

Role of Mass Transport Deposits in the Creation and Fill of Tectonically Active Slope Accommodation, Deepwater Sabah, NW Borneo*

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Abstract

Two types of turbidite accommodation are recognized in the Miocene NW Borneo slope. Type 1 is related to episodic thrust-propagation folding, and Type 2 is related to the emplacement of large mass transport deposits (MTD), triggered by shelf-edge instability. The depositional sequences recording slope accommodation fill are in both cases defined by progressive healing of newly created slope topography.

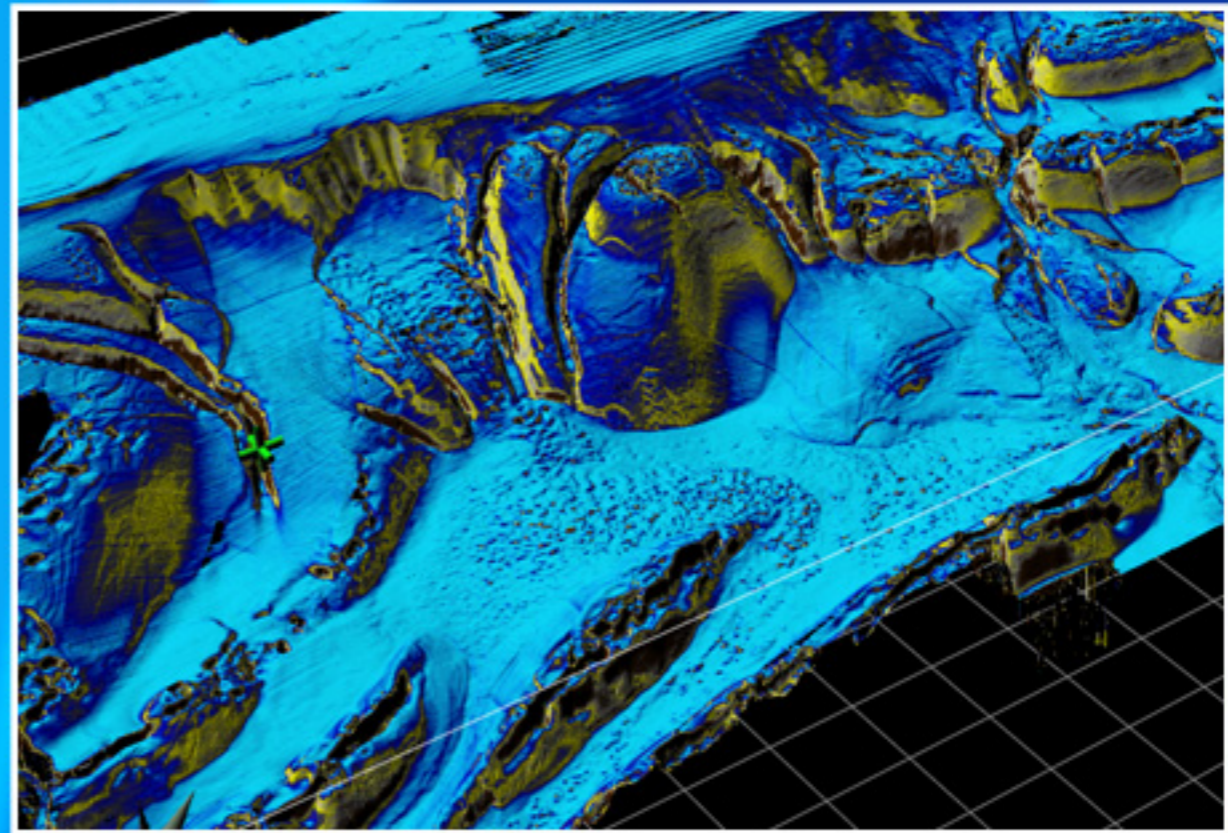
The healing phase of a sequence contains turbidite aprons and unconfined mud-prone slope deposits. In Type 1, the aprons directly overlie, or are interbedded with, smaller scale MTDs, shed from the flanks of growing anticlines. This may cause reservoir thickness variation and poor intrareservoir connectivity in their basal part. Type 2 aprons are laterally offset from large MTDs and consequently show less internal heterogeneity. However, Type 2 accommodation is typically an order of magnitude smaller than Type 1, and the healing-phase aprons are transient in nature, commonly bypassed and dissected by later channelised flows.

The tectonically created Type 1 accommodation fill represents a typical NW Borneo slope high-frequency sequence. Type 2 sequences are less common, and their occurrence may indicate 3rd order sea-level drops. The superposition of sequences controlled by different mechanisms creates an apparently random, poorly predictable basin-fill succession. The correct identification and detailed local mapping of Type 1 sequences are required to predict reservoir distribution on a prospect scale. Identification of the Type 2 MTD emplacement events allows the delineation of lower-order sequences and the relative risking of sand presence in successive Type 1 high-frequency sequences.

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Acknowledgments

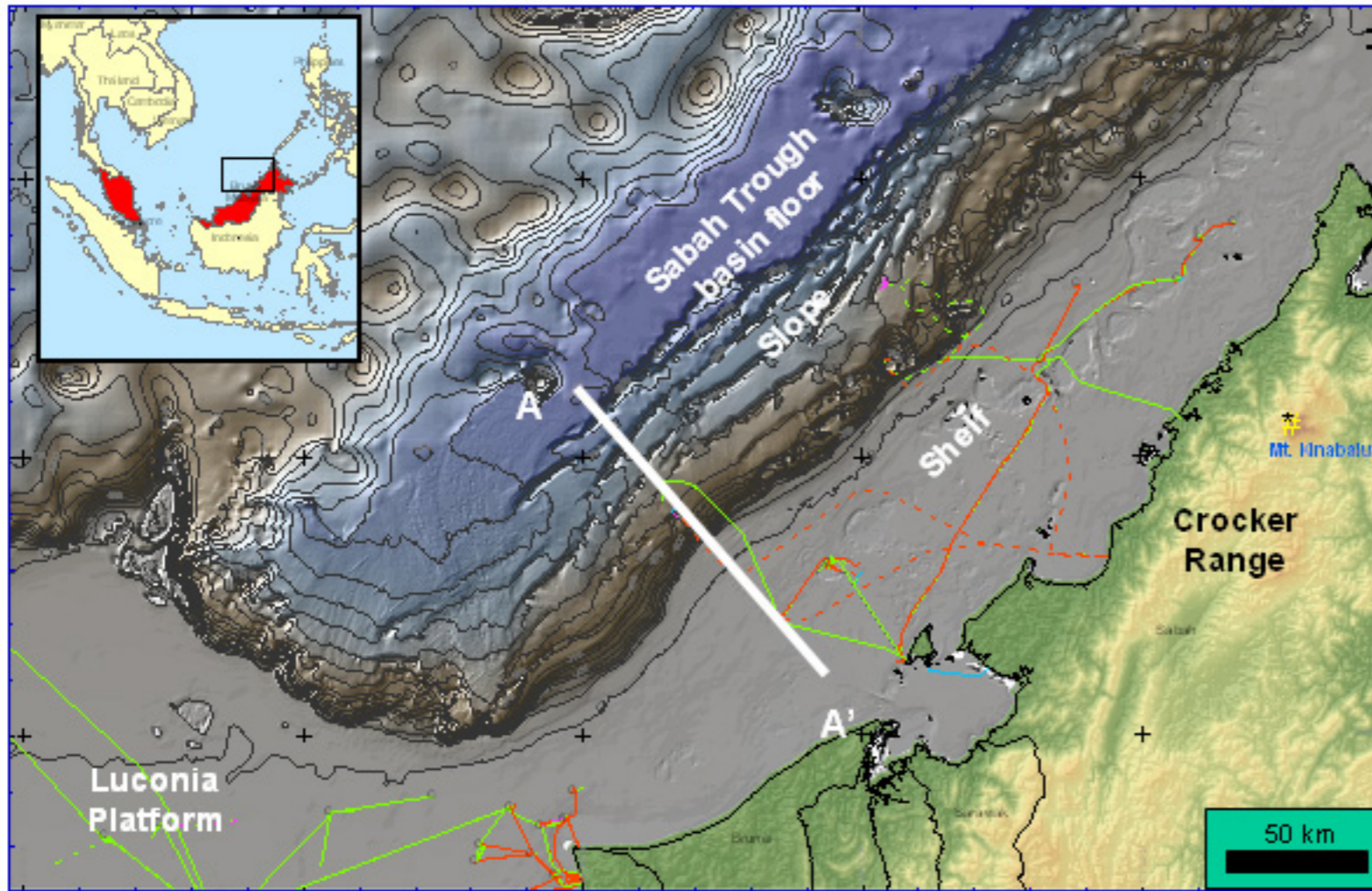
- Our national sponsor PETRONAS are thanked for their permission to publish this work
- Our co-venturers PETRONAS Carigali and ConocoPhillips are thanked for their support during the exploration programme
- Our colleagues from the deepwater exploration and development teams in Miri for on-going discussions



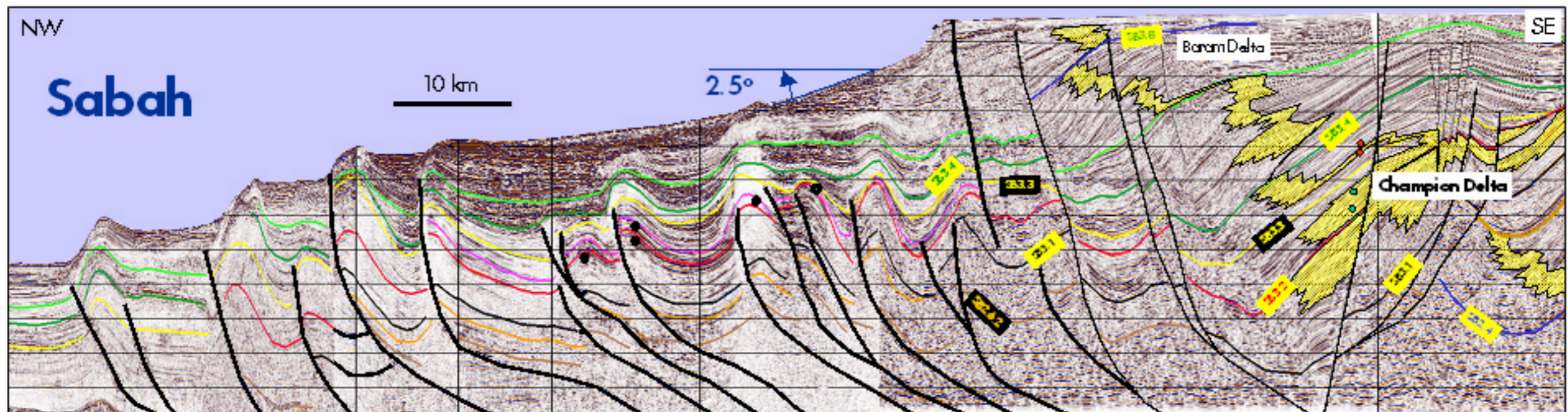
Outline

- NW Borneo slope dynamics
- Character and distribution of depositional sequences
- Types of slope accommodation
- Role of mass transport processes in the creation & fill of the slope accommodation
- Slope healing by deepwater depositional systems
- Unstable slope growth pattern

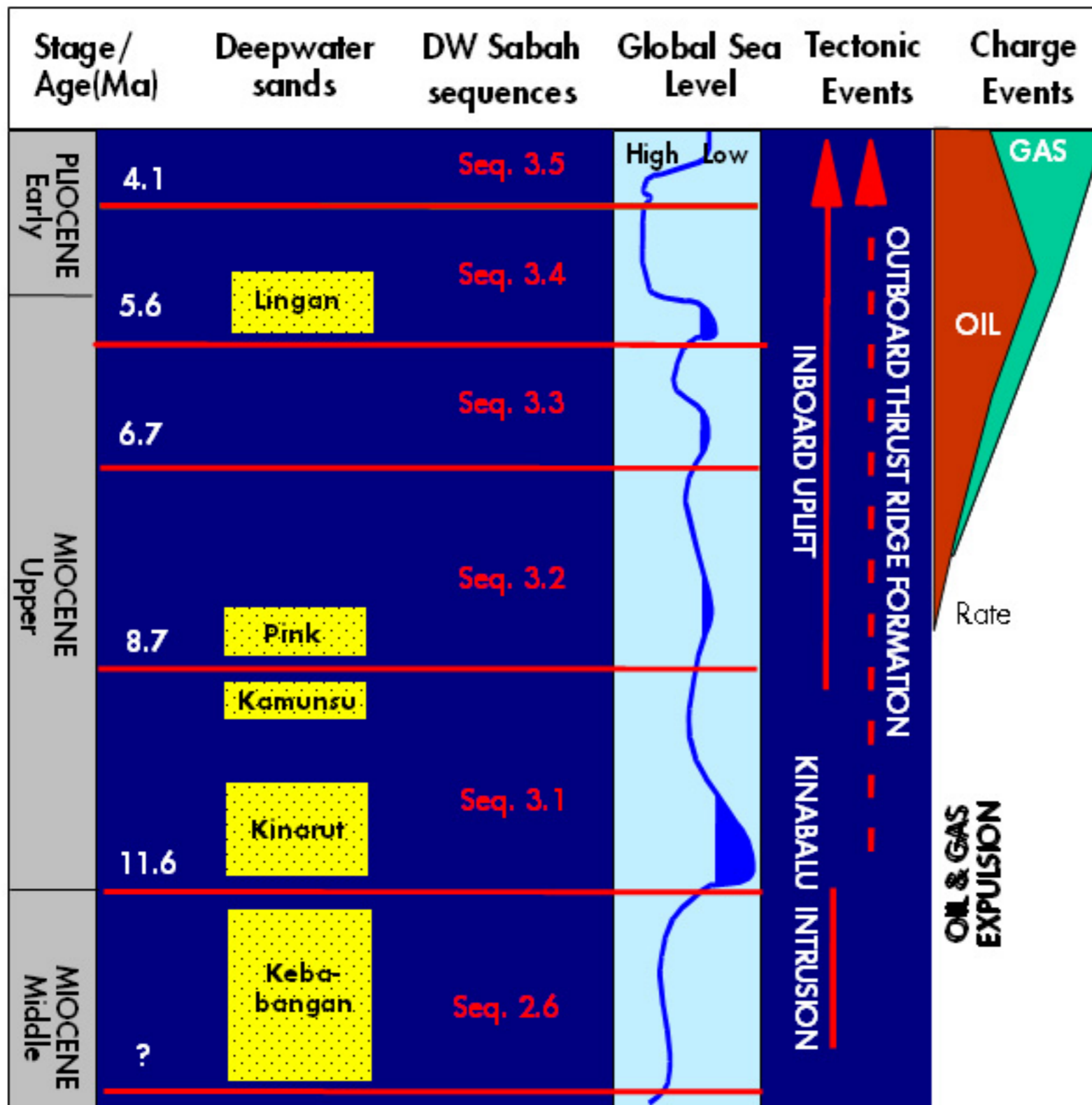
Tectonic Setting



- Basin margin succession deposited on an intermittently active foreland fold/thrust belt
- Interaction of crustal shortening with thin-skinned delta deformation
- Frequent shelf-edge sediment instability events

