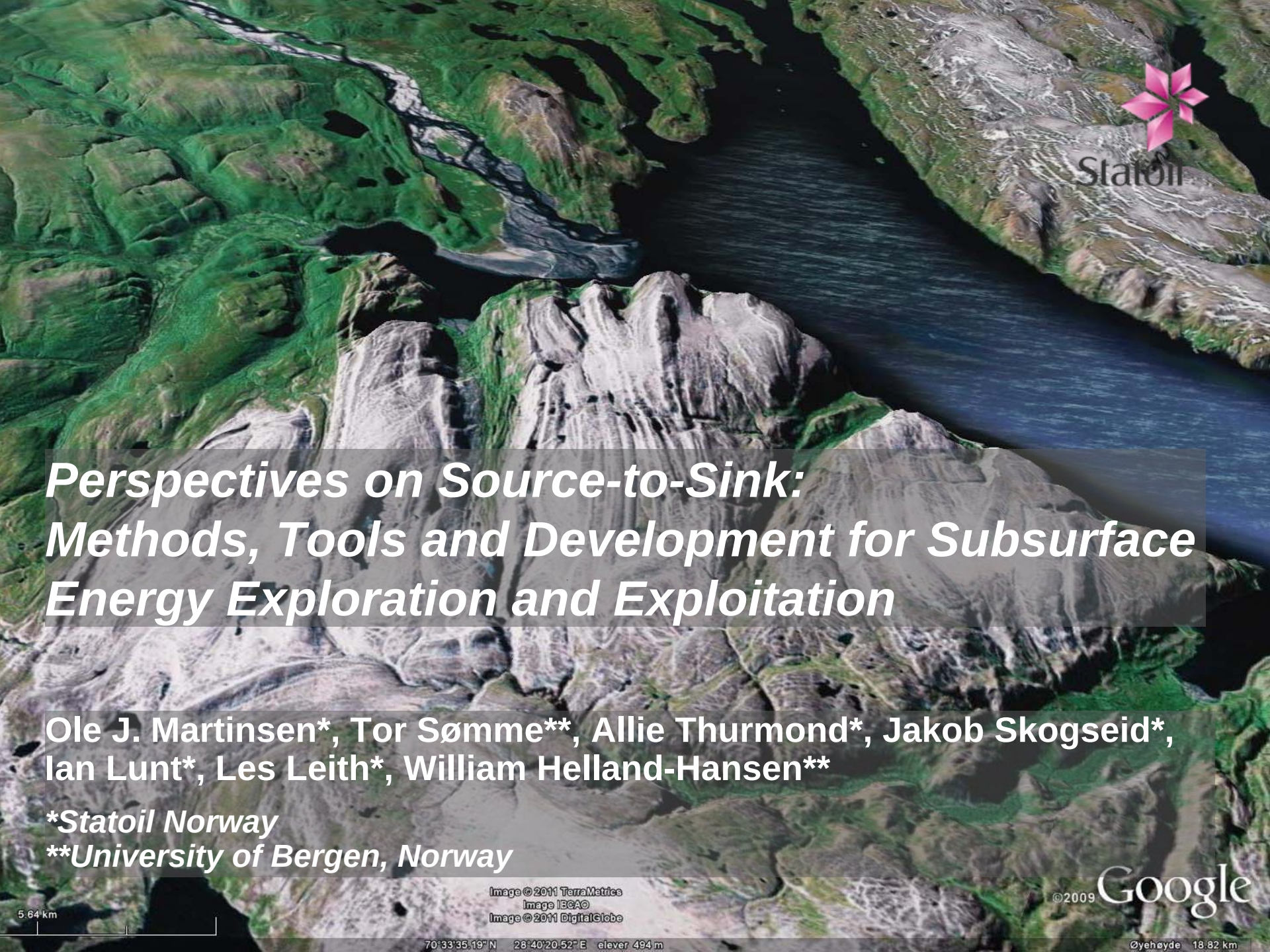

Perspectives on Source-to-Sink: Methods, Tools and Development for Subsurface Energy Exploration and Exploitation

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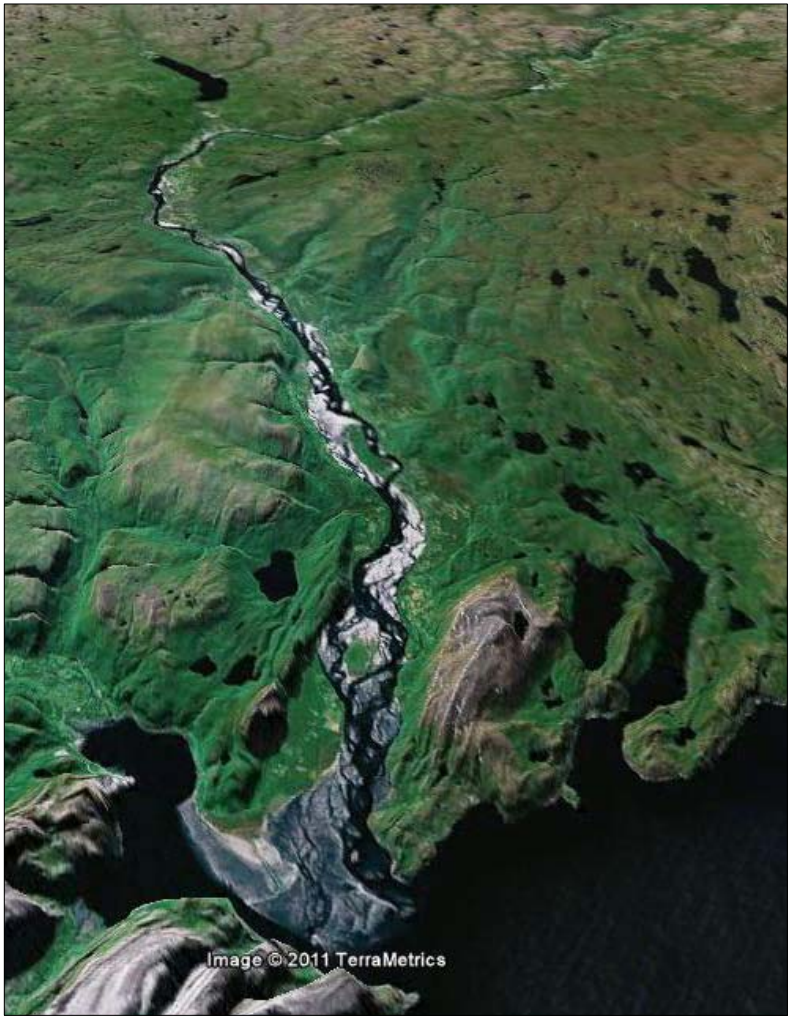
**Statoil Norway*
***University of Bergen, Norway*

Contents

- Development and application of source-to-sink for resource exploration
  - What are we looking for?
- Paleo Source-to-Sink
  - Role of topography
  - Dynamic landscapes, segments and segment boundaries vs. stratigraphy
    - Onshore-to-shelf boundary
- Conclusions



Tana River and delta, northern Norway

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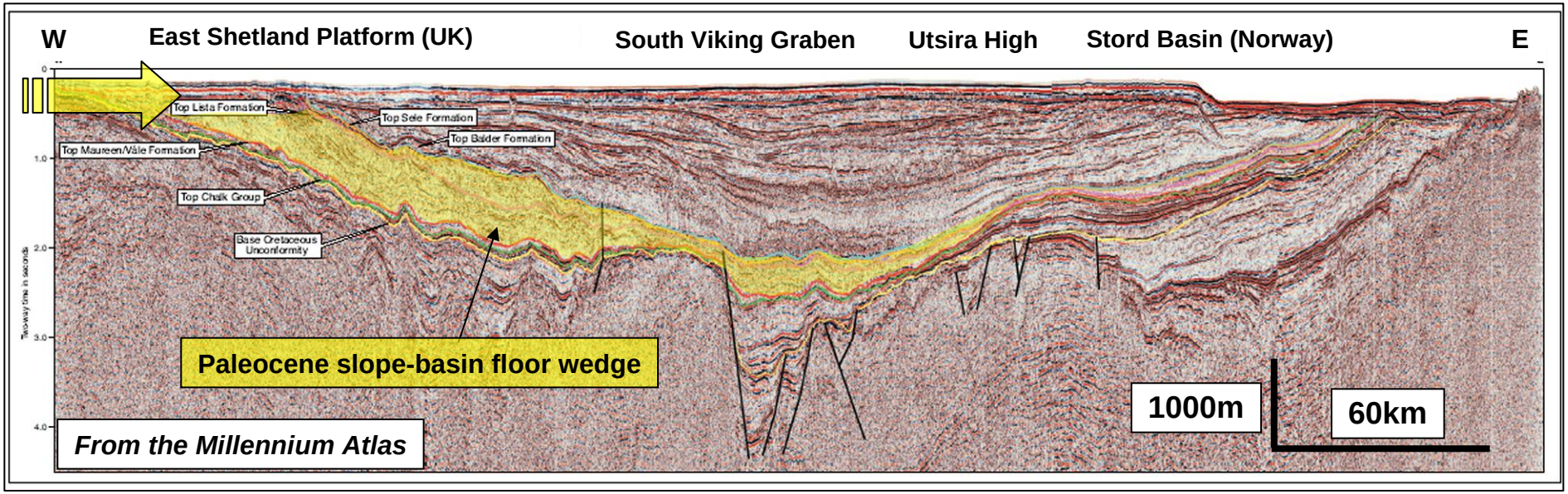
Challenge and Need

***"S2S becomes increasingly important with increasing time scales"* (Chris Paola)**

- Rationale
  - Combining processes, resulting landscapes, and source-to-sink for ***prediction*** of lithologies that store natural resources
  - Problem to solve: most subsurface systems are ***not complete*** source-to-sink systems or lack significant data…



