Petroleum System Analysis of Small Scale Miocene Troughs in the Pannonian Basin, Results of a 3D Basin Modeling Case Study from Southern Hungary*

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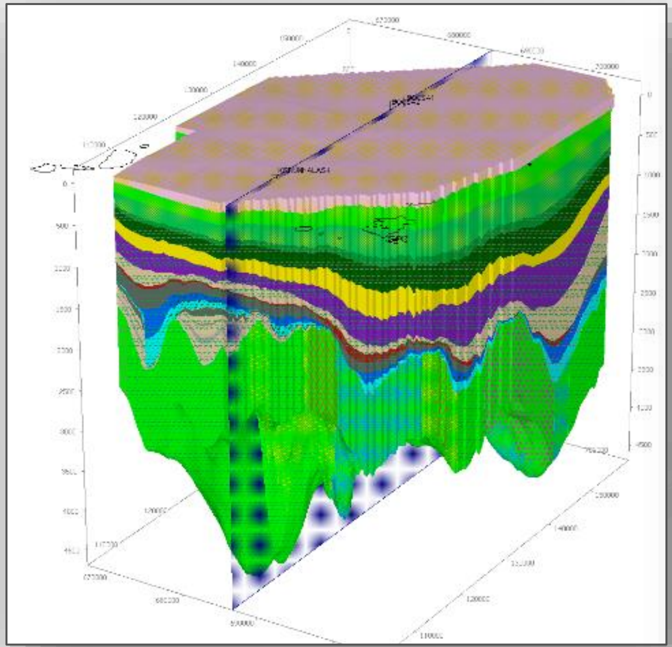
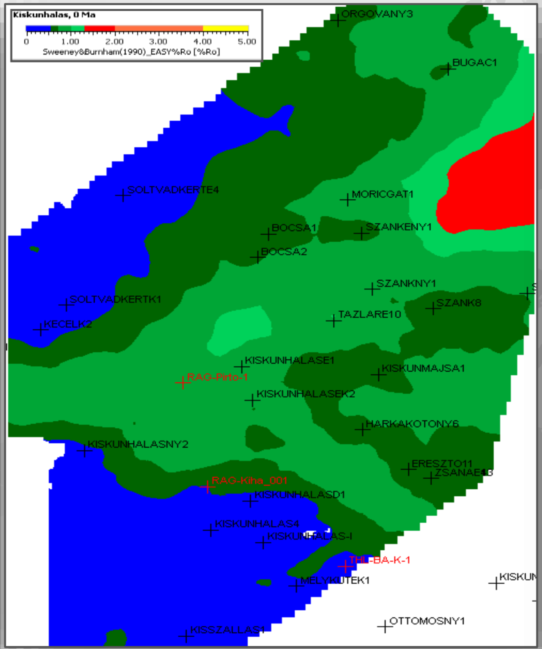
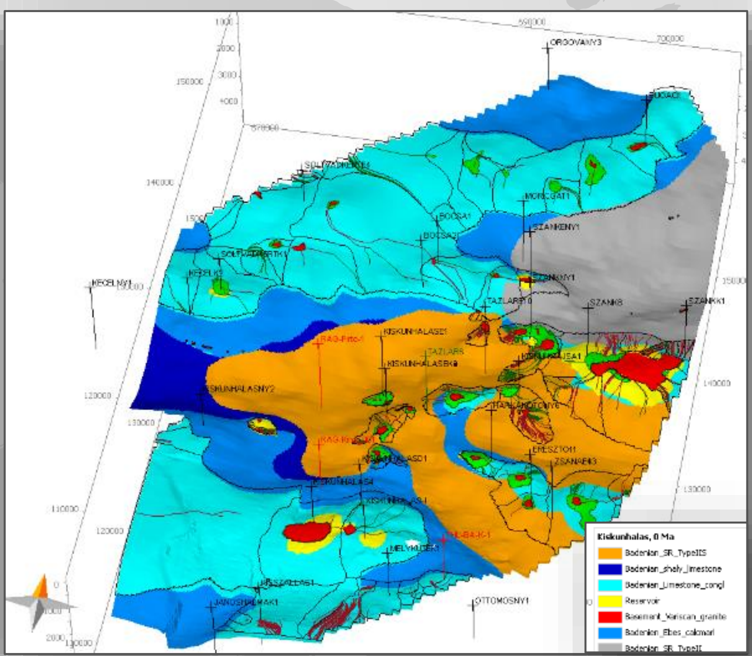
Abstract

The role of the Early to Late Miocene age source rocks in the Late Neogene petroleum system of the Pannonian Basin is undoubtedly significant, but less investigated as it would be necessary. Only few general publications exist which describe these sediments and their importance. We focused on the understanding of the Neogene tectono-stratigraphic development and petroleum systems of these small-scale syn-rift grabens in southern Hungary. We have developed a workflow for the organic geochemical, seismic and facies interpretation, basin subsidence and finally 3D basin modeling to better understand the Miocene-Pliocene age hydrocarbon system in a 1620 km^2 study area.

This area covers two, small scale (less than 200-400 km^2 each) troughs fulfilled with syn- and post-rift deposits with large thickness but significantly different structural evolution. During our investigation six source rock beds were identified and built into the model. Thousands of meters of Early-to-Middle Miocene, (Karpatian age) sediment was accumulated in the “pull apart”, but later structurally partly inverted Kiskunhalas Trough in the south, where four moderate-to-good quality (2 wt.% estimated original total organic carbon [TOC], 200 HI), dominantly gas-prone, immature to wet gas mature source rock beds were identified. In the overlying Middle Miocene (Badenian age) sediments, a younger, generally good quality (2 wt.% estimated original [TOC], 300-500 HI, Type II and II-S), oil-prone, dominantly oil mature source bed was identified. This layer as the regional Miocene source rock plays the main role of the known hydrocarbon accumulations. The 3D basin and petroleum system modelling helped understanding the hydrocarbon migration into the already discovered fields as well as identified possible future exploration objects.







PETROLEUM SYSTEM ANALYSIS OF SMALL SCALE MIOCENE TROUGHS IN THE PANNONIAN BASIN, RESULTS OF A 3D BASIN MODELING CASE STUDY FROM SOUTHERN HUNGARY

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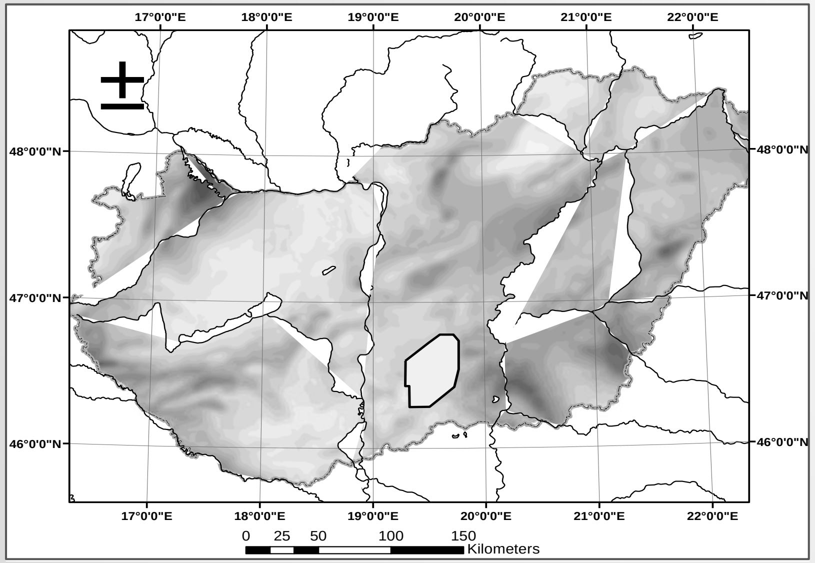
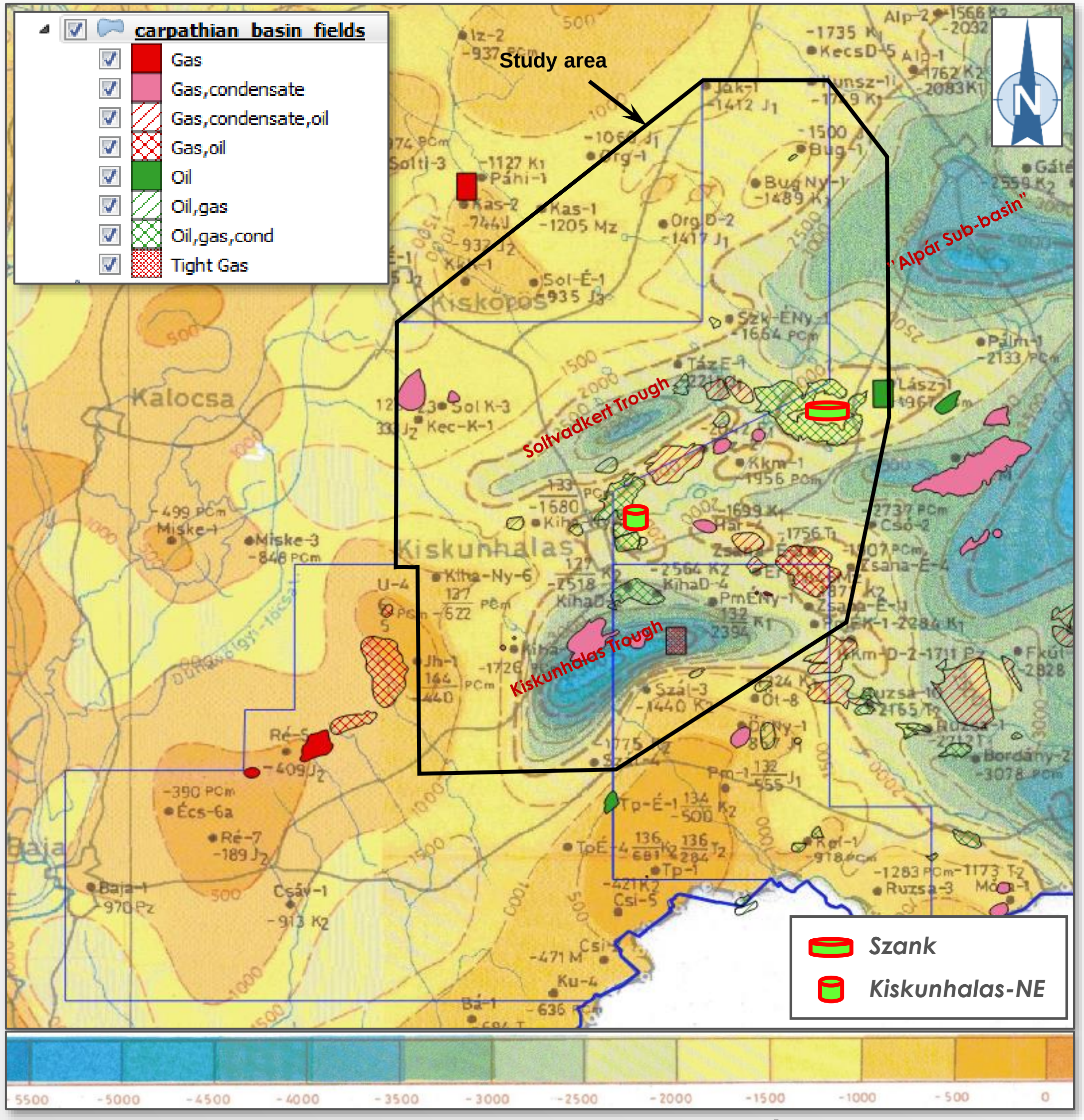
AAPG Europe Region
Paratethys Petroleum Systems
Between Central Europe and the Caspian Region
AAPG European Regional Conference
26-27 March 2019
Hilton Vienna – Vienna, Austria

AREA OF INVESTIGATION

Goals:

- Enhanced understanding of the local petroleum system
- Define the YTF potential
- Mitigate the source/migration risk for future HC exploration targets





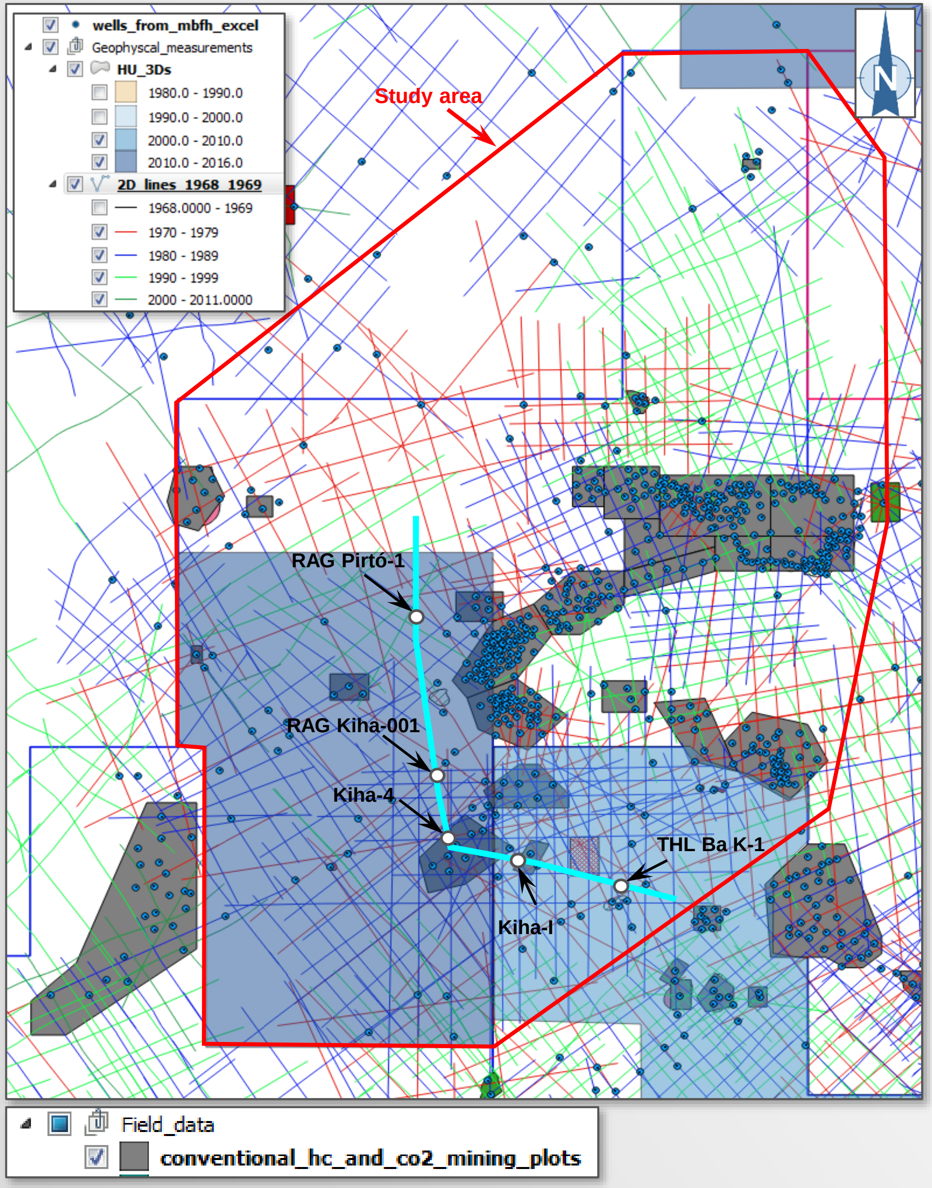
Pre-tertiary basement structure contour map (Kilényi & Sefara 1989)

