3D Petroleum System Model of Southeastern Part of Pannonian Basin*

Goran Bogicevic[1], Ivan Dulic[1], and Janko Sovilj[1]

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Abstract

Regional 3D Petroleum System Model of Pannonian Basin were done in southeastern part of Pannonian basin, with the aim of more efficient planning of the future exploration works and exploration risk and uncertainty reduction. Investigated area encompasses 92.290 km^2, which is covered with 5.681 2D seismic lines (with total 81.582 km) and 58 3D seismic cubes (covering 15.697 km^2), and it includes parts of Serbia, Hungary, Romania, Bosnia and Herzegovina and Croatia. Modelling process was carried out using SLB PetroMod software. Regional 3D petroleum system model was constructed with 500x500 m grid cell, using 8 initial regional structural maps, which were split into 46 layers/sublayers to achieve better vertical model resolution. During preparation of structural framework for 3D modeling, 28 regional 2D models, with total length of over 6600 km, were created and calibrated. Modeling these master sections enabled better understanding of basin dynamics through time, as a key factor of migration routes in 3D. In addition, modeling results from 28 2D models, allow us to create 107 PSE input maps (lithofacies, total organic carbon, hydrogen index, source rocks thickness, heat flow, erosion estimation, paleo water depth etc), necessary for 3D modeling. Based on over 8000 Rock-Eval analysis from 869 wells, and publicly available data, six major source rocks are determined. Distribution and areal characteristics changes of basic parameters (kerogen type, original hydrogen index, original total organic carbon, reaction kinetics and net thickness) were specify for each source rock, and derived distribution maps were used as 3D modeling input. During 3D modeling process, more than 1.000 wells were used for the calibration of basic physical parameters: 932 wells with temperature data, 162 wells with pore pressure data, 214 wells with effective porosity, 103 wells with vitrinite reflection data and 409 for lithofacies analysis. Also, for calibration of petroleum phase definition, data from 293 oil and gas fields with geological reserves totaling 1.080 mil. TOE were used, representing more than 80% of previously discovered reserves in this part of Pannonian Basin. Based on the results of 3D modeling and distribution of the discovered fields, 14 petroleum systems were determined. The amount of already discovered reserves of oil and gas and the remaining yet-to-be-found resources were defined for the whole basin and for each system. During the construction of geological model, more than 300 structures were defined and for each of them was done calculation of already discovered and still undiscovered accumulations of hydrocarbons. All remaining accumulations are risked out based on index of probability of model accuracy, depending on quantity of the available data. It is defined separately for each petroleum system and ranging between 0.46-0.83. In addition, based on modeling results, chance of success maps for this part of Pannonian basin were constructed.

NIS GAZPROM NEFT FUTURE AT WORK

3D Petroleum System Model of Southeastern Part of Pannonian basin

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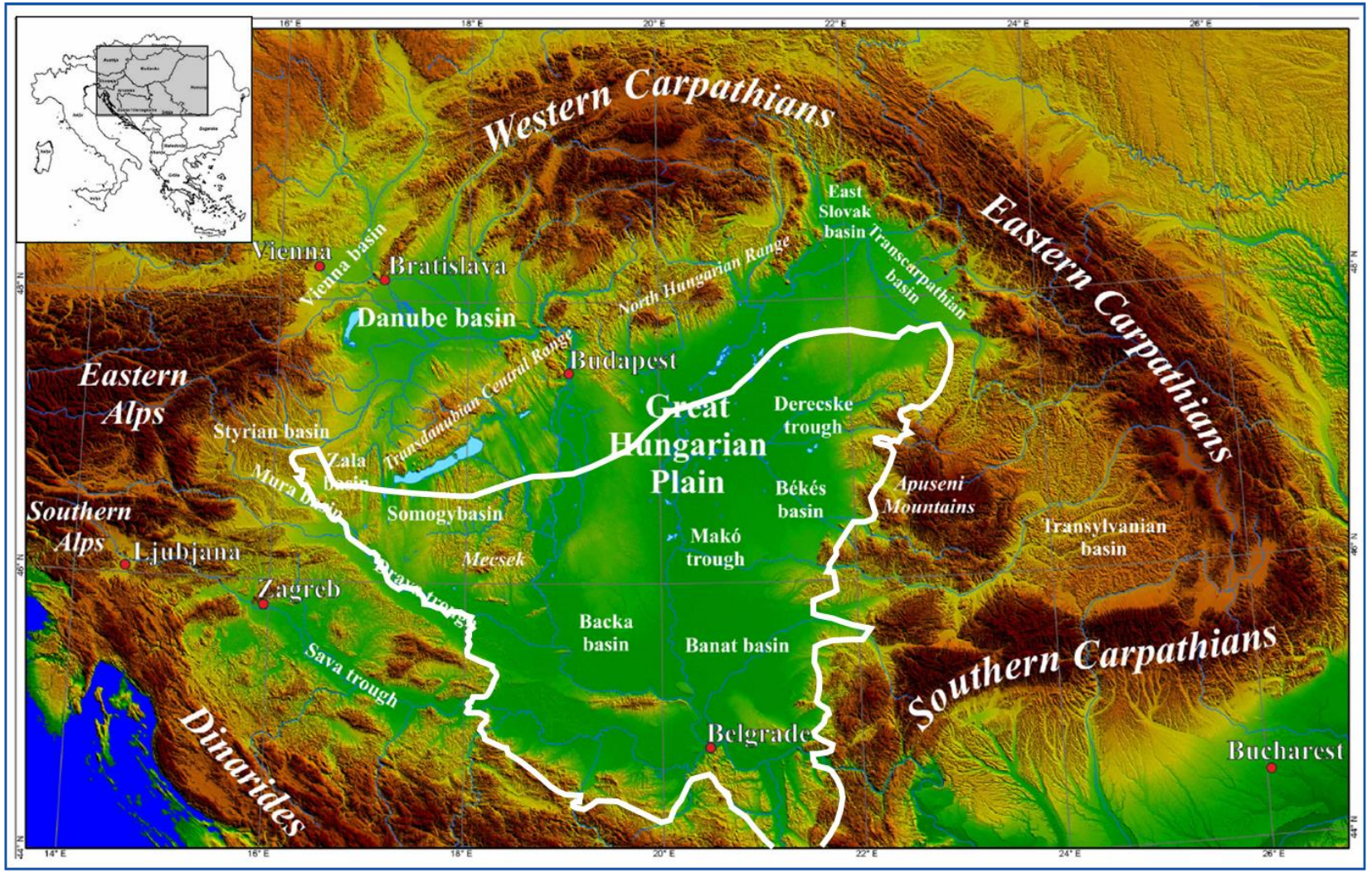
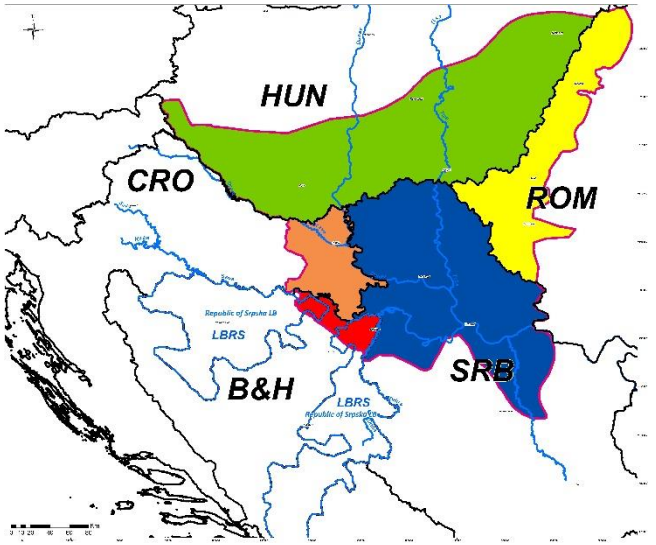
3D Petroleum System Model of Southeastern Part of Pannonian basin

Content

3D Petroleum System Model of Southeastern Part of Pannonian basin
Geographical position



Geographical position of Pannonian basin and other smaller subbasins (Horvath, 2015)