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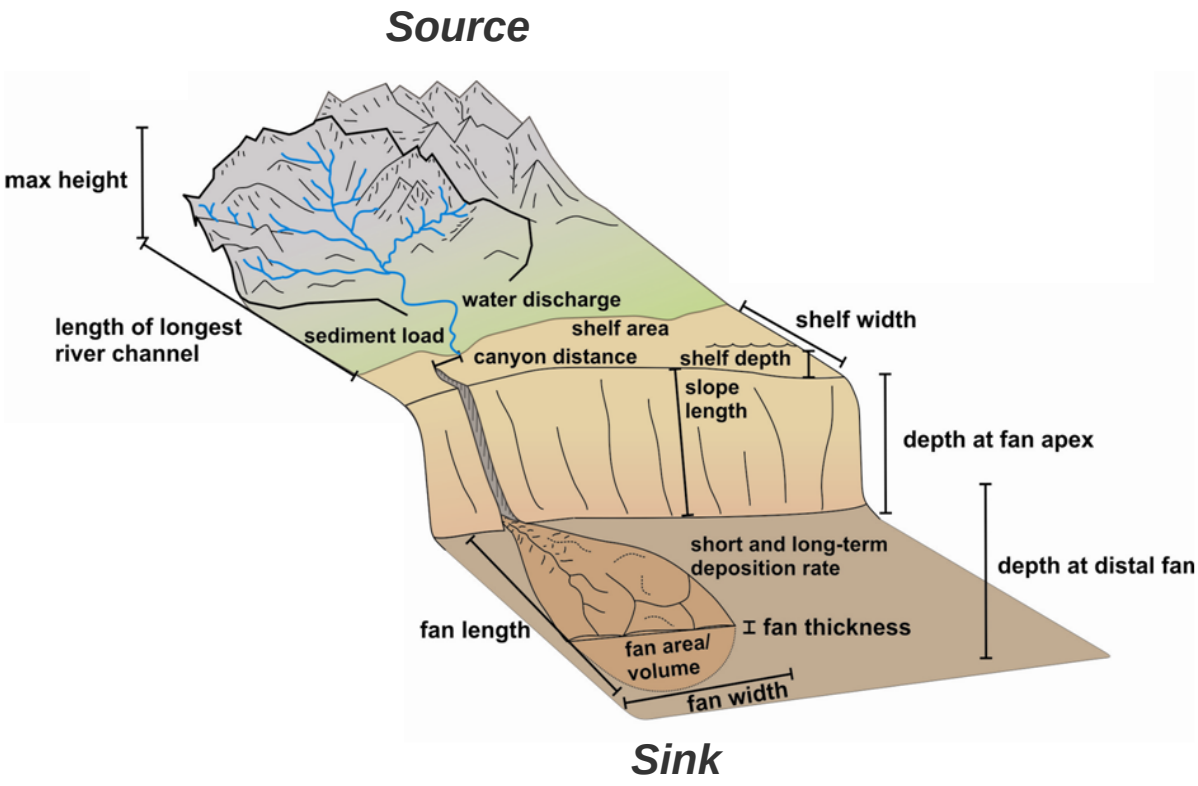
Current S2S Model and Challenges

- ***Holistic approach***
- Need a model to be able to predict
- Static segments and segment boundaries
- Temporal and spatial scale independence?
  - Semi-quantitative for good reasons!
- ***Uniformitarian approach***
  - ***Present/Recent systems are recognizable in the stratigraphic record?***



Sømme et al. 2009 (Basin Research)

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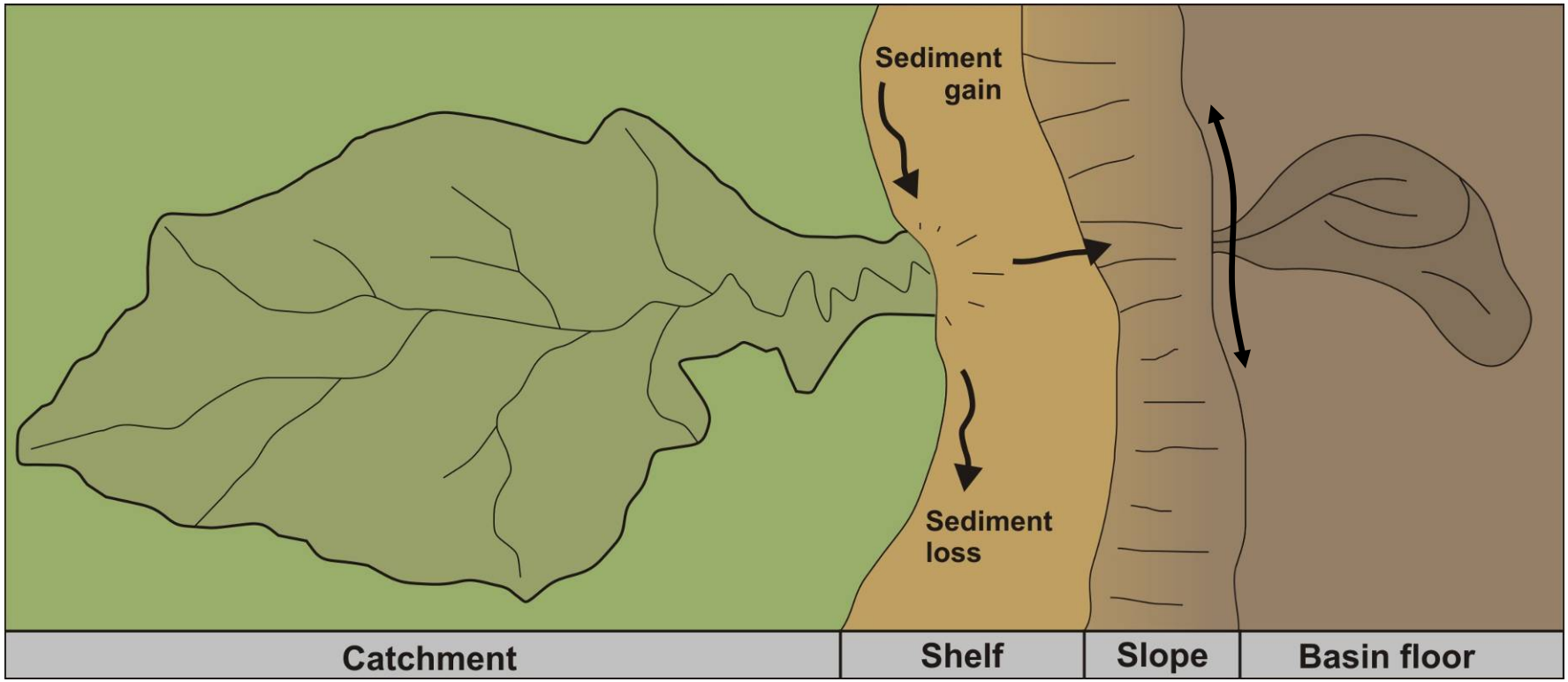
Segments and Segment Boundaries

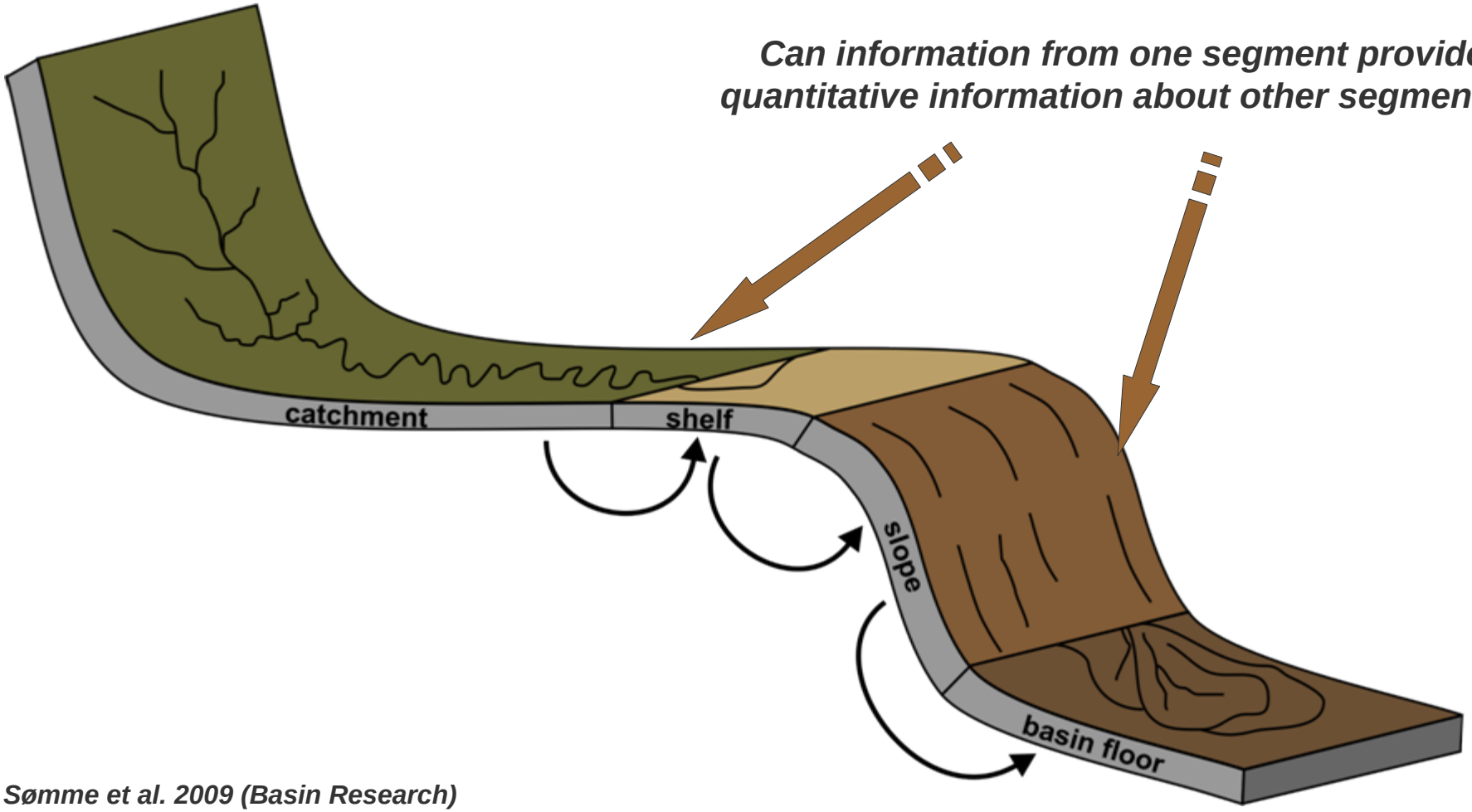
- Static geomorphic model vs. dynamic stratigraphy



Sømme et al. 2009 (Basin Research)

Morphological Approach: Linked Segments

Can information from one segment provide quantitative information about other segments?



