

Pre-Salt Carbonate Reservoirs in the South Atlantic and World-wide Analogs*

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Please refer to related article by the author, Search and Discovery Article #41502 (2014), “Birth and development of continental margin basins: Analogies from the South Atlantic, North Atlantic, and the Red Sea,” http://www.searchanddiscovery.com/documents/2014/41502mohriak/ndx_mohriak.pdf.

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Abstract

This work focuses on the geological, geophysical and petrophysical challenges for interpretation of presalt carbonate rocks that constitute the main reservoirs in the recently discovered giant field accumulations in the South Atlantic, particularly in the Santos Basin. These rocks represent one of the main exploratory plays in several basins worldwide, and have yielded large petroleum discoveries in the southeastern Brazilian continental margin. The presalt microbialite reservoirs have been recognized in several other sedimentary basins worldwide, as for example, in the northern Caspian Sea and in the Kwanza Basin, offshore Angola. These carbonate rocks are sealed by evaporites and their origin is still controversial, with one current of interpretation assuming they are associated with reefs and carbonate buildups formed during periods of sea-level rises in a desiccating basin. Other currents of interpretation assume that these rocks might be related to chemical precipitation of carbonates in a basin affected by volcanic or hydrothermal episodes, resulting in travertine deposits with secondary biogenic growth. We discuss possible microbialite analogs in the sedimentary basins of Brazil dating from Neoproterozoic to Recent, and their similarities and differences in terms of depositional setting and petrophysical parameters from the presalt carbonate rocks observed in the Santos Basin.

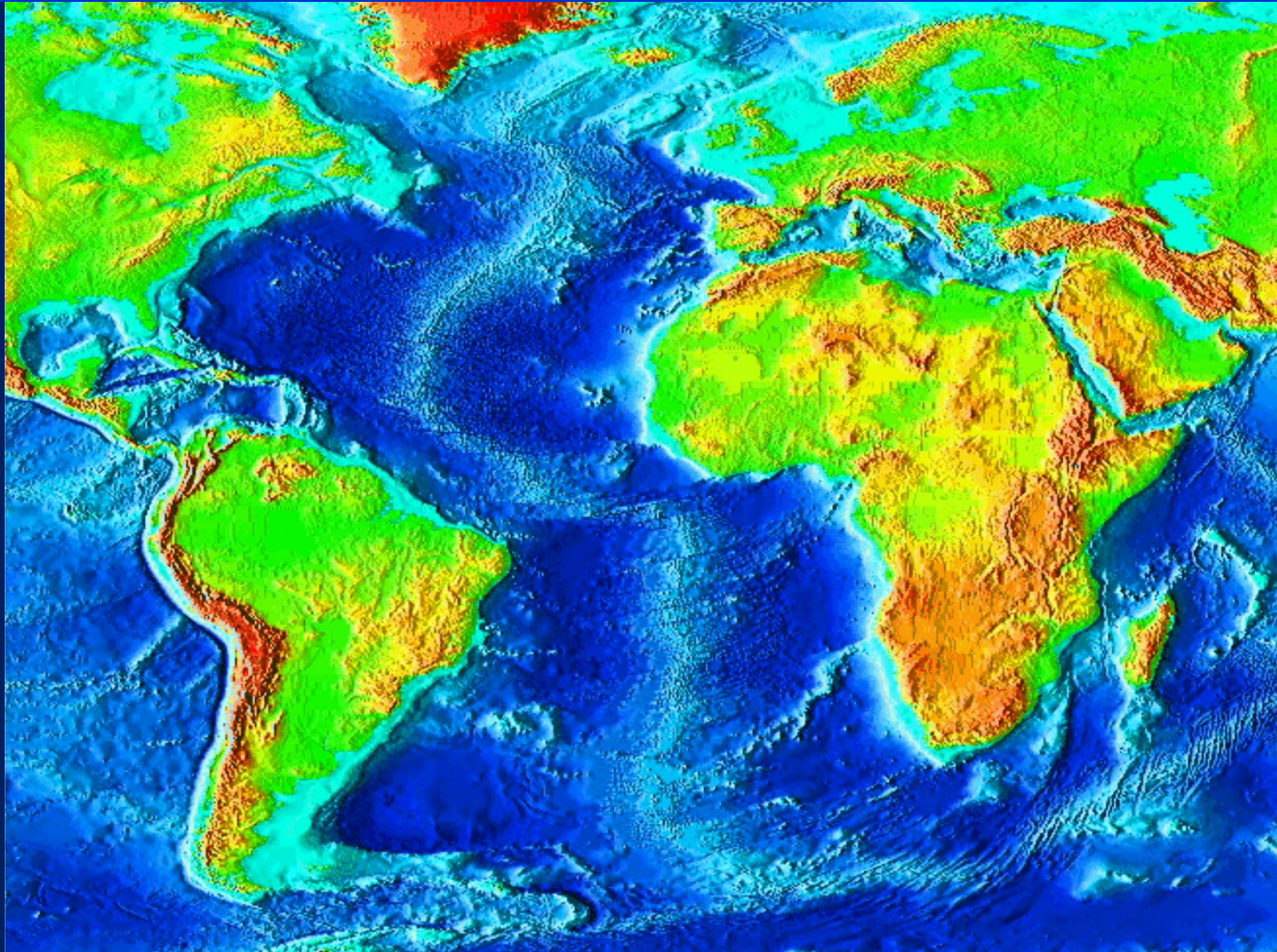
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Pre-Salt Carbonate Reservoirs in the South Atlantic and Worldwide Analogs



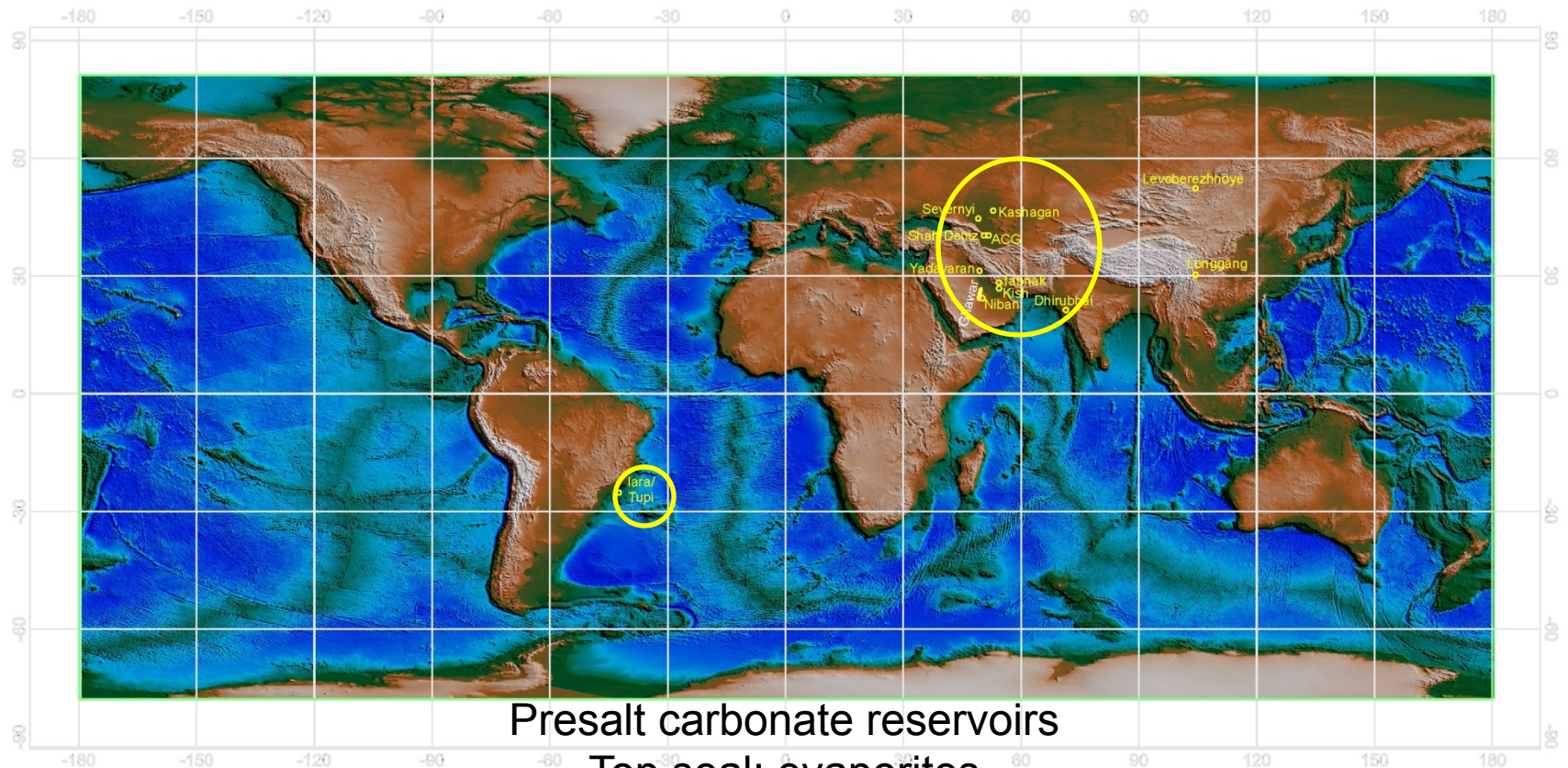
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Pre-salt carbonates exploratory plays

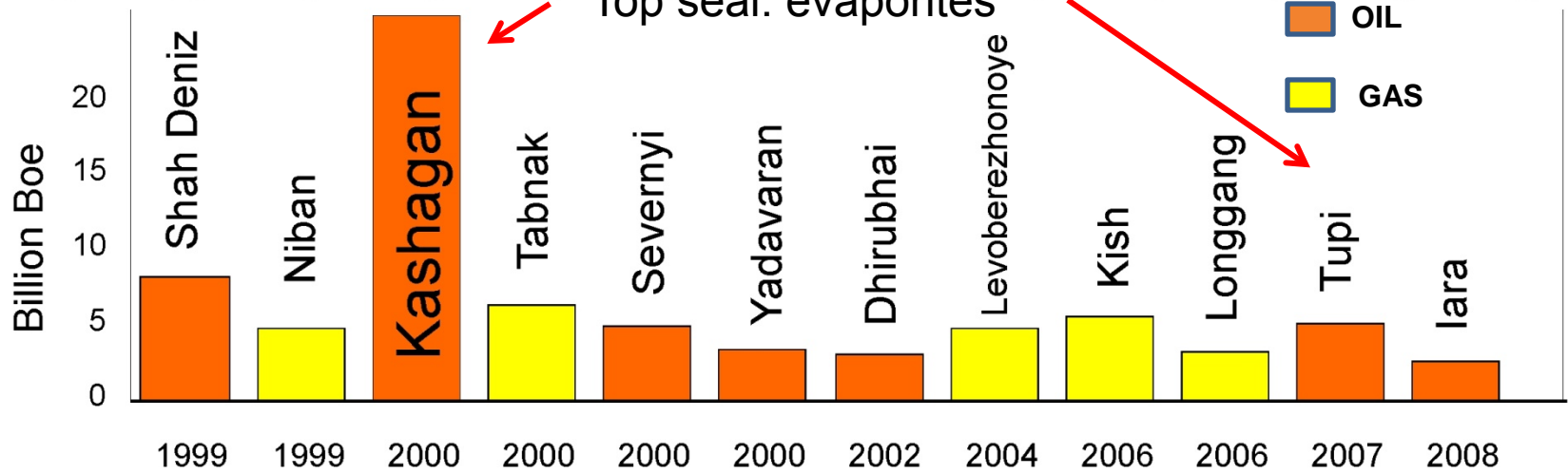
- Geological Setting of Basins
- Petroleum Systems
- Proposed Analogue (Petrobras)
- Alternative Analogues
- Laboratory Petrophysical Analysis
- Well Log and Seismic Interpretation
- Challenges