Facts

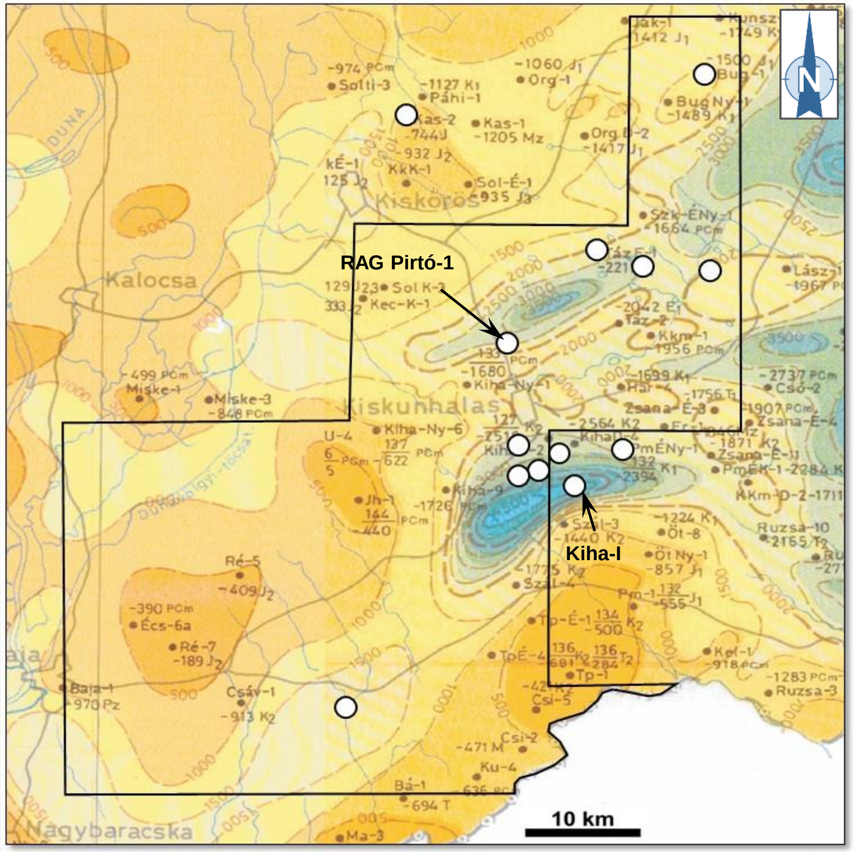
- 1620 km² area of investigation
- In the vicinity of Miocene/Pliocene sediment filled grabens
- Proven HC generation & accumulation area
- 23.3 million Sm³ oil + 25.1 billion Sm3 gas in place volume discovered so far
- Most prolific HC accumulations:
  - *Szank* (10.4 million Sm³ oil + 14.1 billion Sm³ gas in place)
  - *Kiskunhalas-NE* (7.2 million Sm³ oil + 2.2 billion Sm³ gas in place)

DATASET

Basemap with key wells

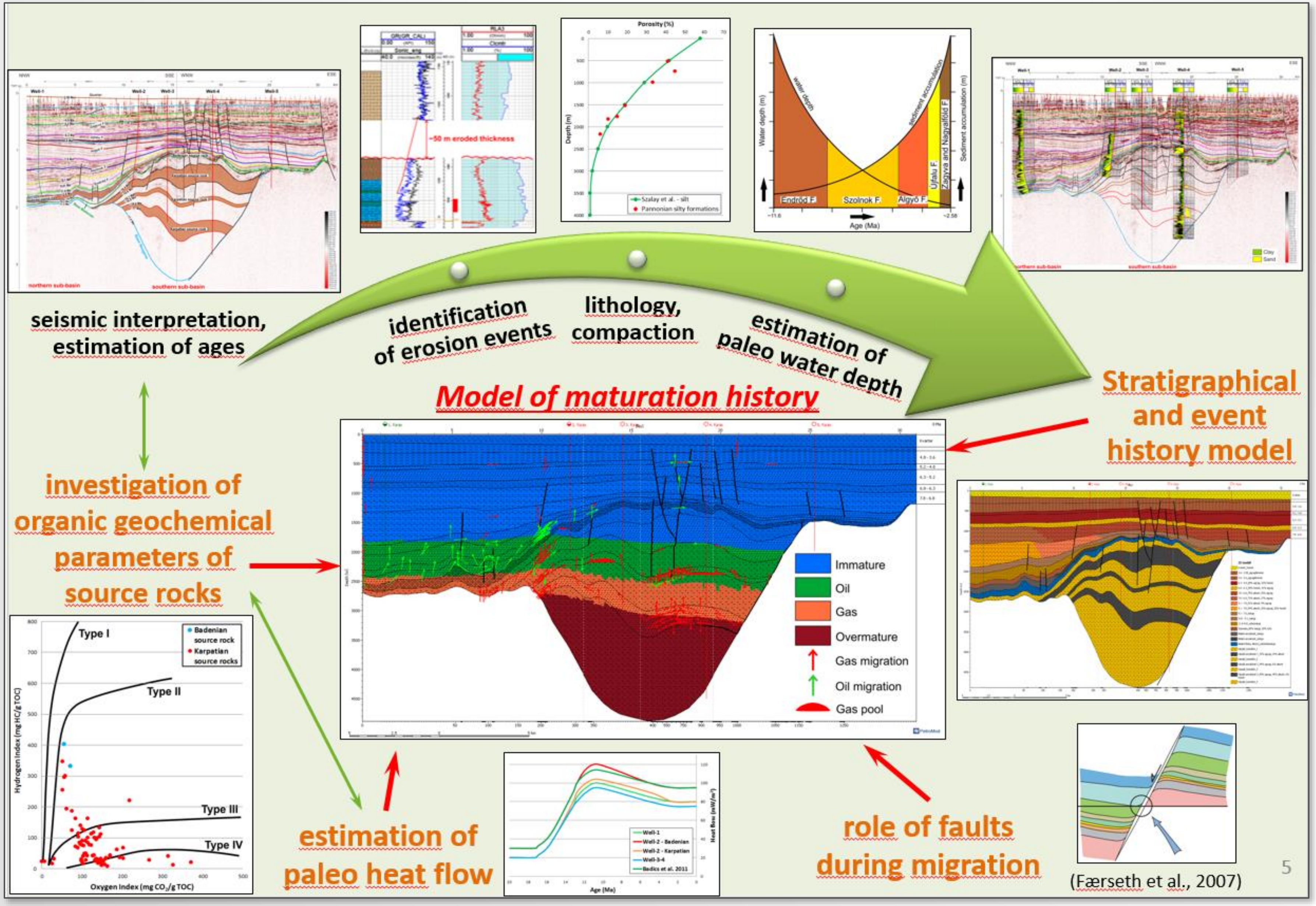


Wells with geochemical data



- Approximately 110 wells and additional field data were available (with limitations inside mining plots)
- Vintage 2D (approx. 200 lines)
- 2 pcs of 3D volumes
- Published datasets and literature (especially for geochemical data)
- **Only 15 wells with any kind of geochemical data in the vicinity of the study area**

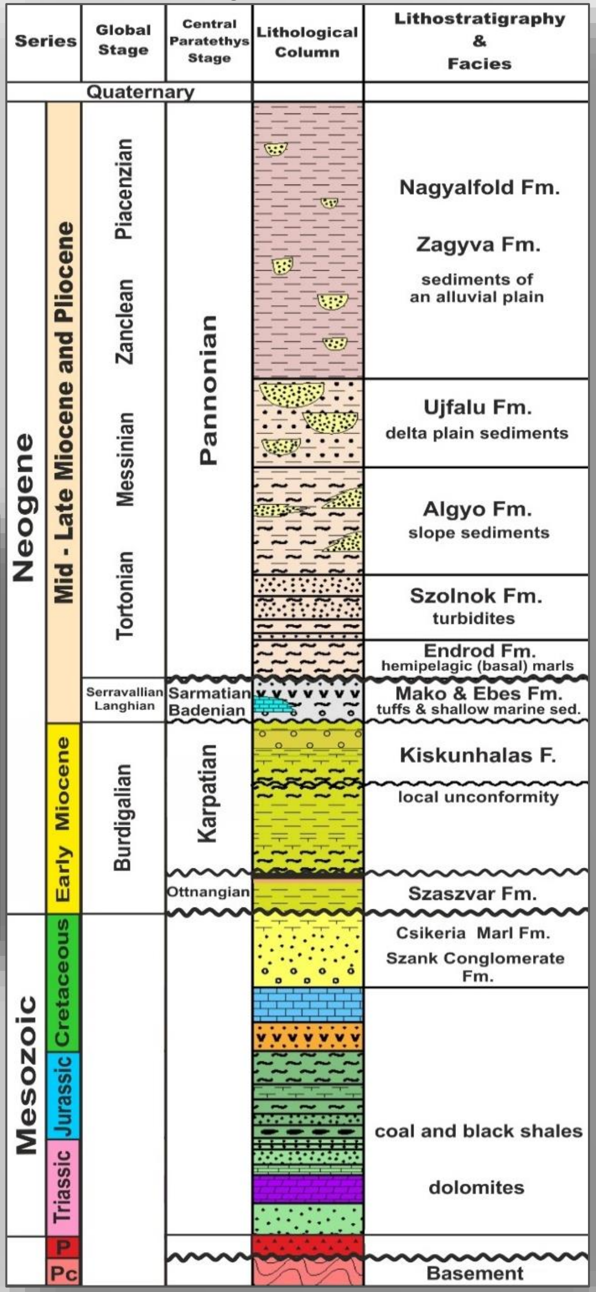
WORKFLOW

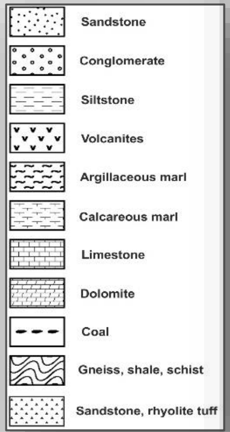


seismic interpretation, estimation of ages
identification of erosion events
lithology, compaction
estimation of paleo water depth
Stratigraphical and event history model
Model of maturation history
investigation of organic geochemical parameters of source rocks
estimation of paleo heat flow
role of faults during migration
Immature
Oil
Gas
Overmature
Gas migration
Oil migration
Gas pool
Type I
Type II
Type III
Type IV
Badenian source rock
Karpatian source rocks
Oxygen Index (mg CO2/g TOC)
Hydrogen Index (mg HC/g TOC)
~50 m eroded thickness
Porosity (%)
Depth (m)
Water depth (m)
Sediment accumulation (m)
Endrőd F.
Szolnok F.
Algyő F.
Újfalu F.
Zagyva and Nagyalföld F.
Age (Ma)
northern sub-basin
southern sub-basin
(Færseth et al., 2007)
5

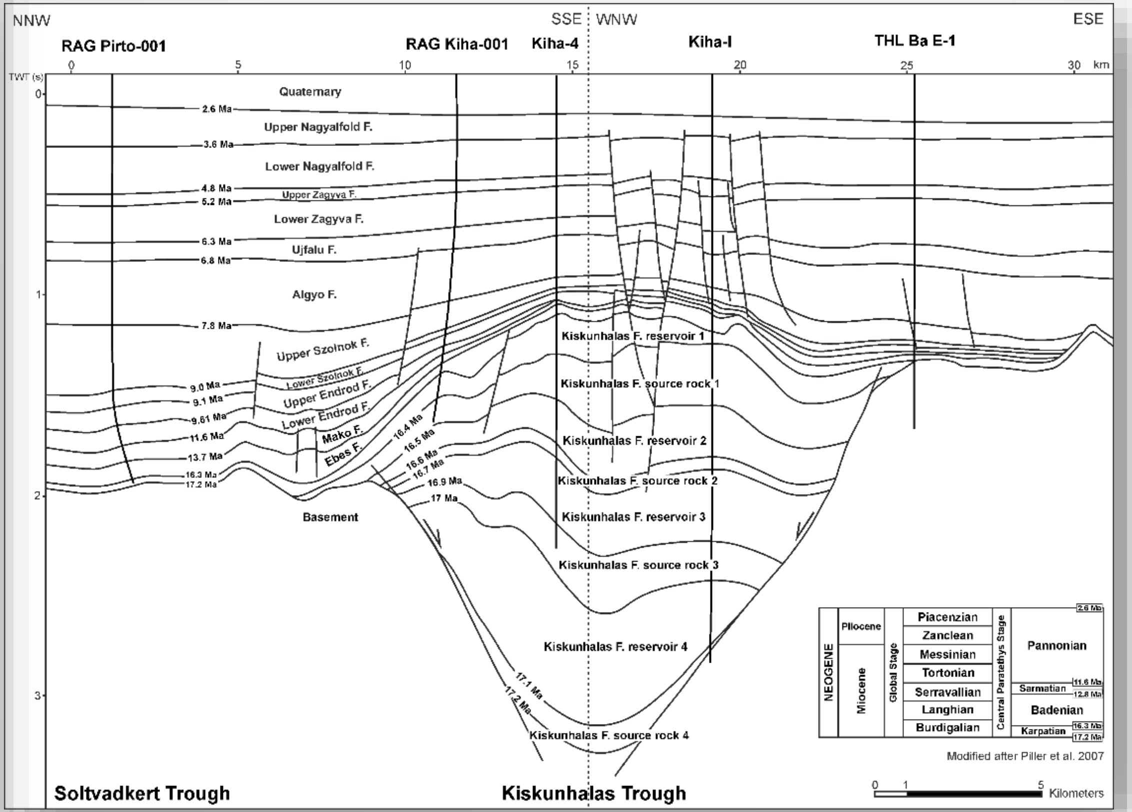
GEOLOGICAL SETTING

Generalized lithological column





Based on Magyar et al. 2006.

