

Seismic-Sequence Stratigraphic Analysis of Regional 2D Lines in the Santos Basin, Offshore Brazil*

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Abstract

The Santos basin, offshore Brazil, has recently generated great interest following large hydrocarbon discoveries in the pre-salt section. However, initial petroleum exploration focused on the post-salt sequence. This consists of Albian carbonates deposited on top of a mobile evaporitic substratum, followed by a clastic sequence whose development reflects the interplay between local salt tectonics, regional subsidence, regional tectonics, and global sea level oscillations. Salt movement had a major impact on basin fill. It started as early as Albian times and accelerated during Santonian-Campanian times, when a large, apparently prograding clastic wedge formed. This “progradation” continued until late Eocene times, when a major phase of backstepping of depositional systems occurred. A common stratigraphic framework can be defined in the basin, but lateral changes in shelf-edge trajectories for the same stratigraphic interval and formation of distinct depocentres indicate how sediment-starved areas or loci of preferential deposition formed in response to local controlling factors.

We present here results of a study on the Santonian-Recent sequence from the central part of the basin, based on six 2D regional PSTM lines, approximately 100km along depositional dip, 300km along depositional strike. The analysis used an original digital workflow for seismic-sequence stratigraphic interpretation. The workflow started with creation of a steering cube (where every sample position contains the dip and azimuth attributes of that particular seismic trace). Data conditioning was followed by automatic data-driven calculation of a chronostratigraphic framework over the entire section under consideration. A series of horizons were generated, auto-tracked simultaneously, placed in stratigraphic order and assigned a relative geological time. This chronostratigraphy includes stratal terminations that can be directly compared with the seismic data for quality control and can be converted to a seismic Wheeler diagram to help with geological interpretation. The chronostratigraphy was detailed enough to extract subtle information on near seismic resolution scale.

Advantages of the workflow include: rapid automated generation of Wheeler diagrams, ideal for studying the development of depositional loci over time; the ability to use all seismic attributes in the Wheeler domain; and improved collaboration between remote teams thanks to the digital and repeatable nature of the results.

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Outline of Talk

- Background - Objectives
- Santos Basin - overview
- Digital seismic-sequence stratigraphic interpretation workflow (SSIS) – MAIN OBJECTIVE
- Application to regional 2D lines
- Results
- Conclusions
- **Acknowledgments:** we thank BG and dGB for permission to present this study, and the TGS/WesternGeco Brasil 2D Alliance for permission to use and show the seismic data

Objectives

This talk

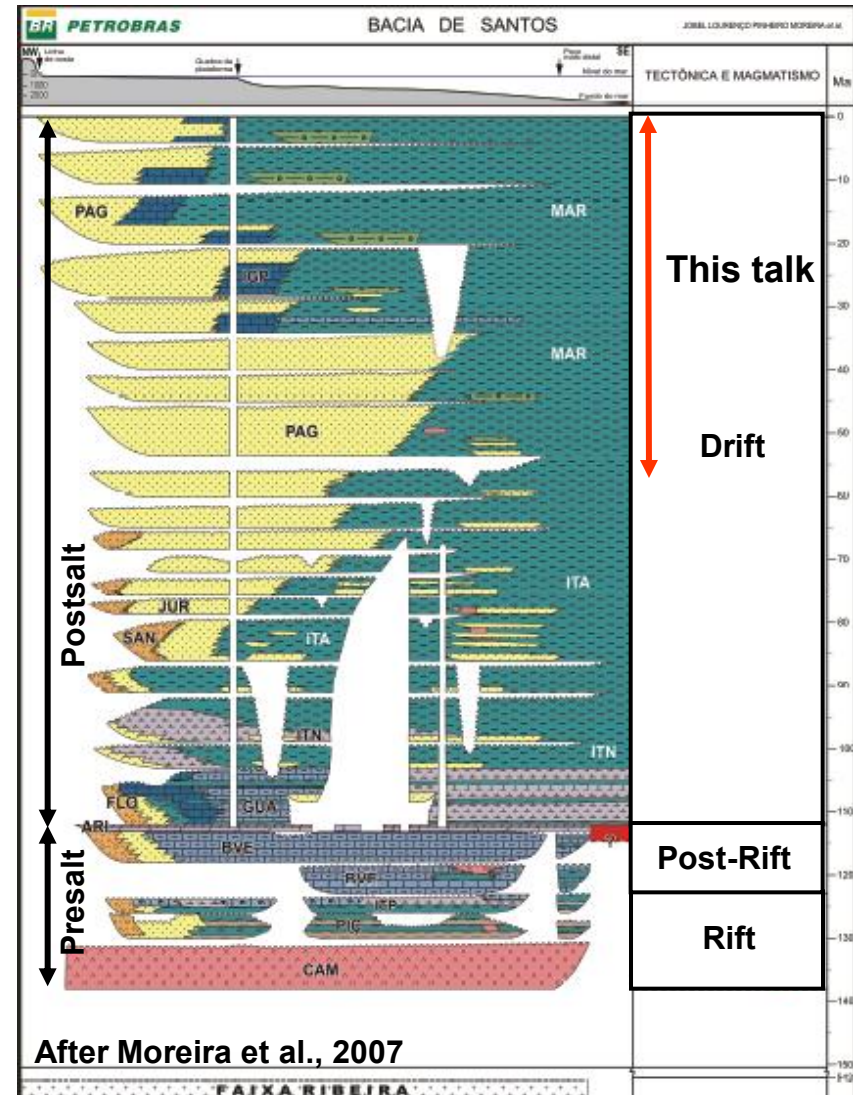
- Test and use an original digital workflow for seismic-sequence stratigraphic interpretation (SSIS)
- Use regional seismic lines to quickly build a digital chronostratigraphic framework for the Santos Basin (Tertiary)
- Generate Wheeler diagrams
- Assign sequence stratigraphic meaning to depositional sequences
- Highlight (and explain) different depositional histories (depositional sequence geometries and stacking patterns) within a common stratigraphic framework

Future applications

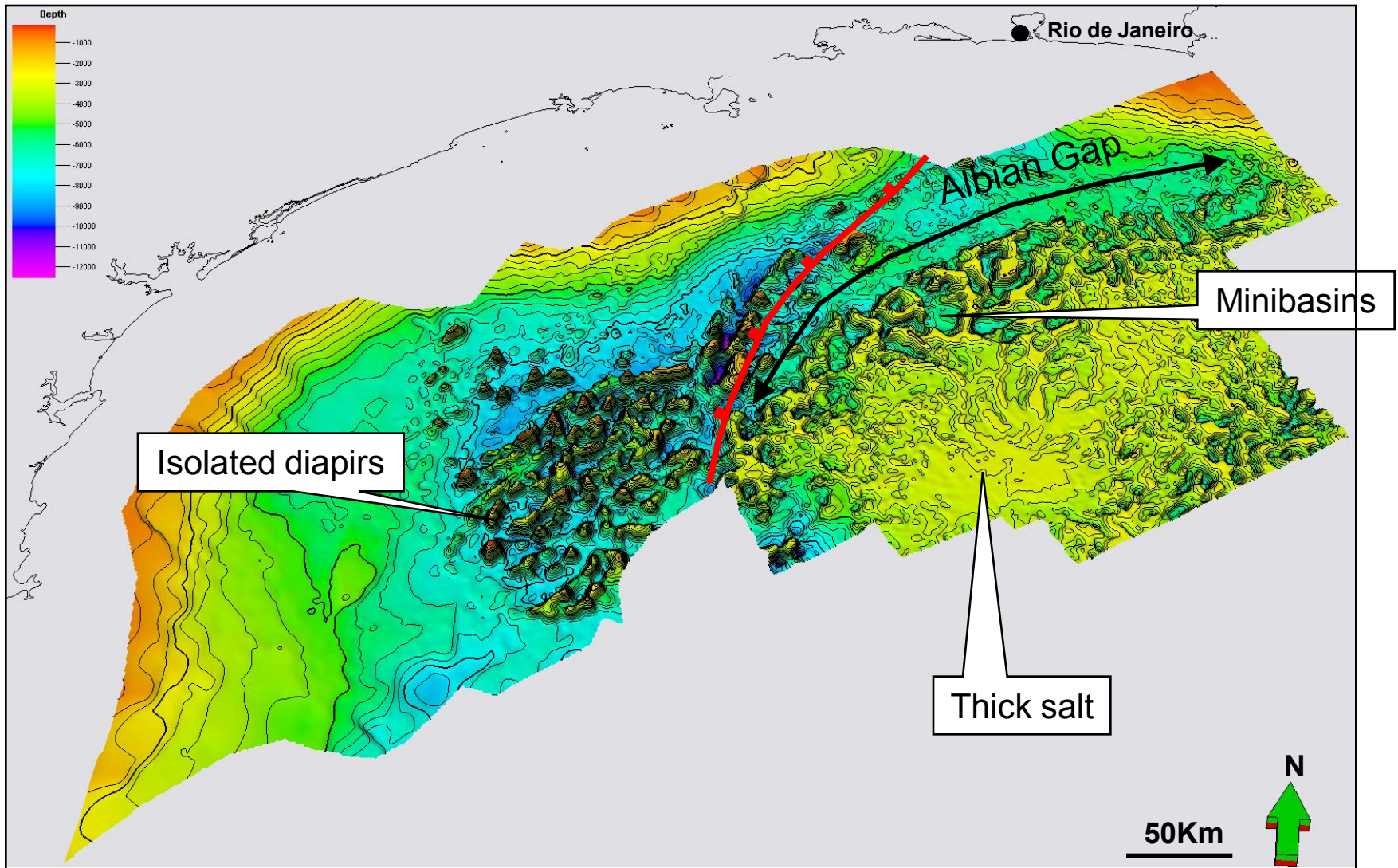
- Apply workflow in frontier/unexplored areas
- Fundamental research and industry applications

Santos Basin stratigraphy

- Regional Events (South Atlantic opening):
 - Three megasequences
 - Pre-existing structural control (basement) on basin development
 - Basin-scale bounding surfaces
- “Local Events”
 - L. Cretaceous Serra do Mar uplift
 - L. Creta.-Paleogene clastic input to N and central Santos. S. Santos relatively starved
 - Oligocene Paraíba do Sul river capture, clastic influx into the Campos basin
 - Starved N. Santos, thick mud-prone upper Oligocene and Neogene sediments to the south

