The Influence of Base-Salt Relief, Rift Topography and Regional Events on Salt Tectonics Offshore Morocco

Leonardo Muniz Pichel[1,2], Mads Huuse[1,2], Jonathan Redfern[1,2], Emma Finch[1]

1. Basin Studies and Petroleum Geoscience, School of Earth and Environmental Sciences, **University of Manchester**, UK

2. North Africa Research Group, School of Earth and Environmental Sciences, **University of Manchester**, UK

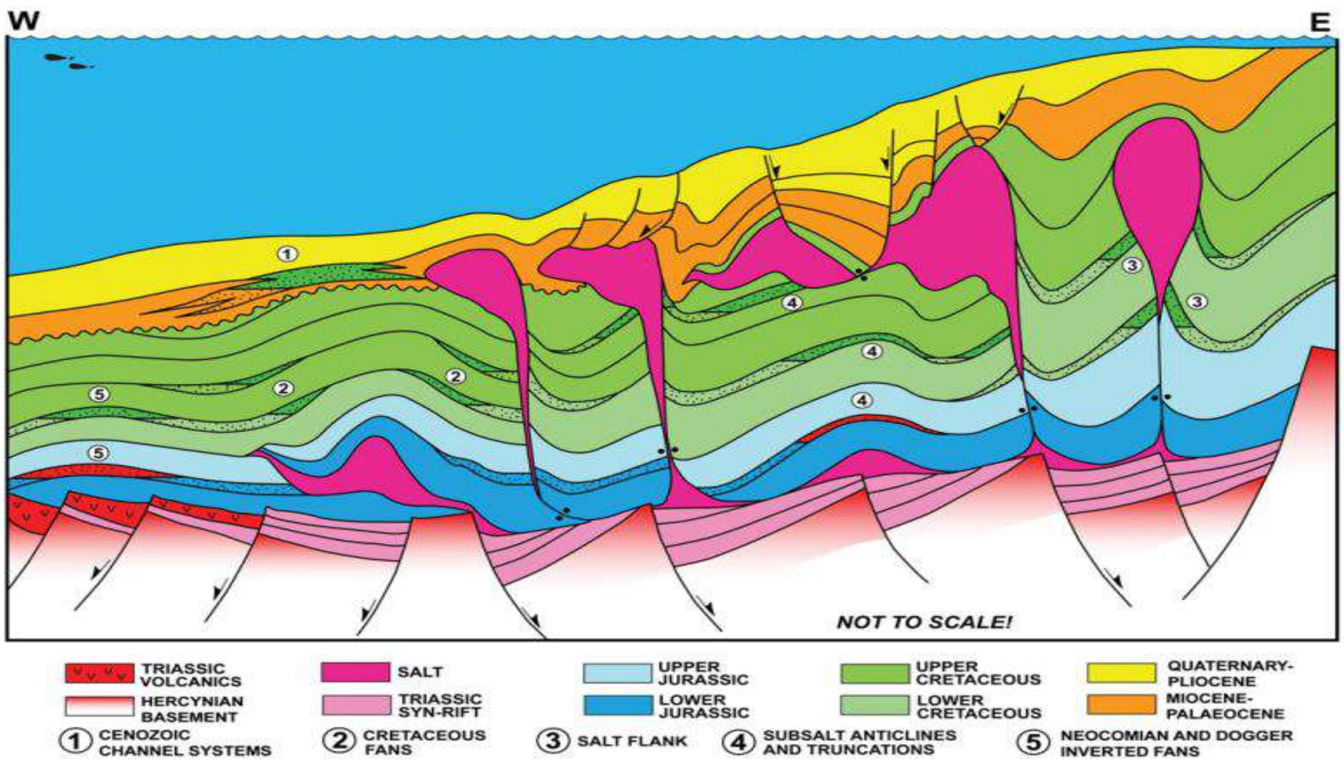
MANCHESTER 1824
The University of Manchester

North Africa Research Group
www.narg.org.uk

Basin studies

MOTIVATION

- Most of the hydrocarbon plays on Morocco are salt-related (Tari & Jabour, 2013)
- Crucial to exploration to better understand the interplay of salt tectonics, sedimentation, timing and evolution of salt structures to assess their controls on petroleum systems key elements (e.g. traps, migration pathways, reservoirs)
- Large variety of structural styles along the margin which makes it one of the most interesting places in the world for the study of salt tectonics.



Tari & Jabbour (2013)

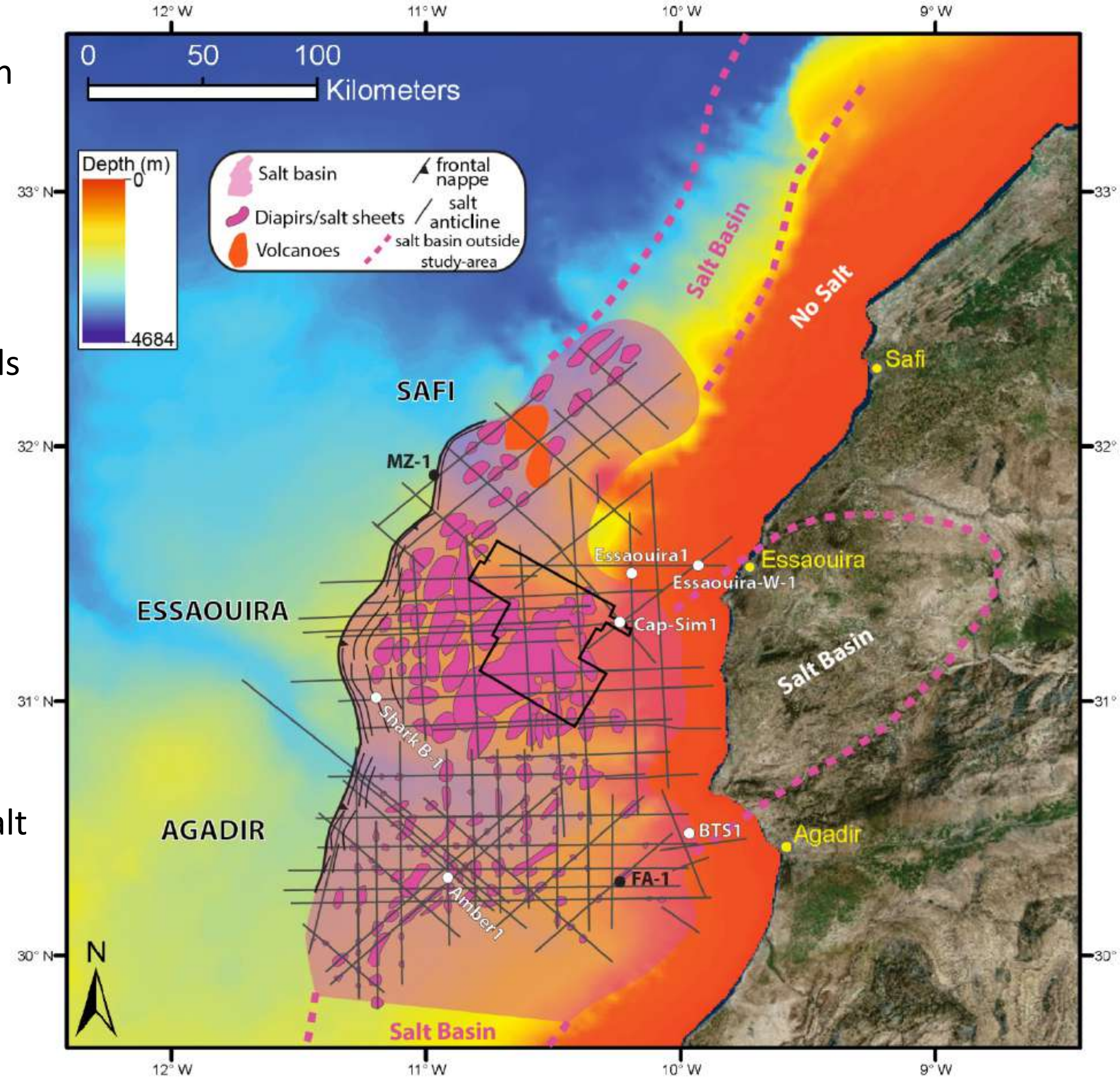
Basin studies

STUDY AREA CHALLENGES

- 3 segments based on structural styles
- Limited 3D control, sub-salt resolution and deep-water wells
- Large volume of allochthonous salt

BUT:

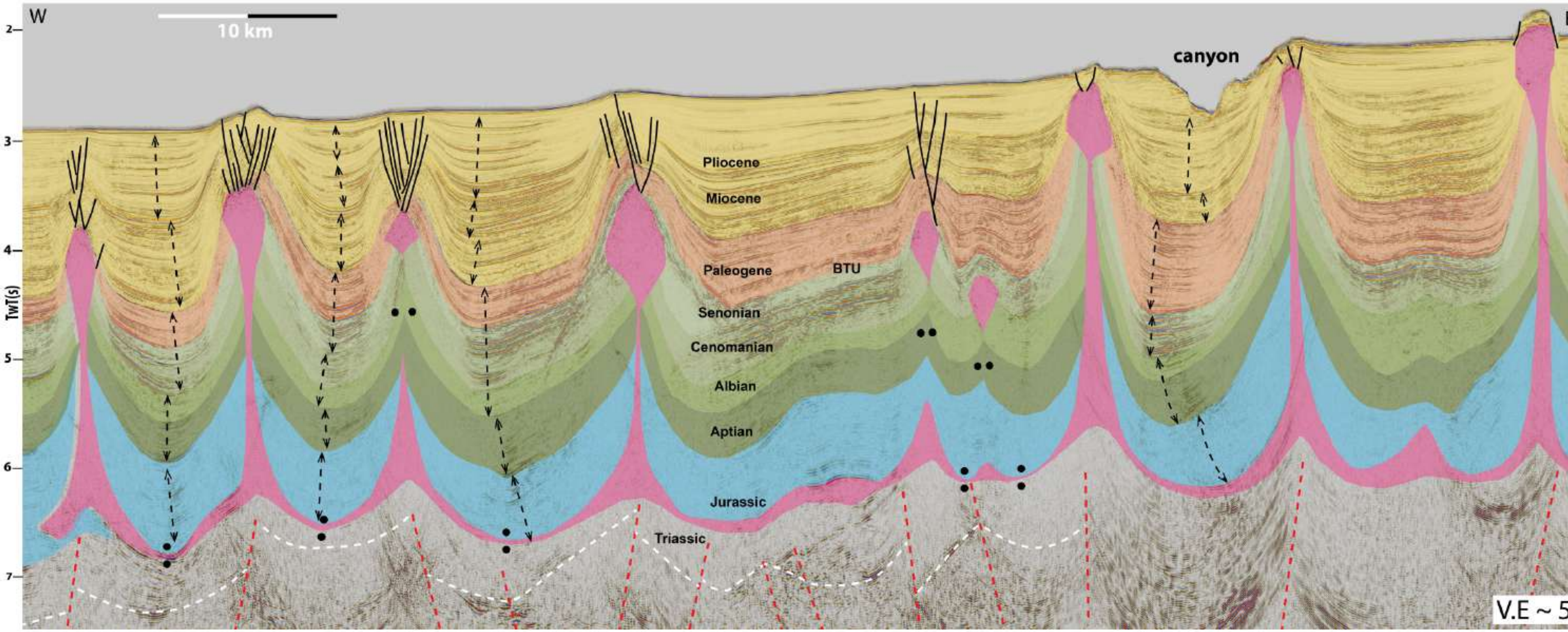
- Novel concepts of salt tectonics
- New modelling methodologies

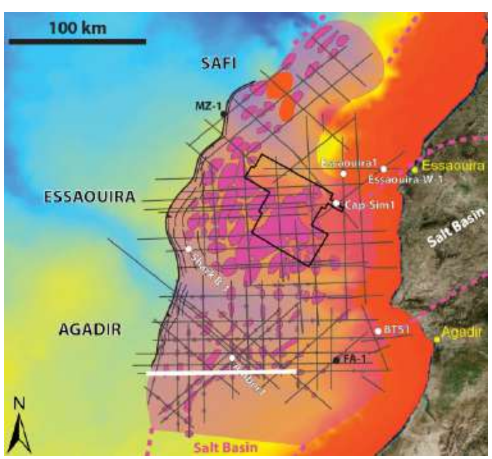


Pichel et al 2019b *(in press)*

Basin studies

AGADIR BASIN





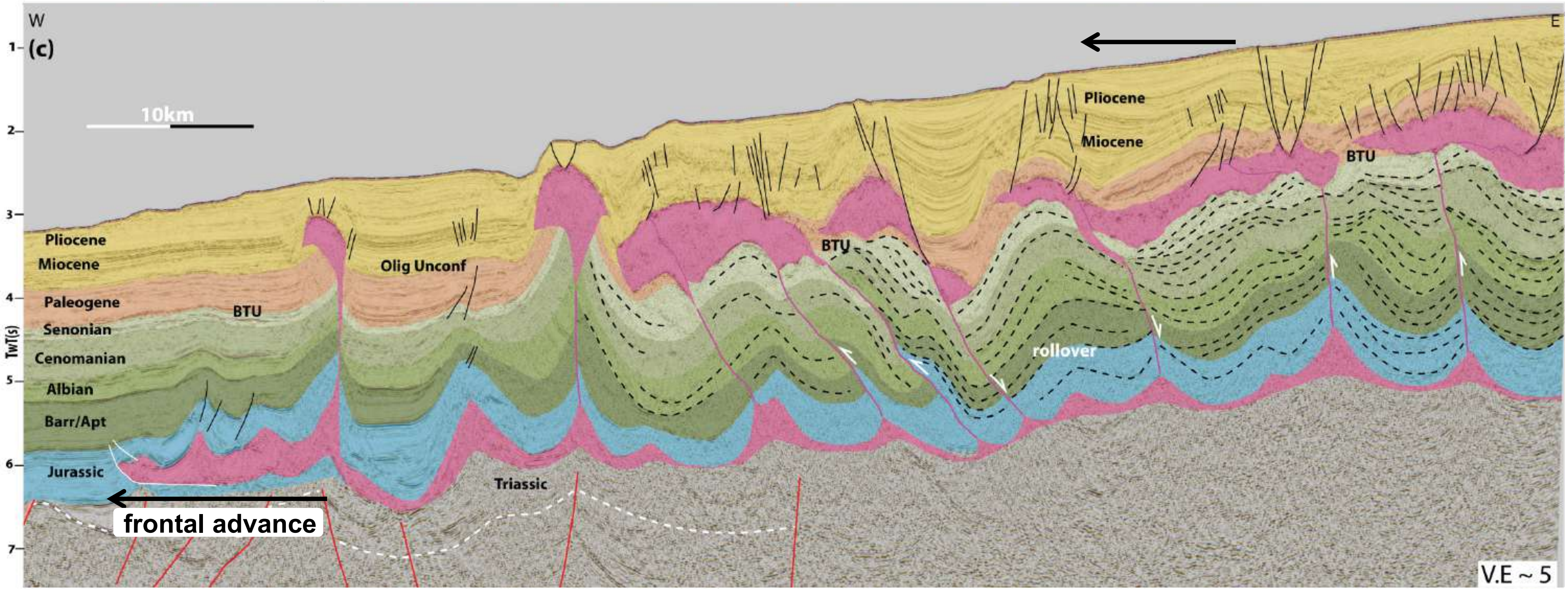
Squeezed and tea-drop diapirs (symmetric and up-right structures)

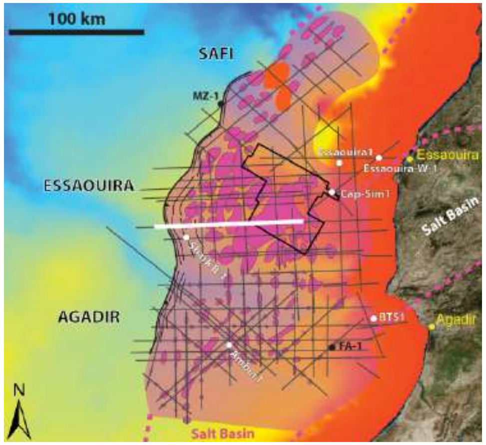
Intense folding and thicknesses variations across minibasins

Early **LOAD-DRIVEN SUBSIDENCE** + late **DIAPIR SHORTENING** – abrupt depocentre shift, uplift of thick diapir's roof and crestal faults

Little (< 5 km) to no downdip translation: lack of a distal salt nappe and dominance of upright structures

