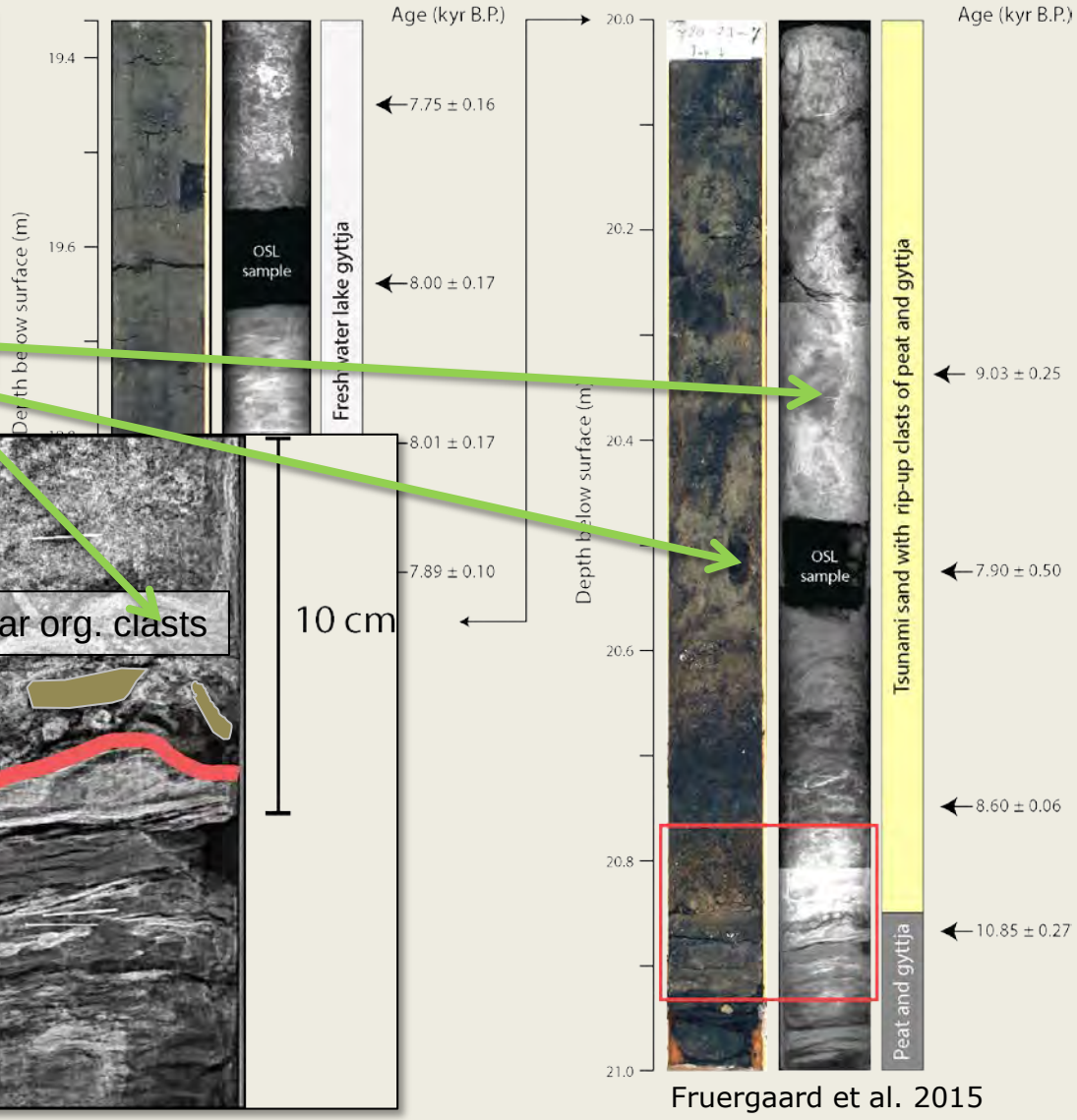

Fruergaard et al. 2015

# Event deposits


Bondevik et al. 2003

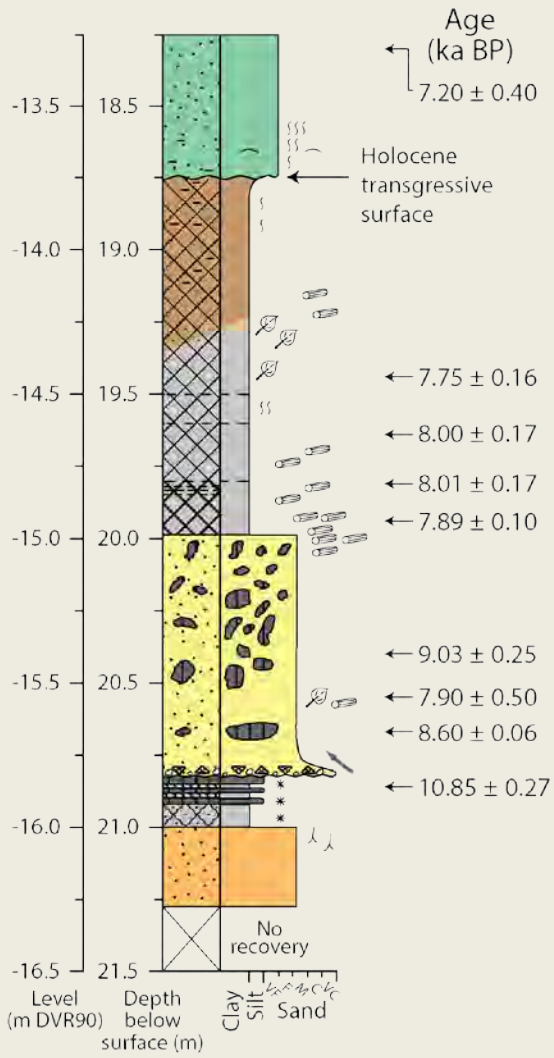



Core R6, Rømø



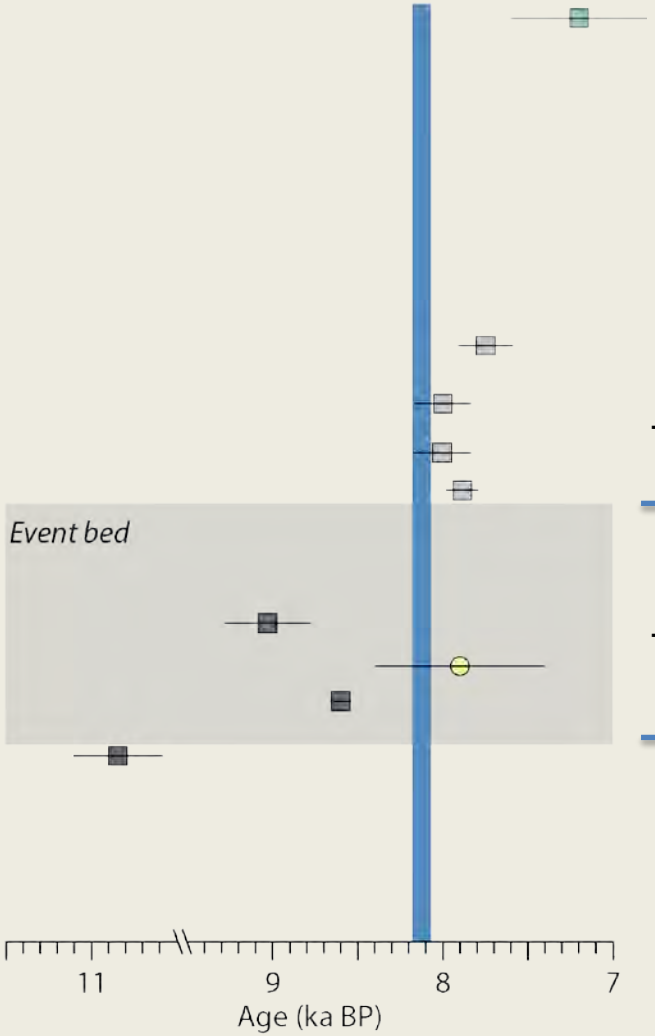

Fruergaard et al. 2015

# Chronology of deposits




Fruergaard et al. 2015

Storregga tsunami
8125 ± 55 yr BP

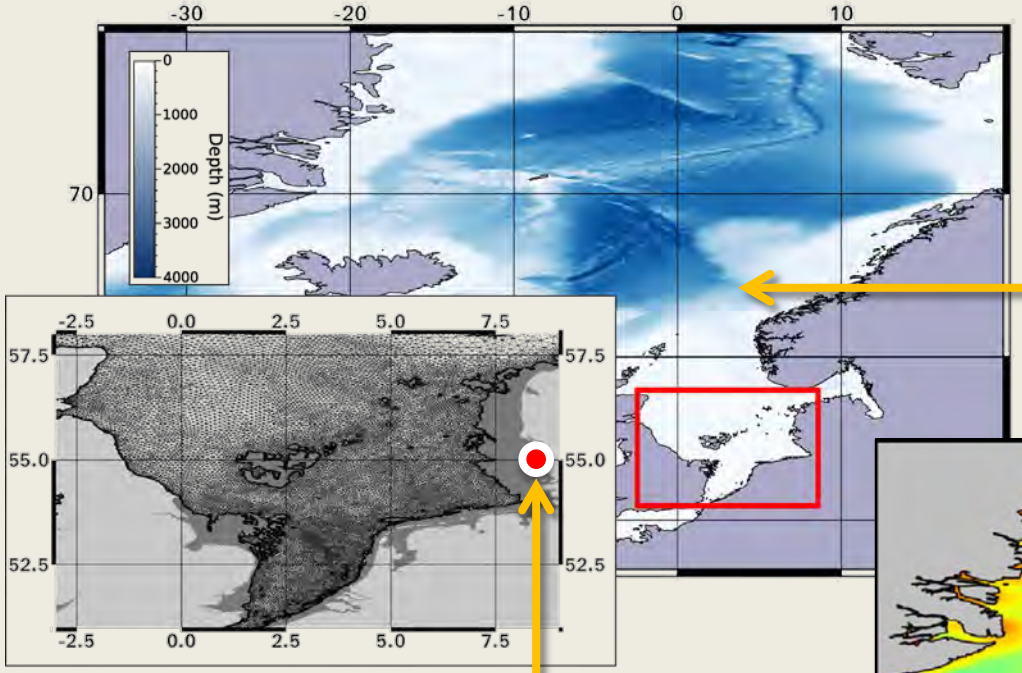



