

Source-to-Sink in Rift Basins - Predicting Reservoir Distribution in Ancient, Subsurface Systems*

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Abstract

Exploration in rift basins is associated with many uncertainties, and one of the most crucial is the determination of lateral distribution and aerial extent of potential reservoir units. The distribution of sandy depositional environments varies greatly throughout the lifetime of a rift basin, primarily due to changes in local and regional tectonics and relative base level, but also in response to climatic fluctuations. Many of these parameters are difficult to constrain for ancient, subsurface systems. At any given time during the filling of a basin, the main factor controlling the spatial distribution of sandy depositional units on the scale of individual subbasins to the scale of the entire rift system is the location of river mouths and sediment input points. Area and thickness of shallow- and deep-marine/lacustrine depositional units are determined by the size of the rivers and by the temporal stability of the outlet location.

Analysis of catchment morphology and outlet spacing in six modern, underfilled rift basins characterized by deep marine/lacustrine basins suggest that the outlet position of transverse drainages can be predicted from the width of the rift-flank escarpment relative to the shoreline. Range-scale basins (the catchments which define the water divide) show a common simple relationship between outlet spacing and rift-flank escarpment width, which appears to be independent of both size and structural characteristics of the rift (e.g. escarpment vs. hinged margin). In general, wide rift flanks are occupied by large catchments forming large depositional units that are spaced farther apart compared to narrower rift flanks. In addition, accommodation zones separating individual subbasins are often associated with pre-rift basement structures intersecting the rift, and represent areas of weakened basement commonly exploited by pre-rift drainage. Combined with low uplift rates, these areas are typically characterized by large catchments and stable outlet positions. Using this relationship together with input on structural characteristics from seismic mapping, the location of potential shallow- and deep-marine/lacustrine reservoir units can be predicted semi-quantitatively in ancient, subsurface systems..

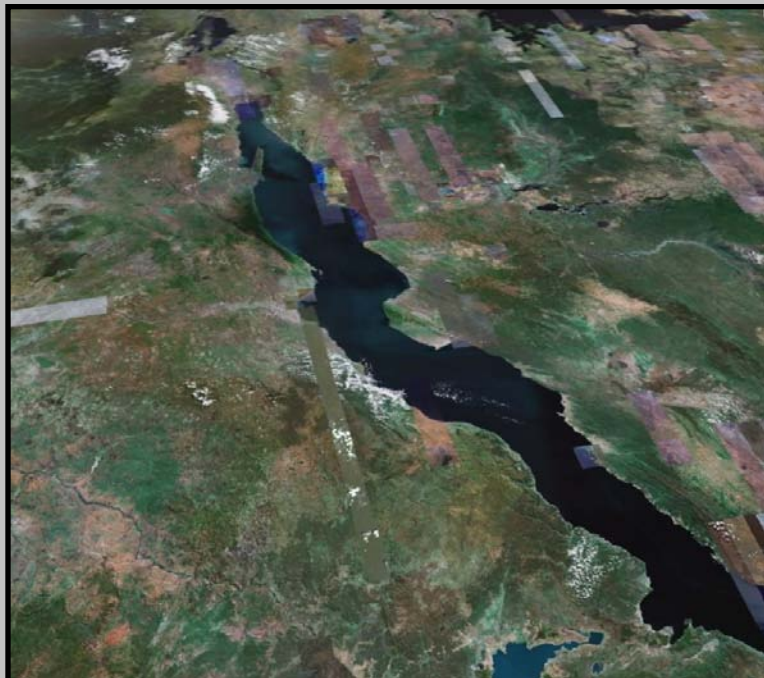
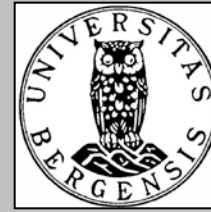
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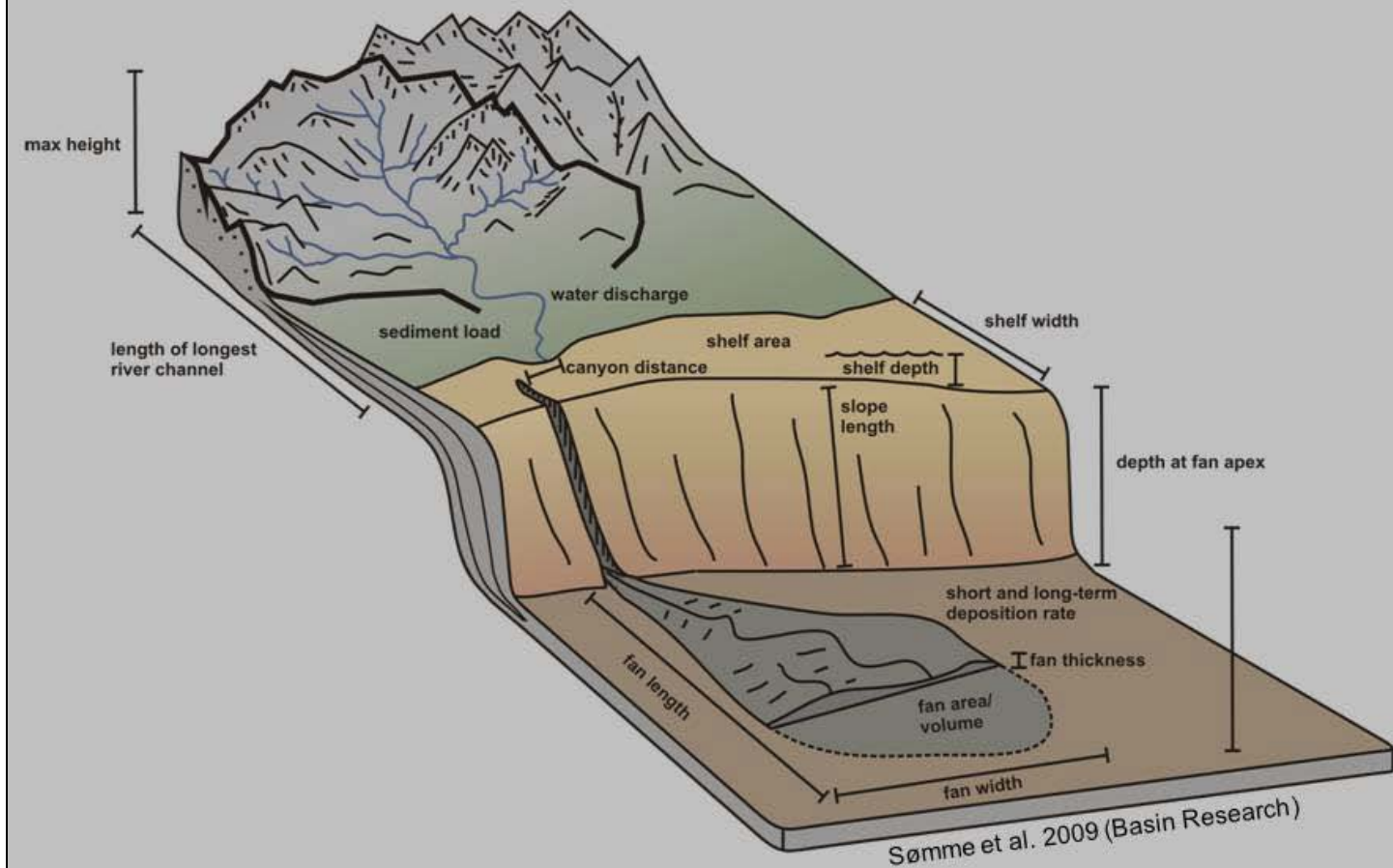
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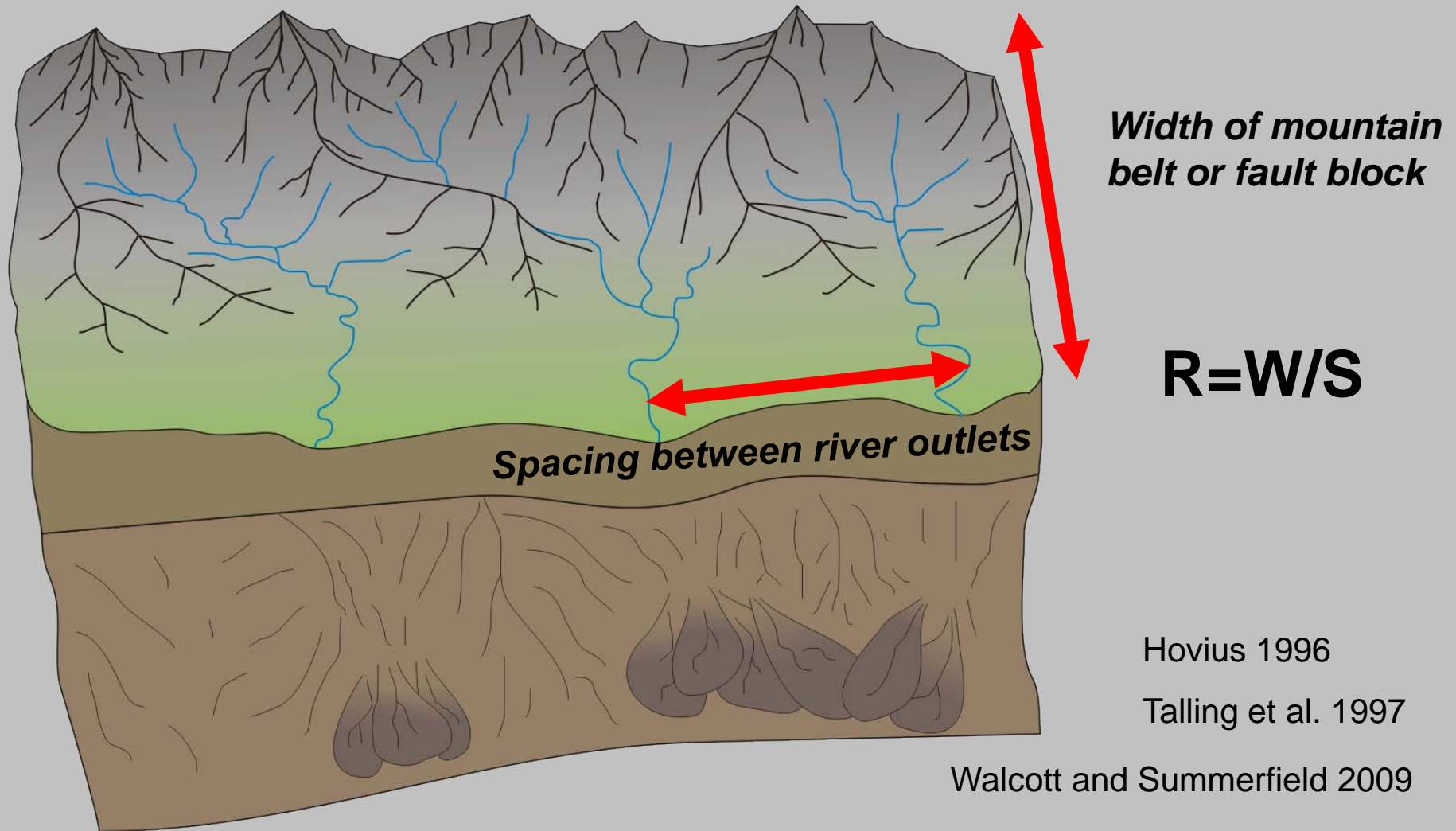
Source-to-sink context



Notes by Presenter:

- In a previous study, we have looked at morphological relationships between various elements and depositional features of S2S systems.
- Apply some of the same concepts to rift basins.
- In addition, looking for potential reservoir rocks in rift basins may be aided by some understanding of how river systems and sediment sources are located and spaced along the rift basin.

Spacing ratios



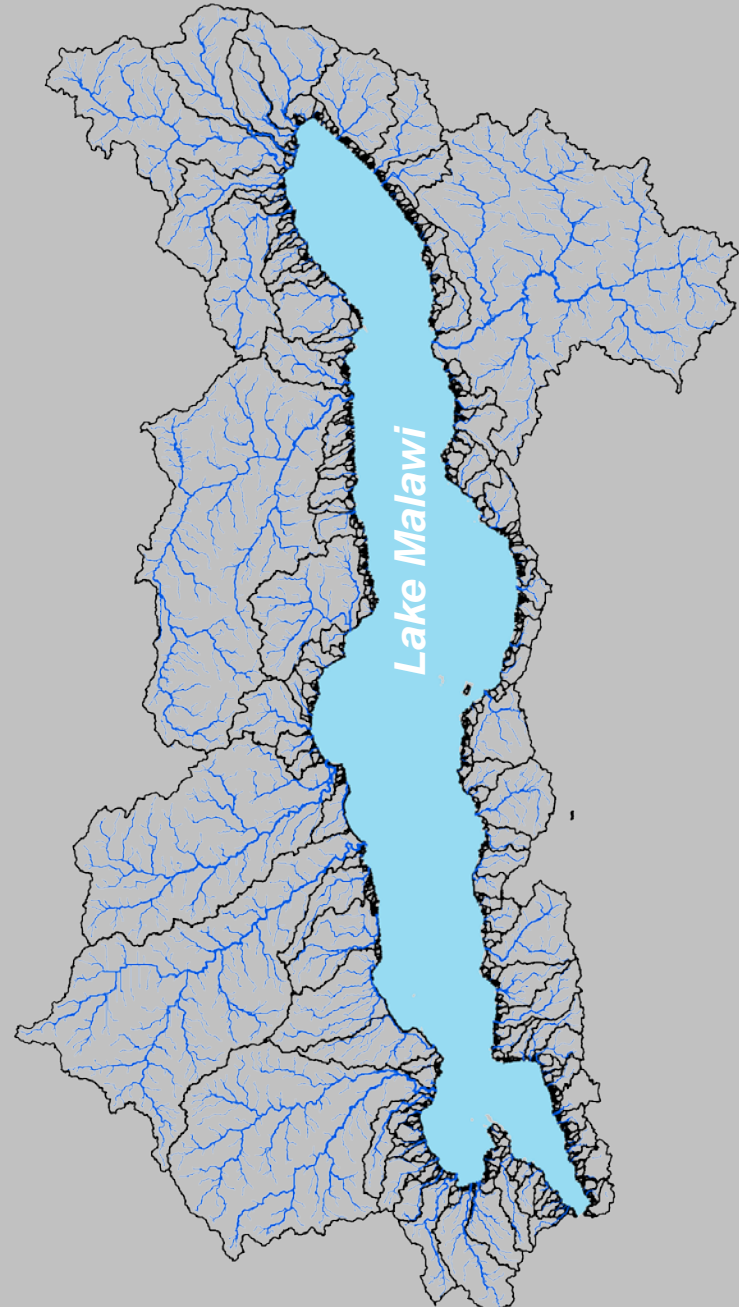
- Relationship was found to be valid for all linear mountain ranges and fault blocks
- What about non-linear rifts?