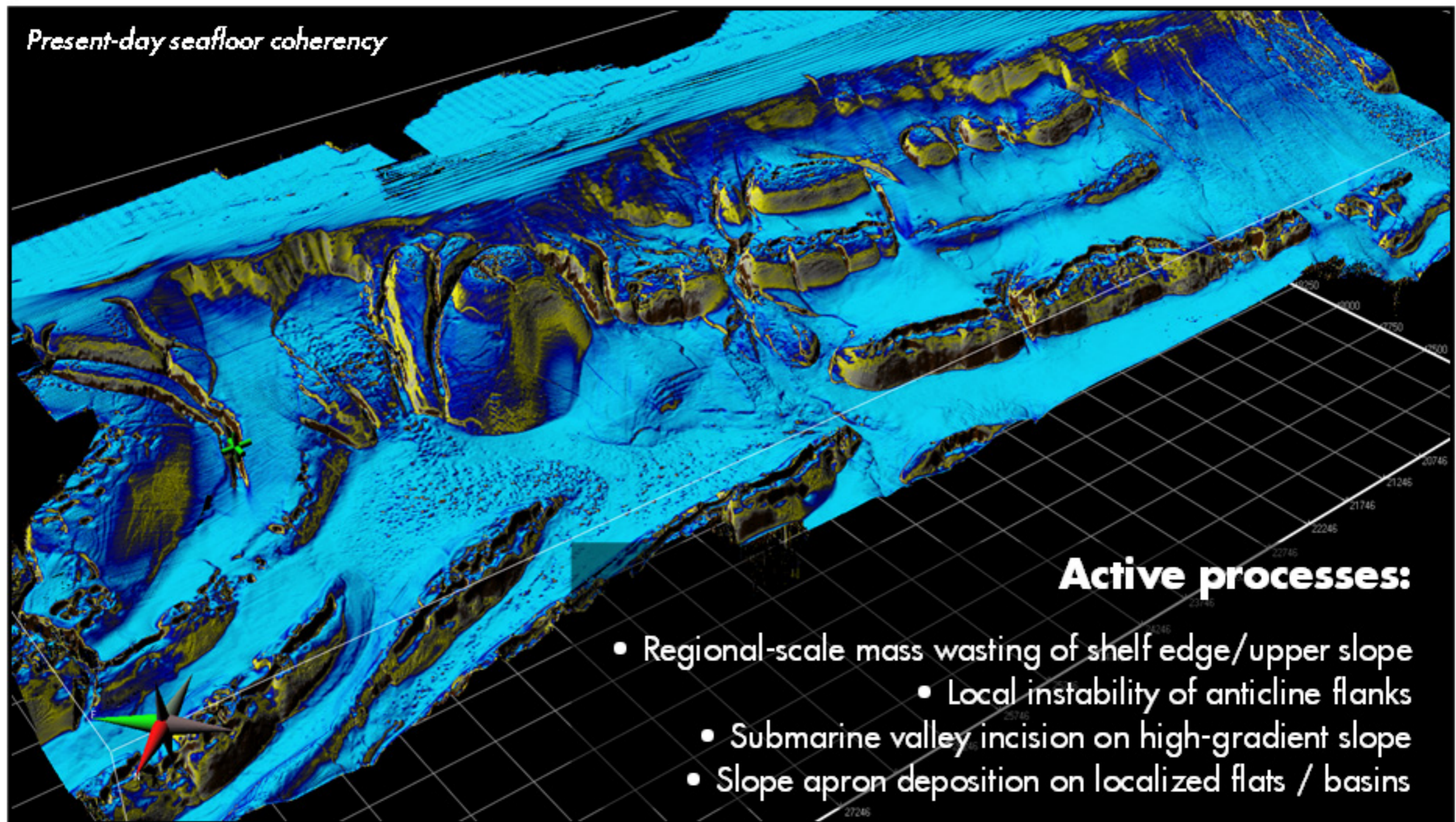


Sea level, tectonics & stratigraphy



- Middle Miocene basin deepening due to an uplift and flexural loading
- Inversion of early normal faults and basinward toe-thrust propagation
- Five major episodes of deepwater sand deposition
- Multiple reservoir-seal pairs
- Moderate correlation with global sea-level lowstands

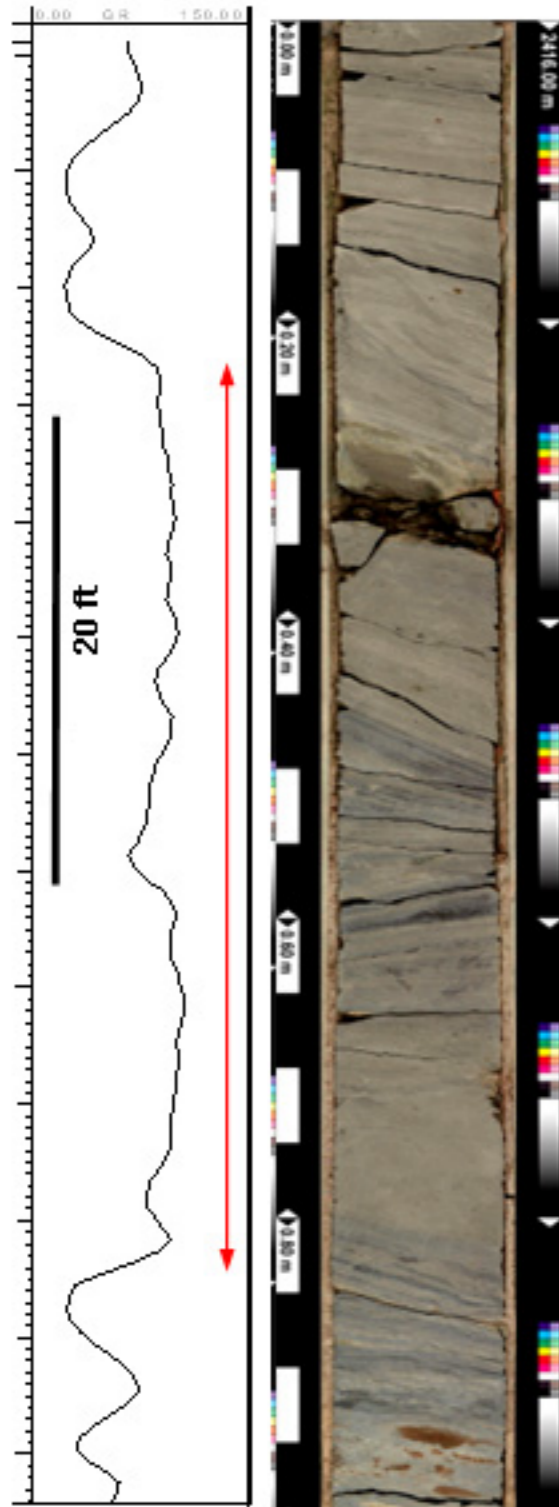
North-West Borneo slope dynamics



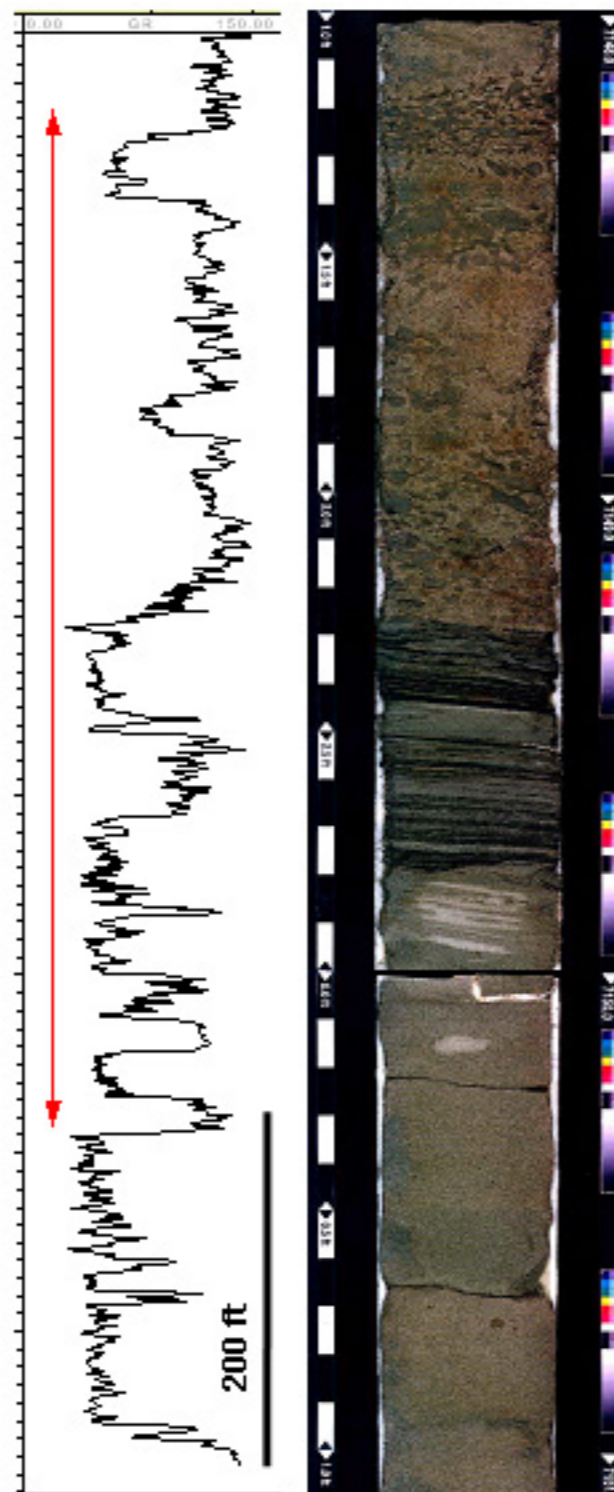
- Topography created by anticline growth and shelf-edge instability
- Slope healing (smoothing towards equilibrium) by a spectrum of deepwater deposits

Slope deposits

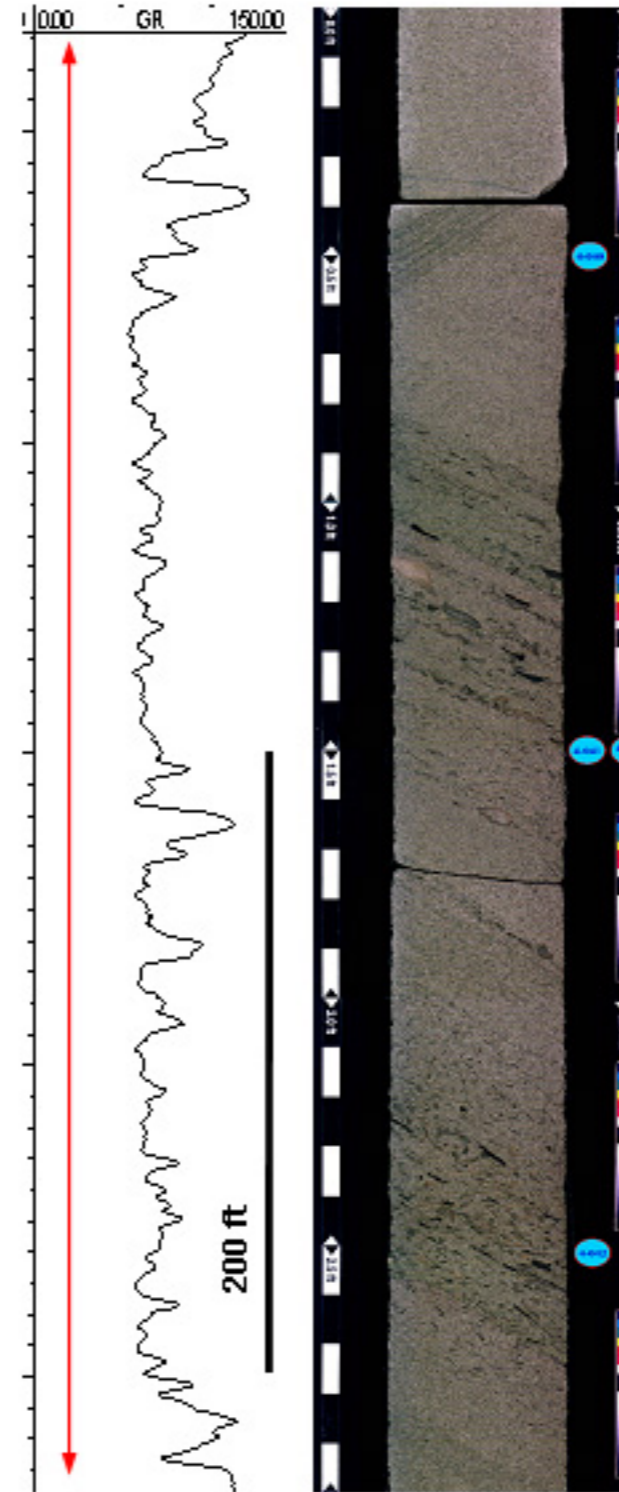
- Mixed sandstone-mudstone systems
- Sand mainly in lobe-dominated aprons
- Mud in MTDs, lack of drape intervals