Older than
7890 ± 100 yr BP

Dated at
7900 ± 500 yr BP

Younger than
8600 ± 60 yr BP

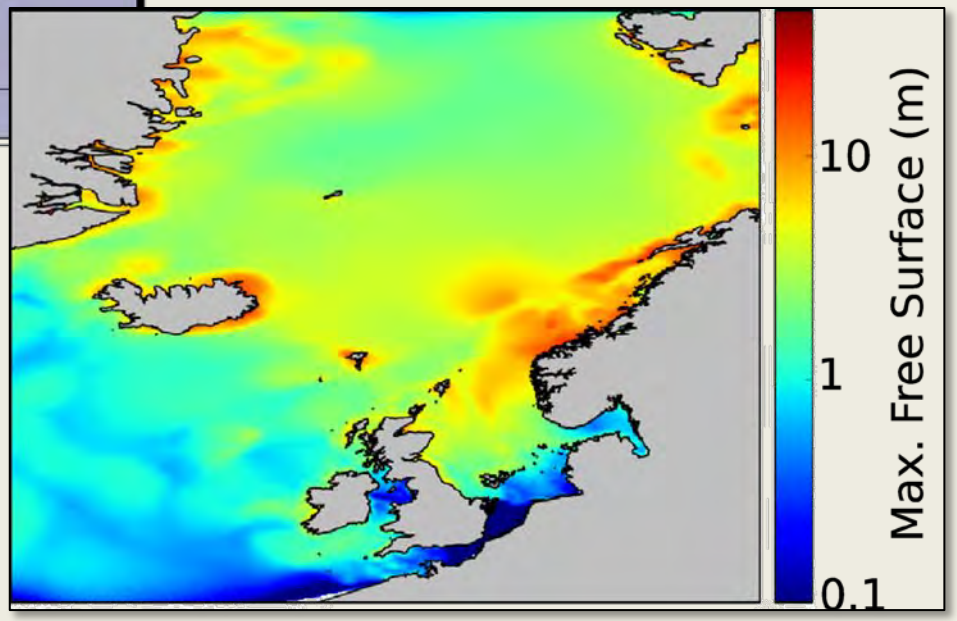
# Modelled tsunami run-up height




Storegga slide

Hill et al. 2014

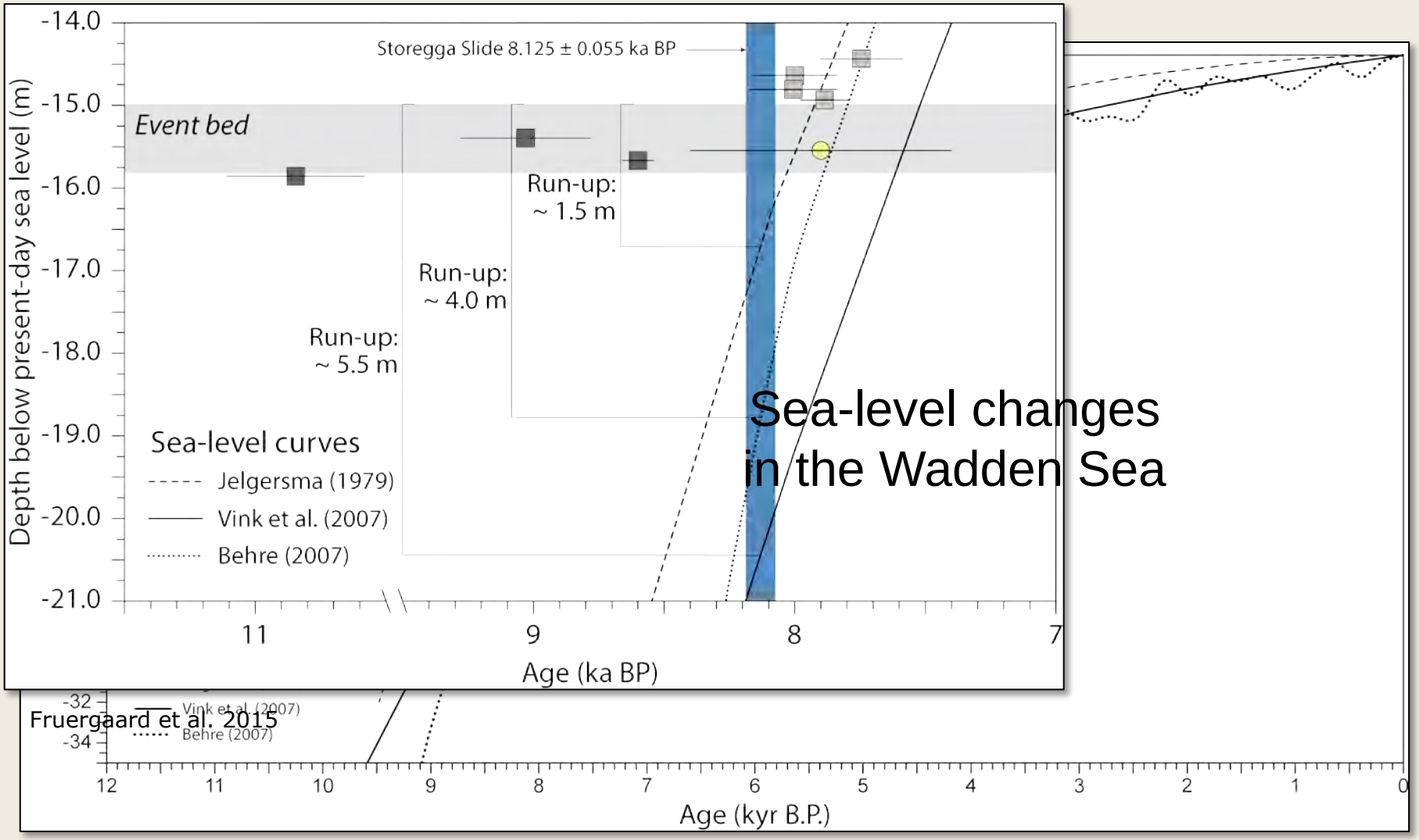
Rømø




Hill et al. 2014

Erroneous North Sea paleo-bathymetry cause underestimation of tsunami run-up height (< 1m).