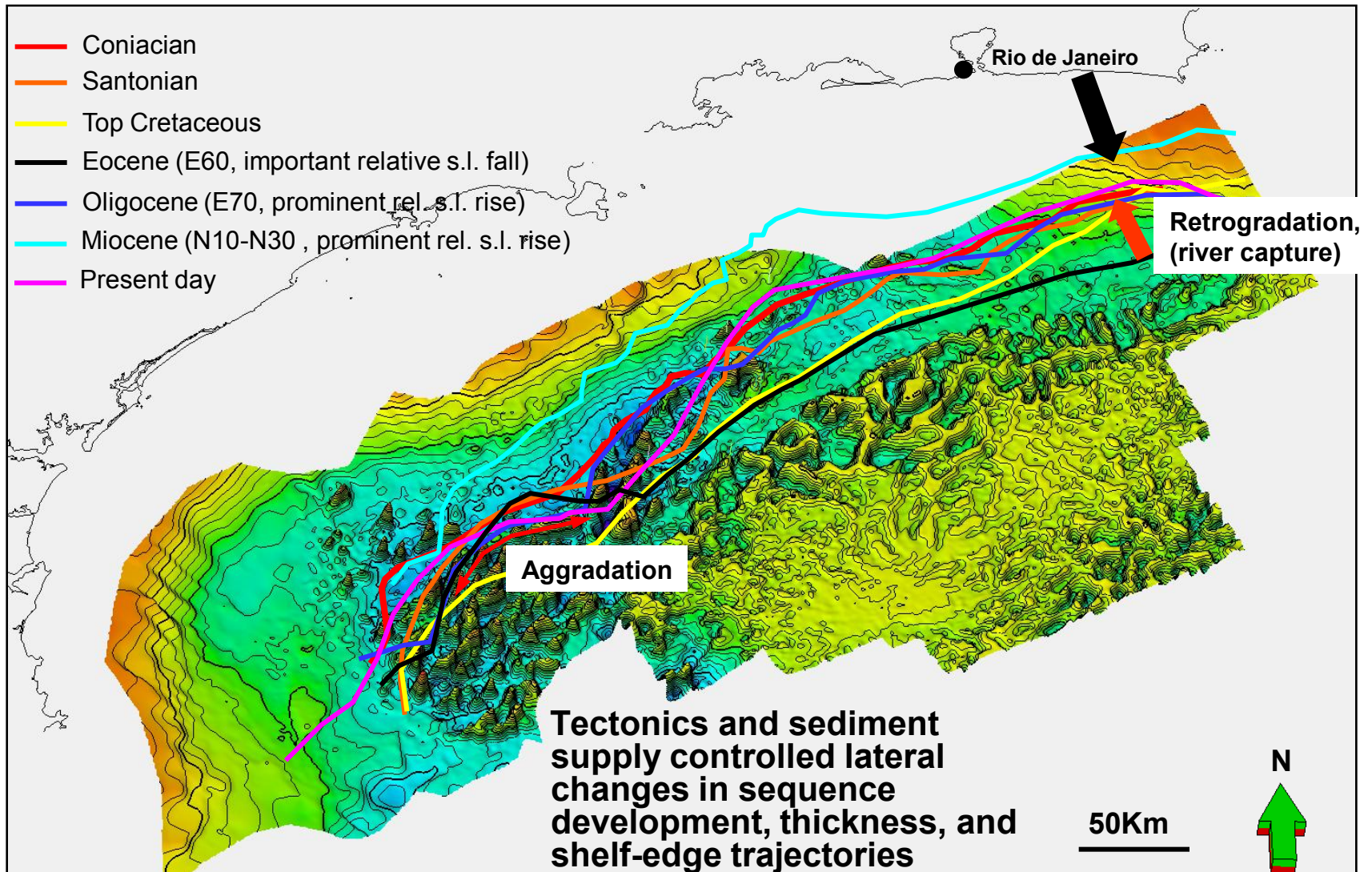


Santos Basin “provinces”