TALFENEY PLATEAU





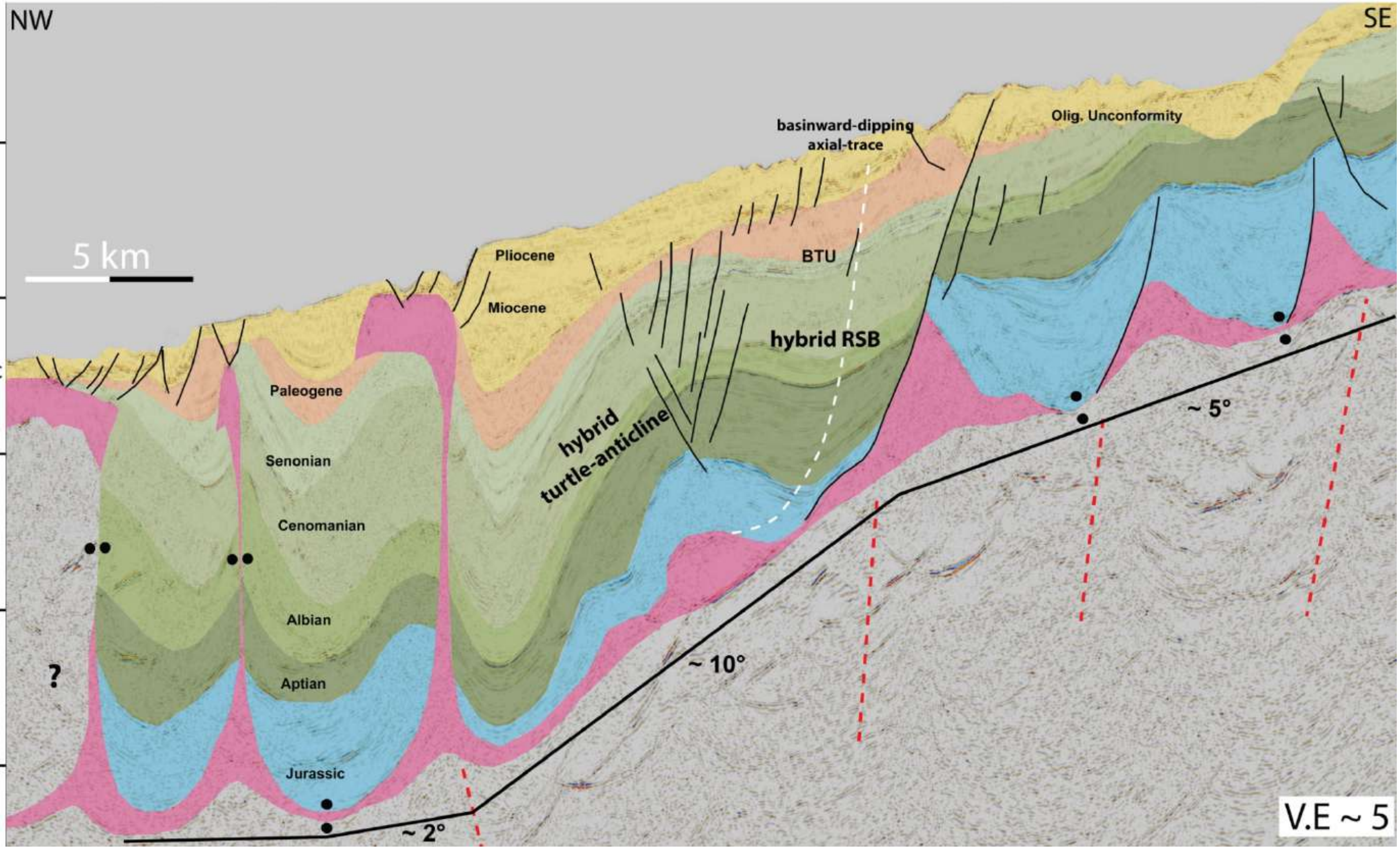
Seaward-leaning salt tongues and sheets coalesced to form canopies

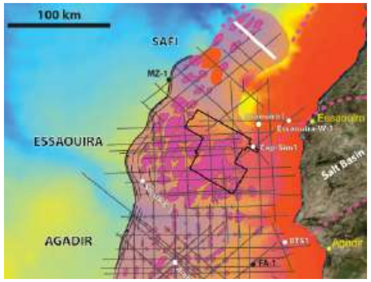
Precursor salt walls/stocks with different origins:
Contraction x Expulsion

Complex distribution of contractional/extensional domains

Ramp-Syncline Basins (RSB) above canopy: 8-10 km of translation
Nappe & fold-belt (Jurassic-Cenomanian): 12-15 km translation

SAFI HAUTE MER





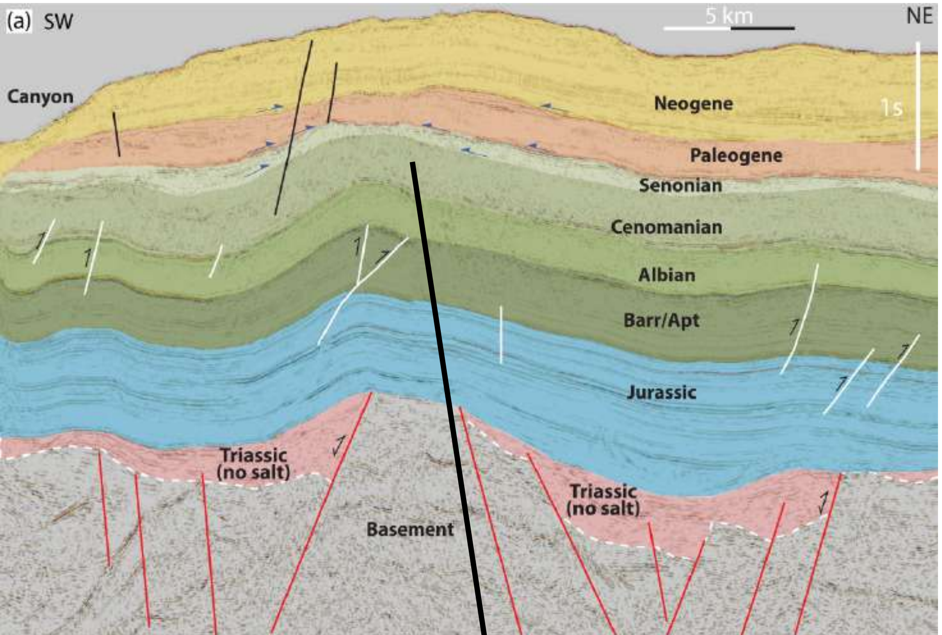
Salt rollers and rafts (shelf-upper-slope) - **EXTENSIONAL**

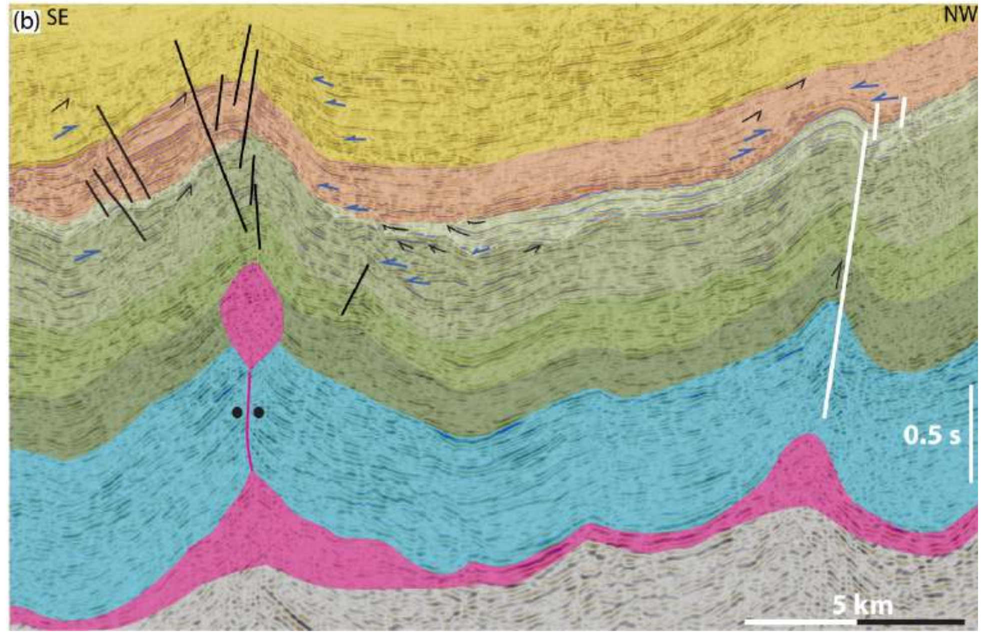
Hybrid RSB and turtle anticline (middle slope) - **TRANSLATIONAL**

