# "Exceptional" Turbidite Systems in High-Latitude and Tectonically Active Settings and the Obsolescence of Ubiquitous Sequence Stratigraphic Models*

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## Abstract

Popular models for the development of deep-sea turbidite systems hypothesize their initiation during falling sea level, when voluminous sand-rich sediment bypasses the continental shelf through incised valleys. Resulting submarine fans are predominated by large erosional canyons and depositional leveed channels on fan surfaces that lap onto the lower continental slope. However, recent studies of turbidite-system development across high-latitude, glacially influenced margins and tectonically active margins show that the timing of initiation, developmental processes, and turbidite architectures can vary from those predicted by such widely used models.

Here, two "exceptional" turbidite systems are compared from the high-latitude, passive Southwest Scotian Slope offshore southeastern Canada and the tectonically active California Borderland. The high-latitude Scotian Slope is sensitive to climatic variability associated with rising sea level during glacial-to-interglacial transitions and, as a result, received voluminous coarse-grained sediment from subglacial outwash. Large subglacial pulses of sediment contemporaneously carved out a line of shelf-indenting canyons, which transition to straight, wide, and flat-based channels that coalesce near the base of slope. These contemporaneous canyons and channels provided sediment to submarine fans generally characterized by coarse-grained, braidplain-plain-like turbidite architectures.

Canyon-and-channel activity in the California Borderland is not as sensitive to sea-level fluctuations during glacial cycles. Rather, tectonic activity maintained a relatively narrow shelf, which facilitated canyon-head incision across the shelf nearly to the modern

beach. During falling and lowstands of sea level, fluvial systems provided sediment to canyon-head point sources; however, during highstands of sea level, such as at present, littoral cells are important contributors of longshore-drift-transported sediment to canyon-head point sources at narrow segments of the shelf. Turbidite architectures include predominantly erosional slope conduits and sand-rich base of slope fan lobes. Results of this study highlight exceptions to the general "rules" of deep-sea deposition. Furthermore, are such high-latitude and tectonically active margins and their turbidite systems really that "exceptional" in the first place?

## Selected References


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# “Exceptional” turbidite systems in high-latitude and tectonically active settings and the obsolescence of ubiquitous sequence stratigraphic models

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## Introduction

- A key concept of sequence stratigraphy is the interplay between sea level, subsidence, and sediment supply…

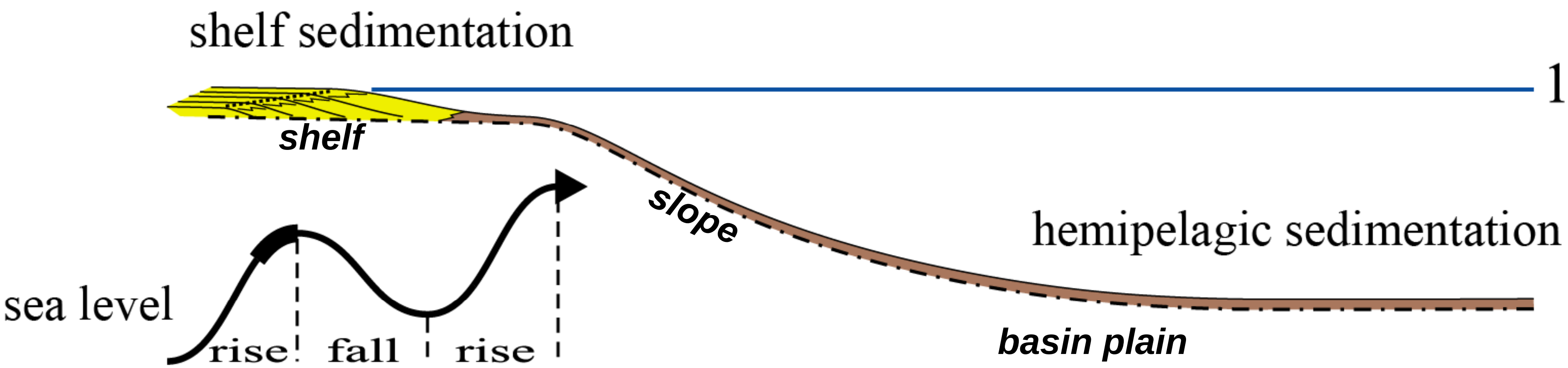
- The generalized models of sequence stratigraphic relationships have demonstrated their usefulness, yet over-application is cautioned.

- There are exceptions in turbidite architectures, whether controlled by tectonic setting or latitude-influenced climate, that generalized sequence stratigraphic models do not predict.

- Ultimately, are these ‘exceptions’ all that exceptional?

**Stratigraphic architecture by varying sea level**

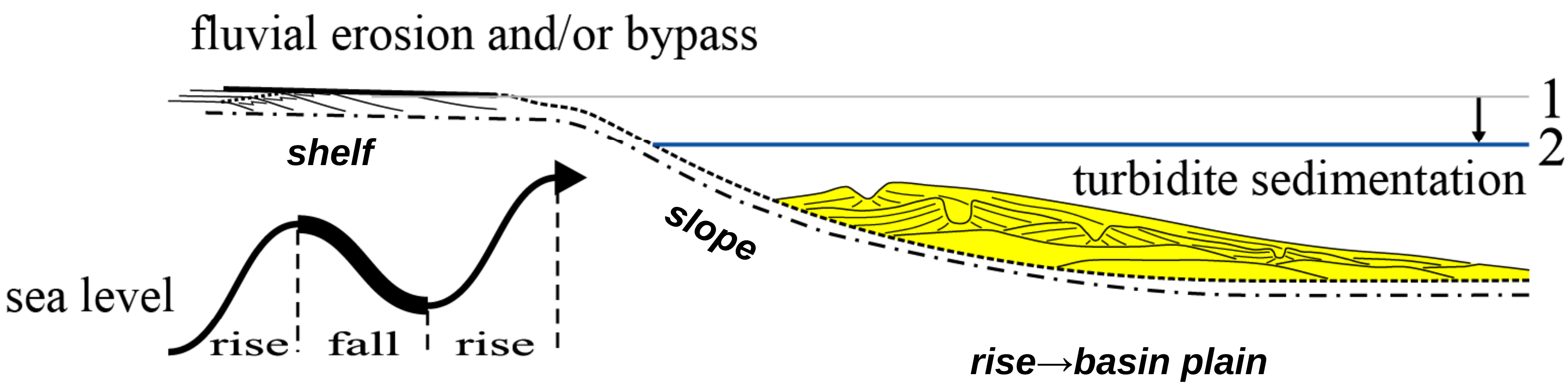
- Sea-level highstand
- Shelf deposits- no deep-water turbidite sedimentation




(Catuneanu, 2002)

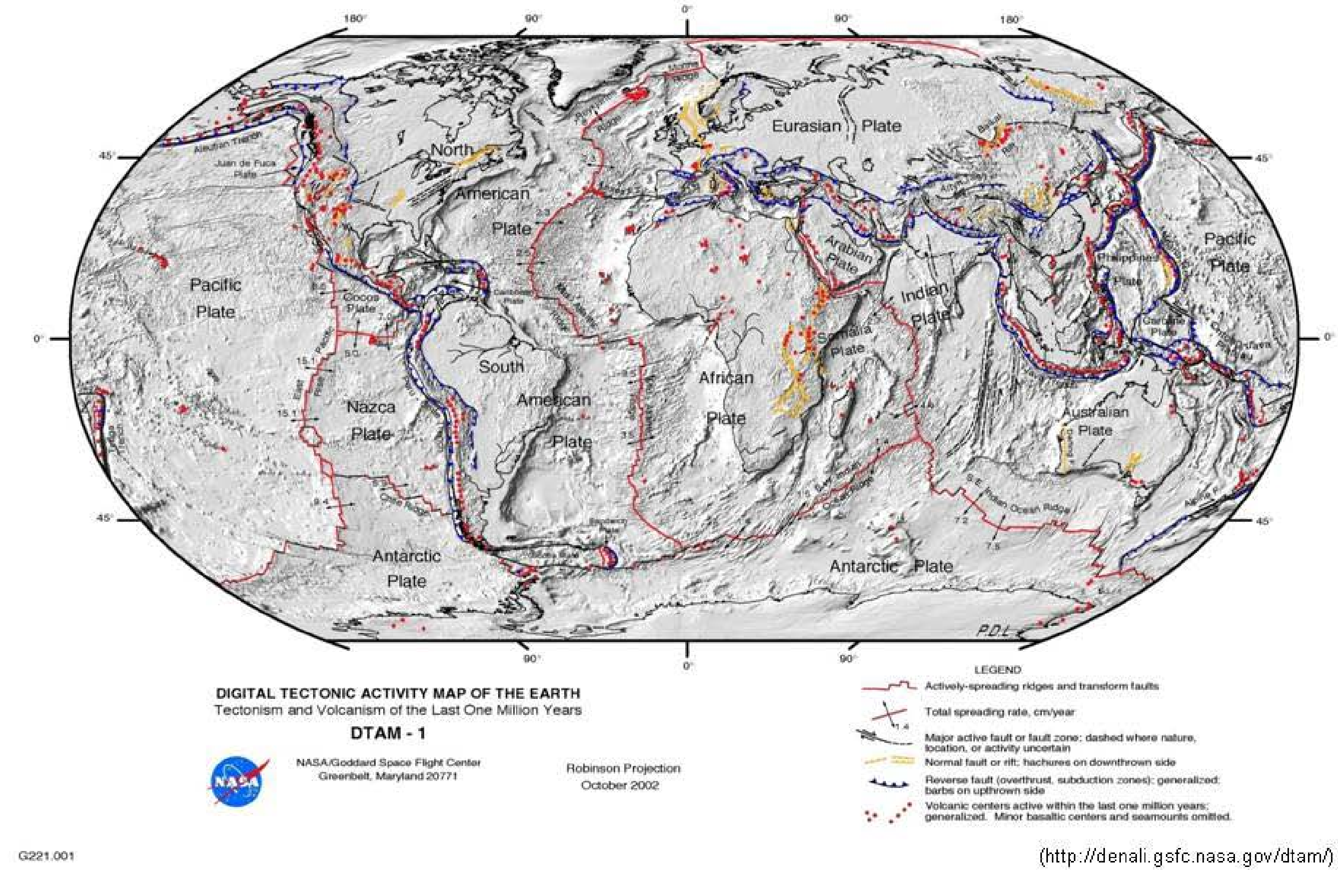
**Stratigraphic architecture by varying sea level**

