Mass Transport Deposits in Offshore Morocco, Safi Haute Mer Area

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Abstract

Recent detailed mapping in a 1,064-km^2 3D seismic survey acquired in offshore Morocco revealed the presence of at least three regional mass transport complexes (MTCs) within the Cretaceous interval of the Safi Haute Mer area, as well as several smaller, younger MTCs. Their extent (up to 100 km^2) and thickness (350 ms) are strongly influenced by surrounding structural features associated with regional tectonics and salt mobilization. Although the MTCs are characterized by chaotic, mounded seismic facies, seismic attribute analysis shows some internal organization. Depositional architectures identified within these units include (1) large-magnitude lateral erosional edges, (2) internal syndepositional thrusts, and (3) 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 average 90 m in width. Clear expression of stacked channel complexes within the mega-blocks indicates that they have preserved their original stratigraphy. Analysis of surrounding highs shows similar-scale channelization, indicating that the blocks may have come from relatively close by. In addition to the larger MTCs, an important number of smaller and younger MTCs have been identified in the study area that are composed of essentially localized slumps and slides. On the basis of limited data, these deposits are thought to be Late Cretaceous or earliest Tertiary in age.

Two working hypotheses address possible triggering mechanisms for generation of these MTCs: (1) Associated step relief along a narrow shelf, presence of salt tectonics, and frequent occurrence of large earthquakes in the area. (2) Mega-tsunamigenic forces associated with the K-T impact in the Yucatan Peninsula. Both hypotheses are currently under consideration.

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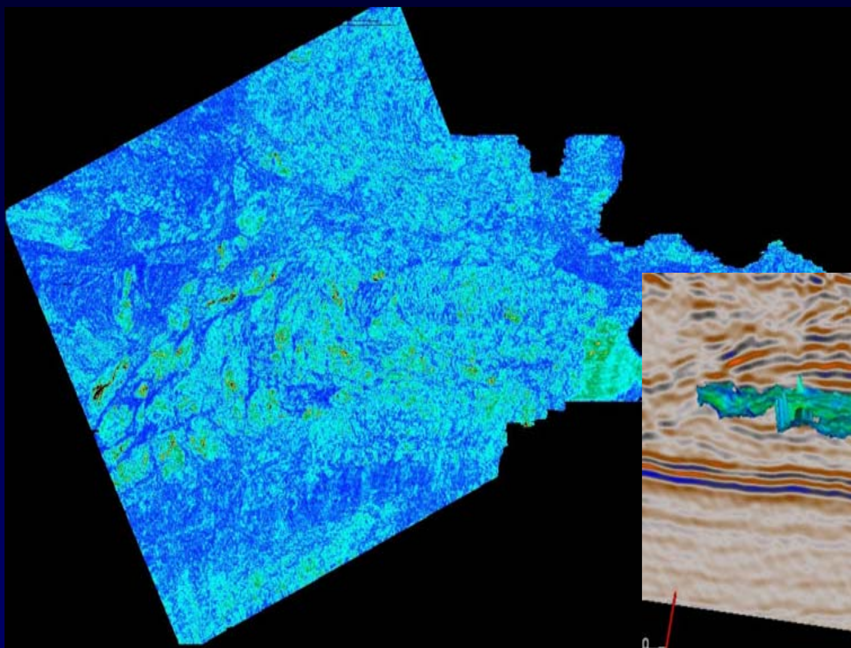
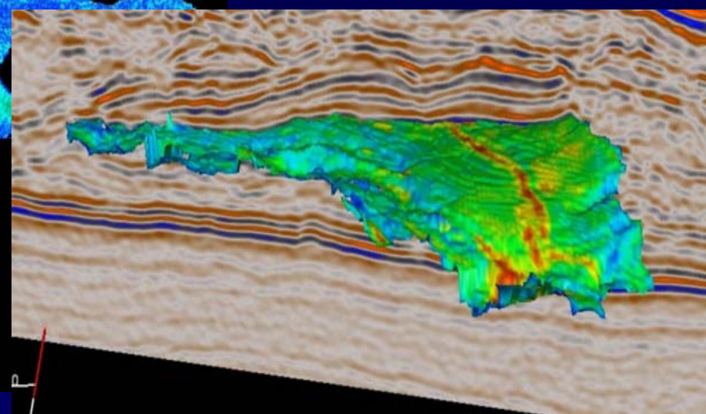
Quantitative Clastics Laboratory IA

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

Quantitative Clastics Laboratory
Bureau of Economic Geology





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 2008

The Problem with MTCs: They are Everywhere

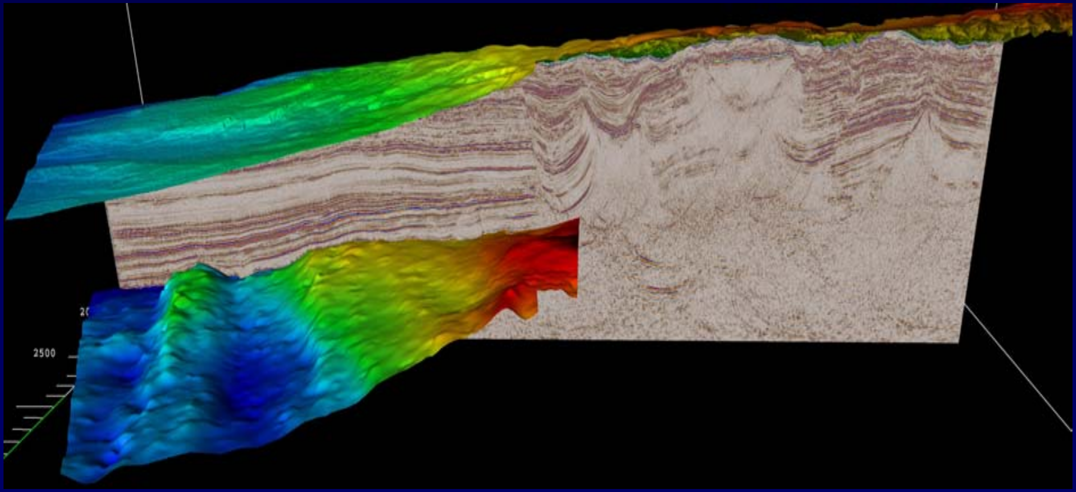
Questions:

◄ What is the nature of the deep water stratigraphic succession in offshore northern Morocco?

◄ What is the seismic geomorphic character of these deep marine deposits?

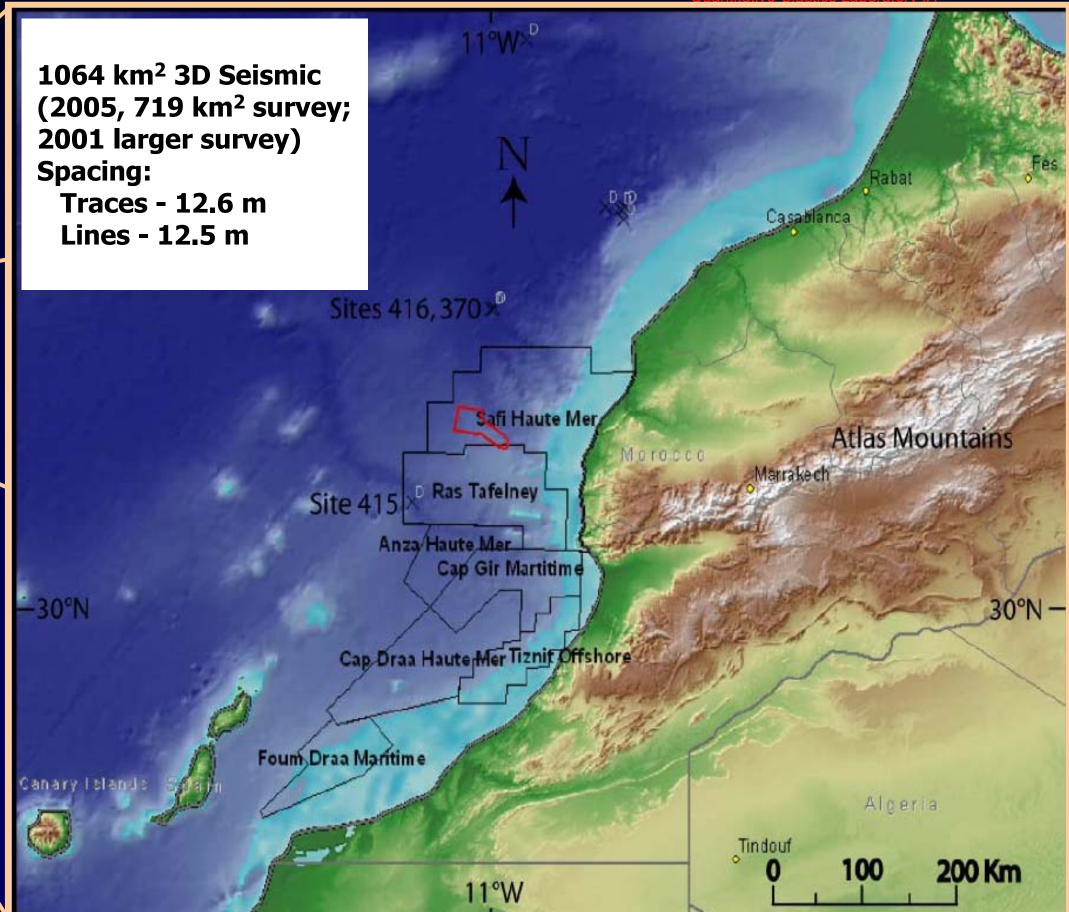
◄ What is the likely architecture, lithology and origin of large mass transport deposits in offshore Safi Haute Mer?

◄ What are the implications of the occurrence of these deposits for marine infrastructure and prospectivity?



