PS Regional Stratigraphic Differentiation of Deepwater Fan and Channel Geometries, Offshore Tanzania and Mozambique: Size Matters*

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Abstract

The emerging deepwater gas province offshore East Africa presents great opportunities and also dilemmas in high-grading a vast region for petroleum potential. Known hydrocarbon play elements are Cretaceous and Early Tertiary deepwater fan systems, structurally-enhanced stratigraphic traps, and a functioning gas petroleum system with unknown liquids potential. The fan/channel reservoirs contain remarkable reservoir properties and a high degree of connectivity; however, their distribution is more problematic. The ability to map reservoir spatial and temporal distribution is a critical undeveloped play element. We outline a workflow that enables this mapping by generating high-resolution horizon interpretations of a coarse regional 2D seismic grid over a 400,000 square kilometer area. Regional mapping of time-correlative stratal packages outlines the broader depositional and tectonic-stratigraphic framework. Detailed mapping of various architectural elements within these stratal packages reveals systematic variation both within and between stratal intervals. Channel morphology and related geo-body types and dimensions vary both up- and down- depositional gradient, but also according to stratigraphic position. Geo-body dimensions and distribution are dictated by the geomorphic gradient and profile controlling sediment deposition. Steeper profiles have greater potential energy and thus higher incision in up-dip positions, with little levee development and more aggradational frontal splays and lobes occurring down-dip. Sediment partitioning favors down-profile deposition and channel concentration in fewer channels. The resulting stratigraphic record favors single-story channel systems and smaller, multi-storied lobes. Lower-gradient profiles generate more low-energy density flows, resulting in less up-dip incision and significant, symmetric levee development and shingled or progradational frontal splays in down dip positions. The resulting stratigraphic record favors multiple, along-strike channel development creating laterally persistent, single-storied sands and aerially larger, shingled fan lobes. Understanding the distribution and stacking of these different architectural elements through time has significant implications for trapping, reservoir distribution and connectivity. Application of this work provides enhanced predictability to exploration efforts, including distribution of reservoir properties in a regional basin context.

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Regional mapping of time-correlative stratal packages outlines the broader depositional and tectonic-stratigraphic framework. Detailed mapping of various architectural elements within these stratal packages reveals systematic variation both within and between stratal intervals.

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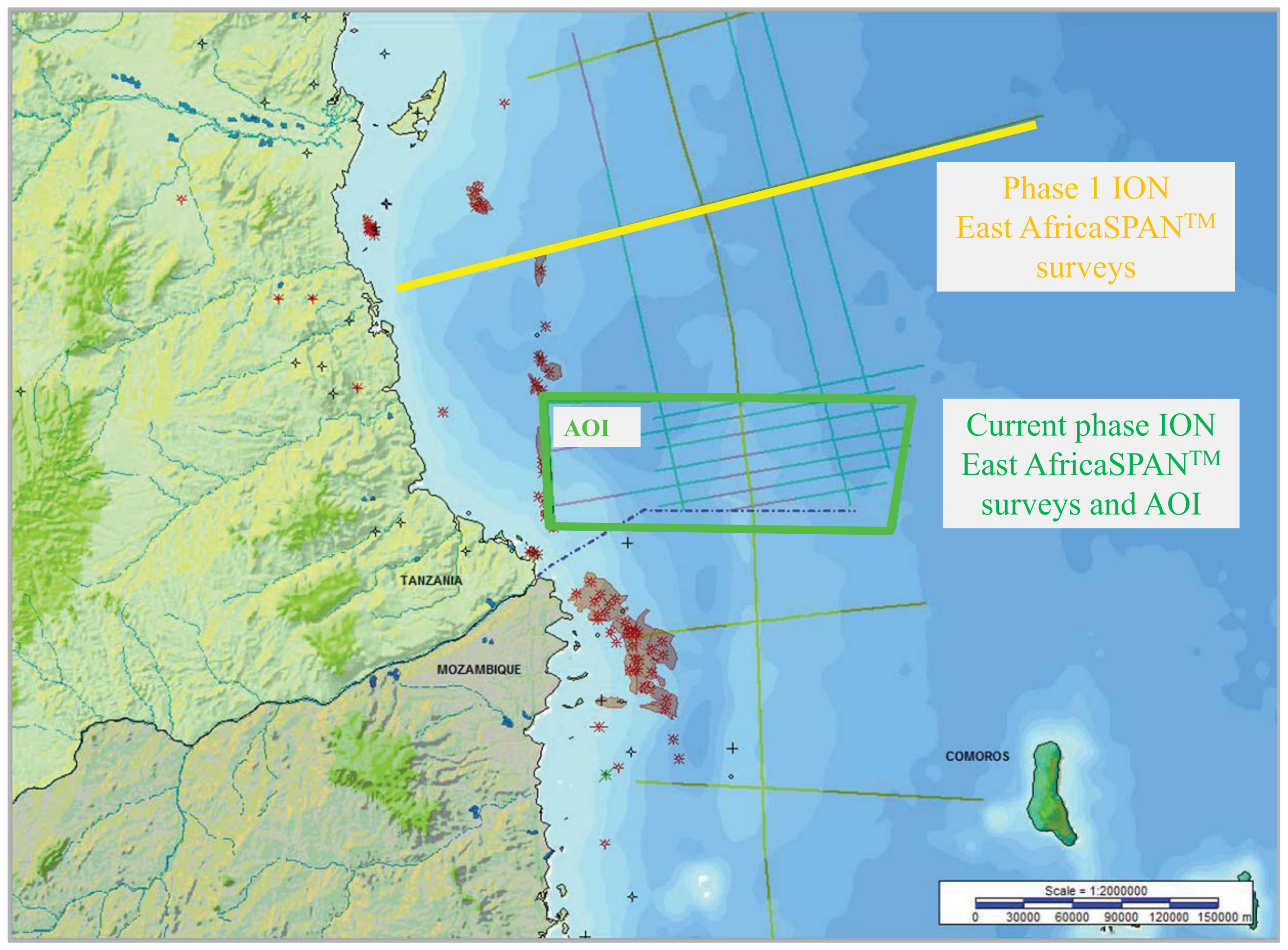
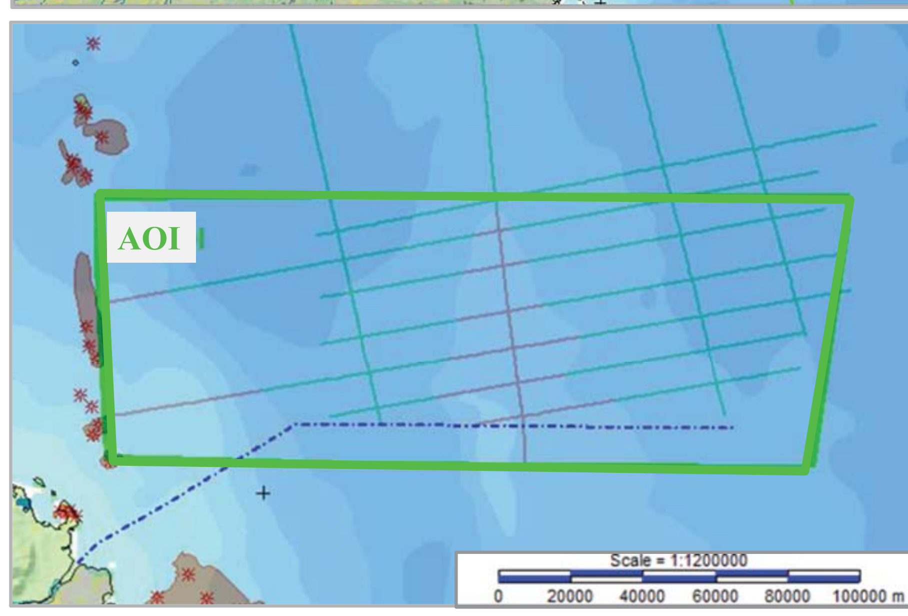
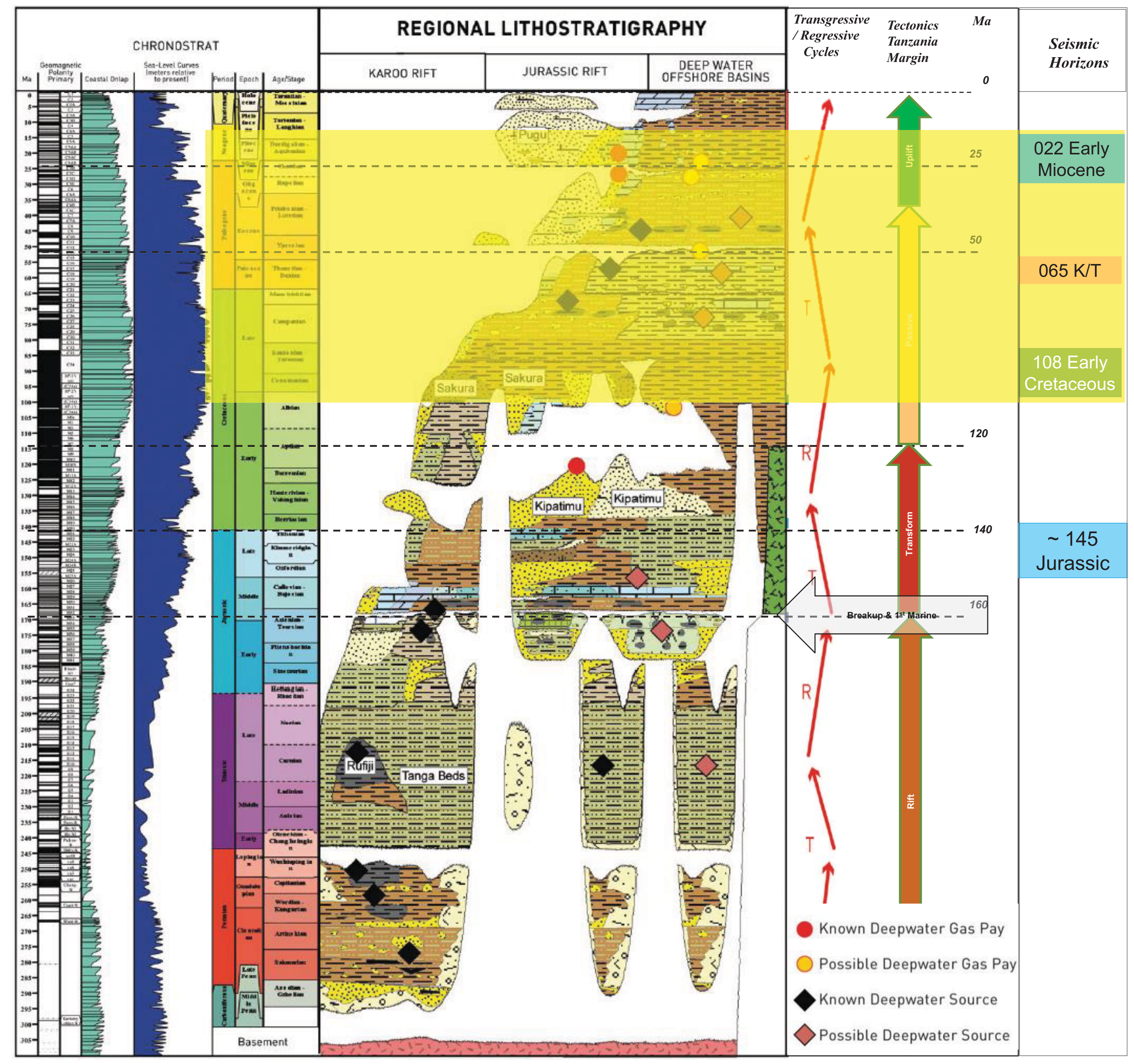
Regional location map showing 2D seismic surveys from ION's East AfricaSPAN™ used in two phases of this work





Regional PSDM seismic profile across the Tanzania Deep Offshore Basin



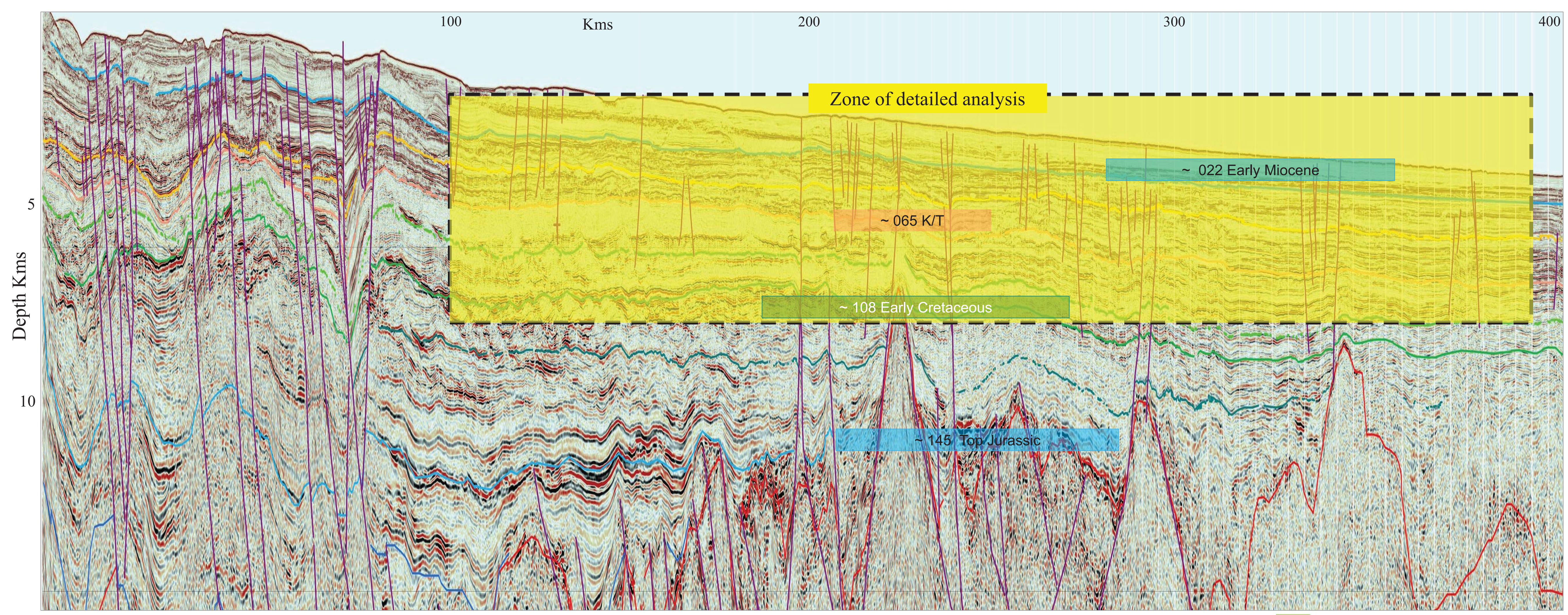
Tectono-stratigraphic Mega Sequences Reveal Long Term Basin Evolution:

4. Uplift and Regression: Late Paleo/Eocene to Recent East Africa Uplift

3. Passive Margin: Mid Cretaceous to Eocene – T/R Cycles

2. Transform Margin: Mid / Late Jurassic to Mid Cretaceous – Gondwana breakup

1. Syn-Rift: Karoo or Late Paleozoic to mid-Jurassic continent-wide rifting



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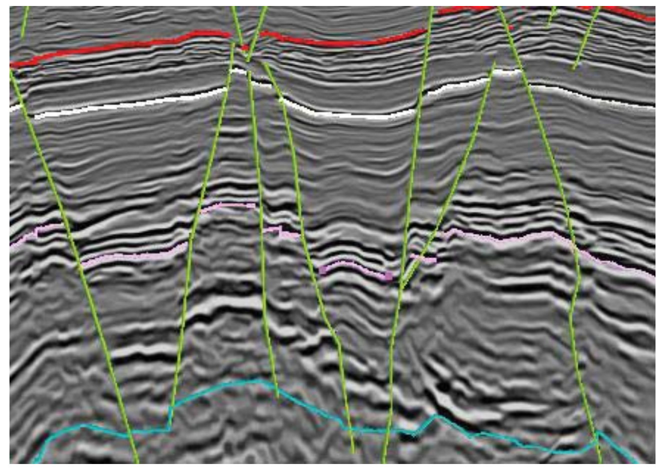
Workflow for Systems Tract & Stratal Package Delineation via HorizonCube-Derived Wheeler Diagrams

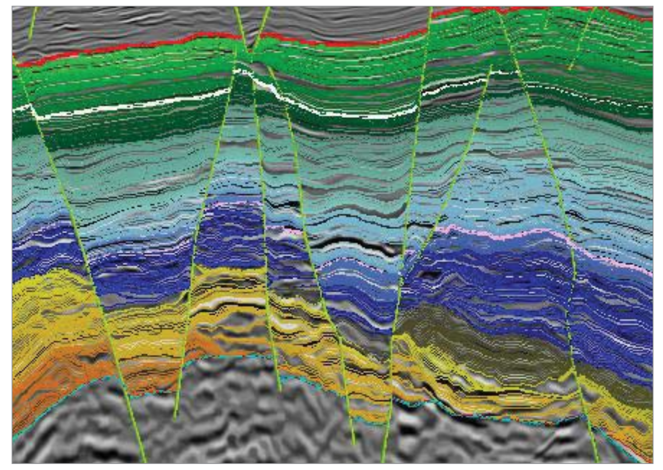
1. Generate HorizonCube

HorizonCube processing input data:

- PSDM or PSTM SEGY data
- 2D Dip Steered Filter
- Framework horizons
- Mapped faults

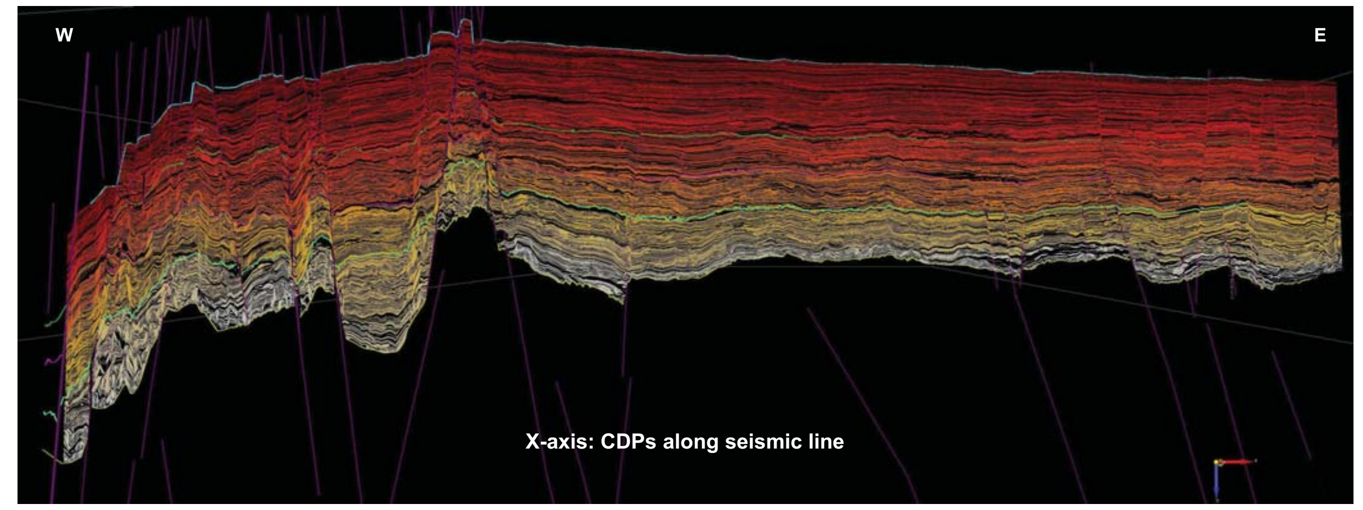


From starting seed points, laterally auto-track thousands of individual seismic horizons at a very closely-spaced vertical sampling rate (up to 2m)



Produce an extremely high-resolution seismic interpretation of most stratal surfaces present in the seismic data

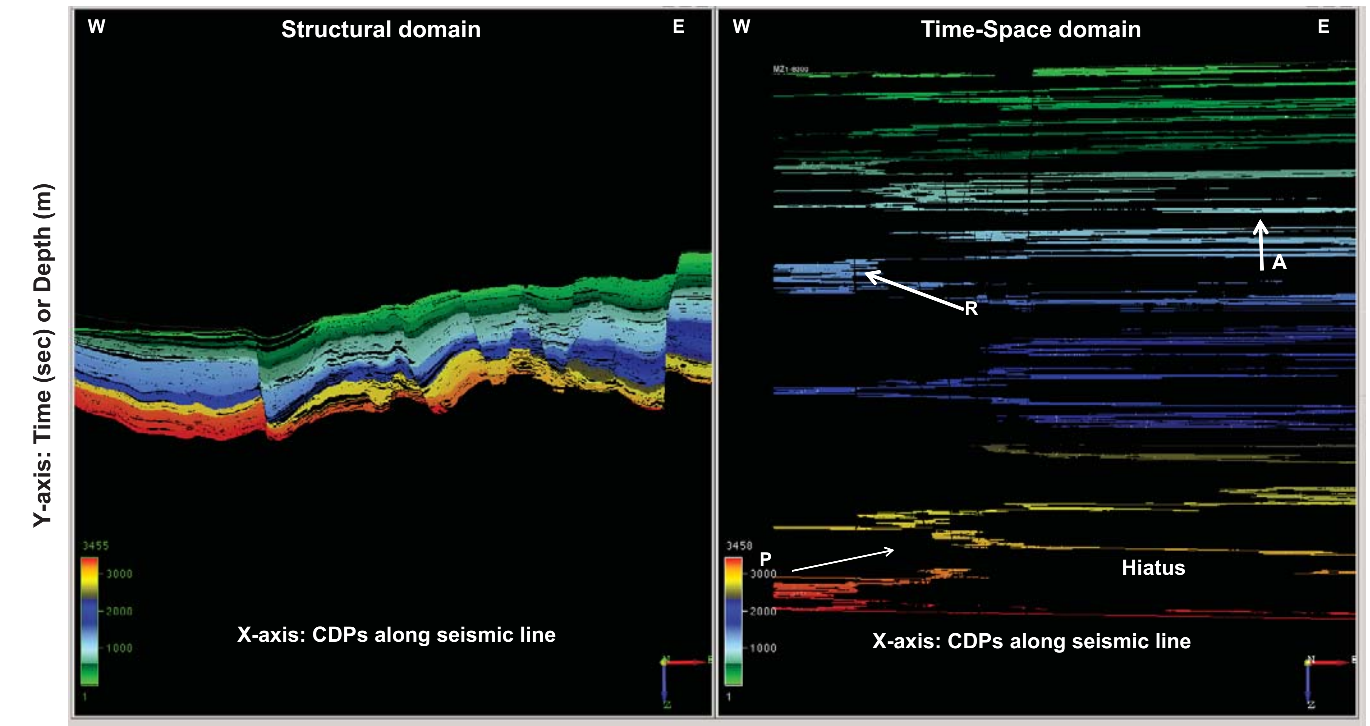
TZ4-2150 HorizonCube



A HorizonCube consists of a set of closely vertically-spaced, correlated stratigraphic surfaces, color coded to facilitate package delineation

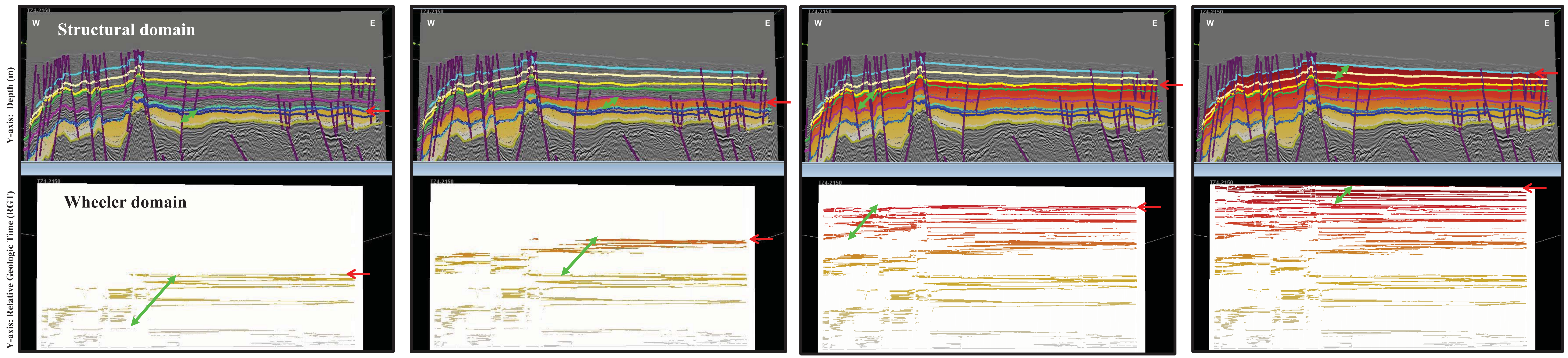
Visualize detailed stratal surfaces, geobodies, architecture and geometries – high-resolution HorizonCube interpretation

Wheeler (Time-Space) Transform



2. Use unflattened (structural domain) and flattened (Wheeler domain) HorizonCube events to visualize and map depocenter shifts in time and space.

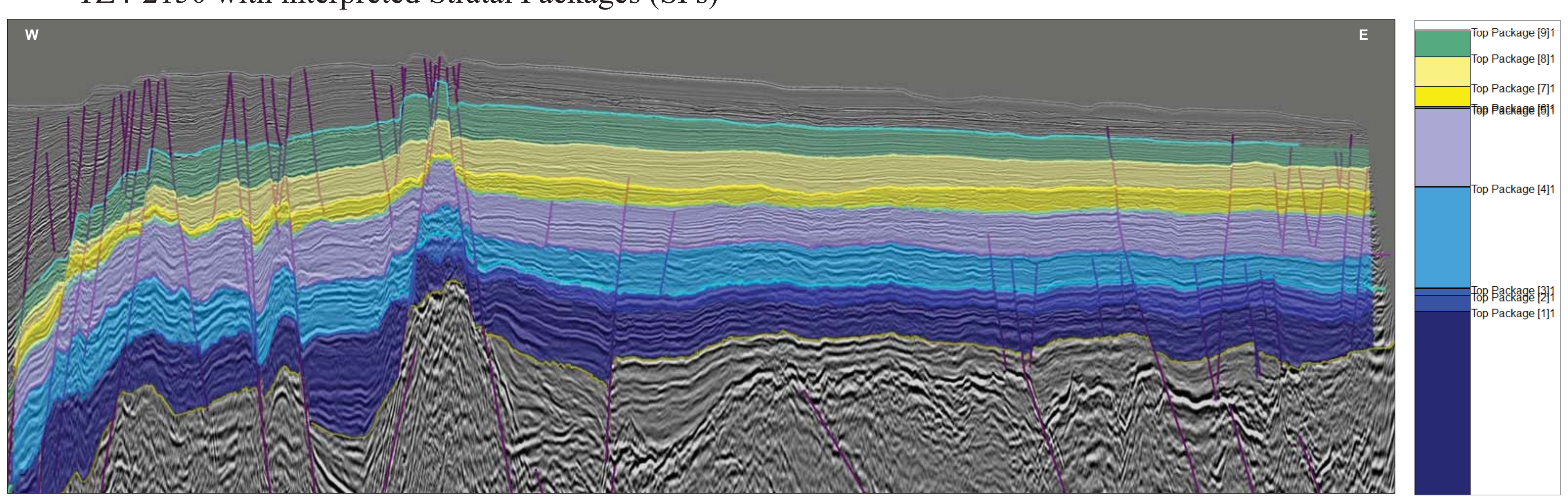
TZ4-2150 showing use of HorizonCube data for progressive stratigraphic interpretation



