Determining the Age and Recurrence Time of Submarine Landslides: Successes and Challenges

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A major hurdle in establishing methods for probabilistic tsunami hazard analysis is determining the source characteristics of submarine landslides, especially the age of failure and recurrence times. Empirical methods of determining submarine landslide probability rely on the dates of events identified in the geologic record. The occurrence rate of major continental slope landslides appears to be variable and linked to glacial cycles, suggesting that submarine landslide occurrence rates are non-stationary. If this is true, determining the present day (last several thousand years) rate of submarine slope failure over a wide (geologically diverse) region becomes more challenging. Several dating techniques are currently being used and/or evaluated for use in the investigation of the age of submarine landslides along the U.S Atlantic margin and offshore Puerto Rico and the Virgin Islands. Absolute dating techniques including AMS ^{14}C radiocarbon dating and regionally-age calibrated oxygen isotope stratigraphy are used to provide limiting and bracketing ages for identified landslide deposits and failure surfaces. Relative dating methods such as cross-cutting relationships, ice-rafted debris and red clay horizons, and visual seafloor inspection of submarine morphology are being explored in order to provide a rapid means for estimating that age of submarine landslides over large regions. Examples of dating efforts of "modern" submarine landslides from the U.S. Atlantic continental margin (Munson-Nygren-Retriever slide complex, Southern New England, Currituck, and Cape Fear), Puerto Rico and the Virgin Islands, and southern California (Goleta, Palos Verdes) are discussed. Long term evolution of the margin via mass sediment movement is addressed in the context of the age of "ancient" submarine landslides offshore New Jersey and Florida. Ongoing collection and assessment of new geological, geophysical, and geotechnical data from submarine landslides and the re-analysis of previously determined landslide ages are vital to the development of a PTHA framework. That said, while significant progress has been made in dating submarine landslides, we are still restricted in our ability to date multiple events and establish robust recurrence rate estimates.

Determining the Age and Recurrence Time of Submarine Landslides: Successes and Challenges

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Outline

- Landslide Ages and PTHA
- Dating Techniques
  - Absolute
  - Relative
- Landslide Ages & Recurrence Times
  - US Atlantic margin ("modern & ancient")
  - Puerto Rico
  - Southern California
  - Prince William Sound
- Concluding Remarks

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Dating Submarine Landslide & PTHA

- Empirical methods of determining submarine landslide probability rely on the dates of events identified in the geologic record.
- The occurrence rate of major continental slope landslides appears to be variable and linked to glacial cycles (Lee, 2009) – Is there enough data available to validate this conclusion.
- If the above statement is true, then landslide occurrence rates are nonstationary…how do you determine the present day (last several thousand years) rate over a wide region?

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Dating Techniques

- **Absolute Dating**

  Short Time Scales

  - ^{7}Be: 53 days
  - ^{210}Pb: 100 years

  Medium Time Scales

  - AMS ^{14}C: 60,000 years (calibration to ~ 25 ka)

  Long Time Scales

  - Oxygen Isotopes: a really, really long time
  - $^{230}Th/^{231}Pa$: (~ 150 to 200 ka)
  - ^{10}Be: ~1.3 million years

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Absolute Dating

- **Radiocarbon (AMS ^{14}C)**

  - ^{14}C (unstable isotope of C) is found in atmospheric carbon dioxide and in products made from atmospheric carbon dioxide (it takes ~ 400 radiocarbon years for carbon to be exchanged between the atmosphere and ocean)

  - As soon as any carbon drops out of the cycle of biological processes (the organism dies), the ^{14}C atoms begin to decay, with a half-life of 5730 years.

  - The AMS (Accelerator Mass Spectrometry) method allows reliable dating 1.0–0.1 mg or even less of carbon. Because of this, specific foraminifera species, which may have low abundances, can be used.

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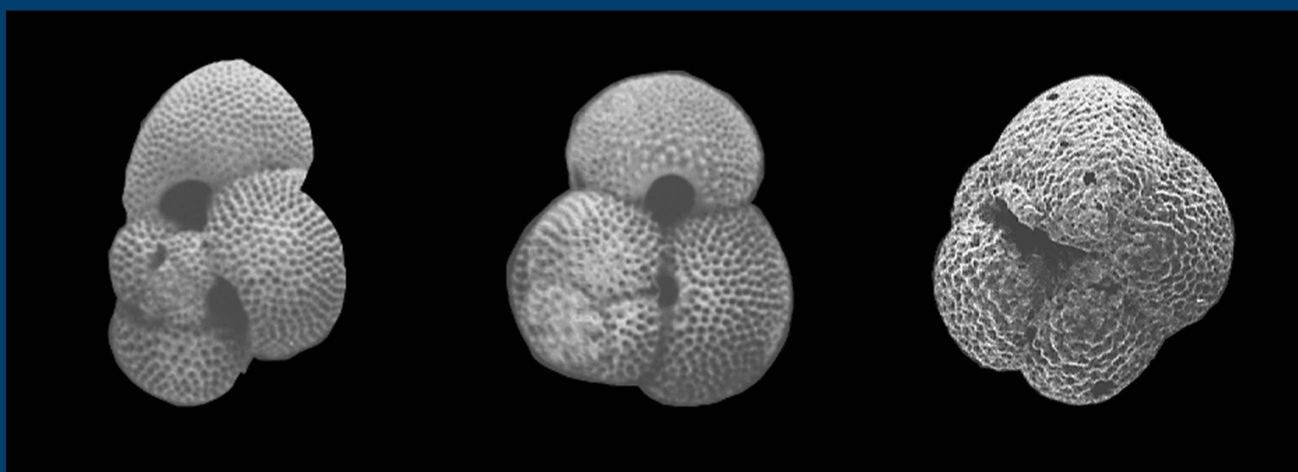
Absolute Dating

- **Radiocarbon (AMS ^{14}C)**

  - Because the specific activity of the ^{14}C in the atmospheric CO_2 has not been constant, ^{14}C dates are corrected using a calibrated dataset (Marine09).



Globigerinoides sacculifer *Globigerinoides ruber* *Neogloboquadrina pachyderma*

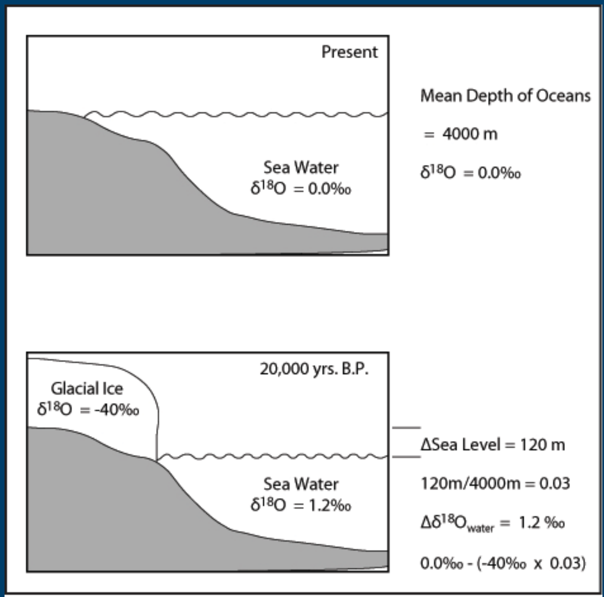
Colus stimpsoni

Absolute Dating

- **Oxygen Isotope Stratigraphy**

  - The $^{18}O/^{16}O$ ratio [$\delta^{18}O$] of calcite (foraminifera, mollusks, etc.) varies as a function of the temperature the mineral precipitated at.

  - Over glacial to inter-glacial timescales, fractionation of O-isotopes associated with the hydrologic cycle causes average $\delta^{18}O$ to vary considerably (^{16}O is preferentially stored in glacial ice).



WRIGHT, 2000

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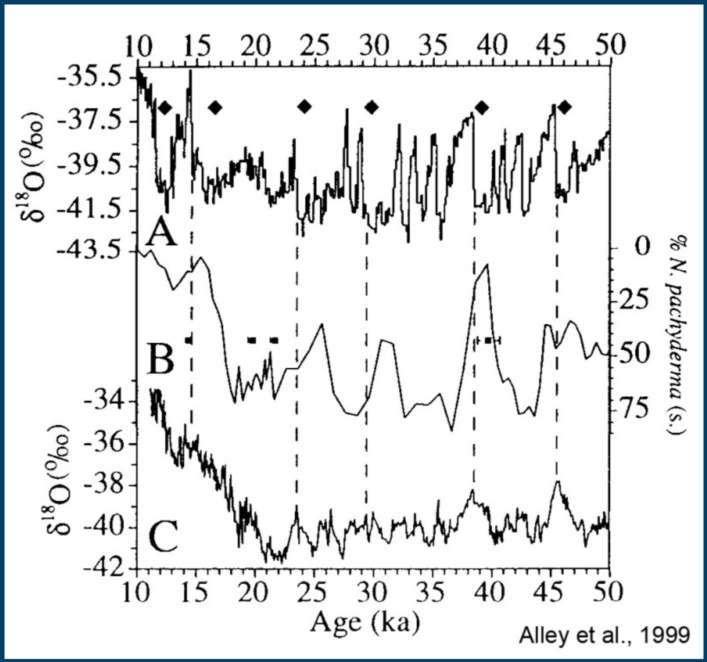
Absolute Dating

- **Oxygen Isotope Stratigraphy**

  - The δ18O stratigraphy of a core can be compared to a regional baseline to date events beyond the radiocarbon dating window.



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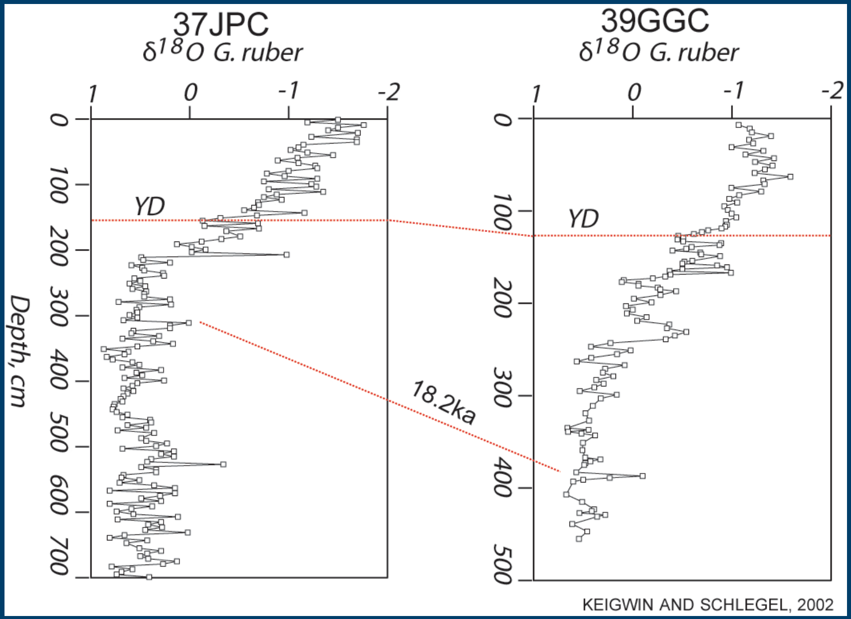
Absolute Dating

- **Oxygen Isotope Stratigraphy**

  - Comparison of $\delta^{18}O$ stratigraphies between nearby cores can be used to identify and date out-of-sequence sediments (i.e., landslide deposits).