Study Area – Safi Haute Mer, Morroco

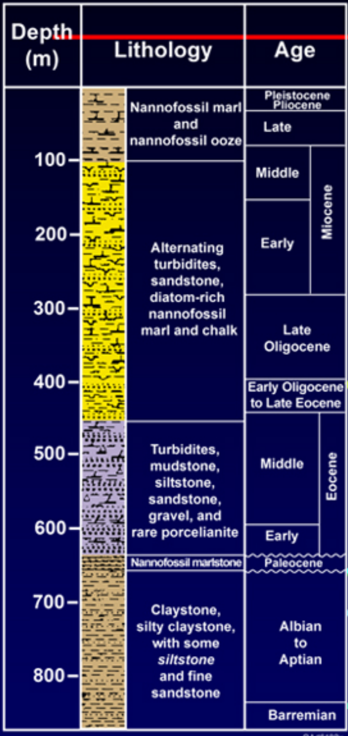
1064 km^2 3D Seismic (2005, 719 km^2 survey; 2001 larger survey)
Spacing:
Traces - 12.6 m
Lines - 12.5 m



Updip to downdip stratigraphy

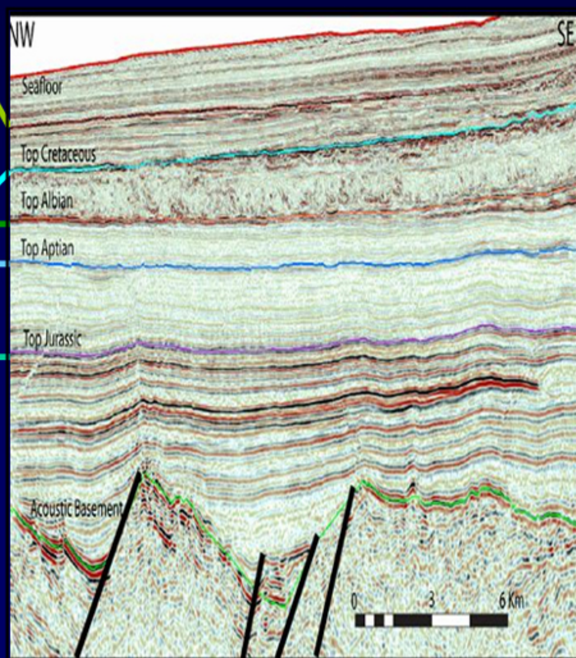
Updip Shelf Margin

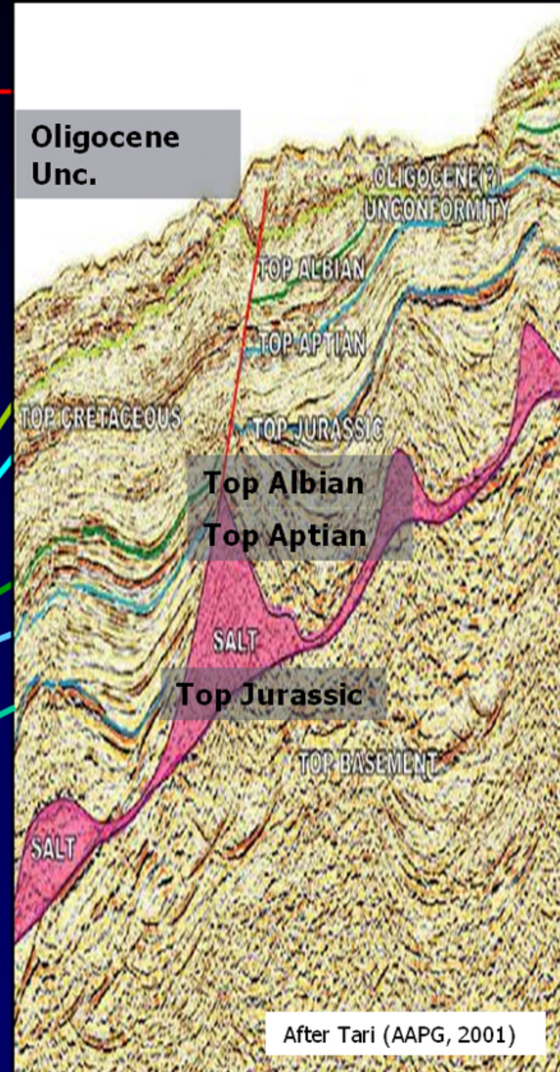
Downdip basin 416



After Lancelot and Winterer (1980)

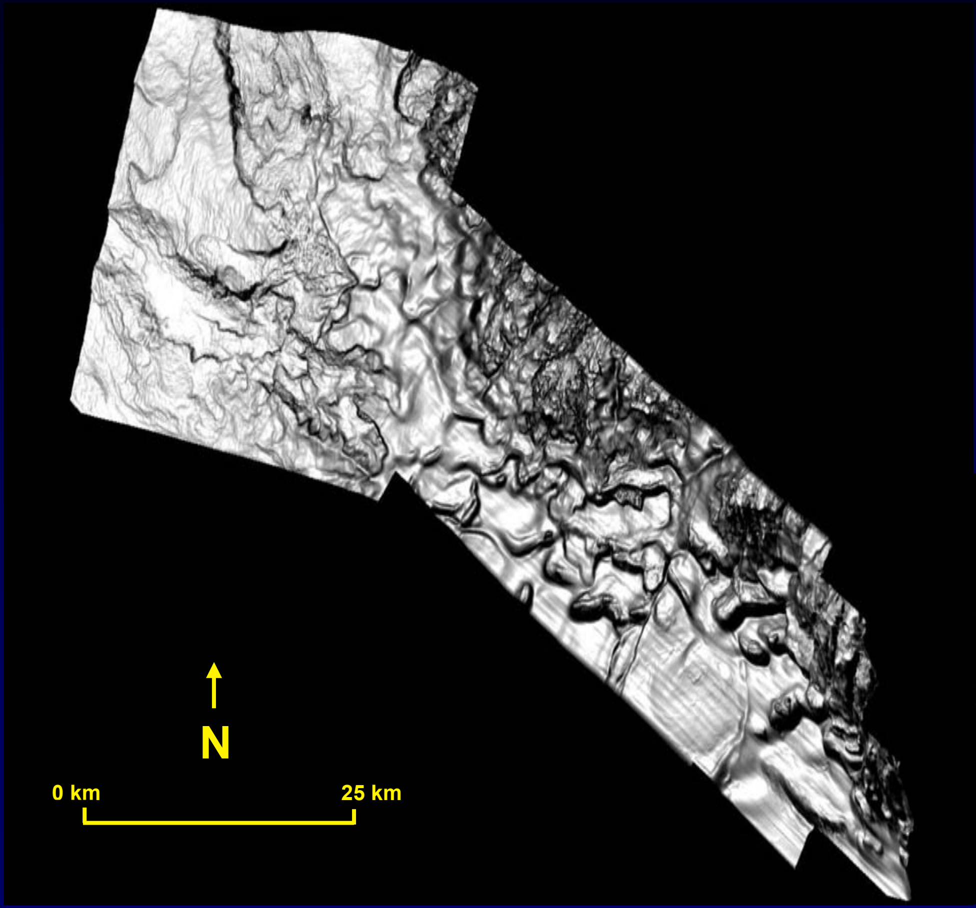
SHM Study Area





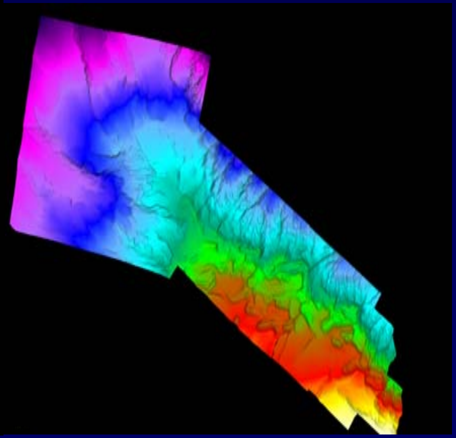
After Tari (AAPG, 2001)

Seafloor Geomorphology

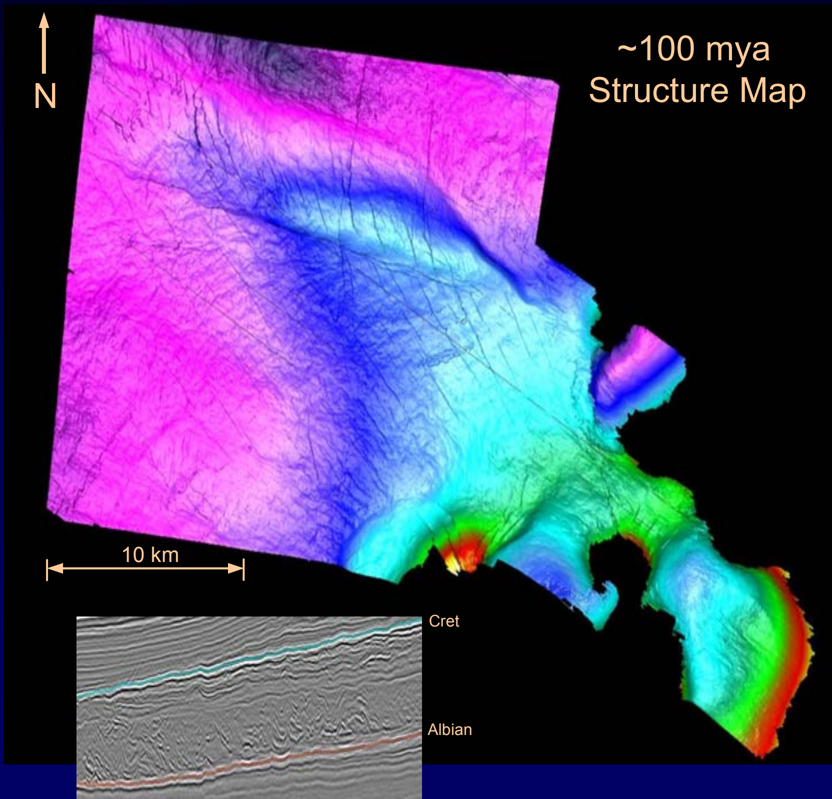


Mobile Salt at depth is strongly expressed in the eastern portions of study area, causing the extremely rugose seafloor bathymetry

In the West, the regional thrust causes uplift expressed on the seafloor and generates significant slumping

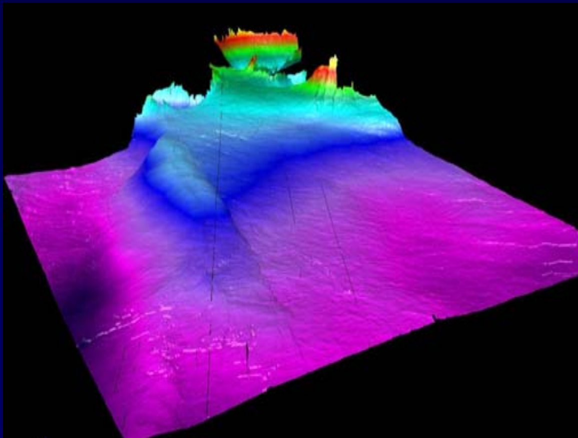


Structure map on the top of the Albian



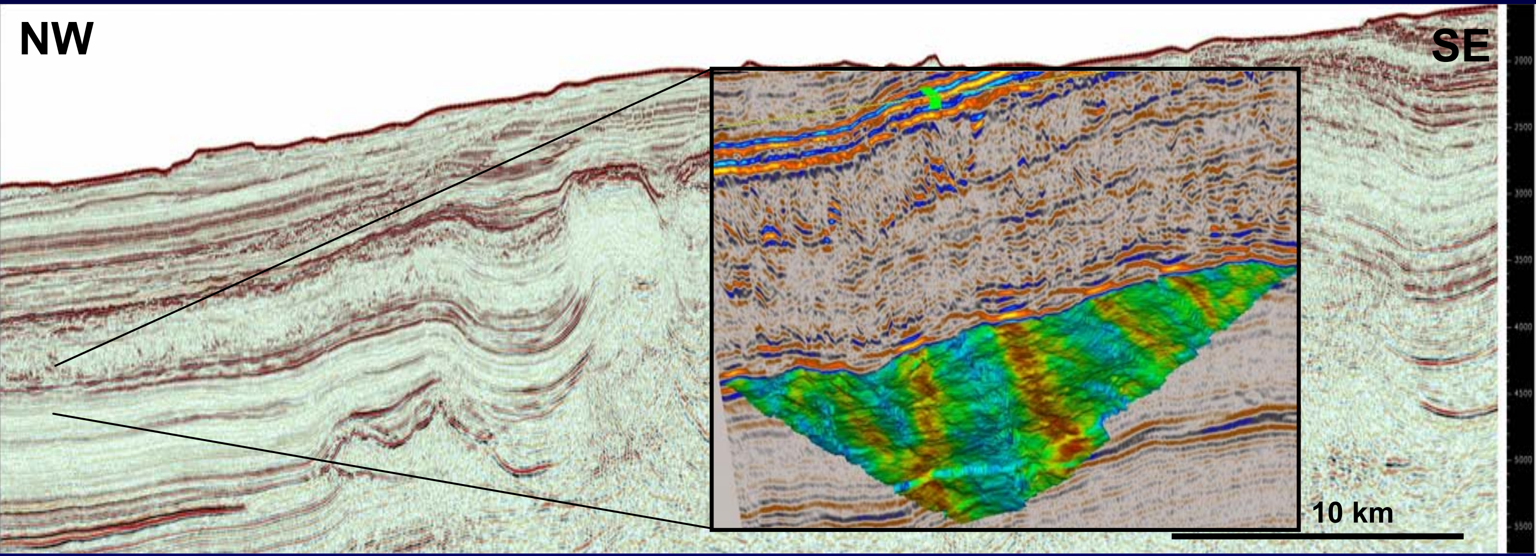
Top Albian

- Strong reflector at base of zone of interest
- Surface prevalent throughout study area
- Use as reference surface for mapping within the Upper Cretaceous