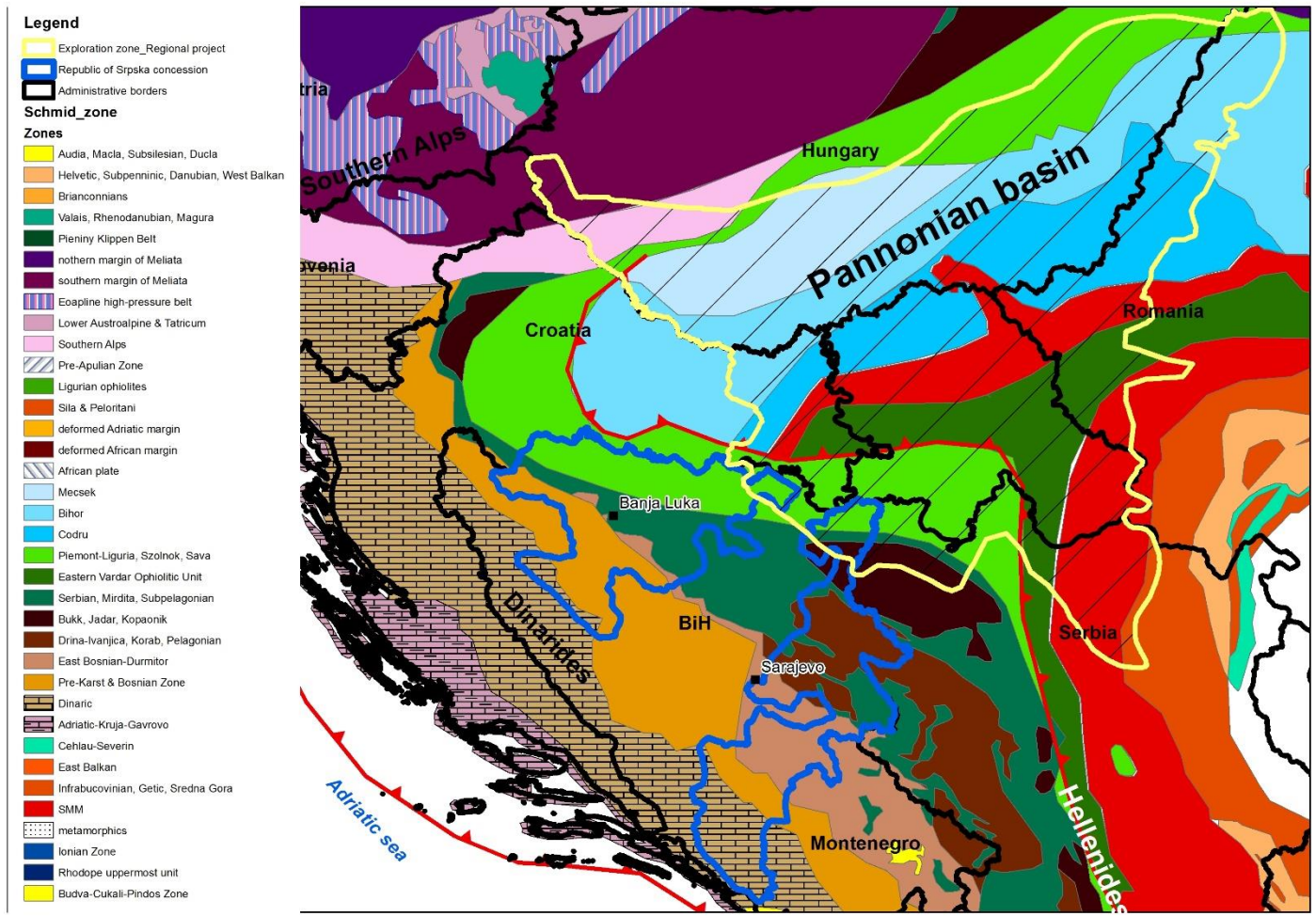
Boundary of the exploration area:
Central and southern part of the Pannonian basin

Total area: **92.290** km^2;

5 countries:
Serbia (30.055 km^2),
Republic of Srpska (2.358 km^2),
Hungary (39.241 km^2),
Romania (14.413 km^2),
Croatia (6.207 km^2).

3D Petroleum System Model of Southeastern Part of Pannonian basin

Geological framework - Basement



Tectonic units of Alps, Carpathians and Dinarides (Schmid et al, 2016)

Neogene basement of Pannonian basin consist of several structural units:

- Serbian-Macedonian massif,
- Eastern Vardar zone,
- Tisza mega unit,
- Sava zone,
- Western Vardar zone,
- Dinaridic ophiolite belt,
- Dinarides and
- Sothern Alps

Basement

- metamorphic complex of Proterozoic-Paleozoic,
- clastic-carbonate and ophiolite complexes of Triassic, Jurasic and Cretaceous
- clastic-carbonate Paleogene complex

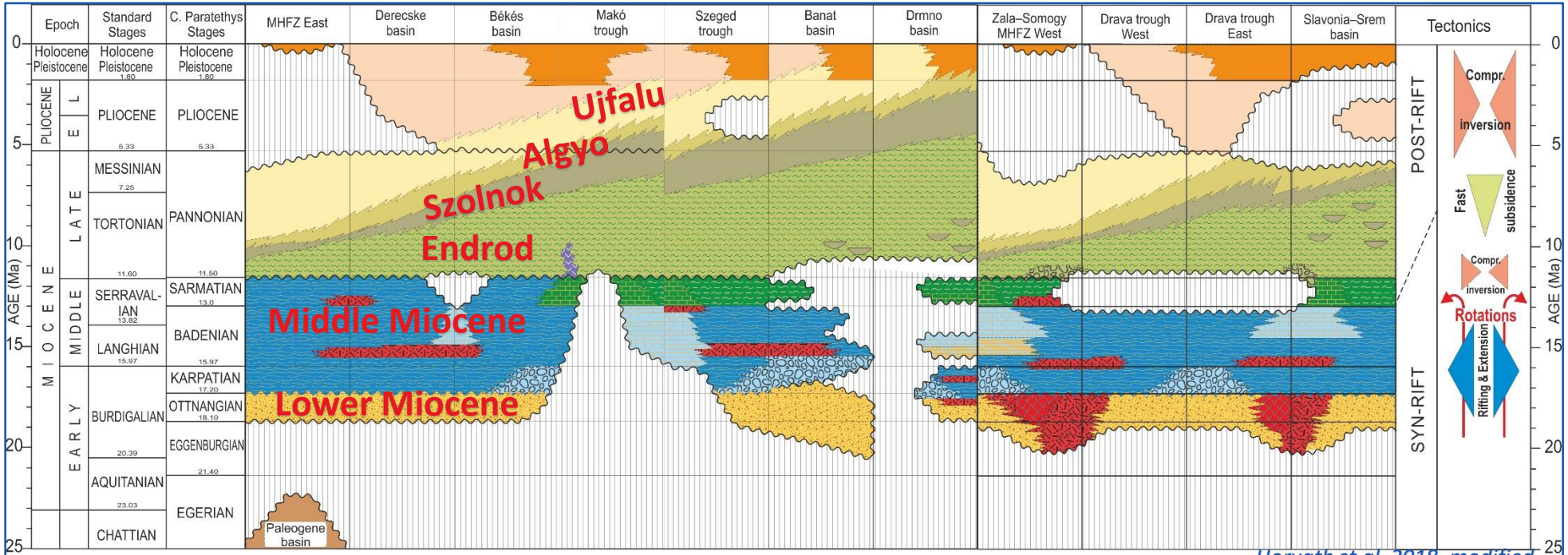
- Very good reservoir rocks in fractured zones,

- Triassic and Paleogene carbonates are very good source rocks.