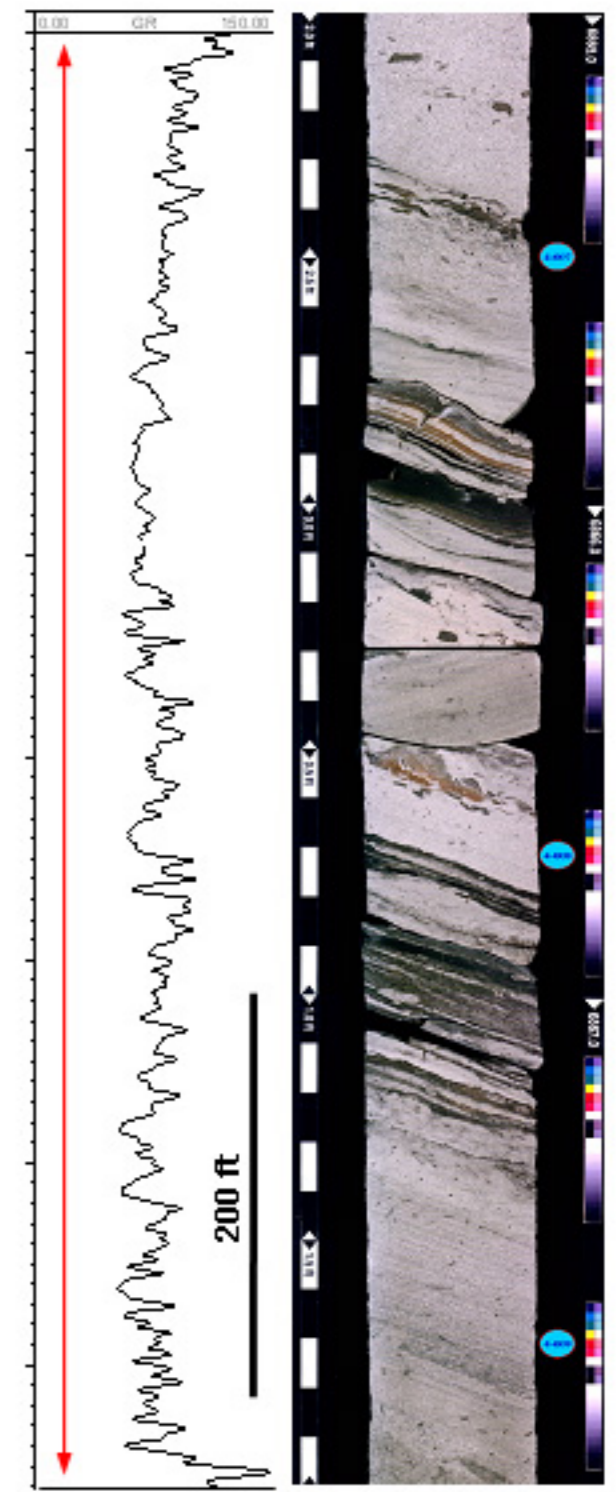
Mass transport deposits



Meander belts / Levees

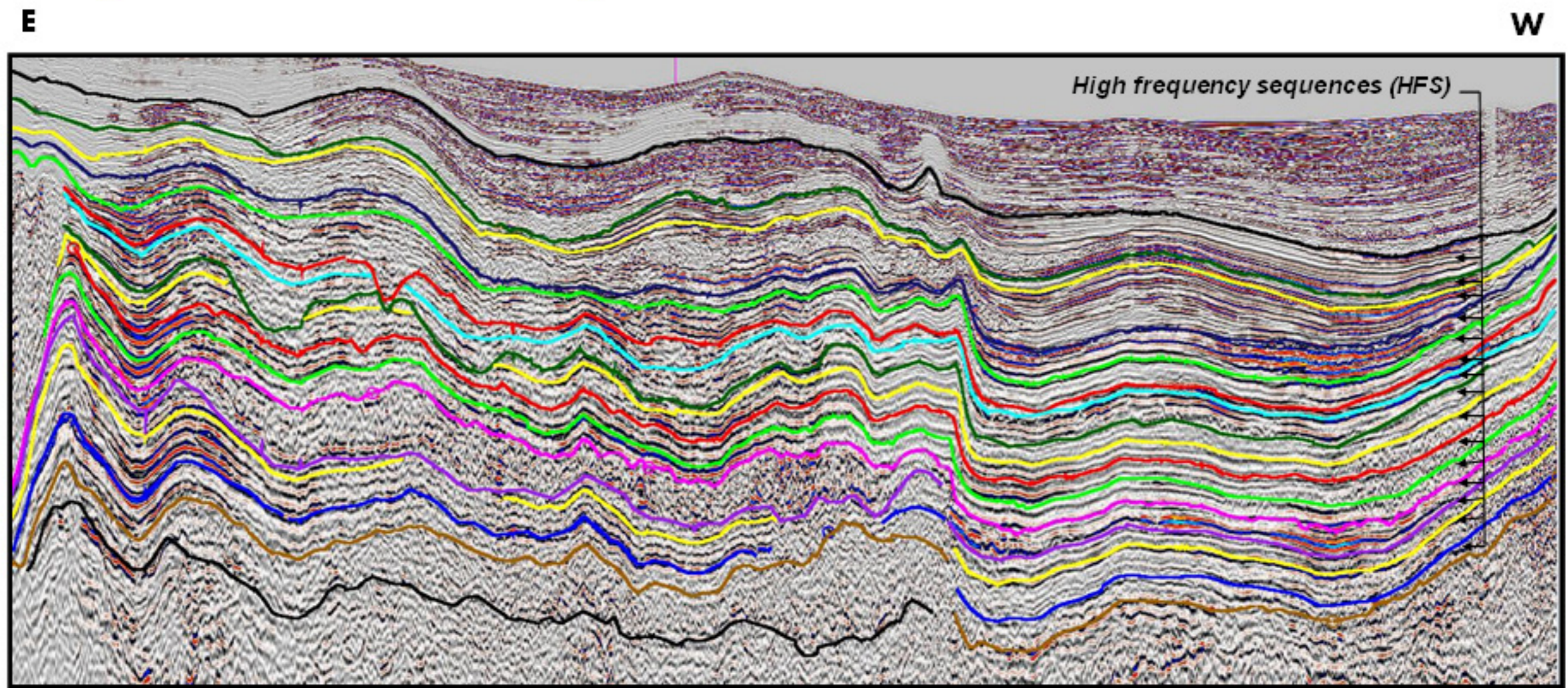


Distributary channels



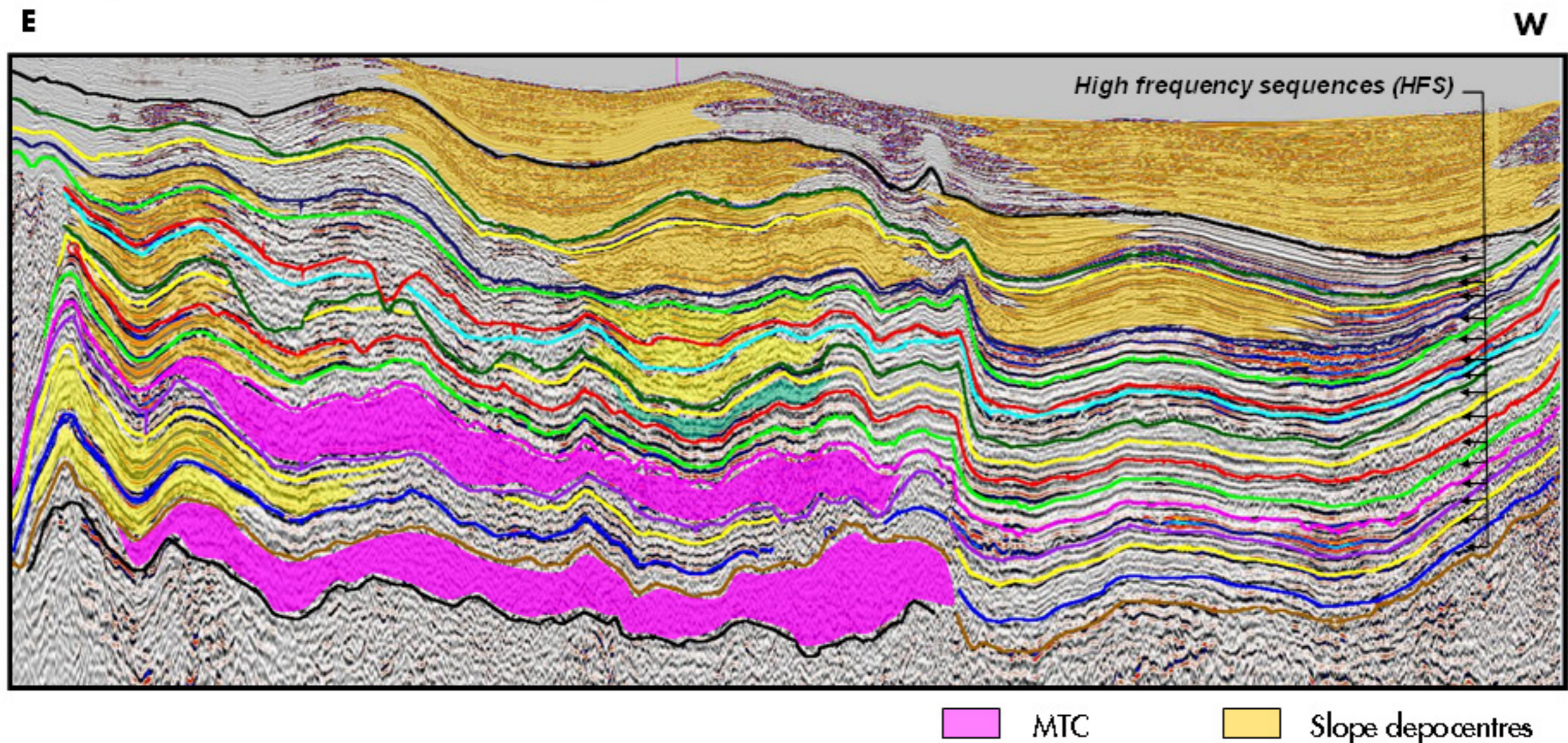
Lobes & Sheets

Depositional sequences



- High-frequency sequences (HFS): Genetically-linked slope depositional units represented by packages of chaotic, high, and low amplitude seismic facies
- HFS record creation and fill of the slope accommodation variation in response to tectonic events, sand supply variation & sea-level change
- Intra-slope accommodation shifts basinward, following the thrust propagation
- Frequent instability creating mass transport complexes (MTCs)

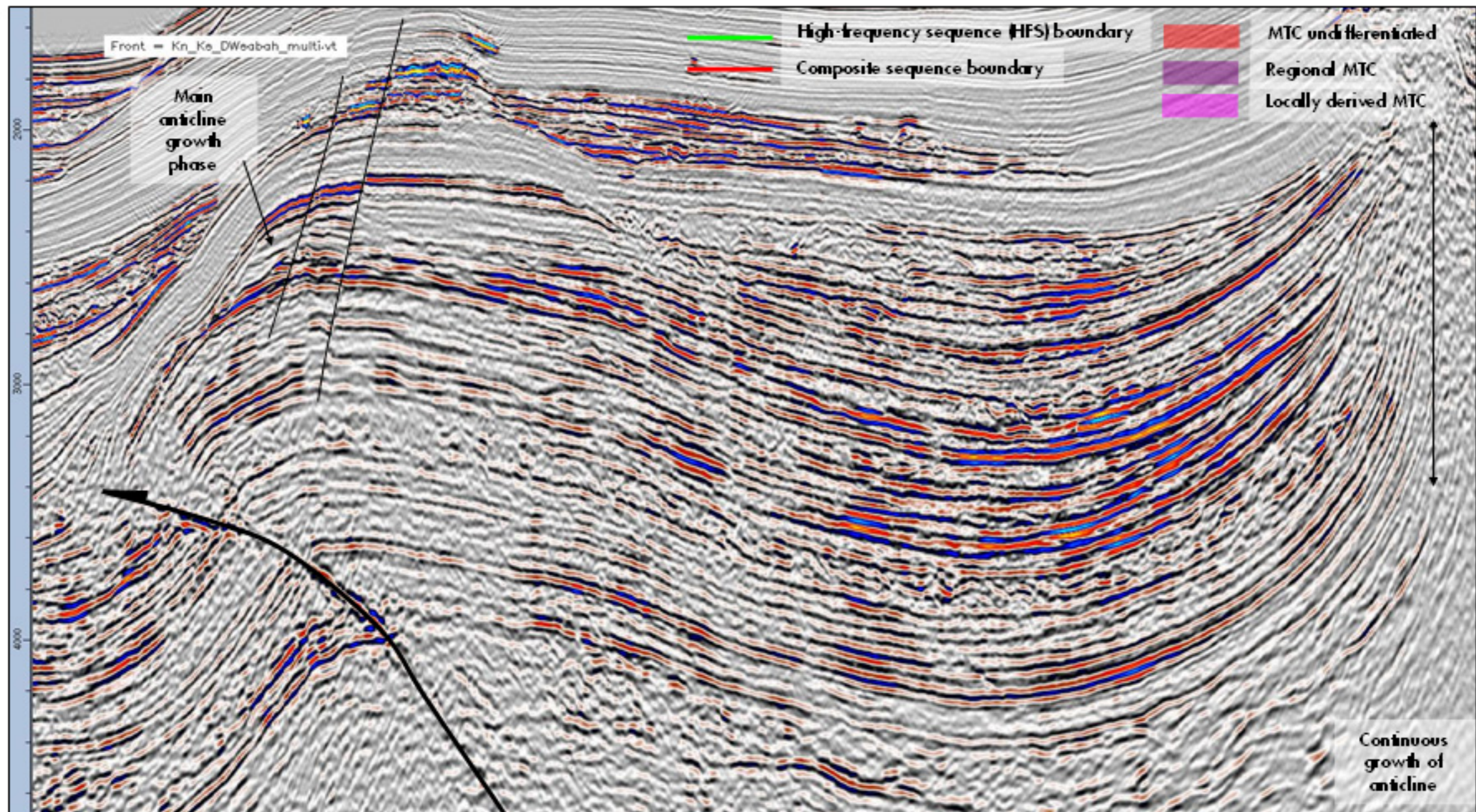
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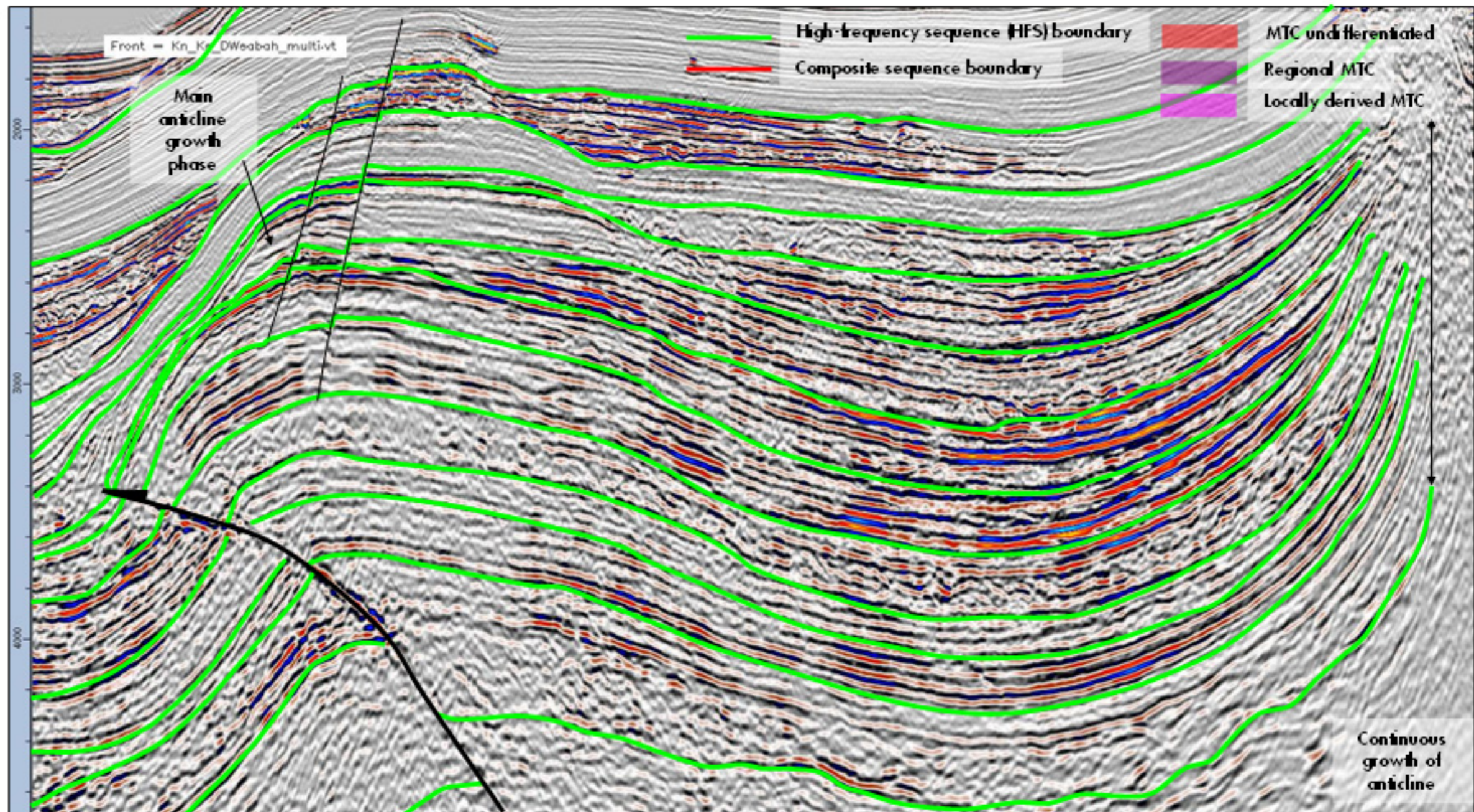
Sequence hierarchy

- Slope healing on different time scales:
 - **HFS** record fill & bypass of slope accommodation defined by the topography of a locally deforming substrate (anticline growth)
 - **Composite sequences** record basin-margin equilibration between major shelf-edge collapses