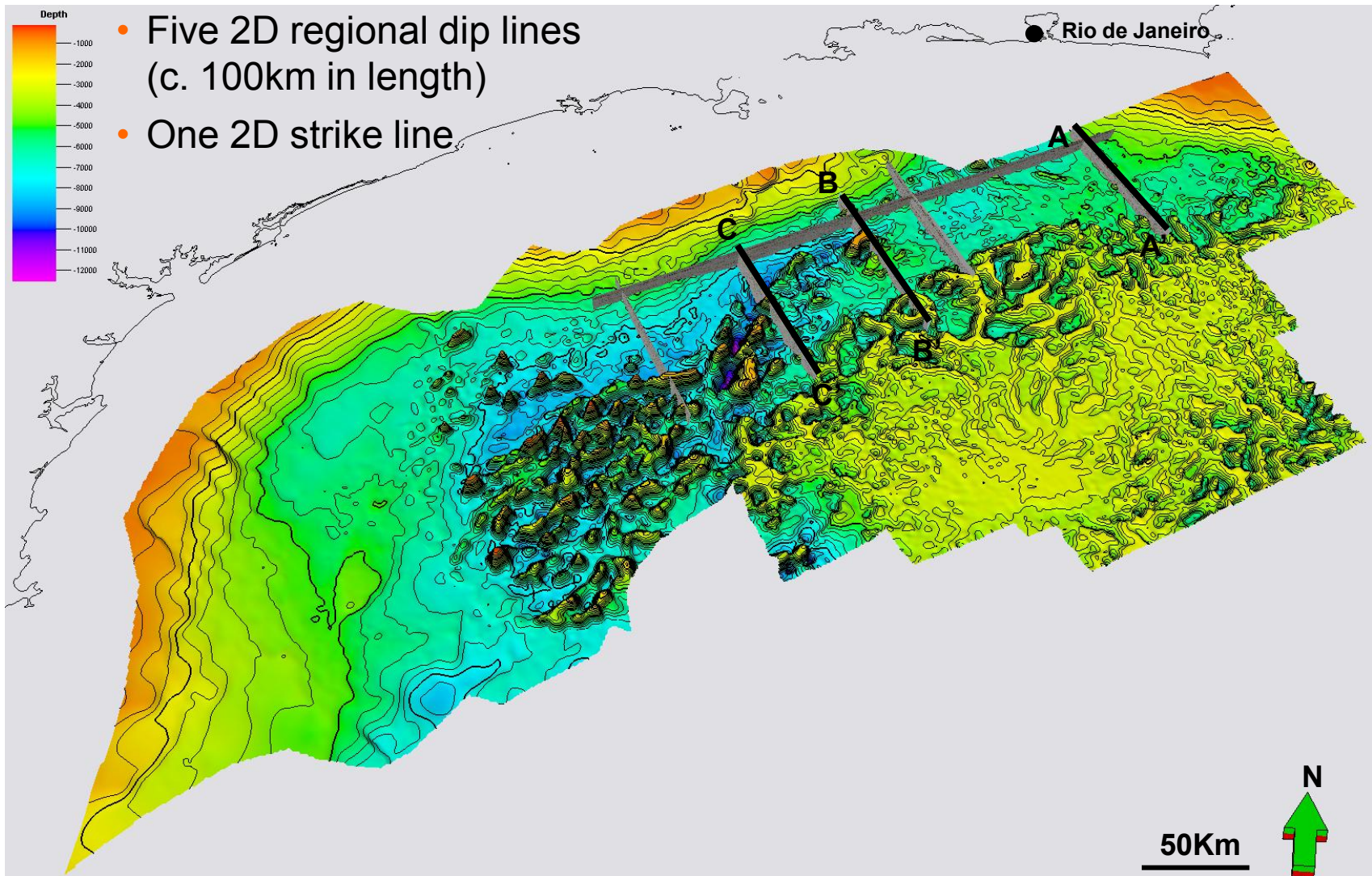


Top salt depth map

Shelf-edge evolution through time

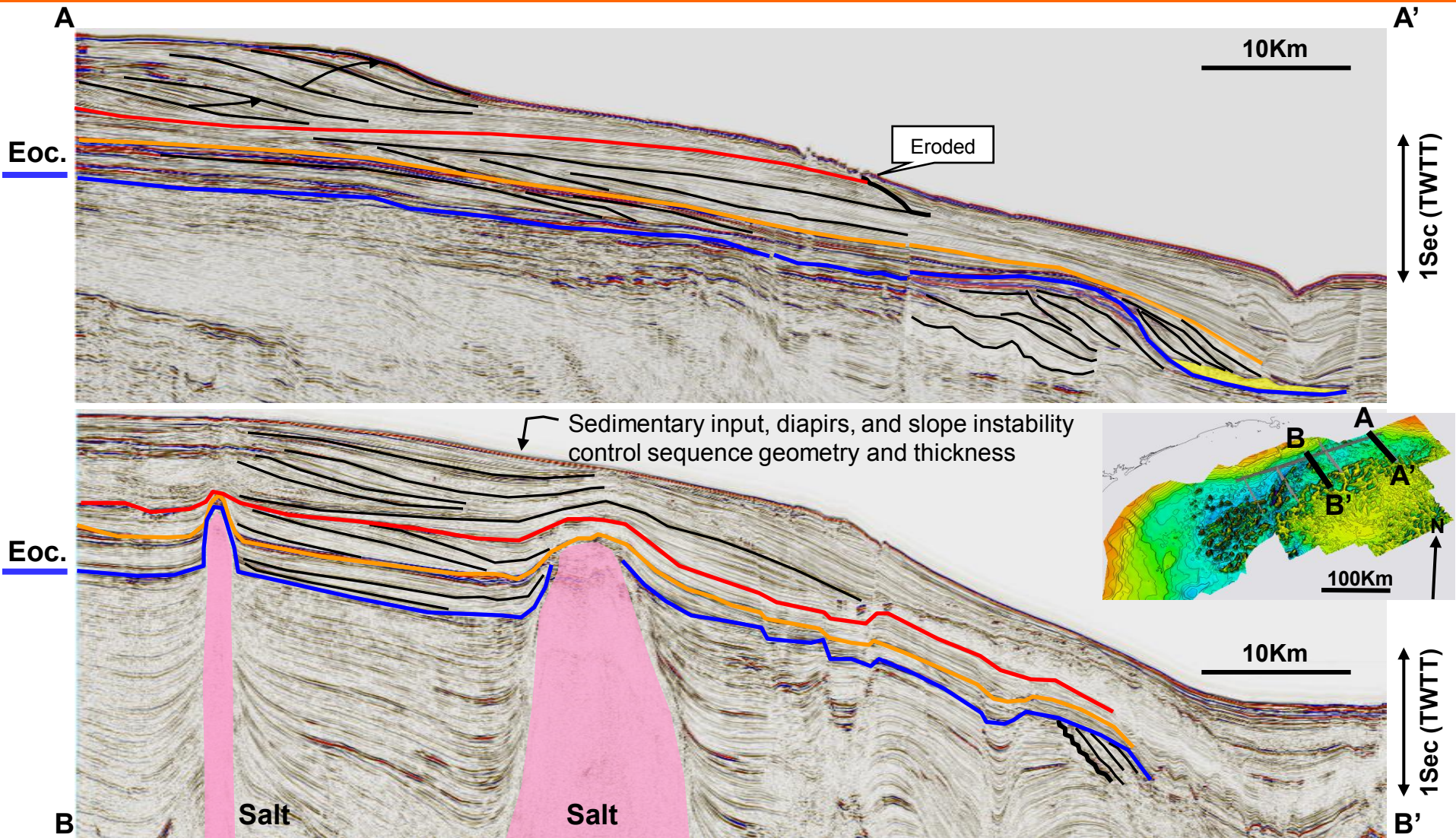


Location of study area and dataset

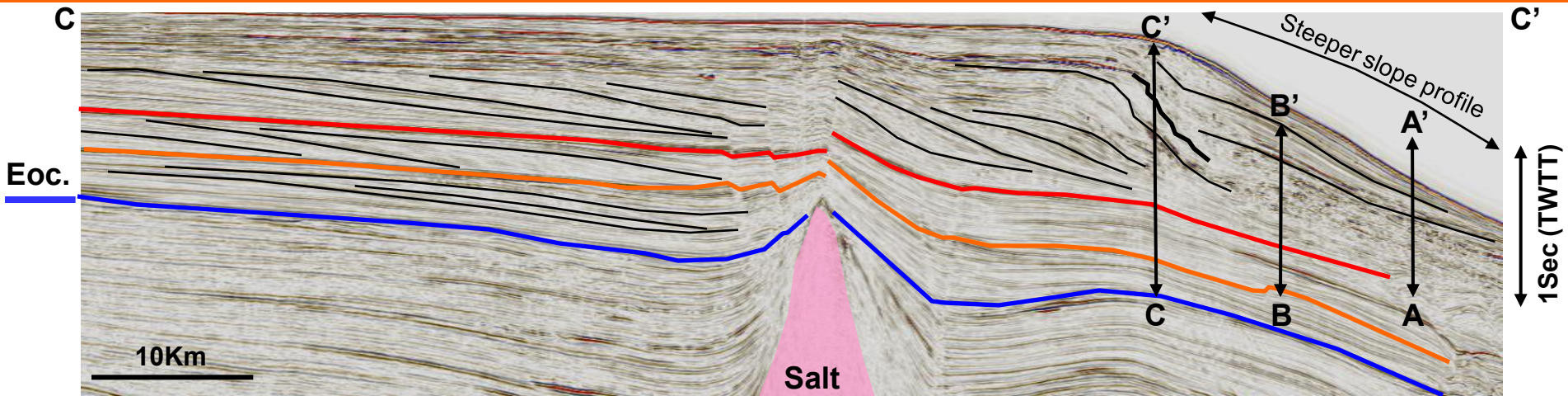


Top salt depth map

Northern and Central Santos

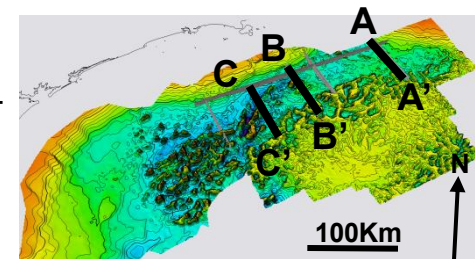
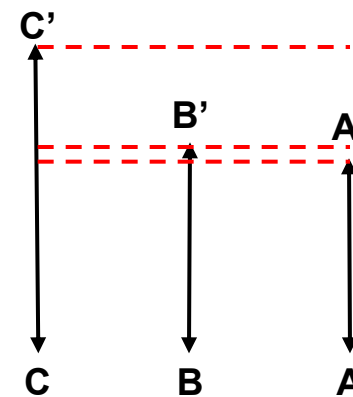


Southern Santos

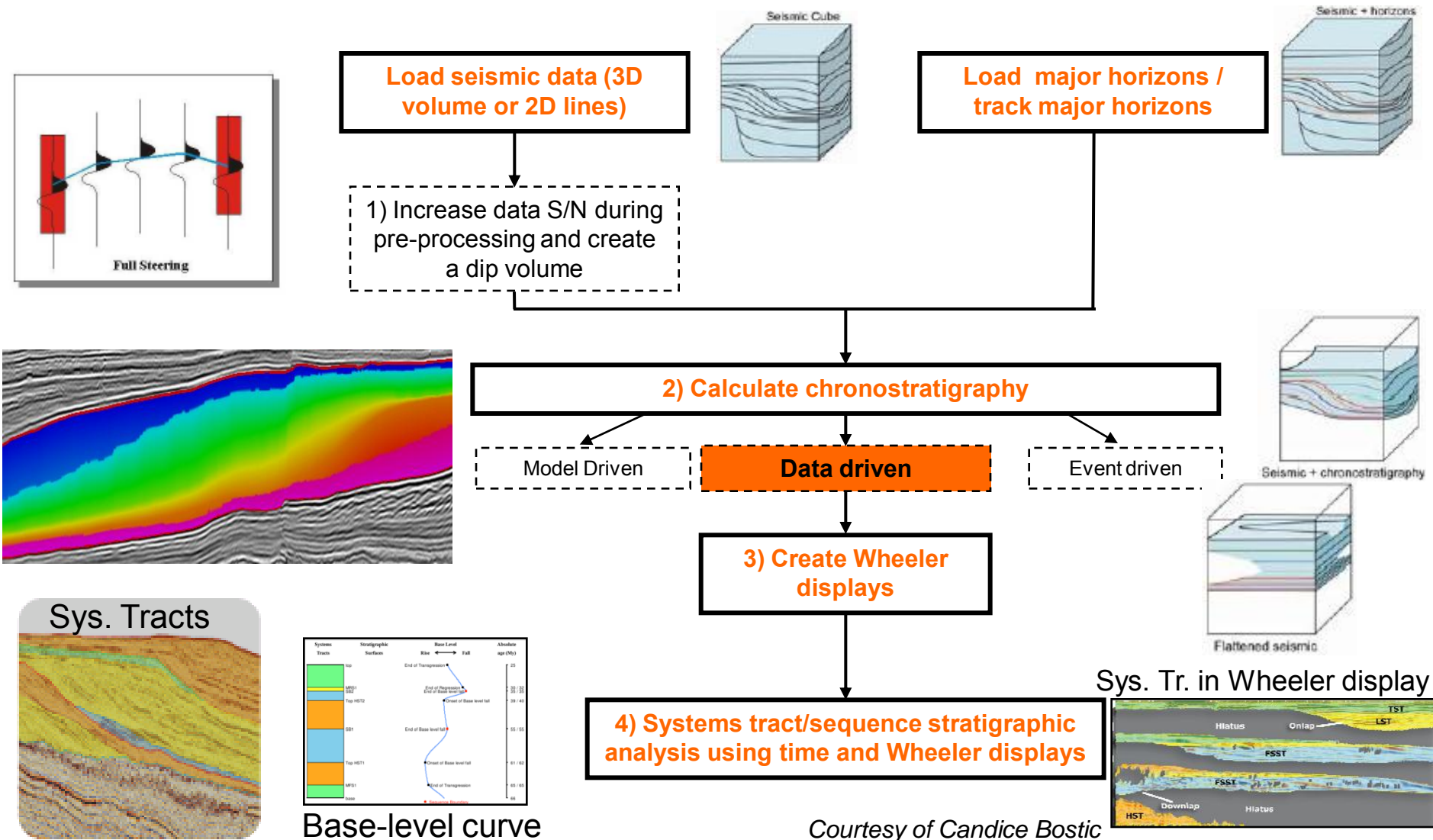


- Difference in present-day and paleo shelf-slope profiles
- Shift in entry points, tectonics and diapirism, and large slope failures control lateral changes in sequence thickness, internal geometries and shelf-edge trajectories

Southward increase in thickness (Eocene-Present)



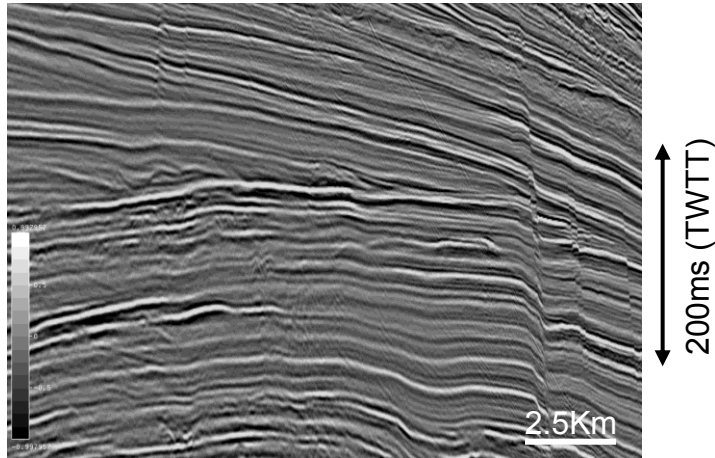
SSIS Workflow



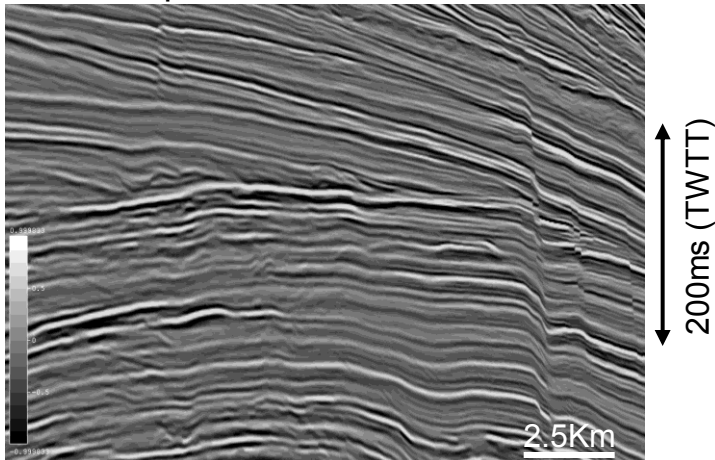
Steps 2 and 3 entirely automatic (and repeatable), 4 requires interpretation

SSIS Workflow: Processing and chronostratigraphy (1-3)