Sømme et al. 2009 (Basin Research)

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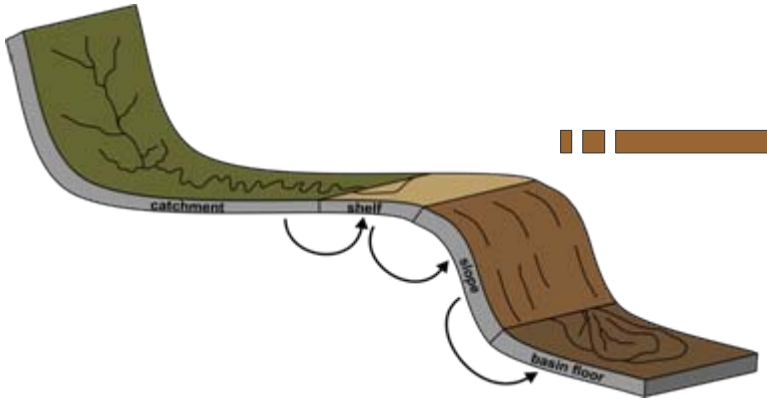
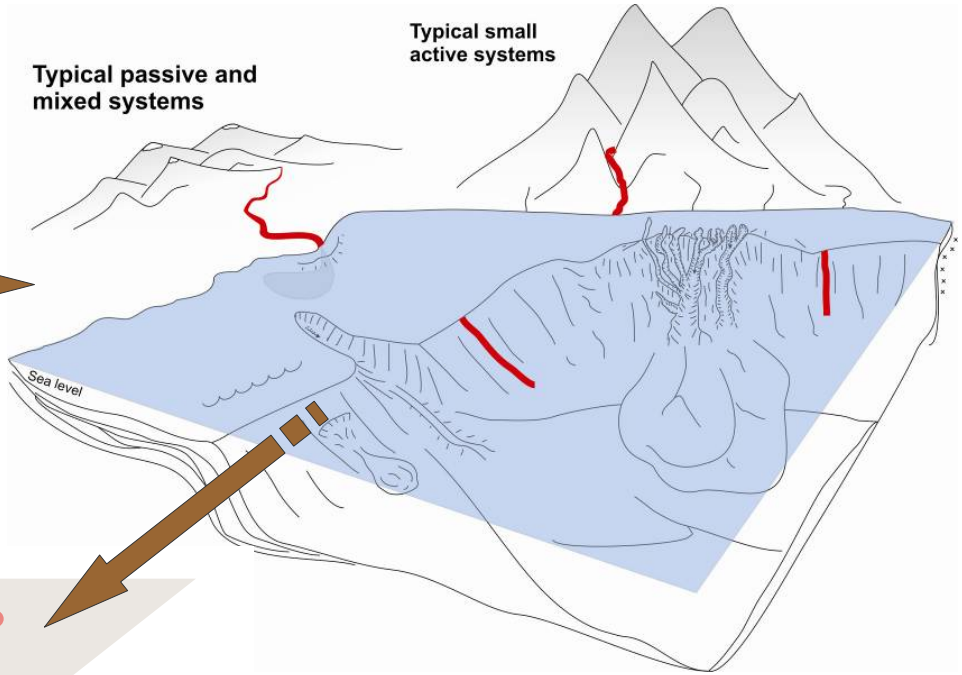
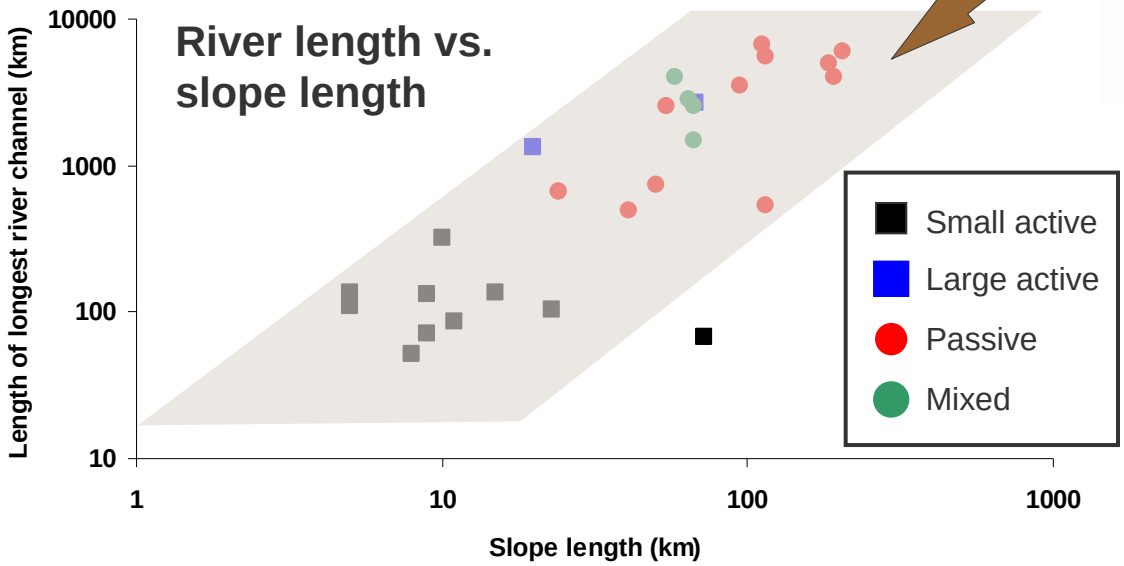
Linkage of Segments







Sømme et al. 2009 (Basin Research)

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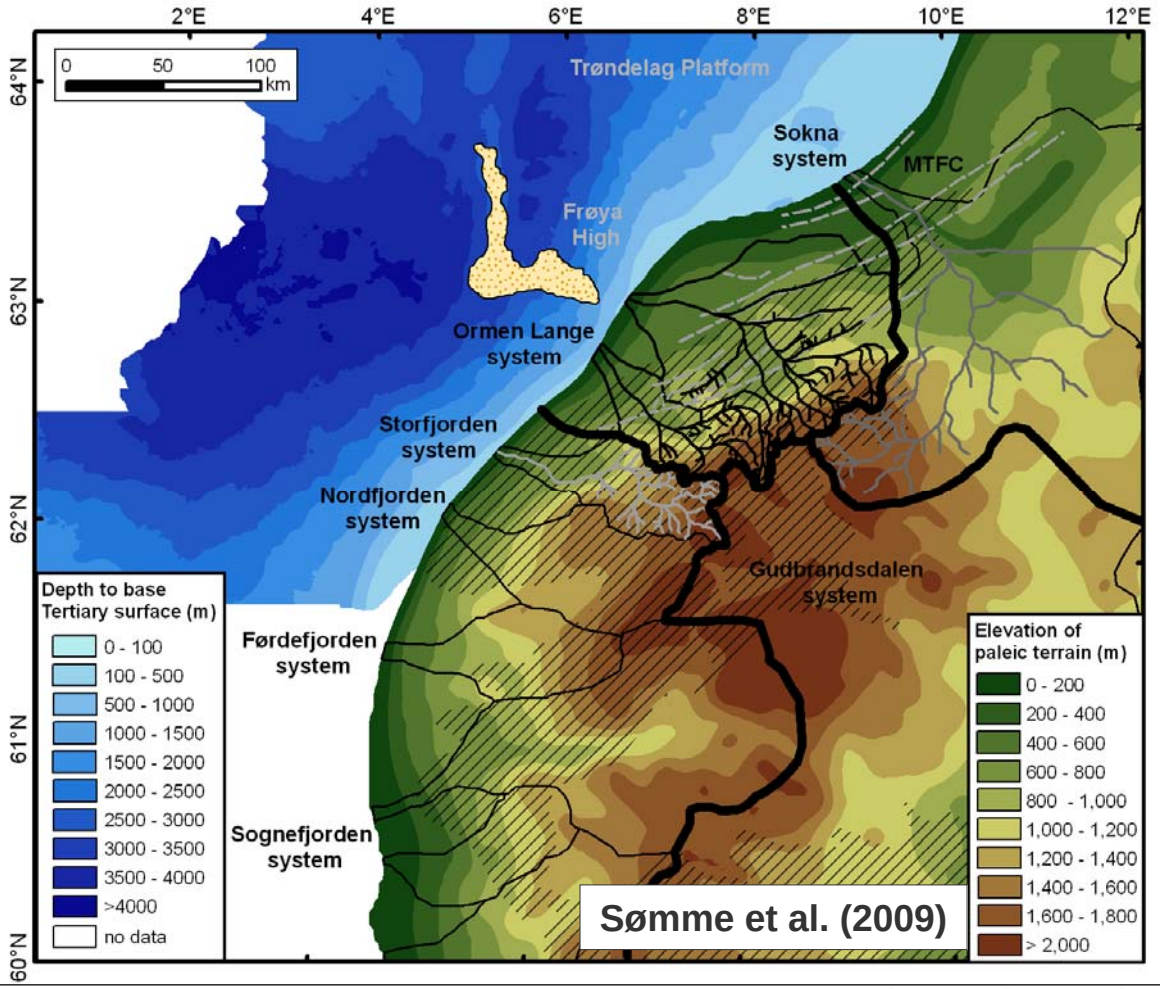
Paleocene Ormen Lange Fan and Catchment: Inversion to Test Model

- Paleo source-to-sink analysis yields
  - Slope length: ~5-15 km
  - Water depth 1000-2000 m
  - Catchment ~20 000 km^2
  - Longest river channel ~200 km
- Potential for prediction of deep-water reservoirs
- Global application



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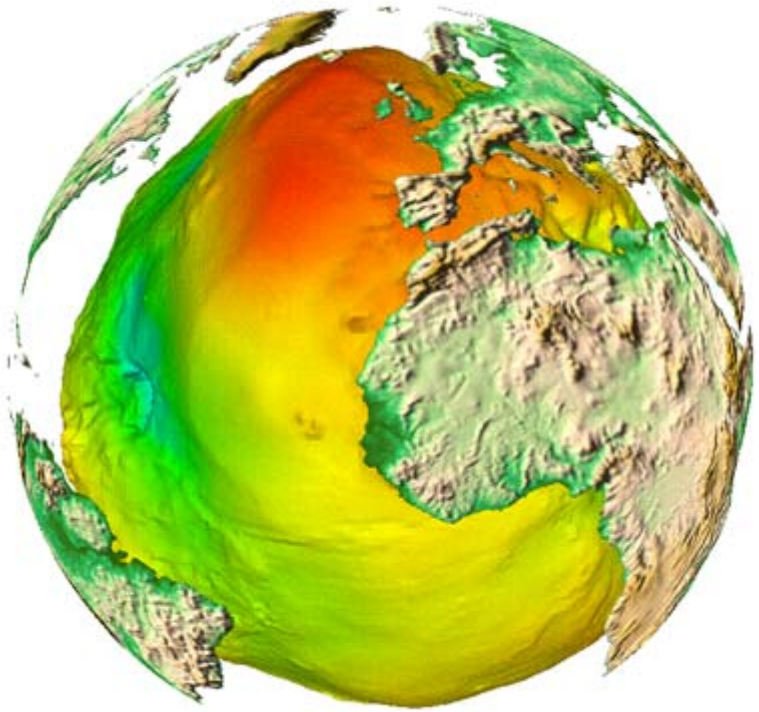
Earth Sciences and Source-to-Sink

- Integration between earth sciences
  - Geodynamics, paleoclimatology, sedimentary geology, geomorphology…
- But is and should Source-to-Sink be ”everything” ?
  - Linkage and prediction essential
  - Scaling: spatial vs. temporal challenges
  - Simplification is needed to apply to the stratigraphic record
- ***Common denominator: ”Topography”***