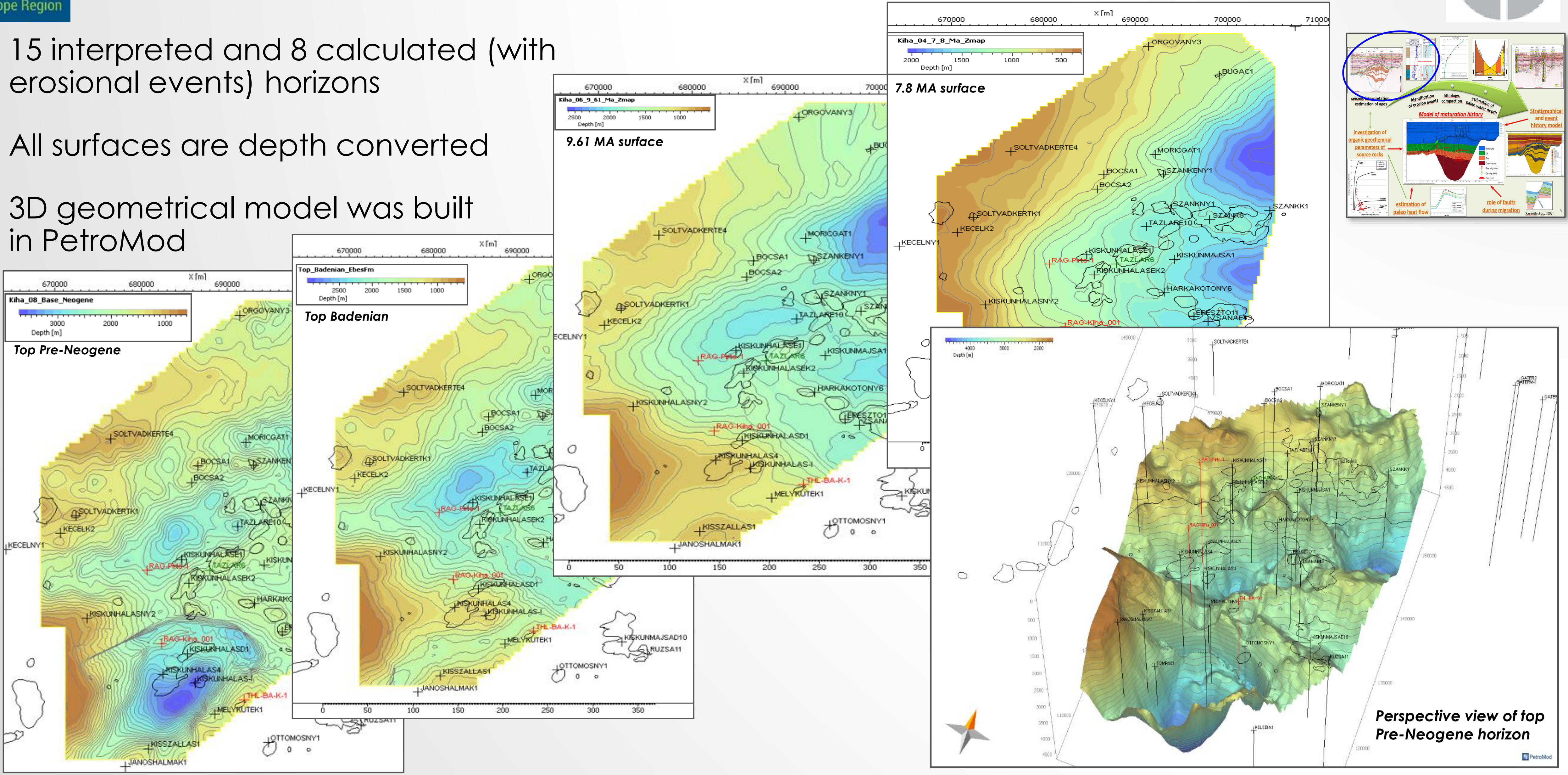


Generalized cross-section across KIHA (Kiskunhalas) and SOL (Soltvadkert) troughs in seismic time (TWT) showing the most important wells and modeled horizons with their absolute ages

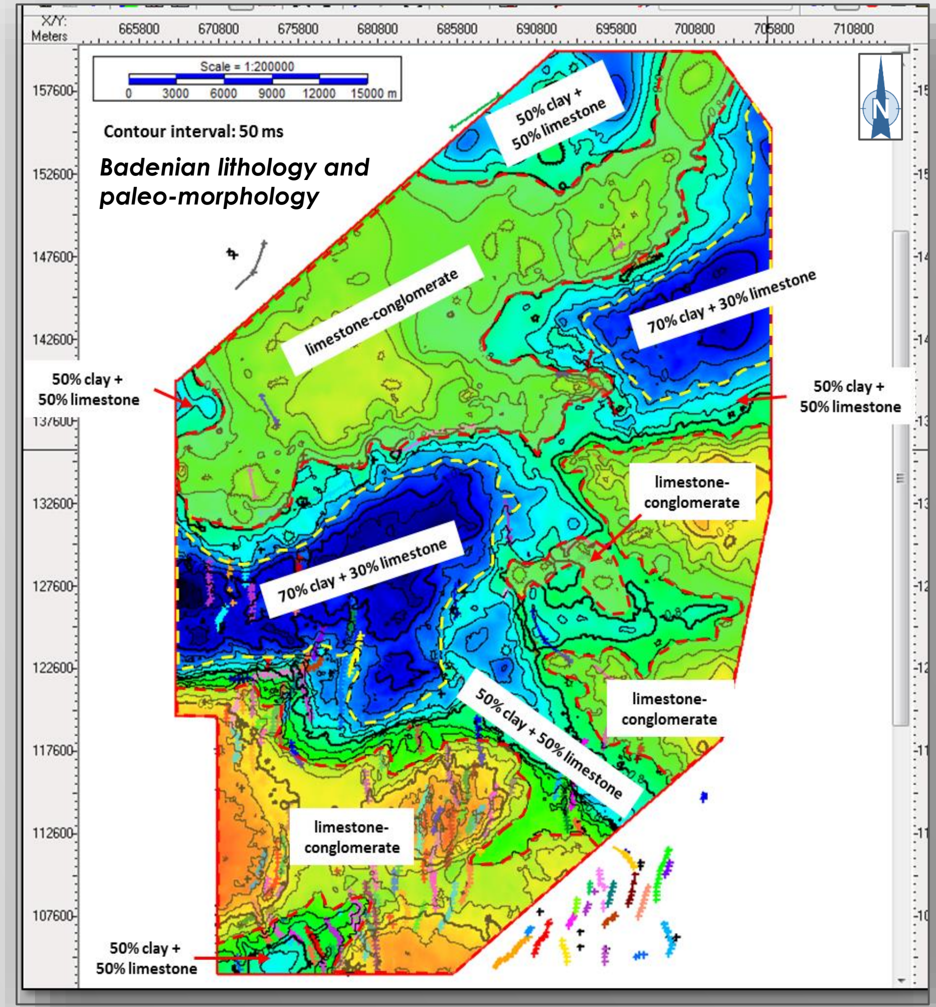
- NE-SW striking half-grabens/pull apart grabens
- Neogene sedimentary system but with major differences in *synrift phase*:
  - **KIHA Trough** rifted from late Ottnangian, rapid sedimentation in Karpatian. Late Karpatian inversion which formed a structural high on the Northern part of the trough
  - **SOL Trough** rifted from Early Badenian (late Karpatian?), no significant Karpatian sedimentation and inversion
- *Postrift phase*: thermal subsidence, deposits of Lake Pannon

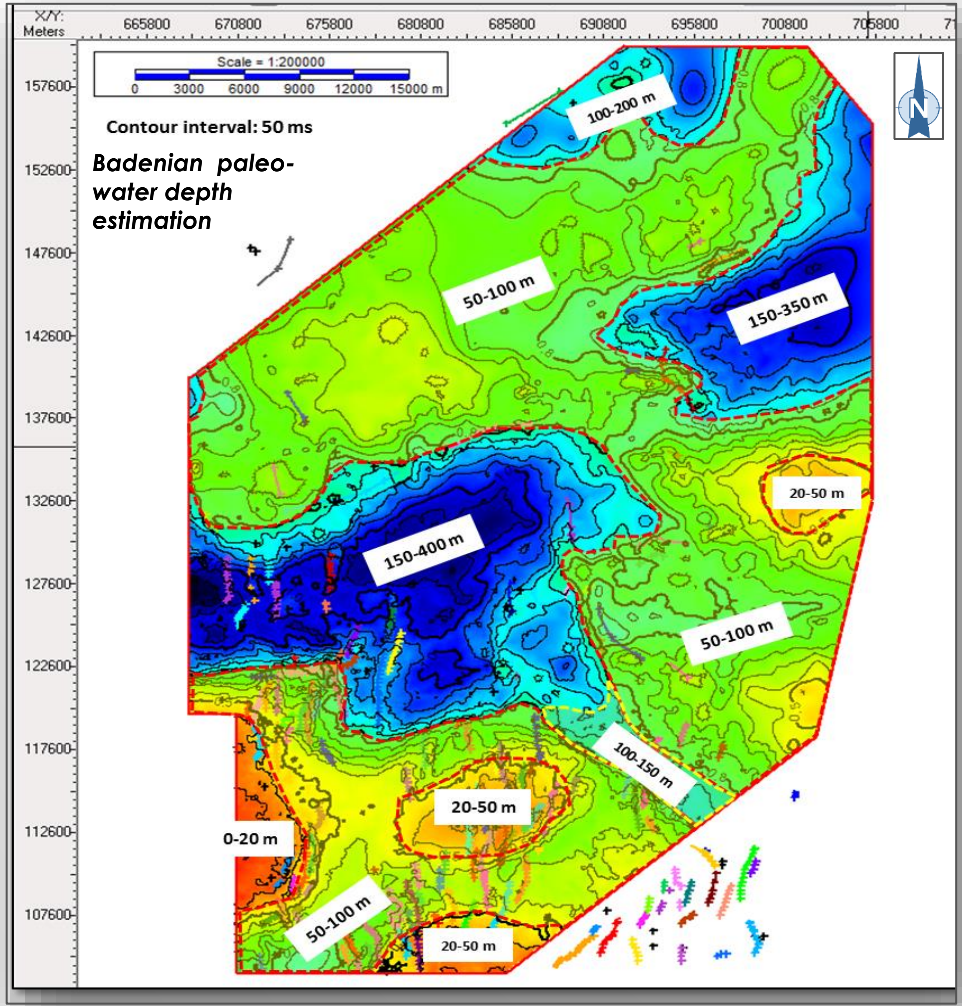
SEISMIC INTERPRETATION – 3D GEOMETRICAL MODEL

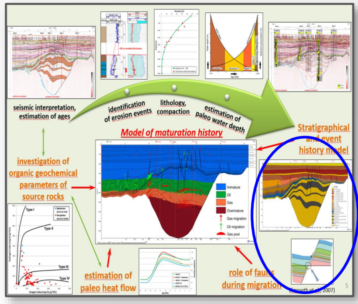
- 15 interpreted and 8 calculated (with erosional events) horizons
- All surfaces are depth converted
- 3D geometrical model was built in PetroMod



FACIES AND PALEO-WATER DEPTH ESTIMATION

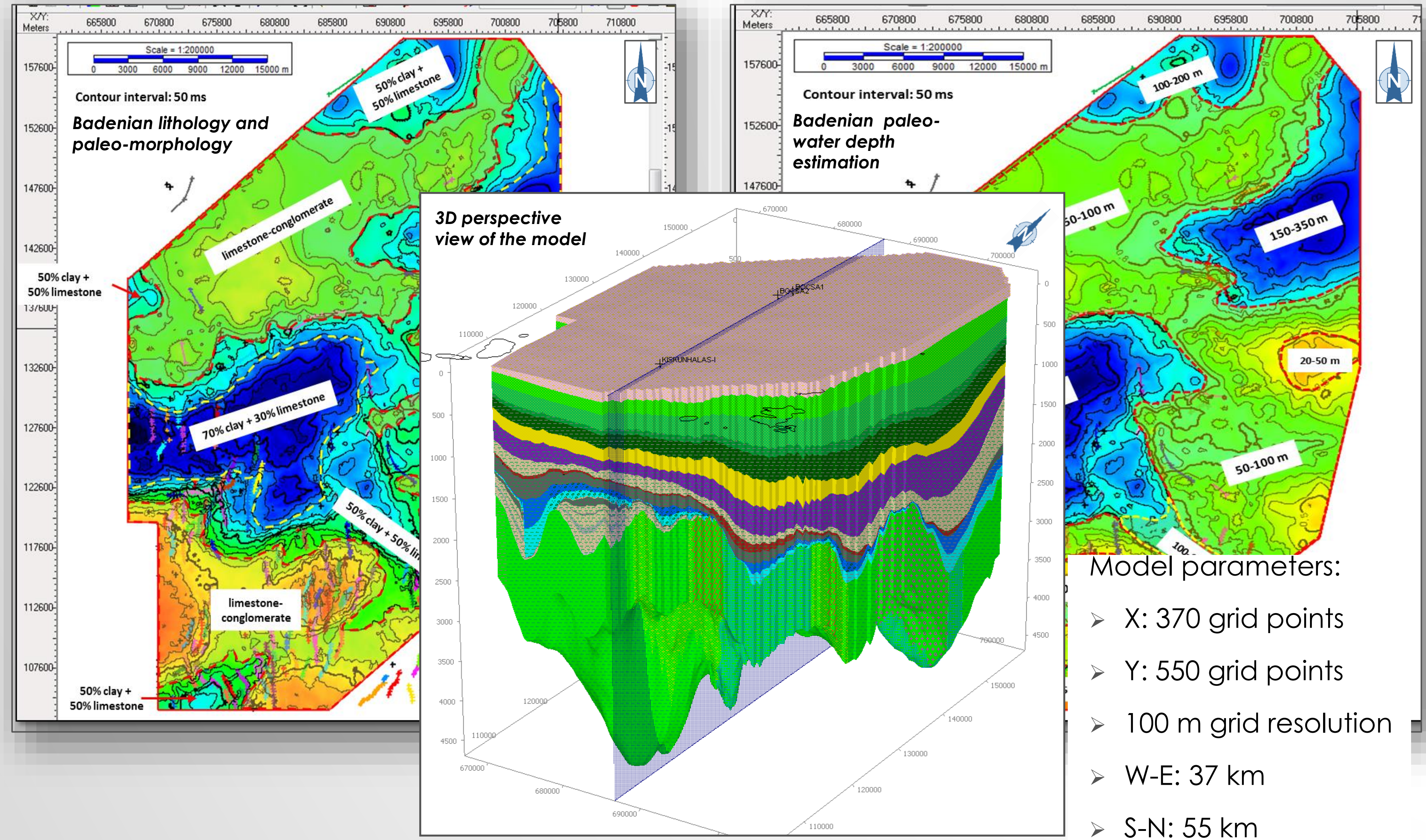






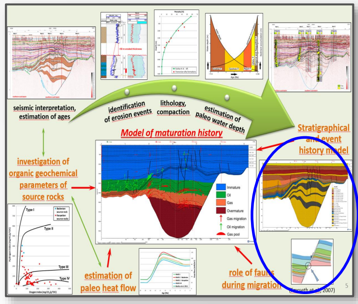
- Paleo-morphological reconstruction – flattening
- Facies determination – wells + paleo-morphology
- Water depth – lithology + paleontology + paleomorphology

FACIES AND PALEO-WATER DEPTH ESTIMATION



Model parameters:

- X: 370 grid points
- Y: 550 grid points
- 100 m grid resolution
- W-E: 37 km
- S-N: 55 km



