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Potential Causal Mechanisms for MTC Generation from the Northwest African Shelf*

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Abstract

Recent detailed mapping in a 1,064 km^2 3D seismic survey acquired in offshore Morocco has revealed the presence of at least three regional mass transport complexes (MTCs) within the Cretaceous interval of the Safi Haute Mer area, in addition to a number of smaller and younger MTCs. Their extent (projected up to 20,000 km^2) and thickness (350 ms) is strongly influenced by surrounding structural features associated with regional tectonics and salt mobilization. The MTCs are characterized by chaotic, mounded seismic facies; however seismic attribute analysis has revealed some degree of internal organization including multiple kilometer-scale transported mega-blocks.

Detailed analysis of the internal architecture of the mega-blocks has revealed the presence of discrete low sinuosity, single thread channels that are 90 m wide on average. The clear expression of stacked channel complexes within the mega-blocks indicates that they have preserved their original stratigraphy and were likely rafted from upslope, possible 100's of kms distance from their source area. Based on limited data, these deposits are suggested to be late Cretaceous or earliest Tertiary in age.

Two working hypotheses address the issue of possible triggering mechanisms for these MTCs. The first one suggests that the causes of the mass failure are associated with the step relief along a narrow shelf and regional uplift associated with the initiation of the Alpine Orogeny. However, the long-distance transport of kilometer-scale, well-lithified mega-blocks supports an alternative catastrophic model. The alternative hypothesis is that the failures were generated by mega-tsunamigenic forces associated with the K-T impact in the Yucatan Peninsula. Modeling of the potential tsunamigenic waves produced from both the failure of the Moroccan paleo shelf edge and from the Chicxulub impact are generated to support either of the two hypothesis.

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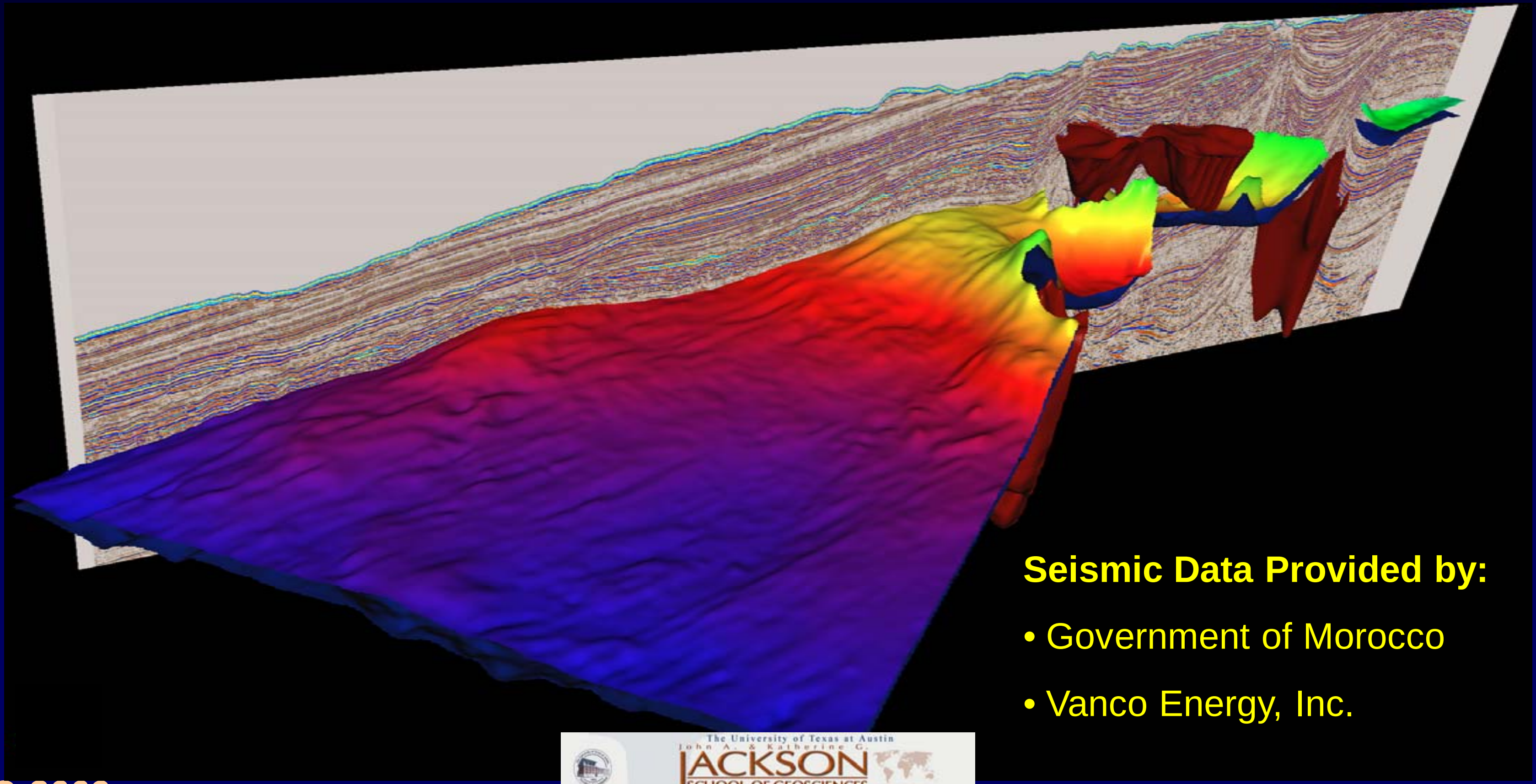
Dallas B. Dunlap, L. Moscardelli, M. Hornbach, and L. Wood



Seismic Data Provided by:

- Government of Morocco
- Vanco Energy, Inc.

The University of Texas at Austin
John A. & Katherine G. JACKSON SCHOOL OF GEOSCIENCES

AAPG 2009

Study Area – Safi Haute Mer Area, Morocco

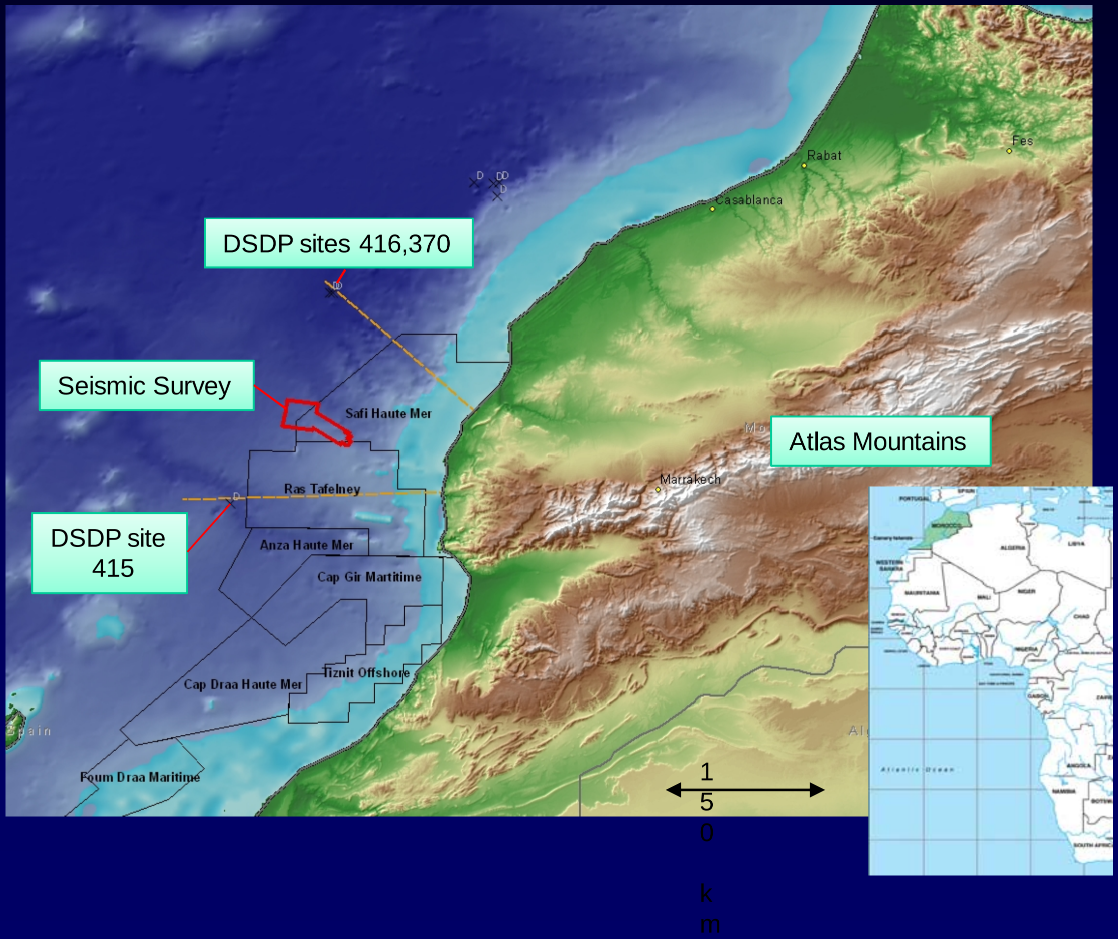
1064 km^2 Seismic Survey,
100 km offshore Safi, Morocco