Salt tongues with sub-vertical welds (lower-slope) - **CONTRACTION**

Steep **base-salt** detachment – favoured gliding & updip extension

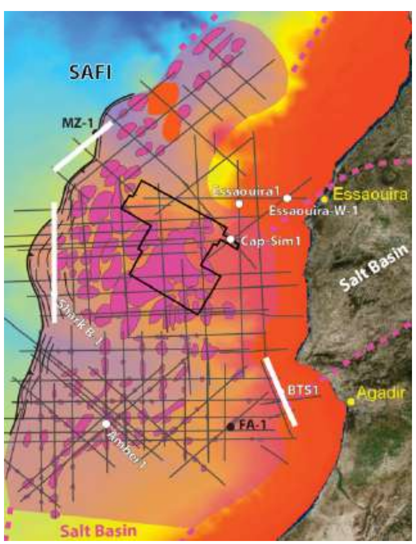
Evidences of Thin-Skinned Shortening

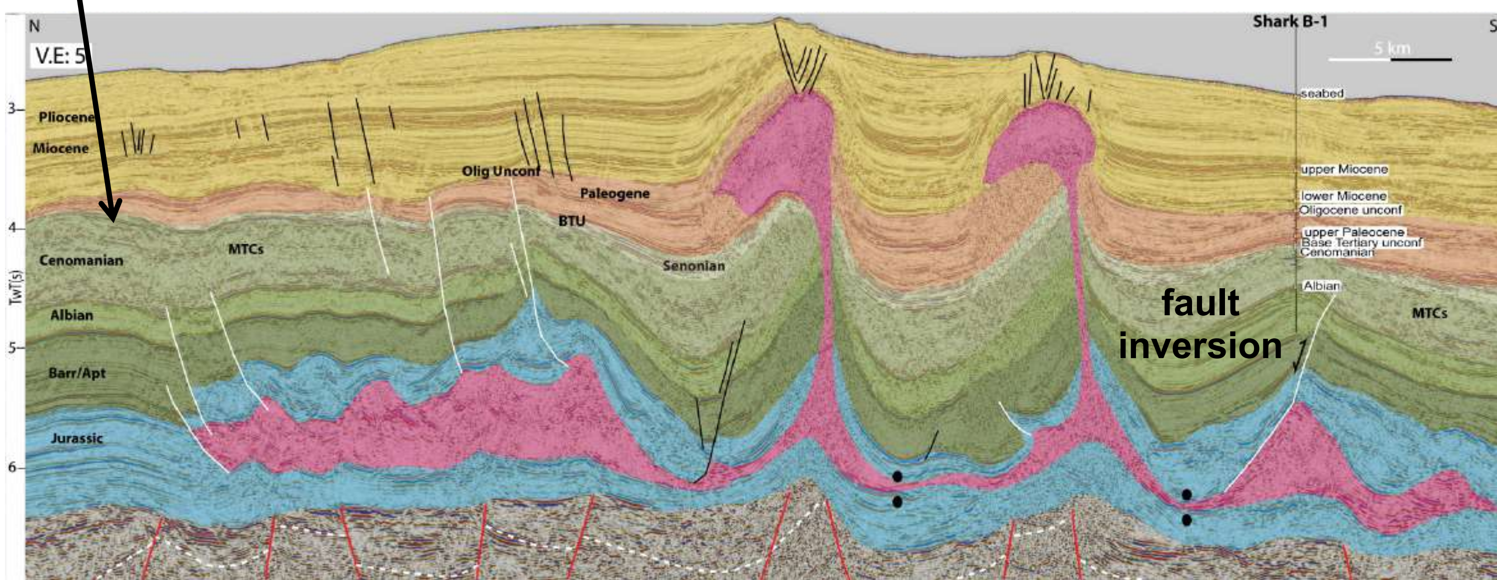




NW-trending anticlines involving inversion of syn-rift normal faults (Senonian – recent)

Contractional structures on the shelf (NE box-fold and squeezed diapir)

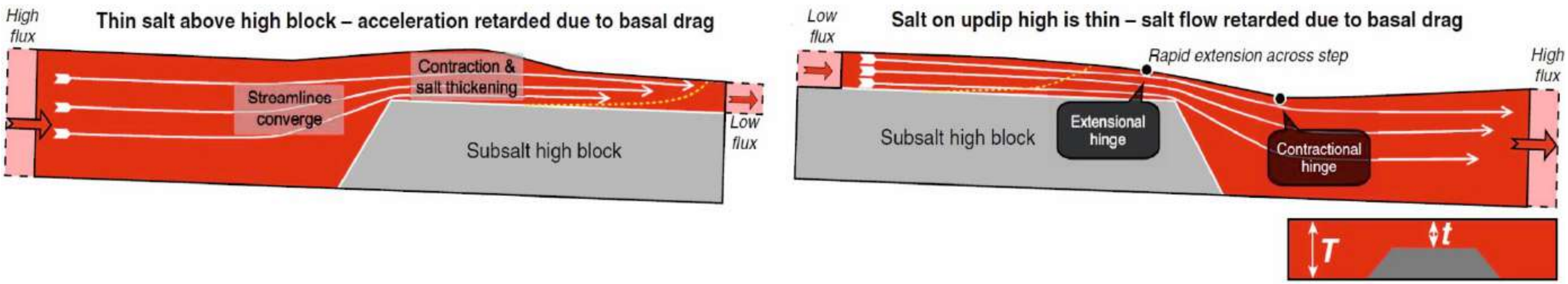




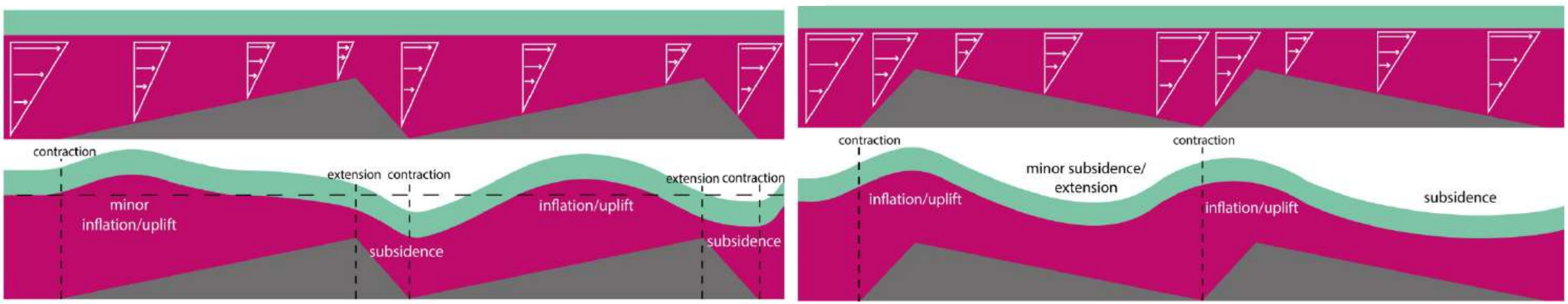
Effects of Base-salt Relief

Produce higher structural complexity than classic models of updip extension-downdip contraction

Alternation of extension (expulsion)- and shortening-drive structures downdip and along-strike



Explained by variations in the initial thickness of salt and base-salt relief, which generate salt flux mismatches, velocity and stress gradients (Dooley et al. 2016; 2018)



Pichel et al., 2019a (*in press)*

These processes can be even stronger in case of syn-rift salt (e.g. tilted fault-blocks) due to variably-dipping base-salt ramps and more complex variations in salt thickness

Effects of Base-salt Relief (Ramp-Syncline Basins)

Ramp Syncline Basins (RSBs):
Form by downdip translation of cover and salt (i.e. gliding) above base-salt ramps