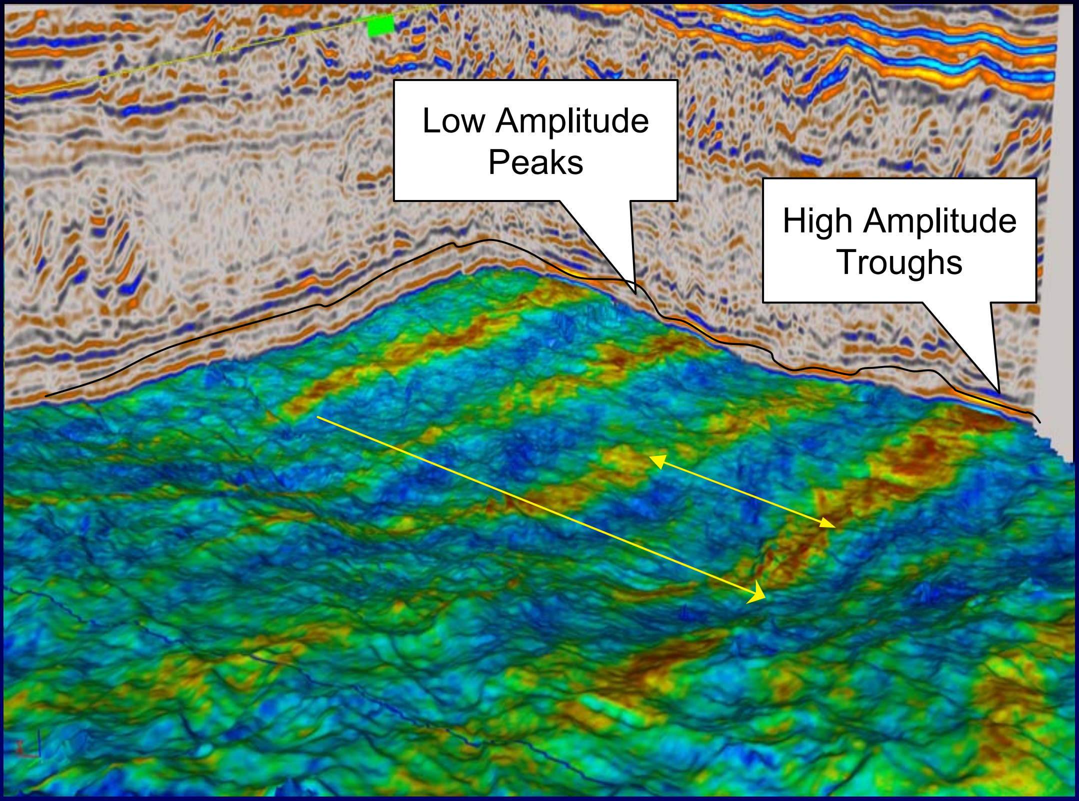


Depositional Elements: Sediment Waves

- Large-scale deep water, sediment waves over pre-MTC intervals
- Indicators for current orientations on the shelf during Middle-Late Cretaceous
- Sediment waves morphometrics = 1600 m across, 40 ms high, 15000 m long



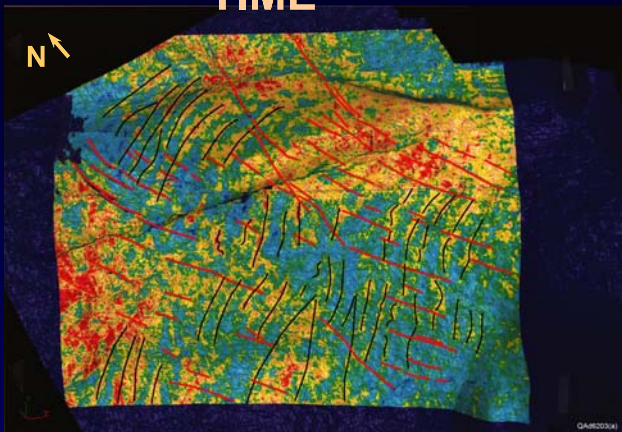
Depositional Elements: Sediment Waves

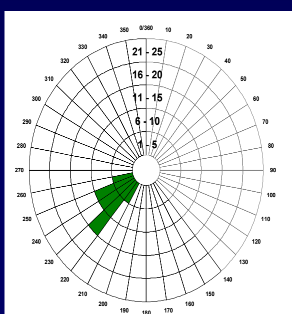


- Downdip orientation
- Average 1.5 km from Trough to Trough
- Very resolvable upper wave seismic response

Depositional Elements: Sediment Waves

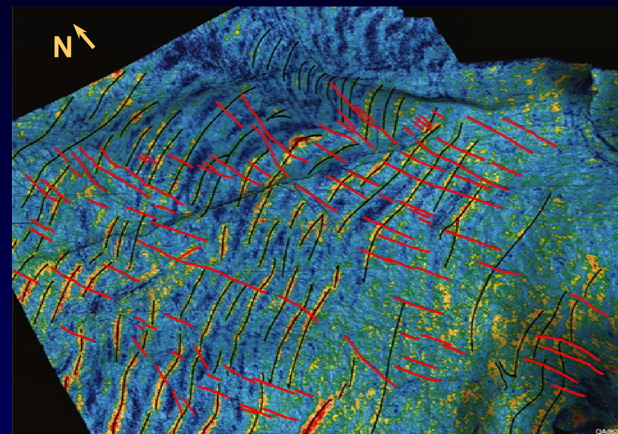
ALBIAN TIME

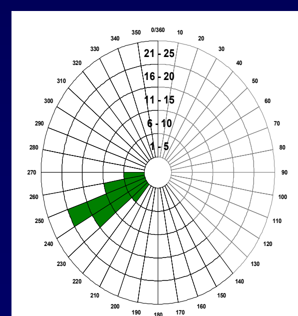




Albian Sediment Waves oriented southwest to northeast

ABOVE TOP ALBIAN



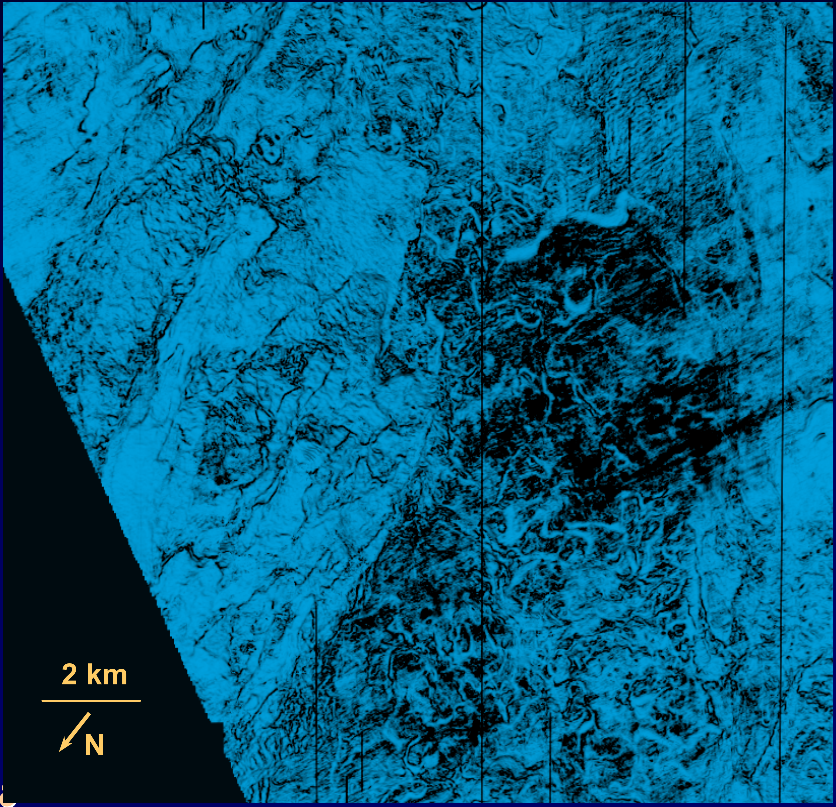


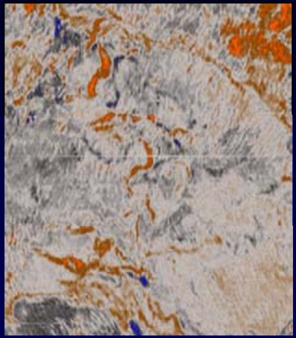
Post-Albian Sediment Waves are oriented slightly more westward then the older Albian field.

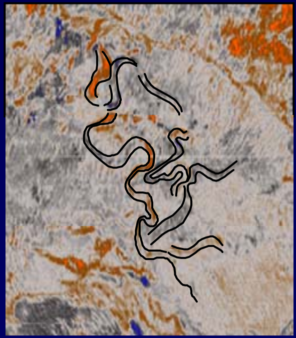
Depositional Elements: Slope channels

Channels show single thread character, no clear levees, amplitude brights.

High sinuosity, ~100m wide.

