

The Tømte Symposium October 24th 2022 Quick clays – geological constraints and occurrences - Rosenqvist tribute



GEOLOGICAL
SURVEY OF
NORWAY
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Paleoenvironmental conditions favoring the accumulation of (glacio)marine clays in Norwegian fjord valleys

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Photo: Louise Hansen



1. Problems related to sensitive clays and quick clay in Norway have their root in geology and the Ice Age!

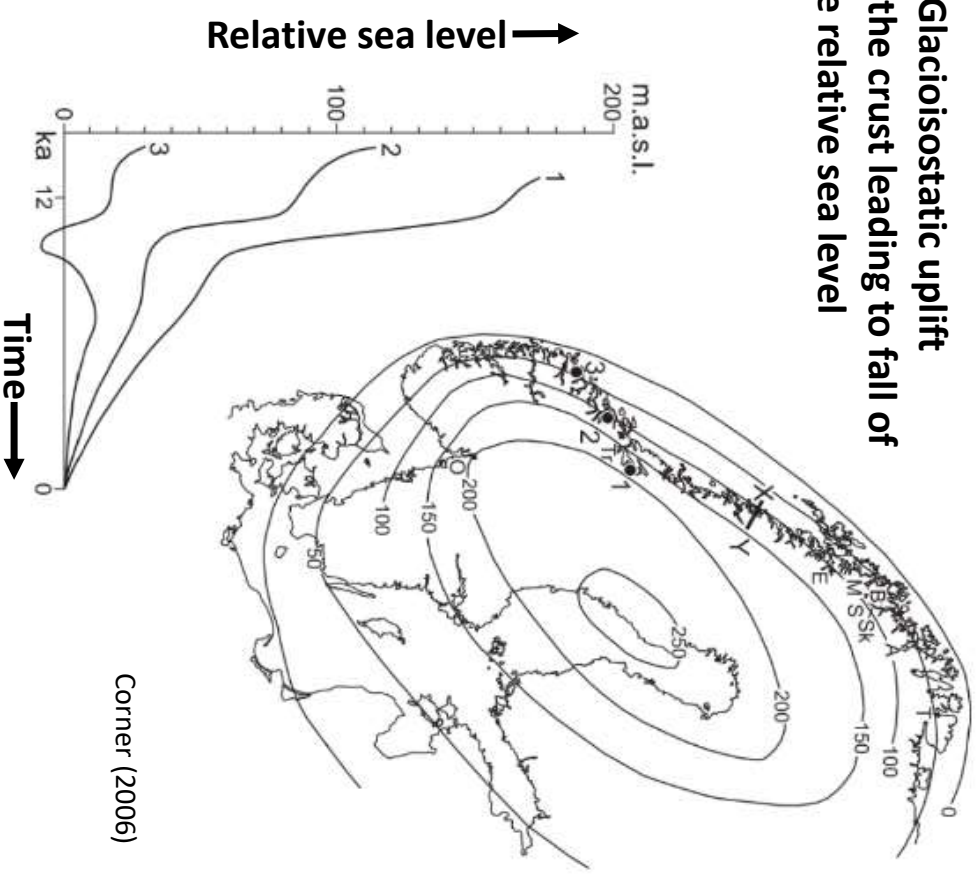
1. Glaciation, glacier retreat
and accumulation of
(glacio)marine clays in the
fjords

flocculation.....



Foto: Louise Hansen

2. Glacioisostatic uplift
of the crust leading to fall of
the relative sea level



3. Emergence of clay deposits, erosion and leaching of salts/geochemical alterations:

Development of
sensitive sediments
including quick clay

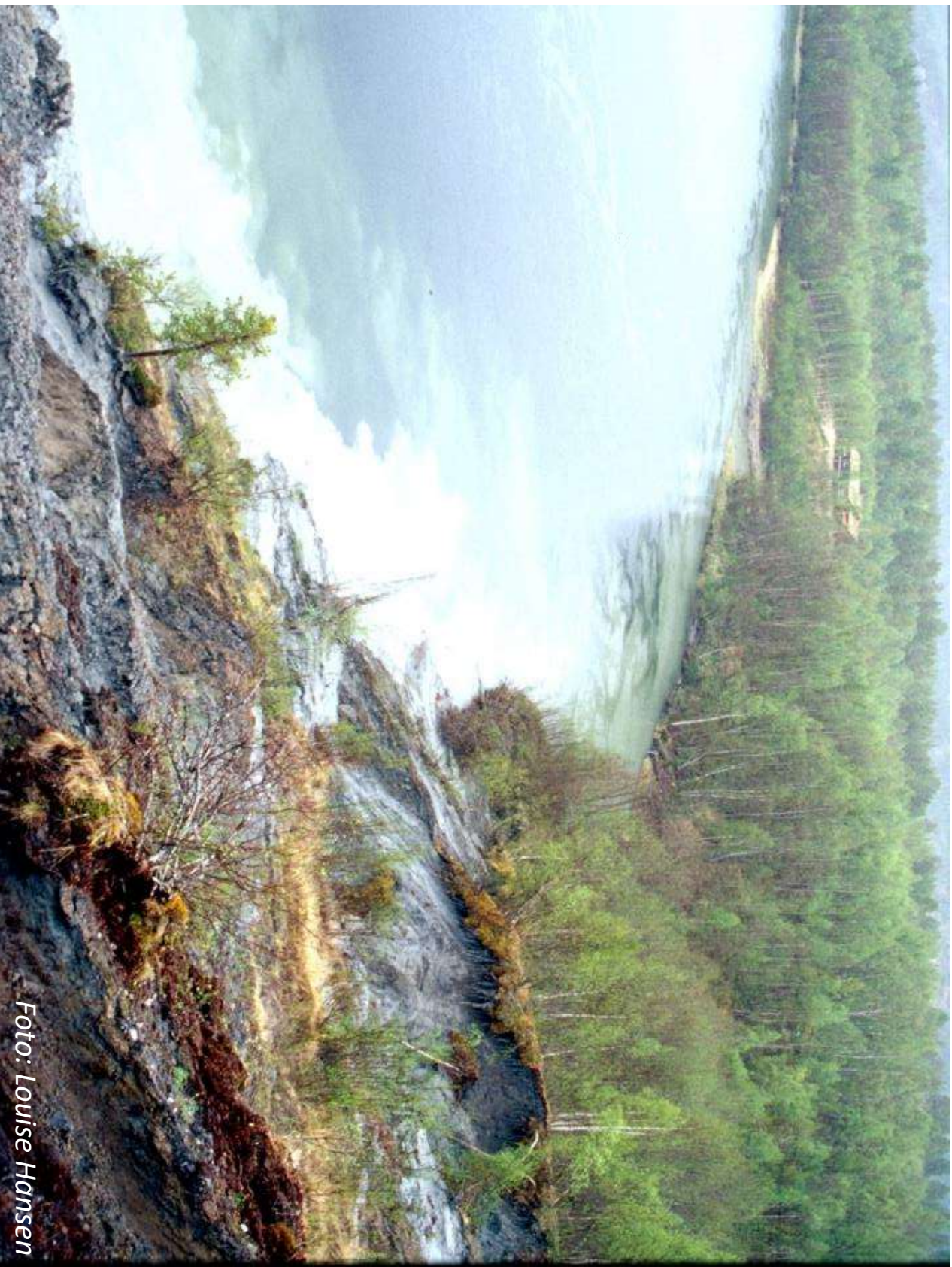
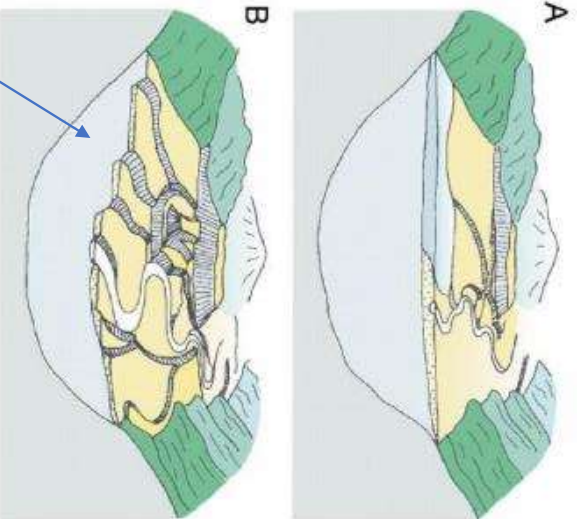