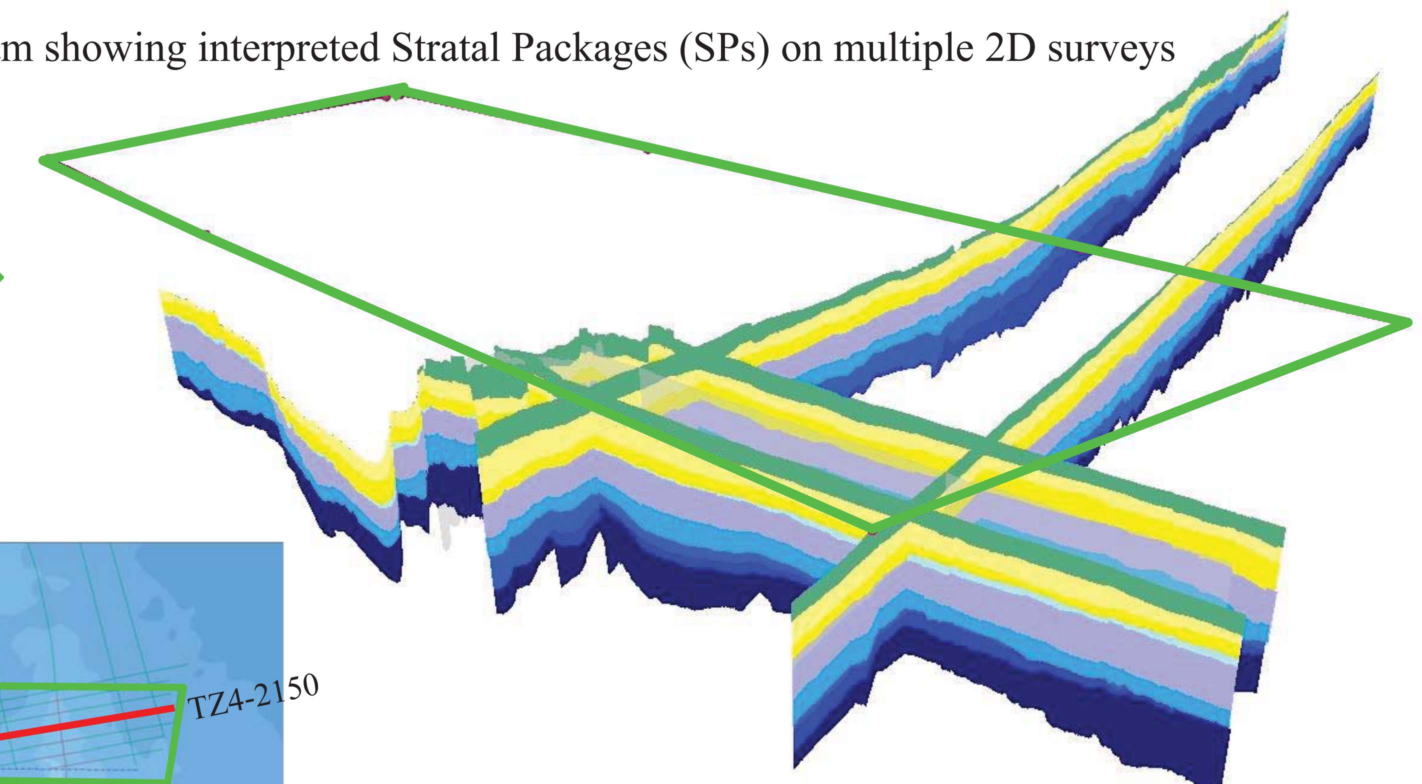
Candidate stratal packages and their boundaries

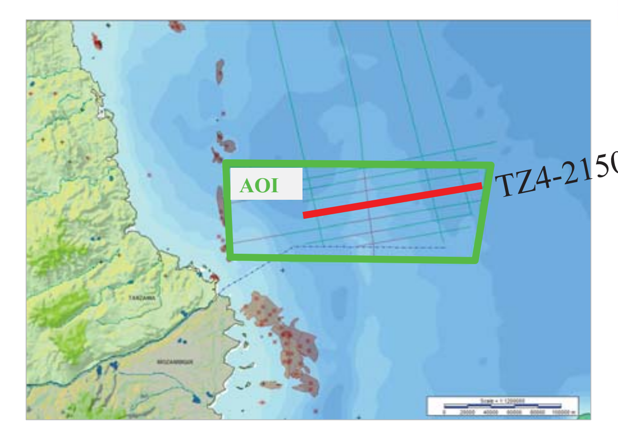
3. Using flattened HorizonCube events (Wheeler Diagrams), delineate and correlate Stratal Package (or systems tract) boundaries based upon areal shifts in depocenters and seismic facies variations.

TZ4-2150 with interpreted Stratal Packages (SPs)



Fence diagram showing interpreted Stratal Packages (SPs) on multiple 2D surveys





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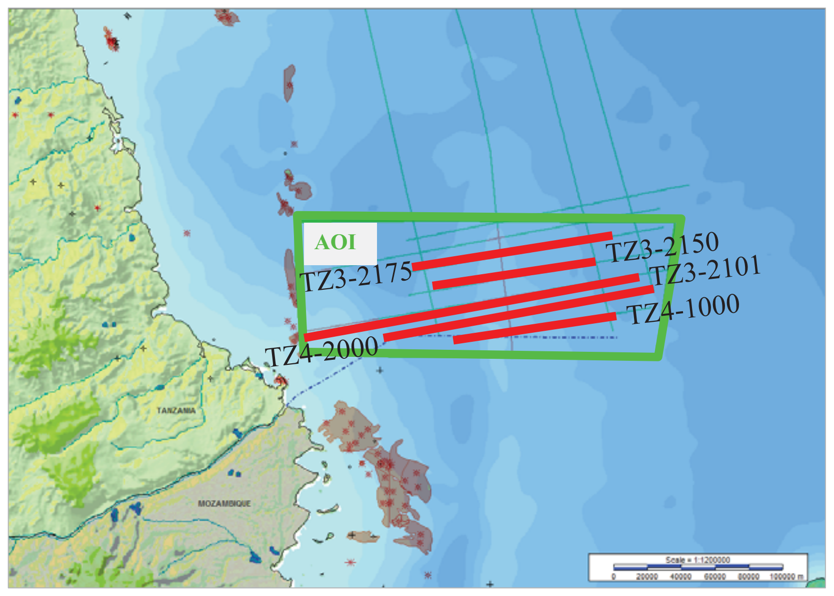
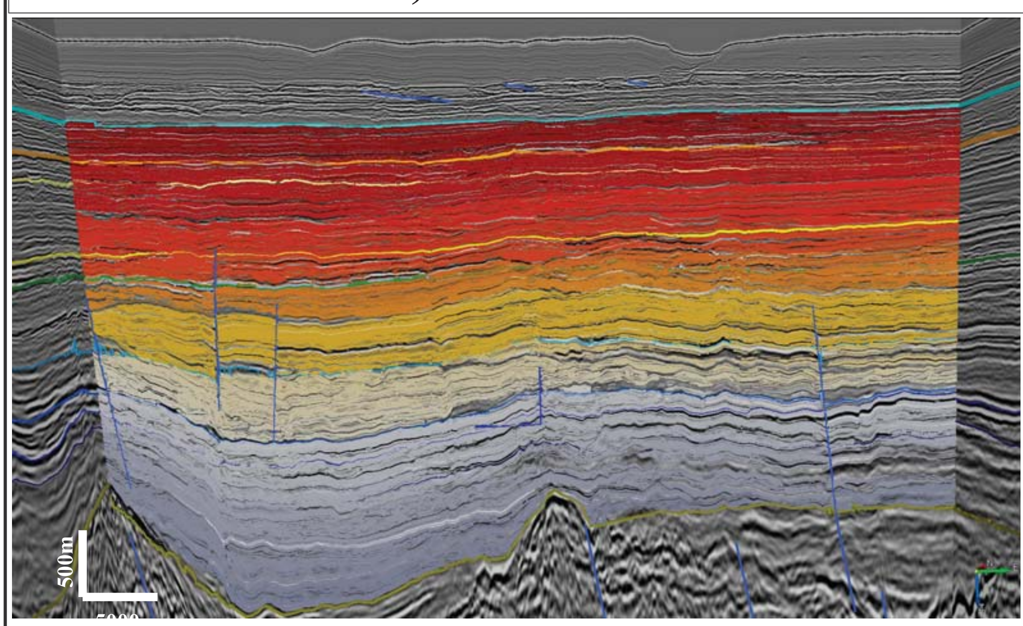
Stratigraphic Variability:
HorizonCube Event Density Reveals Fan / Channel Geobody Geometries

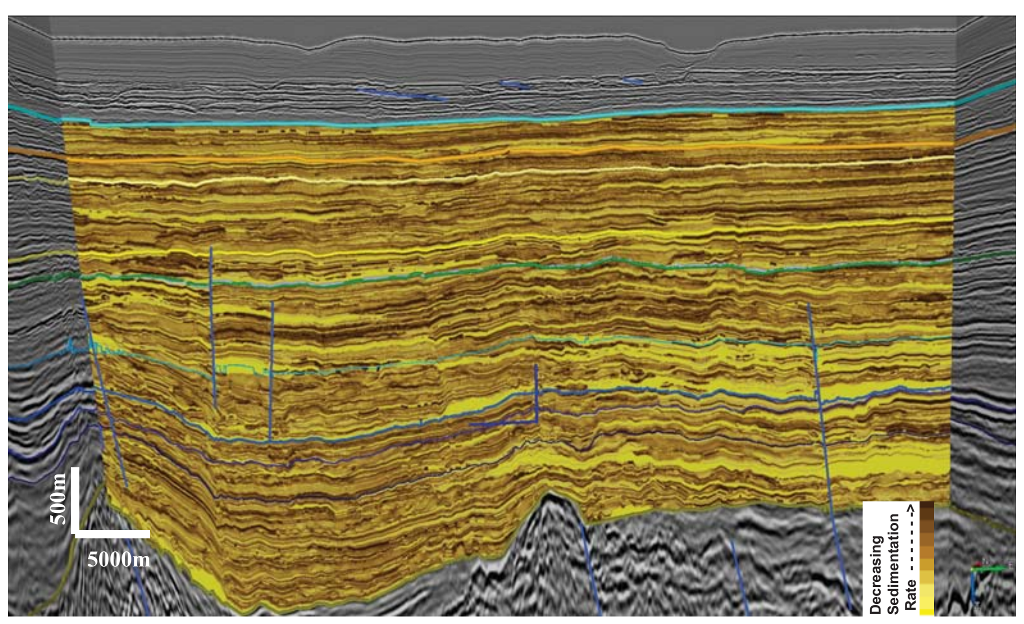


HorizonCube density attribute tallies the vertical density of auto-tracked HorizonCube events (horizons). Low event density is interpreted as a higher sedimentation rate (inferred proxy for sand-prone); high event density assumes a slower sedimentation rate (inferred proxy for mud-prone).

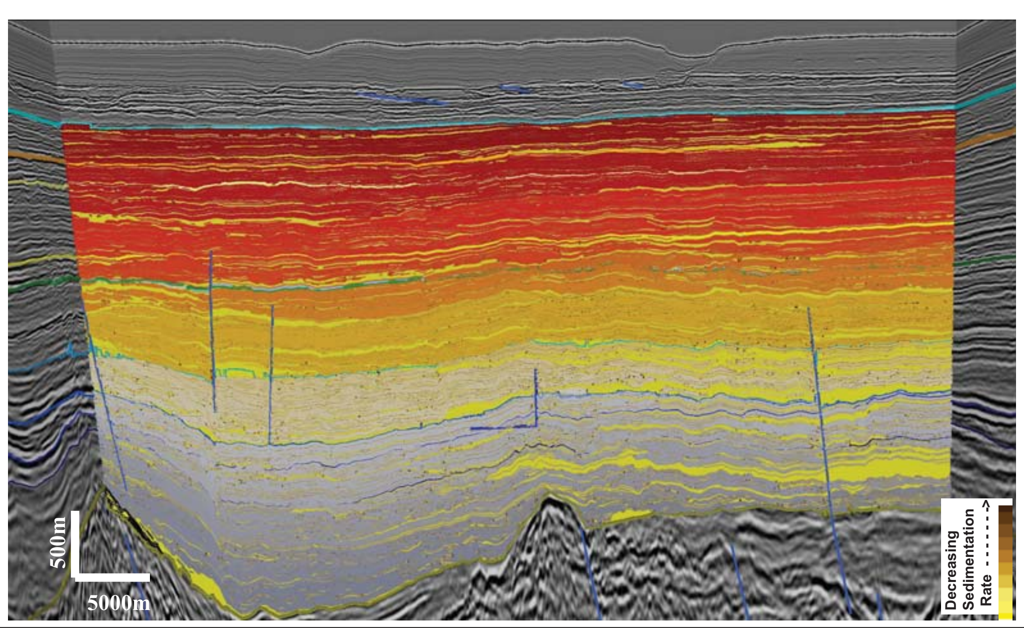
HorizonCube + density attribute reveals architecture and ~ sediment accumulation rate (proxy for sand-rich or mud-rich?)



TZ3-2101 HorizonCube overlying PSDM data



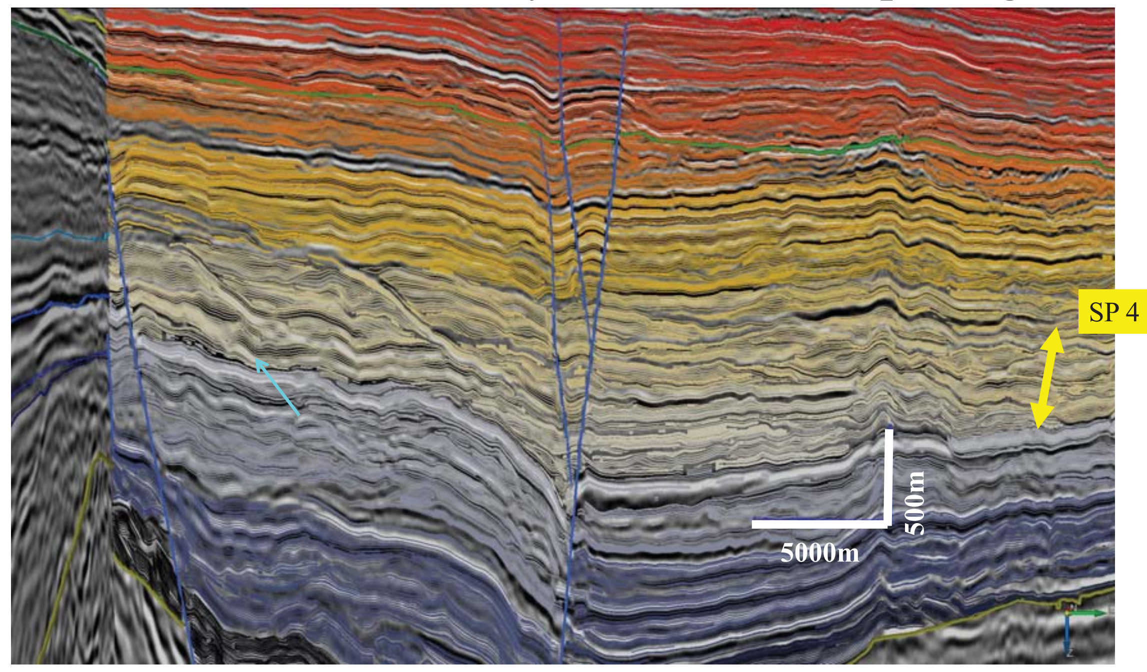
TZ3-2101 with density attribute over PSDM data