3D Petroleum System Model of Southeastern Part of Pannonian basin

Geological framework - Stratigraphy

Integrated Stratigraphy → Geophysics (8 regional horizons) → Petroleum System Elements (46 layers)



Horvath et al, 2018, modified

- Basal conglomerate, fluvial-lacustrine clastics
- Marine basin margin: gravel (a), near shore mud and limestone with lignite (b) and biogenic limestone (c)
- Open-marine clay and marl
- Brackish water biogenic limestone (a) and offshore marl (b)
- Volcanites: andesites (a), rhyolitic ignimbrites and tuffs (b)
- Volcanites: alkali basalts
- Lacustrine shoreline conglomerate (a), and open-water marl (b)
- Turbidites from the shelf slope (a), and local sources (b)
- Shelf slope (a), and shelf margin to plain sequence (b)
- Alluvial plain deposits
- Red clays and loesses with paleosols, windblown sand and silt, river gravel and sand
- Unconformity with stratigraphic gap (a) and correlative conformity (b)

Neogene deposits

- numerous formations of the Miocene and Pliocene, consisting of continental molasses, marine, brackish and freshwater deposits of lakes, rivers and marshes.
- Most important source rocks.
- Most of oil and gas deposits are found in the clastic and carbonate deposits of the Miocene and Pliocene.

Lower Miocene
Fluvial-lacustrine sediments

Middle Miocene
Open marine and brackish in upper parts

Endrod Fm
Basin fill sediments

Szolnok Fm
Deep water turbidites

Algyo Fm
Slope deposits represented by prograding clinoforms

Ujfalu Fm
Deltaic and fluvial on top

3D Petroleum System Model of Southeastern Part of Pannonian basin

3D modeling - Workflow

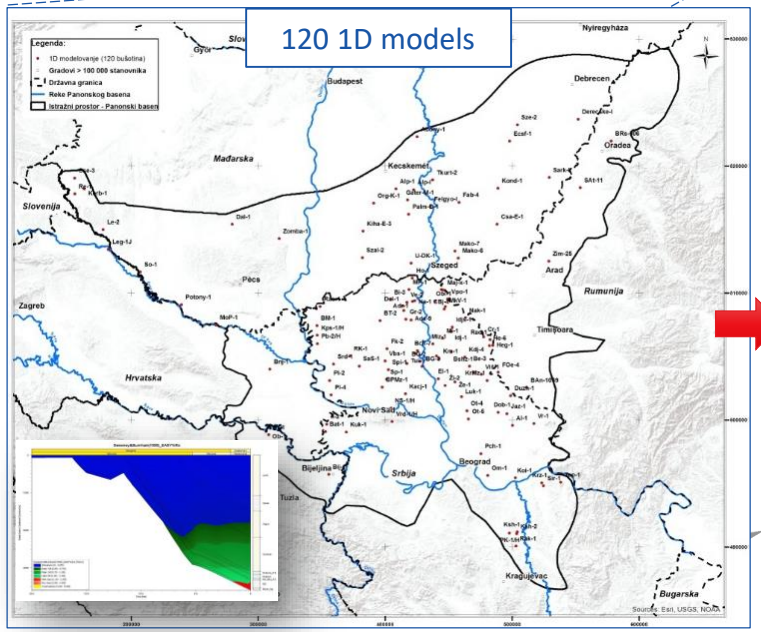
2014						2015											
7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
I phase				**II phase**					**III phase**					**IV phase**			
Database creation				1D modeling, preparation for 2D modeling					2D modeling, preparation for 3D modeling					3D modeling, results analysis			

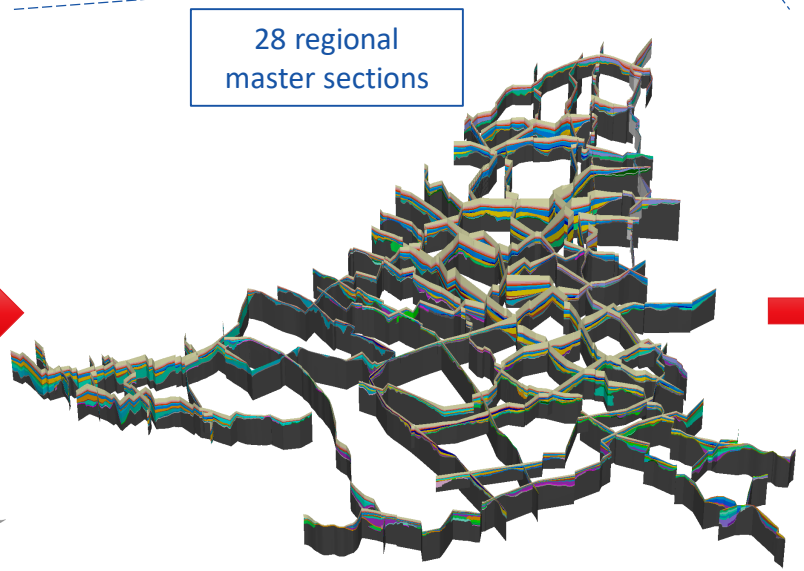
ArcGIS project
-Database evaluation

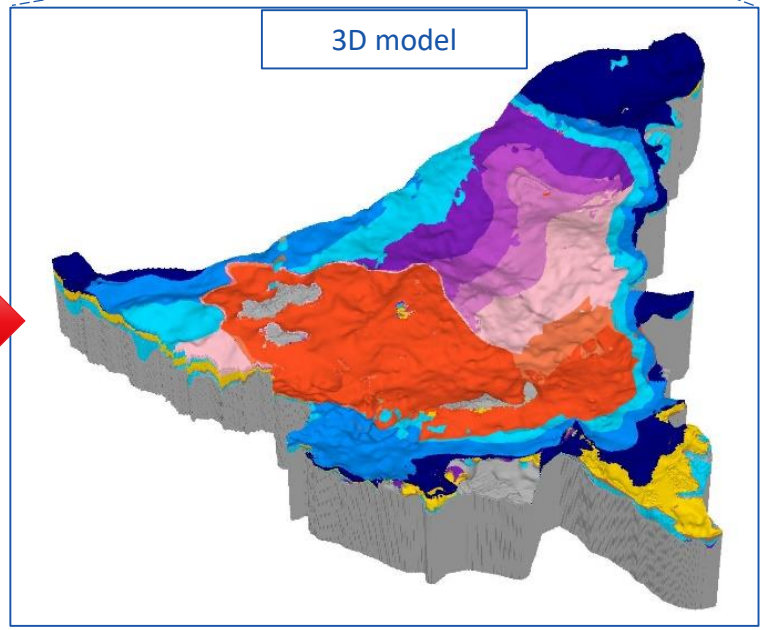
Petrel project
2D seismic interpretation
TechLog project
-Geology
-Petrophysics
-Geochemistry
PetroMod 1D

Petrel project
-Mapping
TechLog project
-Well section correlation
PetroMod 2D
2D modeling

Petrel project
-Chance of success mapping
PetroMod 3D
3D modeling
Results analysis

