Wings, Mushrooms and Christmas Trees: Insights from Carbonate Seismic Geomorphology into the Evolution of Central Luconia*

E. Kosa[1]

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[1]Exploration, Sarawak Shell Bhd, Miri, Malaysia (eduard.kosa@shell.com)

Abstract

Central Luconia is a gas province located offshore Sarawak, NW Borneo. More than 200 Miocene to Recent carbonate build-ups are known to exist in the province, many of them hydrocarbon bearing. Despite more than 50 years of E&P activity, little is known about the carbonate geomorphology. Since the proliferation of interpretation-workstation technology, a simplistic interpretation of the 'Top Carbonate' seismic reflection has been accepted as a definite representation of the carbonate province. Owing to limitations of seismic-interpretation techniques and technology, build-ups are depicted as smooth, cylindrical or conical structures linked together by 'Basal Carbonate'. Miocene to Recent, deltaic sediments overlie the province. The prevalent model of evolution of Central Luconia infers (i) a 'maximum transgression' initiating the carbonate growth in the Middle Miocene, followed by (ii) progressive burial of the province under Borneo-sourced clastic deltas. The model invokes a hiatus between the demise through 'drowning' of the build-ups and the deposition of deltaic 'megaforesets'. Deep-water sediments are implied to surround the 'drowned' carbonates, which consequently appear to form enormous, sealed tanks ready to contain hydrocarbons. Drilling results do not support this, however. Hydrocarbon columns in Central Luconia tend to be short and terminate at intersections of the carbonate edifices with clastic sequence boundaries. Owing to the perceived temporal disparity between carbonate and clastic deposition, overburden stratigraphy is also deemed unusable for correlation between carbonate-reservoir layers. Recently, an alternative model of the clastic stratigraphy has been proposed, interpreting it as a succession of stacked delta-lobes punctuated by exposure and/or flooding surfaces and evolving contemporaneously with carbonates. In this study, carbonate-seismic geomorphology is used to unravel the history of carbonate growth and thus to tie it to the clastic stratigraphy. Clinoforms, back-steps, karst, erosion, and carbonate-clastic intercalations are used to demonstrate the temporal relationships between carbonate and clastic strata. Clastic stratigraphy is shown to provide a template for zone-correlation between isolated carbonate build-ups. The result is a coherent model of the tectono-stratigraphic evolution of Central Luconia, which can serve the purposes of future exploration as well as improved understanding and management of current fields.

Selected References

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Wings, Mushrooms,

and Christmas Trees:

Insights from

Carbonate Seismic Geomorphology

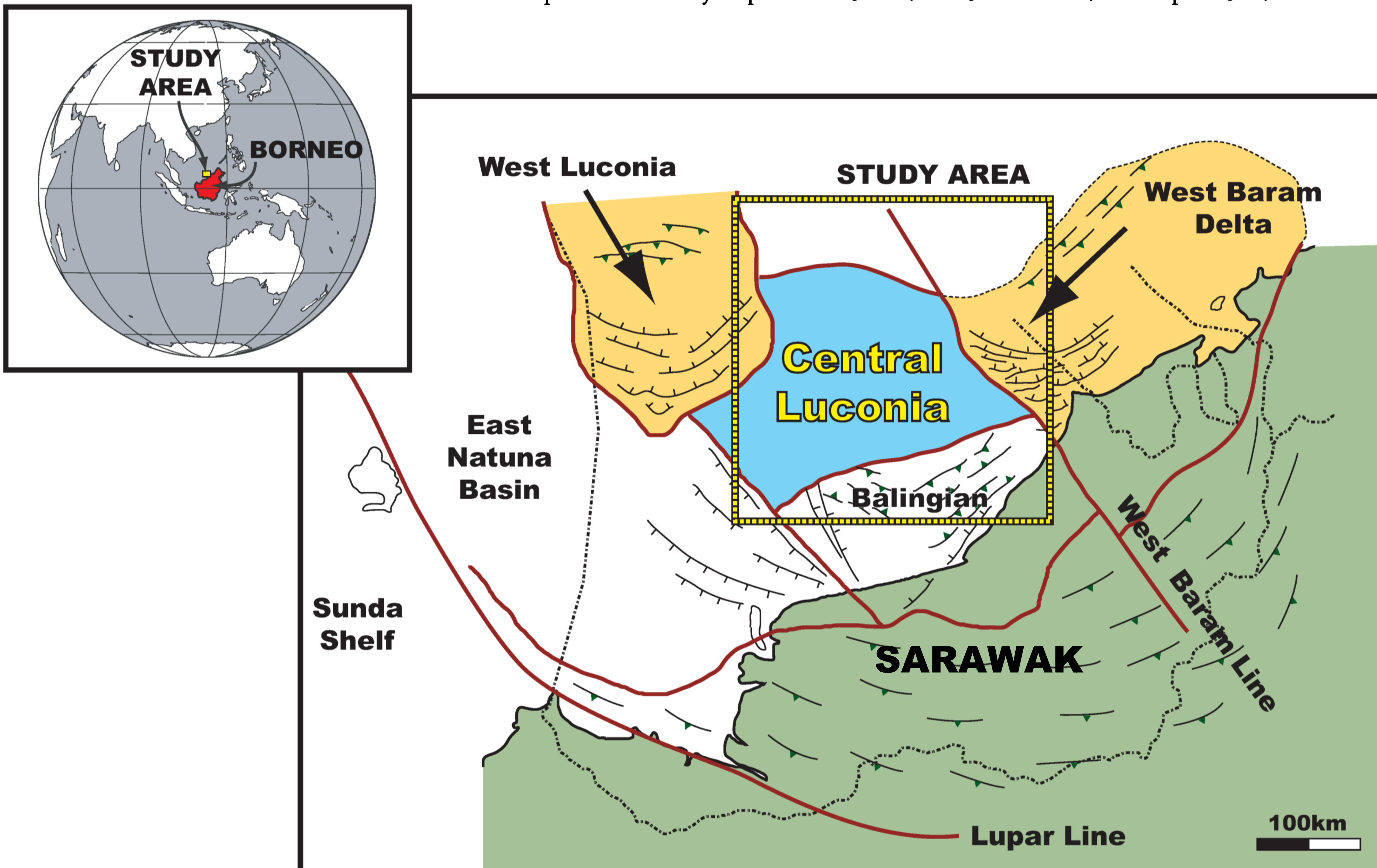
into the Evolution of Central Luconia

E. Koša

Sarawak Shell Bhd, Malaysia

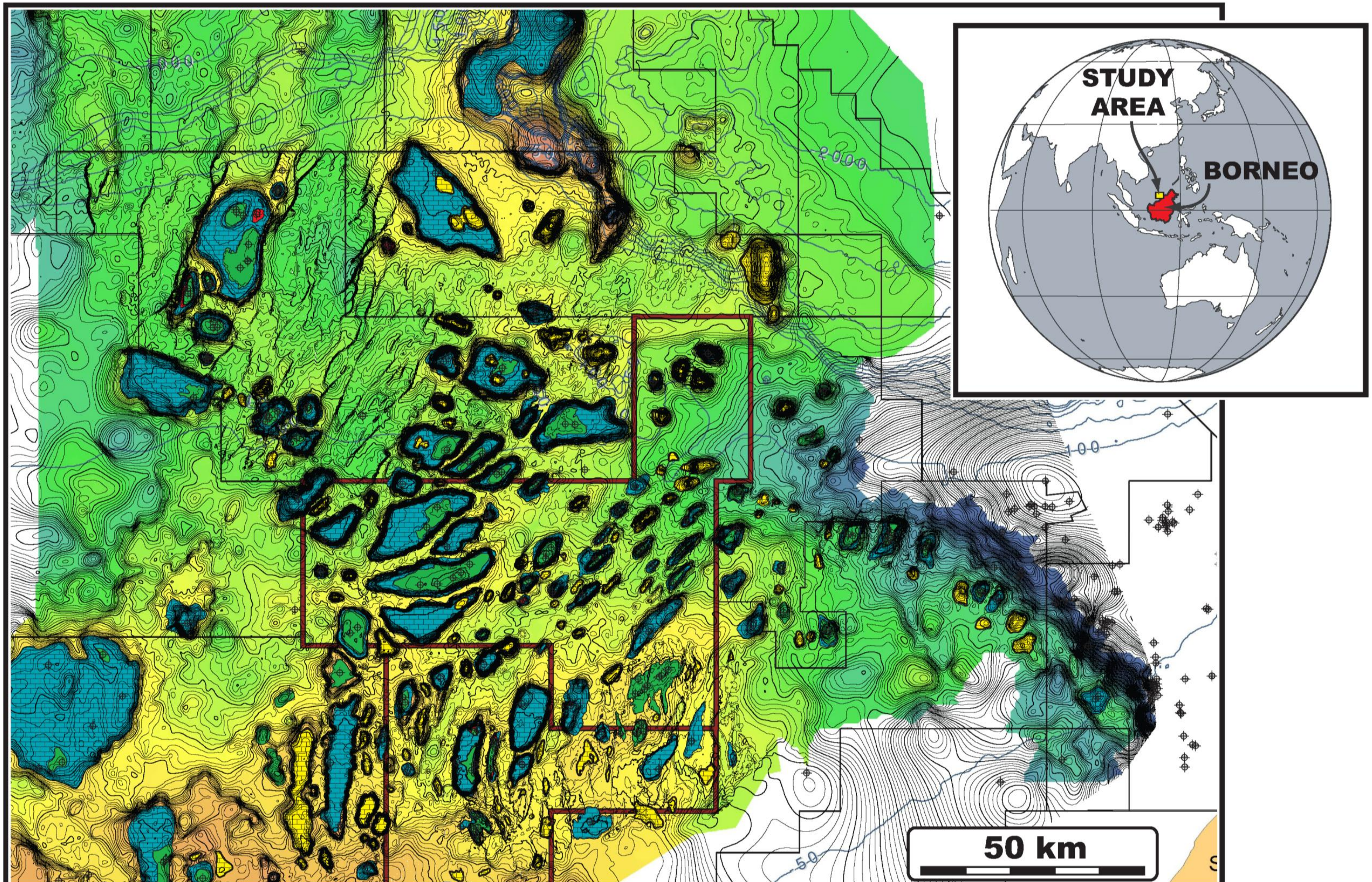
Geography

Stable microplate surrounded by deep basins on 3 sides; 100-250km offshore; water depth <250m; 40.000km^2



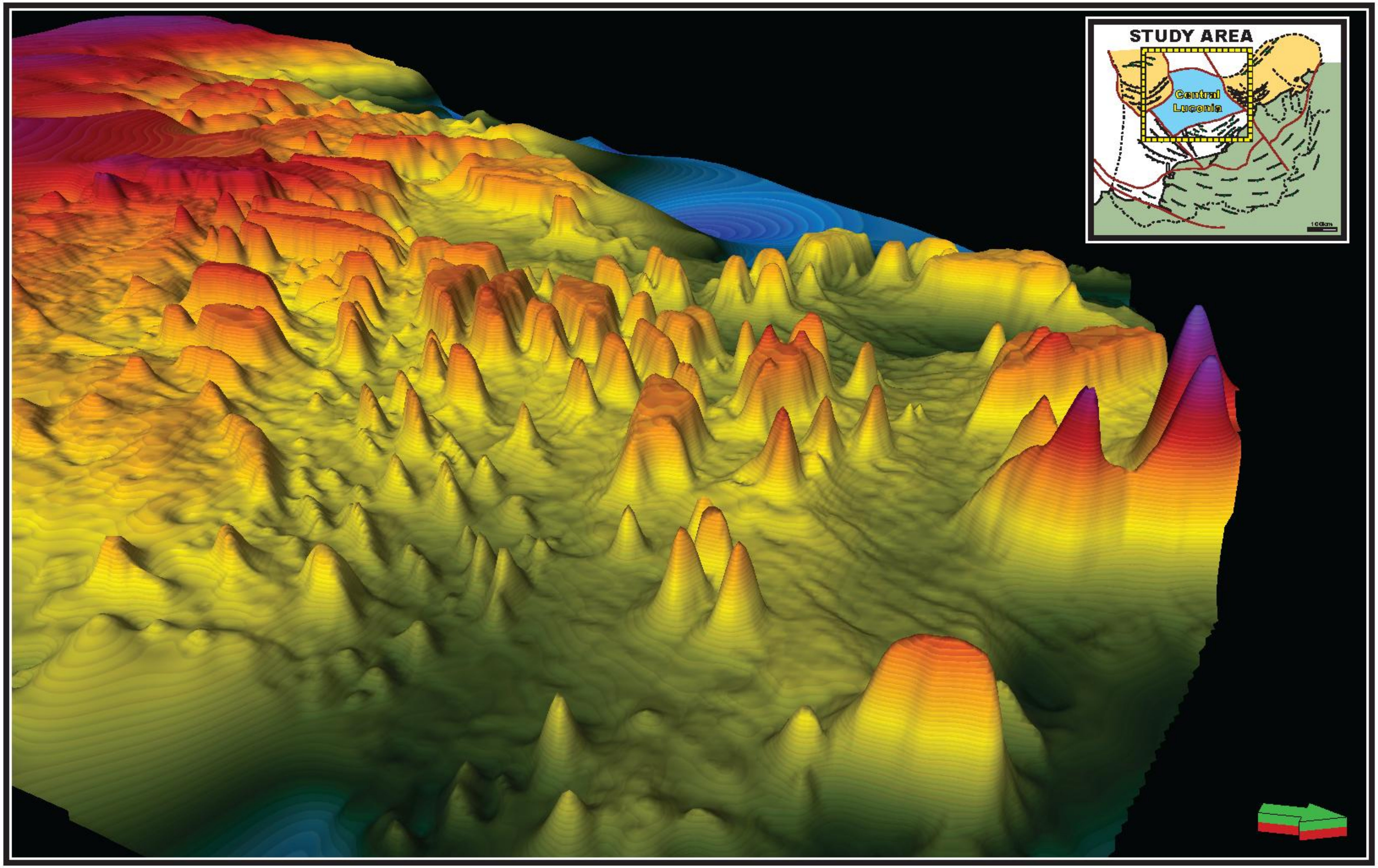
The Petroleum Province

Over 200 carbonate build-ups; >100 wells; >45tcf recoverable gas reserves; 3.7bcf/d production

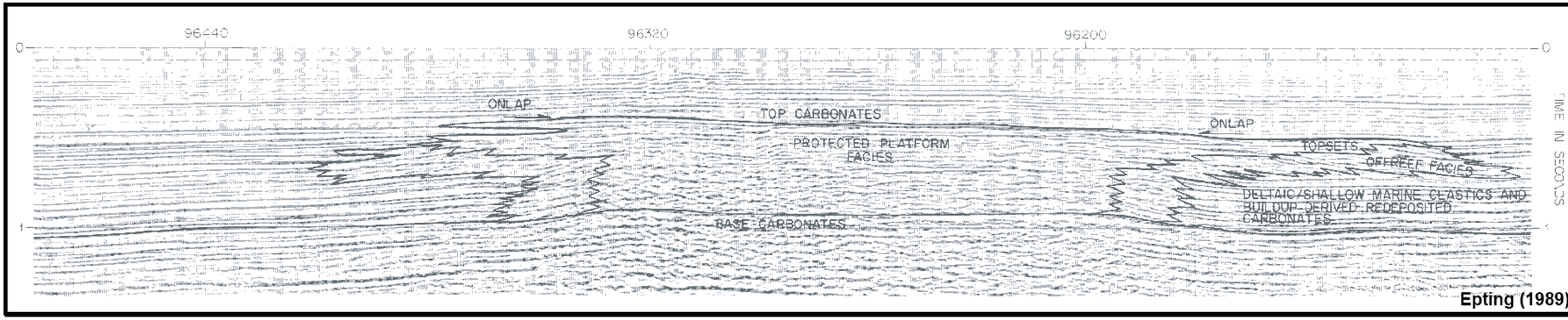


Carbonate Province at a Glance

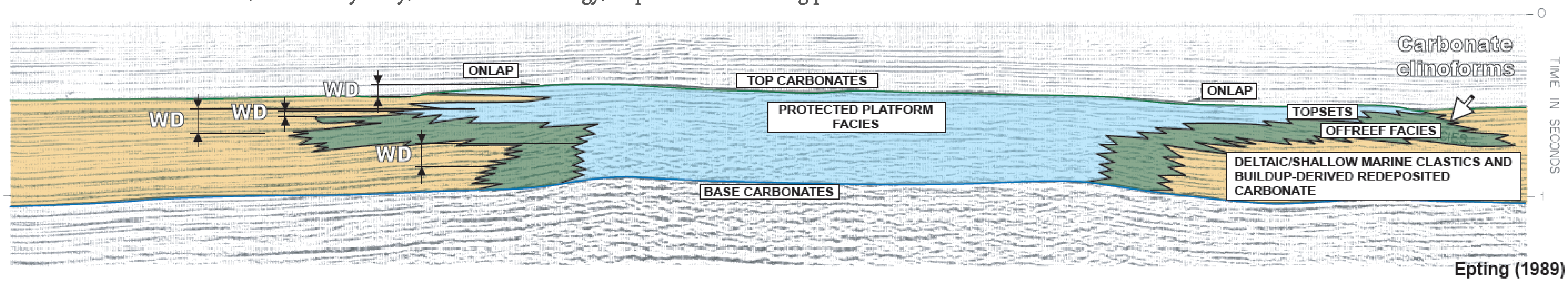
Carbonate build-ups portrayed as smooth convex structures increasing in relief Northward



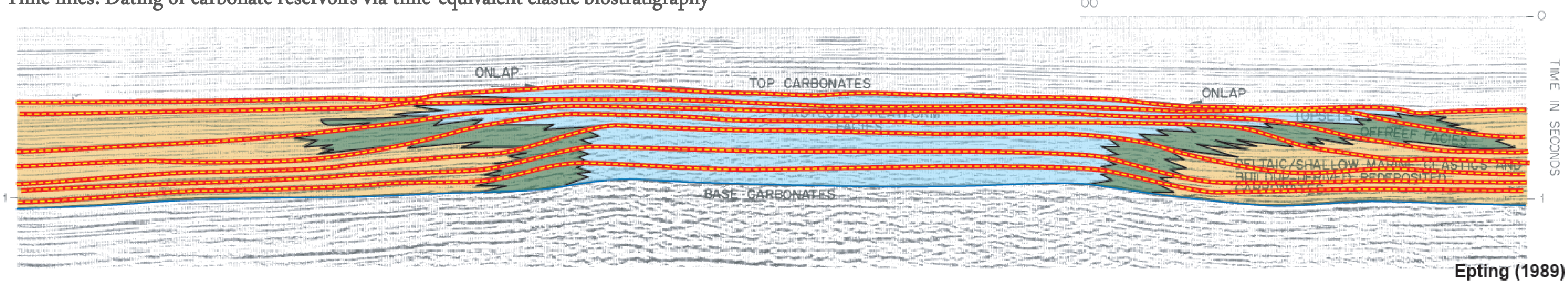
Example of an Early Interpretation of a Luconia Carbonate



Carbonate-clastic interactions; Palaeobathymetry; Clastic sedimentology; Implications for sealing potential

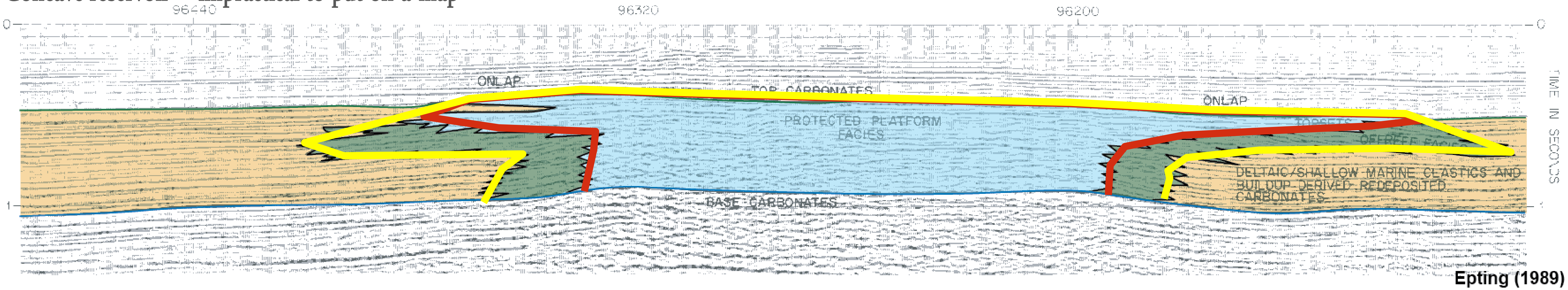


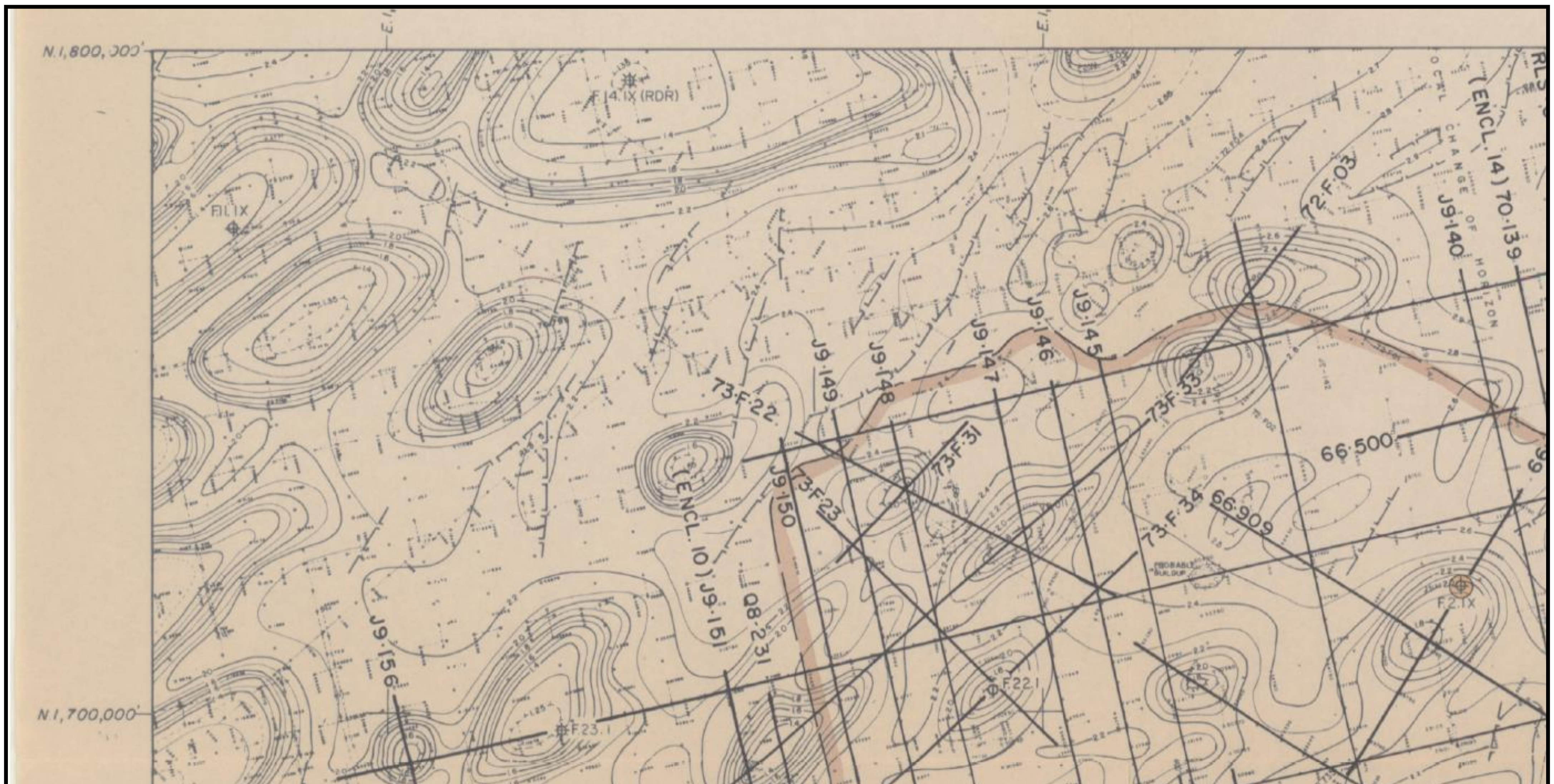
Time lines: Dating of carbonate reservoirs via time-equivalent clastic biostratigraphy



Reservoir Delineation: Concave (Mushroom)

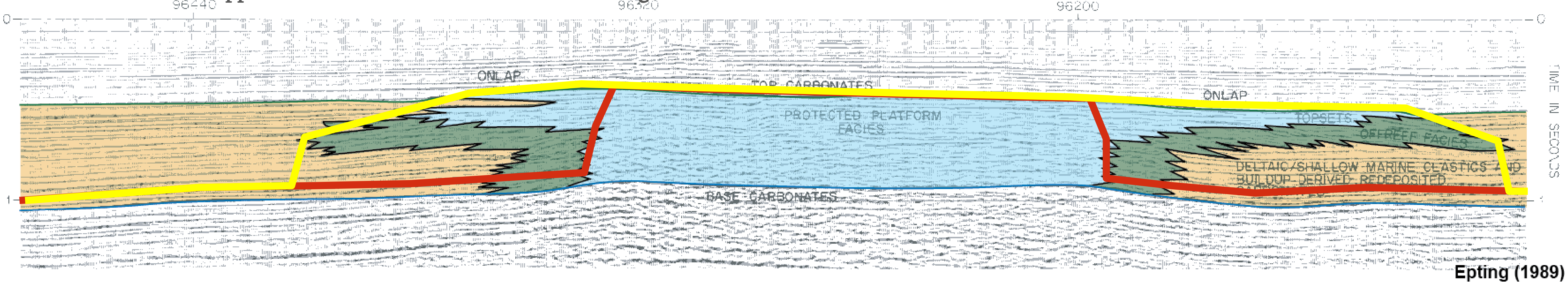
Concave reservoir – impractical to put on a map



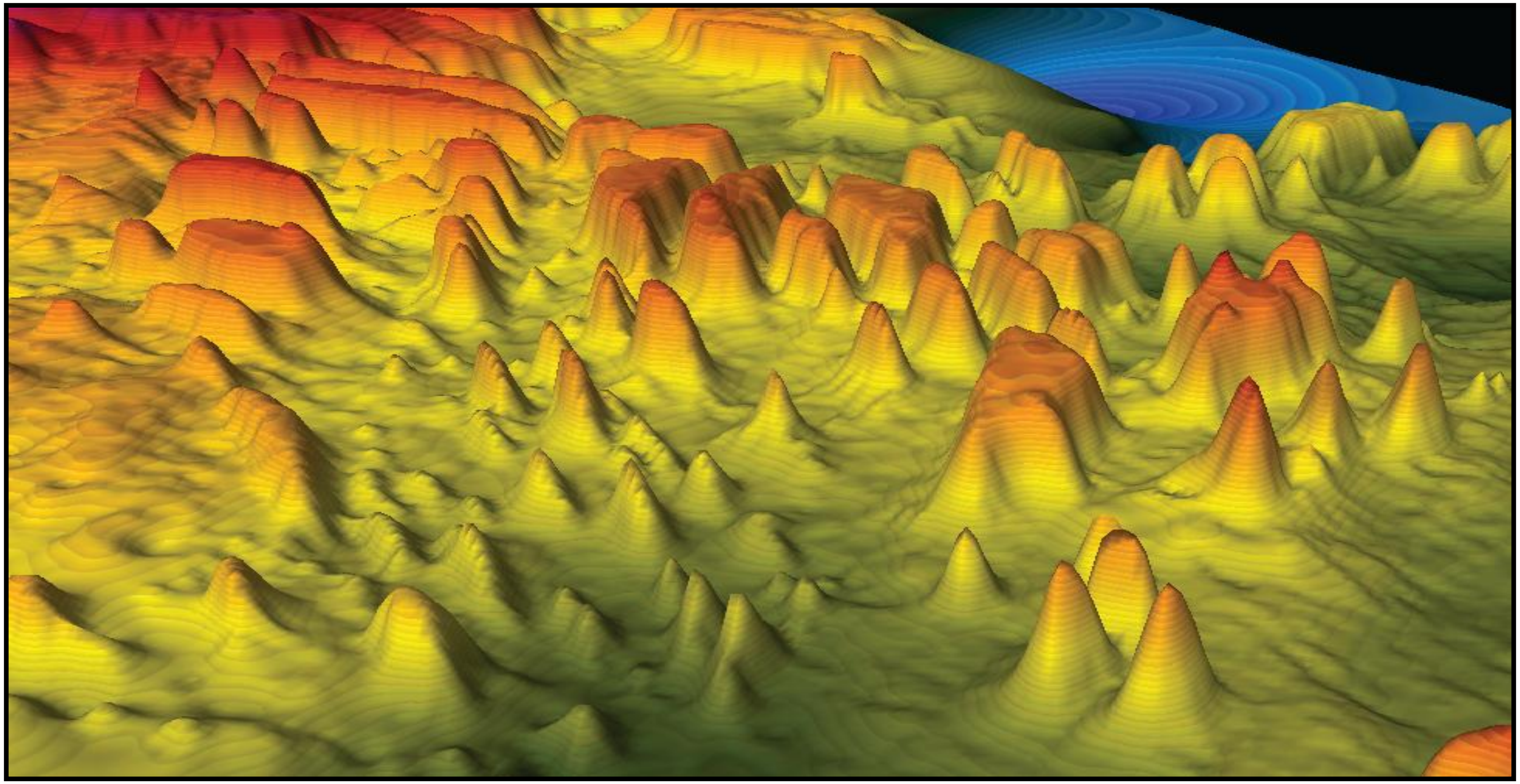


Reservoir Delineation: Convex (Condominium)