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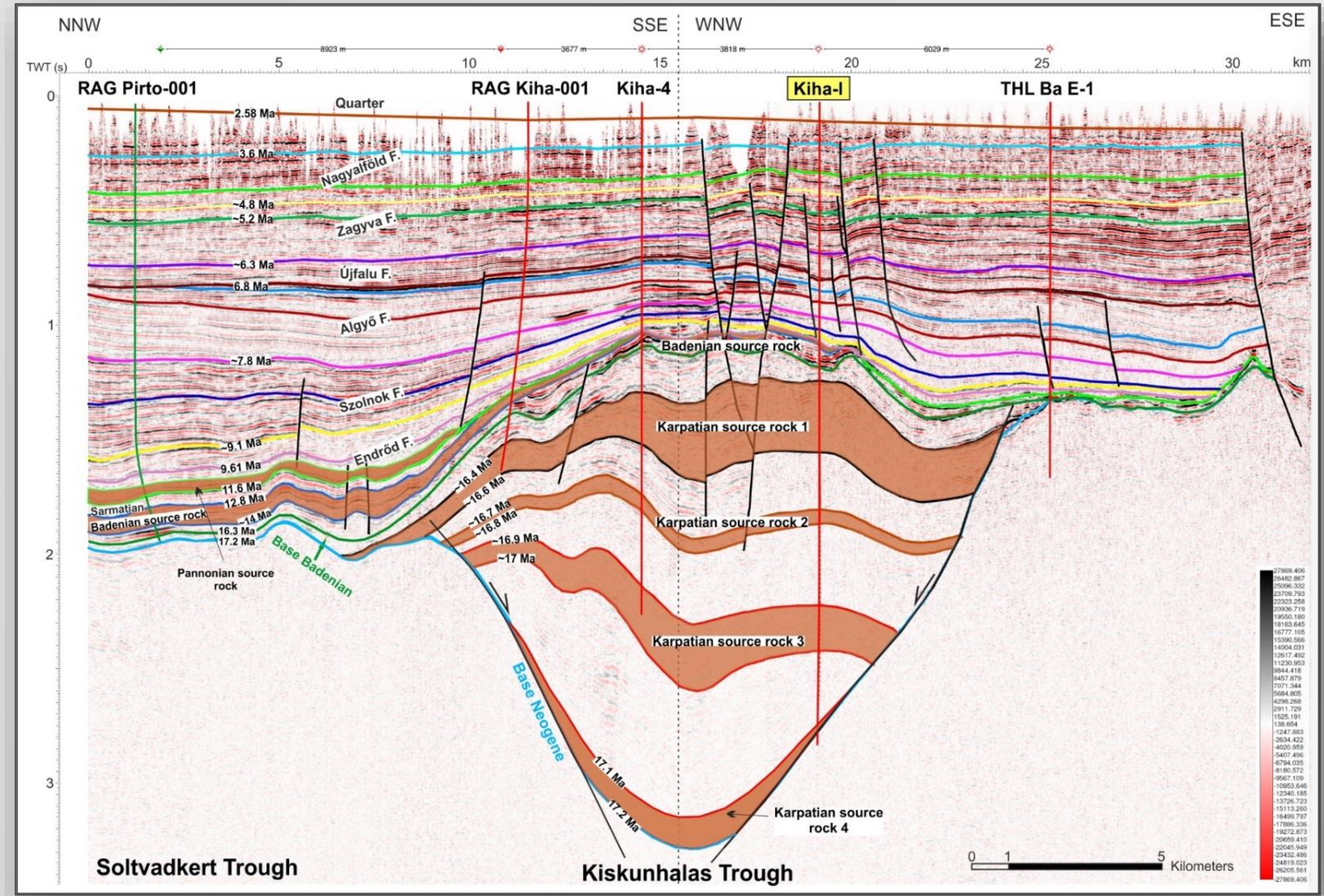
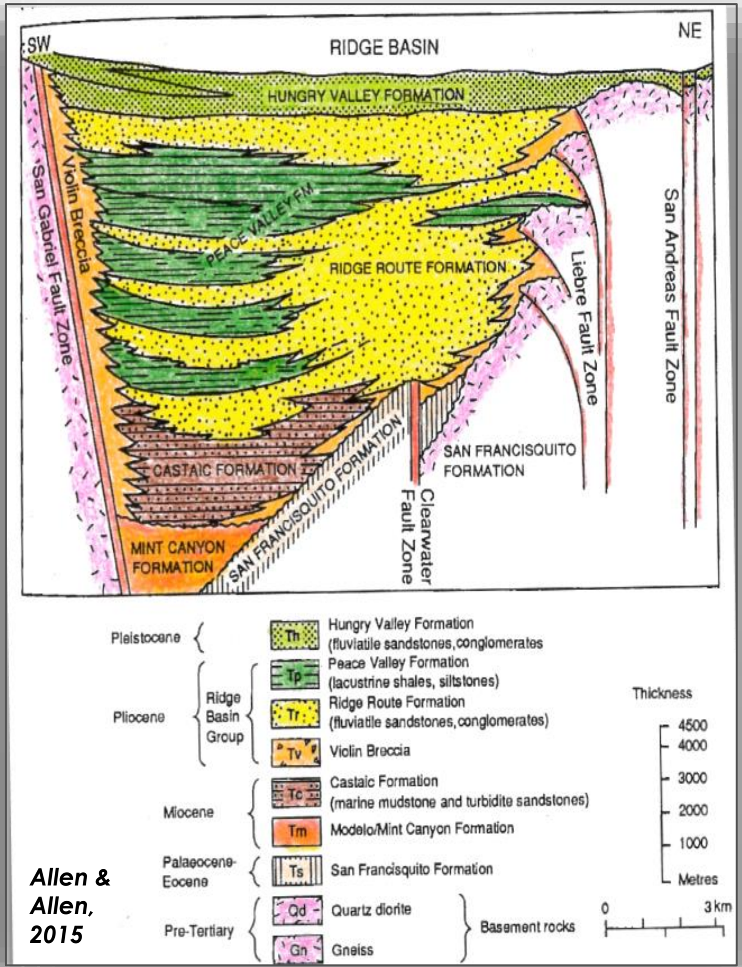
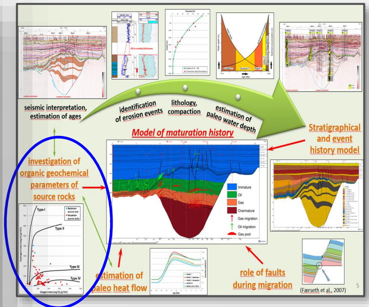
SOURCE ROCK IDENTIFICATION



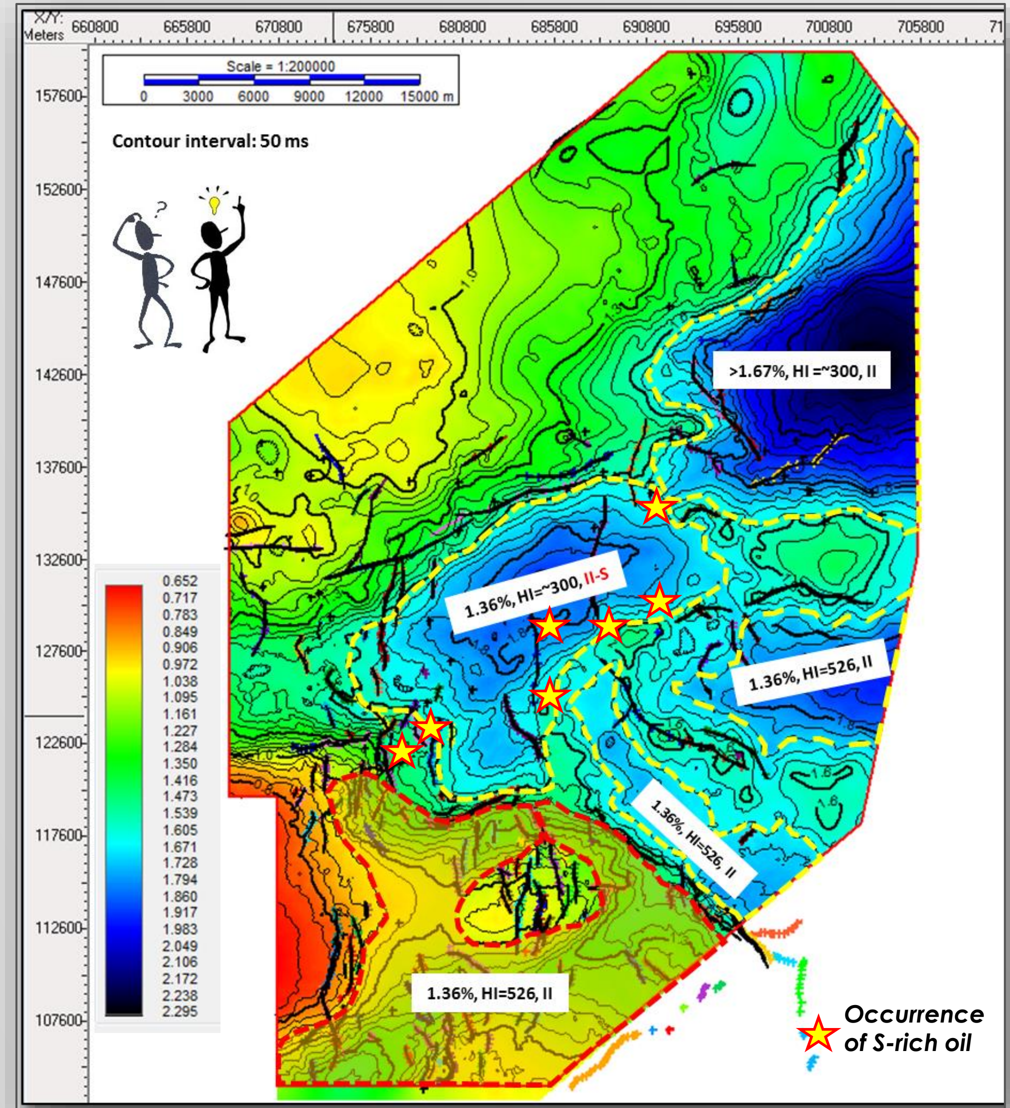




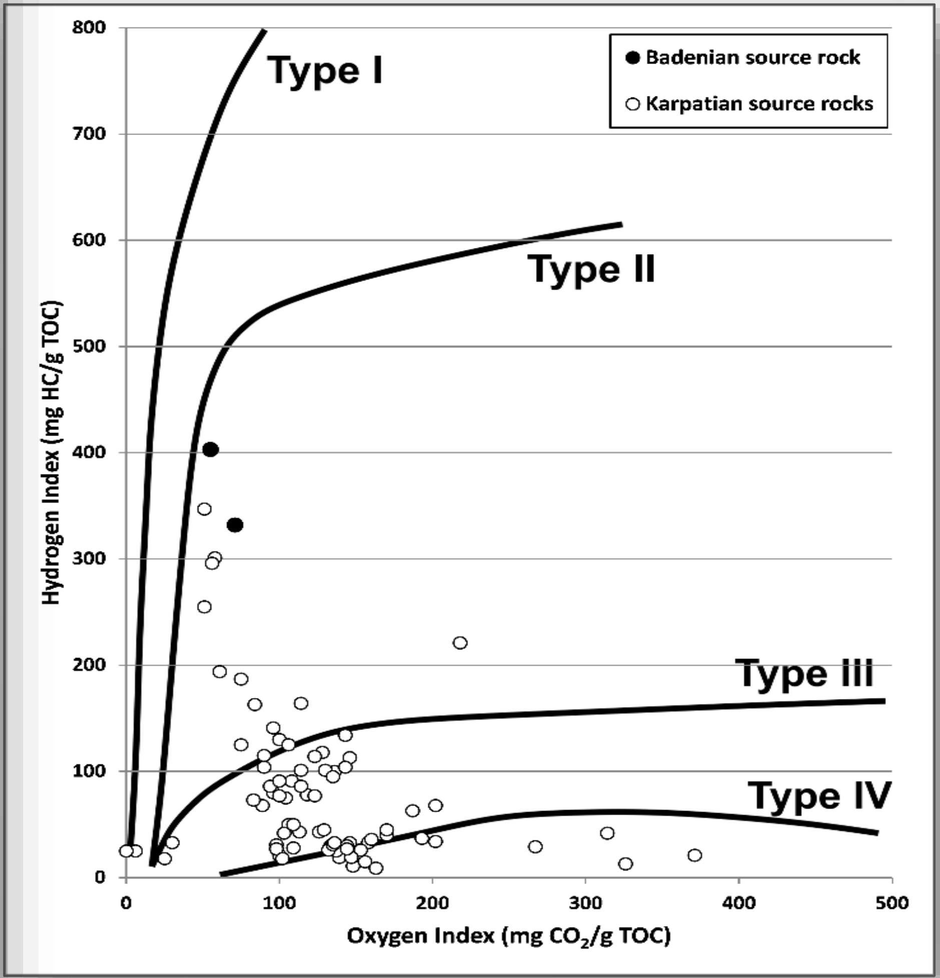
- **4 source rock layers in the Karpatian sequence** (3 in Kiha-I and 1 in THL Ba E-1) – distribution heterogeneity?
- **1 Badenian source layer** (Makó F.), evidence in the study area
- **1 Lower Pannonian source layer** (Endrőd F.), based on literature, no direct data

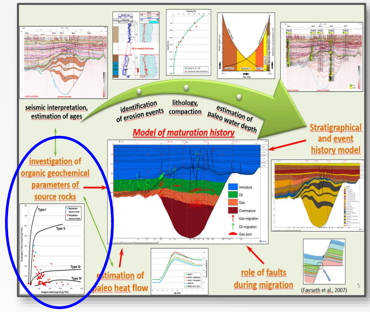
ORGANIC GEOCHEMISTRY – BADENIAN SOURCES

Distribution of Badenian source rock sub-types



Kerogen type of Badenian and Karpatian source rocks shown on Van Krevelen diagram, measured OI vs. HI values

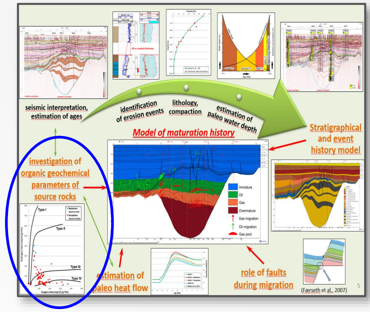




- ***S-rich oil*** + evaporite occurrences indicate (indirectly) the presence of Type II-S kerogen in SOL trough
- Understanding of spatial and quality distribution of source rock facies
  - TOC:1.36-1.67 wt%,
  - HI: 300-526 mg/g
  - Type-II, II-S