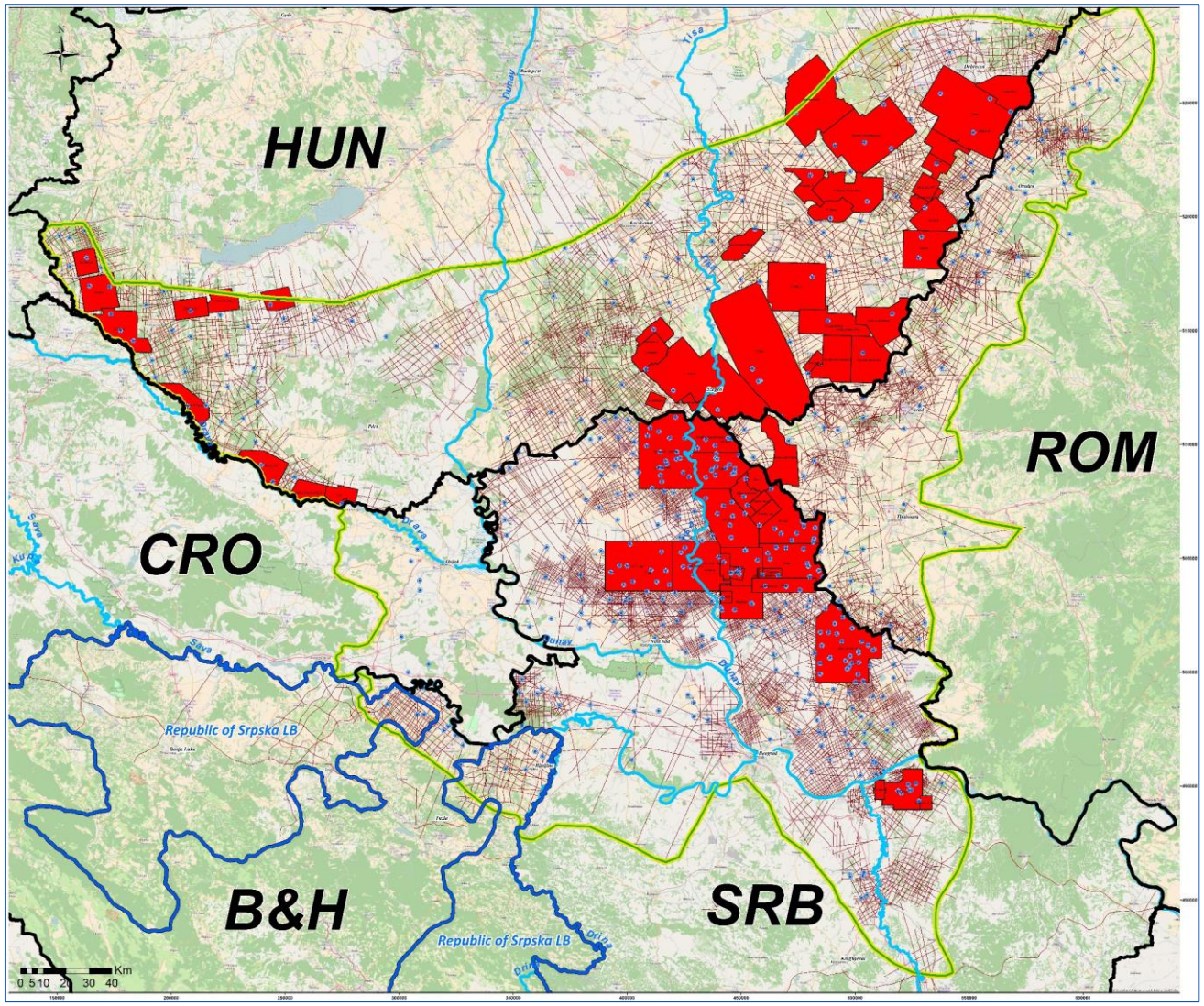






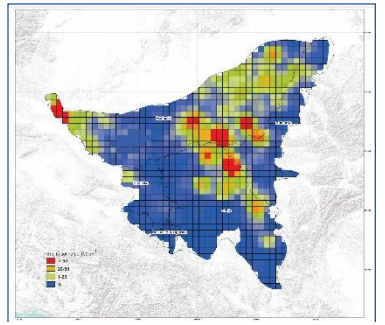
NIS GAZPROM NEFT FUTURE AT WORK

3D Petroleum System Model of Southeastern Part of Pannonian basin
Database

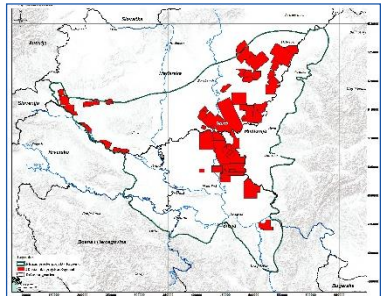


Map with available G&G data

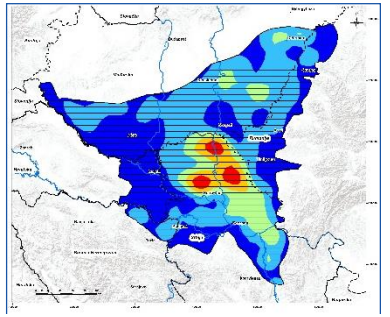
- Database was formed based on the available data of NTC NIS for Serbia and Republic of Srpska, acquired data from Hungary and Romania and published data for eastern Croatia.
- For the model forming were used 81.582 km of 2D and 15.691 km^2 of 3D seismics.
- Number of wells: 3251 (554 reference wells)
- The database contains data for 293 fields (1 080 mil. TOE), which represents more than 80% of discovered reserves within the exploration area.