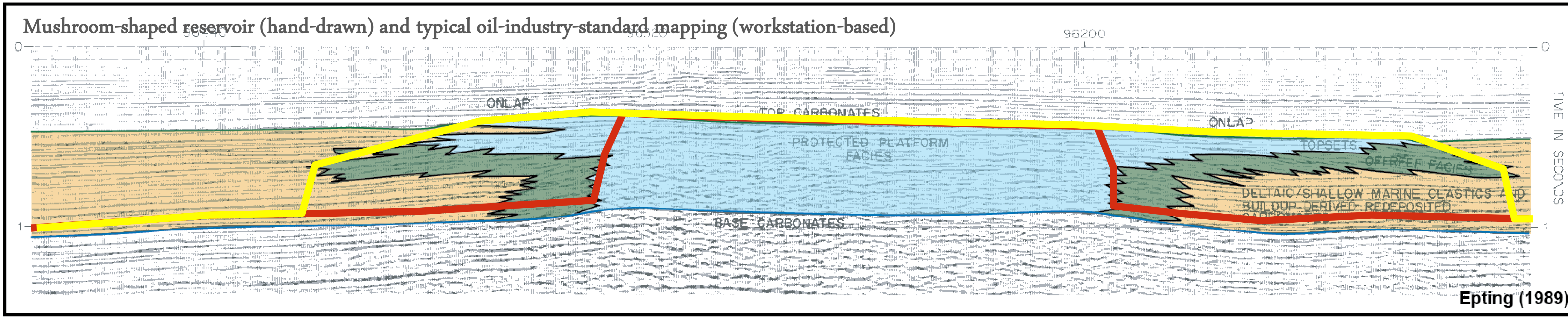
Convex reservoir – mapped on the outside or the inside of the marginal carbonate facies

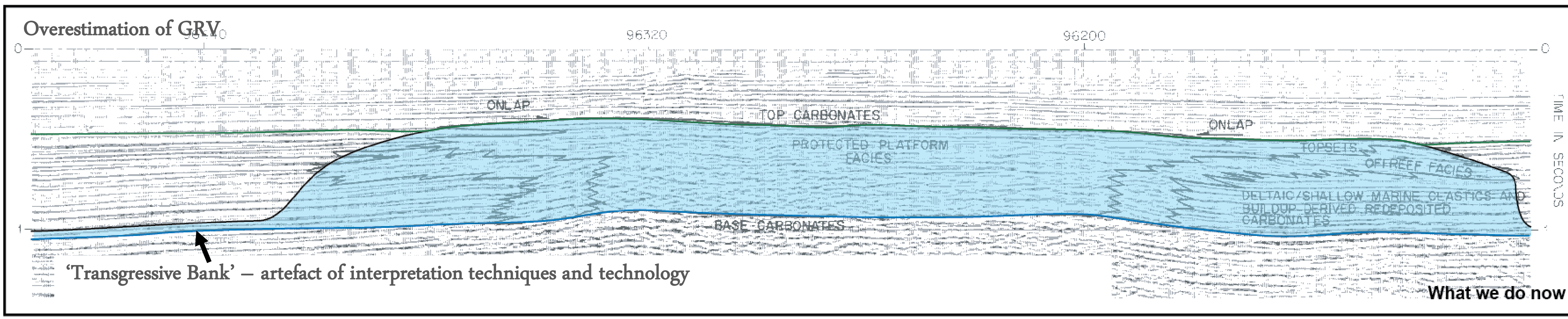


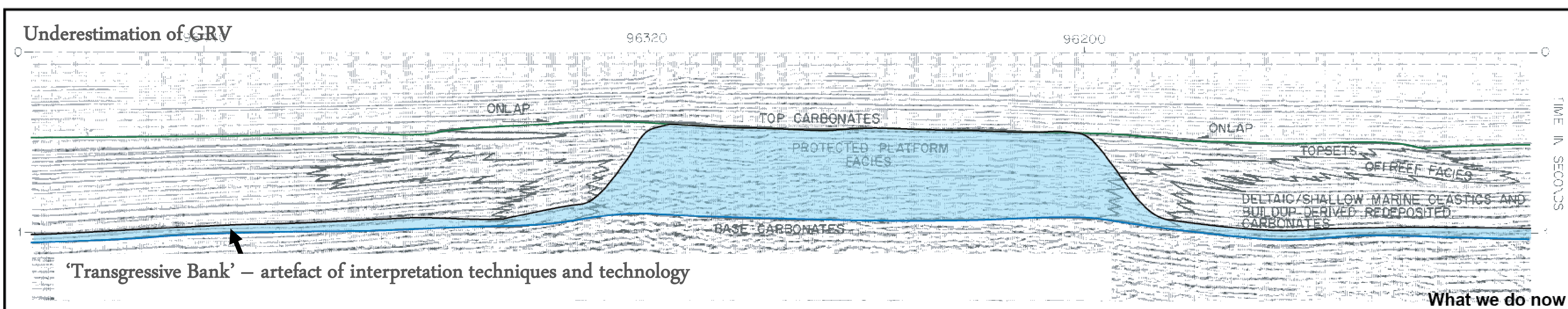
Epting (1989)



Early vs. Modern Interpretation of a Luconia Carbonate

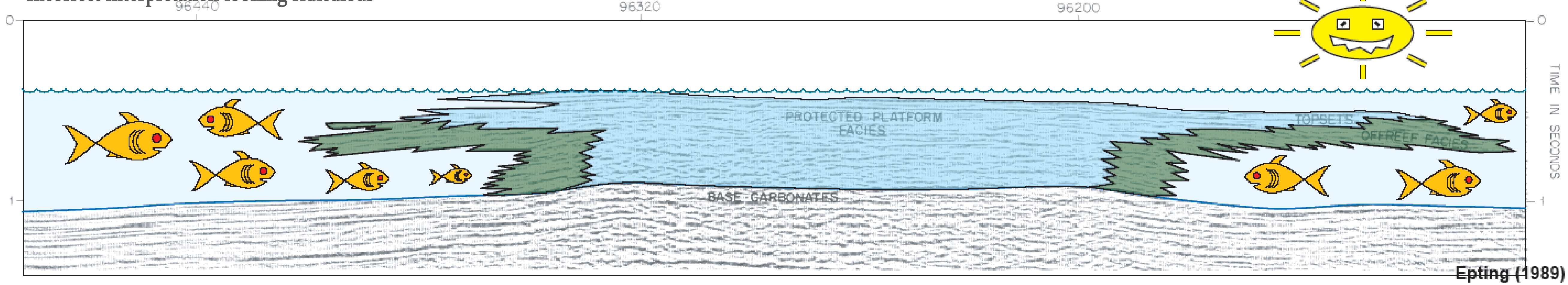




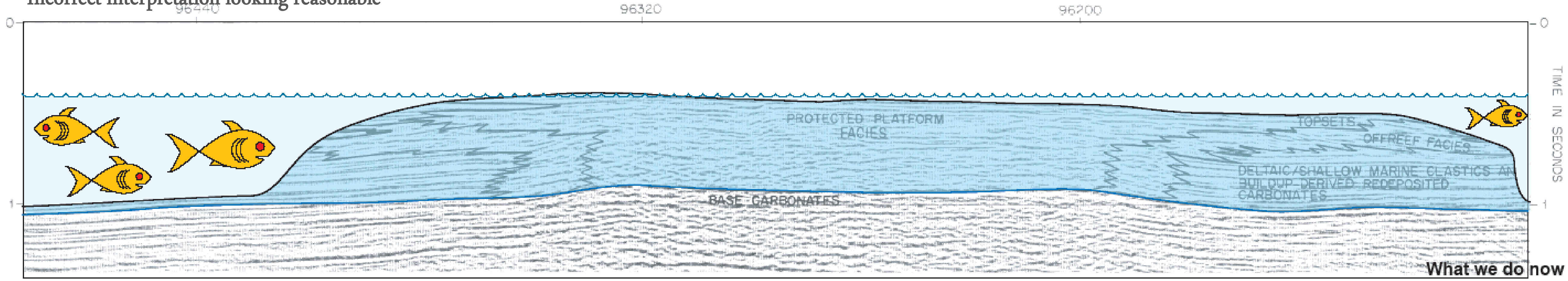


Interpretation of Palaeobathymetry

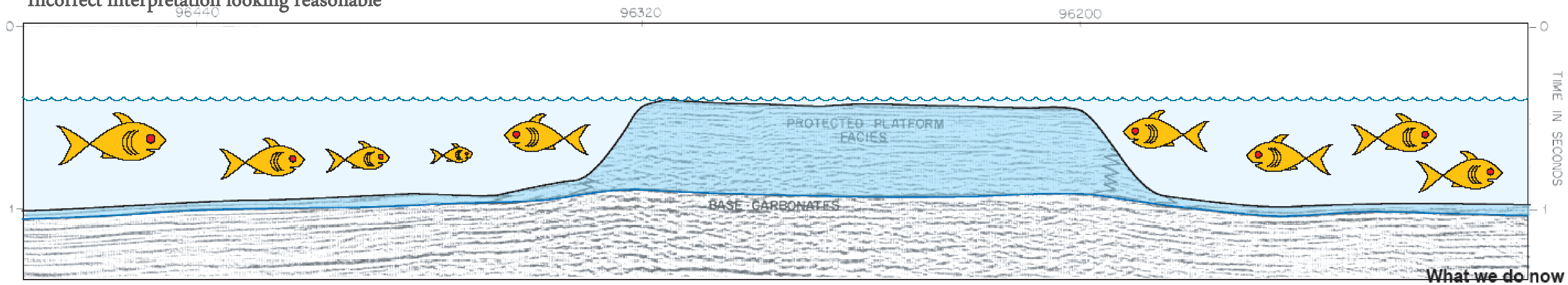
Incorrect interpretation looking ridiculous



Incorrect interpretation looking reasonable

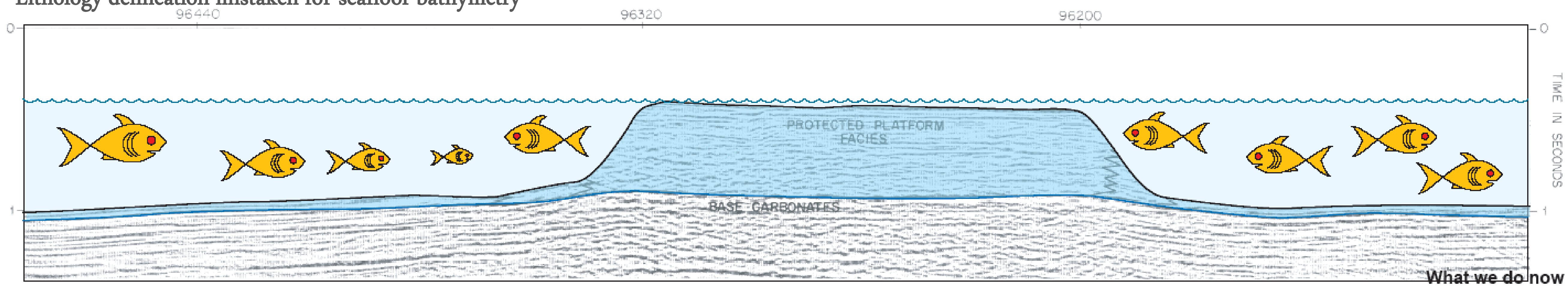


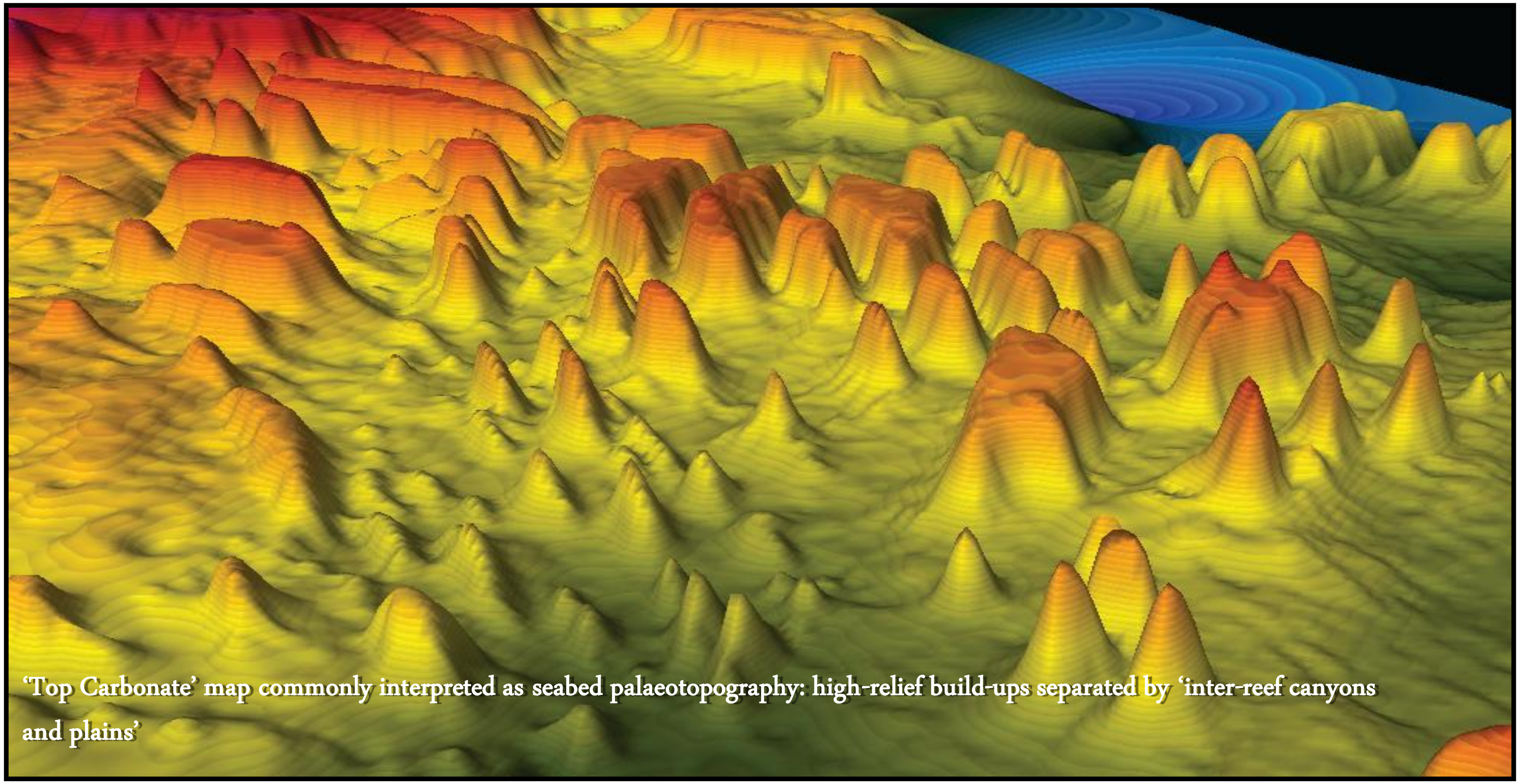
Incorrect interpretation looking reasonable



Interpretation of Palaeobathymetry

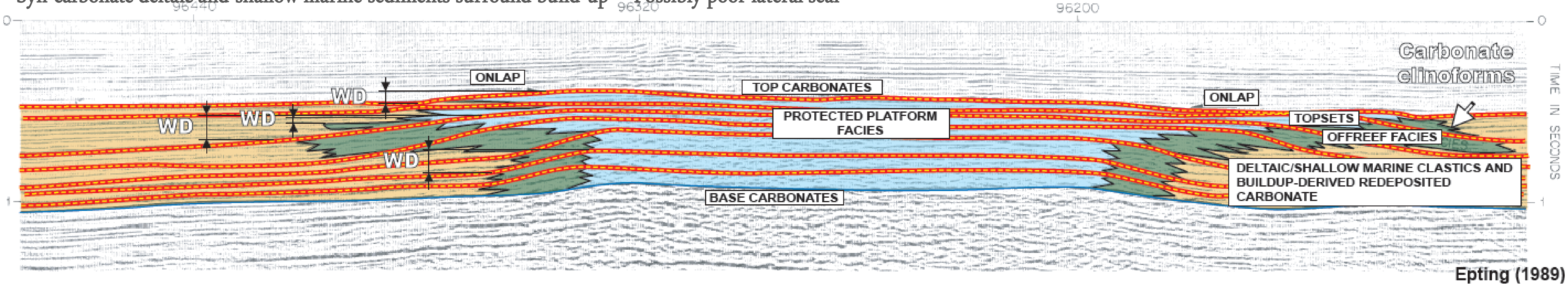
Lithology delineation mistaken for seafloor bathymetry



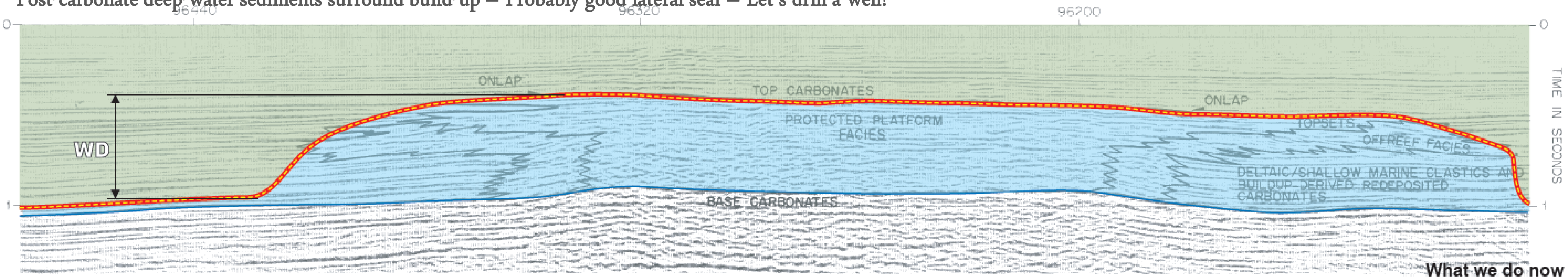


Carbonate Timing and Overburden Sedimentology

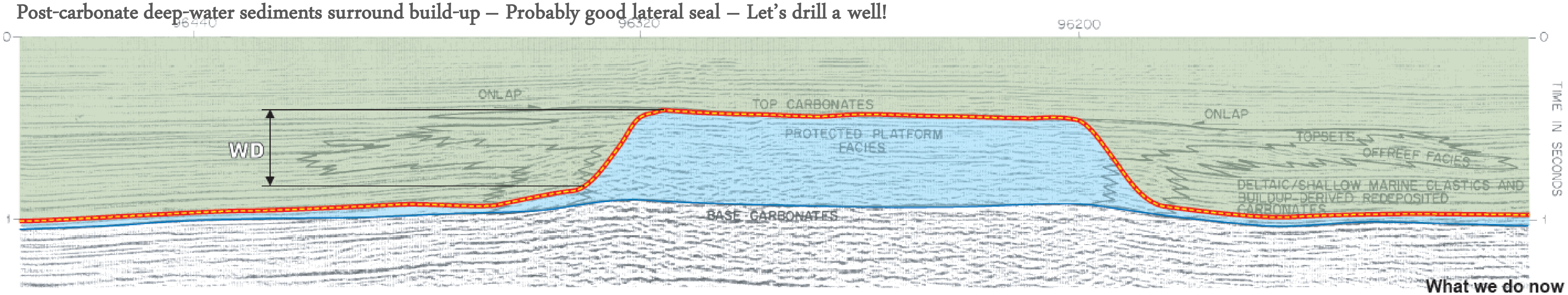
Syn-carbonate deltaic and shallow marine sediments surround build-up – Possibly poor lateral seal



Post-carbonate deep-water sediments surround build-up – Probably good lateral seal – Let's drill a well!

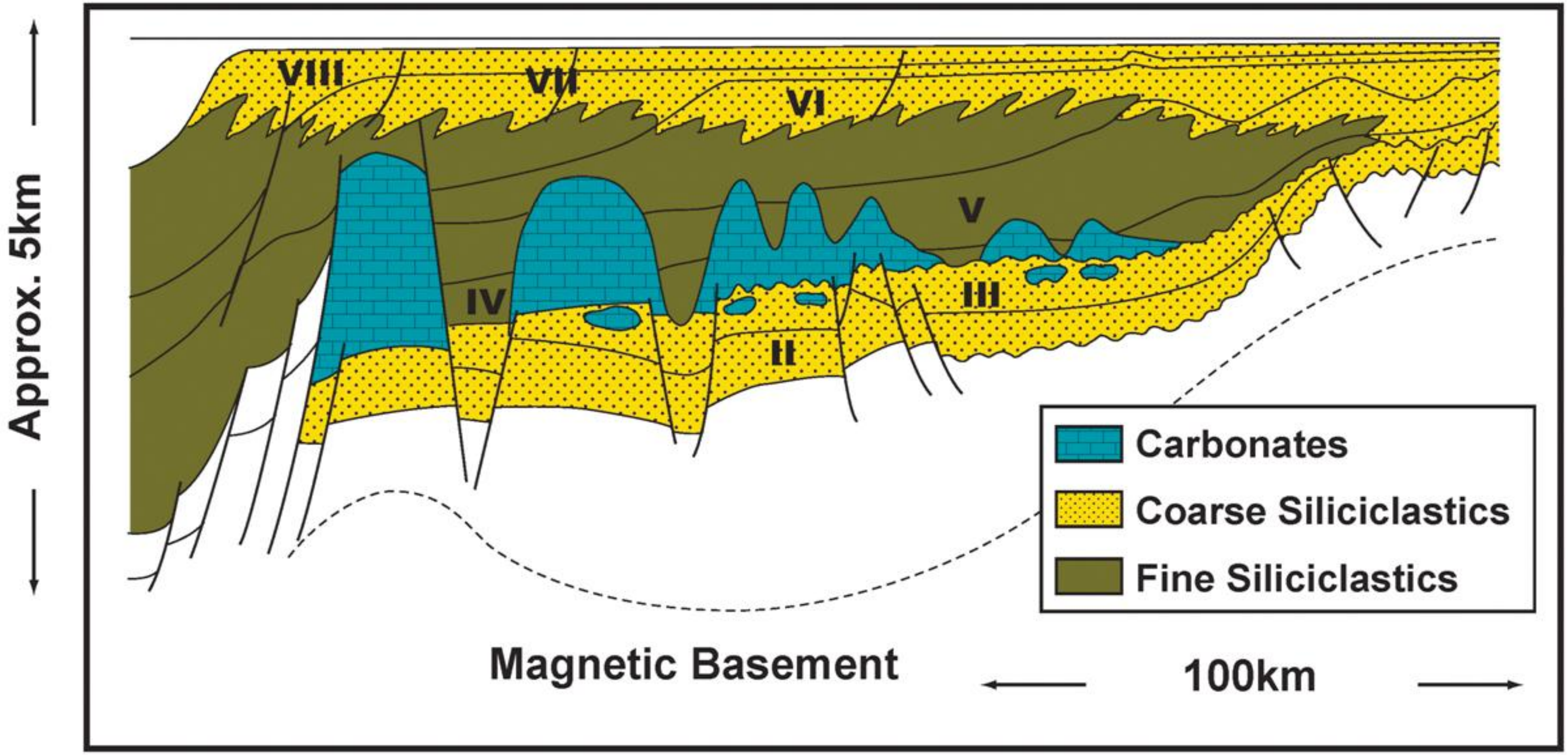


Post-carbonate deep-water sediments surround build-up – Probably good lateral seal – Let's drill a well!



Overburden Stratigraphy: Single Delta, Drowned Build-Ups

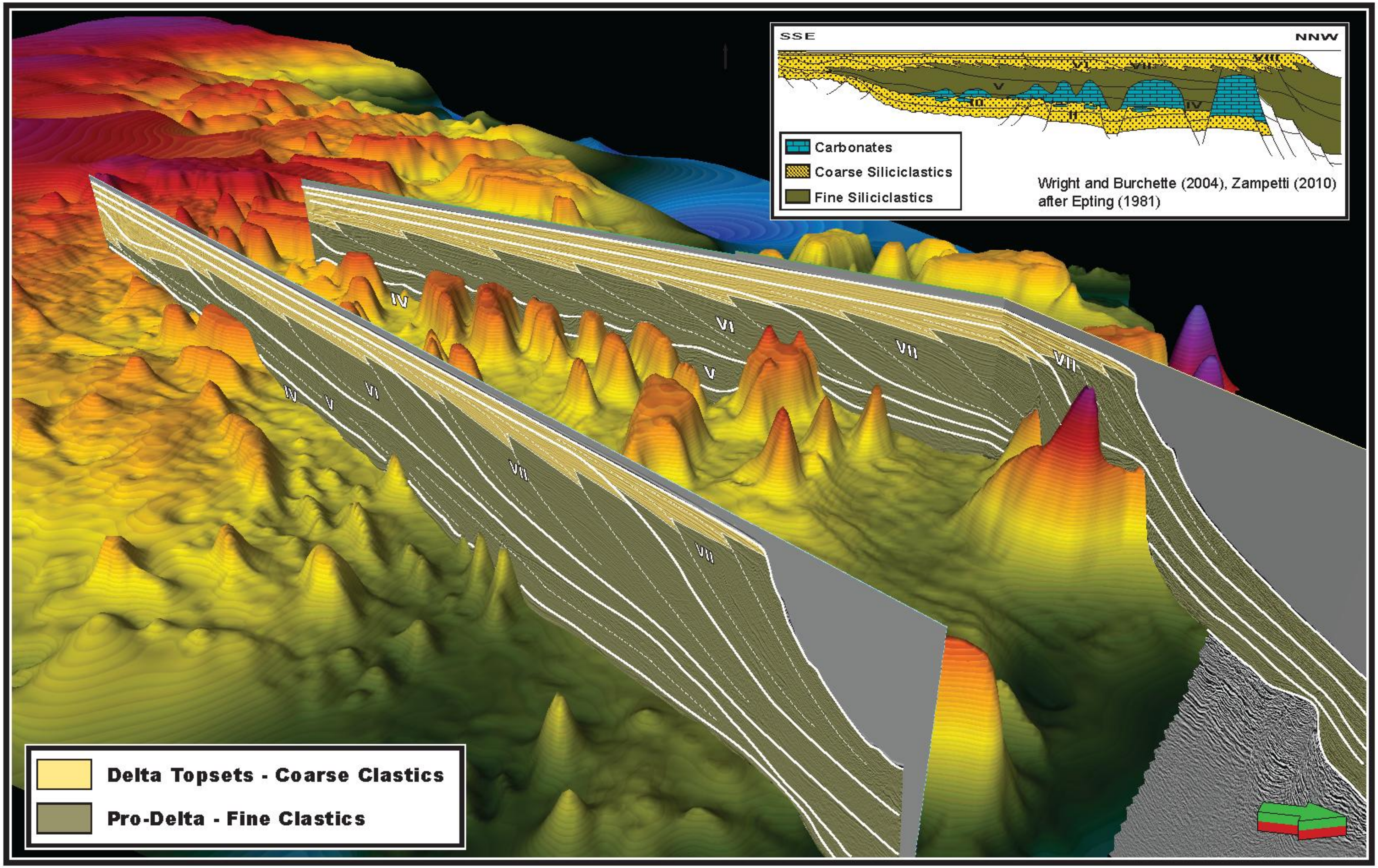
Single delta prograding over Luconia; Drowned build-ups buried under pro-delta mud



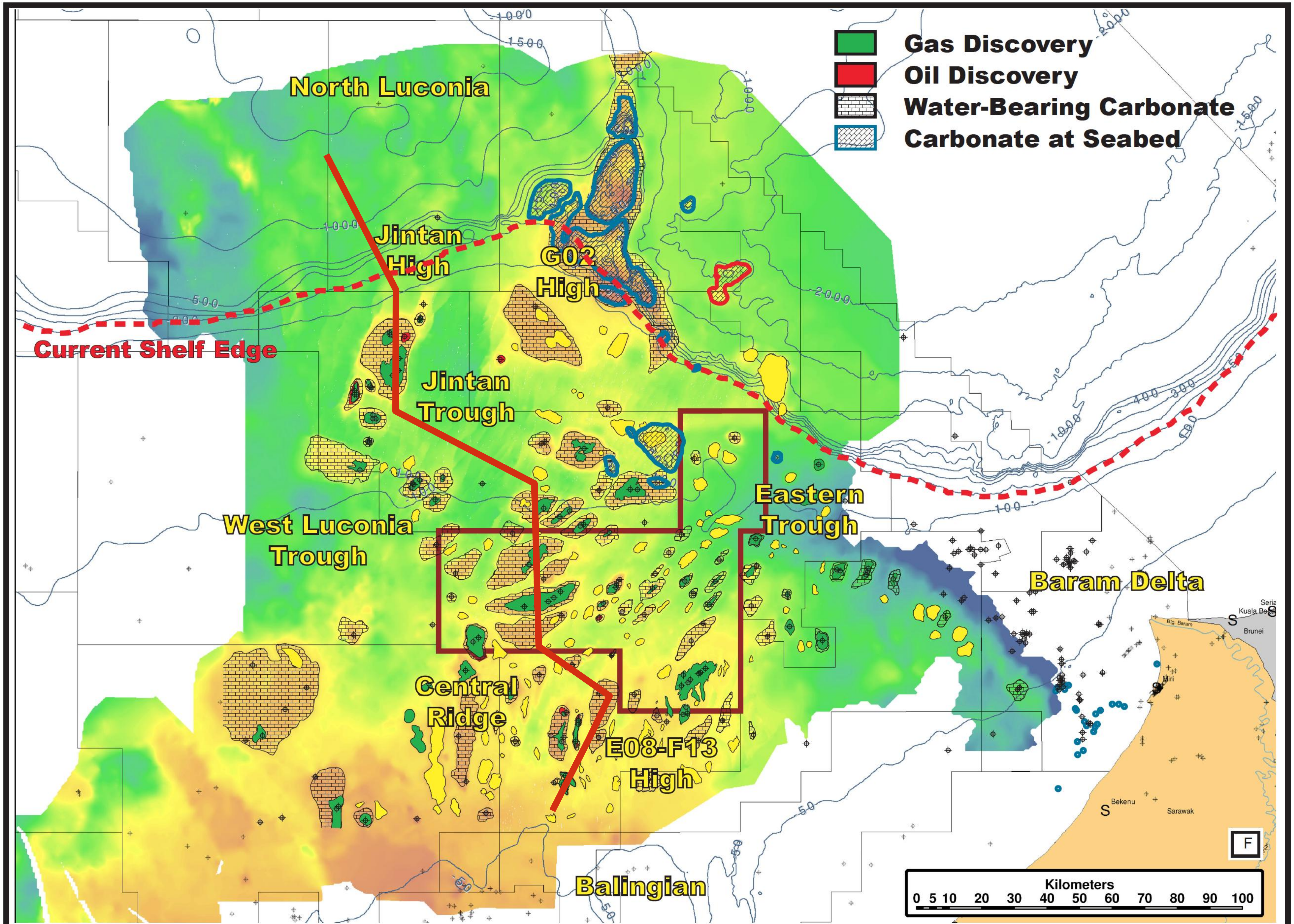
Wright and Burchette (2004), Zampetti (2010) after Epting (1980, 1989)

