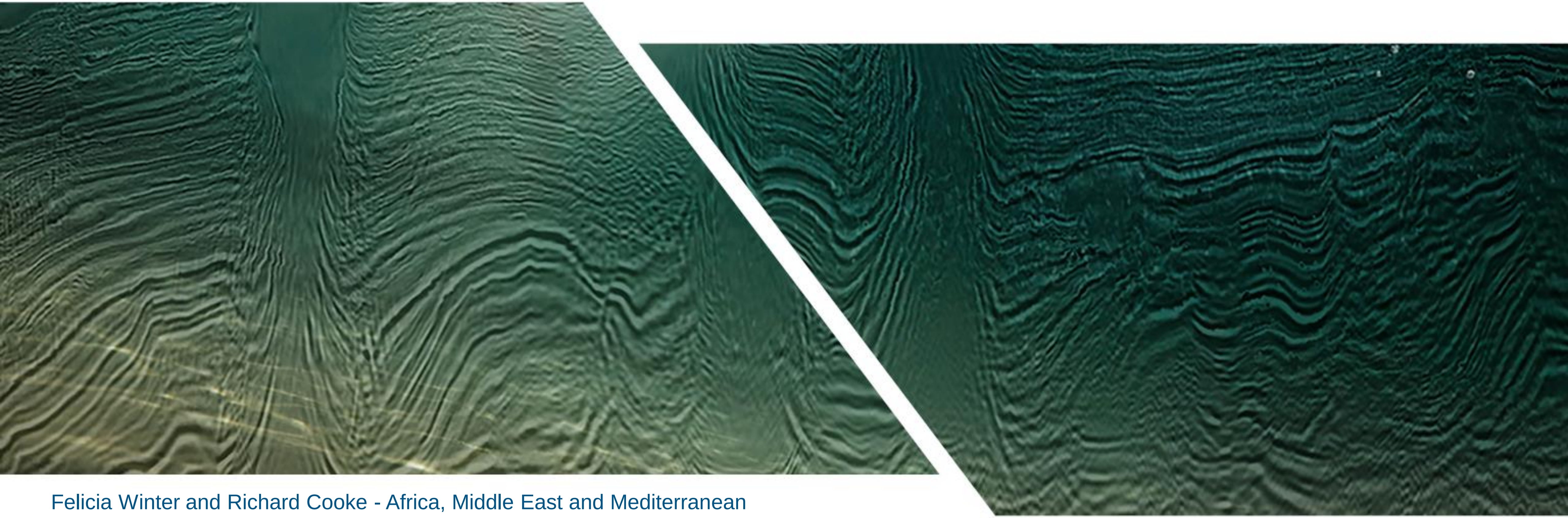
Malta and Libya
Opportunities with TGS Data



Felicia Winter and Richard Cooke - Africa, Middle East and Mediterranean

Finding Petroleum Opportunities in the Eastern Mediterranean, 20 September 2018.

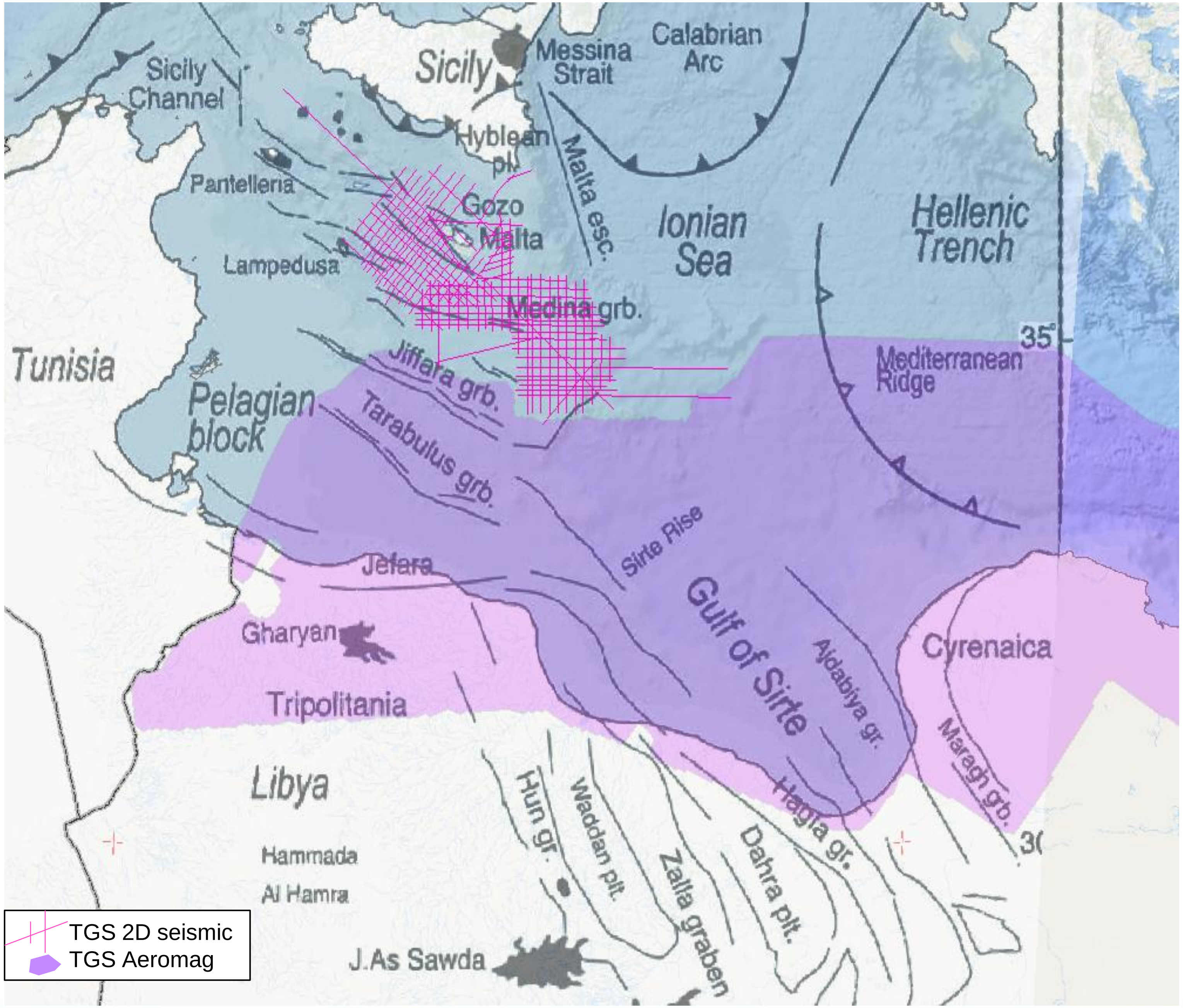
LEGAL NOTICE

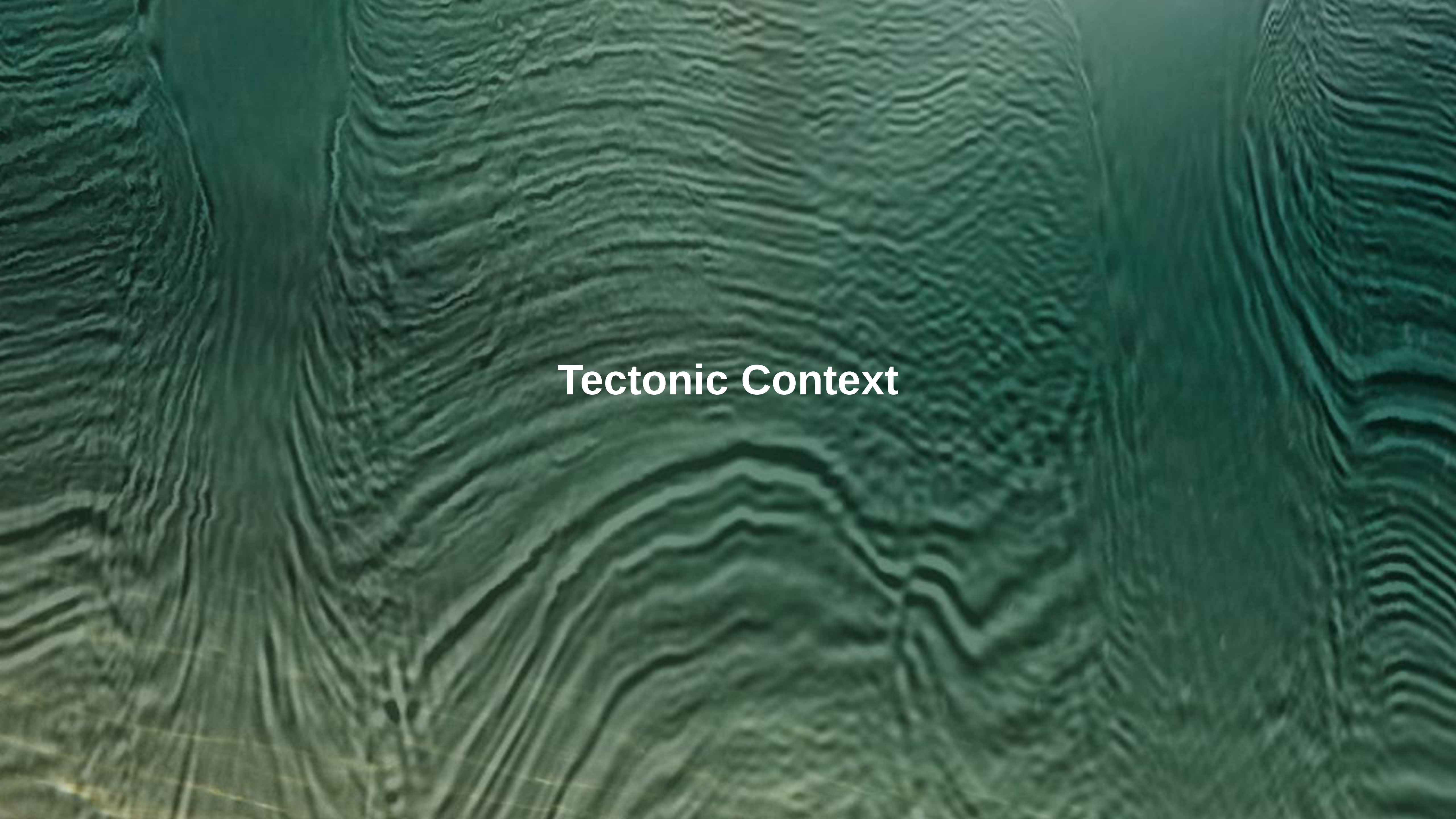
Malta – Libya – Why?

- Underexplored! (wells and seismic)
- Connection or Differentiation to other proven plays to be established!
- Joint initial basin evolution – connected petroleum system today?
    1. Petroleum knowledge offshore Malta
    2. Dis/Similarities to offshore Libya
    3. New opportunities

TGS' collaboration with the Maltese government continues.

Malta is keen on renewing the interest in their area.





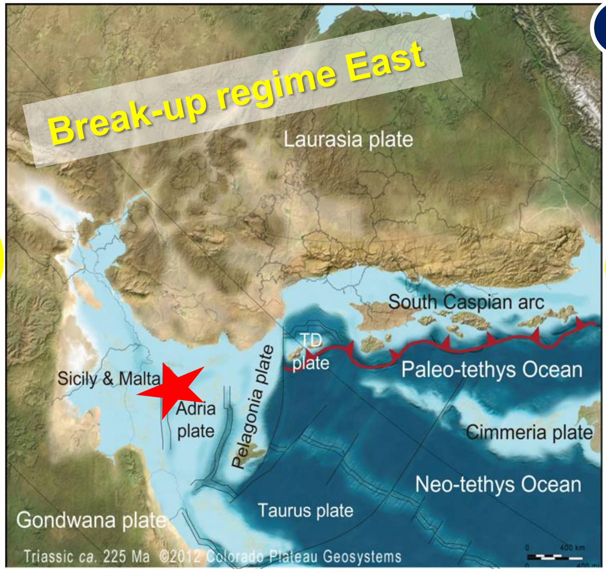
Tectonic Context

Tectonic Reconstruction

K. Jongkook, 2017. (Modified from Deep time map™)

1 **L. Paleozoic -Triassic**

- ✓ **Breakup of Gonwana** (Smith et al, 1982)
- ✓ **Opening the Neo-Tethys ocean** (Grasso, 1999)

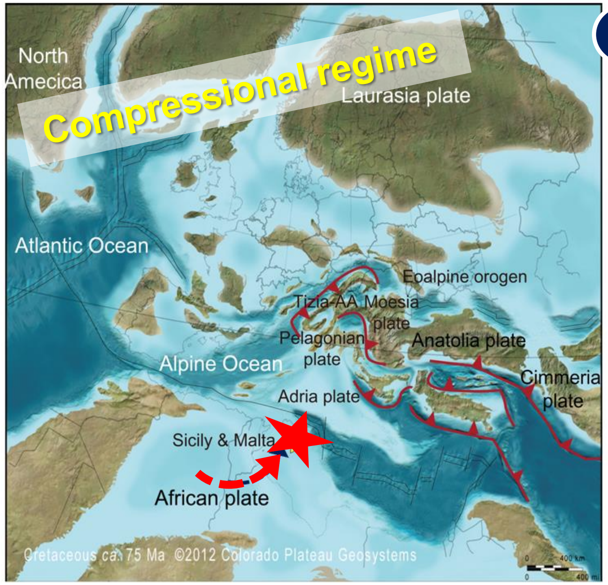


2 **Jurassic- E. Cretaceous**

- ✓ **Passive margin** (Barnaby, 2002)
- ✓ **Episodic rifting & volcanism** (Gatt, 2012)

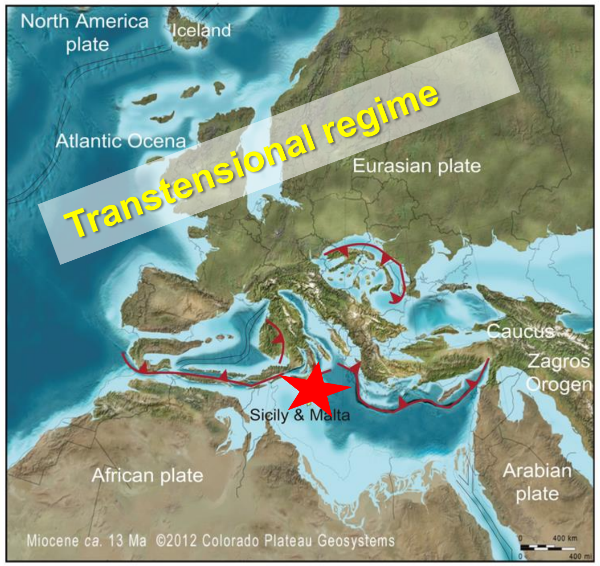
3 **Late Cretaceous**

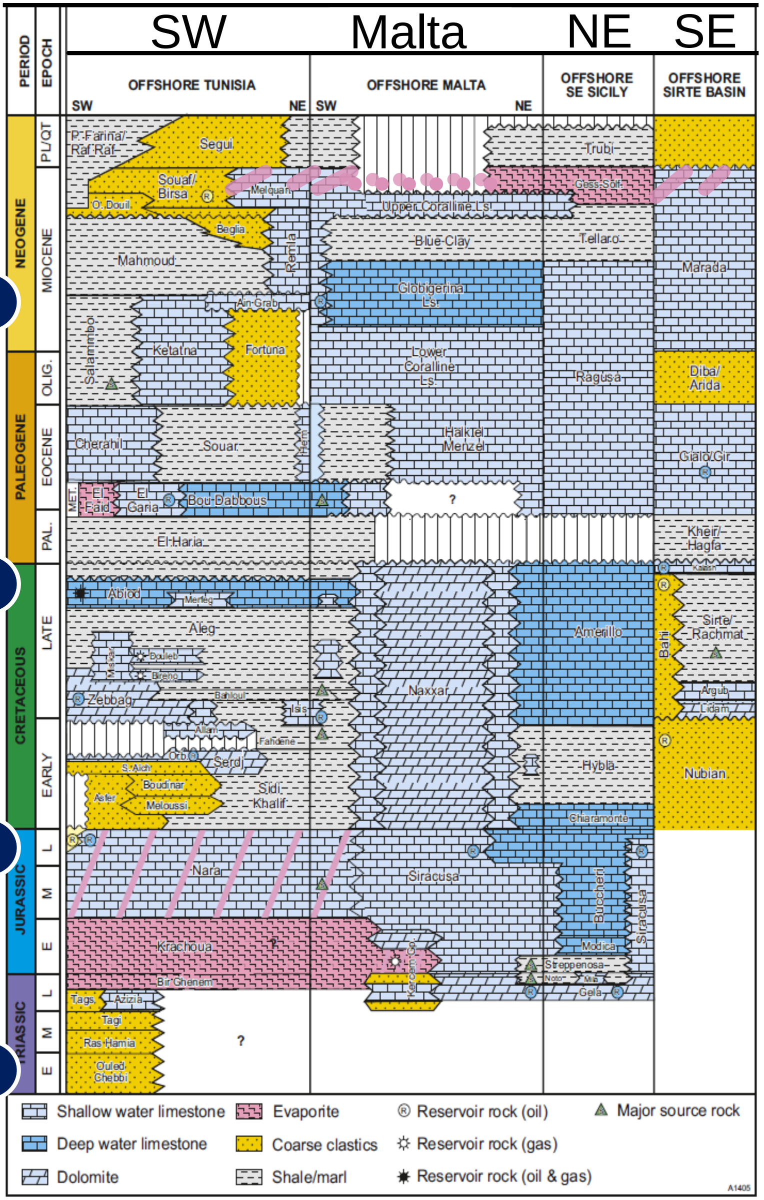
- ✓ **Onset of convergence between African and Laurasia Plate** (Jongsma et al, 1985)



4 **Tertiary -Quaternary**

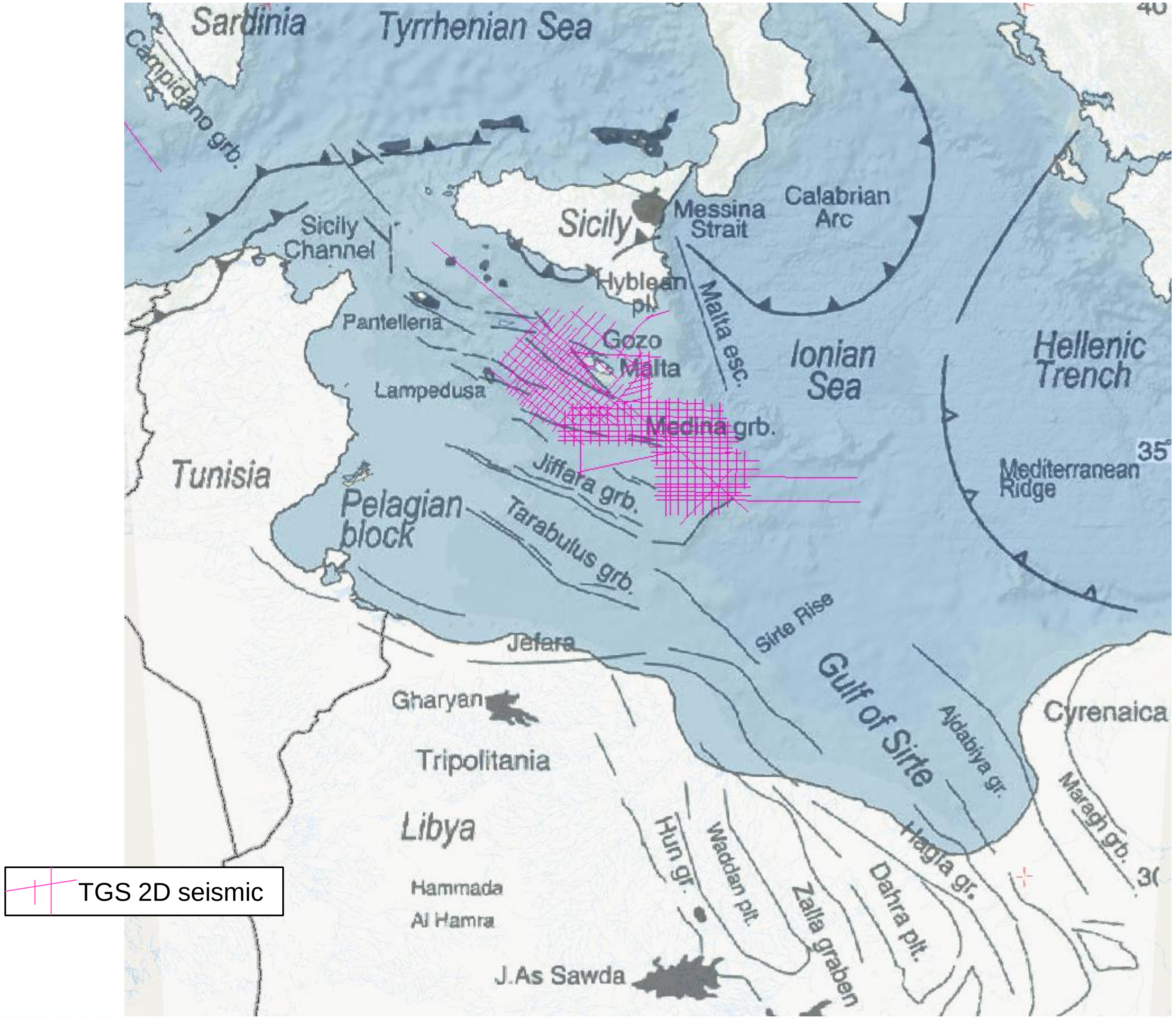
- ✓ **Slab pull extension** (Dart et al., 1993)
- ✓ **Developed the Sicily channel rift zone** (Jongsma et al. 1985)





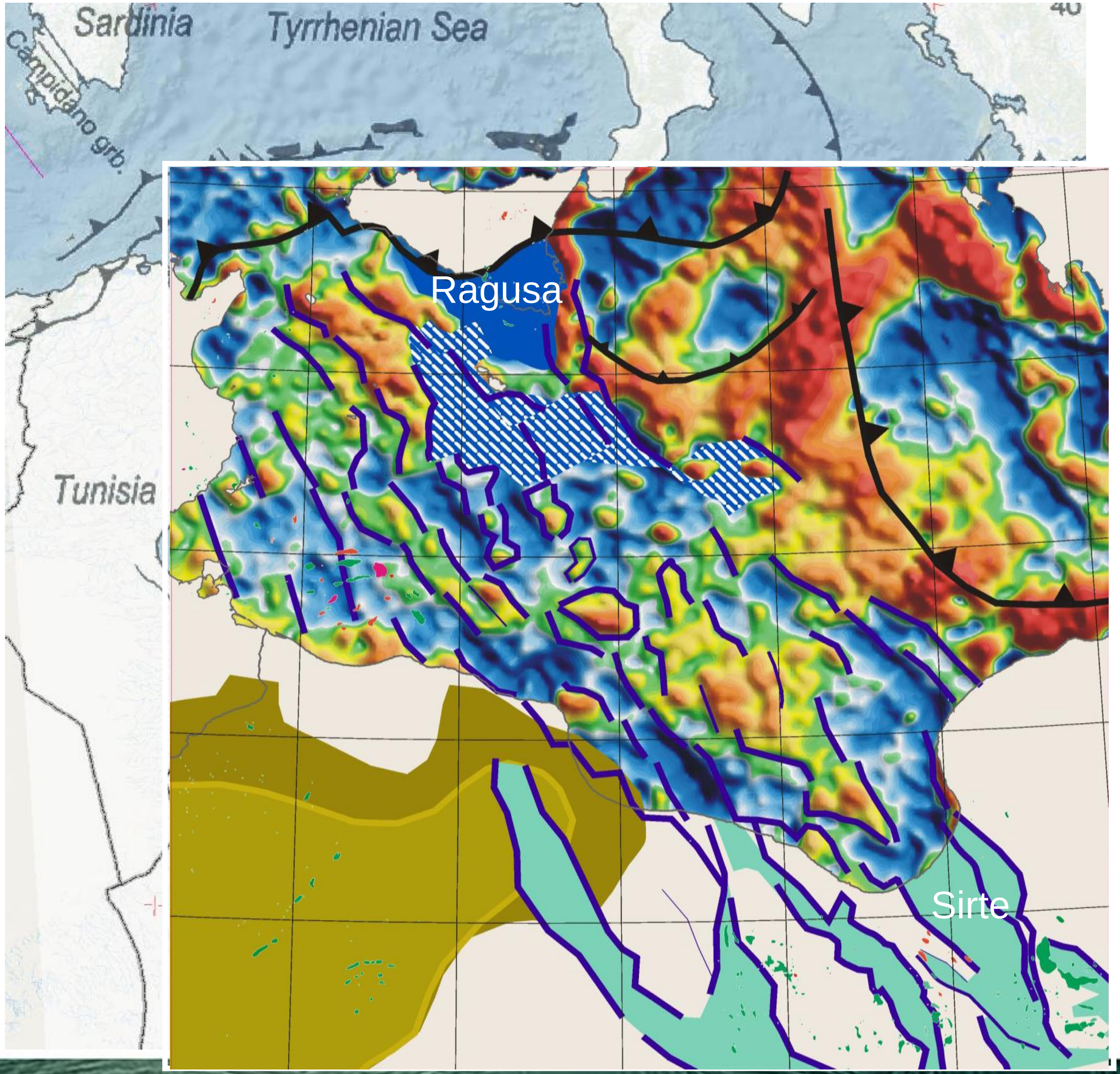
TGS

Regional Structural Trends Today



Capitanio 2011 (after Anketell 1992 and Finetti 1984)