Map of well data coverage



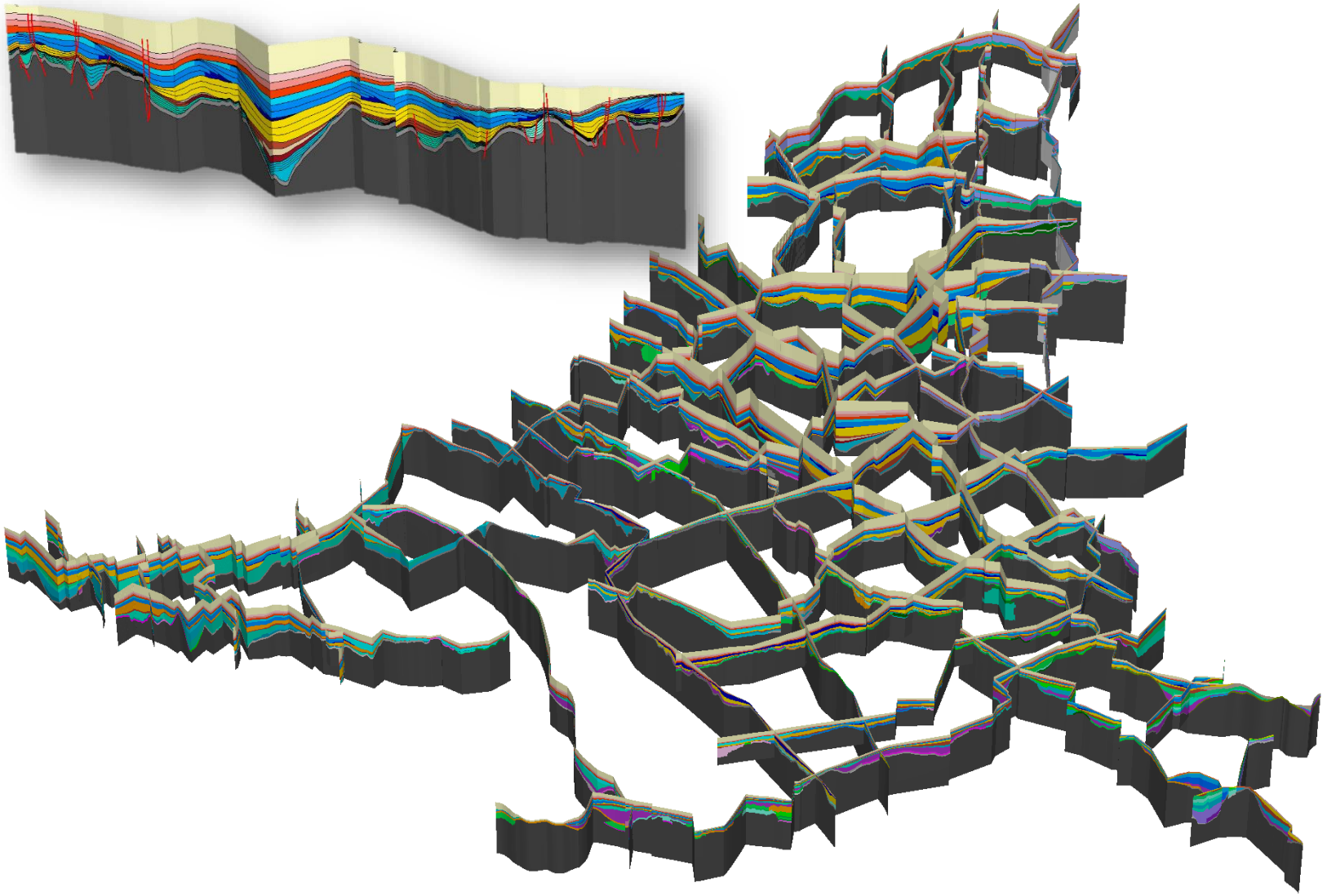
Map of 3D seismic coverage



Map of 2D seismic coverage

3D Petroleum System Model of Southeastern Part of Pannonian basin
2D modeling

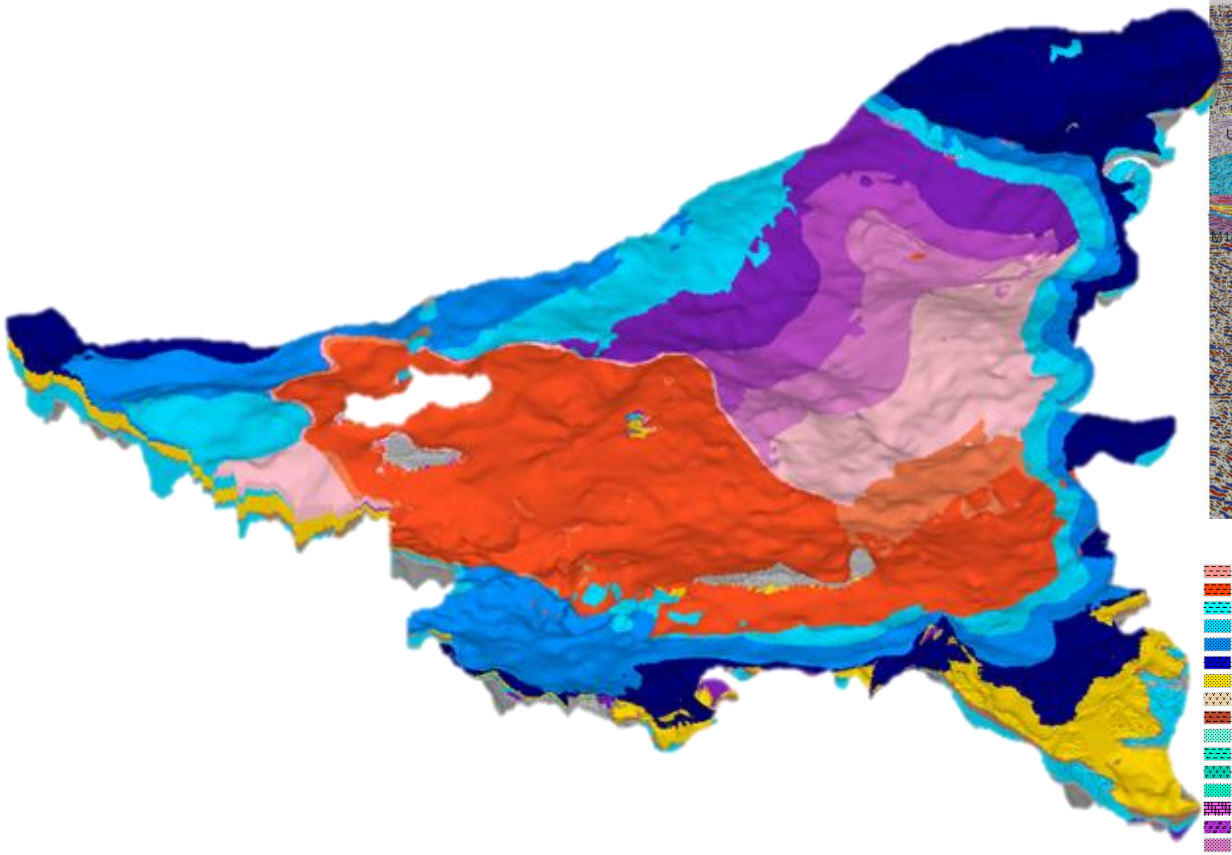
- **28** 2D models with well data calibration were created (total lenght of master sections: 6670 km);
- Interpolating results from 28 2D models, PSE input maps necessary for 3D modeling were created, such as lithofacies, total organic carbon, hydrogen index, source rocks thickness, heat flow and paleo water depth maps;

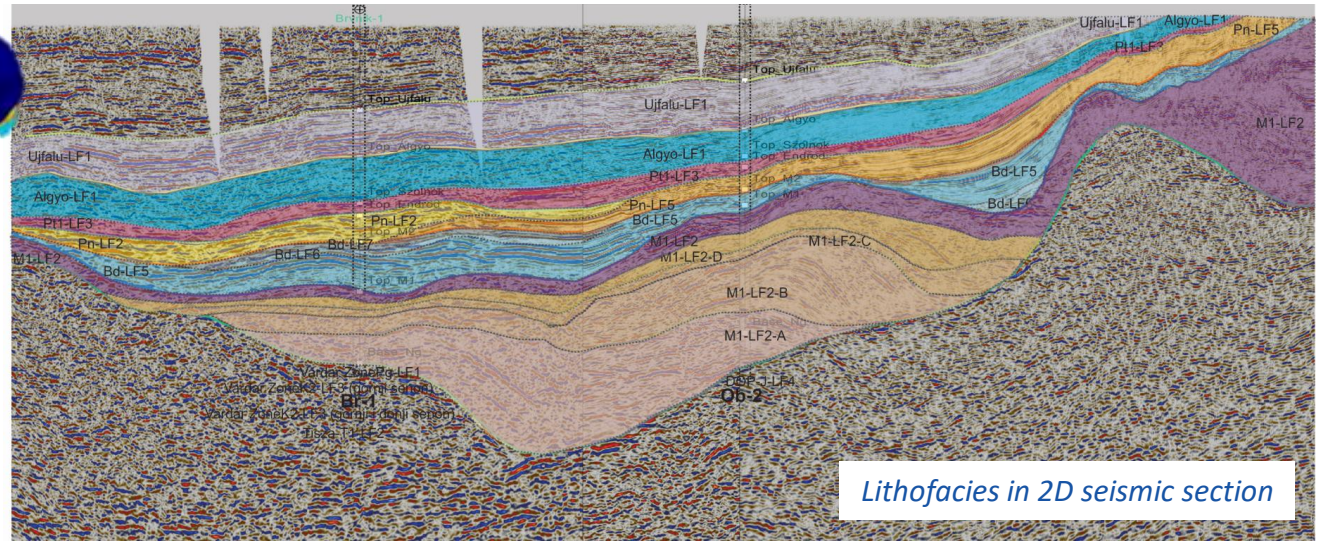


Position of 28 regional 2D sections

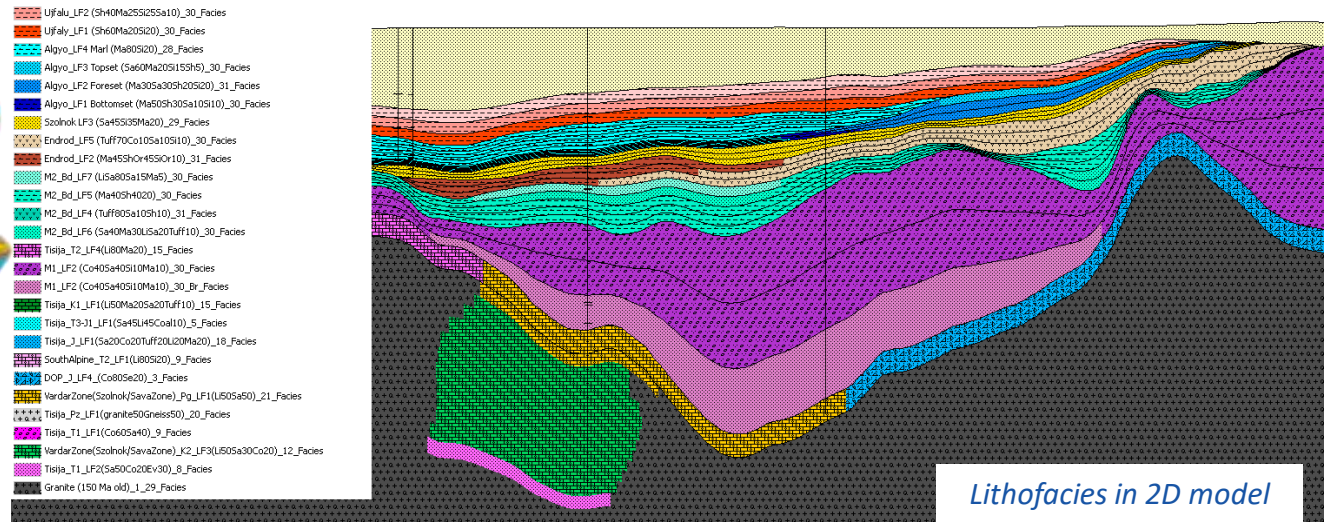
3D Petroleum System Model of Southeastern Part of Pannonian basin