Notes by Presenter (for previous slide):

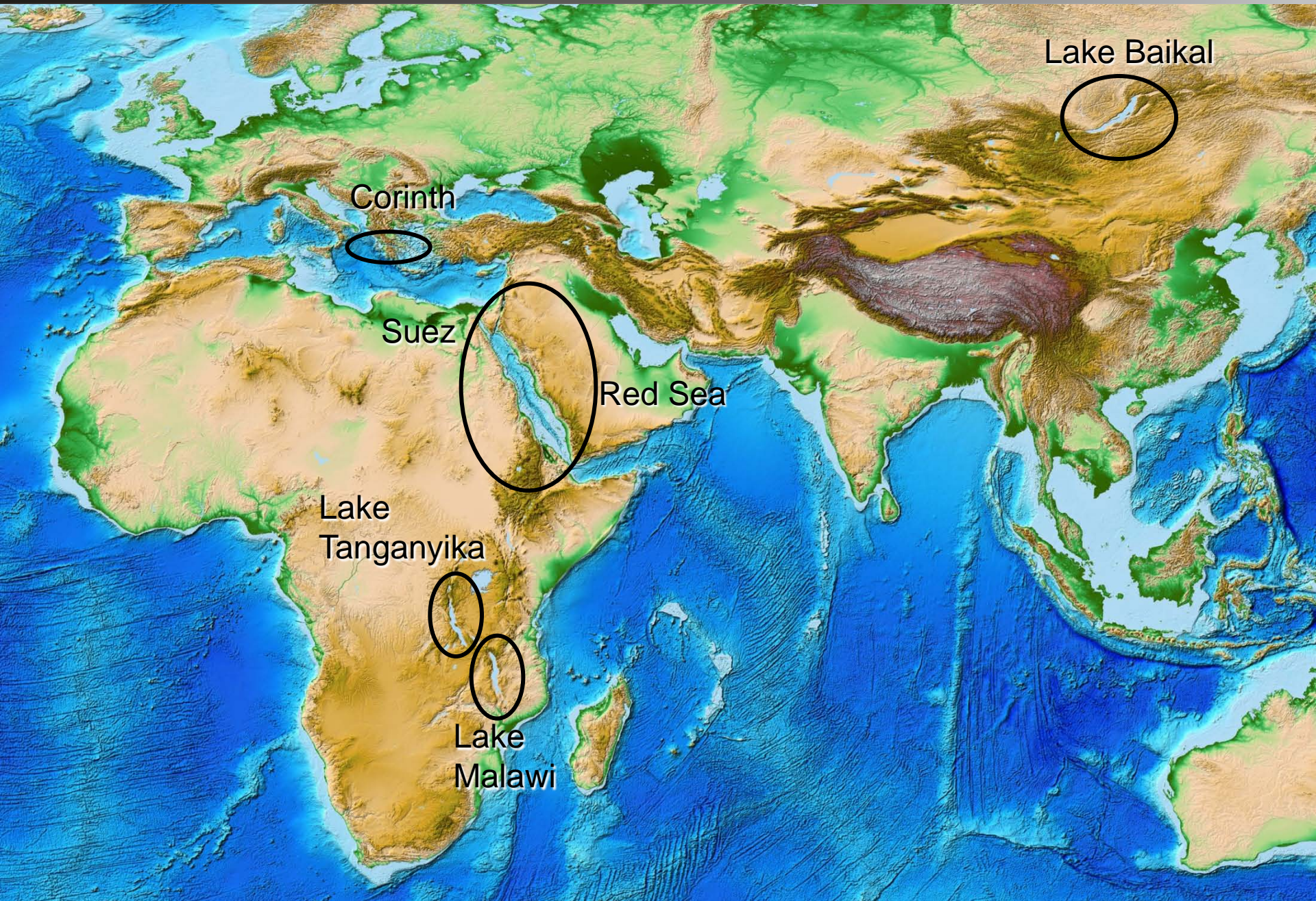
- This is where the concept of spacing ratios come in.
- Key papers on this work from the mid 90's.
- Concept investigates the relationship between width of topographic feature and spacing of rivers that drain from it.
- This gives the spacing ratio.
- This previous work investigated only linear drainages extending to the regional drainage divide, and was found to be very similar for different tectonic regimes.
- Walcott & Summerfield also looked at drainages which does not extend all the way to the main drainage divide, and that these shear the same relationship
- How does this apply to rift basins in general with no constraints on linearity and weather the drainage extend to the regional water divide or not?

Outline

- Does the relationship between drainage length and outlet spacing also apply to rift systems in general?
- What controls the variability in outlet position?
- Application for ancient systems:
 - Constrain paleotopography
 - Predict outlet positions



Study areas

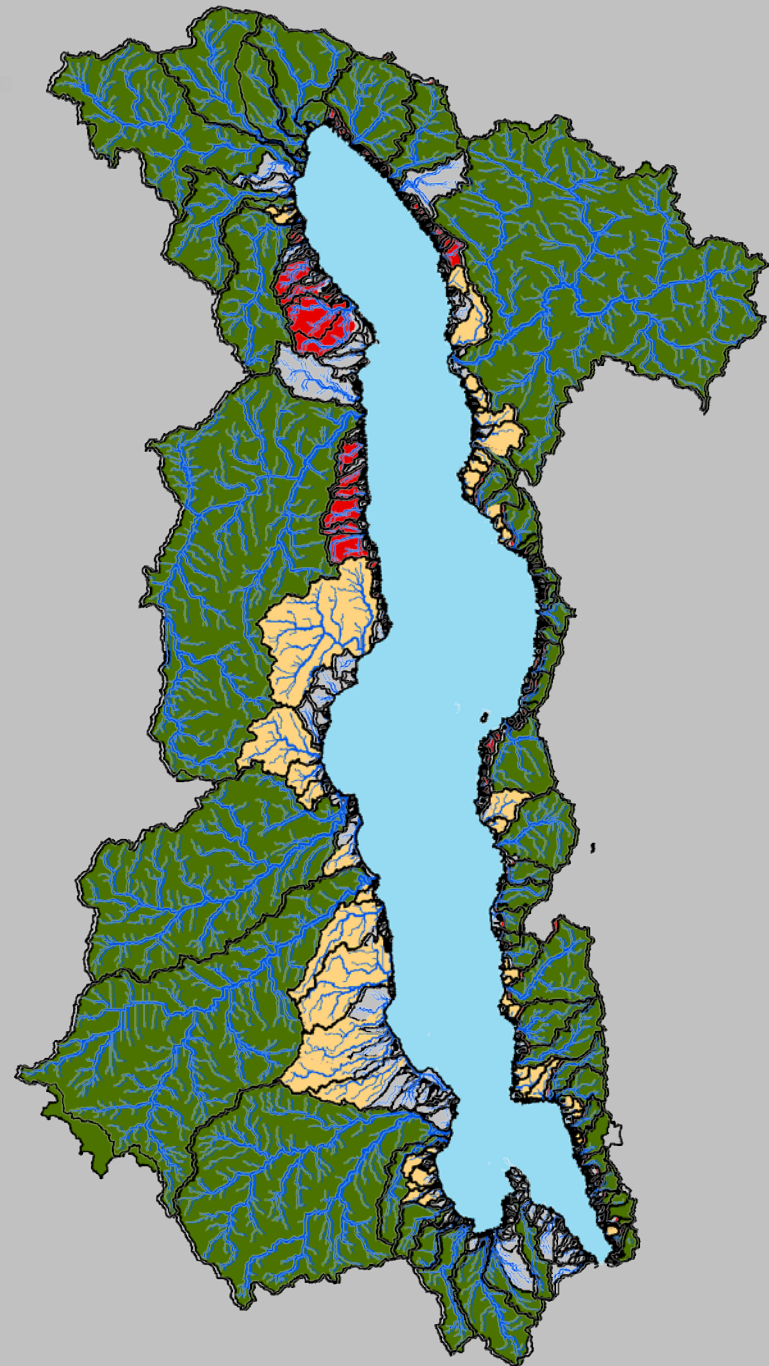


Catchment types

Three types of drainage basins:

(modified from Walcott and Summerfield 2009)

- *range-scale drainages*
(encircle the rift)
- *interstitial drainages*
(located basinward from the range-scale basins)
- *structural drainages*
(structurally controlled divide, either range-scale or internal)

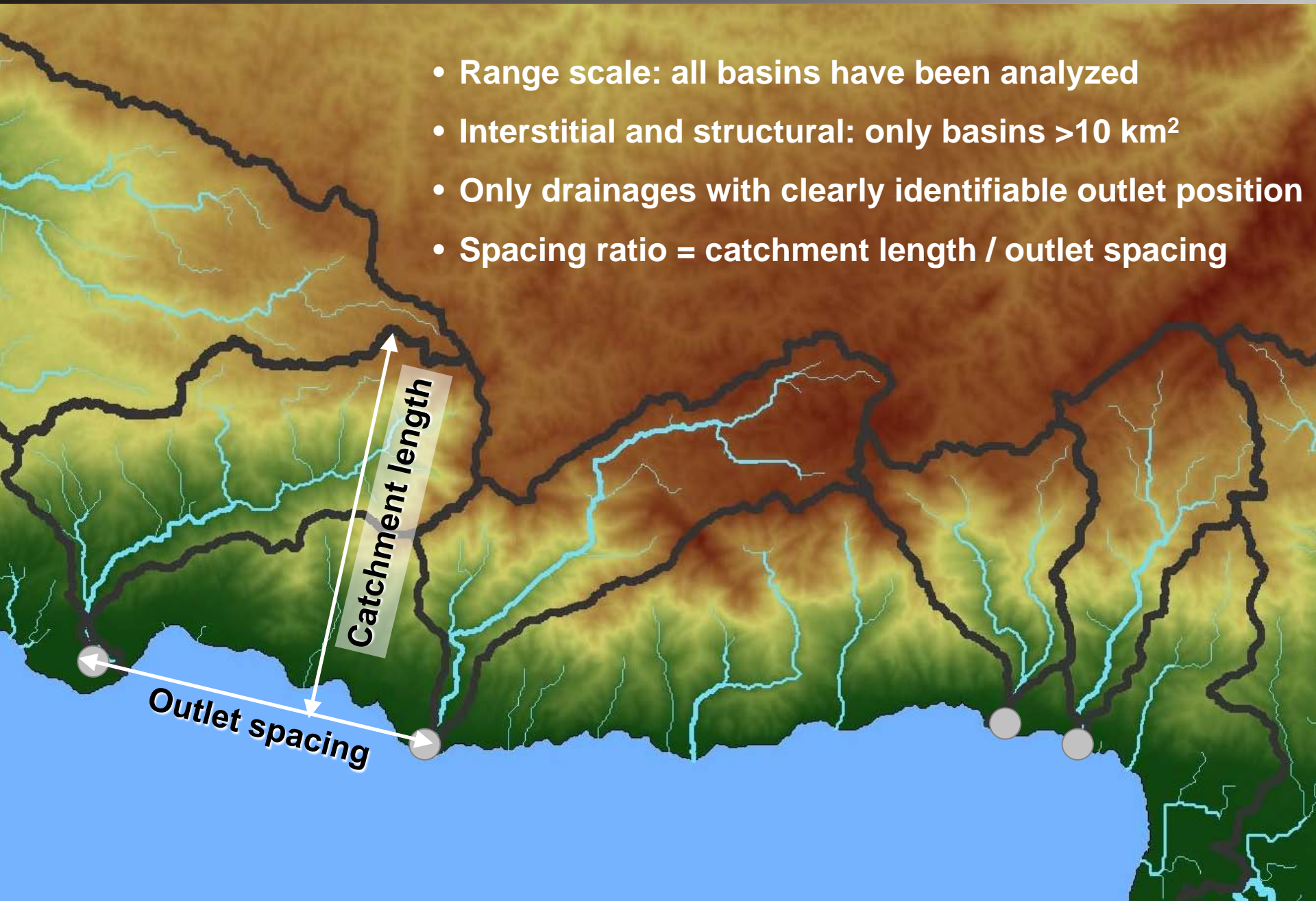


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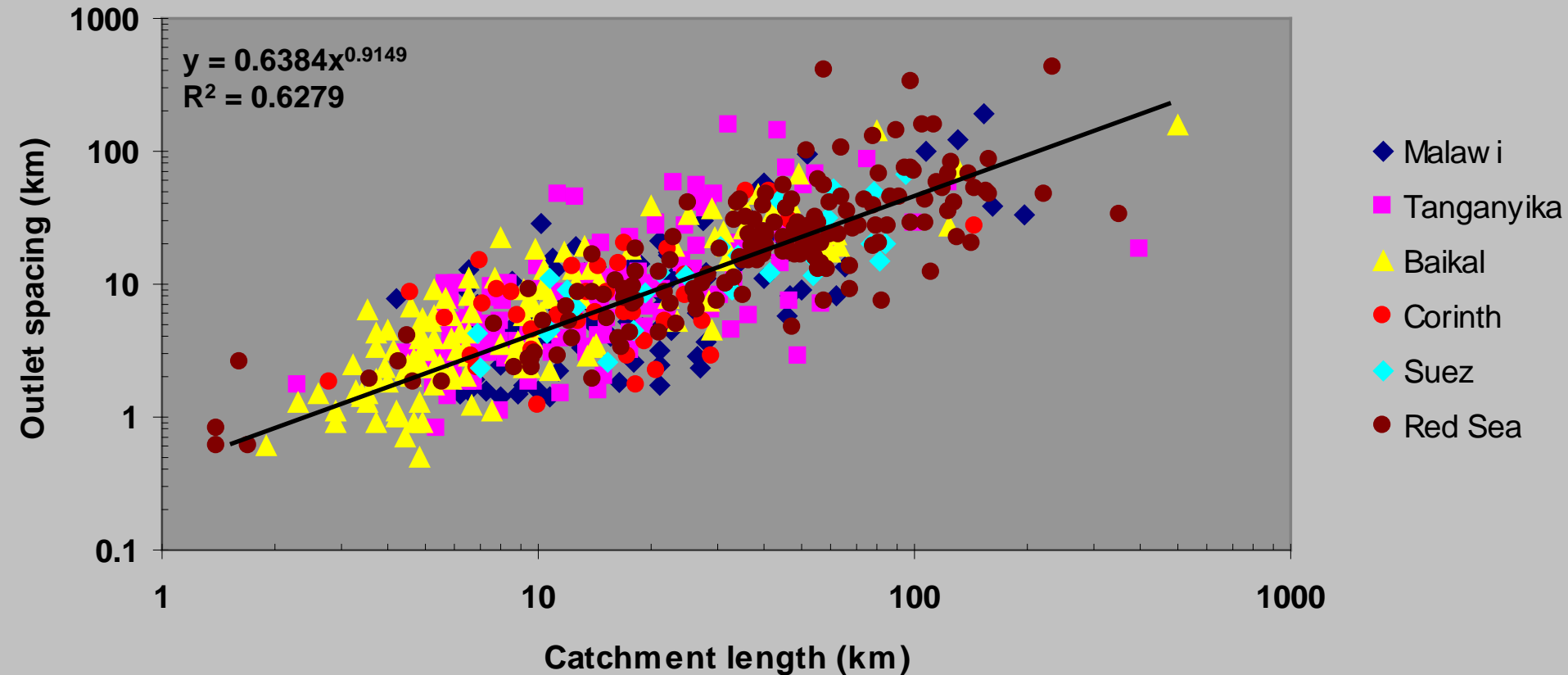
- Range scale drainages define the water divide along the entire rift basin, and are always the largest drainage basins in a given region – hence, most important.
- Smaller drainage basins located between range scale basins and the lake/sea, no structural control.
- Structural drainages are linear, and are directly controlled by structurally / tectonically related drainage divide.
- Reason for subdivision is to determine if any of these controls on drainage are relevant for outlet spacing.