- Sea-level fall
- "Lowstand fan"



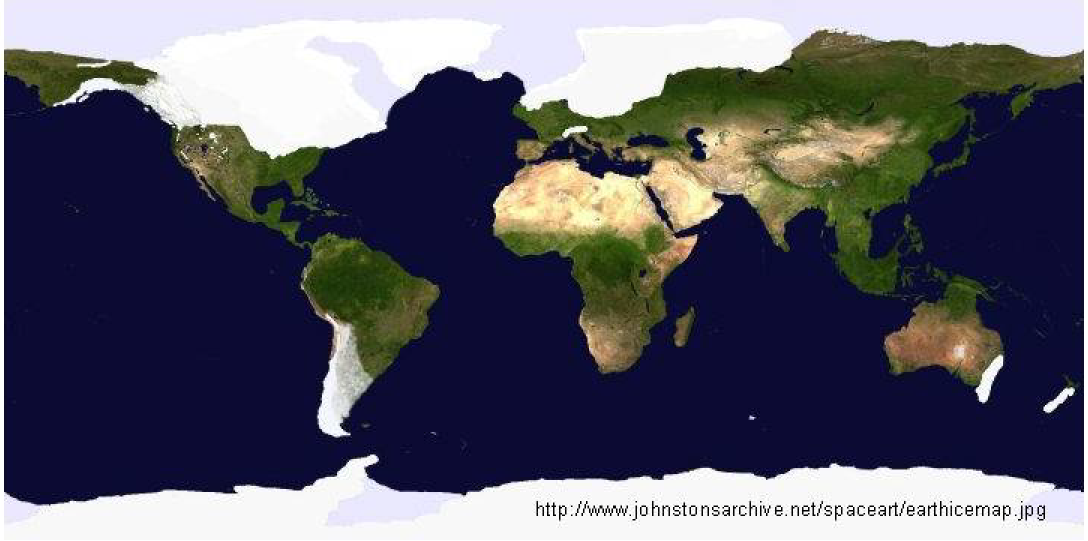

(Catuneanu, 2002)

# Continental margins in active tectonic settings are common…




Notes by Presenter: Many examples of narrow shelves and volcanic centers. Narrow shelves facilitate the transfer of sediment into deep-water. Earthquakes can trigger the movement of significant quantities of sediment, such as the 1929 Grand Banks EQ. This current travelled at a velocity that peaked at more than 19 m s−1 and deposited **> 150 km3** of sediment on the Sohm Abyssal Plain. Focus on California Boderlands.

**Additionally, throughout Earth's history significant areas of continental margin have been influenced by climate…**

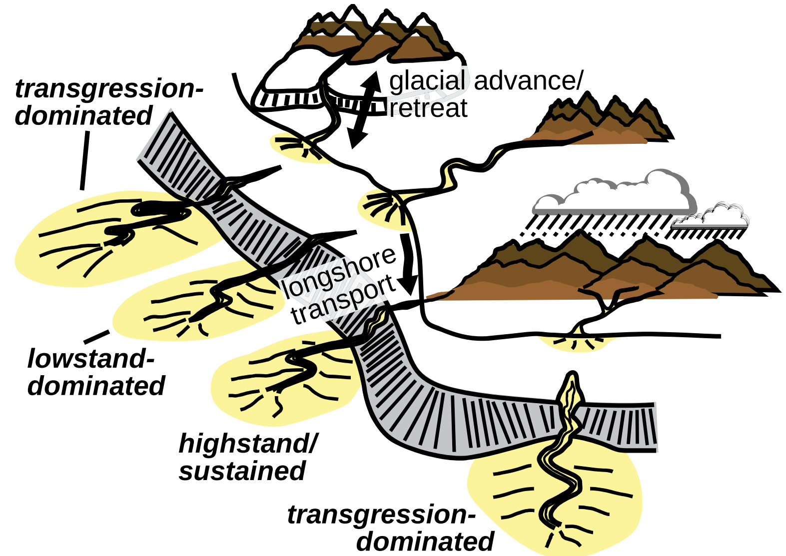



- Ice cover in mid- and high-latitude regions during the last glacial maximum.
- Numerous episodes of ice-related outburst floods, during sea level rise, have been recorded.

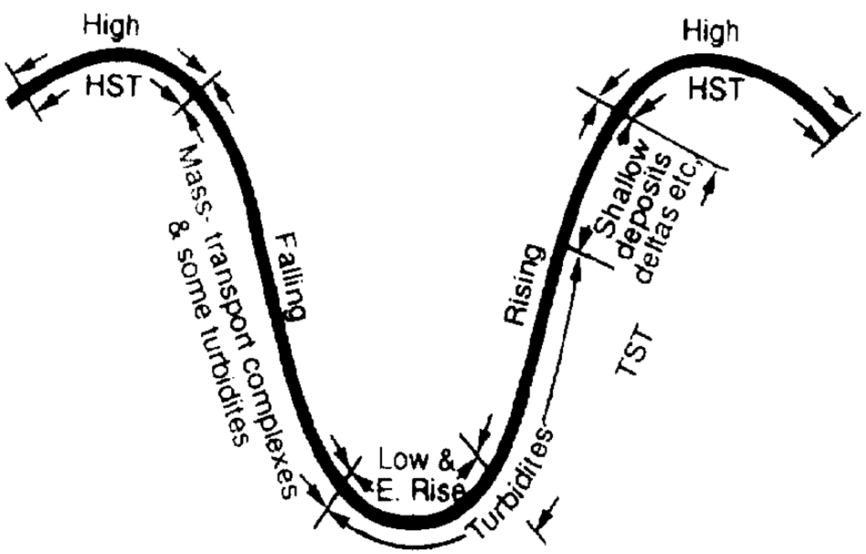
Notes by Presenter: Missoula Floods and the Astoria Fan (~15 ka). Large volumes of coarse-grained sediment.
Mississippi Fan – Turbidites deposited during SL rise due to meltwater discharge.
Focus on SW Grand Banks Slope.