# Estimated tsunami run-up height




Fruergaard et al. 2015

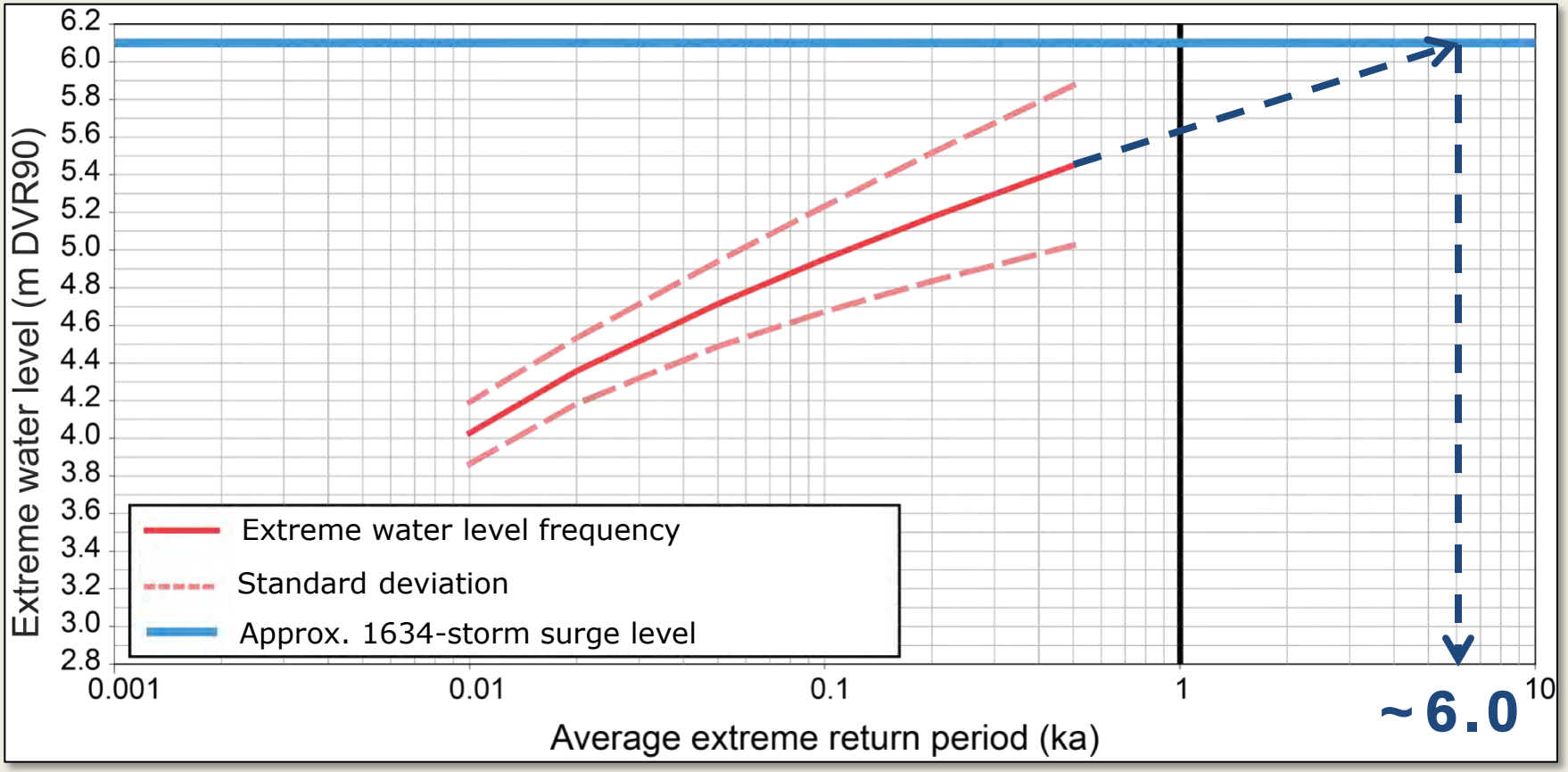
Fruergaard et al. 2015

# The 1634 AD storm


**The 1634 AD storm**

- The "Second Grote Mandrenke"
- More than 8000 people drowned

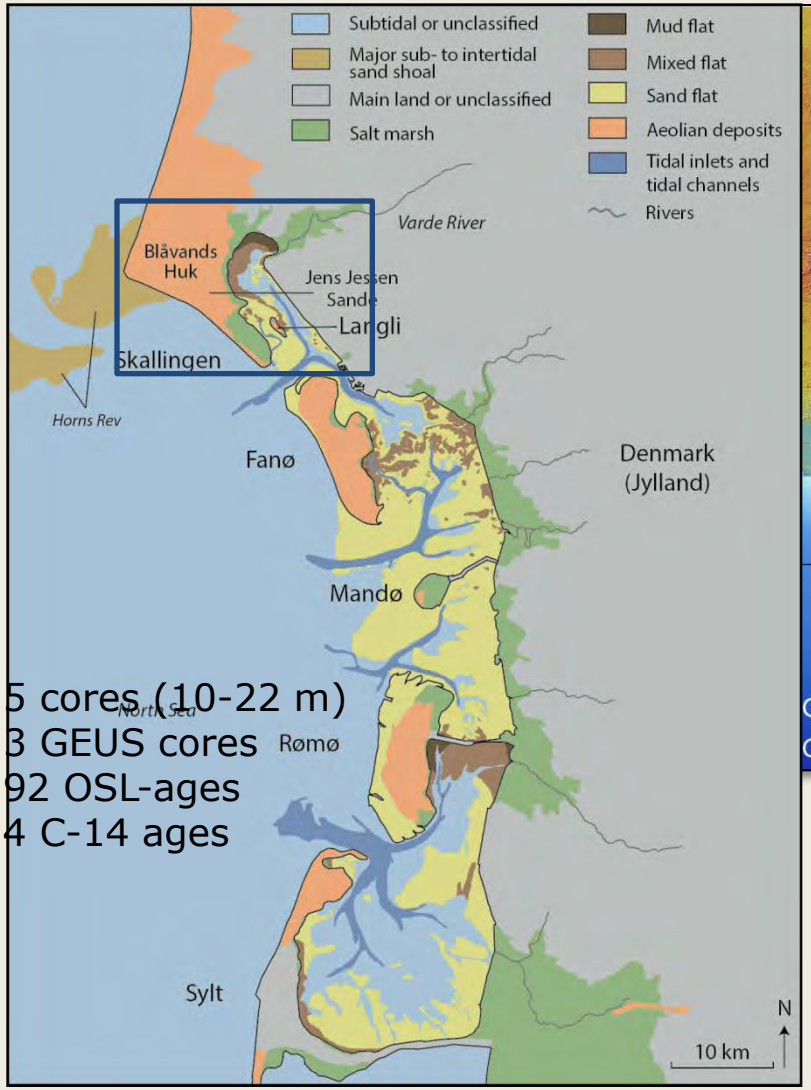
# The 1634 AD storm

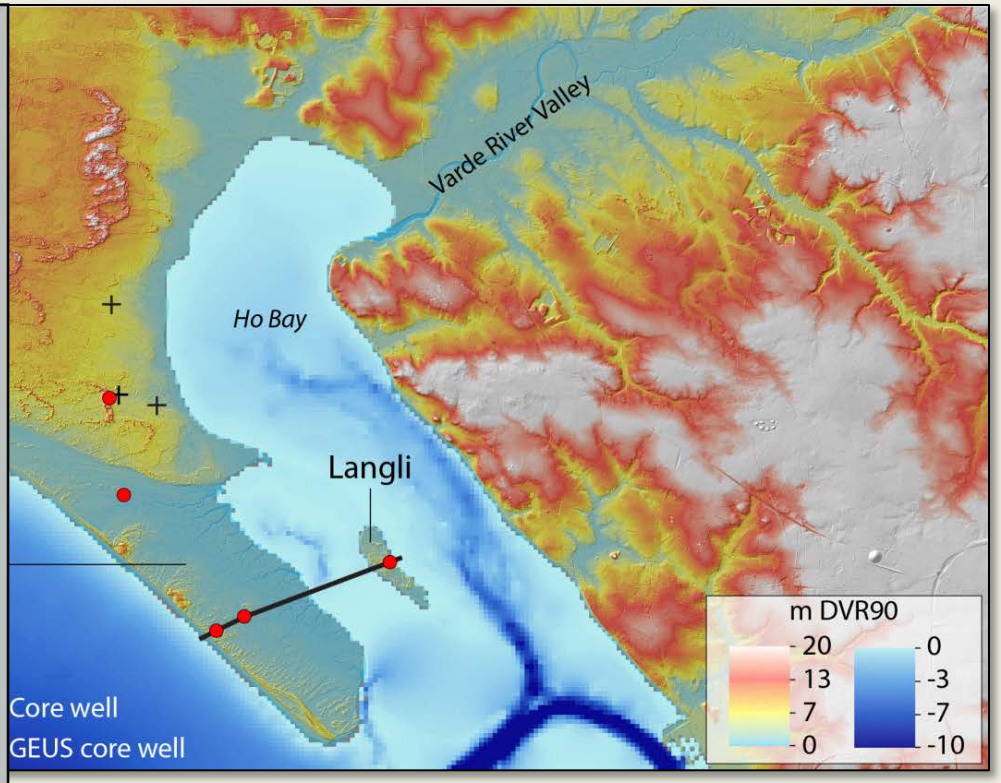



Modified from Sørensen (2013) and Fruergaard et al. 2013

- Highest recorded sea-level in Denmark ~6.10 m
- Classifies as a 5000 to 6000 year event