Overburden Stratigraphy: Single Delta, Drowned Build-Ups

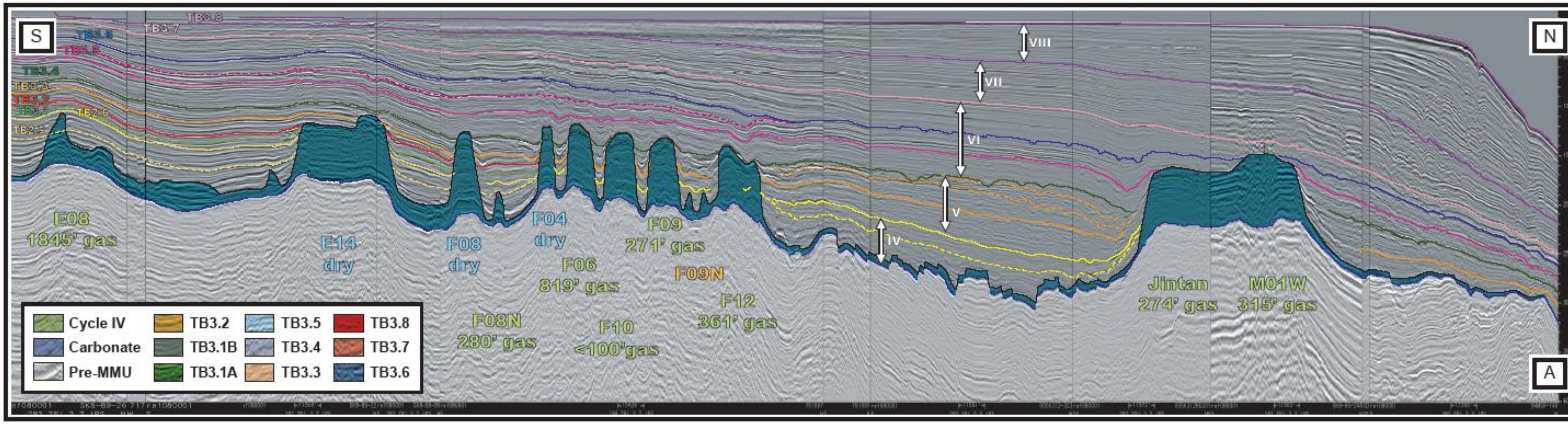
Single delta prograding over Luconia; Drowned build-ups buried under pro-delta mud

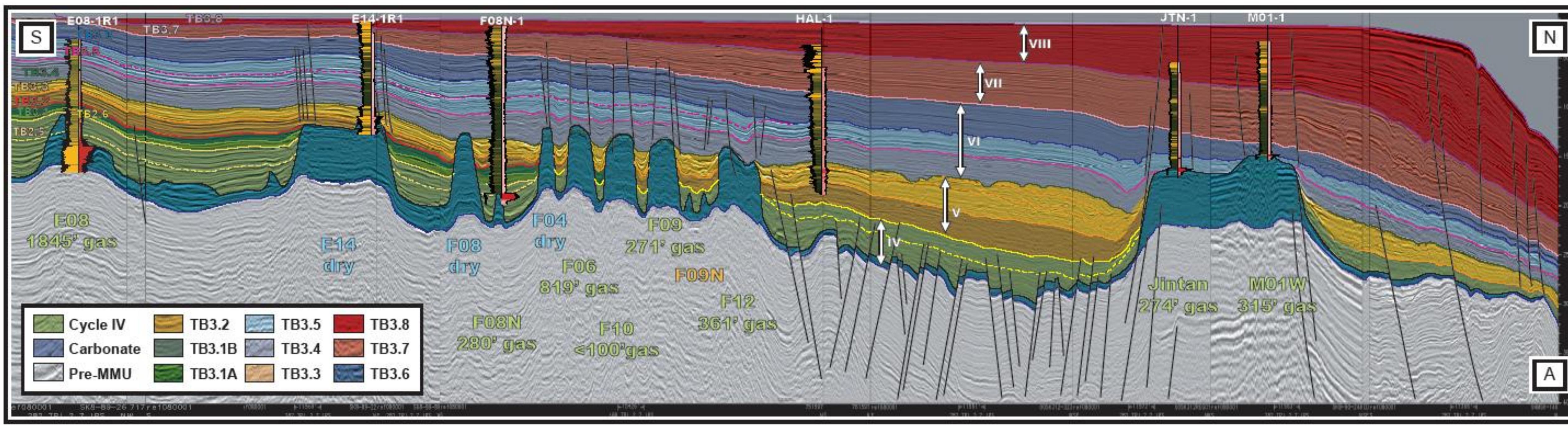


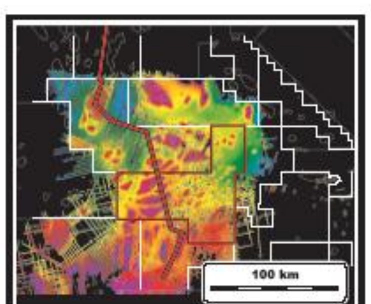
Regional Section – E08 - E14 - Central Ridge - Jintan



Regional Section – E08 - E14 - Central Ridge - Jintan

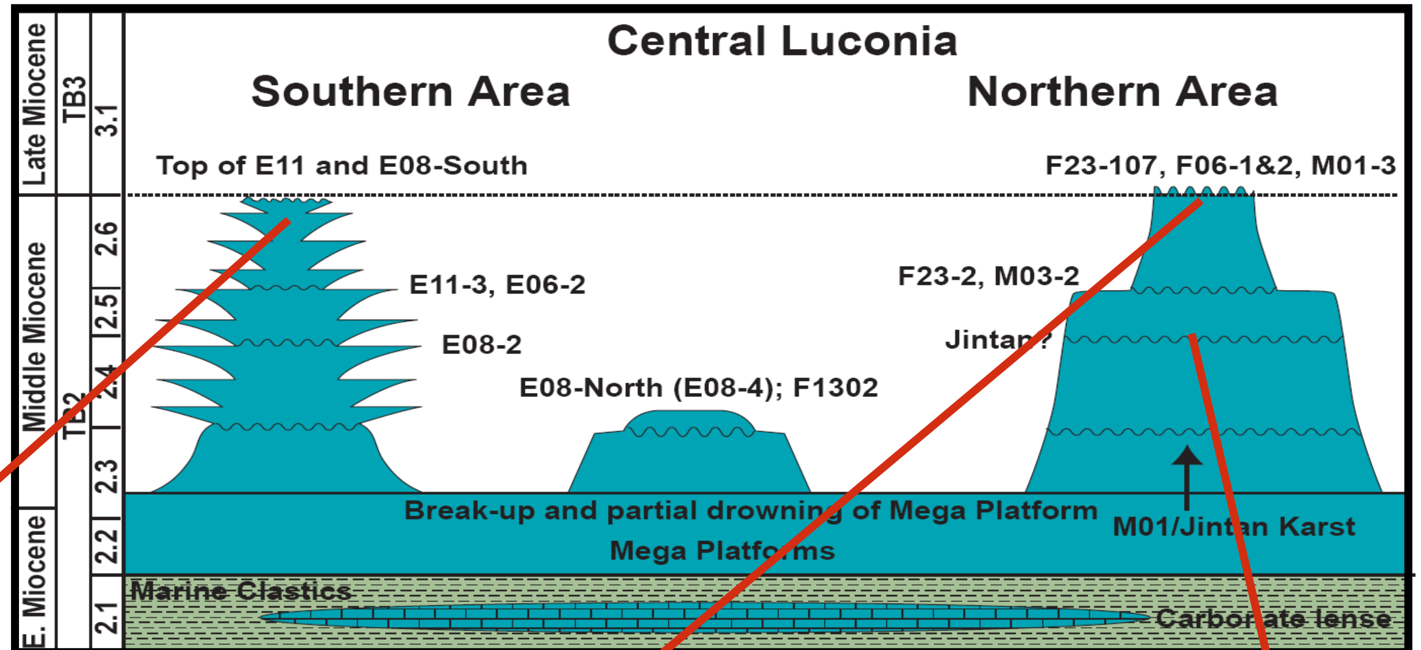




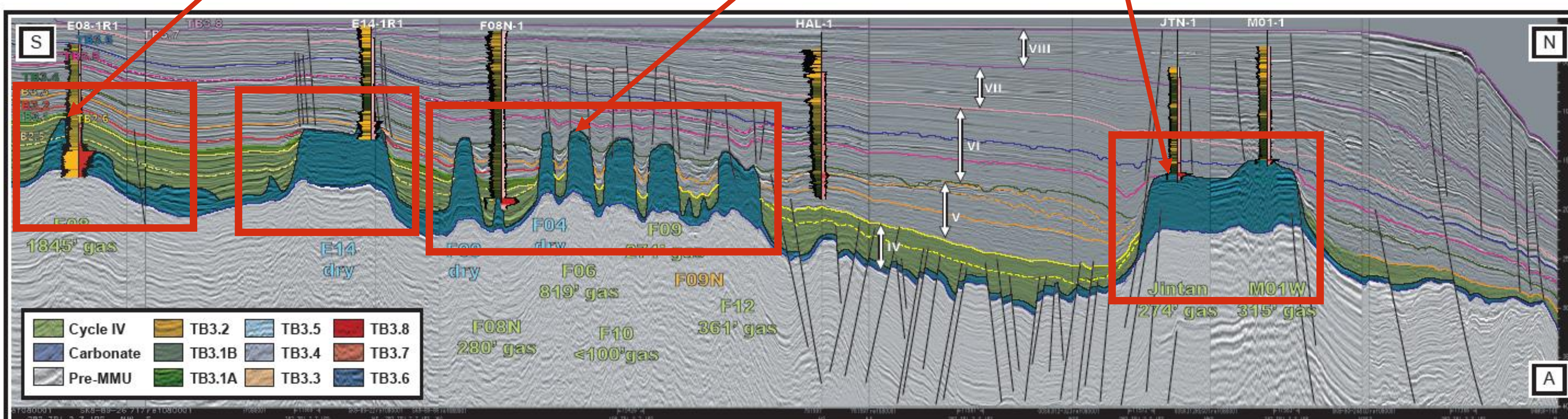


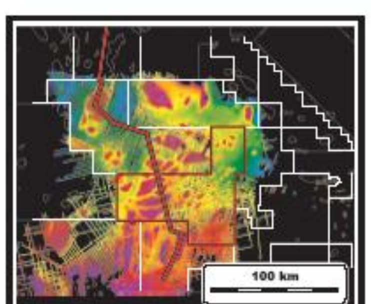
Regional section, 250km long, TWT, VE=10x. Industry-standard interpretation of the carbonate province: 'Base Carbonate' ~ Mid-Miocene Unconformity, 'Top Carbonate' delineates smooth build-ups and 'Transgressive Bank'. Overburden sequence stratigraphy subdivided into Cycles IV-VIII and TB sequences 2.5-3.8.

Regional Section – E08 - E14 - Central Ridge - Jintan



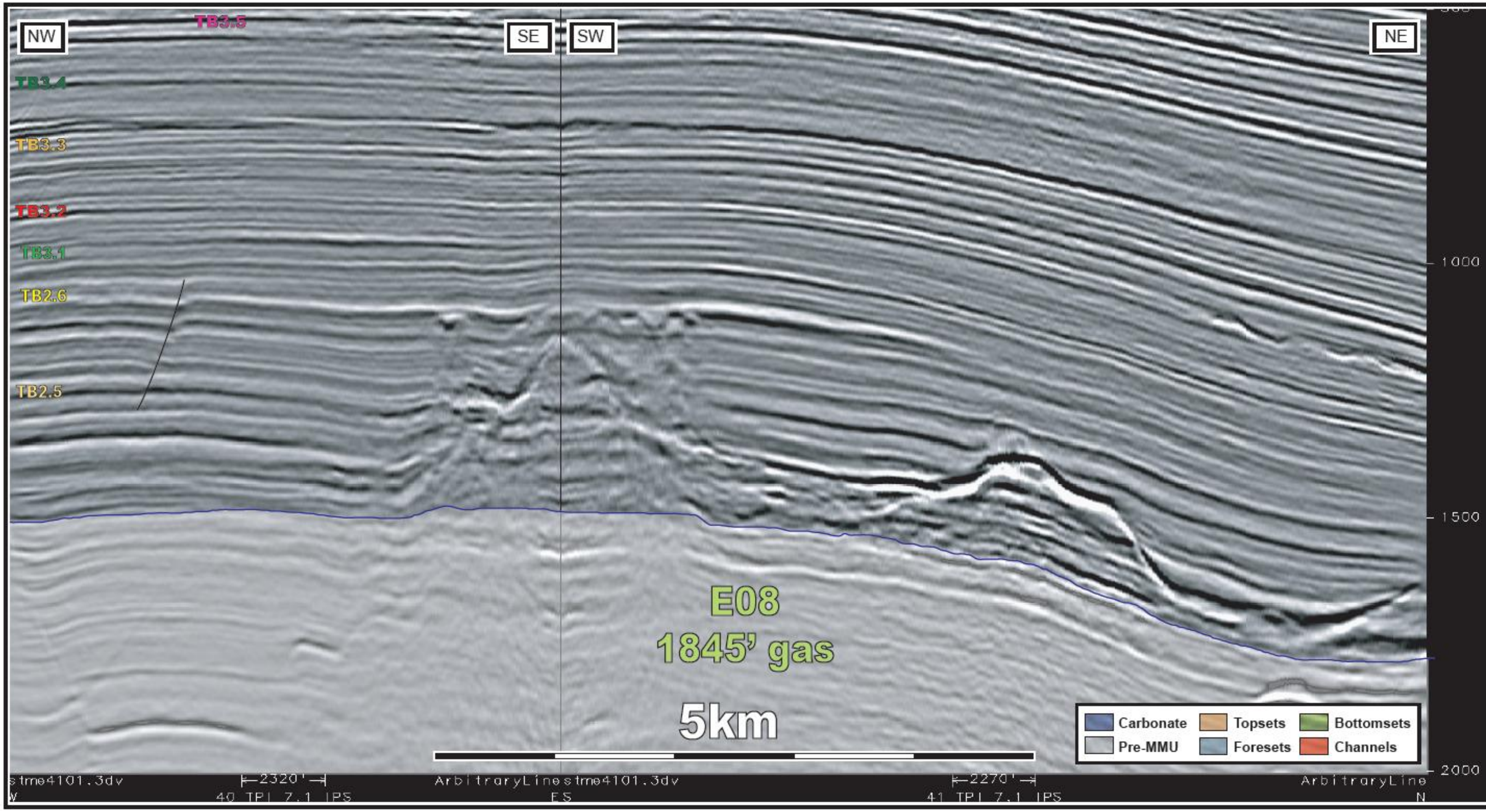
Vahrenkamp (1998)

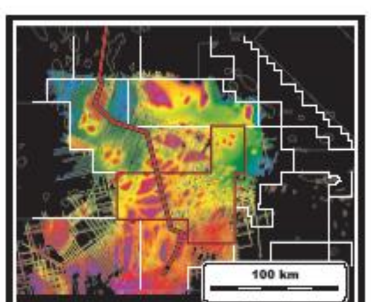


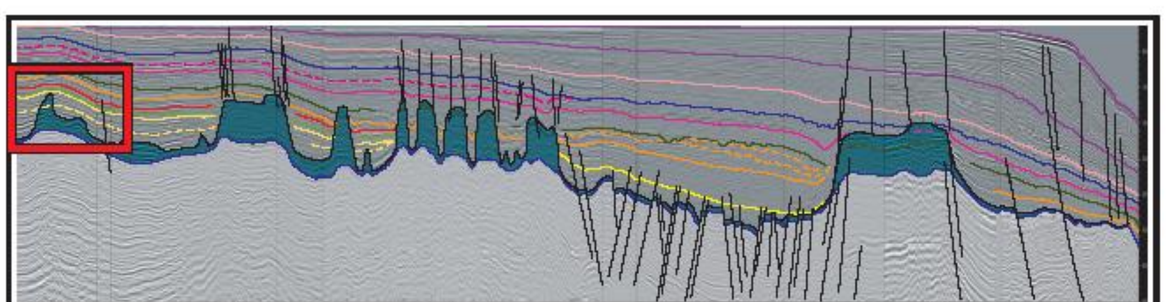


Timing of carbonate build-ups and inter-reservoir correlation based on Sr-isotope stratigraphy. All carbonate build-ups are considered to have grown within TB2, after which they are interpreted to have drowned and become buried under pro-delta 'megaforesets' and 'inter-reef prograding turbidite complexes'.

Detail: E08



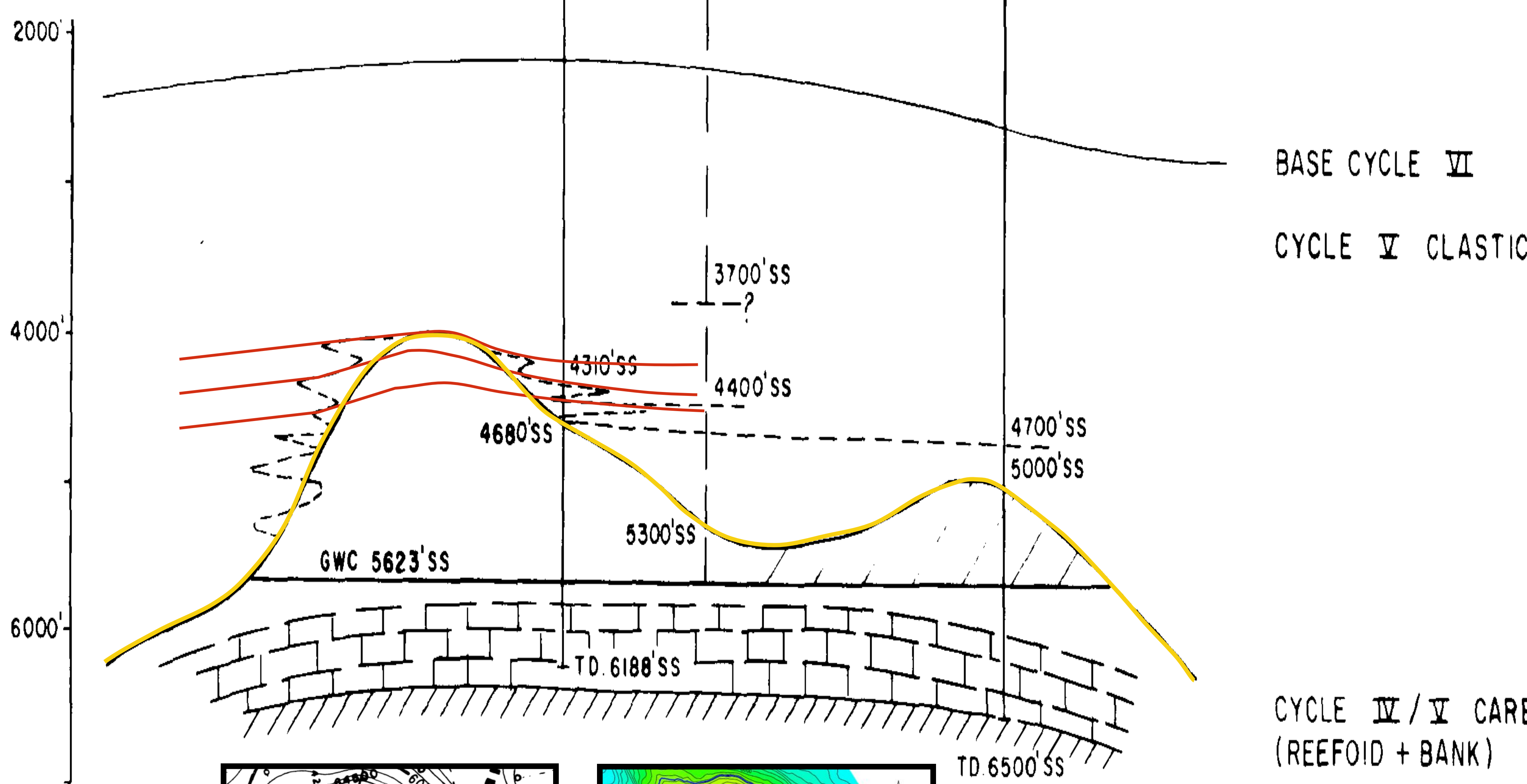


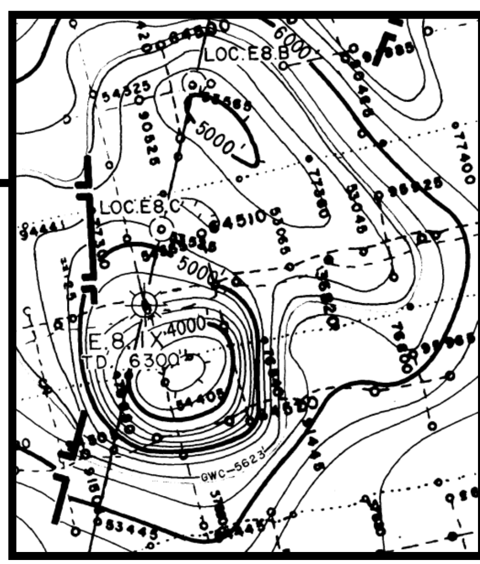


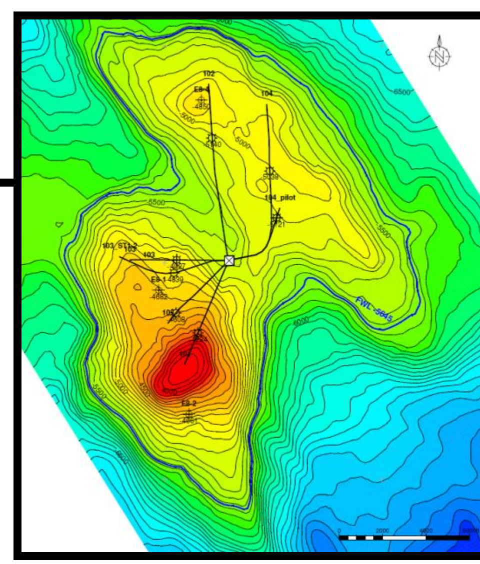
A classic 'Christmas Tree' in early models. Portrayed as a smooth mound in maps.

Detail: E08

A ‘Christmas Tree’ in early interpretations

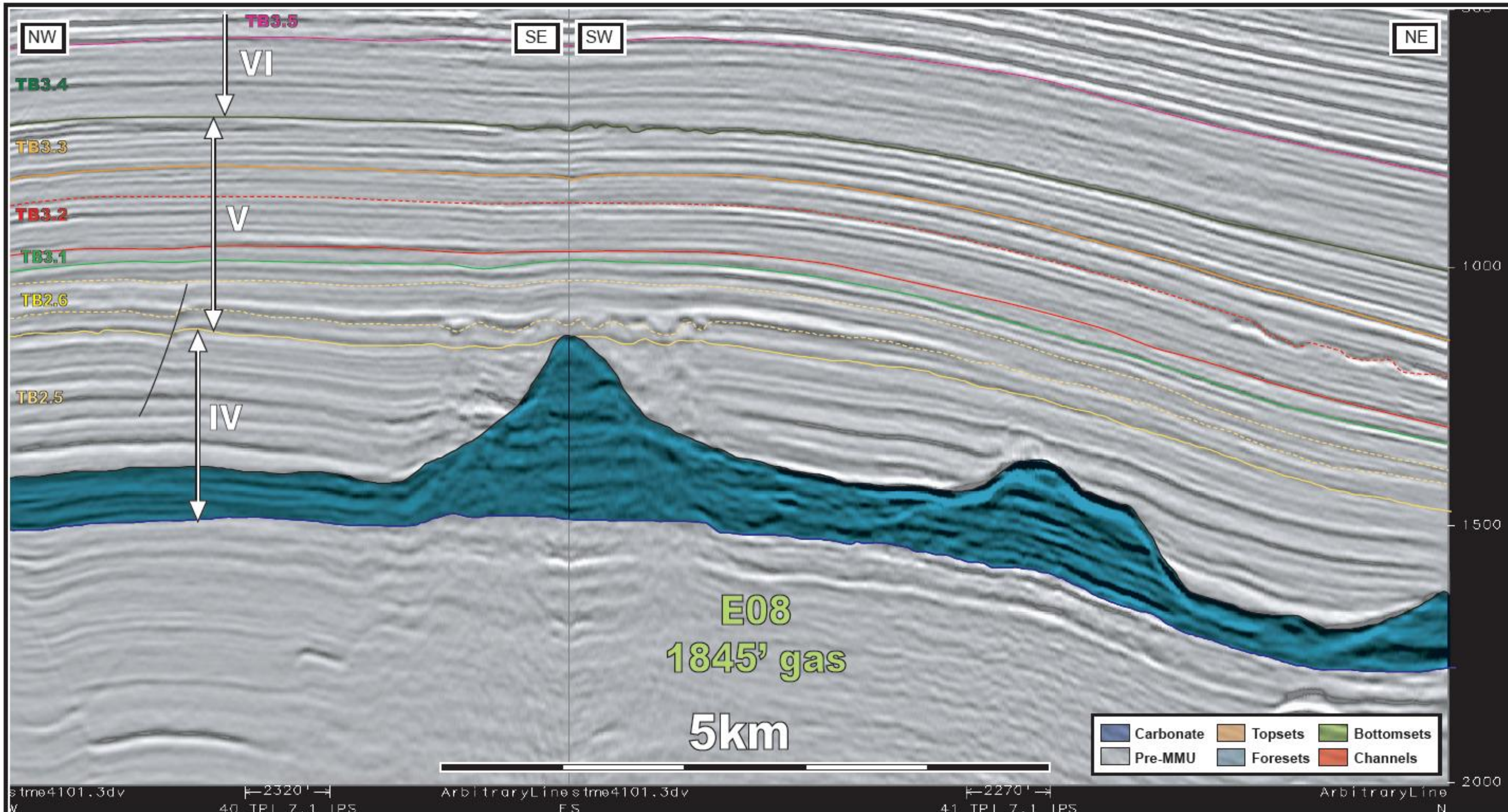


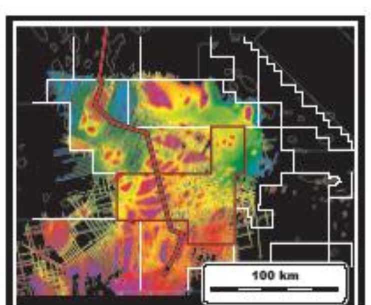


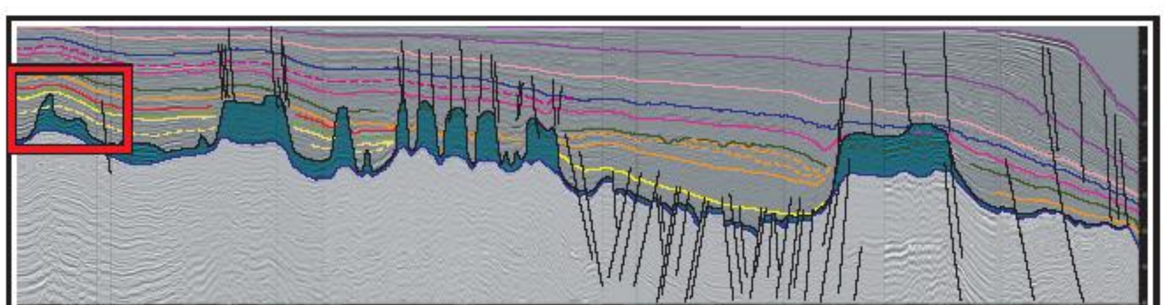


However, for practical reasons portrayed as a smooth convex structure in maps

Detail: E08

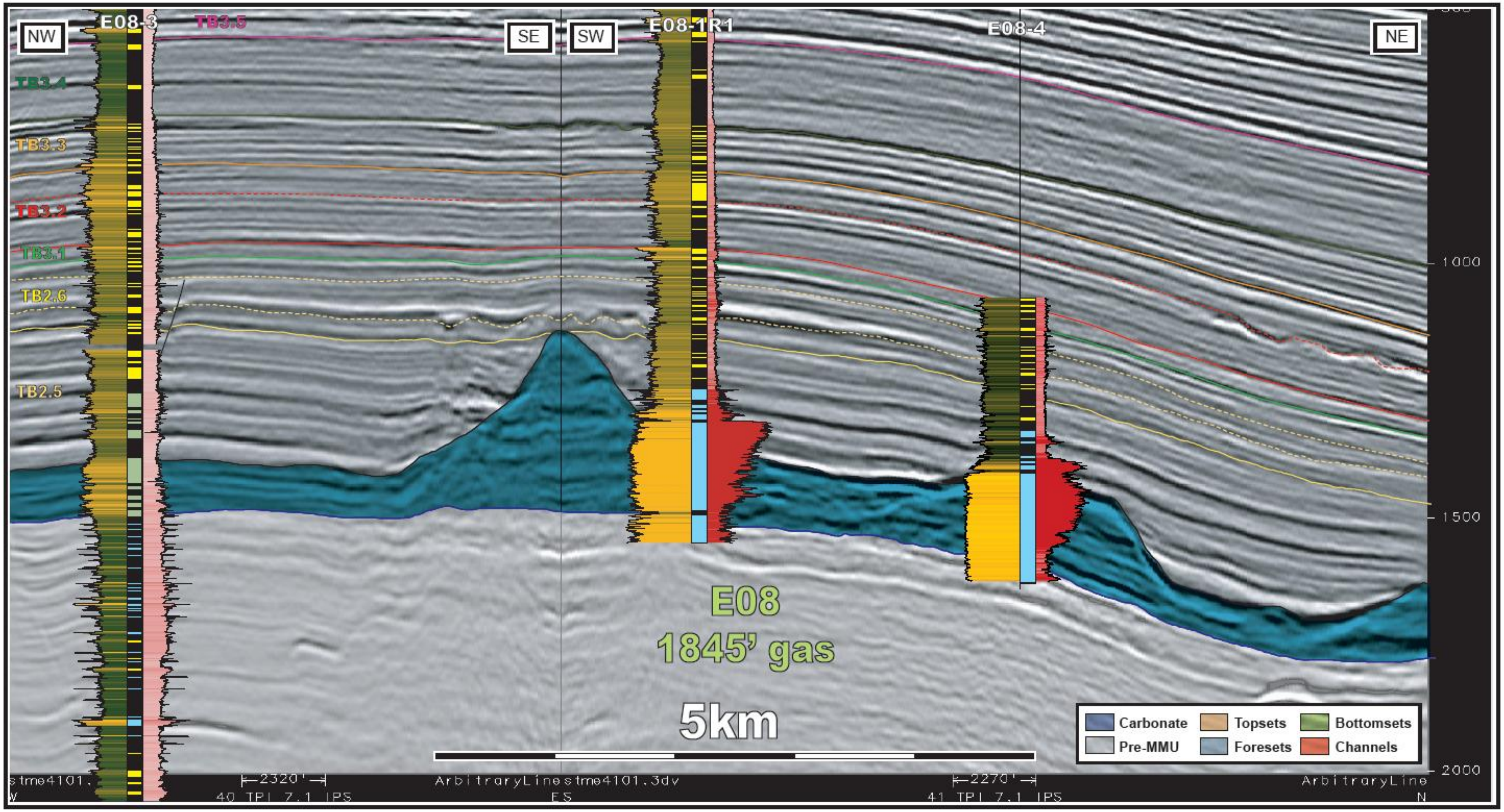


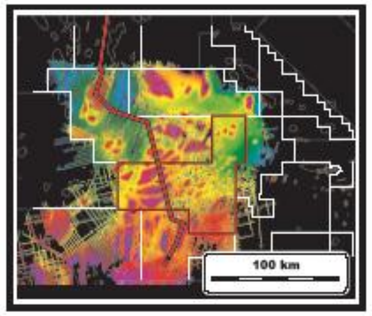


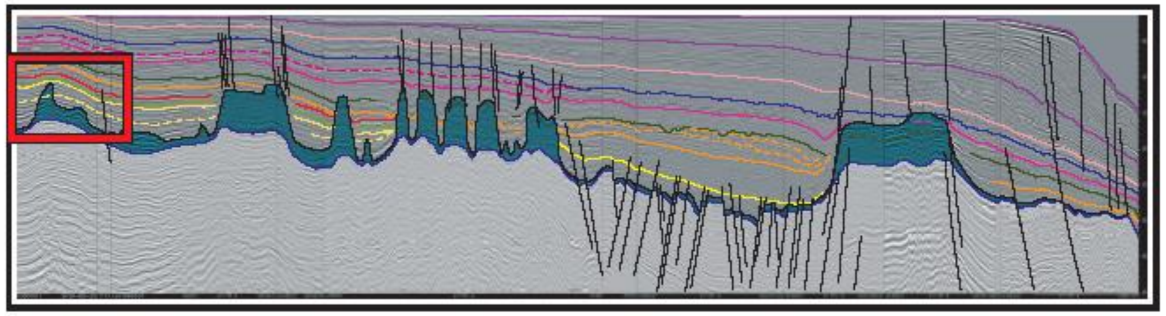


Standard interpretation. No genetic relationship between carbonates and clastics. Clastics seem most likely to post-date carbonate.