Largest (VOIP) oil fields discovered in the last decade



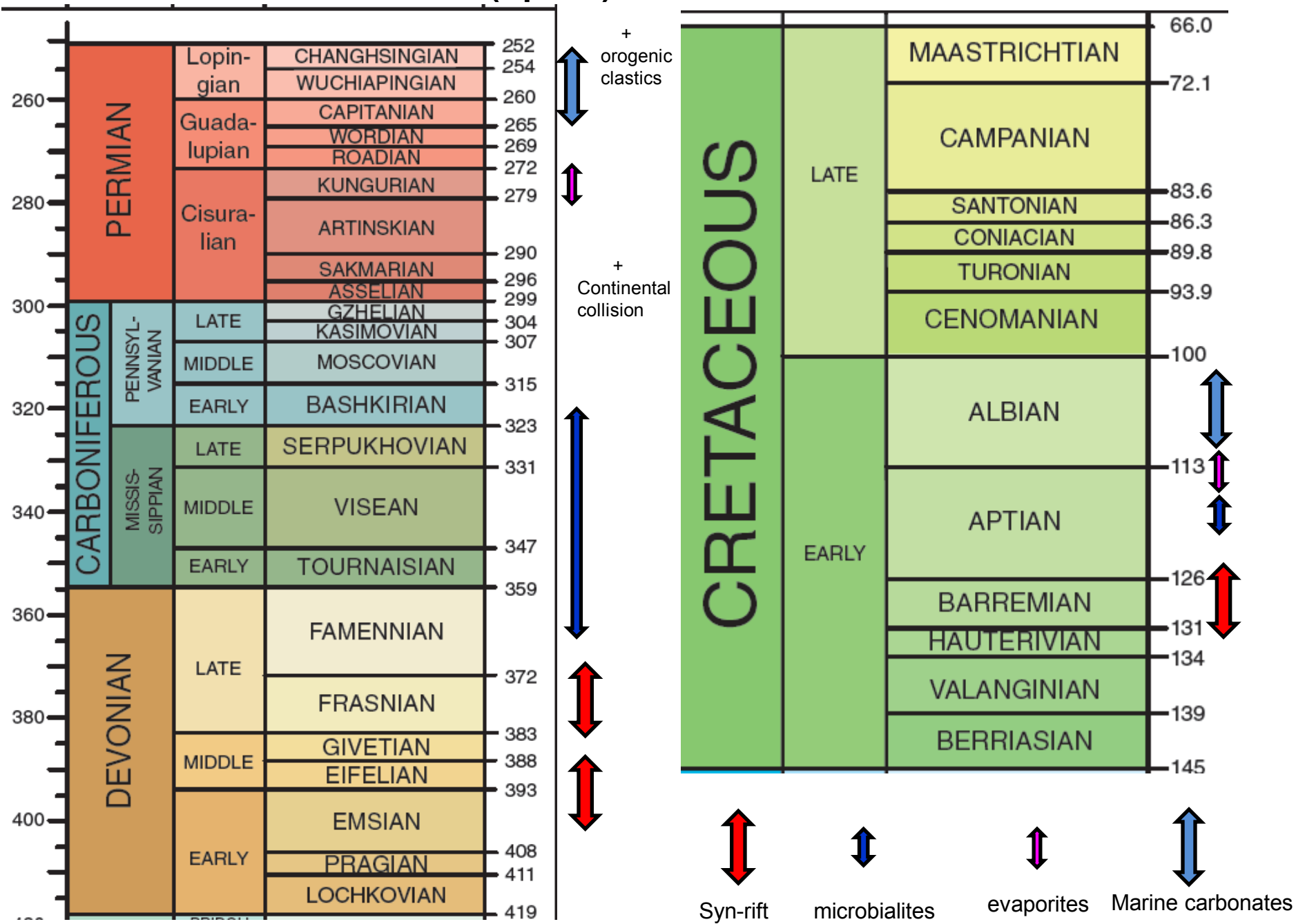
Presalt carbonate reservoirs

Top seal: evaporites



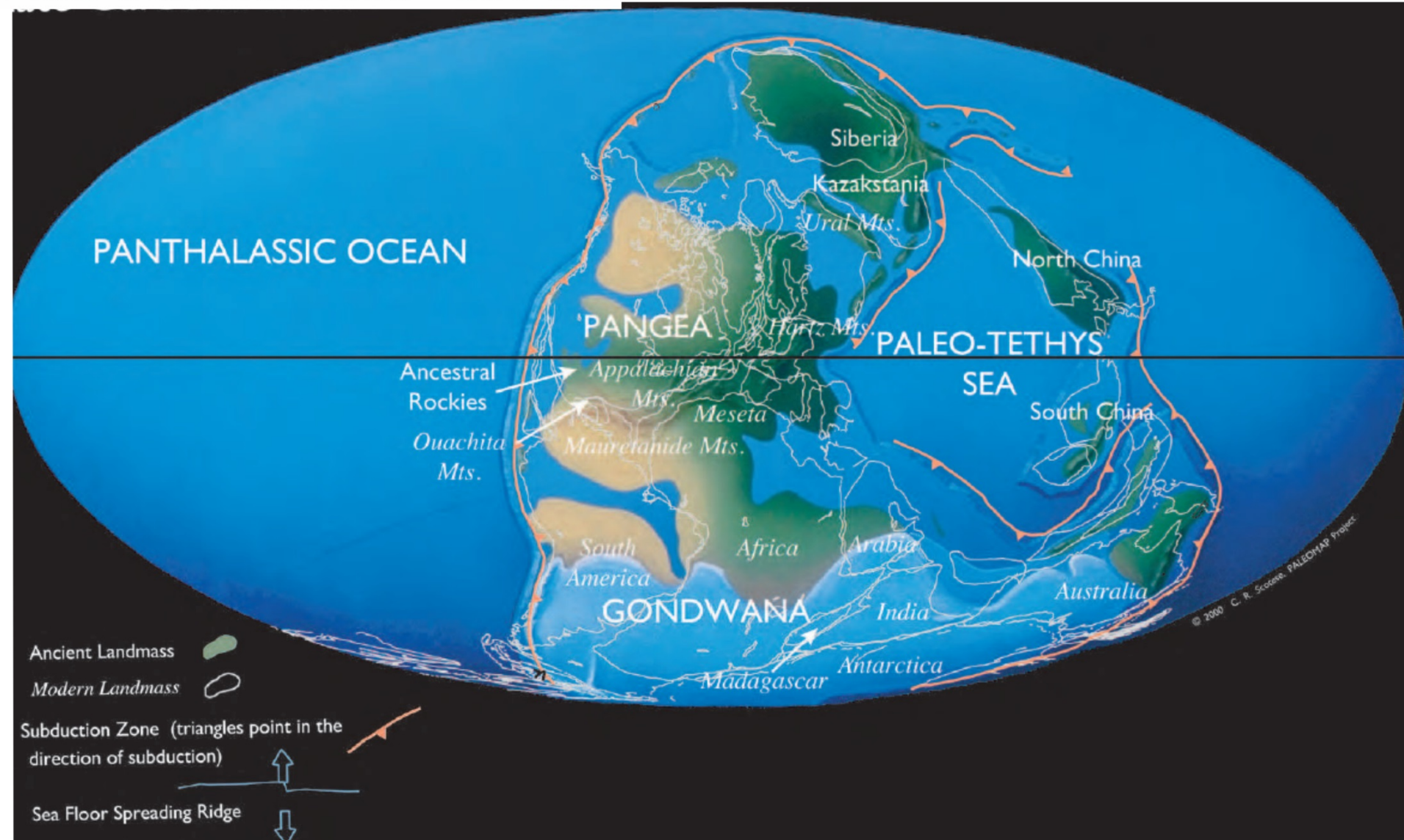
Paleozoic (Carboniferous) carbonates – North Caspian

Mesozoic (Aptian) carbonates – Santos Basin

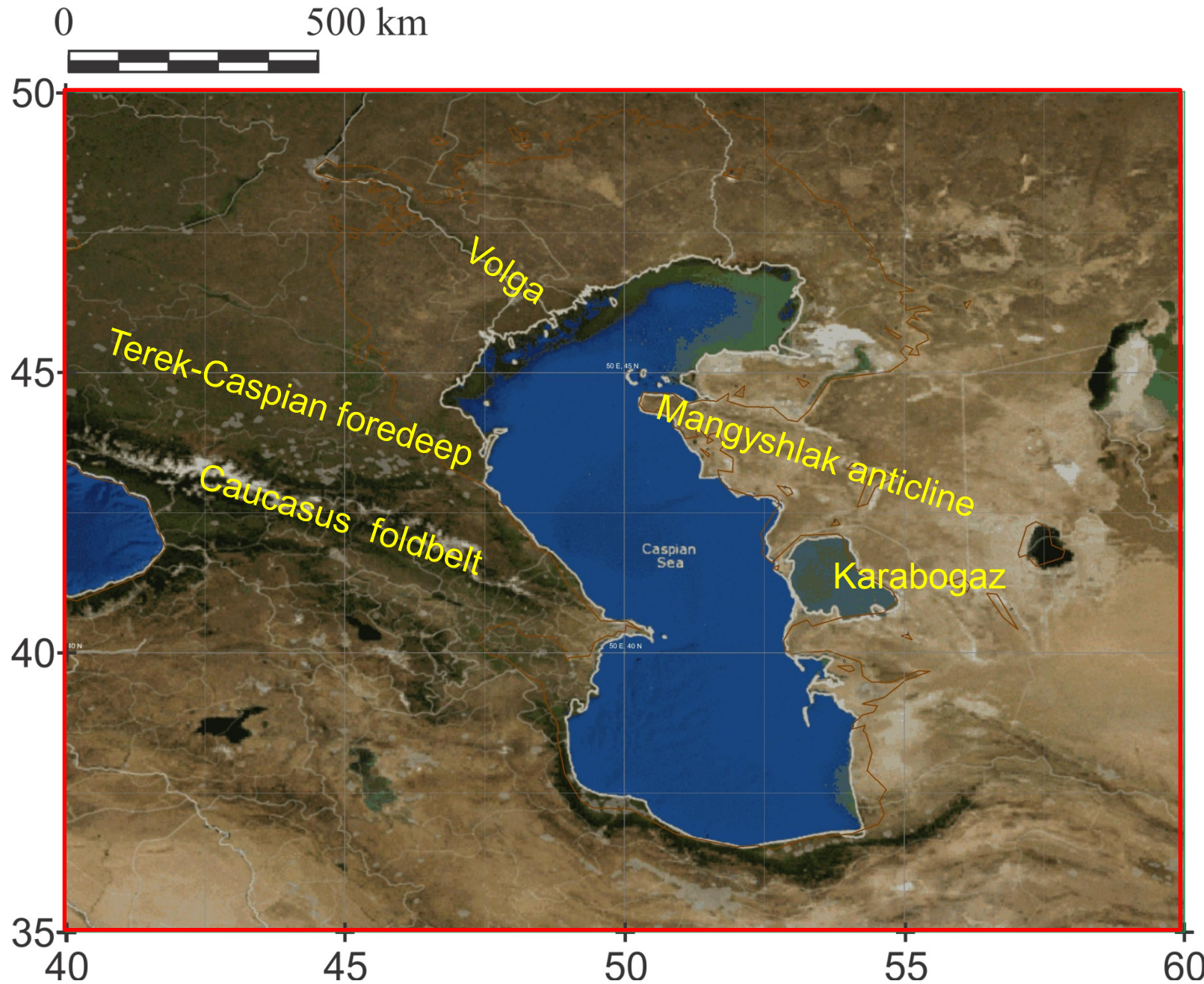


Late Carboniferous paleogeography continental collision followed by salt deposition

Late Carboniferous - 306 Ma



Caspian Sea Basin – satellite image

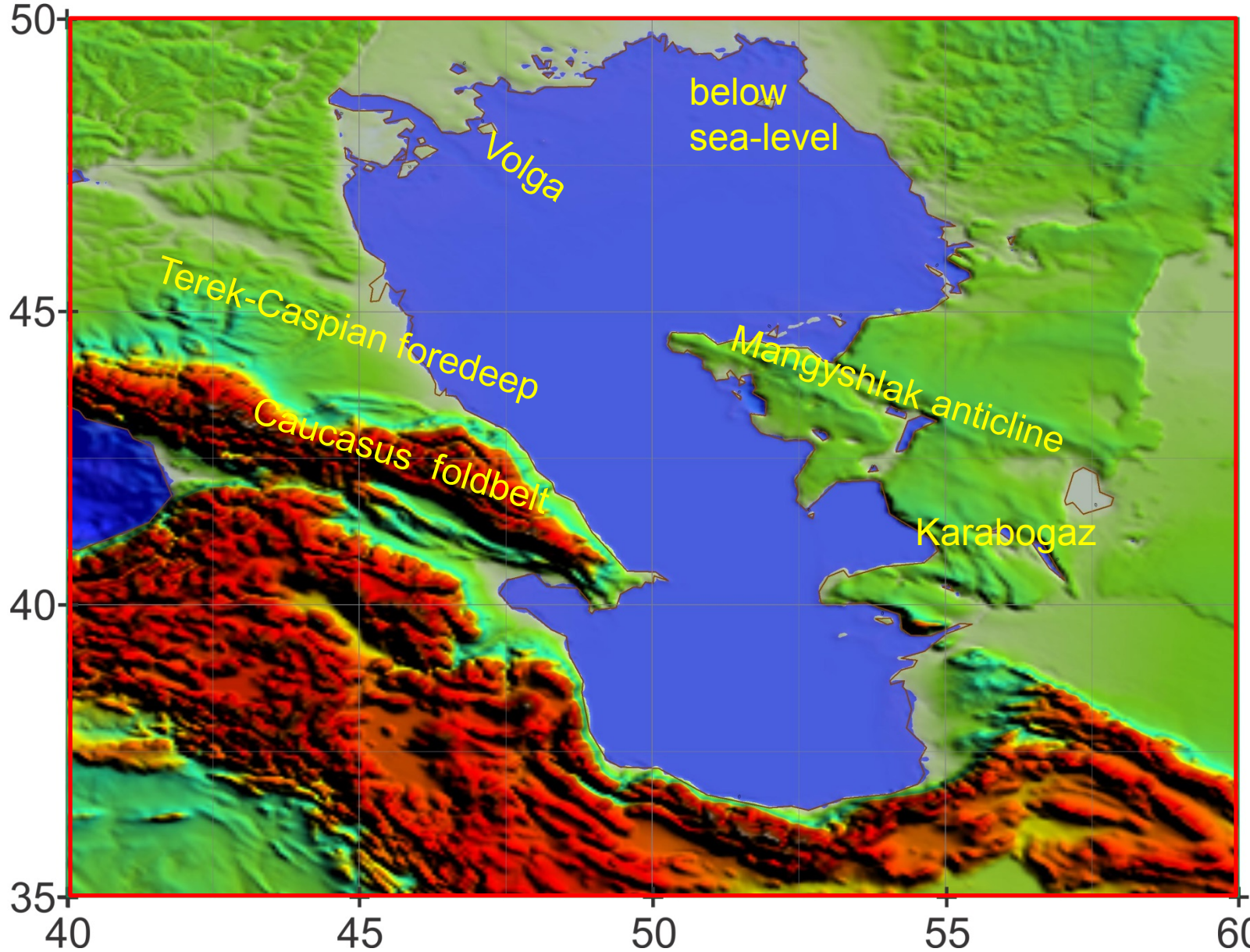
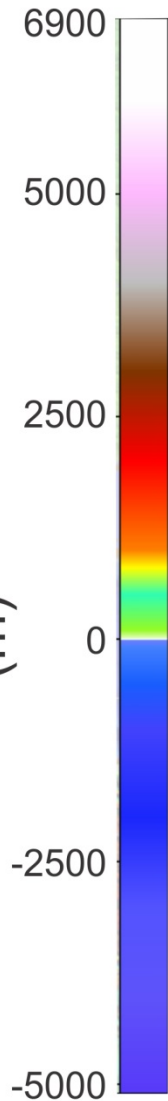