2D modeling: Lithofacies





Lithofacies in 2D seismic section

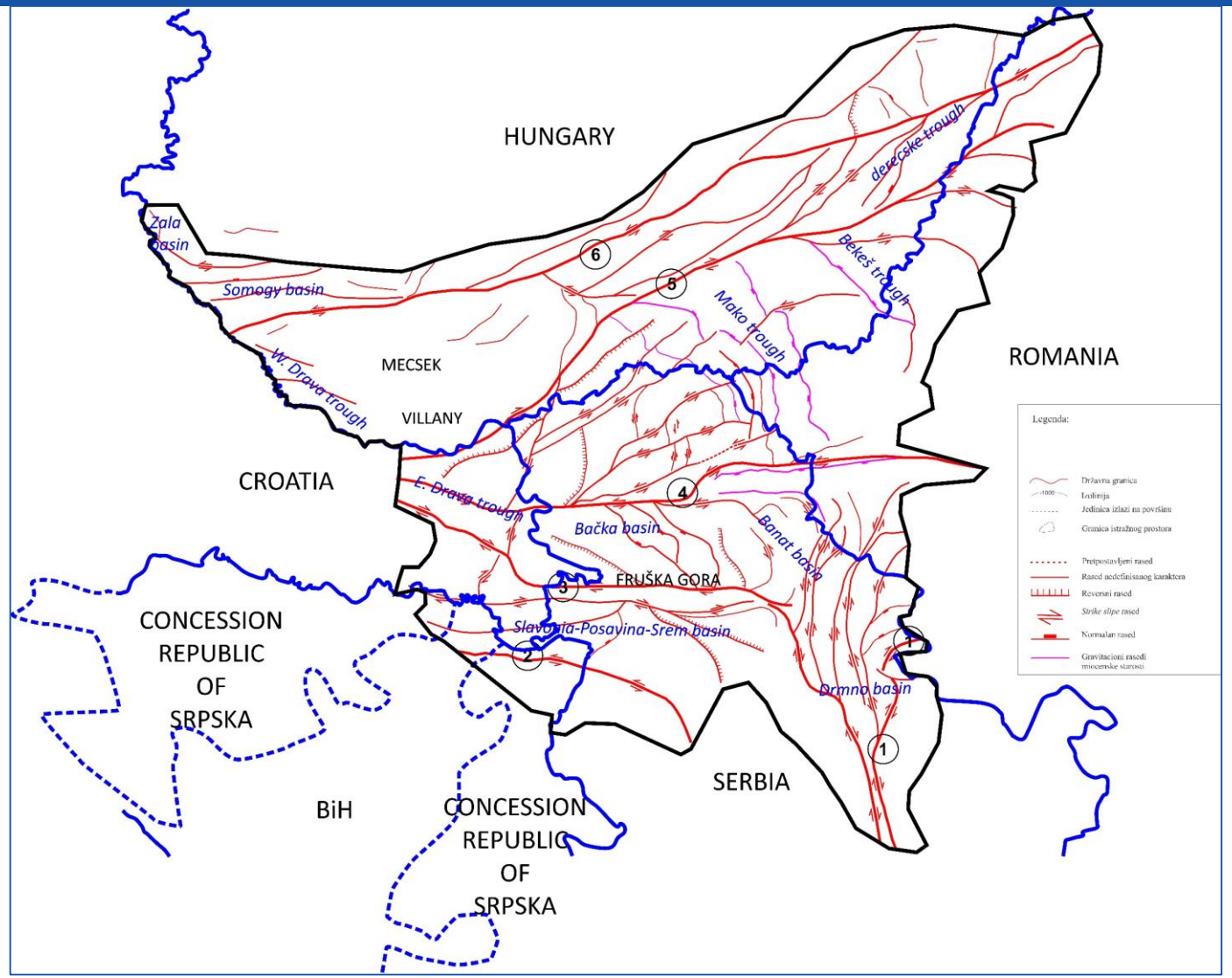


Lithofacies in 2D model

Based on lithofacies analysis of **409** wells, **37** lithofacies of Neogene deposits and **44** in the basements were defined.

3D Petroleum System Model of Southeastern Part of Pannonian basin

2D modeling: Tectonics



Map of structural framework in exploration area

2D modeling enabled better understanding of basin dynamics through time as a key factor of migration routes in 3D.

During the process of paleotectonic analysis main tectonc stages were defined, as well as conditions of basement formation and sedimentary cover deposition with main sedimentation intervals;

Structural setting and tectonic maps were created;

Based on the analysis of structural maps and the interpretation of 2D and 3D seismic, 6 primary zones with strike-slip faults of the first order were identified:

1. **Morava strike-slip zone**
2. **Northern Majevica strike-slip zone**
3. **Fruska gora strike-slip zone**
4. **Backa strike-slip zone**
5. **Batina-Bekes strike-slip zone**
6. **Zagreb-Derecke strike-slip zone**

Between the zones of regional strike-slip faults, horizontal faults of class II and III are formed, which are significant for the formation of the petroleum system of the Pannonian basin.

Large number of oil fields and gas fields in the area of the Derecske depression, Bačka and Banat systems were formed in such zones of horizontal movement.

3D Petroleum System Model of Southeastern Part of Pannonian basin
3D modeling: Model parameters

Project passport

Project time frame: 2014.-2015.

Region: Pannonian basin

Model surface: 92 290 km^2

Number of cells in model: 38.905.425

Cell dimension: 500x500m

Contractor: NIS-STC

Used software: Petrel 2014.1, PetroMod 2014.1

Number of simulation runs: 23

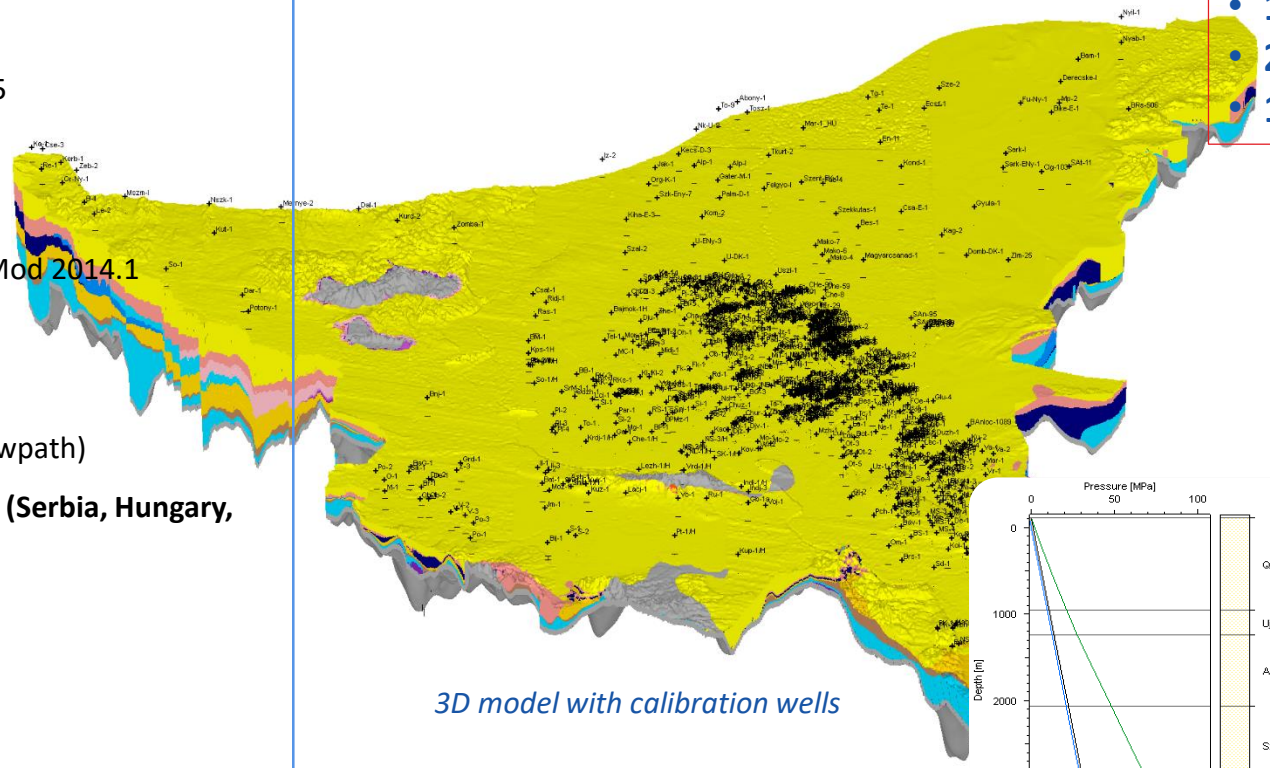
FINAL RUN: 18.12.2015.