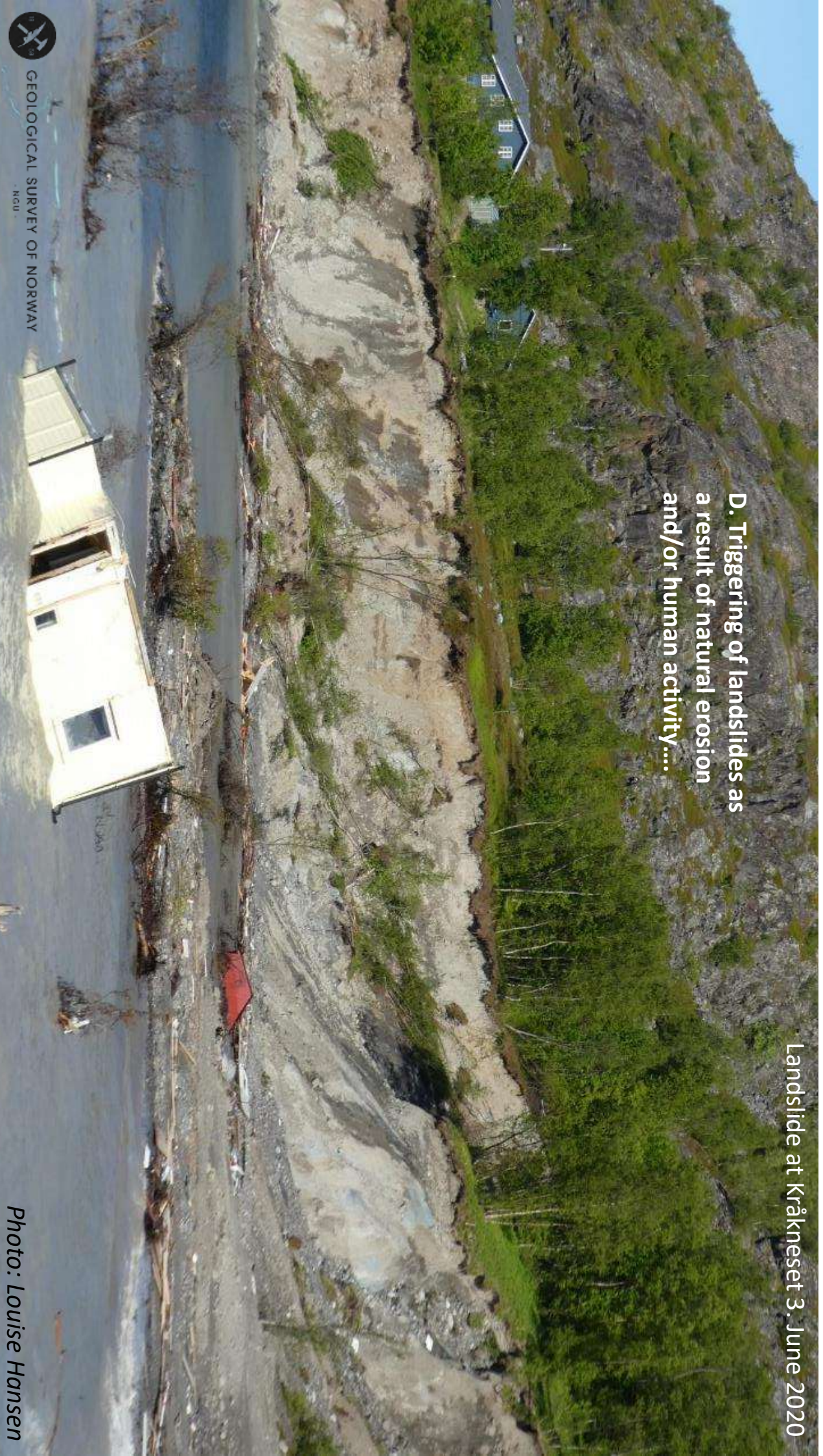
Foto: Louise Hansen



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Landslide at Kråkneset 3. June 2020

D. Triggering of landslides as
a result of natural erosion
and/or human activity....



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Photo: Louise Hansen

“Why bother??”

Because knowledge on paleoenvironments provides important GEOLOGICAL CONSTRAINTS for marine clay occurrences:

1. Marine limit (ML)

2. Maps over the Quaternary geology

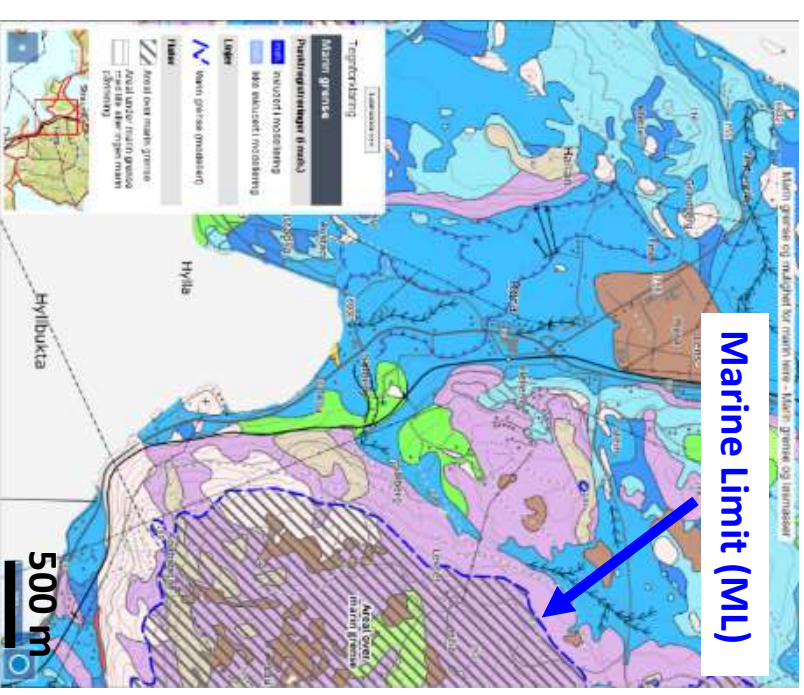
3. Communicated to society via the internet (www.ngu.no)

—used in planning/quick clay-related work



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‘Quaternary map’



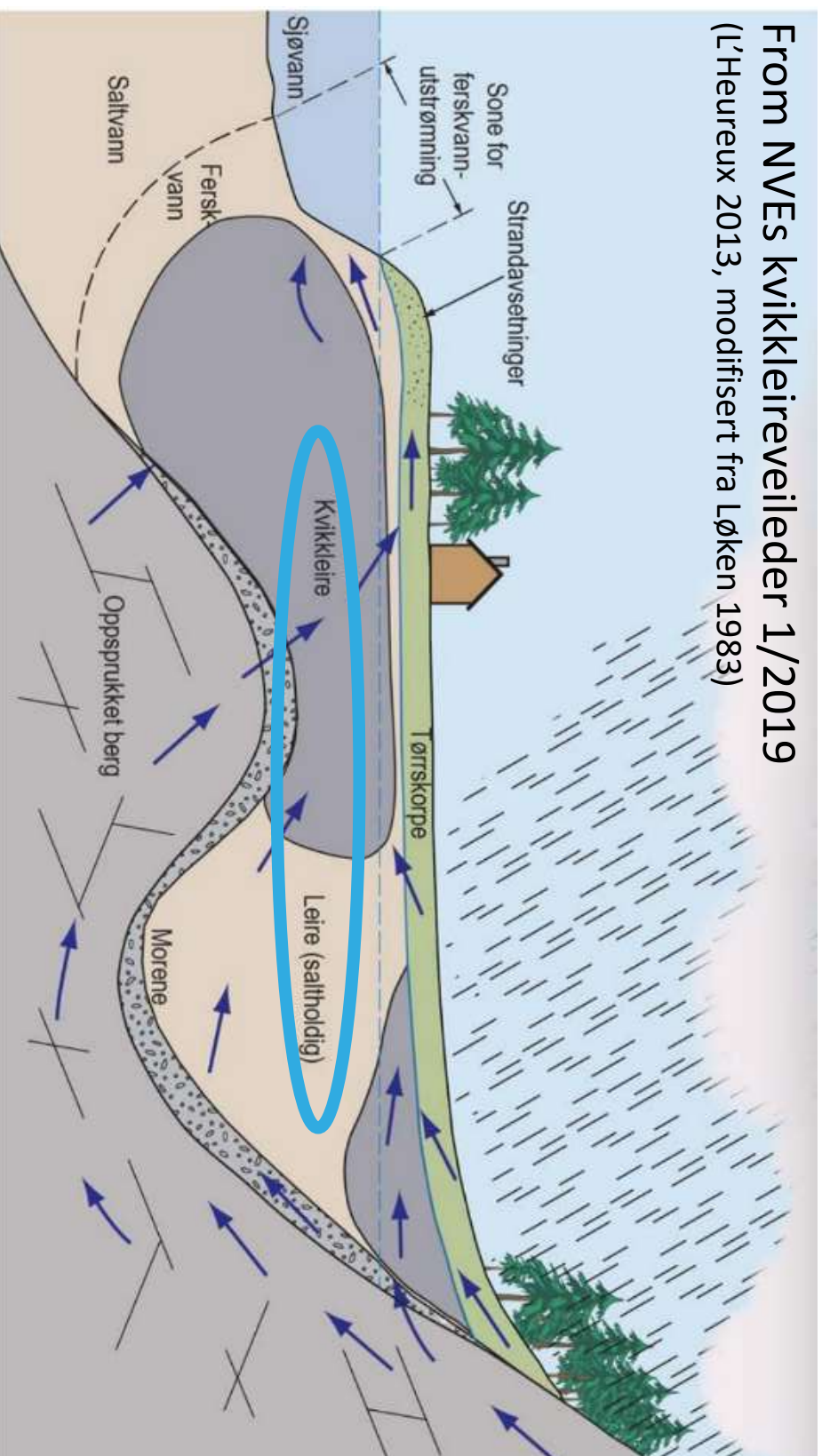
From www.ngu.no

Financial support from NVE



Models on quick clay formation focus on post-depositional leaching in association to fractured bedrock/acquifers.....

From NVEs kvikkleireveileder 1/2019
(L'Heureux 2013, modifisert fra Løken 1983)



Figur 2.4 Illustrasjon etter NIFS-rapport 26/2013 (6) som viser hvordan ferskvann som over tid strømmer gjennom marin leire, kan medføre utvasking av salt i leira.