Methods and constraints

- Range scale: all basins have been analyzed
- Interstitial and structural: only basins $>10 \text{ km}^2$
- Only drainages with clearly identifiable outlet position
- Spacing ratio = catchment length / outlet spacing

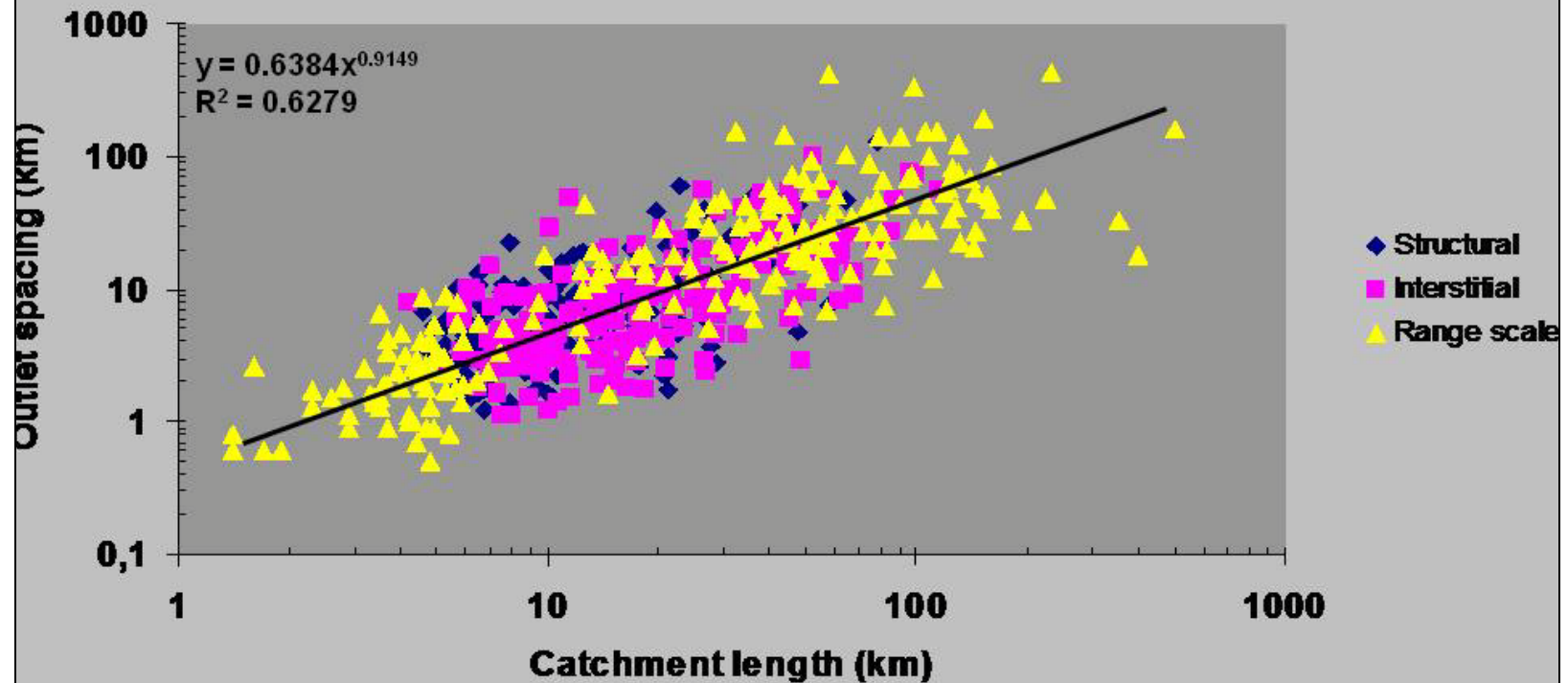


Catchment length vs. outlet spacing



- No major difference between different modern rifts
- No major difference between drainage types
(also suggested by Walcott and Summerfield 2009)

Catchment length vs. outlet spacing

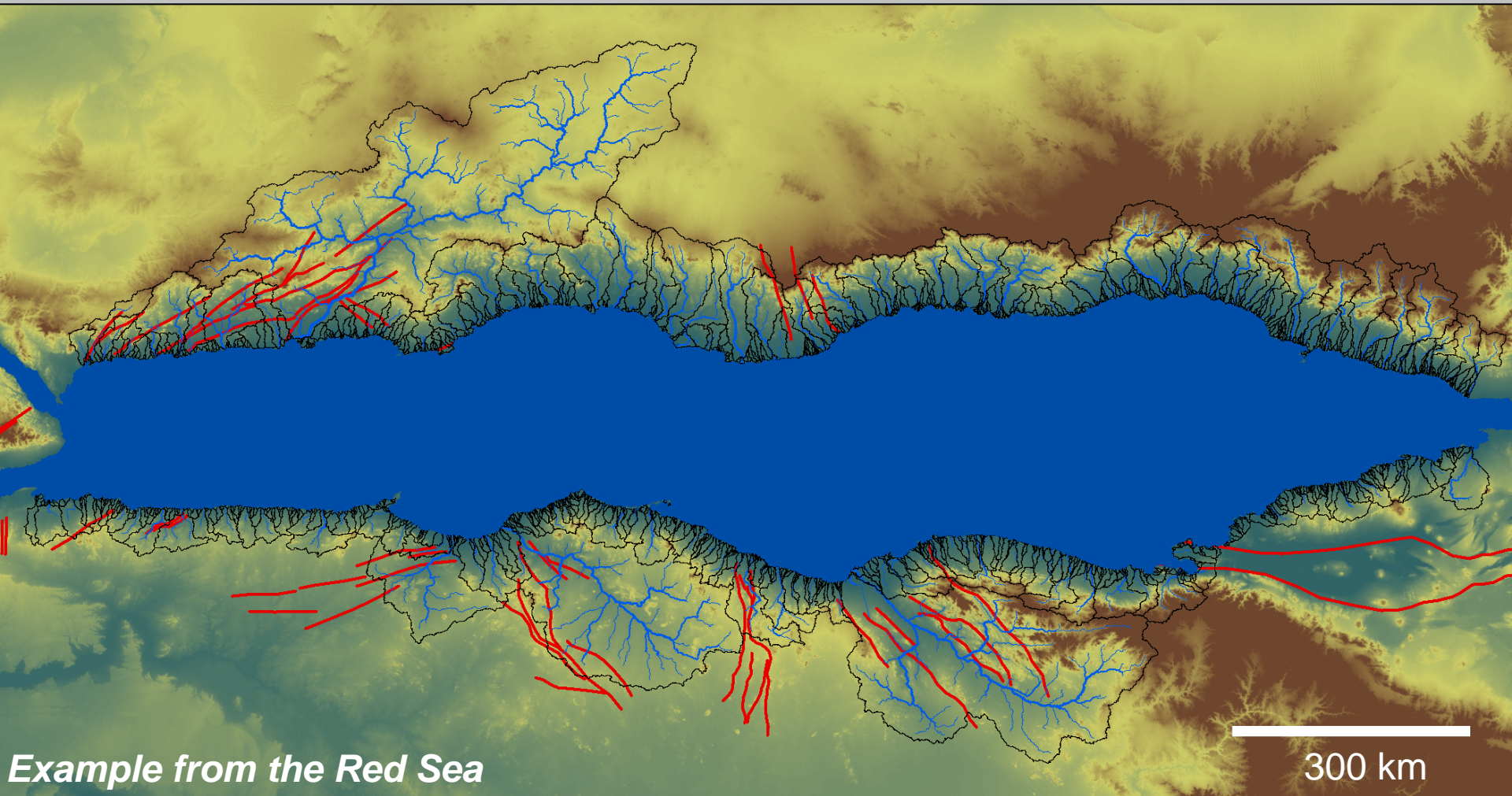


- No major difference between different modern rifts
- No major difference between drainage types
(also suggested by Walcott and Summerfield 2009)

Notes by Presenter:

- No major difference between different rifts.
- No major difference between different catchment types.
- However, some large range scale catchments have anomalous high and low spacing ratios

Regional control on spacing ratios

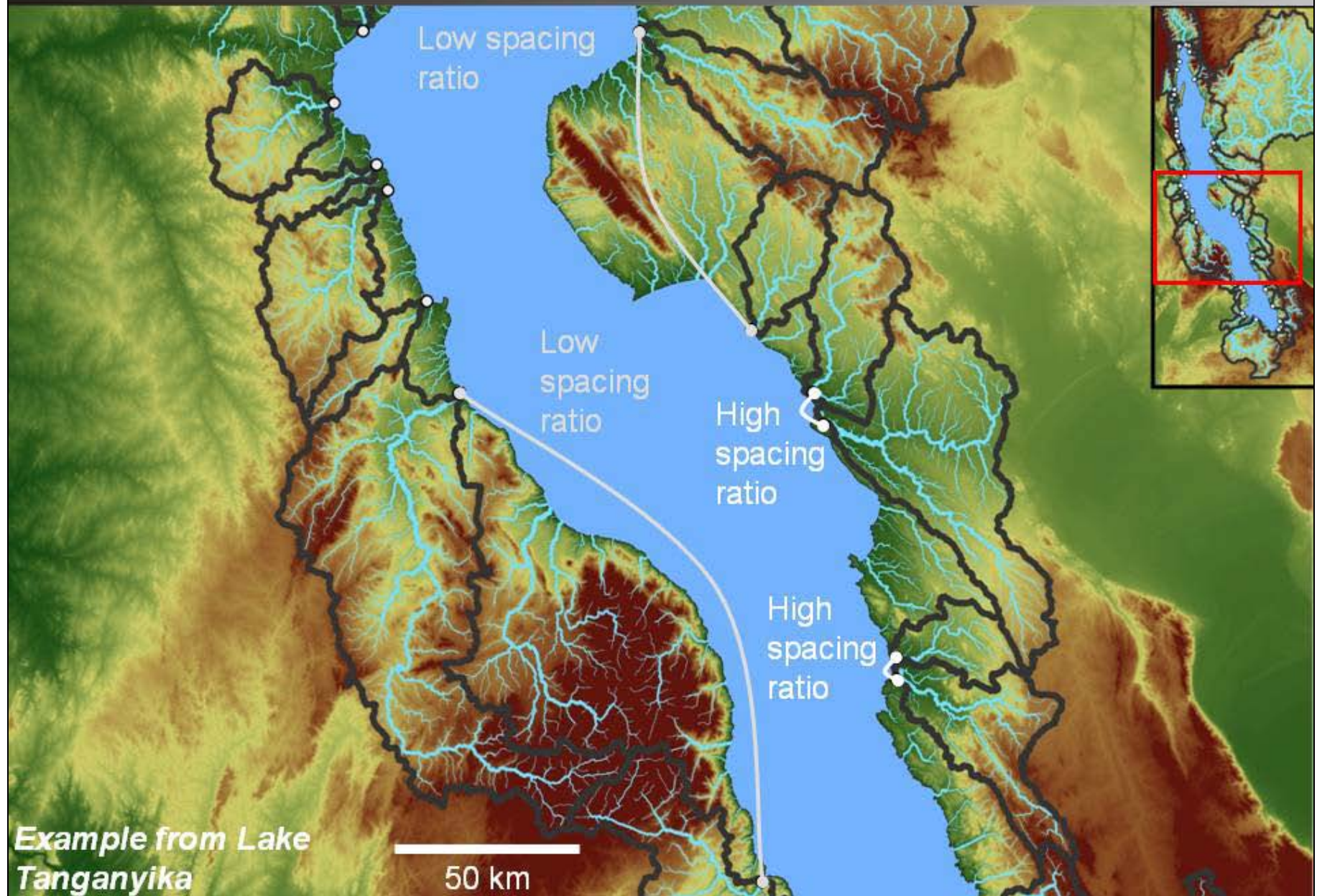


- Pre-rift basement fabric and antecedent drainage determine where catchments extend beyond the rift shoulder