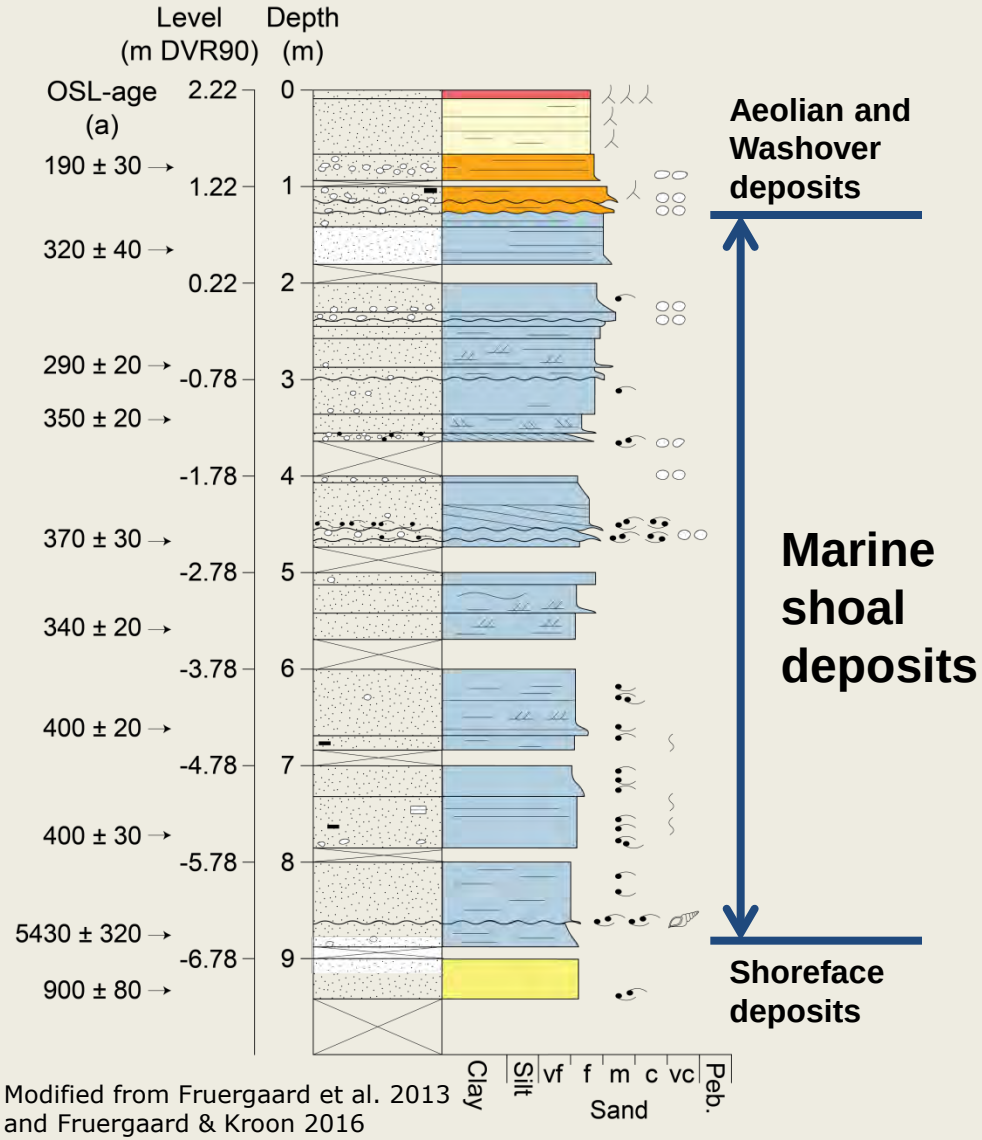
# Study site




- 5 cores (10-22 m)
- 3 GEUS cores
- 92 OSL-ages
- 4 C-14 ages

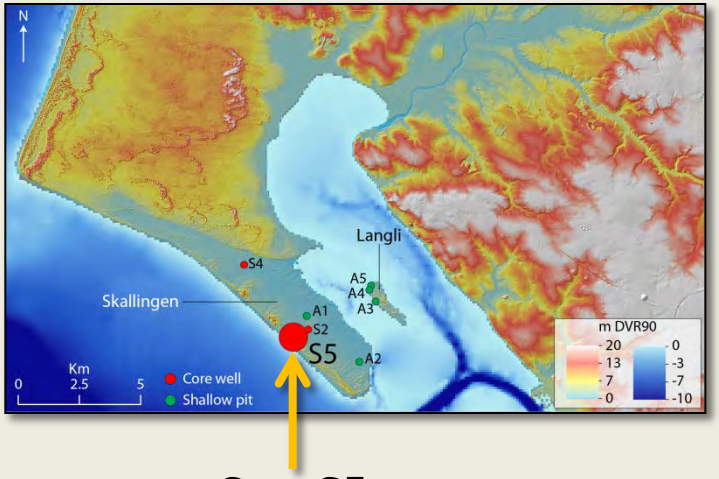
# Core stratigraphy



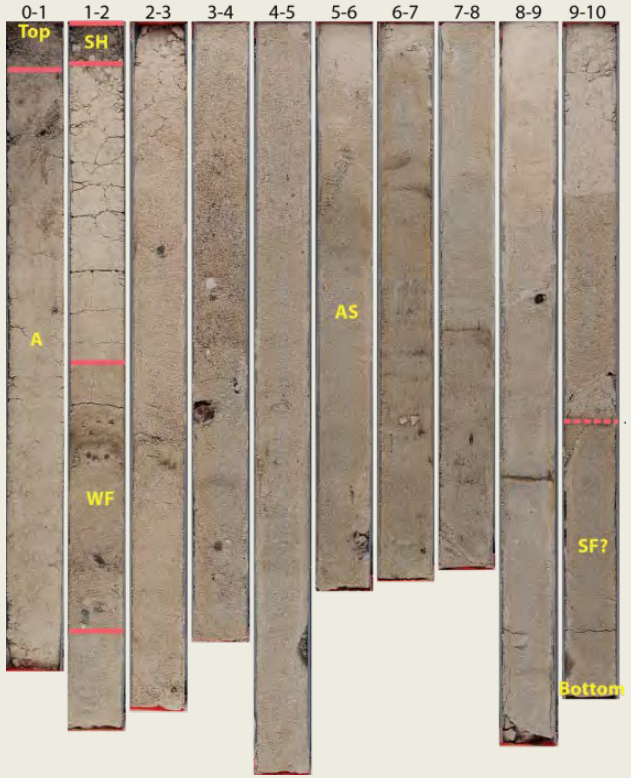

**Aeolian and Washover deposits**

**Marine shoal deposits**