**Transgression-dominated high-latitude systems**
“Flashy” subglacial meltwater discharge
(e.g., Mississippi; Kolla & Perlmutter, 1993)

**Transgression-dominated lower-latitude systems**
“Flashy” monsoonal pulses
(e.g., Bengal and Indus)

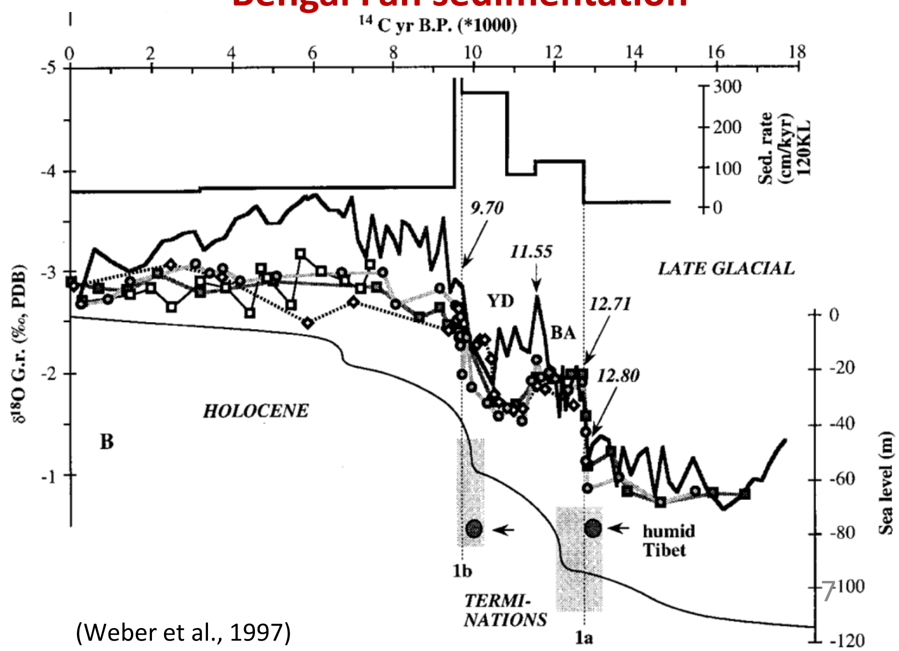



## Mississippi Fan sedimentation



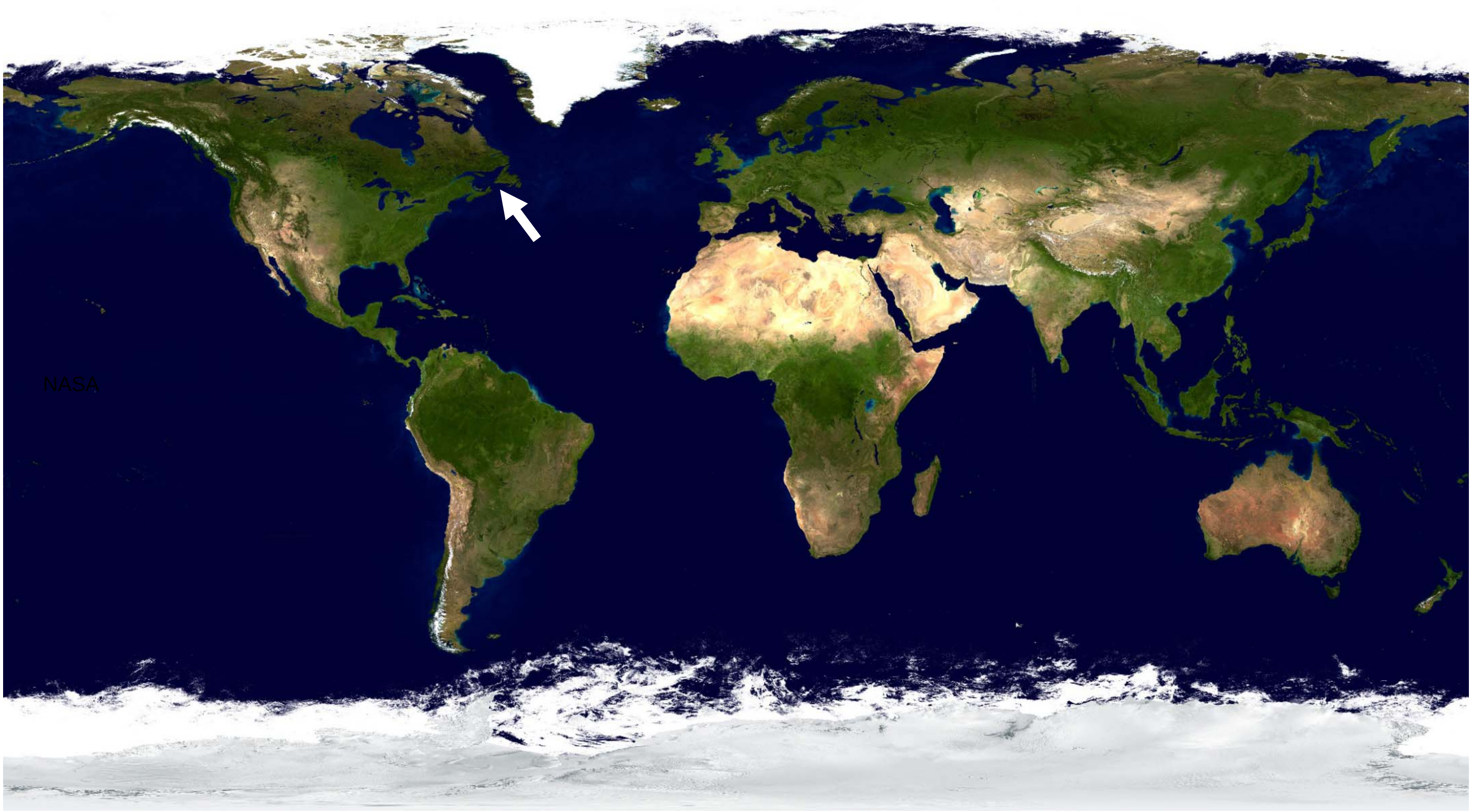

(Kolla & Perlmutter, 1993)

## Bengal Fan sedimentation



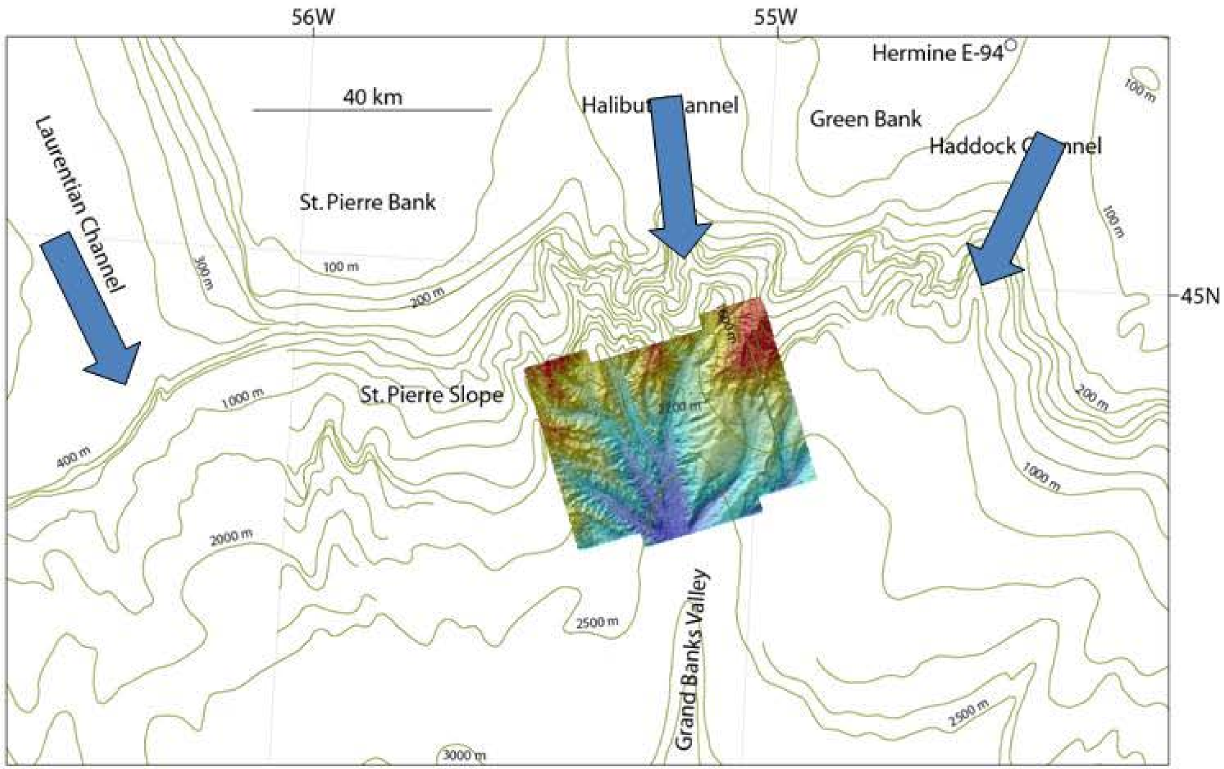

(Weber et al., 1997)

# Southwest Grand Banks Slope



## Ice-influenced margin

- Ice covered the area until ~ 11 ka.
- Numerous episodes of subglacial outburst floods from ice-streams have been previously recognized.