Detail: E08

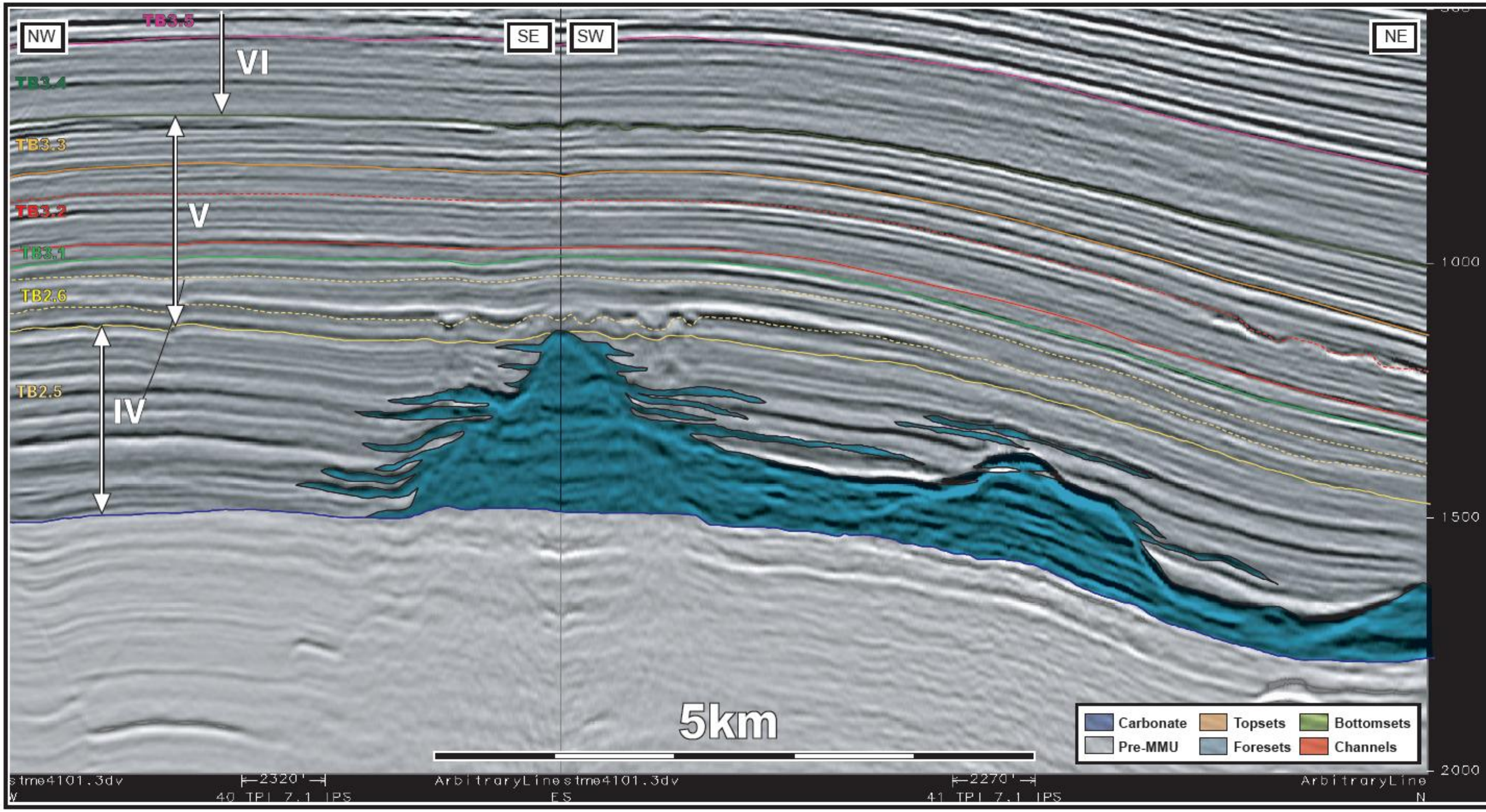


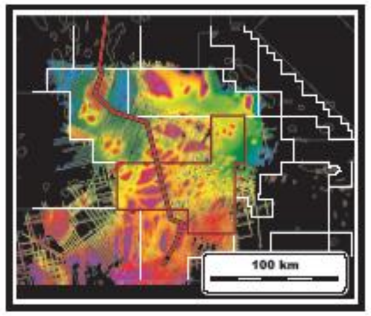


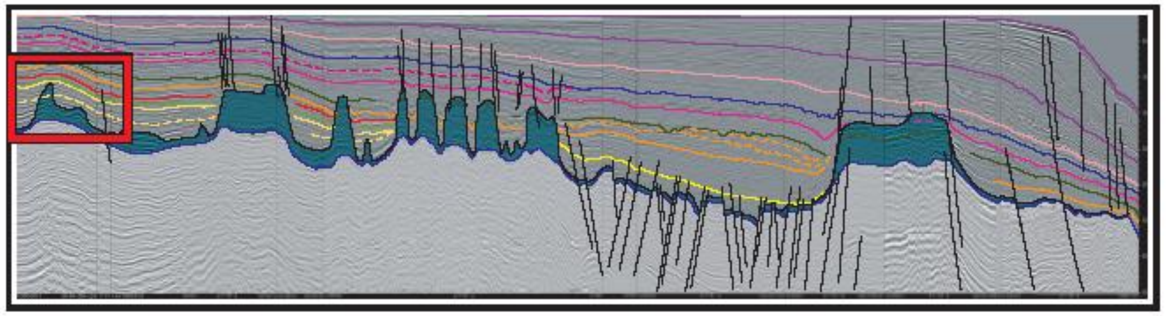


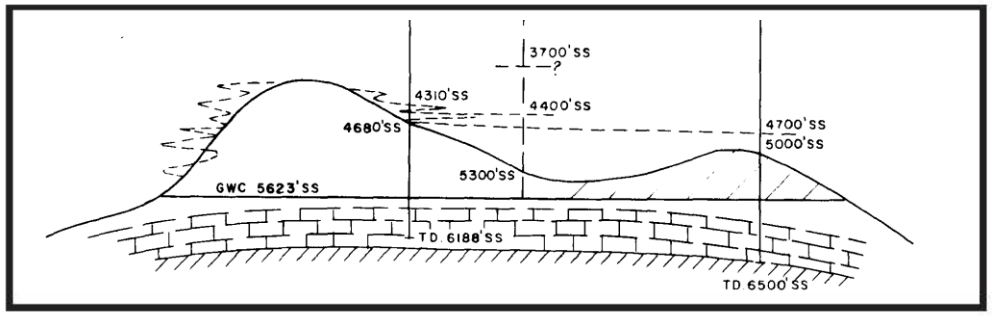
Carbonate 'stringers' and carb/clast intercalations clearly visible on seismic and in well logs. In contrast, no carbonate in E08-3.

Detail: E08

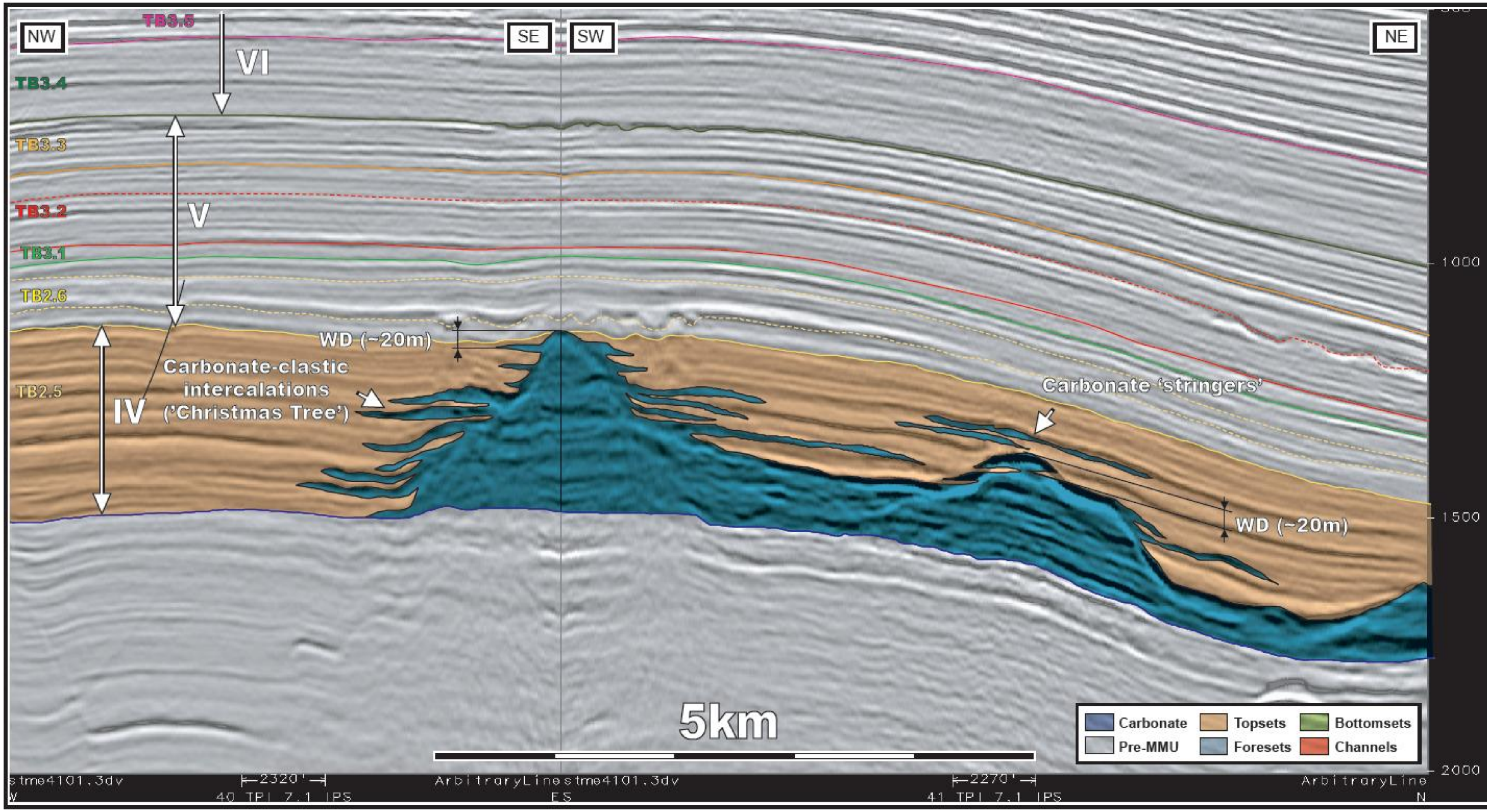

NW
SE
SW
NE
TB3.5
VI
TB3.4
TB3.3
V
TB3.2
TB3.1
TB2.6
TB2.5
IV
1000
1500
2000
5km
Carbonate
Topsets
Bottomsets
Pre-MMU
Foresets
Channels
stme4101.3dv
2320'
40 TPI 7.1 IPS
ArbitraryLinestme4101.3dv
2270'
41 TPI 7.1 IPS
ArbitraryLine

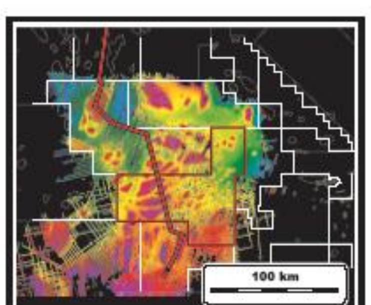

100 km

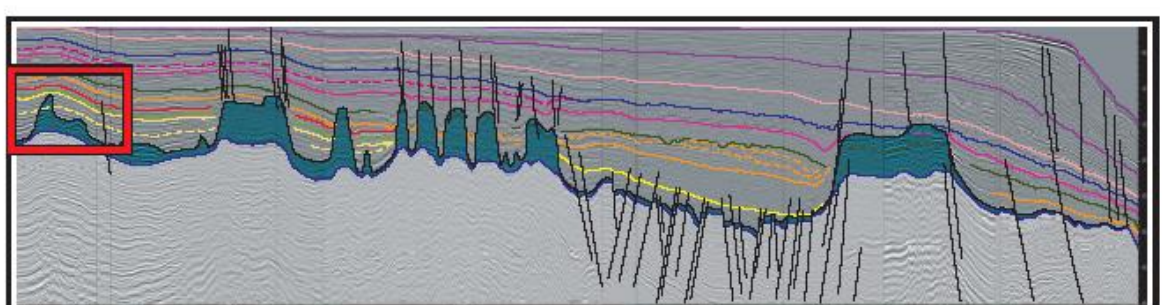



3700'SS
4310'SS
4400'SS
4680'SS
4700'SS
5000'SS
5300'SS
GWC 5623'SS
TD 6188'SS
TD 6500'SS

Detail: E08

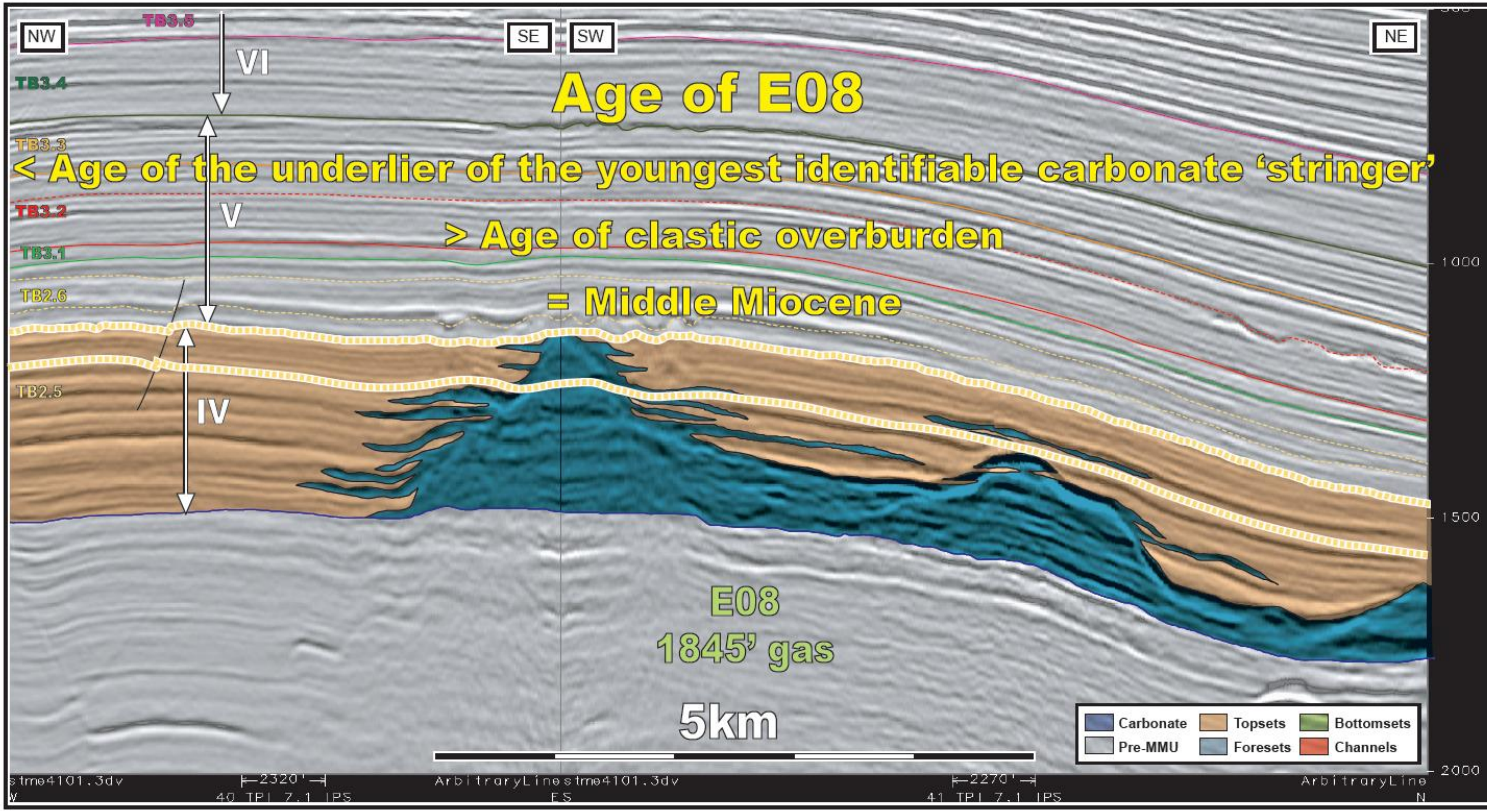


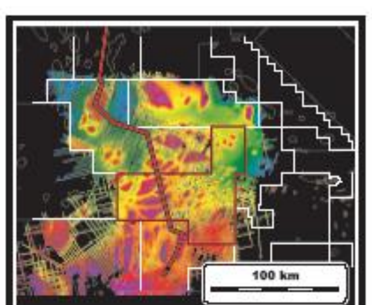


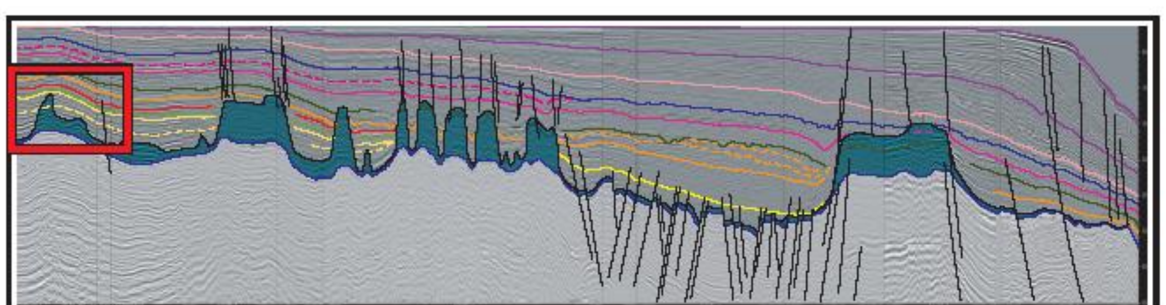


Depth to carbonate stringers and thickness of carbonate grown over clastics provide information on palaeobathymetry (shallow).

Detail: E08

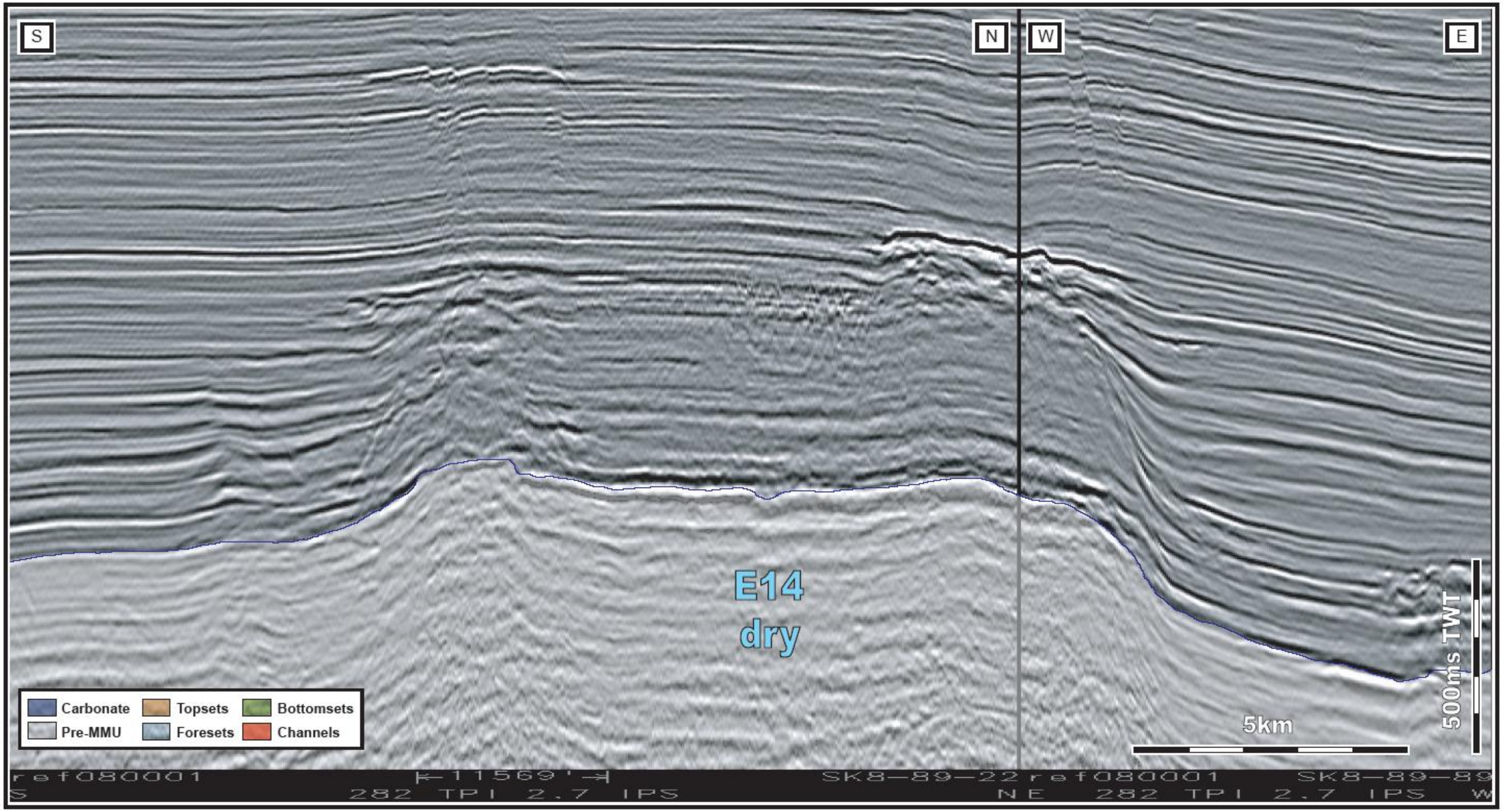


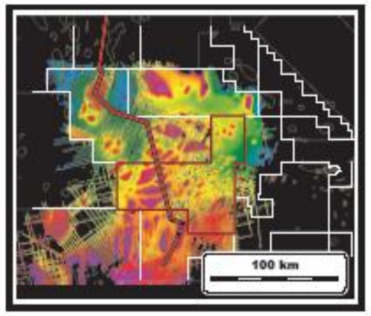


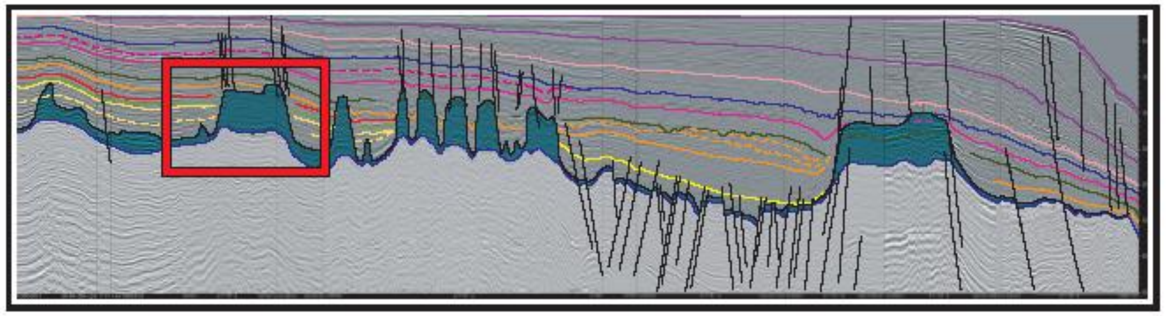


Carbonate/clastic intercalations can be used for precise dating of carbonate through clastic biostratigraphy.