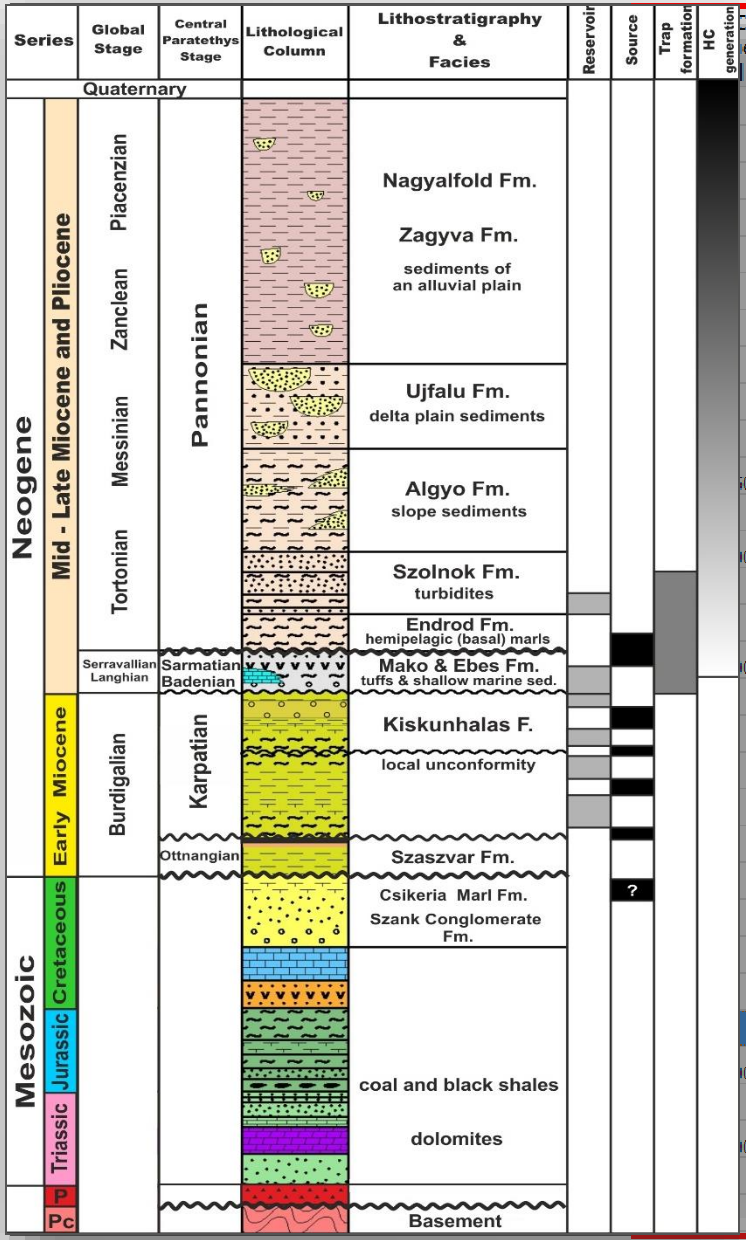
ELEMENTS OF HC SYSTEM

Name	Color	Lithology Value	TOC Mode	TOC Value [%]	TOC Map	Kinetics	HI Mode	HI Value [mgHC/gTOC]	HI Map	Petroleum System Elements
Quarternary		Sandstone (clay rich)								Overburden Rock
3.6-2-6		50_shale_50_sand								Overburden Rock
4.8-3.6		50_shale_50_sand								Overburden Rock
6.3-4.8		68_shale_32_sand								Overburden Rock
6.8-6.3		41_shale_59_sand								Overburden Rock
7.8-6.8		25_shale_75_silt								Overburden Rock
9.1-7.8_shaly		09_shale_91_silt								Overburden Rock
9.1-7.8_sandy		Sandstone (clay poor)								Reservoir Rock
9.1-7.8_marl		Marl								Overburden Rock
9.6-9.1_marl		Marl								Overburden Rock
11.6-9.6_calcmarl		Marl	Value	1.50		Pepper&Corvi(1995)_TIIIH(DE)	Value	150.00		Source Rock
Sarmatian_marl		Marl								Overburden Rock
Badenian_SR_TypeII		Shale_SR	Value	2.00		Pepper&Corvi(1995)_TII(B)	Value	300.00		Source Rock
Badenien_Ebes_calcmarl		Marl								Seal Rock
Karpatian_sandstone		26_shale_54_silt_20_sand								Reservoir Rock
Karpatian_SR		Shale_SR	Value	2.00		Pepper&Corvi(1995)_TII(B)	Value	300.00		Source Rock
Basement_Variscan_granite		Granite (500 Ma old)								Underburden Rock
Basement_Variscan_Gneis		Gneiss								Underburden Rock
LowerTriassic_Clastics		Sandstone (clay rich)								Underburden Rock
UJura-LowCret_pelagic_carbonates		Limestone (shaly)								Underburden Rock
LowerJurassic_coaly_unit		Shale (organic lean, sandy)								Underburden Rock
LowerCret_basinal		Limestone (shaly)								Underburden Rock
UpperCret_shallow_marine		Marl								Underburden Rock
Reservoir		Sandstone (typical)								Reservoir Rock
Badenian_Limestone_congl		50_lime_50_congl								Reservoir Rock
Badenian_shaly_limestone		70_shale_30_lime								Seal Rock
Karpatian_SR_deep		Shale_SR	Value	2.00		Pepper&Corvi(1995)_TIIIH(DE)	Value	200.00		Source Rock
Karpatian_Claymarl		Marl								Overburden Rock
Badenian_SR_TypeIIS		Shale_SR	Value	2.00		Pepper&Corvi(1995)_TII-S(A)	Value	500.00		Source Rock
Fault		Shale_SR								Seal Rock



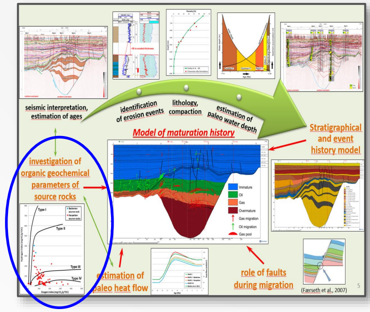
- The preparation work defined the elements of the HC system
- For each of the source layers the input parameters were determined (data or literature)

ELEMENTS OF HC SYSTEM



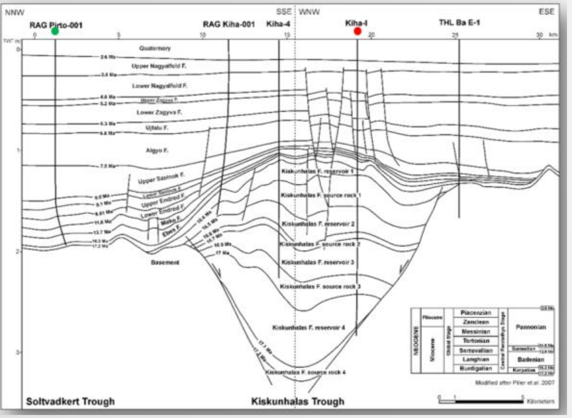
TOC Map	Kinetics	HI Mode	HI Value [mgHC/gTOC]	HI Map	Petroleum System Elements
					Overburden Rock
					Overburden Rock
					Overburden Rock
					Overburden Rock
					Overburden Rock
					Overburden Rock
					Overburden Rock
					Reservoir Rock
					Overburden Rock
					Overburden Rock
	Pepper&Corvi(1995)_TIIIH(DE)	Value	150.00		Source Rock
					Overburden Rock
	Pepper&Corvi(1995)_TII(B)	Value	300.00		Source Rock
					Seal Rock
					Reservoir Rock
	Pepper&Corvi(1995)_TII(B)	Value	300.00		Source Rock
					Underburden Rock
					Underburden Rock
					Underburden Rock
					Underburden Rock
					Underburden Rock
					Underburden Rock
					Underburden Rock
					Reservoir Rock
					Reservoir Rock
					Seal Rock
	Pepper&Corvi(1995)_TIIIH(DE)	Value	200.00		Source Rock
					Overburden Rock
	Pepper&Corvi(1995)_TII-S(A)	Value	500.00		Source Rock
					Seal Rock

Based on Magyar et al. 2006, Badics et al. 2011.

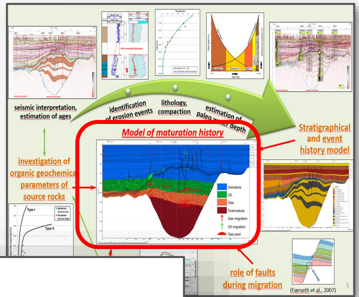


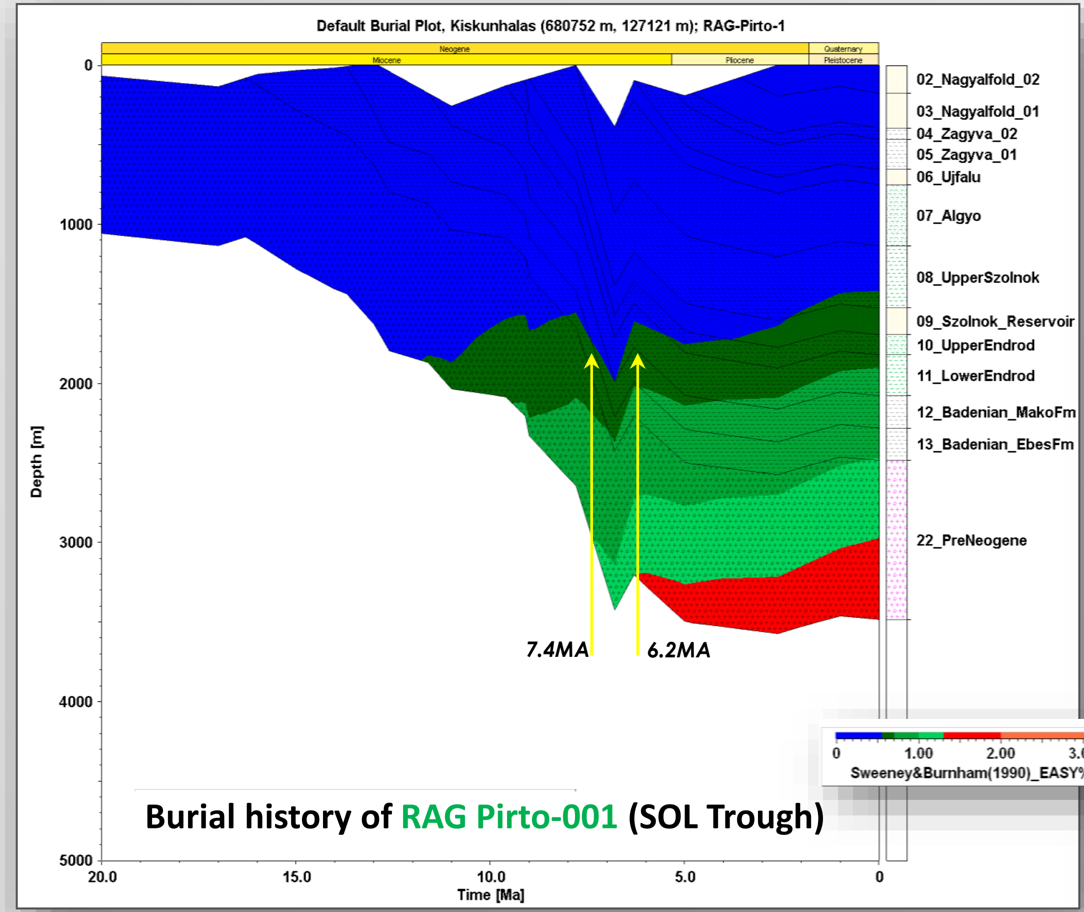
- The preparation work defined the elements of the HC system
- For each of the source layers the input parameters were determined (data or literature)
- **The spatial and genetic relationships between the HC system elements were properly clarified**

MODELING RESULTS – MATURATION HISTORY

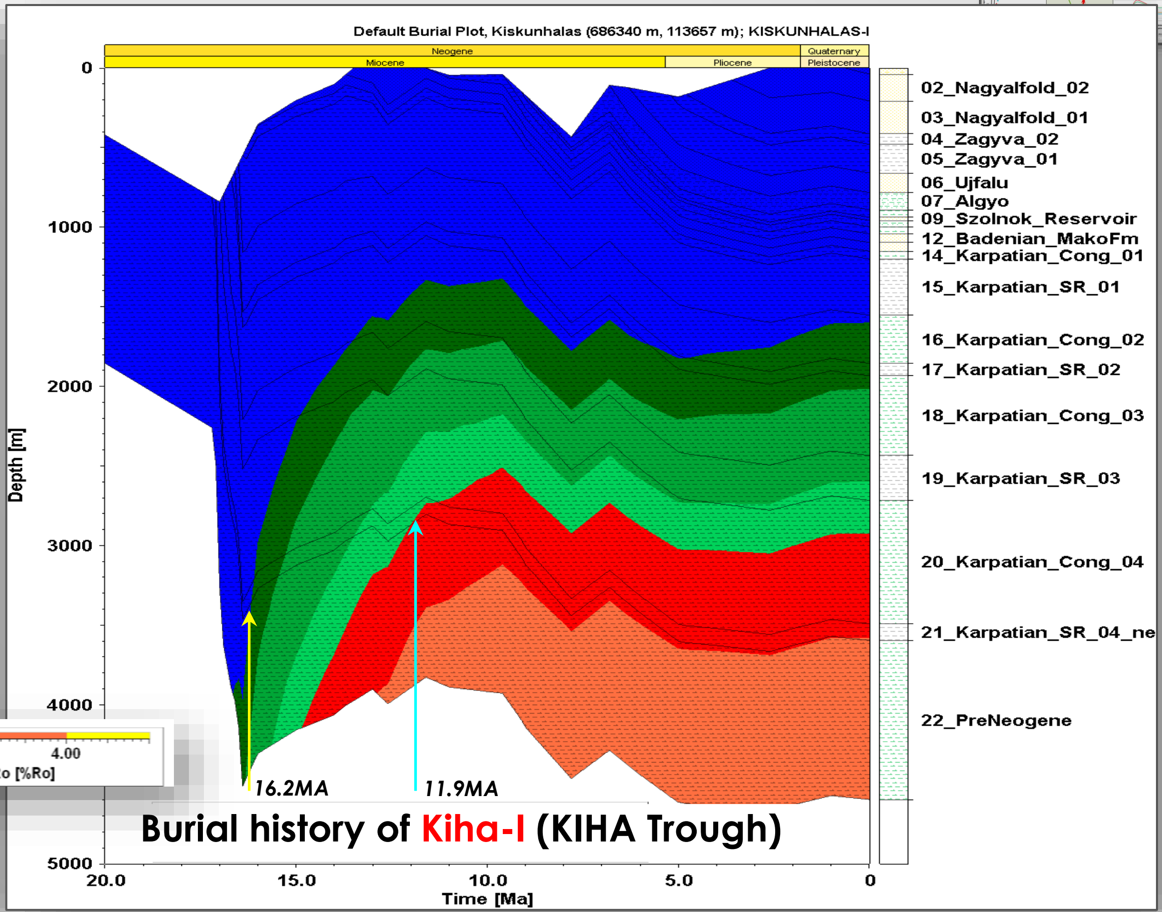


- Complex burial history because of the complicated tectonic/gelogical settings = ***different maturation history for the subbasins***
- In general the Kiskunhalas Trough is more gas prone, the Soltvadkert Trough is more oil prone, and the timing of maturation is significantly different



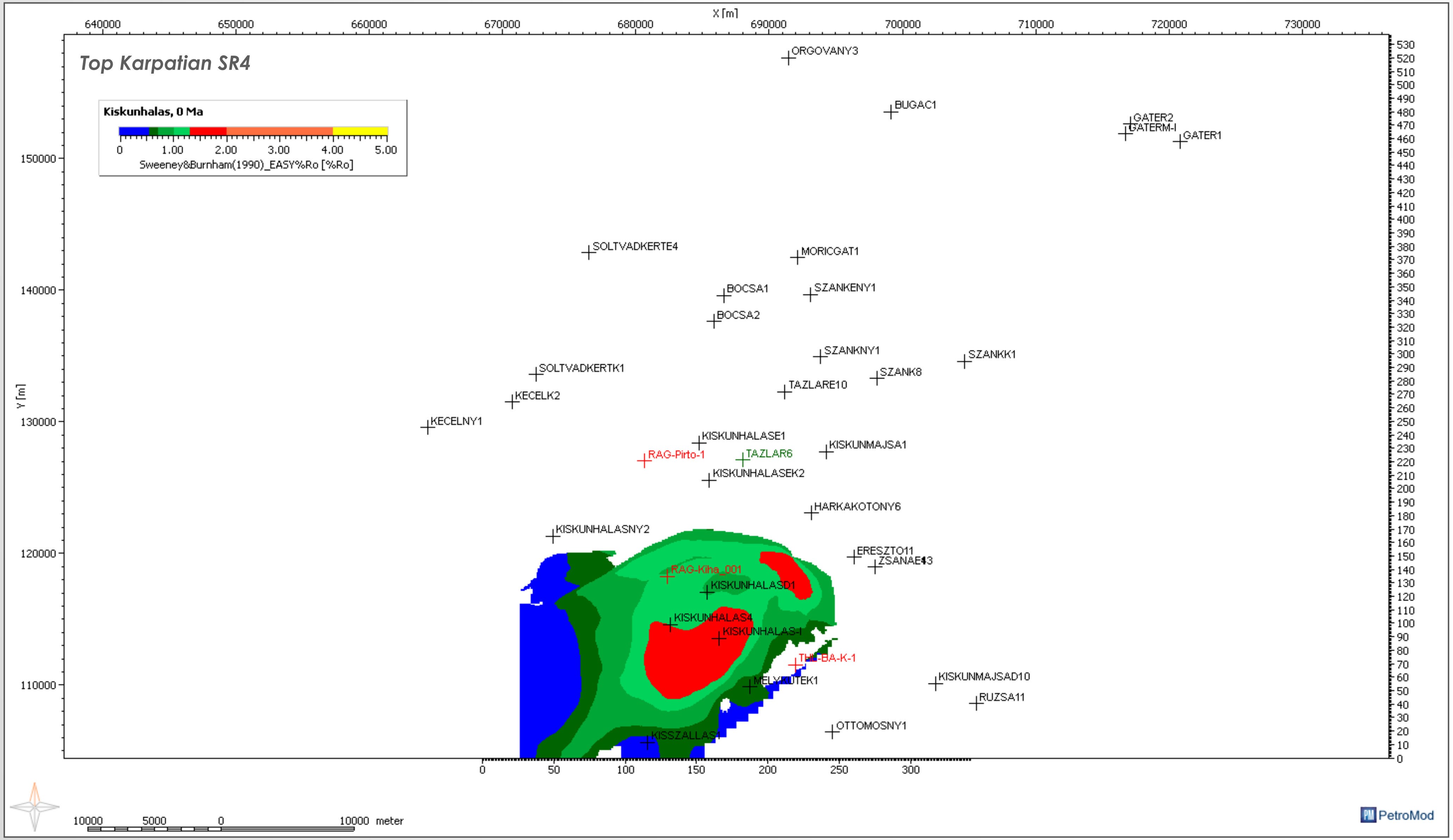


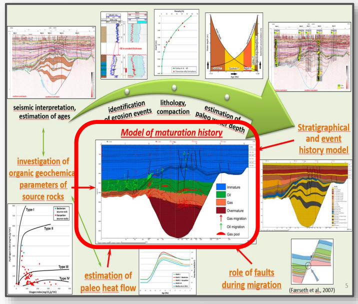
Burial history of RAG Pirto-001 (SOL Trough)