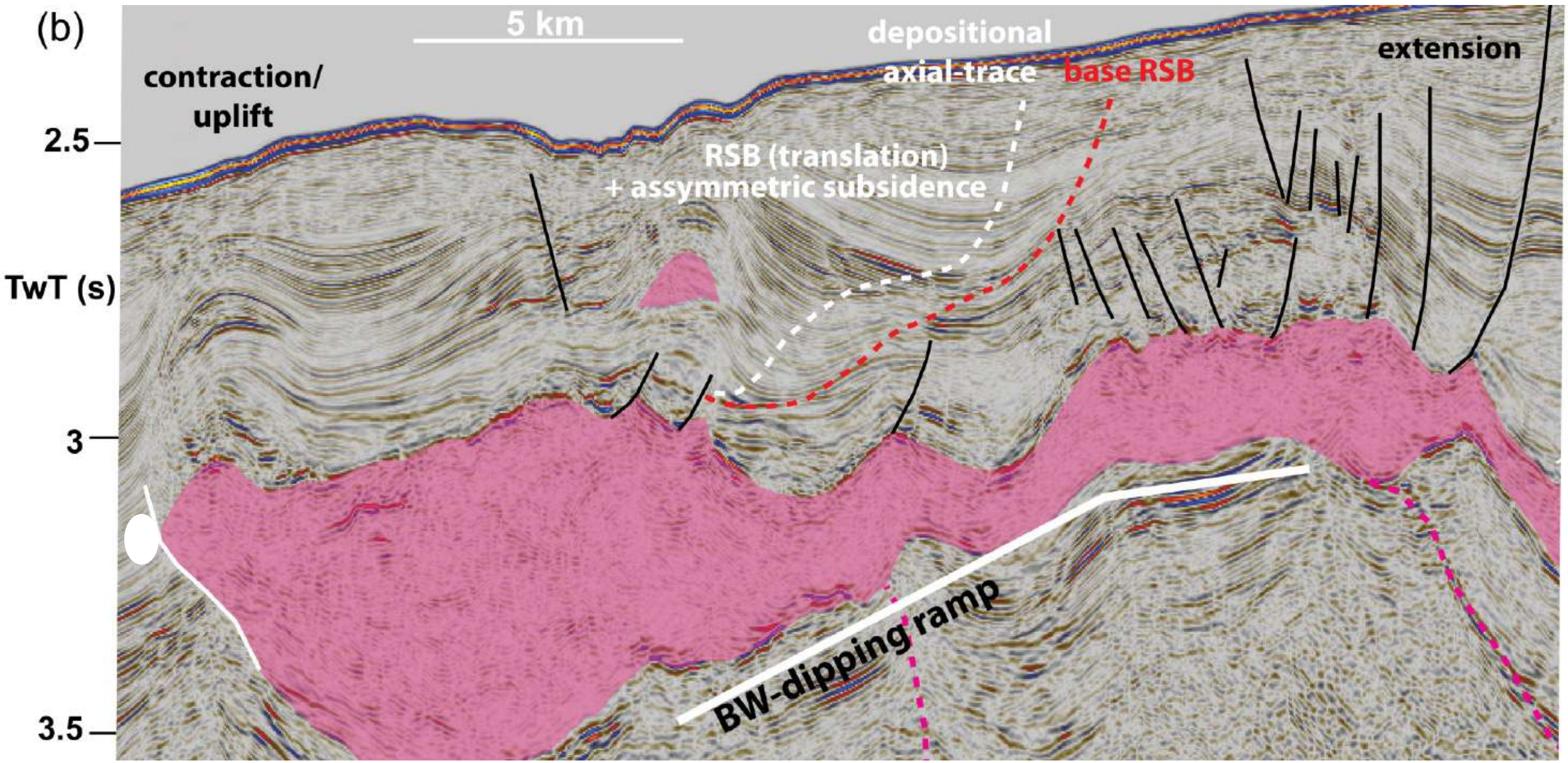
Provide a confident record of the translation history along salt basins
(e.g. magnitude, rates and direction)

Guide identification of pre-salt structures in areas of limited sub-salt resolution

Landward-dipping and thickening growth strata (basinward-dipping axial trace)
Total translation: distance of 1st onlap point to top of base-salt ramp

Type-area in Kwanza Basin, Angola (Jackson and Hudec, 2005)
Recently identified in the Santos Basin, Brazil (Pichel et al., 2018)

Ramp Syncline Basins (RSBs)



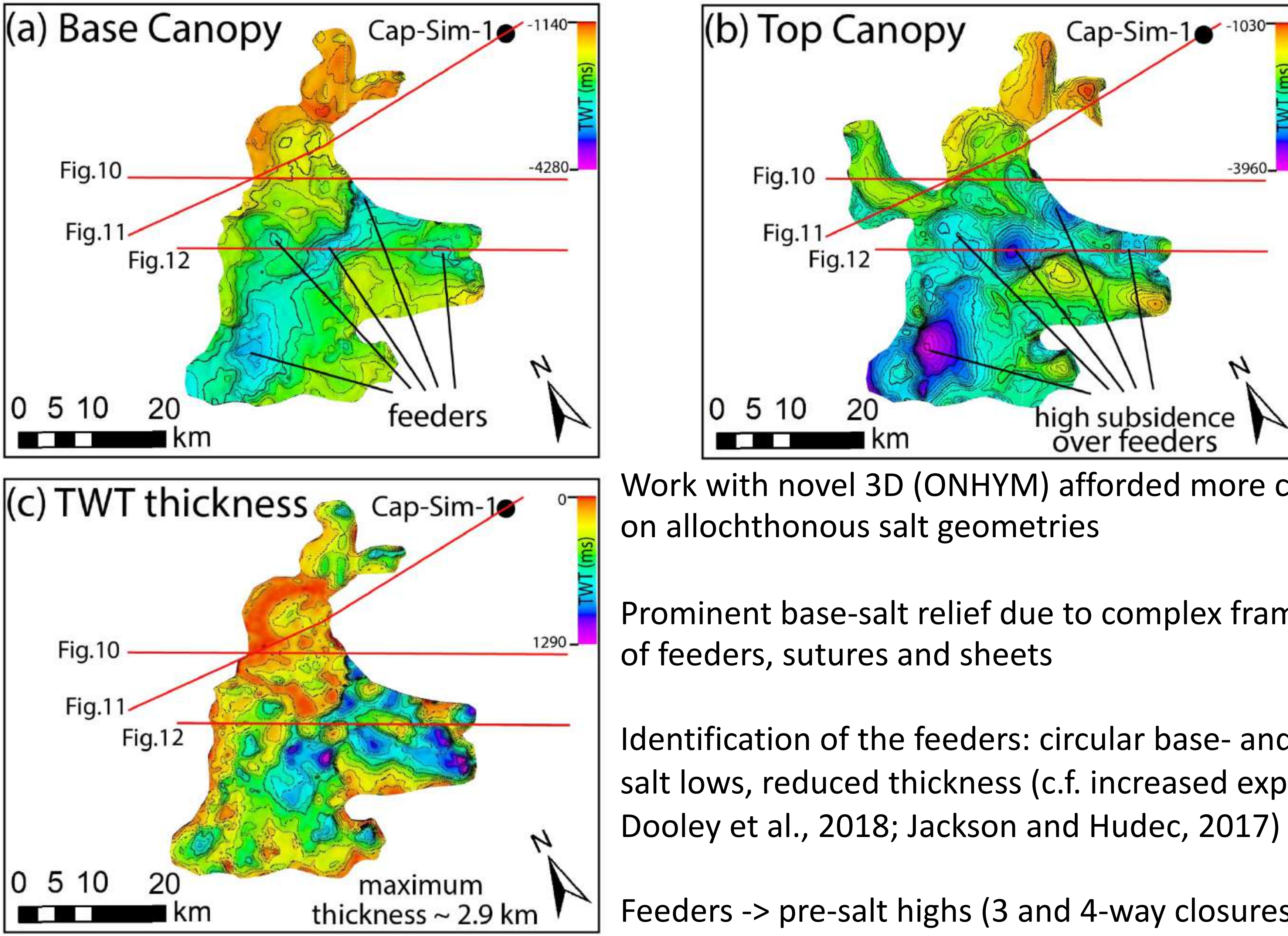
RSBs above allochthonous salt sheets (1-2 km thick)

Updip extension | intermediate translation (RSB) | downdip salt inflation and contraction

8-10 km of translation during Cenozoic ~ 0.2 mm/year

Other occurrences: GoM (Hudec, pers. comm.), Campos Basin (Dooley et al., 2017) Nova Scotia (Peel, pers. comm.), Levante Basin (Mediterranean) and Red Sea (Jackson, pers. comm)

Base-salt Relief on Allochthonous Salt (new 3D data-set)