Caspian Sea Basin - topobathymetry

0 500 km

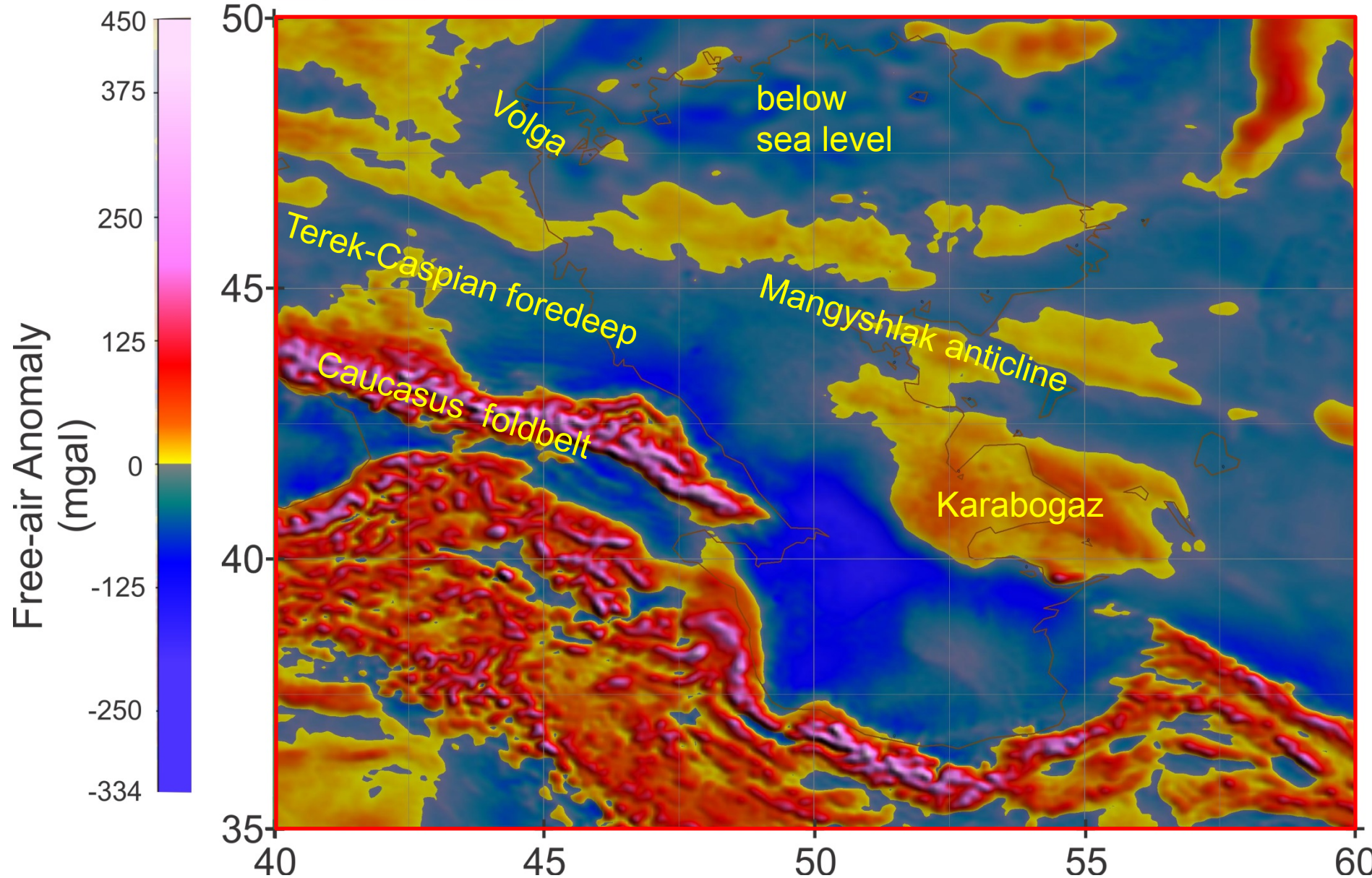


Bathymetry / Topography
(m)

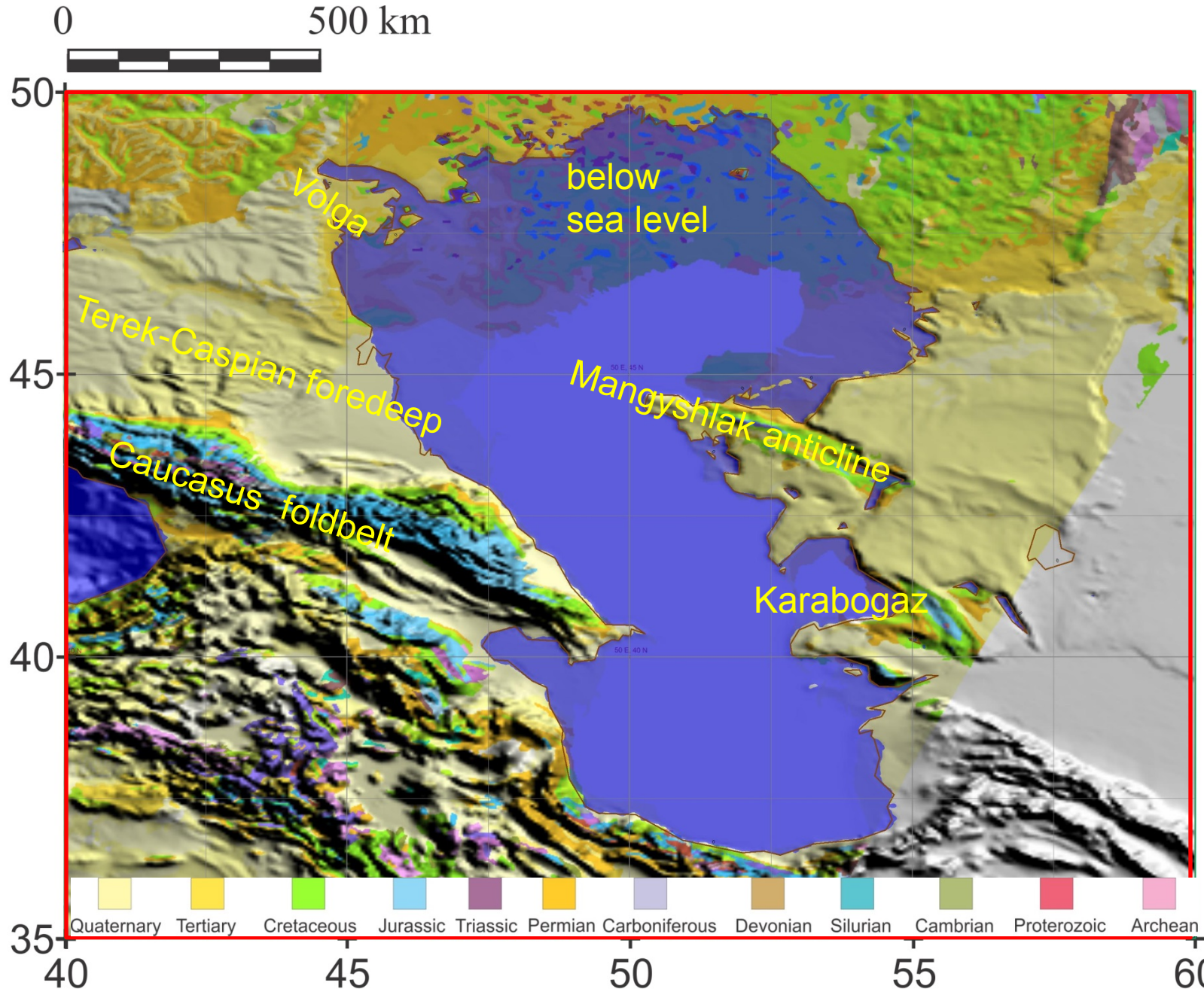


Caspian Sea Basin – free-air anomaly

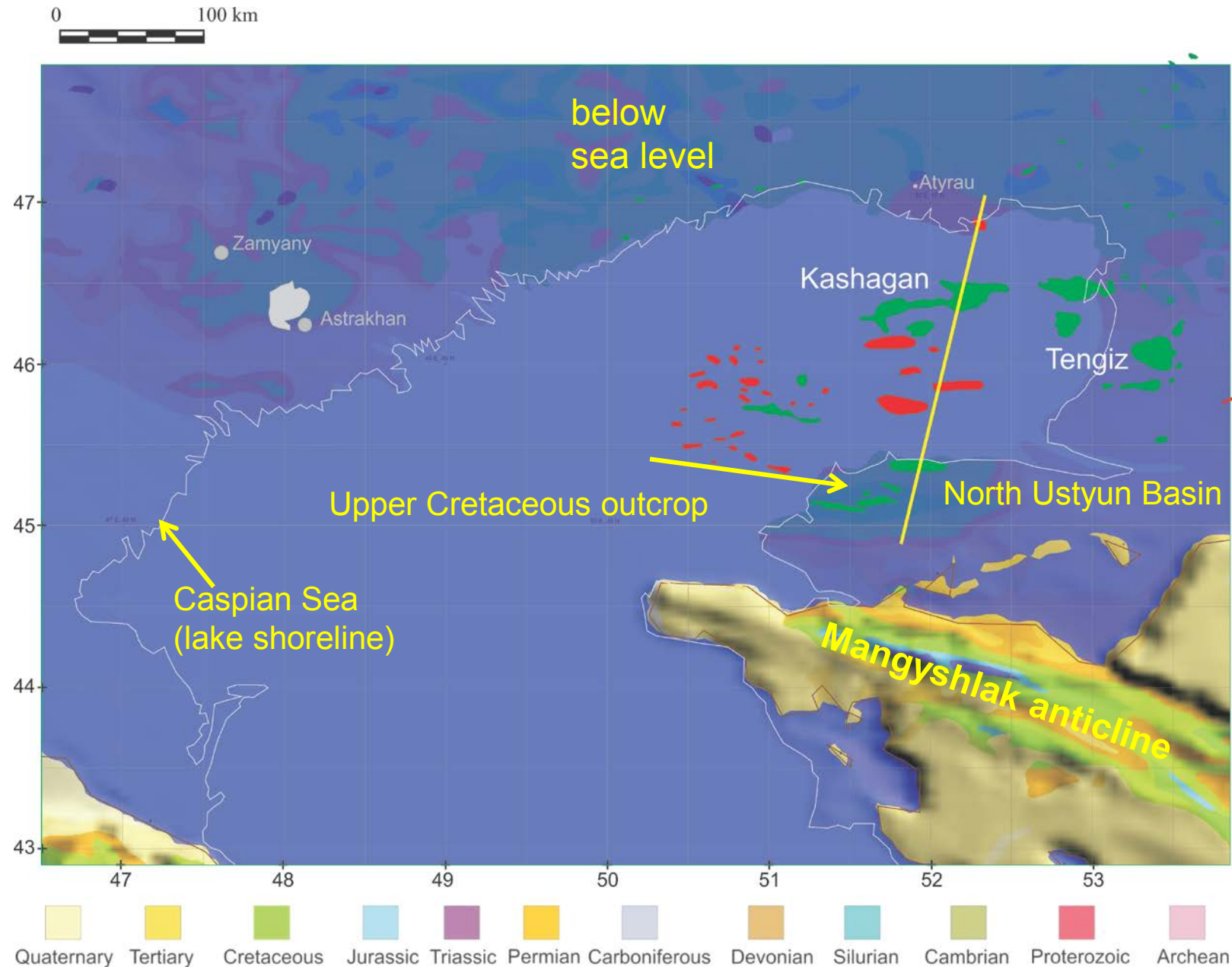
0 500 km



North Caspian Sea Basin - geology

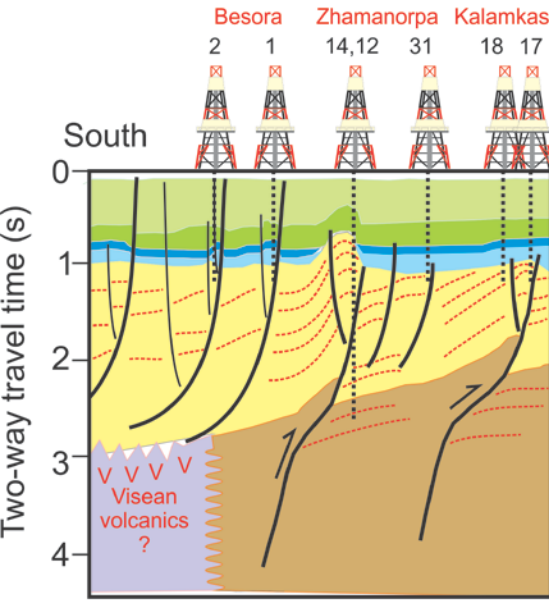


North Caspian Sea Basin geoseismic profile (S-N) salt limit, structural domains, petroleum plays (Kashagan and Tengiz oil fields)

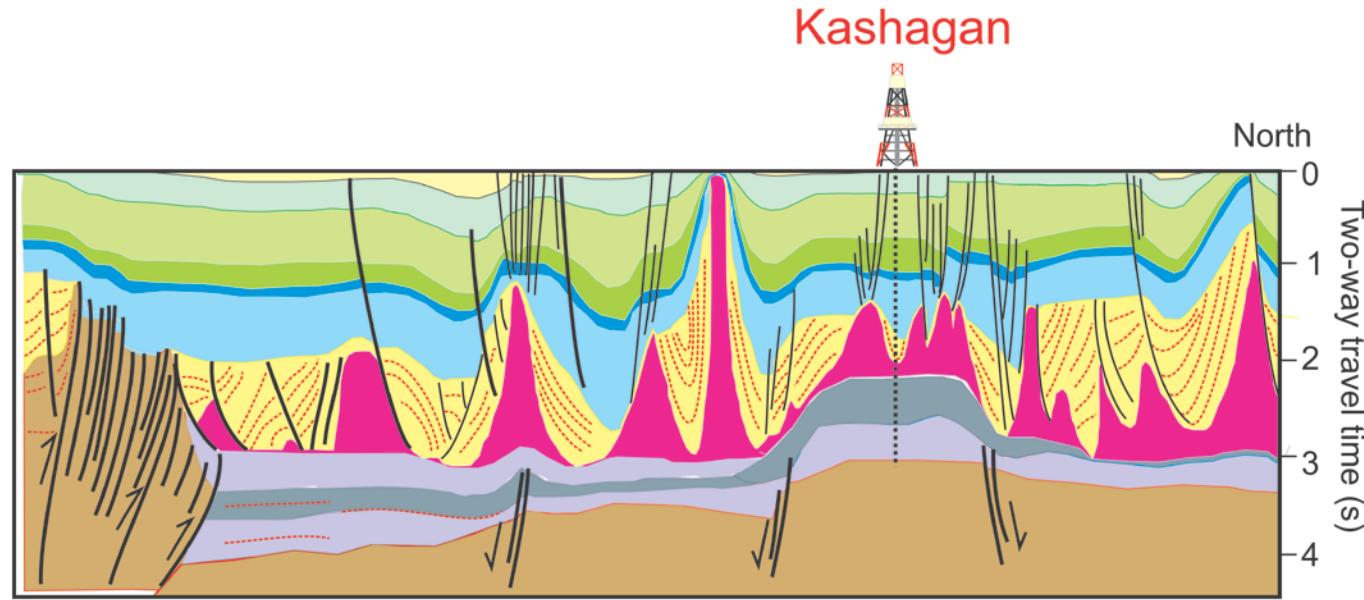


Geoseismic profile in the North Caspian Basin (S-N) (pre-Devonian not imaged)