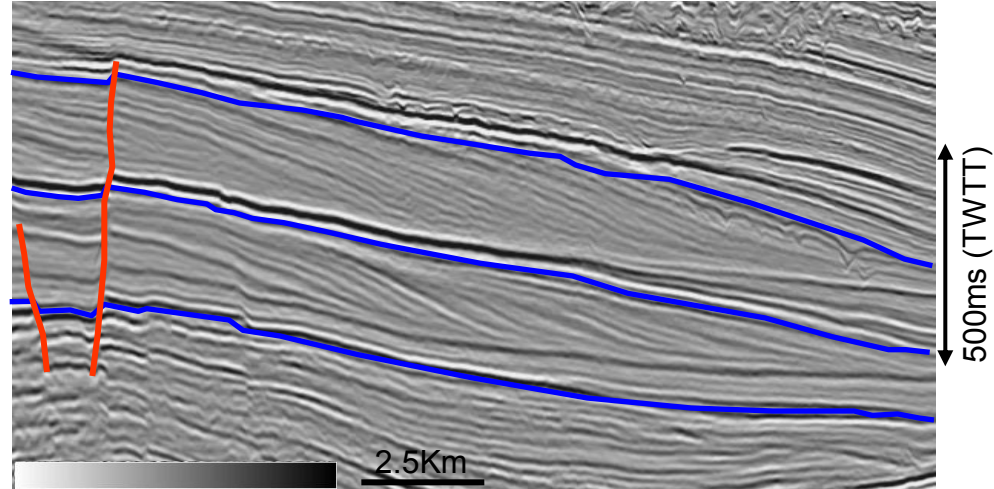
Original data, noise visible



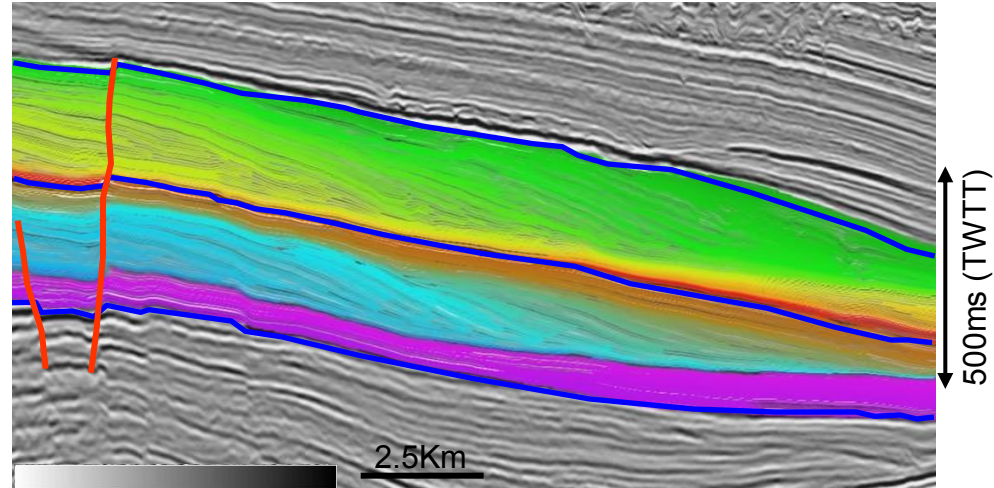
Data cleaned with a structurally oriented median dip filter, used to calculate seismic dips



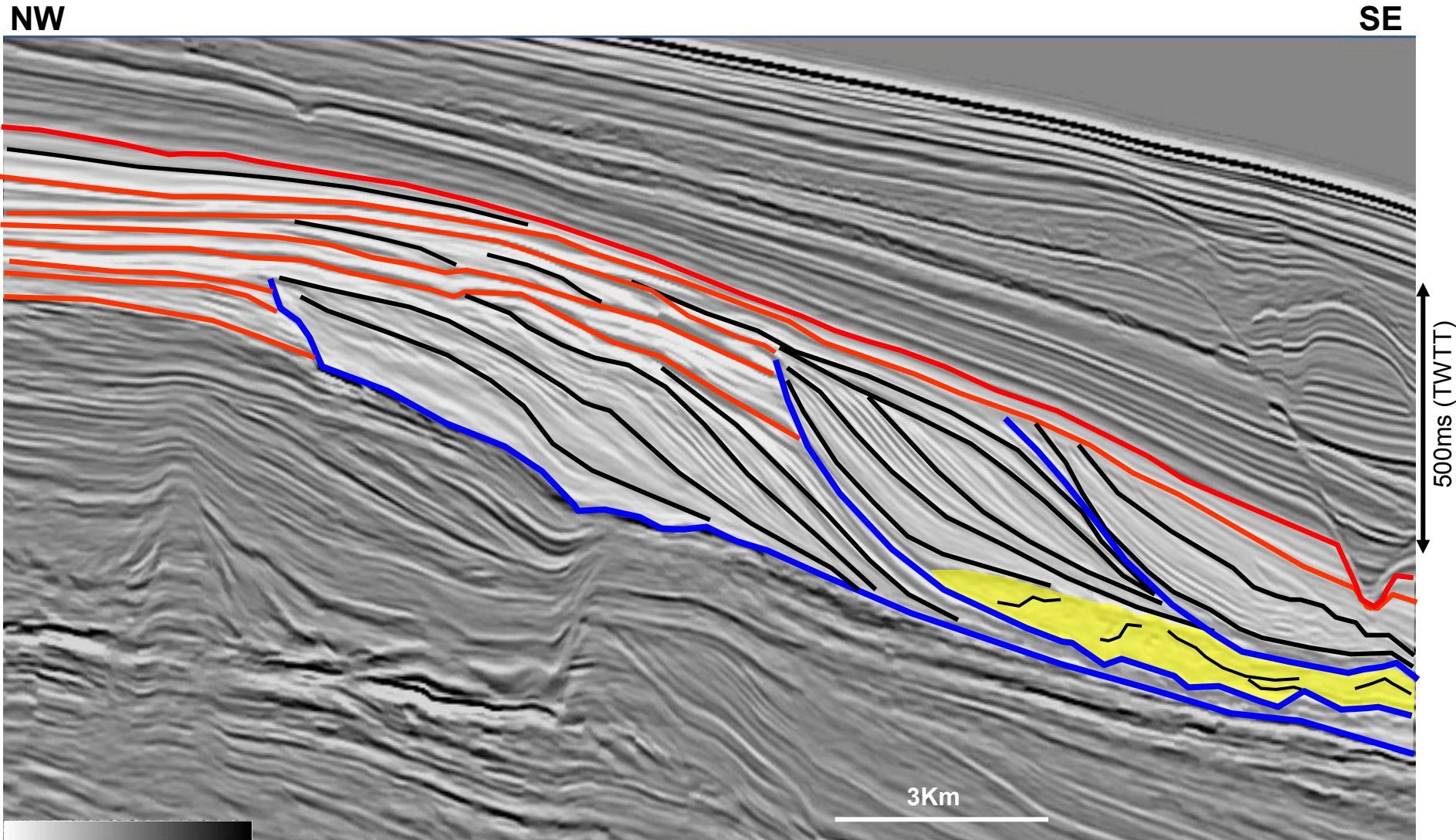
Key horizons and dip vol.: generation of chronostratigraphy



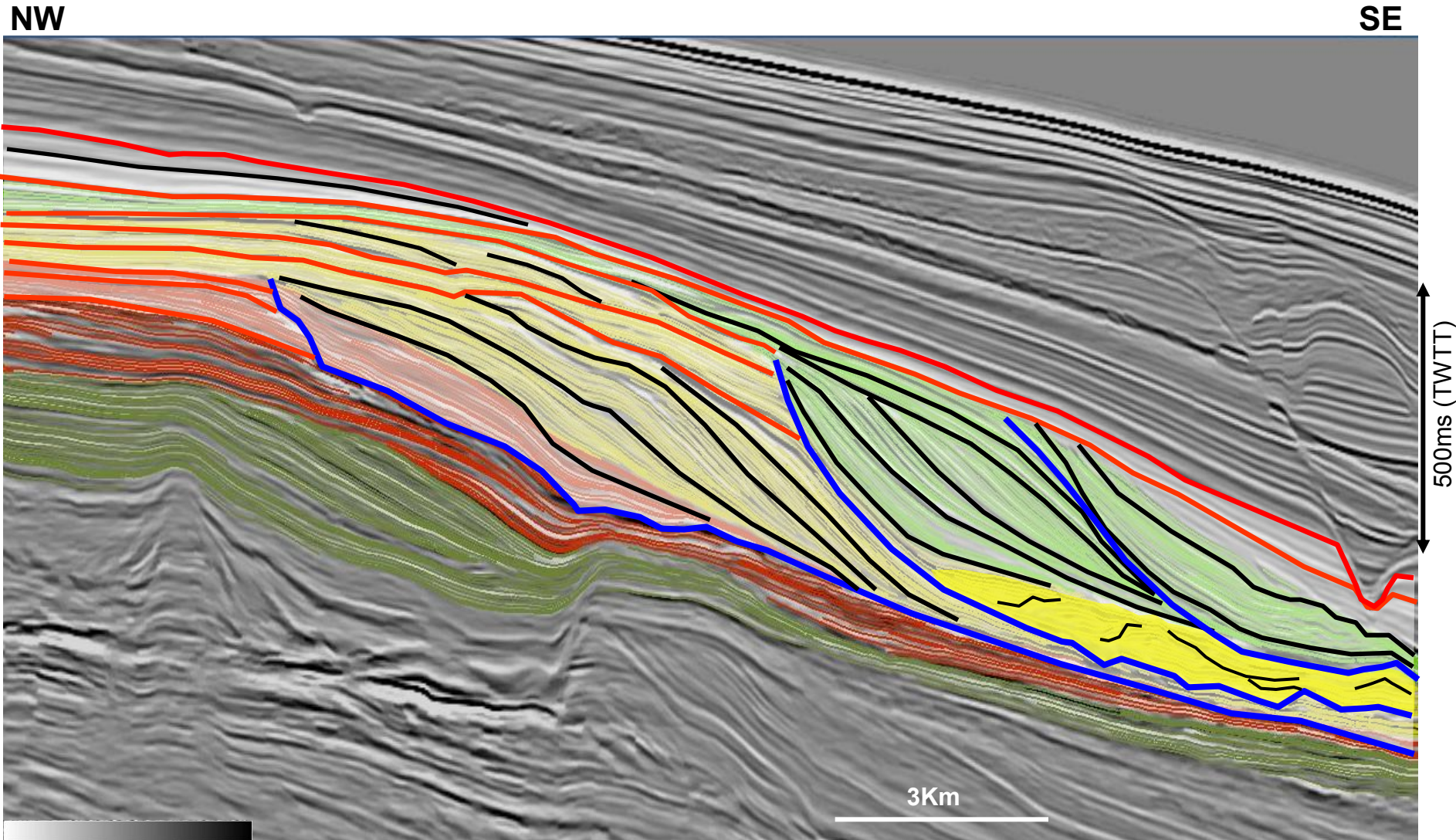
Resulting (automatic) chronostratigraphy



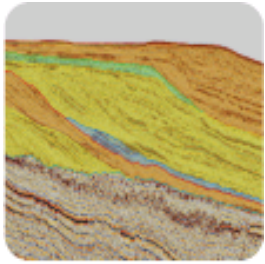
Seismic stratigraphic interpretation - manual picking



Seismic stratigraphic interpretation - automatic picking (3)



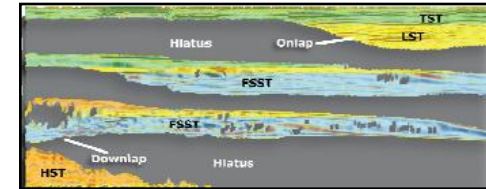
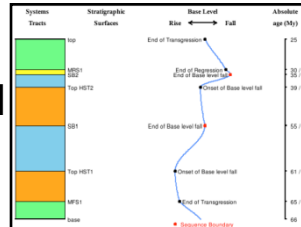
Systems tract definition (4) – spoilt for choice!!