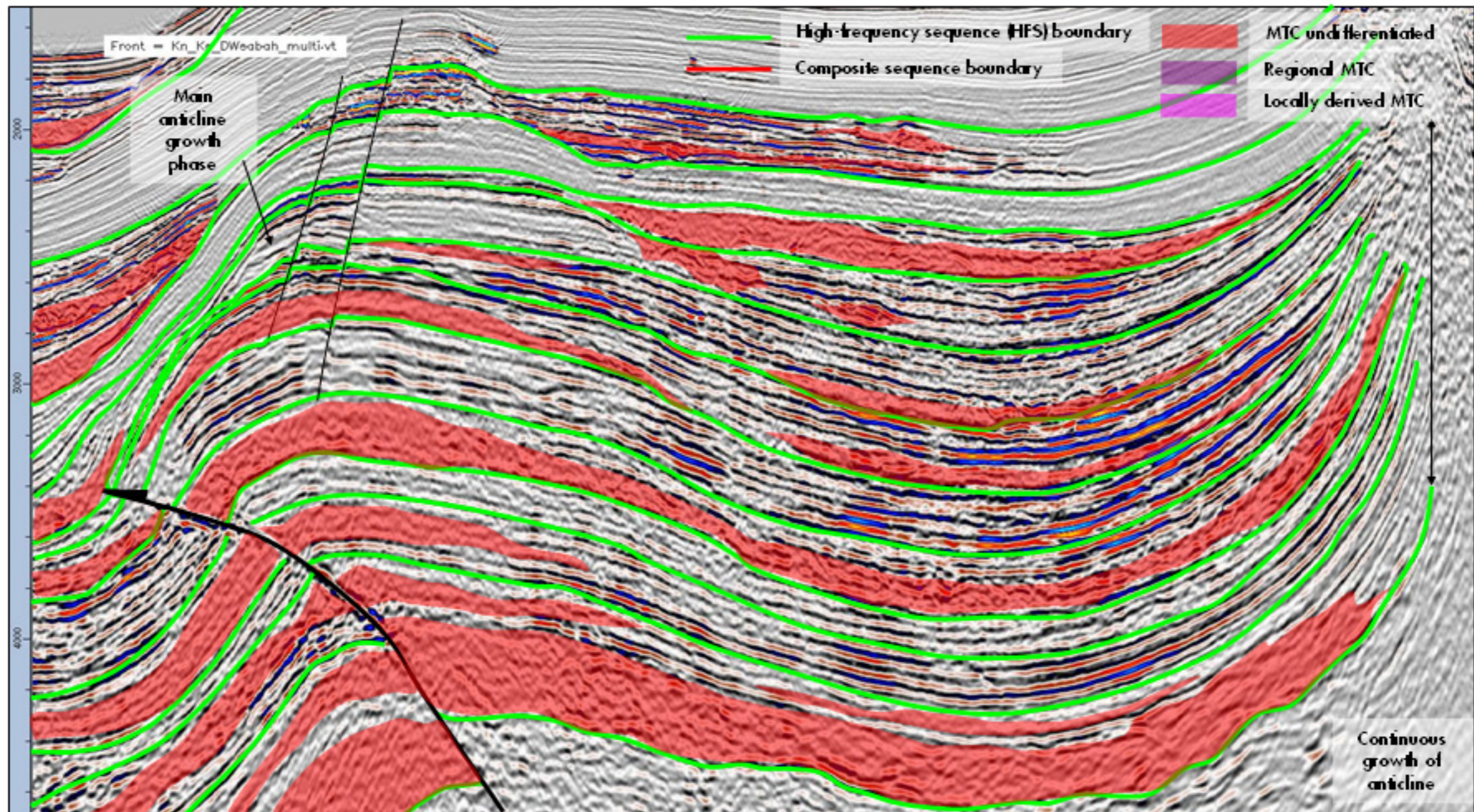
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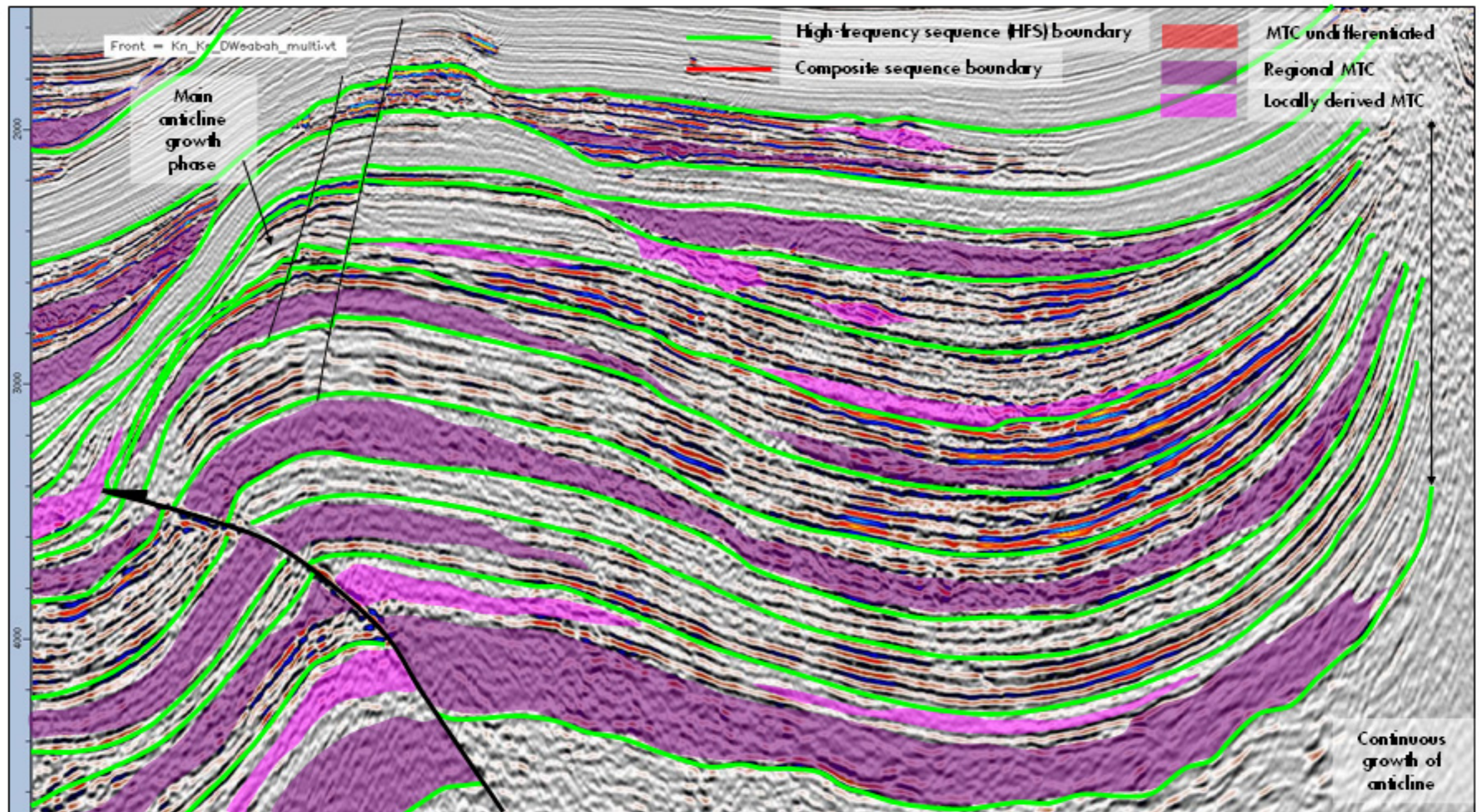
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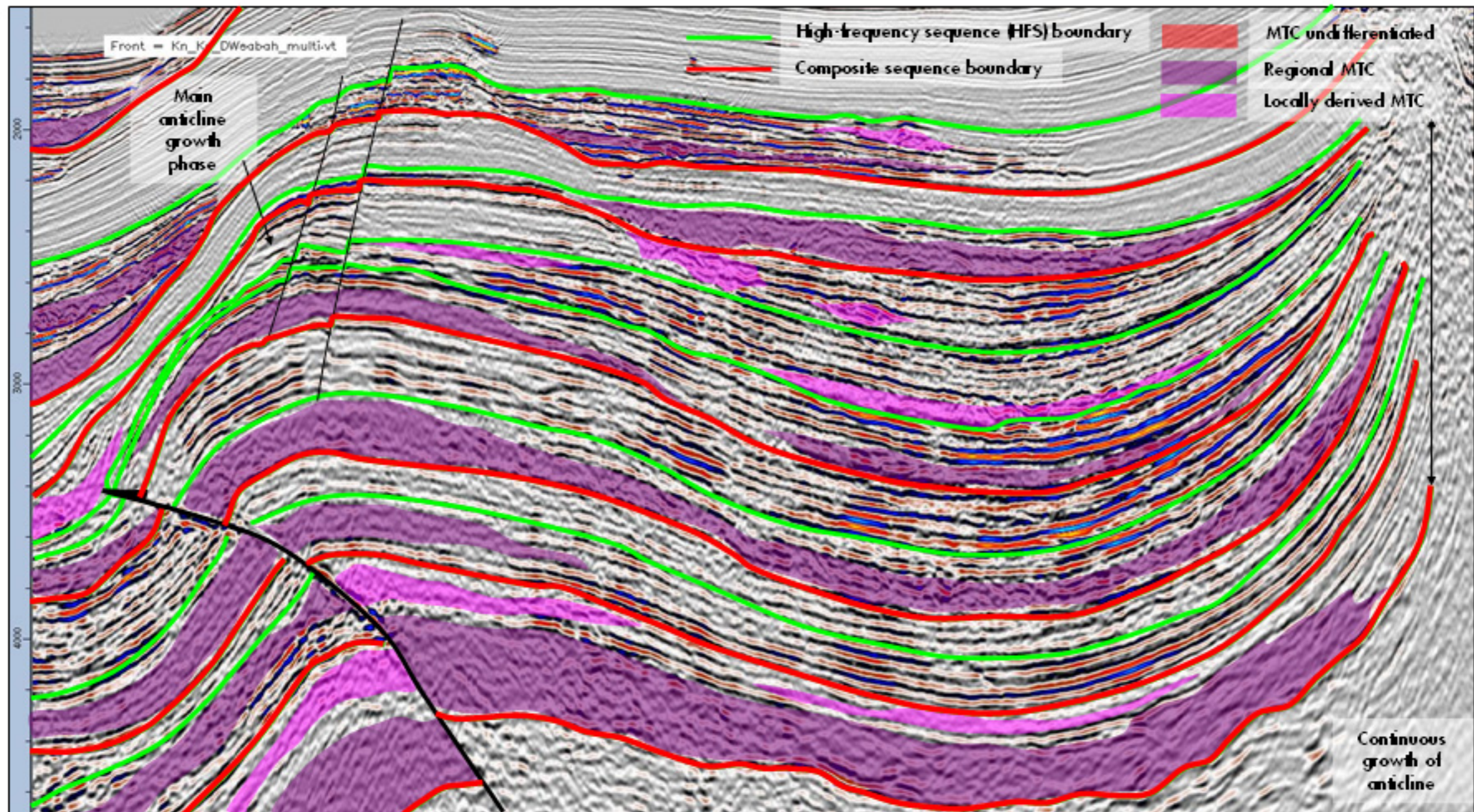
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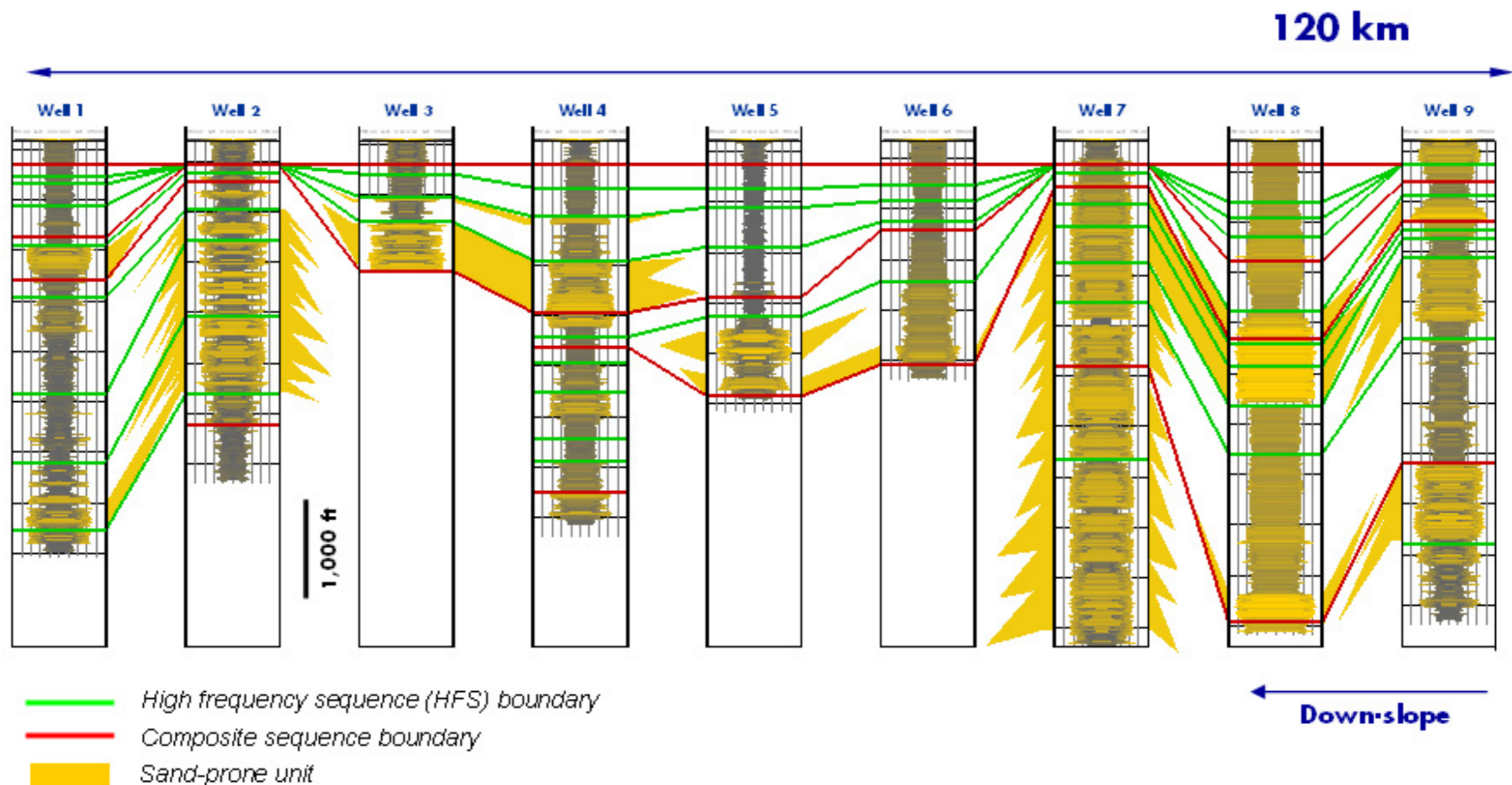
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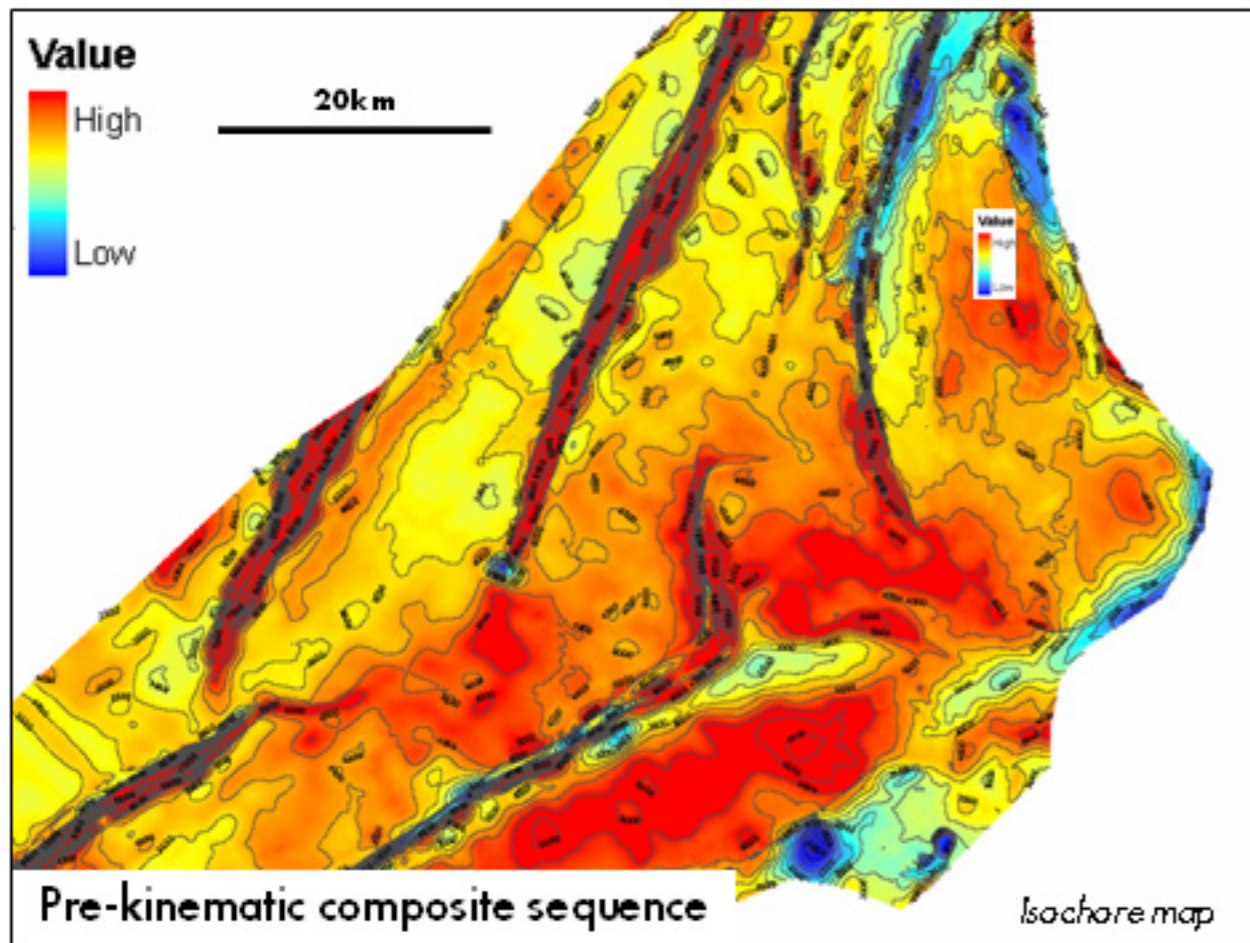


Reservoir distribution

- Depocentre fill / inversion as the slope enters syn-tectonic depositional phase
- Pre-tectonic slope accommodation locally contains thick stacked sands
- Syn-tectonic HFS contain smaller sand depocentres, showing larger spatial shifts in the successive units compared to pre-tectonic HFS

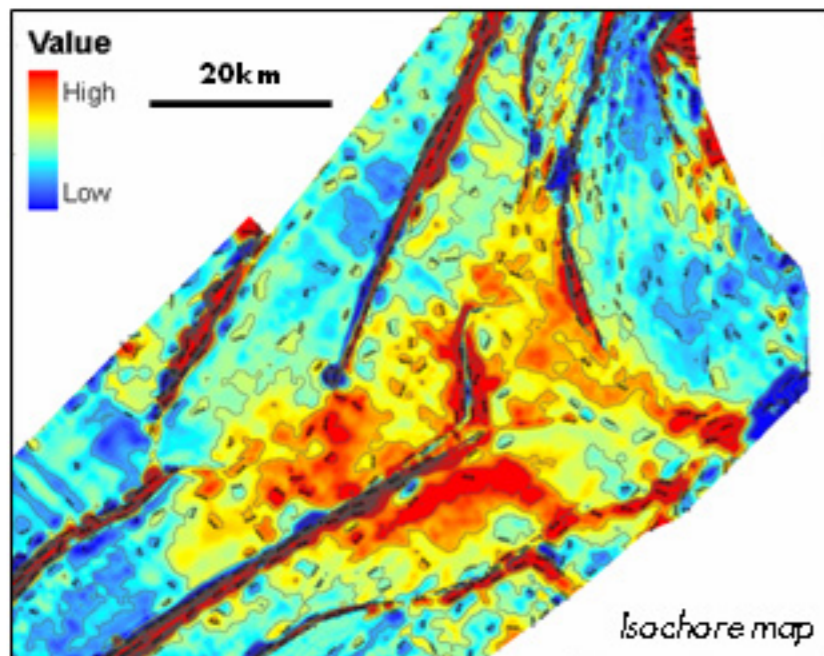


Instability & Accommodation

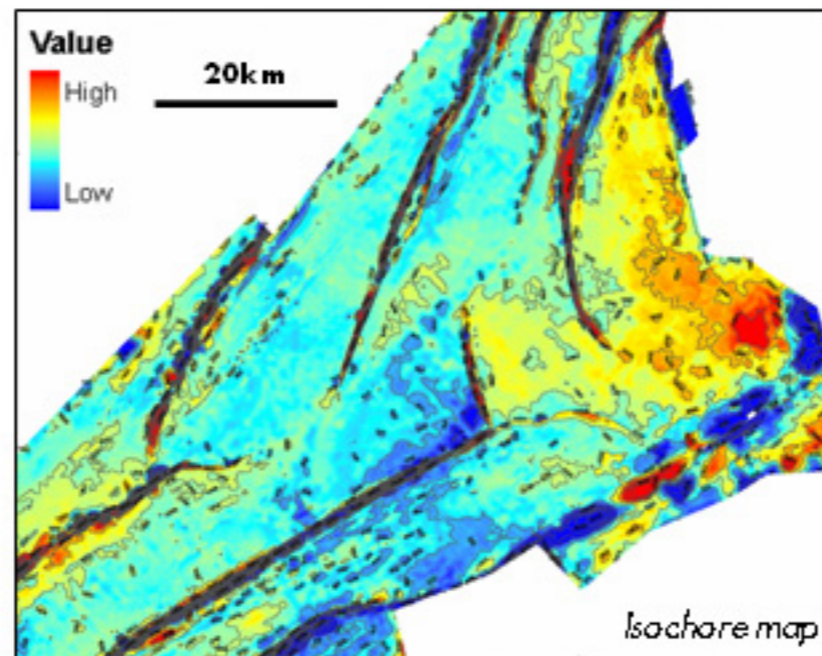


- Gradual basinward thickness decrease in a composite pre-tectonic sequence
- Basal part dominated by a mounded regional-scale MTC fan
- Successive HFS record mainly turbidite deposition upslope from the MTC topography