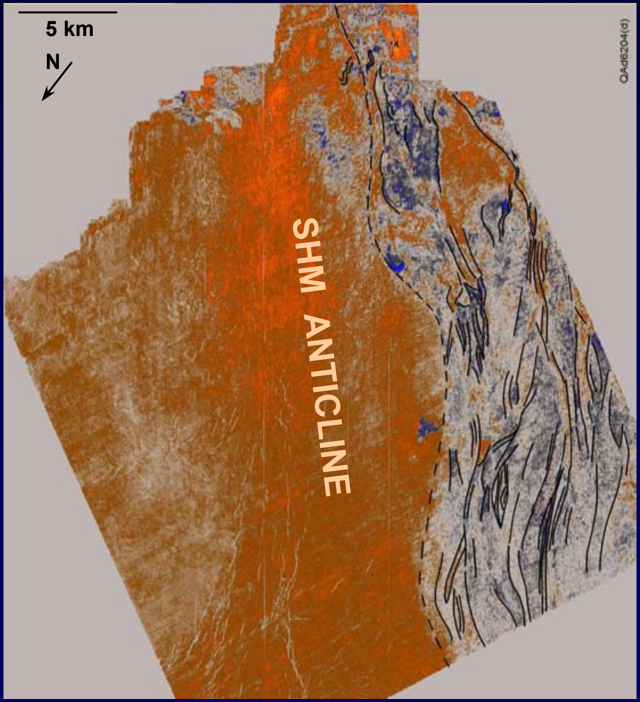


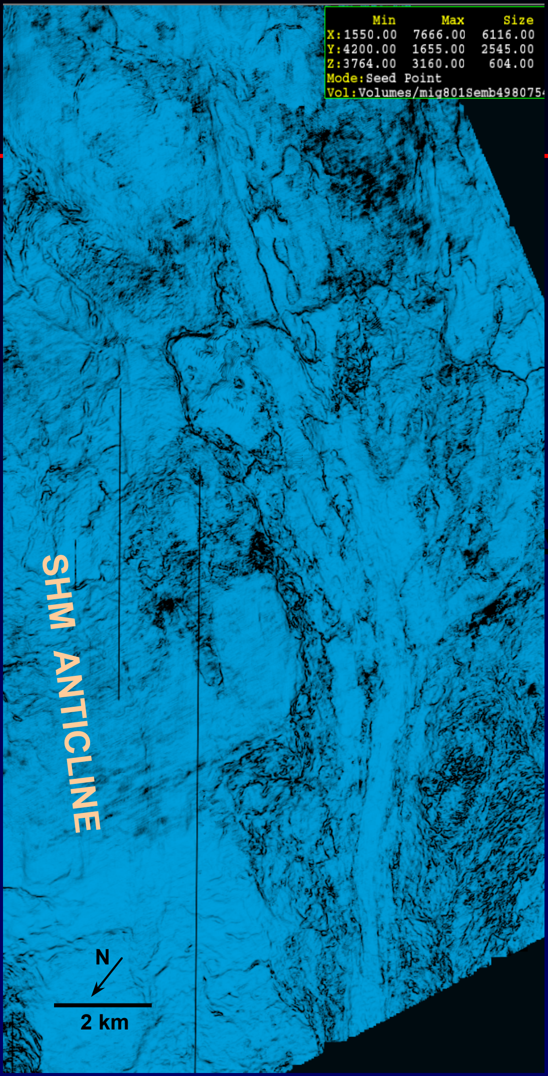




Depositional Elements: Major channel fairways

Large structurally controlled fairways of sedimentation, persist throughout the Cenozoic section

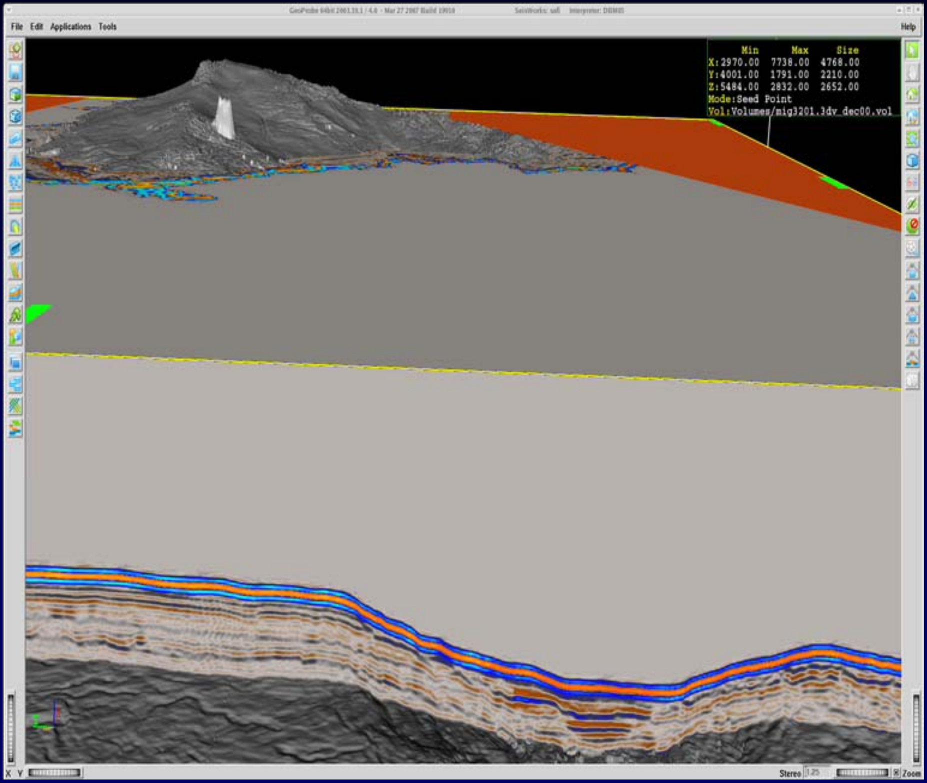




Depositional Elements: Major channel fairways

Quantitative Clastics Laboratory IA

- S1.0 surface just below seafloor, looking to the SE
- Large source area, originating in the Southern Salt Province with additional contributions from the SHM Anticline and from the southwest
- What makes of the fill in these pathways?

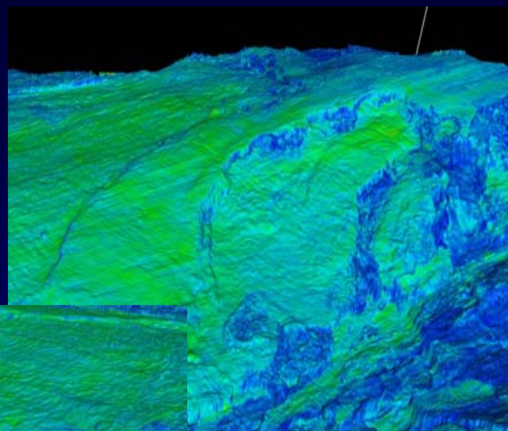


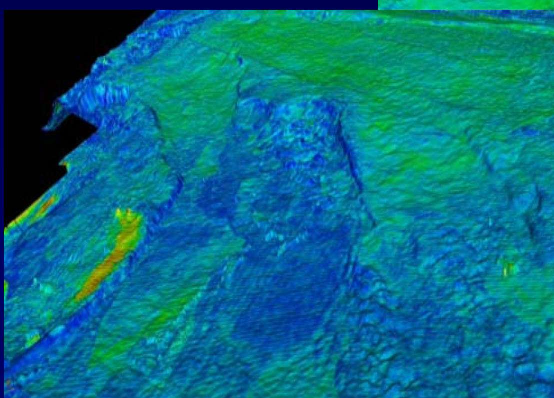
Looking West to the East

Depositional Elements: Debris Flows and Slides

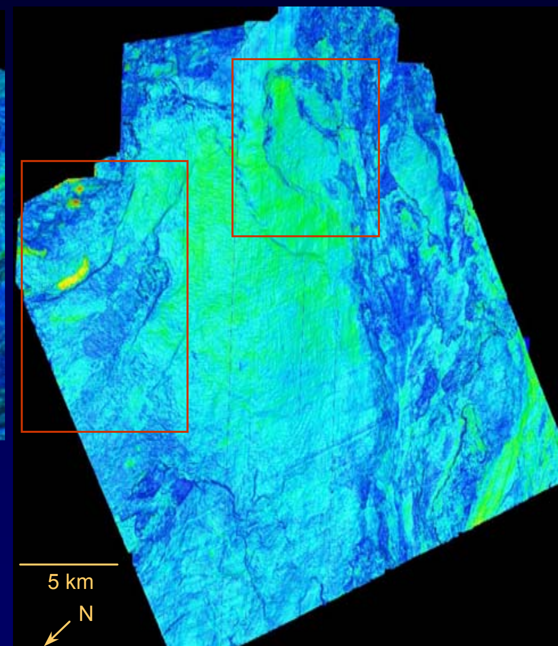
Varying styles of seafloor failures from the late Cretaceous through modern.

Southern dipping Cenozoic debris flows are commonly associated with failure into the evolving sediment fairways

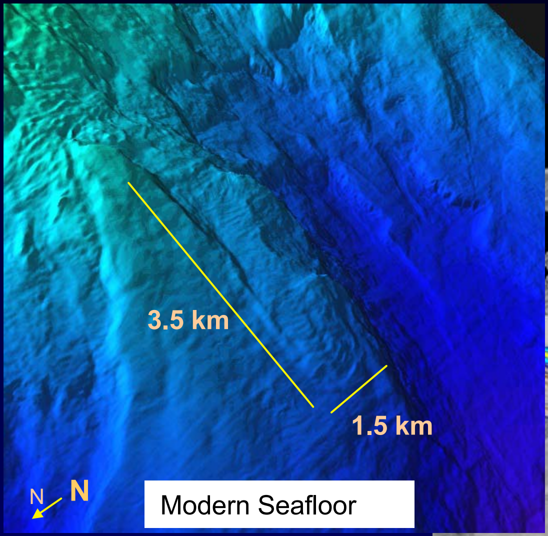




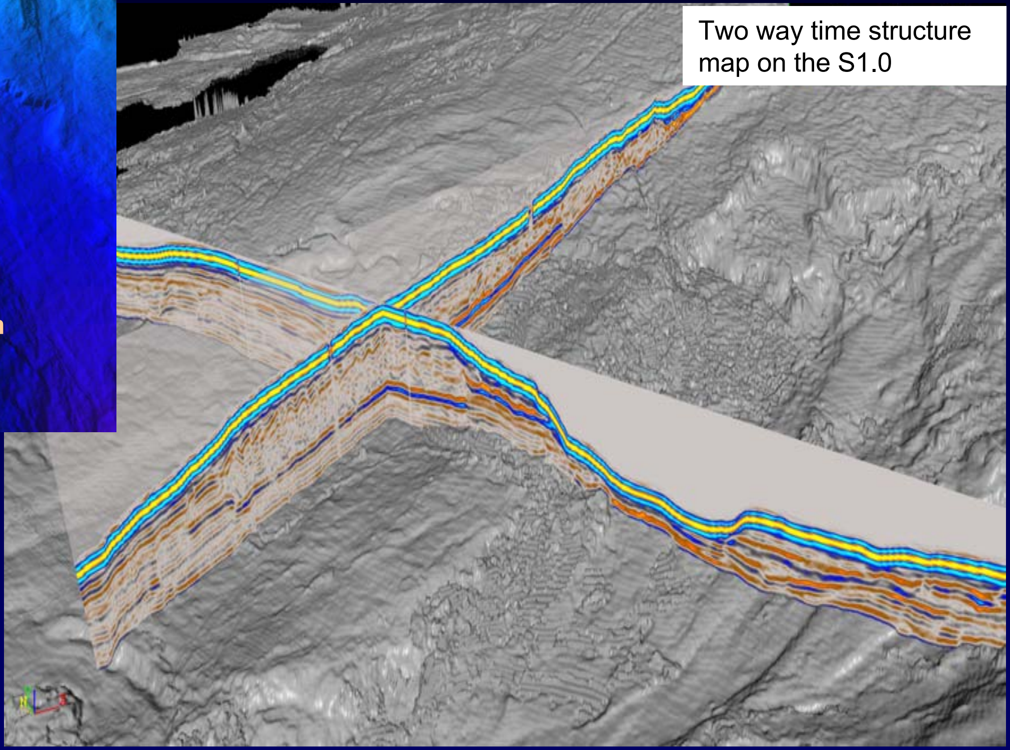
Examples of sheet gravity slides caused by change in dip from the uplift associated with the SHM Anticline