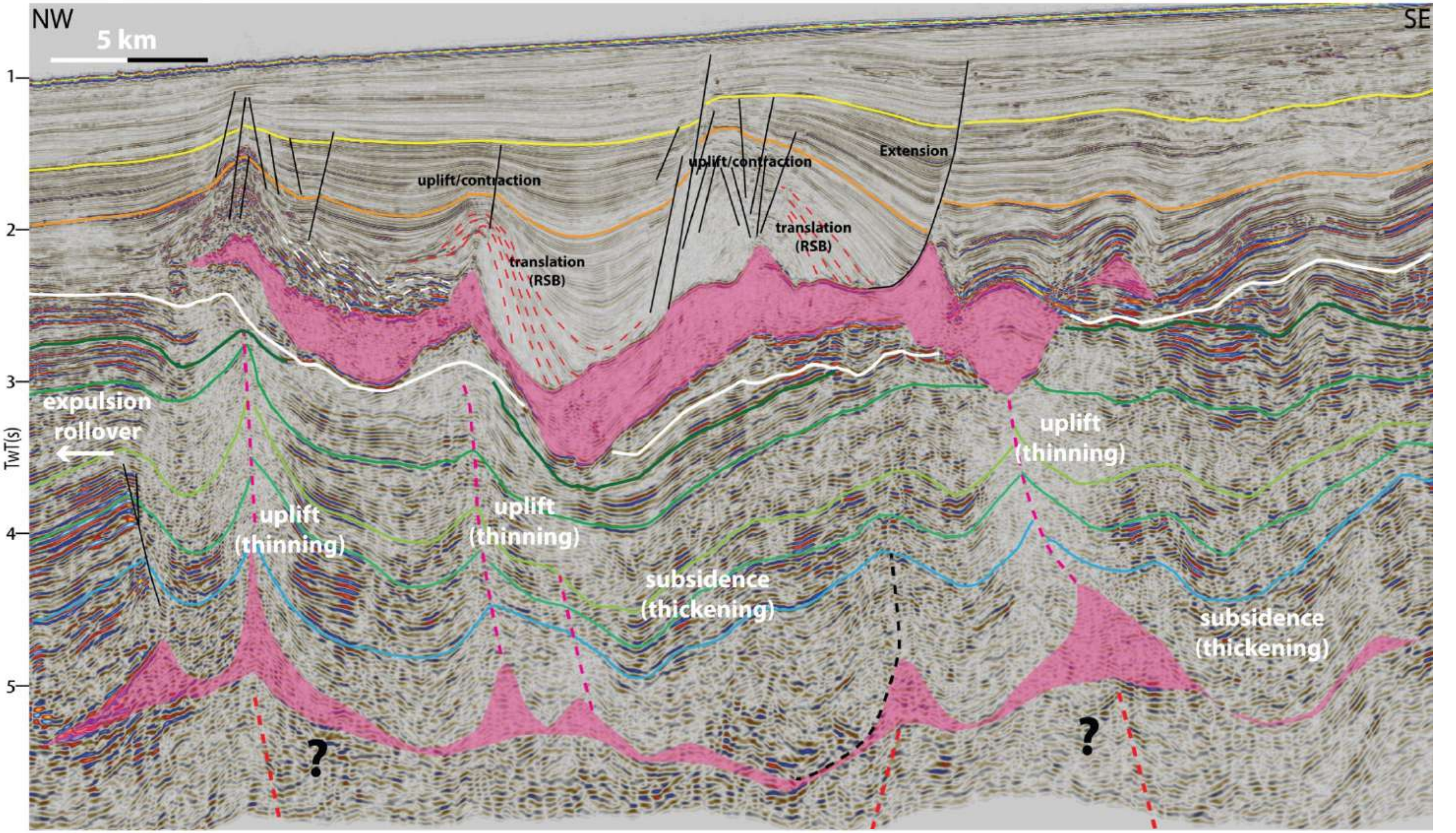
Work with novel 3D (ONHYM) afforded more control on allochthonous salt geometries

Prominent base-salt relief due to complex framework of feeders, sutures and sheets

Identification of the feeders: circular base- and top-salt lows, reduced thickness (c.f. increased expulsion, Dooley et al., 2018; Jackson and Hudec, 2017)

Feeders -> pre-salt highs (3 and 4-way closures)

Base-salt Relief on Allochthonous Salt



Base-salt relief: alternation of extensional & contractional domains linked by an intermediate zone of translation (small RSBs with asymmetric, highly-rotated growth strata)

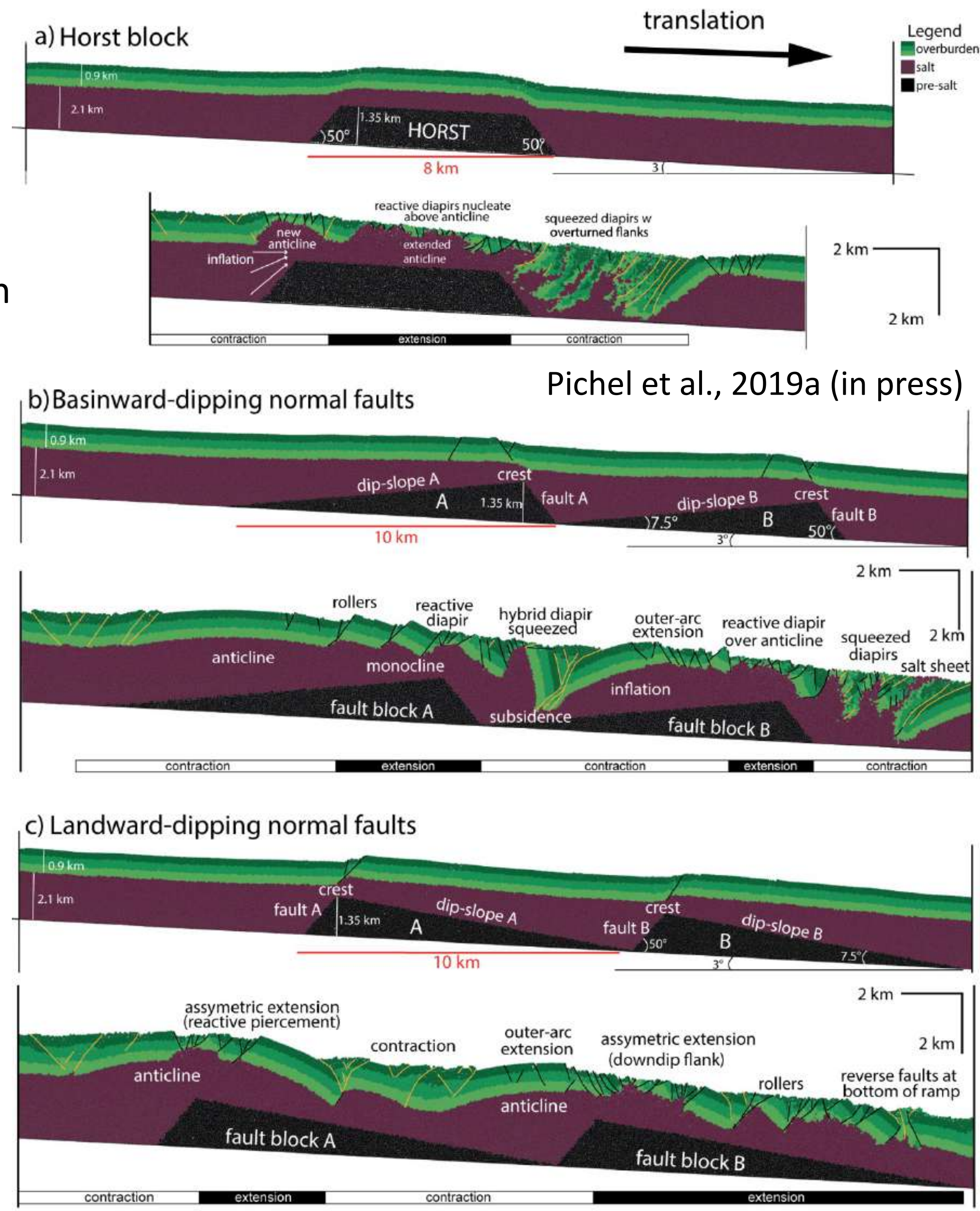
- These formed after smaller sheets merged to originate the large canopy

3D data - increased sub-salt illumination/resolution: complex patterns of uplift and subsidence