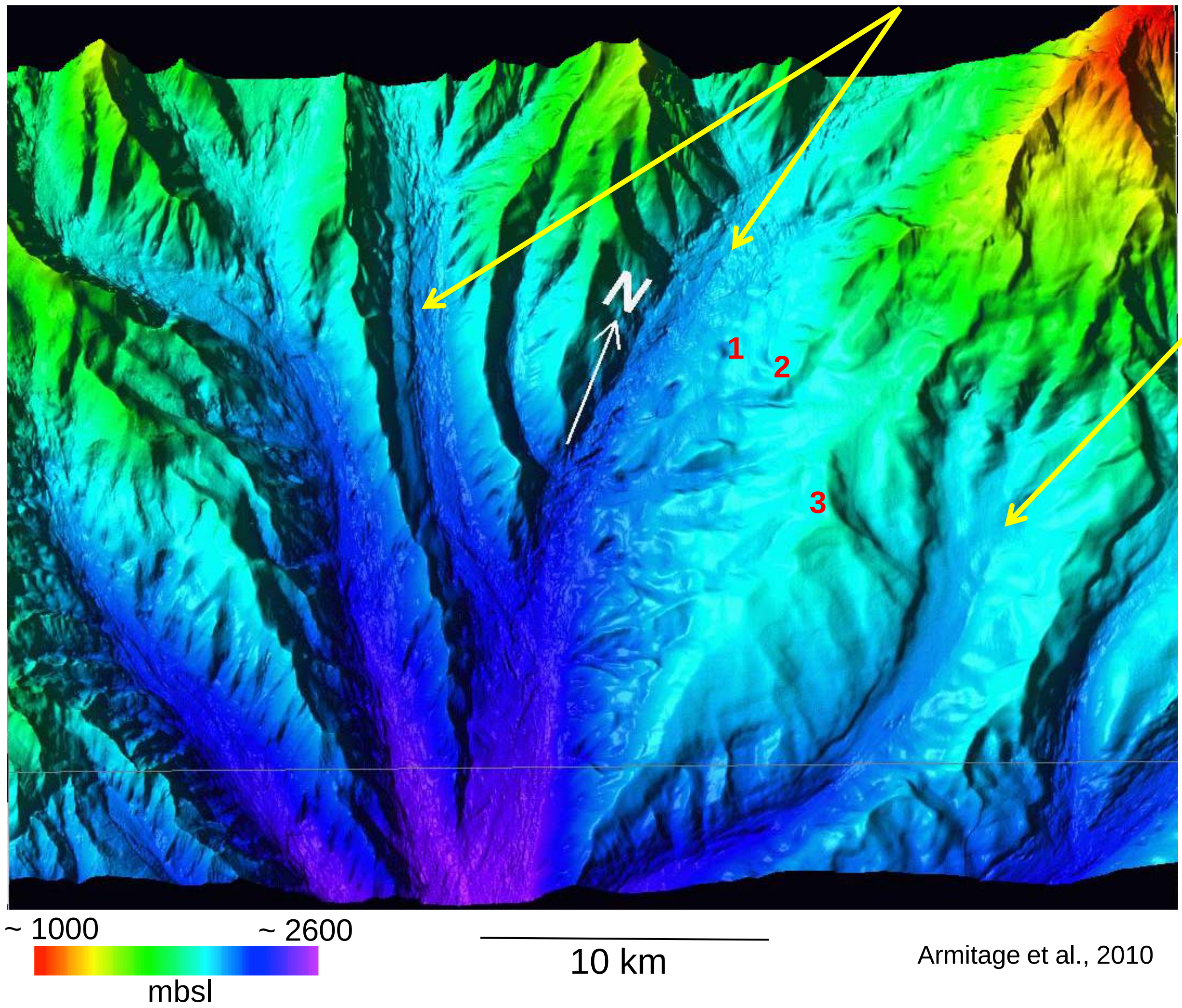



Armitage et al., 2010

Notes by Presenter: Subglacial pulses during rising SL (cf. NAMOC). Storm and EQ related gravity flows.

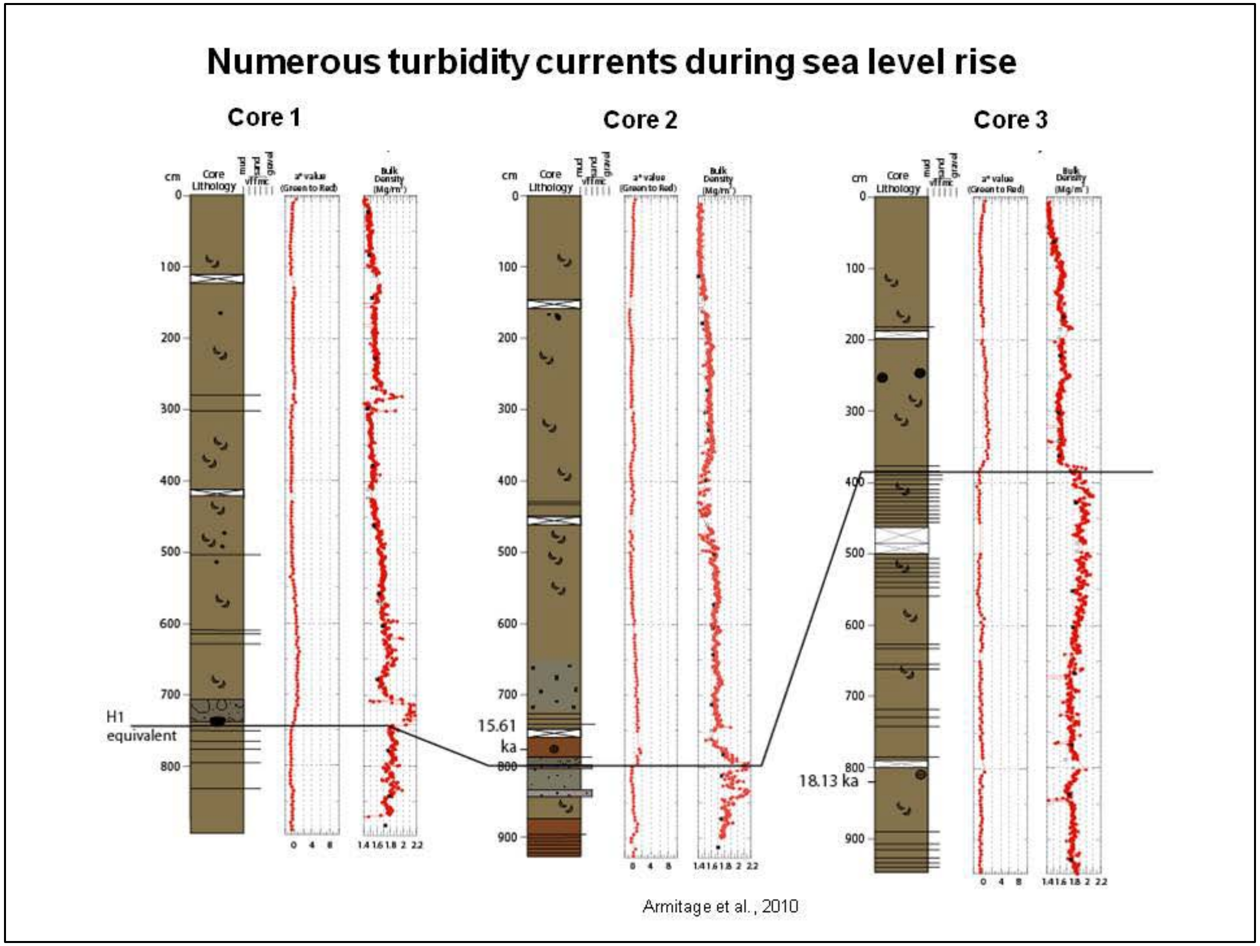
# Canyon Morphologies

Canyons connected to shelf formed by turbidity currents sourced from subglacial outwash




Canyons not connected to the shelf (although erosion is present on its floor)