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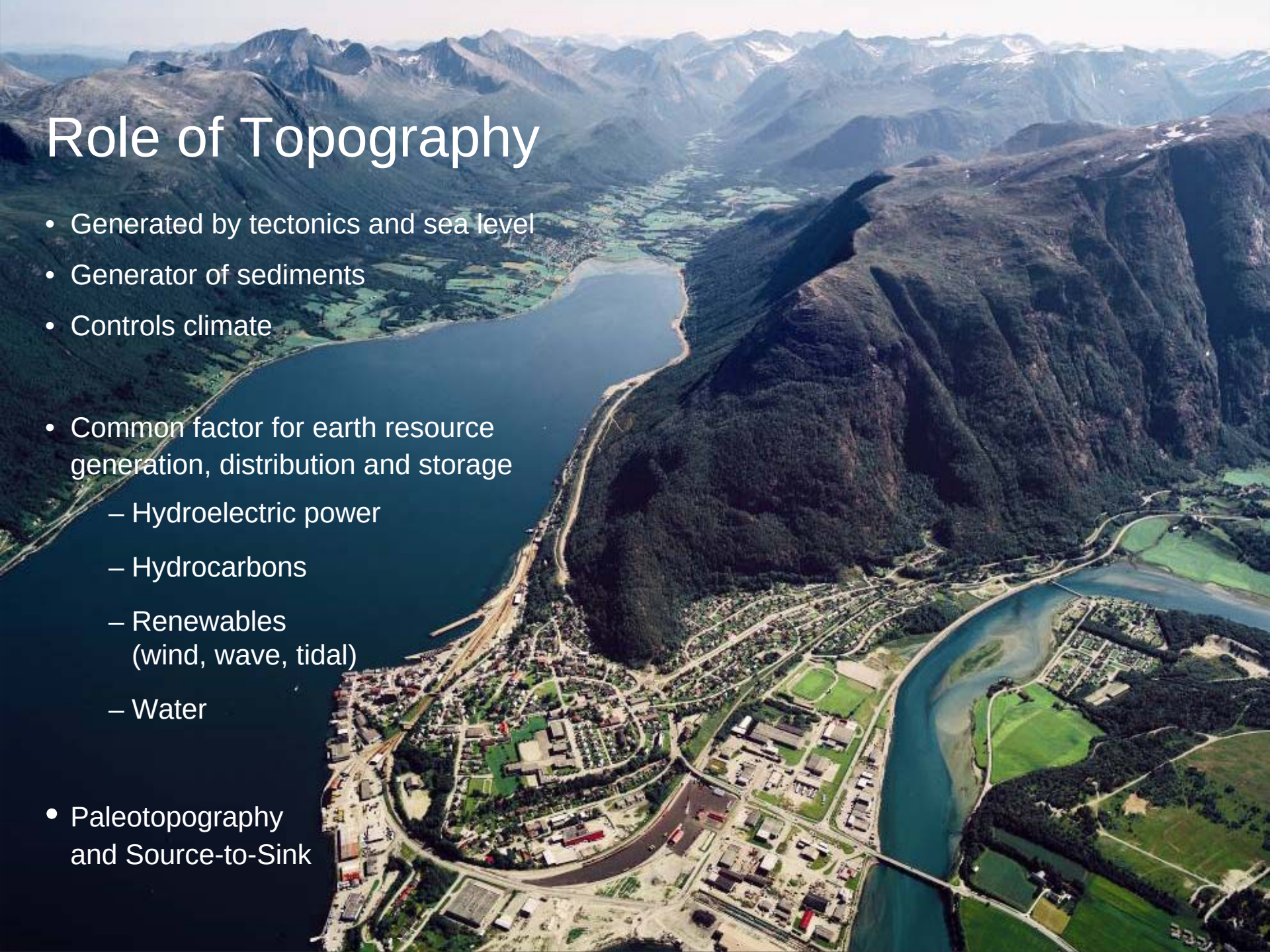
Role of Topography

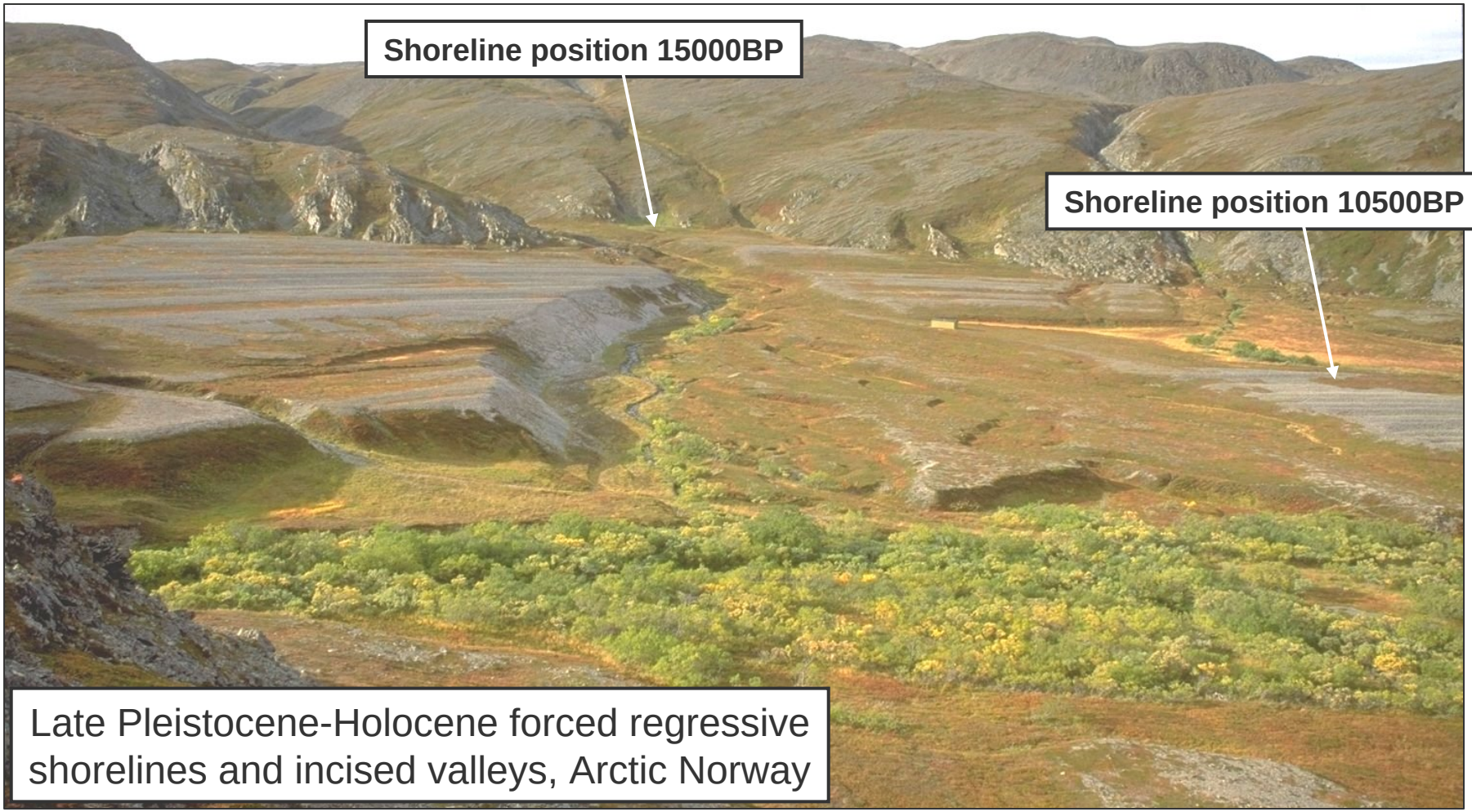
- Generated by tectonics and sea level
- Generator of sediments
- Controls climate

- Common factor for earth resource generation, distribution and storage
  - Hydroelectric power
  - Hydrocarbons
  - Renewables (wind, wave, tidal)
  - Water

- Paleotopography and Source-to-Sink



Coupling Landscapes to Stratigraphy: Segments and Segment Boundaries



Late Pleistocene-Holocene forced regressive shorelines and incised valleys, Arctic Norway

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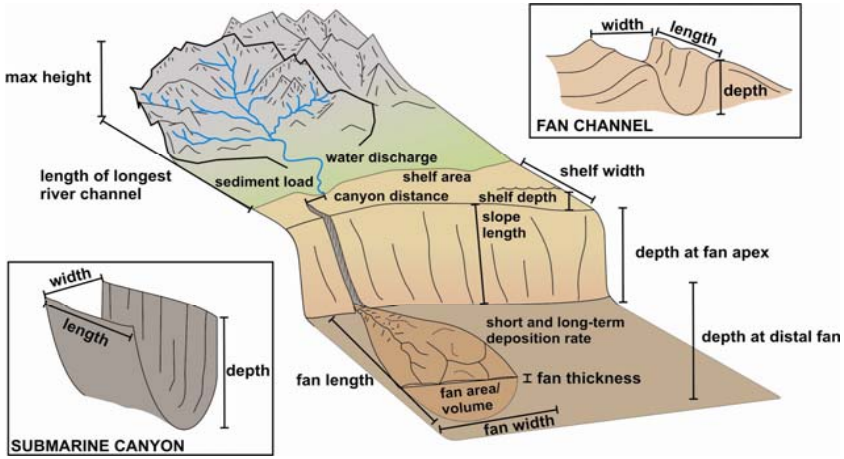
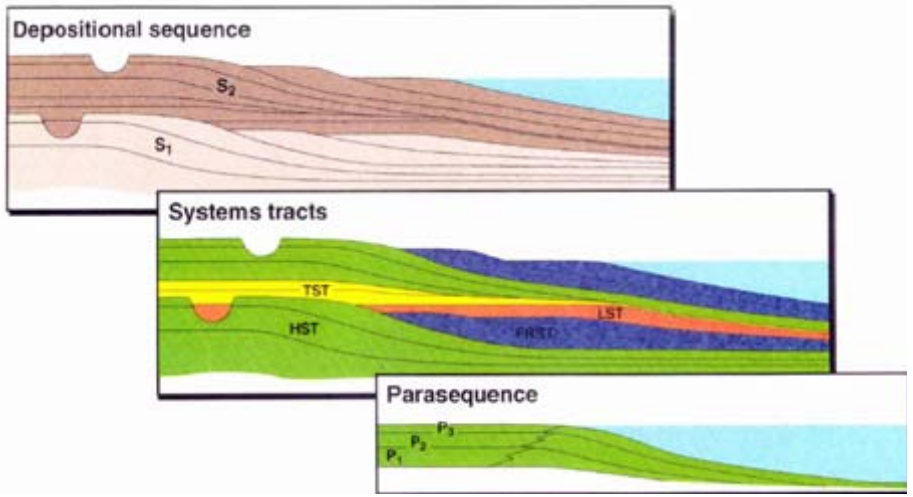
Source-to-Sink vs. Sequence Stratigraphy

Complementary Approaches to Predict Sediment Partitioning

- **Holistic basin analysis**
- **Process-oriented**
- **Integration of earth processes**
- **Natural systems with inherent complexity**
- **Map-view and volumetric focus**