The area sits in the Essaouria Basin, on the north flank of the Tafelnay Plateau

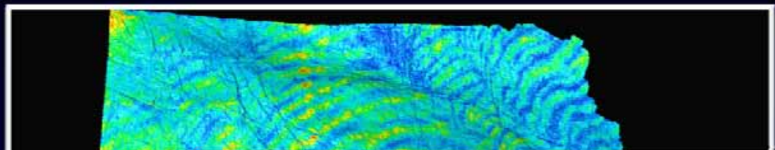
Deposition started in the late Triassic/Early Jurassic with the opening of the proto-Atlantic

Highly effected by the Uplift associated with the Alpine Orogeny

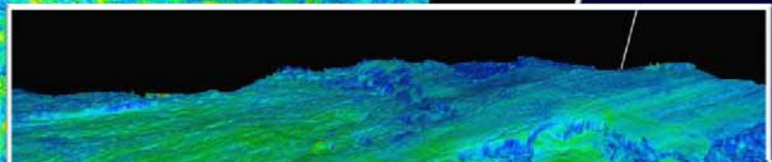
Salt mobilization from Jurassic to present within study area



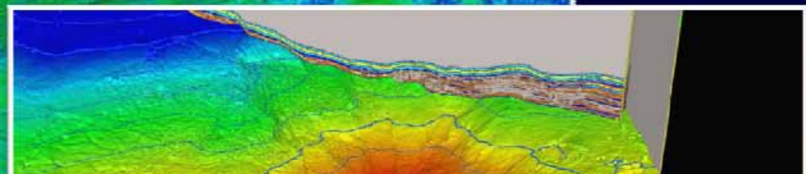
Early Geomorphic findings in study



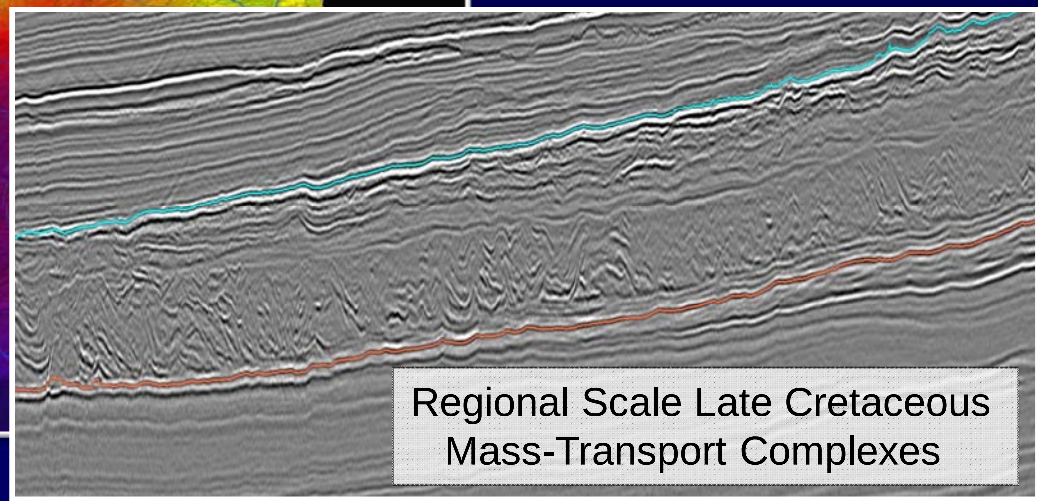
Expansive Deepwater Sediment Waves
(End Albian time)



Debris Flows, Slides, and Slumps

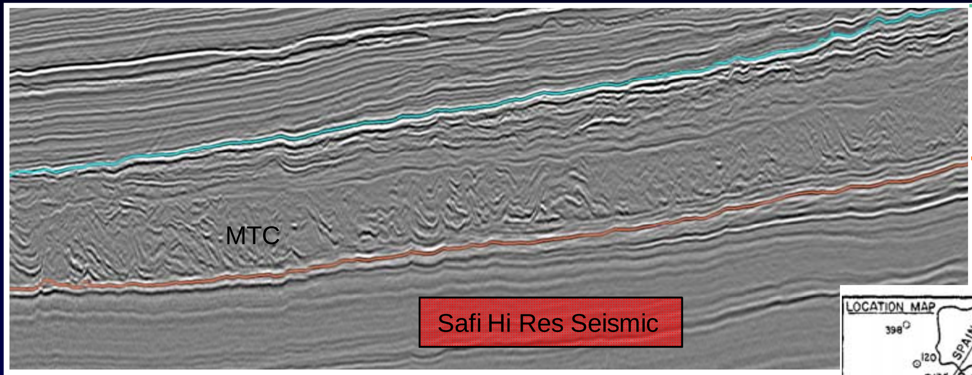


Sediment Fairways and
Canyon Systems



Regional Scale Late Cretaceous
Mass-Transport Complexes

Cretaceous Mass-Transport Complexes



Top Cretaceous

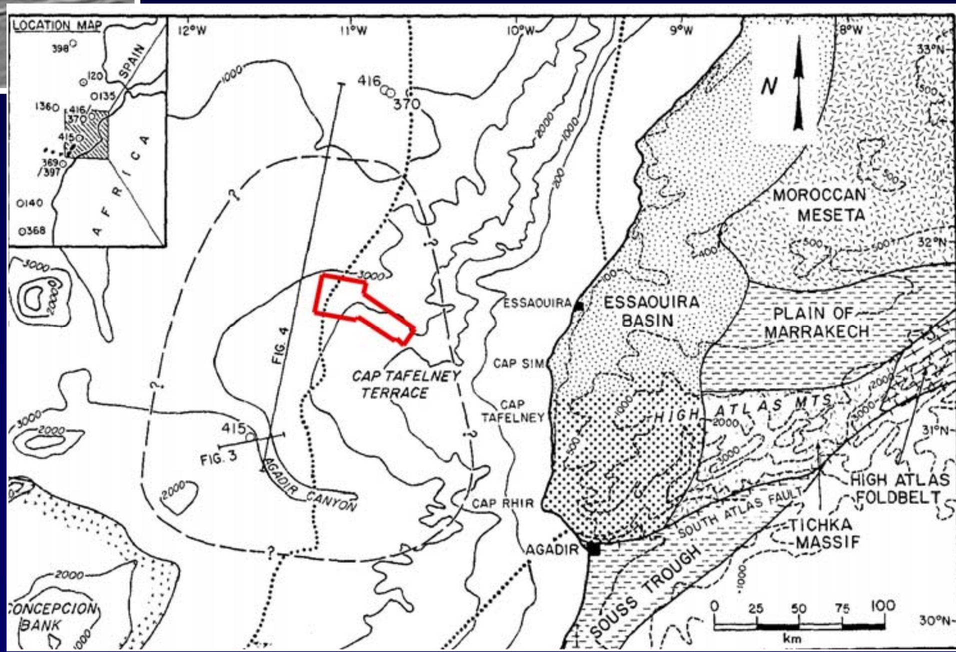
250 ms

Top Albian (Middle Cretaceous)

2D multichannel regional seismic and DSDP leg 50 drilling sites were used to map the lower slope

Initial description of a 20,000 km^2 debris apron over the Tefelney Plateau

“Upper Cretaceous Allochthon” with several overthrusts was documented



Price (1980)

Problems?

◄ in addition to tectonic uplift and over-steepening, could other mechanisms contribute to shelf instability?