Inverted Dnieper-Donetz-Buzachi rifts



Precaspian salt basin

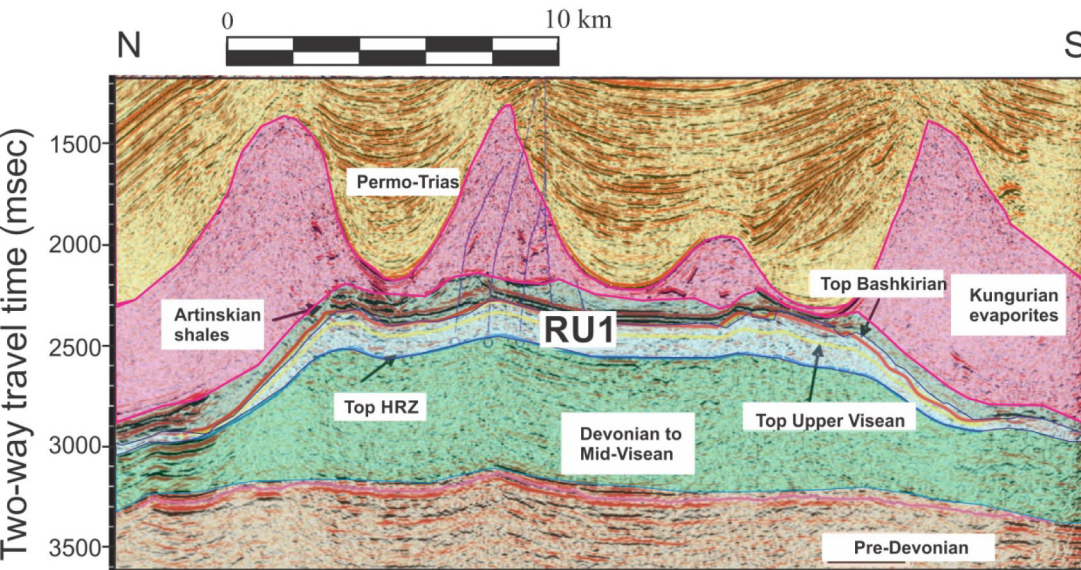
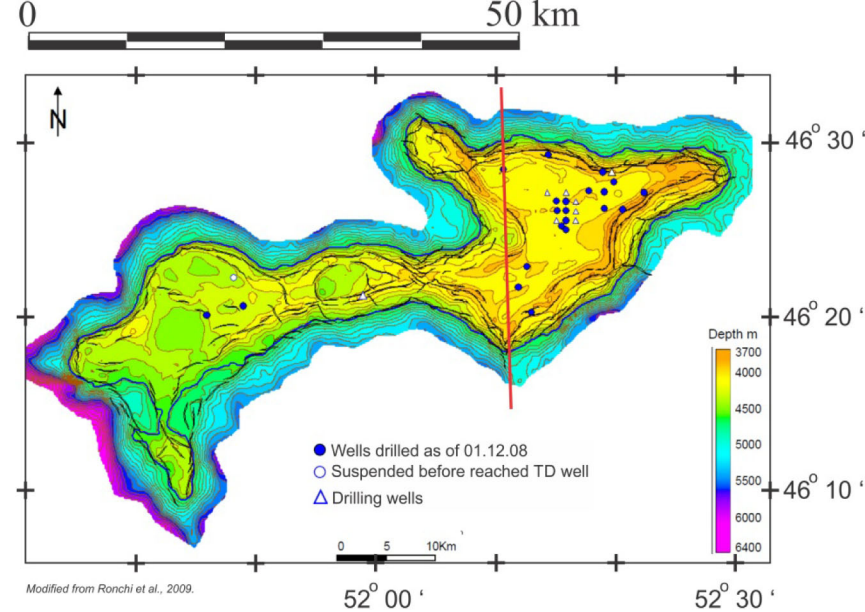


Modified from Cramez, 2003.



Seismic profile in the Kashagan Field

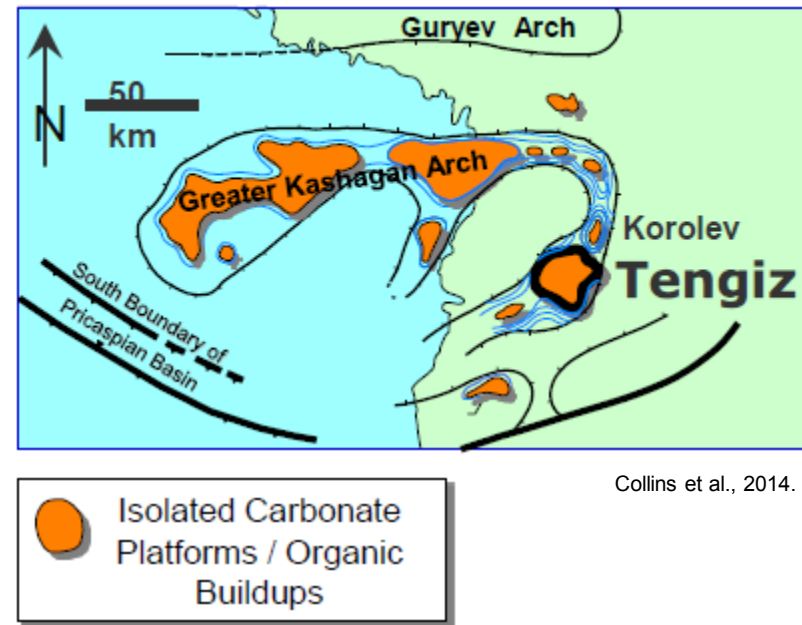
Reef buildup measuring 75 km x 35 km
 Top of reservoir 4.5 km below sea level
 Oil column exceeds 1000 m, high pressures
 Carbonate rocks with low porosity and permeability
 Oil with 45° API, high GOR, 19% H₂S



Microbialites as a pre-salt reservoir

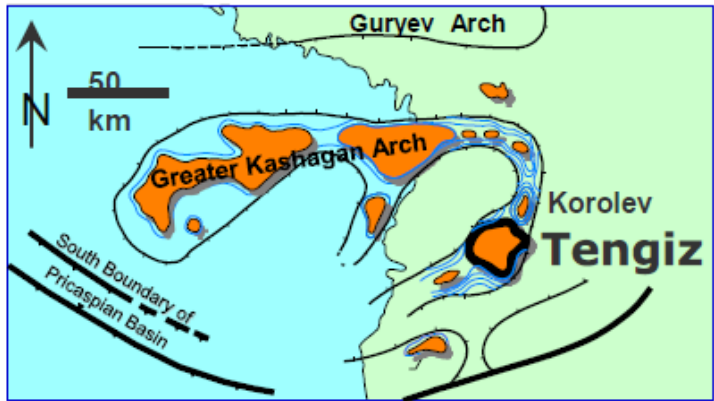
Kashagan and Tengiz carbonate buildups

Production in Kashagan has started in 2013 but many reservoir issues exist concerning the best strategy for oil recovery (including a future 4D acquisition). Production was halted in 2014. Tengiz is a better well known carbonate buildup field with reservoir model constrained by exploration and appraisal wells, cores and plugs.

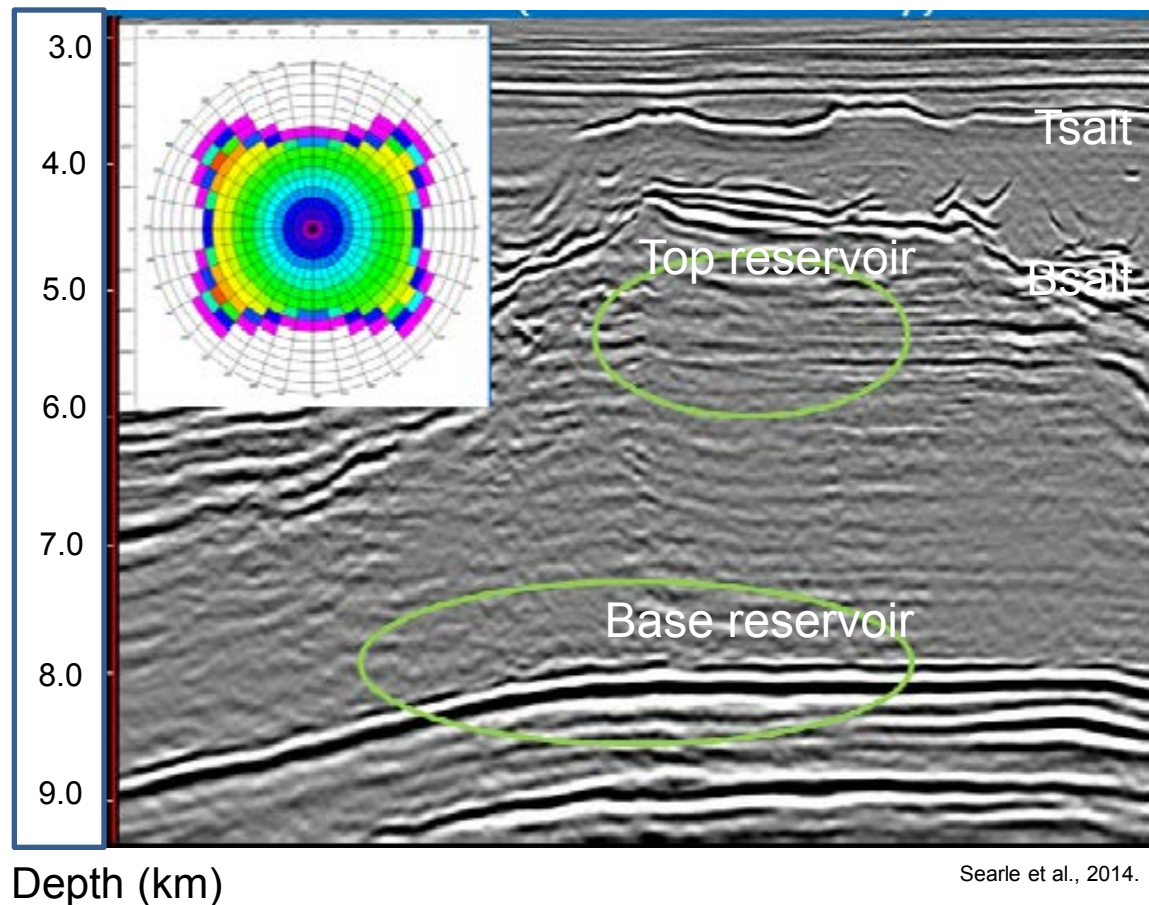
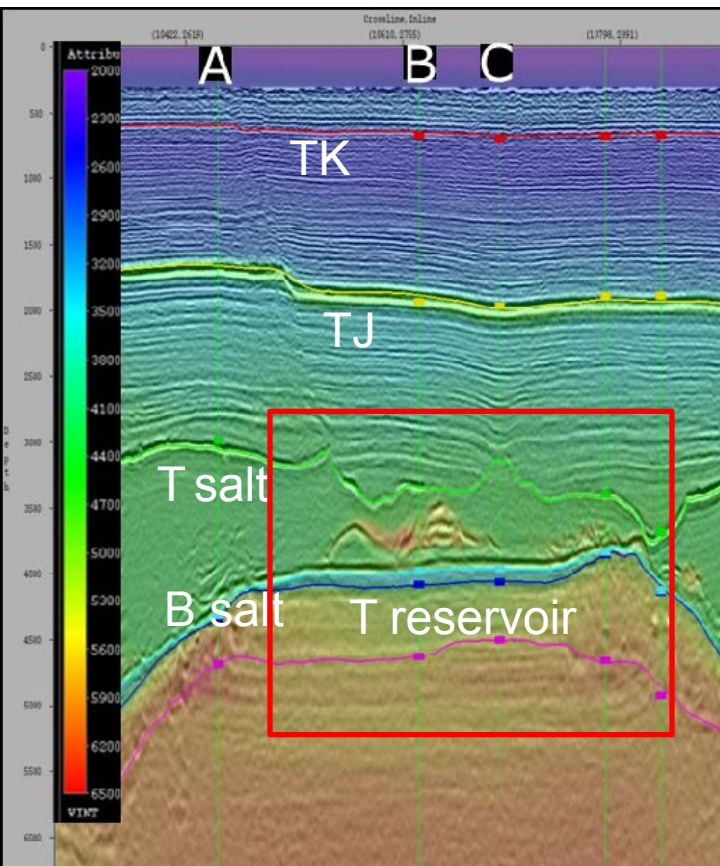


Collins et al., 2014.