- **Stratigraphy-dominated**
- **Product-oriented**
- **Sink-focused**
- **Model-oriented 3D concepts, 2D practice**
- **Cross-sectional/depth focus**





Dave Hunt, unpublished

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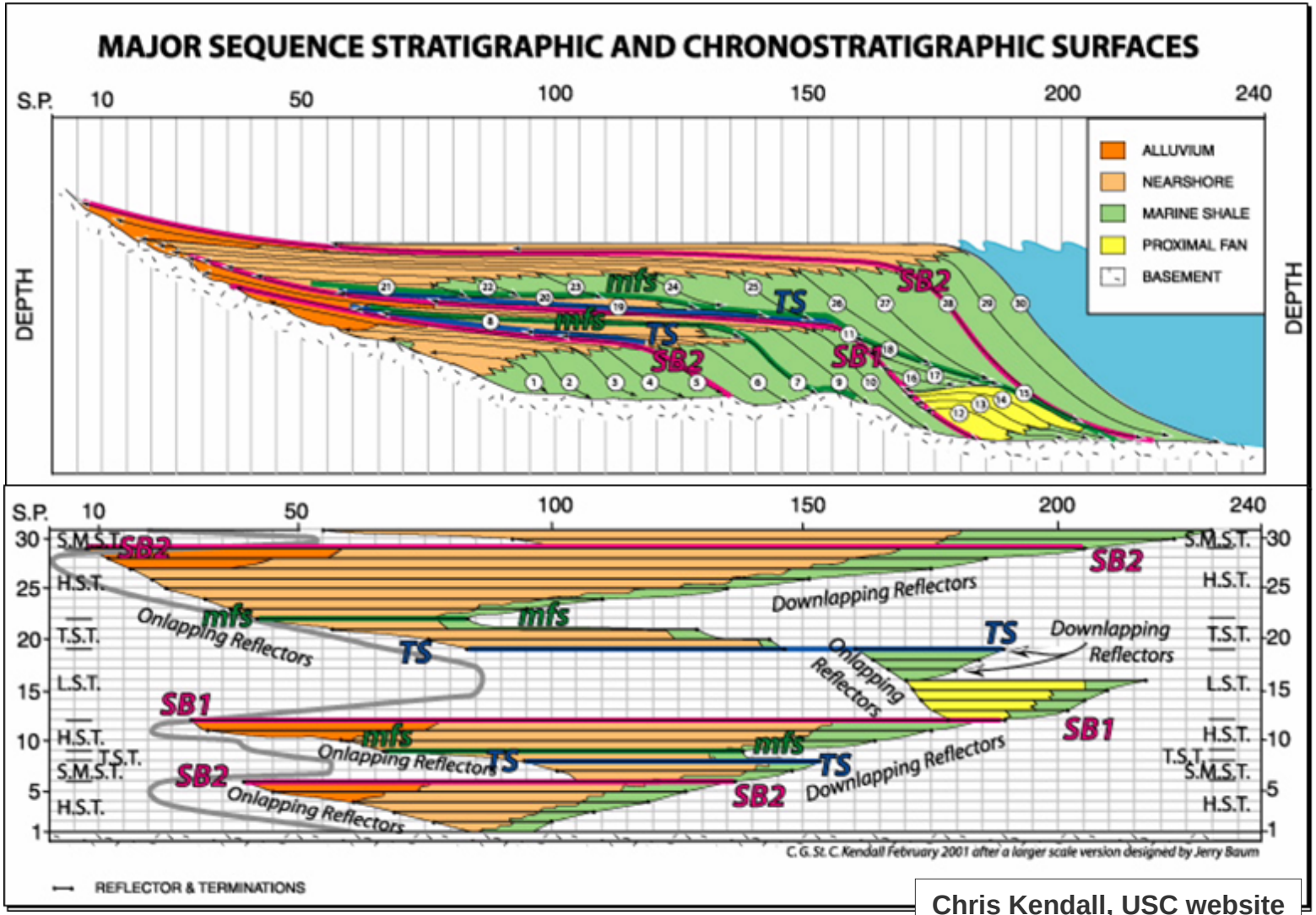
Dynamic Stratigraphy = Dynamic Segments



Chris Kendall, USC website

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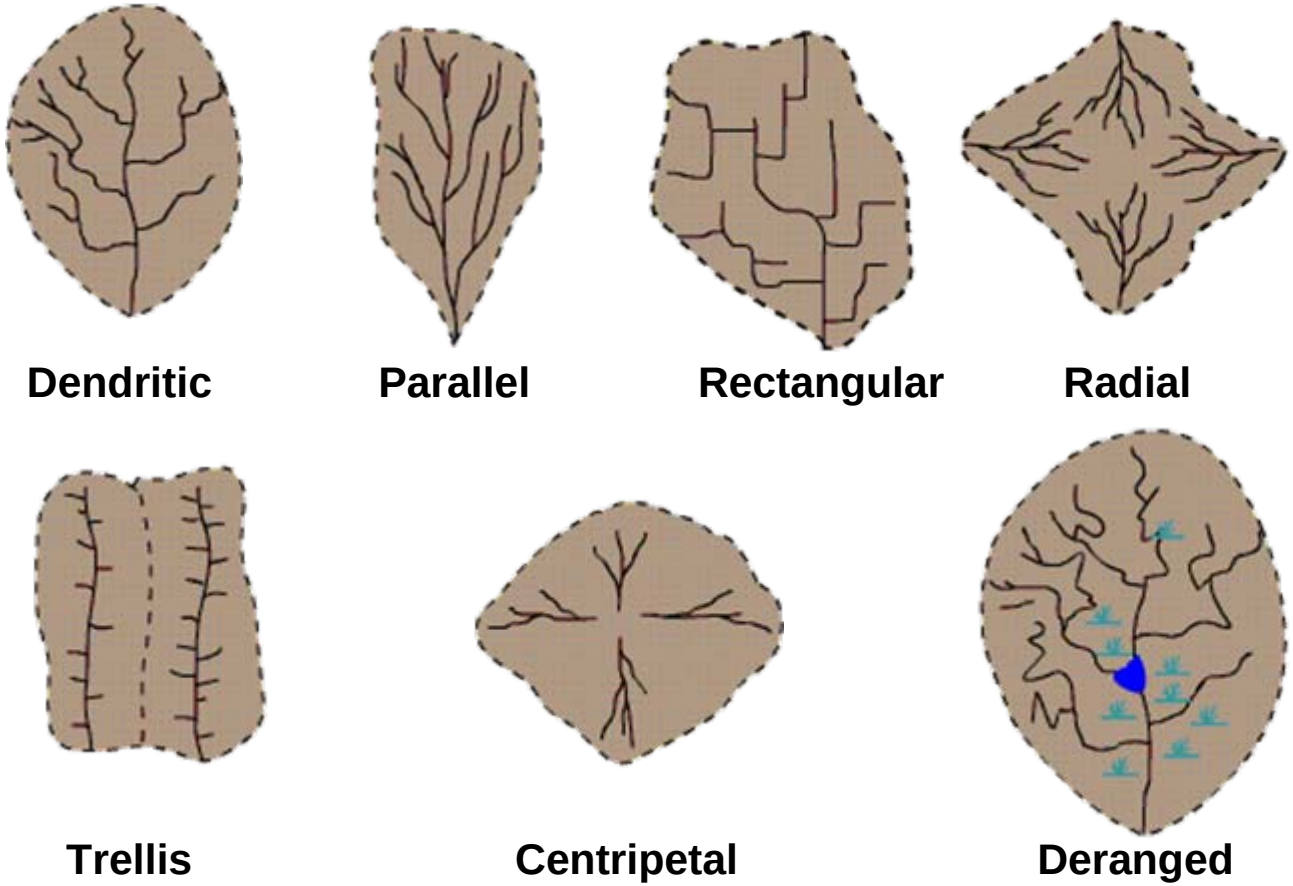
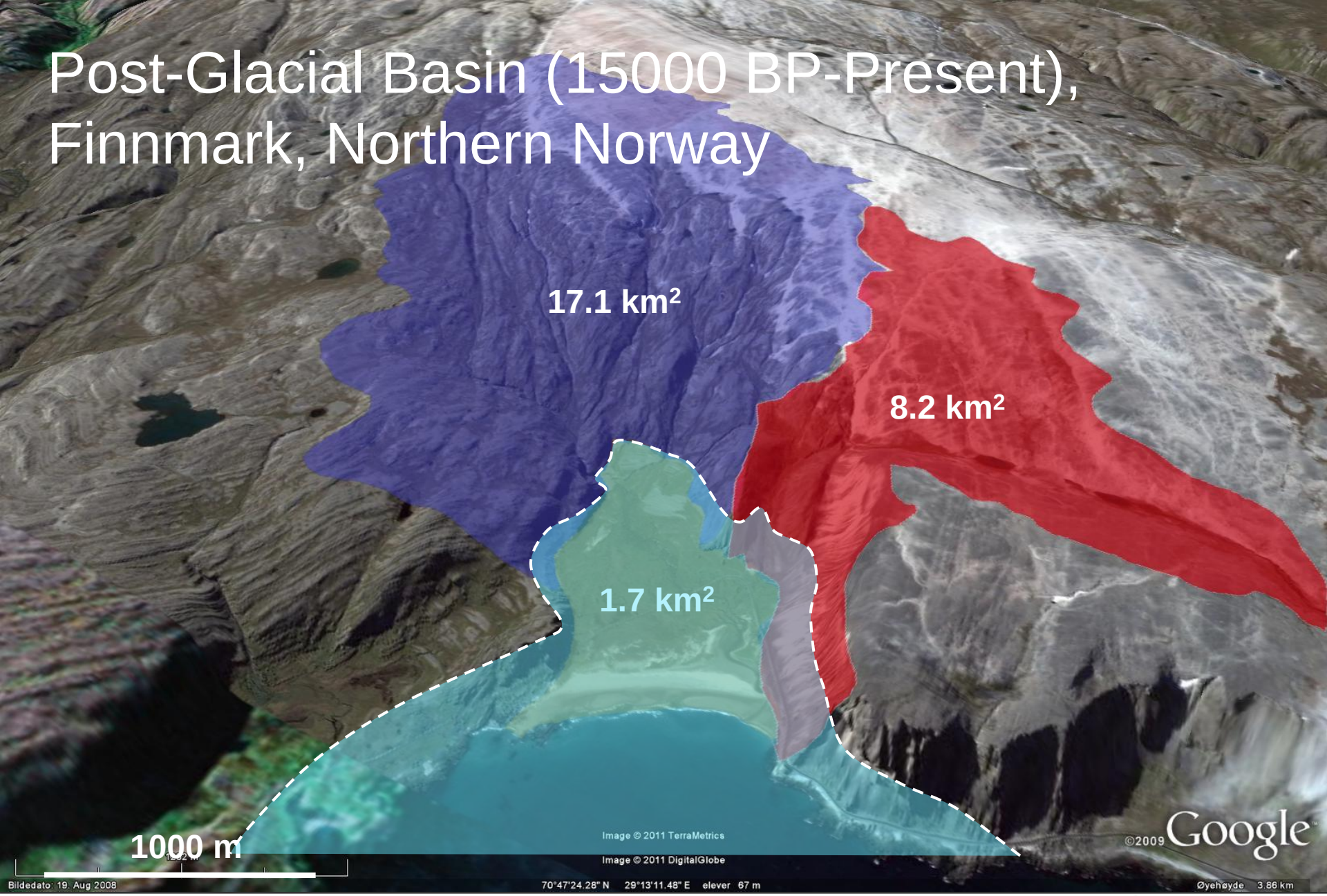
Catchments (A Topographic Derivative): Useful for Prediction of Ancient Segment Boundaries?