**Shoreface deposits**

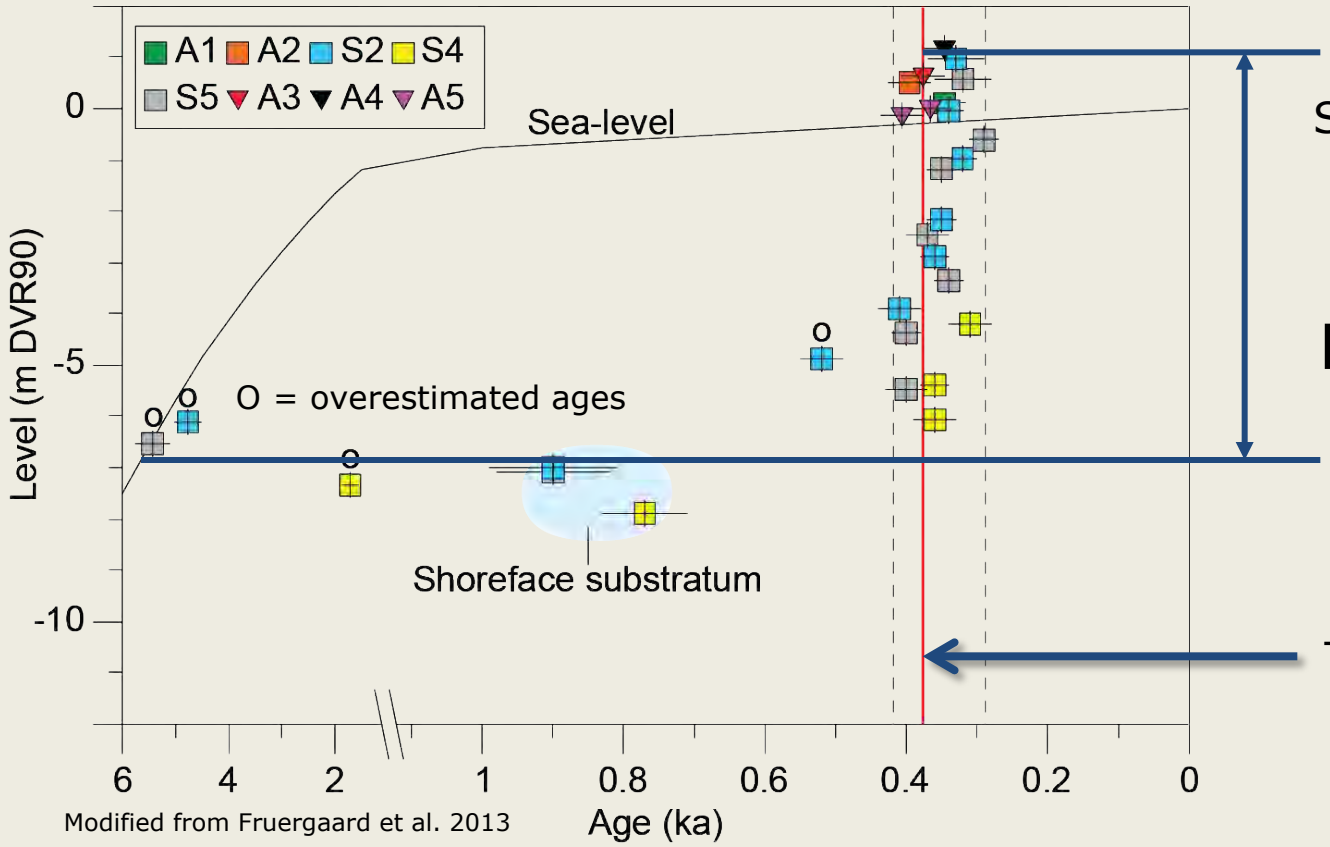



Core S5




Modified from Fruergaard et al. 2013 and Fruergaard & Kroon 2016

# Barrier spit formation



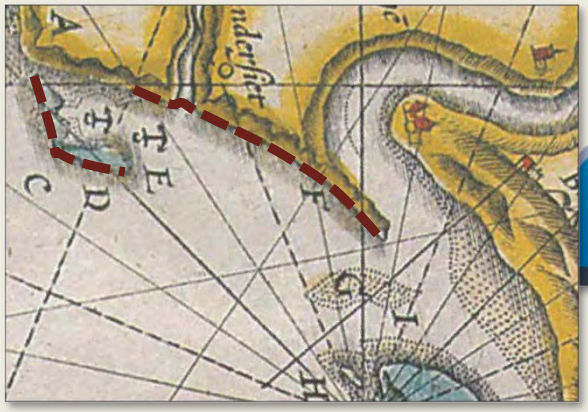

Modified from Fruergaard et al. 2013

Storm related vertical deposition 7–8 m.