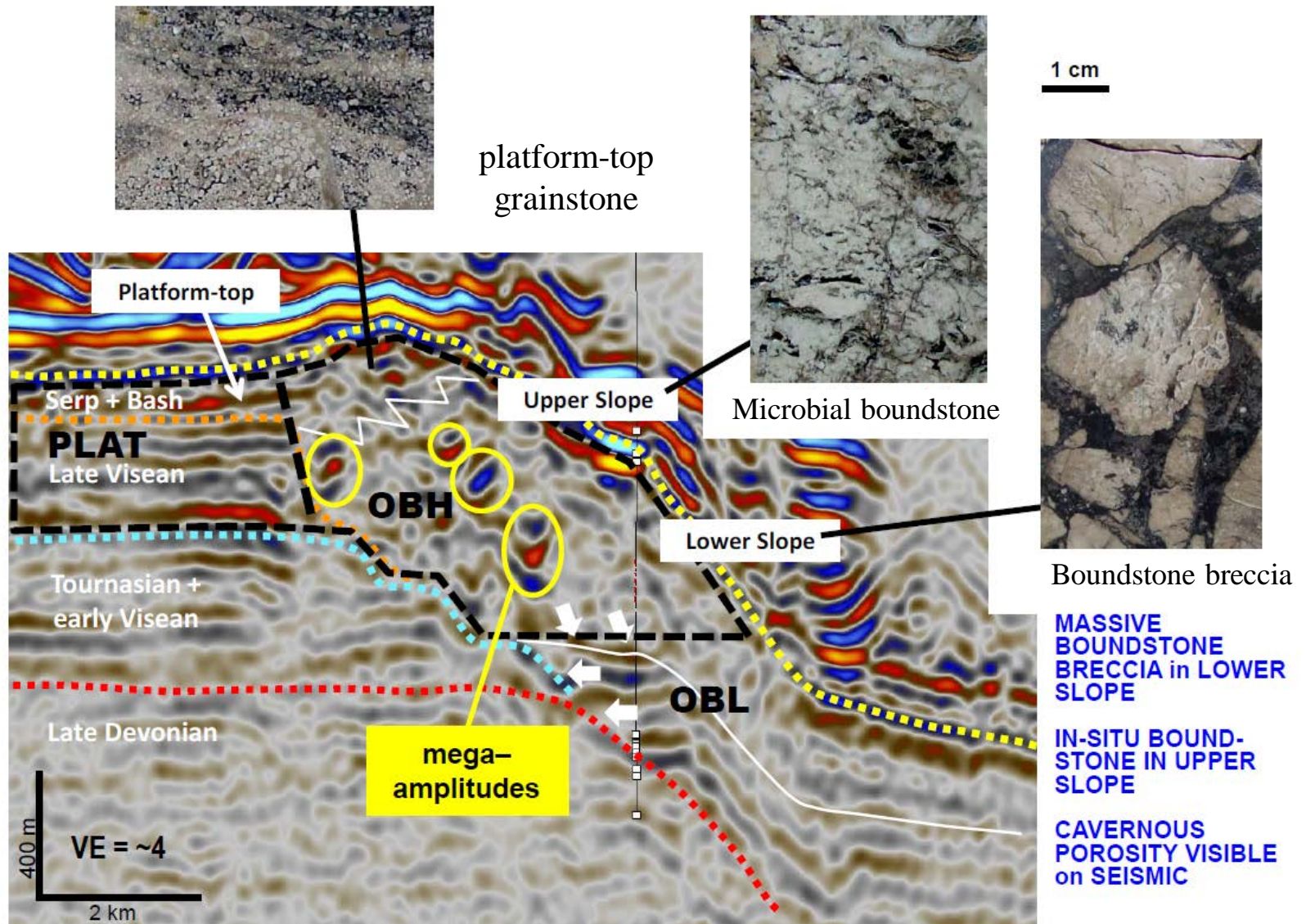
Tengiz Field seismic profile: Carboniferous reservoir (Visean) sealed by Kungurian salt



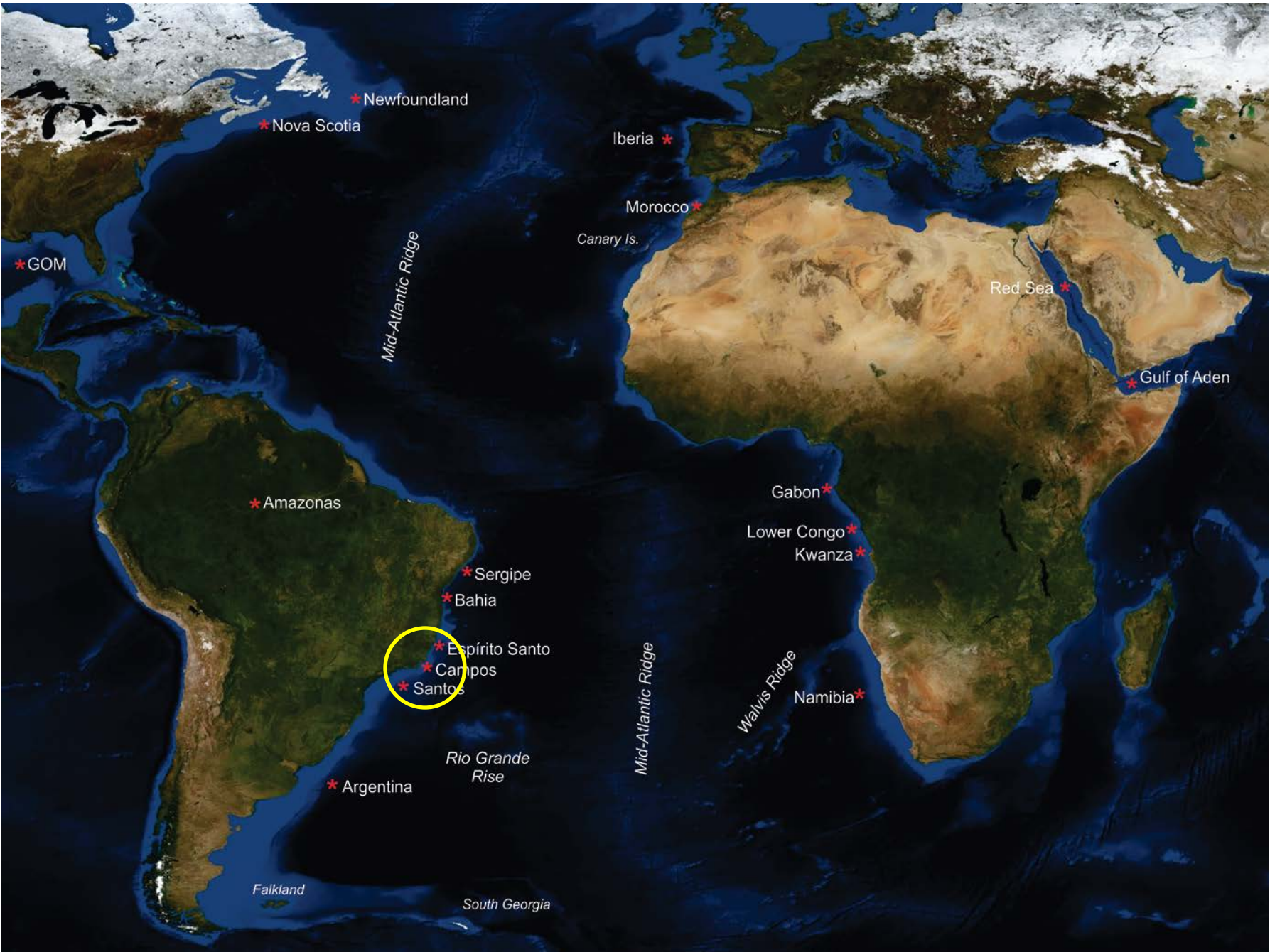
PSDM seismic



Tengiz Field seismic data and rock facies



Sedimentary basins in the Atlantic Ocean – divergent margins



Schematic (but insightful) geological section of the Campos Basin syn-rift, salt, post-salt and main petroleum systems

rafts and turtles

pillows and diapirs

massive salt

SHALLOW WATER

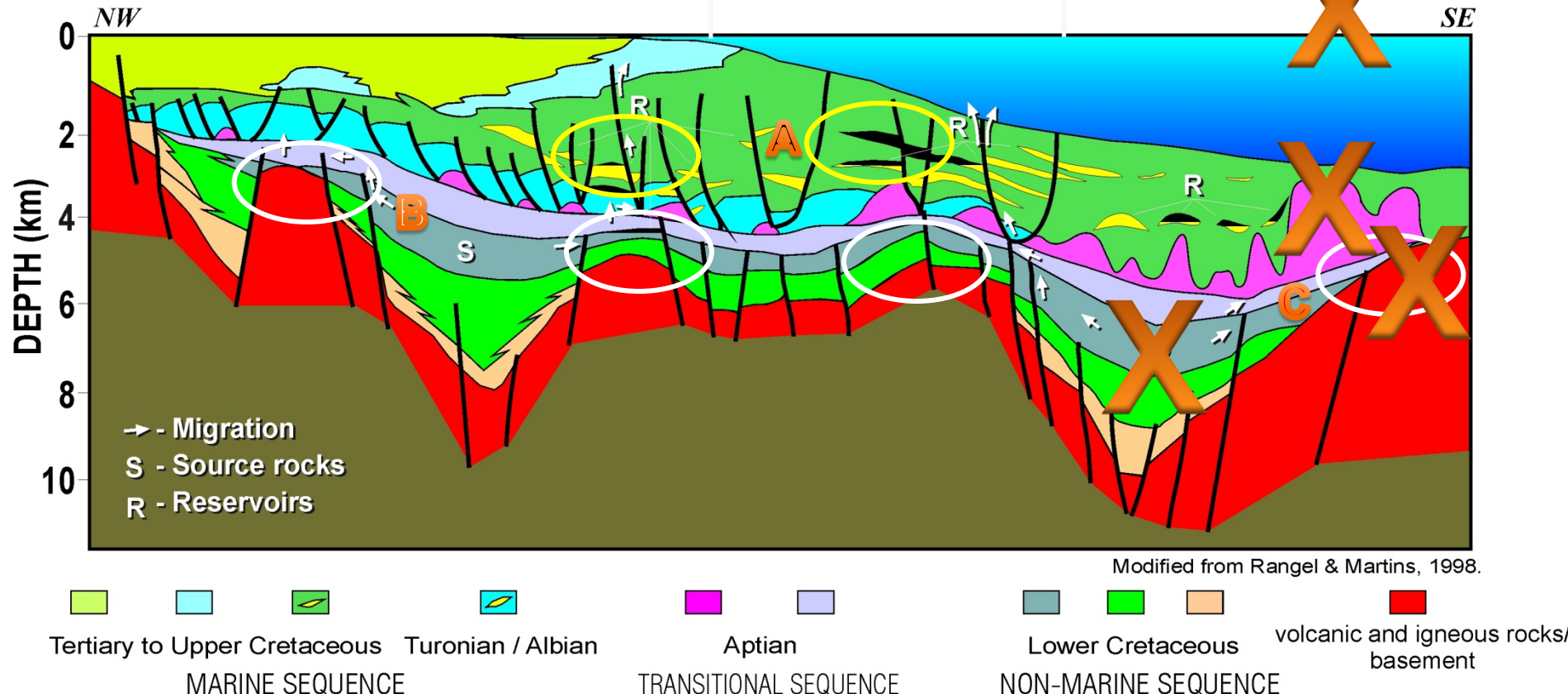
Total Reserves: 1.16 Bboe

DEEP WATER

Total Reserves: 12,0 Bboe

ULTRA-DEEP WATER

Total Reserves: 1,0 Bboe



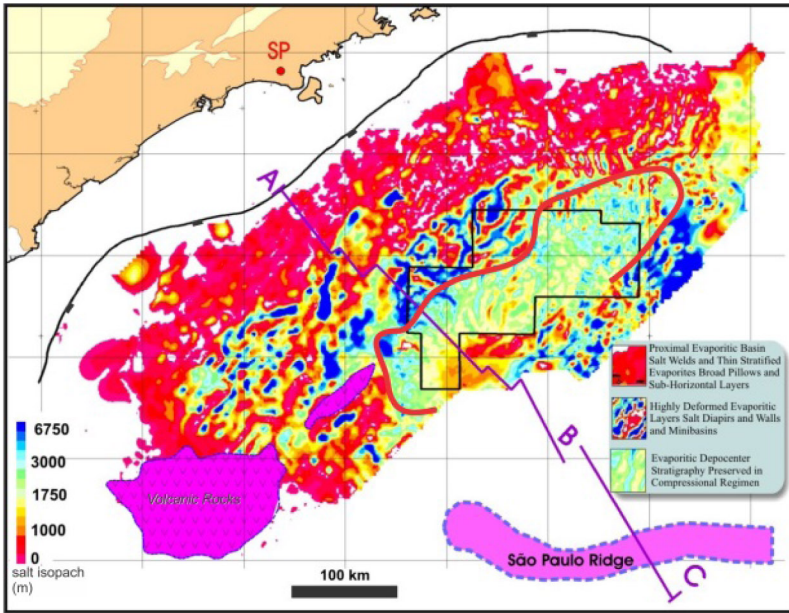
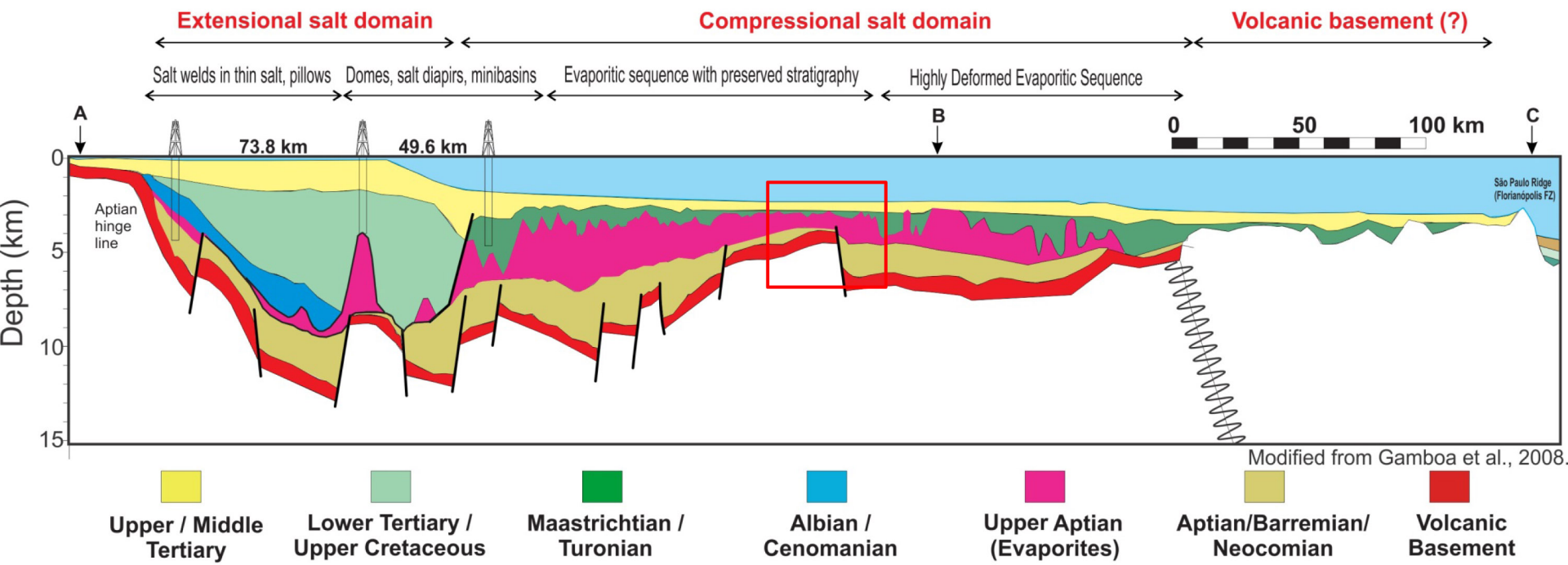
A: post-salt carbonate and turbidite reservoirs

B: pre-salt source rocks - reservoirs

C: Deep-water exploration: new plays in the distal margin ?