- 1) To increase the awareness about depositional environments and 'genetics' of marine clay deposits
- 2) To highlight some syndimentary factors that play role in the development of sensitive clays

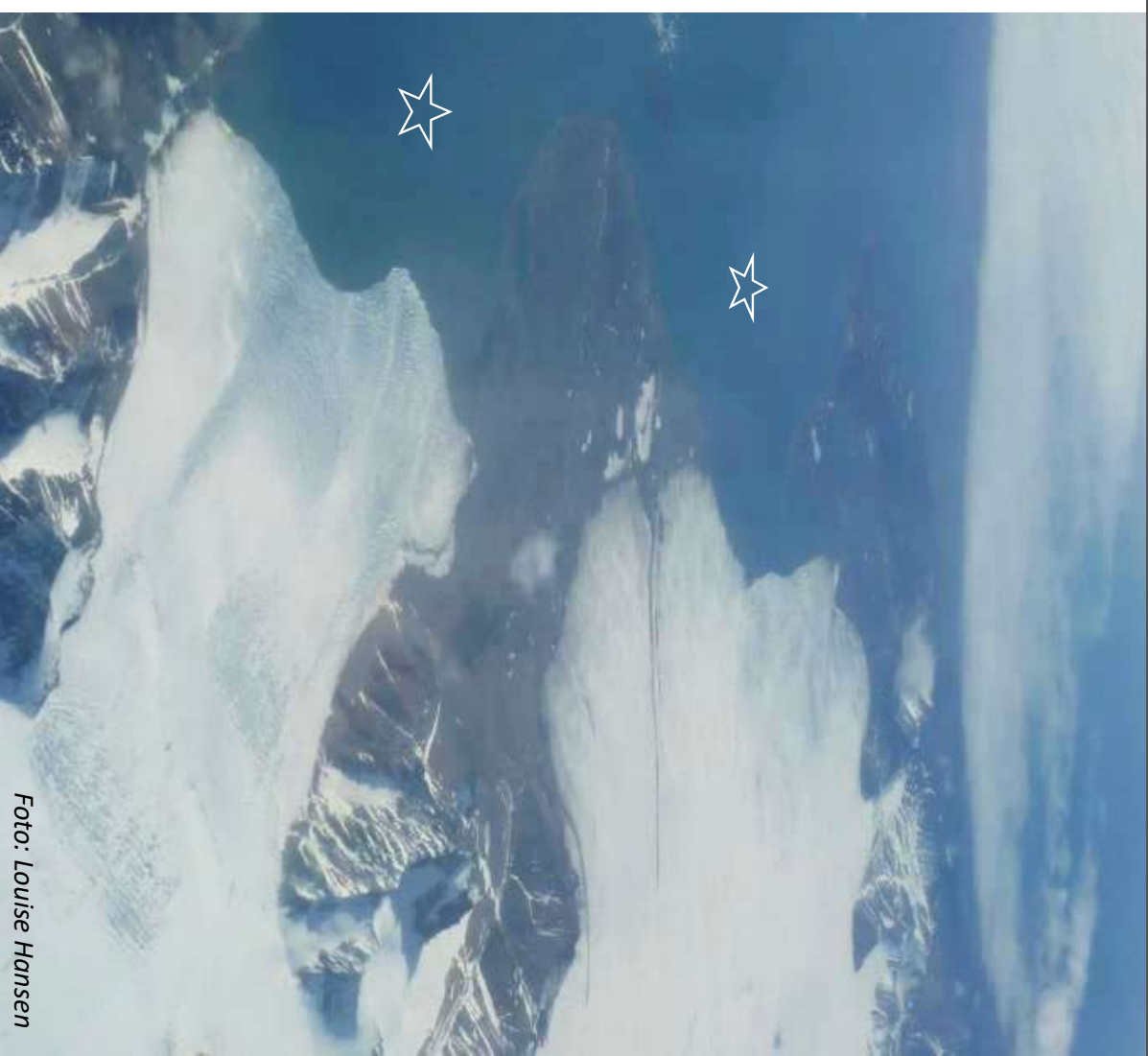
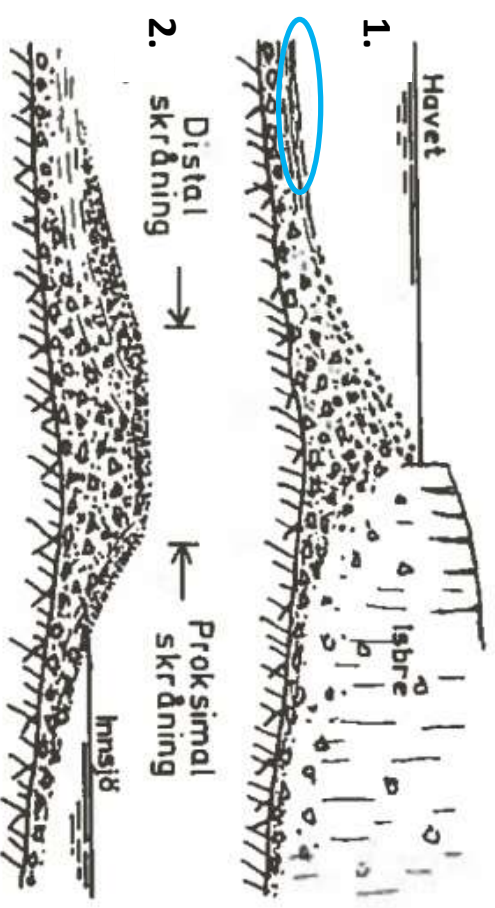


Foto: Louise Hansen



Paleoenvironmental models help us explain the geology we encounter:

- Embrace the range of processes involved
- Reflect their causal relationships
- Provide a context for understanding the deposits



Selmer-Olsen (1976) - Textbook in Engineering Geology

....good! –but a bit oversimplified!



Detailed depositional model for proximal ice-contact delta:

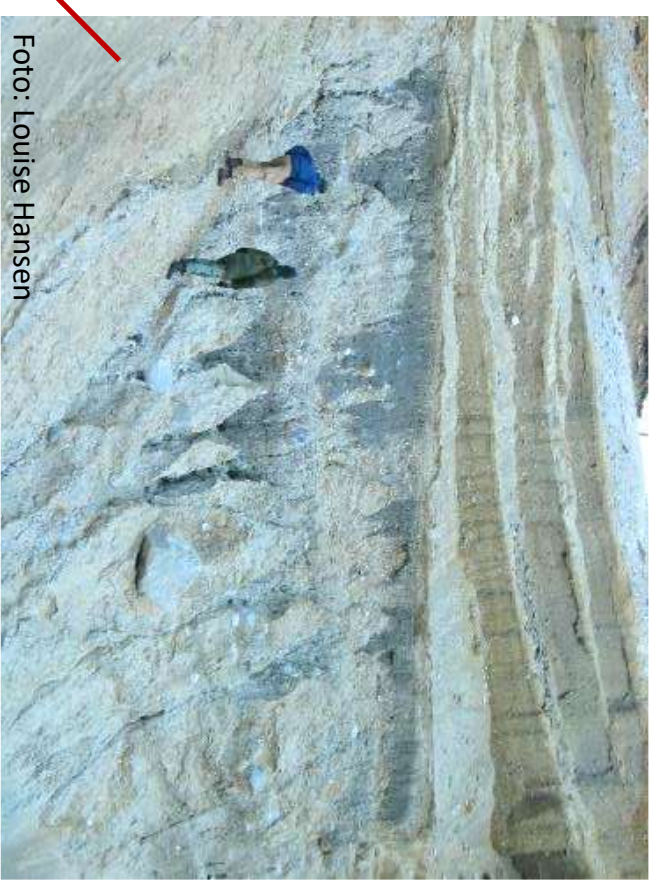
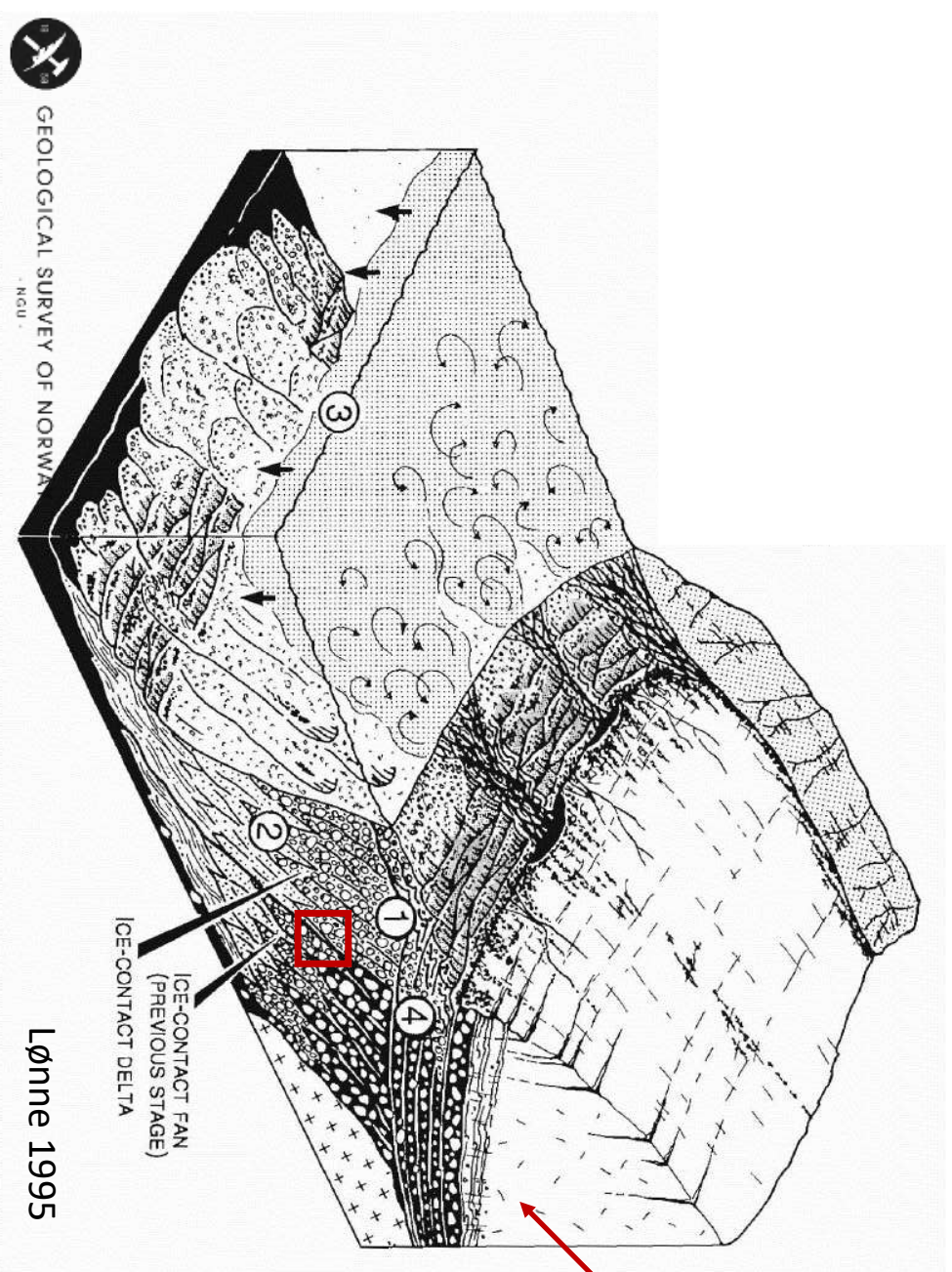
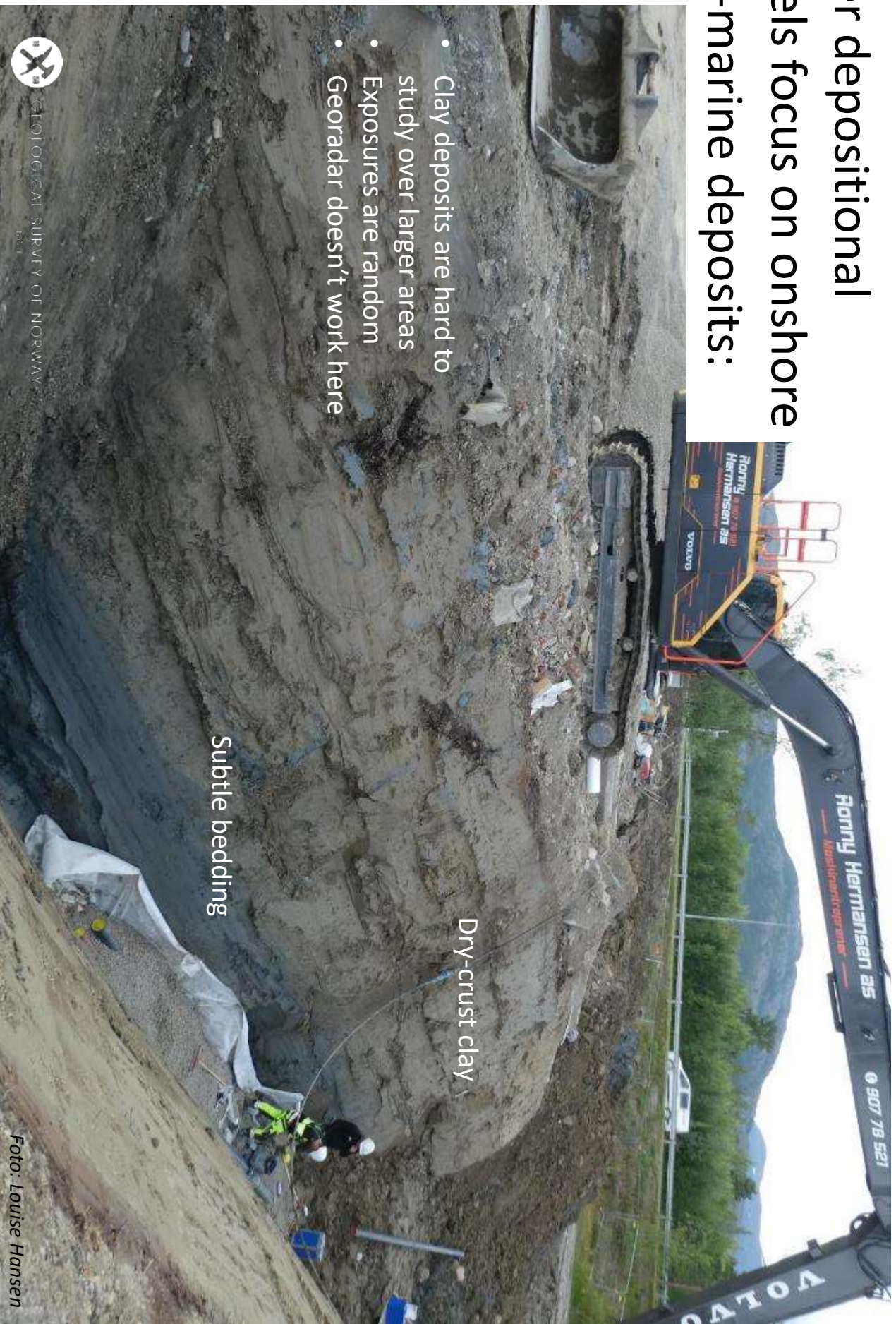


Foto: Louise Hansen

Data on internal structures are easy to access...
Gravel pits/georadar

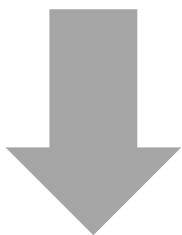
Fewer depositional models focus on onshore fjord-marine deposits:

- Clay deposits are hard to study over larger areas
- Exposures are random
- Georadar doesn't work here



The sedimentation processes are
(often) inferred:

“Clay deposits have
accumulated through ‘passive’
suspension sedimentation of
flocculated clay and silt...”



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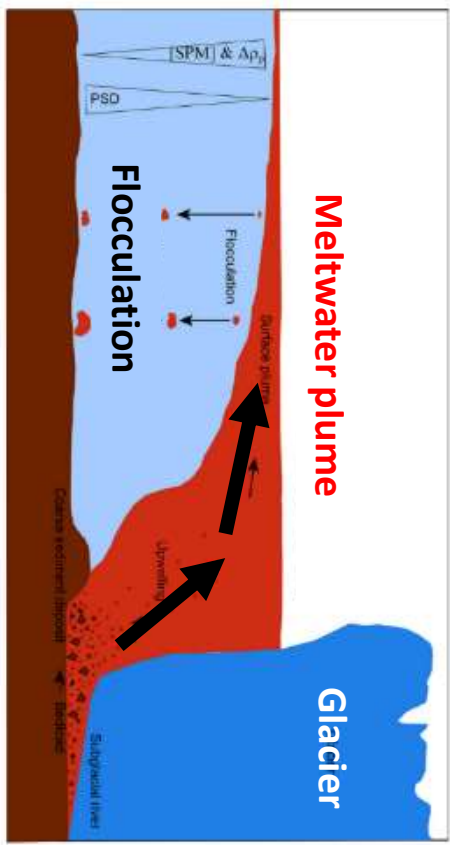
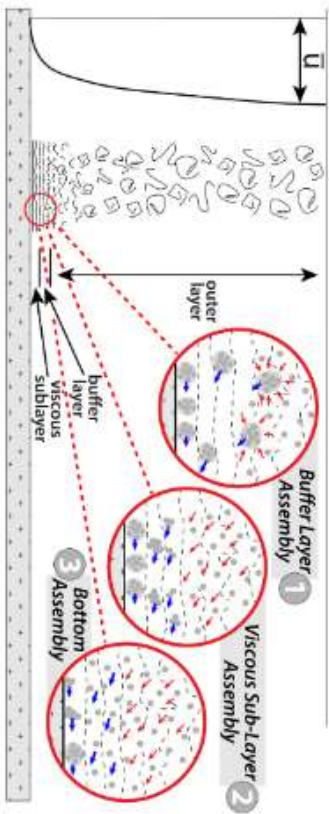