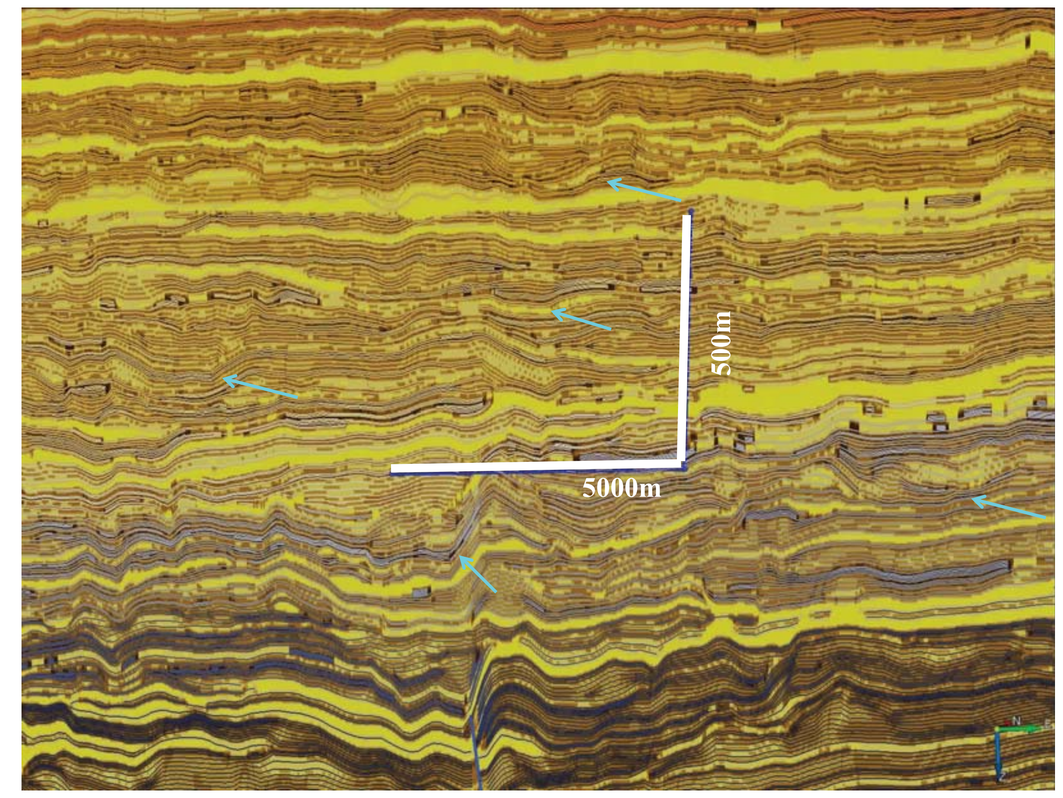
TZ3-2101 with density attribute co-rendered with HorizonCube (proxy ~ sand distribution)

HorizonCube and density attribute highlight architectural elements and dimensions from stratal packages:

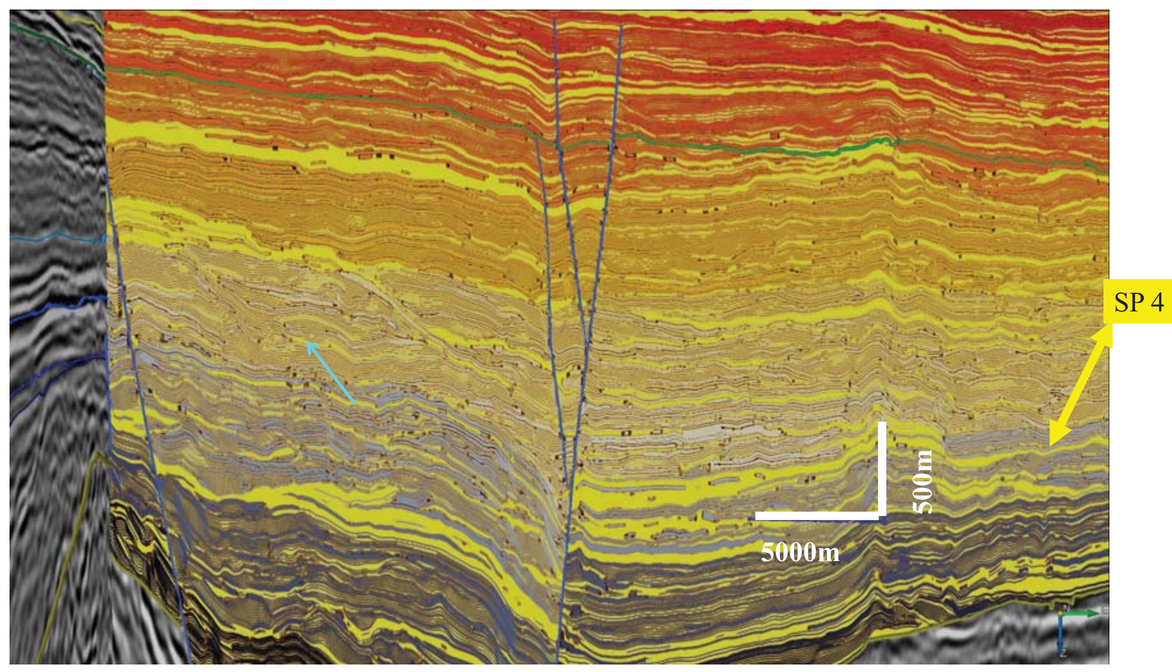
Element dimensions vary between stratal packages, inferring changing depositional gradients



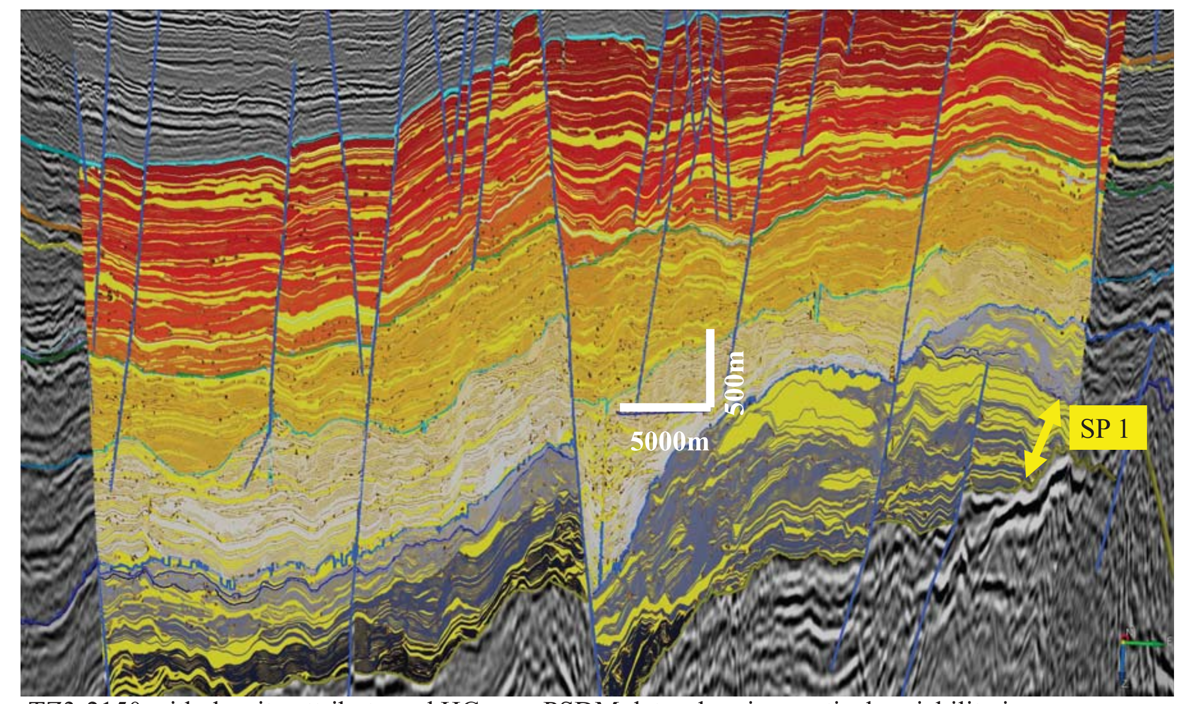
TZ4-2175 with HorizonCube showing slope channels with growth fault feature. See density, below.



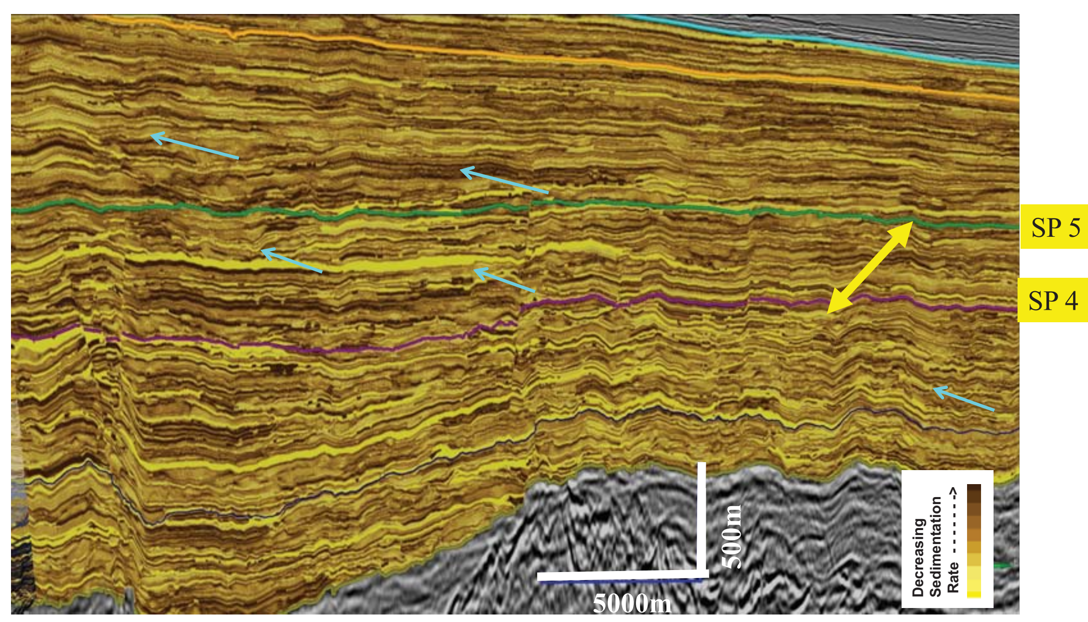
TZ4-2175 HorizonCube with density attribute showing multiple cut-and-fill channels wih small asymmetric levees.



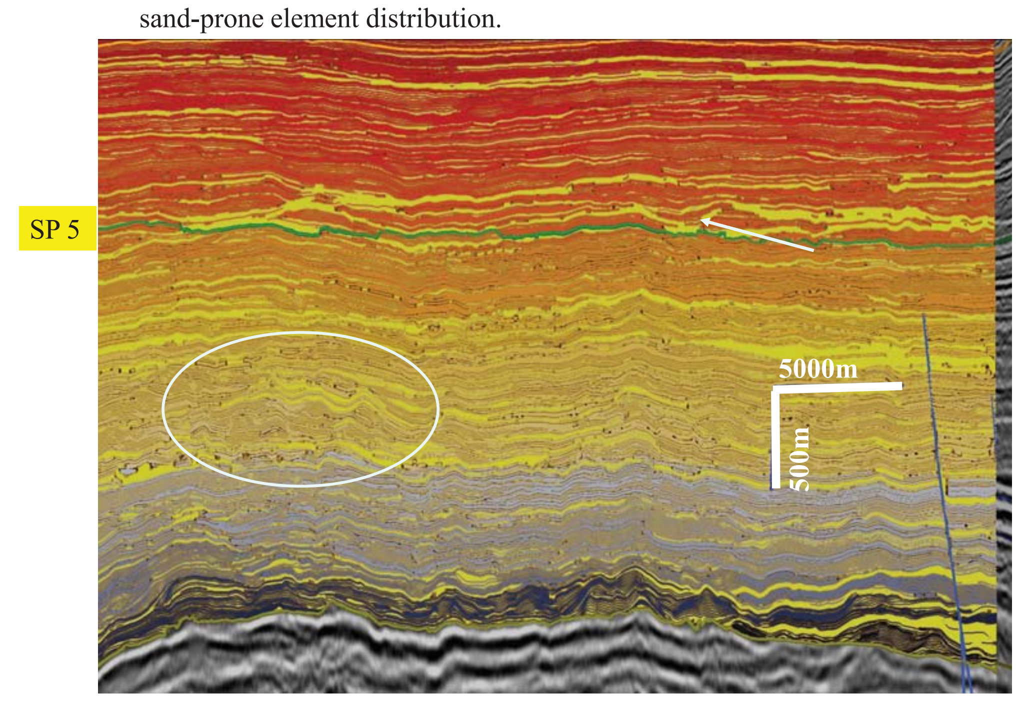
TZ4-2175 HorizonCube with co-rendered density attribute showing slope channel geometry and sand (?) distribution.



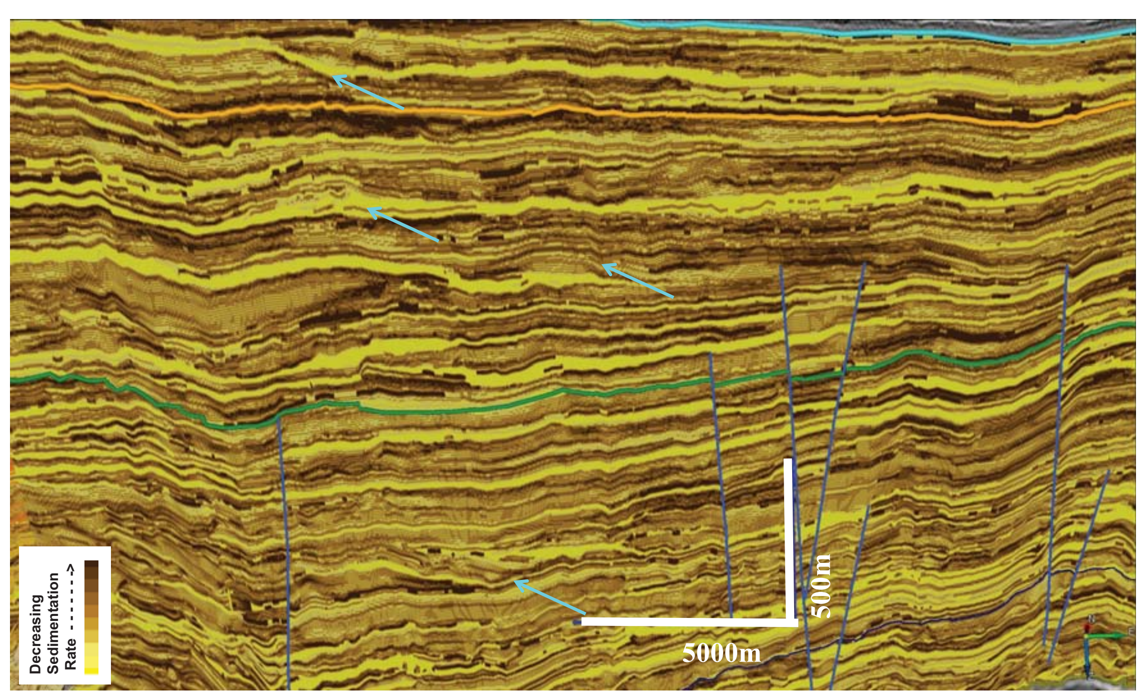
TZ3-2150 with density attribute and HC over PSDM data, showing vertical variability in sand-prone element distribution.