Burial history of Kiha-I (KIHA Trough)

MODELING RESULTS – PRESENT DAY MATURITIES





Maturity maps

- Constant 1000 m thick Pre-Neogene Basement with facies belts (Haas et al., 2010)
- Detailed paleogeography
- Slight Pliocene & late Sarmatian inversion & erosion included

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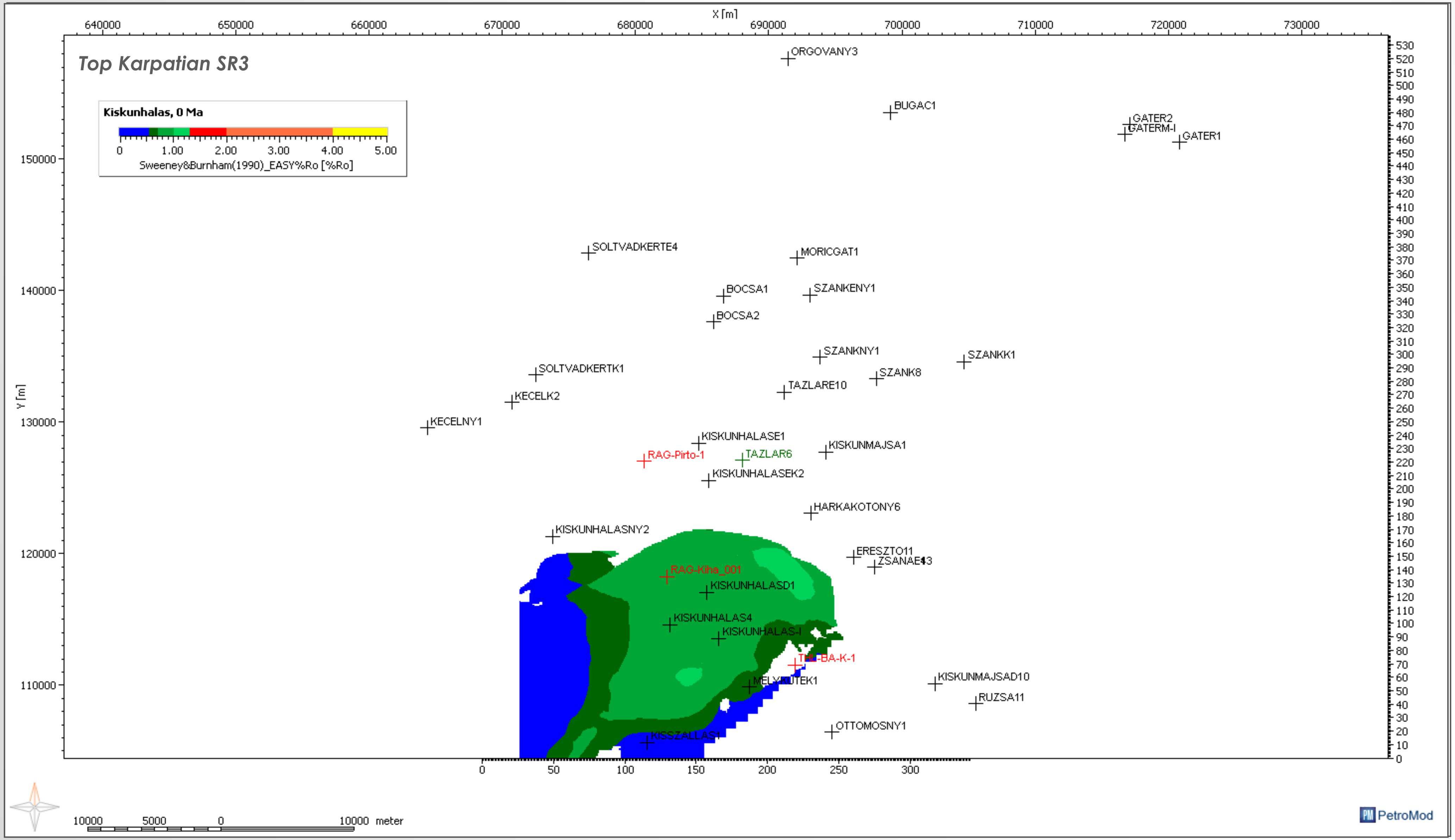

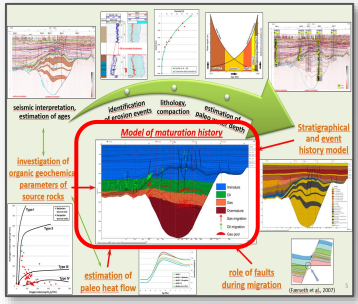

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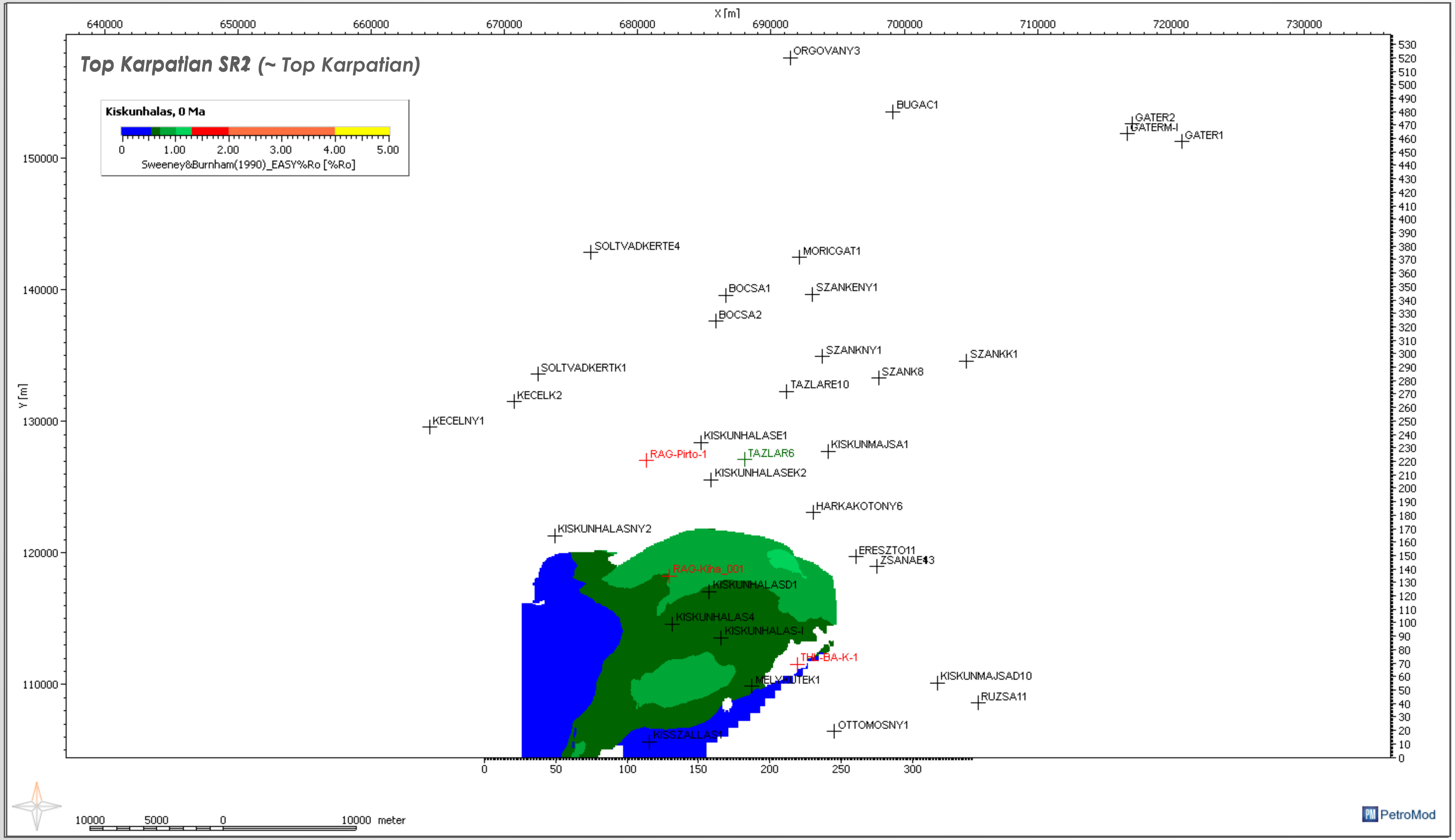

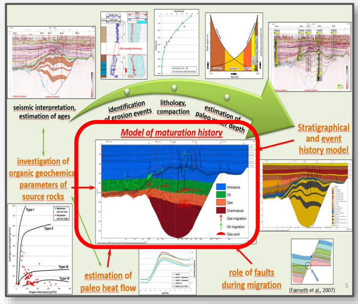

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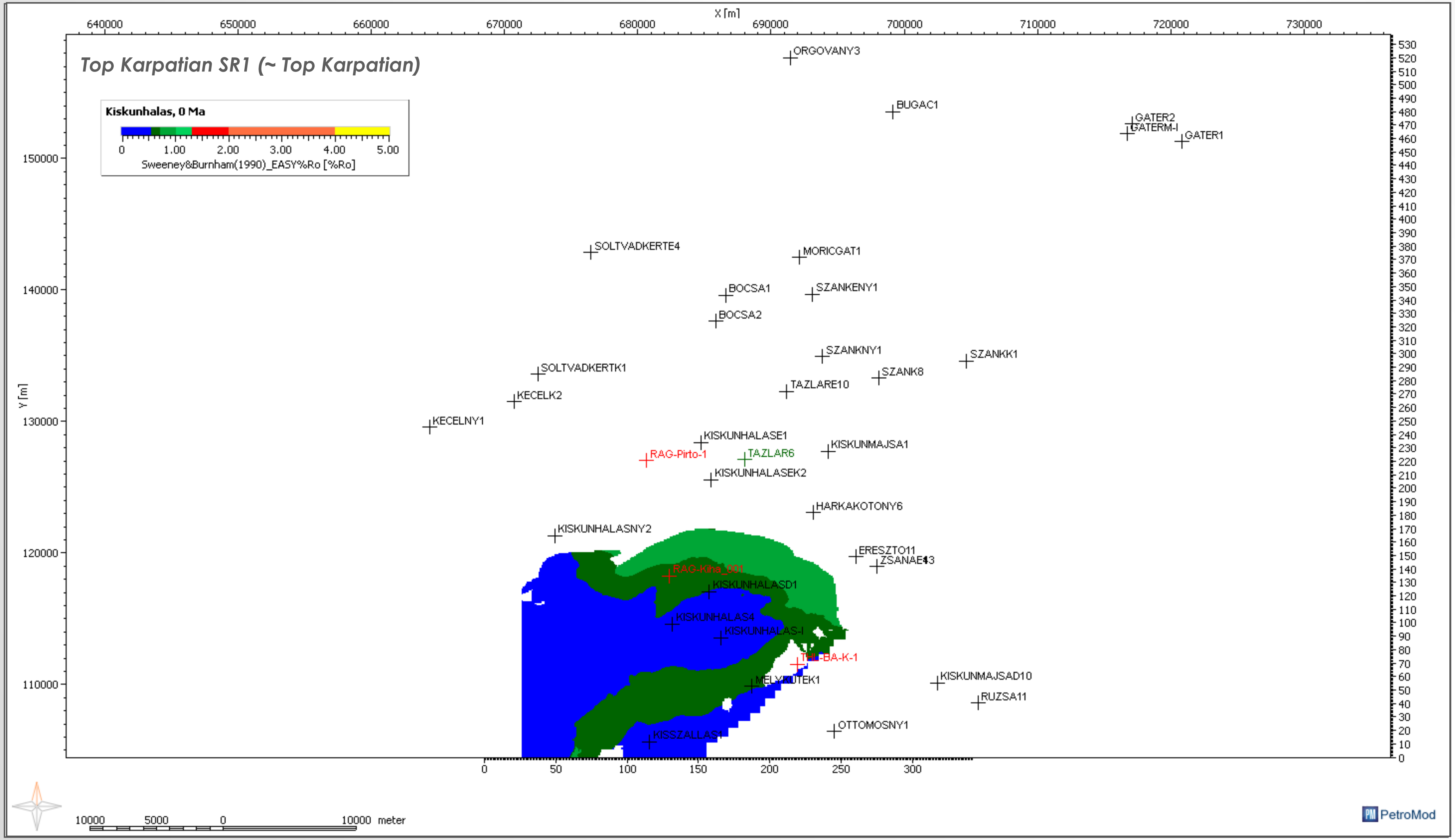

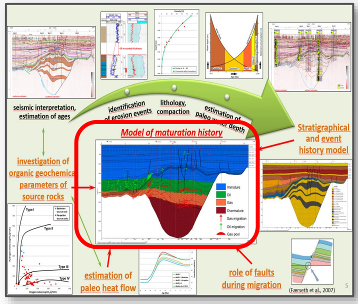

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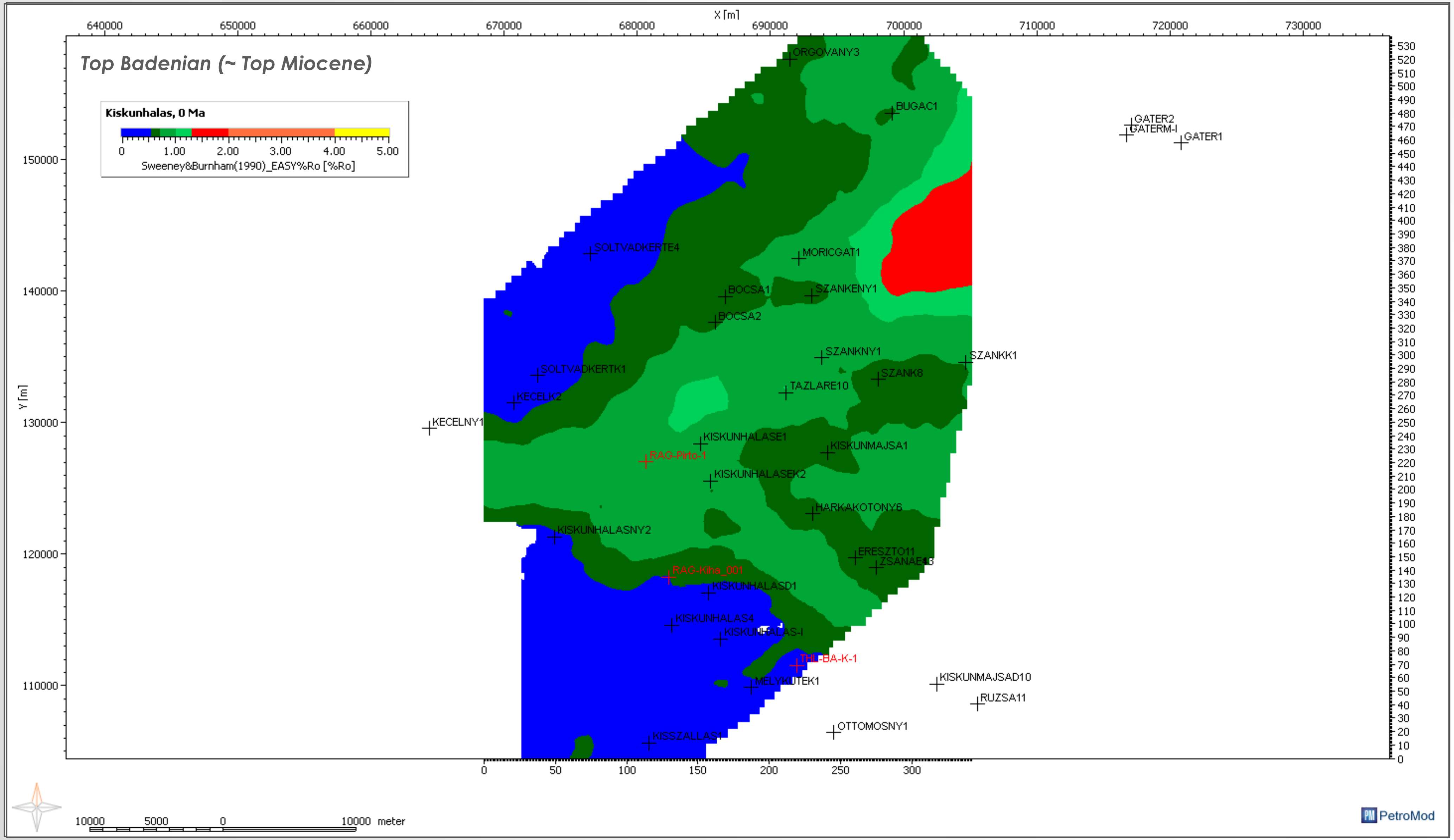