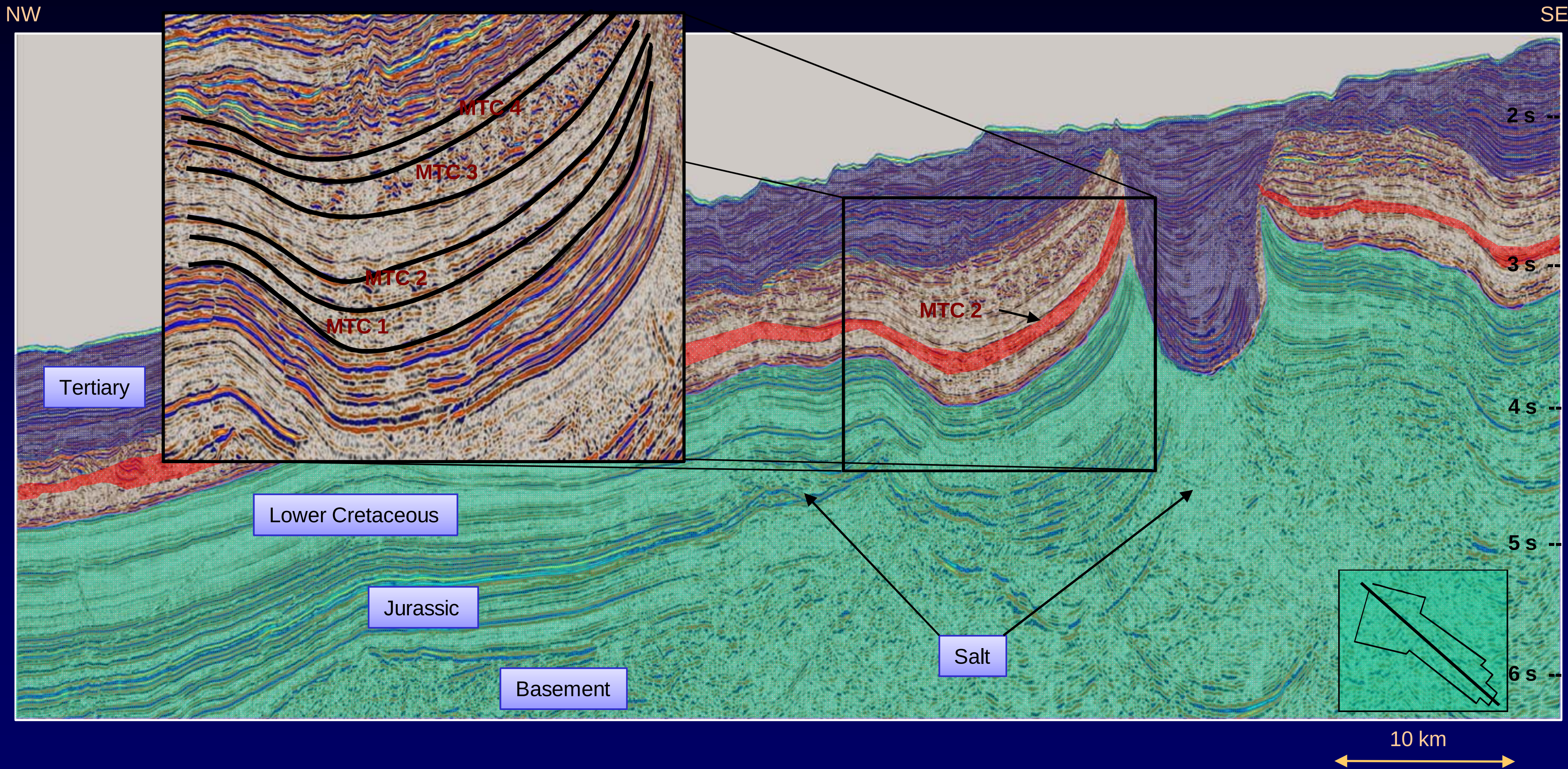
◄ Could these MTC's be related to the K-T event in the Yucatan?

◄ What are the implications of impacts to shelf stability along the margin?

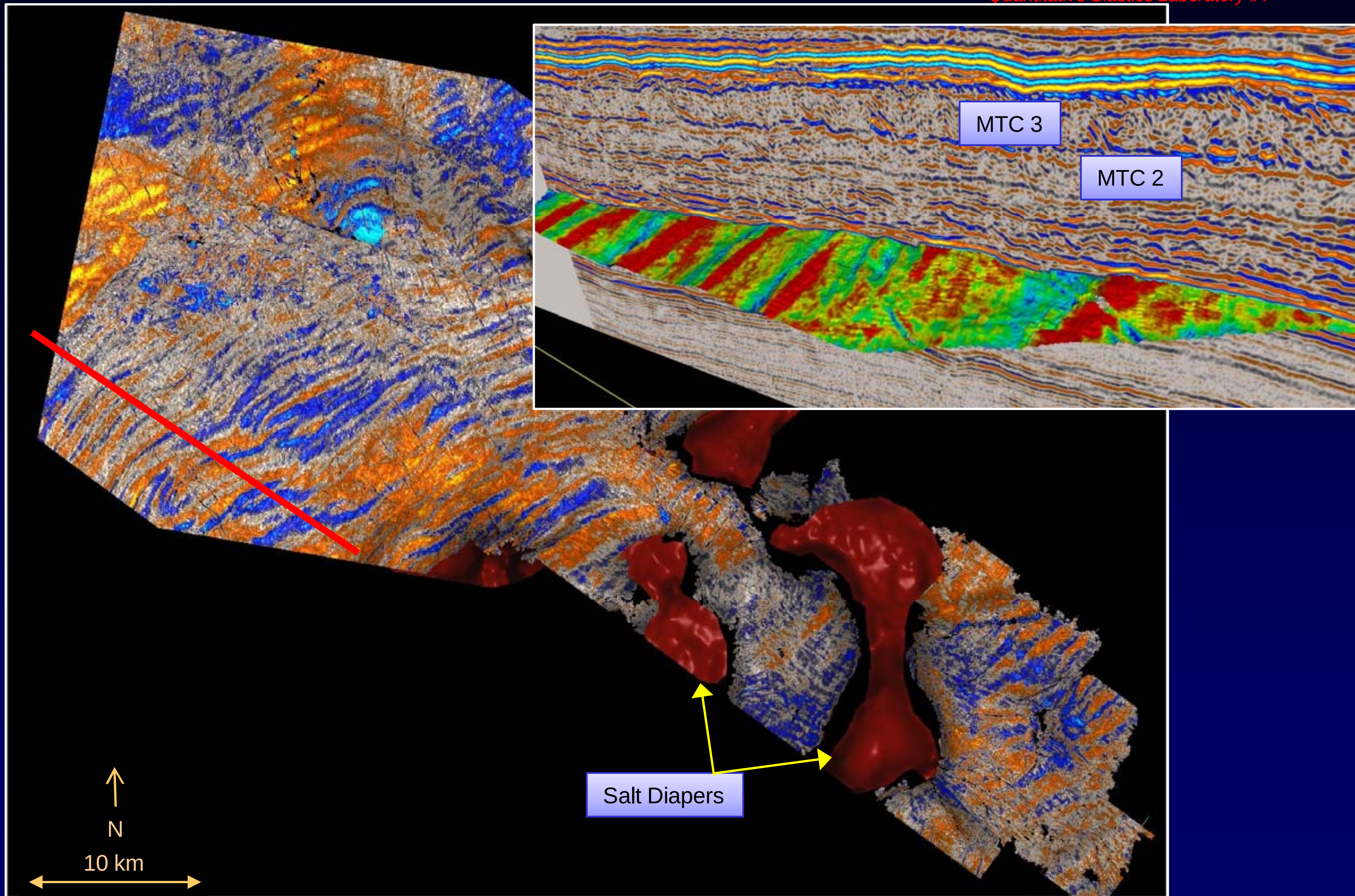
◄ What kind of Tsunamigenic processes would we expect from these MTCs?

◄ Can these slide deposits and their causal mechanisms have an impact on prospectivity?