X
Change in paradigms

Schematic cross section in the Santos Basin

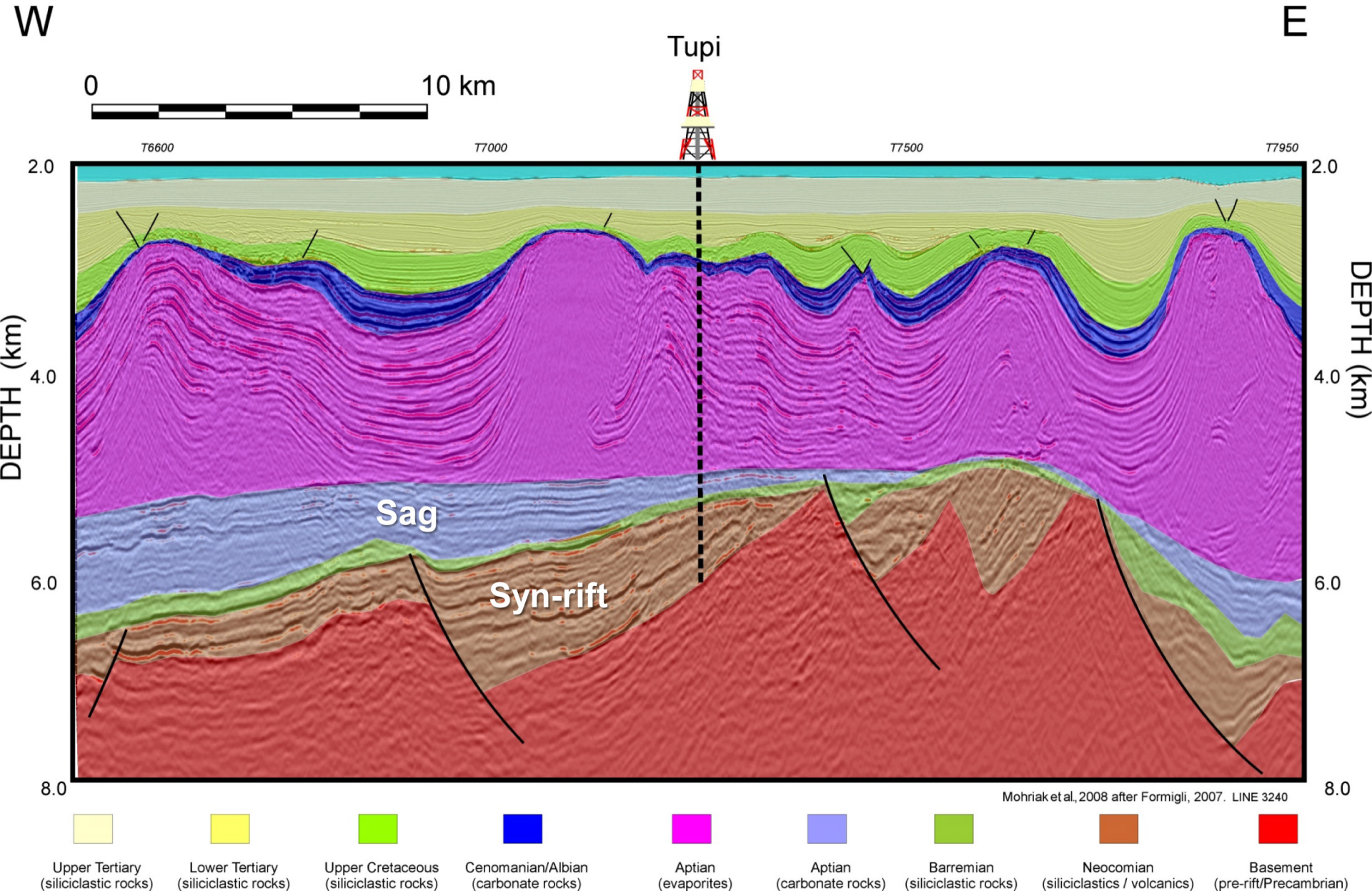


- Proximal evaporitic basin with broad pillows and diapirs, salt welds
- Highly deformed evaporitic basin with diapirs, salt walls, minibasins
- Highly deformed stratified evaporites and salt tongues

Seismic section showing the Santos Basin pre-salt carbonate reservoir: microbialites below the massive stratified evaporites. This is the largest oil field in the western world discovered in the last decade.

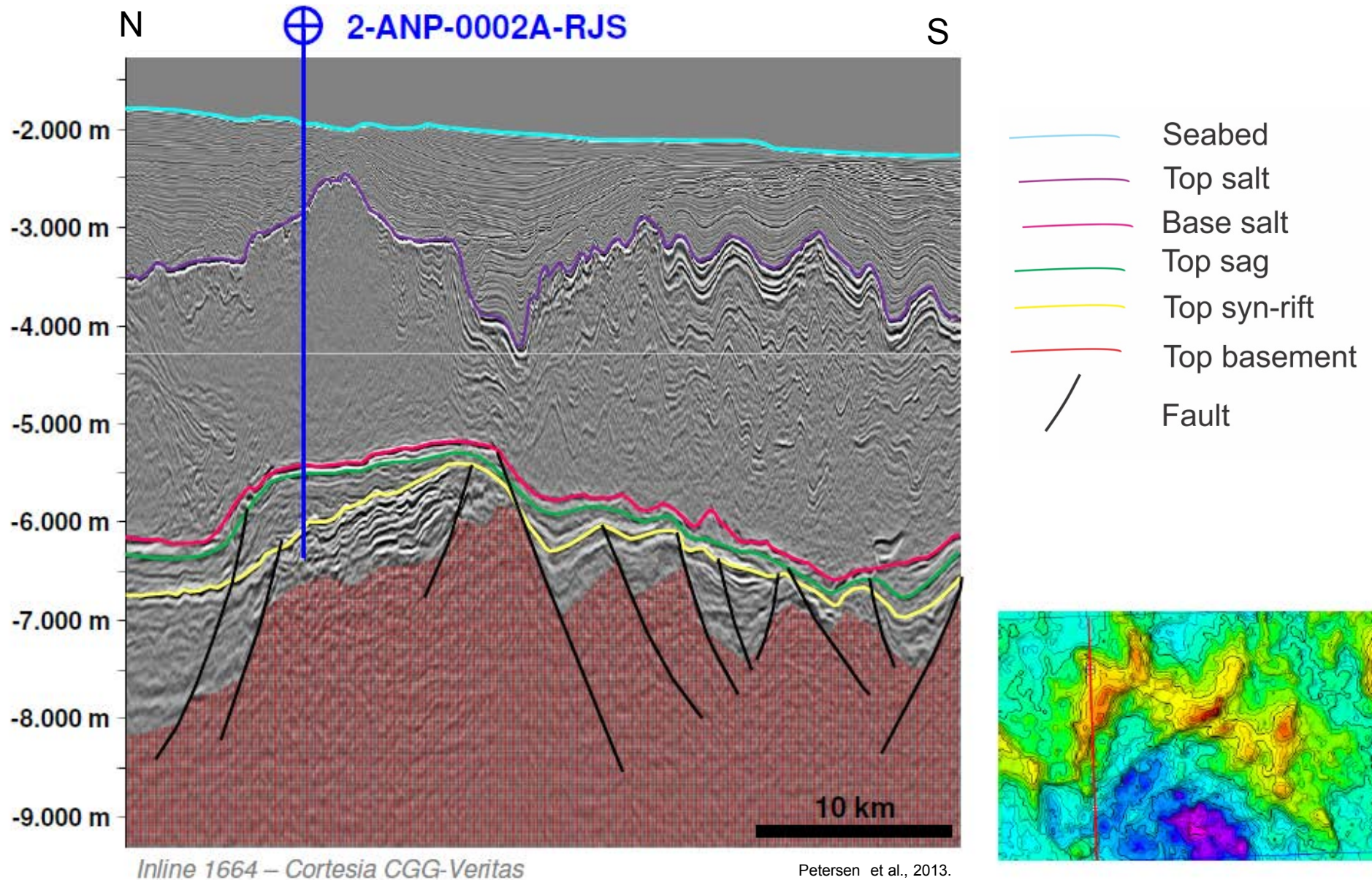
Lula Field (1-RJS-628A, Tupi prospect) seismic with well tie for pre-salt carbonates in the sag basin.

Microbialite lithologies from cores.

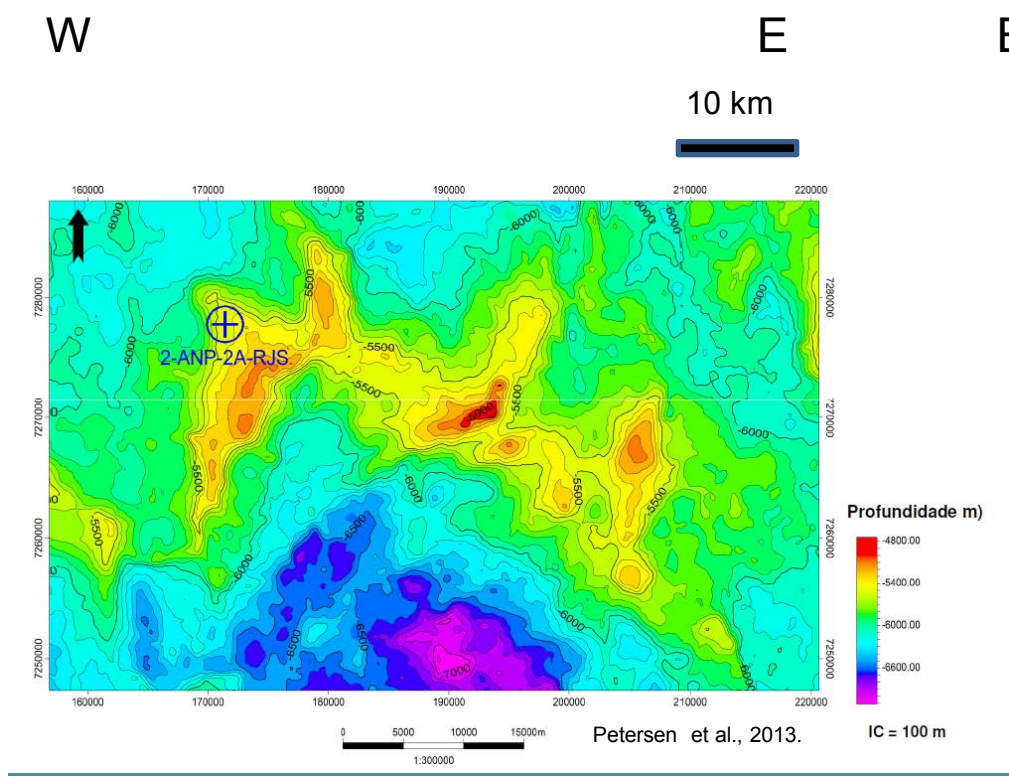


Pre-salt carbonates in Libra Field, Santos Basin

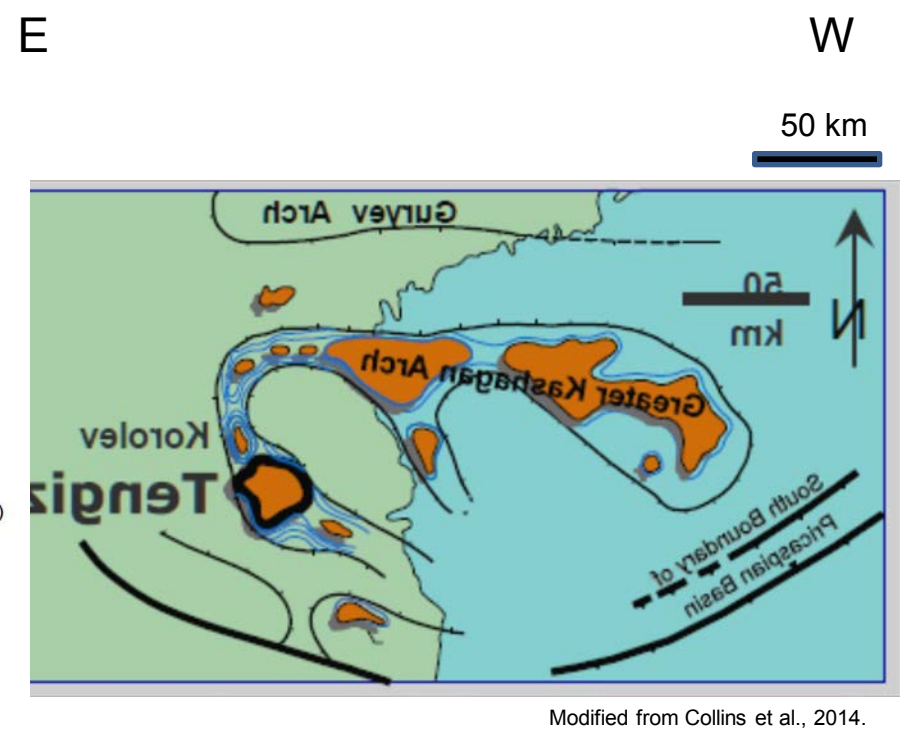
The pre-salt carbonate reservoirs may produce > 20,000 bbl/d (one well)



Libra field (2-ANP-2-RJS) and Tengiz field seismic comparison
arcuate topographic highs (carbonate buildups).