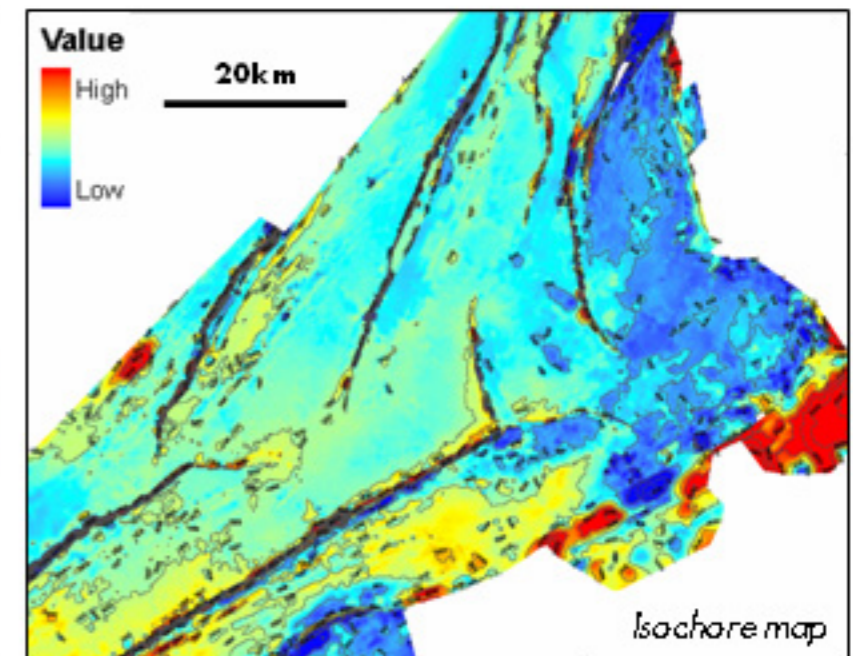
HFS 1



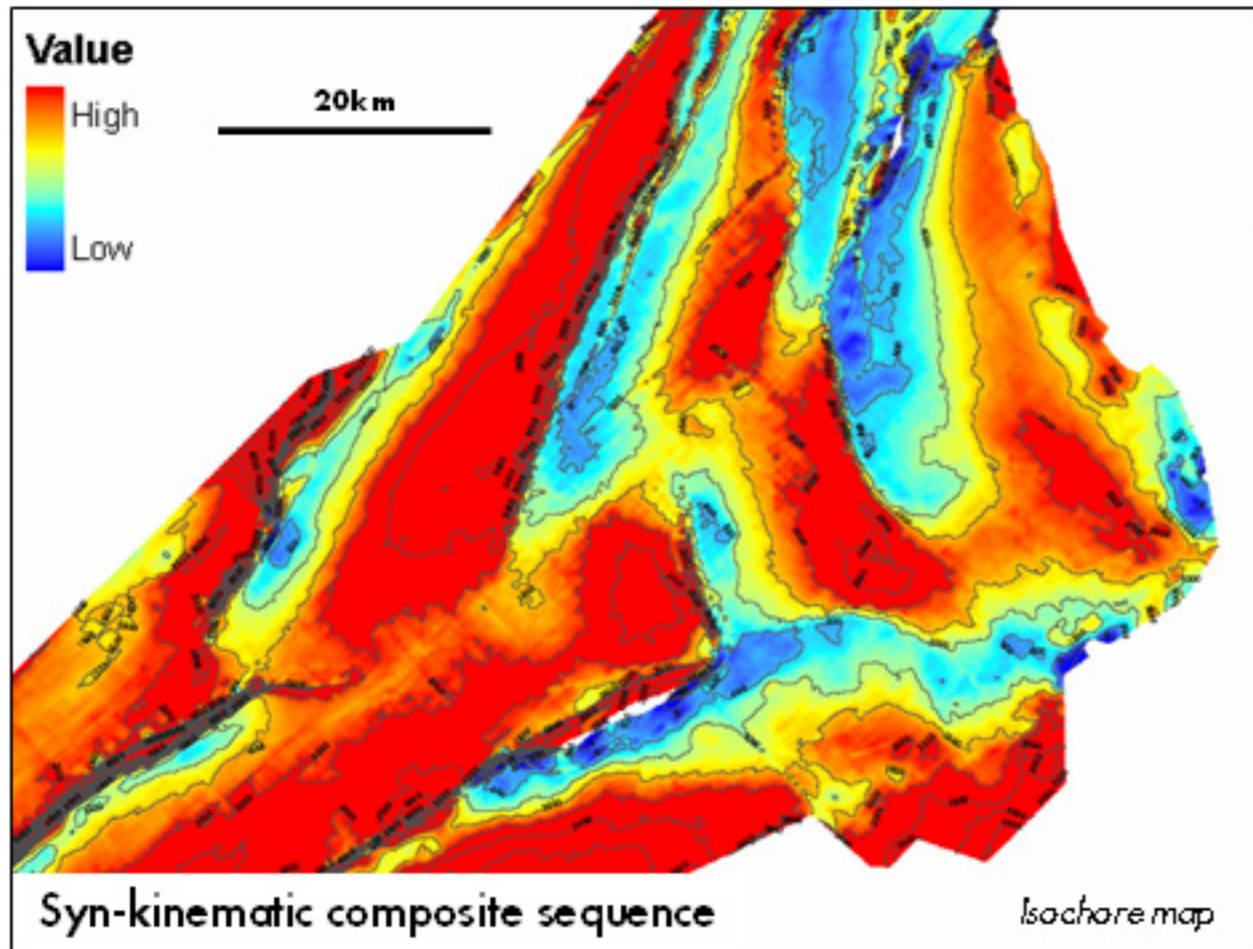
HFS 2



HFS 3

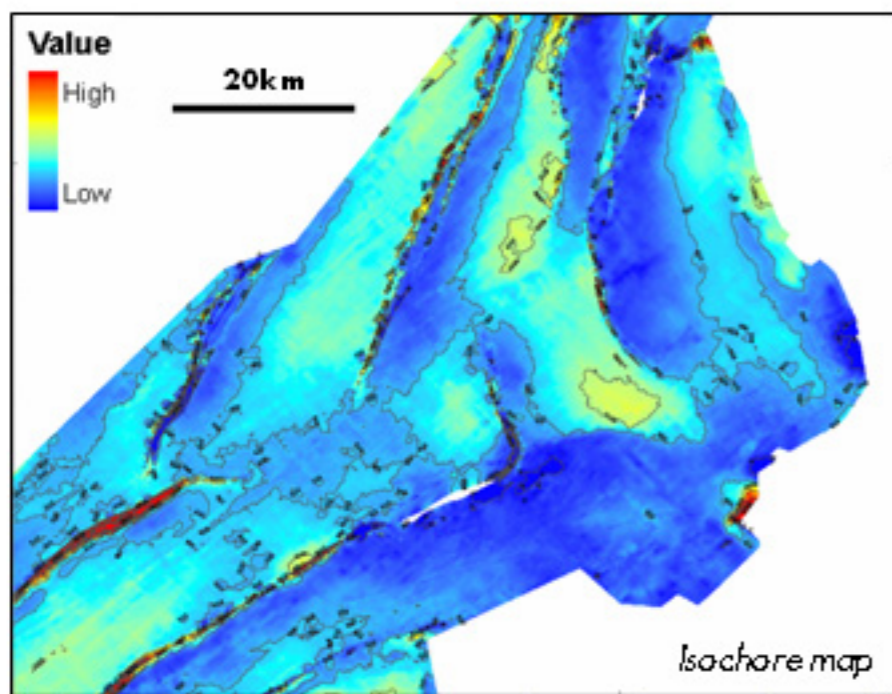


Deformation & Accommodation

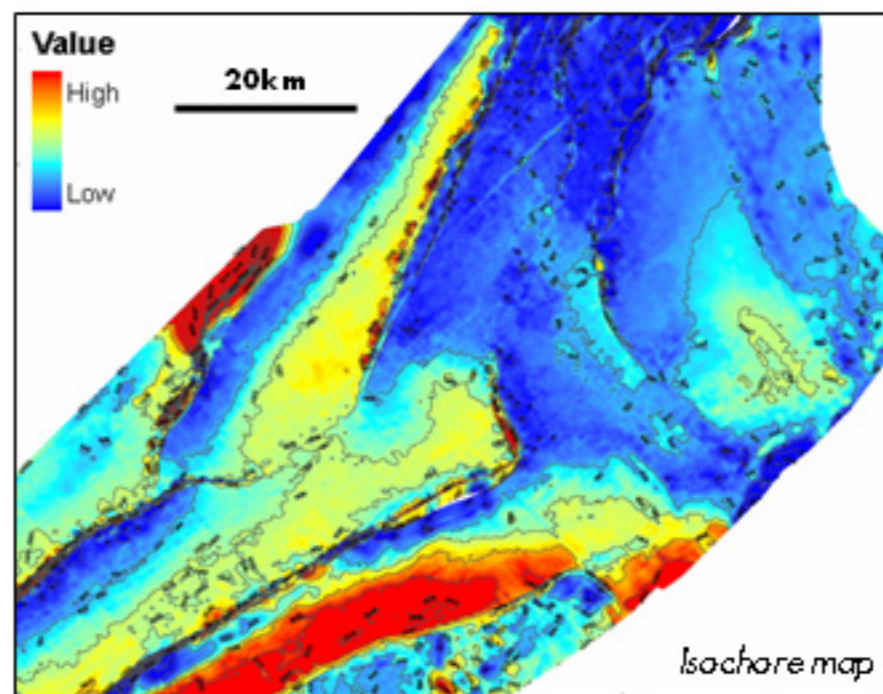


- Strongly variable thickness of a composite syn-tectonic sequence
- Loosely connected depocentres confined to synclines
- Partial to full ponding of slope aprons dependent on the geometry of tectonically created accommodation

HFS 1



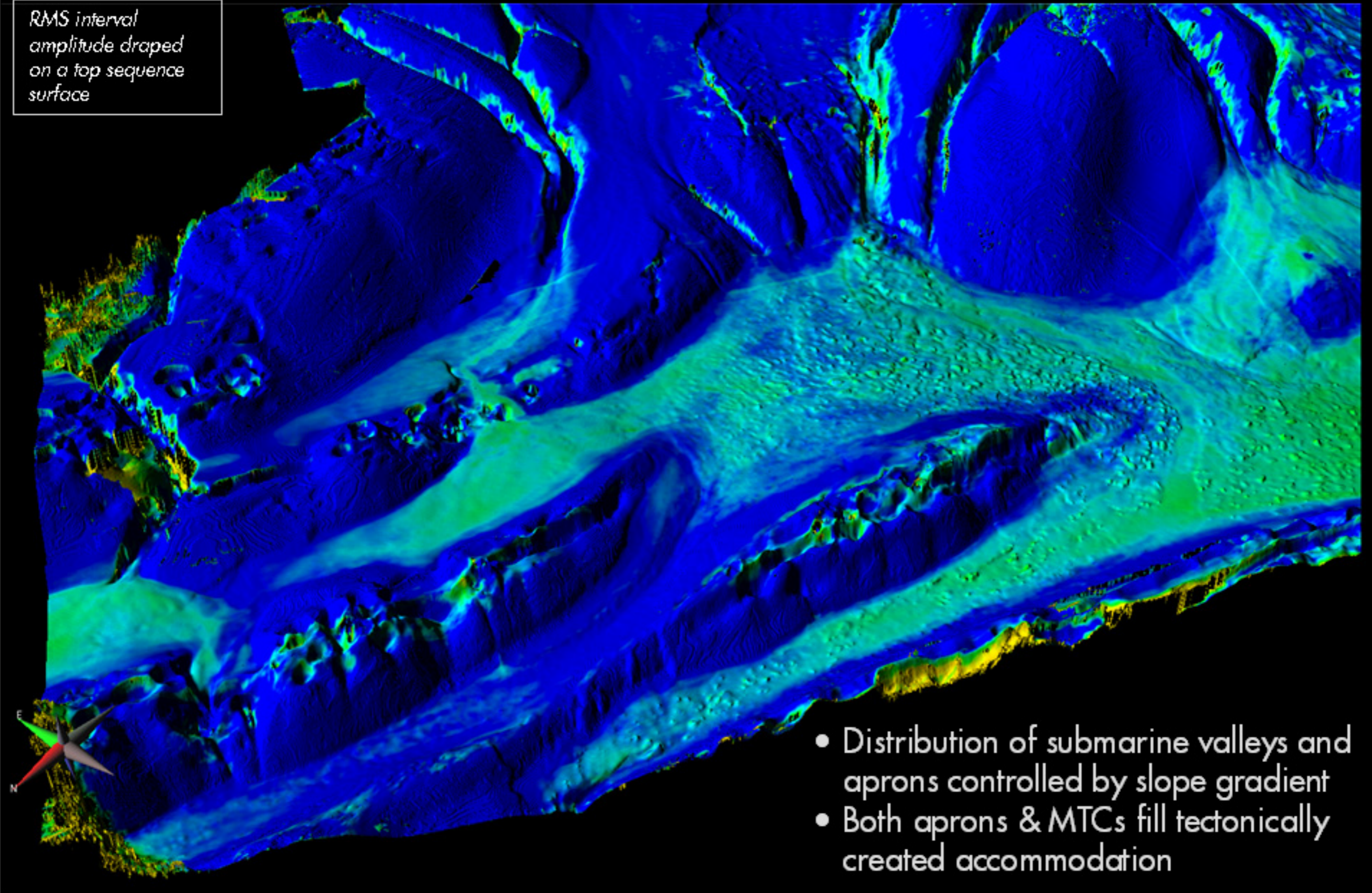
HFS 2



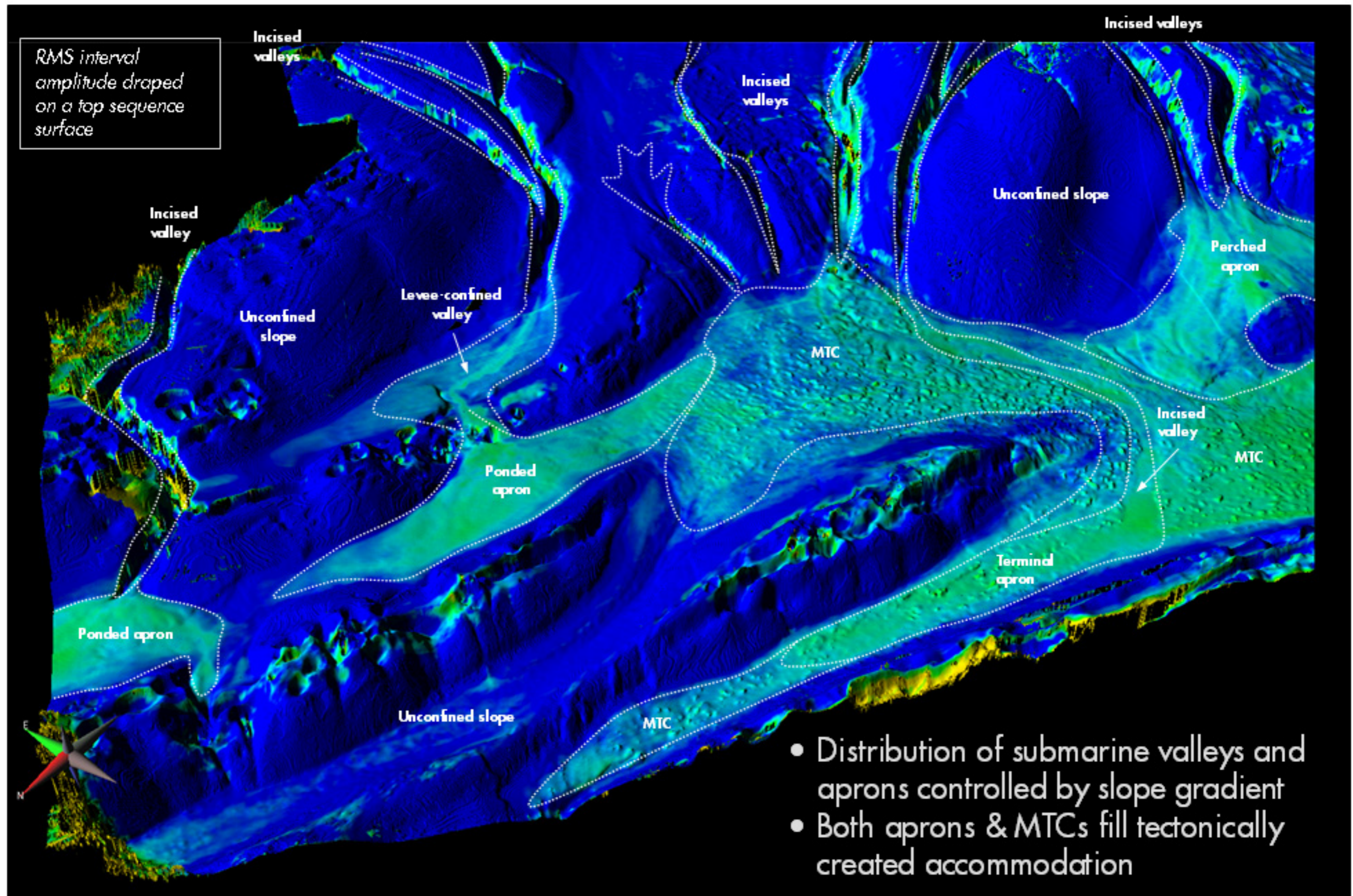
- Fill-and-spill process or depocentre migration between connected slope accumulations