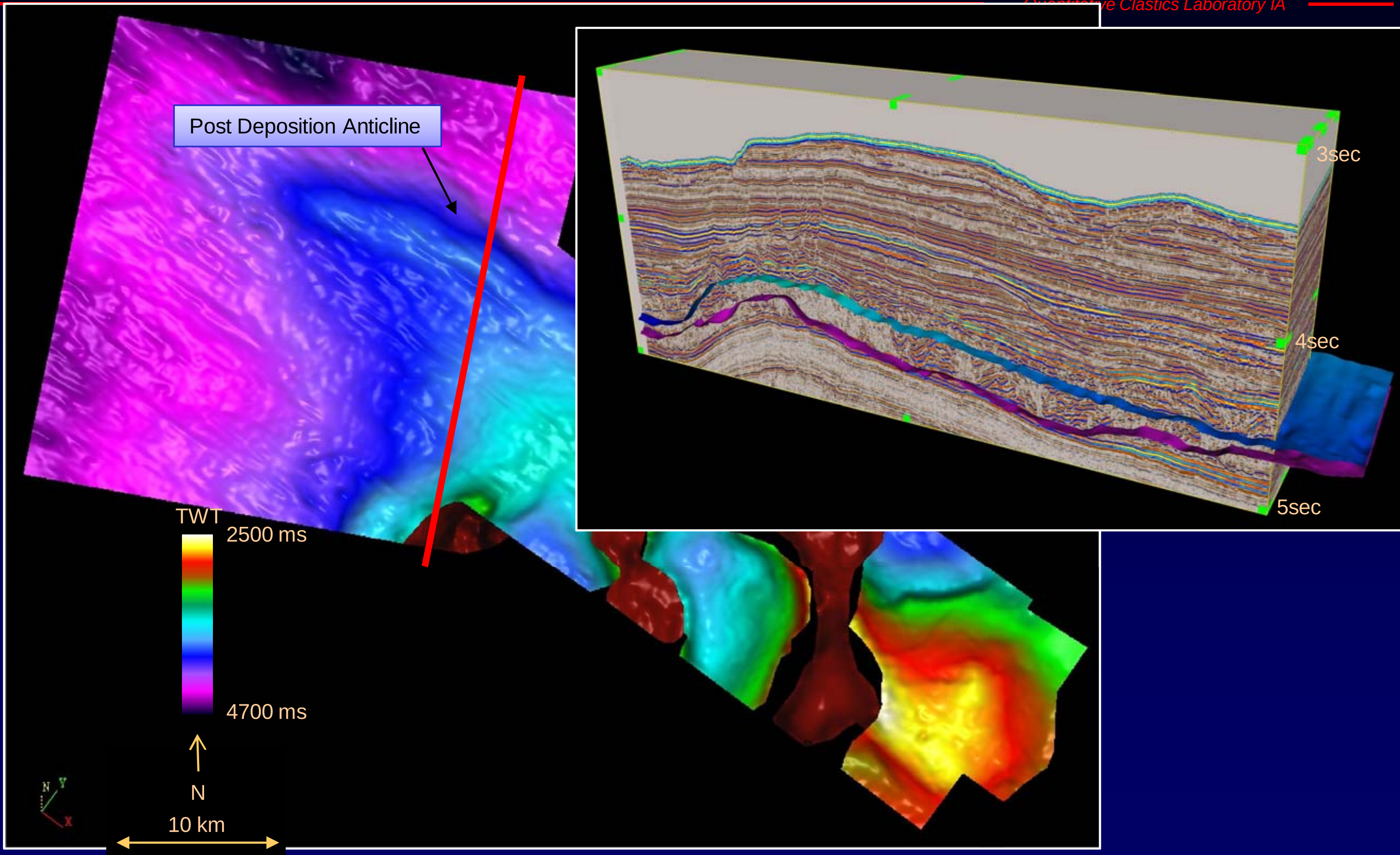
Stratigraphy in the late Cretaceous



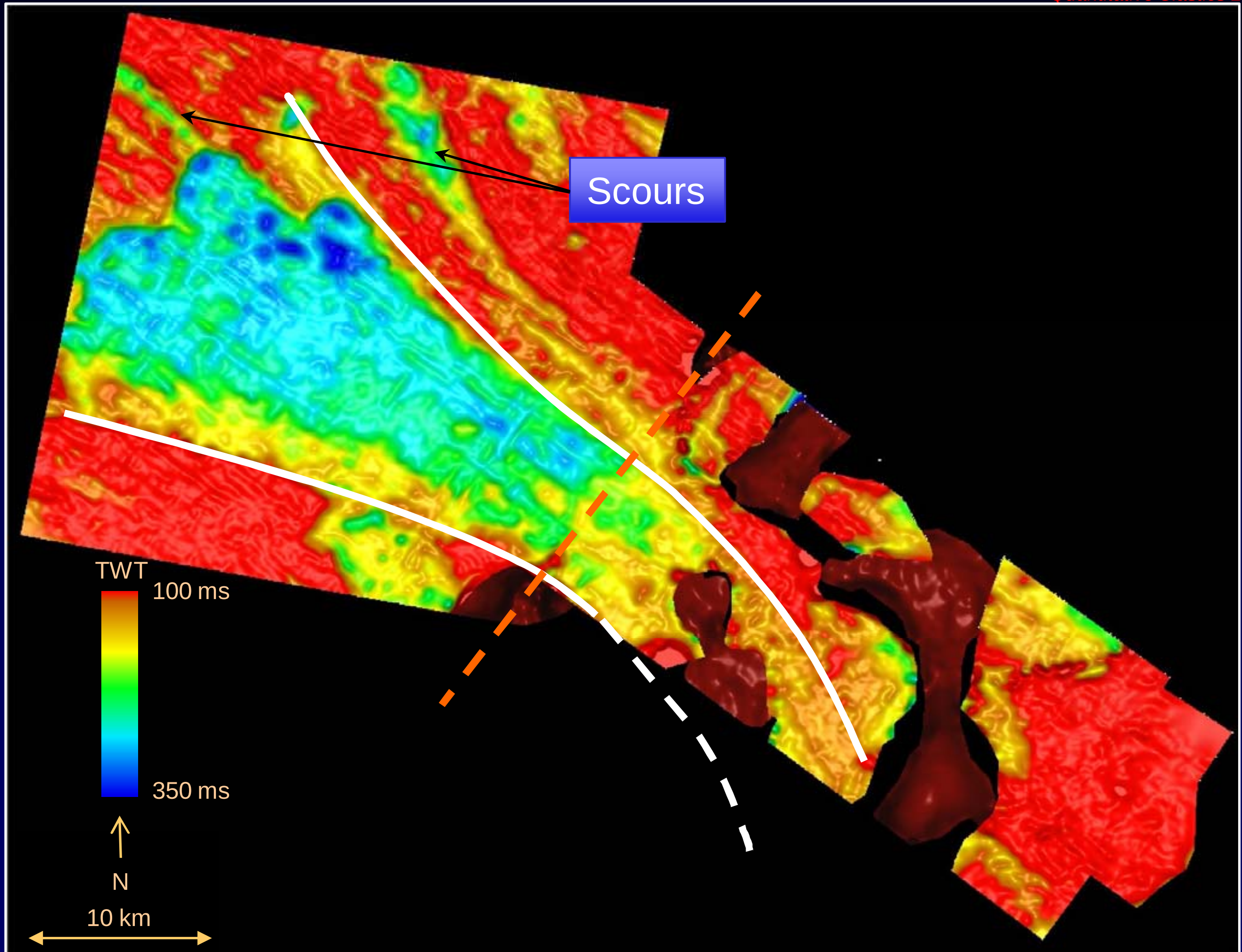
Top Albian Sediment Waves just below the MTCs