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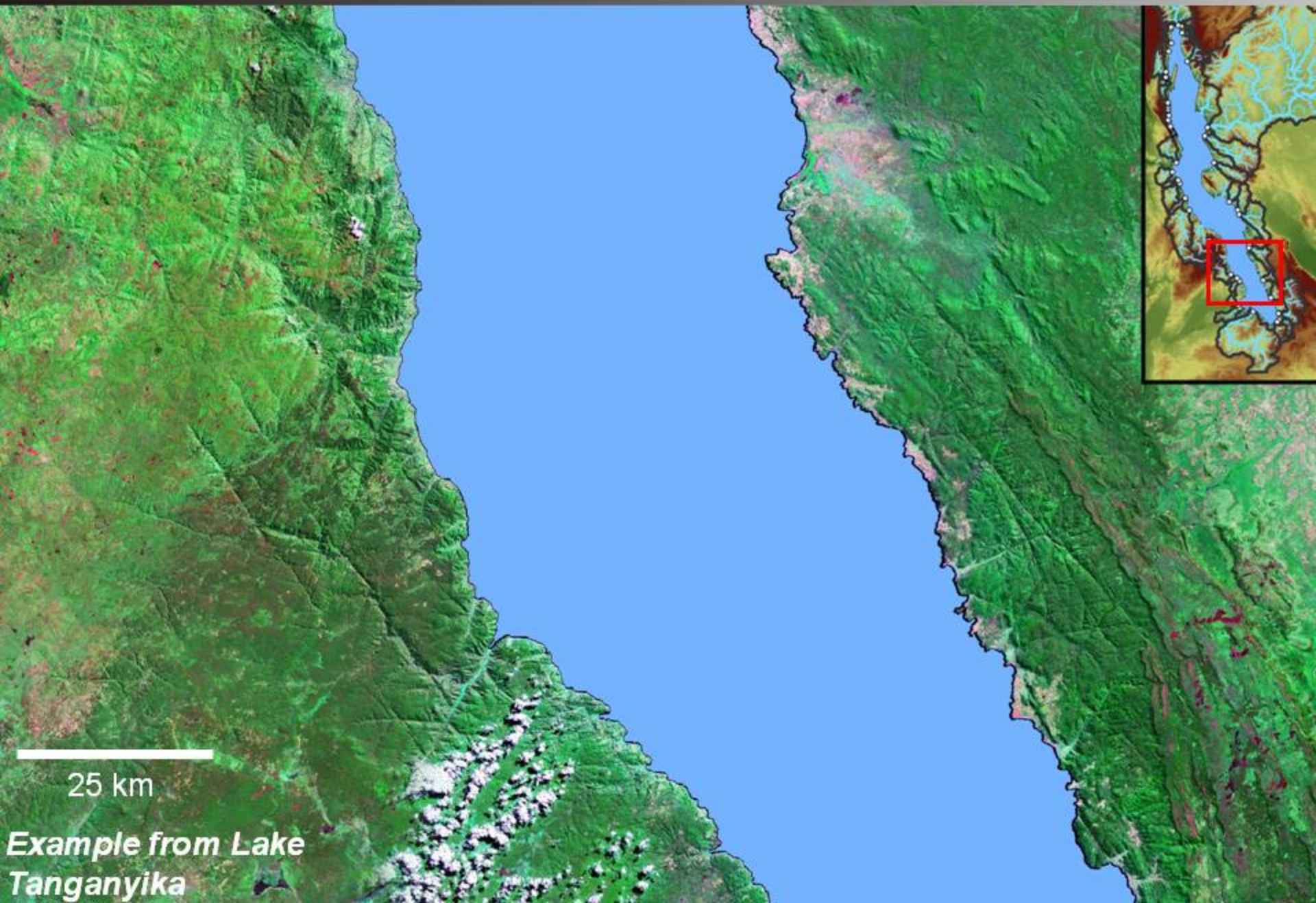
- What causes some of the range scale basins to deviate?
- Some of the variability is caused intersection of fault zones and suture zones that guides the rivers though the rift shoulders.
- Also, when rift cuts antecedent drainage, the intersection may provide important areas where large rivers enter the rift zone.
- Problem: these are difficult to spot and some ideas on pre rift drainage and location of large fault zones is crucial to determine the location of these “outliers”.

Local structural control

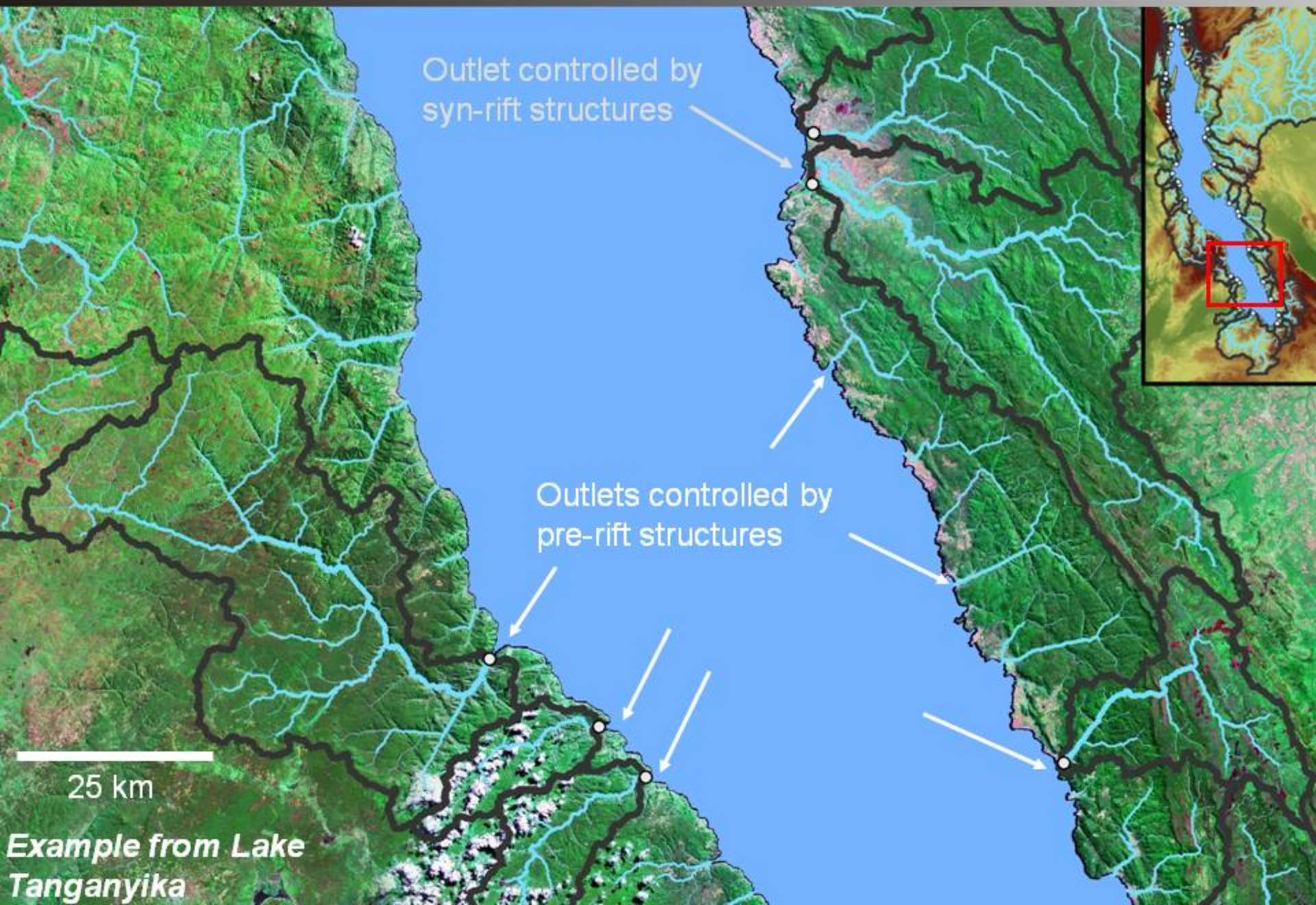


Notes by Presenter: Spacing ratios vary significantly when structures intersect the rift basin with a steep angle.

Local structural control



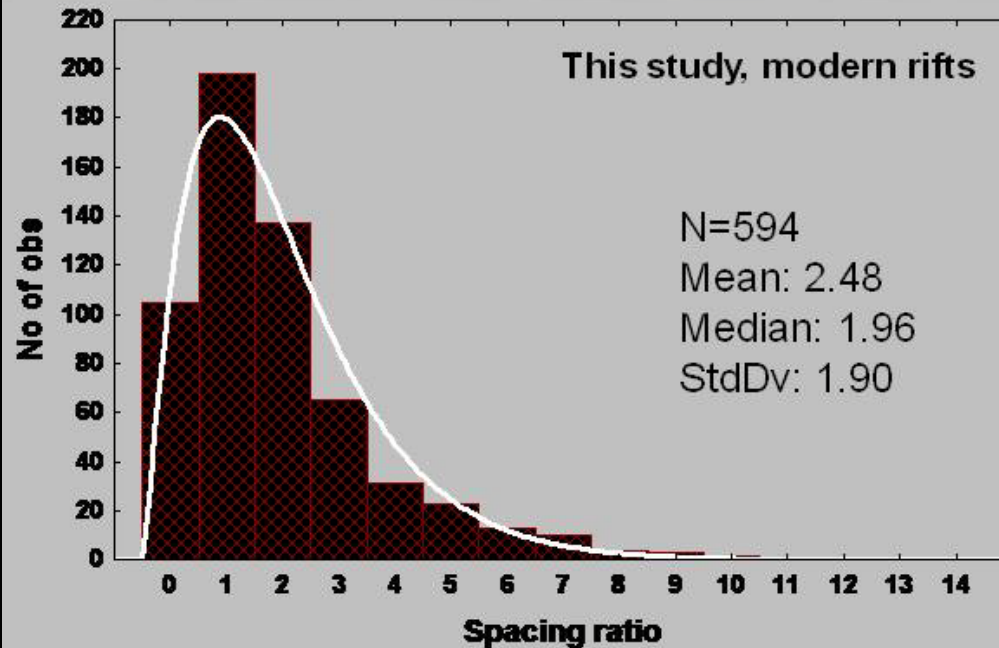
Local structural control



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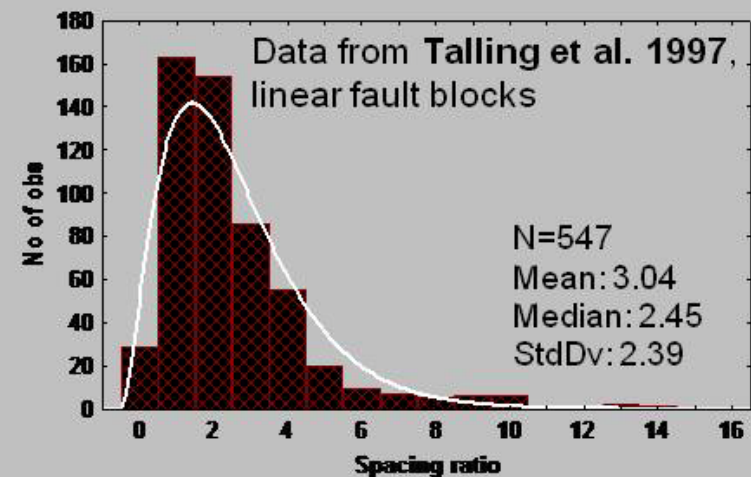
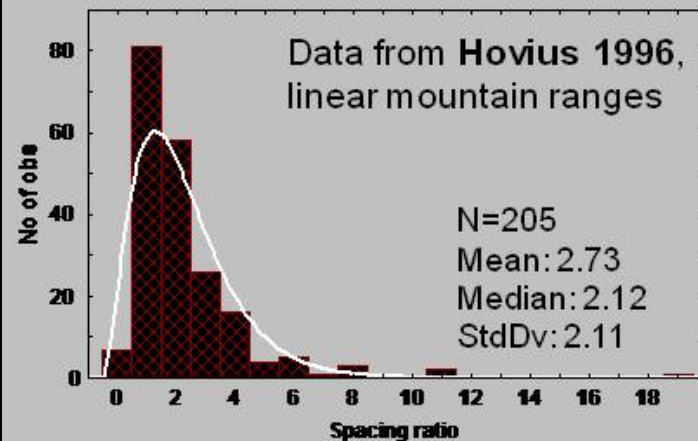
- In more detail, the exact position of the outlets is controlled by fault intersection.
- In the case of Lake Tanganyika, there are two dominant orientation of basement fabric:
- One NE that intersects the rift with a steep angle.
- One NW that is sub-parallel to the rift axis.
- Almost every outlet is following a lineament.
- In addition, the shape of the catchment and the drainage network also follows the structures, deviating from typical dendritic network, and gives rise to variability in spacing ratios.