Detail: E14

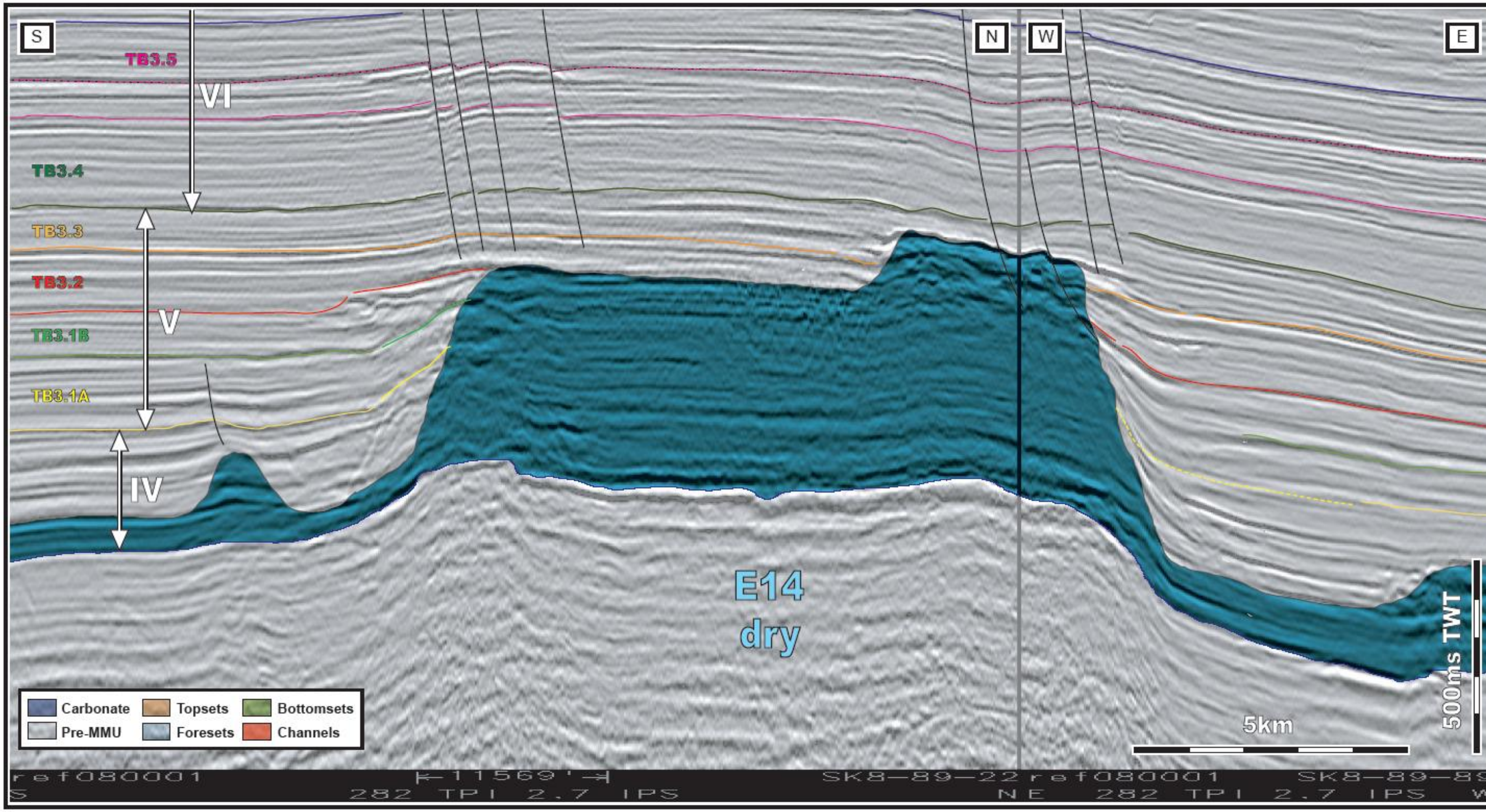


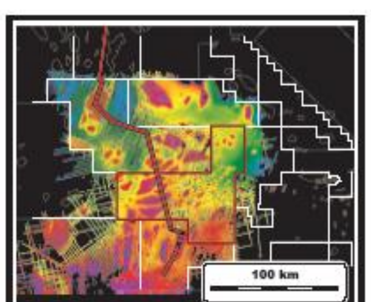


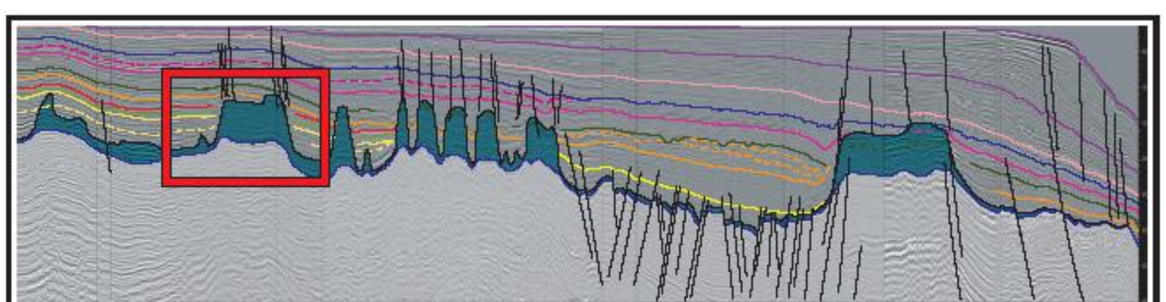


A large platform, not much studied since it does not contain hydrocarbons.

Detail: E14

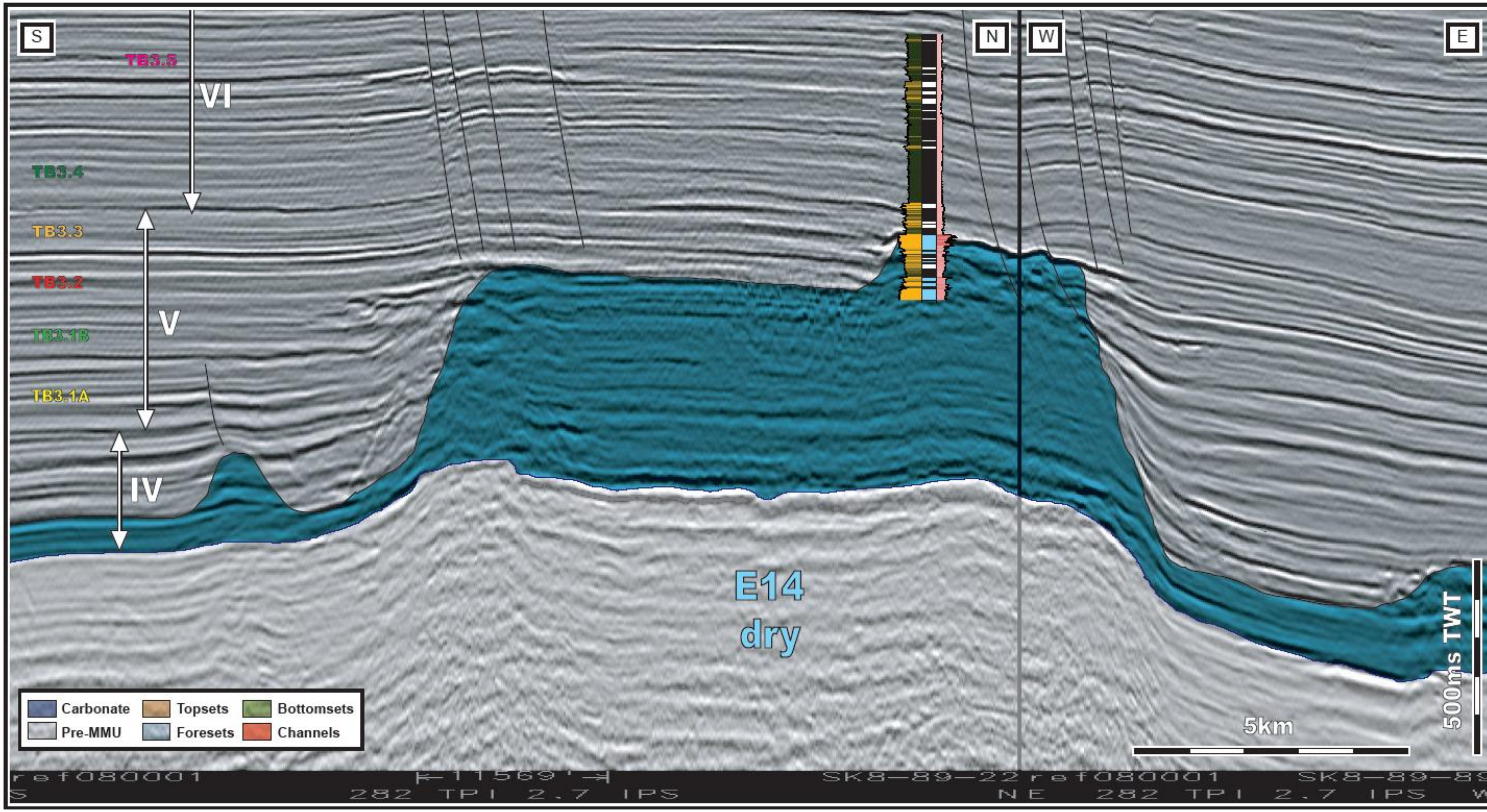


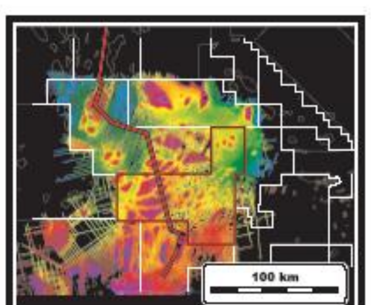


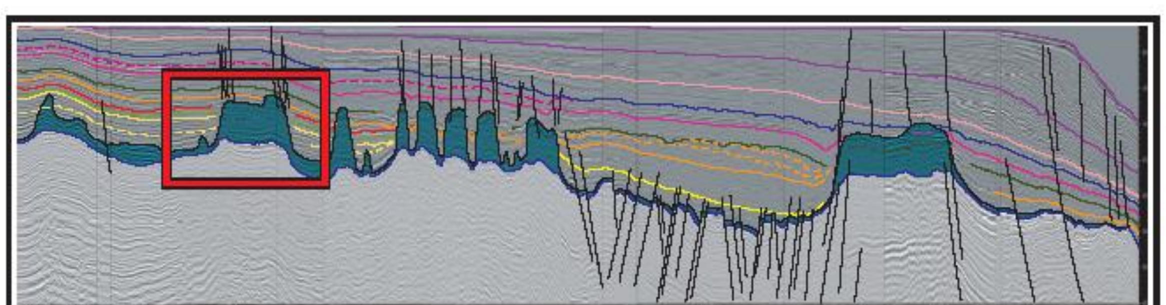


Industry-standard interpretation. Steep-walled, high-relief, flat-topped platform. No relationship between carbonates and clastics.

Detail: E14

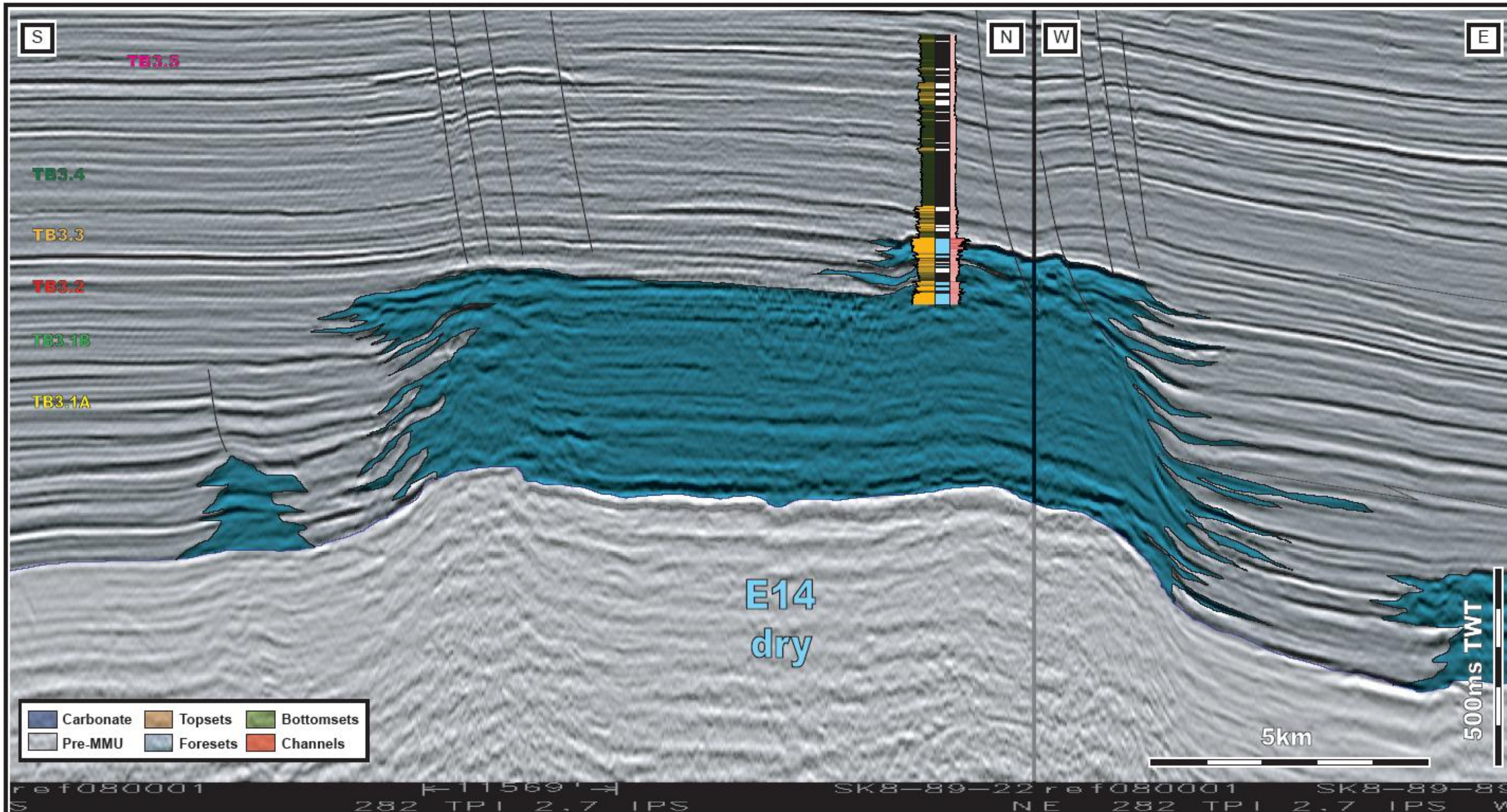


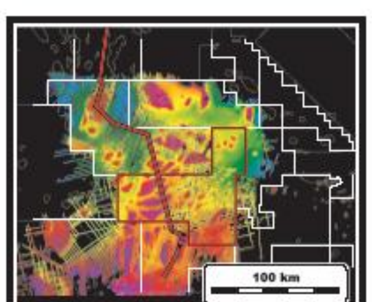


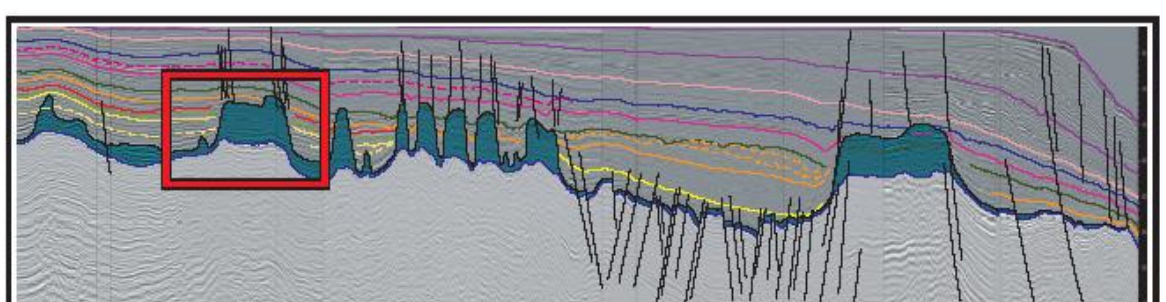


Clinoforms and 'wings' extending from the platform clearly visible on seismic. F14-1 well penetrated carbonate grown over clastics.

Detail: E14

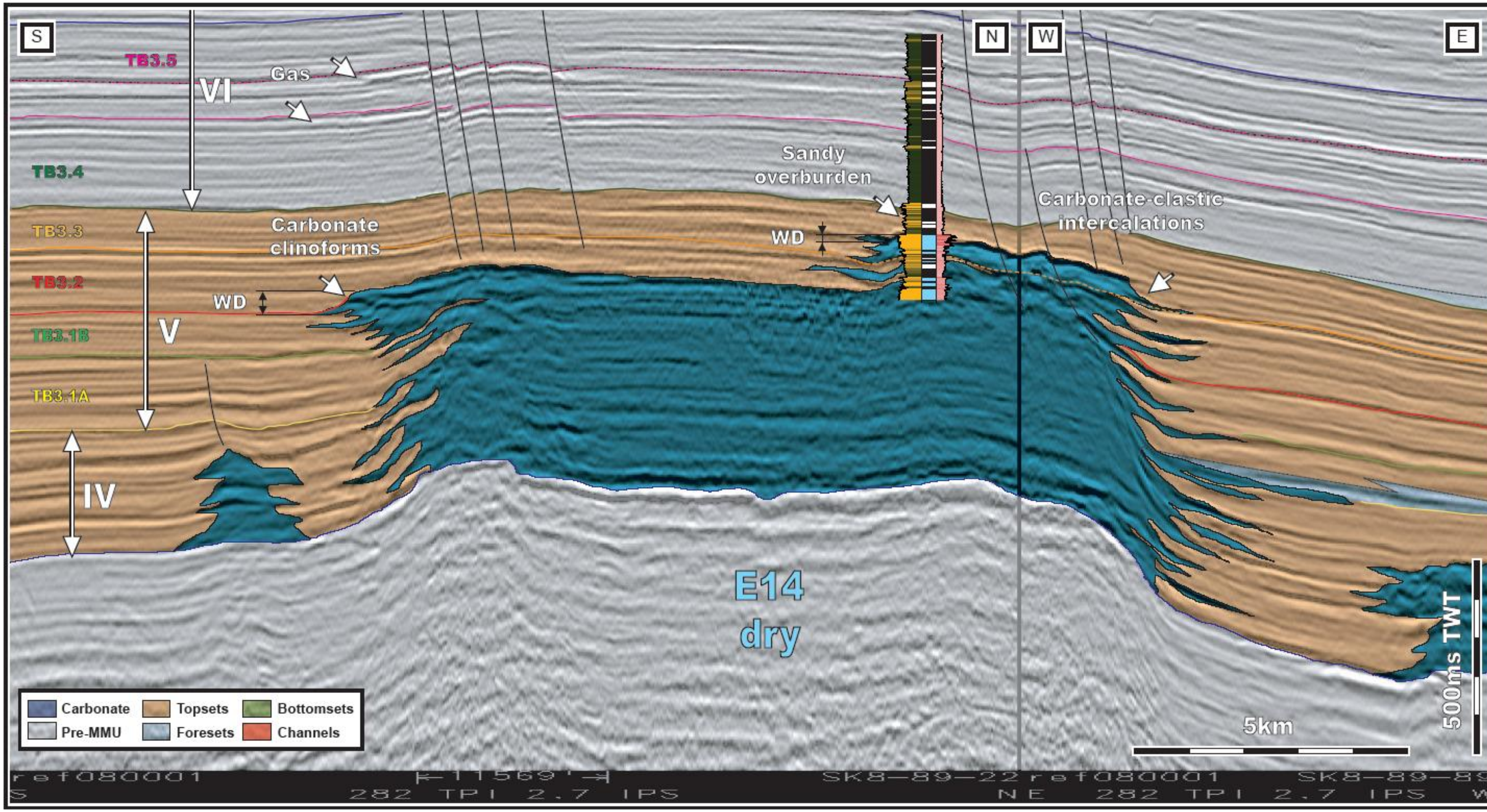


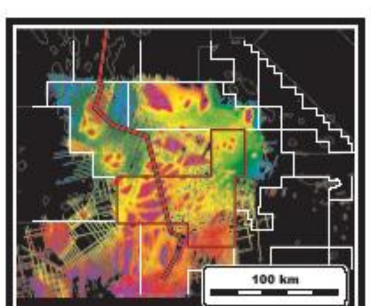


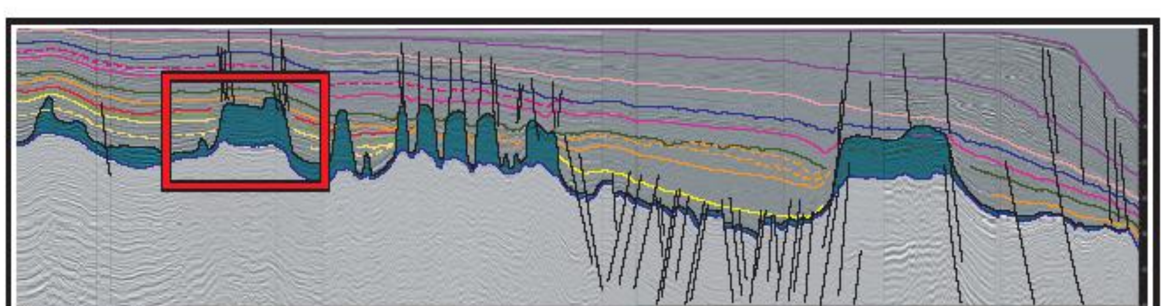


Clinoforms and ‘wings’ extending from the platform clearly visible on seismic. E14 well penetrated carbonate grown over clastics.

Detail: E14

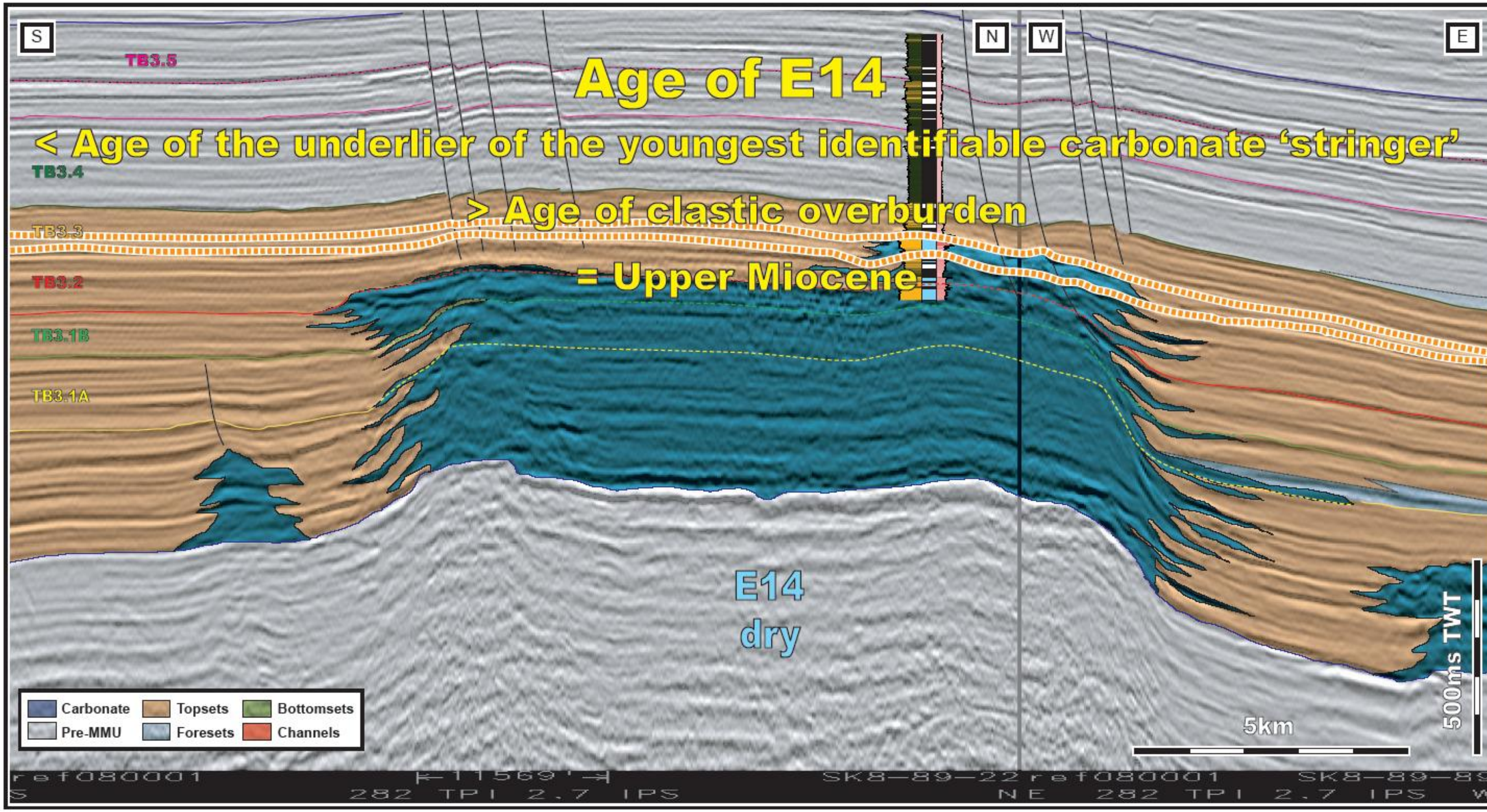


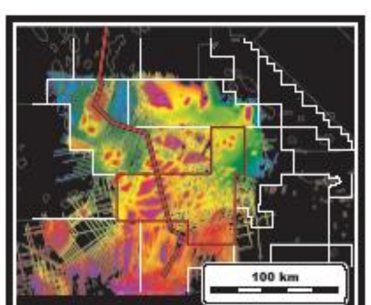


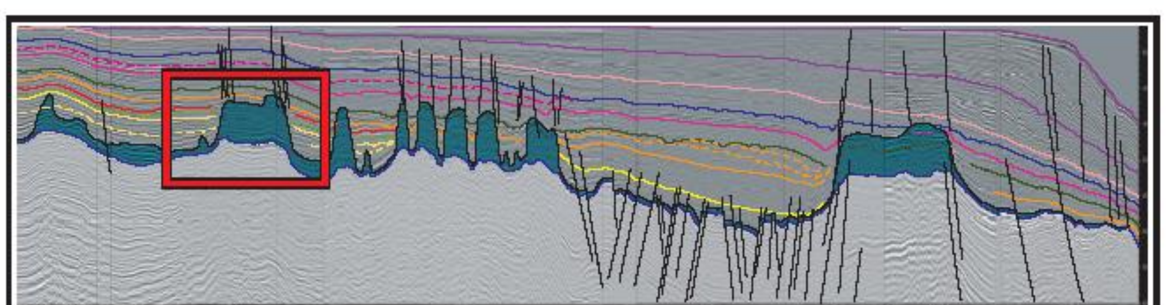


Carbonate clinoforms and thickness of carbonate grown over clastics provide information on palaeobathymetry (shallow).

Detail: E14

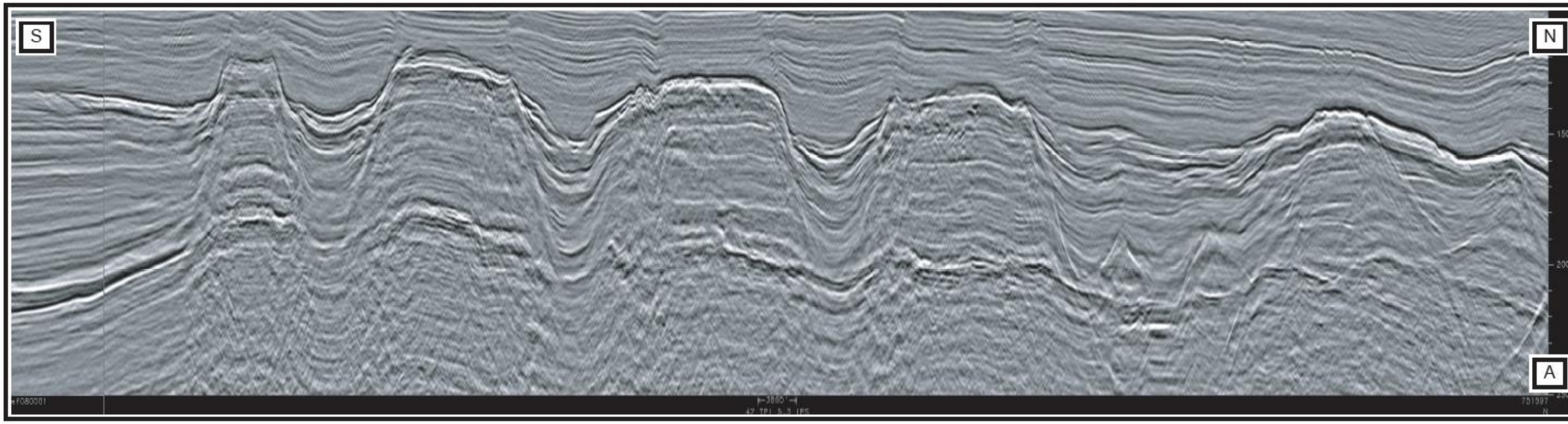


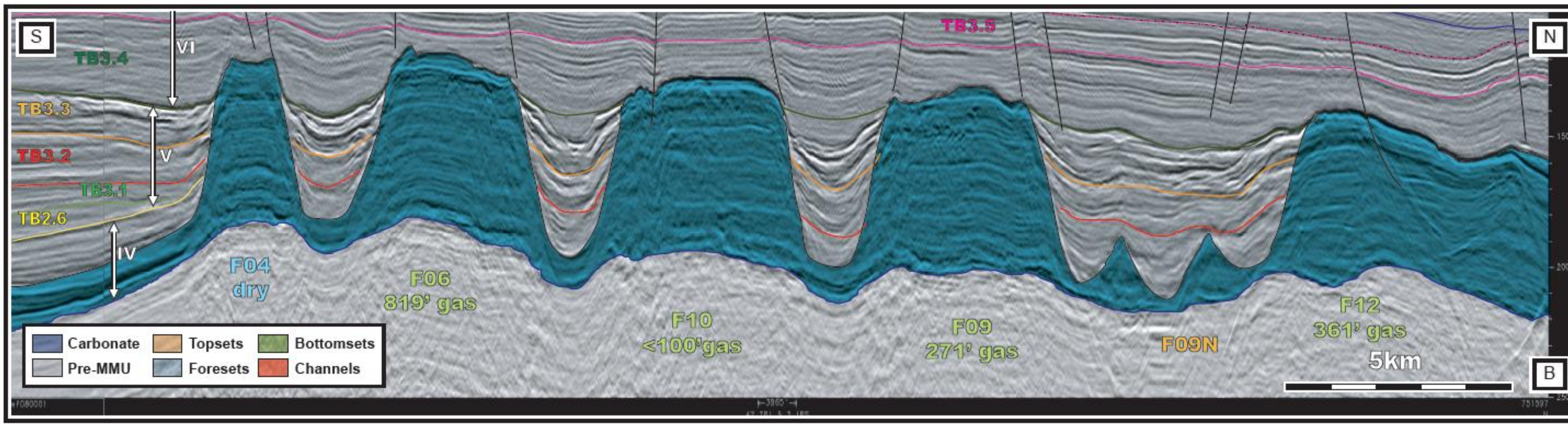


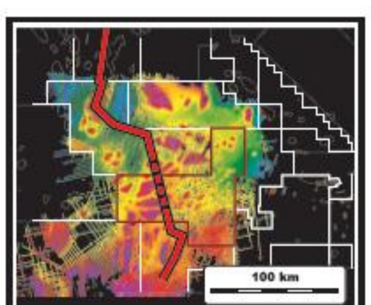


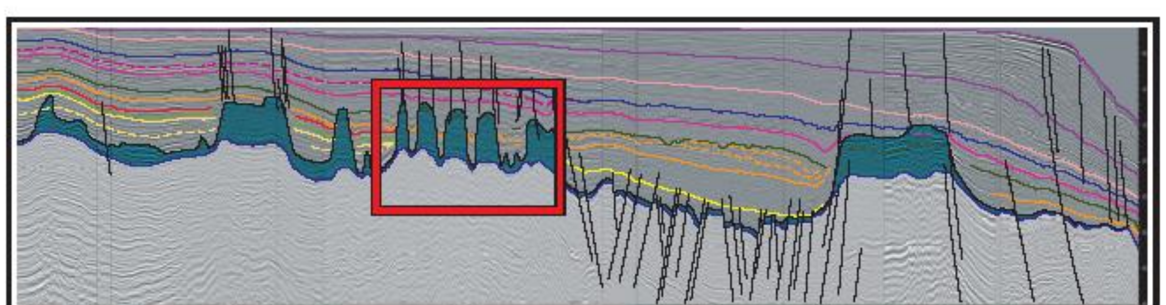
Carbonate/clastic intercalations can be used for precise dating of carbonate through clastic biostratigraphy.