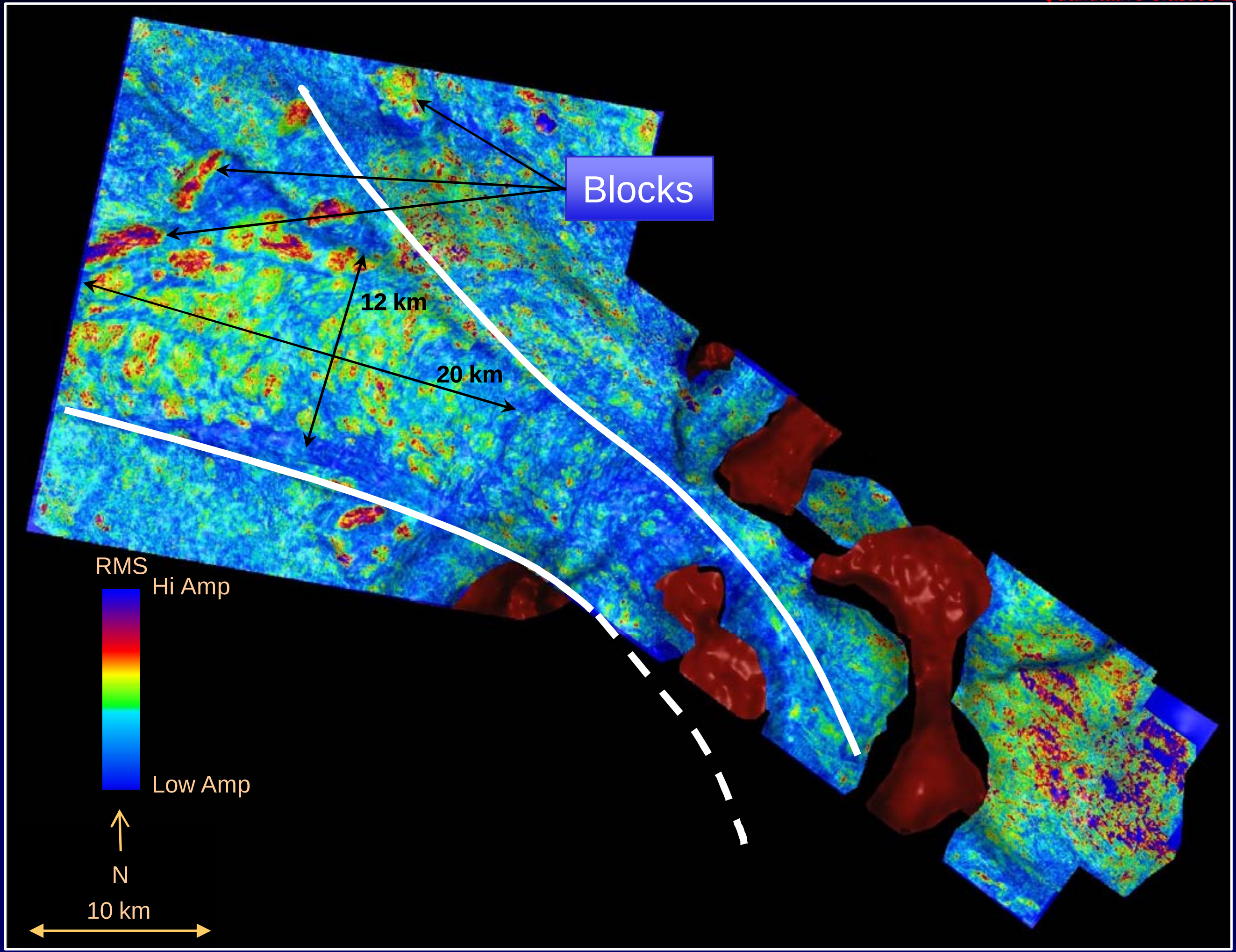
Two-Way Time Map of Top MTC 2



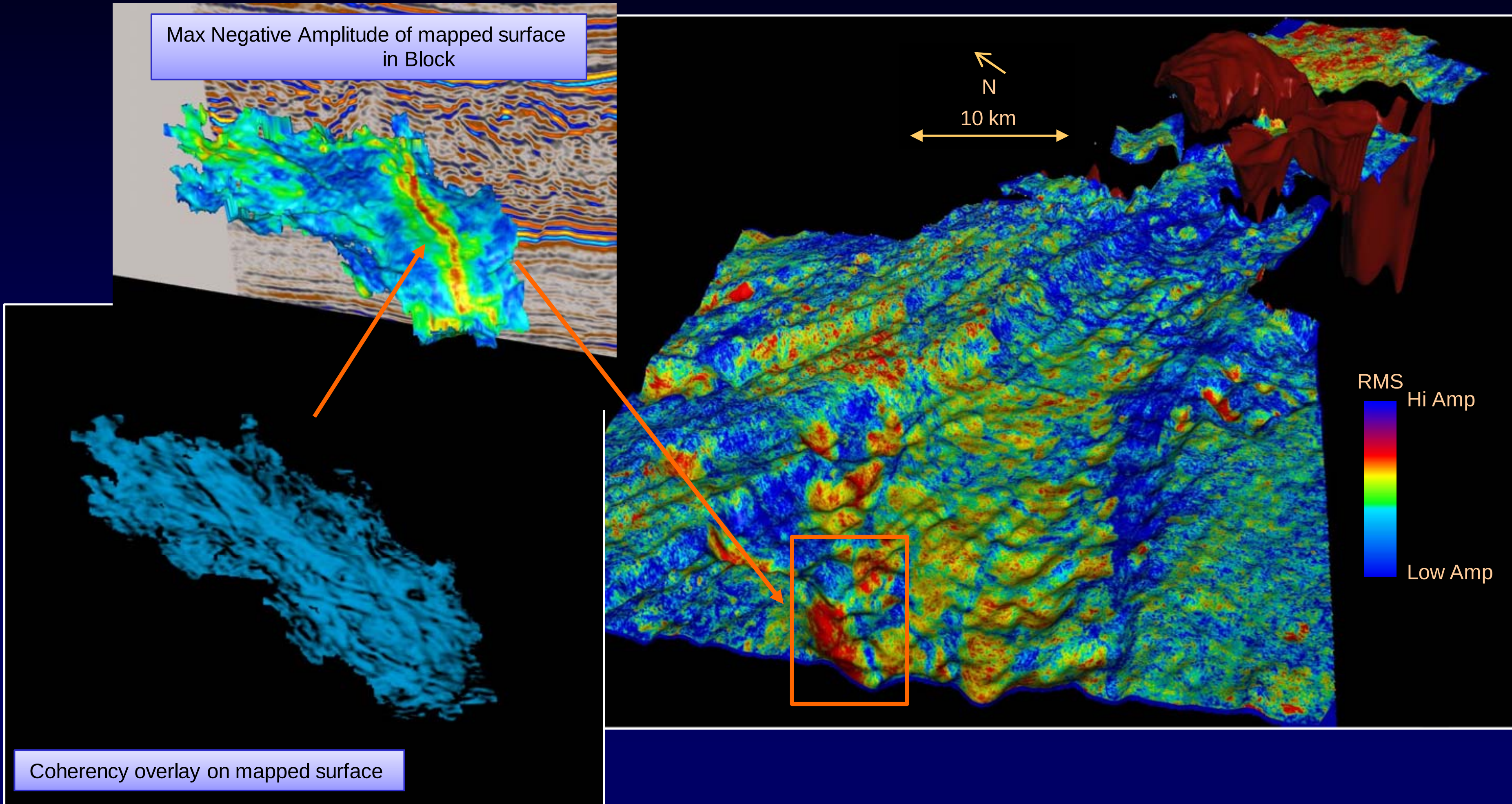
Two-Way Time Thickness Map of MTC 2



RMS Amplitude Map within MTC 2



Large Rafted Blocks with internal Stratigraphy



What are the mechanisms of MTCs generation?

Large submarine failures and mass wasting can be produced by many processes including

- Rapid Sedimentation/oversteepening
- Sea level Fluctuations
- Slope Erosion
- Changes in Pore Pressure
- Seismic Shocks →

Earthquakes

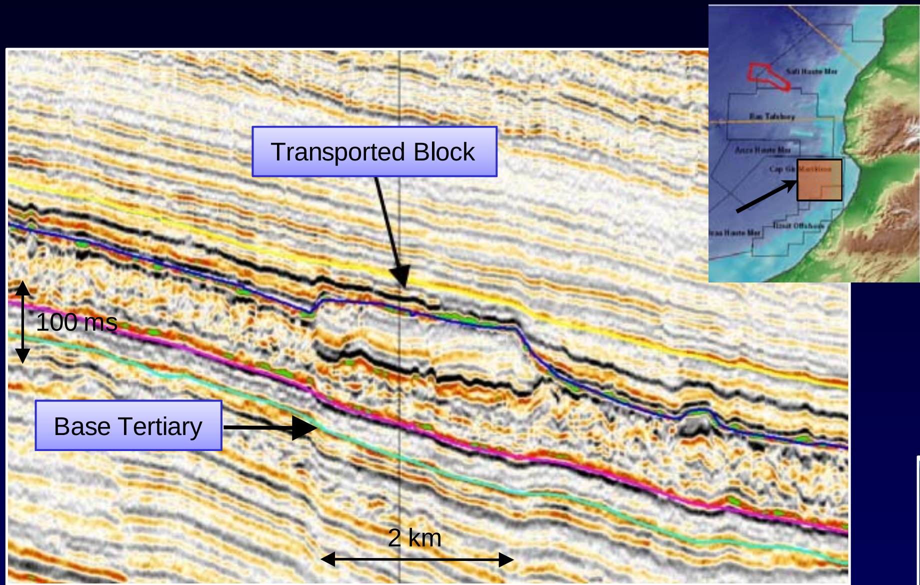
Volcanism

Meteor Impacts

→ Tsunamis

Morton (1993)

What are the implications of bolide impacts as a triggering mechanism for MTCs?

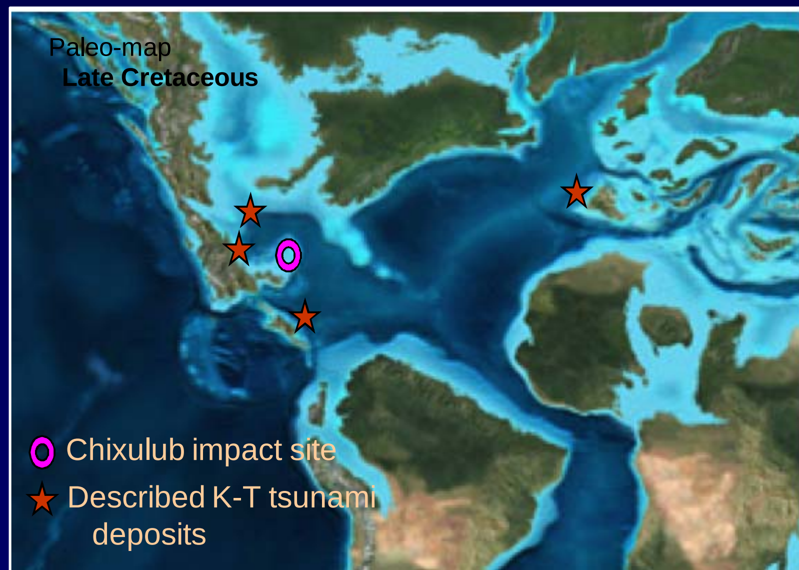


Lee et al, 2004

MTCs with large rafted blocks just above the K-T boundary were described in the Agadir Basin directly south of study area

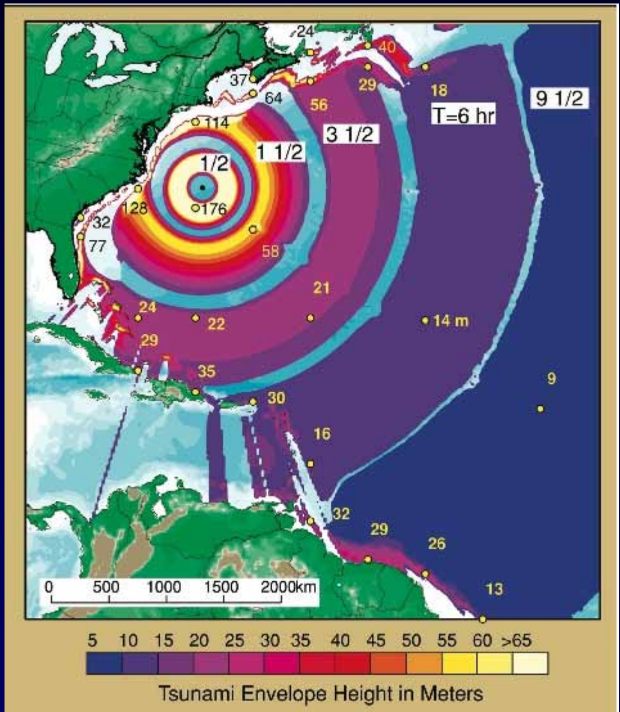
One model proposed for the cause of this mass wasting was from the exposure to tsunamigenic waves from the Yucatán-Chicxulub impact