Systems tracts

4) Systems tract/sequence stratigraphic analysis using time and Wheeler displays

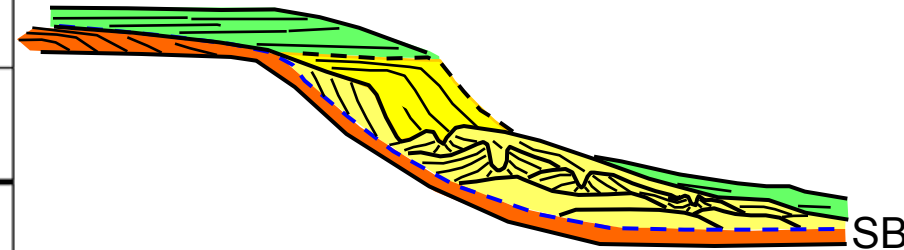
Base-level curve



Systems tracts in Wheeler display

Sequence model	Depositional Sequence			Genetic Sequence	T-R Sequence
Events	<i>Haq et al (1987)</i> <i>Posamentier et al (1988)</i>	<i>Van Wagoner et al (1988, 1990)</i> <i>Christie-Blick (1991)</i>	<i>Hunt & Tucker (1992, 1995)</i> <i>Plint & Nummedal (2000)</i>	<i>Frazier (1974)</i> <i>Galloway (1989)</i>	<i>Curray (1964)</i> <i>Embry (1993, 1995)</i>
end of transgression	HST	early HST	HST	HST	RST
end of regression	TST	TST	TST	TST	TST
end of base level fall	late LST (wedge)	LST	LST	late LST (wedge)	RST
onset of base level fall	early LST (fan)	late HST (fan)	FSST	early LST (fan)	
	HST	early HST (wedge)	HST	HST	

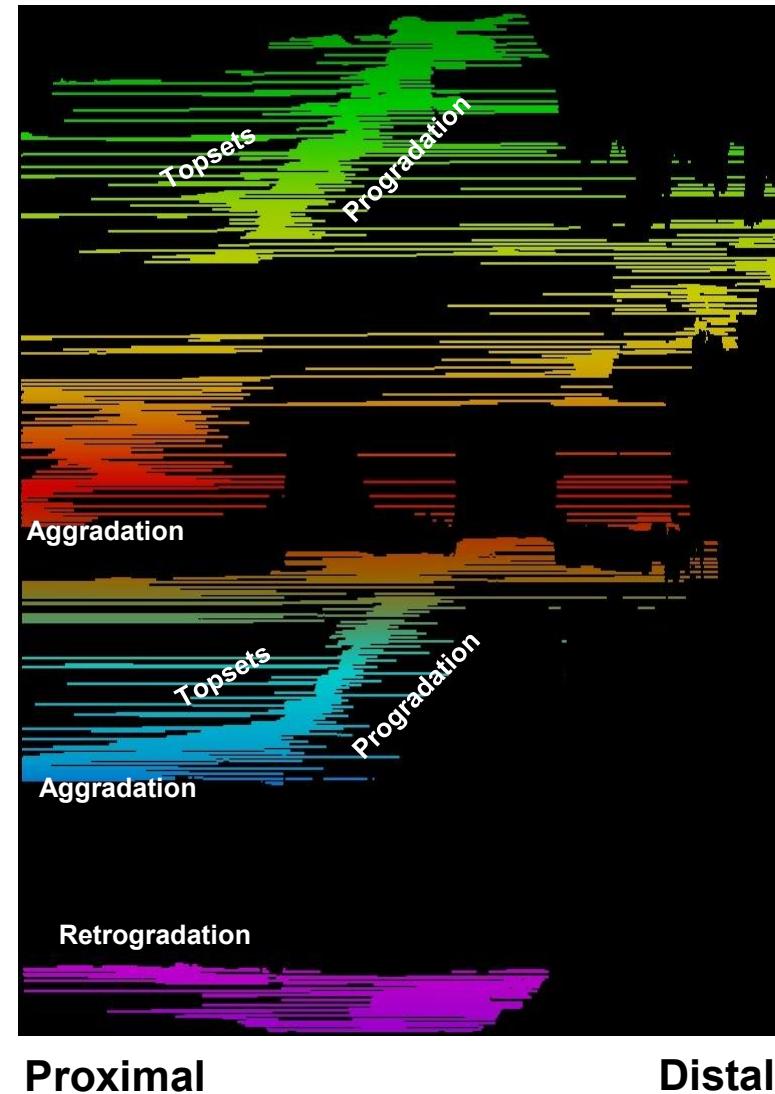
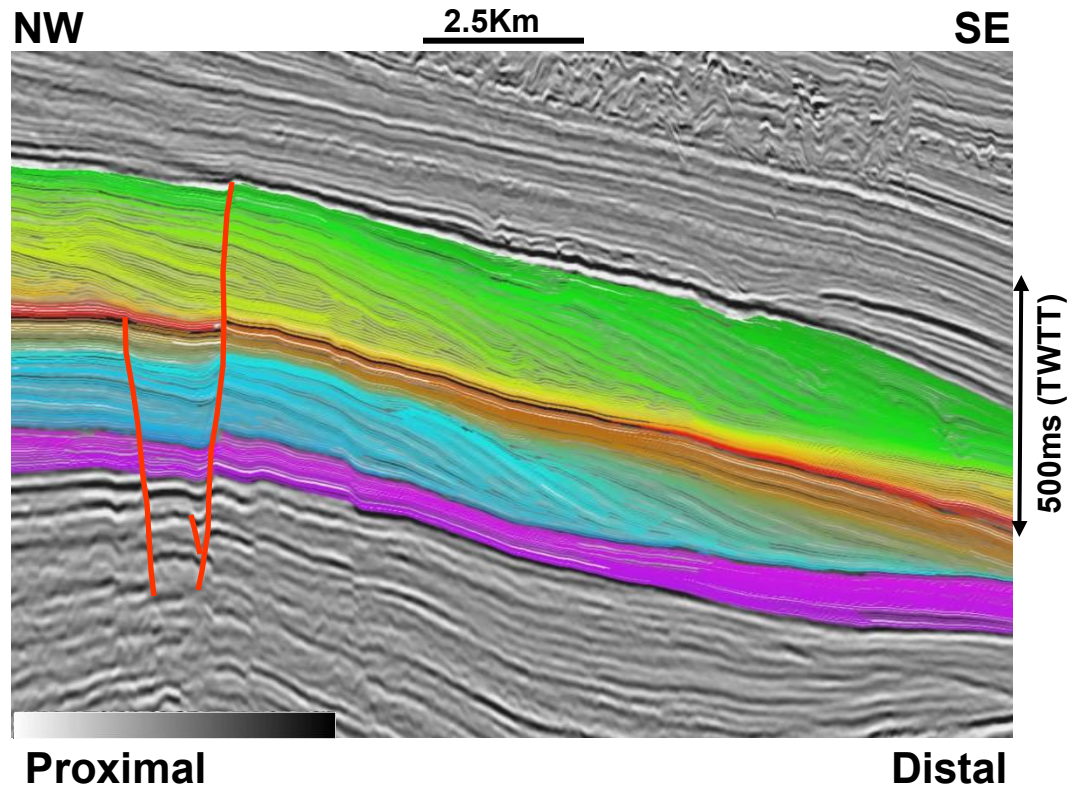
— sequence boundary
- - - within systems tract surface



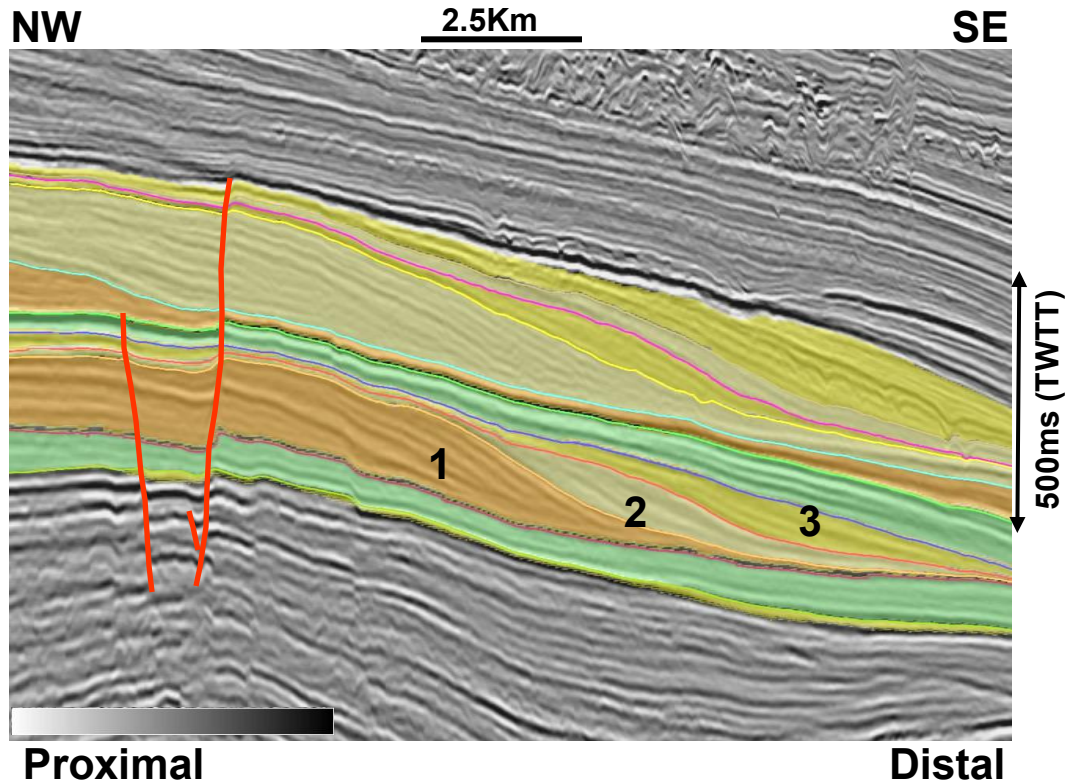
Depositional Sequence II

Name	Colour
HST	Orange
TST	Green
Late LST	Yellow
Early LST	Light Yellow

Wheeler domain generation (3)