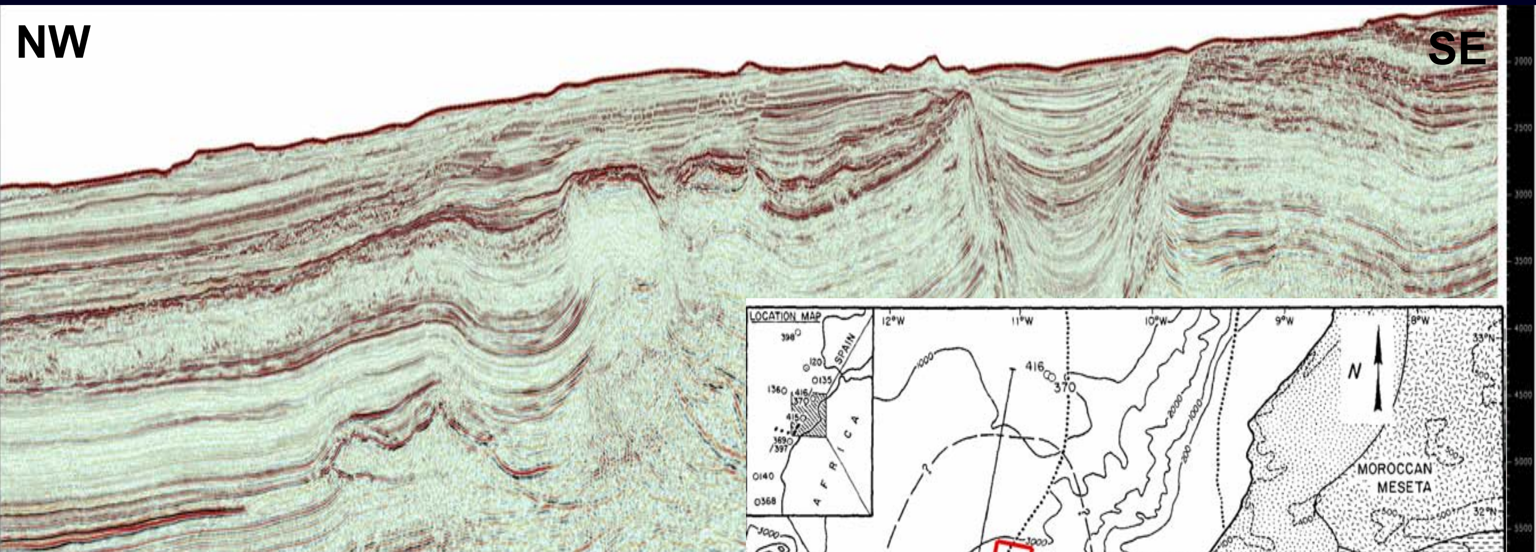
Depositional Elements: Gravity Slumps

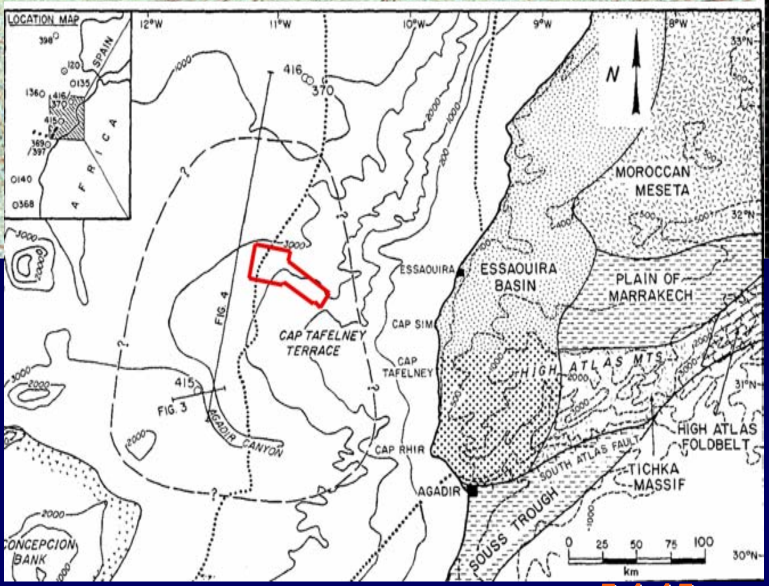


6.5 sq km Gravity Slump



Depositional Elements: MTC's



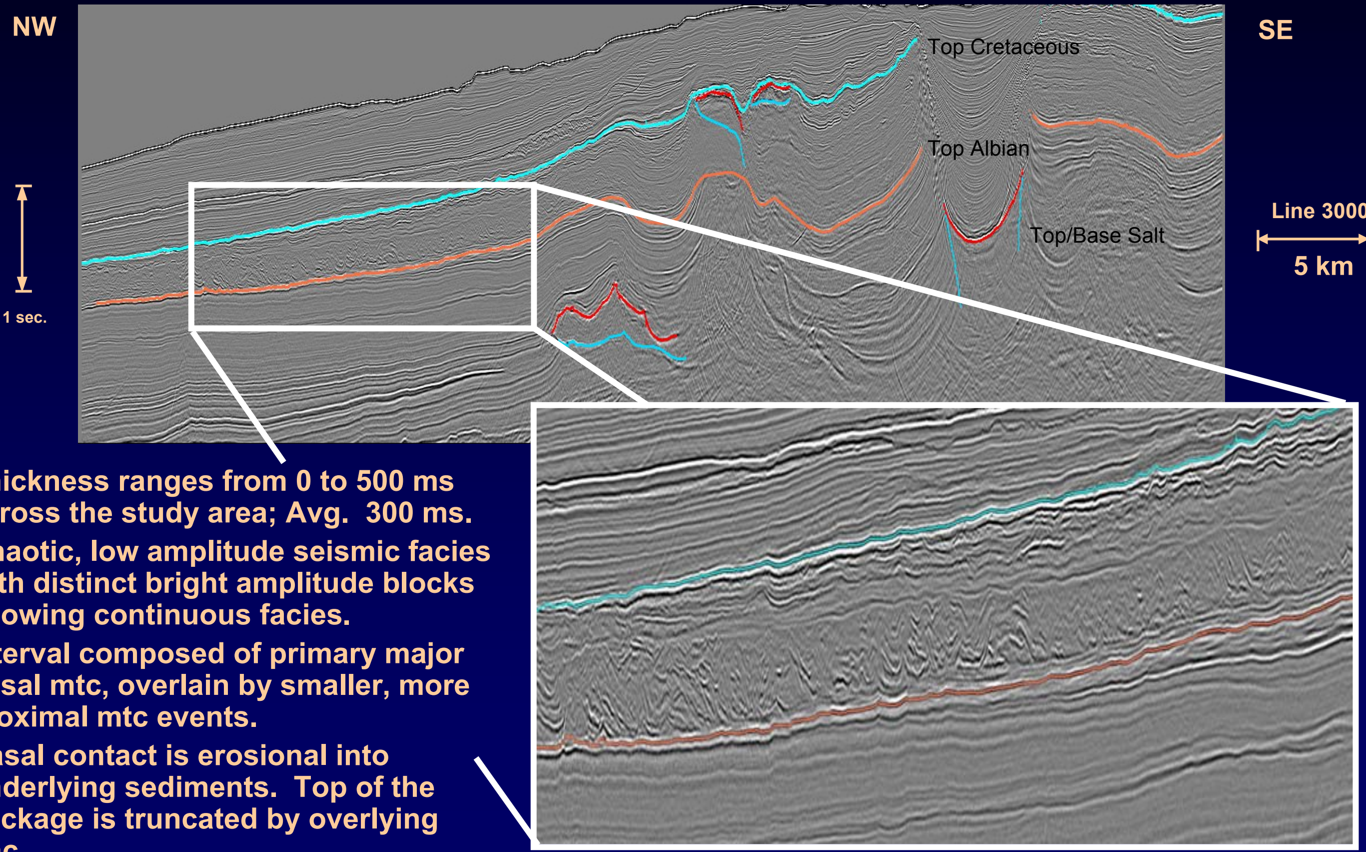


Disturbed bedding, large rafted blocks, flow lines, highly variable material and matrix make up the Upper Cretaceous Mass Transport Complex

Supposed penetration in the ODP 415 suggested a 20,000 sq km flow.

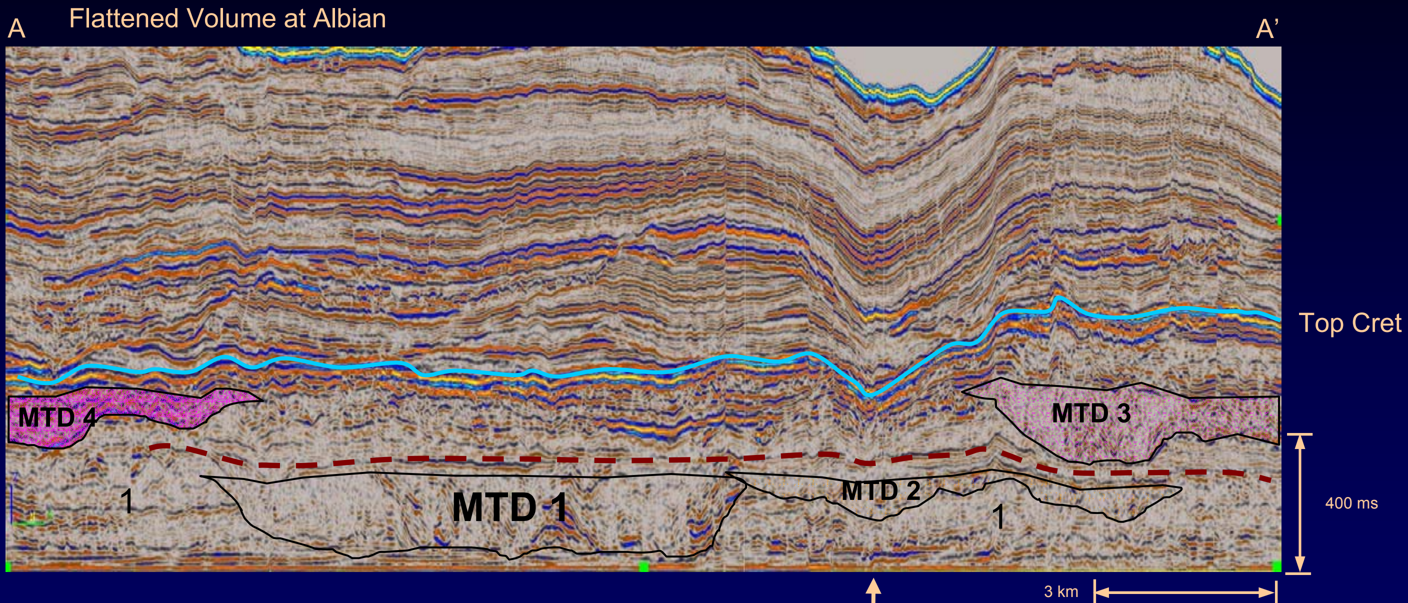
Price (1980)

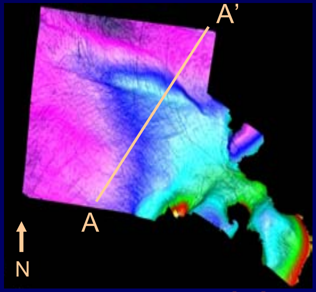
Upper Cretaceous Mass Transport Deposits



- Thickness ranges from 0 to 500 ms across the study area; Avg. 300 ms.
- Chaotic, low amplitude seismic facies with distinct bright amplitude blocks showing continuous facies.
- Interval composed of primary major basal mtc, overlain by smaller, more proximal mtc events.
- Basal contact is erosional into underlying sediments. Top of the package is truncated by overlying unc.