Detail: Central Ridge



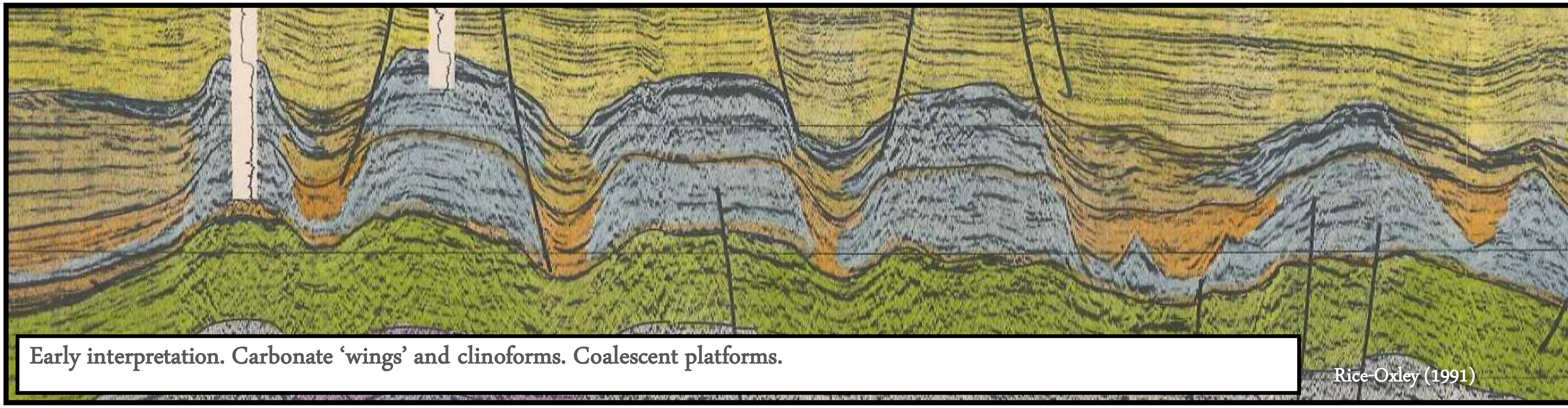




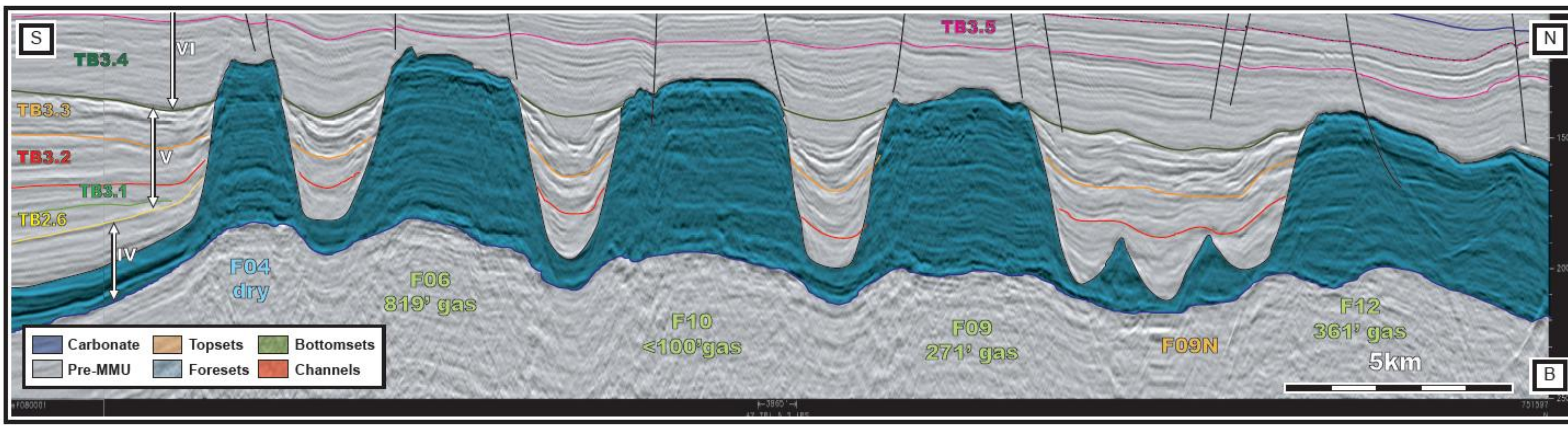


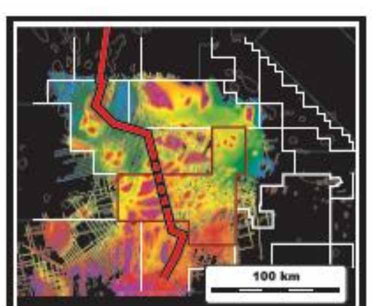
High-relief carbonate platforms on a regional high. Numerous gas fields with thin columns. Pressure communication between build-ups.

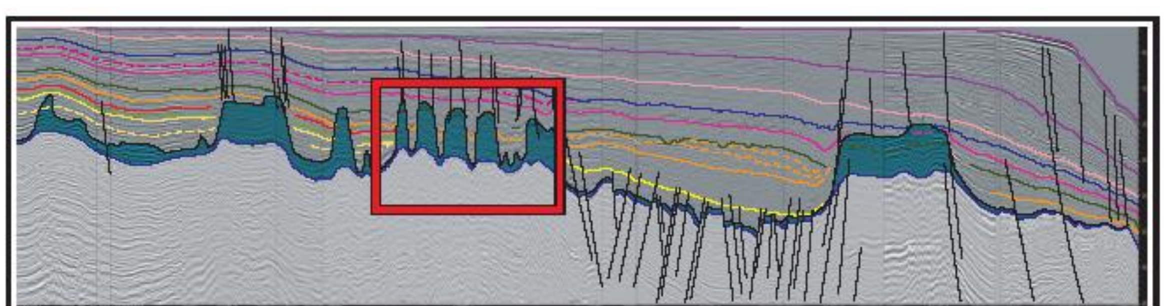
Detail: Central Ridge



Early interpretation. Carbonate 'wings' and clinoforms. Coalescent platforms.

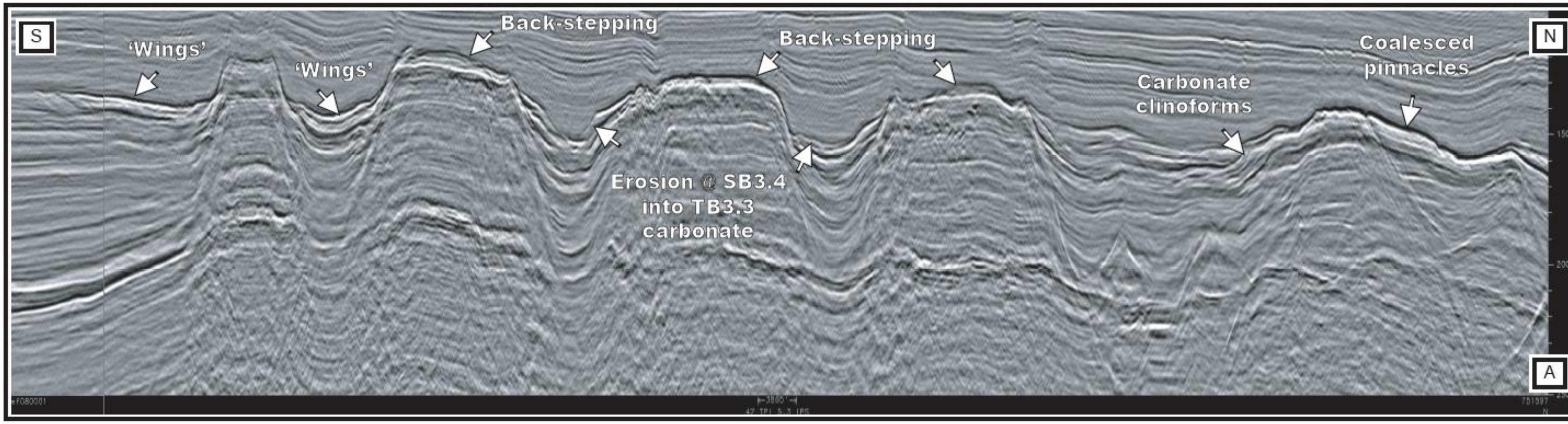


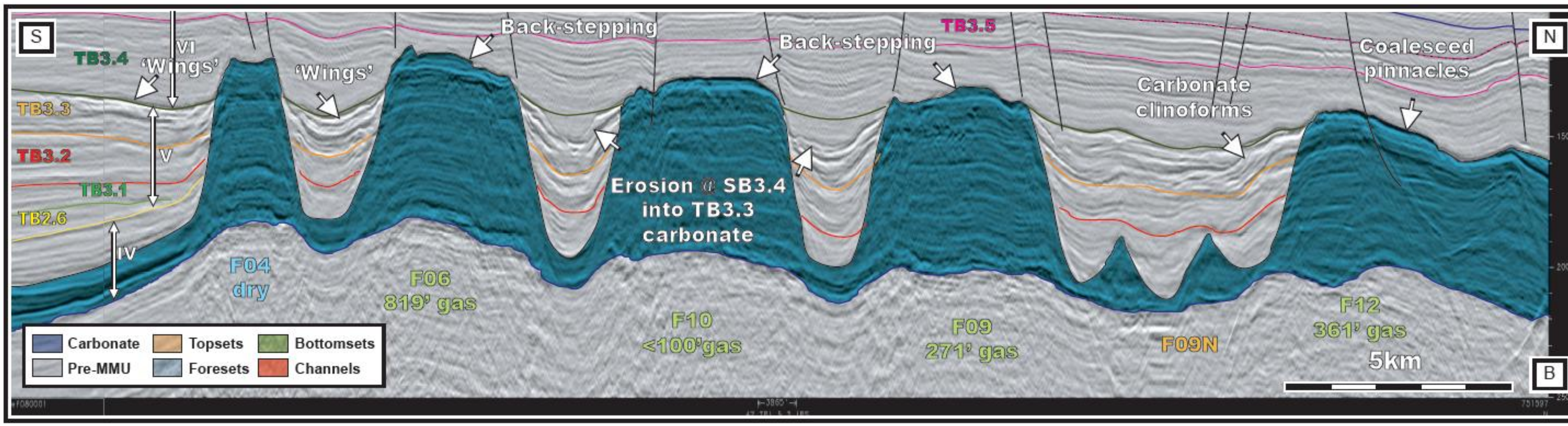


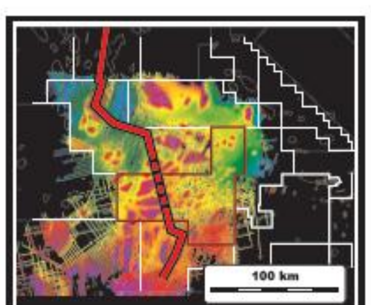


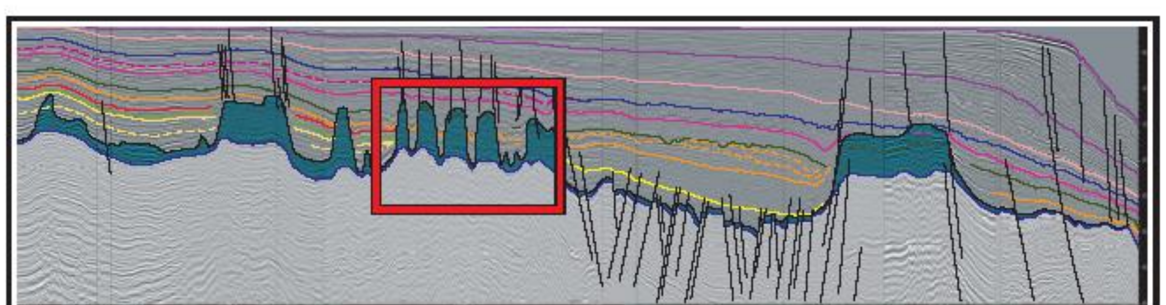
Industry-standard interpretation. Steep-walled, high-relief, flat-topped platforms. No relationship between carbonates and clastics.

Detail: Central Ridge



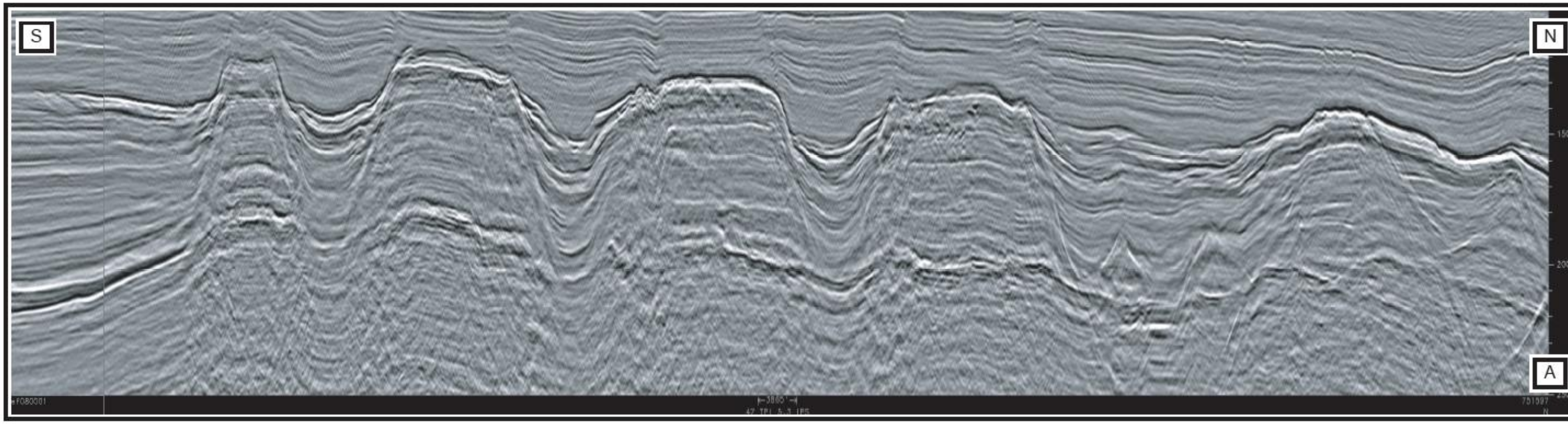


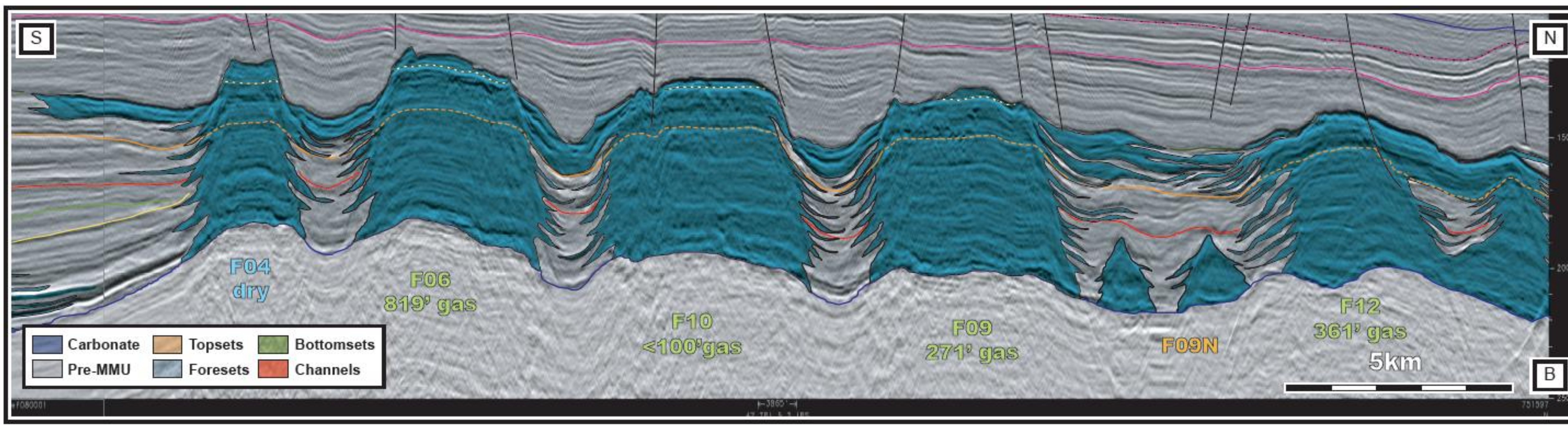


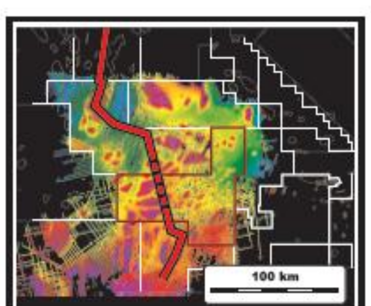


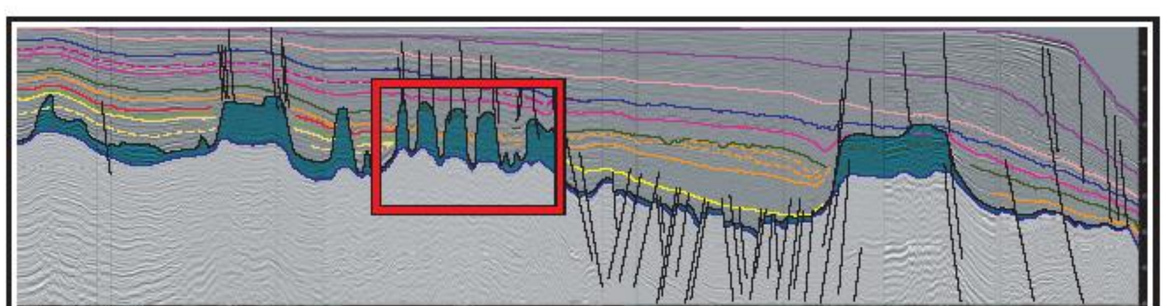
Carbonate clinoforms and 'wings' clearly visible on seismic, as is coalescence of isolated build-ups. Erosion (120m) into carbonate.

Detail: Central Ridge









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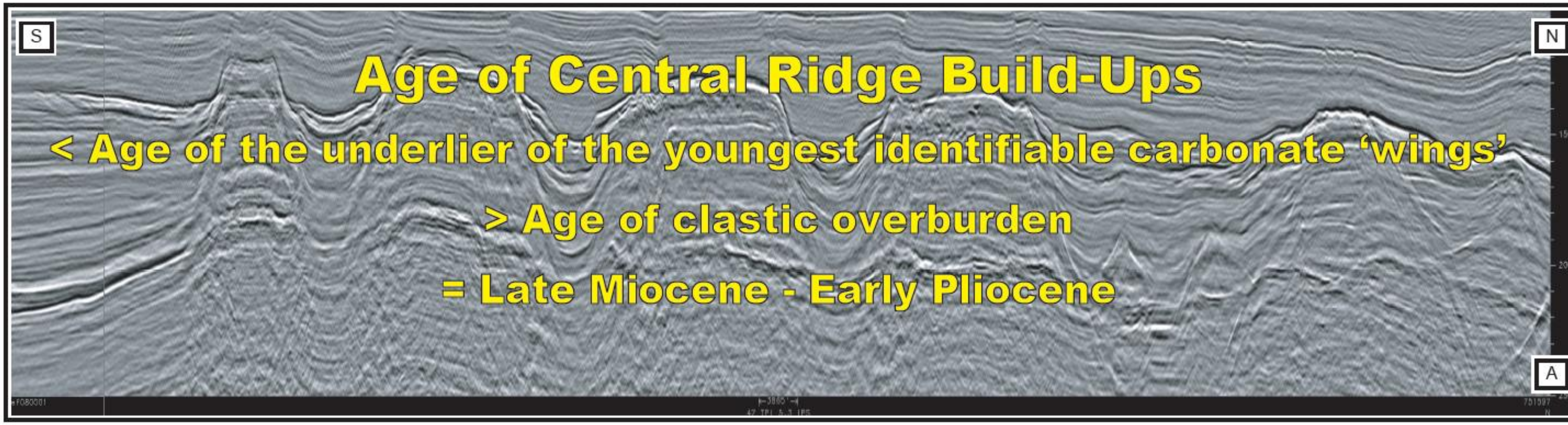
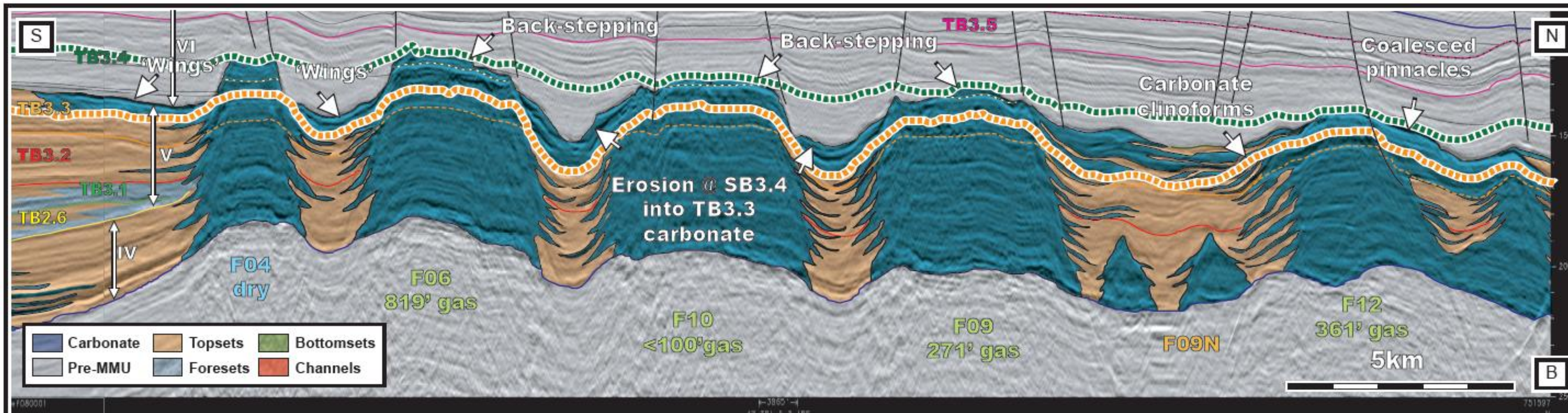
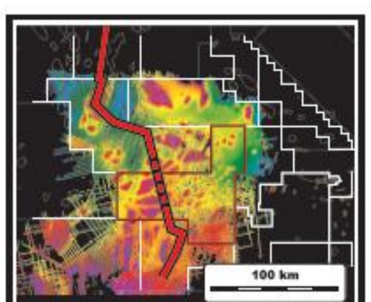
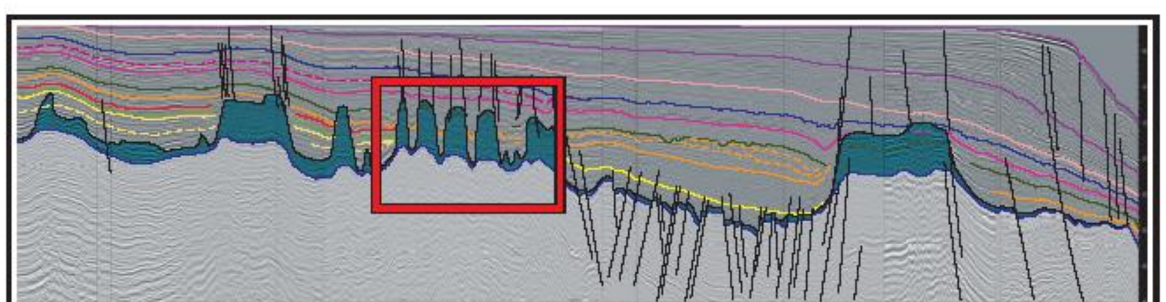


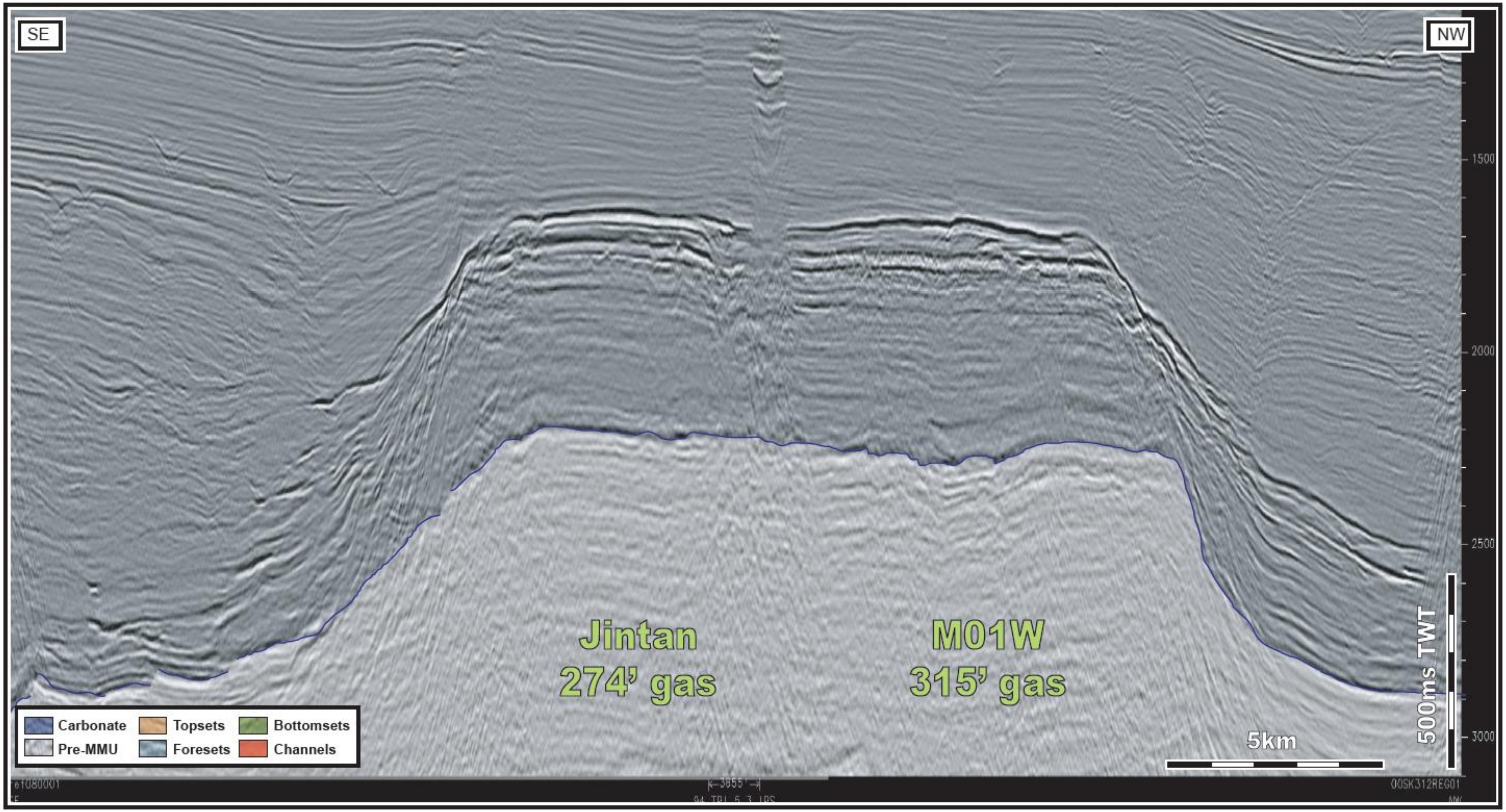


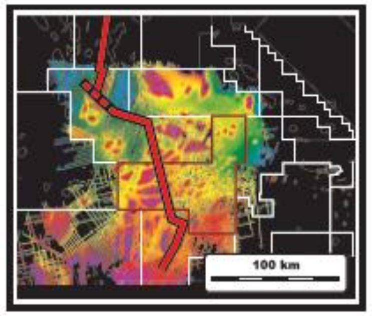


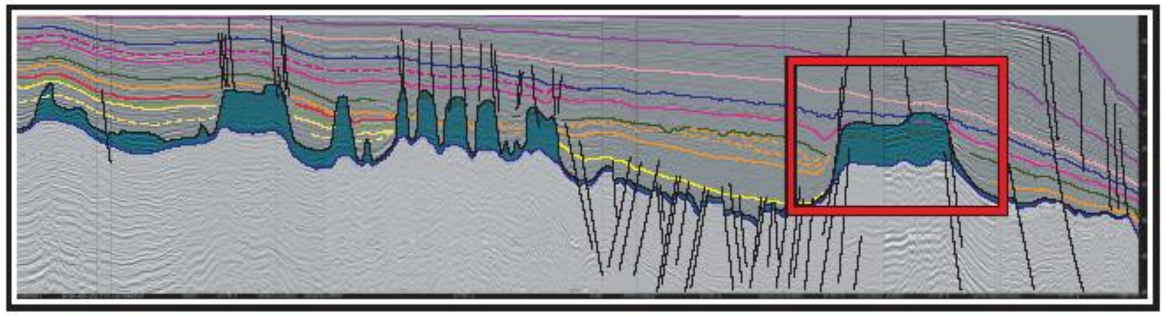


Carbonate/clastic intercalations can be used for precise dating of carbonate through clastic biostratigraphy.