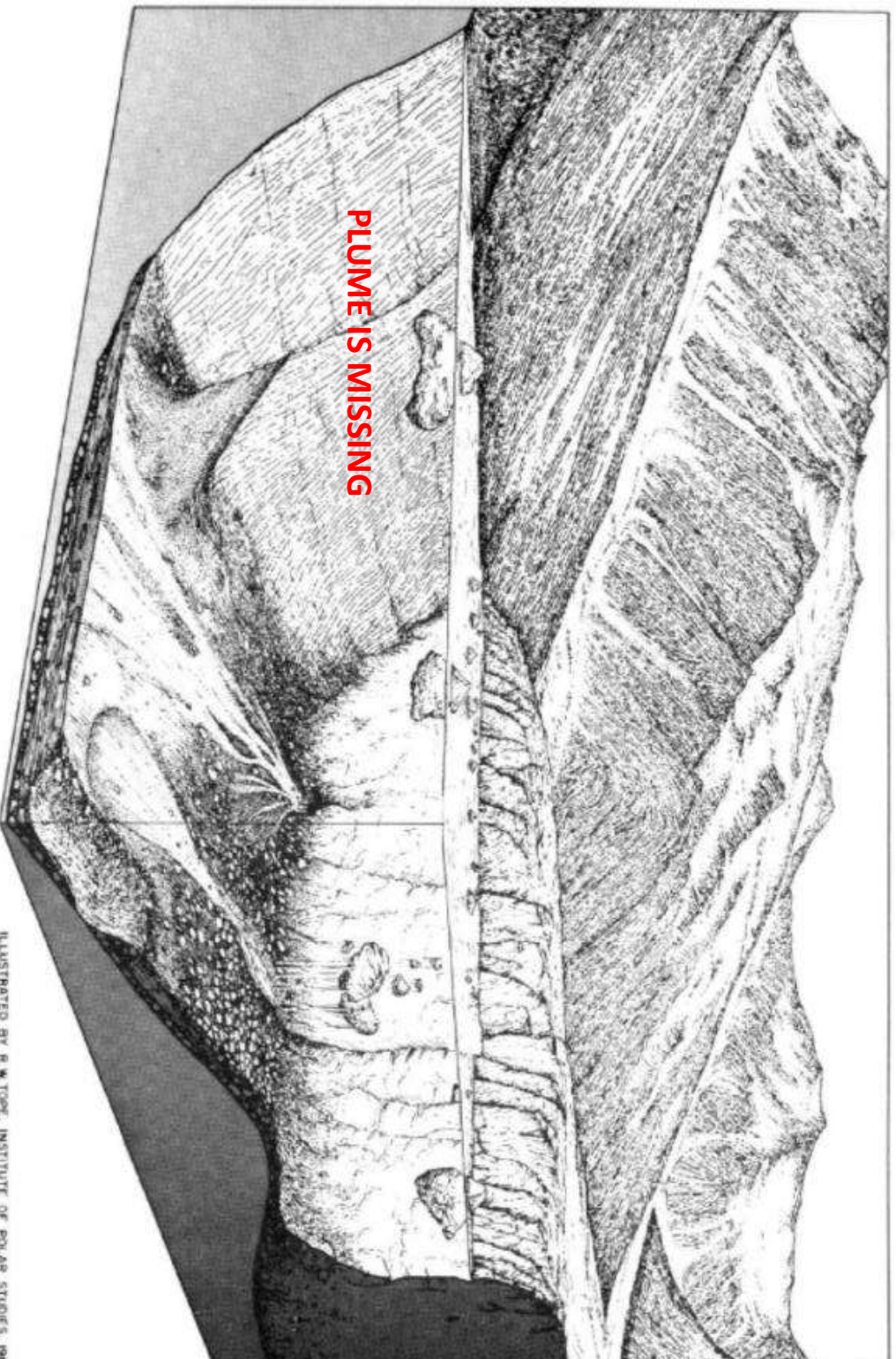
Fig. 8. Conceptual model of the particle dynamics of a typical glacial upwelling system in front of the Kroneveien glacier into the Kongsvordent

Meslard et al. 2022

New research: Role of moving suspensions?

Possible scenarios for production sand size bedload
flocules from moving suspensions: The small grey dots
represent in-flow flocules that are merged into larger
aggregates (Schieber et al. 2022).

4. GLACIATED FJORD ENVIRONMENTS

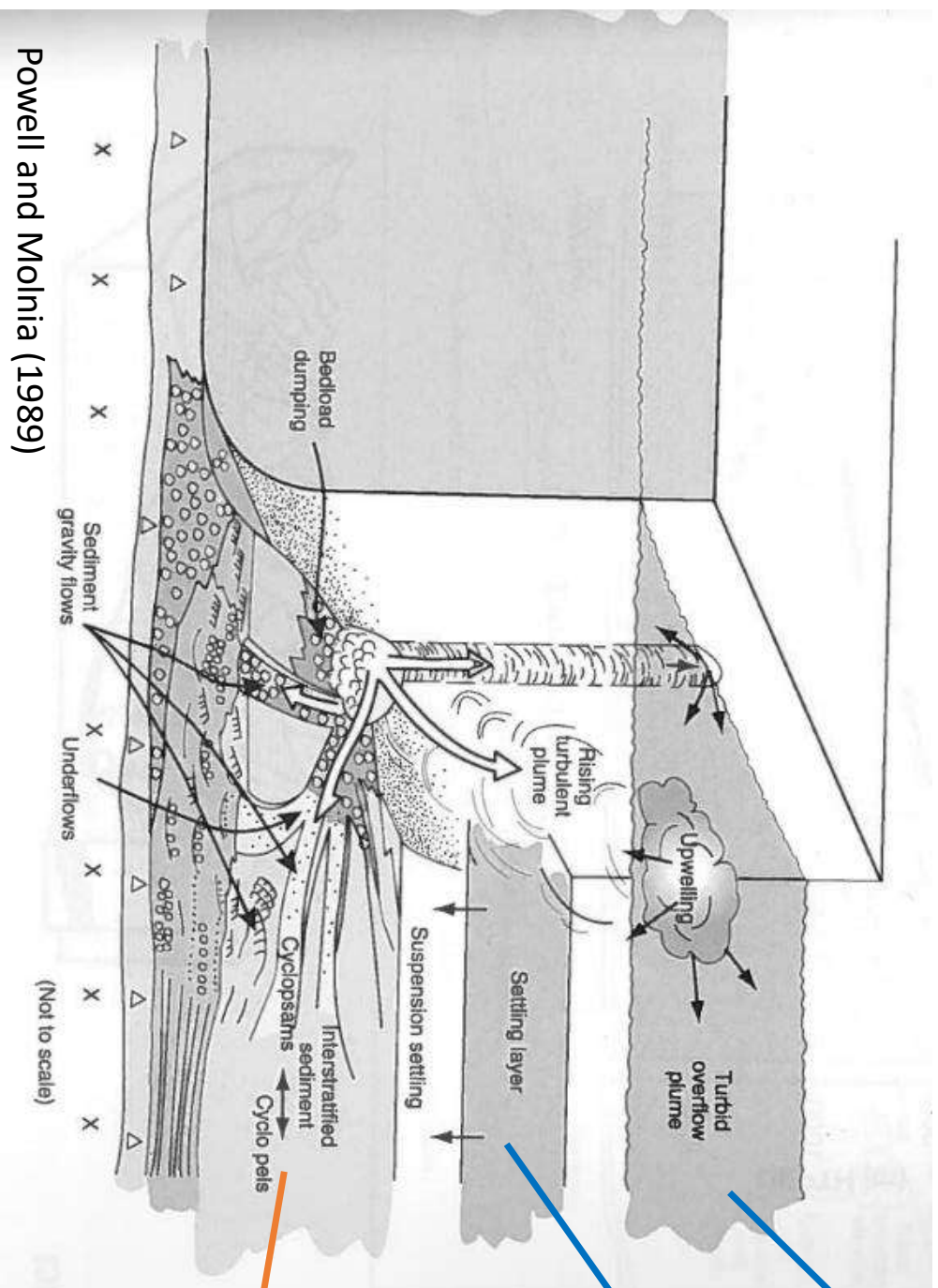


ILLUSTRATED BY R. W. TOPEL, INSTITUTE OF POLAR STUDIES, 1980

Fig.2. Slowly retreating tidewater glacier actively calving in shallow water. Sediment facies shown are Facies Association II.

A) SEDIMENT TRANSFER FROM MARGIN AT FIORD GLACIER:

Effluent plumes are spread according to density and water column stratification/salinity, seasonality



Overflow plumes
sand/silt/clay in suspension

Interflow plumes
sand/silt/clay in suspension

+ flocculation

Underflows (dense effluents)
-channels
-coarser material
-turbidity currents

....transported to distal areas/protected embayments along the way (topography)



PROCESSES AND DEPOSITS IN GLACIATED FJORD BASINS

Glacial sources

Sedimentation processes:

- Hemipelagic (varying)
- Ice-berg drop
- Tidal currents/circulation
- Turbidity currents/muddy
- Resedimentation/slumps
- Major mass flow events
- Reduced/no bioturbation
- Specific biota
- Annual variation
-

Processes change over time during glacier advance/retreat (climate)

Deposits:

Facies:

- Rhythmically laminated mud
- Diffusely stratified mud
- Graded/massive mud
- Banded mud
- Deformed mud
- Bioturbated mud
- +/- Fossil content

Core photographs/CT scans:

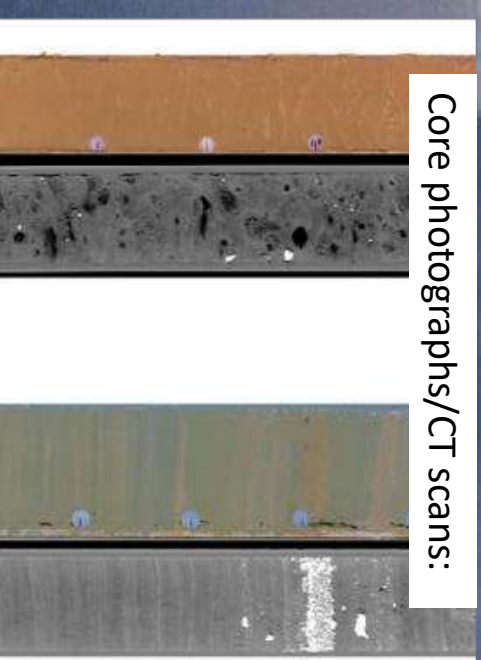




Photo: Louise Hansen

Onshores exposures:

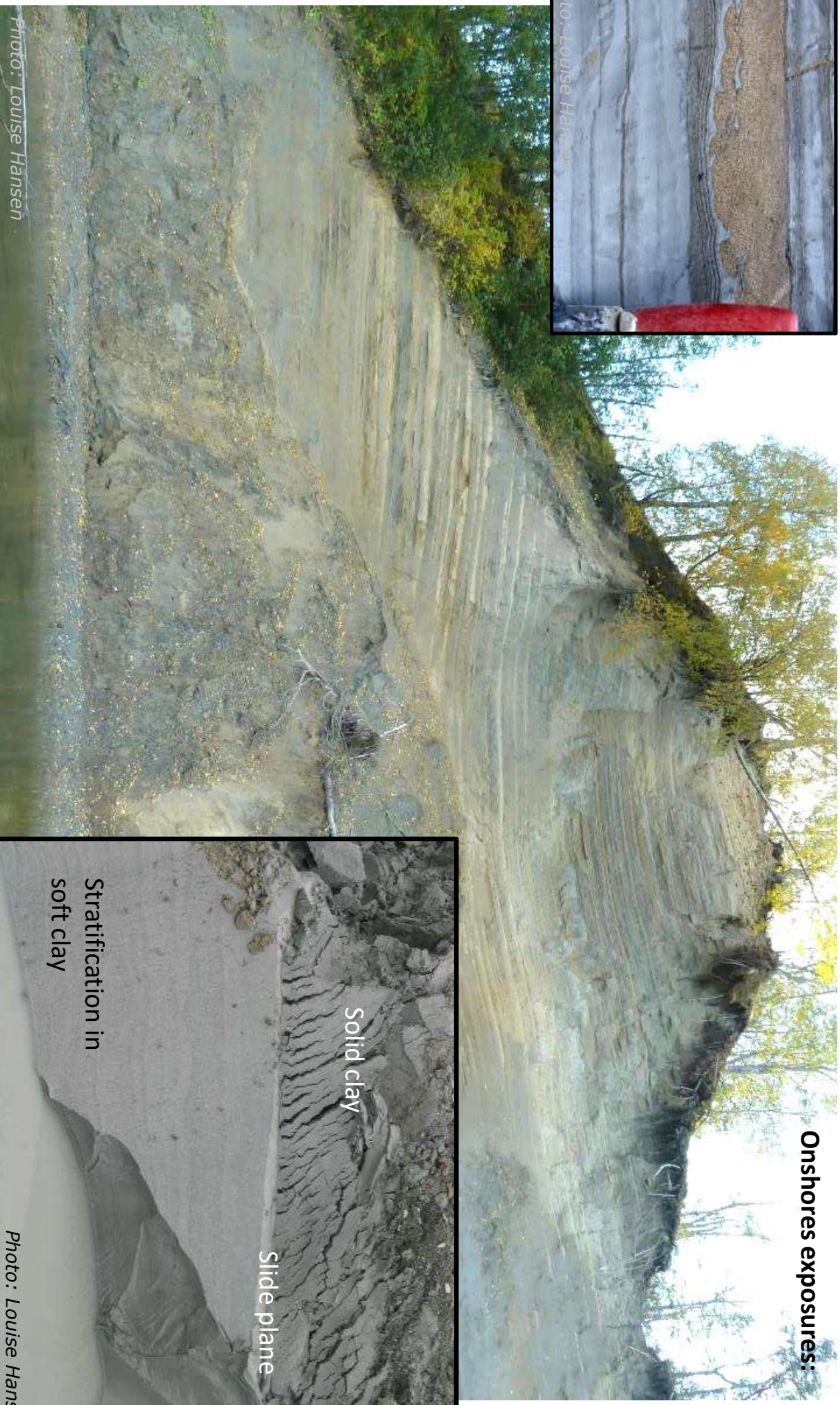
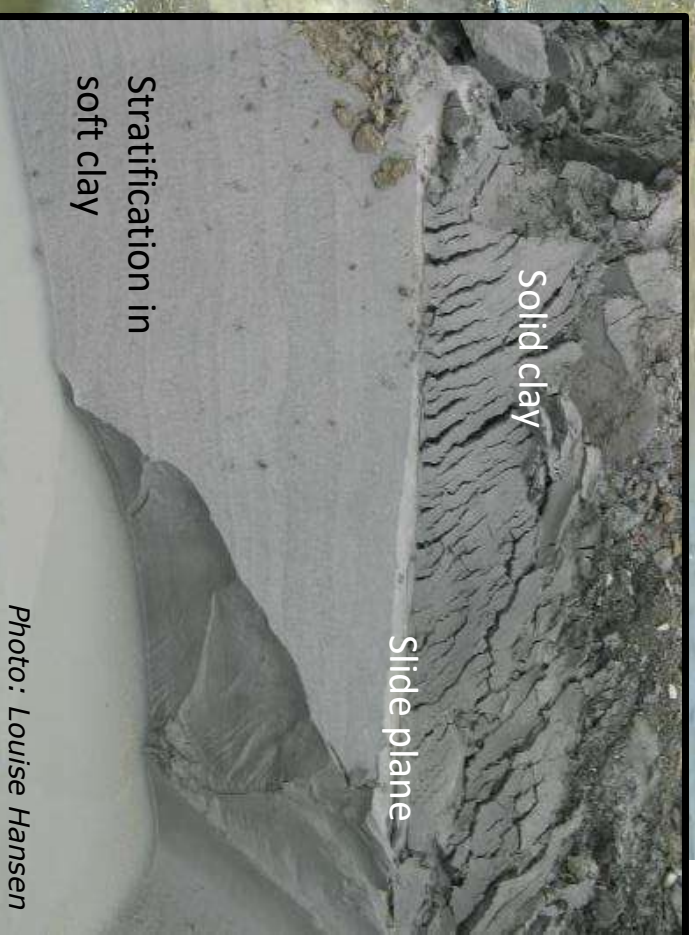


Photo: Louise Hansen



Solid clay

Slide plane

Stratification in
soft clay

Photo: Louise Hansen

Nordfjorden, western Norway, Hjelstuen et al. (2009)



Large-scale structures in onshore exposure (Mid Norway):

Large exposures are rare!