Dating Techniques

- **Relative Dating**

  Cross-Cutting Relationships

  - Debris/Scarp, Debris/Channel (Canyon), Channel (Canyon)/Scarp

  Sedimentation

  - Ice-Rafted Debris
  - Red beds
  - Sedimentation Rate
  - Cold/Warm water foram abundance

  Seafloor Texture

  - Scarp morphology
  - Sediment drape

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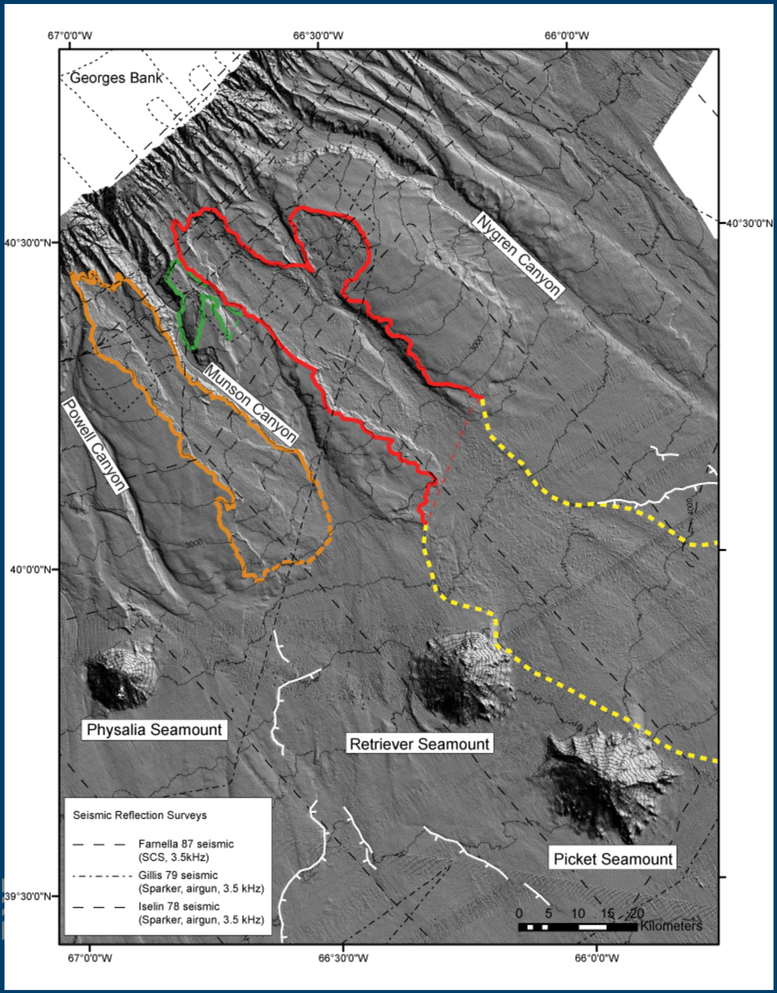
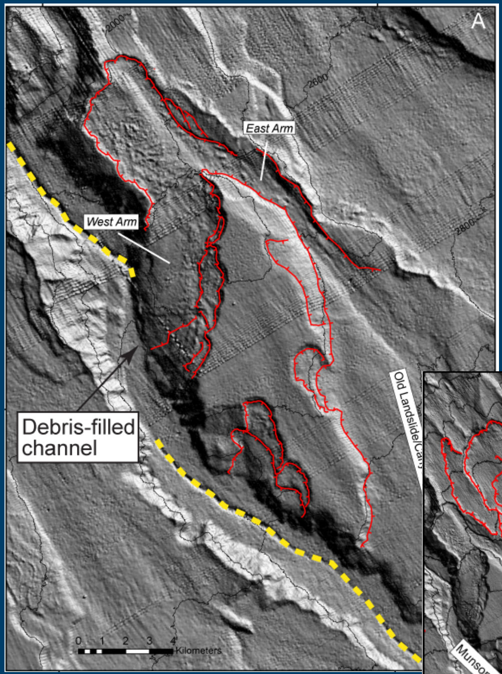
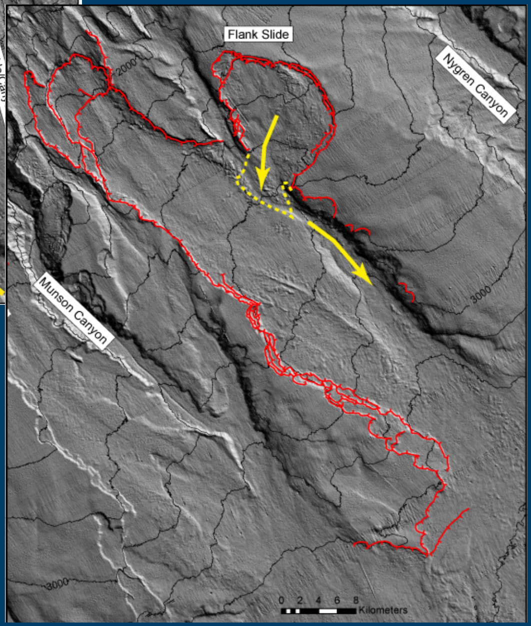
Relative Dating

- **Cross-Cutting Relationships – Scarp/debris & Canyon/ Debris**

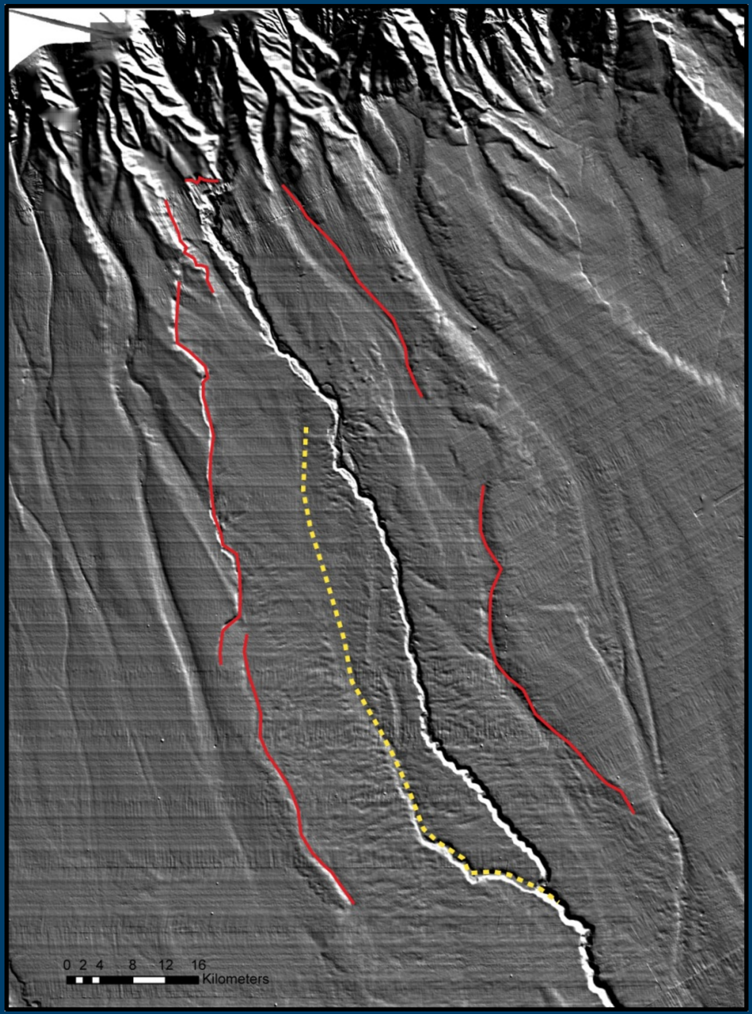






Relative Dating

- **Cross-Cutting Relationships – Canyon/Debris**



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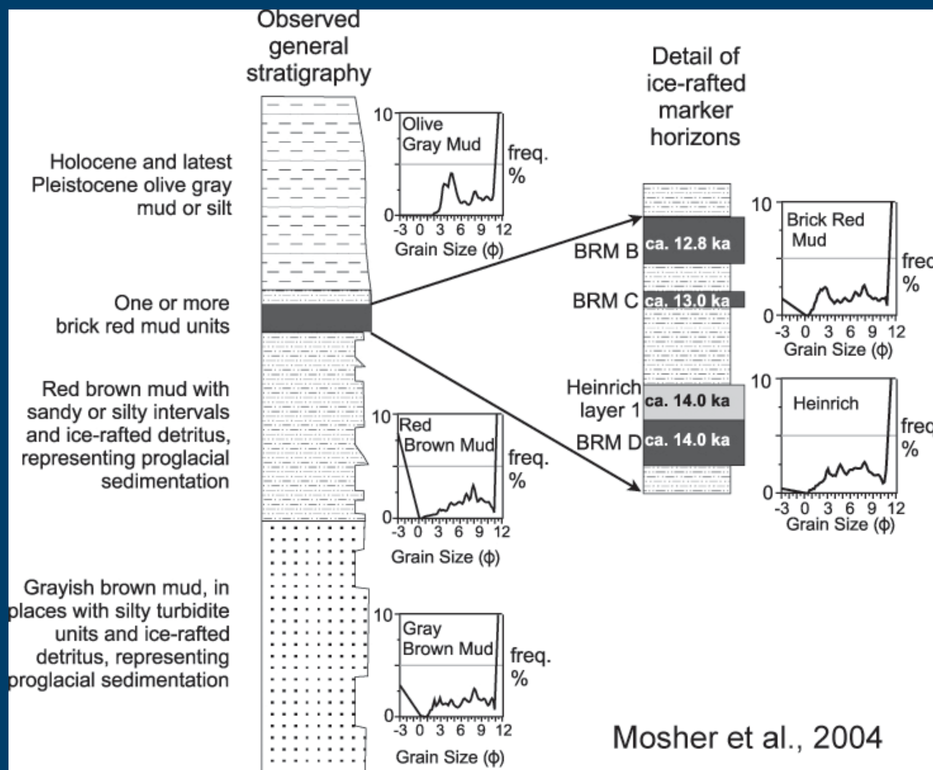
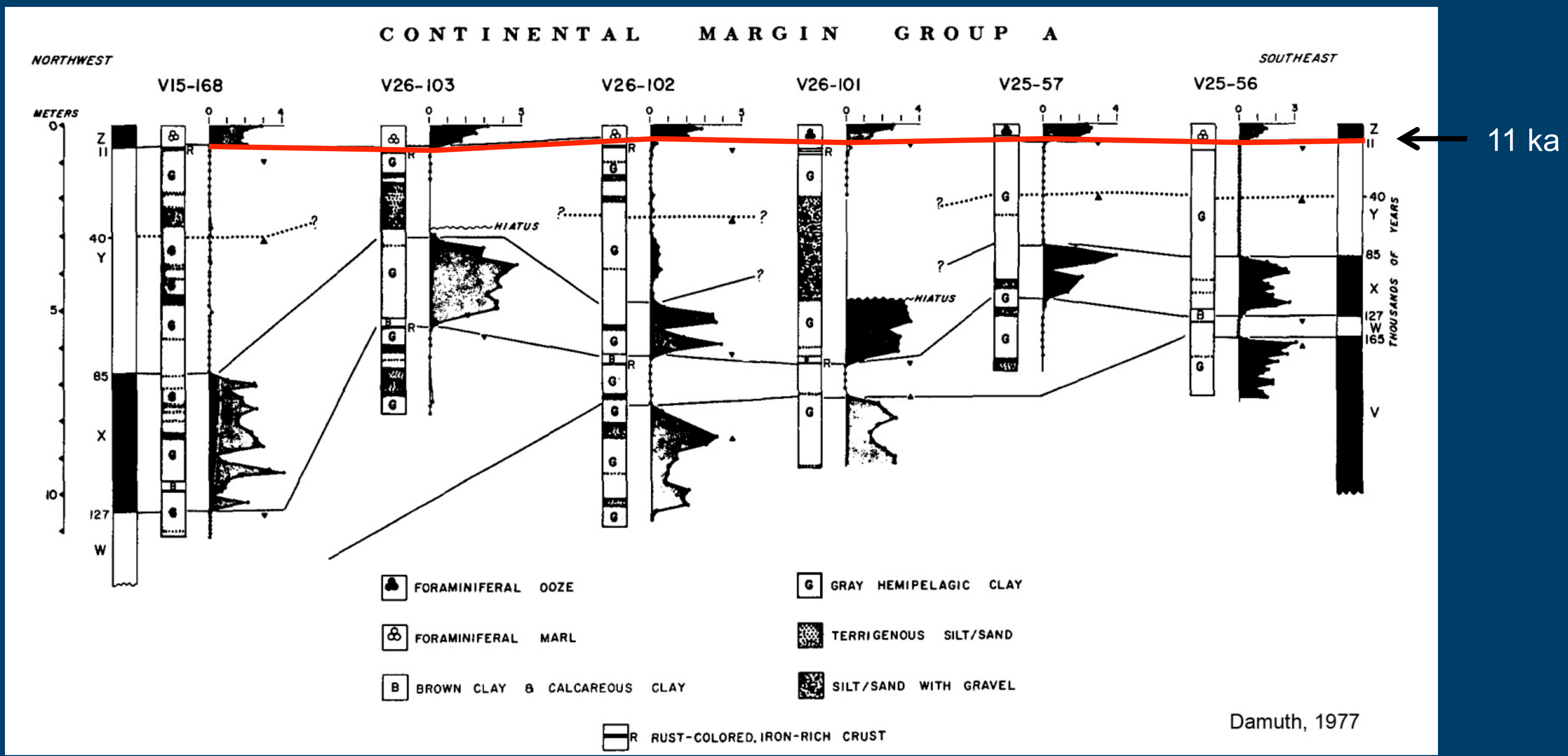
Relative Dating