Jurassic Basins Continued Trend



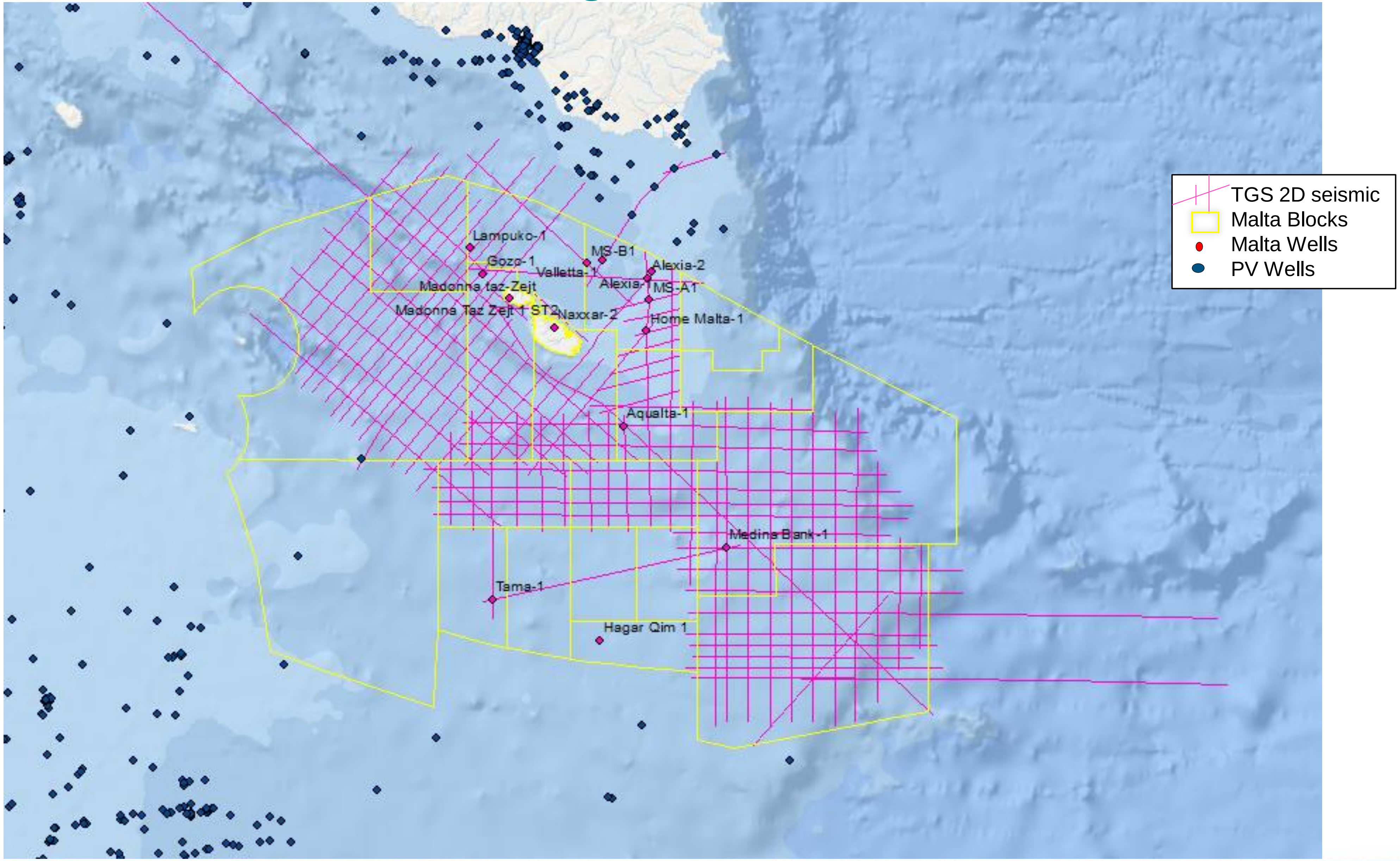
Exploration Offshore Malta

Exploration History – 1970s Open for Offshore Area

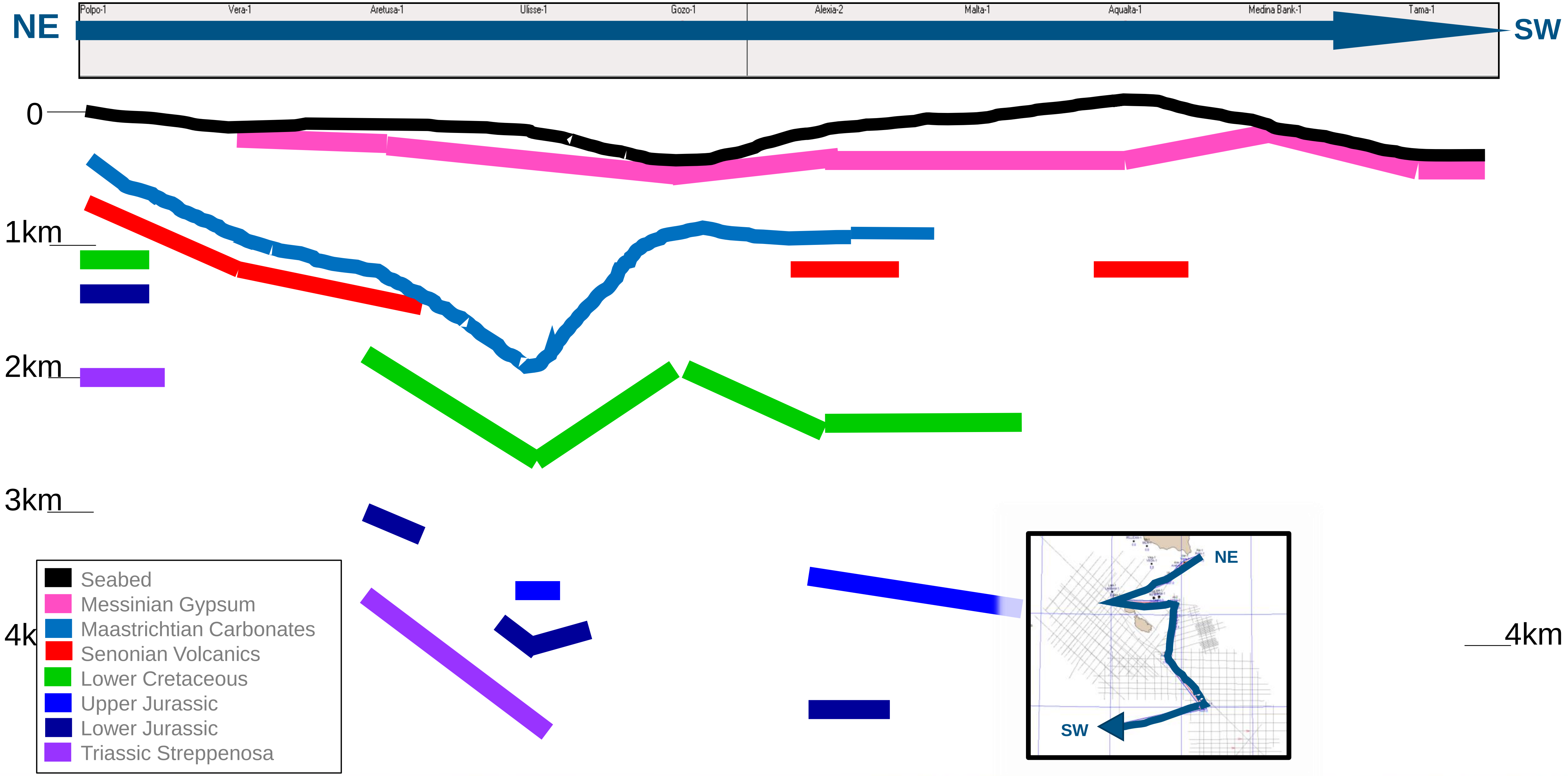
14 wells to date

Completed	Well	OPERATOR	BLOCK/AREA	Blocks	Well status
1954	Naxxar-2	D'Arcy (BP)	Onshore (Area 3)		Dry
1971	MS-A1	Shell	Area 3	Block 3	Dry
1971	MS-B1	Shell	Area 3	Block 2	Dry
1971	Aqualta-1	Aquitaine	Area 3	Block 6	Dry
1972	Home Malta-1	Home Oil	Area 3	Block 3	Oil shows
1974	Medina Bank-1	Texaco	Area 2		Gas shows
1982	Alexia-1	IEOC	Area 3	Block 3	Junked following drilling problems
1984	Alexia-2	IEOC	Area 3	Block 3	Oil shows
1982	Gozo-1	Reading and Bates	Area 3	Block 8	Dry
1992	Valletta-1	Amoco/BHP	Area 3	Block 3	Dry
1993	Tama-1	Amoco/AGIP	Area 4	Block 3	Oil shows
1998	Madonna Taz-Zejt	Malta Government	Onshore (Area 3)		Gas shows
2002	Lampuko-1	ENI	Area 3	Block 2	Oil & Gas shows
2014	Hagar Qim-1	GENEL	Area 4	5 & 7	Dry

Well Locations – Malta and Region



Preliminary Well Correlation – Malta / Sicily



TGS Database

Malta TGS Multi-client 2D Seismic Data

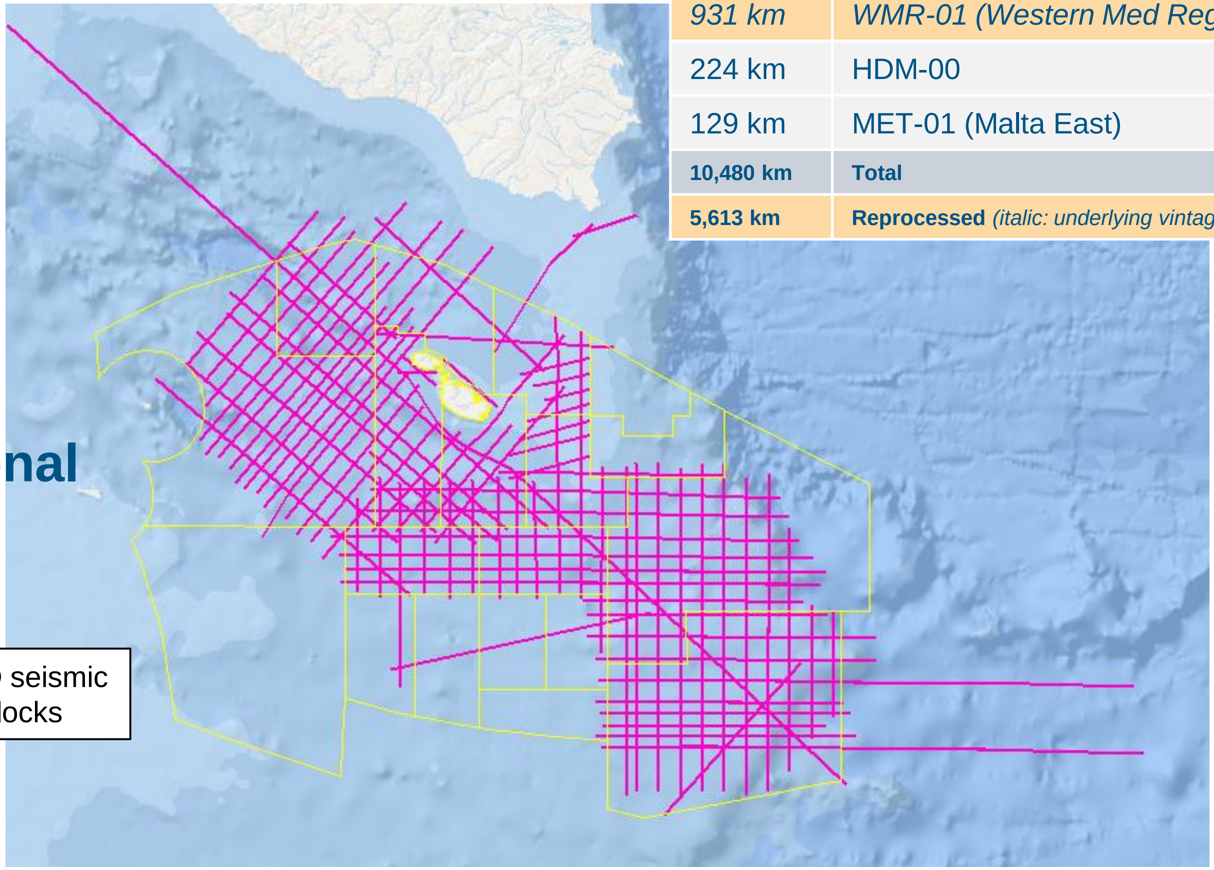
- 224 km	Malta 2000
- 5,522 km	Malta Sicily Channel 2001
- 3,146 km	Medina Bank 2001
- 109 km	Malta 2002
- 109 km	Malta East 2002
- 328 km	Medina Bank 2004

Reprocessed 2013

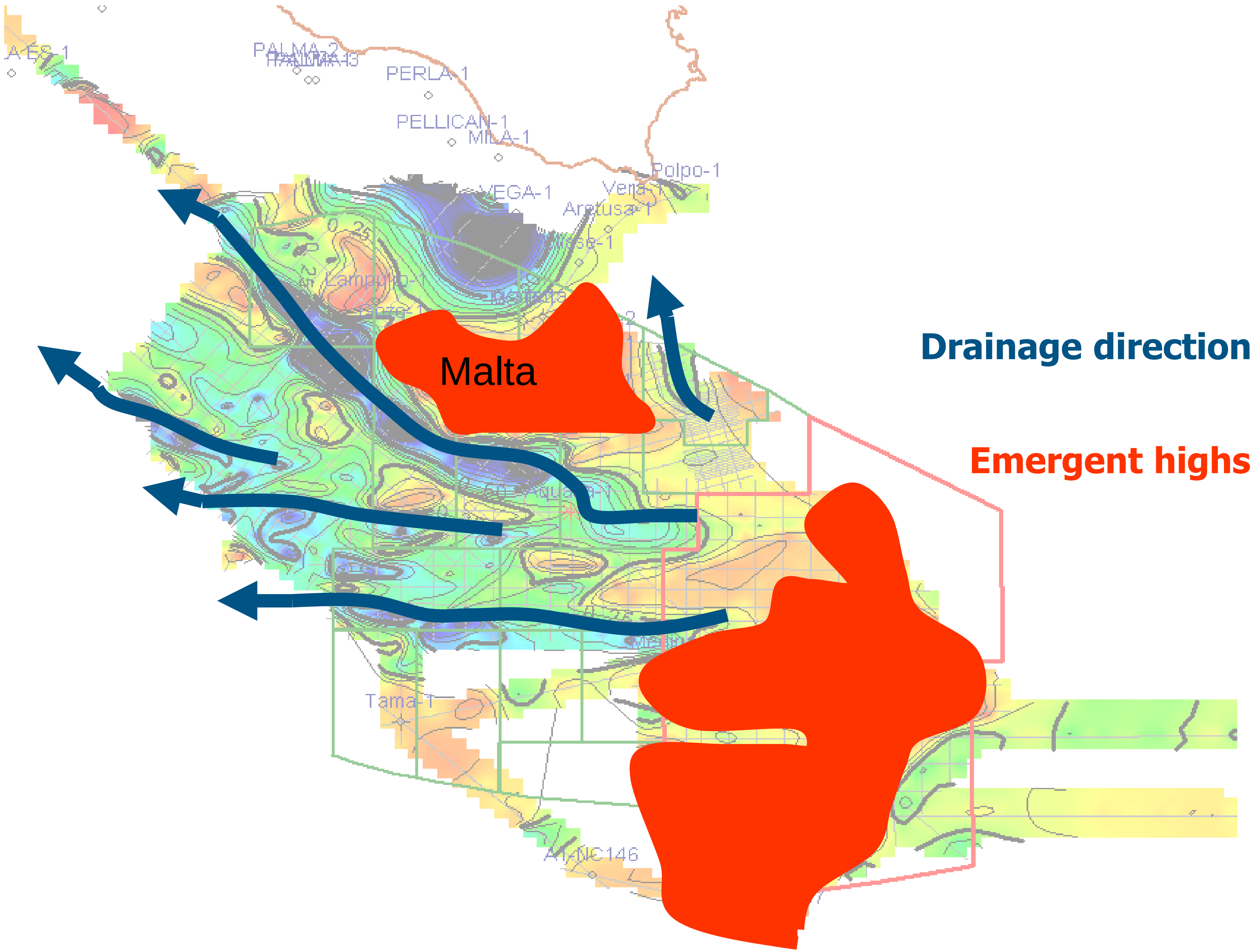
Malta Sicily Channel / Western Regional

5,613.325 km

Size	Survey	Acquired
5,613 km	MSC0102RE13	2001/2002
5,522 km	*MSC-01 (Malta Sicily Channel)*	*2001*
109 km	*MSC -02 (Malta Sicily Channel)*	*2002*
3,146 km	MB-01 (Medina Bank)	2001
328 km	MB-04 (Medina Bank)	2004
109 km	ME-02 (Malta East)	2002
931 km	WMR01RE13	2001
931 km	*WMR-01 (Western Med Regional)*	*2001*
224 km	HDM-00	2000
129 km	MET-01 (Malta East)	2001
10,480 km	**Total**	
5,613 km	**Reprocessed** *(italic: underlying vintage of repro)*	2013