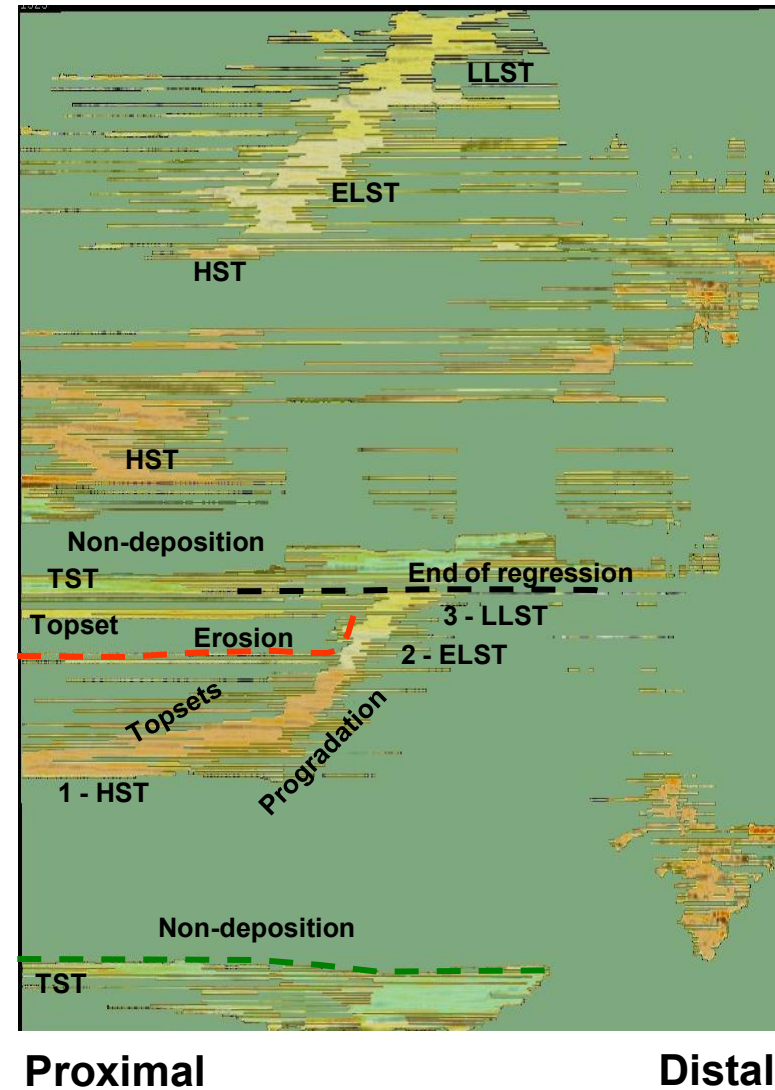


Systems tract definition (4)



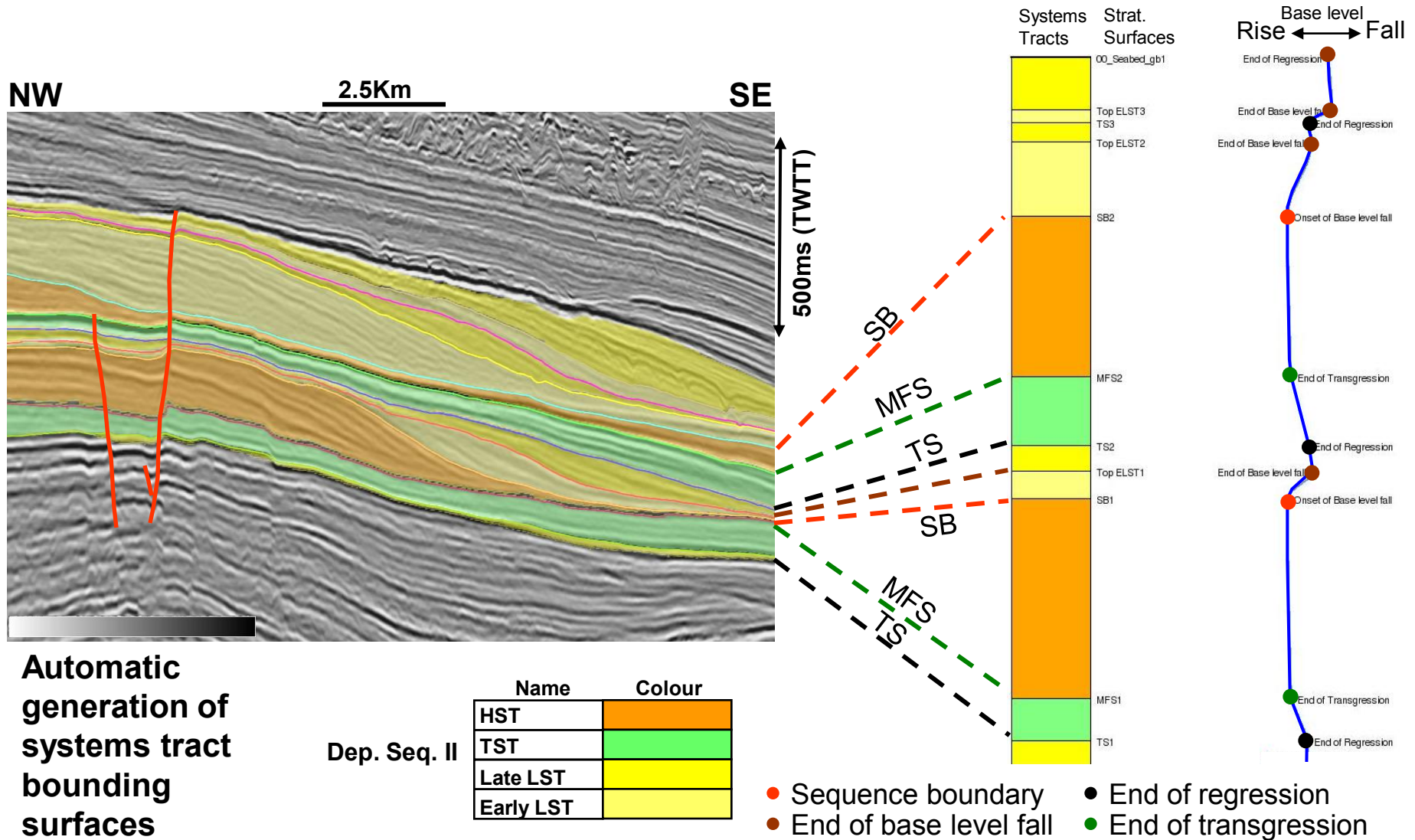
Depositional Seq. II

Name	Colour
HST	
TST	
Late LST	
Early LST	



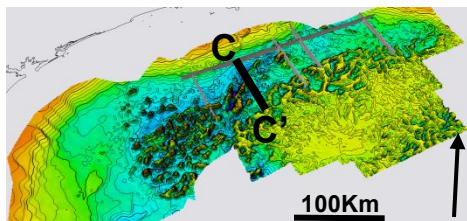
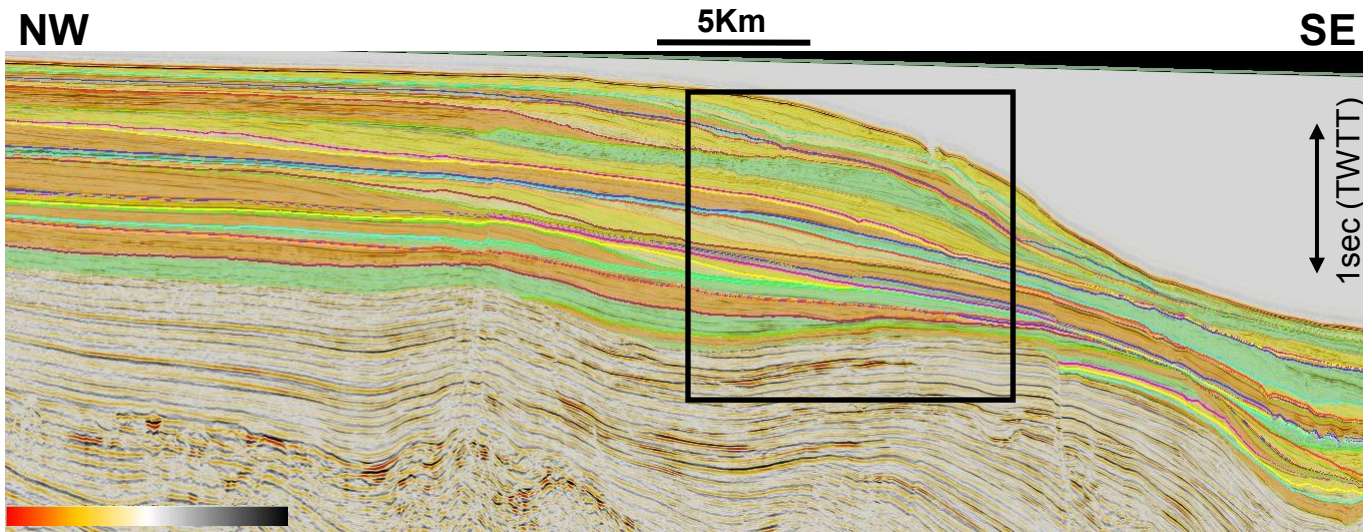
Data quality allows third order (and higher) sequence definition

Base-level curve generation (4)



Data quality allows third order (and higher) sequence definition

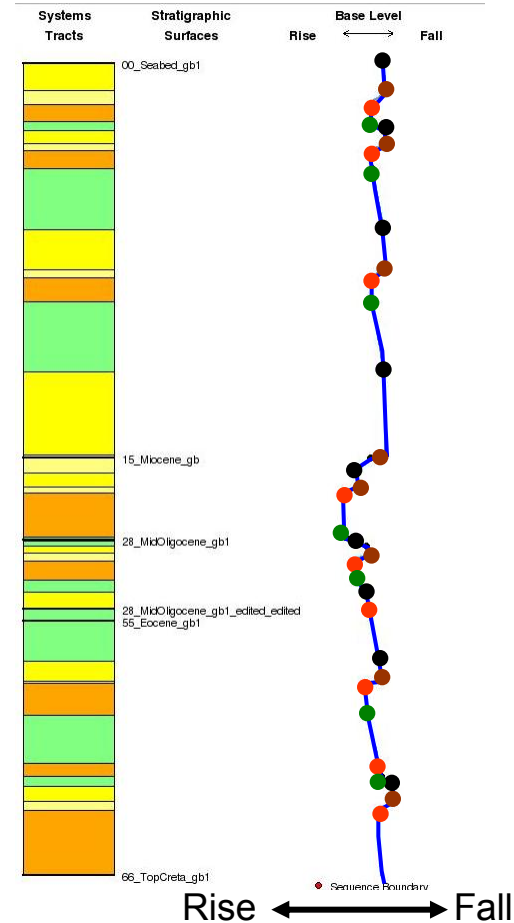
Systems tract definition and base-level curve generation