Comparison with other studies



Conclusion:

these relationships appear to be valid for all types of drainages, and are not related to geographic location, scale, climate, age or structural control

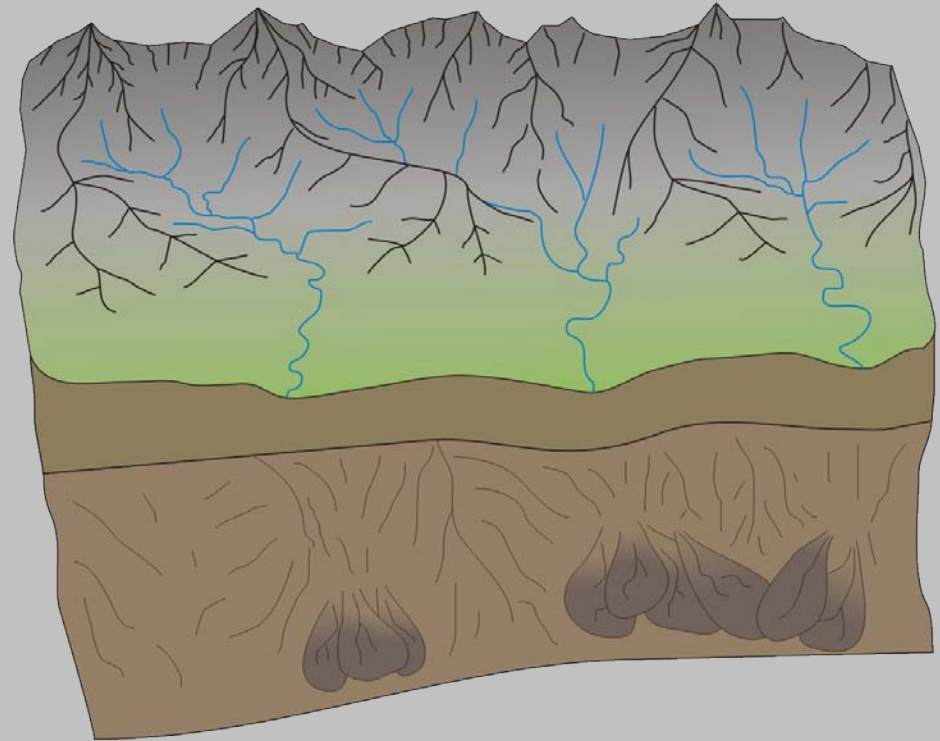


Notes by Presenter:

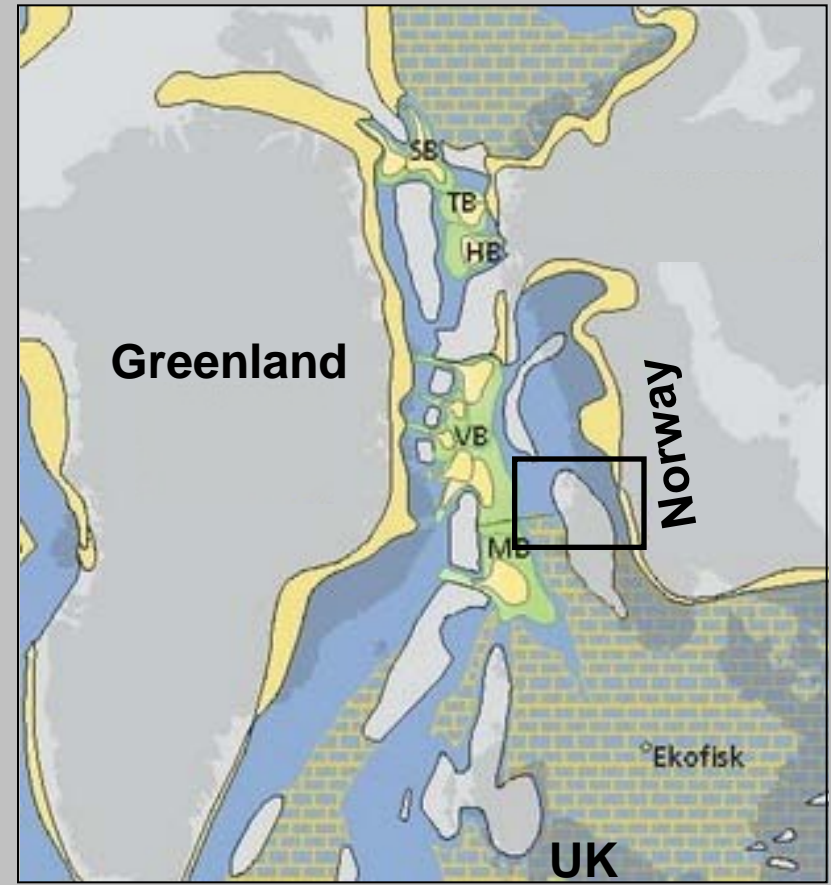
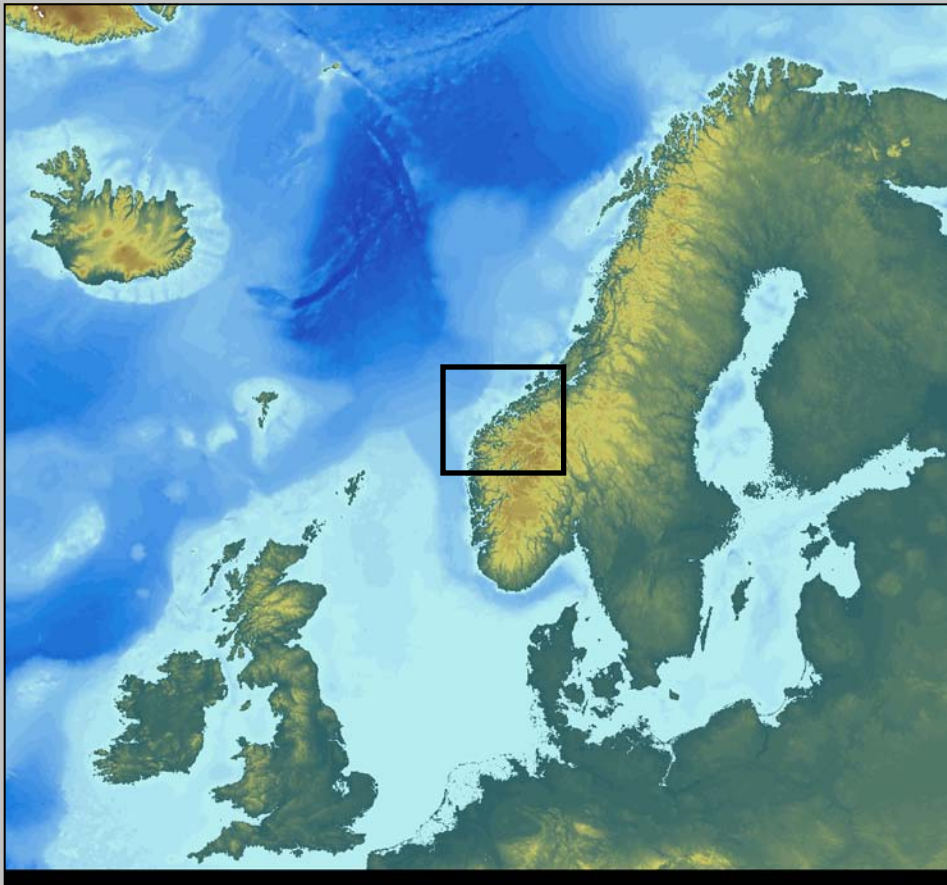
- Mean, median and the variation in spacing ratios are very comparable in very different settings.
- What causes the overall consistency and internal variability?

Summary: modern rift drainage

- The observed relationships appears to be valid for all types of rifts, and are not related to geographic location, scale, climate, age or structural control
- Supports previous conclusions suggesting a natural organization of drainages
- Should also be valid for ancient, subsurface systems



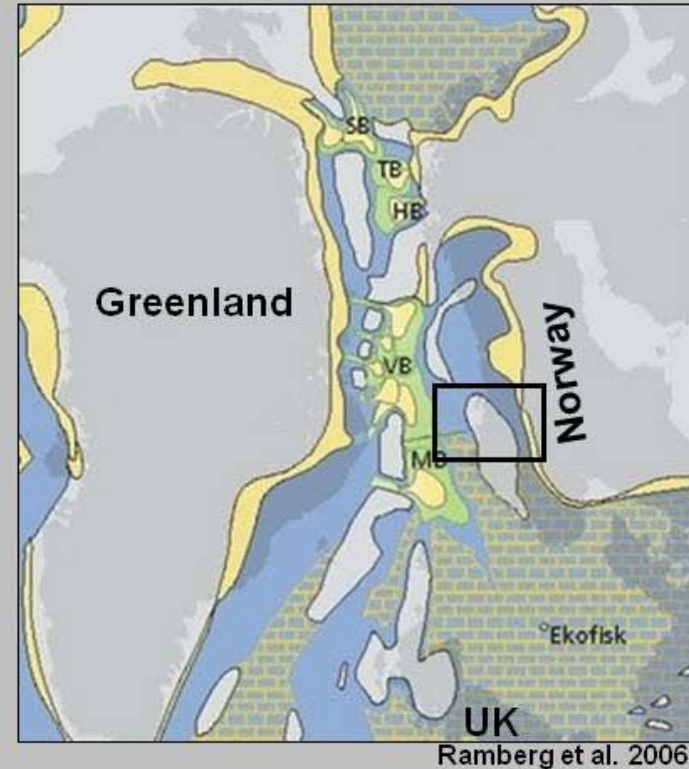
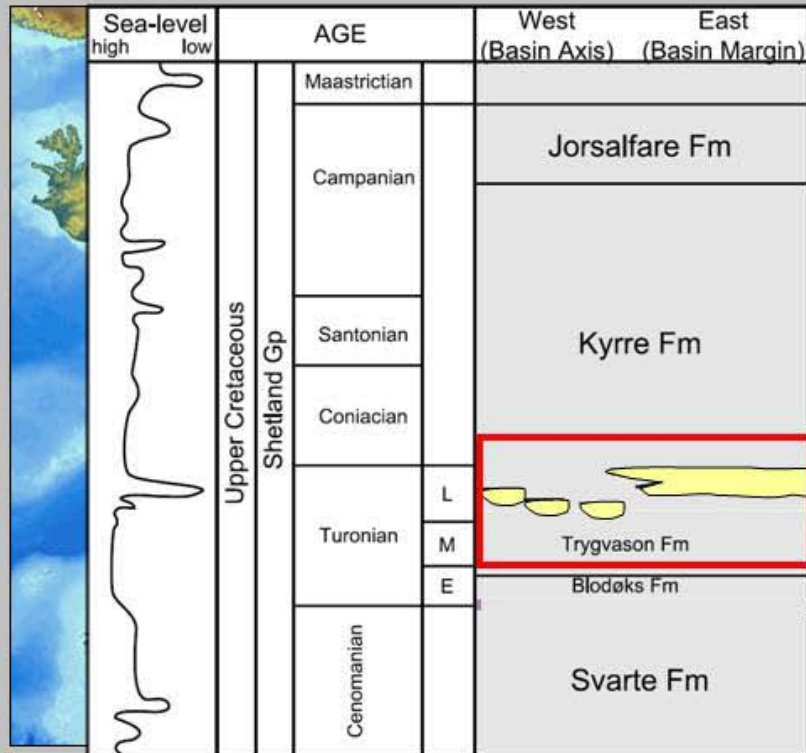
Case study: North Sea



Ramberg et al. 2006

- Upper Cretaceous (Turonian), Northern North Sea (Slørebotn Basin)
- Regional tectonic quiescence and thermal subsidence
- Interrupted by tectonic reactivation

Case study: North Sea

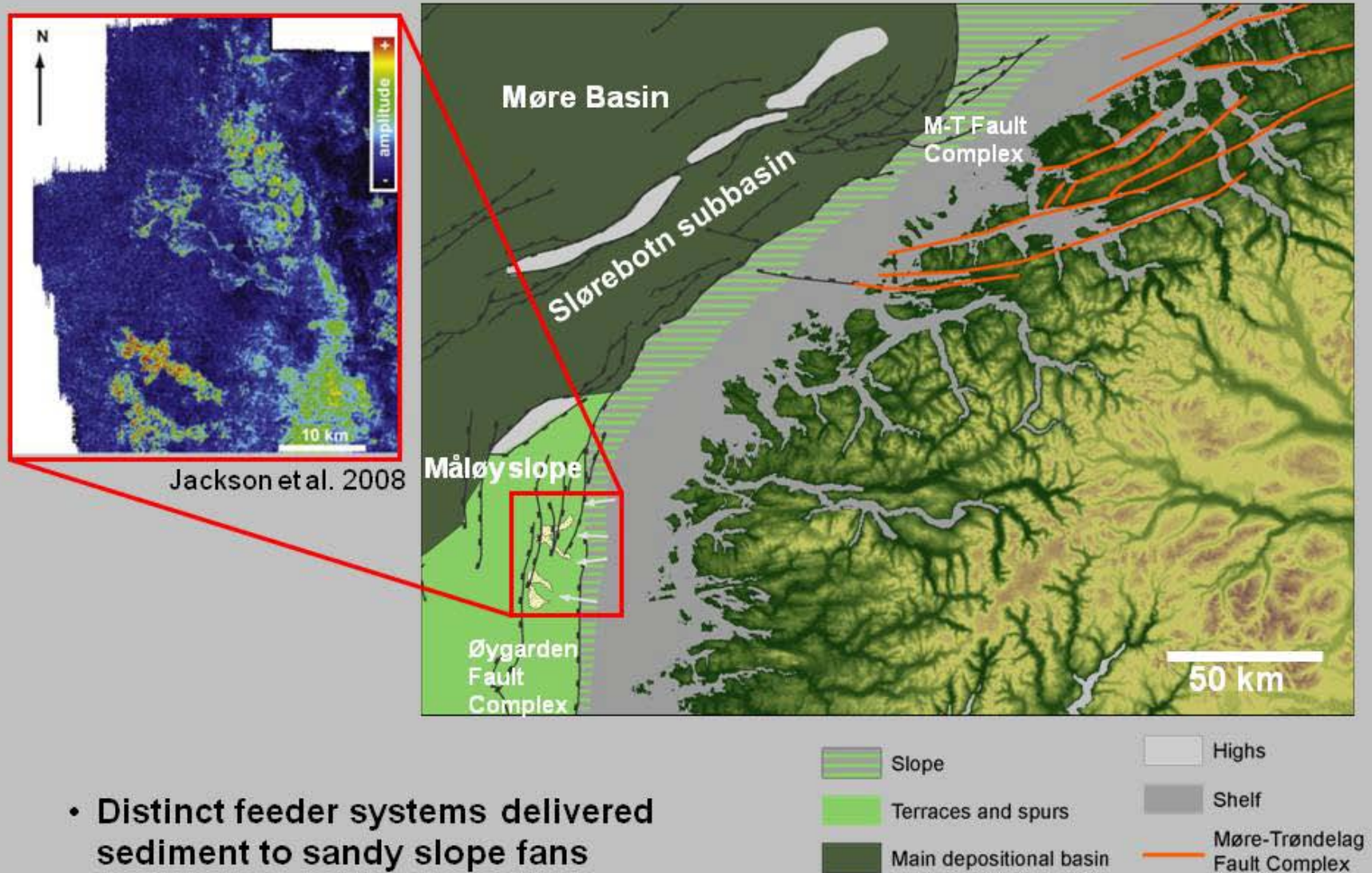


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Notes by Presenter:

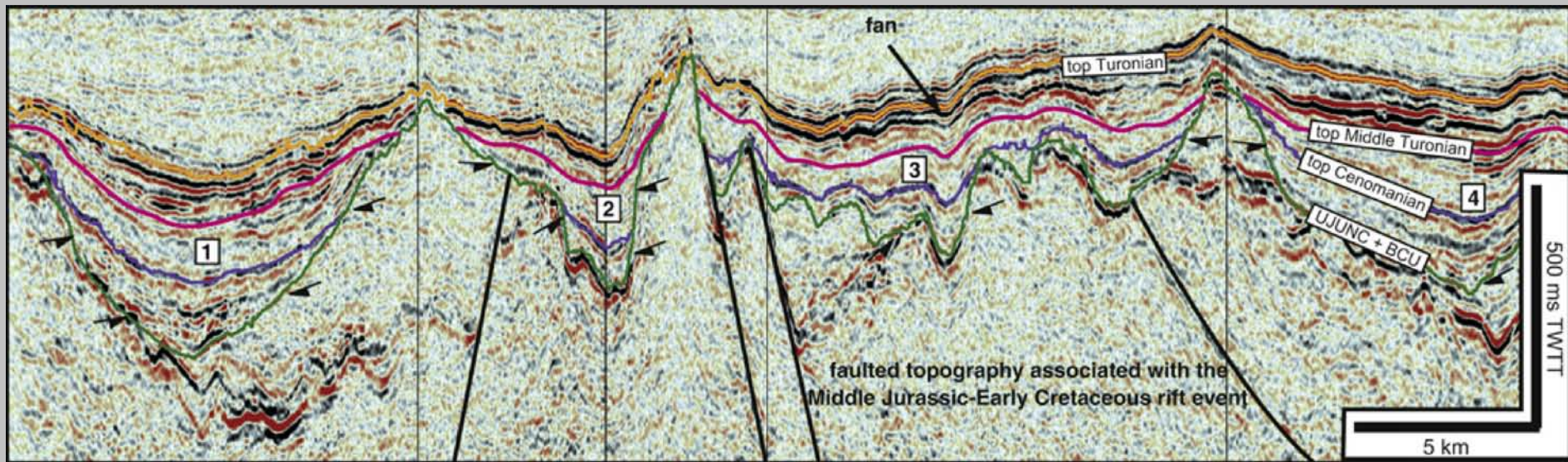
- Last part will discuss how this can be applied in an ancient subsurface setting.
- Northern North Sea, outside Norway as an example.
- We will use mapped outlet positions to constrain paleotopography and determine where the sediment came from.