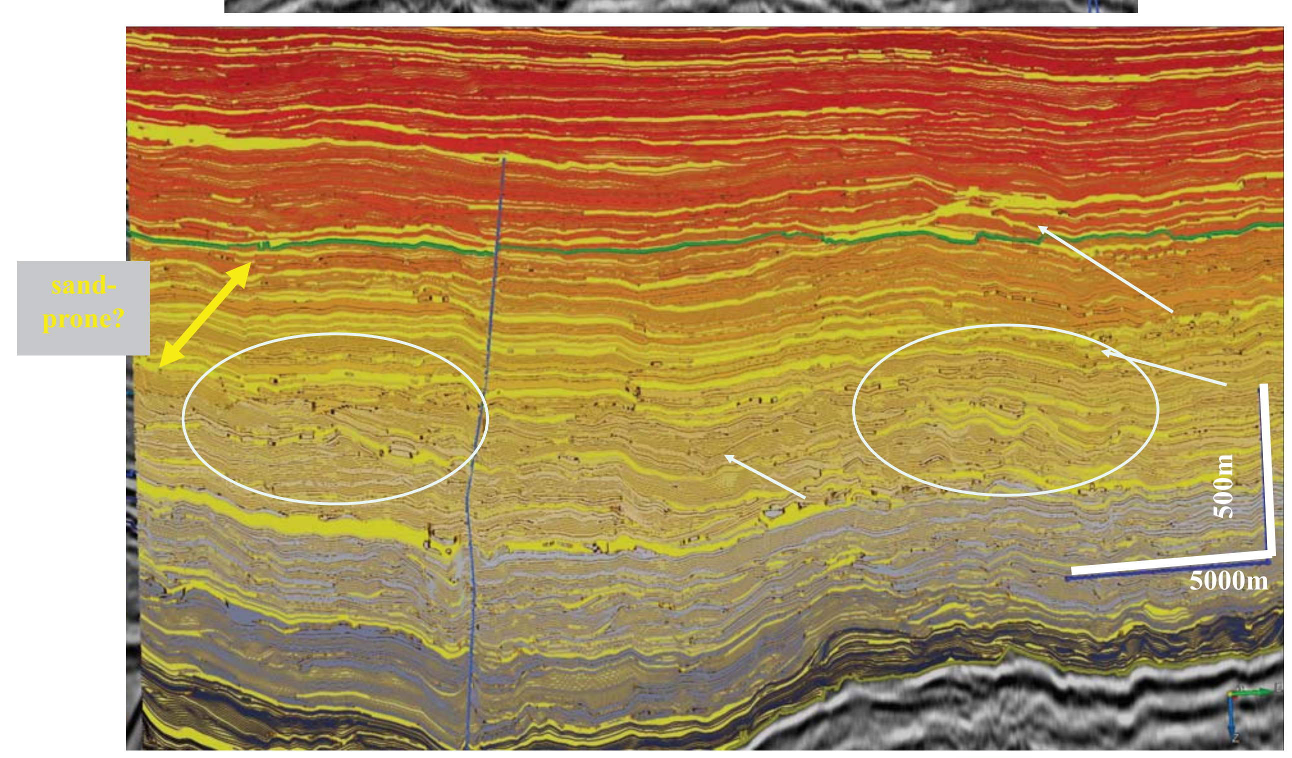
TZ4-1000 with density attribute over PSDM, showing long-wavelength (>10k meters), landward-stepping lobes (mud-prone) above SP5 overlying sand-prone (?) lobes with some cut-and-fill.



TZ4-2150 with HorizonCube and density attribute showing thicker, short wavelength cut-and-fill above levee (below SP5) and thinner, low-incision cut-and-fill above SP5.



TZ4-2000 PSDM with density attribute showing variable levee development between SPs.



TZ4-2150 with density attribute showing cut-and-fill zone evolving to higher sedimentatio n rate above.

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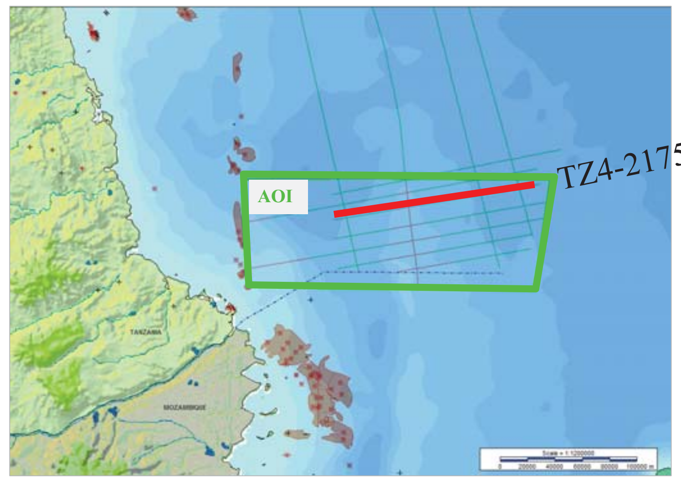
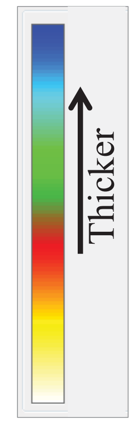
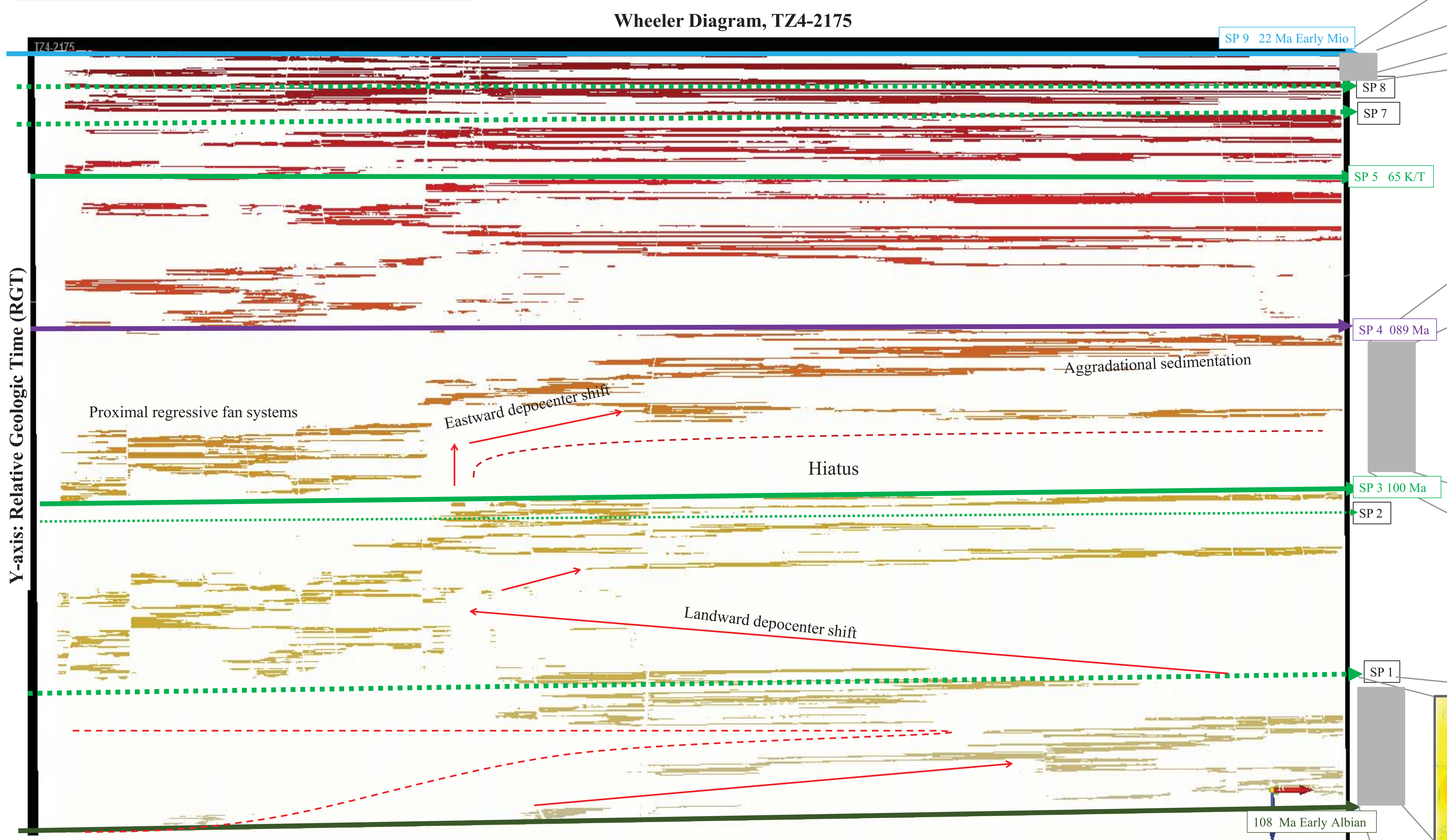
Study area profile locations lie seaward of Cretaceous/Tertiary shelf edges; therefore depositional high-gradient versus low-gradient profiles inferred from regional mapping of individual stratal packages.

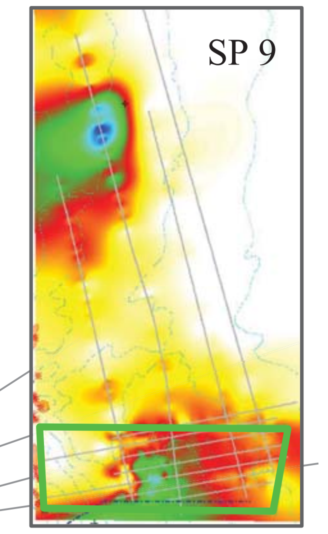
Systematic Stratigraphic Variability: Comparison of Strata Architecture and Geometry within Channel / Fan Systems from Different Stratal Packages (SPs)

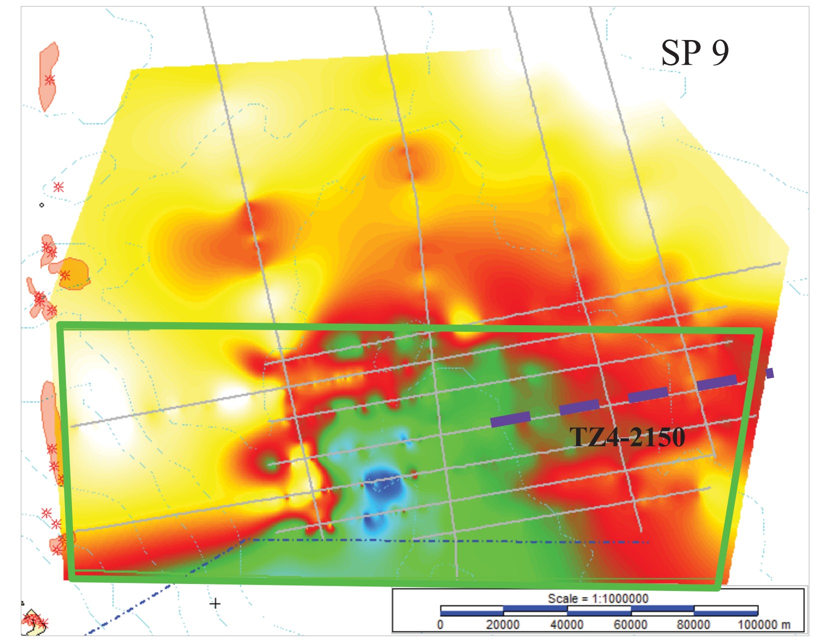


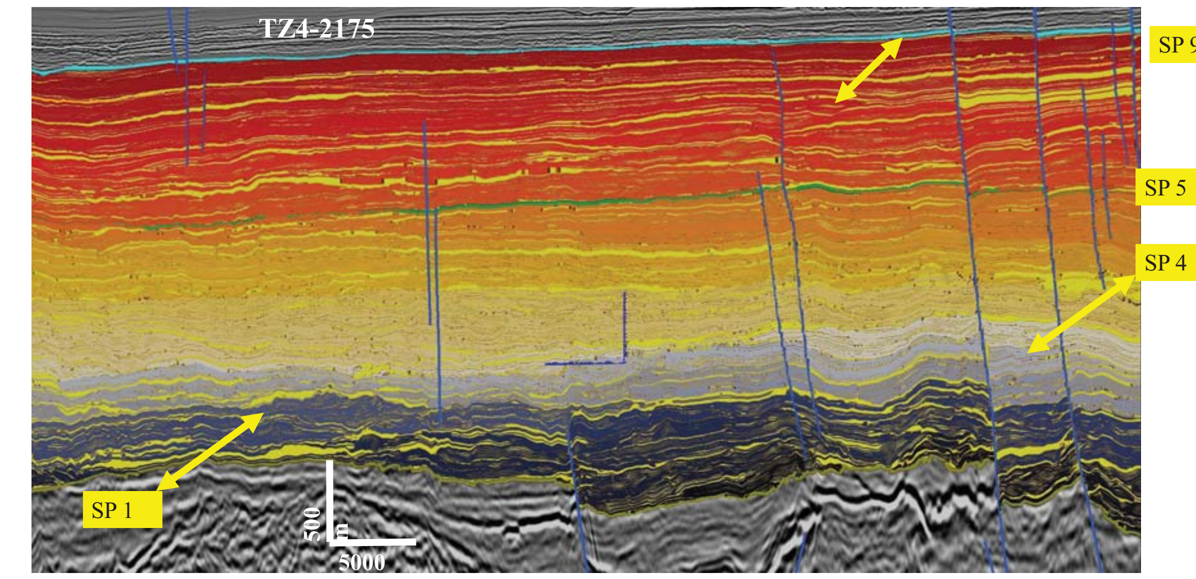
Isopach maps constructed from the identified Stratal Packages (SPs) allow reconstruction of depocenters through time. Then internal geometries and architecture within each SP are analyzed using HorizonCube and co-rendered density attribute data. Stratigraphic architecture within SPs may be compared and contrasted.