Multiple stages of MTC development





Stage 1) Post Albian Deposition

Stage 2) Mass Transport Complex - MTD 1

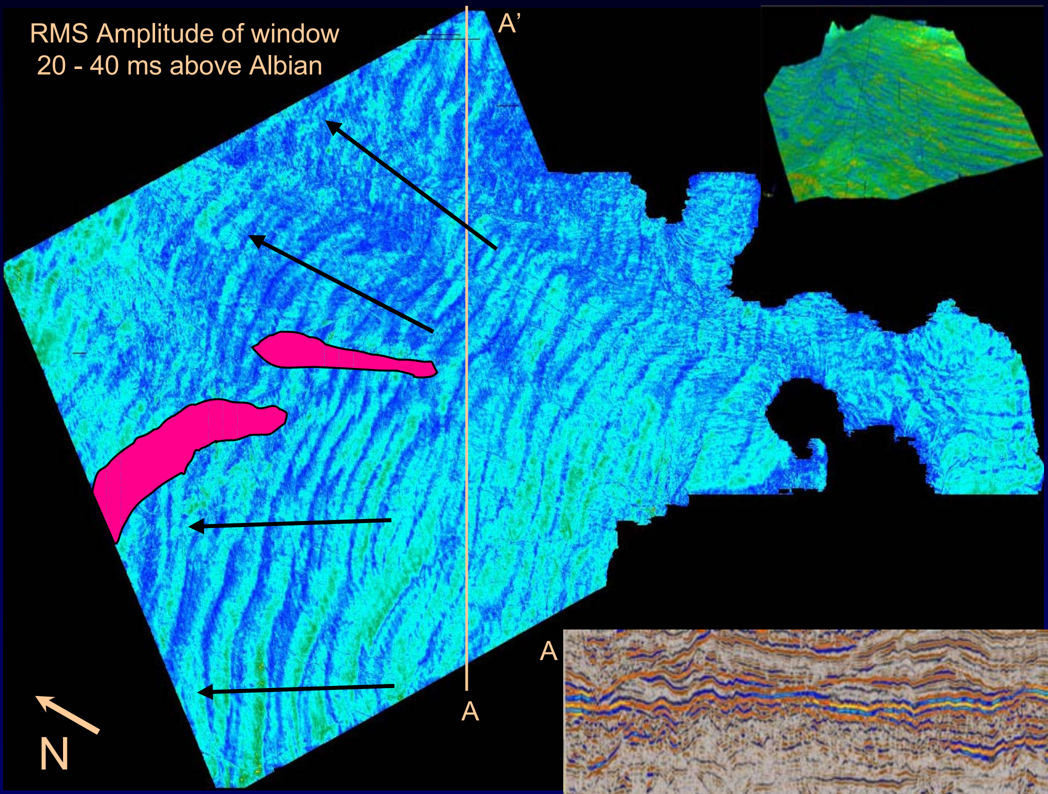
Stage 3) Mass Transport Complex - MTD 2

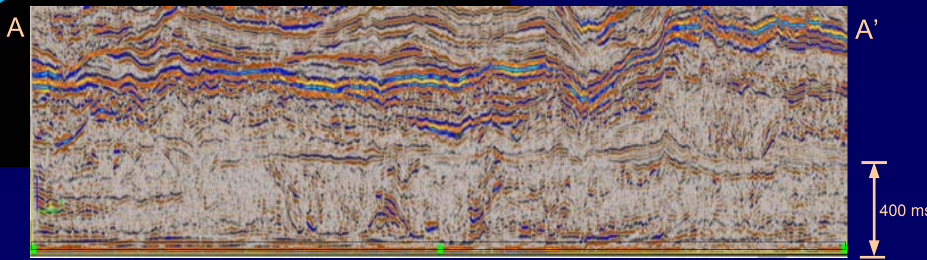
Stage 4) Survey wide conformable reflectors

Stage 5) Activation of reverse fault in late Cret. causing E-W anticline

Stage 6) MTD 3 and 4 on flanks of anticline

Mass Transport Complexes



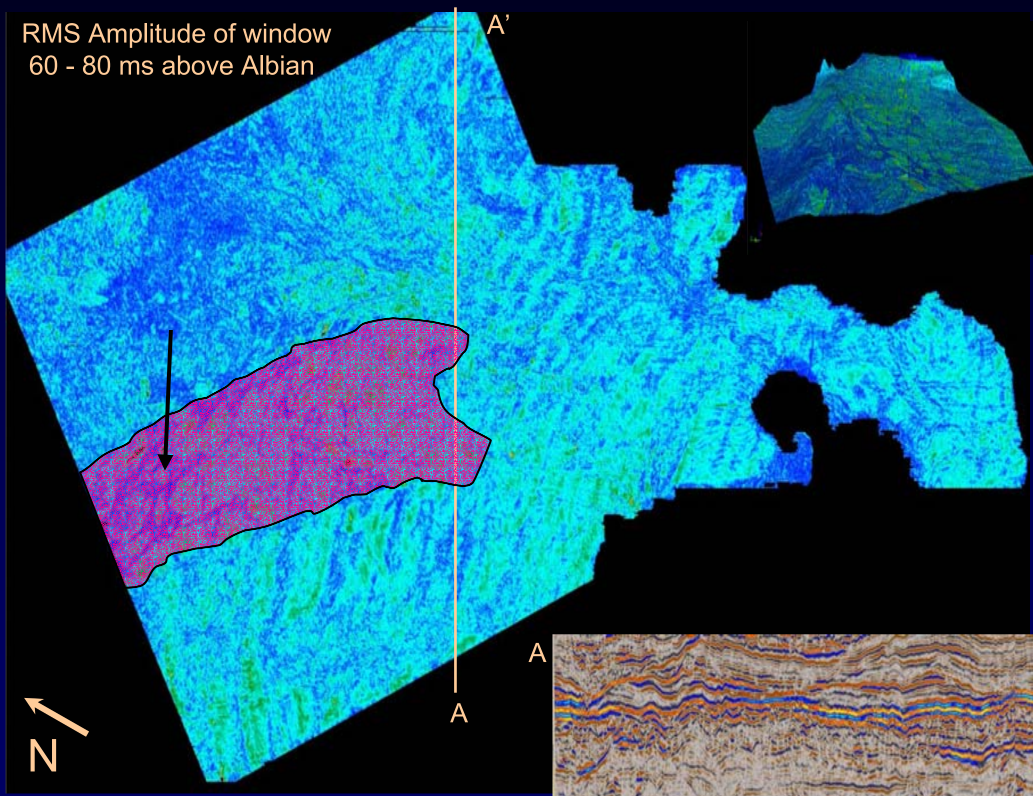


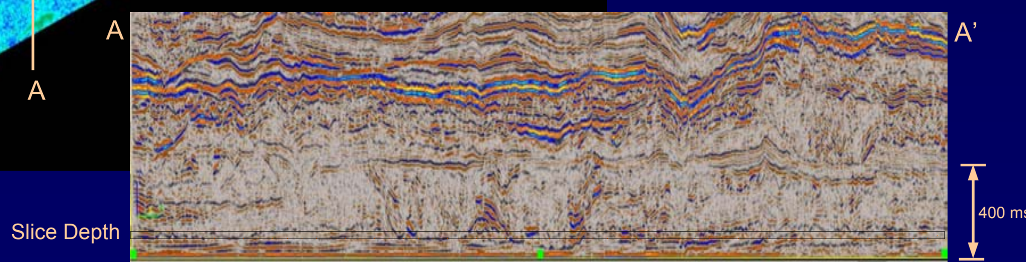
Wavy seismic attribute is characteristic of the sediments at base of upper Cretaceous