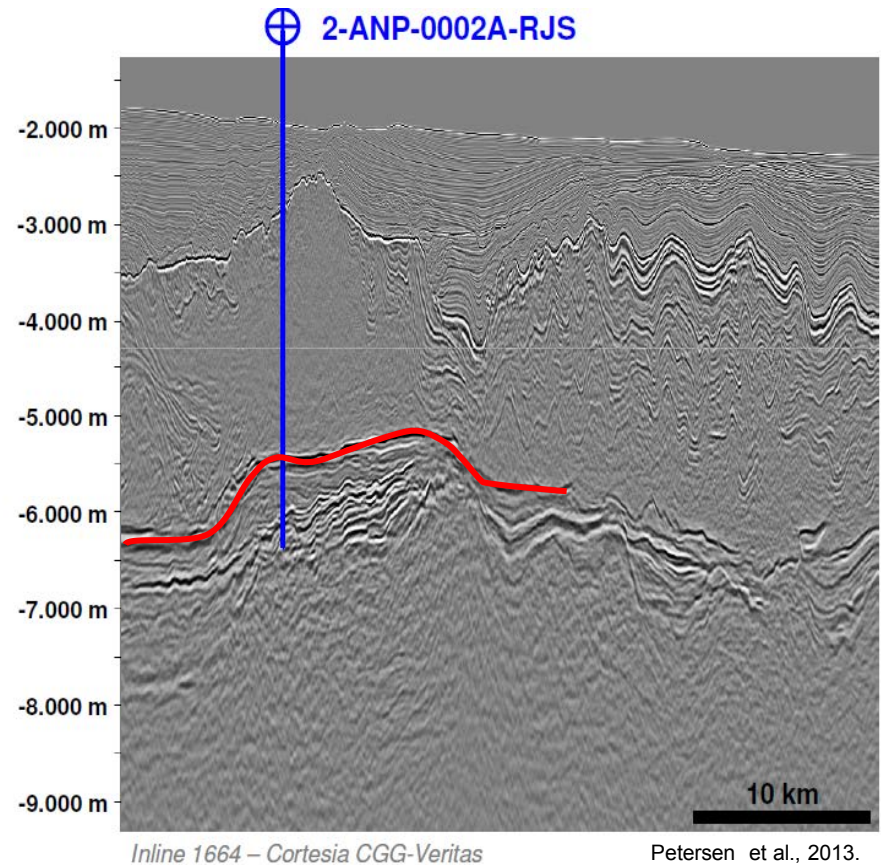


**Libra field
Santos Basin**

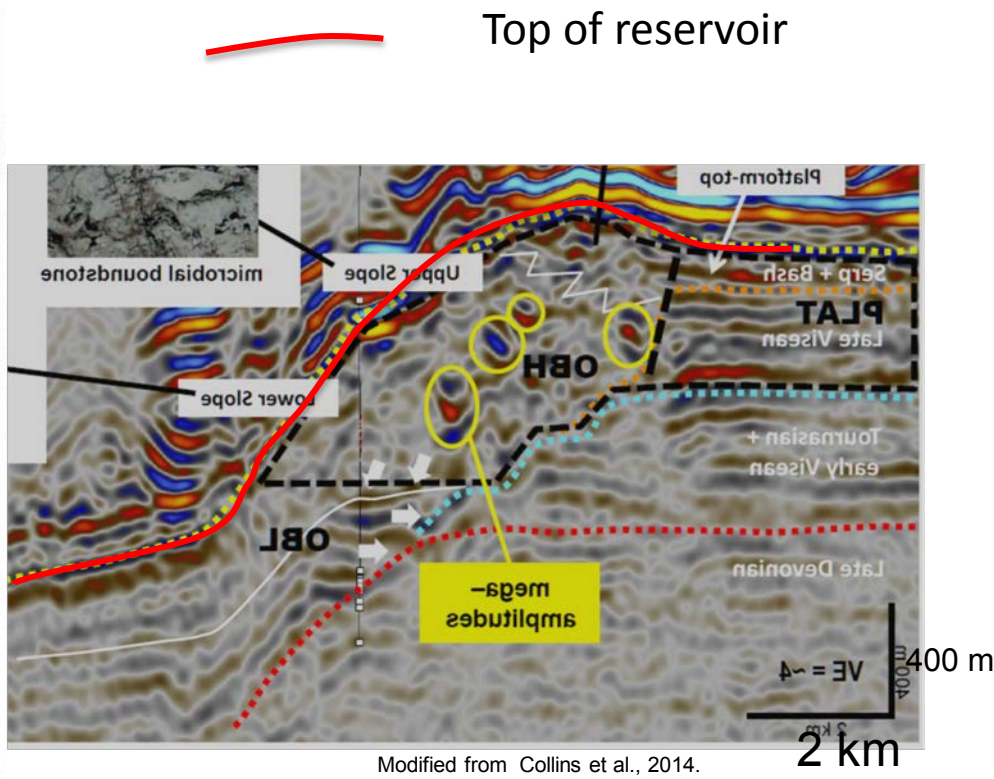


**Kashagan complex,
North Caspian Basin**

Libra field (2-ANP-2-RJS) and Tengiz field seismic comparison.

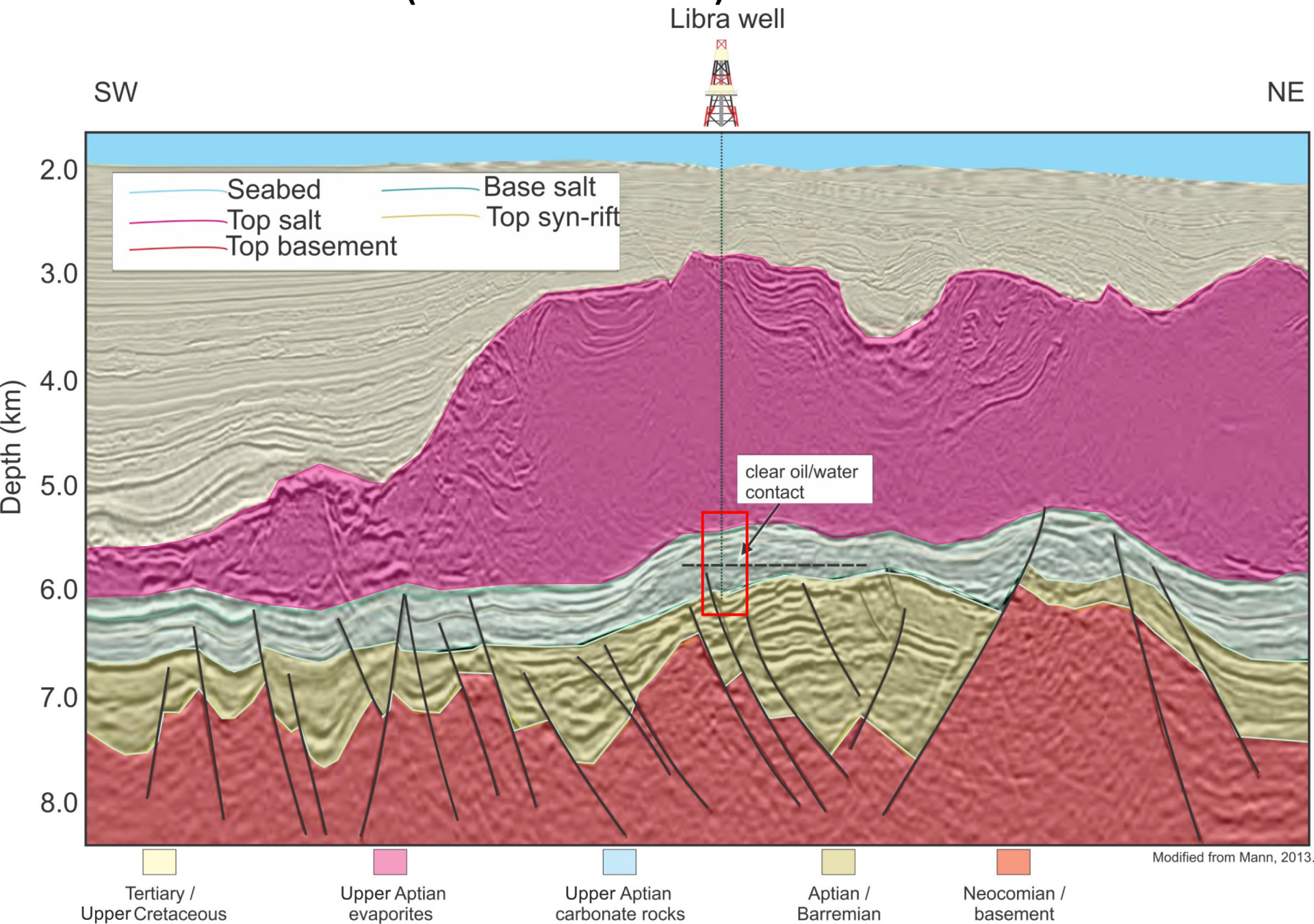


**Libra field
Santos Basin**

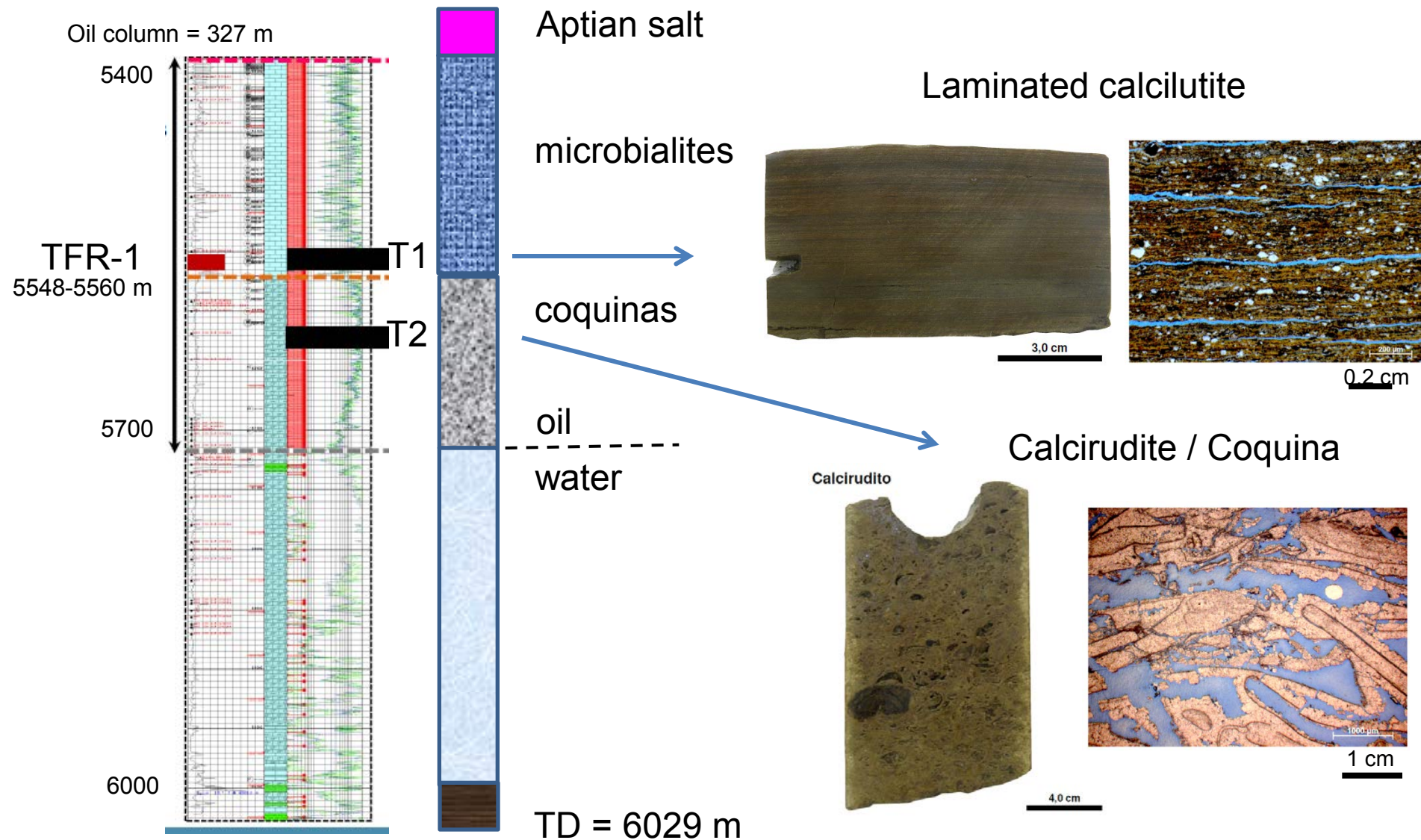


**Tengiz field – Kashagan complex,
North Caspian Basin**

Libra well (2-ANP-2A-RJS) in the Santos Basin



Libra Field (2-ANP-0002A-RJS) well log with lithologies from cores T1 (5548-5566 m) : coarse-grained and fine-grained carbonate rocks T2 (5613-5631 m) : coarse-grained carbonate rocks (coquinas)



Pre-salt microbialites – origin of these rocks?

Microbialites have formed in the geological history from Neoproterozoic to Recent.

They are recognized in diverse basin types formed in different tectonic regimes.