Messinian Erosion with Carbonate Infill challenge Seismic Imaging



Drainage direction

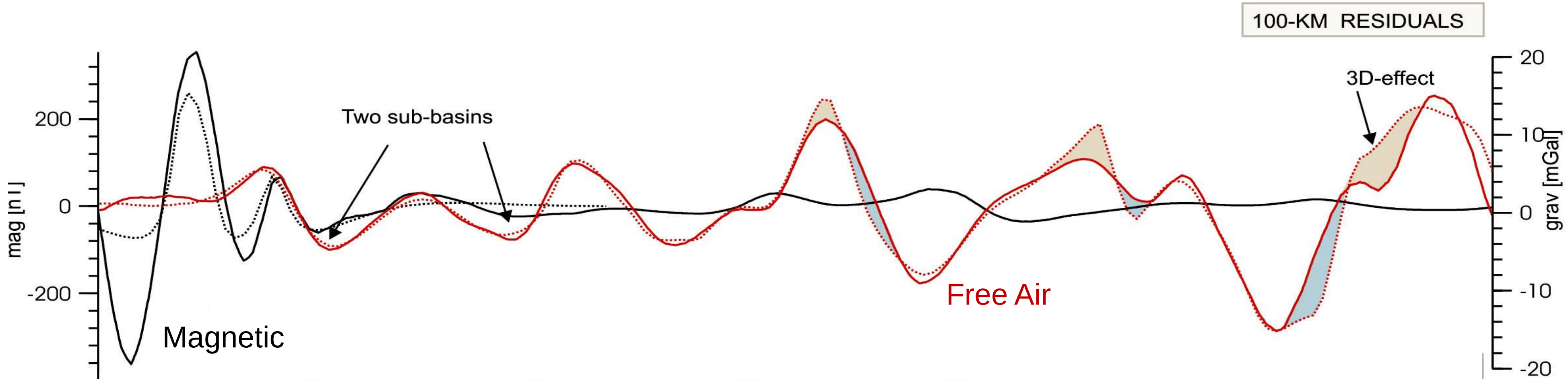
Emergent highs

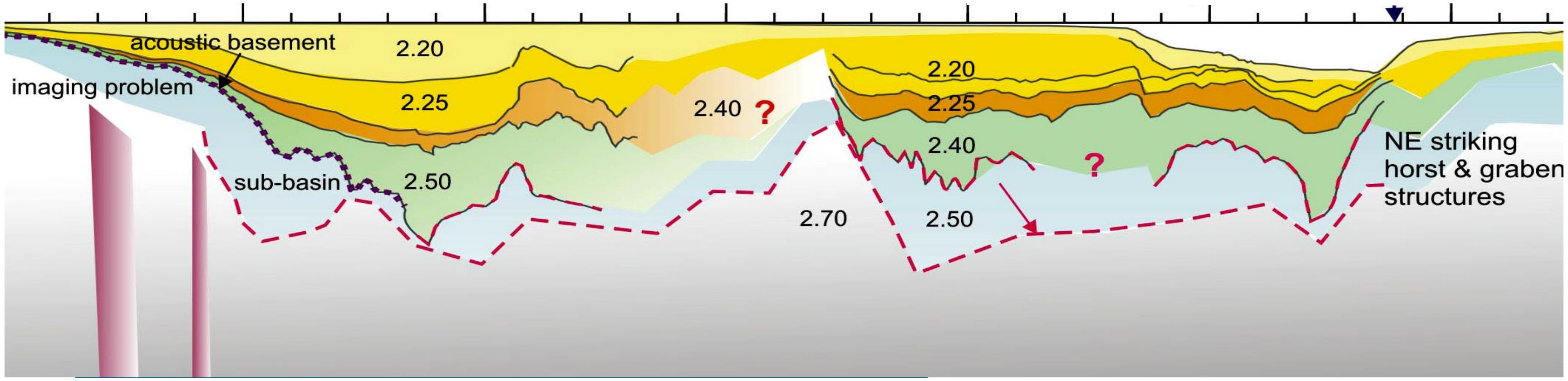
Post-Messinian Isochron

TGS

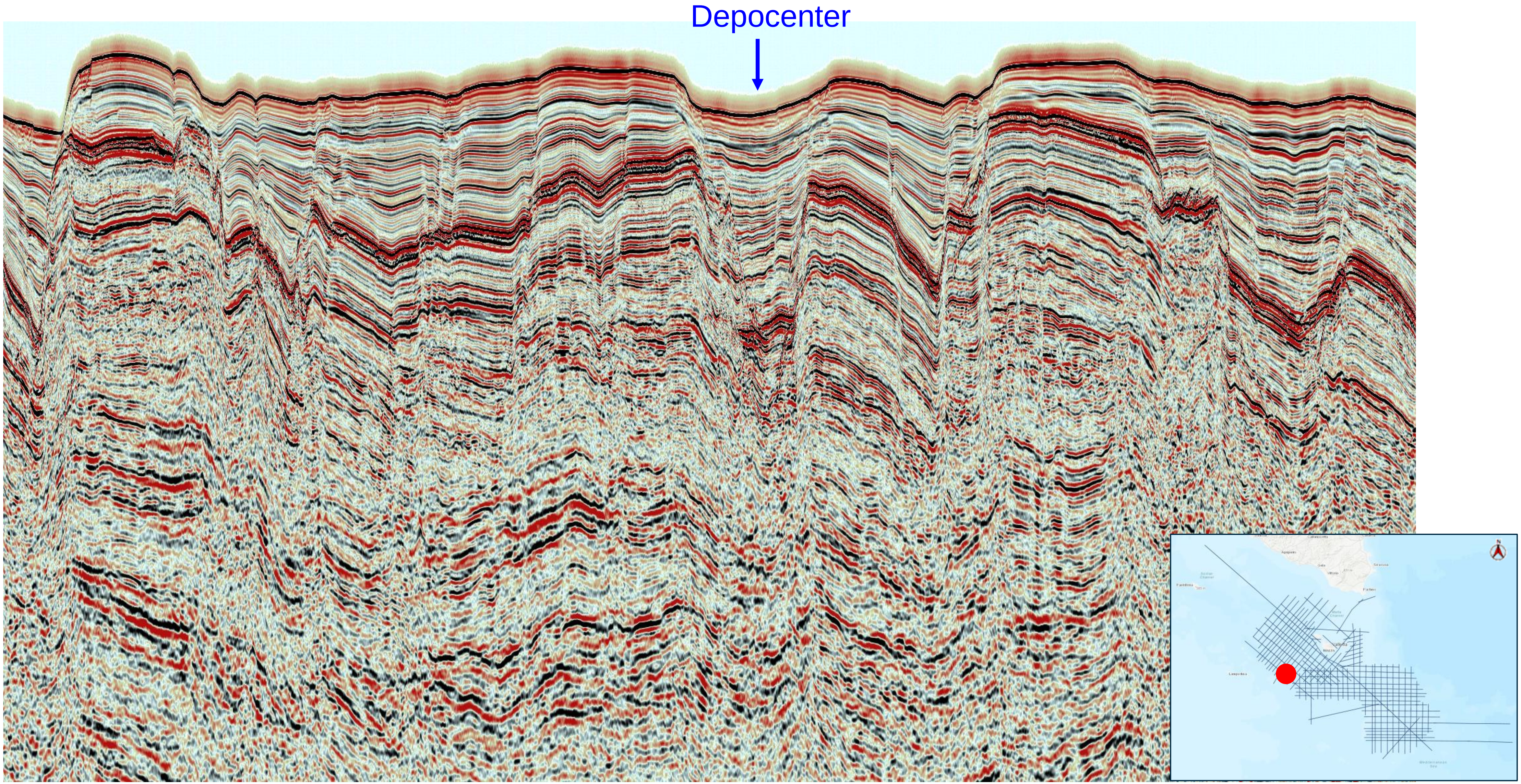
2D Modelling of Sedimentary Sub-basins

Areas with imaging problems due to carbonates and / or volcanic rocks





Typical Horst and Graben Structures



Petroleum Systems

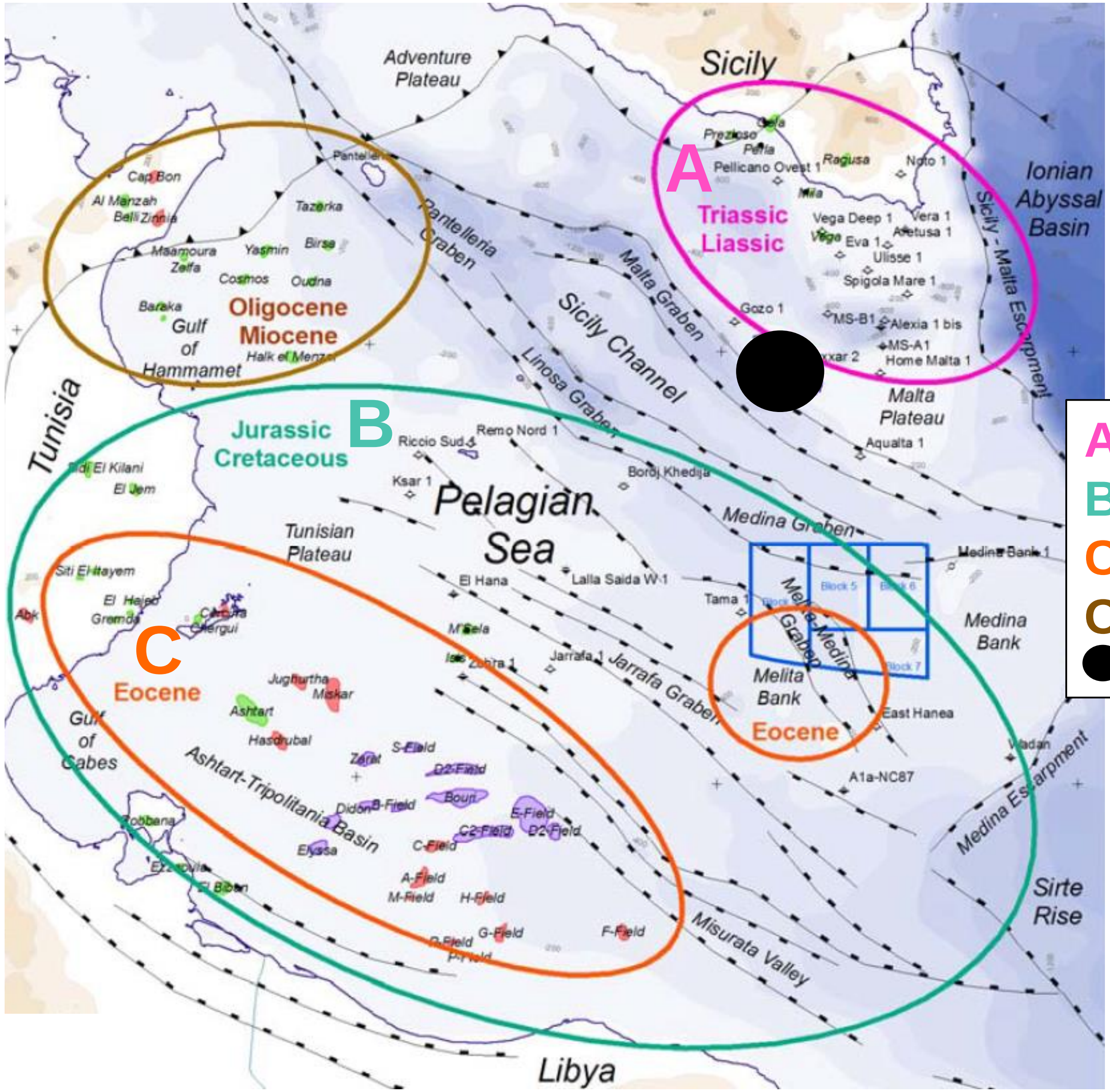
Petroleum Systems Regional Correlation

Offshore Tunisia
Pelagian Basin

B C

Offshore Libya
Pelagian (West) and
Sirt Basin (East)

B C



Sicily Channel-
Ragusa Basin

A

A Triassic Liassic
B Jurassic Cretaceous
C Eocene
O Oligocene Miocene
Malta

Marsili et al., 2017

Main Source Rocks

C Lower Eocene ▲ - Equiv. to the Bou Dabbous Fm of Tunisia.

Basinal limestones

Equiv. to .Nummulitic limestone reservoirs

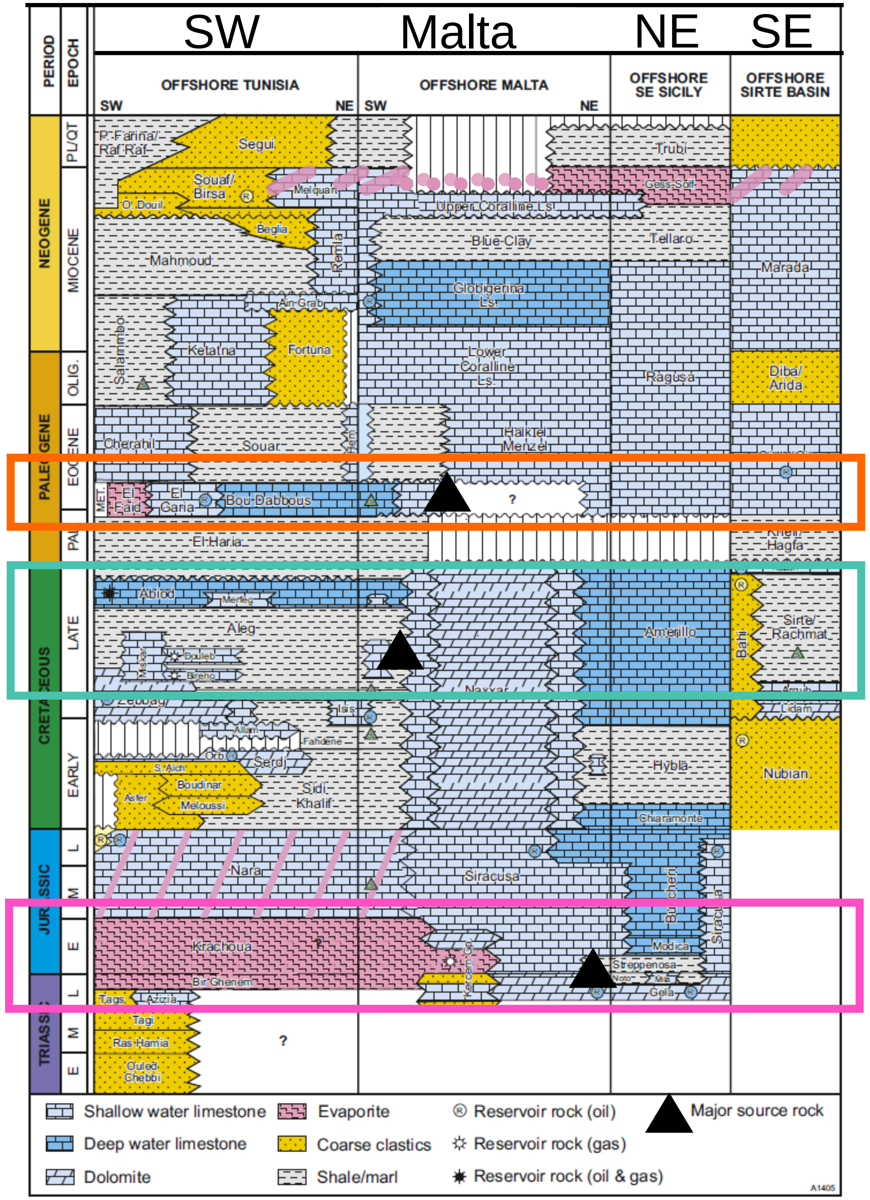
B Turonian shales & carbonates ▲ - Equiv. to the Bahloul & Annaba-Bireno Fms. of Tunisia.

Basinal shales and limestones

A Upper Triassic & Lowermost Jurassic ▲ - Streppenosa & Noto Fm. of Libya and Sicily.

Basinal carbonates and shales

Equiv. to Siracusa, Modica and Buccheri reservoirs



Main potential reservoirs

1 Upper Coralline limestone – Upr Miocene – Beneath Messinian salt, but likely to be too shallow to be prospective.

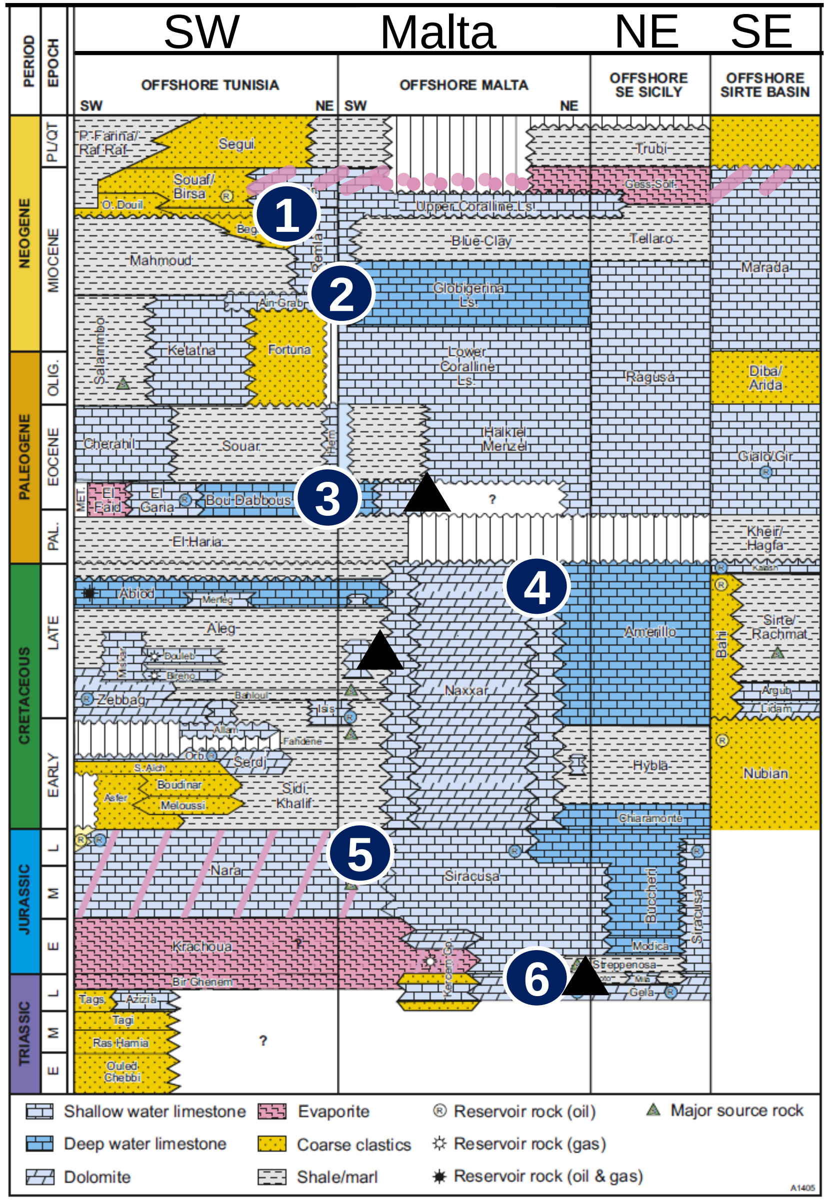
2 Lower Coralline limestone – Lwr Miocene –Oligocene

3 Numulitic limestones – Lwr Eocene Halk al Menzel -Metlaoui Fm. Shelfal and shelf margin forams carbonate build-up (Bouri Field). Equiv. Libya

4 Platform carbonates – Upr Cretaceous Amerillo Fm. equivalent to the Apulian Carbonates of S. Italy, especially if marginal “reef” build-ups can be located. Fractured and karstified.

5 Platform carbonates – Jurassic Siracusa Fm. May also include carbonates of the Upr -Mid Jurassic Buccheri & Lwr Jurassic Modica Fms. Platform carbonates defined in the Sicily Channel (Vega Field). Karstified and fractured.

6 Gela dolomites – Upr Triassic Gela Fm. Platform carbonates defined onshore Sicily and the Sicily Channel.



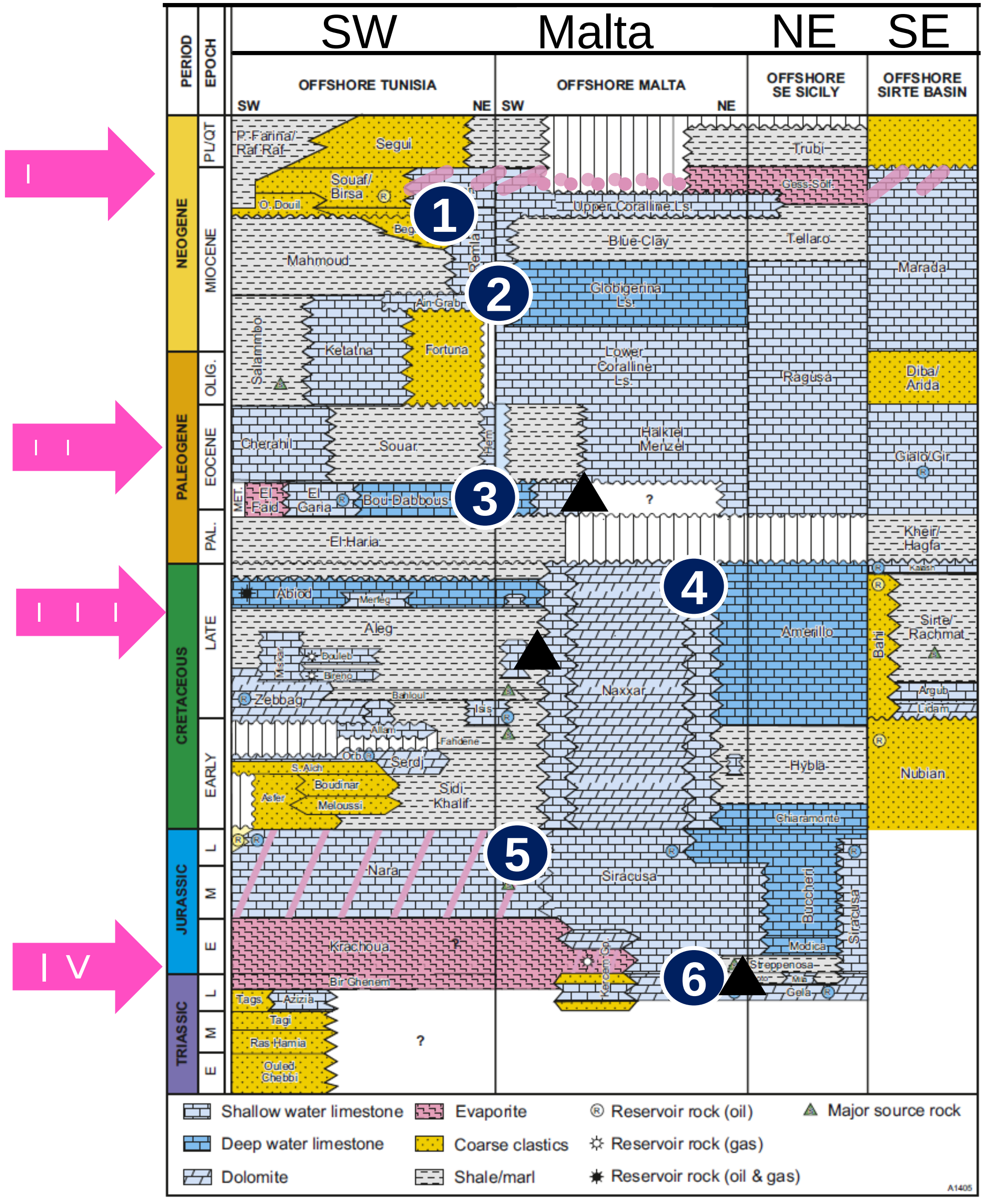
Seal – Different Seals in Different Areas

I. Messinian erosion and evaporites

II. Mid-Upper Eocene shales

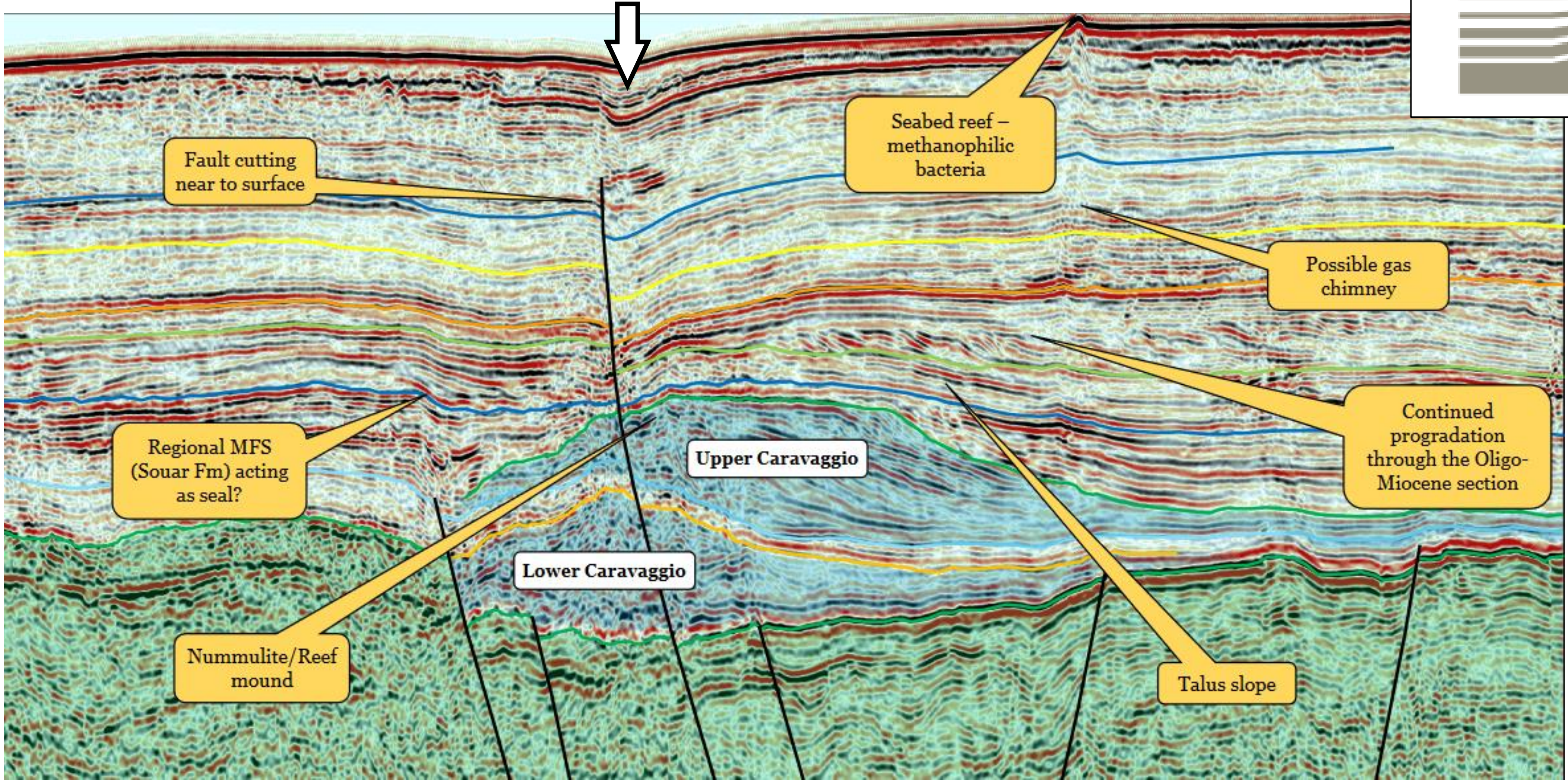
III. Maastrichtian – Paleogene shales and marls

IV. Triassic – Jurassic shales and marls and evaporites



Targeted Closure created from Stacked Reefs

Brightening in the right spot?

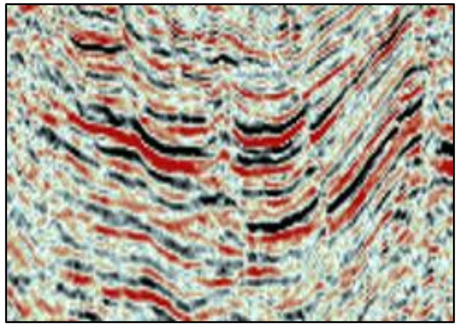


Traps and Features

Traps, Features and Leads

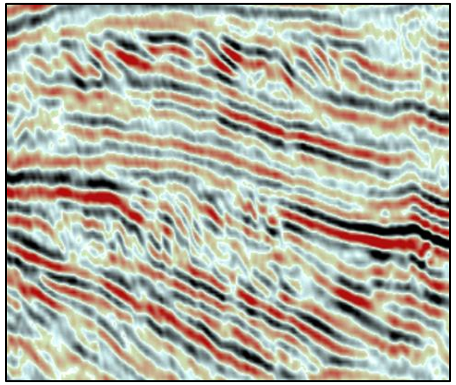
- Erosional Truncation and Seal
- Incised Channel Infill Onlap
- Transgressive Up-lap
- Thrust Features

Environment change



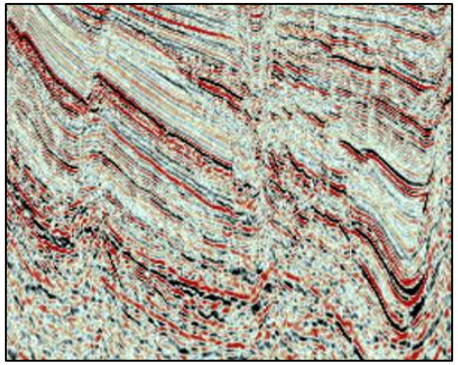
- Stacked Reefs
- Clinoforms
- Slumps
- Wedges

Depositional change



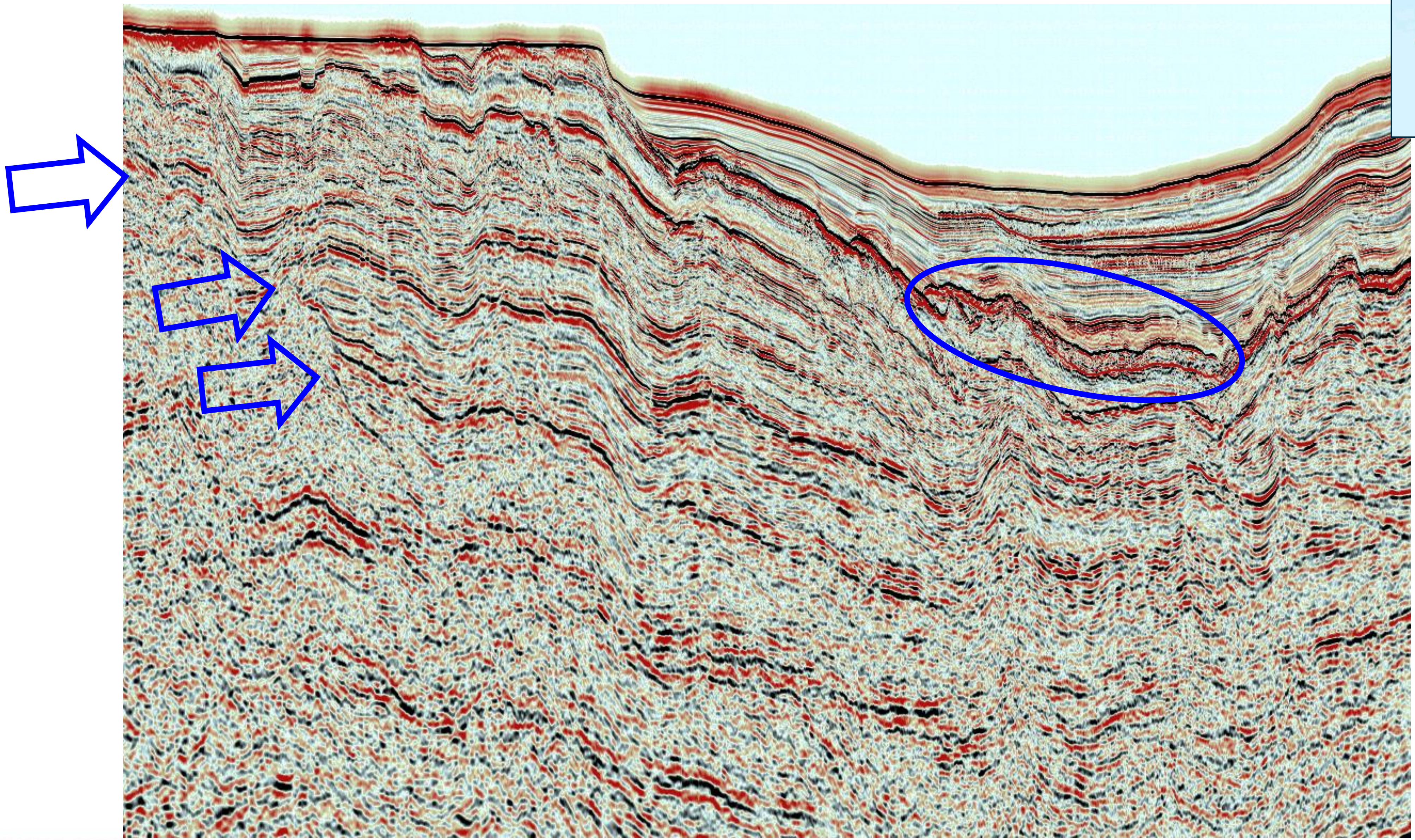
- Tilted Fault Blocks
- Rift Basin Up-dip Pinch-out
- Inversion and roll-over anticlines