Example of syn-/postdepositional deformation

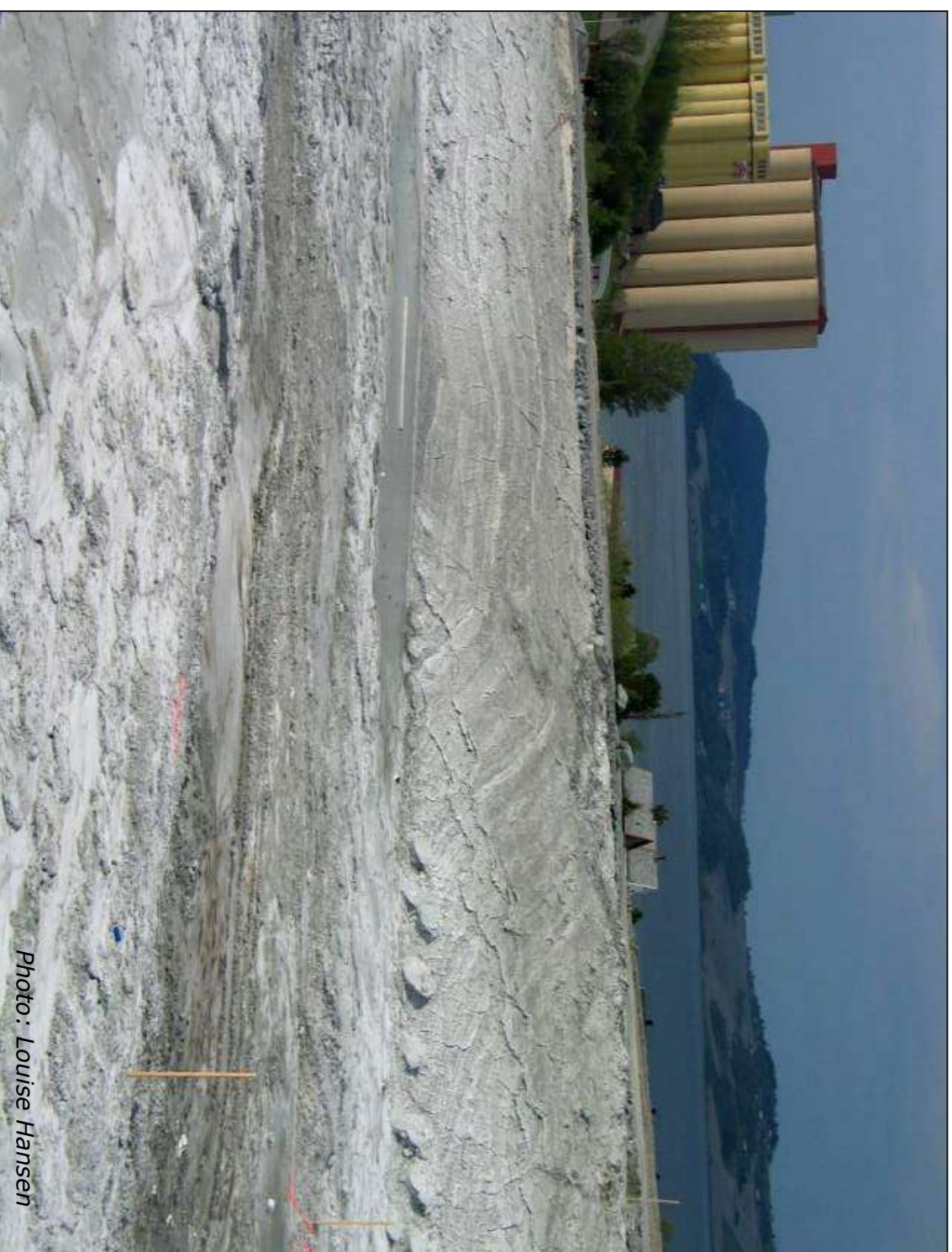


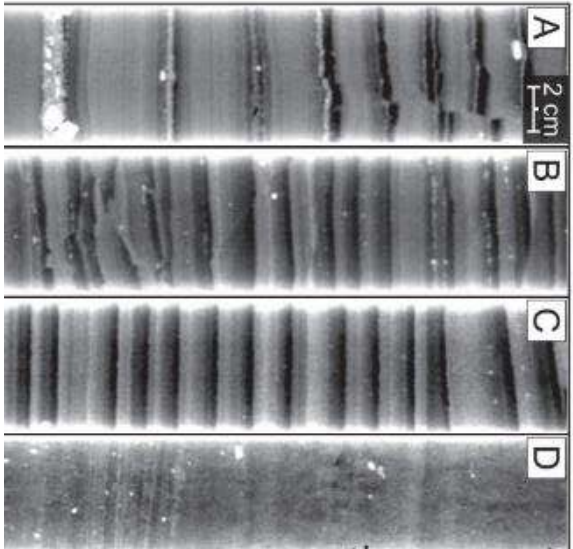
Photo: Louise Hansen



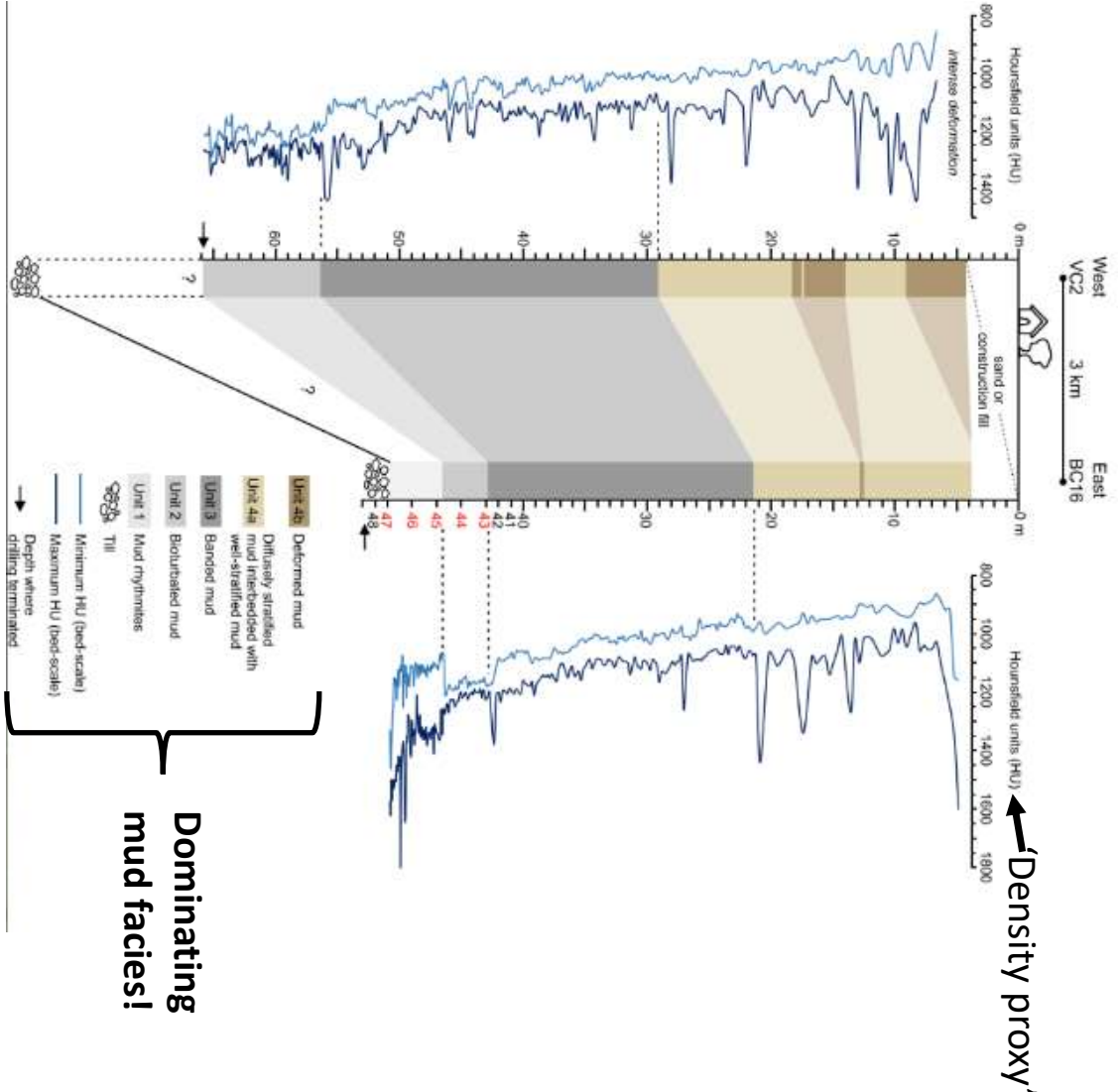
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Few onshore studies of clay/silt deposits address the details in processes and depositional environments

Example from Champlain sea in Canada:
Sedimentary structures from CT canned cores



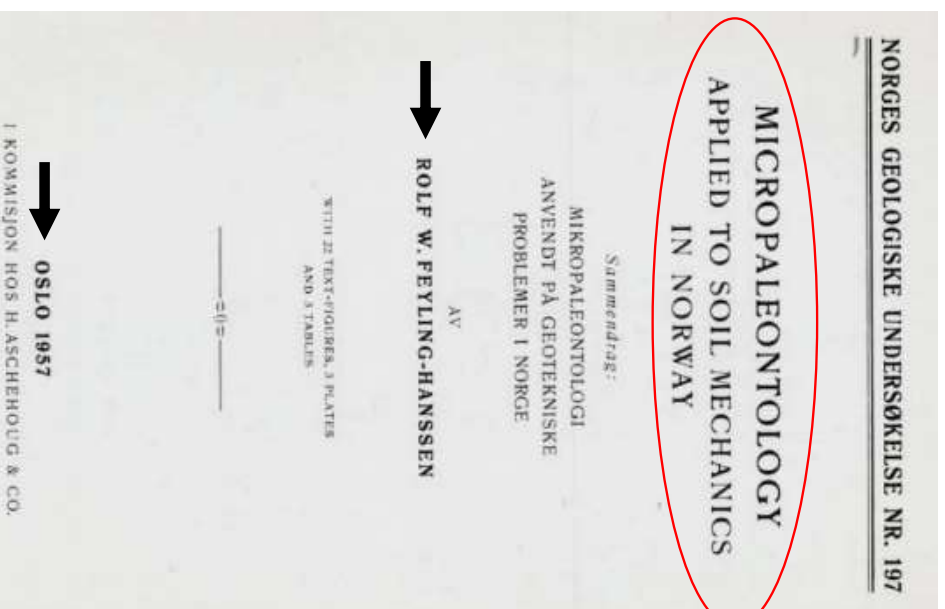
CT-scanned cores



Relationship between bedding types and properties?

Al-Mufti et al. 2022

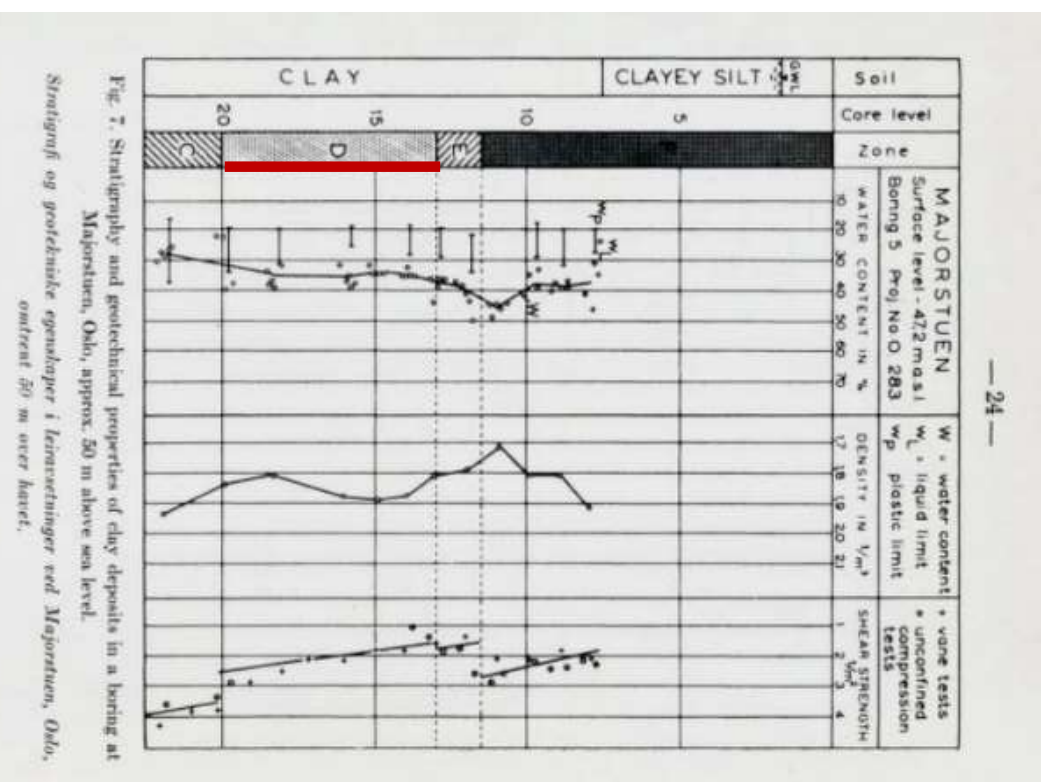
A classical paleoenvironmental study on micropaleontology!



Foraminifer species assemblages
(zones A-G) tell about salinity



Low salt contents are in part inherited from the depositional environment!