Many documented debris flow and tsunamigenic deposits from the Chicxulub Impact have been found in Mexico, Belize, the US, and as far away as offshore Spain



Blakey 1996

Atlantic Impact Scenerio

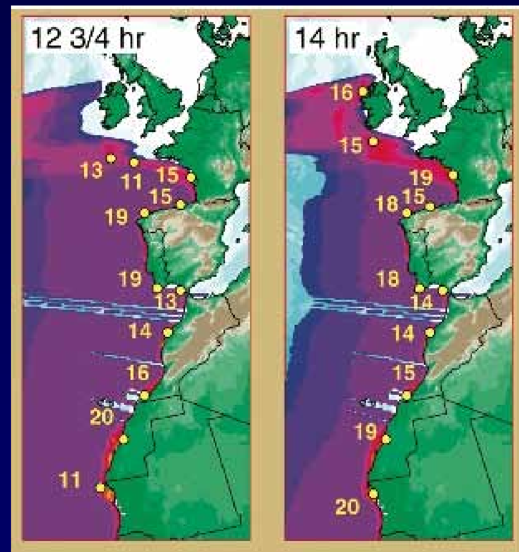


Ward and Asphaug, 2003

Ward and Asphaug (2002) Modeled the year 2880 1950DA possible impact in a hypothetical North Atlantic scenario

The modeling was done on a 1.1km diameter object traveling at 17.8 km s^{-1} that would produce a 19 km cavity 5 km deep to the seafloor

The height of the wave as it reaches the Moroccan shelf grows to between 14-16 meters in the study area 12-15 hours after the impact



Impact Tsunamis vs Mass-wasting Tsunamis

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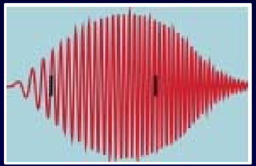
Debate remains for the ”wave heights vs distance” of meteor impact generated Tsunami’s

Ward and Asphaug discuss the rapid dropoff in amplitude of Tsunamigenic waves generated from Impacts due to the extremely high frequency of the resulting waveform.

Because these high frequency waves scatter quickly and their complexity in modeling the run-up heights could be over-estimated.



Another mechanism for Tsunami generation is from the resulting wave from a terrestrial Impact and subsequent earthquake induced mega-slides.

Many large MTCs have been triggered from earthquakes of Magnitude 7 or greater, but Mosher et al, concluded smaller Magnitude >3 are also capably of generating failures

(Imamura and Hashi, 2003) and (Mosher et al,1994)

Did the Yucatan-Chicxulub Impact Contribute to the Safi MTCs?

No, Three lines of evidence negate the possibility that Chicxulub caused the Safi MTCs

1) Greater confidence that the initially interpreted Base Tertiary unconformity sits noticeably higher, above MTCs 1-4, indicating they pre-date the Impact.

2) Continued detailed mapping of the Upper Cretaceous revealed several periods of mass-wasting and conformable bedding up to the K-T unconformity.

3) Dated deep-water cores from DSDP well 415 show repeat sections of disturbed bedding of Middle Cenomanian age deposits

These don't rule out the possibility that debris flows or MTCs could have been generated by Chicxulub, only that the Base Tertiary Unconformity would have eroded any deposits.

Other Possible Middle Cenomanian North Atlantic Impact Candidates?

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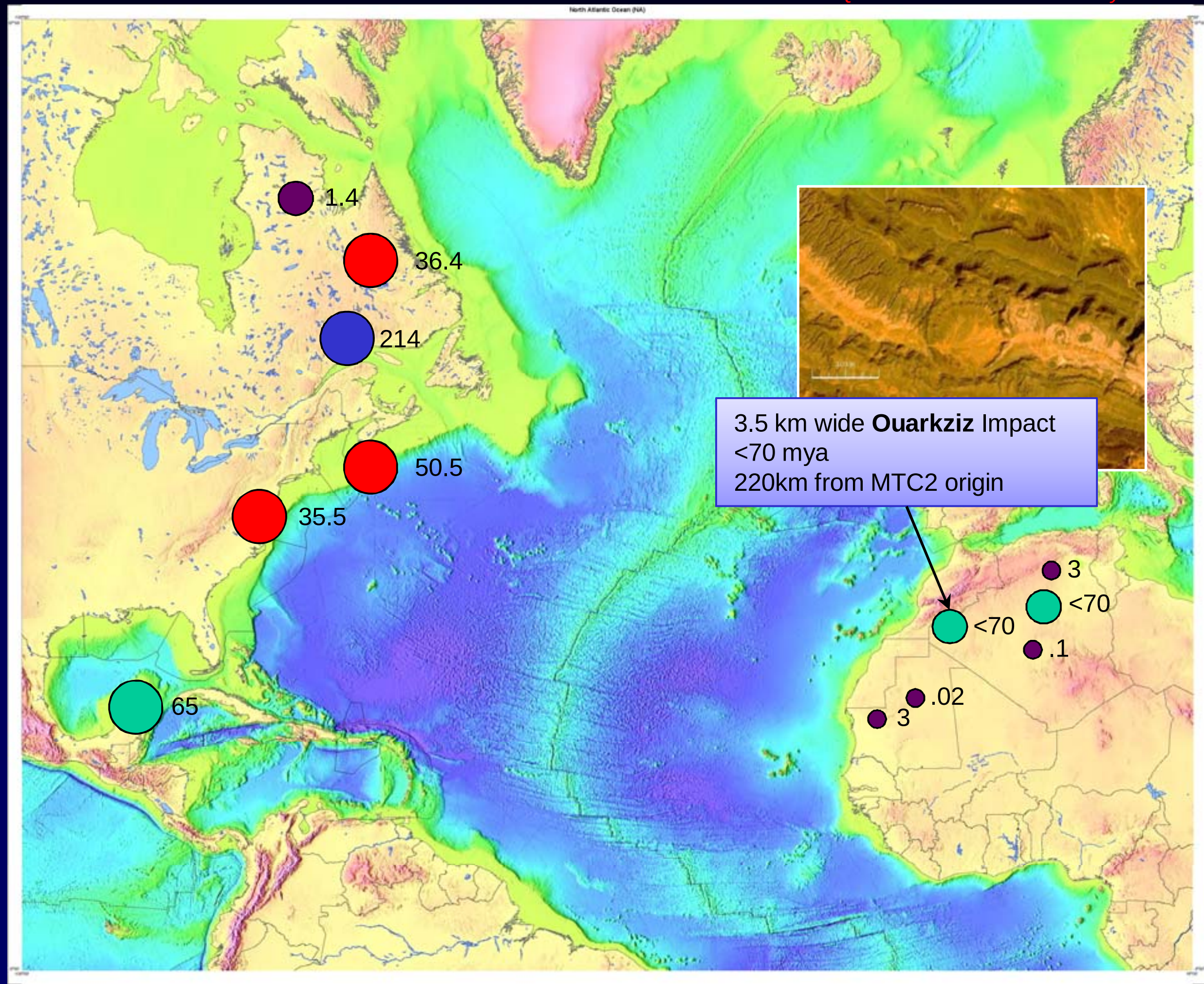
North Atlantic known Impacts from 250mya-Present

- Quaternary impacts (<5 mya)
- Tertiary Impacts
- Cretaceous impacts
- Triassic/Jurassic impacts

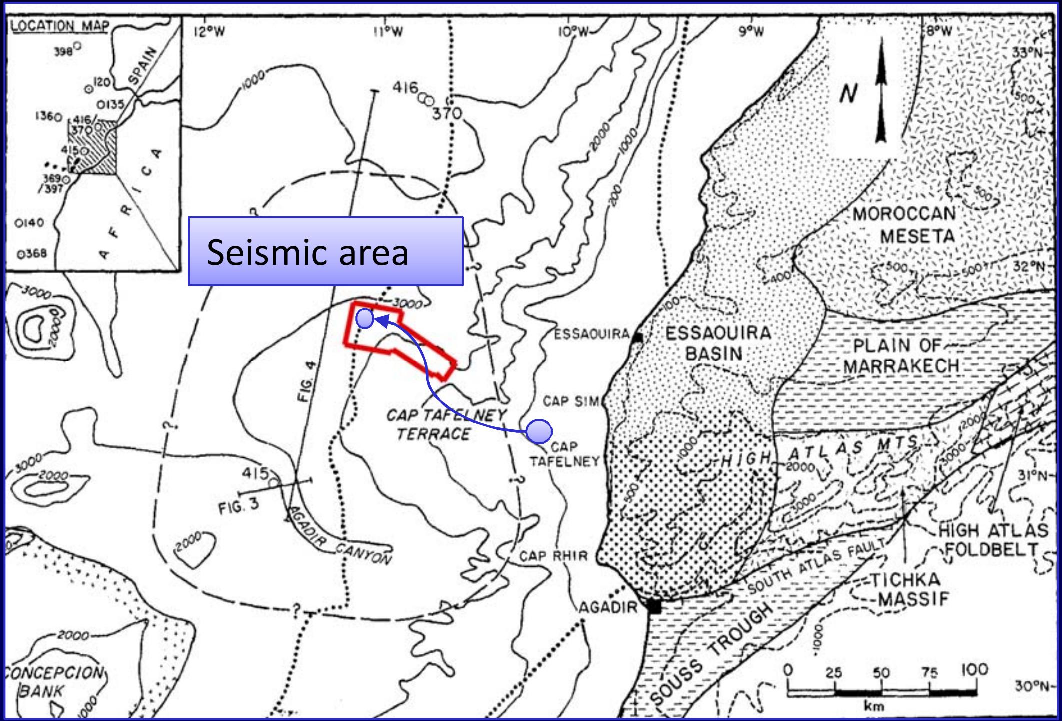
- 0.1-2 km diameter
- 2 – 10 km diameter
- >10 km diameter

Possible trigger for Agadir earliest-Tertiary MTC?