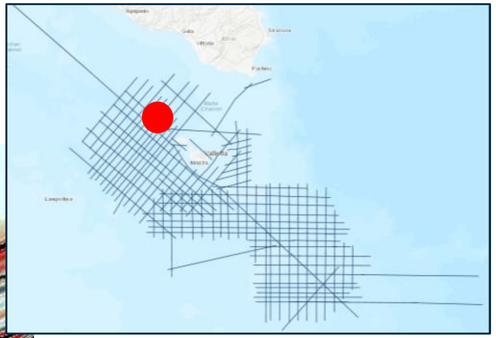
Tectonic change



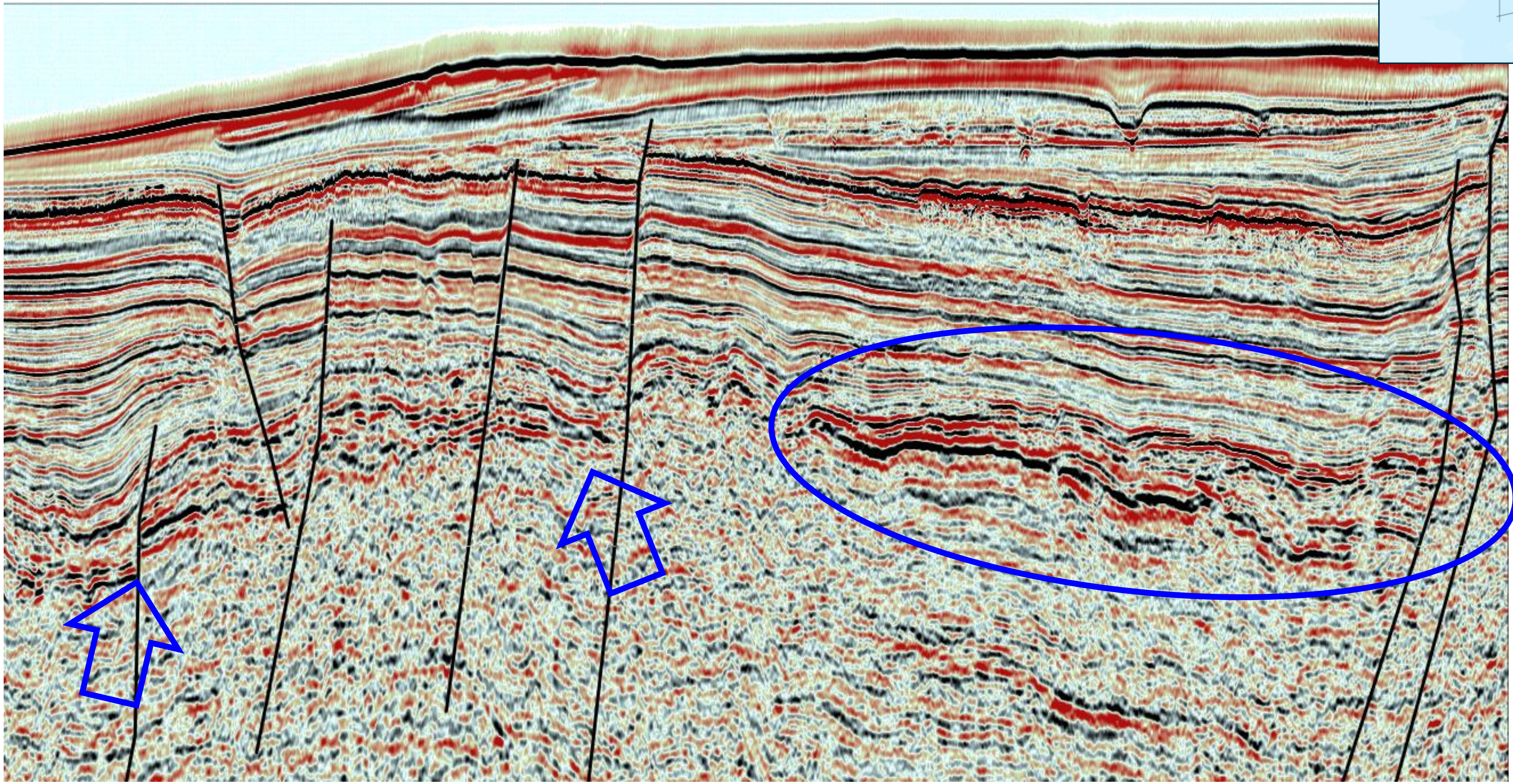
TGS

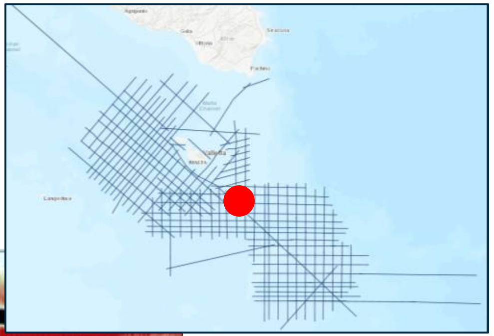
Synrift Pinch-outs and Mass Flow Closures





Channel Infill, Basinfloor Fans, Slope Pinch-out





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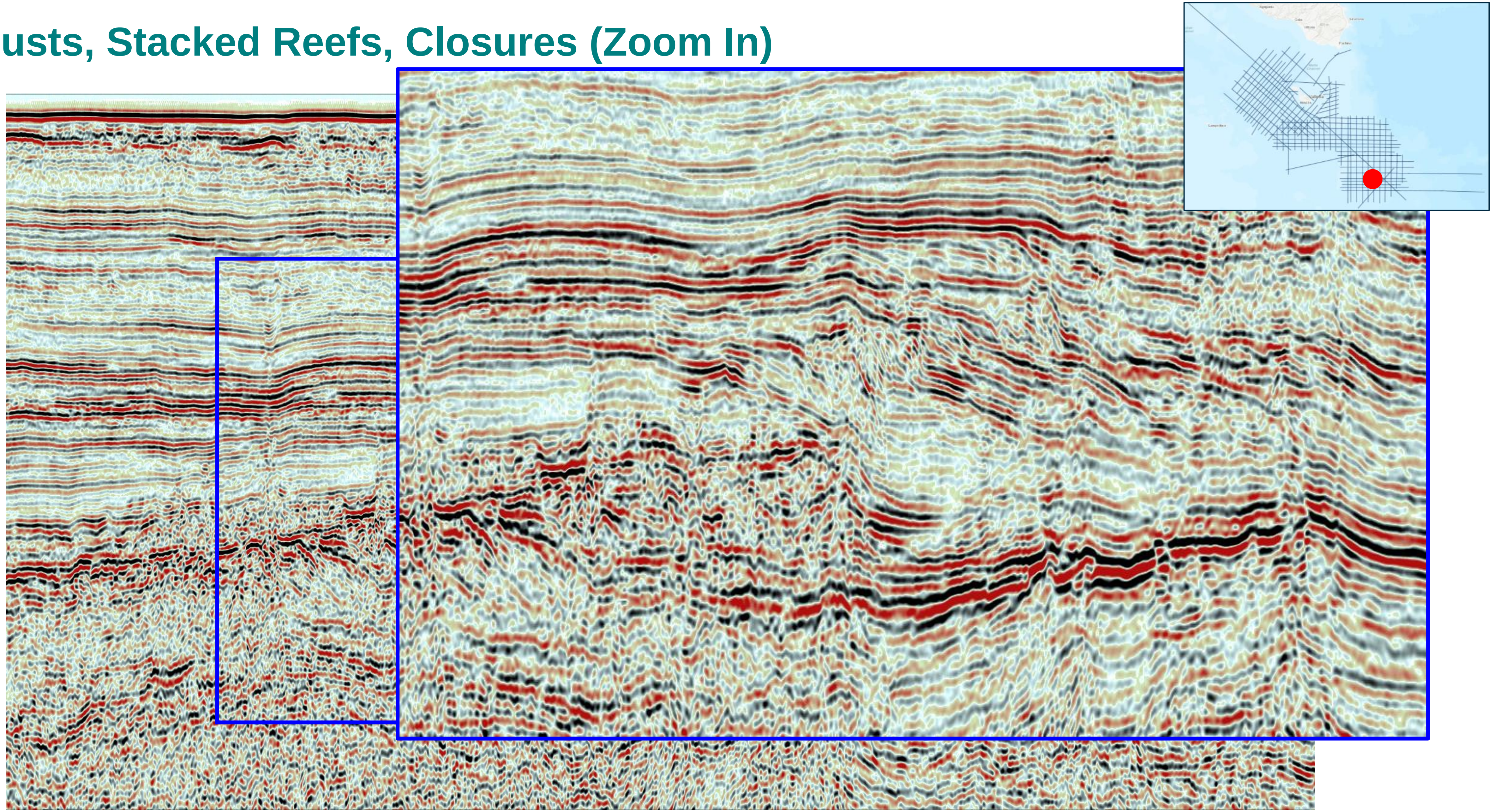
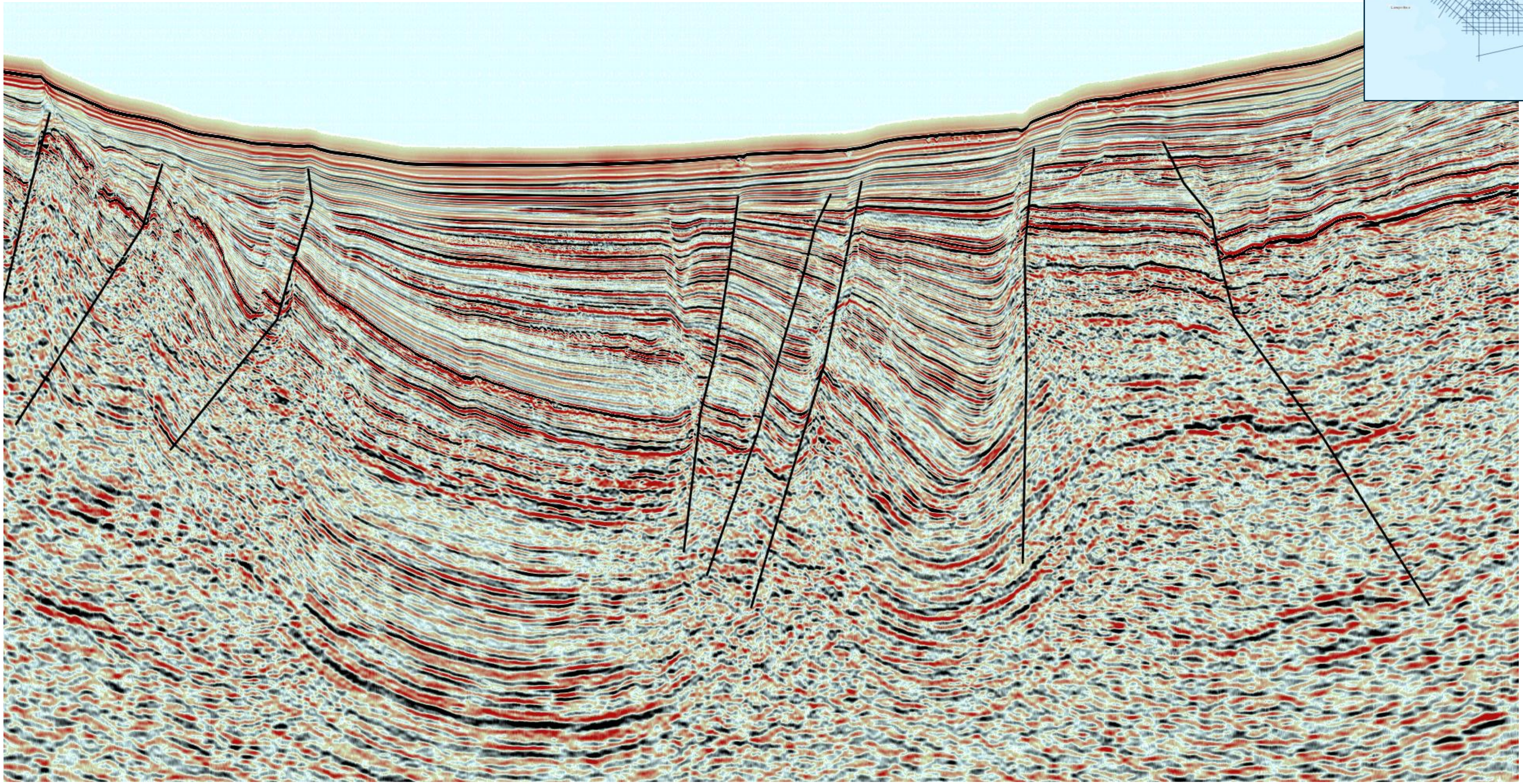
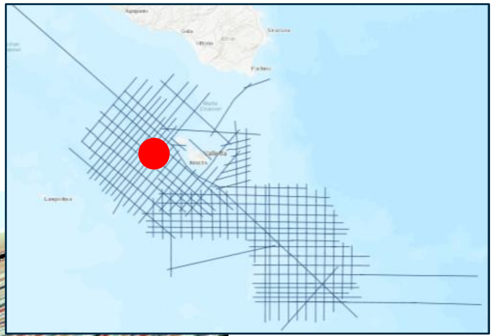
Thrusts, Stacked Reefs, Closures (Zoom In)



Tilted Fault Blocks, Growth Sequences, Rollover Anticlines

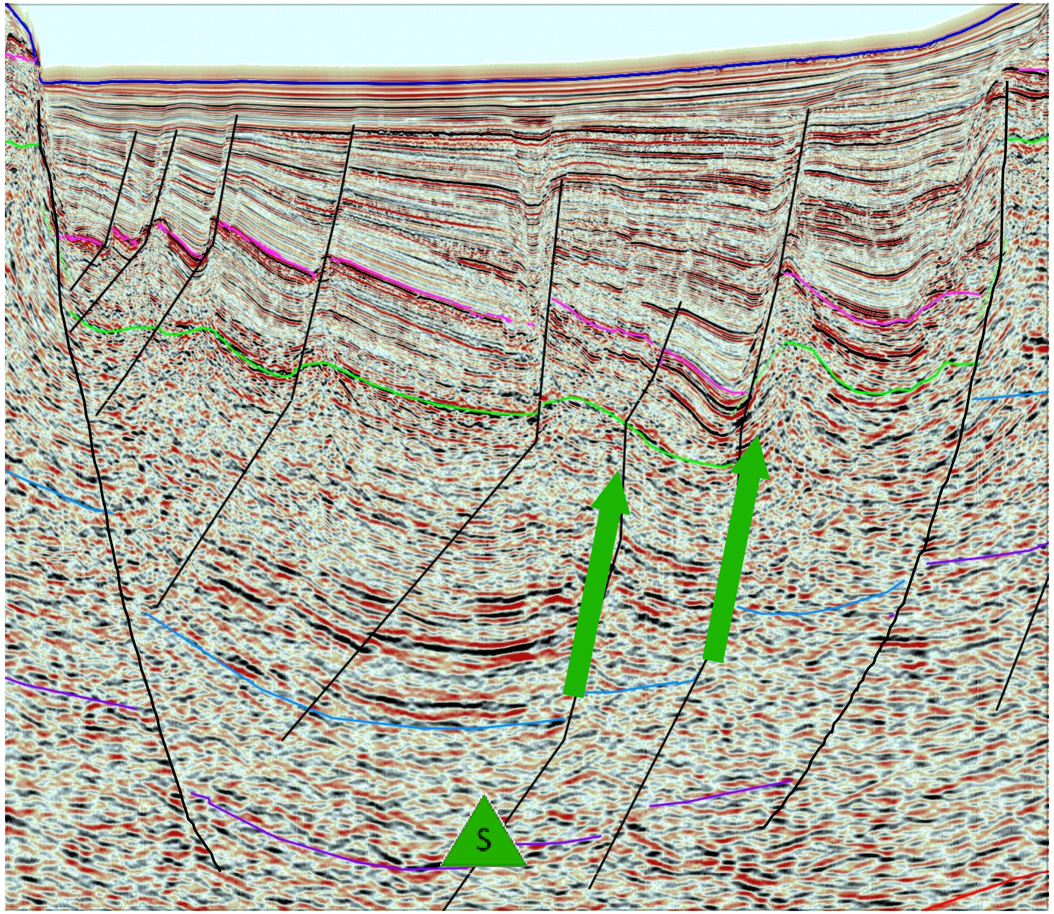




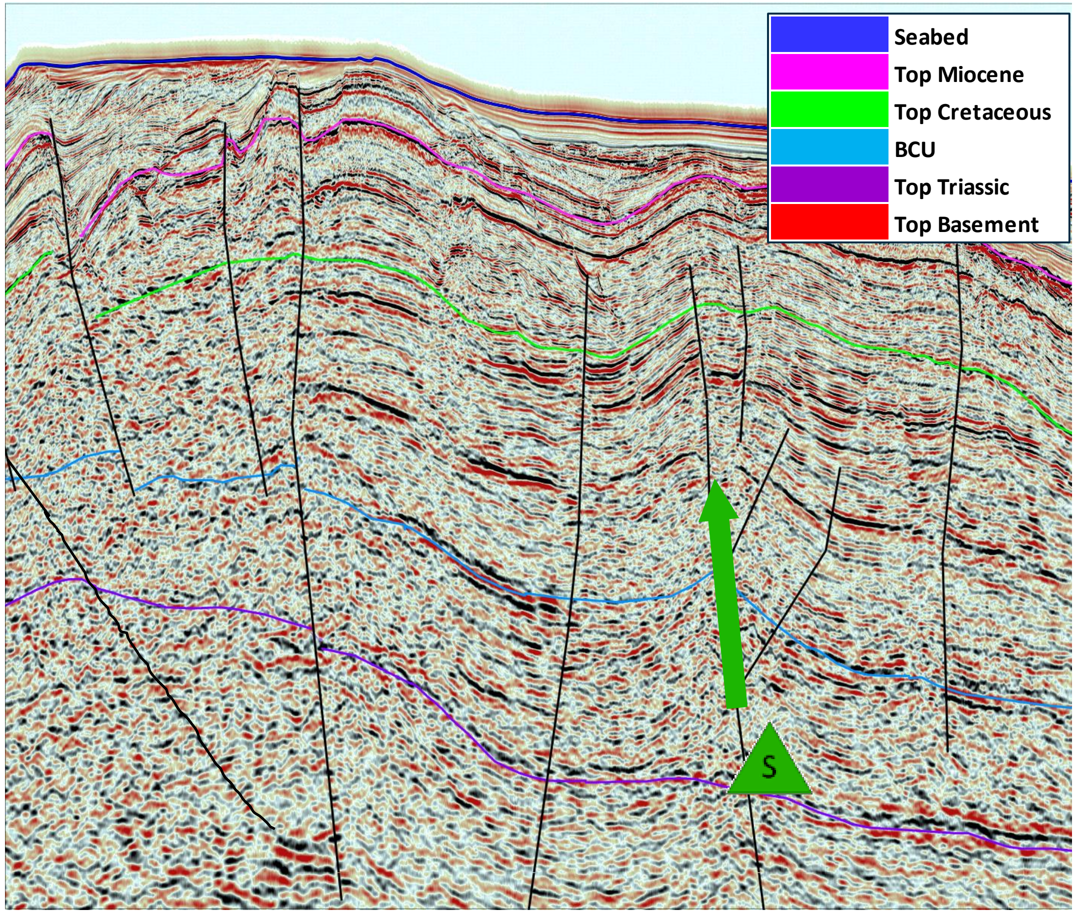
Maturity

Type Section (Zoom In)

Rollover anticlines from extension and later transtension.



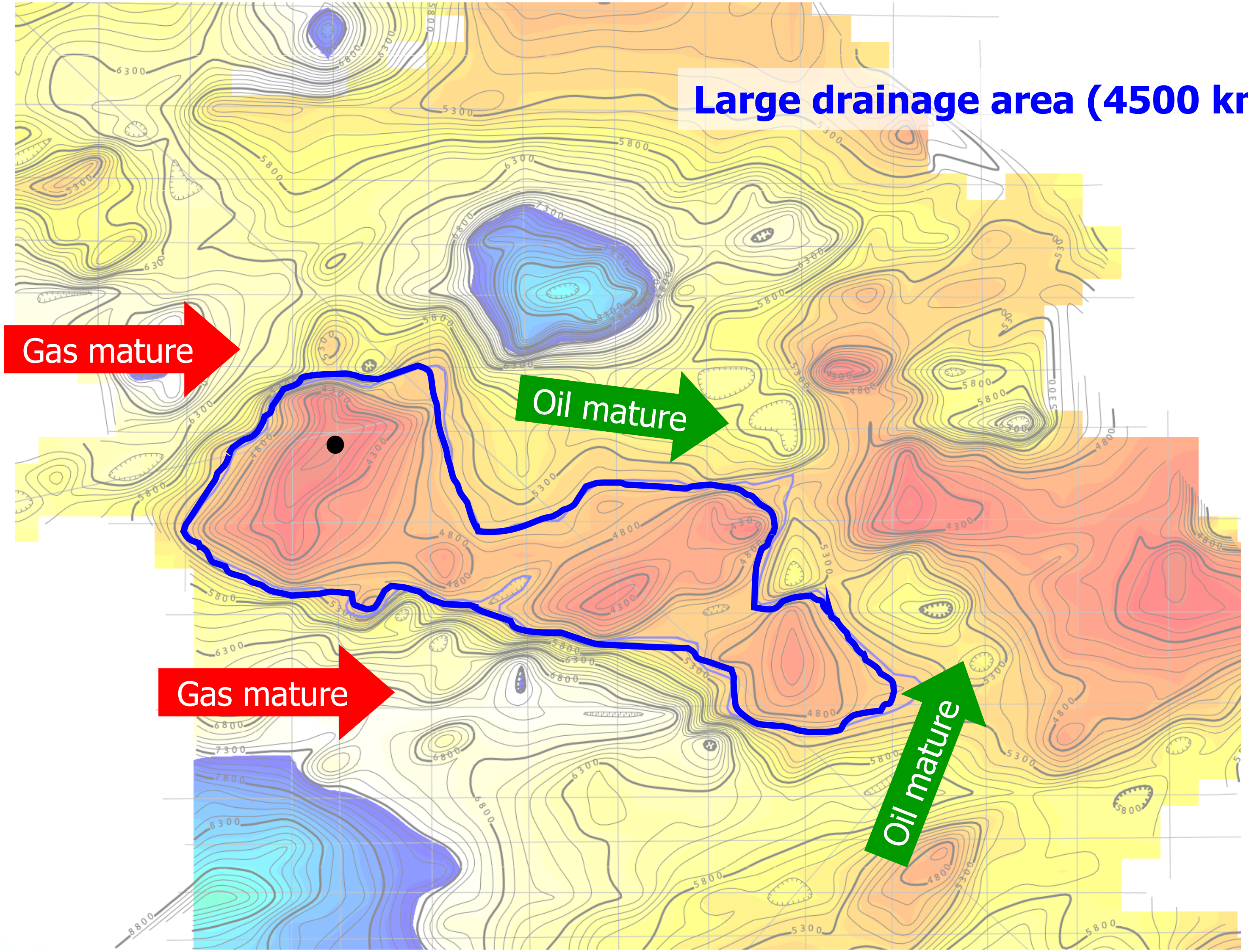
Compression on reactivated extensionfaults. Anticlines.