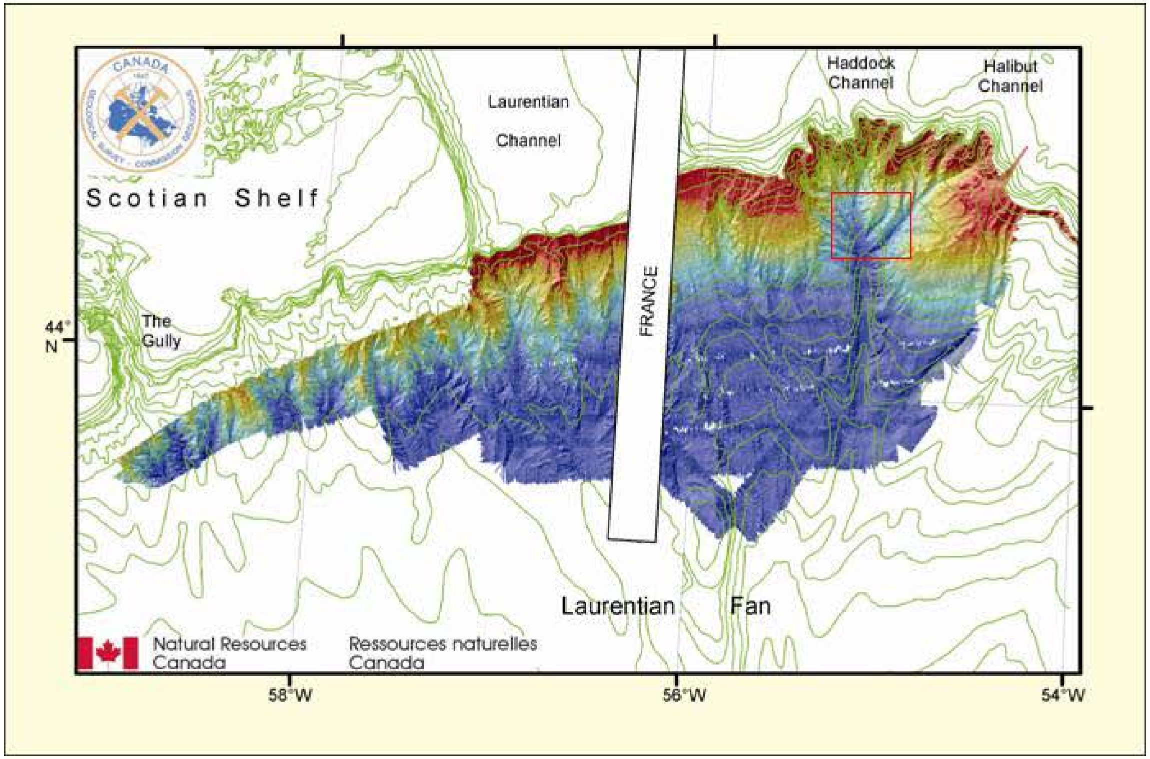
Armitage et al., 2010




Notes by Presenter: Subglacial outburst floods in the late Quat most probably produced the flows responsible for depositing on and spilling over a 400-m-high ridge at least 30 km from shelf break.
E.g., A single outburst flood, during SL rise, deposited an estimated 325 km3 of gravel, sand, and mud on Laurentian Fan.
Peak sediment input is coincident with relative sea level rise, not relative lowstand (due to melting ice).
By comparison, estimates of sediment delivery to the deep sea for the largest non-glacial systems (using modern estimates of sediment discharge and an average event periodicity of 100 years) show that a single outburst event is almost an order of magnitude larger than the estimated volume characterizing, e.g., Amazon Fan.

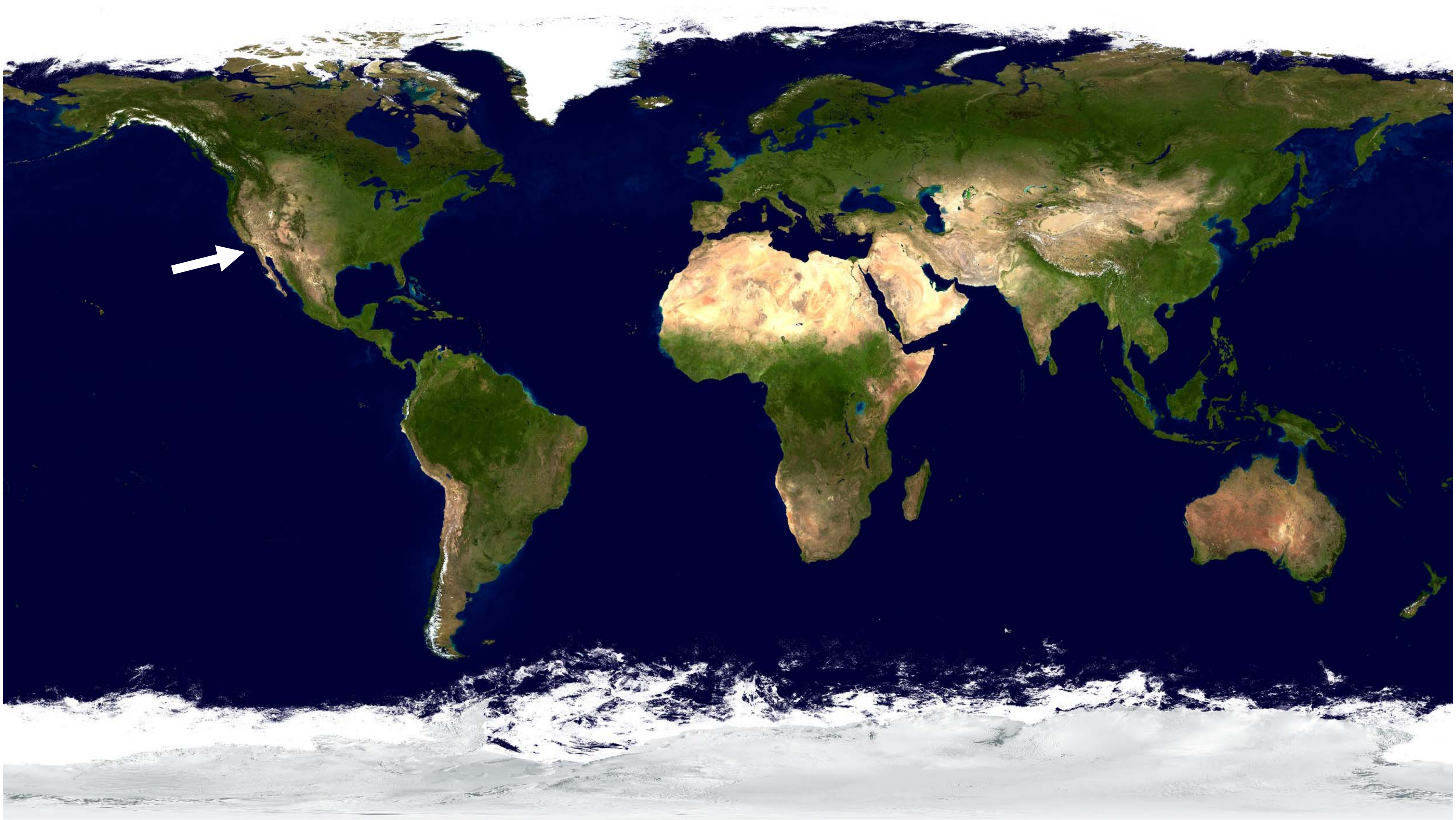
## Margin morphology

- The dendritic pattern of canyons (in this study) develops downslope from the limit of glacial till and are best developed in areas down-flow from ice streams (e.g., Halibut Channel).