Previous work: Måløy slope



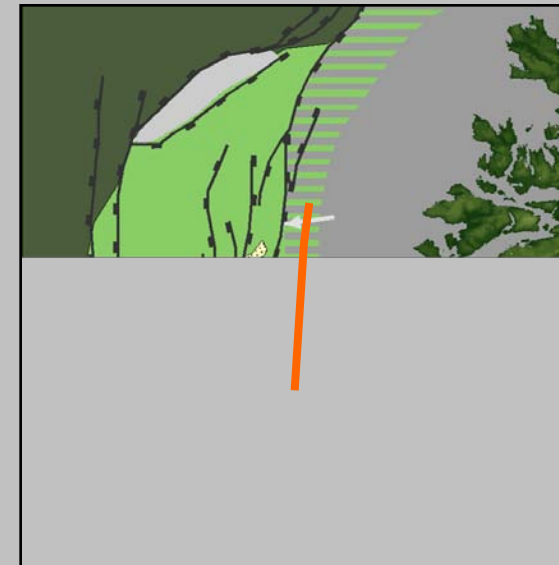
Notes by Presenter: Previous work by Jackson identified several sandy slope fans along the Måløy slope that were sources by distinct canyon feeder systems on the slope.

Sediment fairways

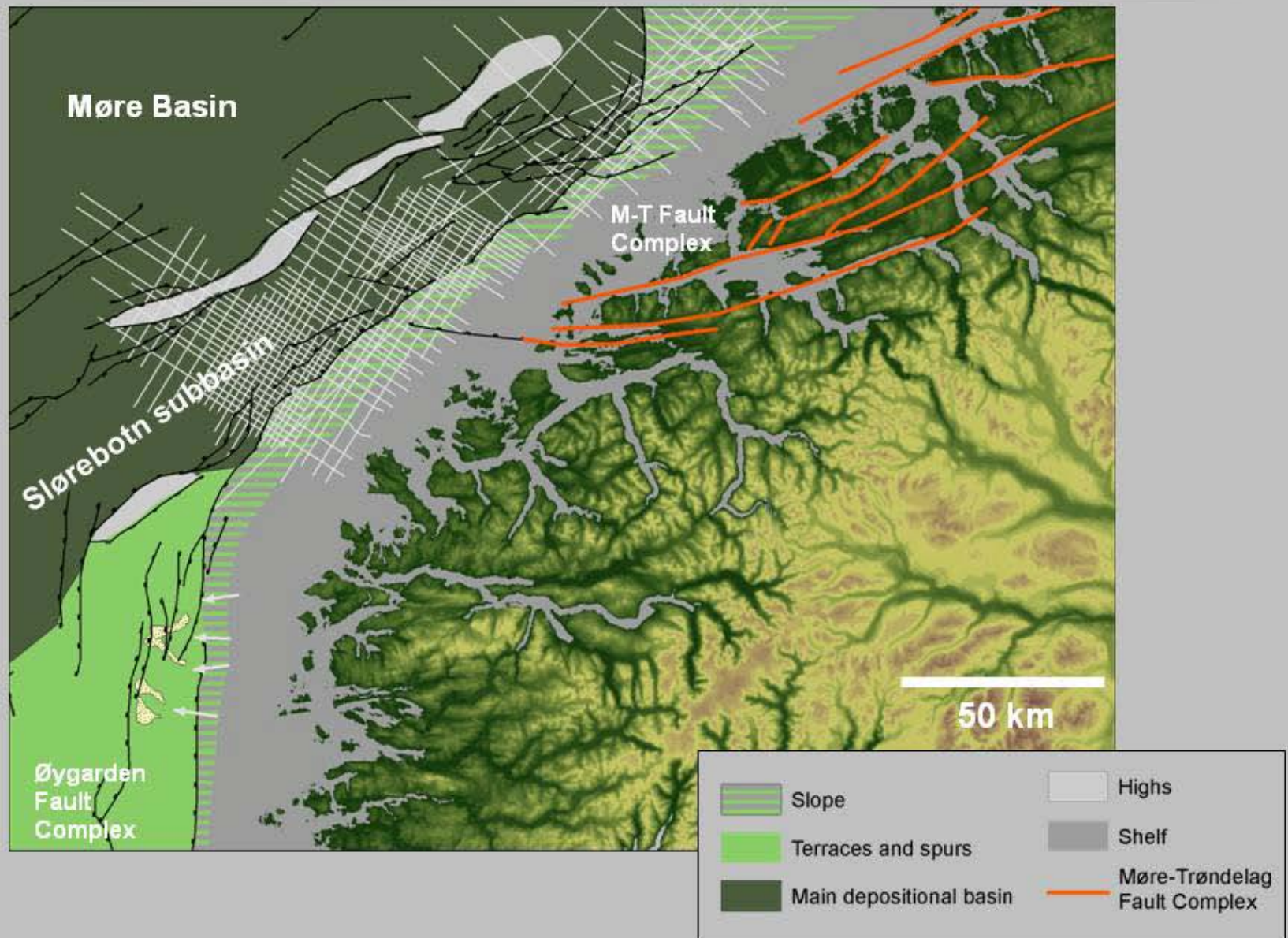


Jackson et al. 2008

- Sediment fairways along the Måløy slope
- High amplitude reflectors on-lapping canyon margins
- Local structural control

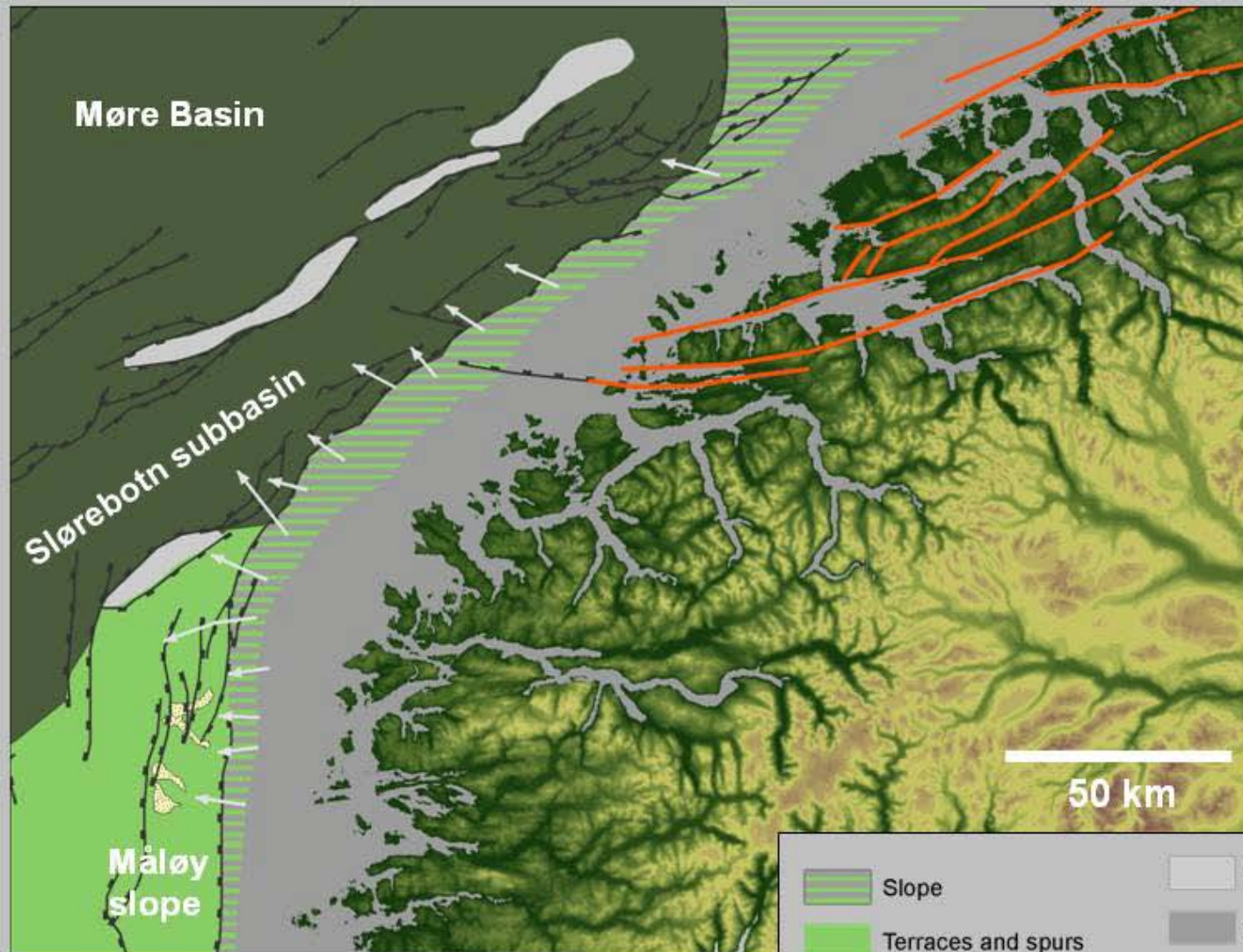


Sediment fairways



Notes by Presenter: In addition to this, we have looked at seismic to see if we can identify more feeder systems to the NE.

Sediment fairways

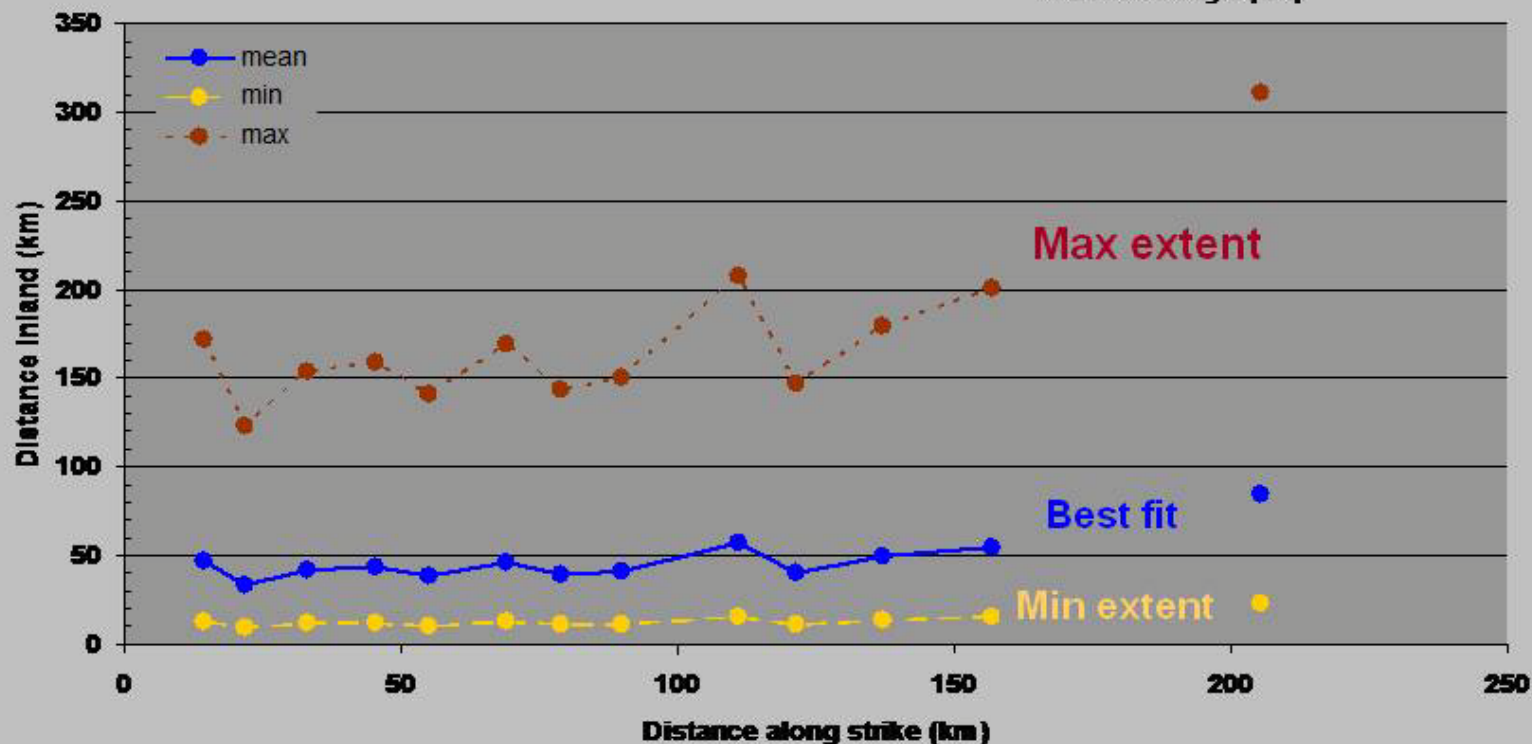
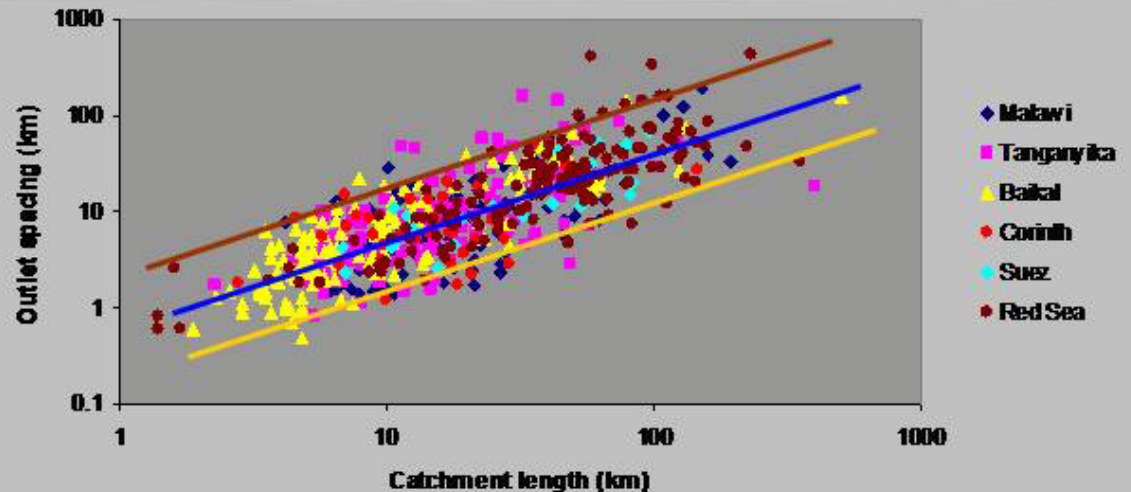