Lower Jurassic Streppenosa Shales may charge the Reservoirs in Upper Sequences via the faults.

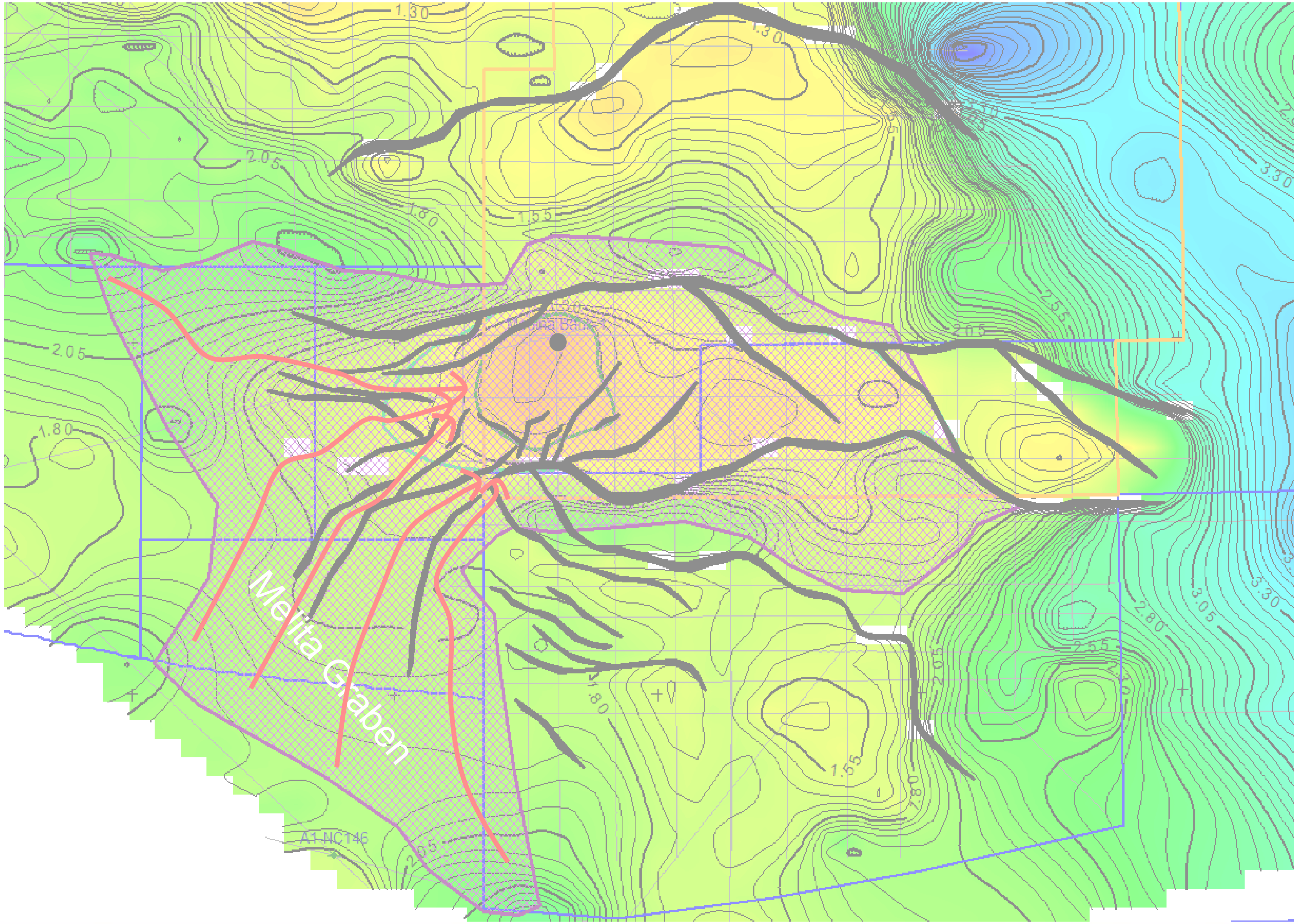
Prospectivity from TGS Data

Medina Bank Prospect – Migration Paths



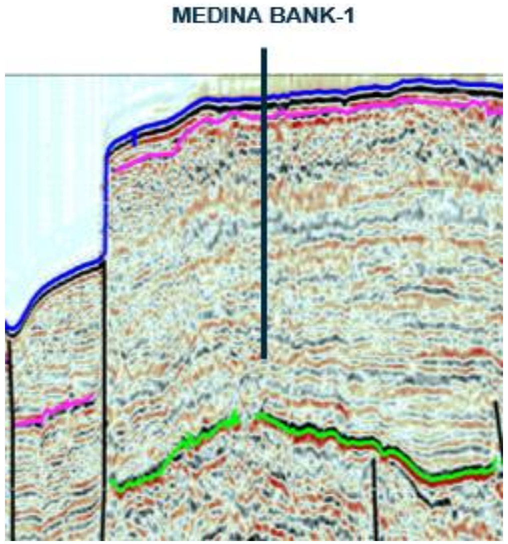
Base Cretaceous (TVD)

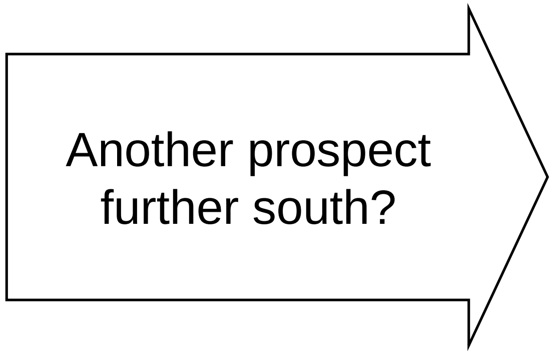
Medina Bank Prospect – Migration Paths

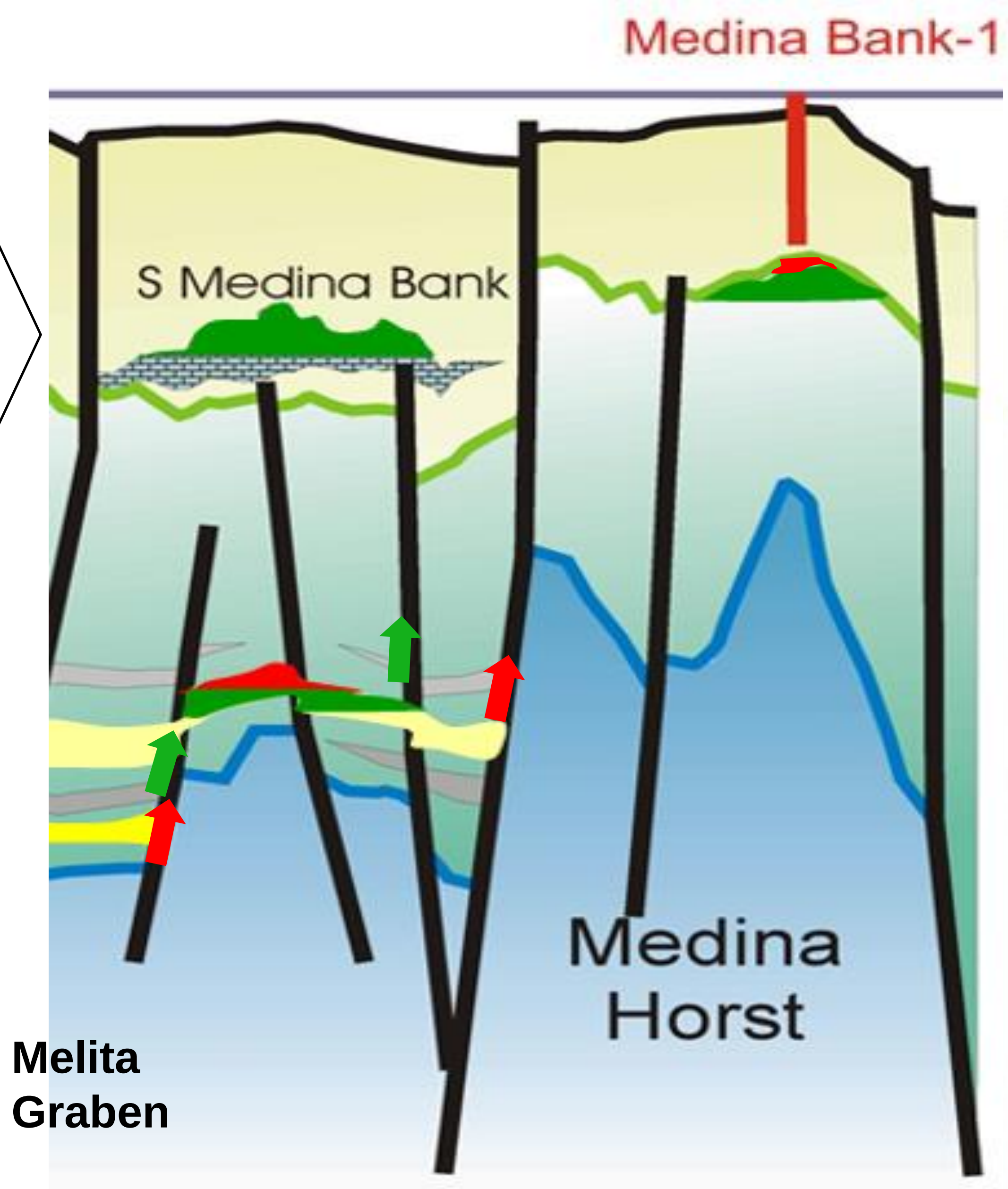


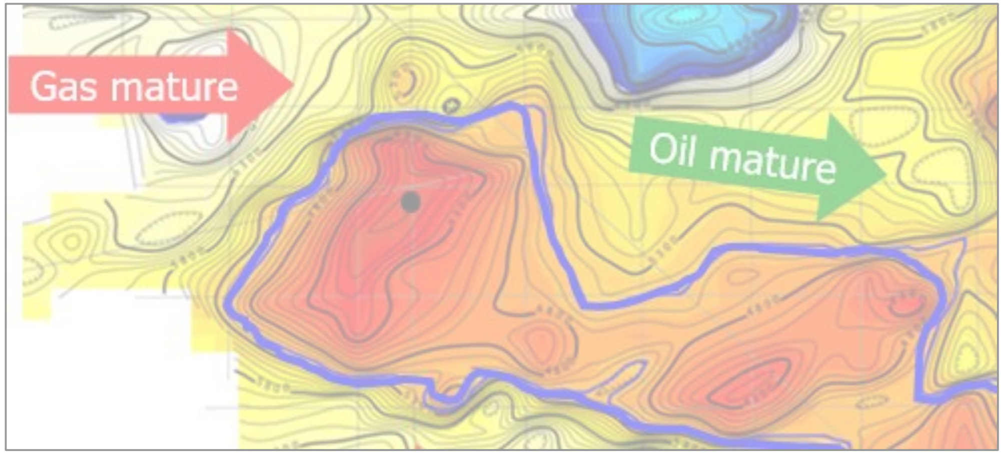
Base Tertiary (TWT)

What might have happened…



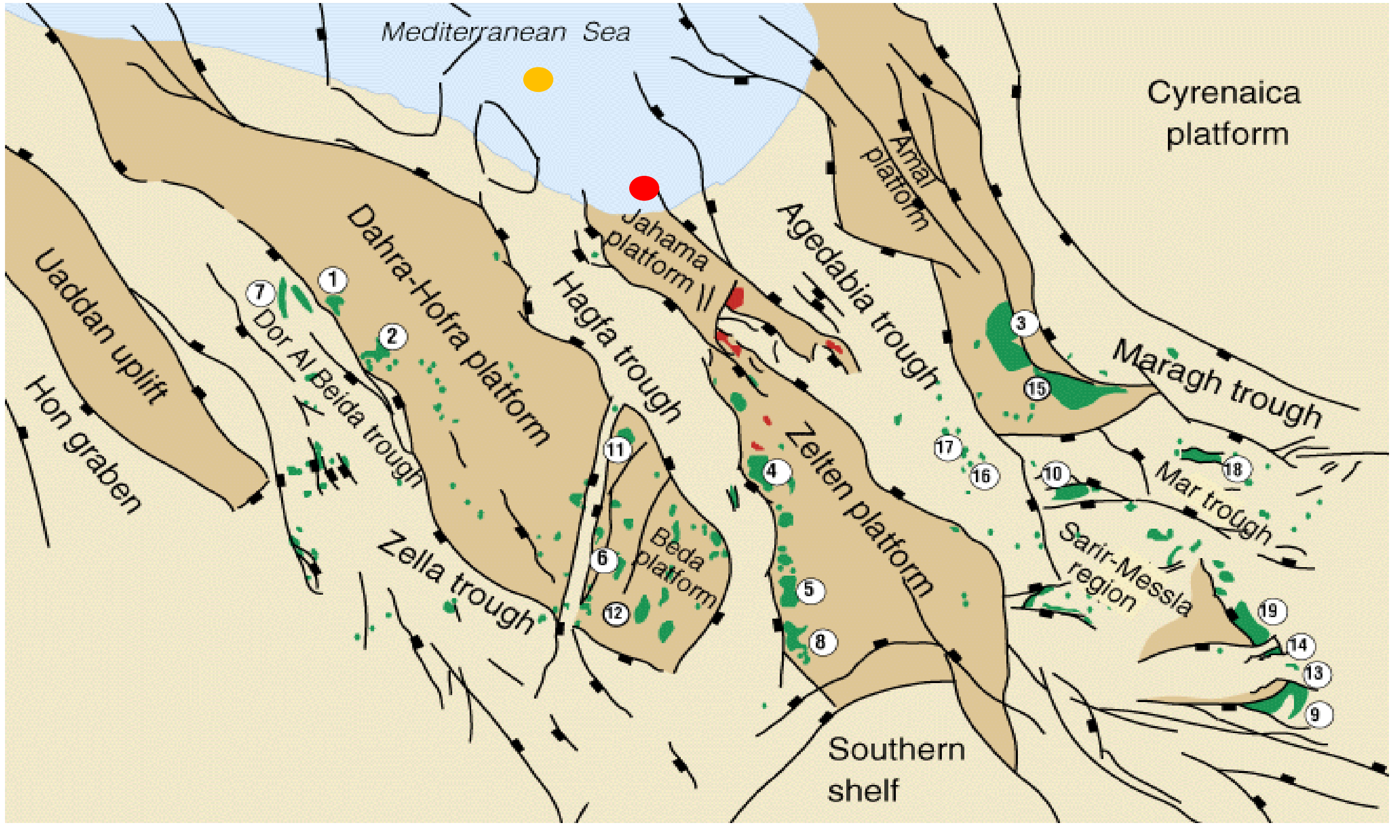






Southern Extension of Malta to Offshore Libya

Offshore Libya



1. HC evidence, fields and shows

2. Petroleum System is working:
   - Good Reservoir Thickness (seismic)
   - Good Reservoir Quality (wells)
     (e.g. Eocene Carbonates, Cretaceous Clastics)
   - Generation and Charge (HC shows)

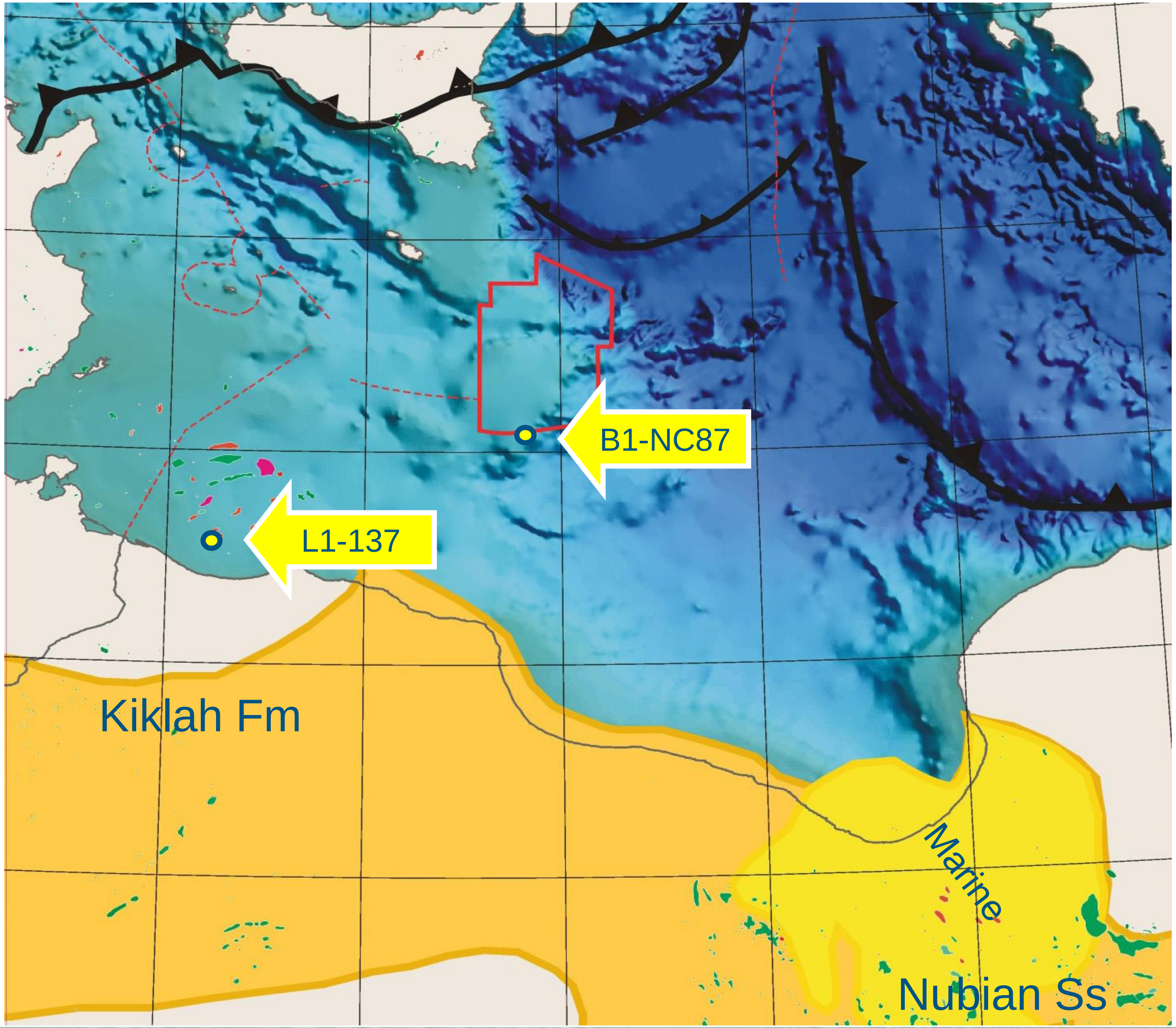
3. According to Seismic interpretation and Basin modelling studies in the south:
   The Sirt shales offshore Libya may have passed Oil window 78 Ma and Gas window 62 Ma

4. Underexplored with 30 wells in last 60 years!

Oil & Gas Journal, 1995. Exploration Limited Since '70s in Libya's Sirte Basin. Accessed August 2018.

TGS

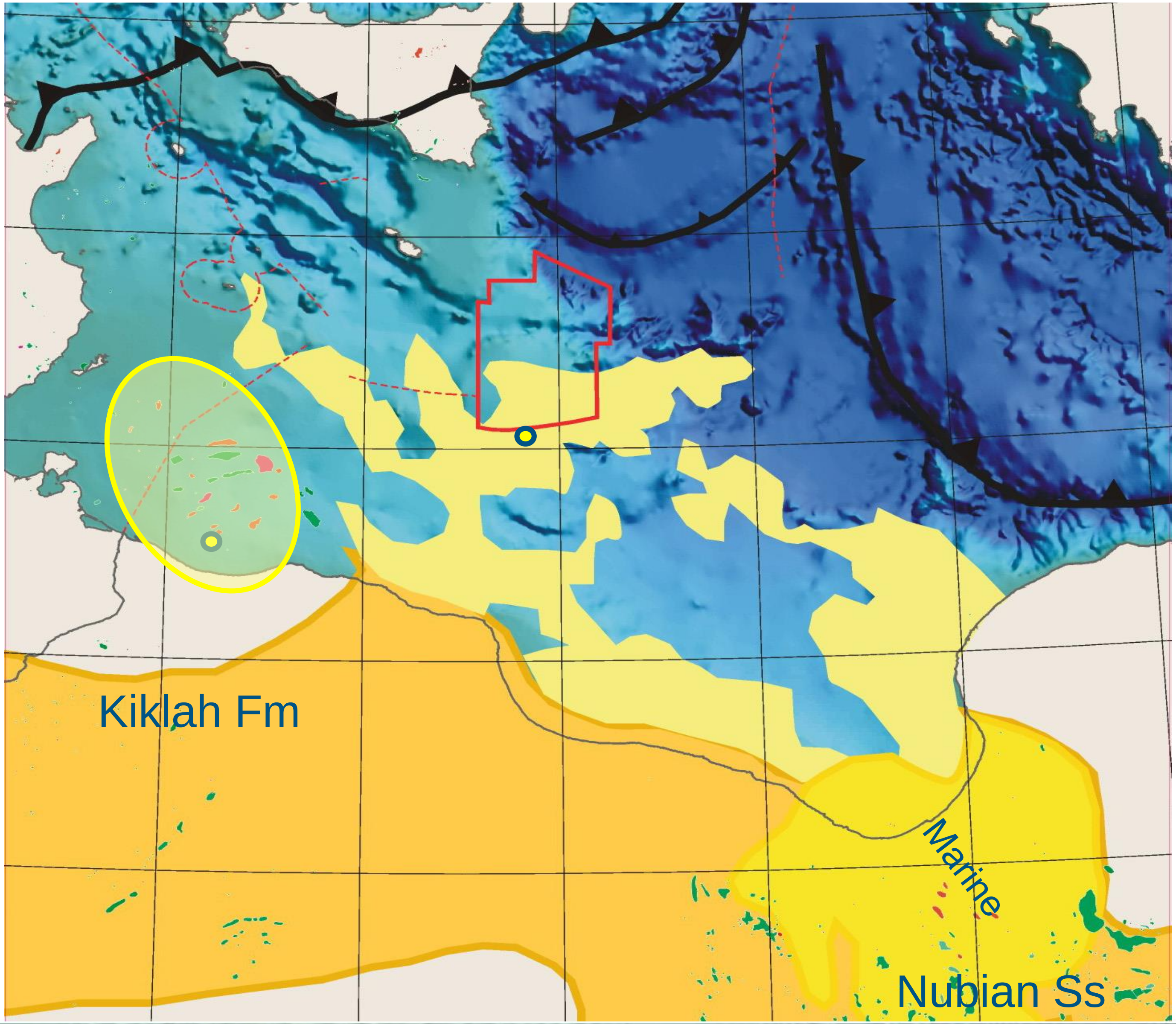
Lower Cretaceous Sandstone



→ Encountered in wells

→ Present onshore

Lower Cretaceous Sandstone Fairway



Mapped on satellite gravity residual maps

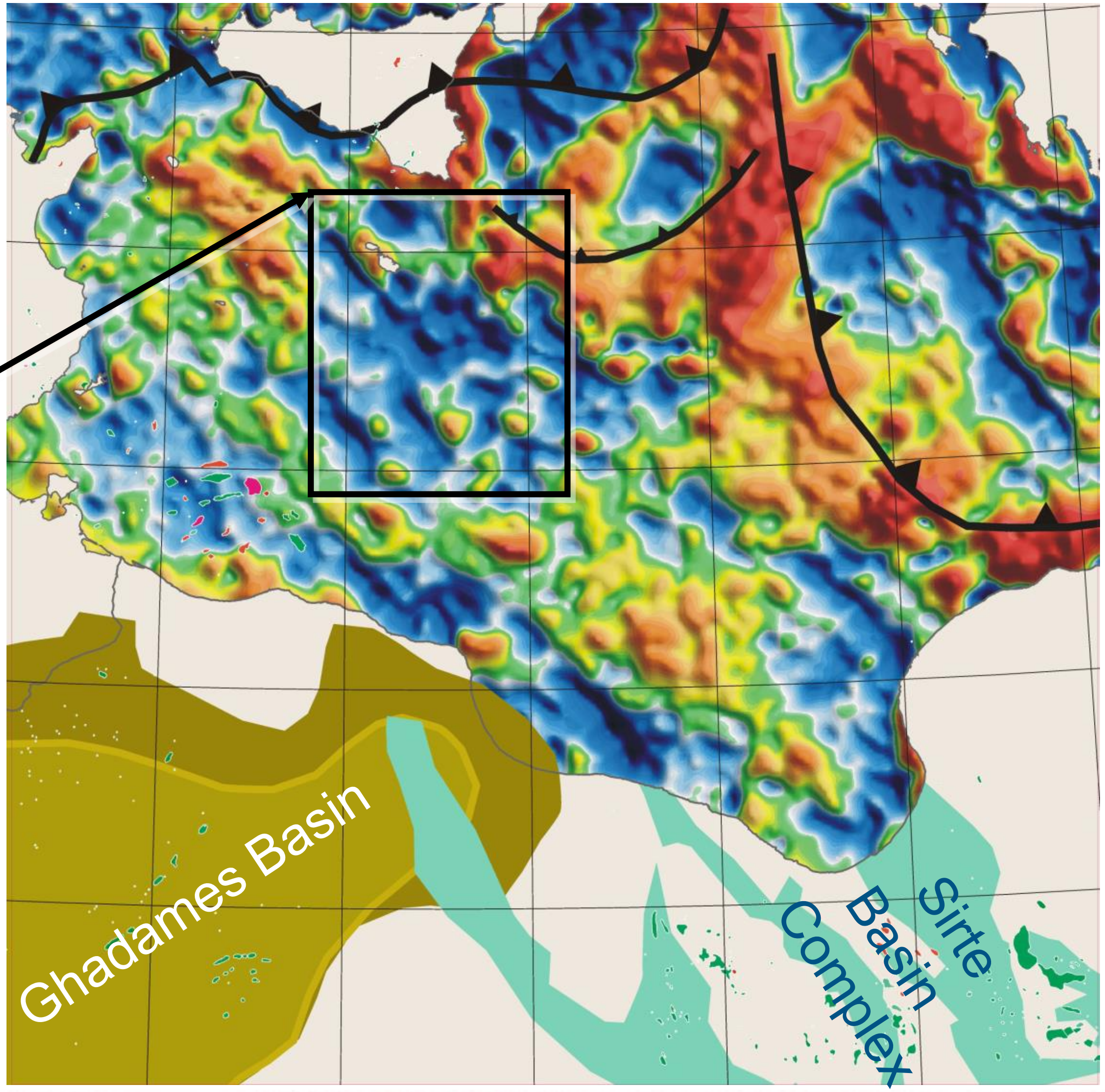
Southern Extension of Malta to Offshore Libya