Dep. Seq. II

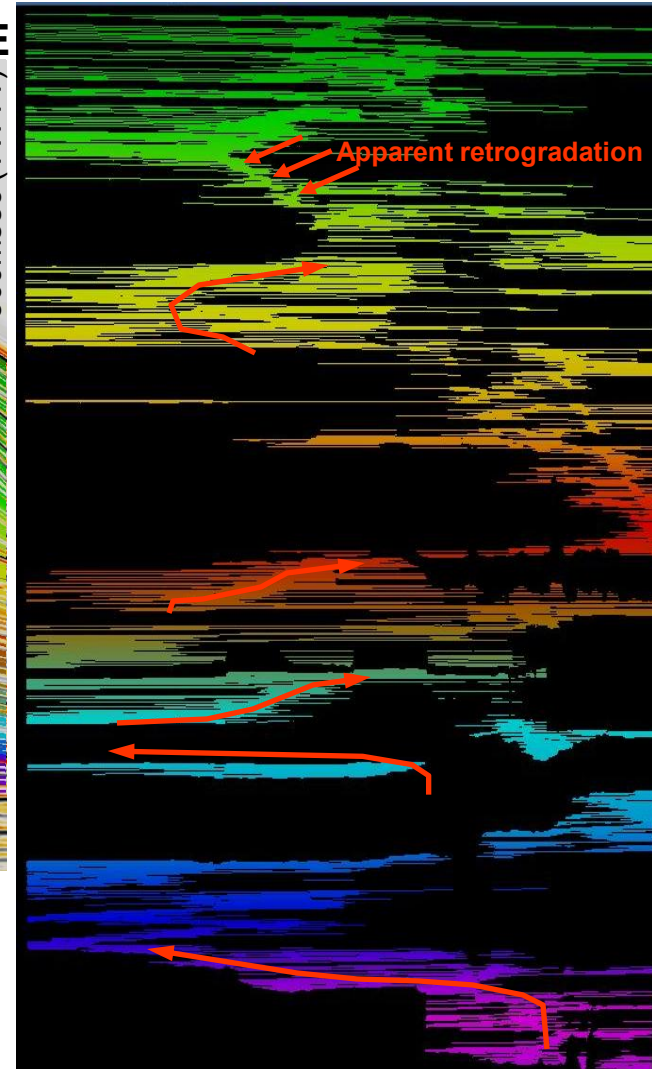
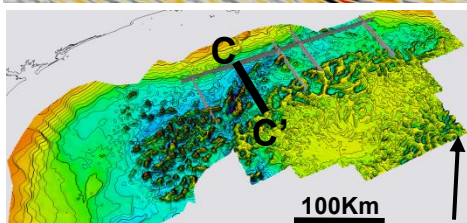
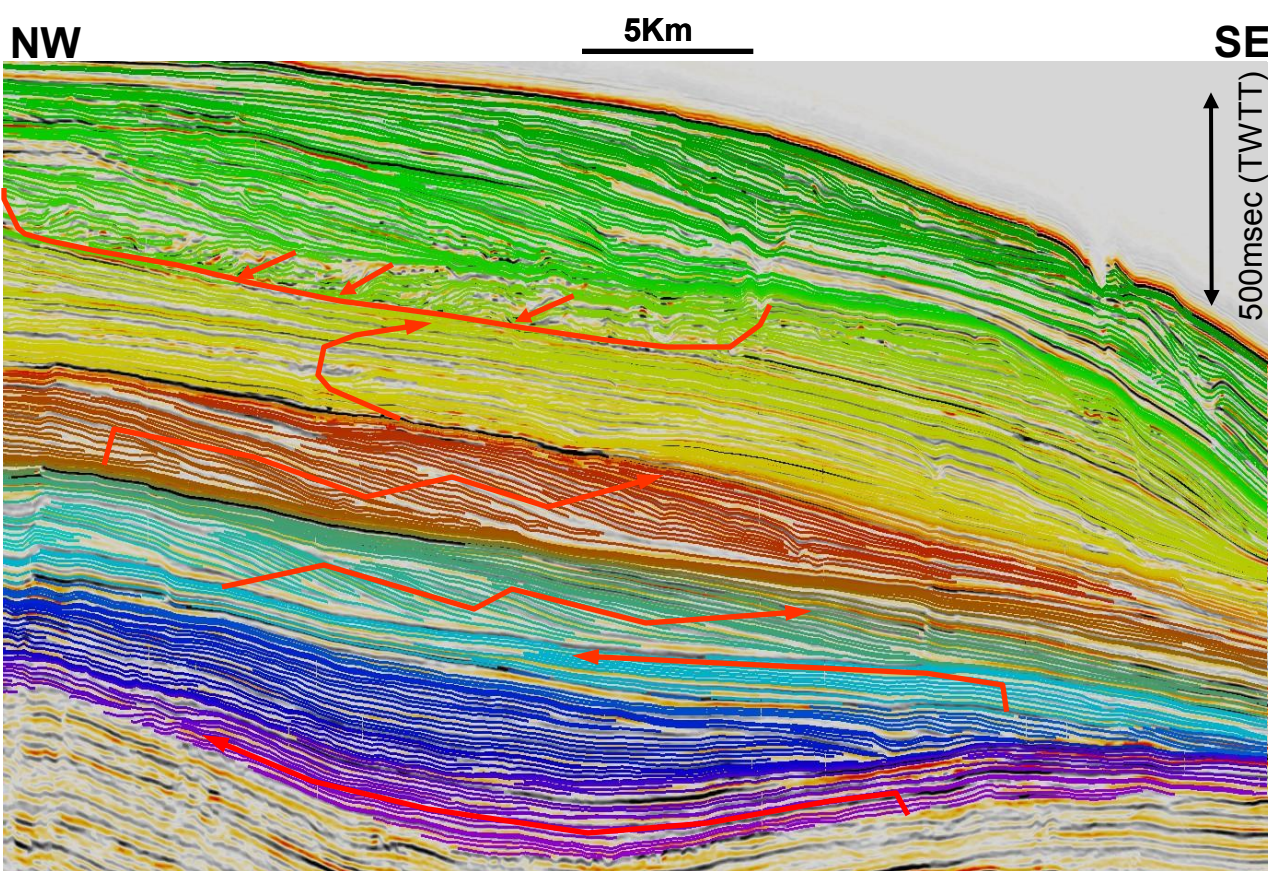
Name	Colour
HST	Orange
TST	Green
Late LST	Yellow
Early LST	Light Yellow

Base-level curve

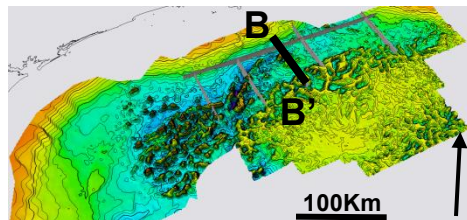
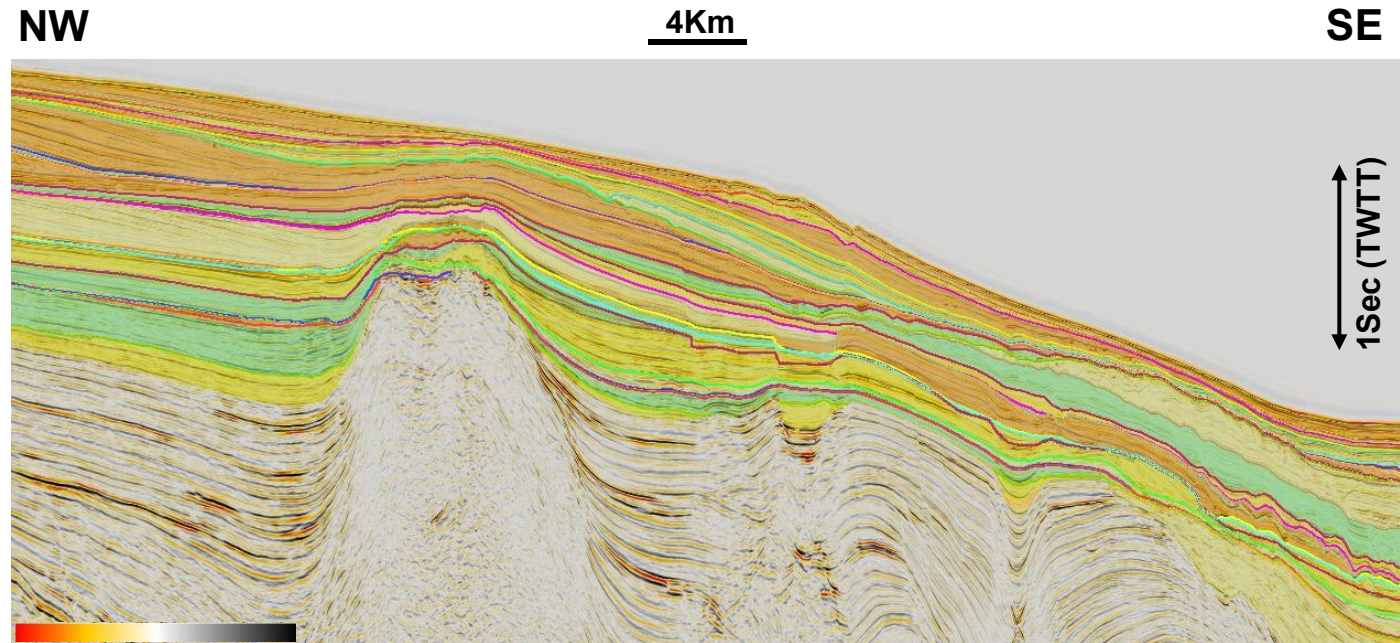