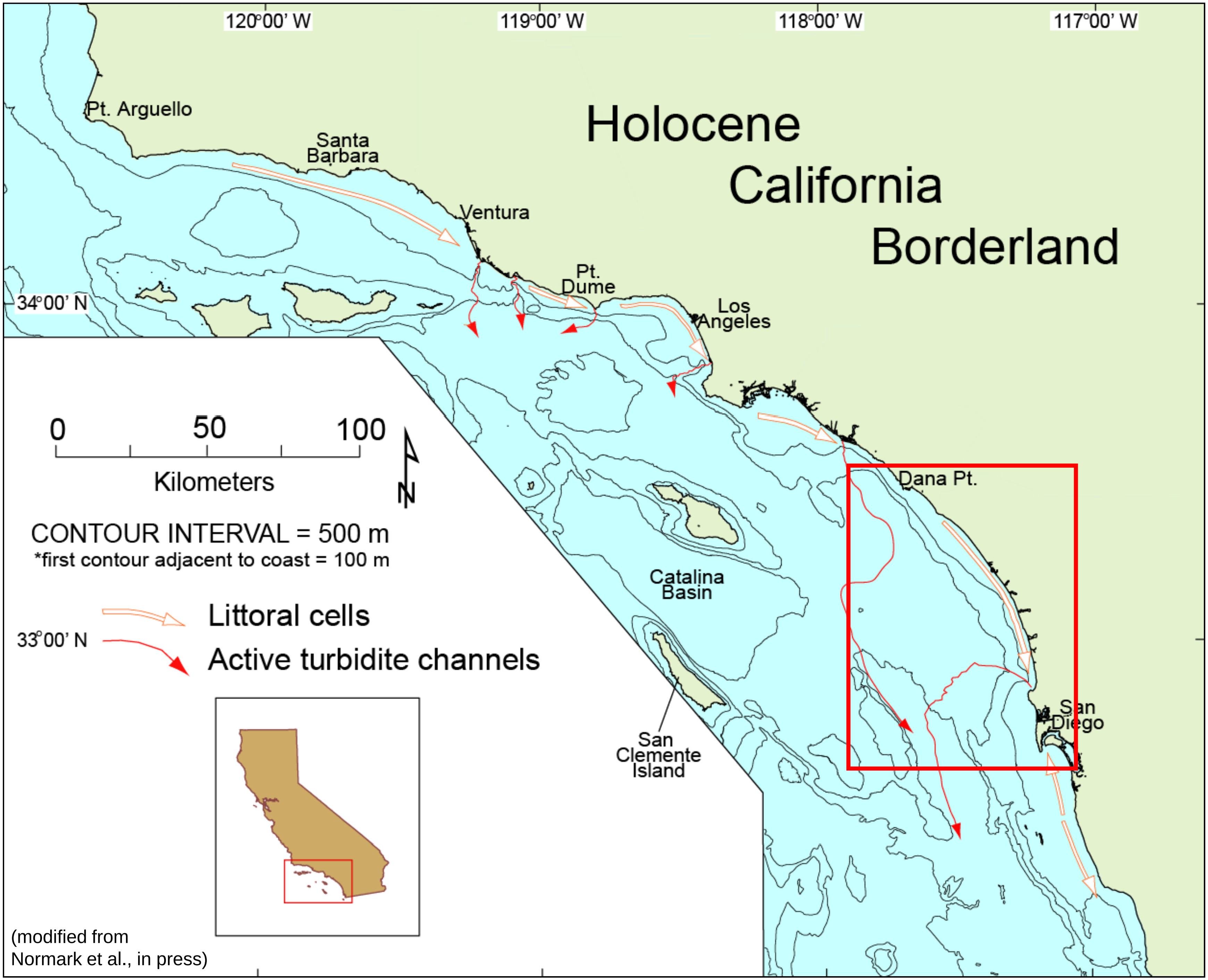



Notes by Presenter: Contemporaneous canyon (and channel) development.

# California Borderland



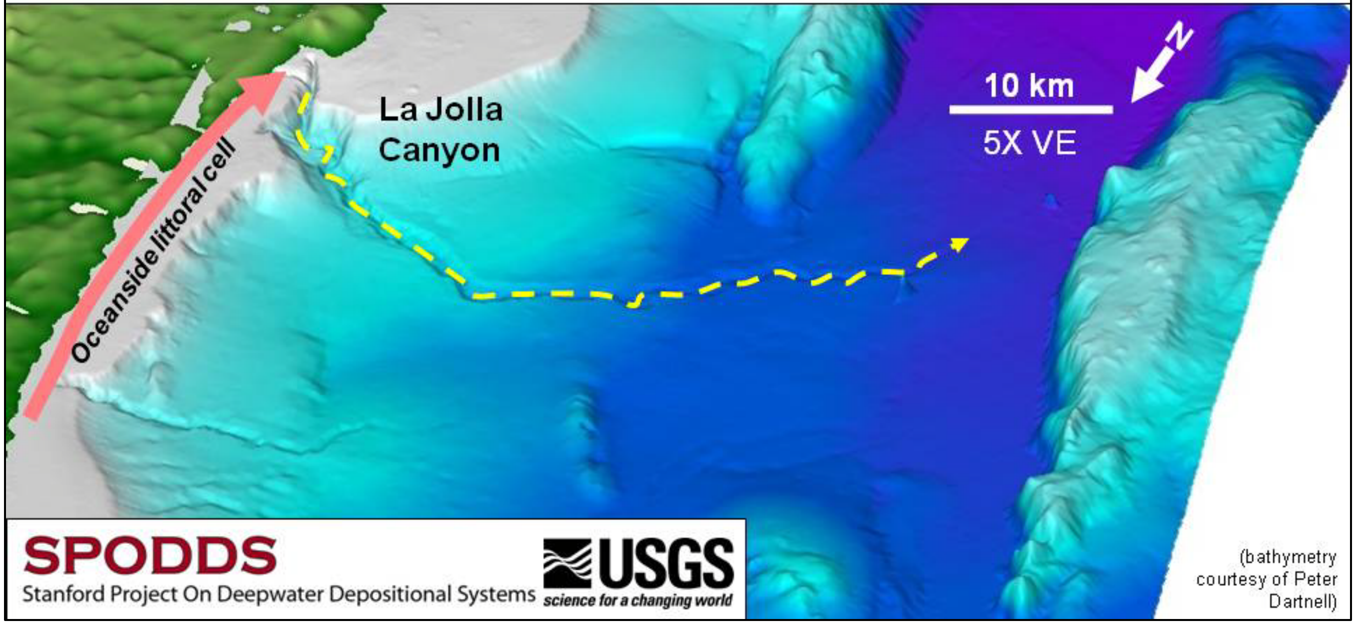
(NASA)



120°00' W
119°00' W
118°00' W
117°00' W
34°00' N
33°00' N
Holocene
California
Borderland
Pt. Arguello
Santa Barbara
Ventura
Pt. Dume
Los Angeles
Dana Pt.
San Diego
Catalina Basin
San Clemente Island
0
50
100
Kilometers
N
CONTOUR INTERVAL = 500 m
*first contour adjacent to coast = 100 m
Littoral cells
Active turbidite channels
(modified from Normark et al., in press)

## Results

- Integrated radiocarbon and seismic-stratigraphic study.
- Relatively voluminous, coarse-grained turbidite deposition occurs during sea-level **highstands**
- Consistent link between subaerial and submarine segments of continental margin and basin plain
- Application: timing of deep-water turbidite deposition in predictive models




SPODDS
Stanford Project On Deepwater Depositional Systems
USGS
science for a changing world

Notes by Presenter: During sea-level fluctuation, shelf width between the canyon head and the littoral zone is the primary control on canyon-channel system activity. Highstand fan deposition occurs when a majority of the sediment within the Oceanside littoral cell is intercepted by one of the canyon heads, currently La Jolla Canyon. Since 40 ka, the sedimentation rate on the La Jolla highstand fan has been >2 times the combined rates on the Oceanside and Carlsbad lowstand fans.

Nearly half of the submarine canyons in the tectonically active California borderland are active at the present sea-level highstand

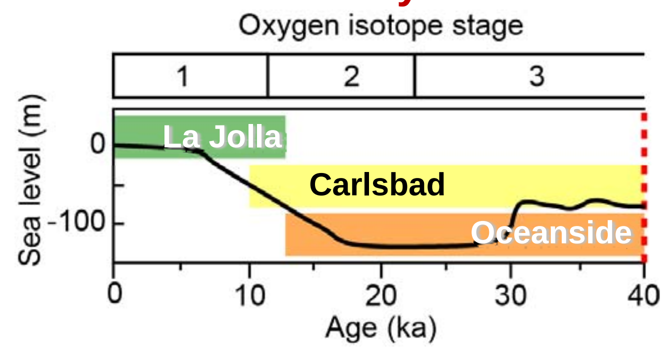
# Deep-sea seismic-chrono-stratigraphy from the CA Borderland

- Relatively voluminous, coarse-grained turbidite deposition occurs during sea-level **highstands**