“A close correlation exists between the stratigraphical zones and the shear strengths of a clay deposit”

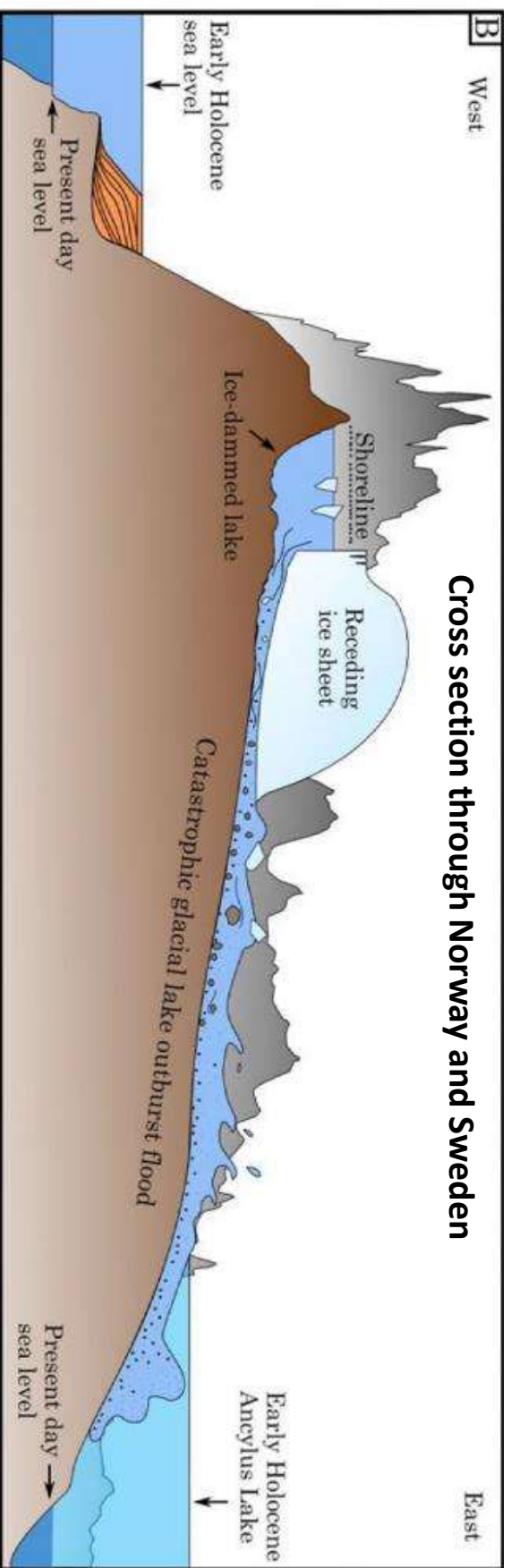
“A clay belonging to **zone D**, which was **deposited in water of low salinity**, will, during the process of leaching, probably reach this critical value * some thousand years before a clay which had a high original salt content in its pore water (fig. 10)”

* Salt content

5. GLACIAL LAKE OUTBURST FLOODS (GLOFs)

GLOFs are catastrophic floodings caused by the drainage of major glacial lake basins during final deglaciation!

- Sudden influx of freshwater to marine basins
- Loads of suspended fines
- Rapid deposition of event beds
- (Feyling-Hanssen zone D???)



Cross section through Norway and Sweden



6. NON-GLACIATED FIORD ENVIRONMENT

PROCESSES AND DEPOSITS IN NON-GLACIATED FIORD BASINS

Deltaic sources

Typical sedimentation rates:

Glaciated: Max 50-100 cm/yr

Non-glaciated: Max 5-10 cm/yr

Sedimentation processes:

- Hemipelagic/lower rates
- Currents/circulation
- **More bioturbation**
- Turbidity currents
- Resedimentation/slumps
- Major mass flow events
- Organic production
- Specific biota
- Annual variation
-

Processes change over time
(climate)

Deposits:

Several facies:

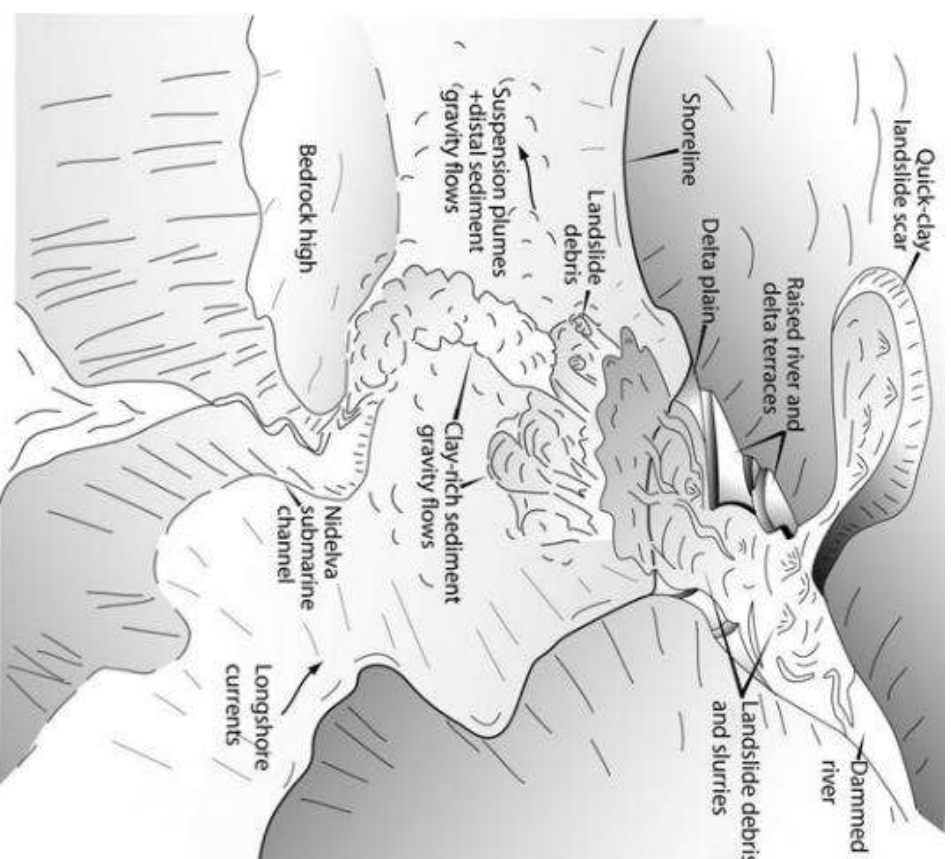
- Bioturbated mud
 - Event beds
- With preserved stratification
- + Fossil content

Photo: Louise Hansen

Some event beds are produced during exceptional events like landslides and/or floods



-provide renewed influx of clay to the fjord



Hansen et al. 2011

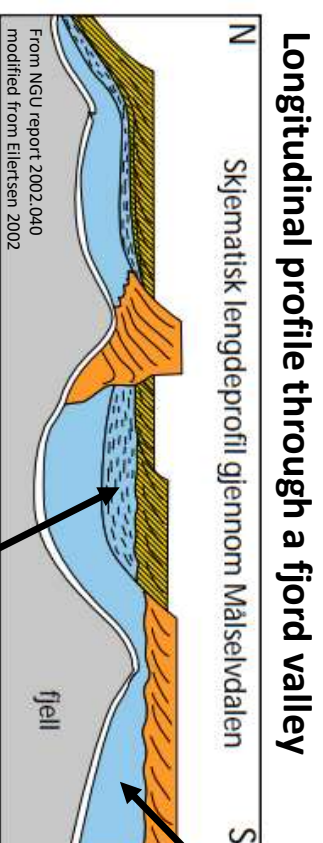
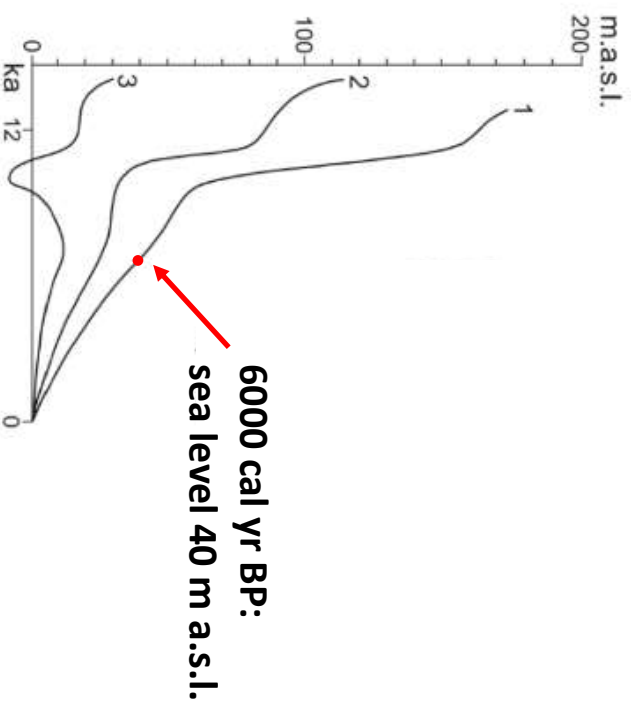
- Clay-rich suspensions
- Flocculation
- Suspension sedimentation
- Sediment gravity flows
- (Reduced salinities)
- Fast sedimentation!!

Event beds may be more sensitive than the surrounding beds



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‘Recycled’ mud potentially accumulate in shallow fjord arms followed by emergence/leaching.....
.....could become young sensitive clays below the valley floor



Postglacial fjord-marine deposits
-Thinner than their glaciomarine counterparts



Paleoenvironmental models:

- 1) Help our understanding of fjord-marine deposits regarding their occurrences/variability in 3D/4D
 - Structural information at all scales/fossil content are important for genetic interpretation
 - Studies are encouraged that improve our knowledge on processes/environments

- 2) Several factors related to sedimentation play a role in the development of sensitive clays:



- Supply of suspended fines with low activity minerals ('rock flour')
- Salinity/flocculation
- High suspended concentrations (large flocs)
- Protected conditions facilitating fast suspension sedimentation
- High sedimentation rates leading to large pore spaces/high water contents
- Interbedded coarser layers facilitating later leaching
- Low activity of shear forces that reduce floc sizes/ Little/no bioturbation
- Role of bedload floccules? Organic material?





Thank you for the attention!