- Can we use spacing ratios to determine catchment configuration during the Turonian?

Notes by Presenter: We can identify a total 14 canyons or feeder system along this area.

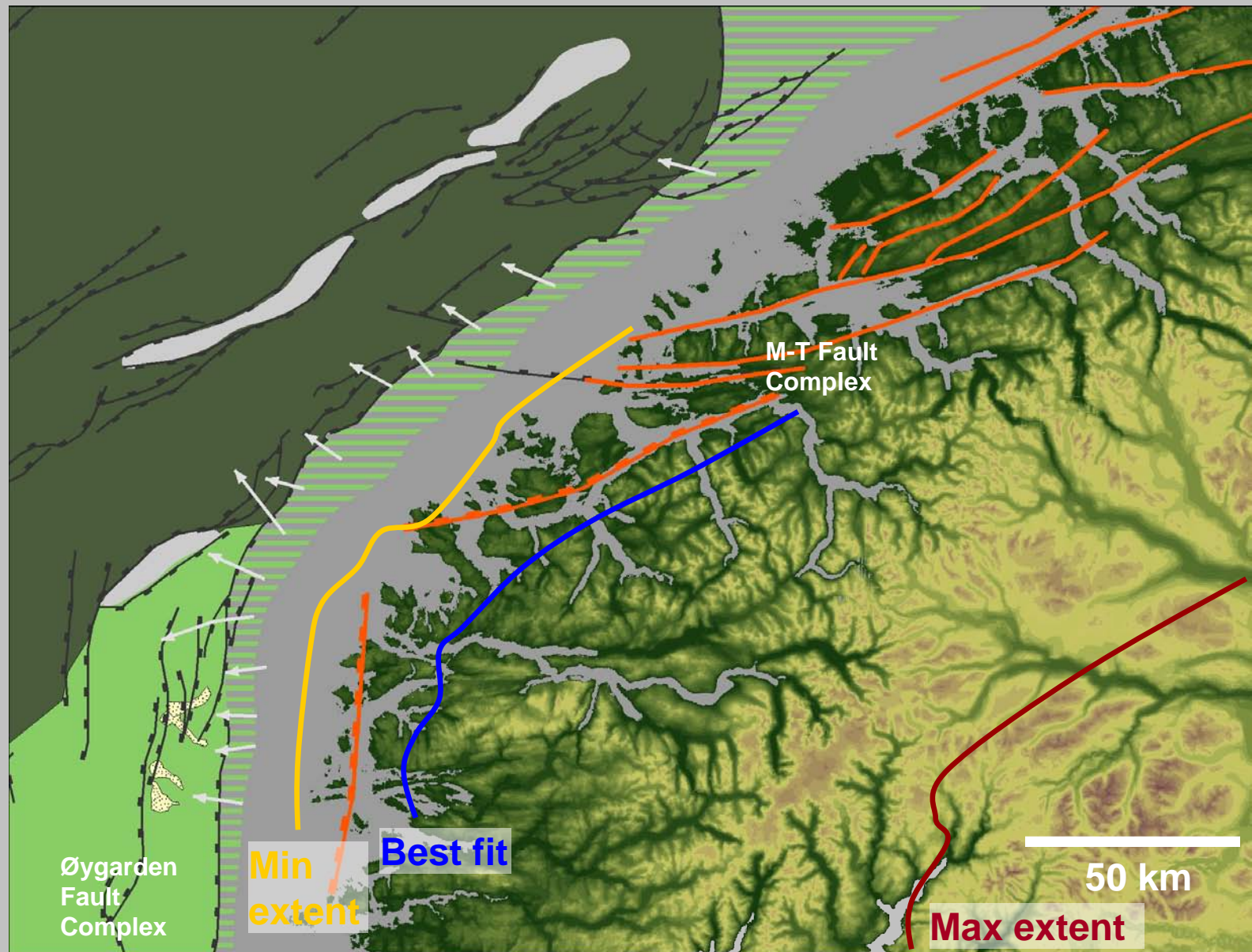
Estimating catchment extent

- Use modern outlet relationships to estimate Turonian catchment extent

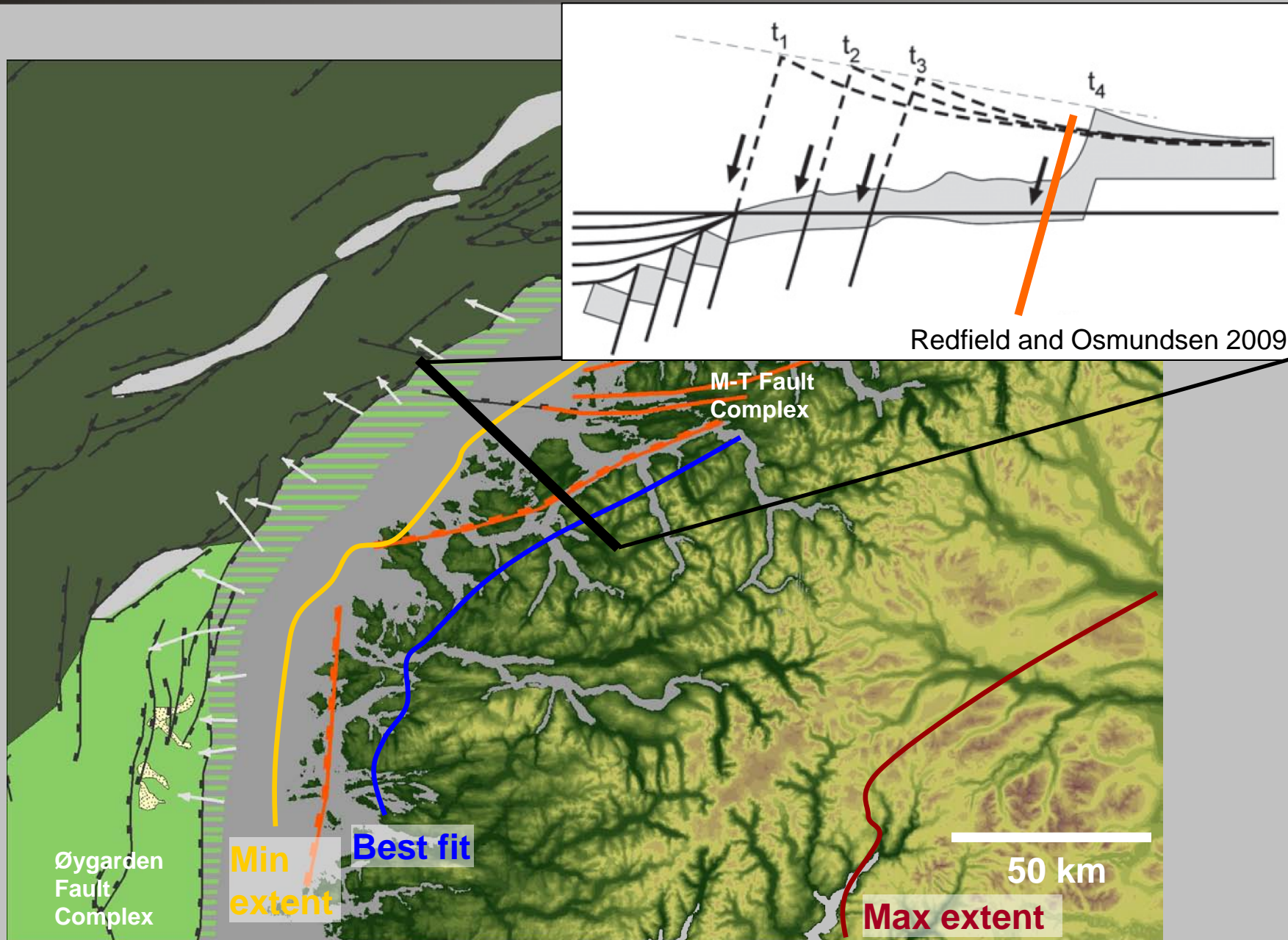


Notes by Presenter: Use the relationship found in modern rifts to estimate catchment extent with a 90% uncertainty envelope.