Opportunities – Gravity & Magnetics

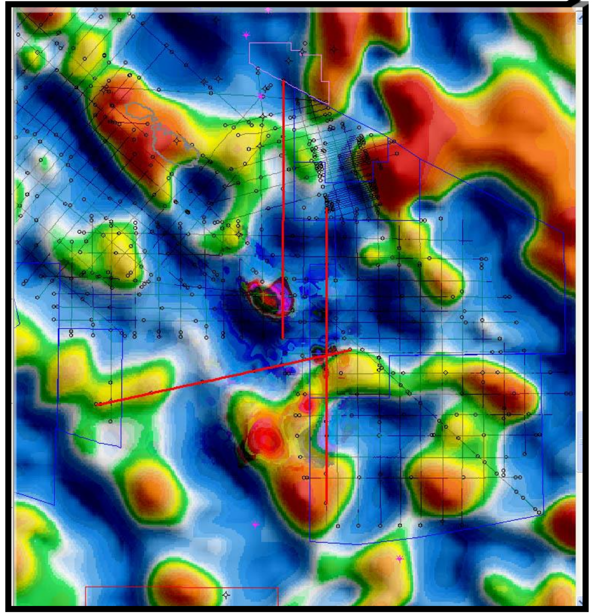
Shipborne Data Quality and Grid Resolution

Satellite derived Bouguer gravity

400km High-pass Bouguer

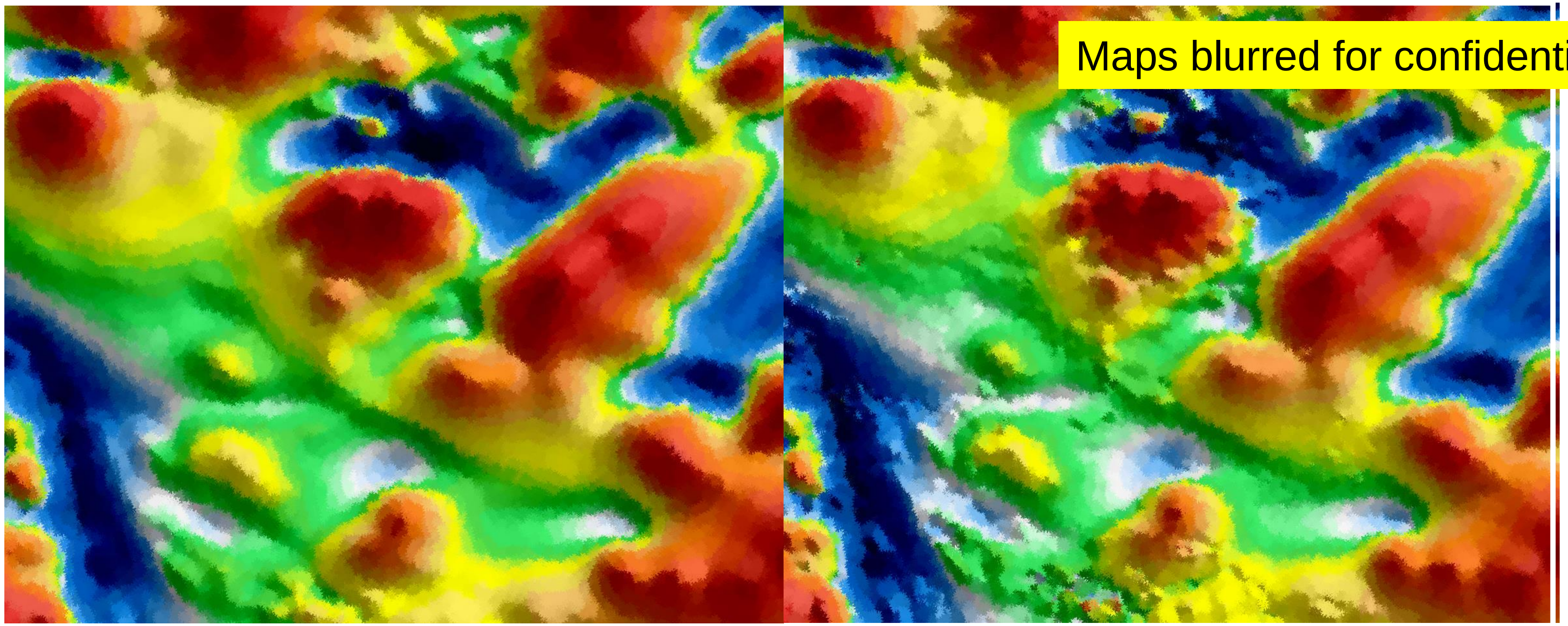


Marine gravity with higher resolution



Airborne Data Quality & Grid Resolution

Magnetic anomalies - unfiltered

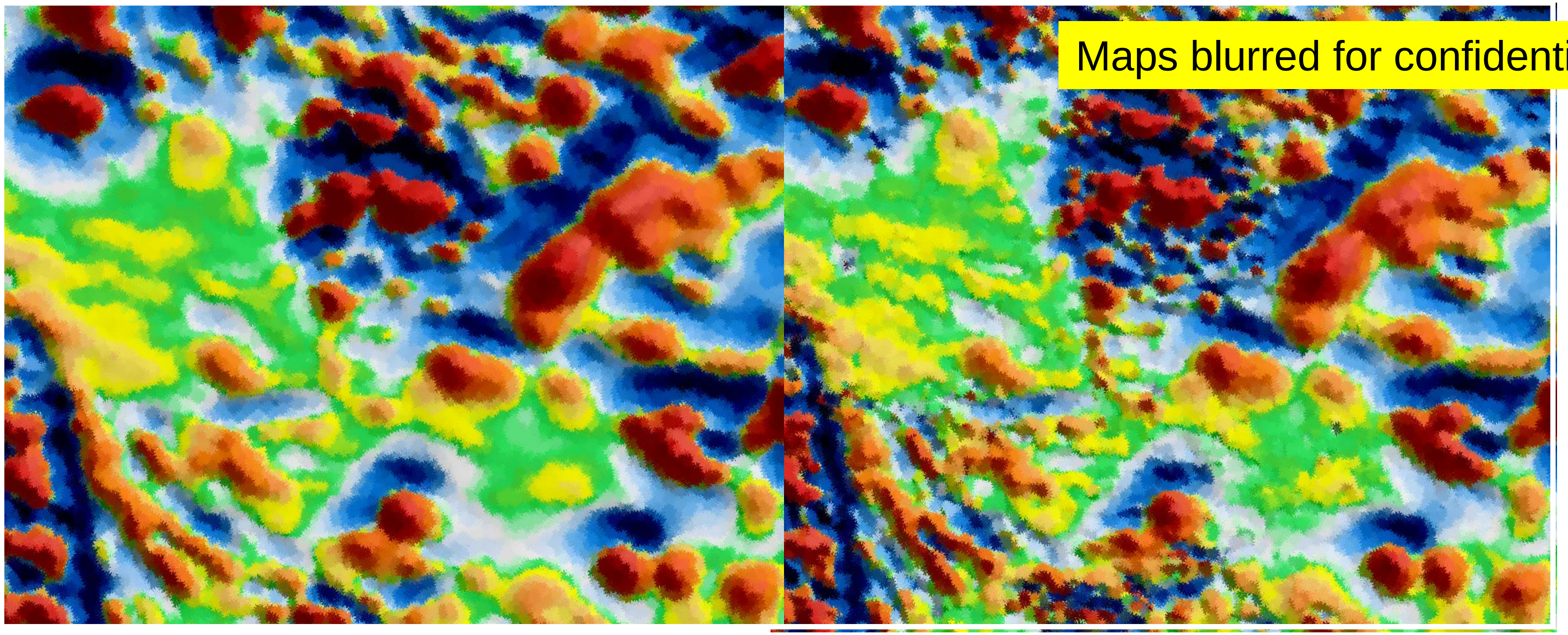


Open 10x10 km grid

Dense 2x2 km grid

Airborne Data Quality & Grid Resolution

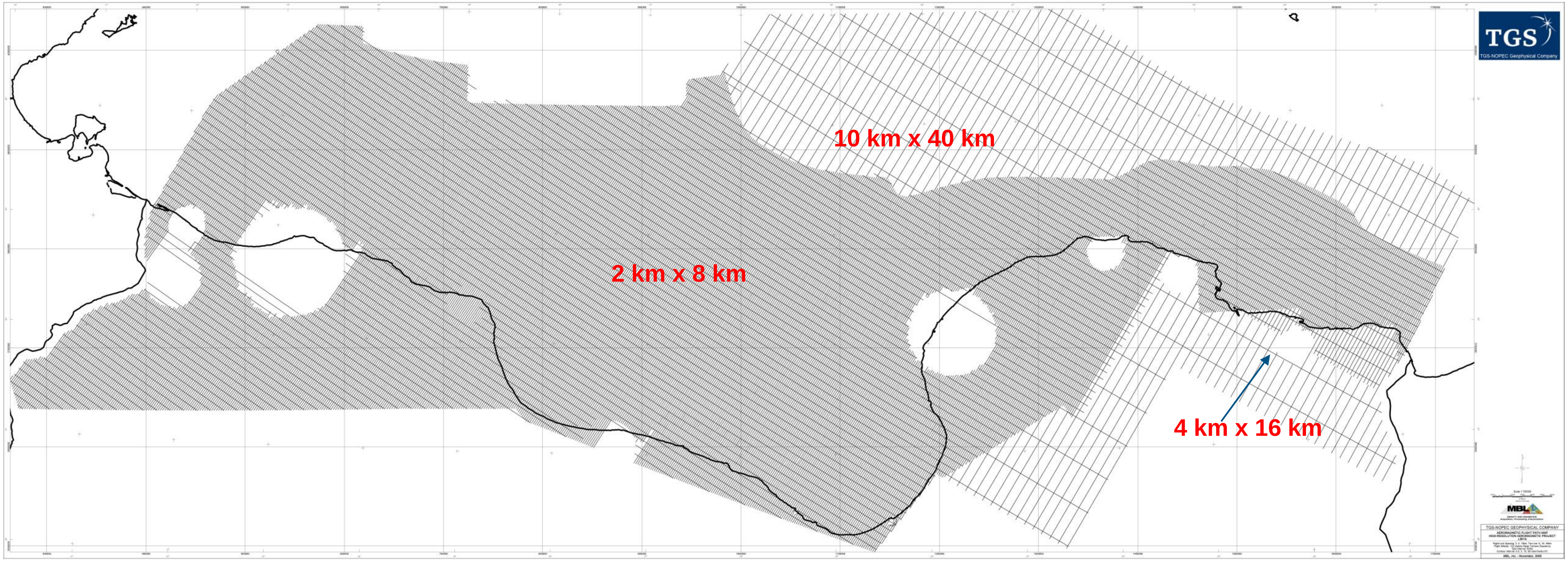
Magnetic anomalies – 30km high-pass filtered



Open 10x10 km grid

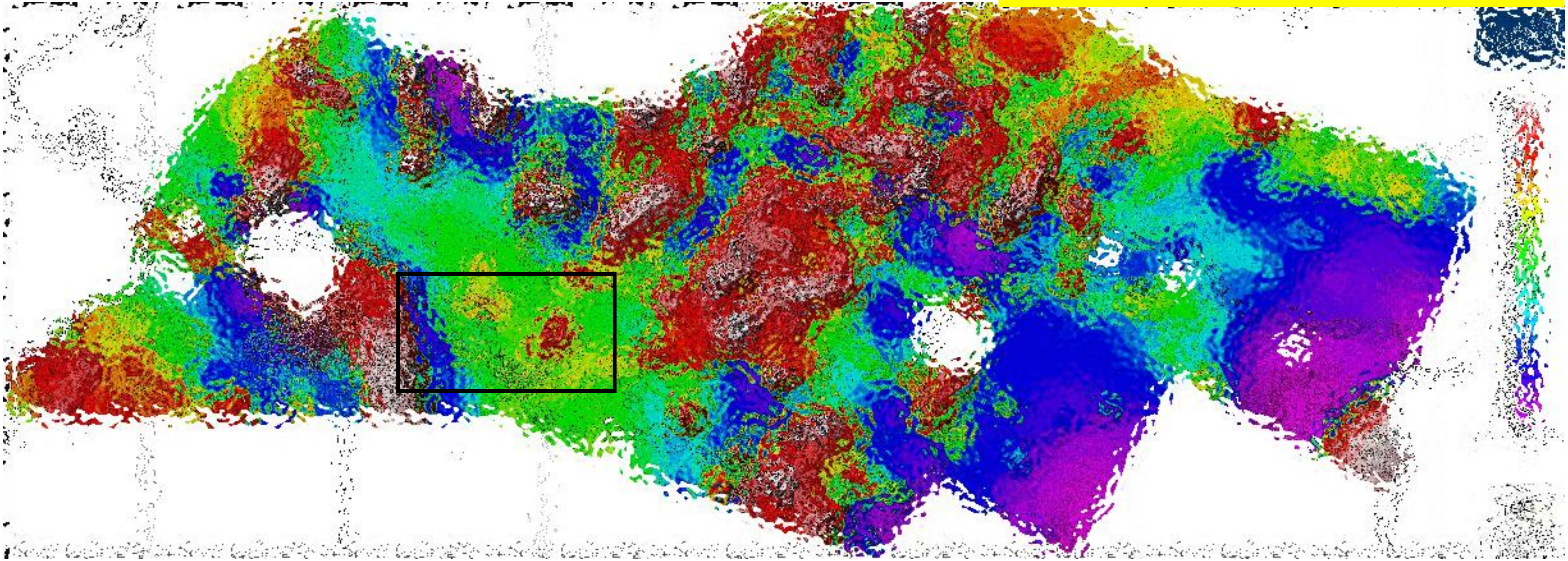
Dense 2x2 km grid

TGS High-Resolution Aeromagnetic (HRAM) Flight Path

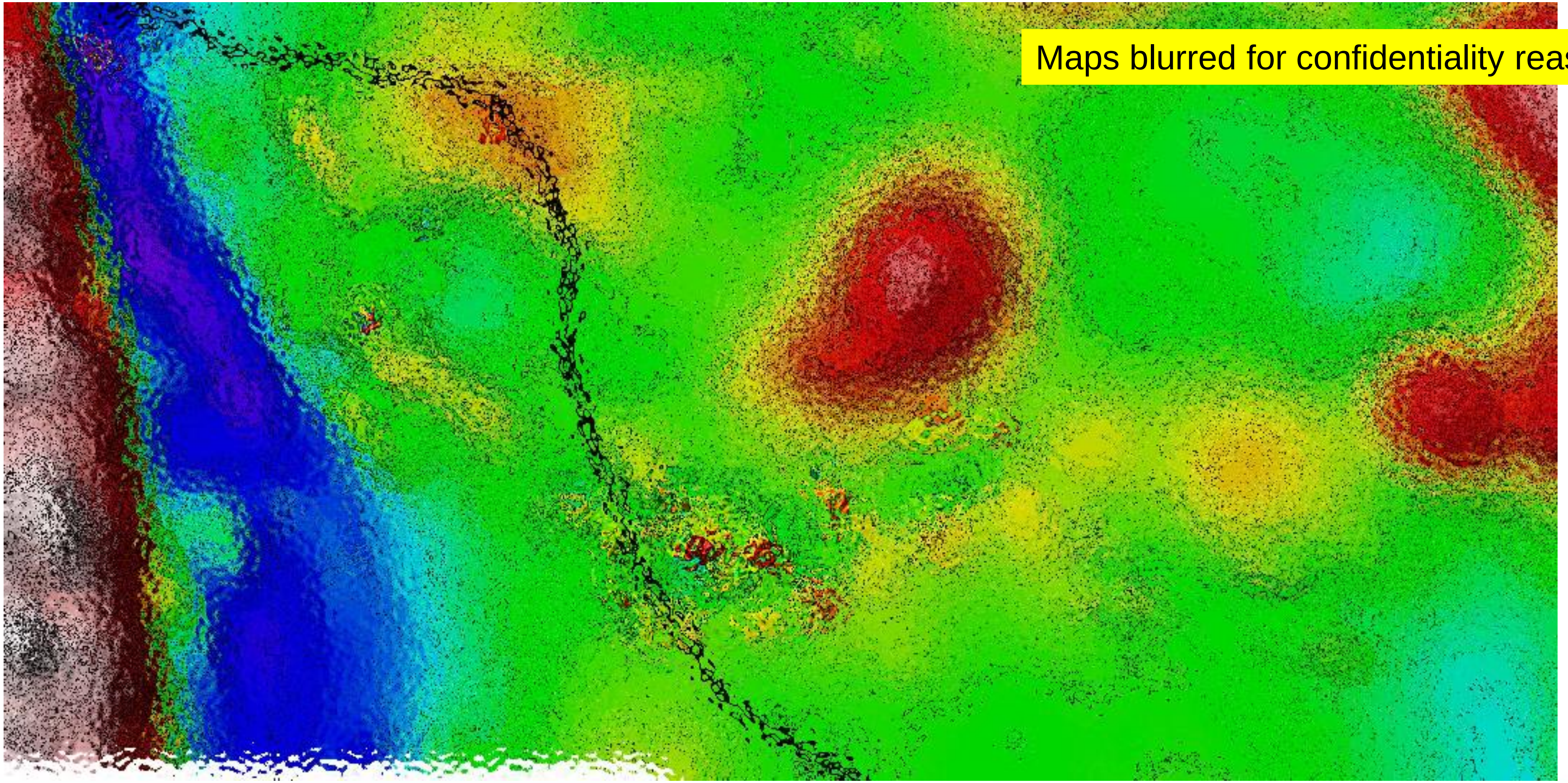


Reduced to the Pole (RTP) Magnetics

Maps blurred for confidentiality reasons



Reduced to the Pole (RTP) Magnetics



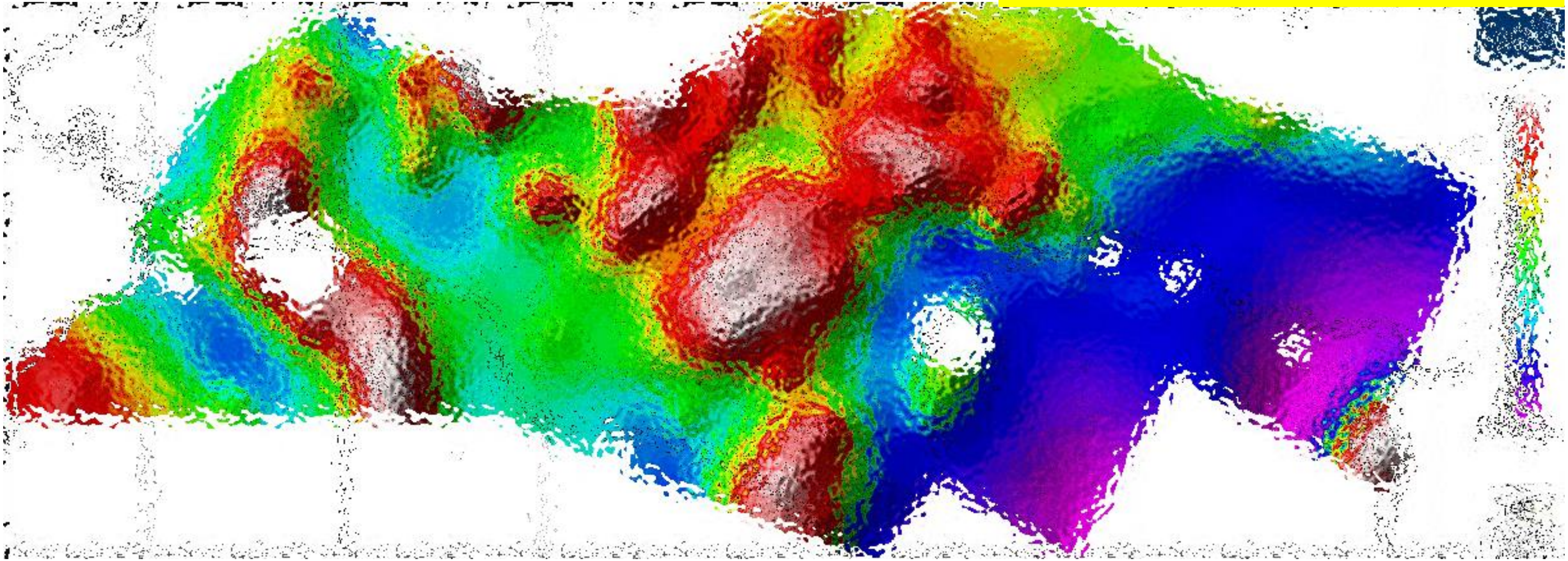
Maps blurred for confidentiality reasons

Application of Magnetic & Gravity Data

- Structural Map View (3D correlation of 2D seismic sections)
- Structure in Depth (Interpretation of Deep Structure)
- Cost effective Crustal Studies
- Optimum Design of Seismic Programs
- Objective Testing of Seismic Interpretations
- Basement, Intra-crustal and Mantle Densities by inversion
- Vice Versa Moho Depths extrapolated from seismic reflection verified