Syn-Rift Salt

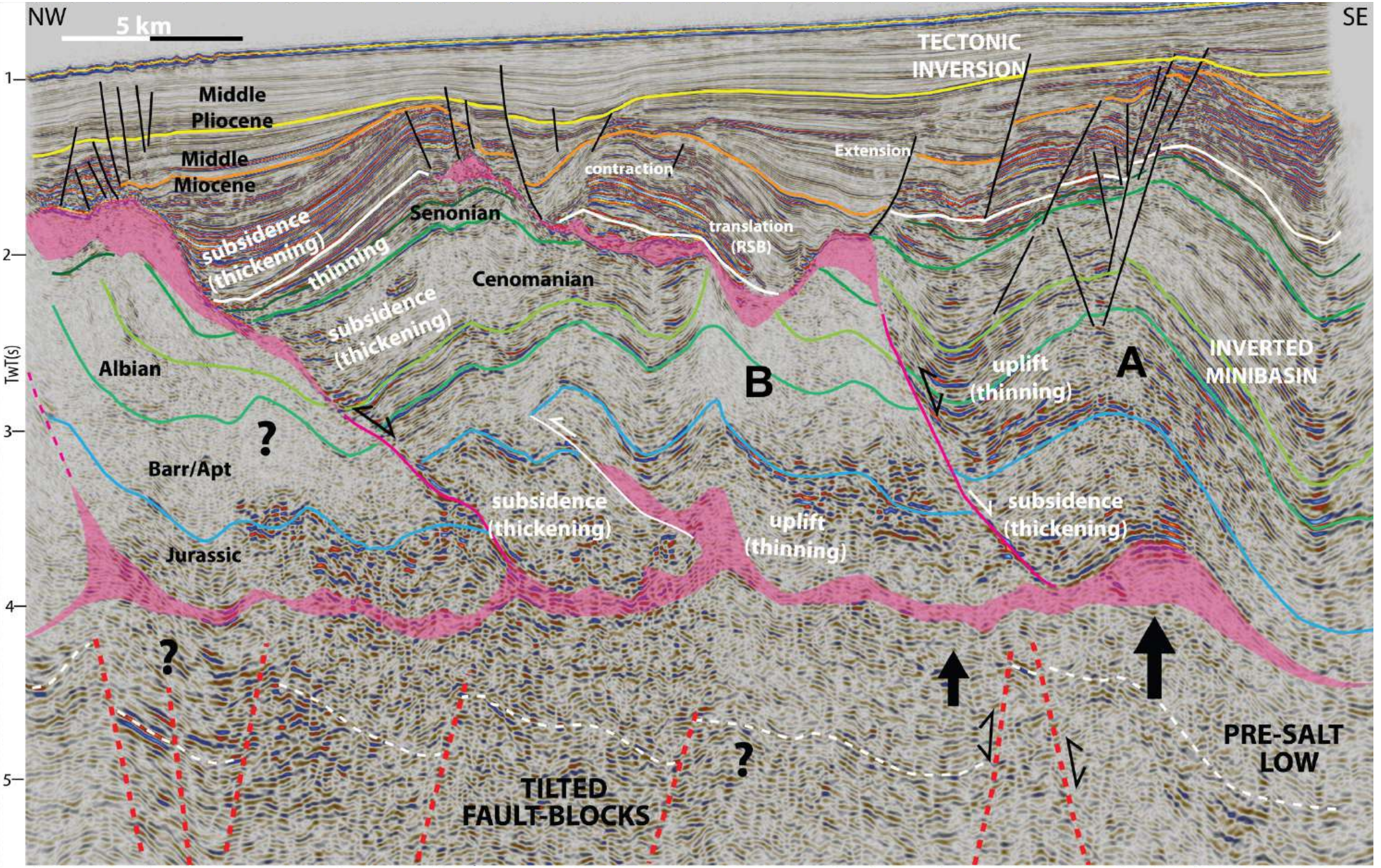
Pronounced impact of base-salt relief and salt thickness variations:

- Complex alternation of salt inflation and thinning/subsidence
- Repetition of zones of contraction and extension
- Salt inflation and contraction over LW-dipping base-salt ramps (footwalls and normal faults)
- Subsidence over BW-dipping base-salt ramps (faults) w/ extension at the top and contraction at the base
- Multiphase reactivation & hybrid diapirim
- Similar effects in Nova Scotia (Deptuck & Kendall 2017)



Pichel et al., 2019a (in press)

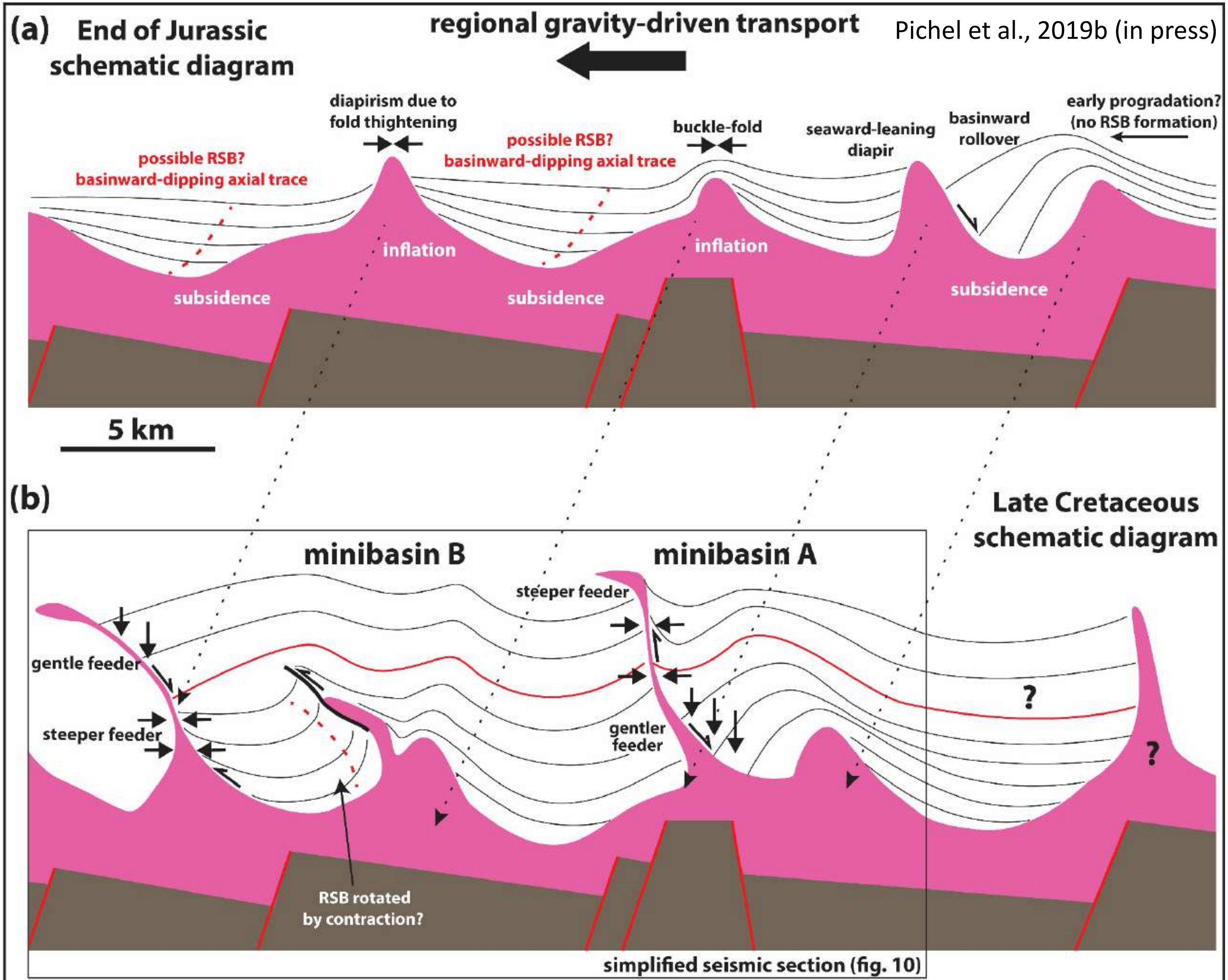
Effects of Pre-salt Rift Topography



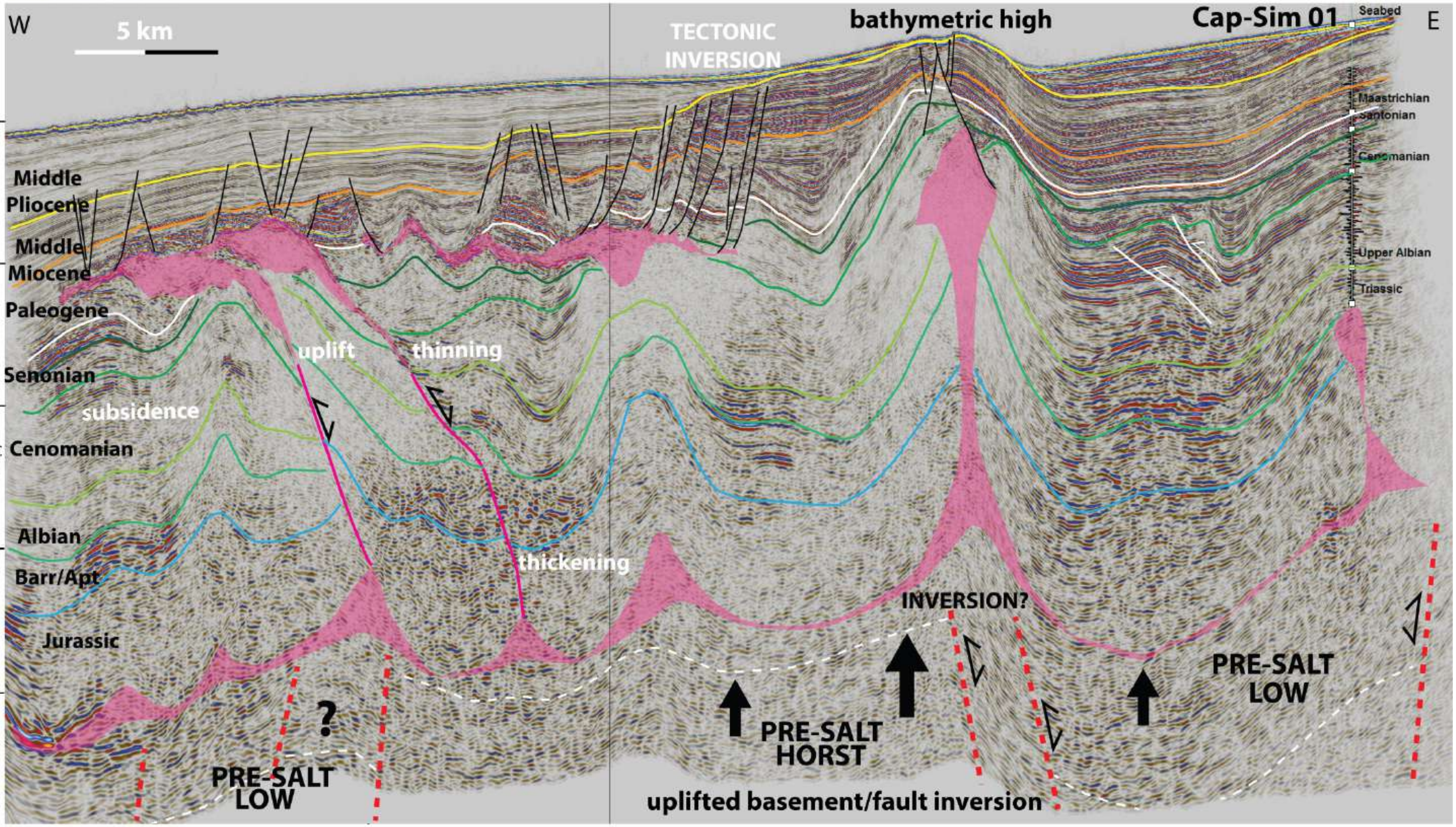
Well-observed in areas of thinner allochthonous salt (alternation of minibasins A and B)