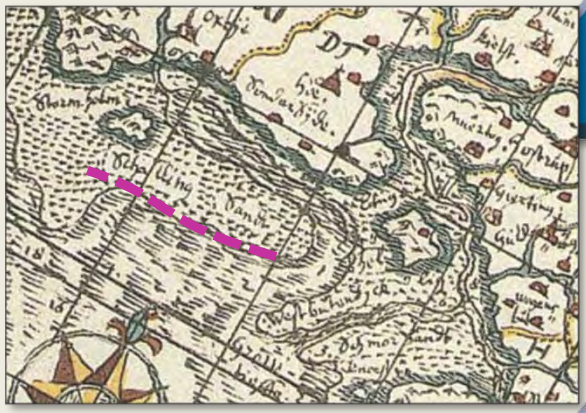
**Barrier island formation**

The 1634 AD storm

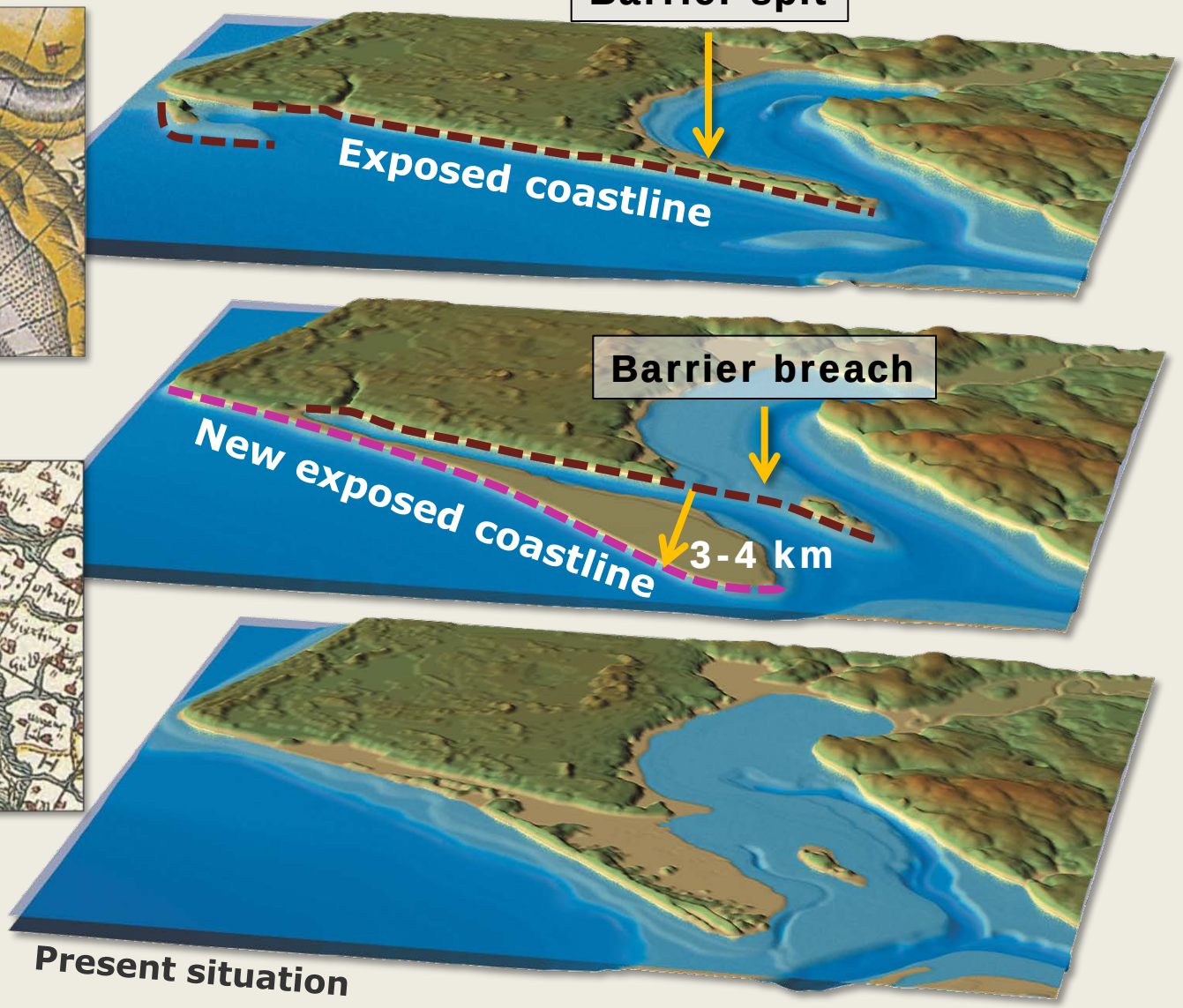
# Large-scale coastal change



**1612** Willem Janszoon Blaeu

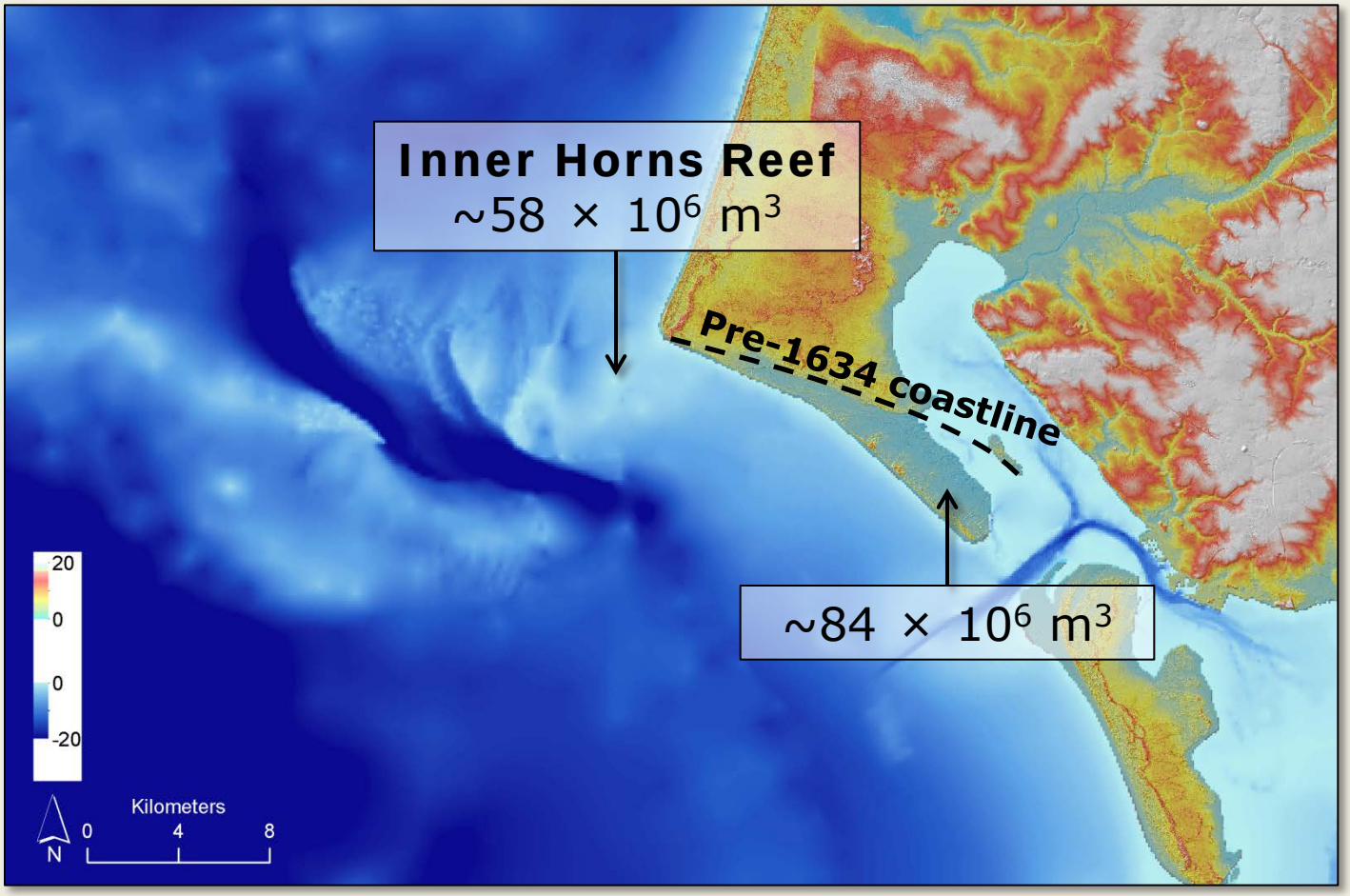


**1650** Johannes Mejer

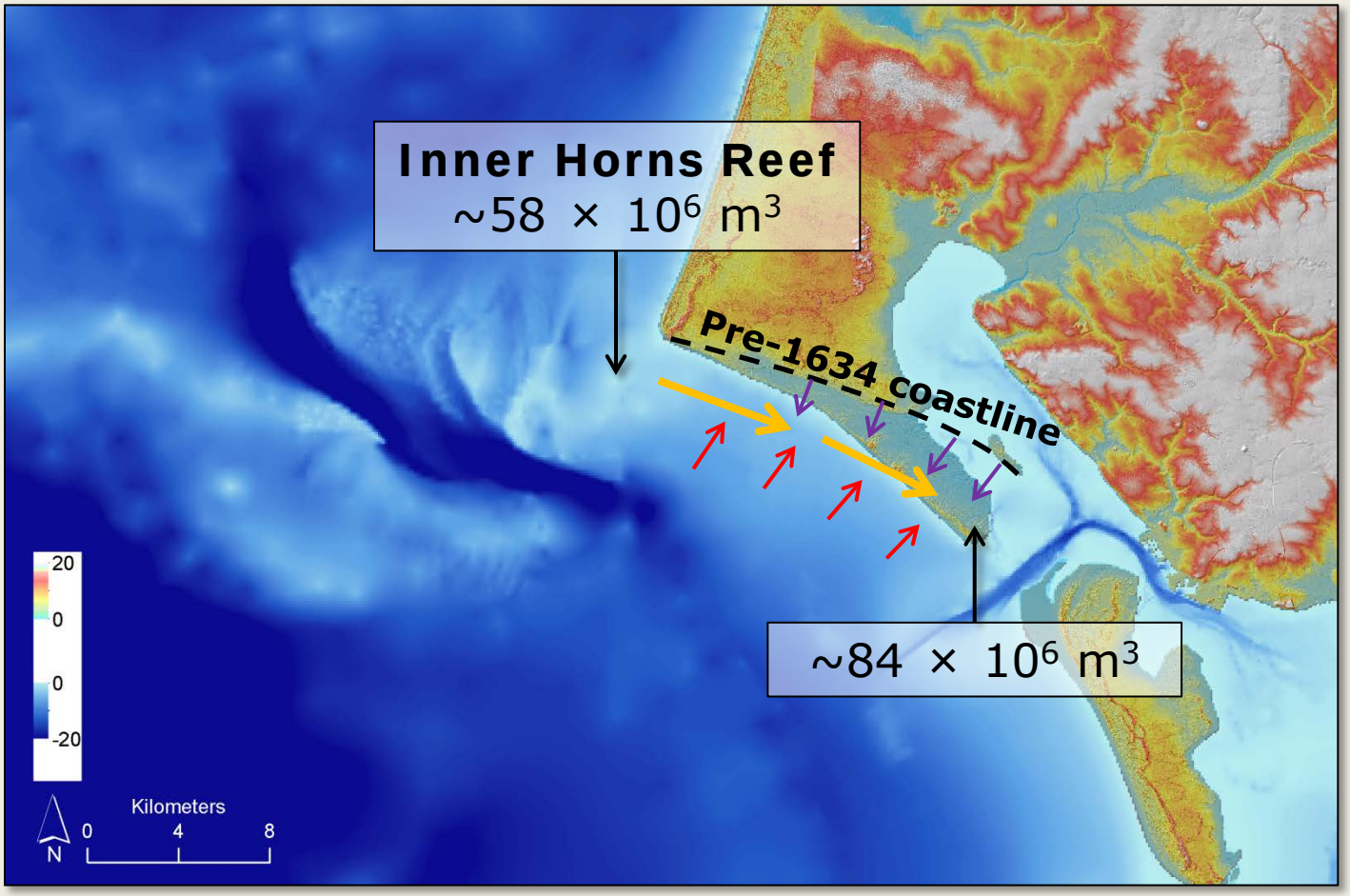