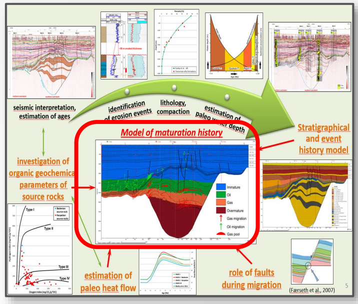

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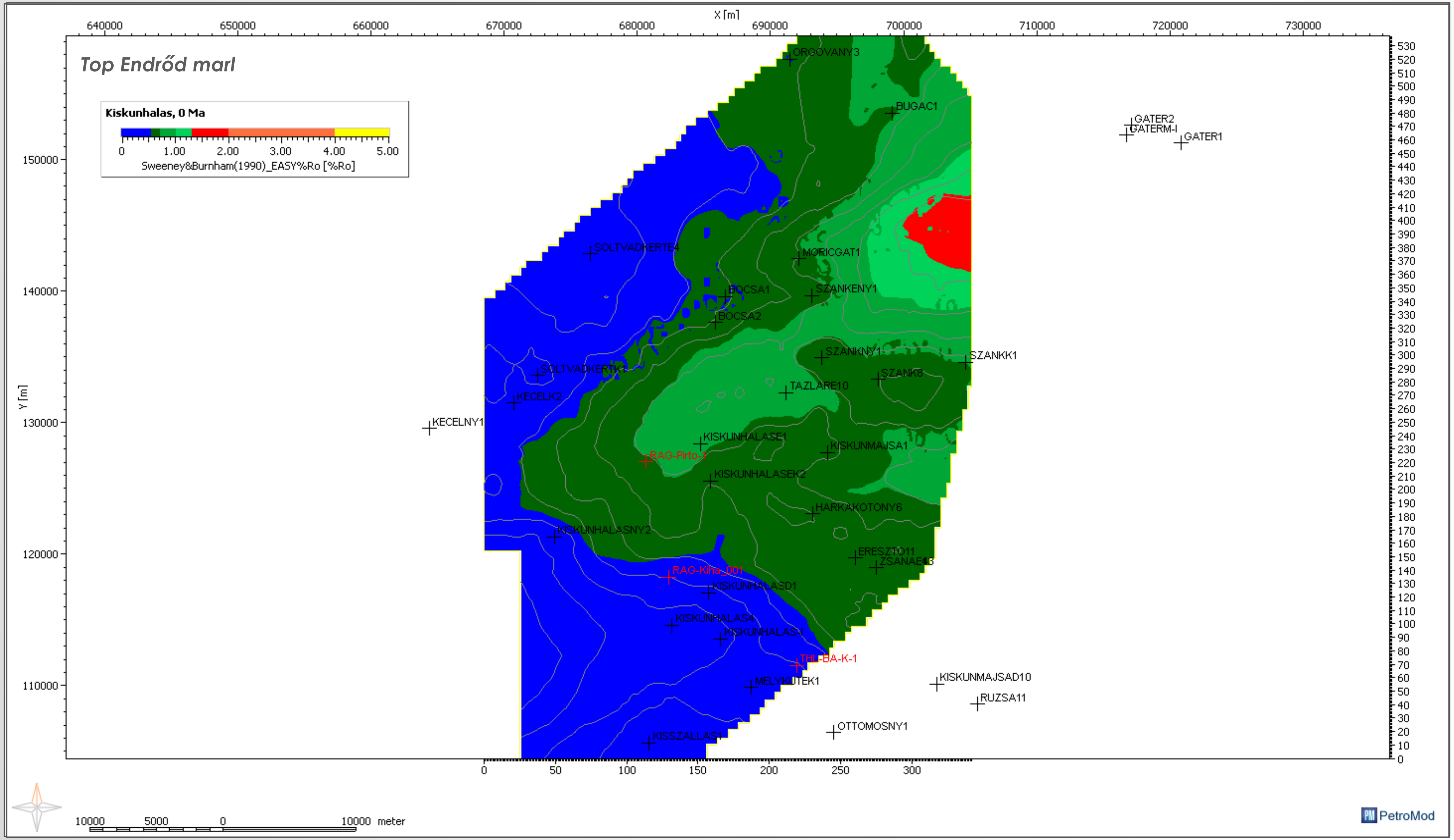
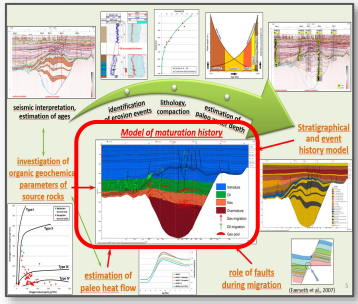
MODELING RESULTS – PRESENT DAY MATURITIES

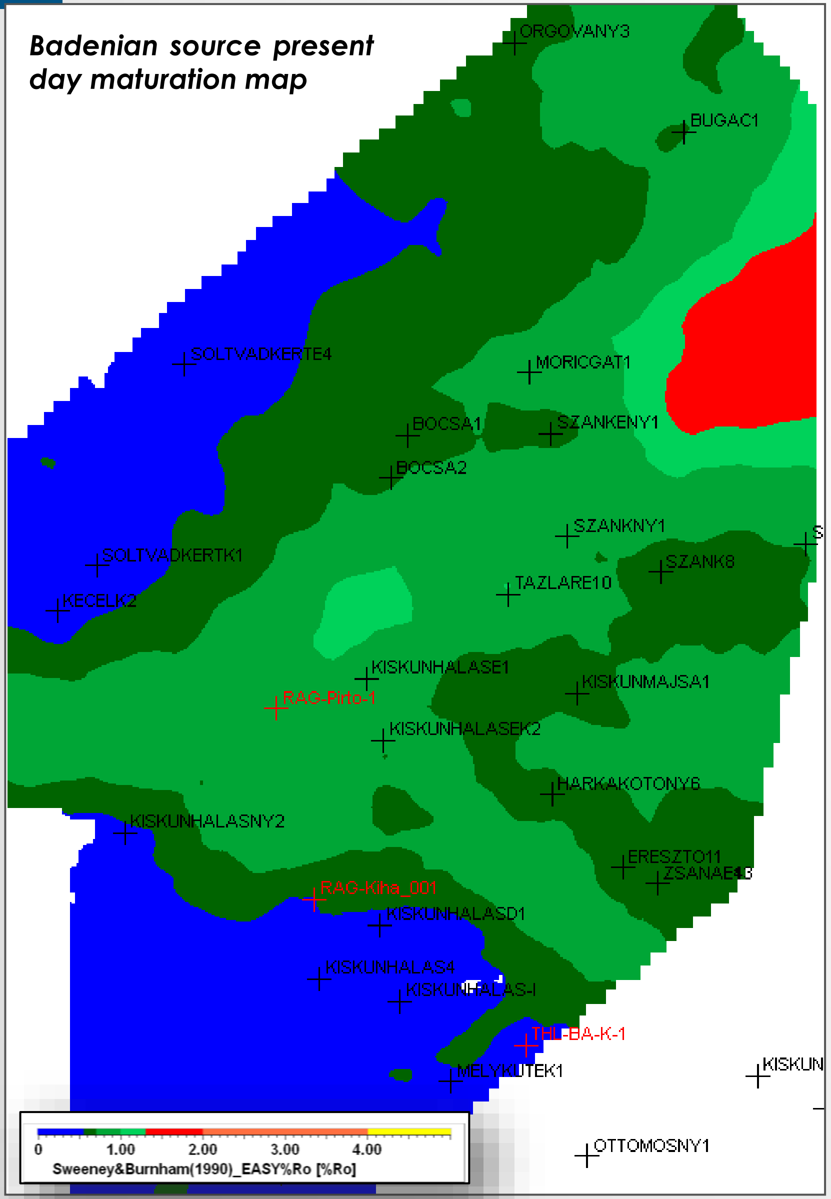


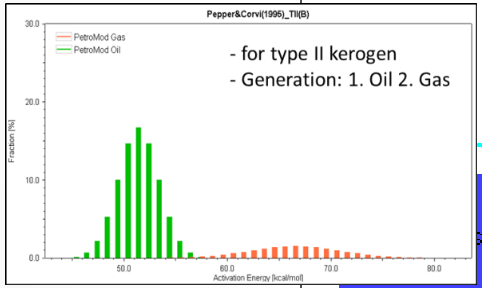


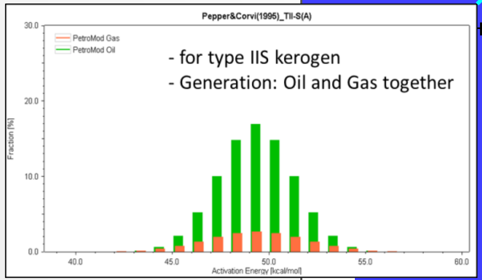
Maturity maps

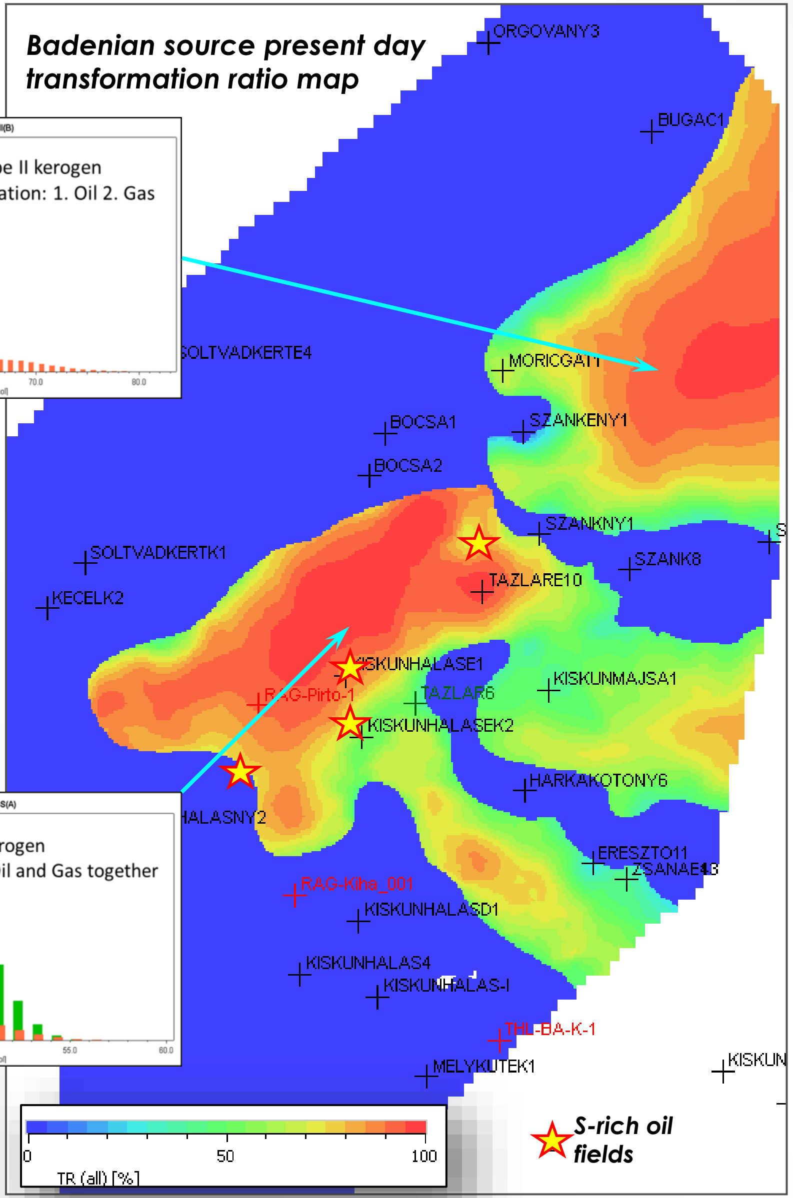
- Constant 1000 m thick Pre-Neogene Basement with facies belts (Haas et al., 2010)
- Detailed paleogeography
- Slight Pliocene & late Sarmatian inversion & erosion included