- **Ice-Rafted Debris/Red-Beds/Foram Abundance**



Relative Dating

- **Foraminifera Abundance**



Globorotalia menardii

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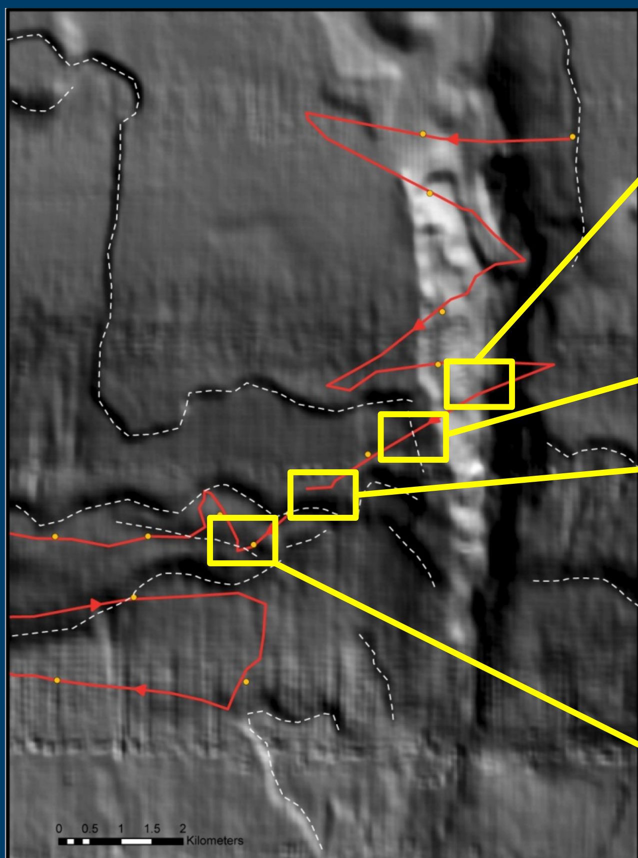
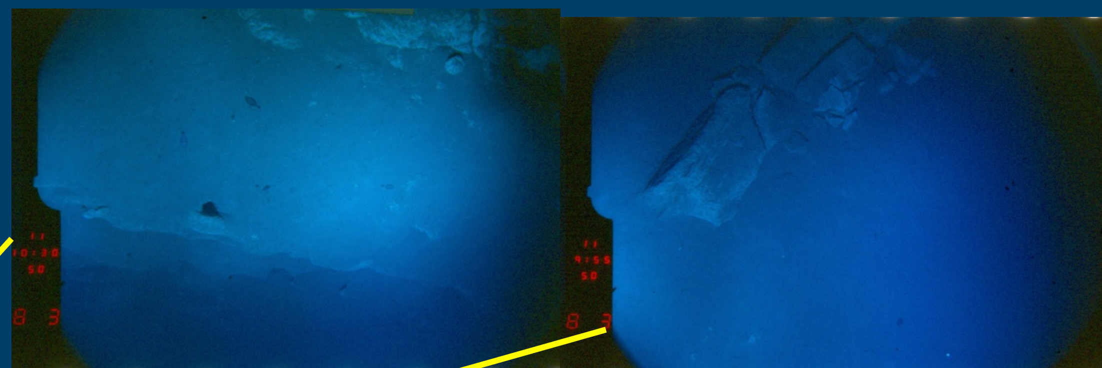
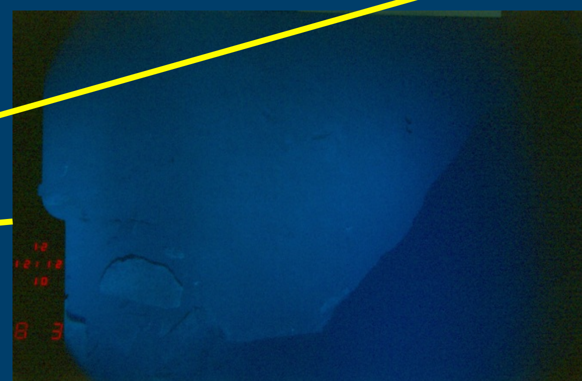
Relative Dating

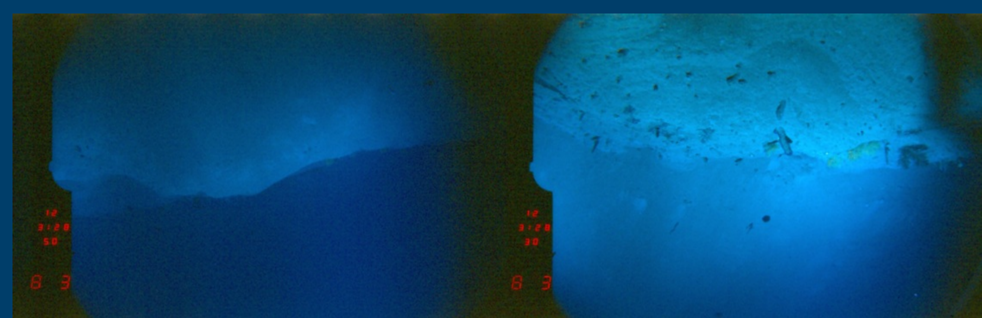
- **Seafloor Texture**







1982 USGS ANGUS camera tows (image width ~ 5-7 m)



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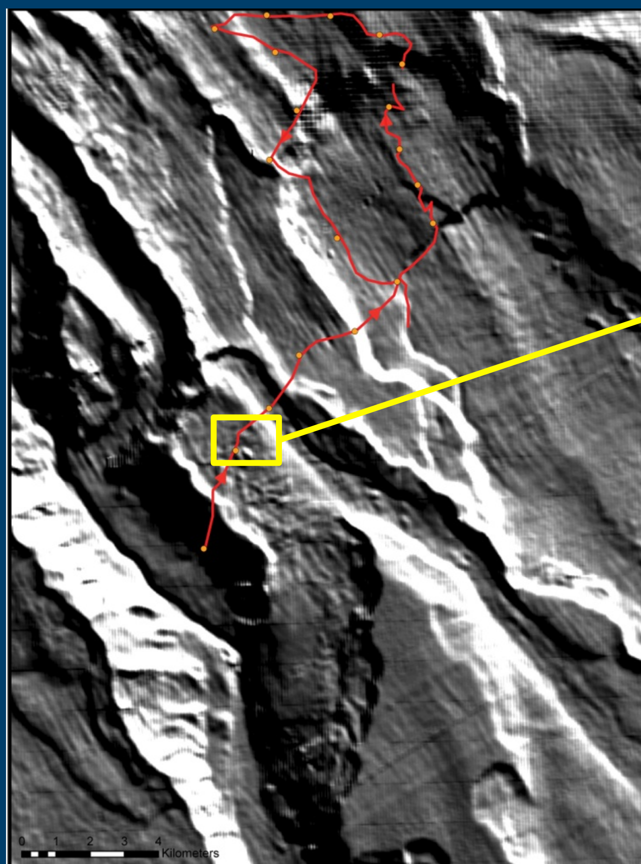
Relative Dating