Residual RTP – Low-Pass 200km

Maps blurred for confidentiality reasons

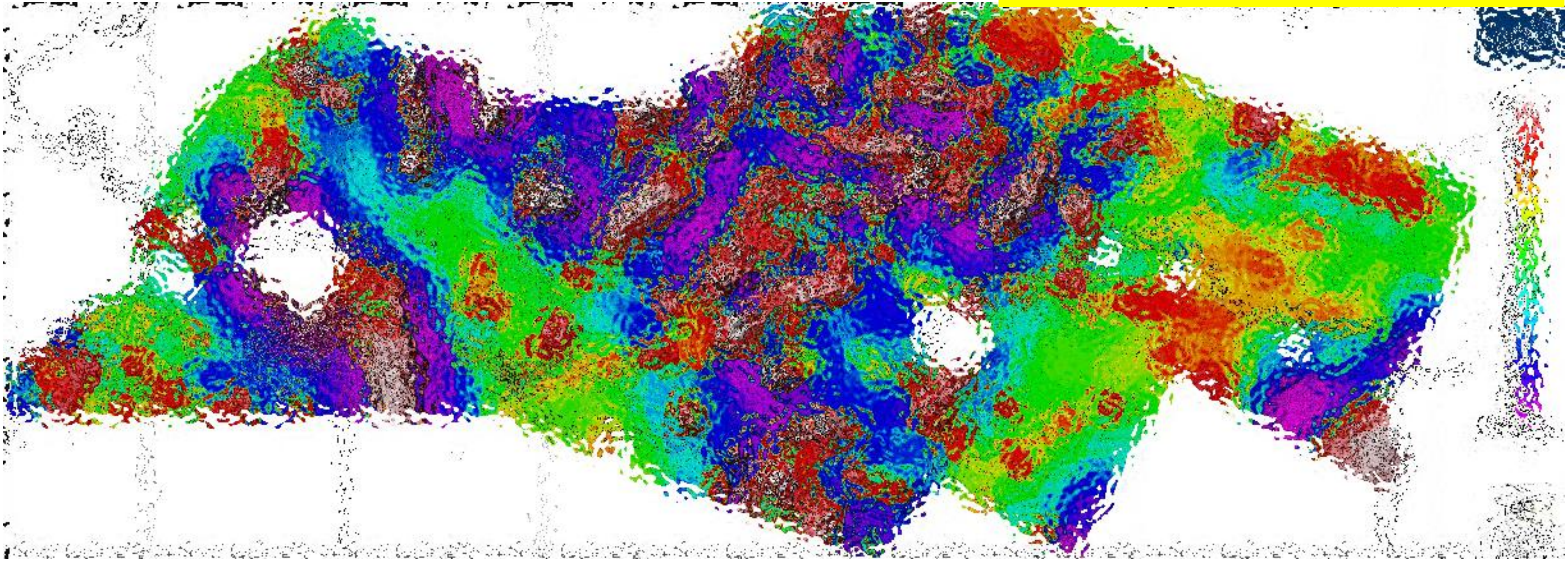


Application of High Resolution Magnetic & Gravity Data

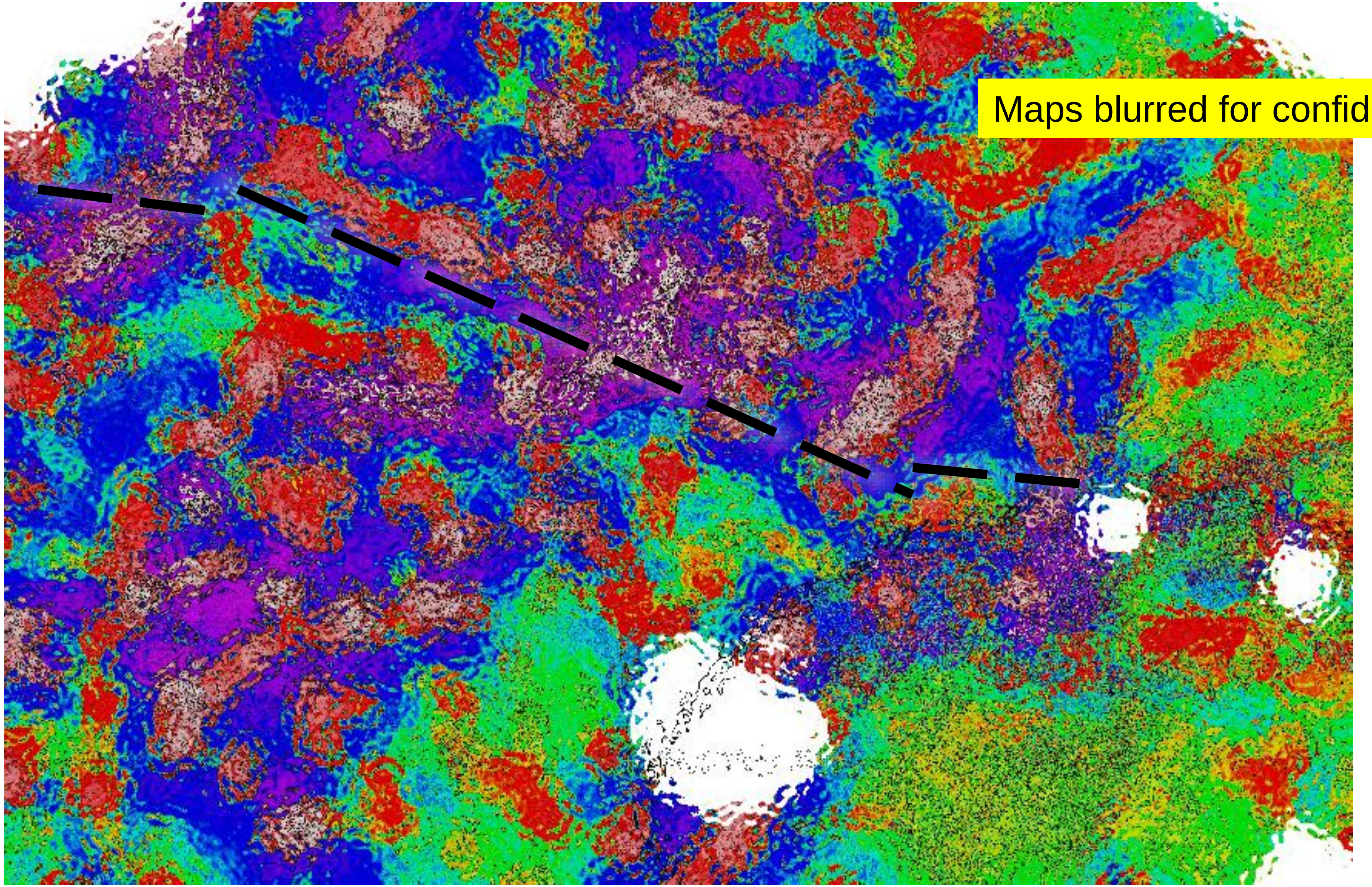
- Delineation of reflectivity masking Volcanics and Dikes
- Mapping Lithic Fragments in Reservoir
- Basement Surface – Seismic / Magnetics
- Detailed Density-Depth Function in pseudo 3D
- Ingress Issues (airborne or minimal impact)
- Coverage effective Regional Studies

Residual RTP – High-Pass 200km

Maps blurred for confidentiality reasons

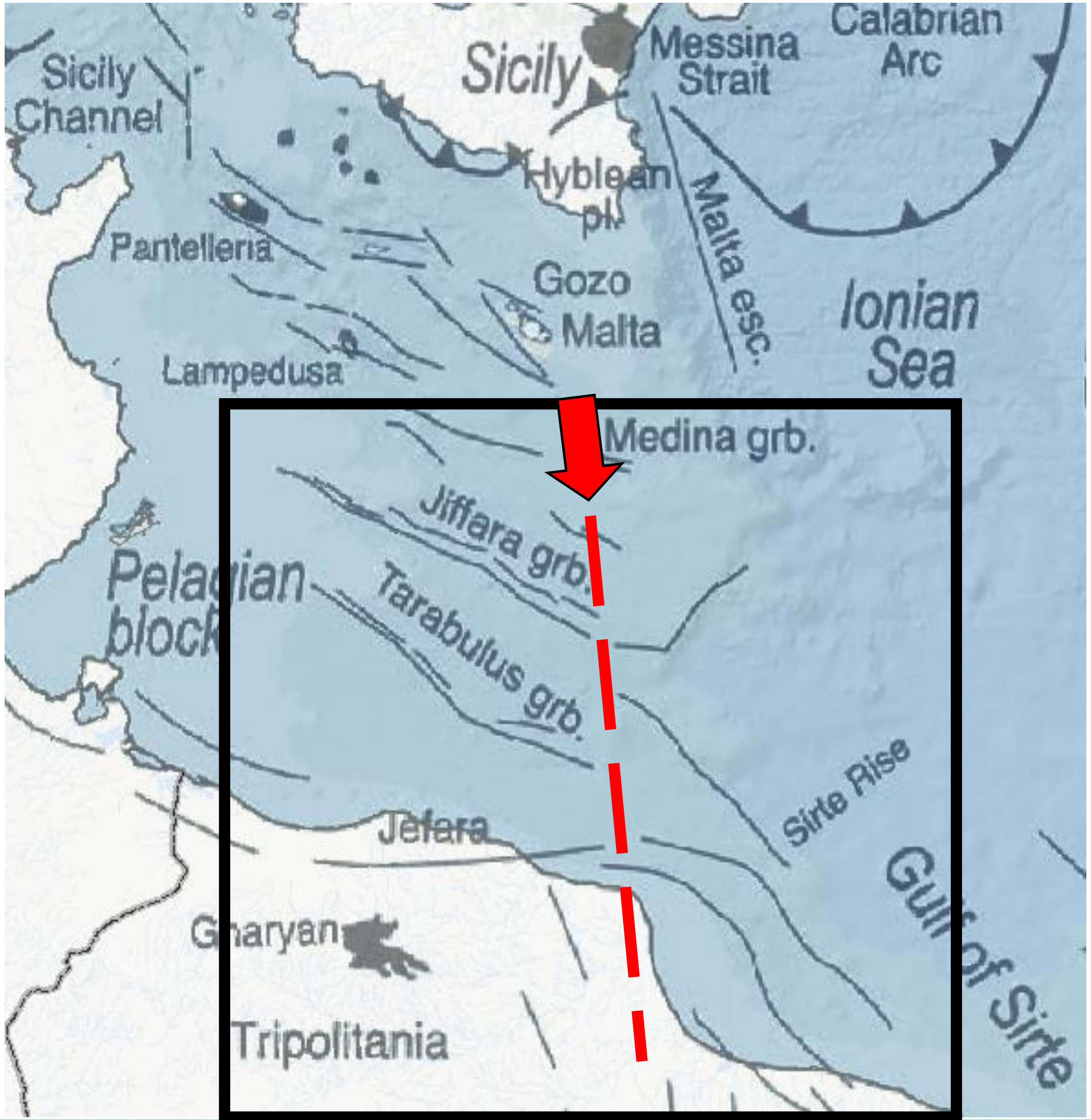


Structural Features on 10 km HP Aeromagnetic Zoom In

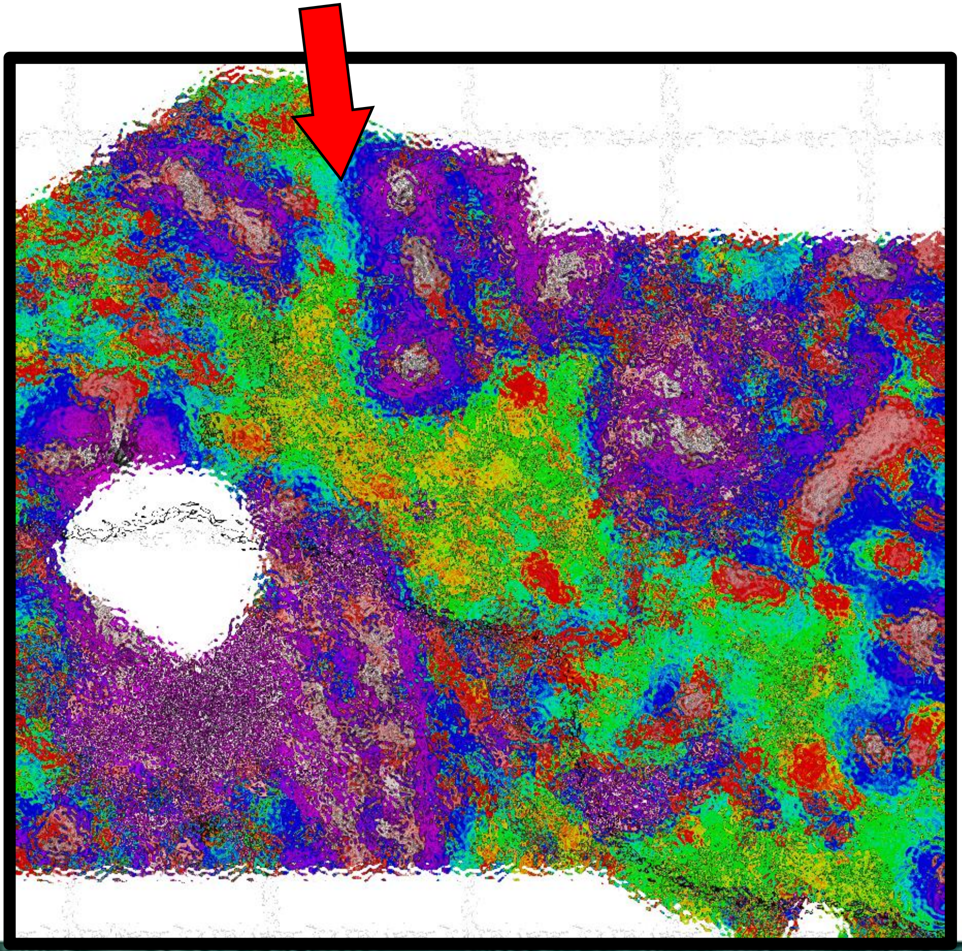


Maps blurred for confidentiality reasons

Structural Features on 10 km HP Aeromagnetic Zoom In



Maps blurred for confidentiality reasons

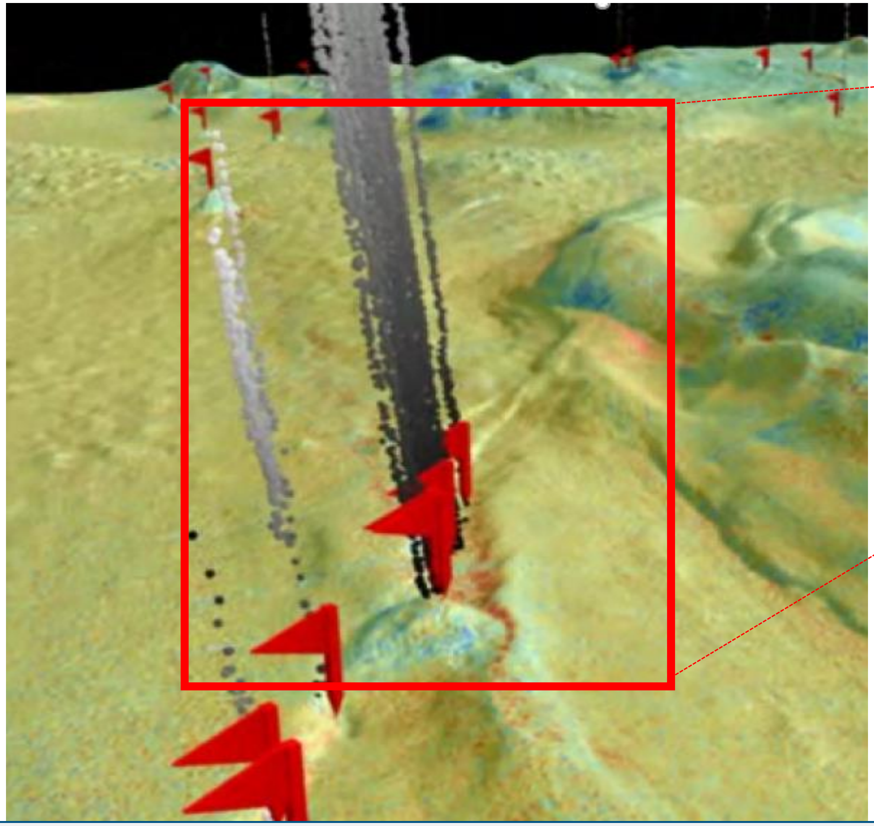


Southern Extension of Malta to Offshore Libya

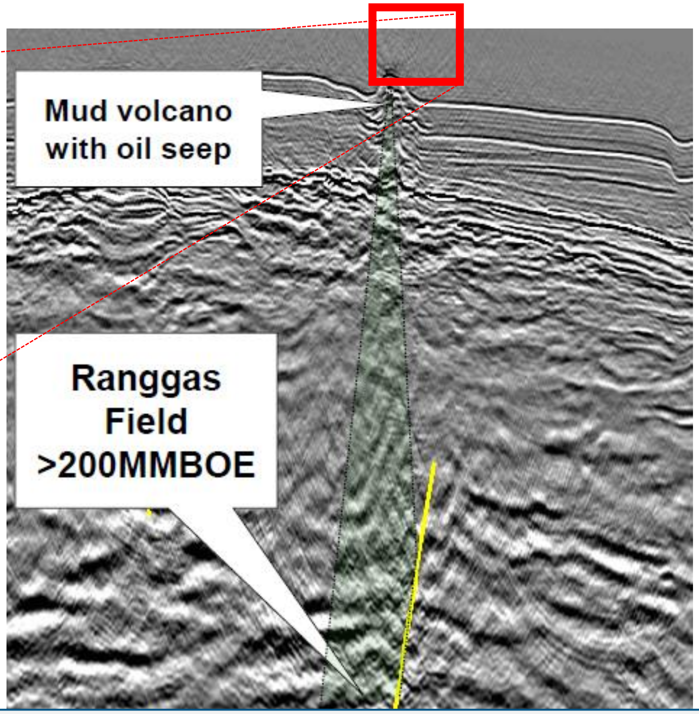
Opportunities – Sea Seep and Multi-beam

Finding Hydrocarbons at Sea

Water column acts as barrier for finding seeps → high resolution Multi-beam has changed that



1. Multibeam and Backscatter Image with Gas Escape



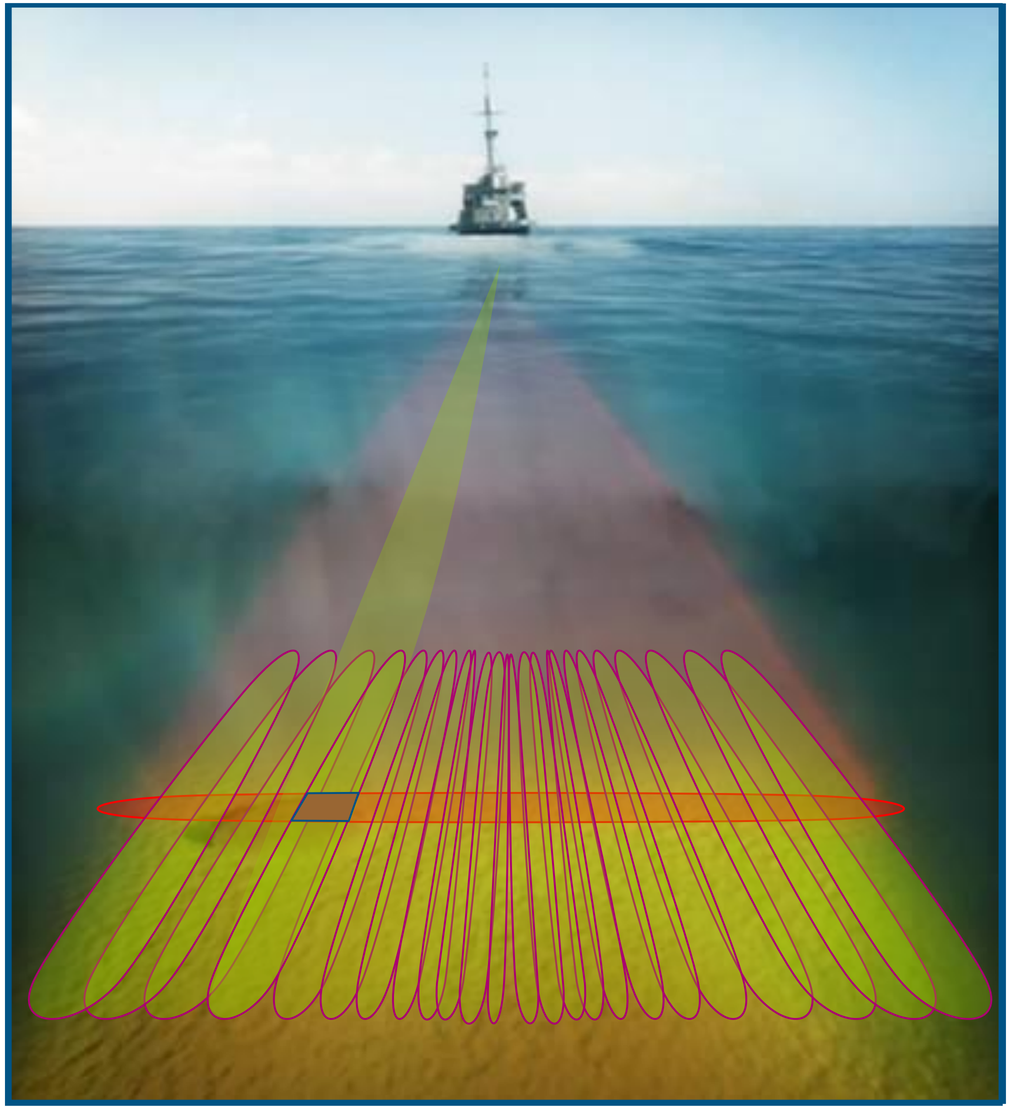
2. Subsurface assessed (seismic)

- **Prospect identified and drilled and Oil discovered**
- **(seep geochem ties to reservoir)**

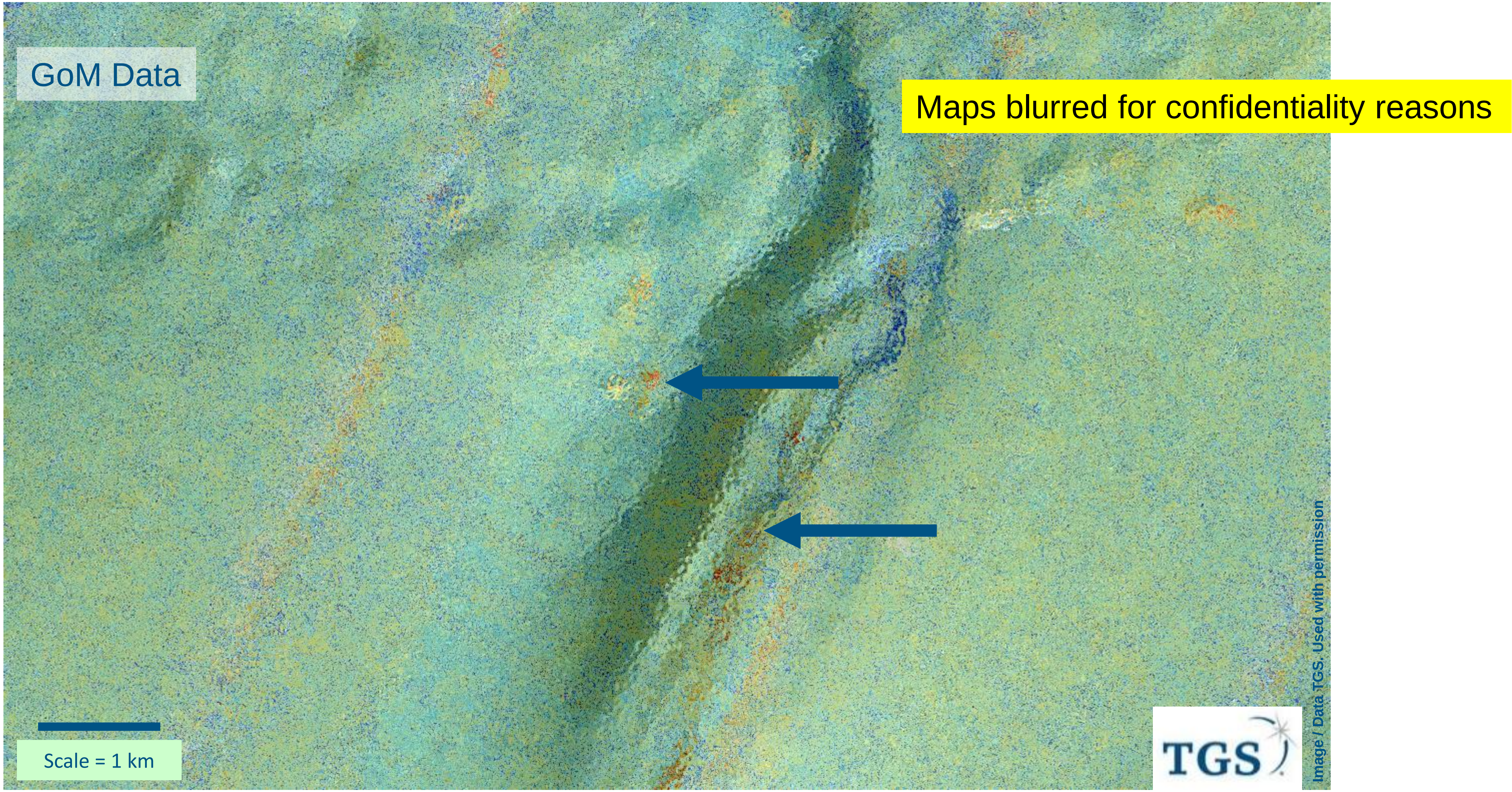
What is Multibeam? High Resolution Bathymetry