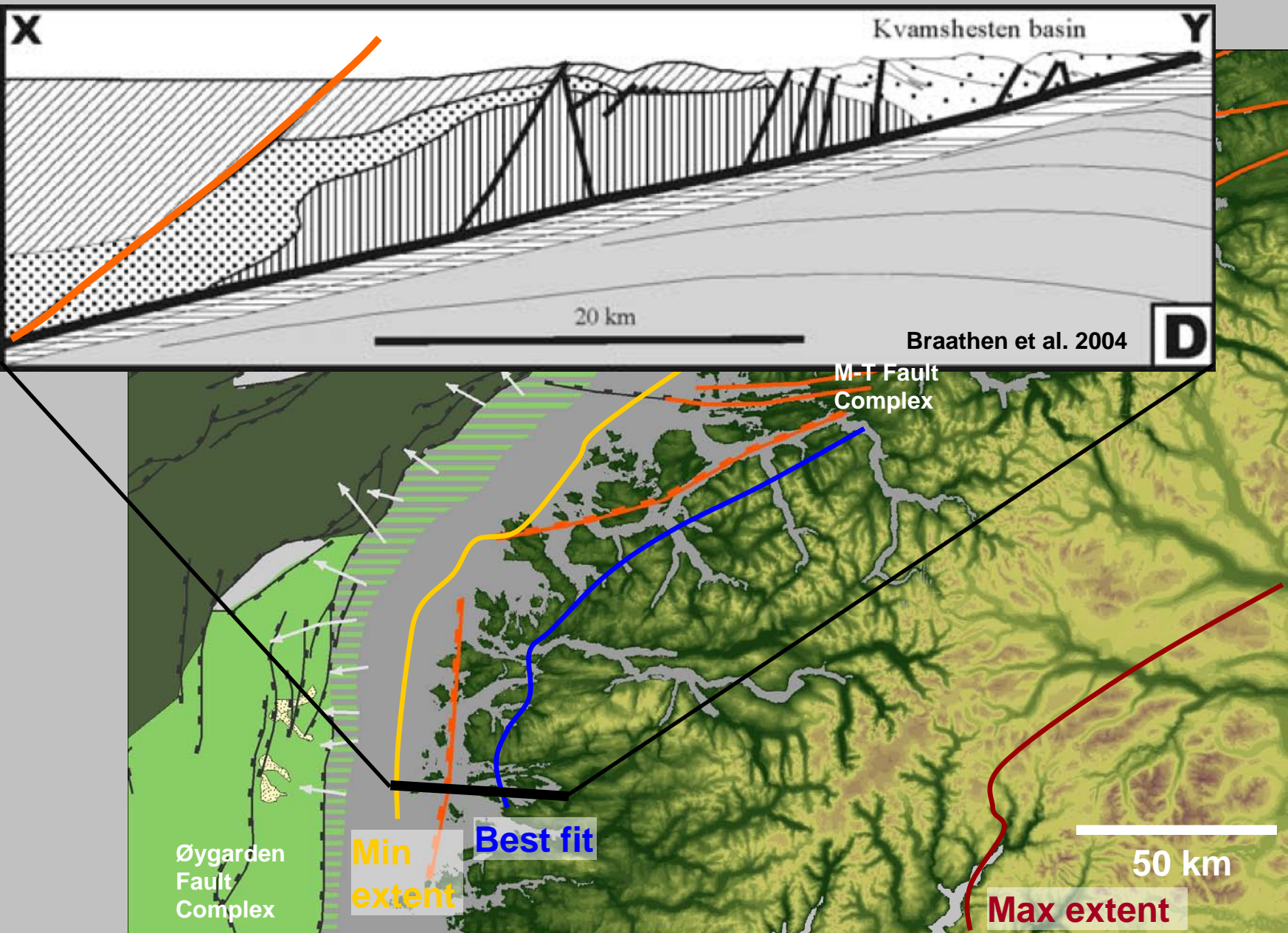
Estimating catchment extent



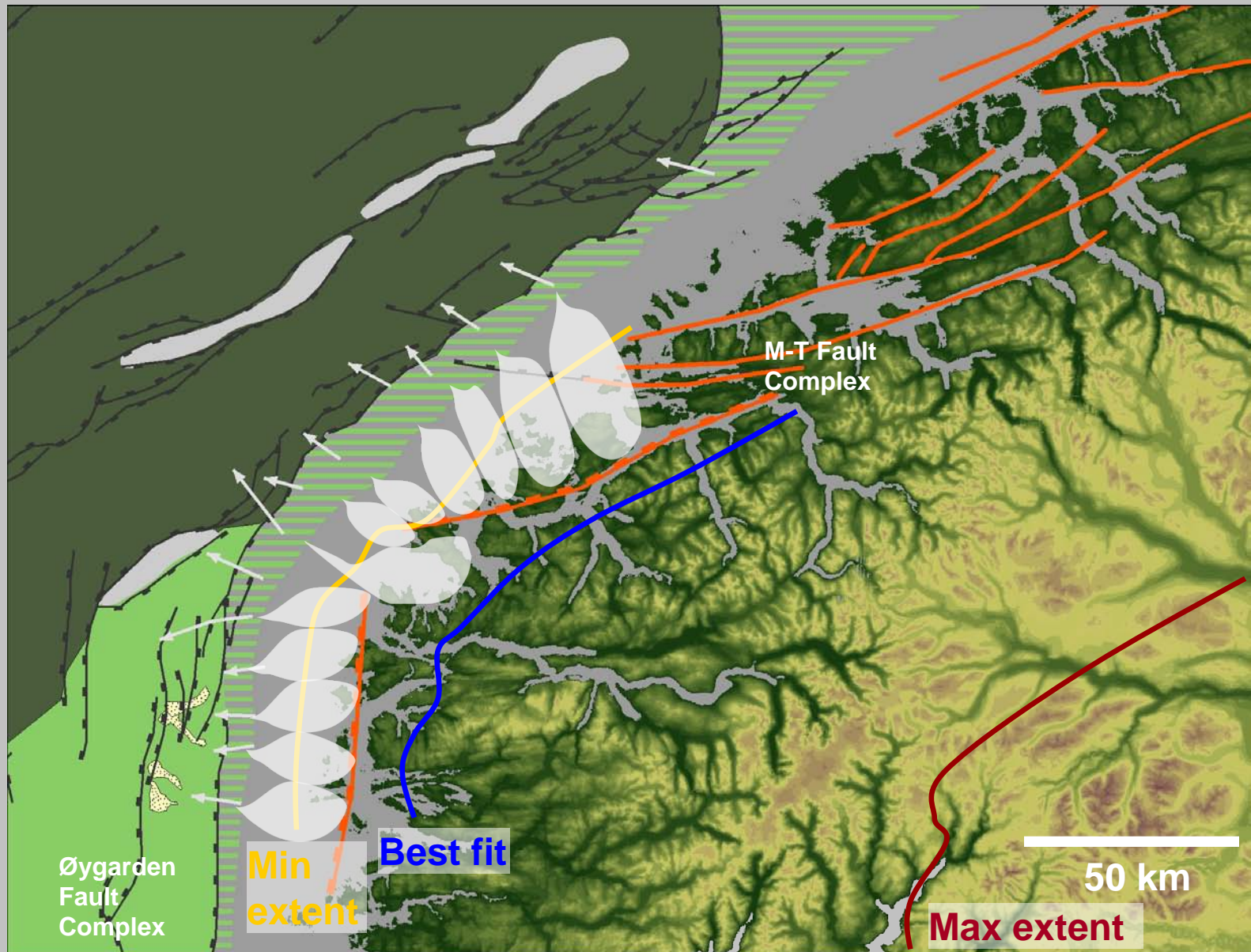
Estimating catchment extent



Estimating catchment extent



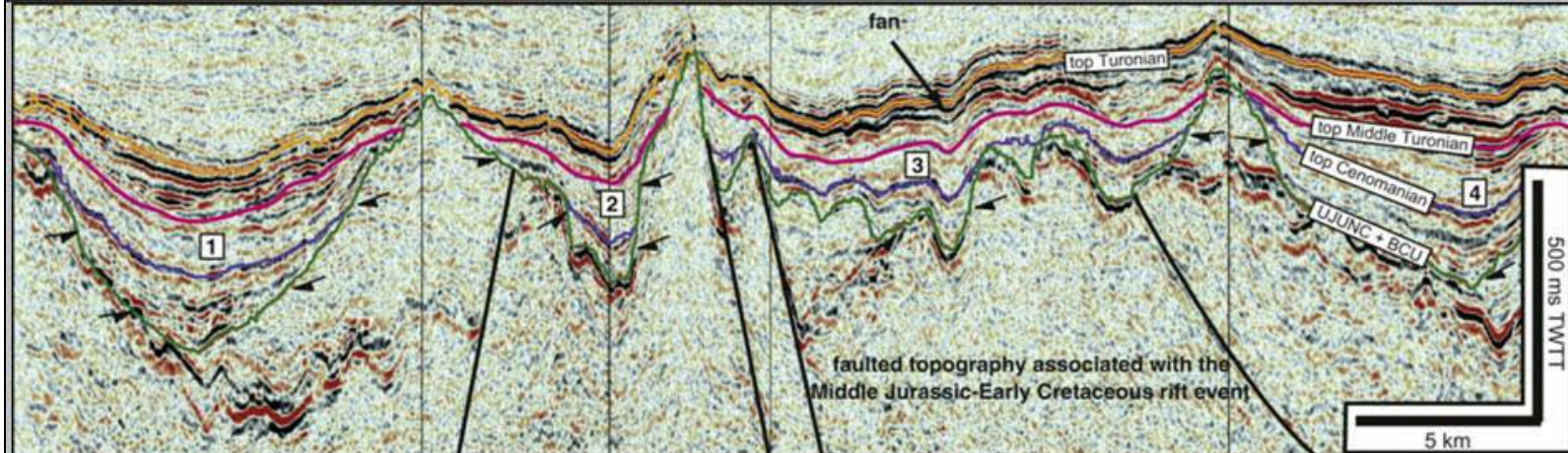
Estimating catchment extent



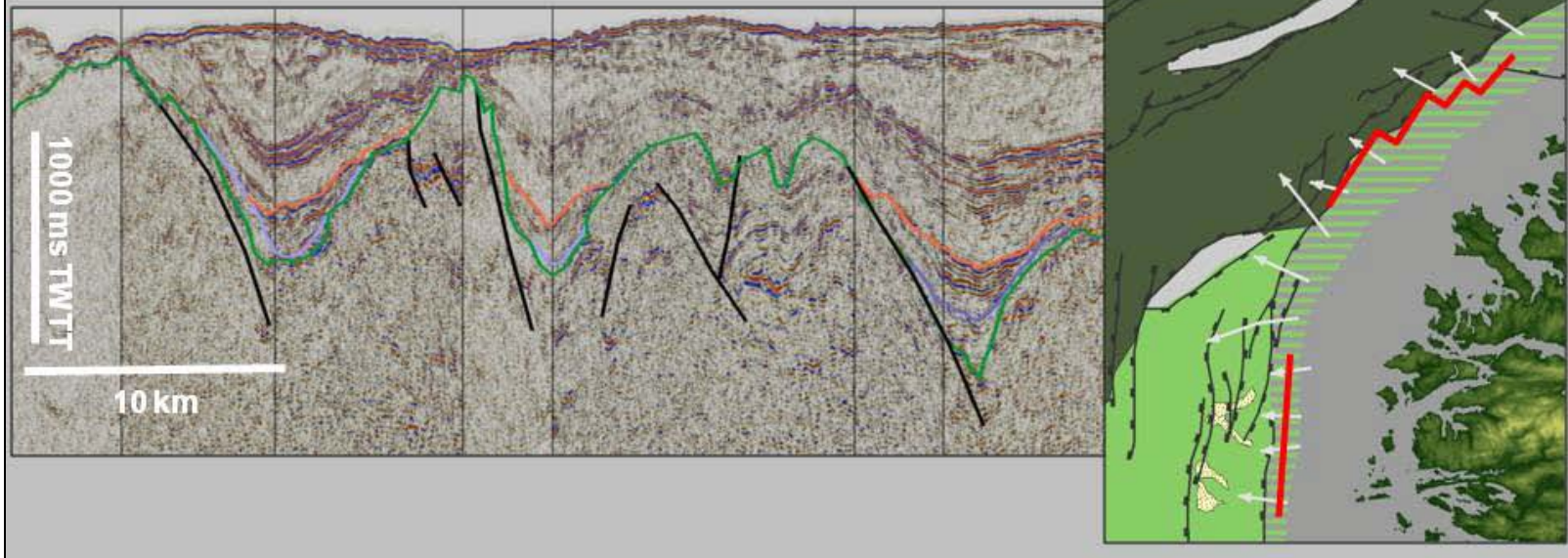
Notes by Presenter (for previous slide):

- Drawn the Min, Best Fit and Max on map.
- If we look at map from the MTFC, we see that the best-fit estimate is just inland of the innermost fault in the MTFC.
- If we go to the Måløy slope, the best-fit line is just inland of the innermost major fault.
- Our best interpretation is therefore that this reactivation event was regional in that it reactivated several faults.
- It was probably not caused by local reactivation of individual fault blocks.

Structural control on outlet position



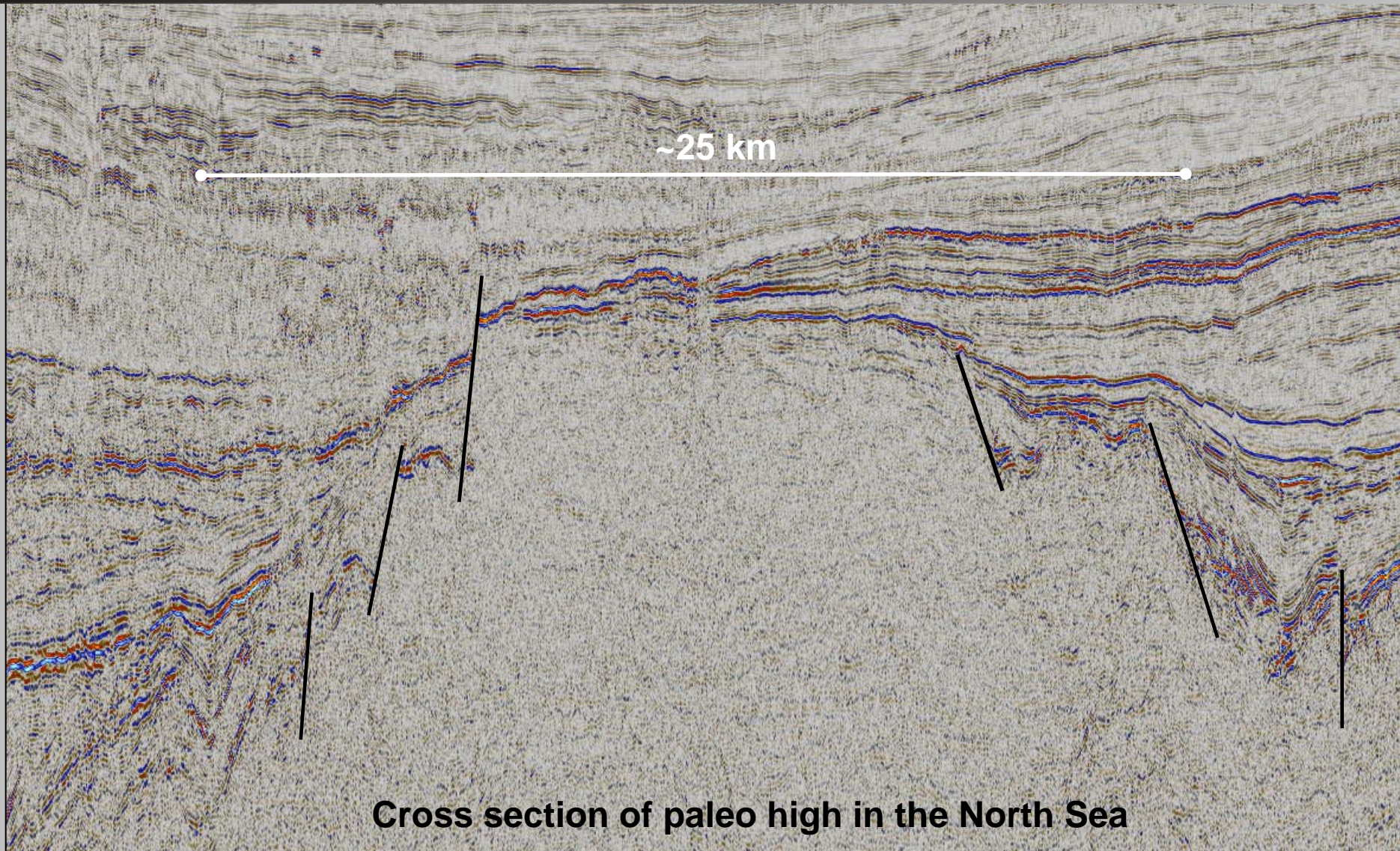
Jackson et al. 2008



Notes by Presenter:

- Two seismic lines showing outlets.
- Most of these channels appears to be controlled by faults.
- Same as in Lake Tanganyika.

Next step: spacing along paleo highs



- How well can we predict outlet spacing along paleo highs?

Notes by Presenter (for previous slide):

- Another approach where we can use this data in an opposite way is where we can constrain the paleotopography.
- This may be the case for smaller fault blocks that acted as uplifted source areas.
- Use the spacing ratio data to make some suggestions of how rivers are spaced along such highs.
- Once we have established such patterns, we can use previously established relationships to get some constraints on the amount of sediment coming out of these rivers.
- And also some constraints on the expected size of the fans.

*Example from Ol'Khon
Island, central Lake
Baikal*

120 km

15-25 km



Notes by Presenter (for previous slide):

- Use modern analogues to investigate drainage along highs.
- This example from Lake Baikal has dimensions very comparable to some ancient highs in the North Sea.
- Drainage and river spacing in such modern highs may give some clues and ideas on how we better can understand paleodrainage of subsurface highs...
- ... and locate where sediment is supplied to the basin.

Summary

- The observed relationships appear to be valid for all types of rifts and all types of drainages
- Locally, basement structures control the outlet position. High impact on spacing ratios
- These relationships can be used to constrain paleotopography
- Alternatively, the relationships can be used to constrain sediment input points along paleo highs