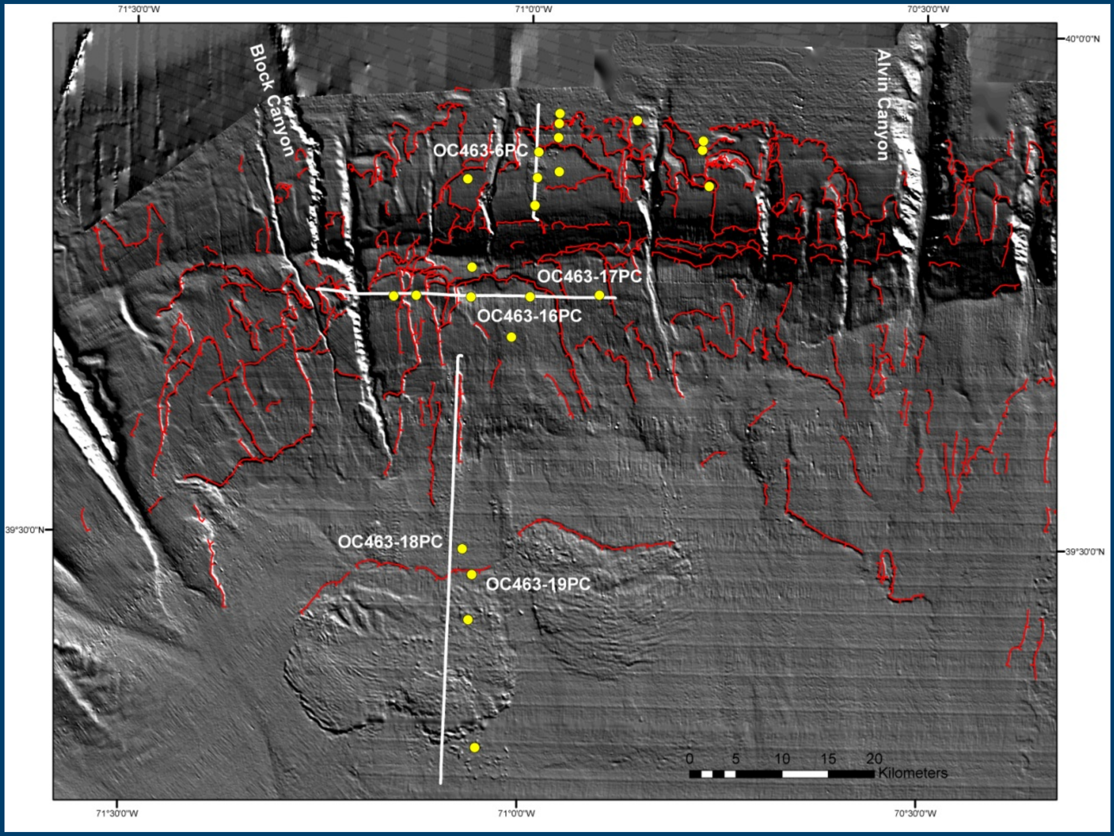
- **Seafloor Texture**



1982 USGS ANGUS camera tows
(image width ~ 5-7 m)

Landslide Ages

- **Atlantic – Southern New England**



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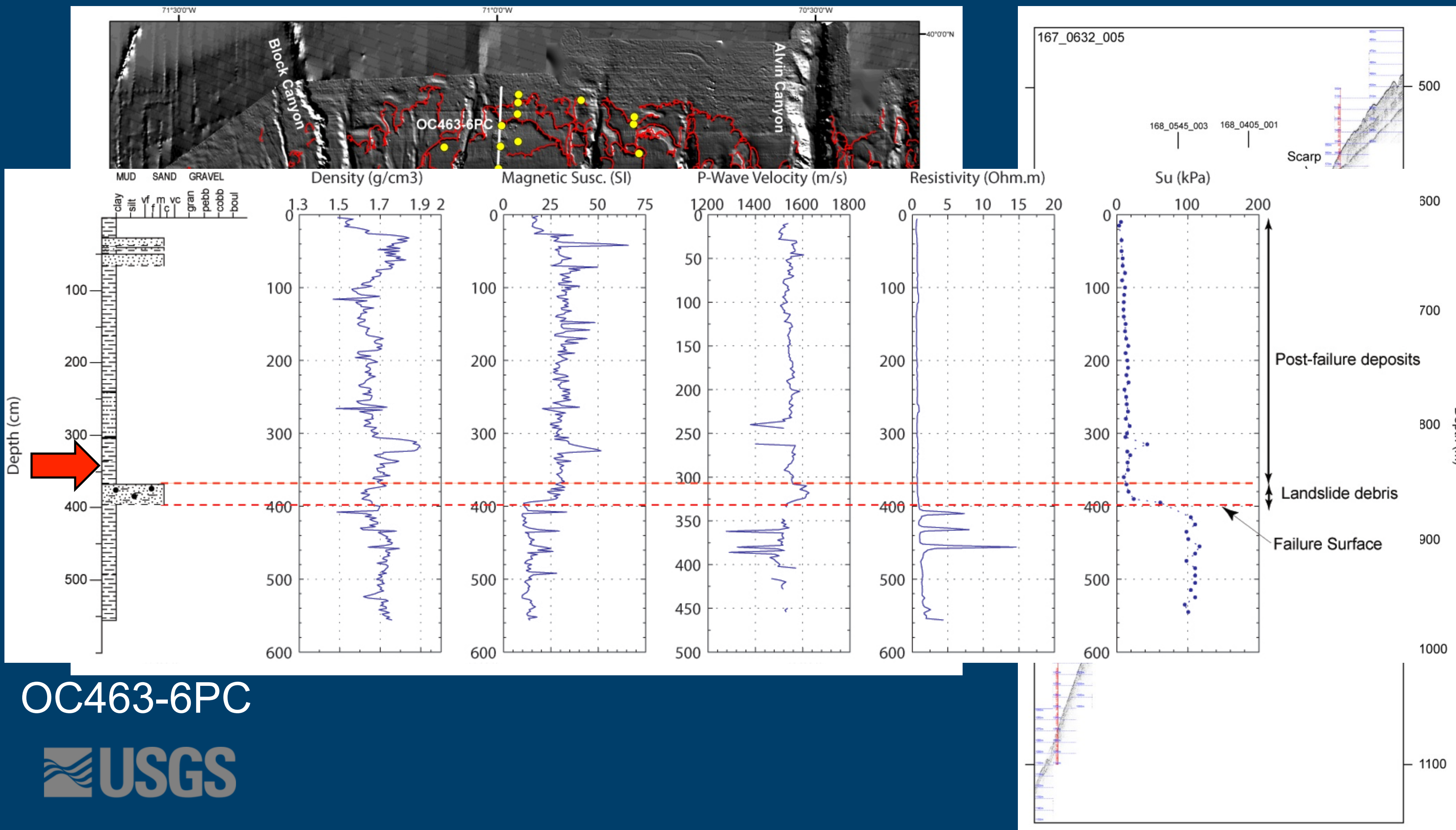
Landslide Ages

- **Atlantic – Southern New England**



OC463-6PC

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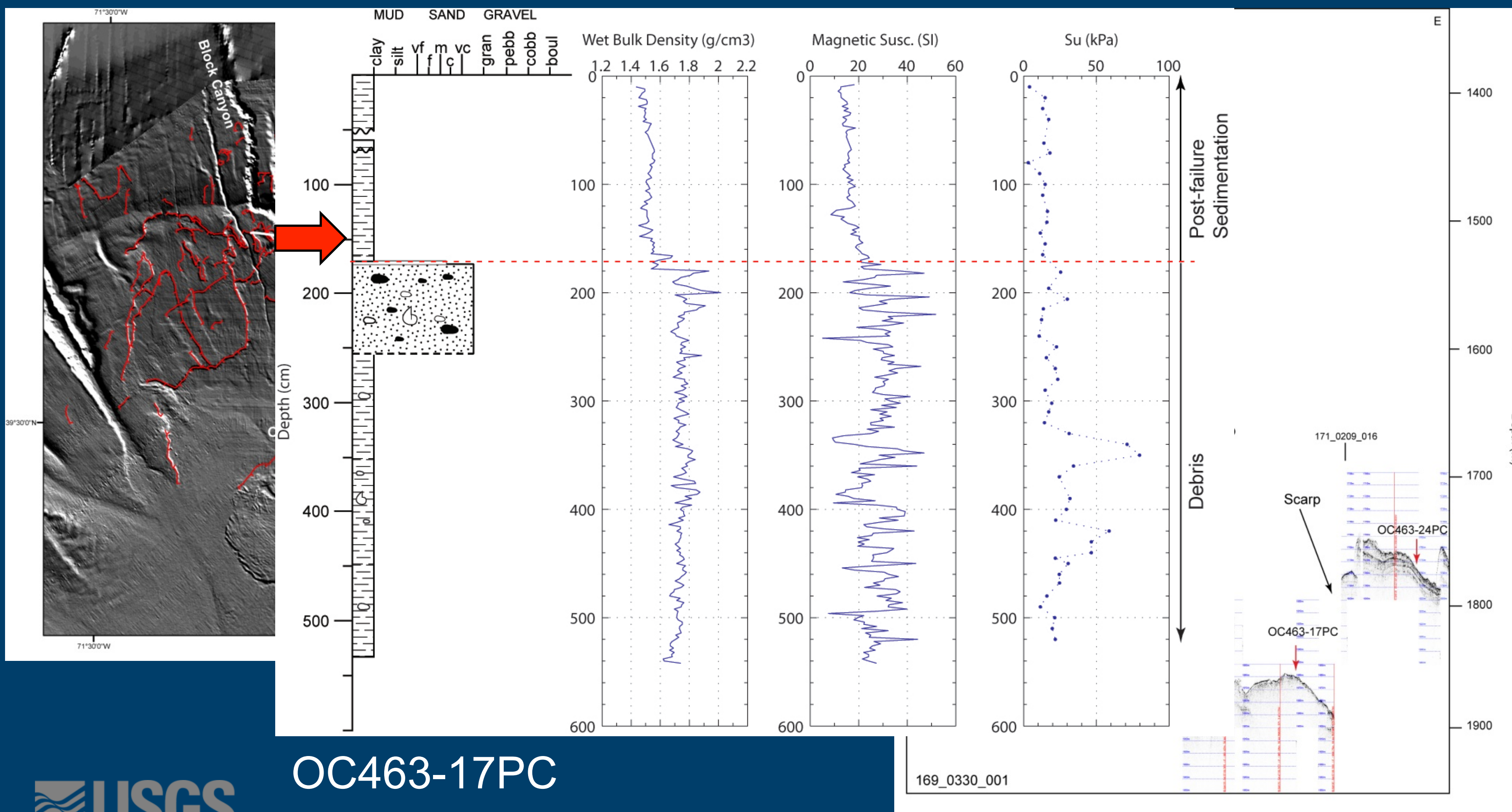
Landslide Ages