Post-Glacial Basin (15000 BP-Present), Finnmark, Northern Norway



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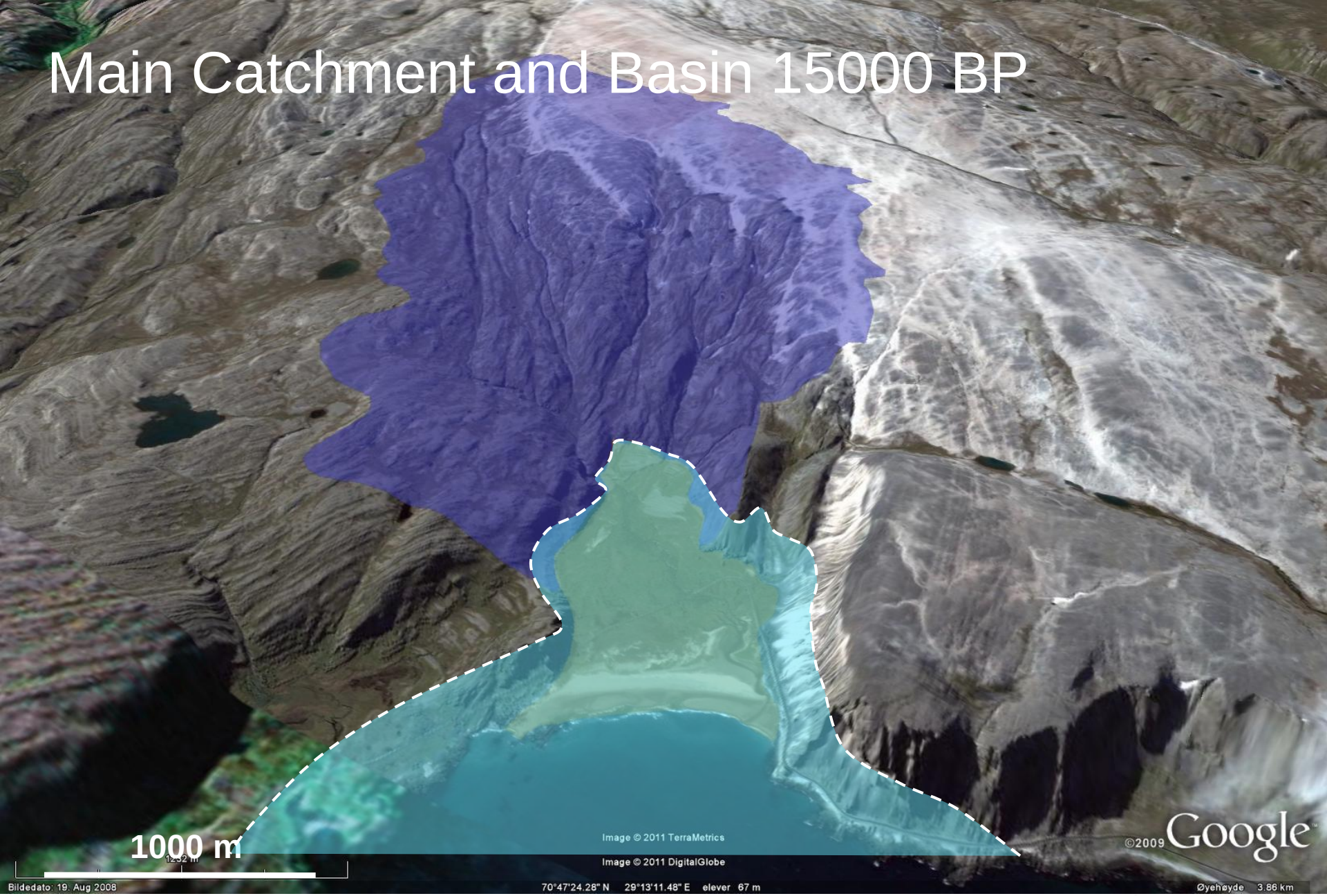
Main Catchment and Basin 15000 BP



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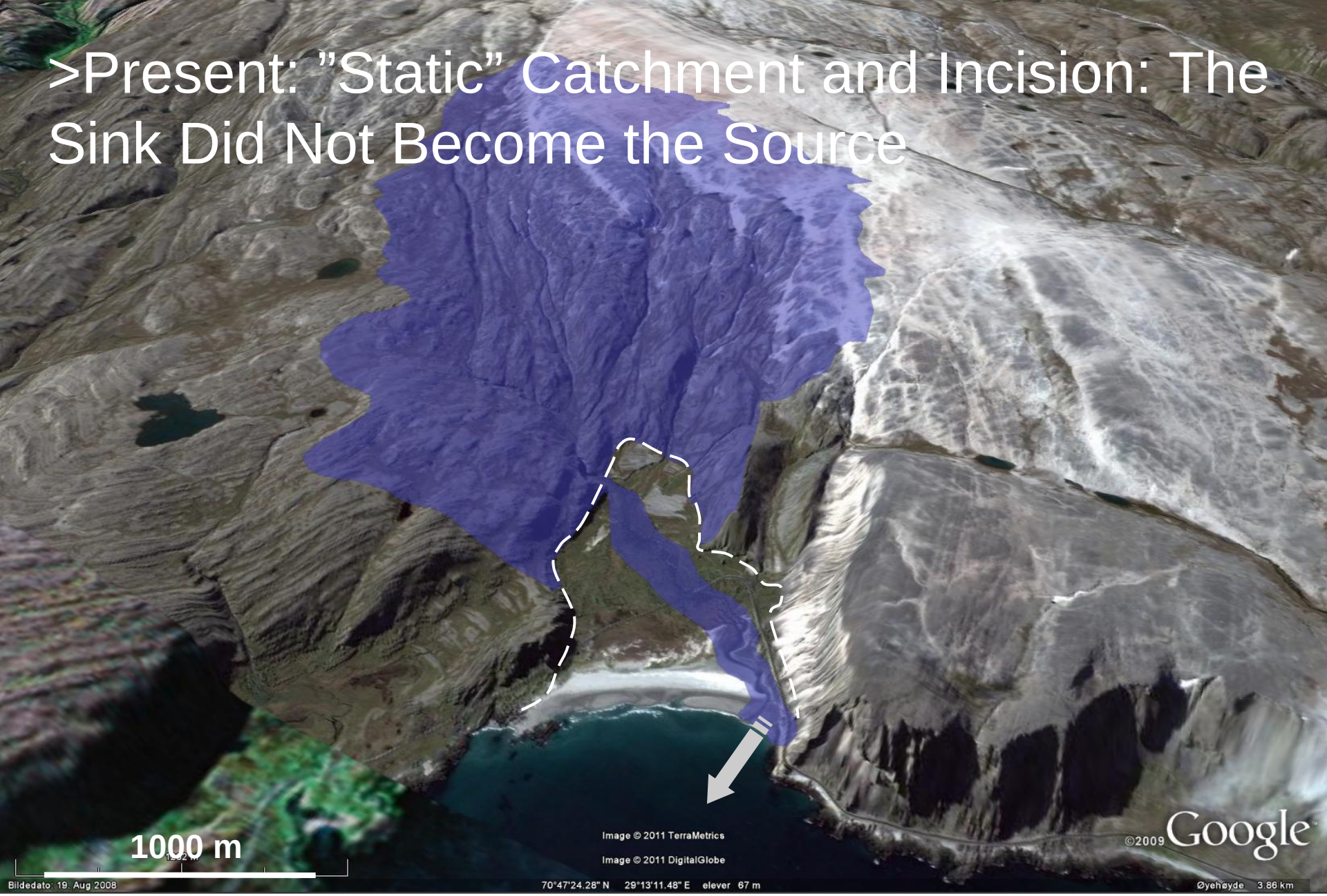
>Present: ”Static” Catchment and Incision: The Sink Did Not Become the Source