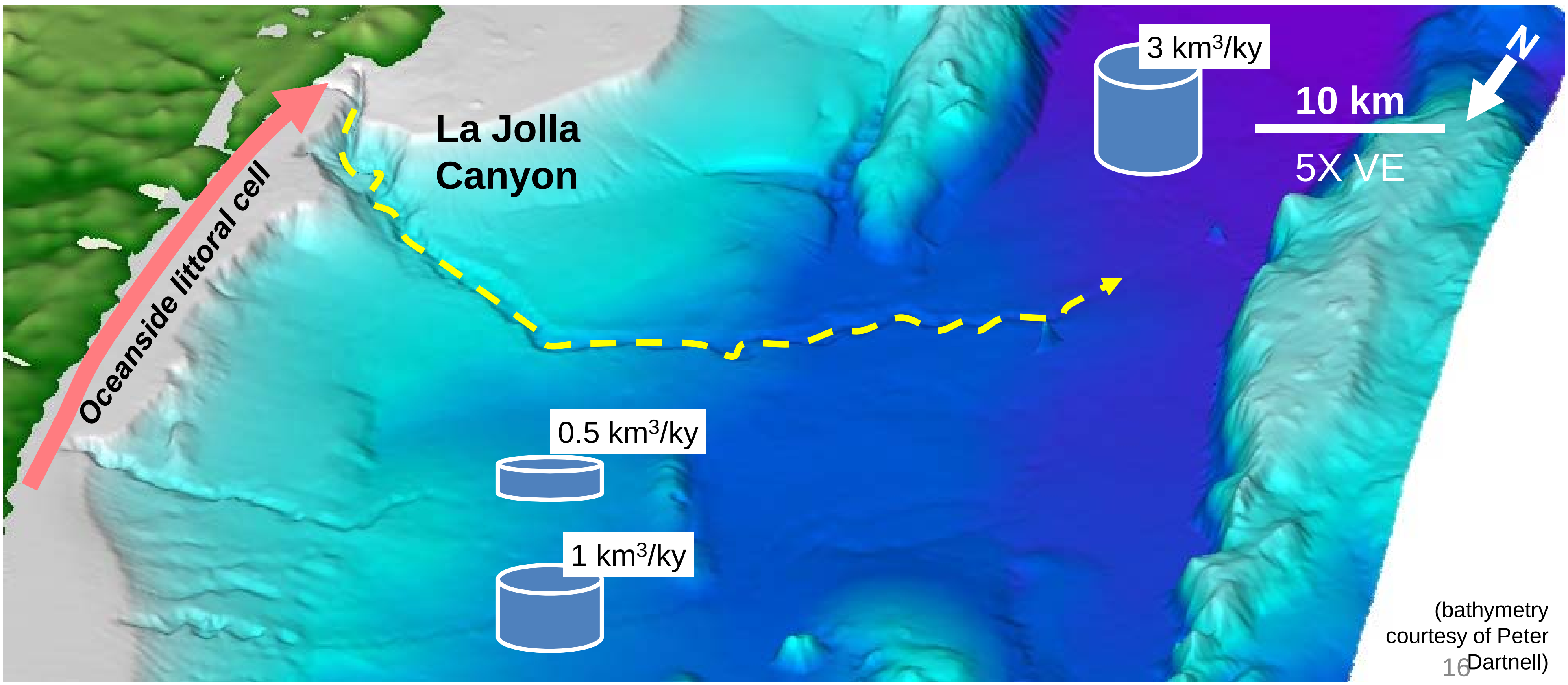
**Sediment volumes**

- La Jolla **highstand** fan (38 km³)
- Carlsbad lowstand fan (12 km³)
- Oceanside lowstand fan (25 km³)

**Duration of activity**

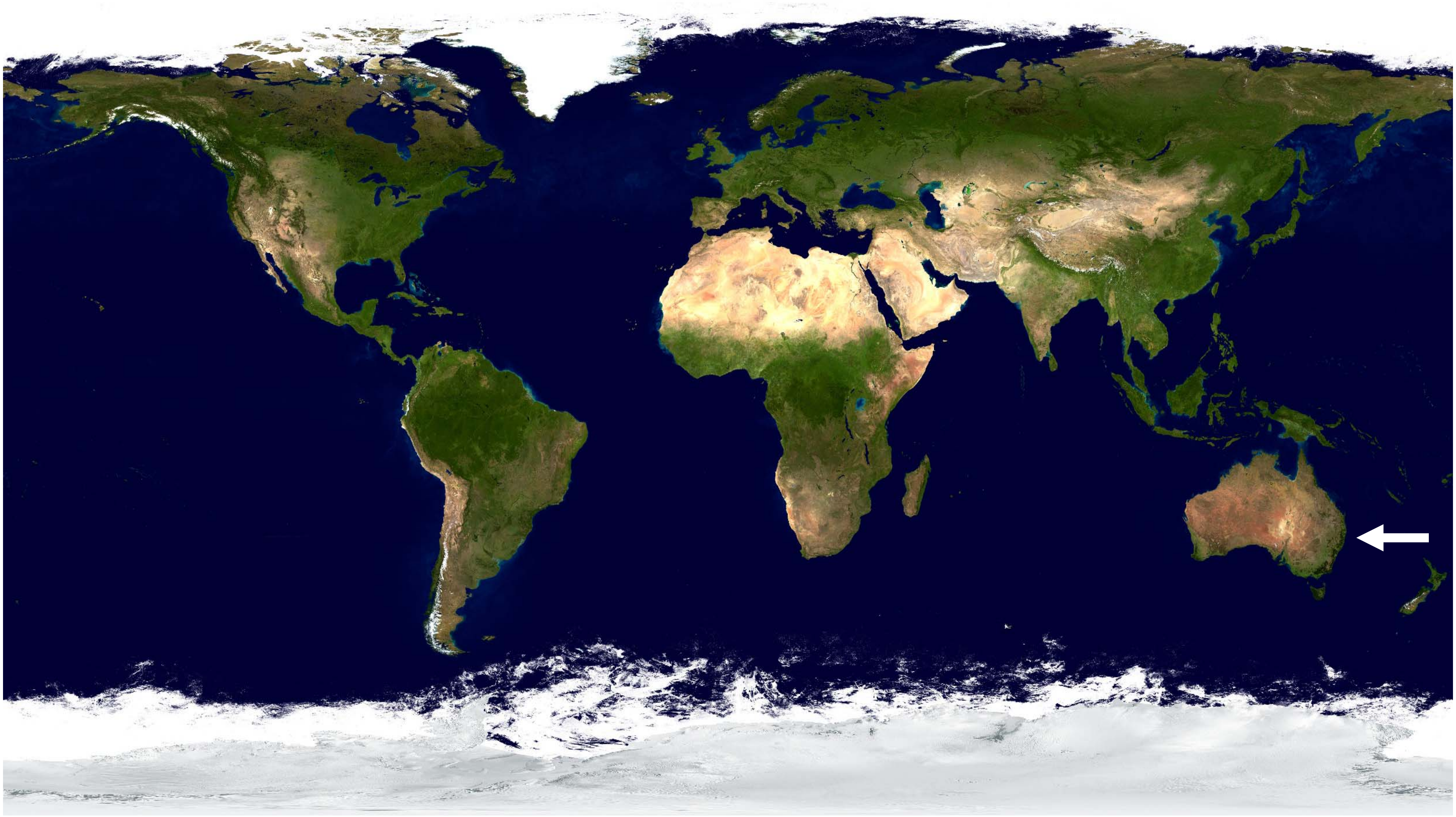



(sea level from Lambeck and Chappell, 2001)



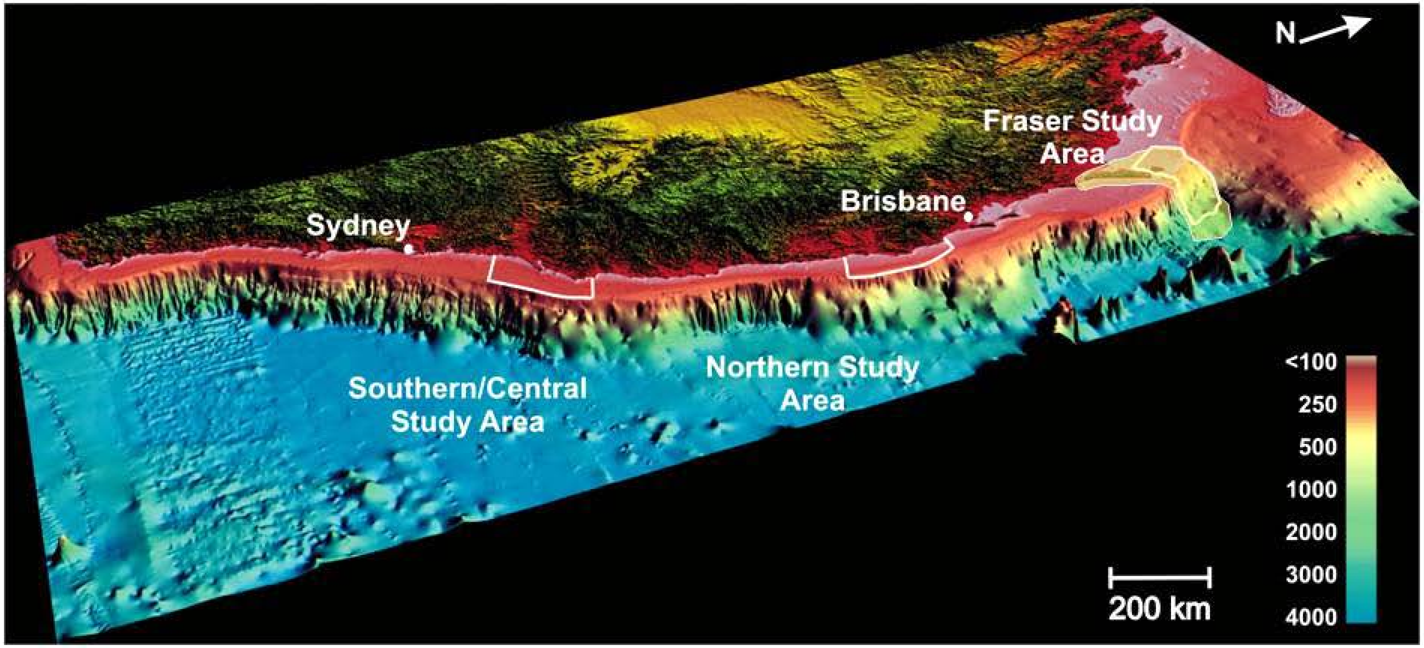

(bathymetry courtesy of Peter Dartnell)

# Eastern Australia



(NASA)