- **Atlantic – Southern New England**



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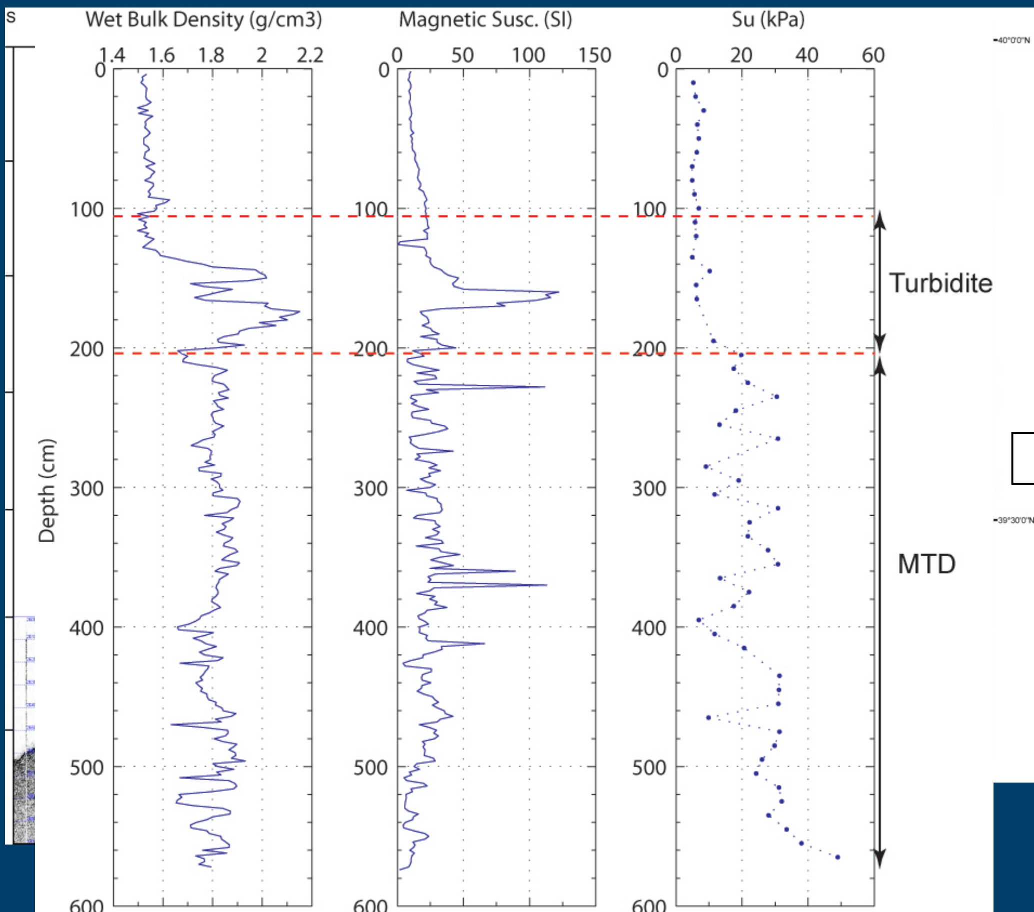
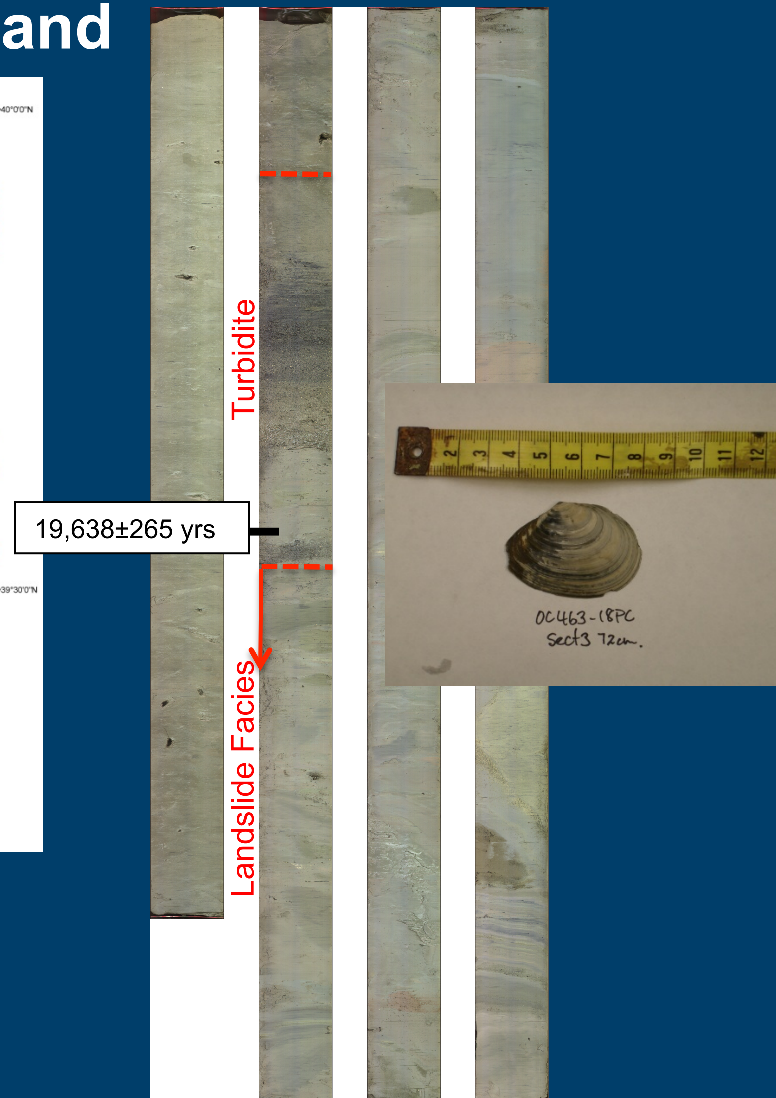
Landslide Ages

- **Atlantic – Southern New England**





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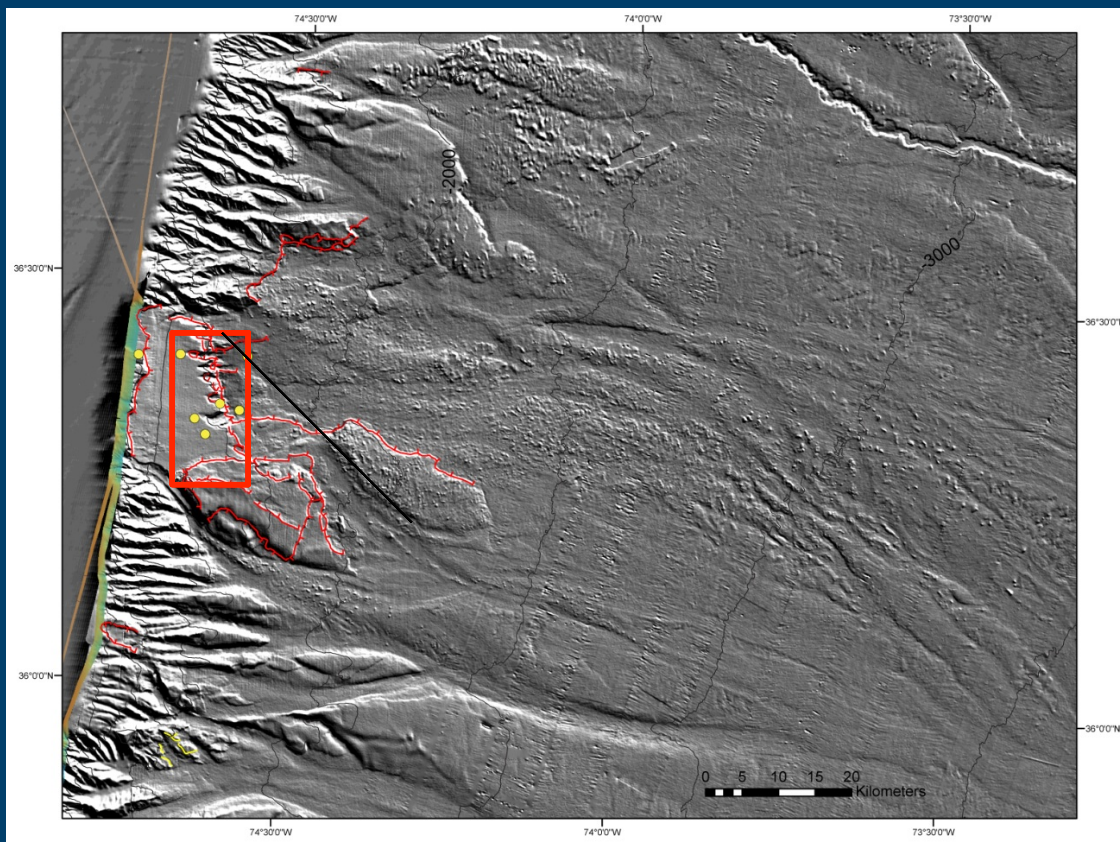
Landslide Ages

- **Atlantic – Currituck Landslide**



Bunn & McGregor (1980)

- post-early Pleistocene

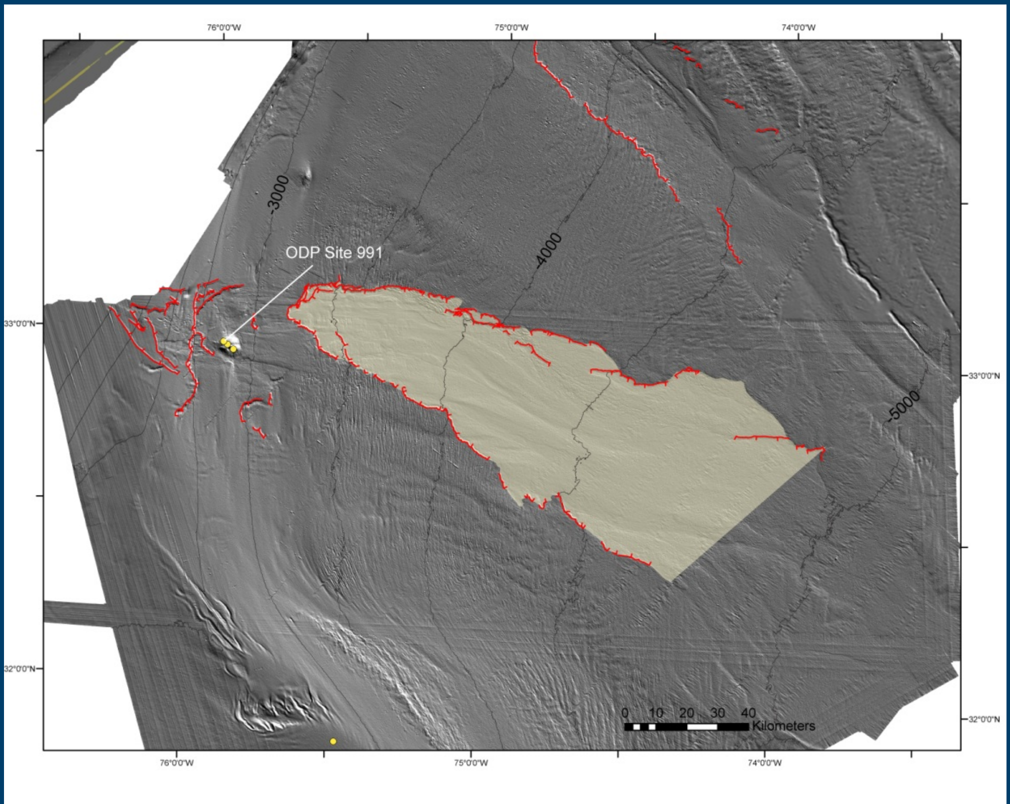
Piper et al. (1986)

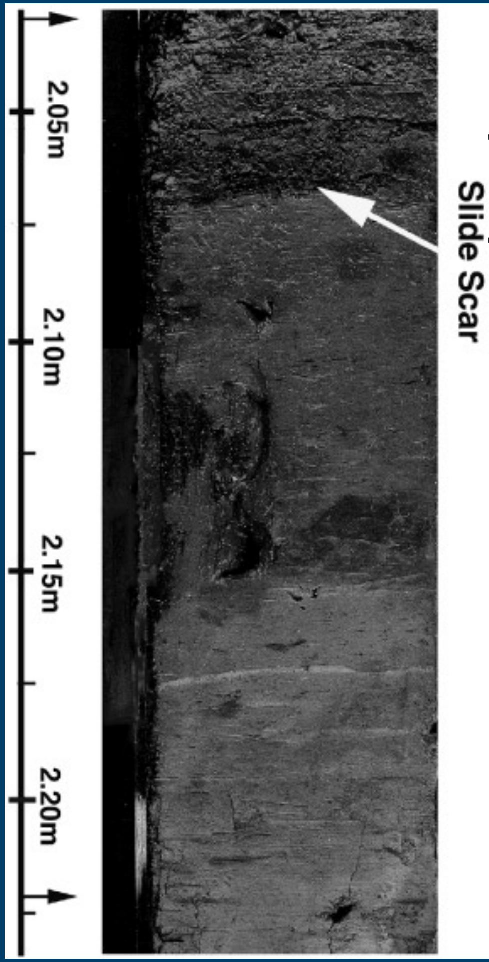
- 16,600 to 48,600 years

- Cores from “flat” bench penetrate layers containing shells, rocks and rock fragments, and clay balls above a <u>dry, friable layer</u>
- A core from below the deep headwall penetrated a dry, friable layer at 2 m bsf.