Slope healing depositional systems

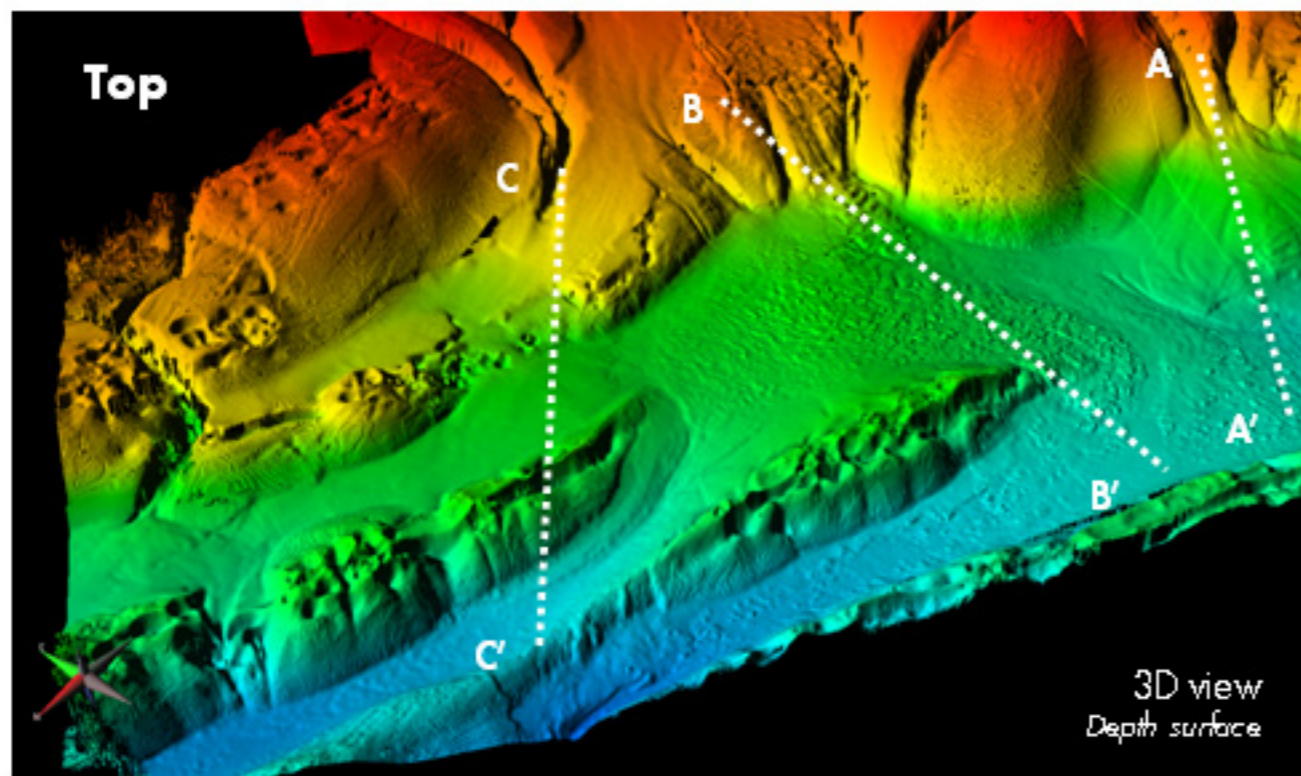
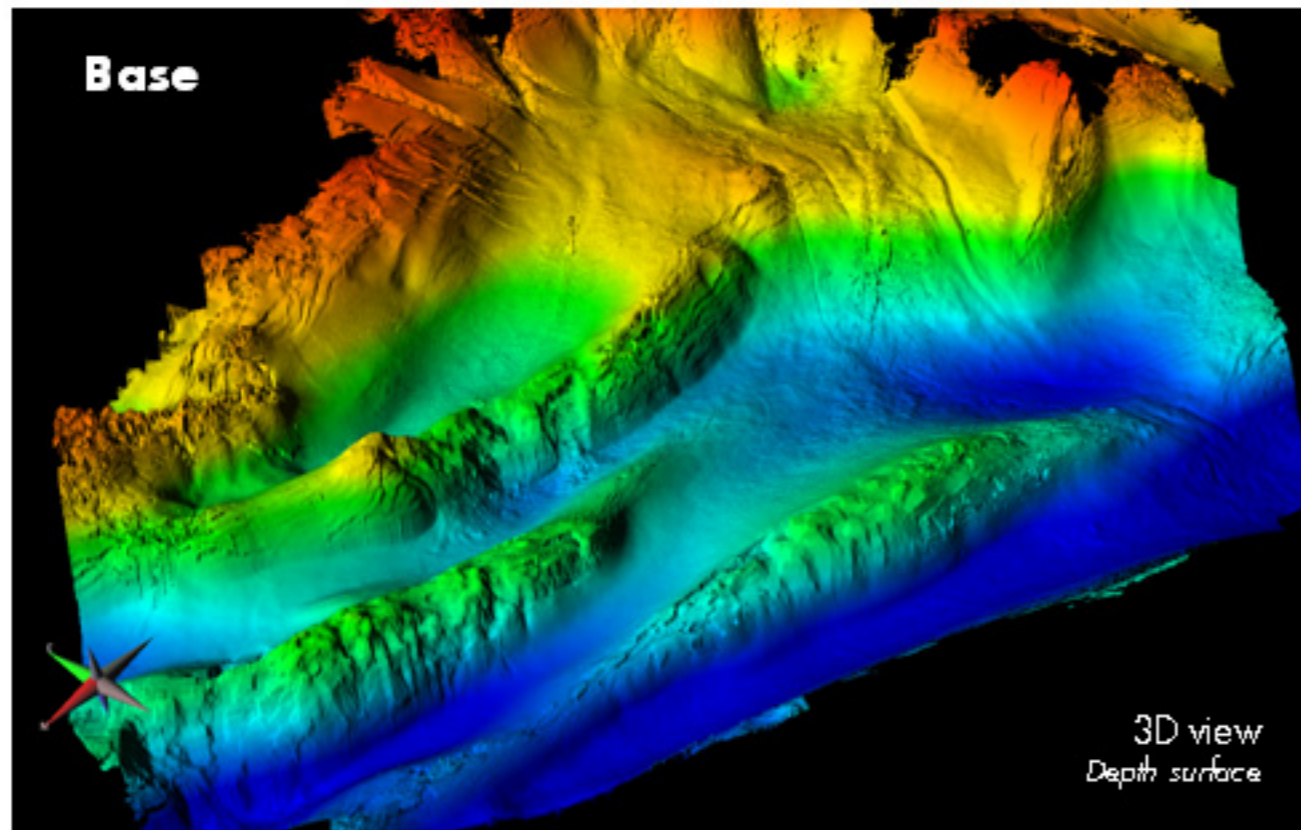
*RMS interval
amplitude draped
on a top sequence
surface*



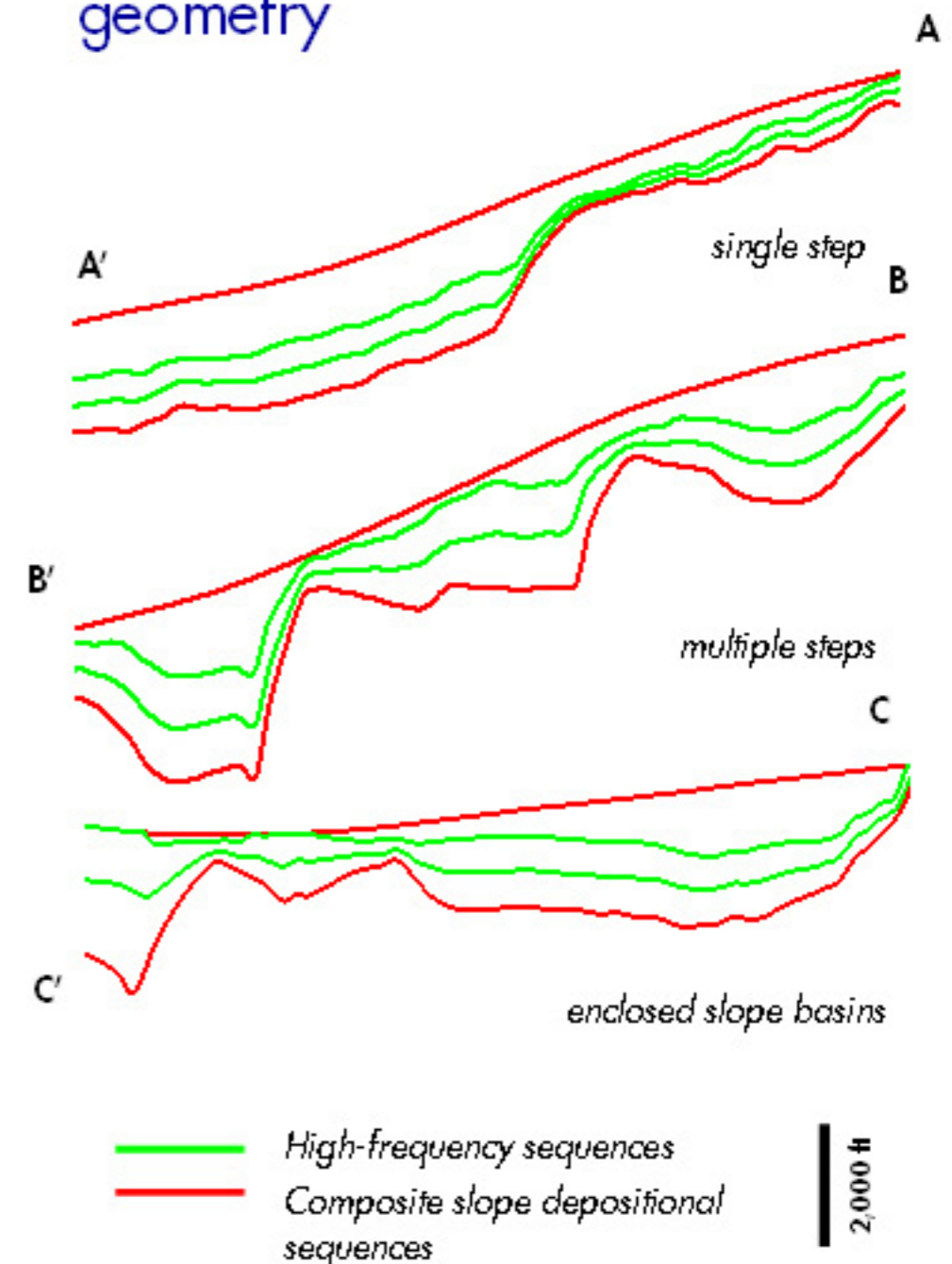
Slope healing depositional systems



Spatial variability of tectonic accommodation

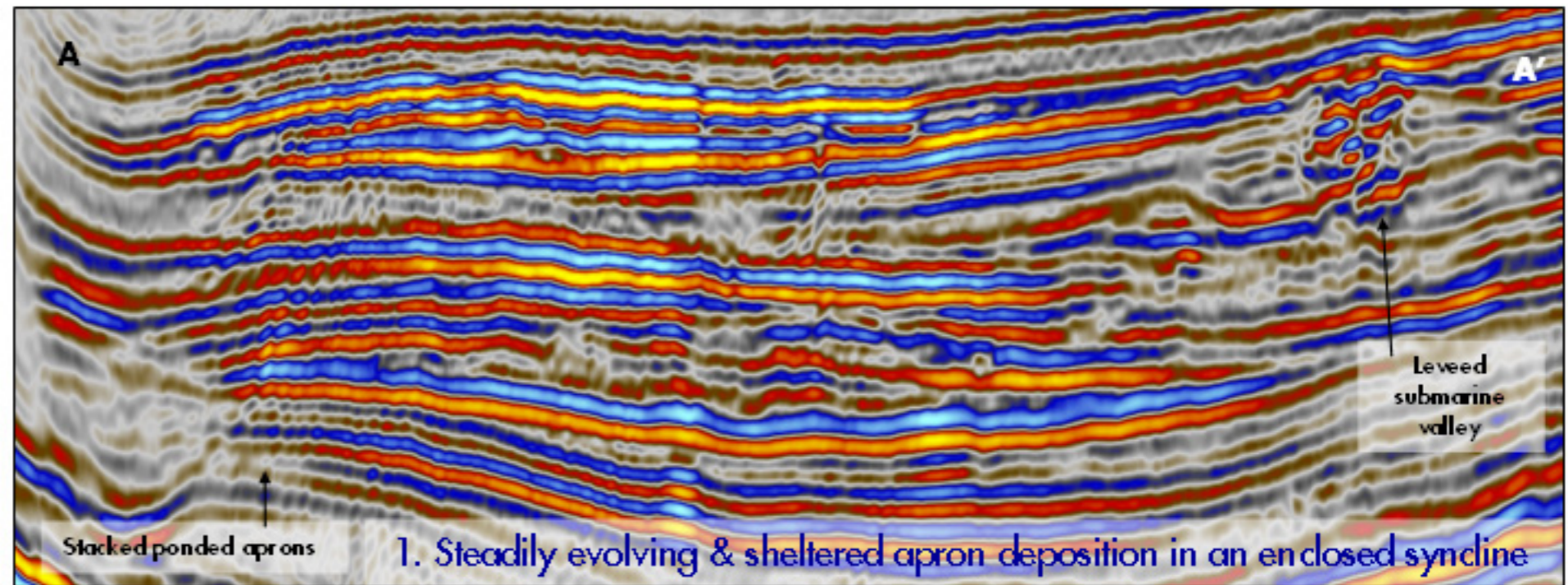
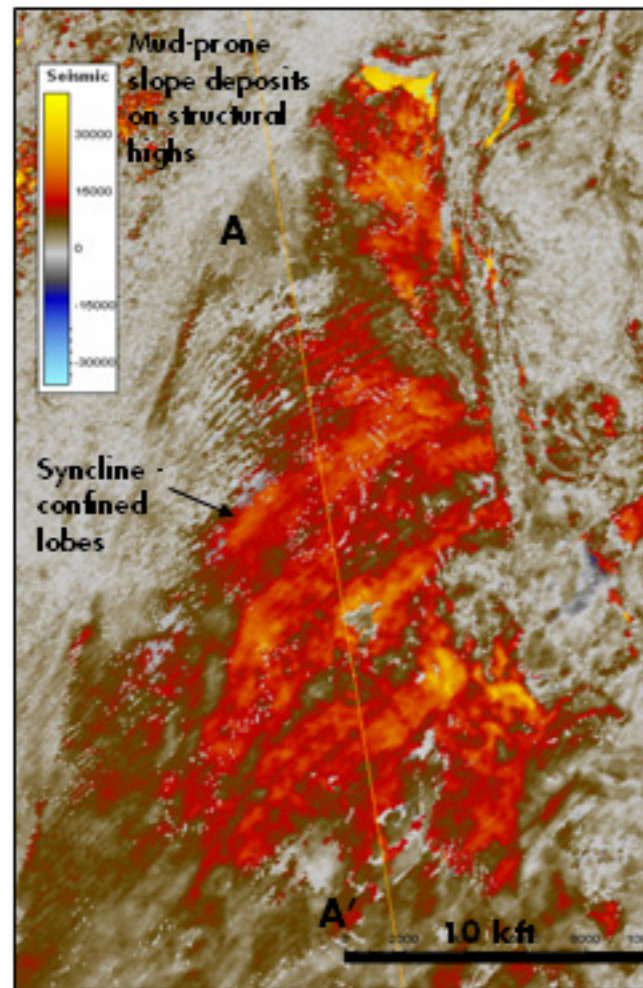