From NOAA

Assuming a triggering mechanism, what would be the resulting Tsunami for MTC 2?



A non-linear shallow water model was generated to determine Tsunami wave propagation in the Northern Atlantic

Inputs:

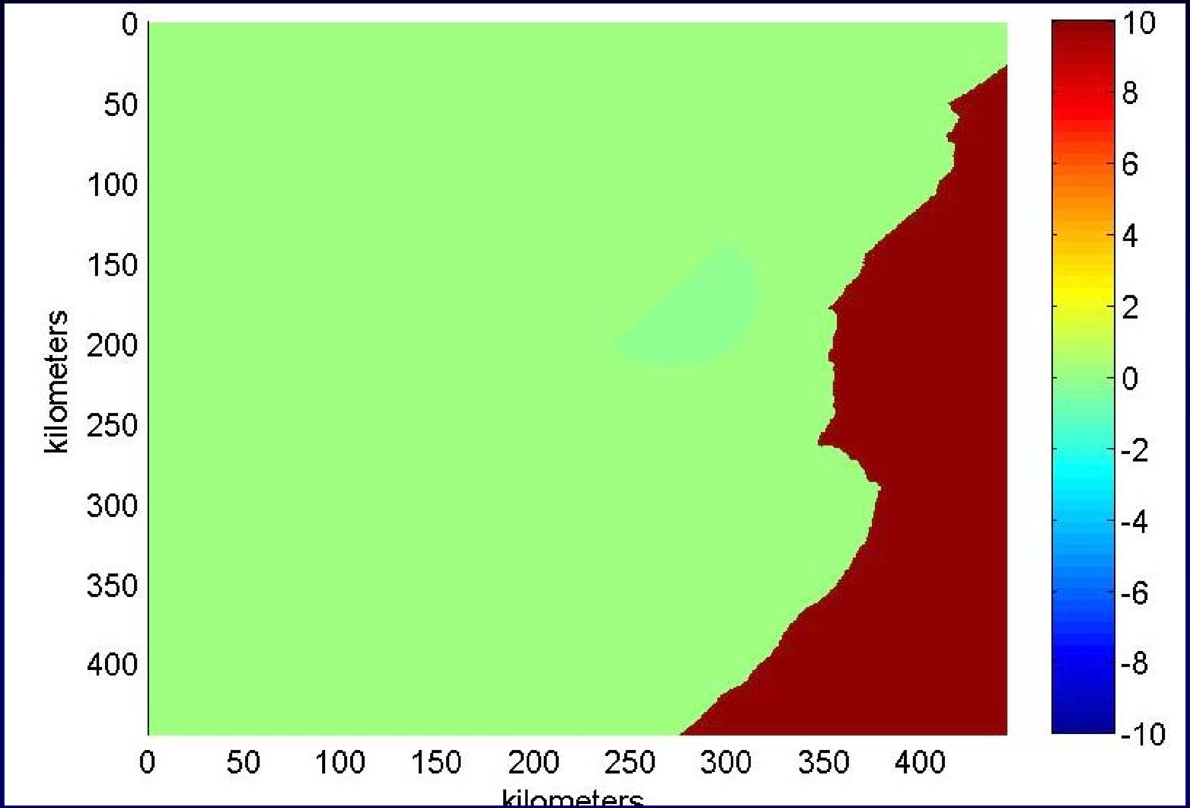
- The "core of MTC 2" was used = 127 km^3 (int vel 2200m/s)
- Starting location was placed at Cretaceous Shelf edge (200m)
- Terminal depth was set to 3500m
- Straight line distance = 98.5 km
- Average dip = 1.92°
- Modern bathymetry

What is the Impact to Near Shore Morocco?

Coastal Wave Propagation using 1000 m^2 grid cells

Wave heights of 2-10m in 100m water depth

This would scale to coastal run-ups of 10-60m

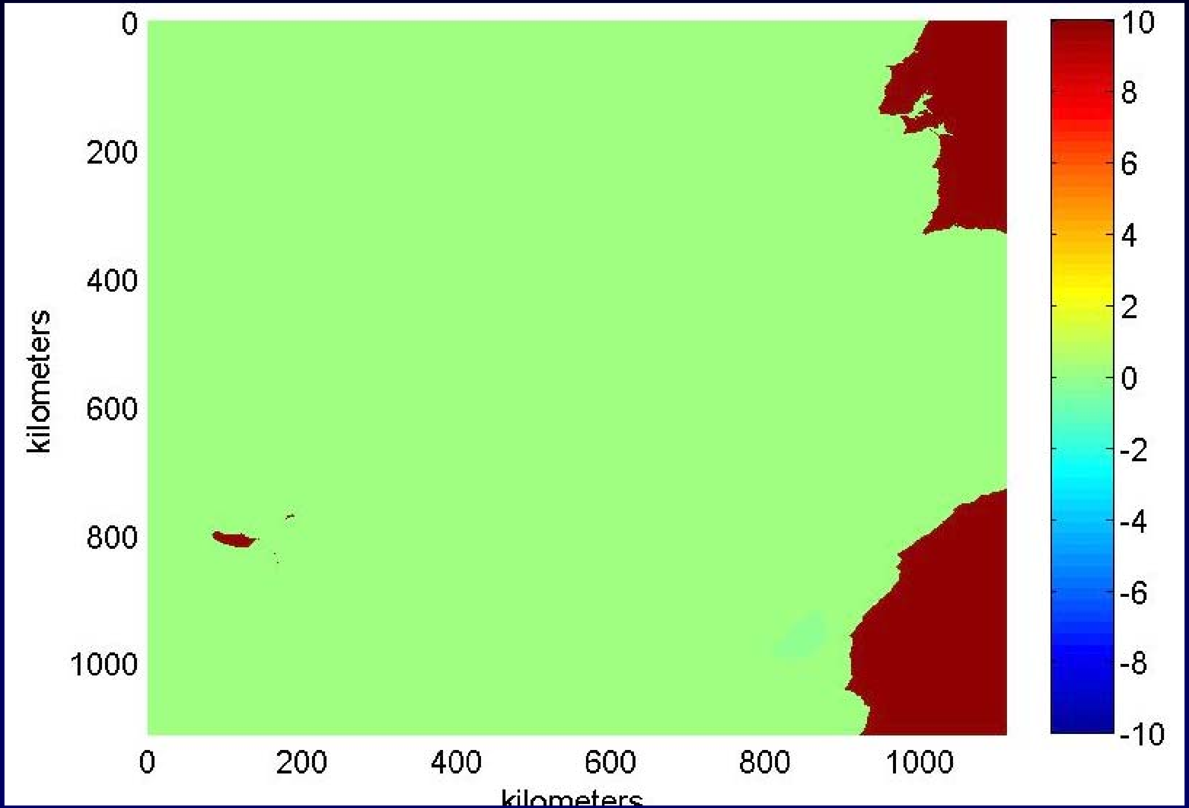


How about Europe?