Can guide recognition of pre-salt, syn-rift geometries?

Effects of Pre-salt Rift Topography



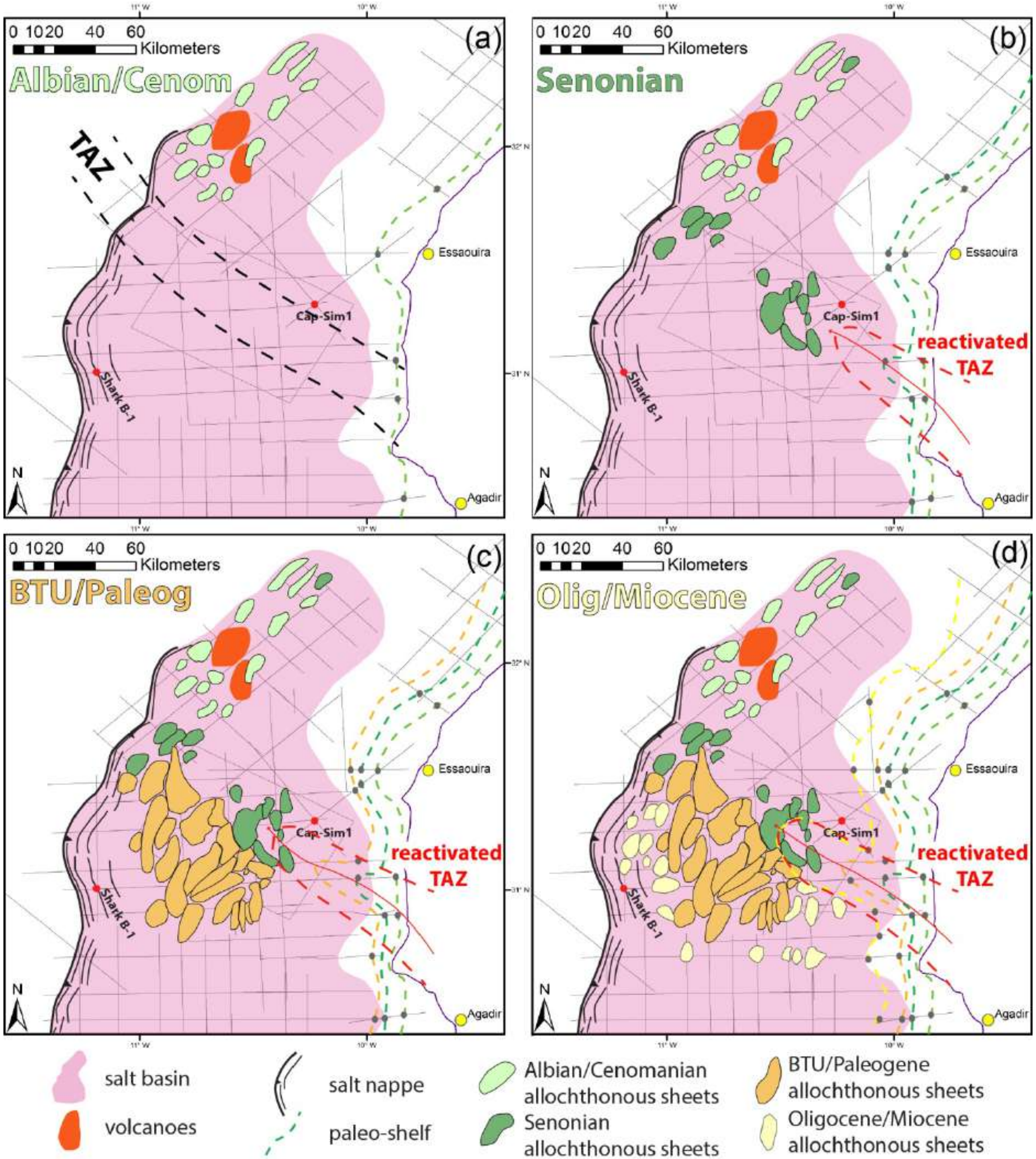
Interplay of Pre-salt Rift Topography, Thick-skinned Shortening and Salt



Improved control of sub- and pre-salt geometries permitted comprehension of the kinematics of basement-uplift and possible reactivation of syn-rift faults (thick-skinned contraction)

Stronger in NE of Essaouira, over the Talfeney Accomodation Zone (TAZ, c.f. Tari et al., 2012)

Generation of allochthonous sheets



Phase **I (Albian/Cenom)**: salt tongues in Safi due to downdip contraction

Phase **II (Senonian)**: sheets form NE of Essaouira associated with continuation of thick-skinned contraction and reactivation of TAZ

Phase **III (Paleogene**) – greater volume of salt extrusion and coalescence of individual sheets

Phase **IV (Olig/Miocene)** – allochthonous sheets continues to propagate SOUTH and SEAWARD

Extrusion controlled primarily by propagation of Late Cret-Cenozoic thick-skinned shortening

Earlier salt sheets (Safi) form by enhanced downdip contraction due to greater detachment steepness and smaller width of salt basin

Pichel et al., 2019b (*in press*)

CONCLUSIONS and IMPLICATIONS

Strong variation of structural styles along the margin:

- Syn-rift salt architecture, variable base-salt relief and initial salt thickness
- Presence of volcanoes limiting gliding and favouring downdip contraction
- Variations of sedimentary input along the margin (Pichel et al., 2017)

Multiple evidence of the impact of thick-skinned shortening on salt tectonics

Sequential evolution of allocthonous salt propagate south- and basinward due to margin configuration and migration/timing of contraction (thin or thick-skinned)

Alternation of supra-canopy structural domains and RSBs indicate control by base-salt (top sub-salt) relief, allochthonous salt budget and thickness variations.

Despite limitation of sub-salt seimic resolution and lack of wells penetrating the interval, we observe similar sub-salt distribution of structural styles

- Caused by syn-rift nature of salt, related thickness contrasts and base salt relief

Mapping of base-canopy, feeders and supra-canopy deformation styles allowed identification of sub-allochthonous salt geometries (i.e. depocentre distribution and sub-salt highs) that can guide and de-risk exploration within these intervals

- This can be also used (with care) as a proxy to understand the pre-salt interval

FURTHER WORK

Continuous use of 3D and/or wide-azimuth seismic to understand sub- and pre-salt geometries and depositional architecture

Detailed 3D mapping of the supra-canopy features and allochthonous salt kinematics documented here to guide recognition of sub-salt architecture and potential

This can also be extrapolated downwards to understand deeper strata and pre-salt geometries in areas of thinner allochthonous salt

Ideally coupled with numerical & physical models (possibly in 3D) testing more variable scenarios involving translation, pre-(sub)salt topography and variable syn-kinematic sedimentation patterns

Basin studies

ACKNOWLEDGMENTS

REPSOL

equinor

bp

eni

Cairn

woodside

Hunt OIL COMPANY

TOTAL

Special Thanks:

CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

ONHYM
OFFICE NATIONAL DES HYDROCARBURES ET DES MINES

Schlumberger

Basin studies