Landslide Ages

- **Atlantic - Cape Fear Landslide**





10 ka

27 ka

^{14}C ages from ODP Site 991;
Rodriguez and Paull, 1998

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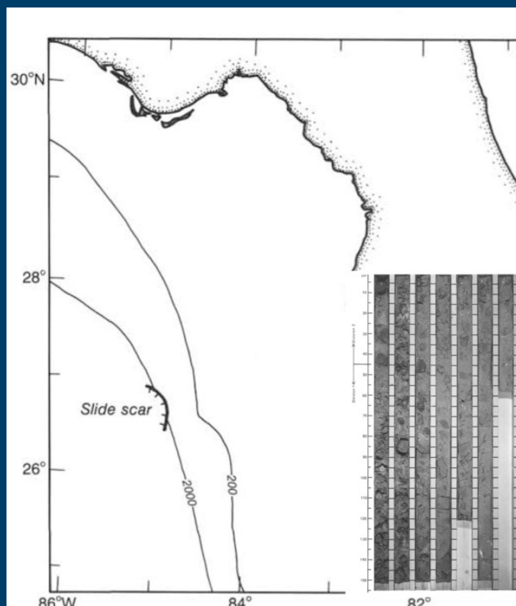
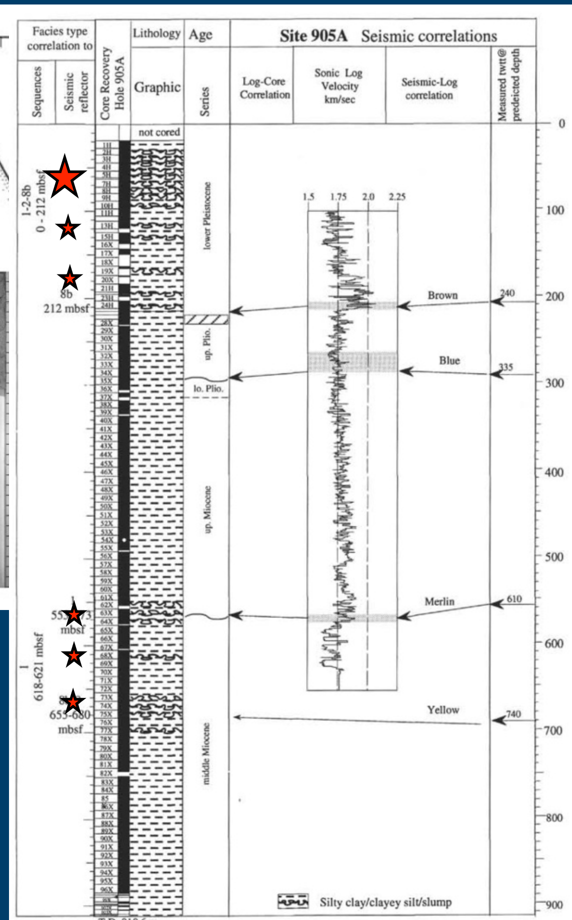
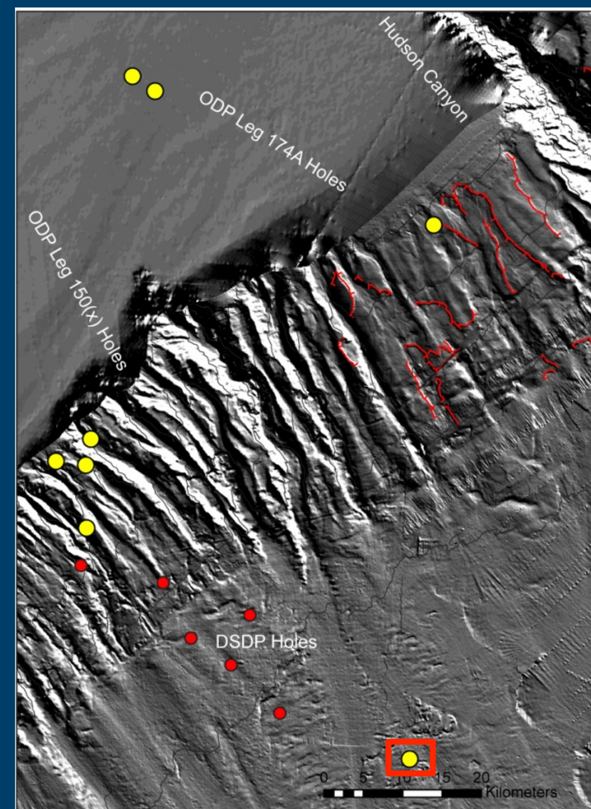
Landslide Ages

- **Atlantic – Florida Straits & New Jersey Ancient Landslides**



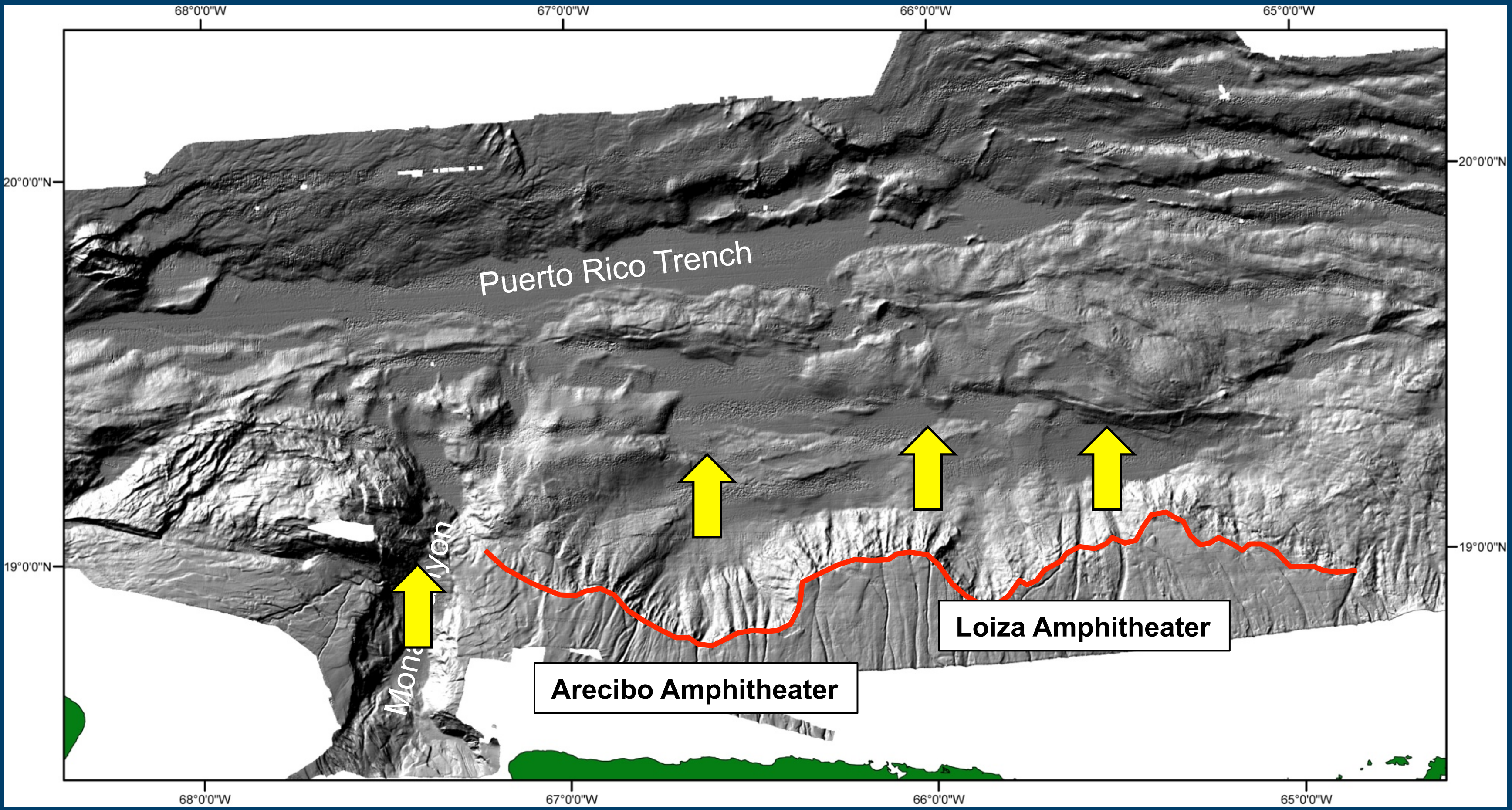
ODP Site 626; Fulthorpe & Melillo, mid-Miocene debris flow





McHugh et al., 1996

Puerto Rico Trench



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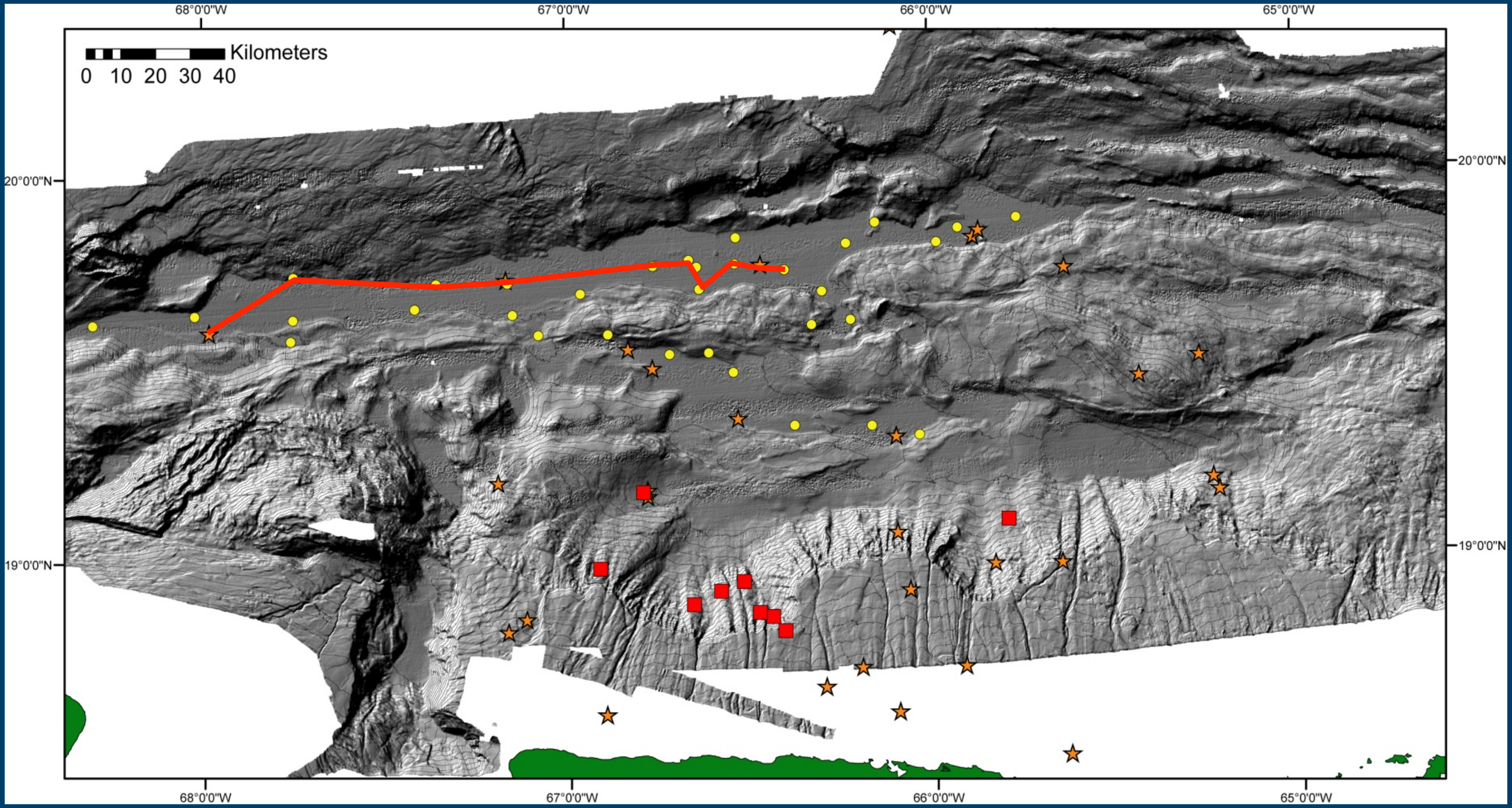
Puerto Rico Trench Cores