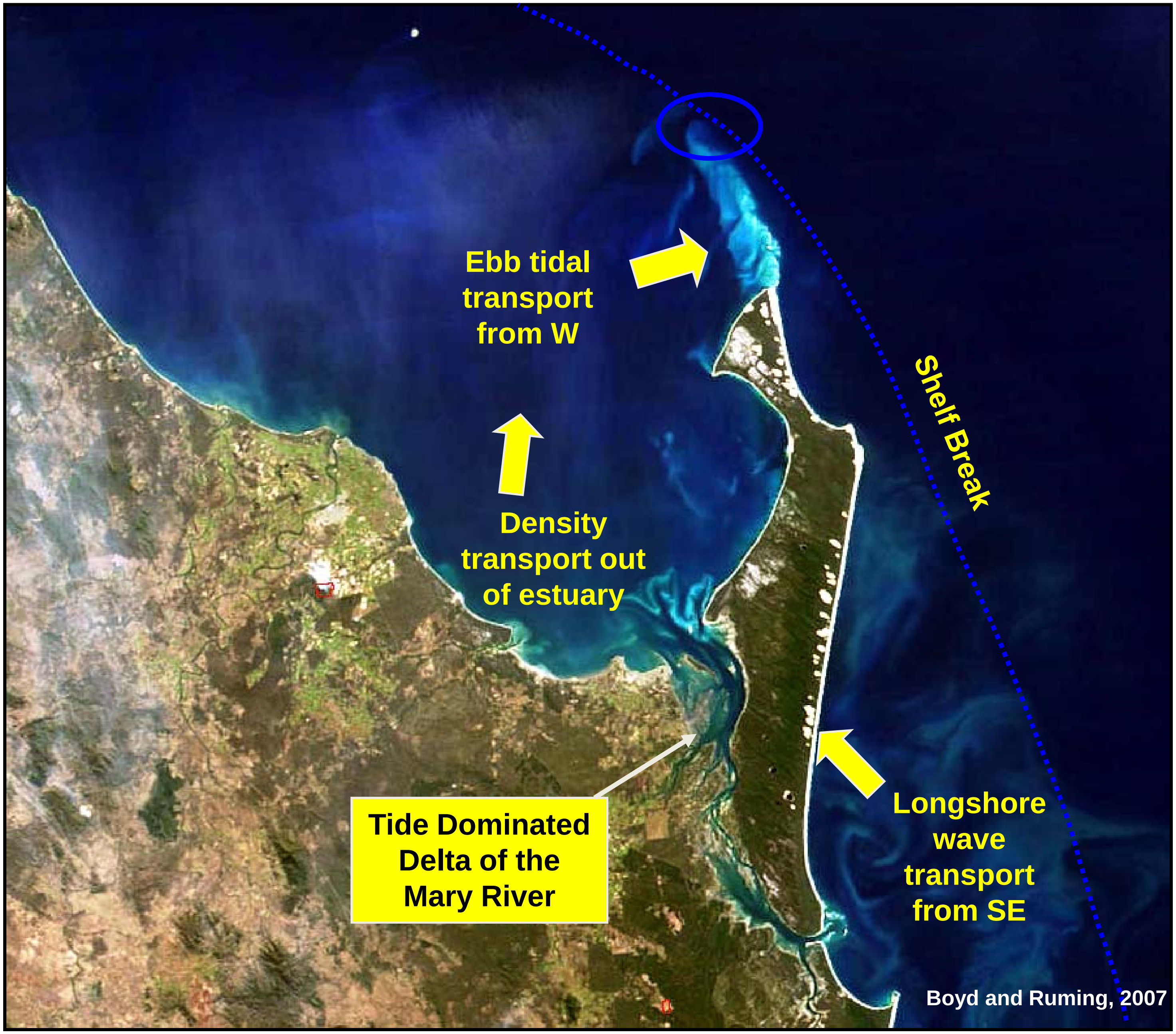
# Highstand fan in Eastern Australia

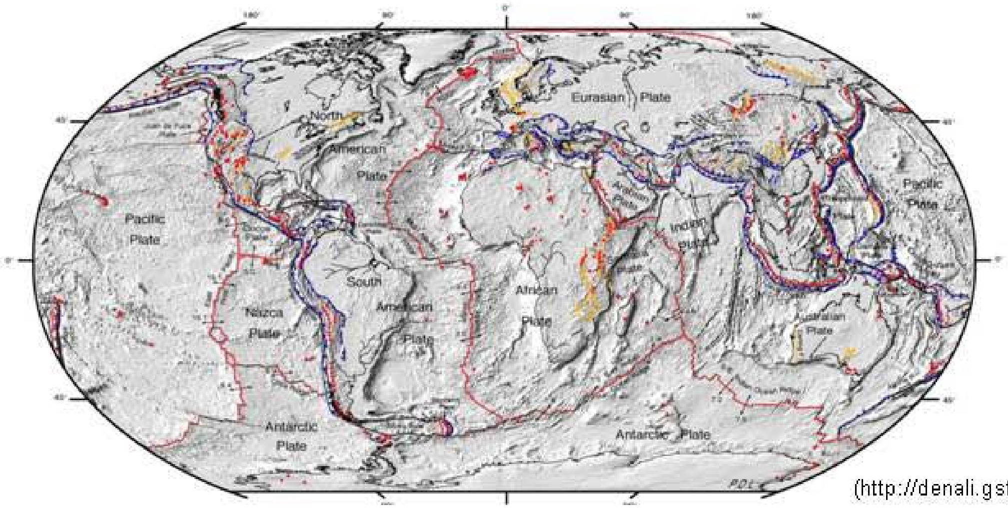


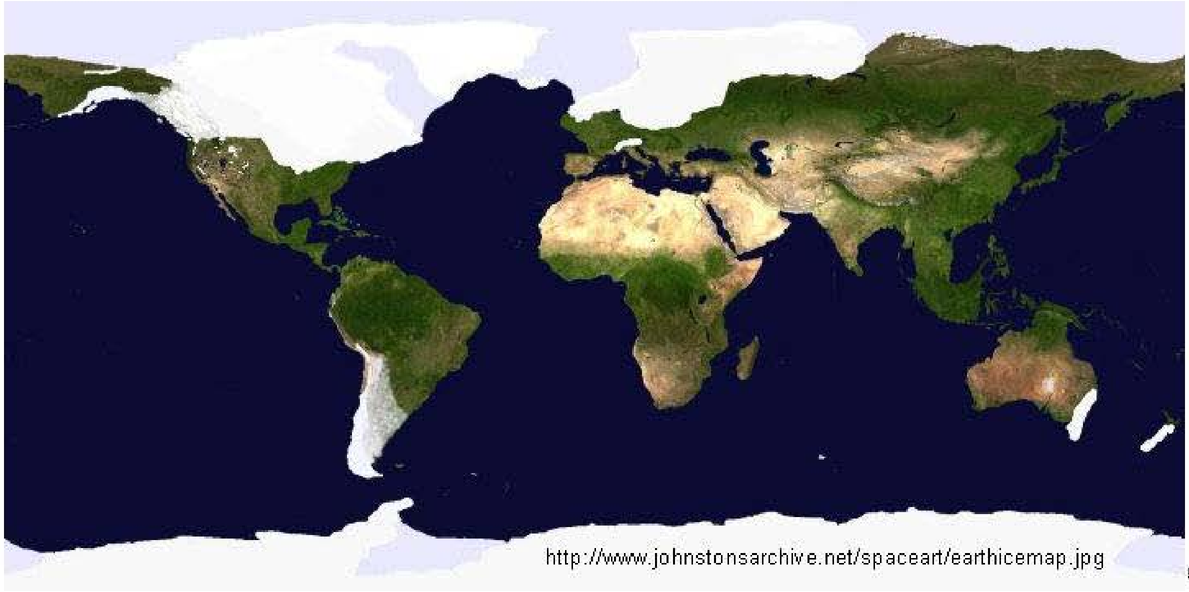

Boyd and Ruming, 2007

Notes by Presenter: Highstand fan example – Australia. 500, 000 cubic m per year of sand transported by longshore drift along strike to a change in margin orientation. Reverse estuarine circulation enhanced by tides provides a mechanism to initiate down slope transport – continued by gravity processes (into the Capricorn Sea Valley and the Tasman Abyssal Plain).

# Controlling Physical Processes






gov/dtam/)

Notes by Presenter: Local tectonic environment and climatic influences can control deep-water .

# Conclusions

- Such ‘exceptions’ are unlikely to be that exceptional.

- Significant volumes of coarse-grained sediment can be delivered to deep-water environments during sea-level rise:
    - This is strongly influenced by external factors such as local climatic and tectonic influences.

- Understanding the paleoclimate and tectonic environment is important when making stratigraphic predictions…