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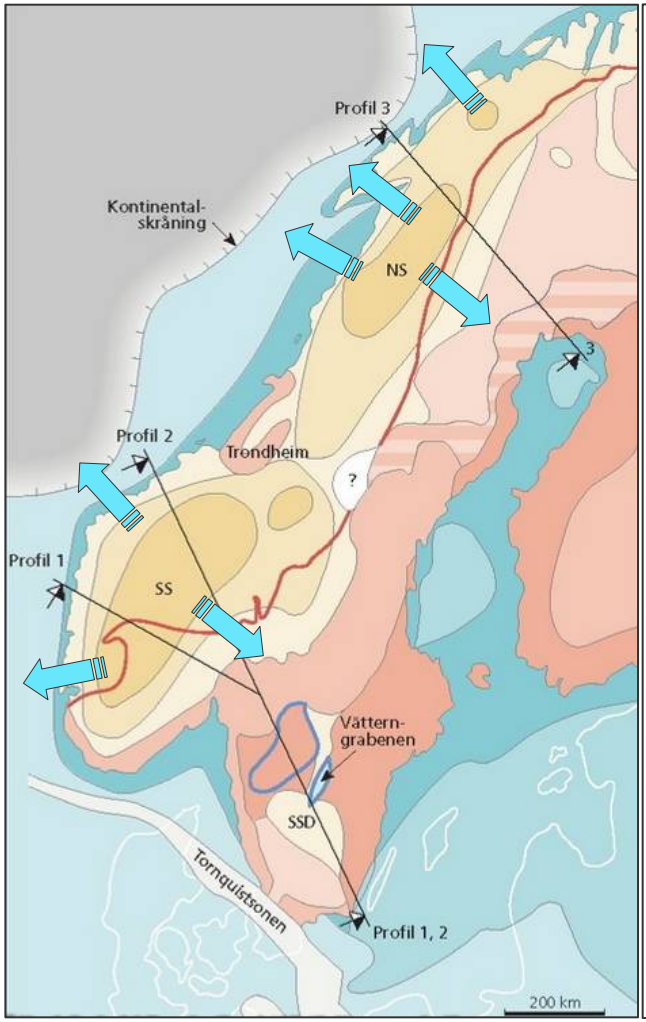
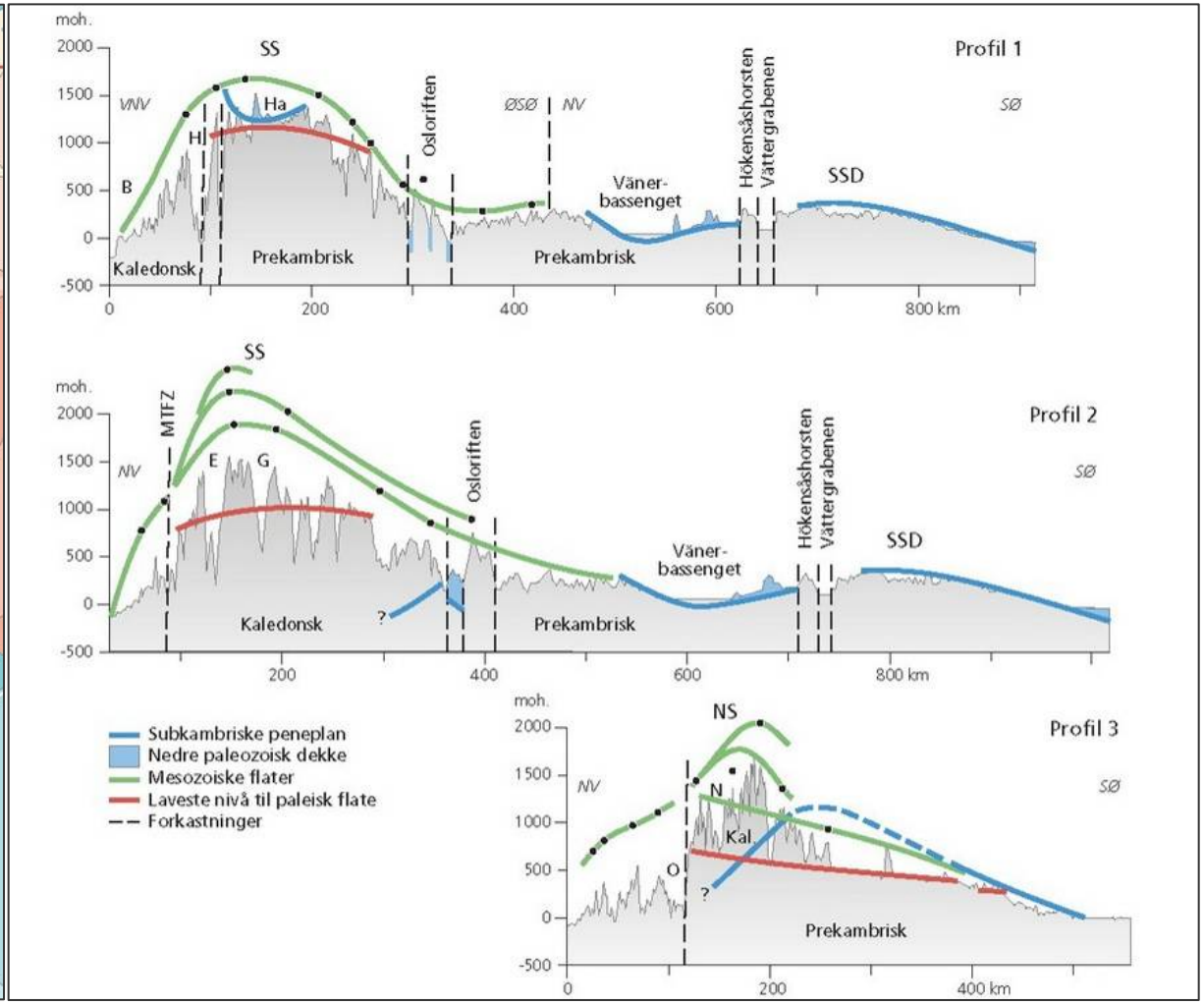
Fennoscandia: Topographic Inheritance, Catchments and Segment Boundaries





Modified from Lidmar-Bergstrøm & Näslund (2002)

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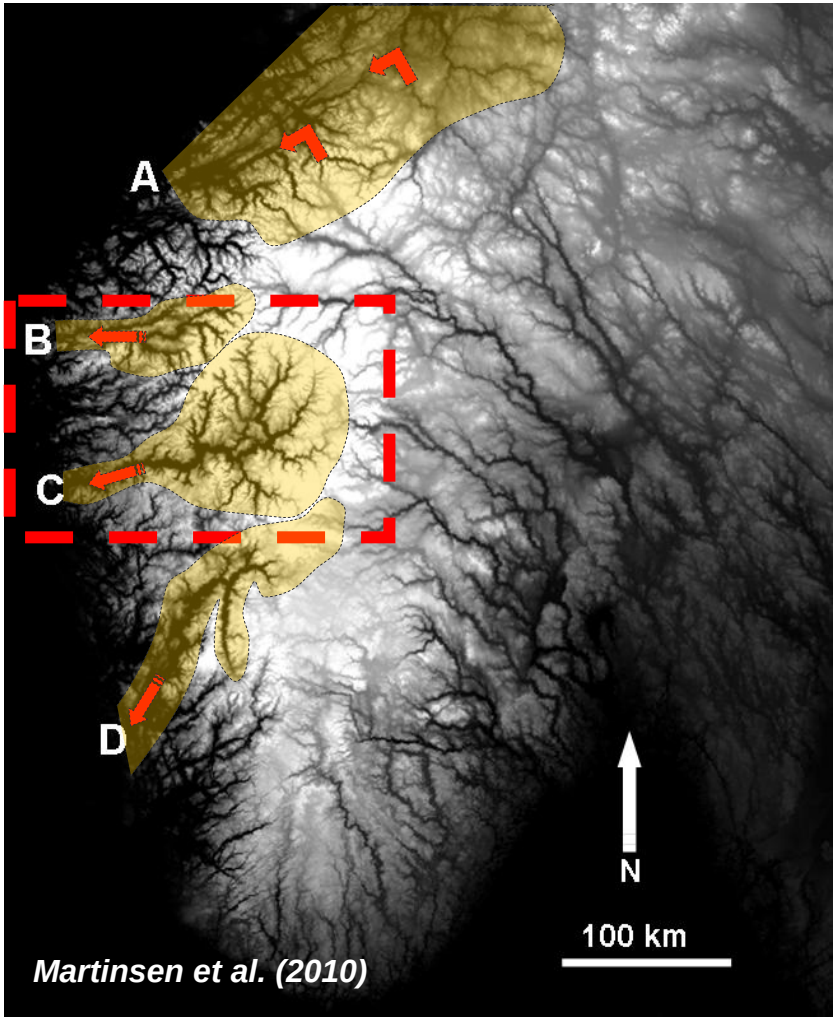
SW Fennoscandia: Catchment Formation and Correlation to Offshore

- 4 main morphologically different catchments
- Influenced by
  - Structural inheritance from Caledonidian orogeny
  - Cenozoic uplift
  - Glacial influence
- Offshore sedimentary rocks studied extensively
  - But effects of onshore processes such as drainage and geomorphology less understood



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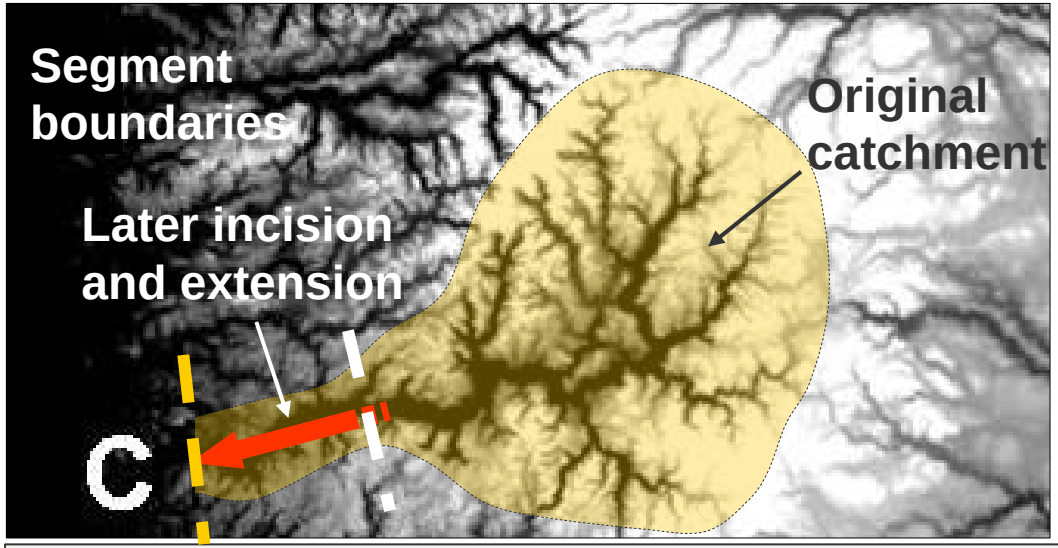
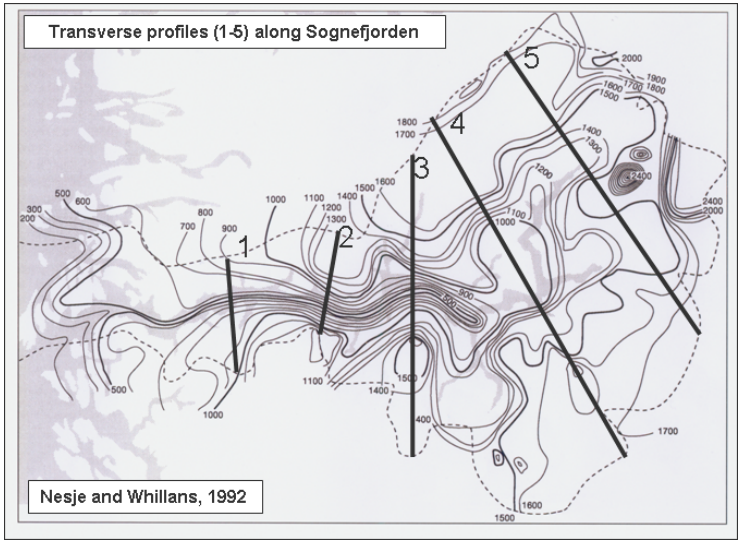
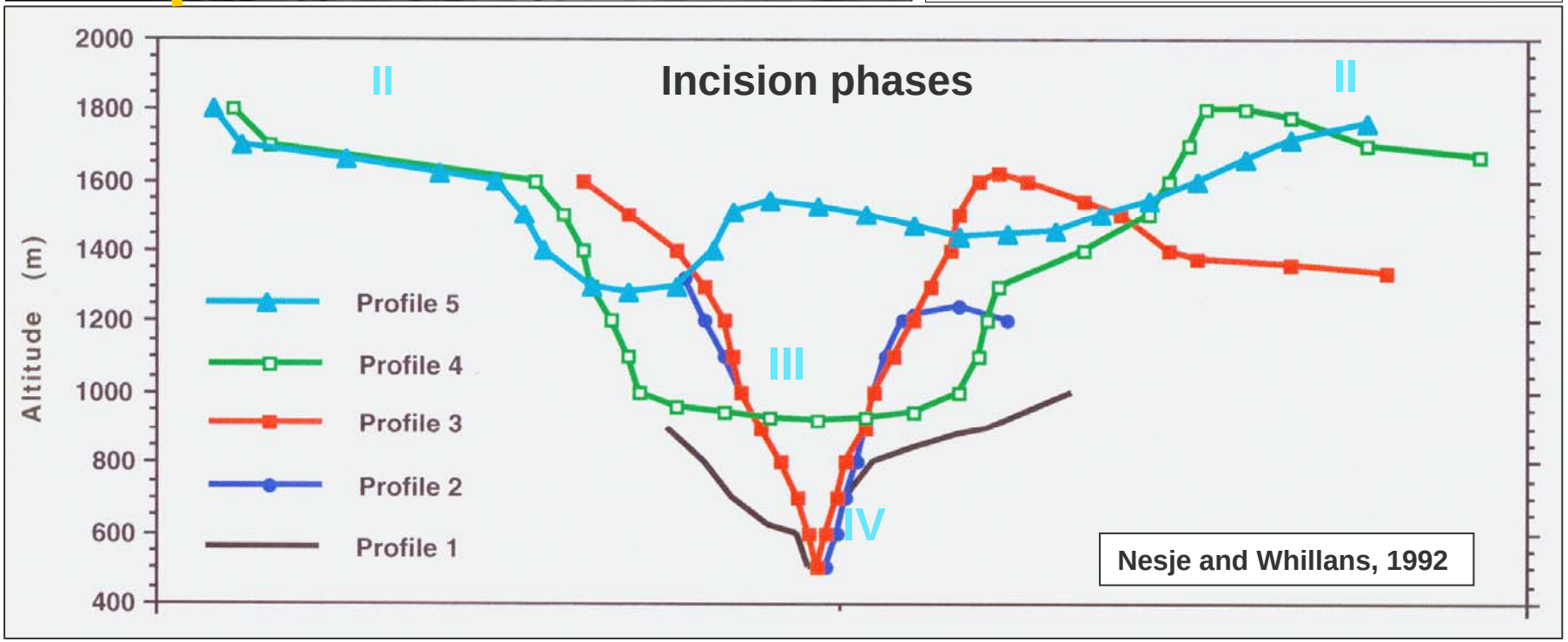