- Syn-tectonic composite sequences show significant differences in depositional geometry



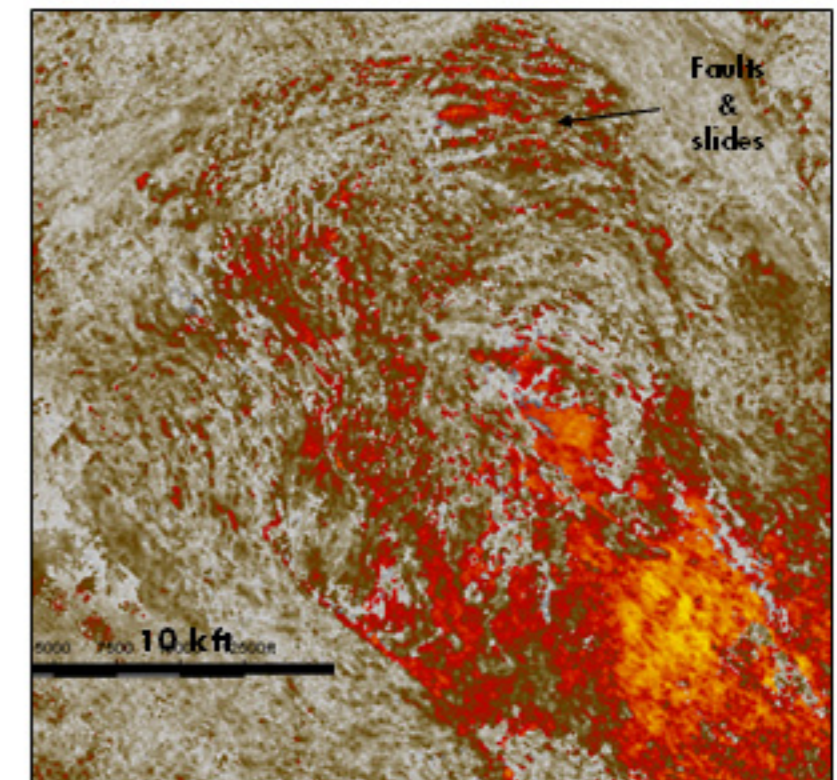
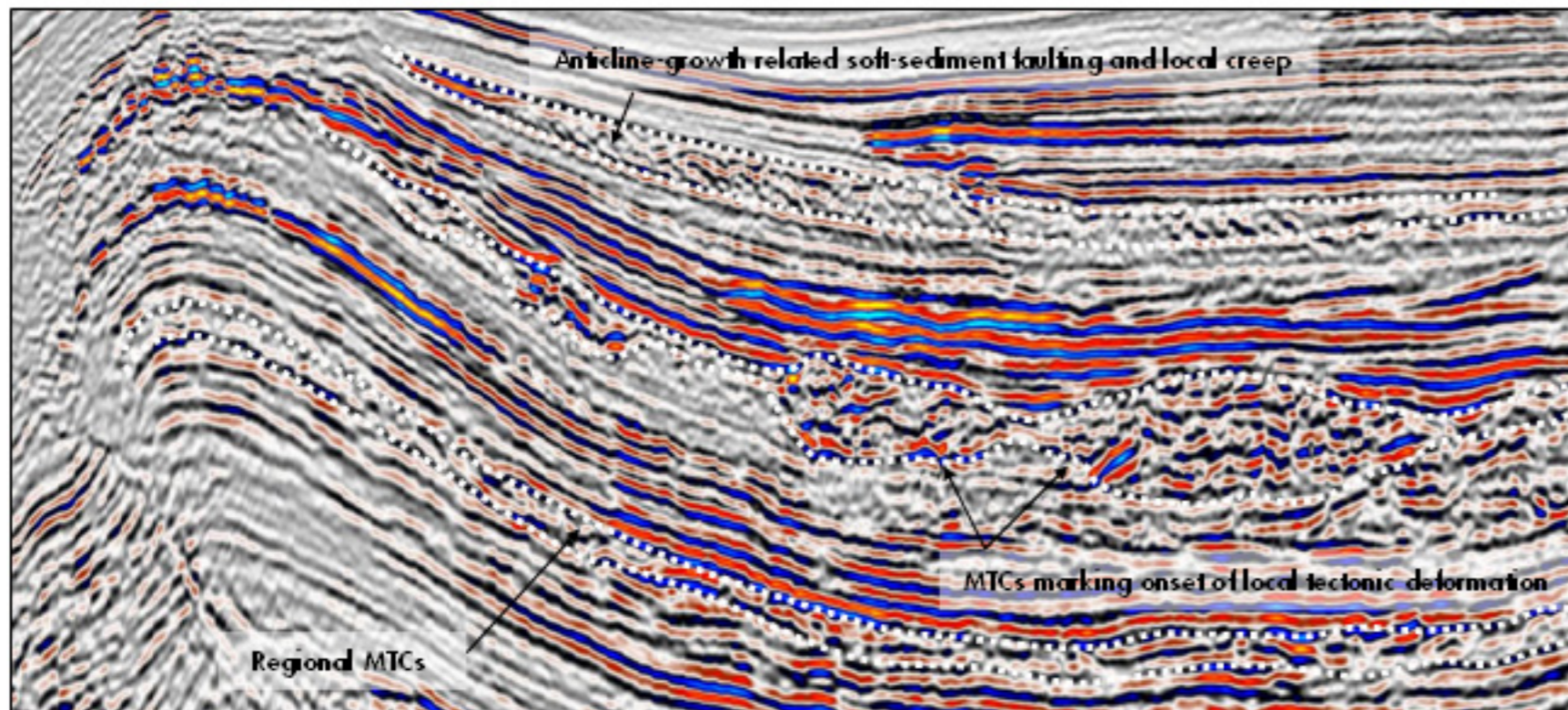
Ponding & remobilization

Lateral continuity & thickness of ponded aprons may be affected by deposition of slumps shed locally from adjacent growth anticlines

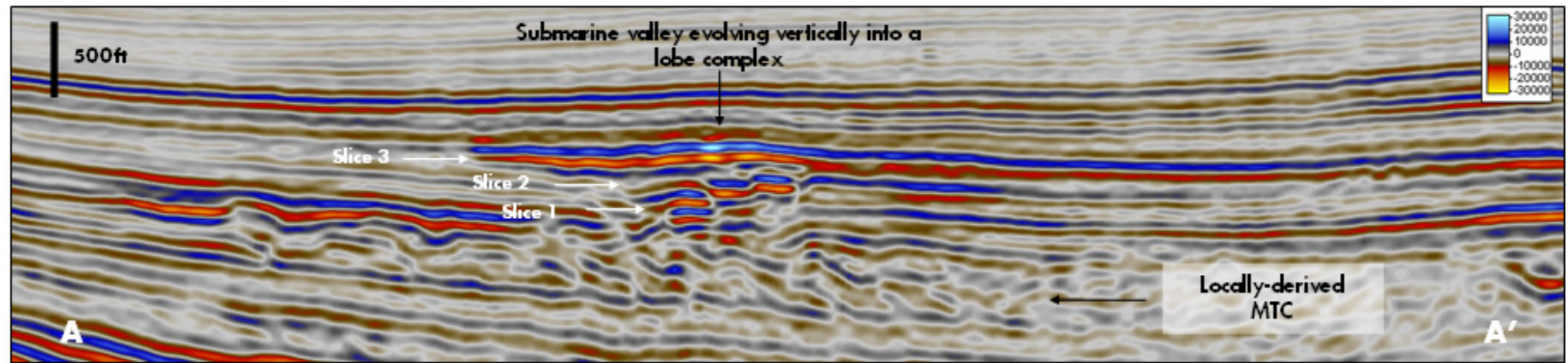


1. Steadily evolving & sheltered apron deposition in an enclosed syncline

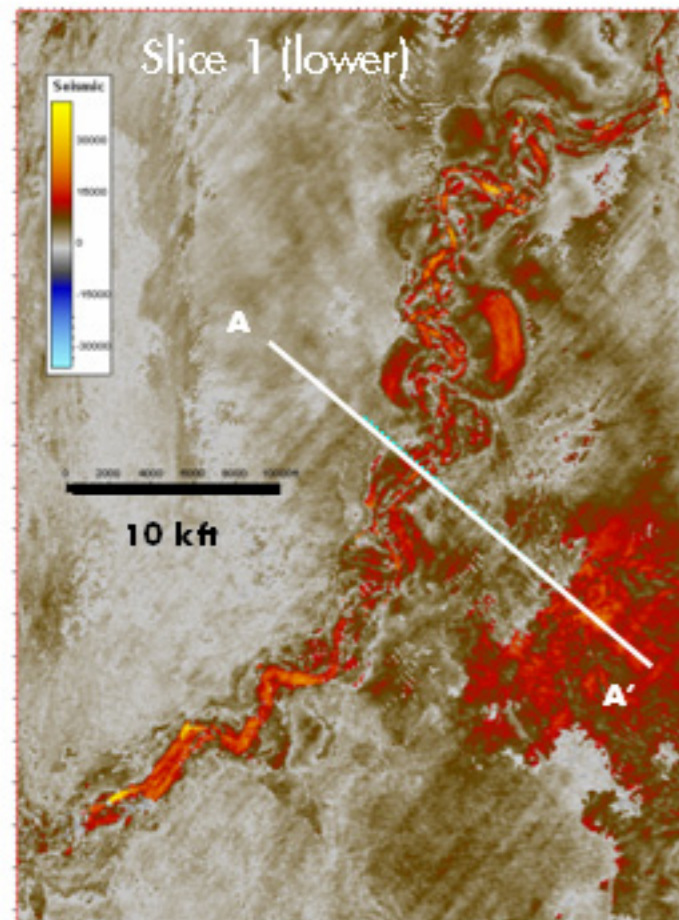
2. Slope apron distribution & continuity influenced by anticline flank instability