Indicator of paleoslope direction

First evidence of incision by MTCs

Mass Transport Complexes

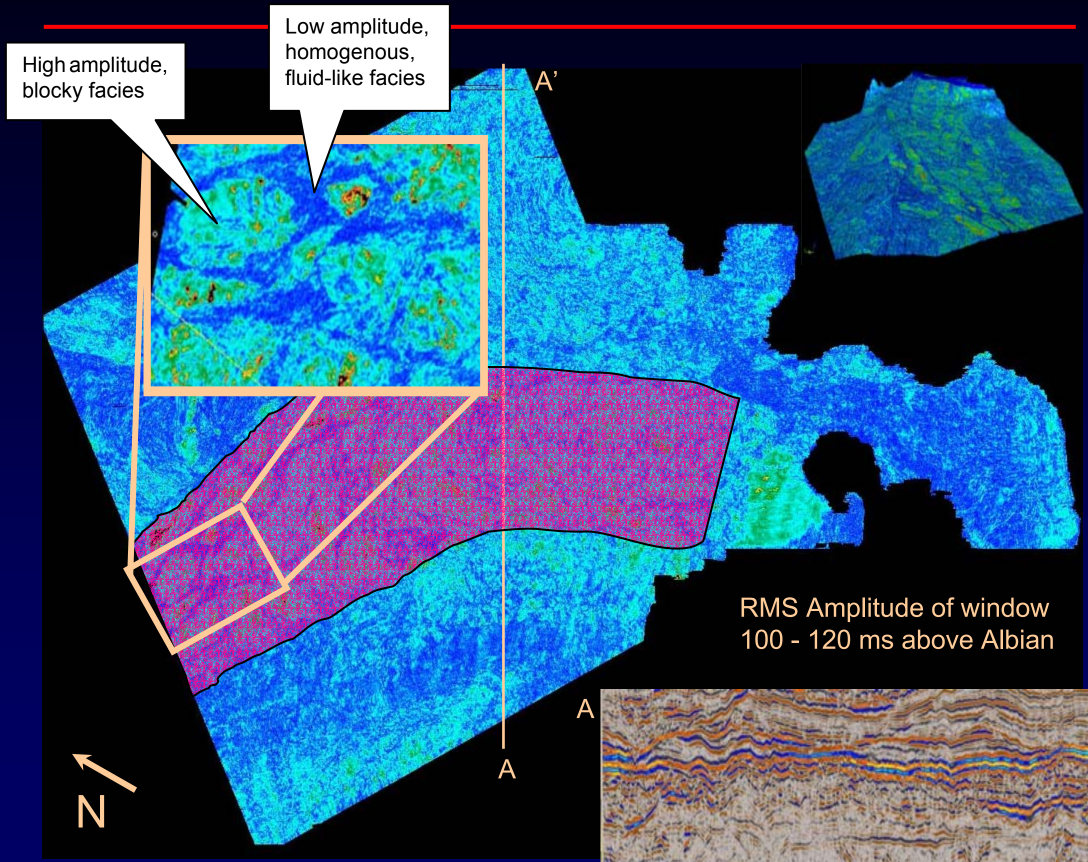




MTD 1 is eroding/replacing more of the preexisting sediment

First observations of bimodal flow within MTD 1

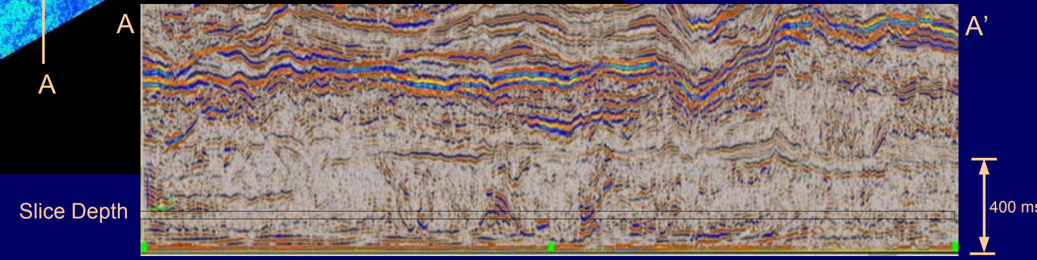
Mass Transport Complexes



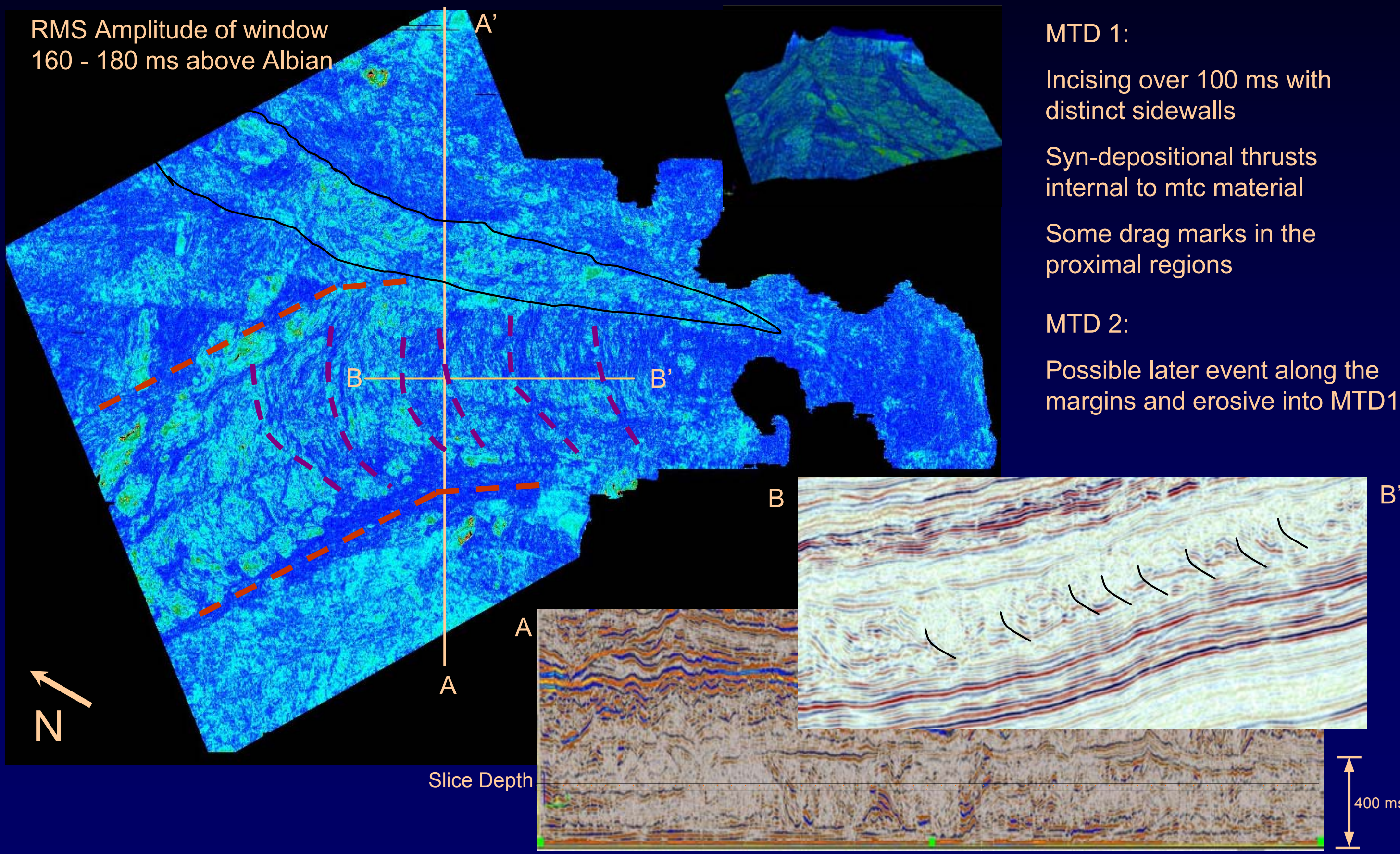
MTD 1 reaches 8 kms in width, mapped with a min length of 30kms

Two distinct seismic facies within MTD 1

RMS Amplitude of window 100 - 120 ms above Albian



Mass Transport Complexes



MTD 1:

Incising over 100 ms with distinct sidewalls

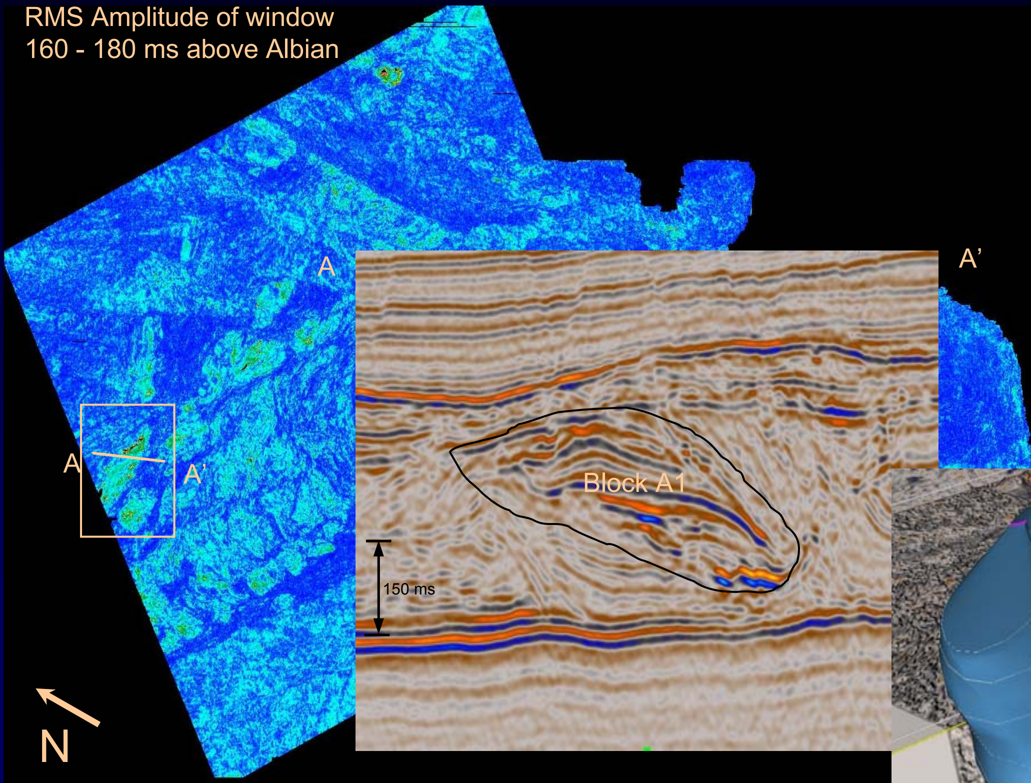
Syn-depositional thrusts internal to mtc material

Some drag marks in the proximal regions

MTD 2:

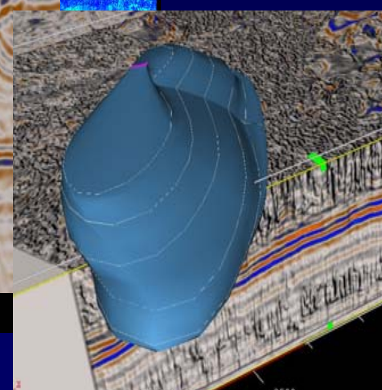
Possible later event along the margins and erosive into MTD1