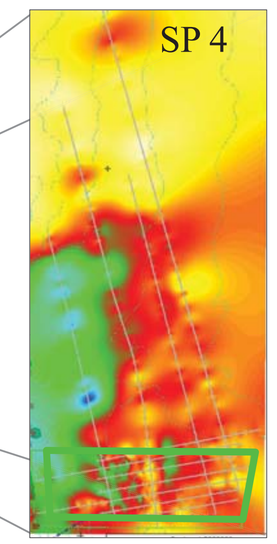


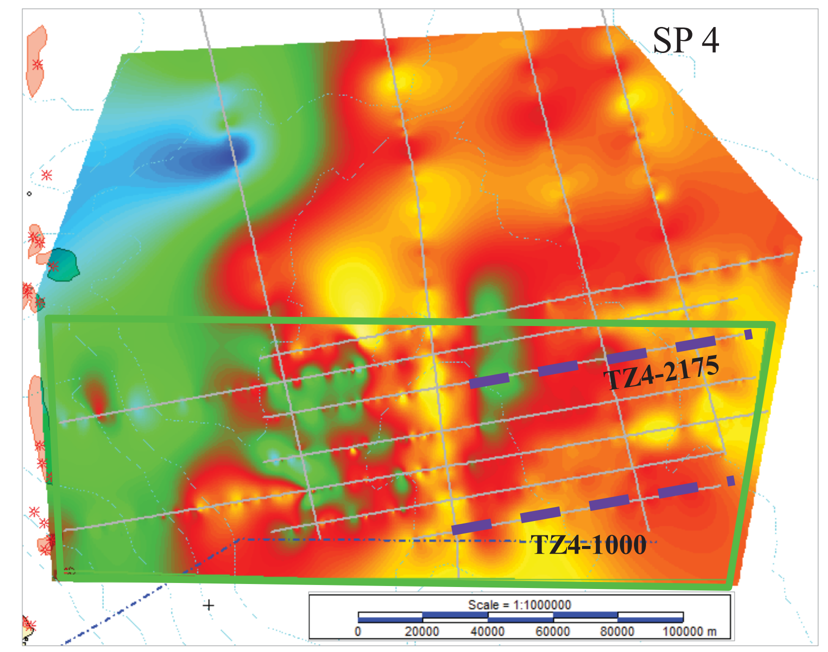


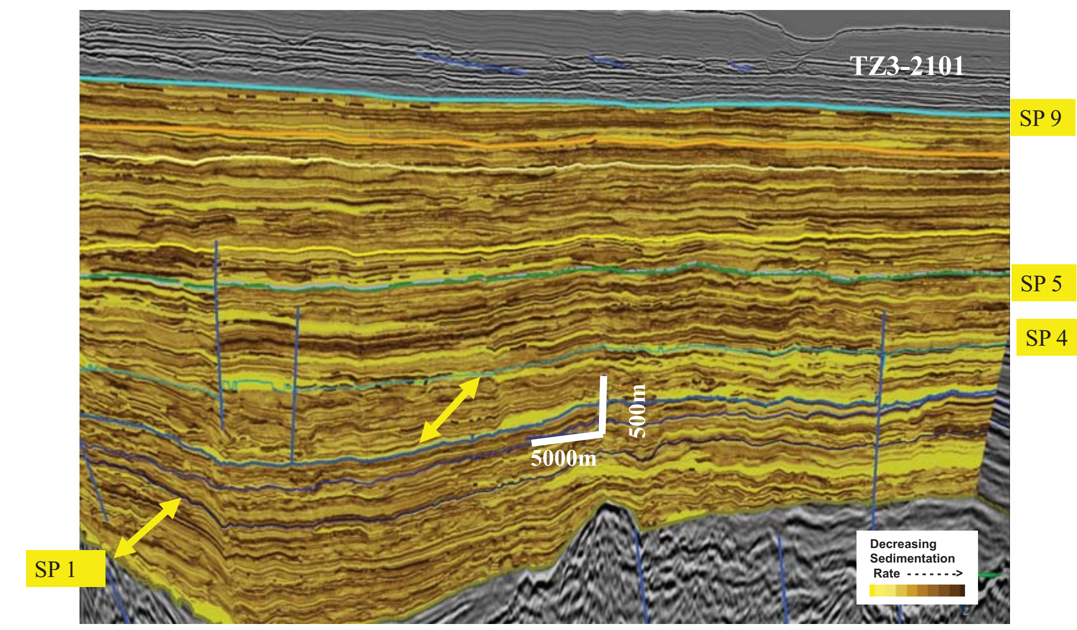




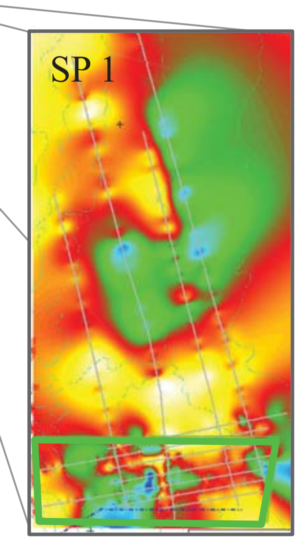


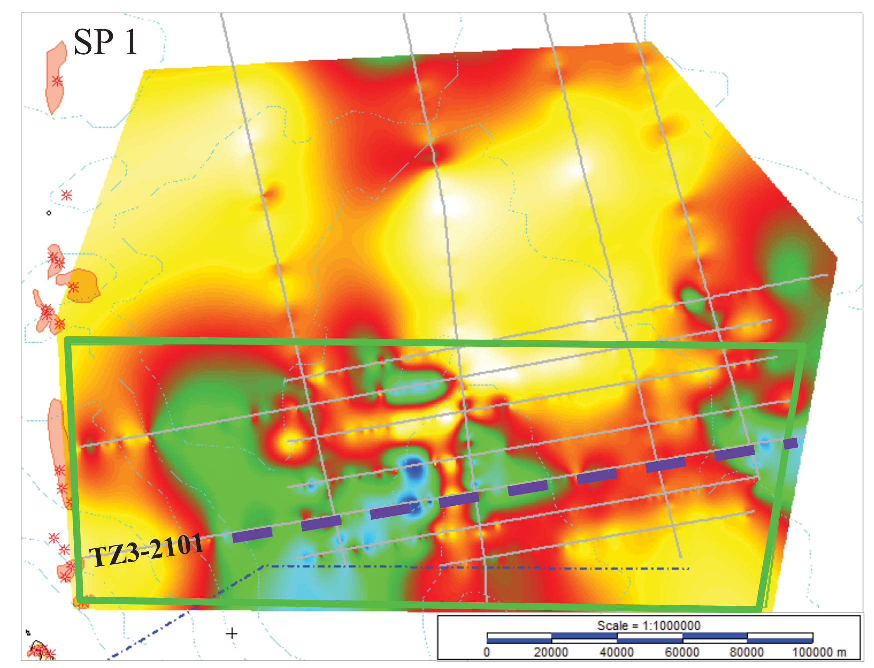


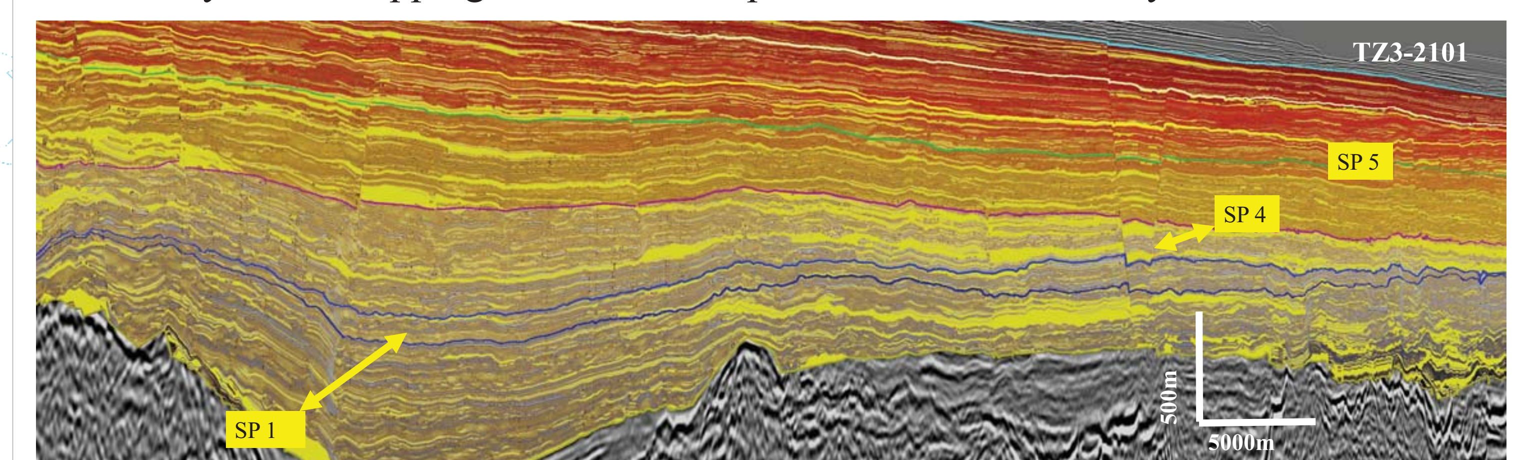


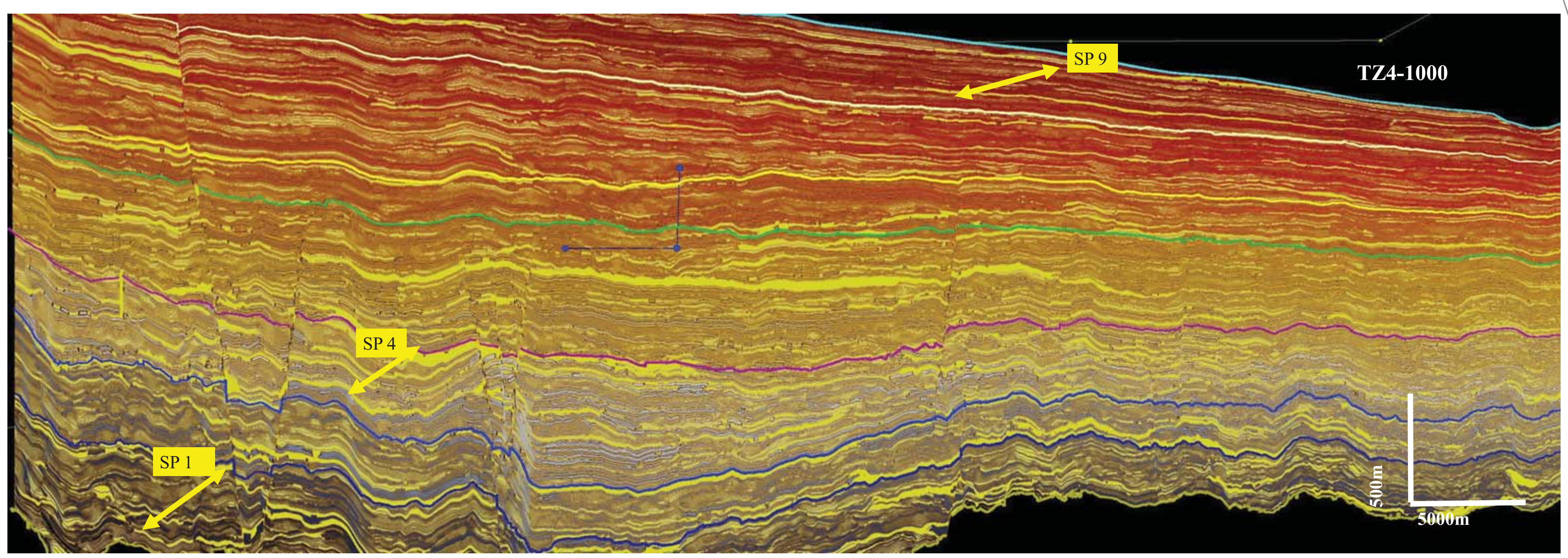


SPs 4 and 5 contain long wavelength (> 10k) wedging, compensatory features (lobes?) and also high sediment accumulation rates. Mapping of SPs (even in 2D) using data-enhancing features such as HorizonCube and event density, may allow mapping distribution of potential fan reservoir systems.



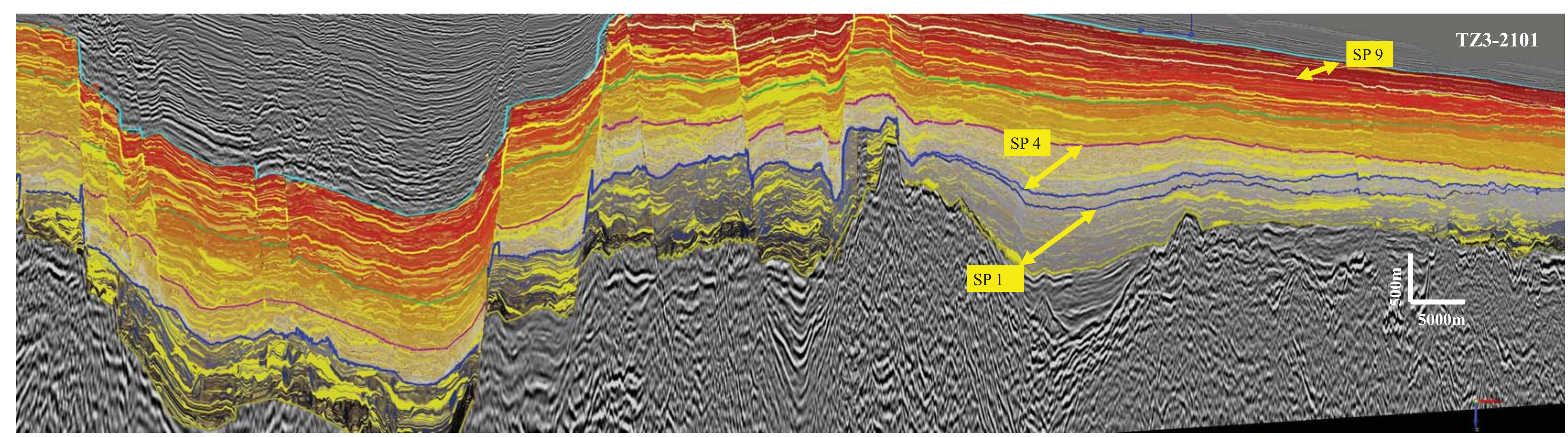






Comparison of internal architecture several stratal packages.

SP 1 contains more high-amplitude cut-and-fill incisional features than other SPs suggesting higher depositional gradients. It also contains more low-density events, suggesting high sedimentation rates. These may be coeval with Albian productive fan reservoirs to the west.