Detail: Jintan

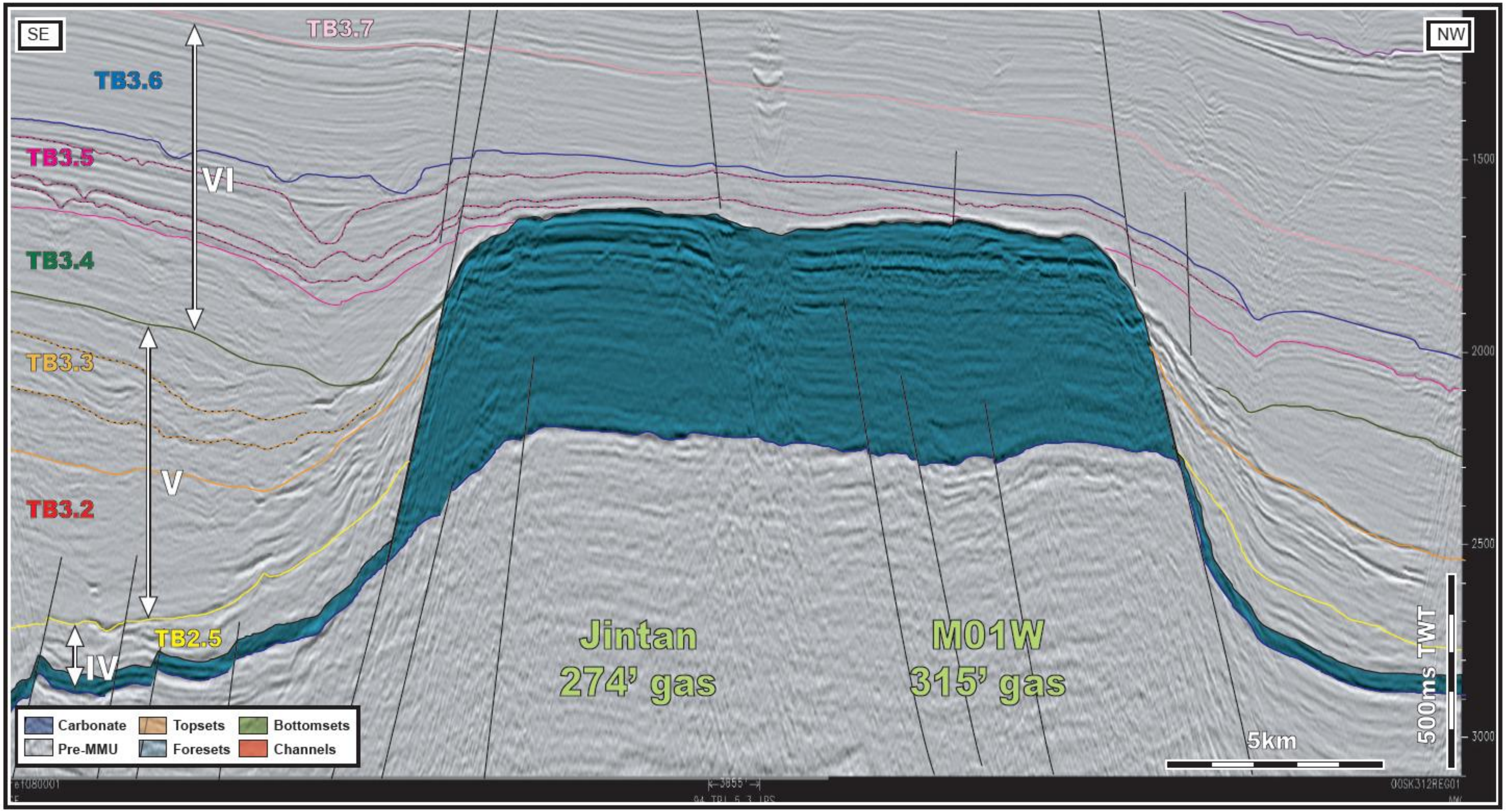


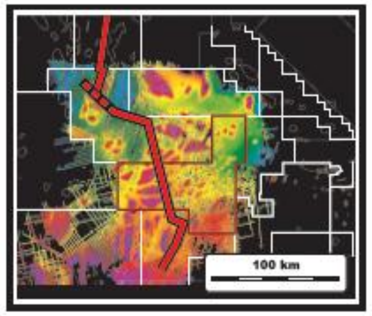


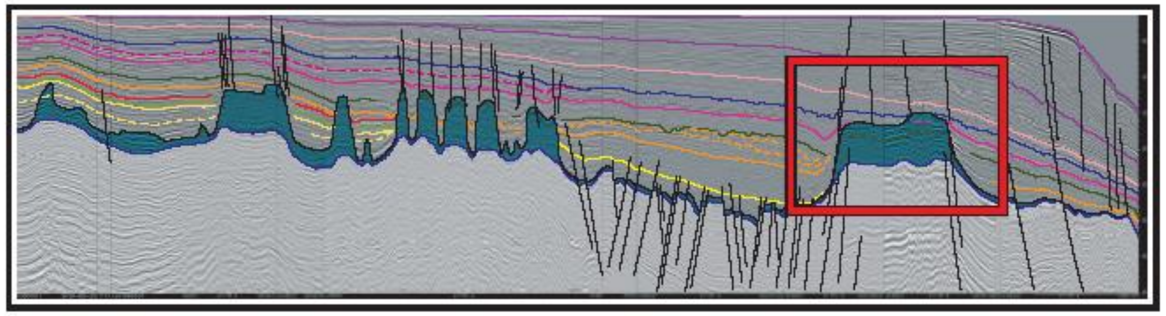


Extensively studied platform. Dated as TB2 by Sr-isotope stratigraphy. Elsewhere described as 'drowned' and buried under 'megaforesets'.

Detail: Jintan

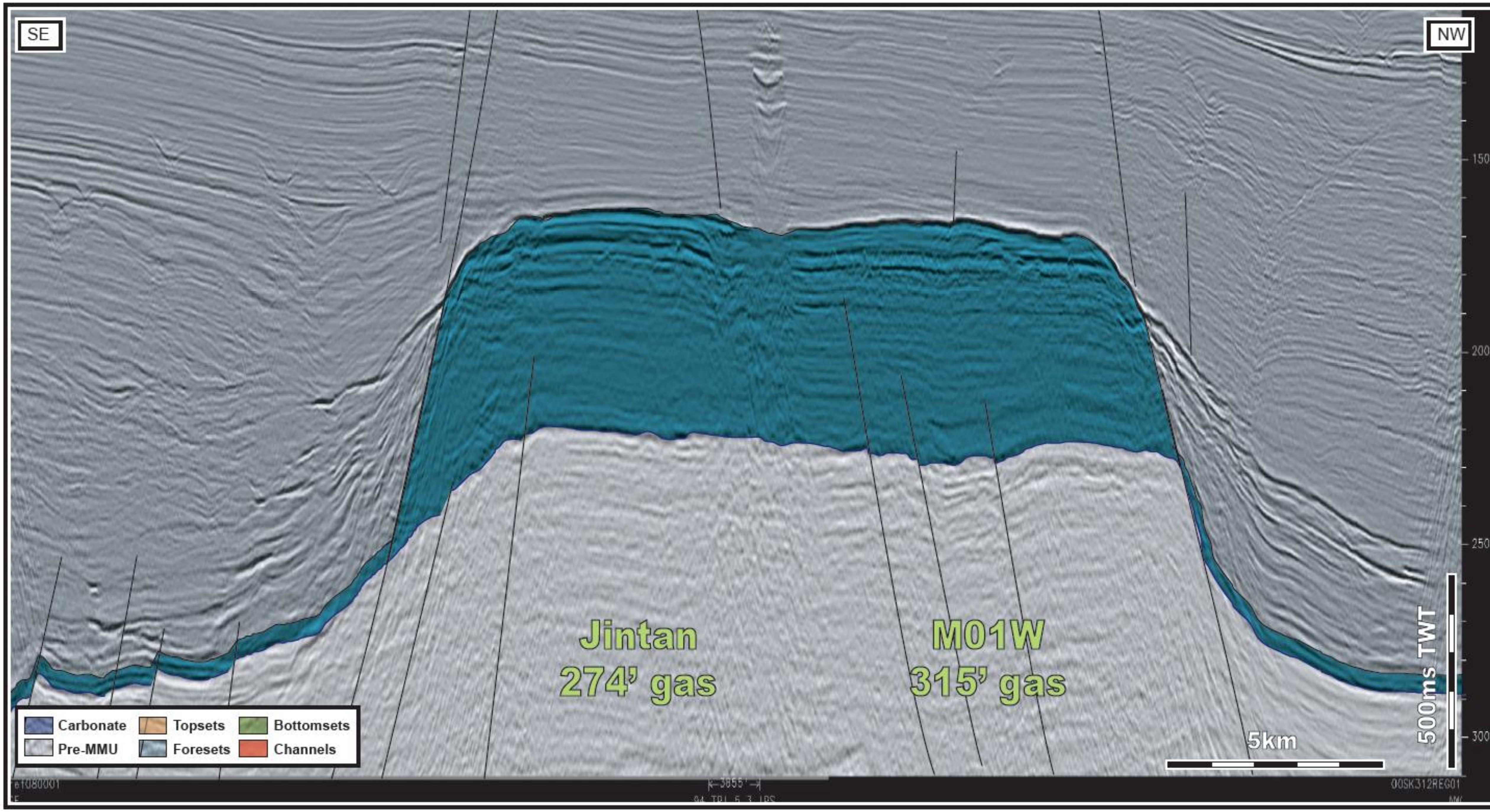


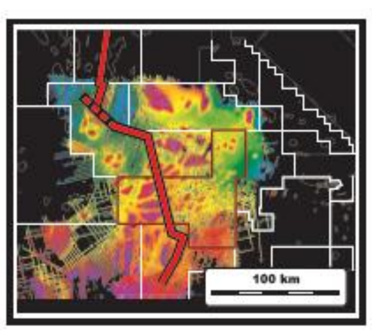


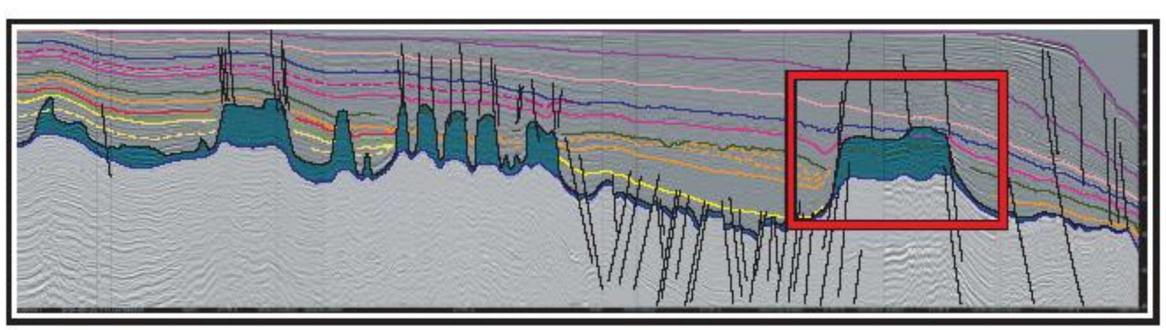


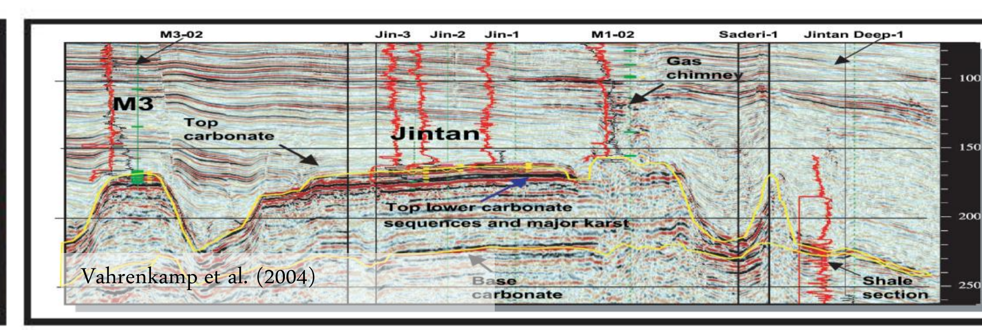
Industry-standard interpretation. Steep-walled, high-relief, flat-topped platform. No relationship between carbonates and clastics.

Detail: Jintan









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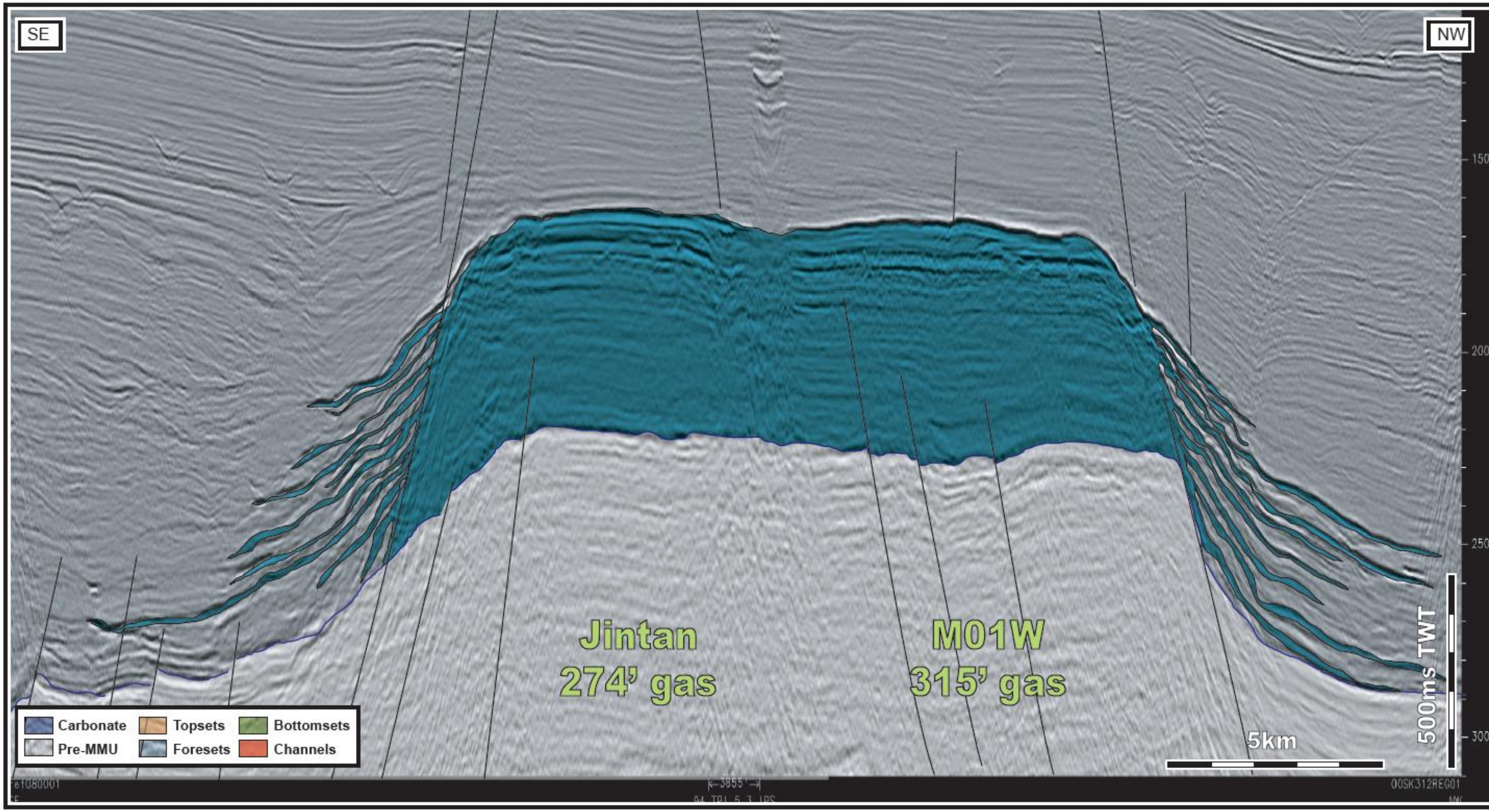
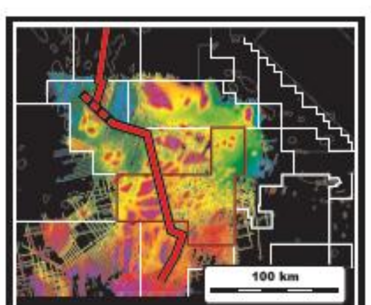
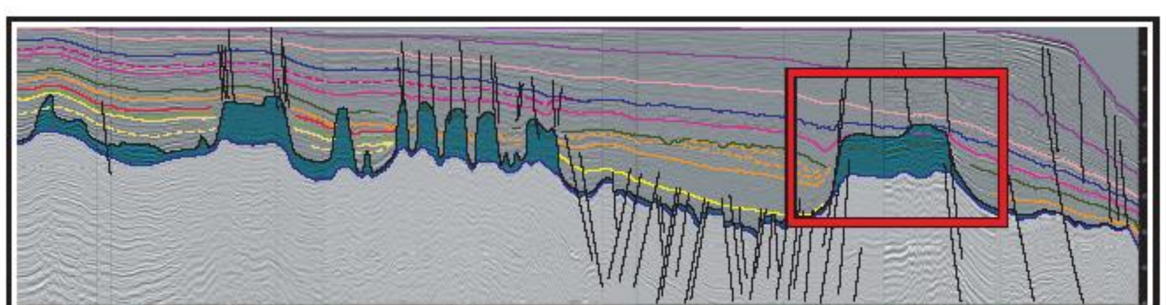
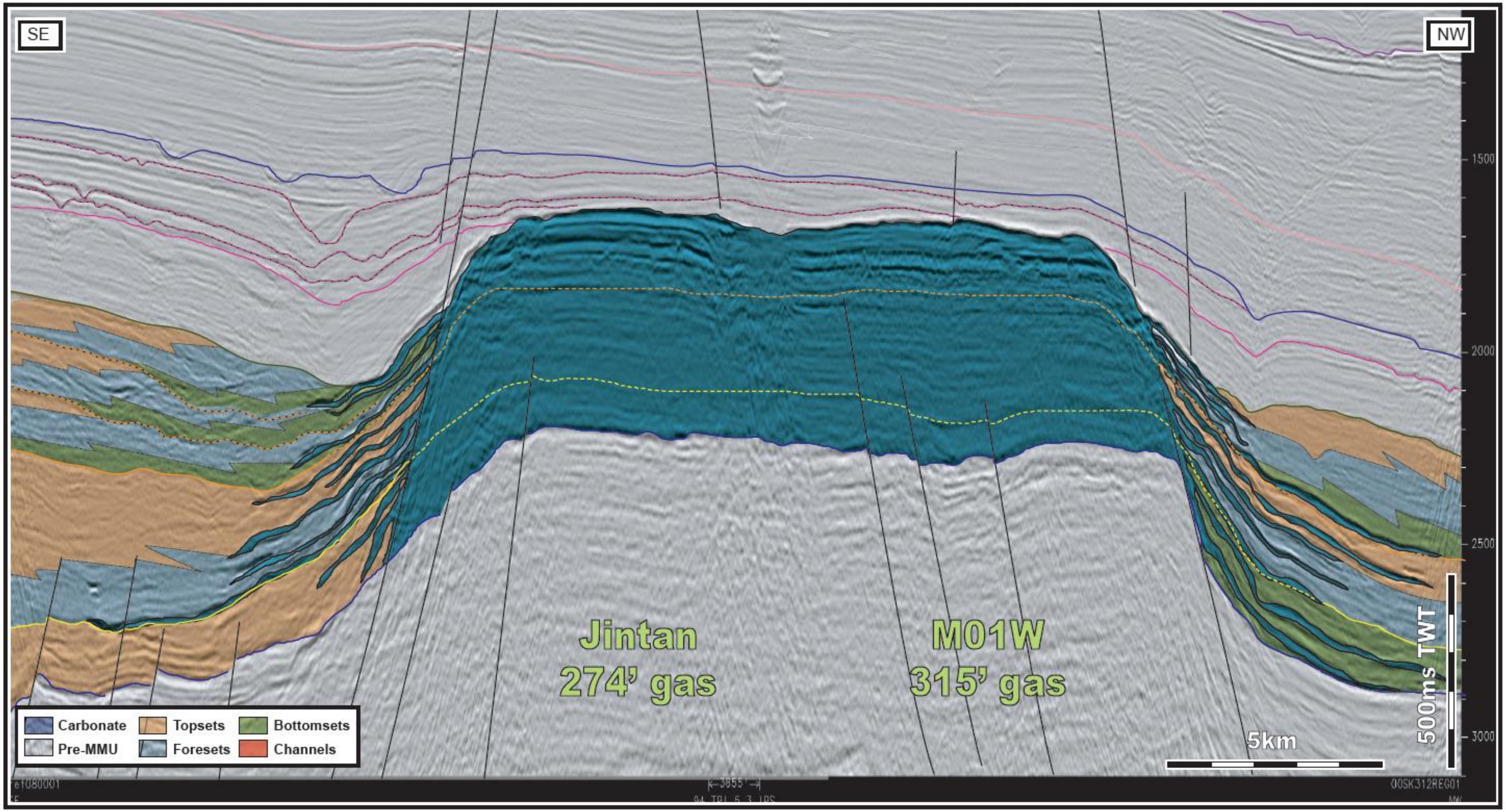


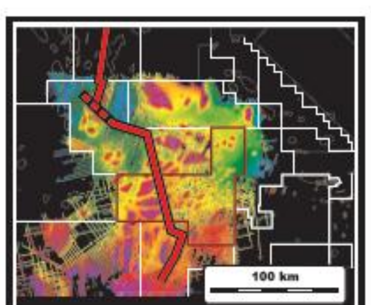


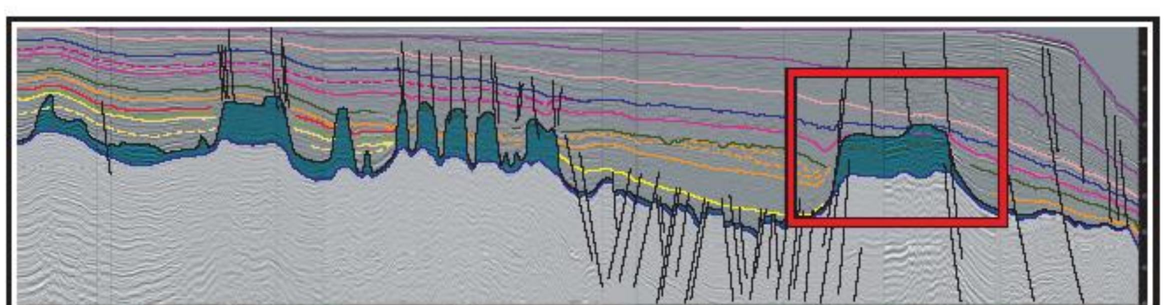


Carbonate 'wings' or 'stringers' clearly visible on seismic. Platform seems to have contributed into the basin through most of its lifespan.

Detail: Jintan







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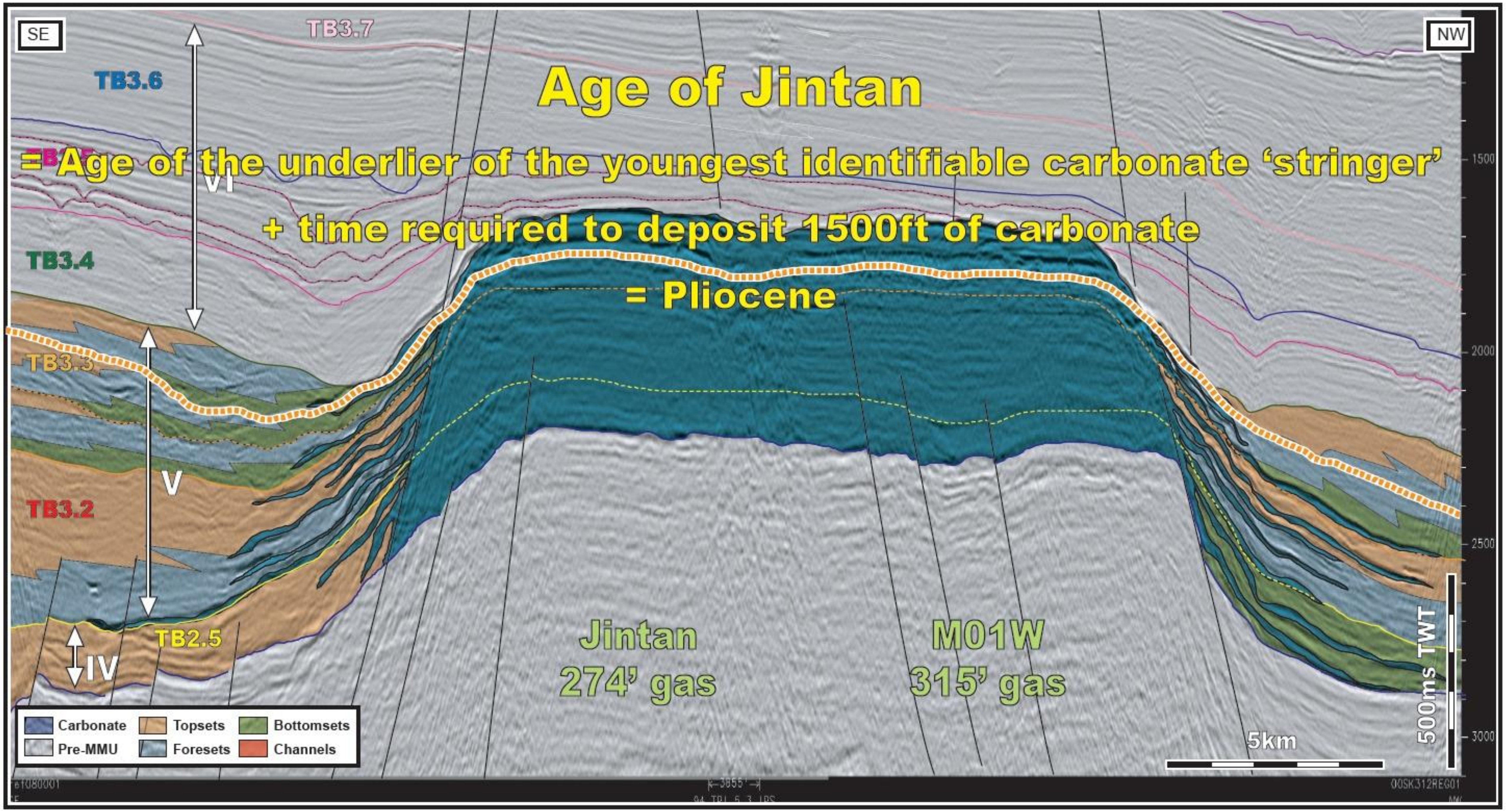
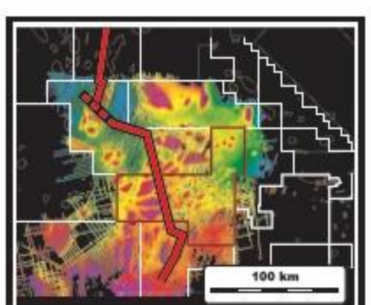
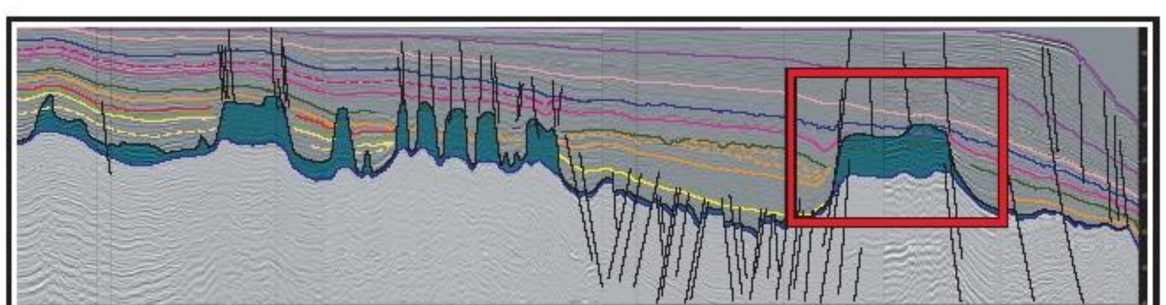
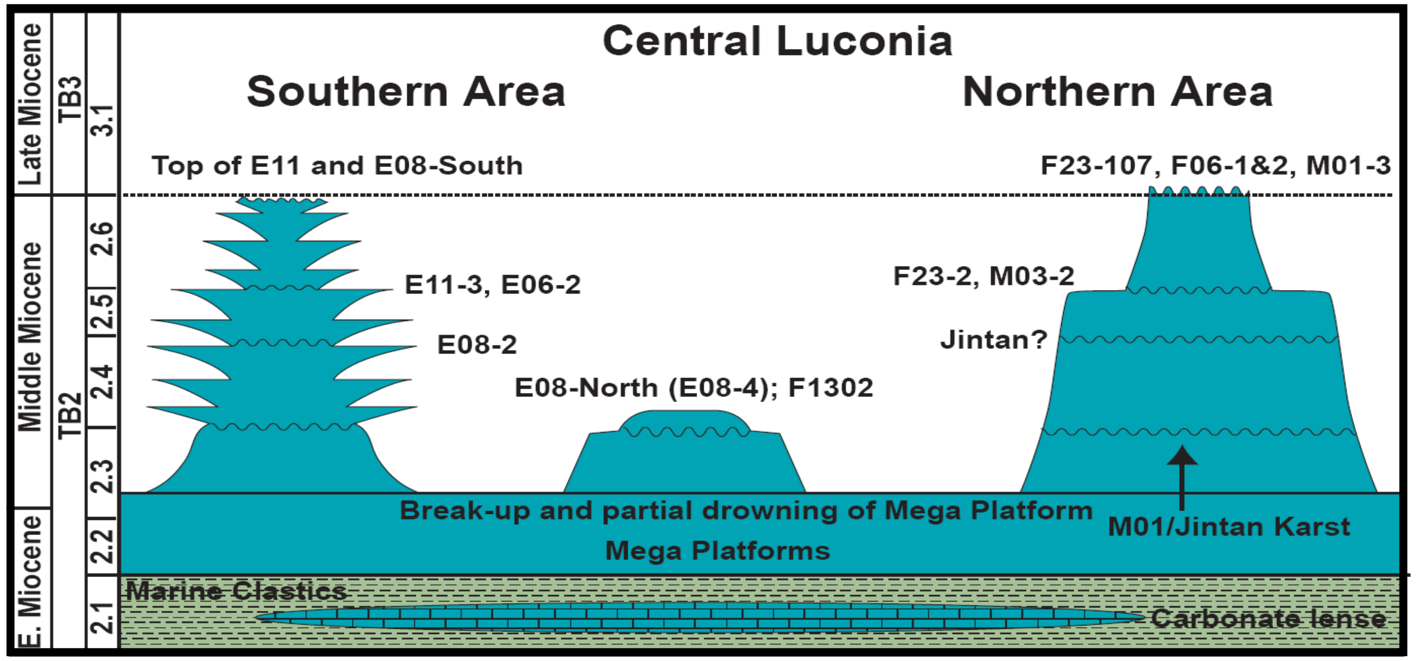




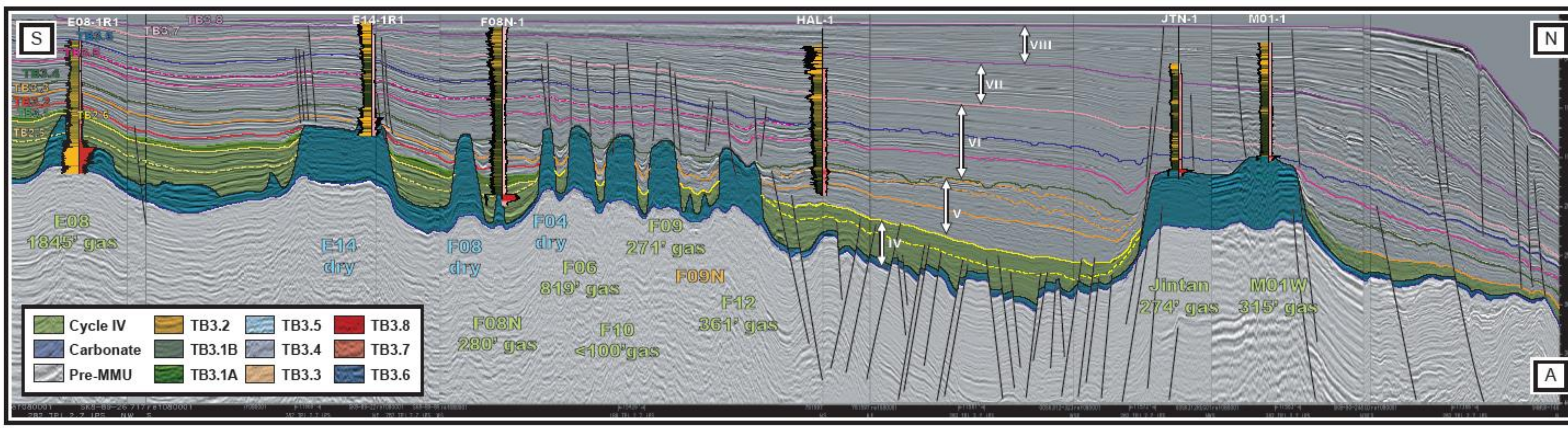


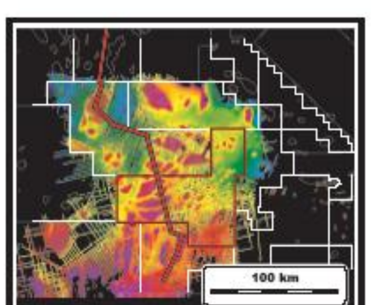
Carbonate/clastic intercalations can be used for precise dating of carbonate through clastic biostratigraphy.