Modified from Fruergaard et al. 2013
and Fruergaard & Kroon 2016

# Sediment availability

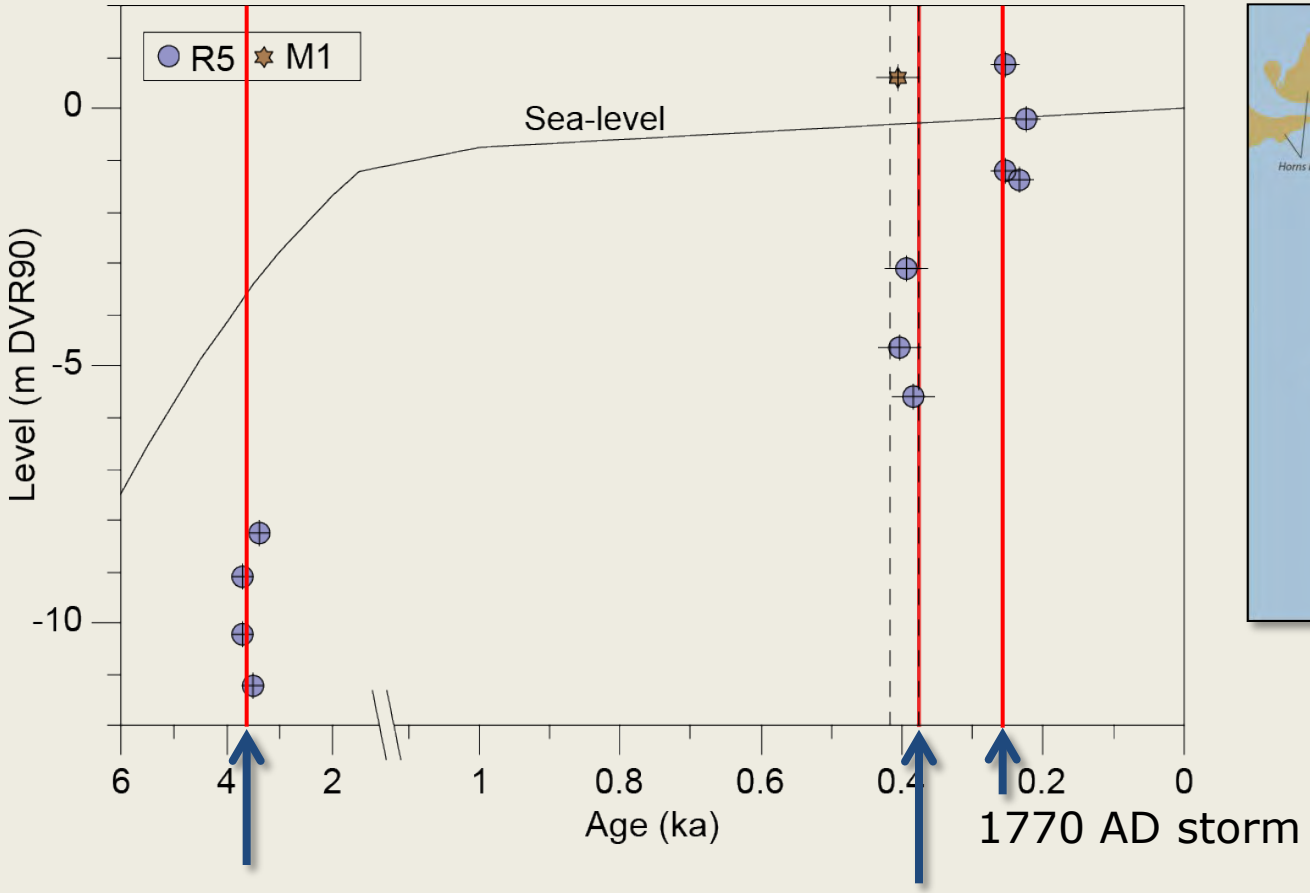


# Sediment availability




- Present-day sediment transport rate = 650.000 $m^3$ / year
- Sedimentation rate after the storm 2 to 3 times higher