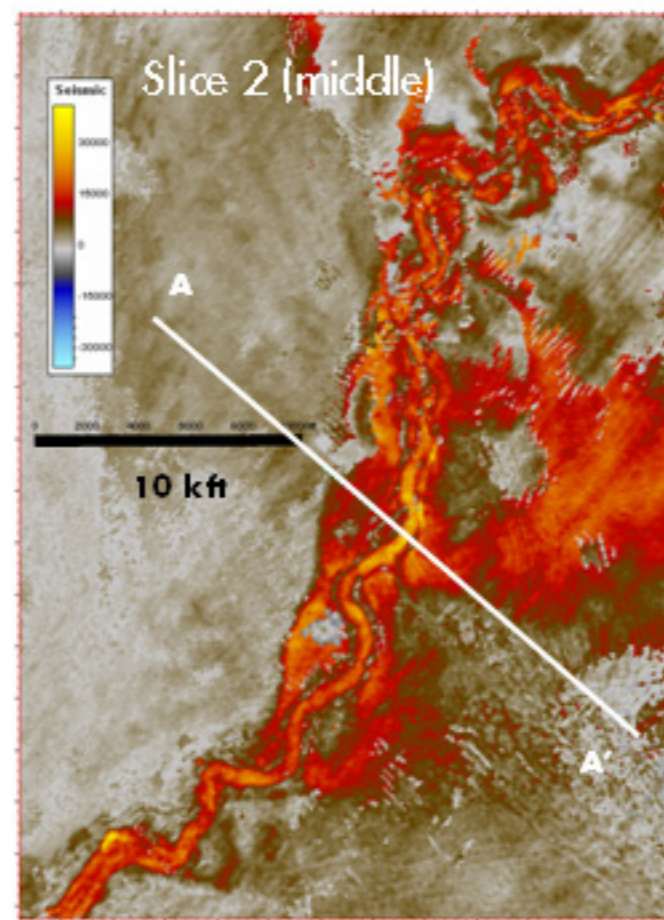
Tectonically controlled valleys



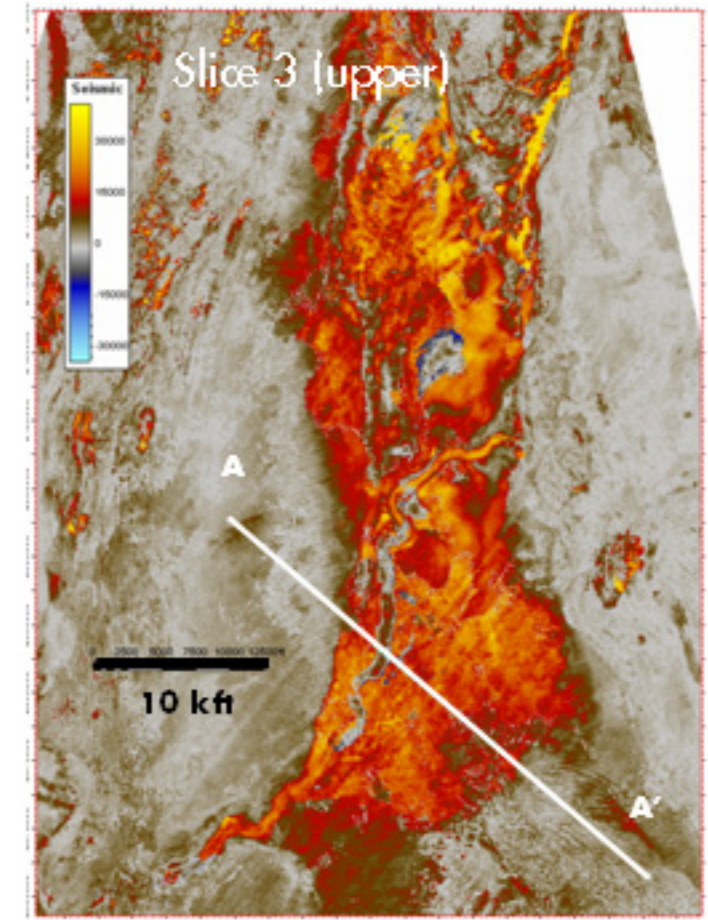
1. Incision & bypass



2. Levee growth & crevassing



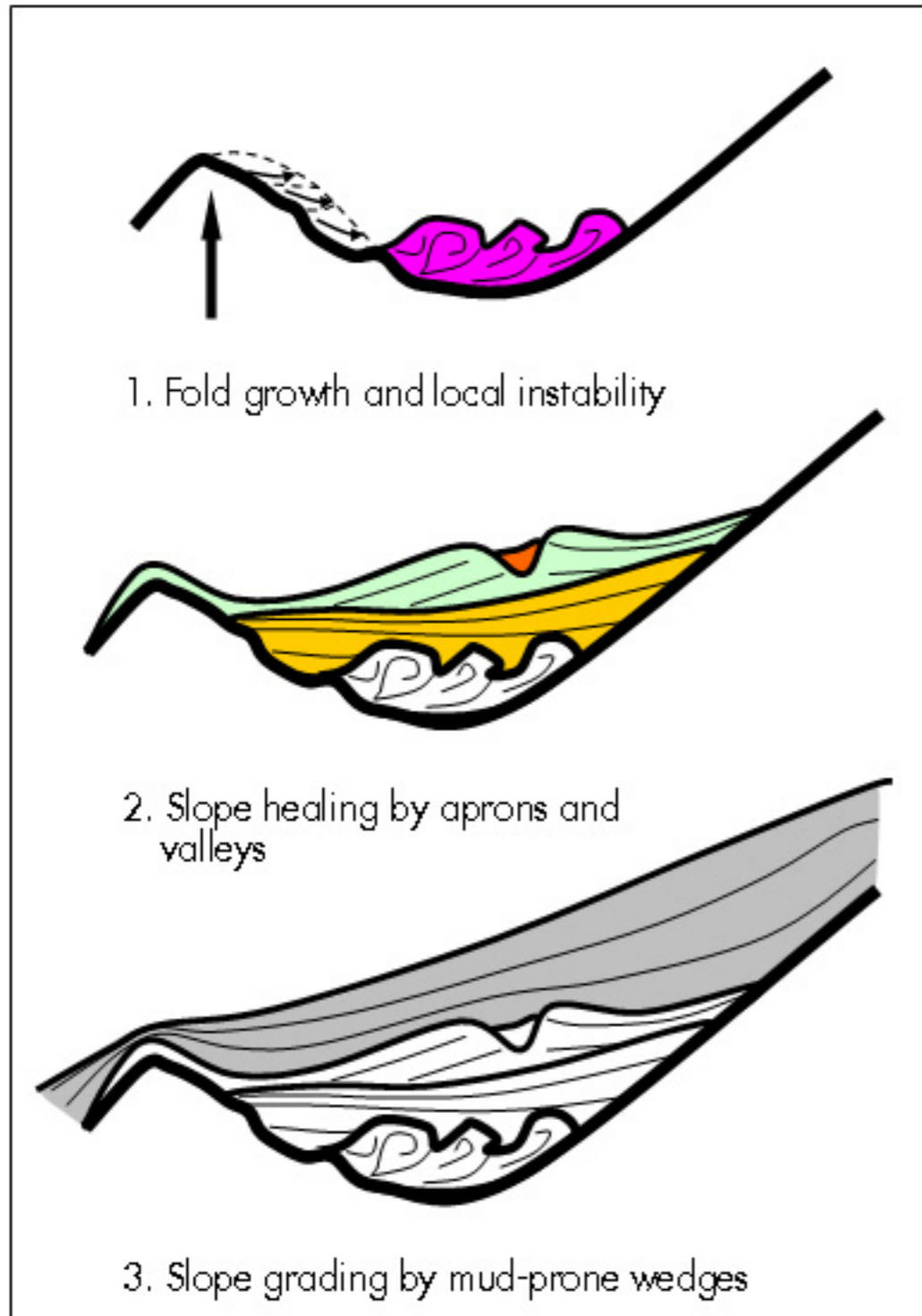
3. Spill phase: Lobe deposition



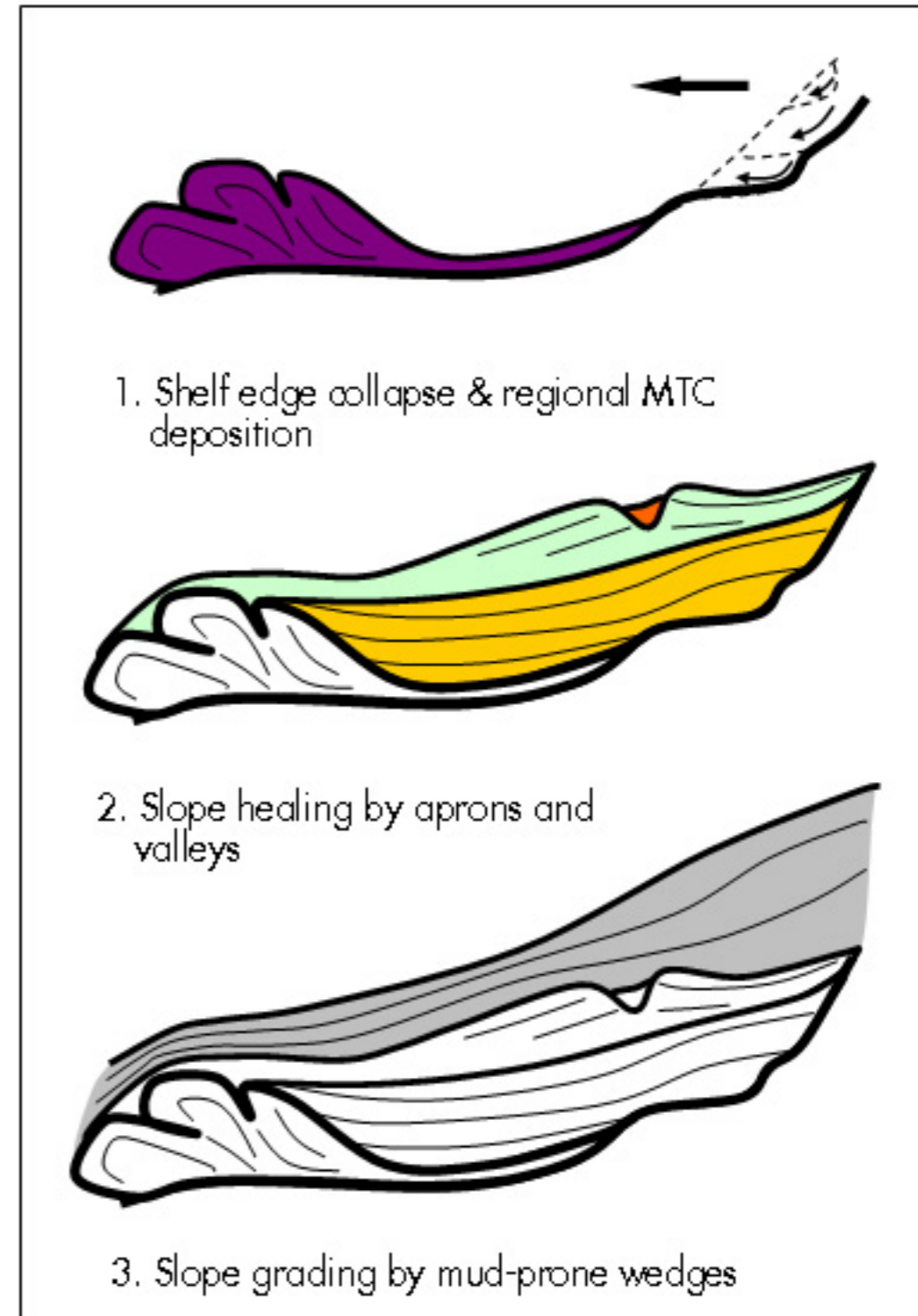
Slope gradient & degree of confinement changes according to rates of deformation & healing

Unstable slope accommodation & fill

- Slope instability processes both create and fill slope accommodation
- MTDs confine or interfere with turbidites and thus affect reservoir quality

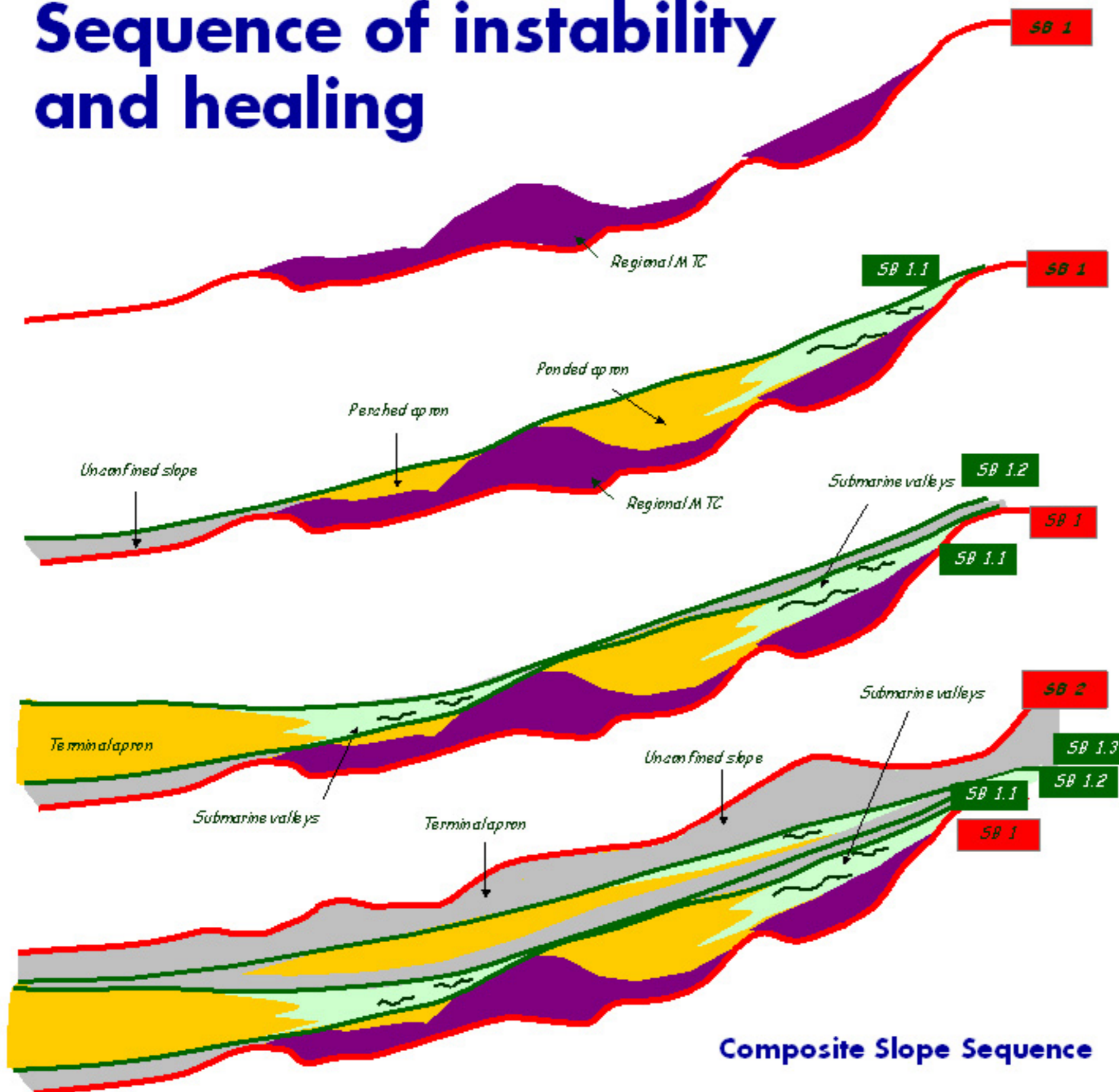


Tectonically created accommodation



Shelf-edge collapse - created accommodation

Sequence of instability and healing



Instability

Shelf-edge instability & emplacement of regional-scale MTCs

Ponding

Deposition of turbidite aprons upslope from the MTC topography

Bypass

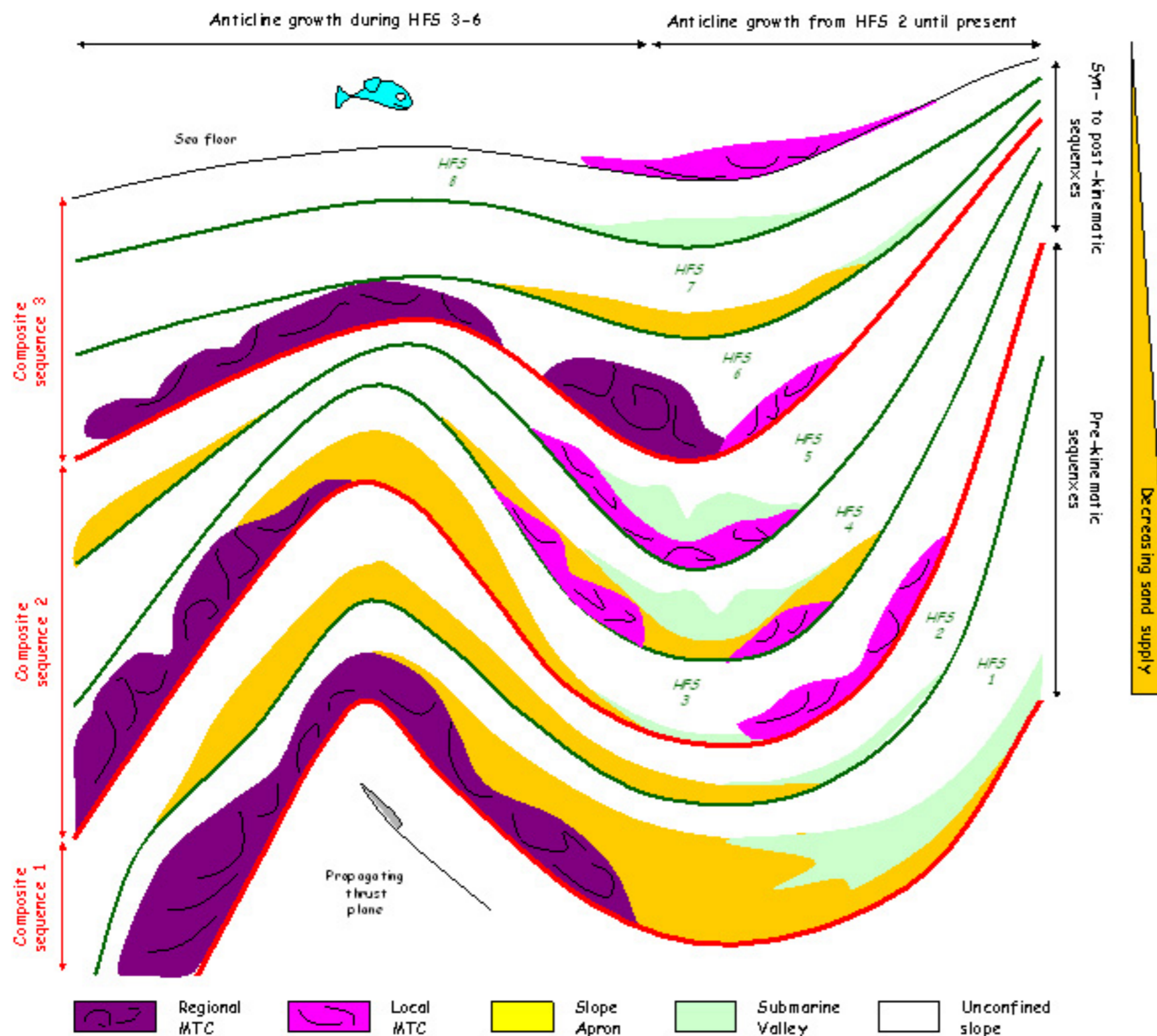
Submarine valleys bypassing healed lower slope and accumulating further basinward

Aggradation

Aggradation / back-stepping of smaller turbidite systems under decreasing sand supply conditions

Composite Slope Sequence

Deposition on tectonically active slopes



- Slope instability and healing repeats in response to allocyclic factors of relative sea-level and sediment supply change and defines composite (low-order) slope sequences.
- Additional complexity is a result of syn-depositional toe-thrust tectonics. Accommodation and bypass patterns recorded in high-frequency sequences are controlled by the geometry of synclines and their position relative to sediment fairways.

Conclusions

- Two types of slope accommodation are recognized in NW Borneo :
 - Accommodation related the emplacement of large mass transport deposits, triggered by the shelf-edge instability
 - Accommodation related to episodic thrust-propagation folding
- The slope depositional sequences are defined by:
 - progressive healing of newly created slope topography
 - changes in sediment supply into deep water
- Regional-scale MTCs created by shelf-edge collapses allow slope deposition of sandy aprons in the pre-tectonic phase
- Mapping of regional MTCs allows identification of composite slope sequences and prediction of vertical probability of sand occurrence
- Locally shed MTCs related to syn-depositional anticline growth commonly interfere with turbidite depositional patterns and may negatively impact reservoir quality

Presentation Notes

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Retro-arc foredeep setting; More than 1,000 m water depth; Dominated by slope instability and gravity-driven tectonics; High rates of shelf aggradation / limited shelf-edge progradation.

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- Not every sea-level lowstand coincides with deepwater sand fan.
- Additional controls and potentially higher frequency event are needed to explain the depositional pattern.

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Variable degree of anticline burial. Slope healing by trapping of sediment shed from the shelf edge behind growing thrust-propagation anticlines. MTC prone areas = structurally complex = active = unstable substrate. MTC rest in topographic lows, but are more cohesive; hence create more pronounced topography. Adjacent to it, new slope accommodation was created.

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Regionally developed depositional sequences stretching from shelf edge to the toe of slope. They reflect fluctuation of the sediment supply from shelf to deep water. Response to a combined effect of hinterland / shelf tectonics and sea-level changes. Link to the shelf sequences not yet established, and therefore the sequence definition is used informally to describe depositional successions bound by events marking significant re-organization of depositional systems. Oldest sequences: small thickness variation; younger ones show thickening/thinning, which progressively extends down-slope, reflecting successive outboard thrust propagation / anticline growth. Pre- and syn-kinematic sequences can be distinguished, although the onset of deformation spatially varies. Chaotic seismic reflectors, indicating substrate deformation and mass transport deposits, occur at various scales. They are NOT limited to syn-kinematic sequences. Regional scale MTCs separate groups of HFS and may be used to distinguish composite (major) slope depositional sequences.

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Depositional cyclicity reflected in the repeating vertical pattern of seismic facies: Schematically: chaotic facies (MTCs) overlain by High-amplitude continuous to semi-continuous facies (indicative of sand deposits), in turn overlain by low-amplitude facies (mud-dominated). Seismic facies development is spatially variable, and locally the pattern breaks down because of the introduction of smaller scale MTCs or thinner high-amplitude packages, defining high-frequency sequence boundaries.

Convergent shape of sequences indicates reduced sedimentation rate over growing substrate topography. Onset of deformation varies spatially: generally getting younger downslope, but also along-strike variation. Syn-kinematic sequence does not mean there is no sand on top of the anticline – “crest retreat” effect recording progressive widening and roll-over.

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Slope – base of slope regions in the pre-kinematic sequences; same in the structurally complex syn-kinematic sequences. A bit of retrogradation in the pre-kinematic sequence (sand at the top of the major sequence in the updip position). Smaller, localized sands in the syn-kinematic sequences. HFS boundaries mark the shifts of sand depocentres. Successive HFS show larger lithological variability compared to the pre-kinematic ones (shorter-lived, migrating accommodation).

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Base of slope & slope accommodation; Perched behind MTCs.

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Base of slope & slope accommodation; Series of loosely connected depocentres controlled by growth fold highs.

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Syn-kinematic depositional sequence: internal architecture.

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