Regional Section: Smooth Top Carbonate



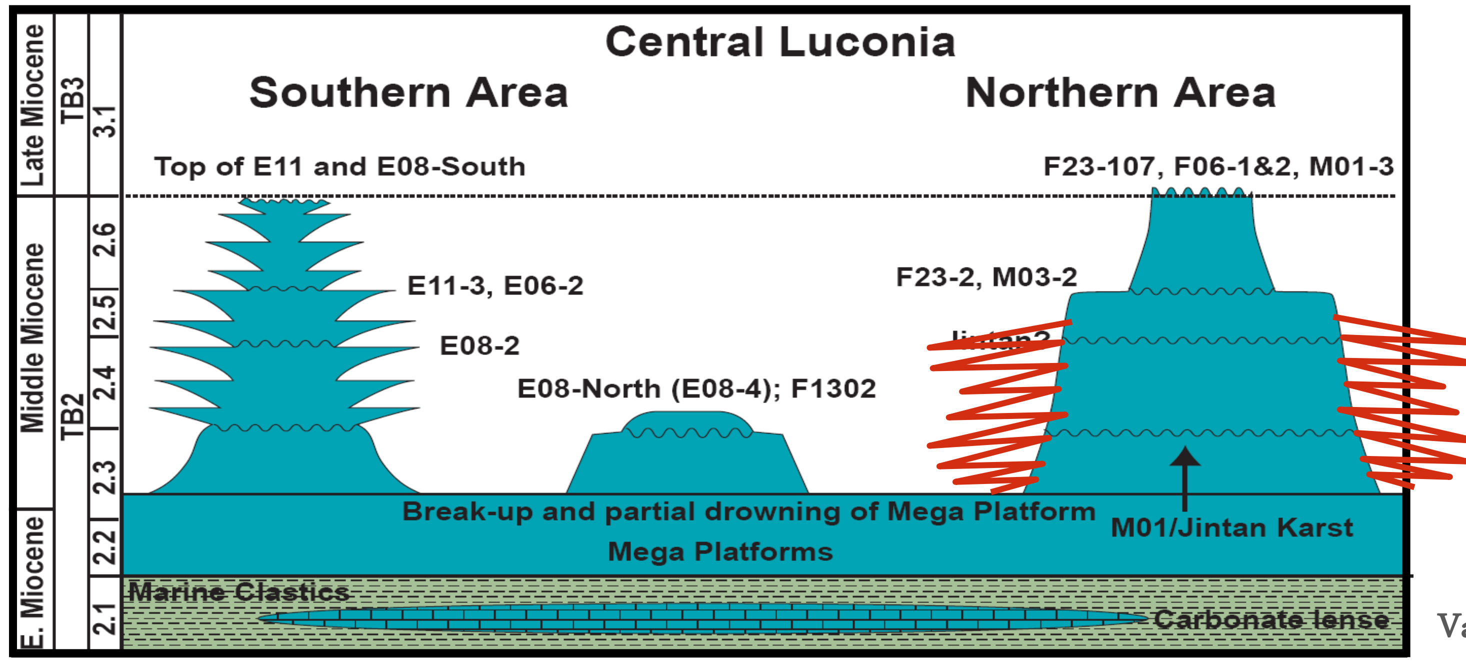
Vahrenkamp (1998)



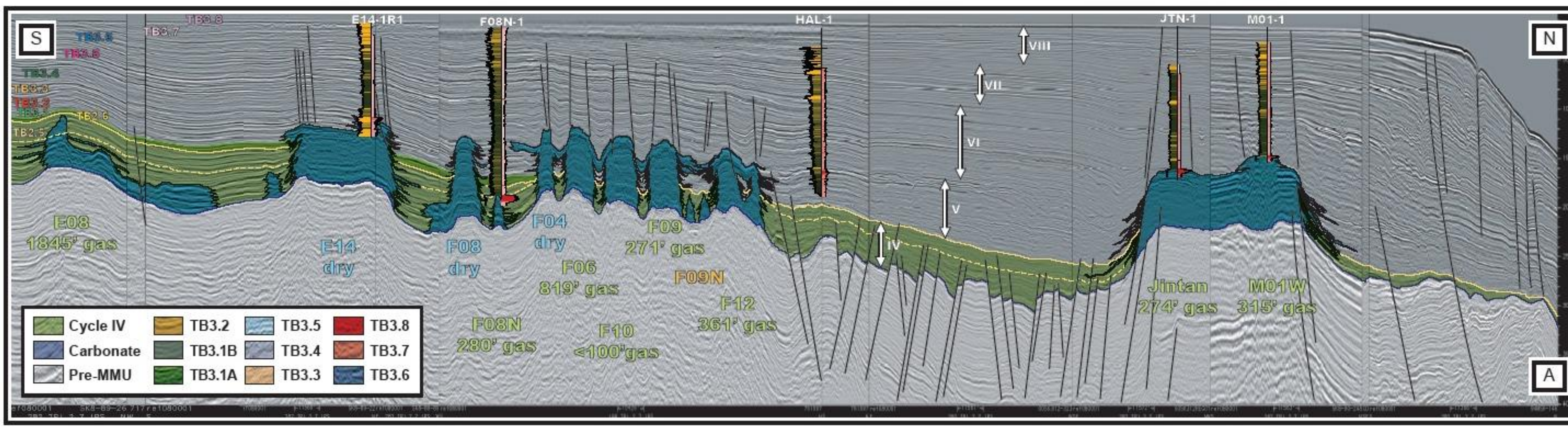


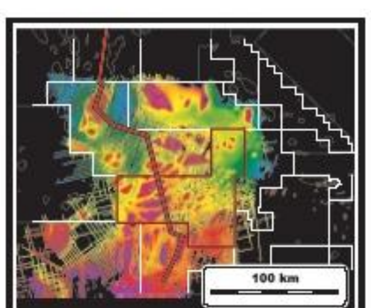
Industry-standard interpretation. Carbonate province may be interpreted as of TB2 age, having been drowned and buried under TB3 'pro-delta shales'. It is entirely plausible to interpret turbidites (e.g., HAL-1) to surround build-ups, filling 'inter-platform canyons and plains'.

Regional Section: Wings, Mushrooms and Christmas Trees



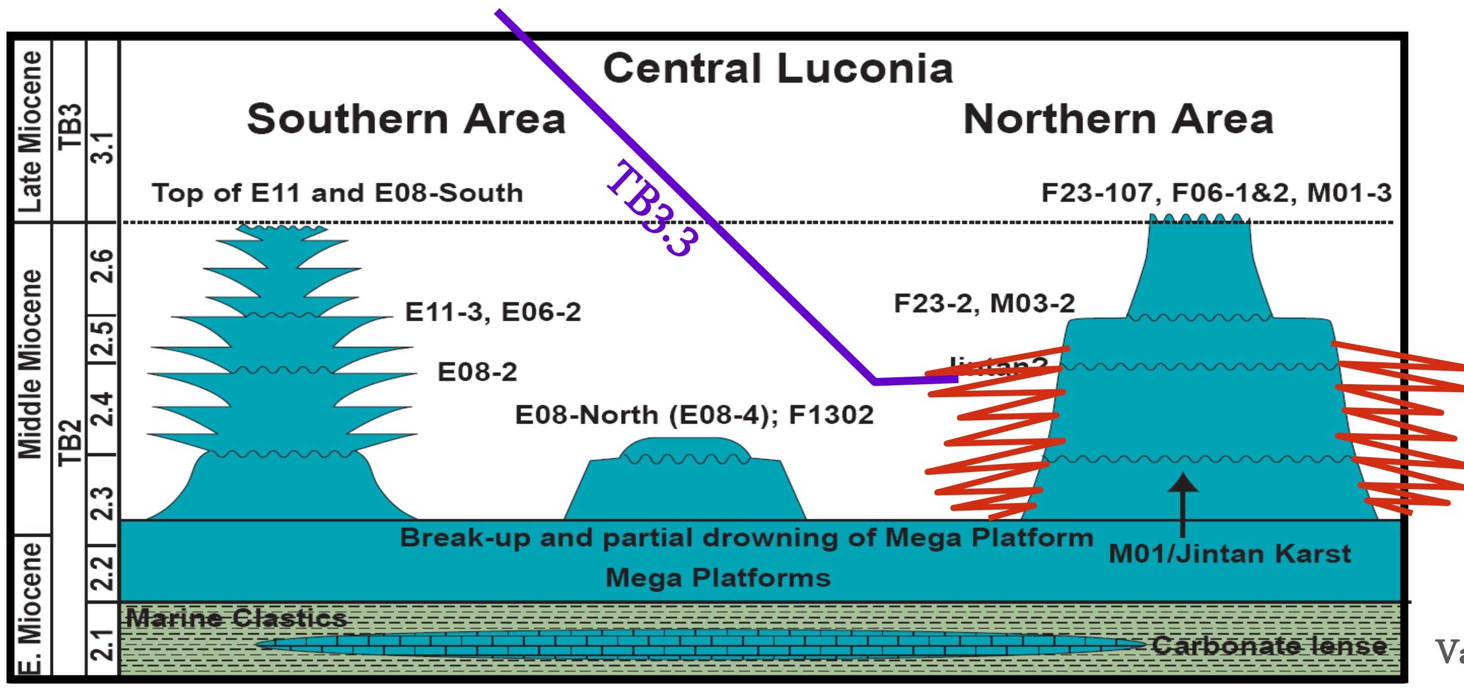
Vahrenkamp (1998)



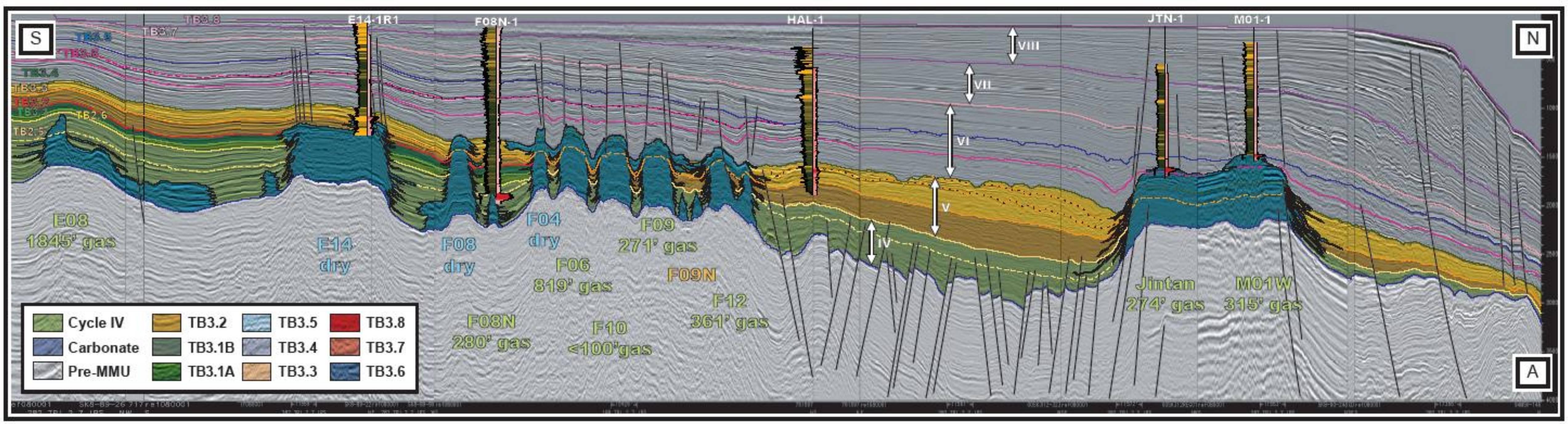


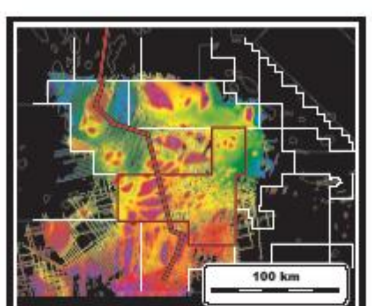
Interpretation including marginal carbonate facies. Carbonate clinoforms, wings, mushrooms, stringers and hairs extend away from build-ups, and are clearly younger than TB2. The timing of the larger platforms N of E08 may require correction of up to 6MA to match the seismic stratigraphy.

Regional Section – Alternative Interpretations



Vahrenkamp (1998)





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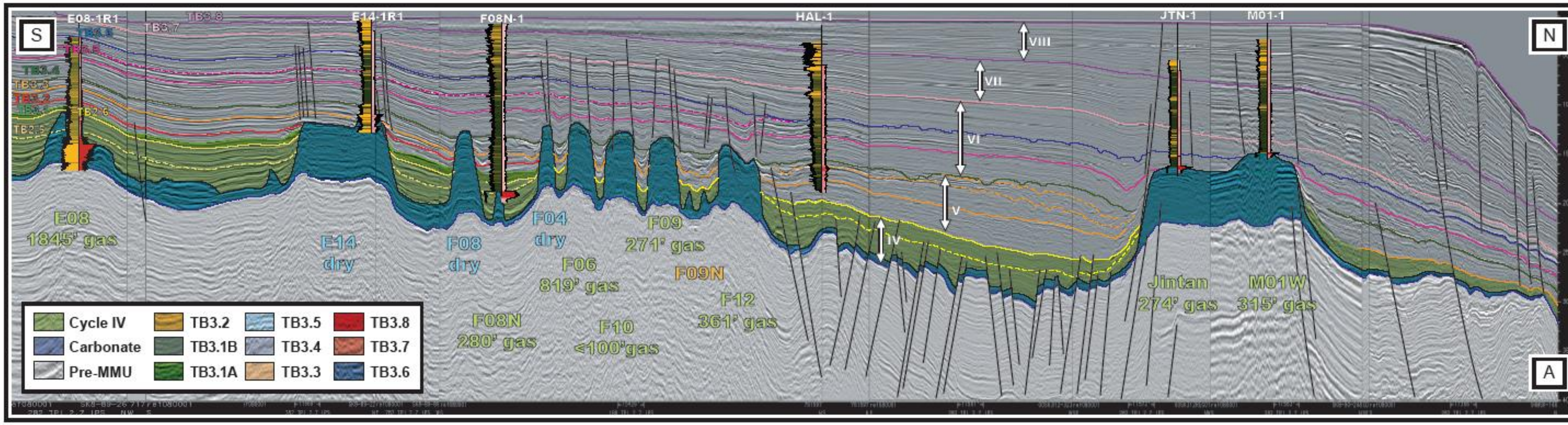
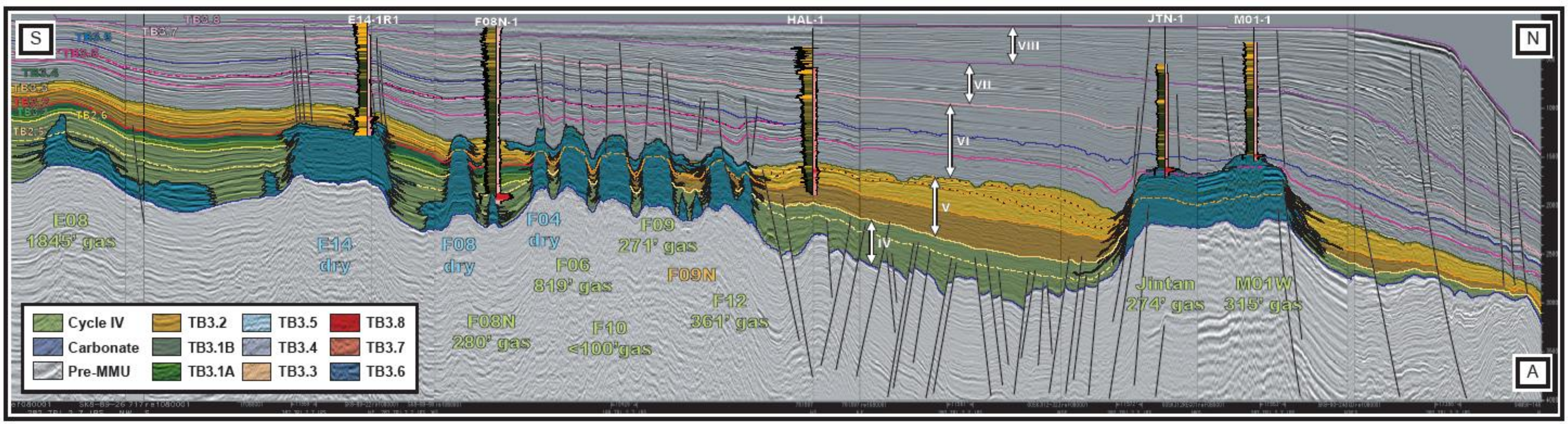
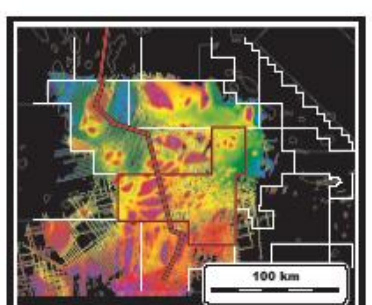


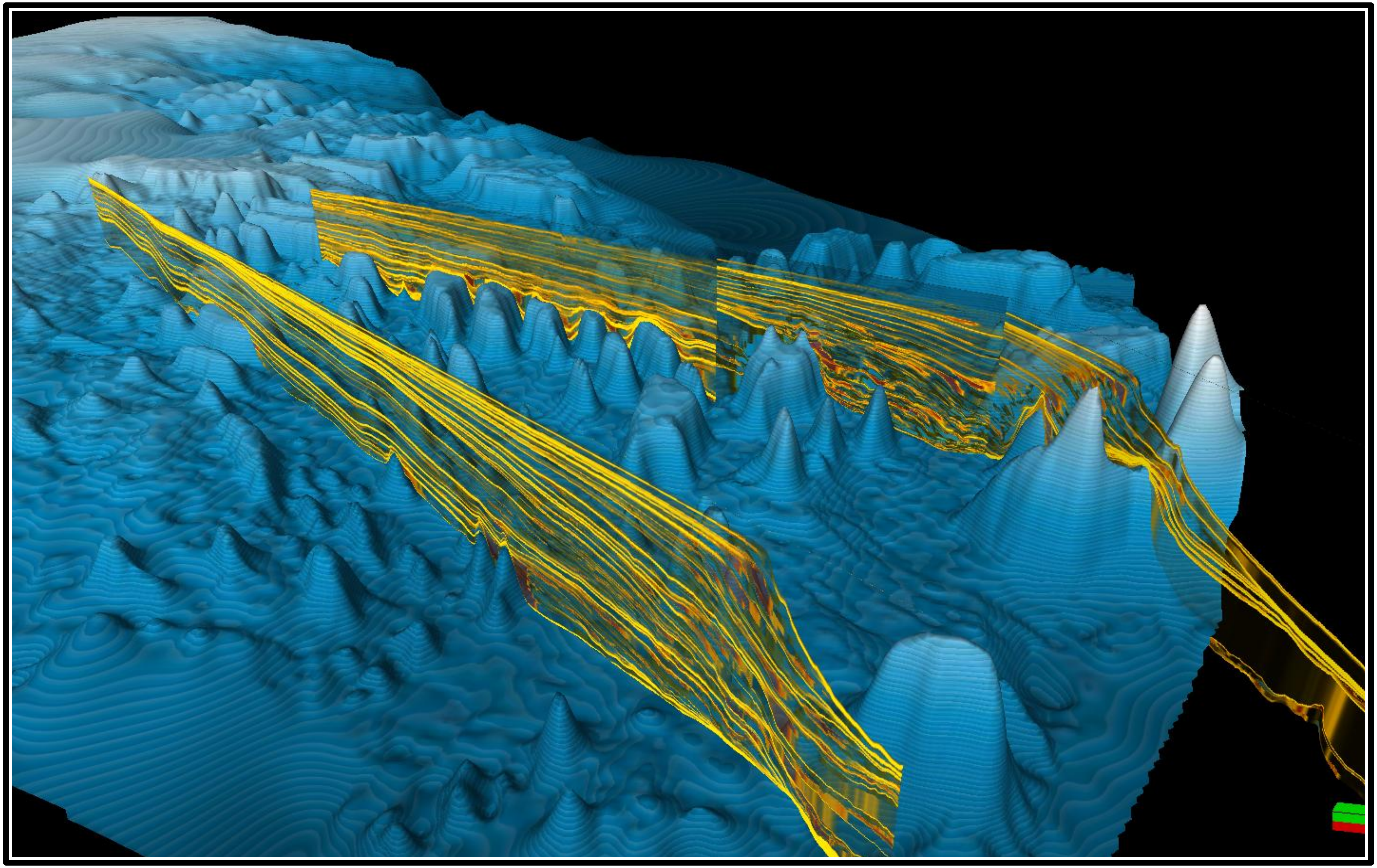




Industry-standard vs. wing-&-mushroom interpretation. Carbonate build-ups N of E08 intercalate with, and extend over, Late Miocene strata. The carbonates are thus Late Miocene and younger age. The underlying clastics cannot be deep-water shales or turbidites.

Link to the Overburden Clastic Stratigraphy

Key Concepts: Stacked shelf units; Topsets surrounding build-ups; Shelf edges along CL fringes



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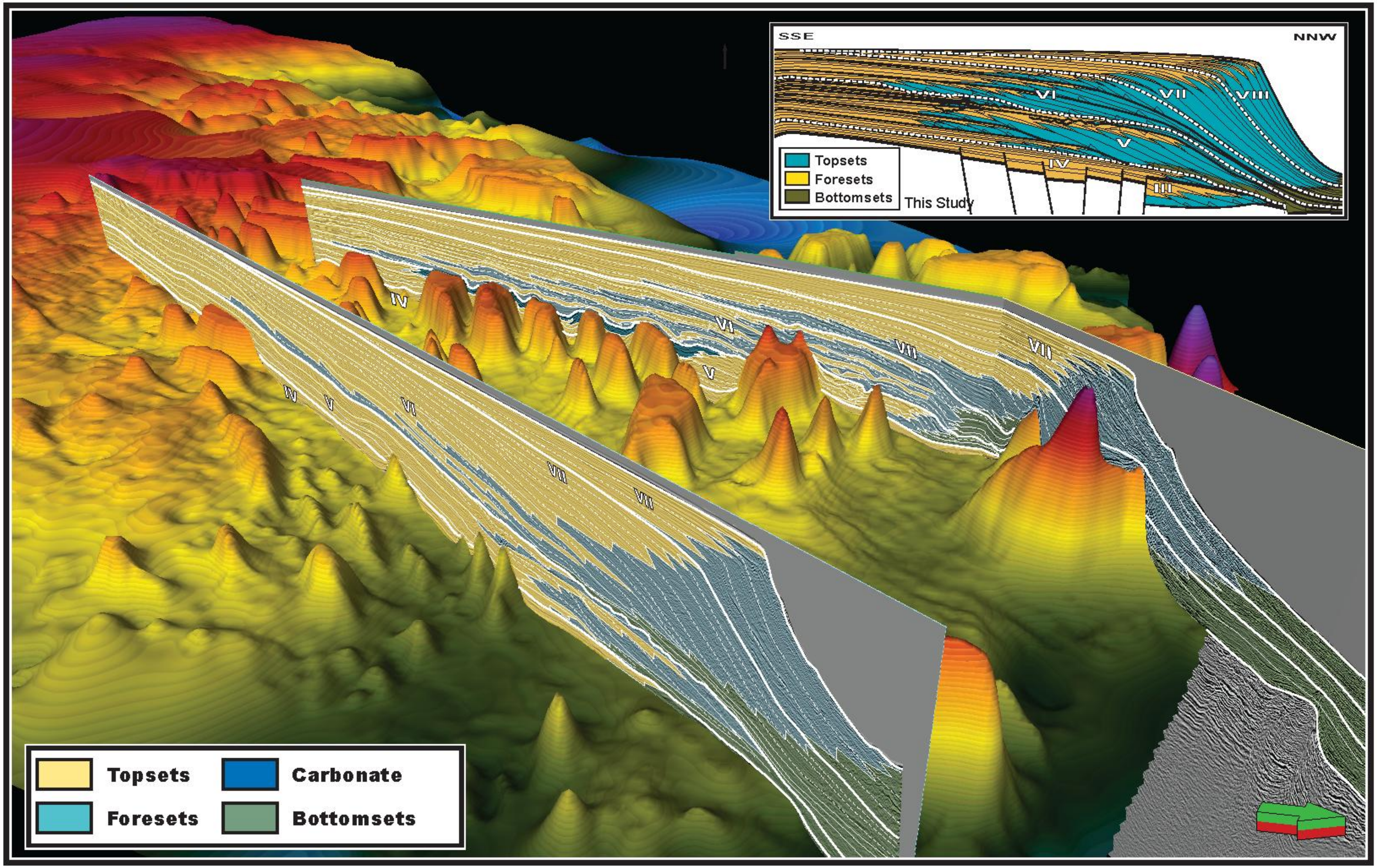

Conclusions

- Carbonate build-ups in Central Luconia have complex margin morphology

- Since the advance of workstation-based seismic interpretation, build-ups have been interpreted as smooth, convex structures, with omnipresent ‘top’ and ‘base’

- Such interpretation hinders understanding of spatial and temporal relationships between carbonates and clastics, leading to miscorrelation, incorrect dating and false depositional models

Conclusions

- Most carbonate strata are interbedded with clastics in marginal facies

- The high frequency of the carbonate-clastic intercalations allows precise dating of carbonates and quantification of palaeobathymetry

- Current inter-carbonate correlations require correction by up to 6MA

- Carbonate-margin geomorphology suggests shallow-marine and deltaic origin of most post-Mid-Miocene clastics

Conclusions

- Integration of carefully mapped carbonate and clastic seismic stratigraphy will allow constructing a unified model of post-Mid-Miocene geology of Central Luconia, with benefits for inter-carbonate correlations, seal risking and clastic prospectivity