# Regional impact



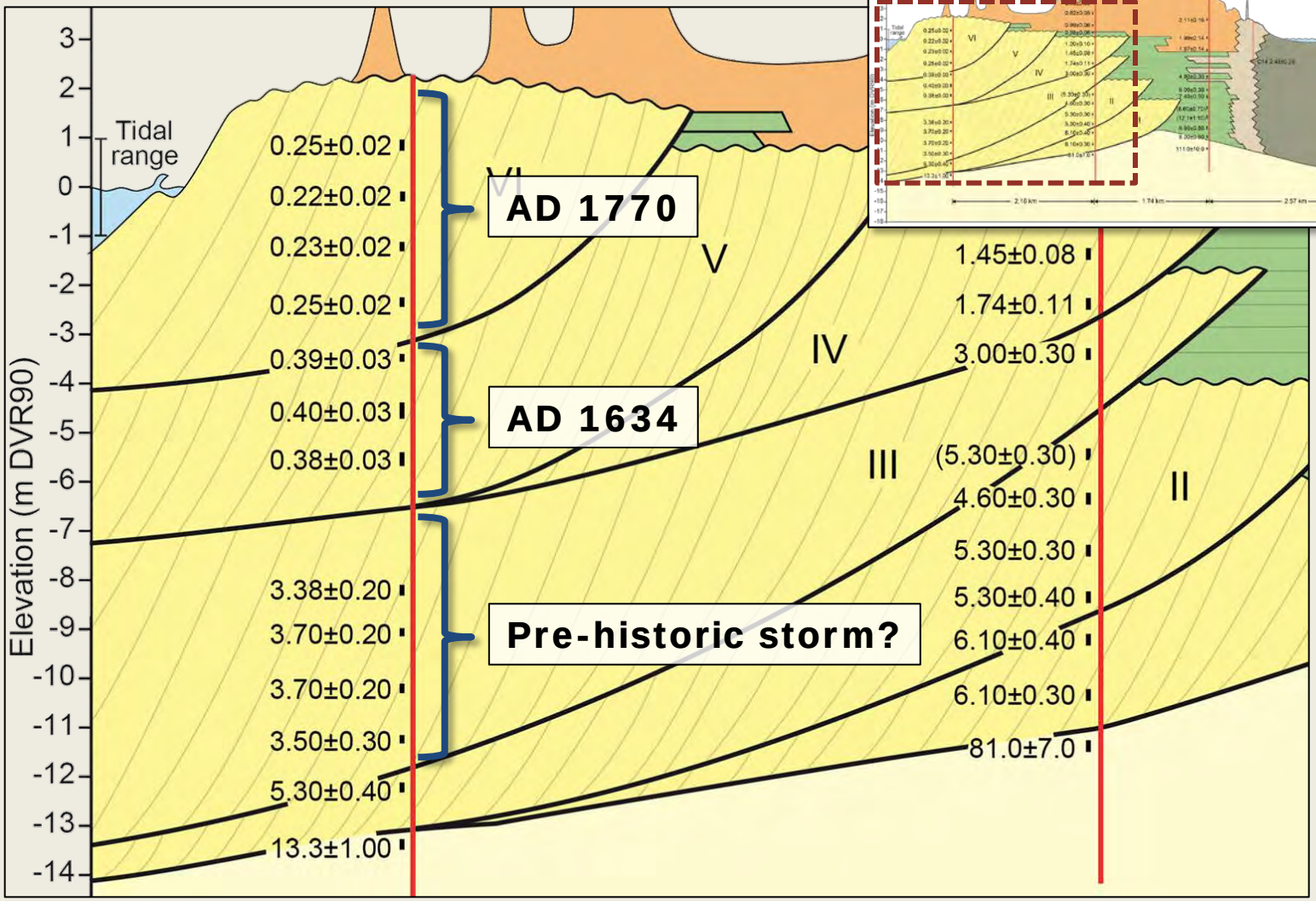


Pre historic storm ~3600 years ago?

The 1634 AD storm

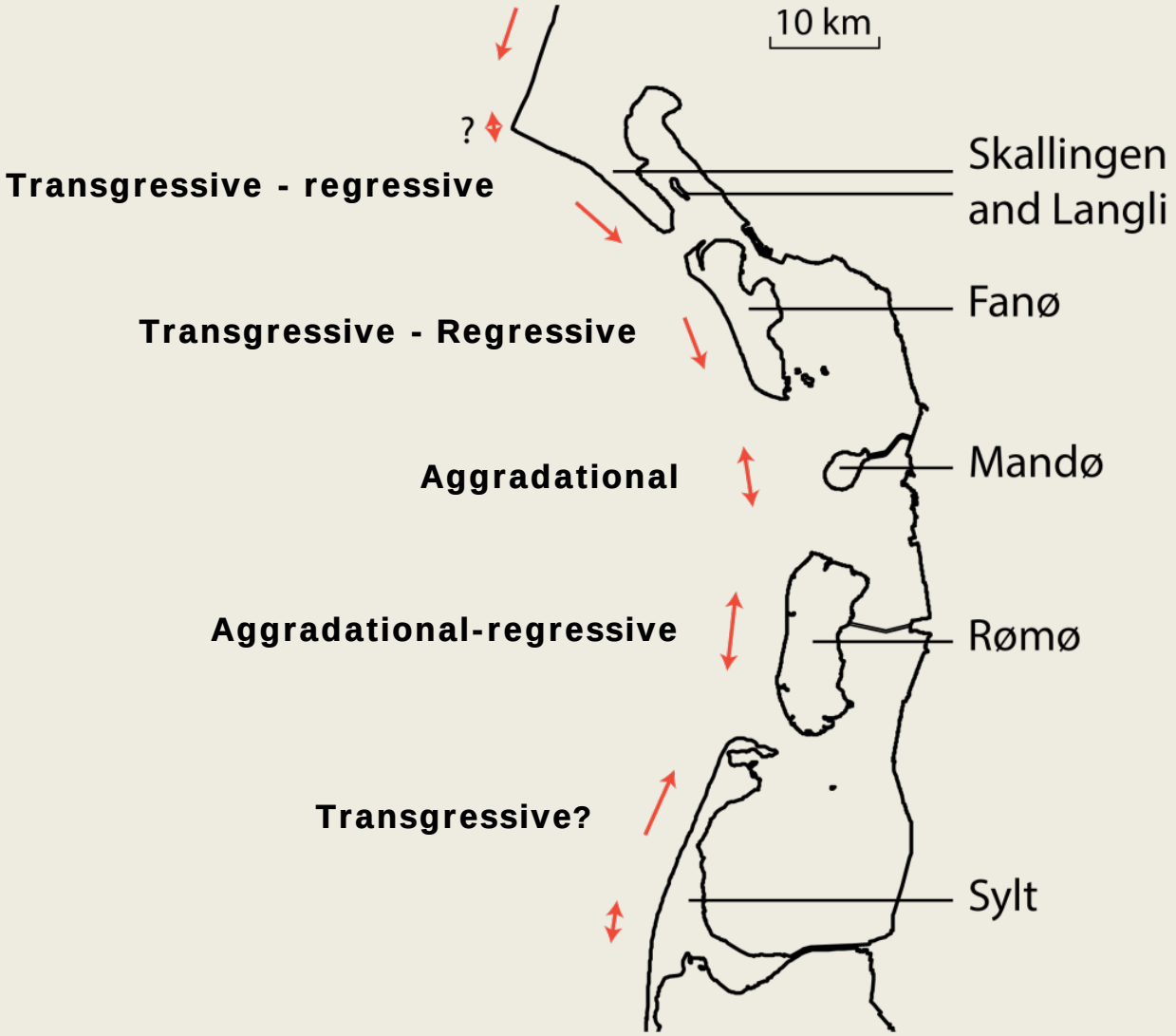
Modified from Fruergaard et al. 2013

# Punctuated coastal progradation




Johannessen et al. in prep.

# Barrier coast development




Fruergaard, 2013 (PhD thesis)

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# Conclusions

- **In the Wadden Sea, storms are a far more important driver of coastal changes than tsunamis.**

**Extreme storms in the Wadden Sea:**

- Create barrier islands and spits.
- Induce large scale coastal progradation.
- Control large-scale and long-term coastal evolution.
- Relatively high risk.

**Tsunamis in the Wadden Sea:**

- Little information exist.
- Local to regional sedimentological importance.
- What about the German and Dutch North Sea coastline?
- Low risk.

Thank you

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# References


Bondevik, S., 2003. Storegga tsunami sand in peat below the Tapes beach ridge at Harøy, western Norway, and its possible relation to an early Stone Age settlement. Boreas 32, 476–483.

Bondevik, S., Stormo, S.K., Skjerdal, G., 2012. Green mosses date the Storegga tsunami to the chilliest decades of the 8.2 ka cold event. Quaternary Science Reviews 45, 1–6.

Church, J.A. et al., 2013. Sea Level Change. In: T.F.Q. Stocker, D.; Plattner,G.-K.; Tignor,M.; Allen,S.K.; Boschung,J.; Nauels,A.; Xia,Y.; Bex,V.; Midgley,P.M. (Ed.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 1137-1216.

Fruergaard, M., 2013. On the Evolution of a Holocene Barrier Coast – Response to sea-level change and sediment supply (PhD thesis), University of Copenhagen, Copenhagen, 183 pp.

Fruergaard, M., Andersen, T.J., Johannessen, P.N., Nielsen, L.H., Pejrup, M., 2013. Major coastal impact induced by a 1000-year storm event. Scientific Reports 3, 1–7.

Fruergaard, M., Kroon, A., 2016. Morphological response of a barrier island system on a catastrophic event: the AD 1634 North Sea storm. Earth Surface Processes and Landforms 41, 420-426.

Fruergaard, M. et al., 2015. Tsunami propagation over a wide, shallow continental shelf caused by the Storegga slide, southeastern North Sea, Denmark. Geology 43, 1047-1050.

Hill, J., Collins, G.S., Avdis, A., Kramer, S.C., Piggott, M.D., 2014. How does multiscale modelling and inclusion of realistic palaeobathymetry affect numerical simulation of the Storegga Slide tsunami? Ocean Modelling 83, 11–25.

IPCC, 2013. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge.

McBride, R.A. et al., 2013. Morphodynamics of Barrier Systems: A Synthesis, Treatise on Geomorphology. Elsevier Inc., pp. 166-244.

Sørensen, C., Madsen, H.T., Knudsen, S.B., 2013. Højvandsstatistikker 2012 (in Danish), Danish Coastal Authority.