Suspended blocks within MTCs



Observed "Mega-Blocks" on northern flank of MTD 1

Block A1
- 3.3 Kms length
- 1.1 Kms width
- 3.63 km^2 area
- 240 ms thickness



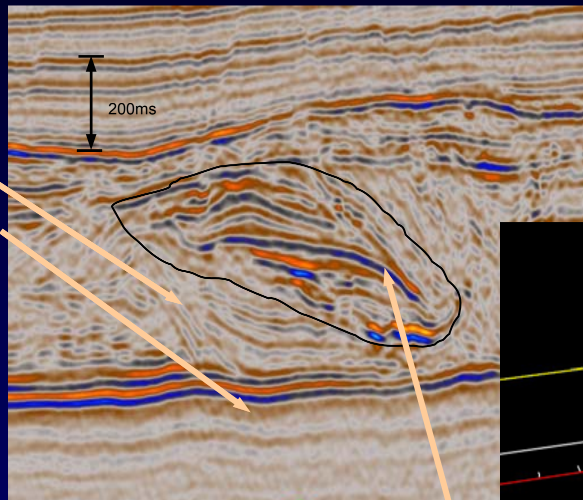
3D Block geometry

Suspended blocks within MTCs

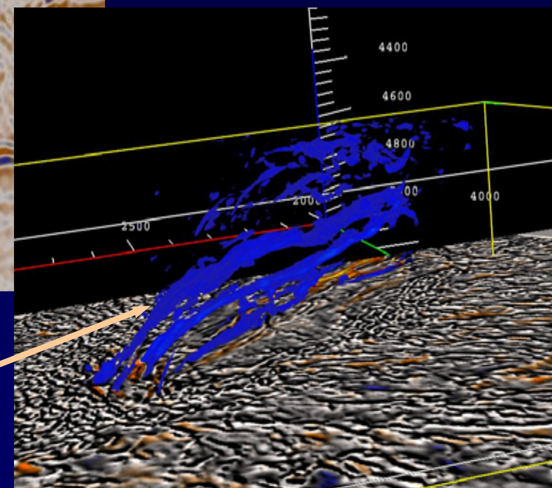
Block A1
Architecture

Ramping of Sediments

Compaction of underling beds



Voxel volume of the internal architecture of Block A1

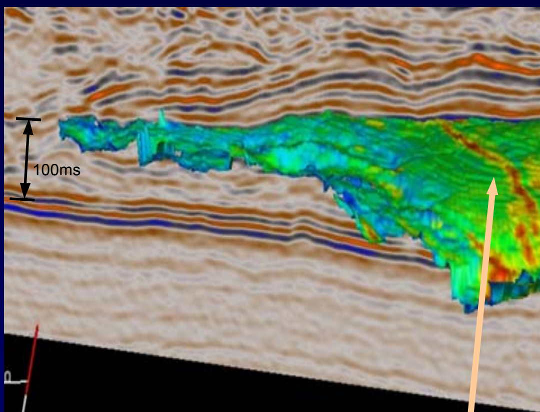


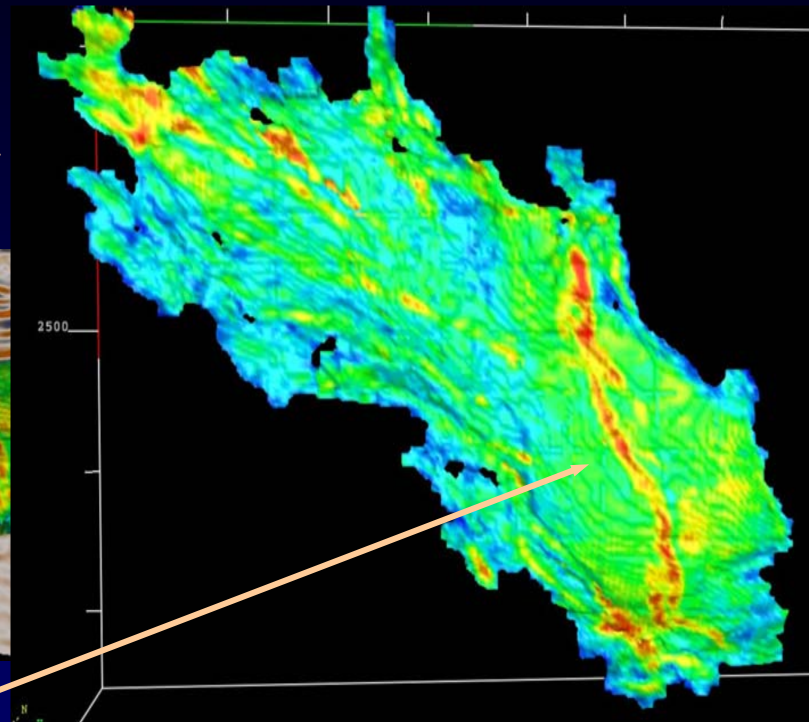
Layering internal to Blocks

Block 1A Architecture

Block 1A

Picking minimum reflector within Block1A
Attribute extraction on surface
(20 ms - Abs Max Amp)





Channelization

Discrete low sinuosity, single thread channels approximately 90 m wide

Where is the source area for these MTCs?

Quantitative Clastics Laboratory IA

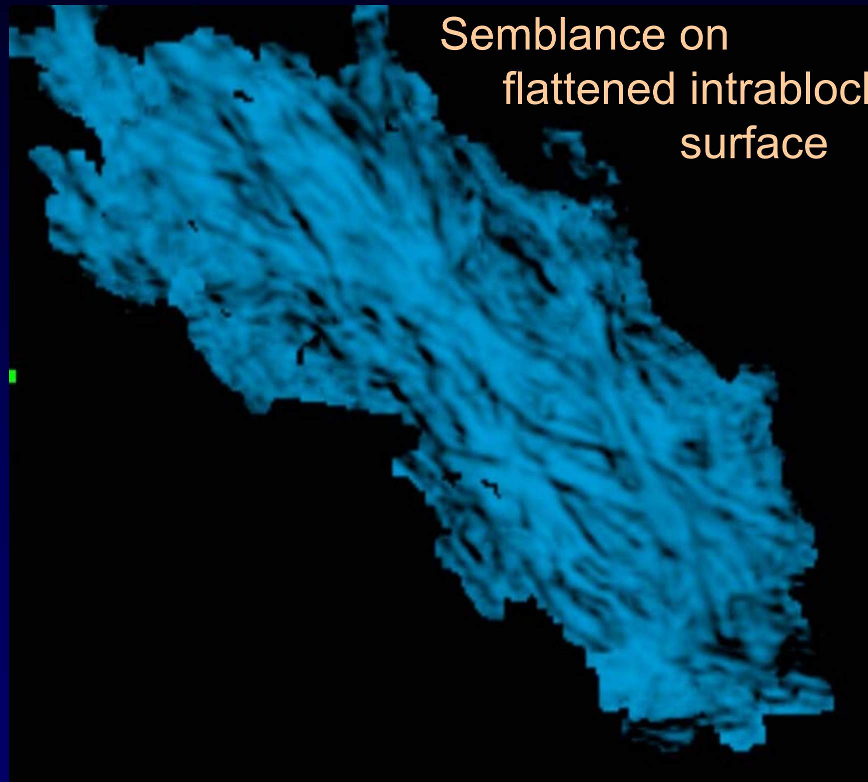
May not be locally derived.

See stacked anastomosing lows sinuosity channels.

Un-fractured character.

Channel systems in these large blocks have not yet been observed anywhere within the Albian to modern in the study area.

It is possible that these blocks were rafted from upslope, possible 100s of kms distance from their source.



What caused this MTC event?

- Debris Flows have been observed just below the Iridium spike associated with the meteor impact at the K-T boundary in various localities around the world*
- Could these latest Cretaceous-age MTC's in offshore Morocco be related to the Chixulub Impact Crater in the Yucatan of Mexico?
- Similar "tsunami-backflow deposit" hypotheses have been proposed for relatively age-equivalent mass transport deposits of the Tejas Series to the south**.
- What opportunity, if any might these deposits offer as hydrocarbon plays in offshore Morocco?

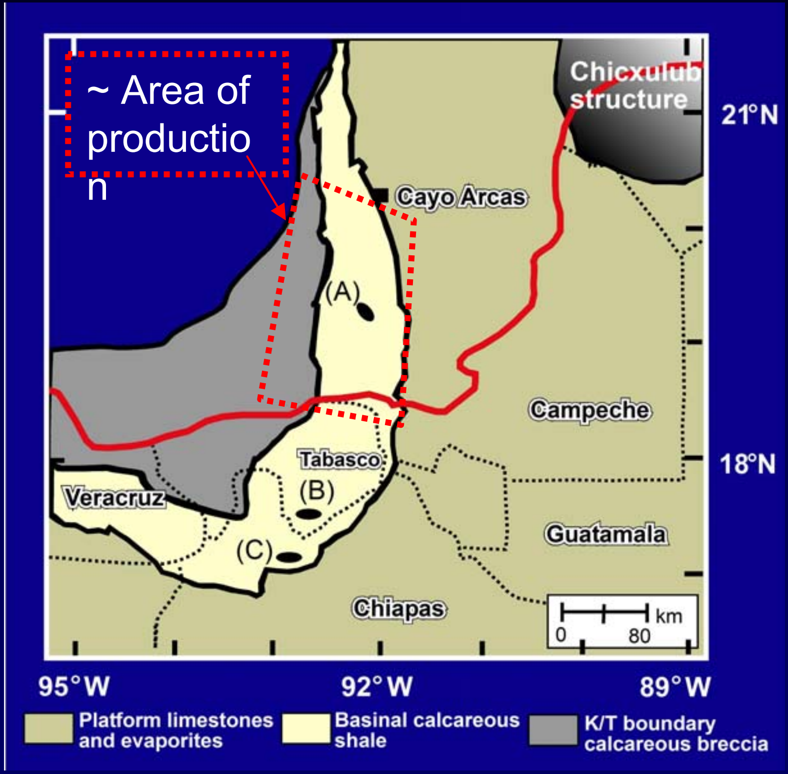
Upper Cretaceous Paleogeographic Map

(from Blakey 1996)

(*Norris et al, 2000) (**Lee et al, 2004)

Implications for Prospectivity? Cantarell Field, Southern Gulf of Mexico

Quantitative Clastics Laboratory IA



Modified after Grajales-Nishimura et al., 2000

Cantarell Field

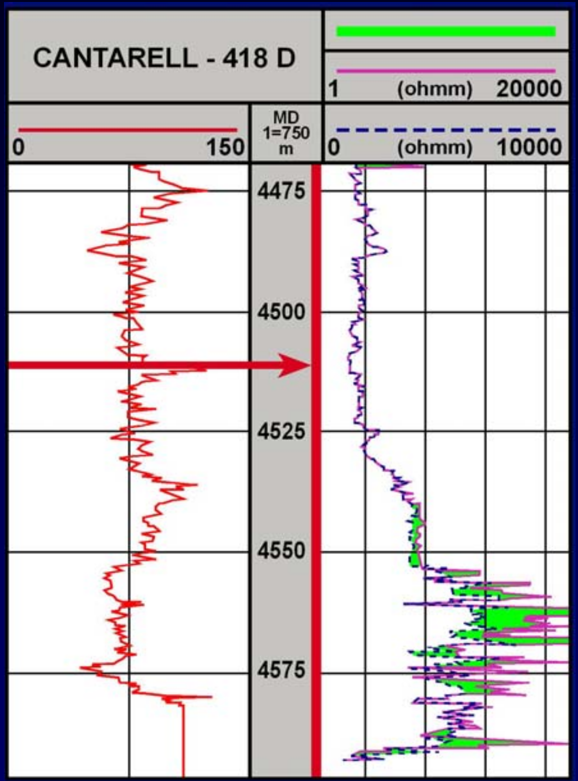
Thrusted anticlinal fold

~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

Implications for prospectivity? Cantarell Field, Southern Gulf of Mexico



After Aquino et al., 2001

Dolomitized sedimentary breccia composed of sub-angular to sub-rounded mudstone exoclasts and wackestone bioclasts depo-sited in a slope environment.

After Grajales-Nishimura et al., 2000

L. Breccia: dolomitized, secondary vuggy porosity due to dissolution. 8-12% porosity, 3000-5000 mD K.

Conclusions

- Numerous depositional morphologies are identifiable in seismic within the SHM area. Some include sediment waves, slope channel complexes, major sediment fairways and mass transport deposits.
- The Cretaceous SHM mass transport complex is composed of multiple seismic facies and multiple episodes of mass failure.
- It spans the entire SHM study area (~1100 sq km) and may span over 20,000 sq km of offshore Morocco. It ranges up to 500 ms thick.
- Large rafted blocks ranging up to +/- 4 sq km in size show preserved stratigraphy and seismic morphologies with low sinuosity, braided channel systems unlike those found in older or younger strata within the study area.
- It is possible that this MTC was derived from upslope. Generated by either regional tectonic activity or possible as a result of the End Cretaceous Impact Event and resulting tsunamigenic waves, which have been modeled to range between 20 m and 200 m in height.
- Similar tsunamigenic generated mass transport deposits are found in offshore Mexico and form reservoir for one of the largest oil fields in the world.


Thank You