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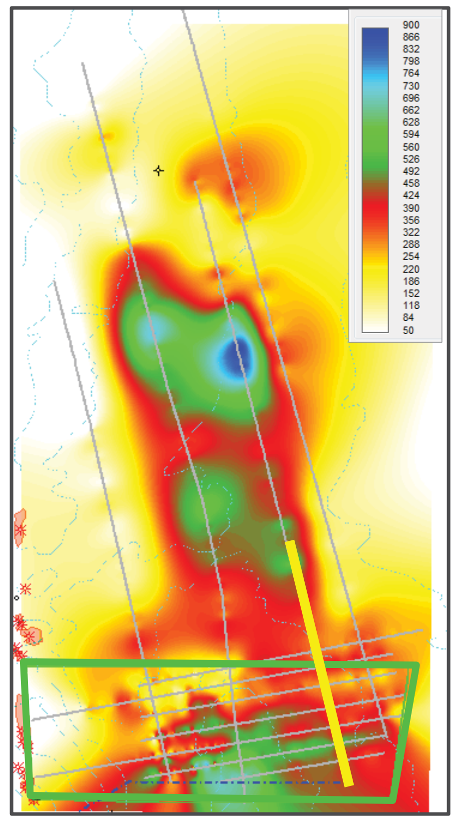
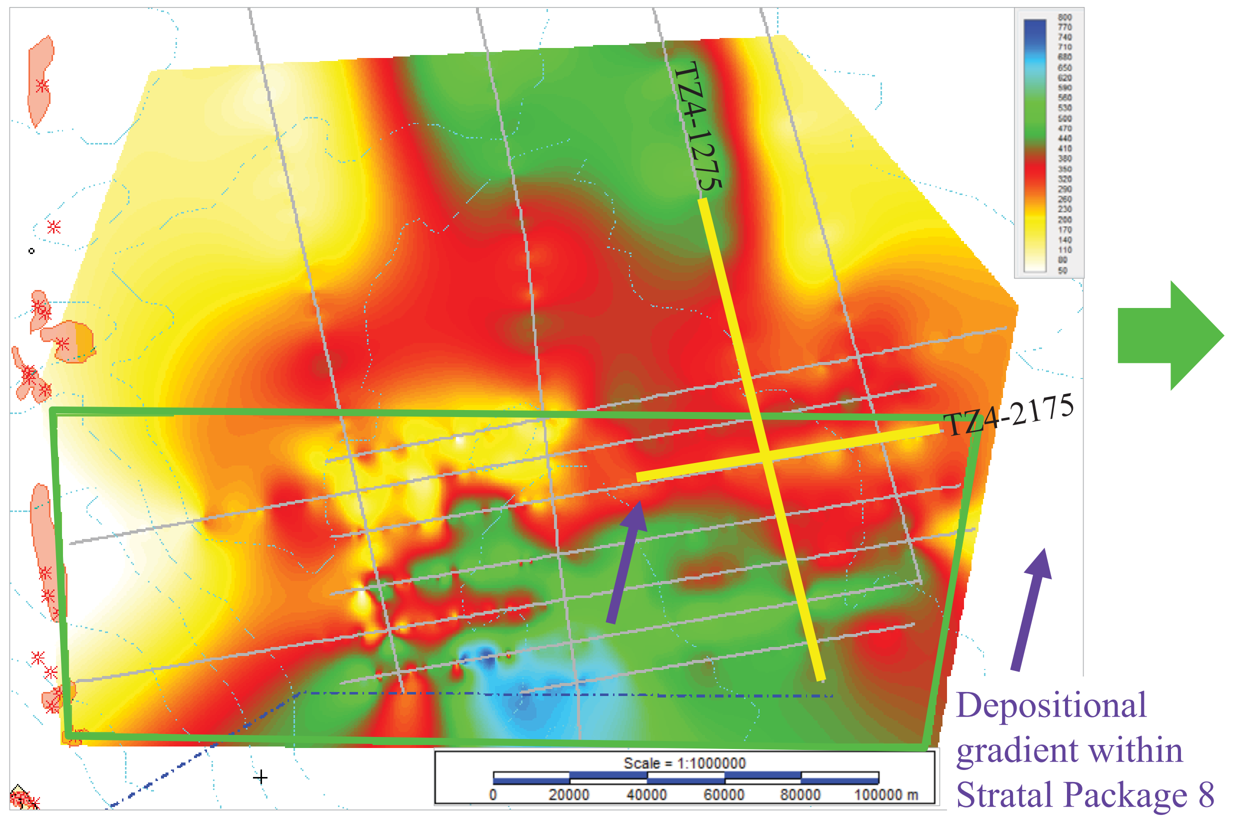
Systematic Depositional Variability: Intra-Stratal Package Down-Gradient Changes in Stratal Architecture and Geometry of Channel / Fan Systems

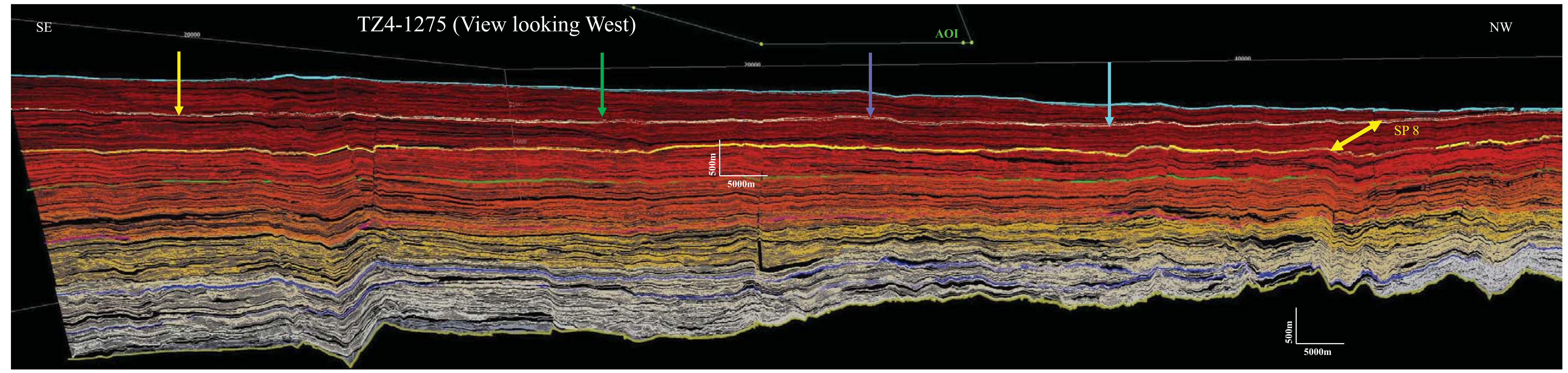
Highlighted line TZ4-1275 trends down depositional gradient toward North within Stratal Package 8

Isopach
SP 8

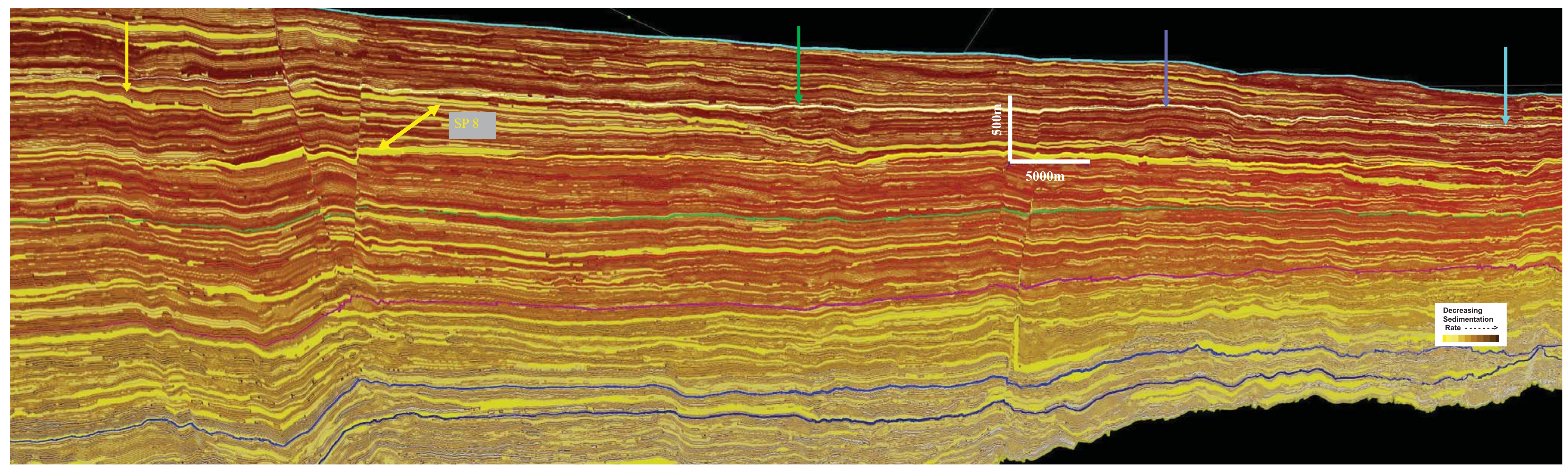


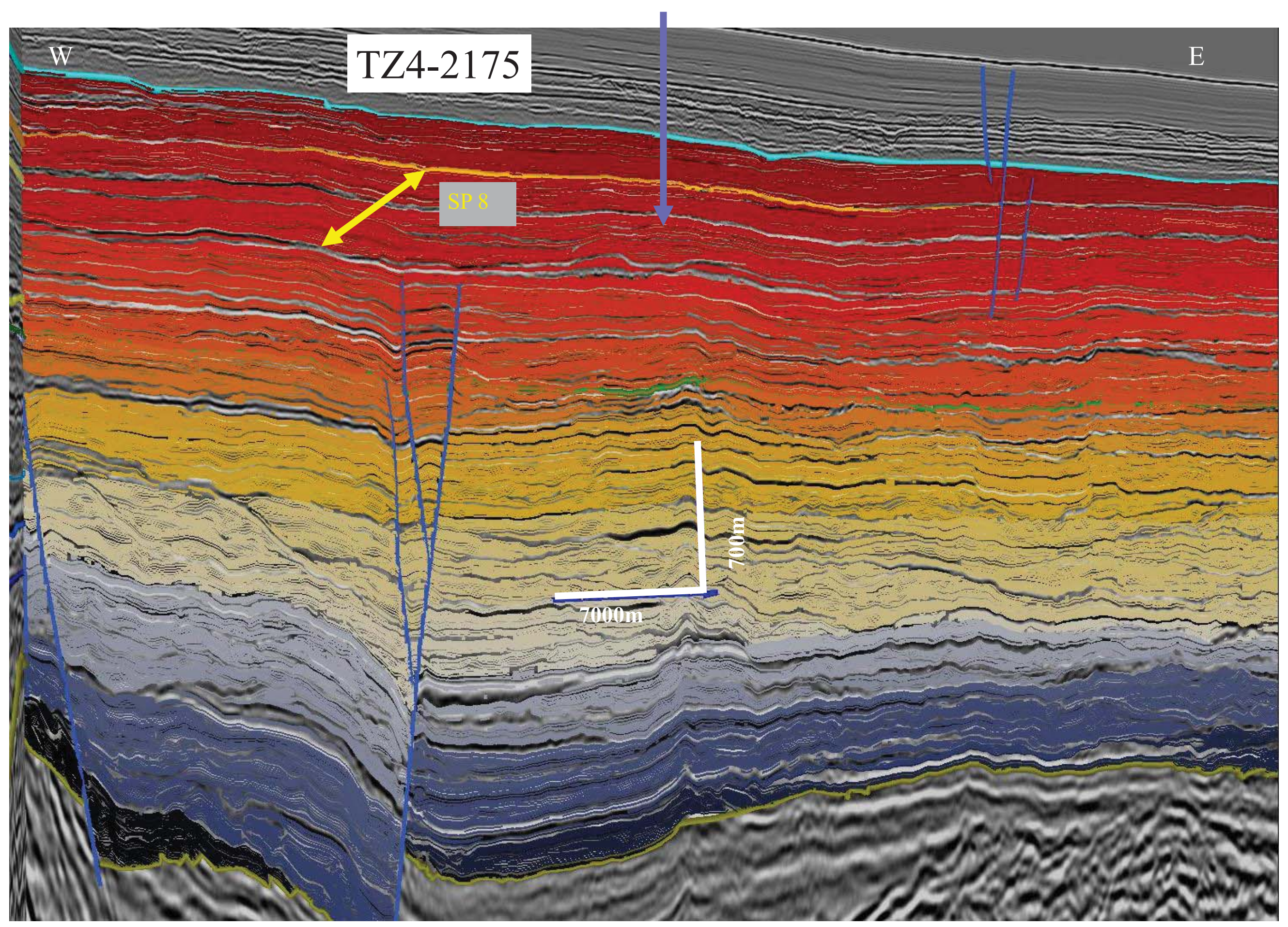


Depositional trends visible in the HorizonCube generated for Stratal Package 8. Northward, down-gradient evolution from >10km-wide compensatorily-stacked lobes and frontal splays with no levee development (yellow and green arrows), downslope to aggradational 5km-wide channel/levee complexes (purple and blue arrows).



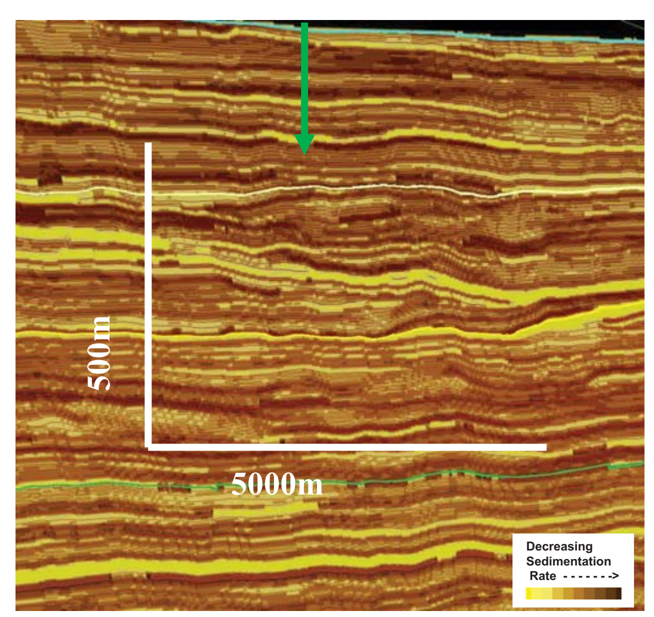
HorizonCube with co-rendered density attribute (a proxy for sediment accumulation rate) reveals internal details of stratal packages. Arrows as above



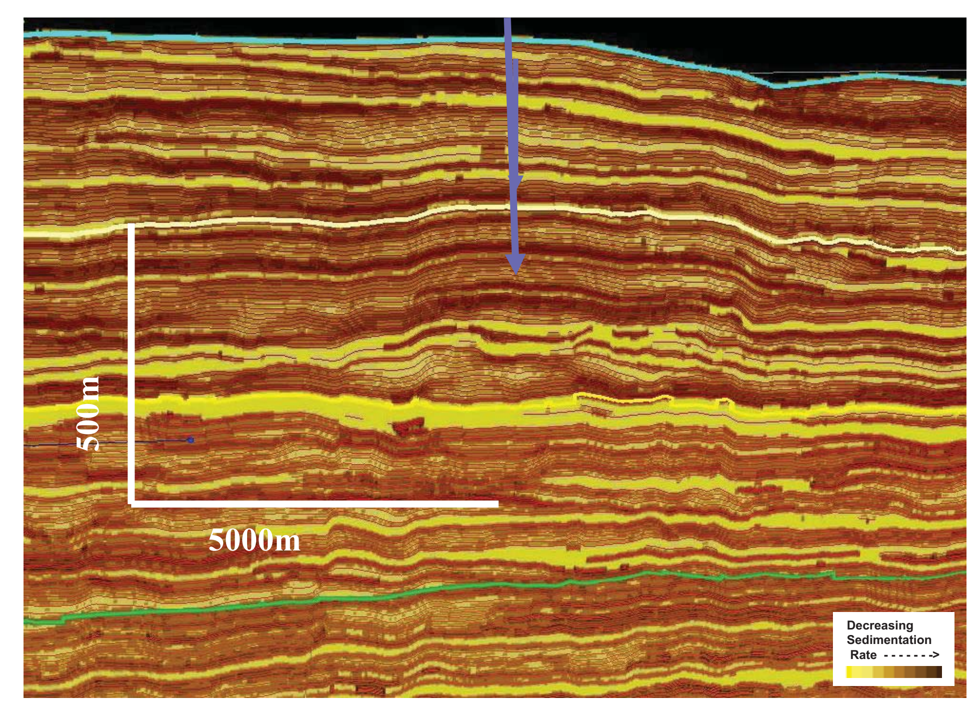


In up-gradient depositional positions within Stratal Package 8, the dominant geometry and architecture observed are >10km-wide and up to 300m thick, compensatorily-stacked lobes and frontal splays with little to no levee development (yellow and green arrows).