Third order (and higher) sequences

High-resolution chronostratigraphy

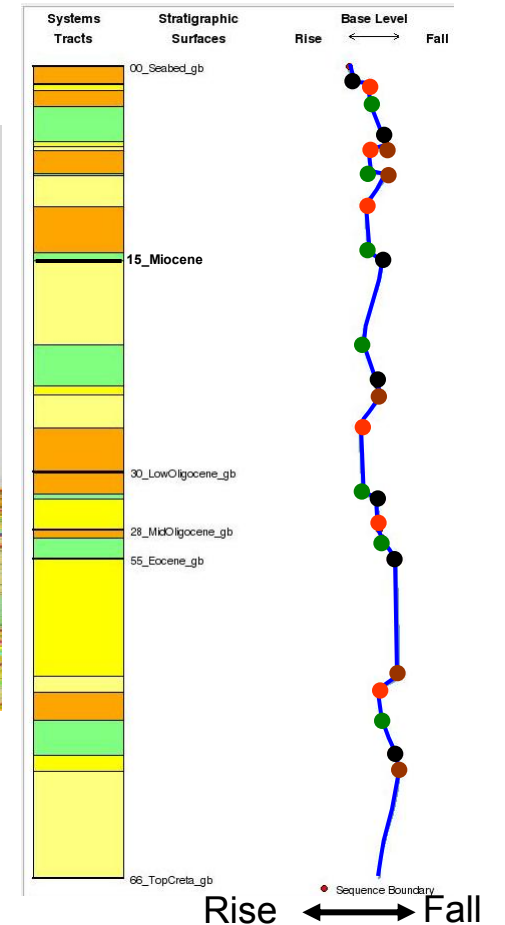


Systems tract definition and base-level curve generation



	Name	Colour
Dep. Seq. II	HST	
	TST	
	Late LST	
	Early LST	

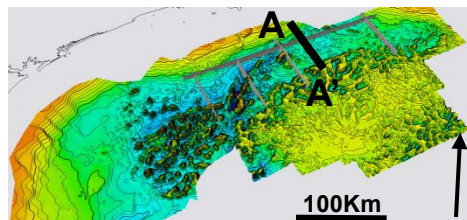
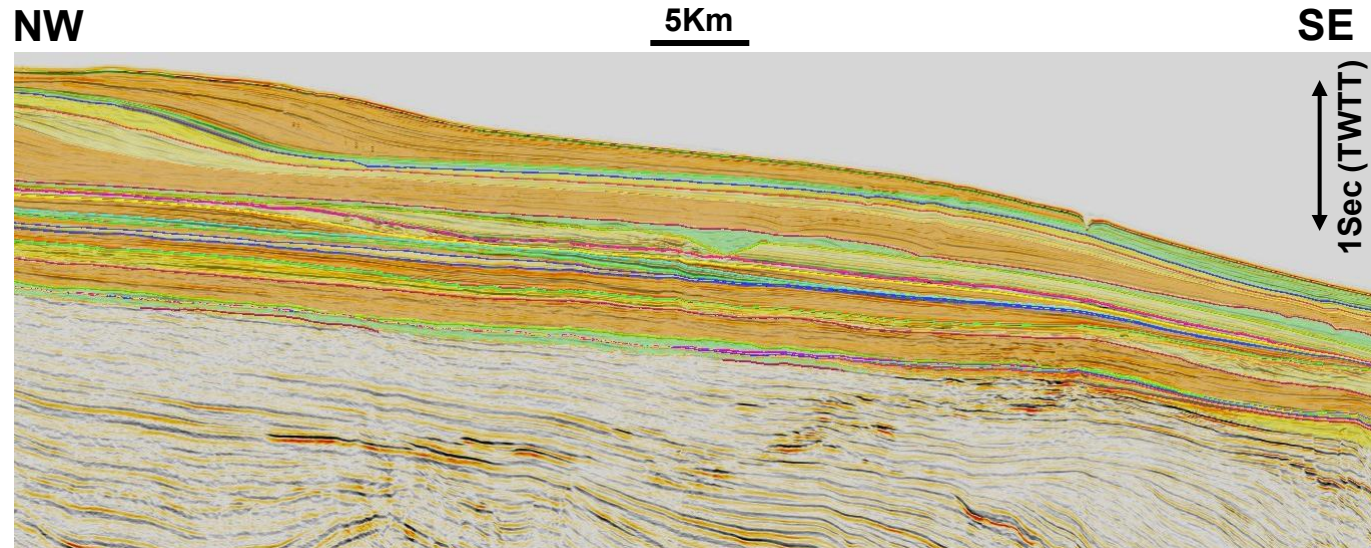
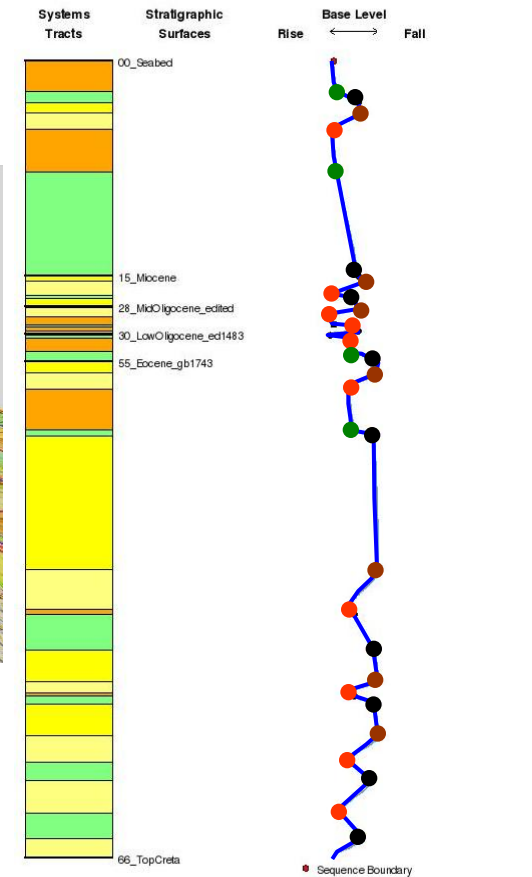
Base-level curve



Third order (and higher) sequences

Systems tract definition and base-level curve generation

Base-level curve



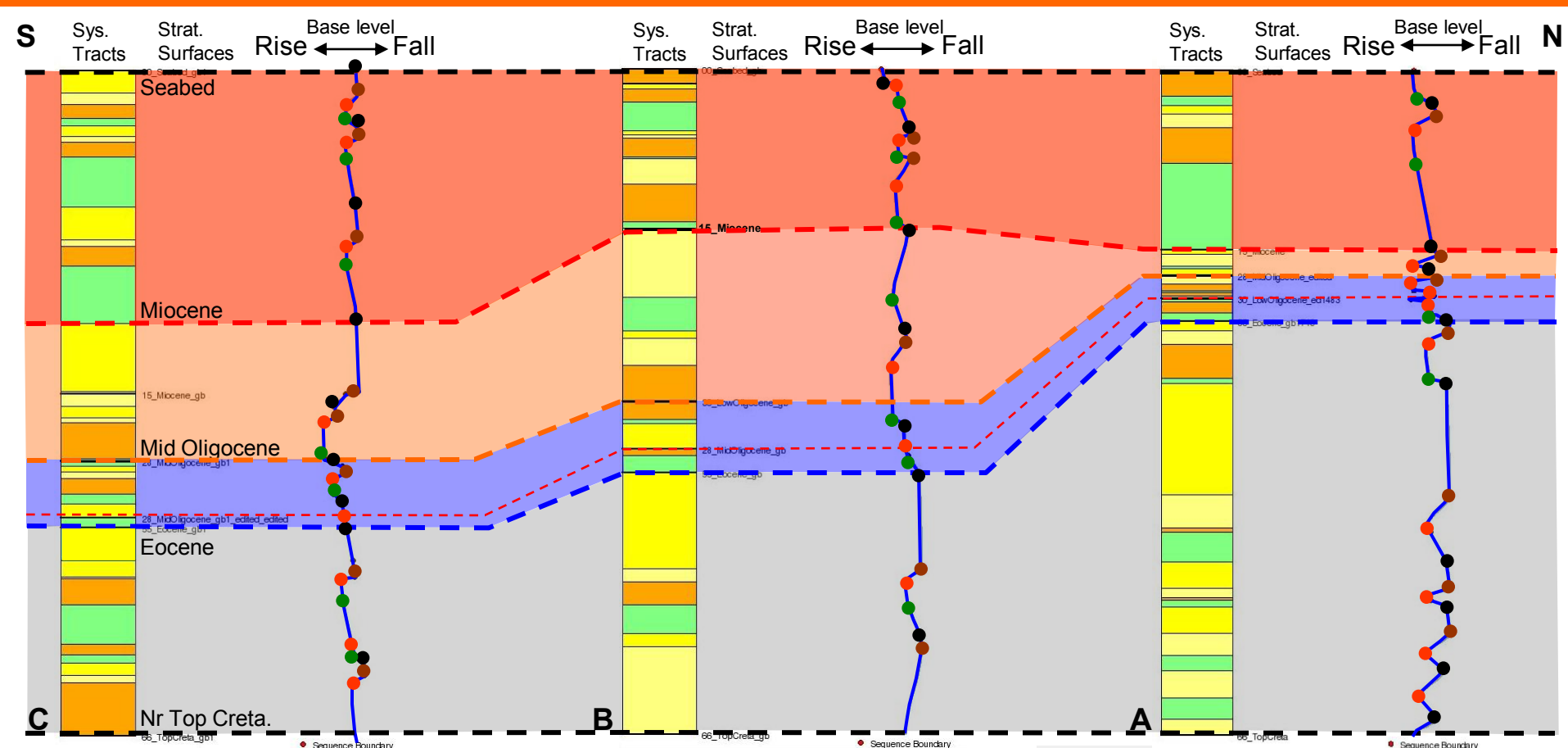
Dep. Seq. II

Name	Colour
HST	Orange
TST	Green
Late LST	Yellow
Early LST	Light Yellow

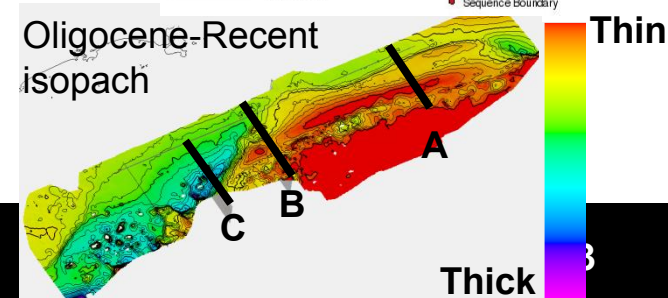
- Sequence boundary
- End of regression
- End of base level fall
- End of transgression

Third order (and higher) sequences

Individual base-level curve (thickness) comparison



- Regional events recognizable
- "Thickness" variations reflect shift in sedimentary input and local tectonics
- Different SB "frequency" (seq. order)



Conclusions

- Tested an original **digital workflow** for seismic-sequence stratigraphic interpretation (development continues, 3D interpretation will be next step)
 - Automatic chronostratigraphy
 - Automatic Wheeler diagrams
 - Interpreted systems tracts and hence base-level curves
- Methodology allows very quick, **repeatable** seismic-sequence stratigraphic interpretation on large dataset
- Generation of **individual base-level curves** allows identification of different depositional histories within a basin
- **Improved collaboration** between remote teams thanks to the digital and repeatable nature of the results

Recommendations and future work

- Further expansion of the capabilities of digital sequence stratigraphic interpretation in 2D and 3D seismic data through the SSIS industry consortium
- Extended analysis of the sequence stratigraphy of the Santos Basin, including:
 - More rigorous correlation between lines (especially along depositional strike)
 - Integration with well information (age, water depth, lithology)
 - Improved understanding of controlling factors: sea level changes, tectonics, sedimentation rate, etc.
 - Implications for the petroleum system (source, reservoir and seal), local and basin-wide