**Reefs and carbonate buildups (stromatolites)
(formed during periods of sea-level rises in a desiccating basin)**

**Chemical abiotic precipitation of carbonates
(in basins affected by volcanic or hydrothermal episodes -
travertine deposits with secondary biogenic growth)**

**Detrital carbonate rocks
(related to reworking of shells and chemical precipitates)**

Pre-salt microbialites – Outcrop Analogs

LAGOA SALGADA, RIO DE JANEIRO: QUATERNARY STROMATOLITES

TRAVERTINES (YELLOWSTONE AND ITALY): HYDROTHERMAL ORIGIN

**TUFAS (BONITO, MS) – REWORKED CARBONATES, SIMILAR TO LIBRA FIELD
CALCARENITES**

Pre-salt carbonates and their Recent analogs (Petrobras)

Stromatolites from Lagoa Salgada, east of Campos, RJ

**Recente no
Brasil - Lagoa
Salgada, litoral
de Campos**

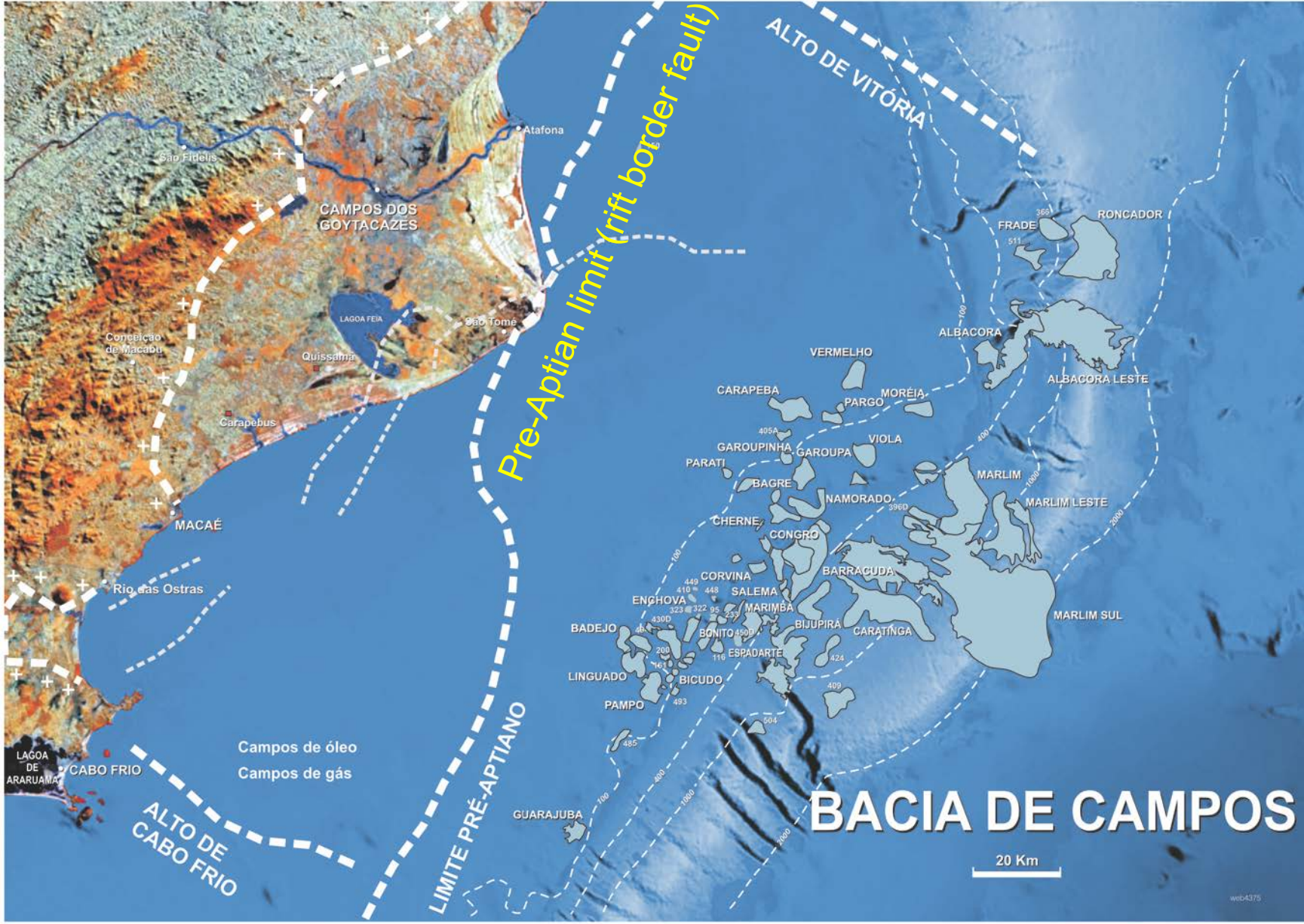
1cm ↑↓

**Testemunho
do Pré-Sal**



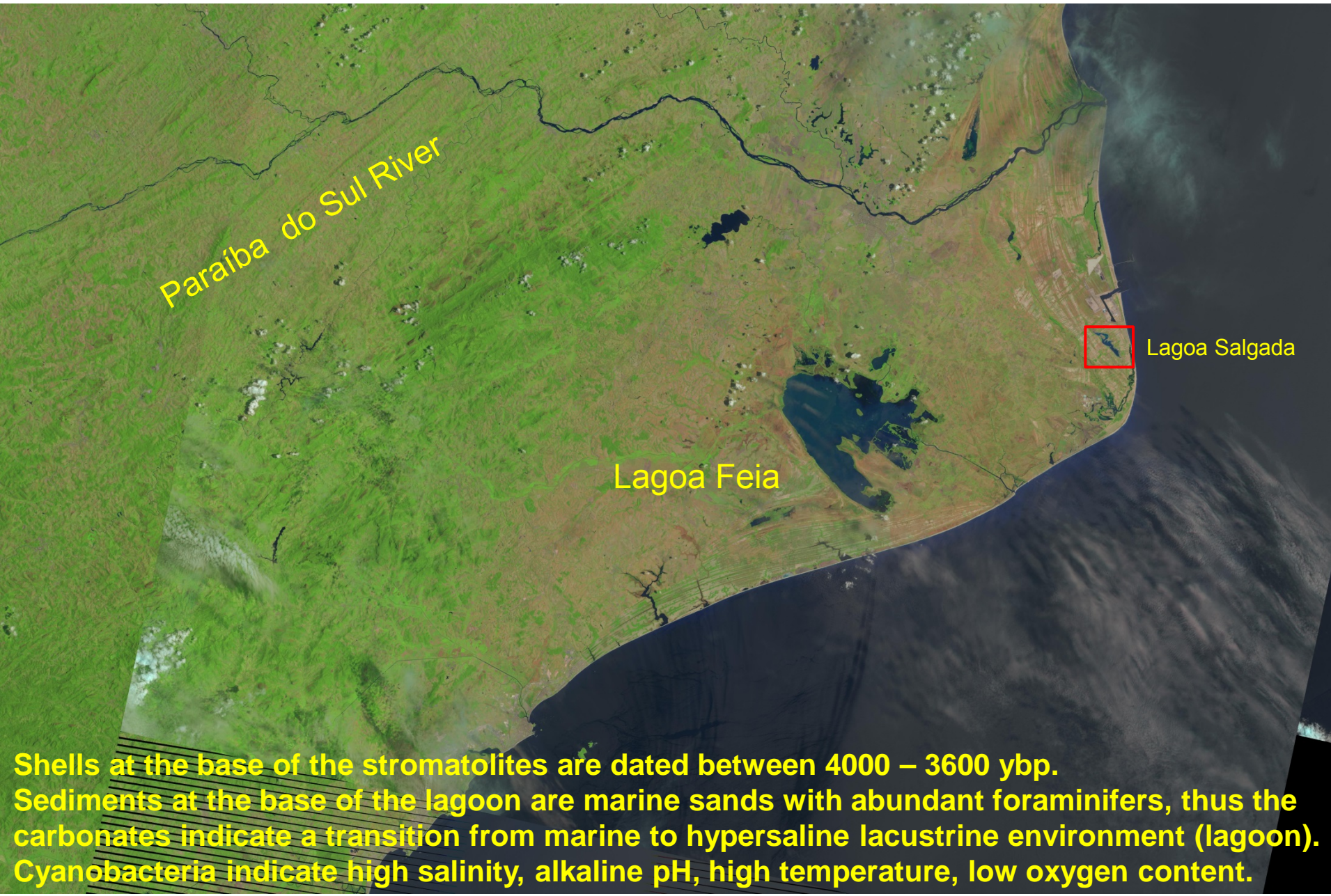
Pre-salt microbialites – Outcrop Analogs

Campos Basin oil fields and onshore features: Paraíba do Sul Delta, Lagoa Feia



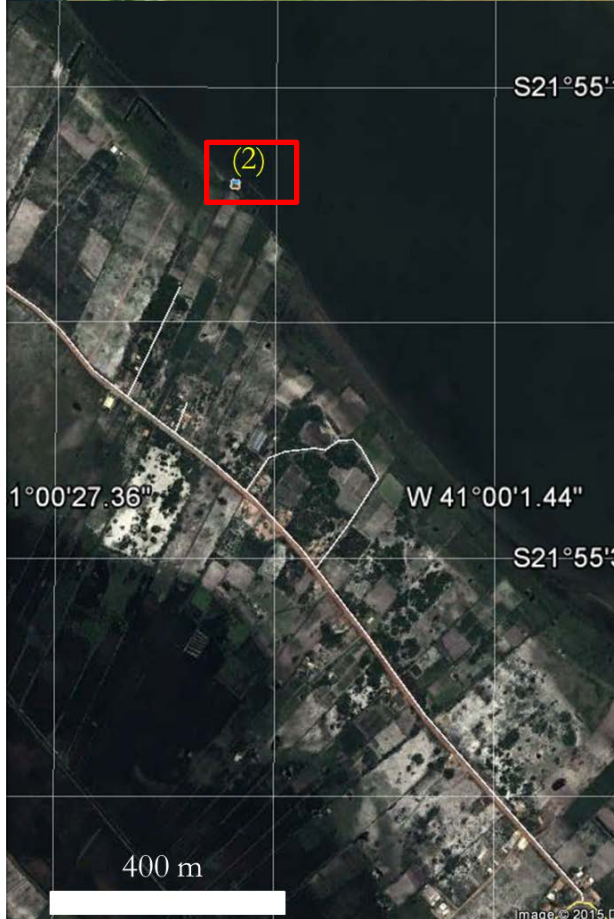
Modified from Mohriak et al., 2008.

Small salt lagoon in the Paraíba do Sul delta (8.5 km by 2 km; about 16 km²) - possibly the only place in South America where columnar, domal and stratiform carbonate stromatolites, thrombolites and oncolites are registered in the Holocene.



Shells at the base of the stromatolites are dated between 4000 – 3600 ybp. Sediments at the base of the lagoon are marine sands with abundant foraminifers, thus the carbonates indicate a transition from marine to hypersaline lacustrine environment (lagoon). Cyanobacteria indicate high salinity, alkaline pH, high temperature, low oxygen content.

Lagoa Feia - Lagoa Salgada



Lagoa Salgada stromatolites – outcrop analogs for the pre-salt microbialites ?



Lagoa Salgada stromatolites – outcrop sample and plugs for petrography and microtomography



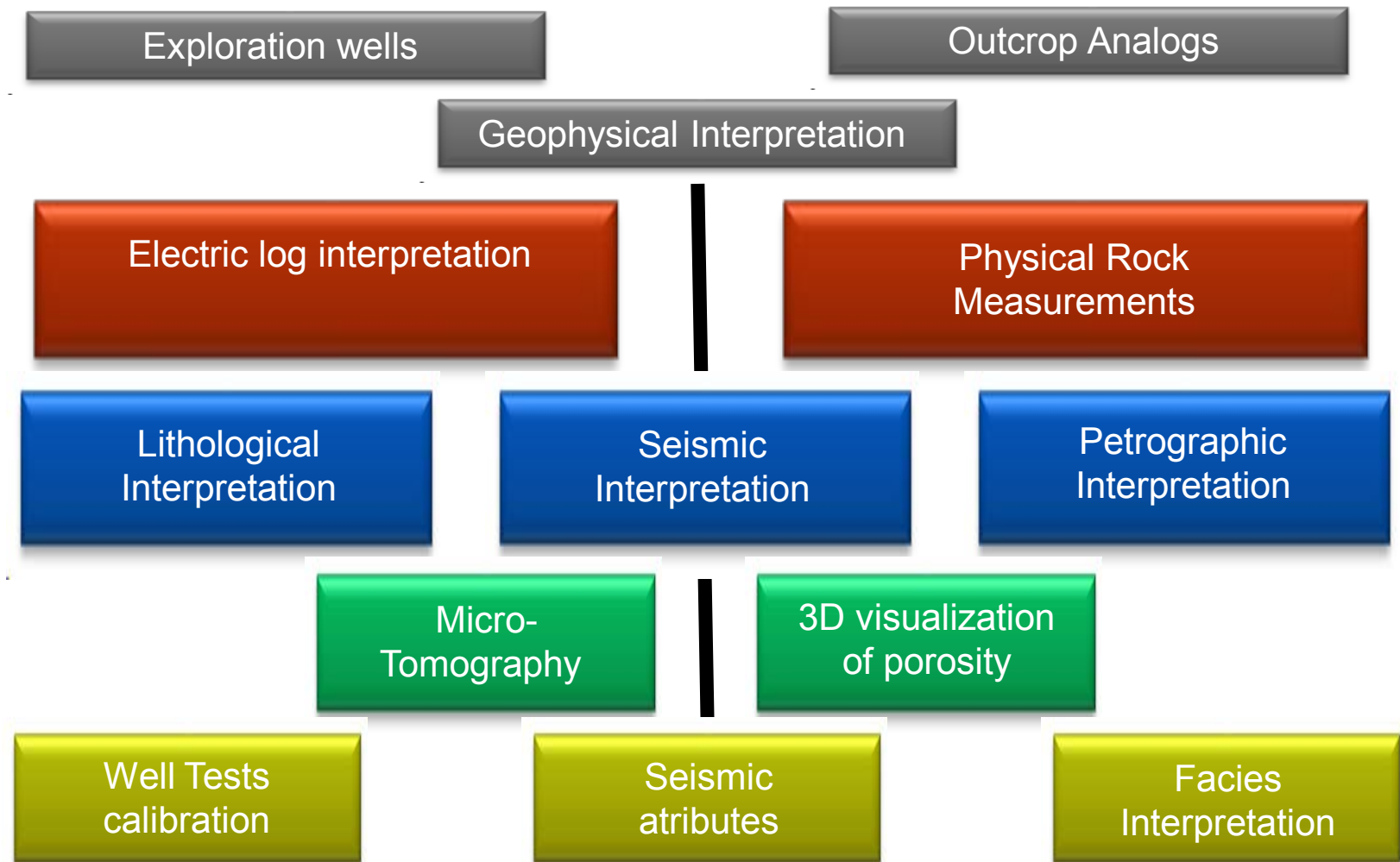
Pre-salt outcrop analog: Travertino (Tivoly, Italy)
slab and plug



Pre-salt outcrop analog : carbonate Tufa (Bonito, Brazil)
outcrop sample and plug



LABORATORY AND DIGITAL ROCK ANALYSIS WORKFLOW



Facies and Porosity / Permeability Distribution
Petrophysics parameters - Reservoir Analysis

Optimizing Exploration and Production Development

CHALLENGES

Geological challenges of pre-salt reservoir characterization

Technological challenges for developing tools for petrophysical analysis

Workflow for reservoir characterization: conventional laboratory analyses and numerical modeling

Accuracy of petrophysical parameters for reservoir and production simulations

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