Segment boundaries
Original catchment
Later incision and extension
C


Transverse profiles (1-5) along Sognefjorden
1
2
3
4
5
Nesje and Whillans, 1992


Incision phases
II
II
III
IV
Profile 5
Profile 4
Profile 3
Profile 2
Profile 1
Altitude (m)
2000
1800
1600
1400
1200
1000
800
600
400
Nesje and Whillans, 1992

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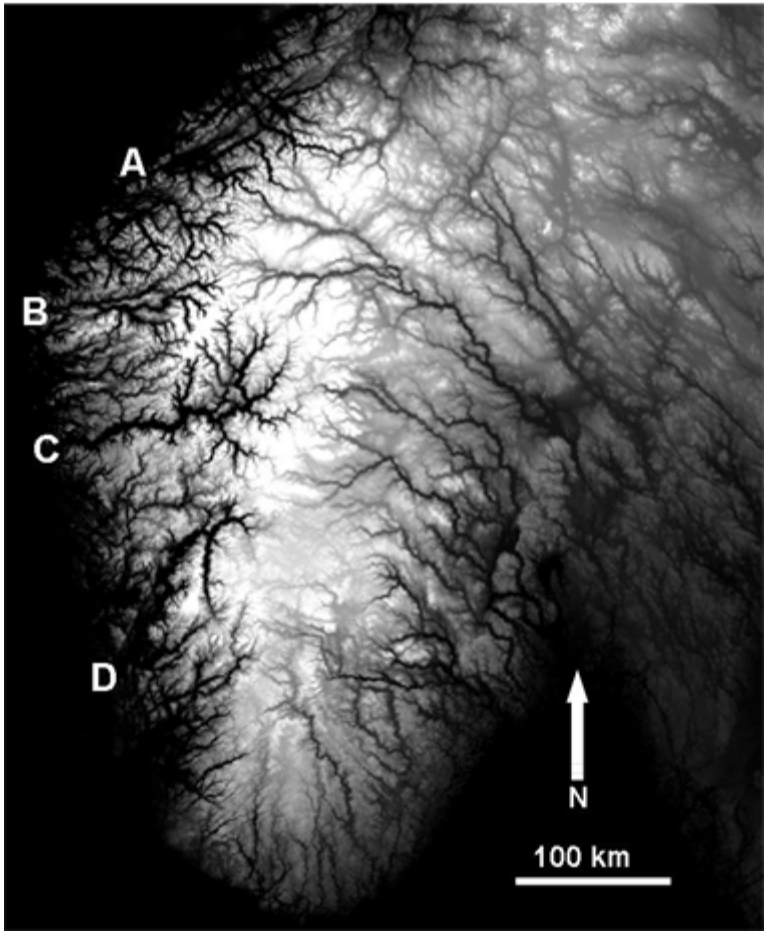
Effects of Dynamic Segments and Boundaries

- Overestimation of paleocatchment size
- Prolonged storage in some segments
  - Stranded alluvial sediments because of entrenchment
- Changed morphology of segment boundary
  - Stretching and narrowing of segment boundaries



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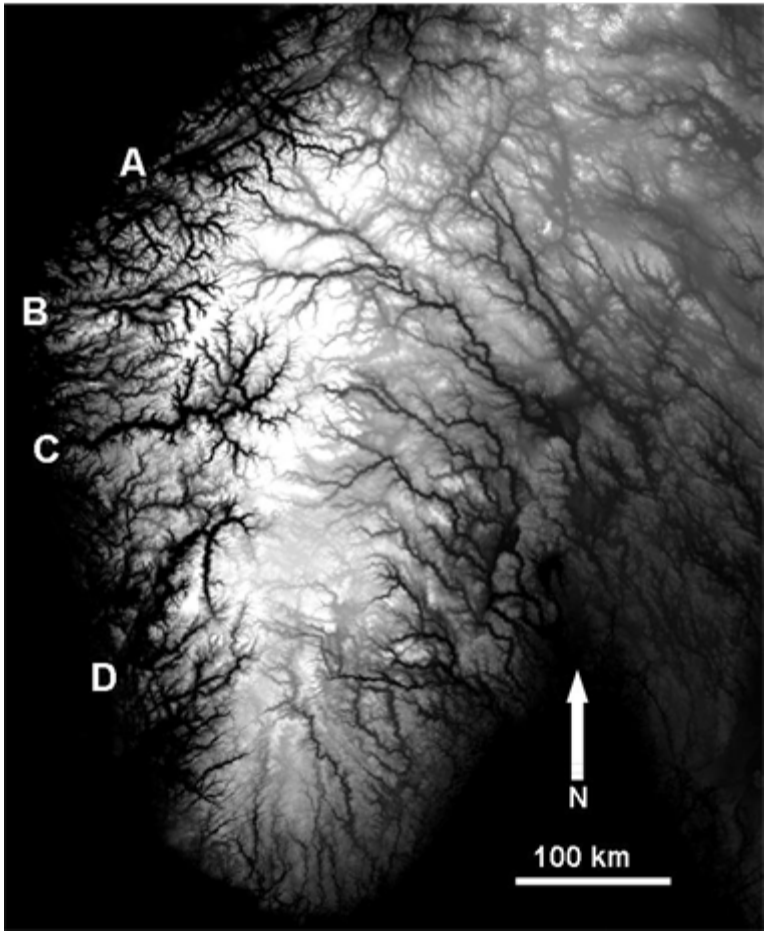
Conclusions and Applications

- Topographic understanding is critical
- Segments and segment boundaries are dynamic
- Major impact for resources: prediction in frontier basins and of lithology
- Also huge potential for water resources, paleoclimate understanding and natural disasters
- **In summary: we are concerned with margin- and basin-scale features to be able to predict and increase probability**



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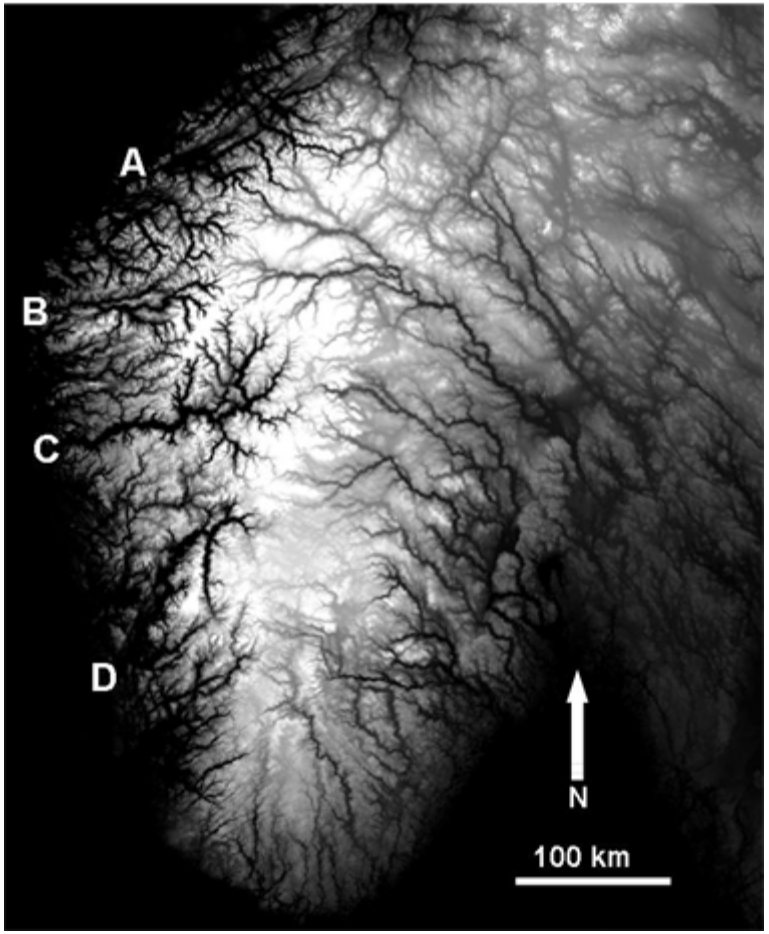
Key Points from Conference

- Details do matter but scaling crucial
  - 100 ky scale bridging time scale (Dave Mohrig)
- 4 key dimensions to consider for bridging
  - Space^2 (strike and dip)
  - Time
  - Climate (icehouse vs. greenhouse)
- Partly abandon uniformitarianism!
- Need to identify common ground



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