More far a field, similar effects would be felt

Wave run-ups of 4-10m in Portugal

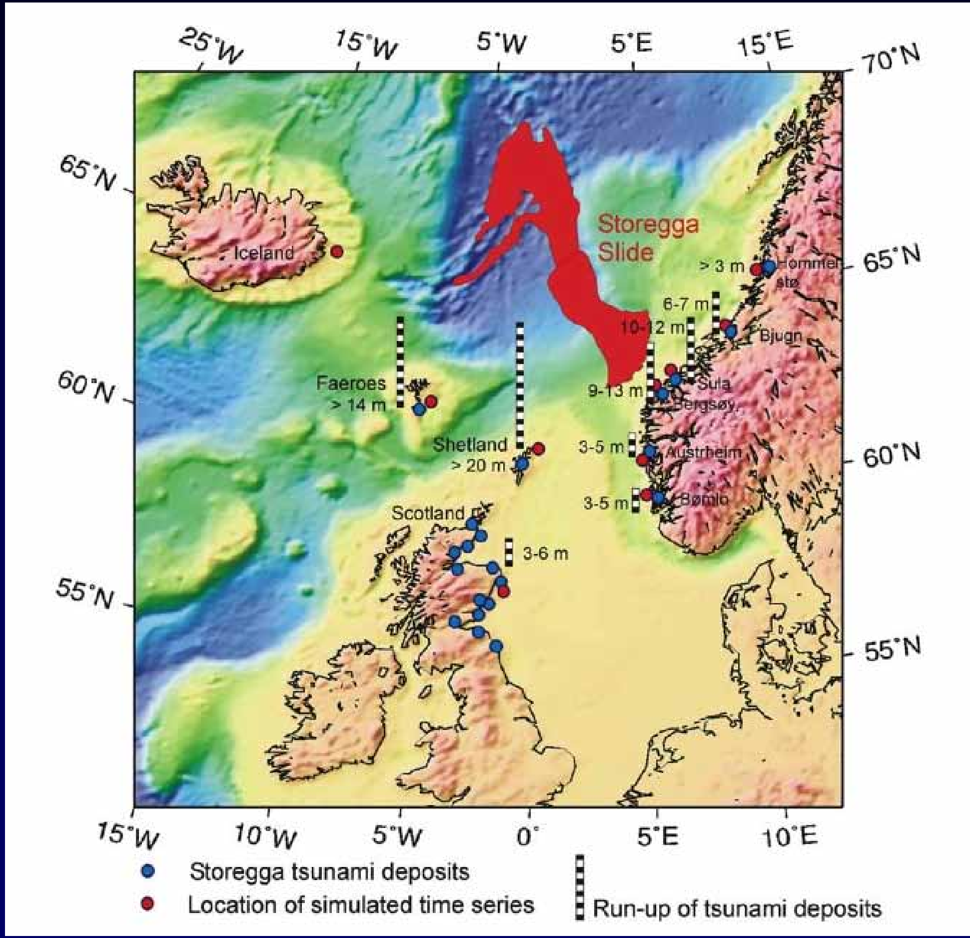
Similar run-ups of 10-60m would be felt in Madeira



How do the run-ups compare to the observed?

These numbers are inline with run-ups from other slides such as the Storegga Slide from Norway.

The 7900 yr BP slide has measured run-ups of 20-25m in the Shetland Islands and more than 14m in the Faeroes (Sea-level adjusted)



Bondavik, et al.(2005)

Implications on Prospectivity

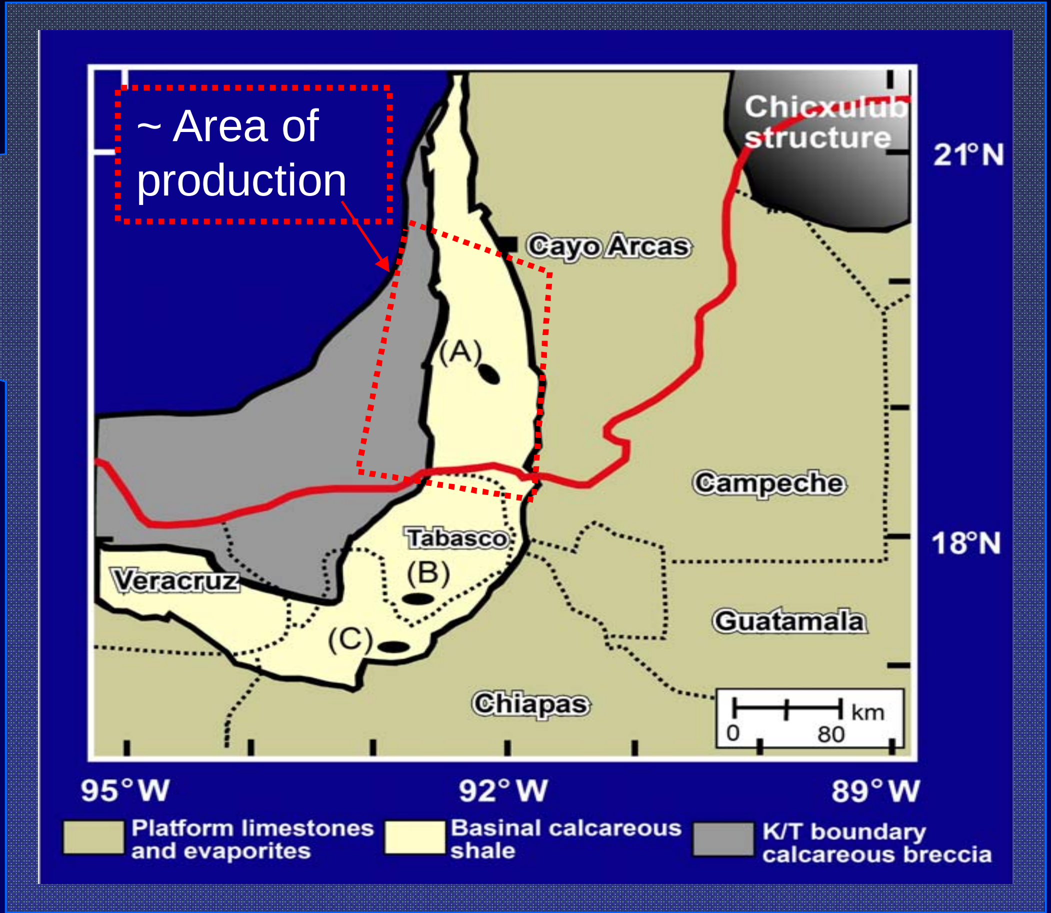
Cantarell Field

Thrusted anticlinal fold

~7 BB of oil and 3.0 TCF gas (April 2000)

10 BB oil and 5 TCF remaining recoverable

70% of reserves in K-T boundary breccias



Modified after Grajales-Nishimura et al., 2000

Conclusions

- These MTCs represent the majority of deposition in the Upper Cretaceous with rafted blocks containing low-sinuosity channels that must be transported from far upslope possibly more than 100km.

- Although these MTCs are not derived from the Yucatán-Chicxulub impact, impacts represent a rare but powerful mechanism to generate seismic shocks.

- Without a clear candidate impact site to trigger the Safi MTCs, the most likely source for the failures remains Late Cretaceous tectonic seismicity related to the initiation of the Alpine Orogeny and Atlas Uplift.

- Modeling of the Safi failures show that the MTCs generated Tsunamis that would of produced African coastal run-ups of 10-60m and European run-ups of 4-20m

- With proven fields such as Cantarell in the Yucatán, Large Regional impact generated MTCs with thick mud-rich packages can provide excellent seals given proper source and reservoir quality

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Thank You!

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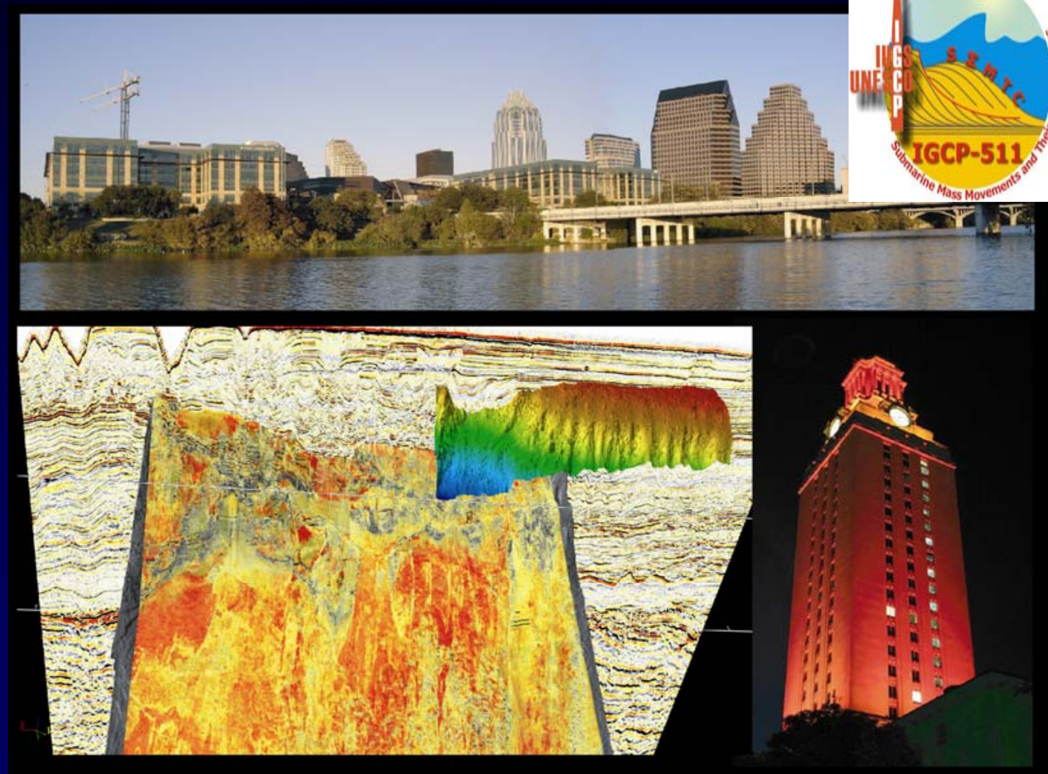

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