- Multibeam is a hull-mounted sonar array
- High-resolution map of the sea floor

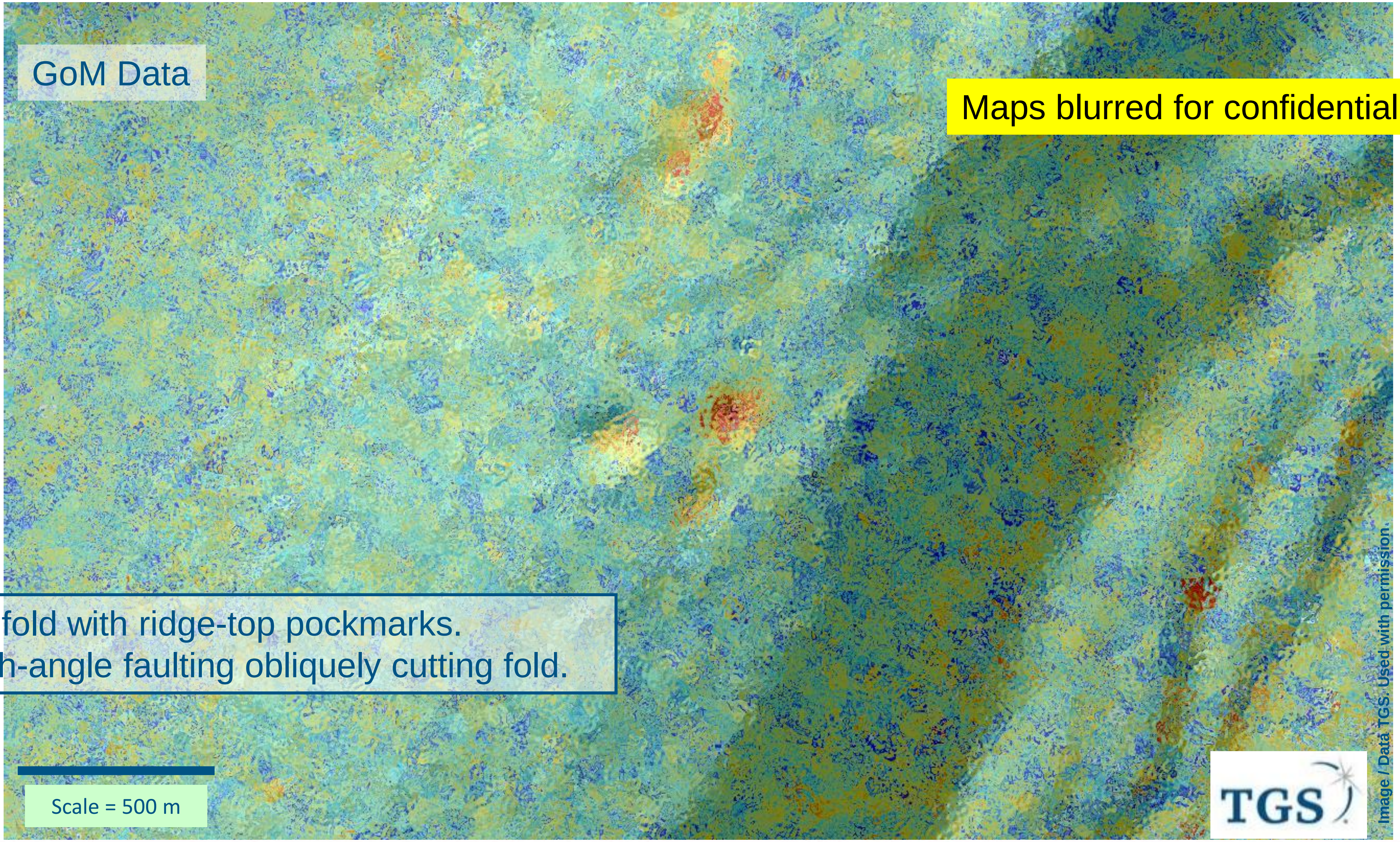
  (15 x 15m)
- Large coverage at low cost



What is Backscatter? Hard Ground – Seep Indication

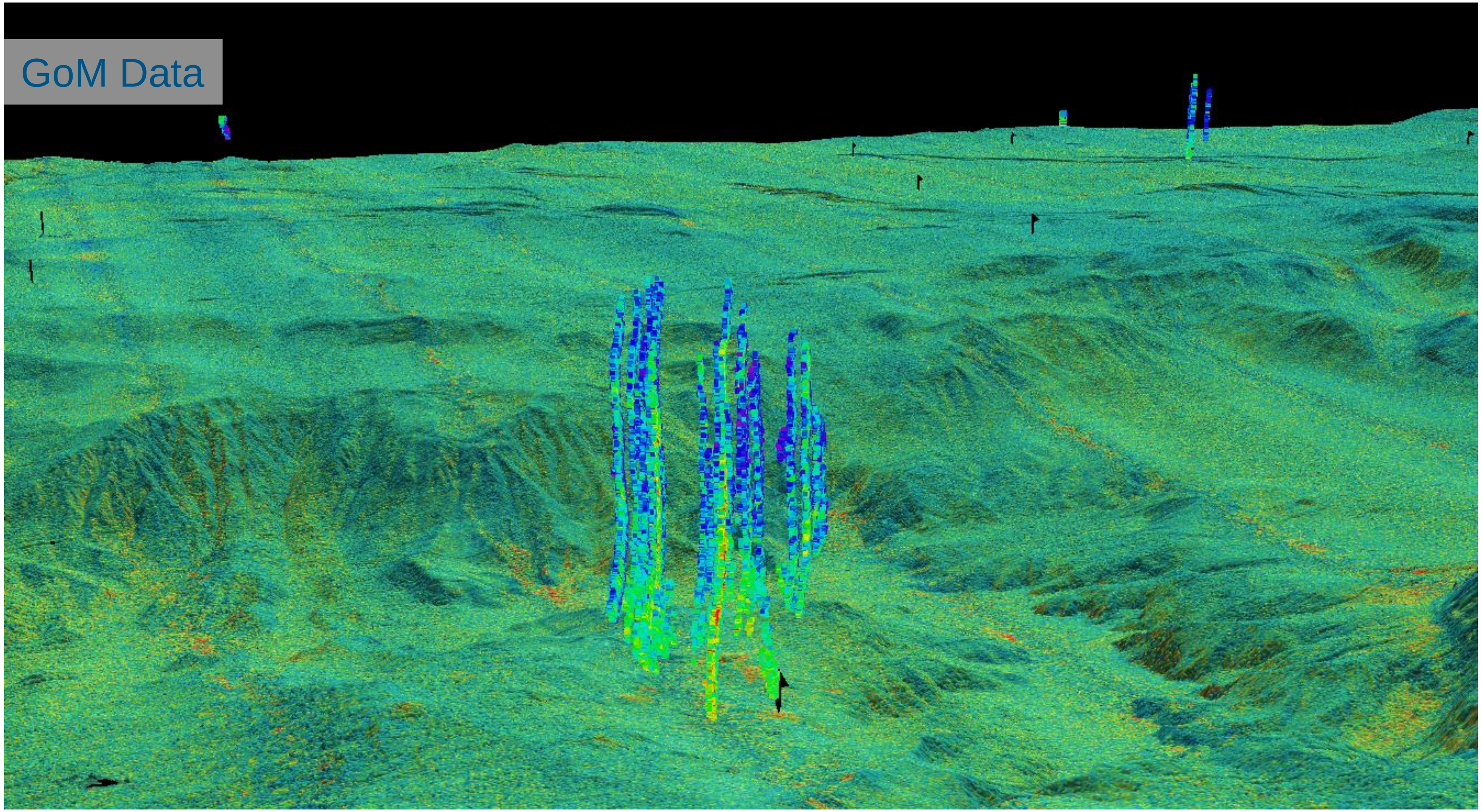


Which Bathymetric Features? Folds and Pockmarks (Zoom In)



We also see ‘Gas Plumes’

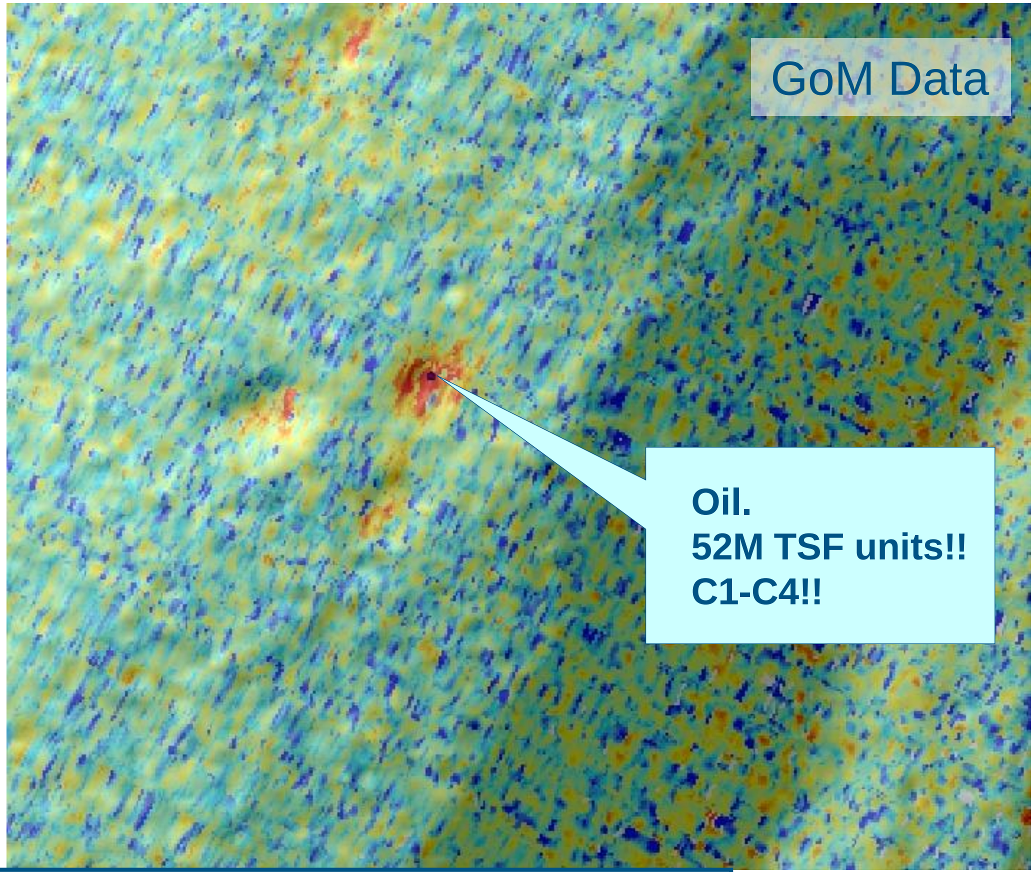
- Multibeam acoustics are disrupted by gas or oil escaping from seeps
- Clear indicator of active seep



Sea Floor Sampling – Core Navigated to Seep

- Piston core recovered (max. 6m)
- Shallow samples of rock fragments
- Hydrocarbon samples for geochem

➔ Yield direct insight into petroleum system
  - Age, maturity, API, biodegradation,
  - biogenic/thermogenic (isotopes),
  - basin evolution



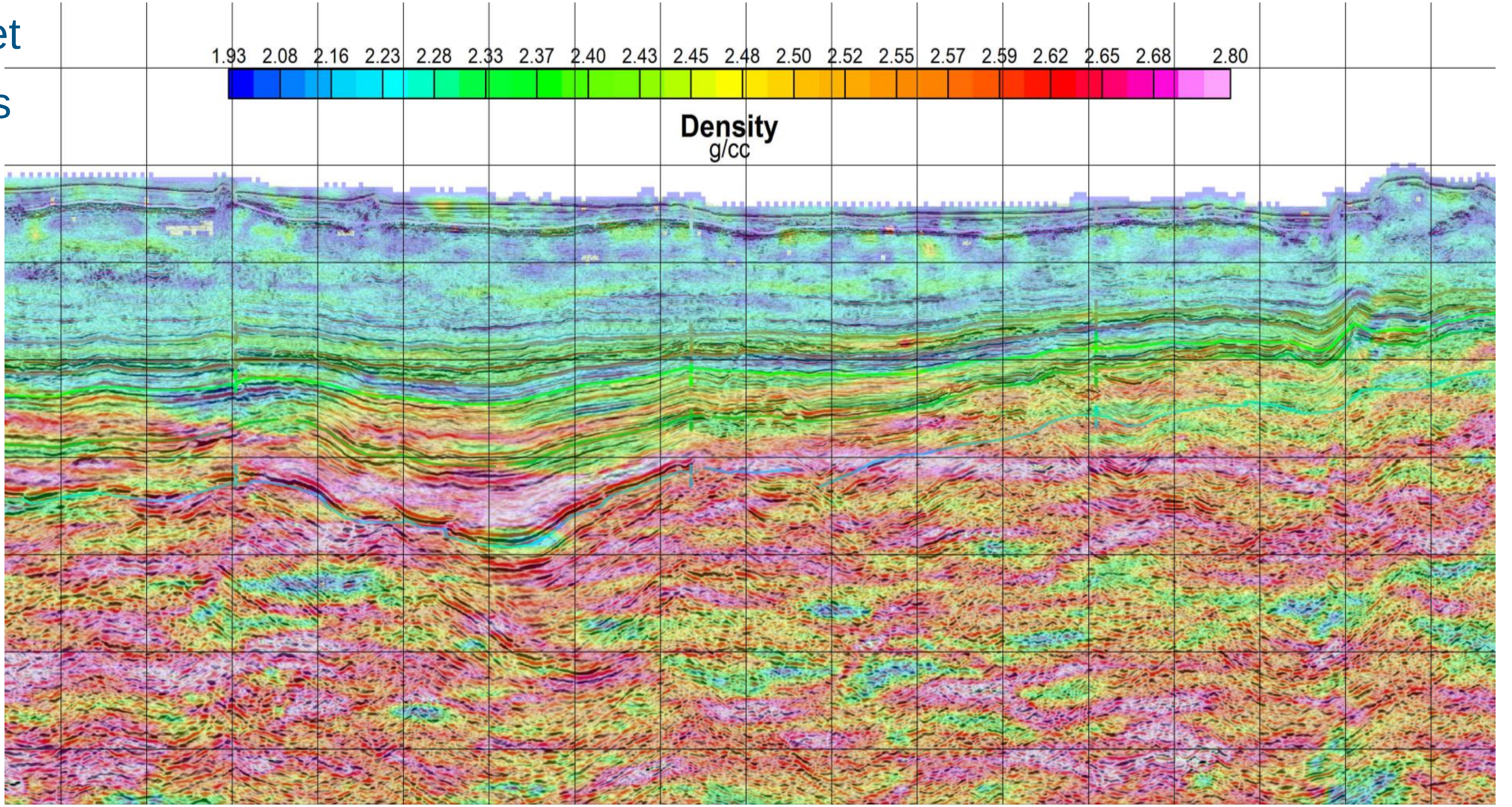
“**H_2S**, **rock fragments** and **oil staining** at all sub-sampled sections in core”

Southern Extension of Malta to Offshore Libya

Opportunities – Further Interpretation and Plans

Opportunities – Further Interpretation and Plans

- Broadband reprocessing 2D to image the deeper structure better
- New 2D with longer offset
- Target 3D over prospects

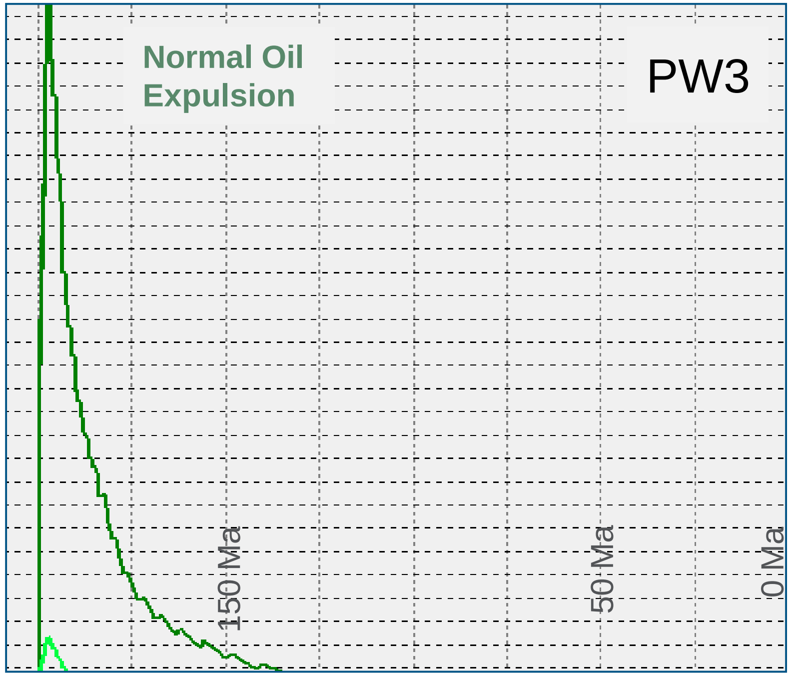


Density Analysis from Seismic Velocities – Forward Modelling Verifies Velocity Field

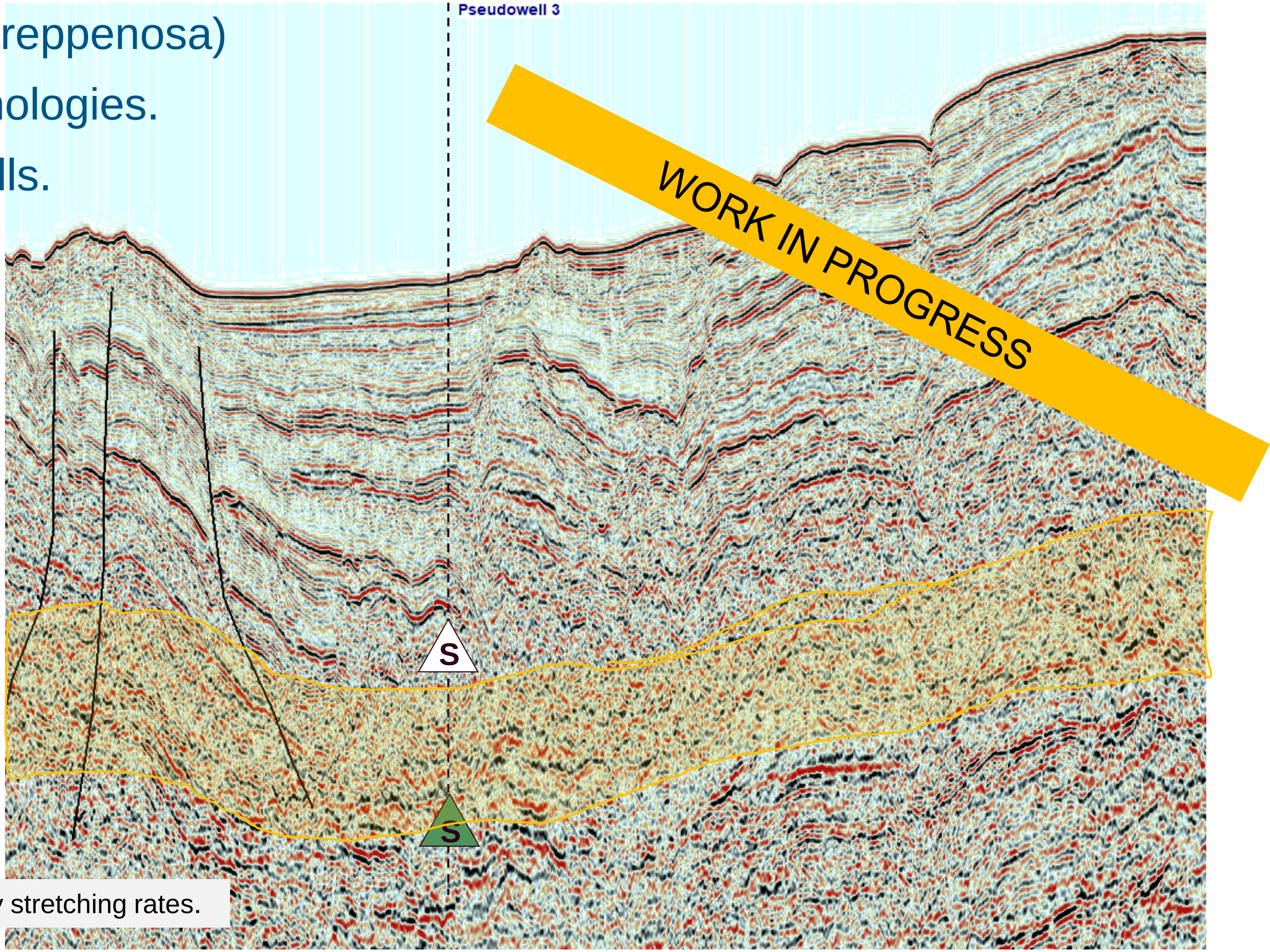
Basin Modelling Example

Pseudowell expulsion models (Type 2 Streppenosa)

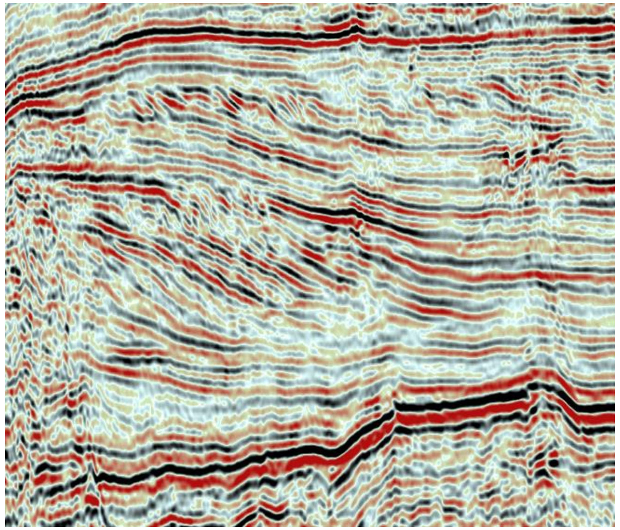
- Seismic provided tops and average lithologies.
- Present day hole temperature from wells.
- Zone of HC generation (120-150°C)

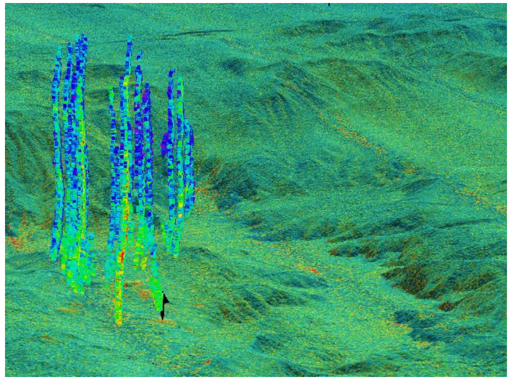


Expulsion takes place throughout the Jurassic due to high early stretching rates.

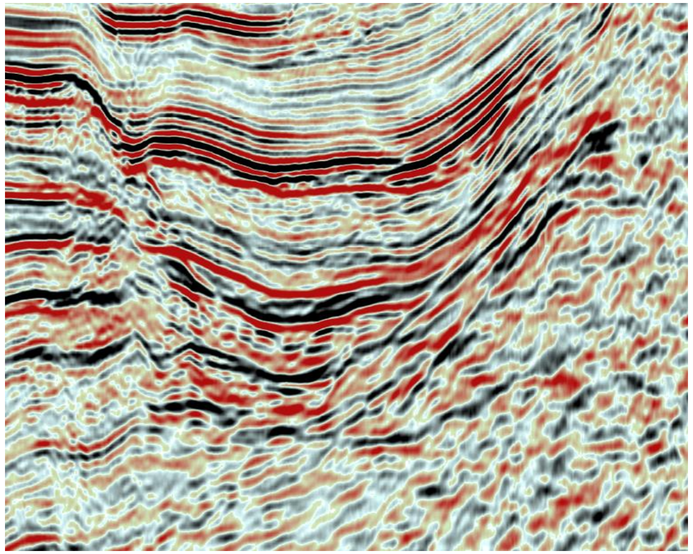


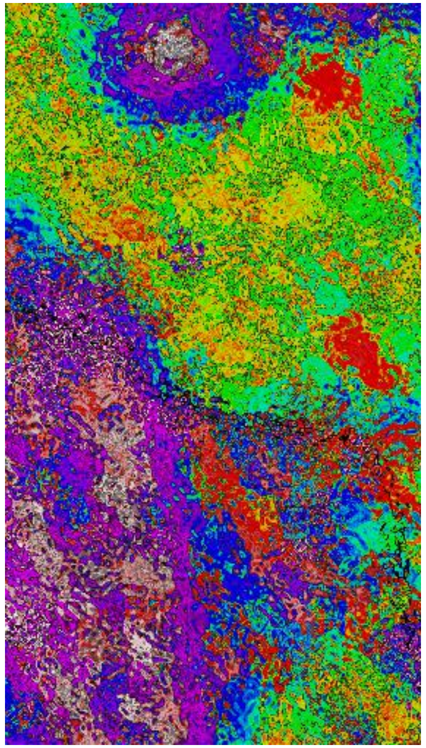
To Sum Up





1. Petroleum system is working North of Malta and North of Libya.
2. Between these proven plays, favourable conditions for HC accumulation have been identified.
3. Area is underexplored regarding well and seismic exploration – Connection or Differentiation to other proven plays still to be established!





- TGS plans to fully re-interpretation the entire Maltese area. Basin modelling included.
- Full well logs and borehole data available to TGS now.

As soon as the Maltese Government moves forward new acquisition is on the plate, TGS considers multi-client multi-year programmes.

The aeromagnetic is a very good place to start survey planning further south and when the Government in Libya approves TGS will invest in the area.

Thank you

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