Duke University (1980 & 1981), LDEO (1950's and 1960's), USGS (2008)

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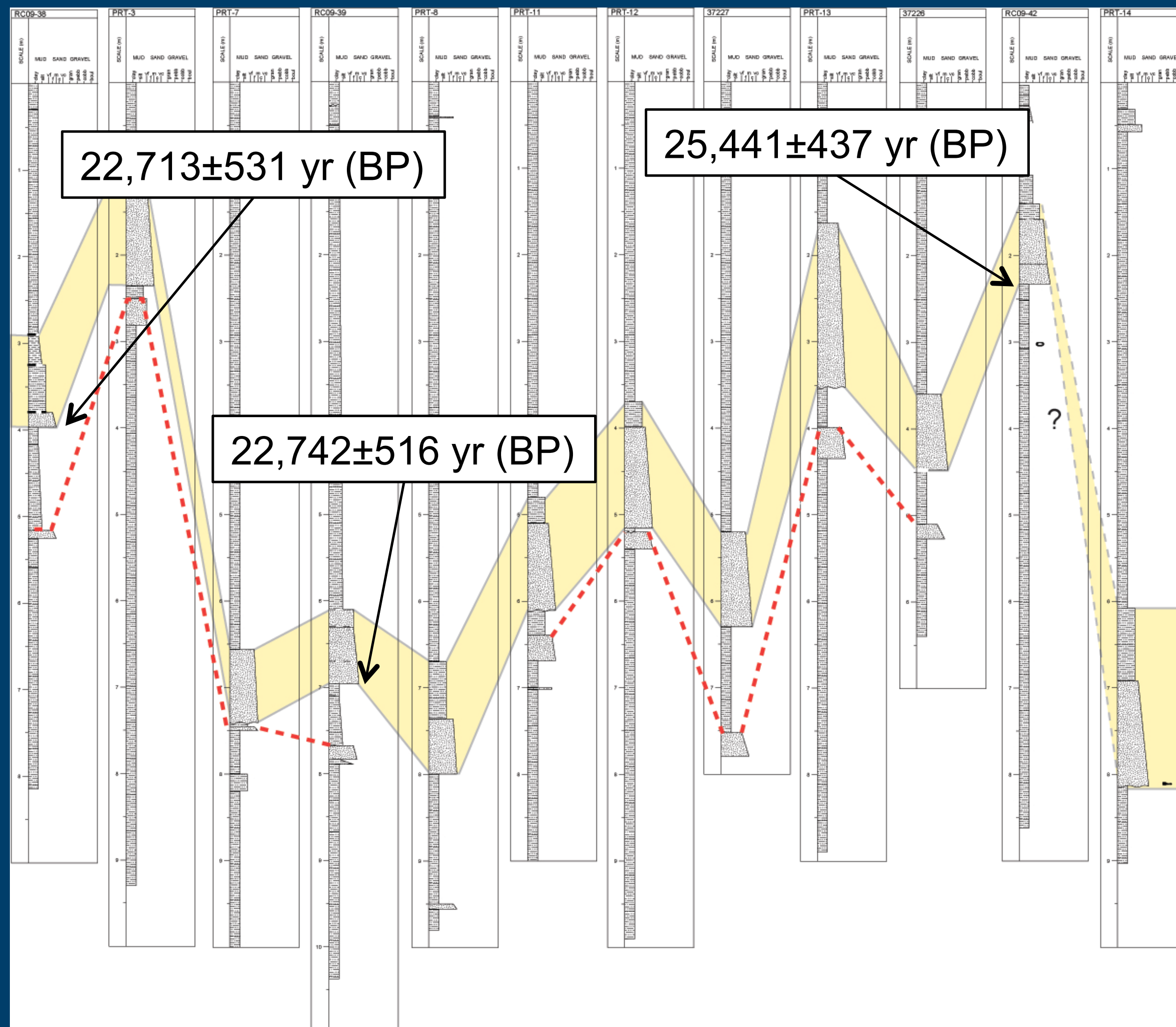
Turbidite Correlations – Trench Axis (West)

- **Most prominent turbidite in the upper 10 m is the MP2 event of Doull et al. (1983).**
- **Sands contain shallow water/upper slope constituents – coiled forams and pteropods, mollusk fragments, sponge spicules, calcareous algae, and carbonate fragments**



2-sigma ages - Calib 6.0 – Marine09 (Reimer et al., 2009)

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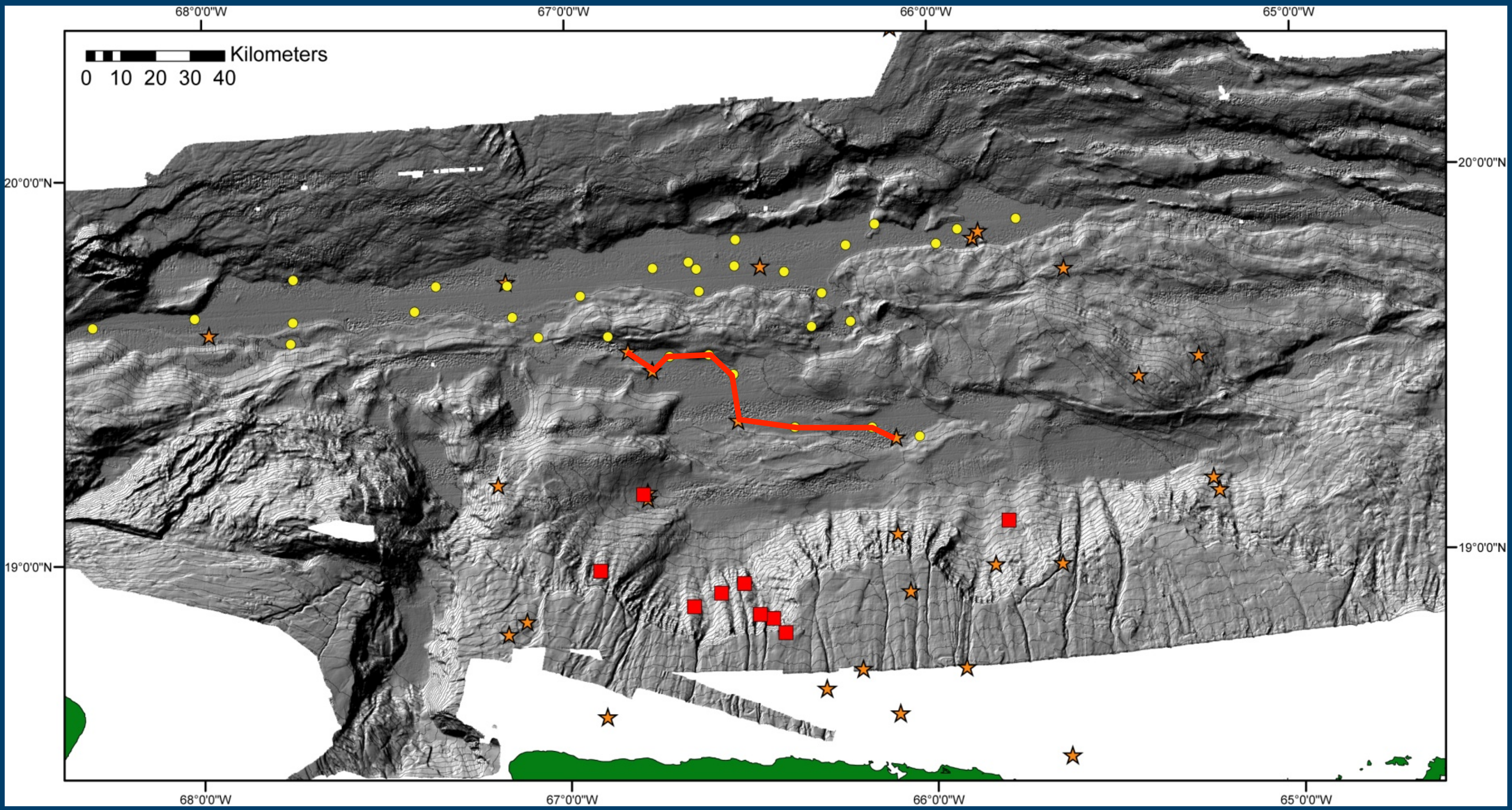
Puerto Rico Trench Cores



Duke University (1980 & 1981) – Doull (1983); LDEO (1950's and 1960's); USGS (2008)