Type of migration: Hybrid (Darcy+Flowpath)

International multidisciplinary team (Serbia, Hungary, Romania, Croatia, Russia):

- Regional geologists
- Seismic interpreters
- Petroleum system modelers
- Biostratigraphers
- Sedimentologists
- Petrologists
- Geochemist
- Petrophysicist

Team leader: Dr. Ivan Dulic

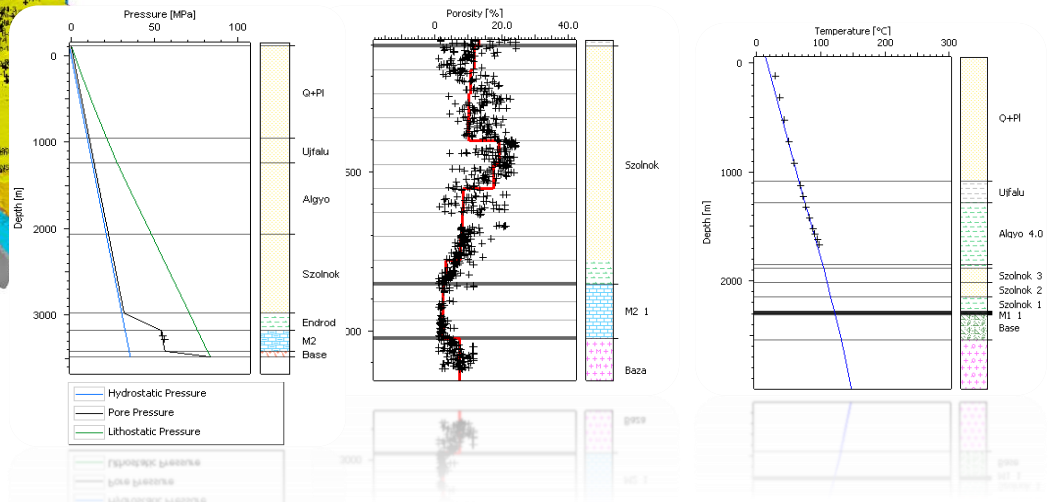


3D model with calibration wells

In 3D model there are 924 wells:

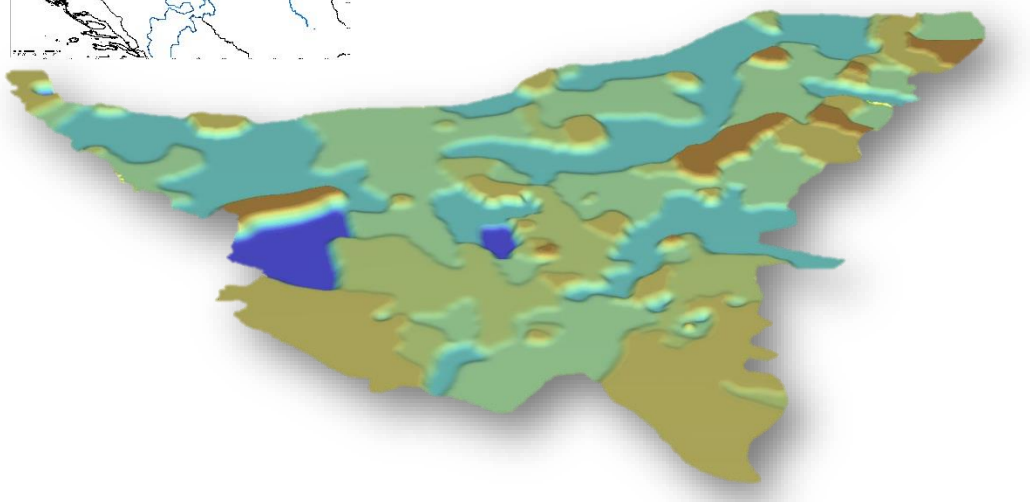
- **905** wells with temperature data
- **162** wells with pore pressure data
- **214** wells with effective porosity
- **103** wells with vitrinite reflection data

Examples of well calibration



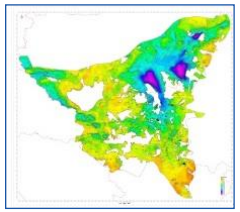
3D Petroleum System Model of Southeastern Part of Pannonian basin

3D modeling: Maps



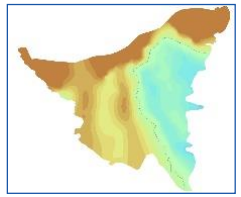
Paleowater depth map in one of the Badenian layers

3D model was created using **8** structural maps, and also other **107** maps created from 2D models.
With splitting the initial 8 into 46 layers/sublayers, better model resolution was achieved.



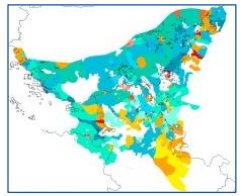
Structural maps

8



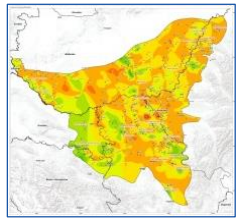
Paleowater depth maps

15



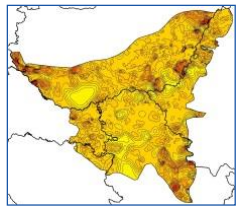
Lithofacies maps

46



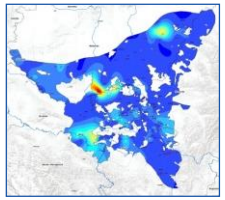
Heat flow maps

16



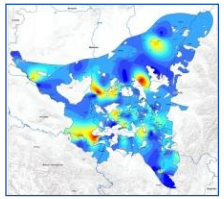
Maps of erosion

4



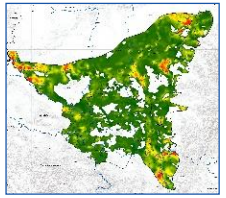
TOC maps

5



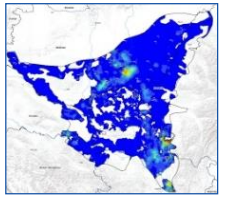
Hydrogen index maps

5



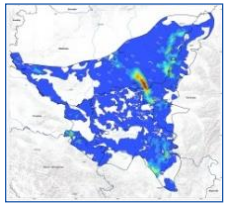
Source rock thickness maps

4



Potentional reservoir rock thickness maps

7



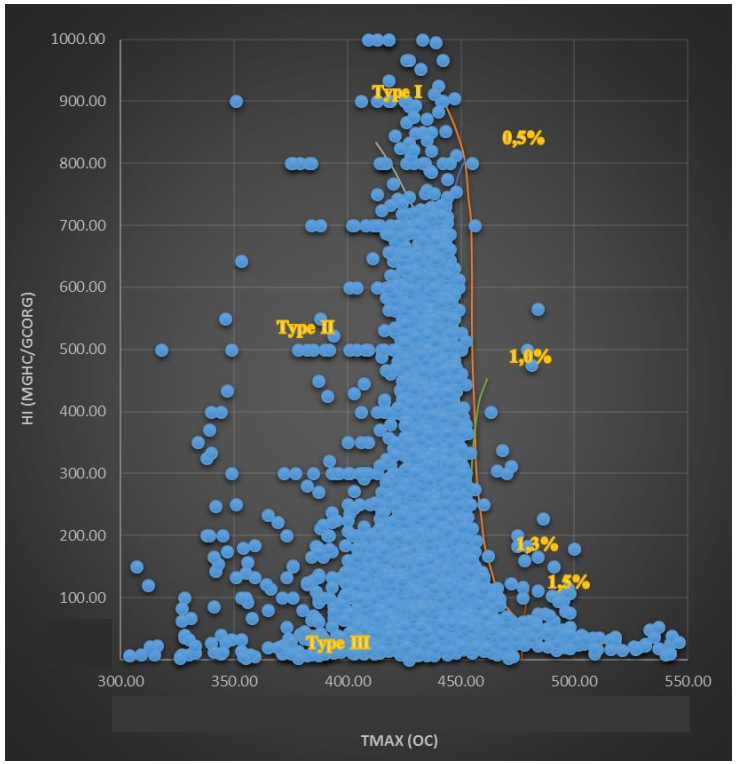
Potentional seal rock thickness maps

5

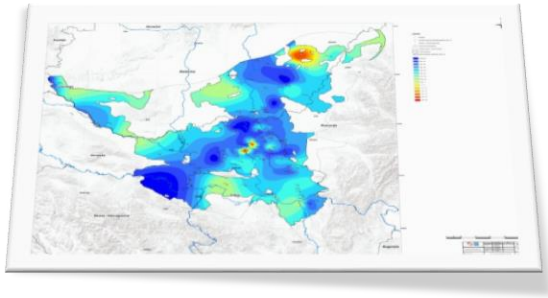
3D Petroleum System Model of Southeastern Part of Pannonian basin