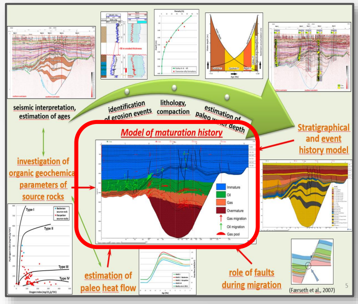
MODELING RESULTS – MATURATION VS TRANSFORMATION RATIO







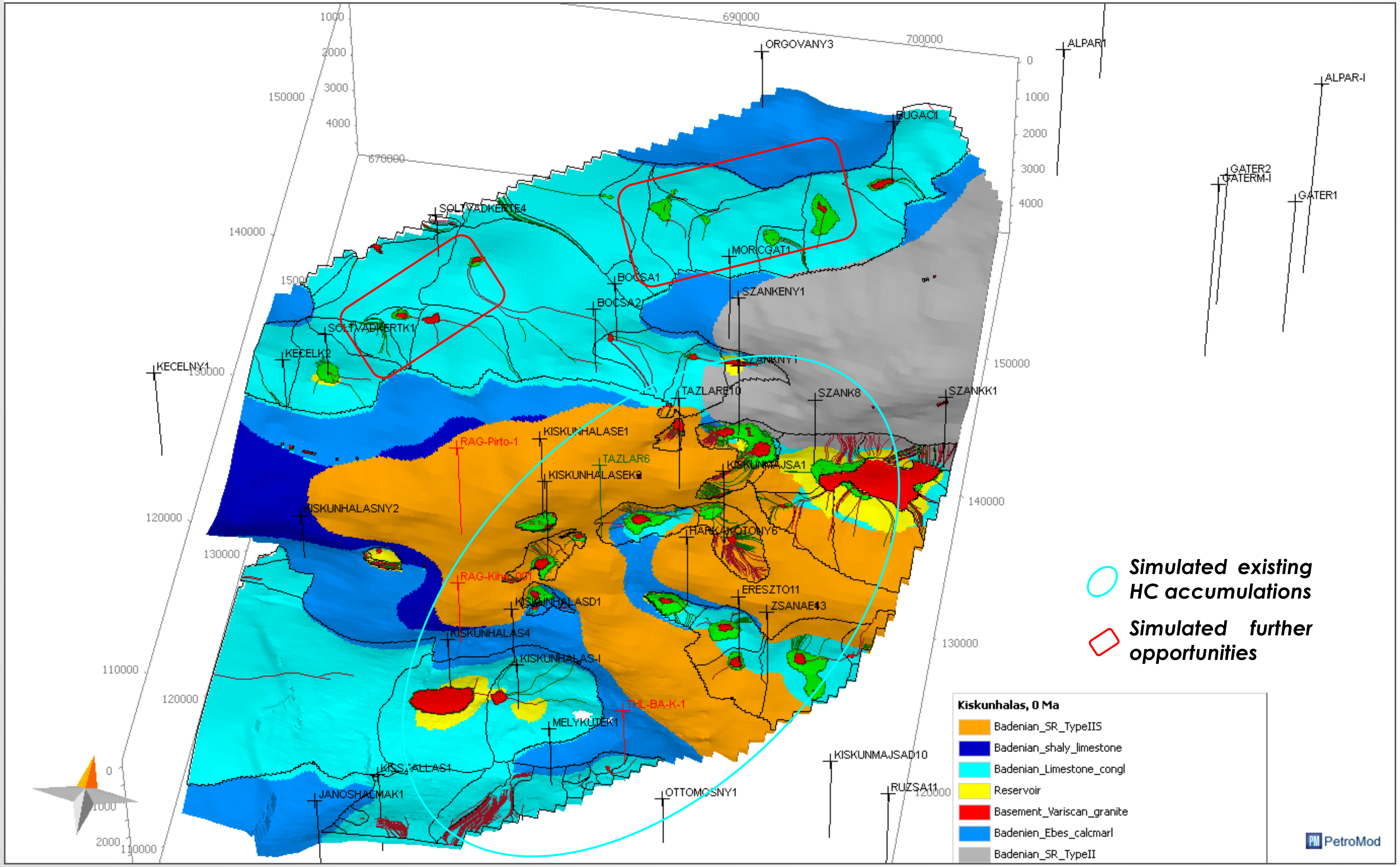


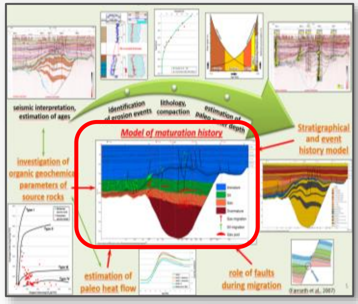


- Relation between applied kinetic vs maturation is visible
- „***Fingerprint***" ***of the source and maturation heterogeneity*** could be observed in the field distribution
- Multi-dimensional understanding is required for the proper HC exploration activity

MODELING RESULTS – MIGRATION AND ACCUMULATION

Simulated oil (green) & gas (red) accumulations & HC flow vectors, Badenian layer, perspective view from SW with the lithology of Badenian layer shown

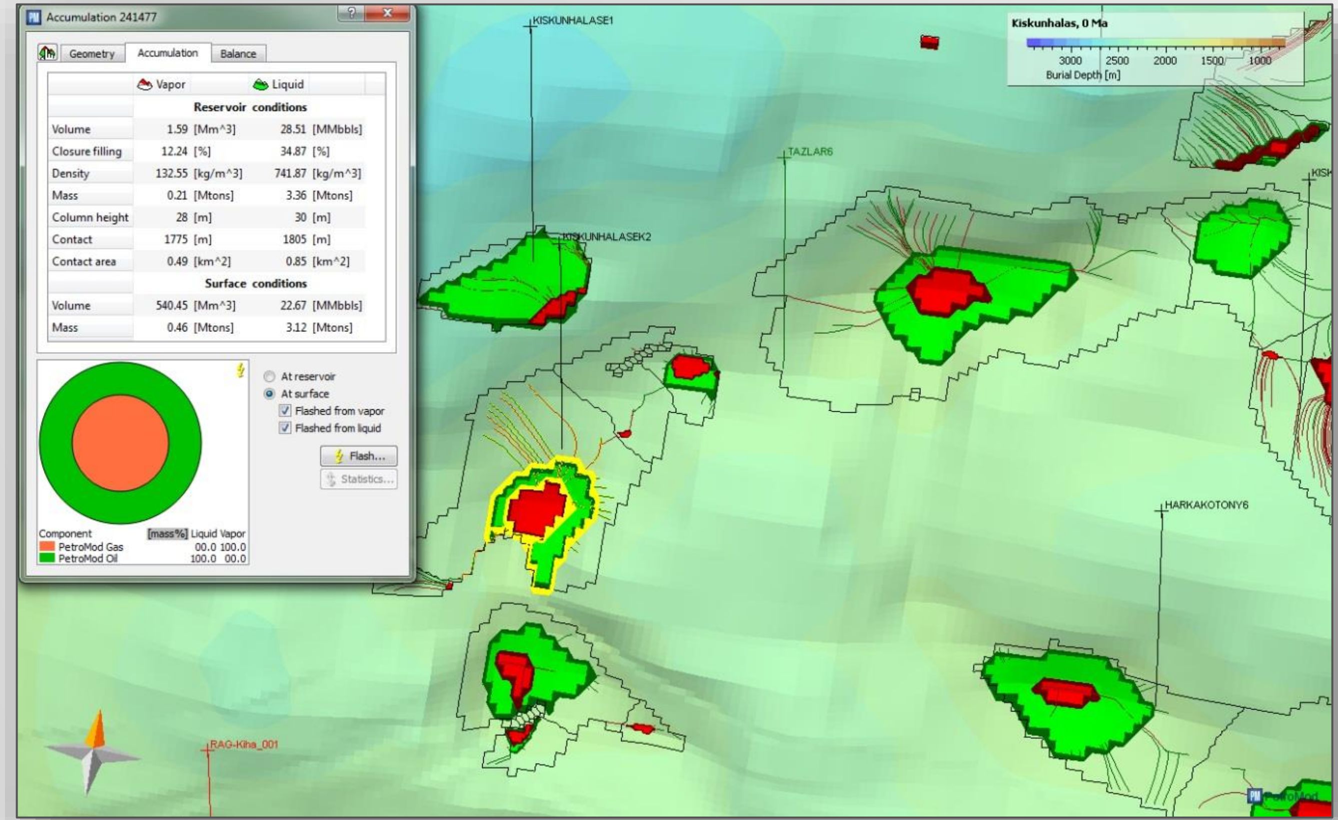




- In the vicinity of the KIHA-SOL-Alpár troughs, the HC generation and accumulation is proved by the model
- The model simulated a possible new trend of HC accumulations on the northern flank of SOL-Alpár troughs

MODELING RESULTS – CALIBRATIONS AND YTF

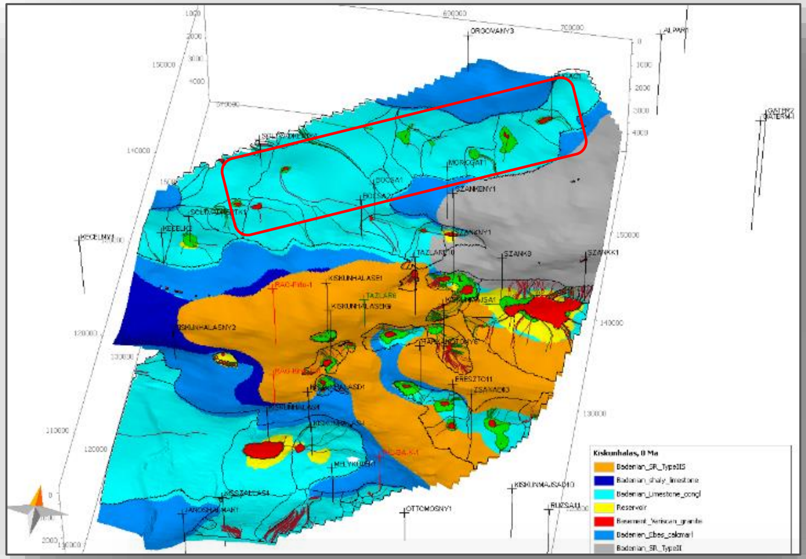
Simulated oil (green) & gas (red) accumulations & HC flow vectors, Badenian layer, present-day, perspective view from SW with Kiskunhalas Northeast field and simulated properties

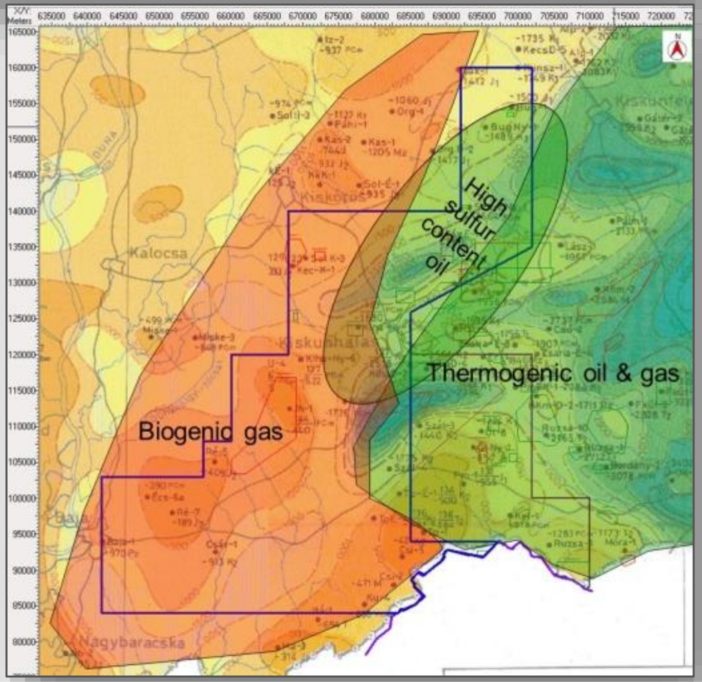


- Calculated OHCIP volumes for each modeled (discovered/predicted) accumulations
- Comparison of modeled vs calculated volumes of discovered accumulations is a good tool for calibration, but large dependency from the input parameters
- ***Conclusion: The model is capable to predict properly the known/possible locations of the accumulations, but do not use for direct volumetric estimation!***

- Within the 3D basin model area, ***1100 Million tons of oil and 422 Million ton oil-equivalent gas has been generated***. Most of the generated volume has been lost (retained within the kerogen and pore network, dispersed in the shaly lithologies and lost to the surface through seepage).
- The current ***total discovered HCIP*** is ***20 Million ton oil and 18 Million ton oil-equivalent gas***.
- In such pull-apart basins, the ***accumulation/generation ratio could be much higher than the observed 2.5%*** (see Biteau et al. 2010).
- Based on our current calculations the study area contains ***approx. 5.5 Million ton oil and 5 Million ton oil-equivalent gas in place as Yet-To-Find potential*** in subtle *conventional* traps.

CONCLUSIONS AND SUGGESTIONS





Conclusions

- Based on the results of the 3D modeling we…
  - Enhanced our **understanding the Neogene HC system**
  - Can estimate the **generated and YTF HC volumes** more accurately than before
  - Defined a **new trend for HC exploration** and
  - Could **influence** and **better define the future exploration efforts** within this geologically complex and matured exploration area

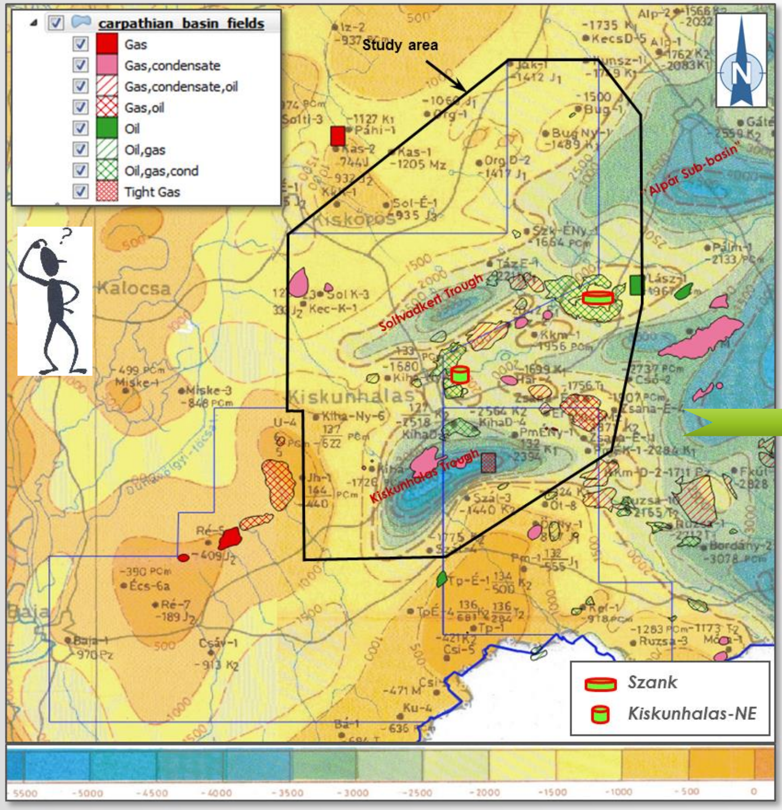
Suggestions, to do

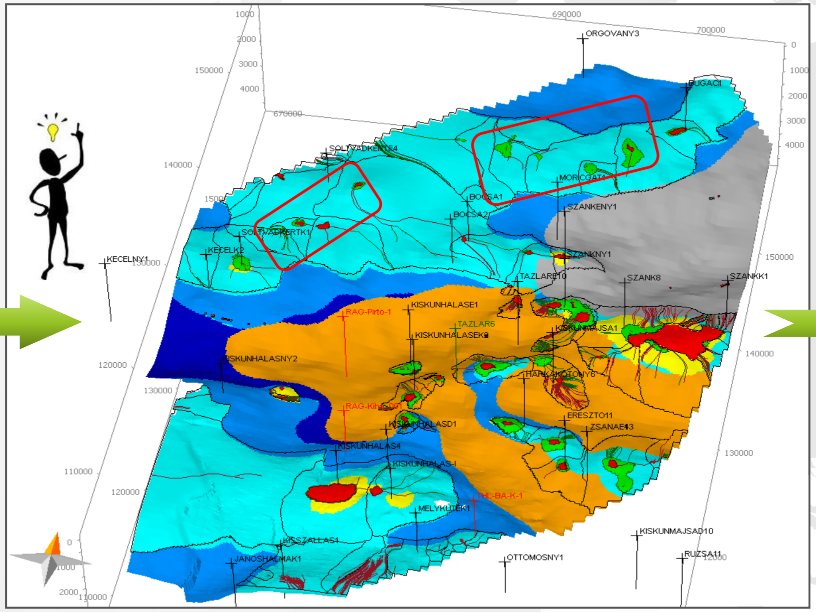
Strategy

- **Focus the further exploration program (3D, drilling) to the northern part of the study area**

Model

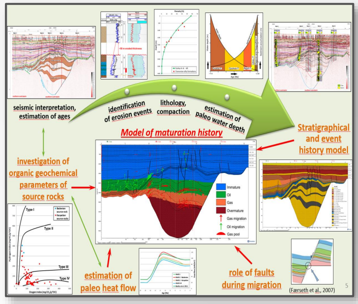
- Develop our understanding of the **spatial and quality variations of the source rocks** and **reservoirs** (e.g. new organic geochemical measurements, test new kinetics, more detailed mapping, etc.)
- **Include the proven bacterial gas generation processes** into the modeling





THANK YOU FOR YOUR KIND ATTENTION!
QUESTIONS?

REFERENCES



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