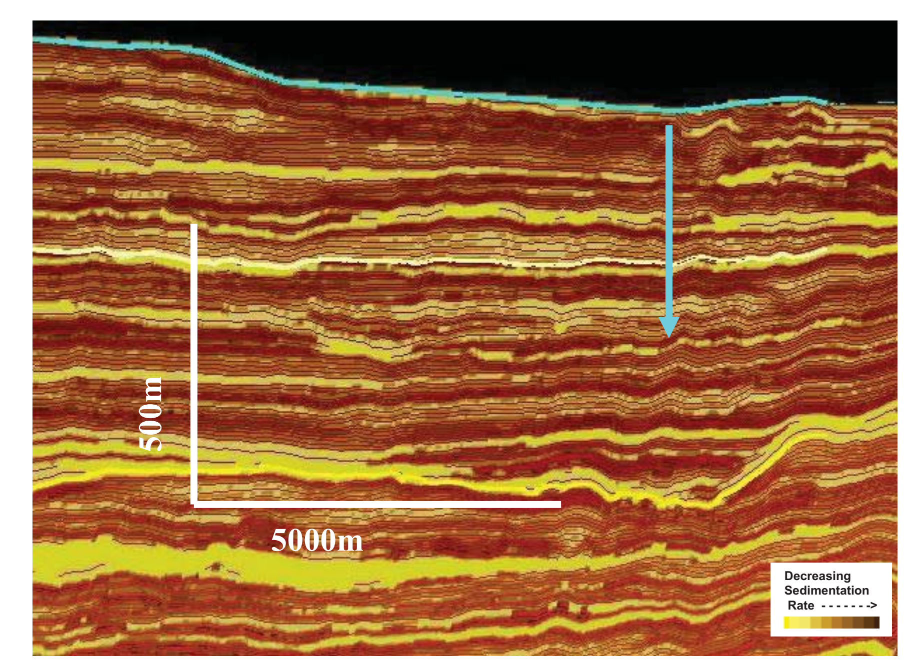
In down-gradient depositional positions within Stratal Package 8 (such as seen on line TZ4-2175), the dominant geometry and architecture observed are aggradational, symmetric 5km-wide channel/levee complexes (purple and blue arrows).



Two interfingering, 10km-wide and up to 300m thick, compensatorily-stacked lobes and frontal splays with little to no levee development (green arrow).



Well-developed, aggradational (multi-story?), symmetric 5km-wide channel/levee complex in down-gradient position (purple arrow). Note the density attribute suggests a sand-prone levee complex with low-accumulation-rate sediments (mudstones) overlying.



Parallel, low-accumulation-rate sedimentation with low-incision channels, likely mudstone-filled (blue arrow) within SP 8.

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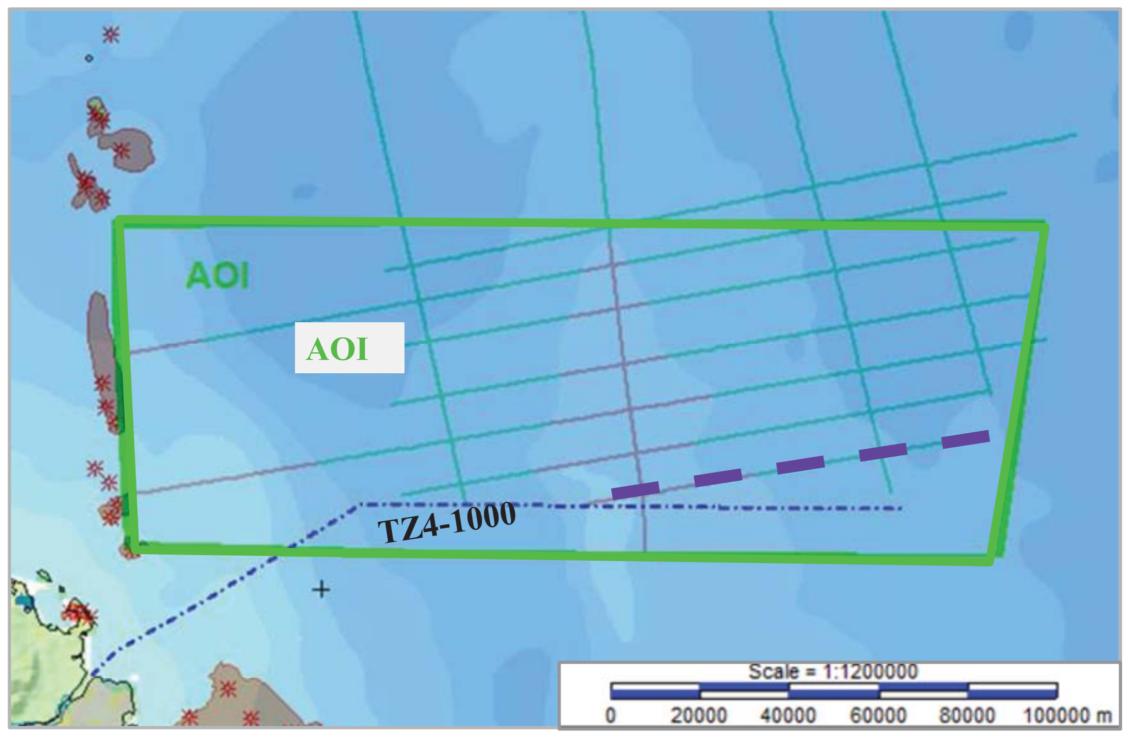
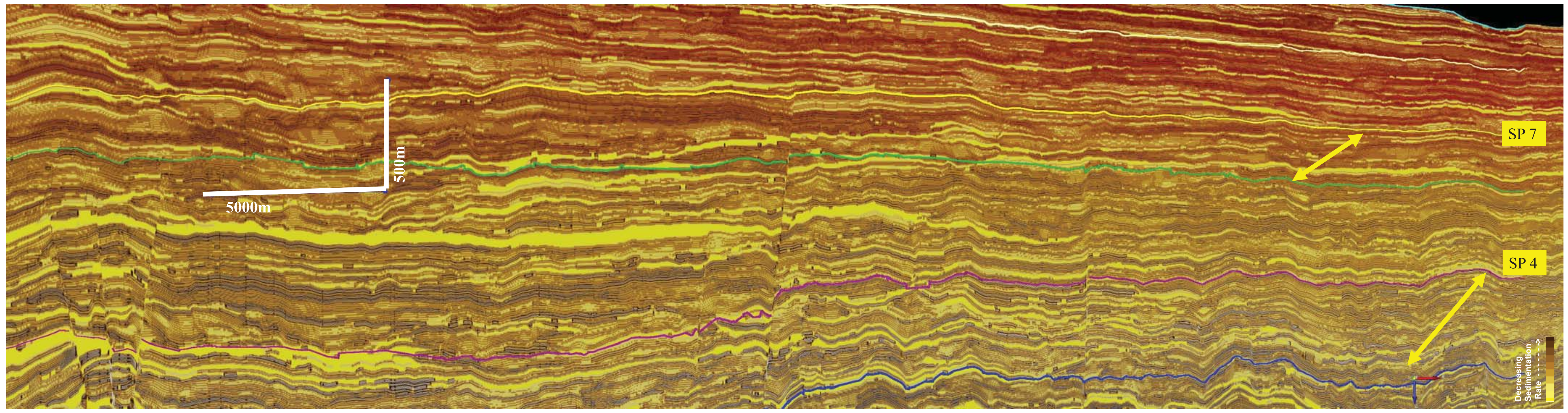
Stratigraphic Matters of Size:
Systematic Variability in Deepwater Fan / Channel Geobody Dimensions



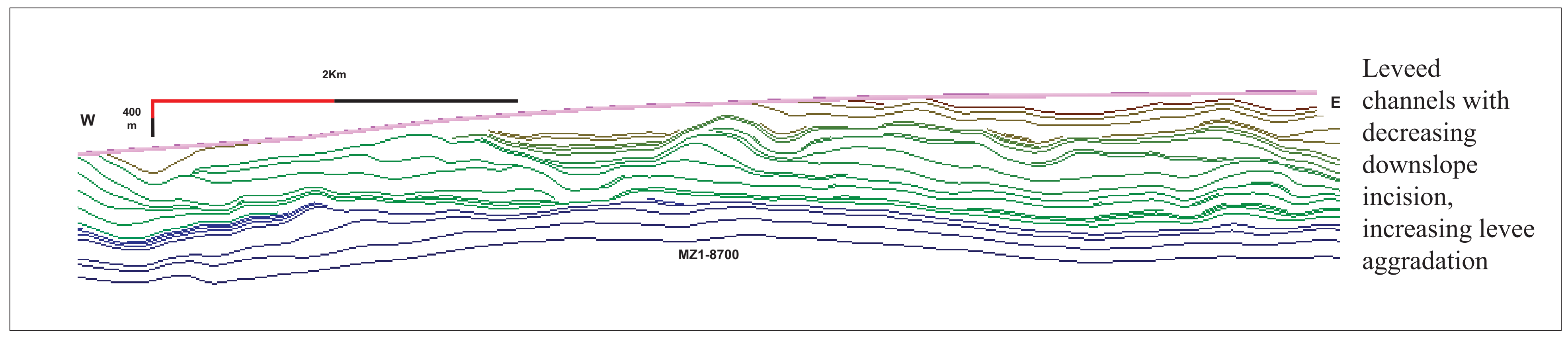


TZ4-1000 summarizing elements common to SP 4 versus SP 7.

The study area lies in a down-slope and distal deep water depositional setting throughout much of the Cretaceous andTertiary. Despite lack of a direct tie to shelf margins or proximal shorelines for the Cretaceous-Tertiary stratigraphic section, we can discern qualitative regional variability in deep water sedimentation patterns and dimensions. Application of HorizonCube and combination with an event density attribute allows us to make regional inferences regarding geobody dimensions from 2D seismic data, which enhances the ability to high grade areas for further prospecting without the expense of 3D data acquisition. We used HorizonCube (HC) detailed stratal interpretation using dGB Earth Science's OpendTect SSIS module, applied to ION Geoventures' **East AfricaSPAN™** 2D data. The SPAN seismic surveys are sufficient to effectively reconstruct detailed chronostratigraphy, map depositional systems tracts and refine play definition and prospectivity.

Matters of size/scale which are regionally consistent:

1) Architectural elements vary systematically between stratal packackes. SPs 1-4 contain more high-amplitude cut-and-fill incisional features as well as concave-down, long wavelength (> 10k) wedging, compensatory features (lobes?) than younger SPs, suggesting steeper depositional gradients and closer proximity to shorelines during this time. Little to no levee development is observed. These SPs also contain more low-density units as shown by event density attribute, suggesting high sedimentation rates. All of these observations align with the known Late Cretaceous movement of the Kerimbas Graben, which would have steepened depositional gradients. Steeper gradients tend to concentrate high-energy flows into fewer channels, and result in single-story channel fills more aggradational frontal splays and lobes occurring down-dip. Sediment partitioning favors down-profile deposition and channel concentration in fewer channels. The resulting stratigraphic record favors single-story channel systems and smaller, multi-storied lobes. These stratal packages are likely coeval with Albian productive fan reservoirs to the west.



HorizonCube illustrating down-gradient evolution of geomorphic element geometry.

2) Lower-gradient profiles (which presumably generate more low-energy density flows) show significant, symmetric levee development and shingled or progradational frontal splays in down dip positions. The resulting stratigraphic record favors multiple, along-strike channel development creating laterally persistent, single-storied sands and aerially larger, shingled fan lobes.

3) Intra-stratal package variation consists of gradual loss of levee development up depositional gradient, likely due to a steepening profile which tends to discourage aggradation.

4) Regional mapping suggests that sediment provenance shifted over time from primary sourcing from the Rufigi River drainage basin in Tanzania to the Rovuma River drainage in Mozambique. The role of the intermittently-active Kerimbas graben, active until present day, has played a significant role in driving axial (N-S) sediment distribution patterns which are reflected in stratal package maps.

Bibliography

Brouwer, F., de Bruin, G., de Groot, P., and Connolly, D. , 2008, Interpretation of seismic data in the Wheeler domain: integration with well logs, regional geology and analogs, 2008 SEG Technical Program Expanded Abstracts, Las Vegas, Nevada.

Law, C., 2011, Northern Mozambique: True "Wildcat" Exploration in East Africa*
Carol Law1, Search and Discovery Article #110157 (2011), http://www.searchanddiscovery.com/documents/2011/110157law/ndx_law.pdf Posted June 20, 2011
Posamentier, H.W., and Kolla, V., 2003, Seismic geomorphology and stratigraphy of depositional elements in deep-water settings: Journal of Sedimentary Research, v.73, p. 367-388.

Qayyum, F., de Groot, P., Yasin, J. and Akhter, G. , 2012, Building a Sequence Stratigraphic Framework from HorizonCube and Well Data, 74th EAGE Conference & Exhibition, Copenhagen, Denmark, 4-7 June 2012.

Weimer, Paul, and Henry S. Pettingill, 2007, Deep-water explor
ation and production: A global overview, *in* T. H. Nilsen, R. D. Shew, G. S. Steffens, and J. R. J. Studlick, eds., Atlas of deep-water outcrops: AAPG Studies in Geology
56, CD-ROM, 29 p.

Wheeler Harry E., 1958, Time Stratigraphy, Bulletin of American Association of Petroleum Geologists: v 42, n. 5, p. 1047-1063.

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