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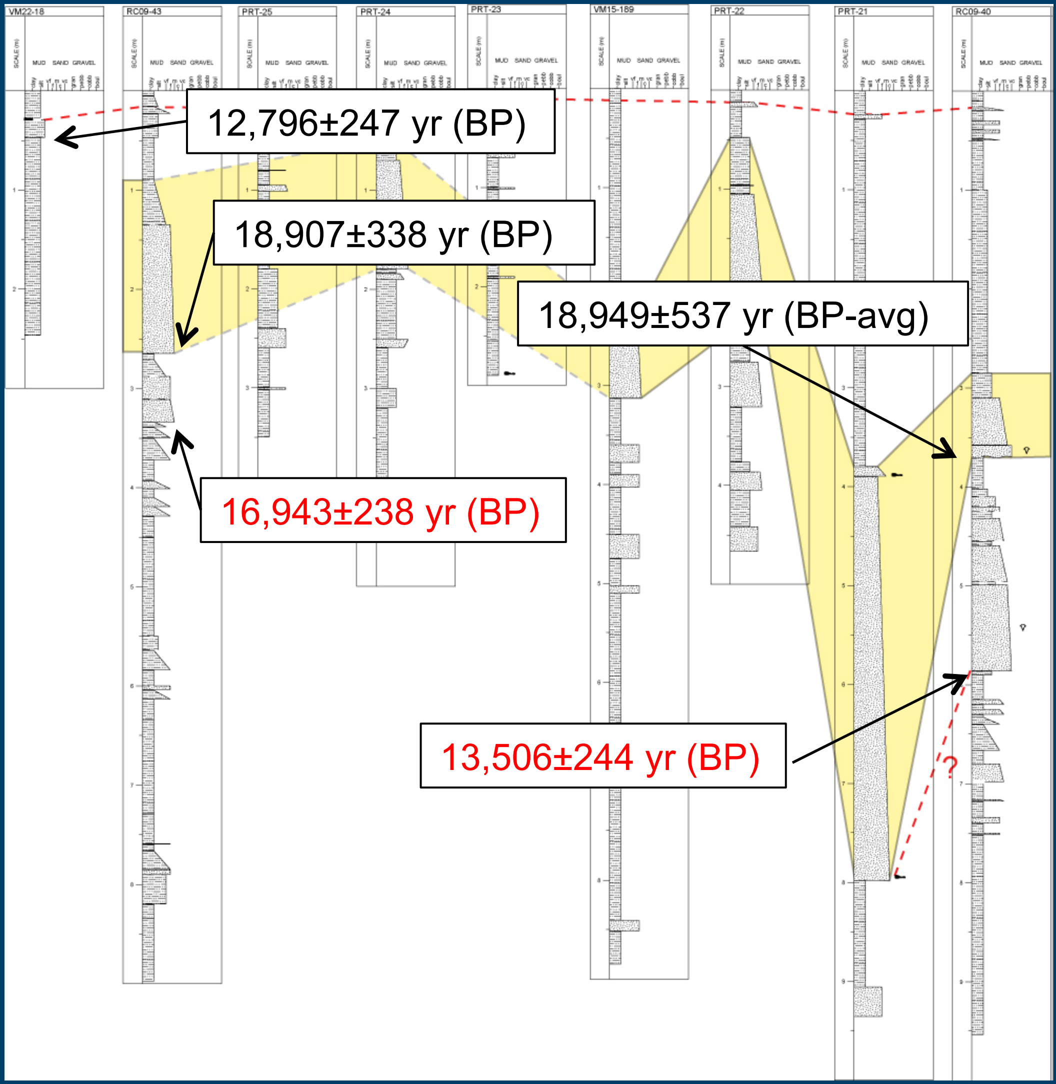
Turbidite Correlations – Base of Slope

- Most prominent turbidite in the upper 10 m is the EP3 event of Doull (1983).
- Sand constituents similar to MP2 turbidite, but with gravel-sized claystones, clam shells, and limestone fragments.
- Numerous fining upward sands suggest localized turbidite/debris flow sources.



2-sigma ages - Calib 6.0 – Marine09 (Reimer et al., 2009)

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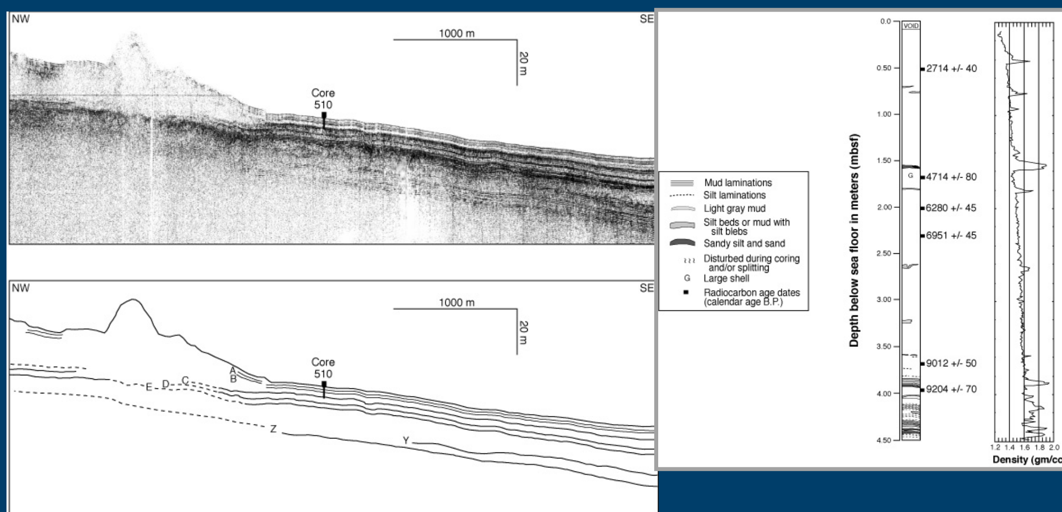
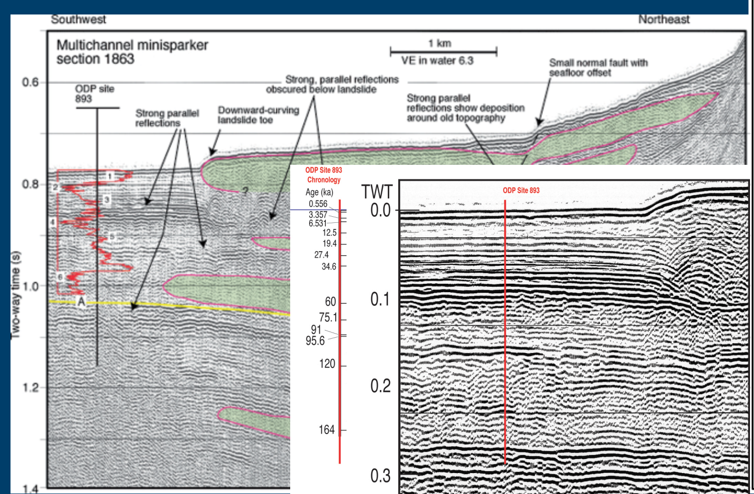
Landslide Ages

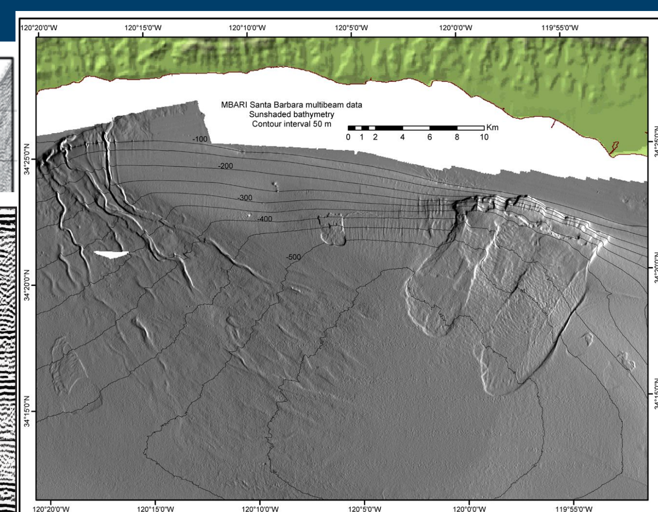
- **Southern California**



Palos Verdes debris avalanche (~ 7 Ka) Normark et al., 2004

Goleta Slide (~6-200 ka) Fisher et al., 2005





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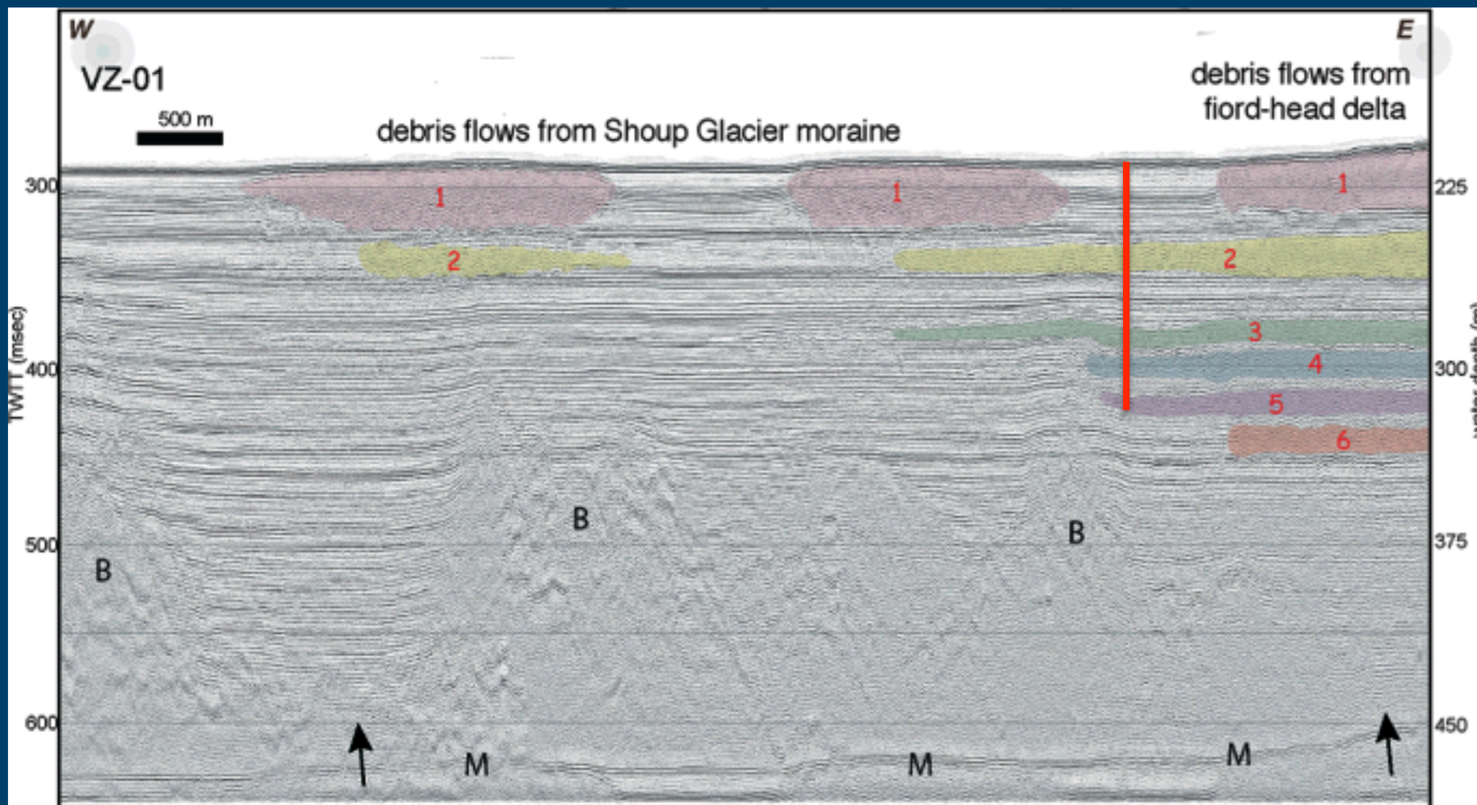
Landslide Ages

- **Prince William Sound**



…Participation in USSSP workshop on PWS drilling

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Concluding Remarks

- While many submarine landslides have been dated, these data need to be re-evaluated in light of modern data – *Need: reanalyze old data and reoccupy field sites.*
- We have been successful in dating the most recent submarine landslides, but are still restricted in our ability to date multiple events – *Need: More and longer cores.*
- Relative dating methods could provide a rapid means of determining the age of the landslides over a wide area – *Need: these methods need to be tested in a region with good ground-truth control.*

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