3D modeling: Source rocks

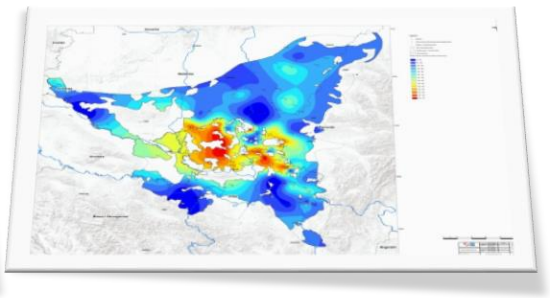
1. Based on over 8000 Rock-Eval analysis from 869 wells, and public available data, in the Pannonian basin were defined 6 basic types of source rocks:
   - **Triassic marls**;
   - **Paleogene shales and marls**;
   - **Lower Miocene marls**;
   - **Middle Miocene marls and shales**;
   - **Endrod Fm marls**;
   - **Szolnok Fm marls.**
2. Distribution and areal characteristics changes of source rocks (kerogen type, HI, TOC).
3. Oil-oil and oil-source rocks correlations were done for limited amount of data, and used for accurate definition of petroleum systems.



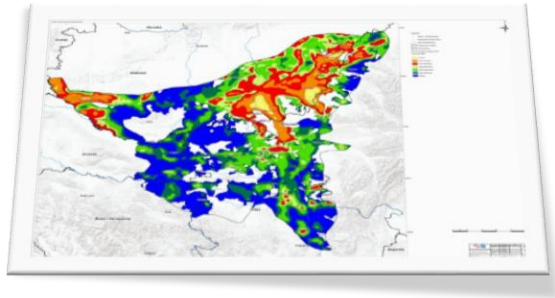
Kerogen types and level of maturation of source rocks



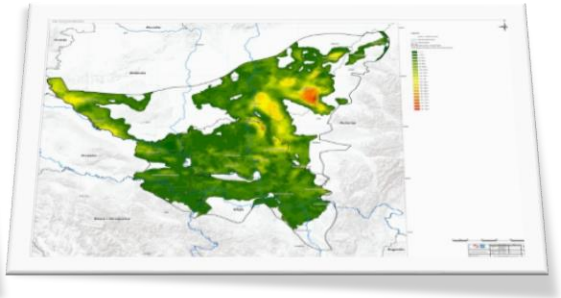
TOC



HI



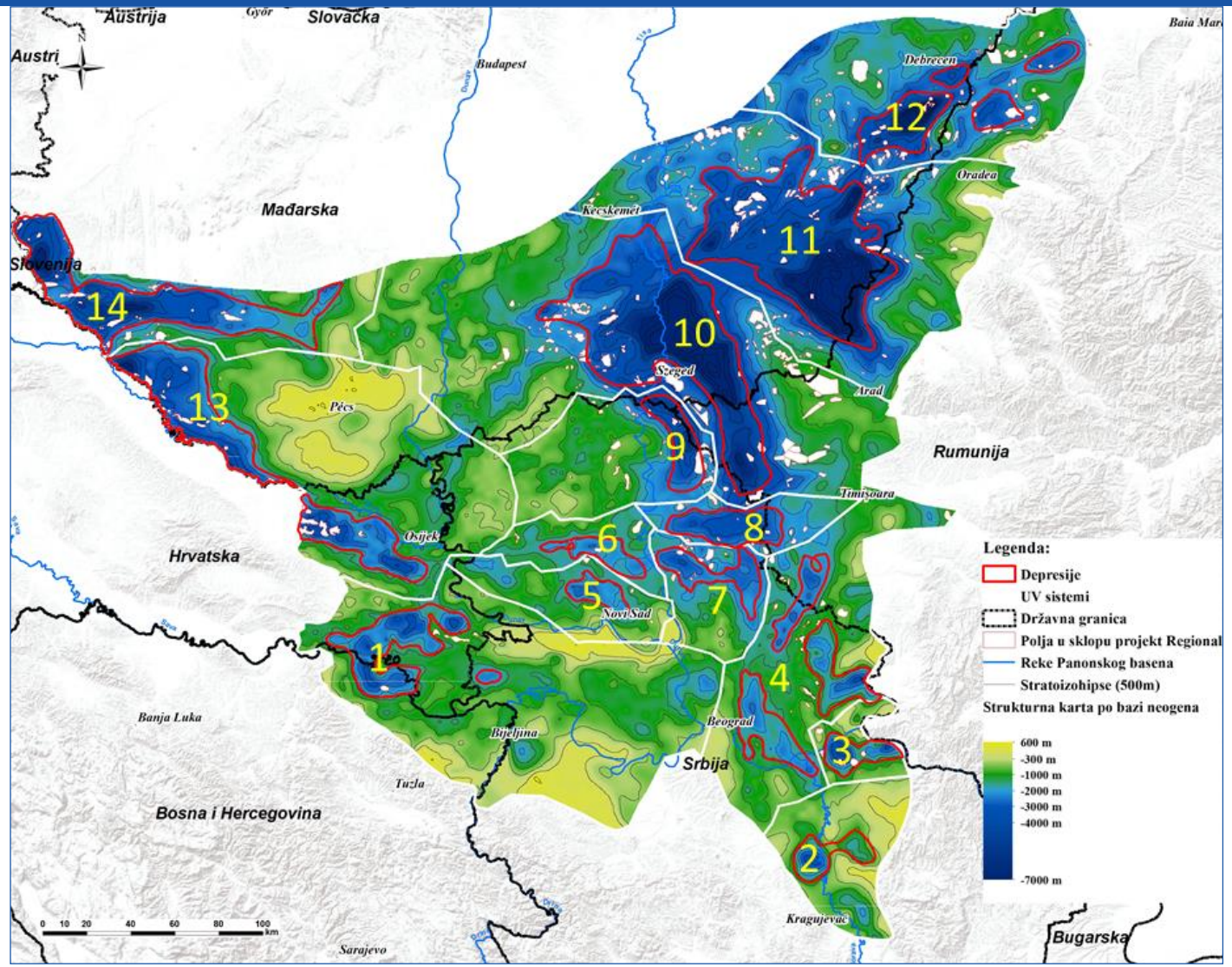
Maturity



Source rocks thickness

3D Petroleum System Model of Southeastern Part of Pannonian basin

3D modeling: Petroleum systems



Map of petroleum systems

14 generative depressions were recognized.
Based on the results of 3D modeling and distribution of the discovered fields, 14 systems were defined, as well as total potential of source rocks and amount of generated and accumulated hydrocarbons. The amount of discovered reserves of existing fields and the remaining modeled accumulations were defined for the whole basin and separate for each of these defined petroleum systems.

1 –Slavonia-Posavina-Srem depression

2 – Markovac depression

3 – Drmno depression

4 – South Banat depression

5 – Kisac depression

6 – Srbobran depression

7 – Melenci depression

8 – Middle Banat depression

9 – Szeged depression

10 – Mako depression

11 – Bekes depression

12 – Derecske depression

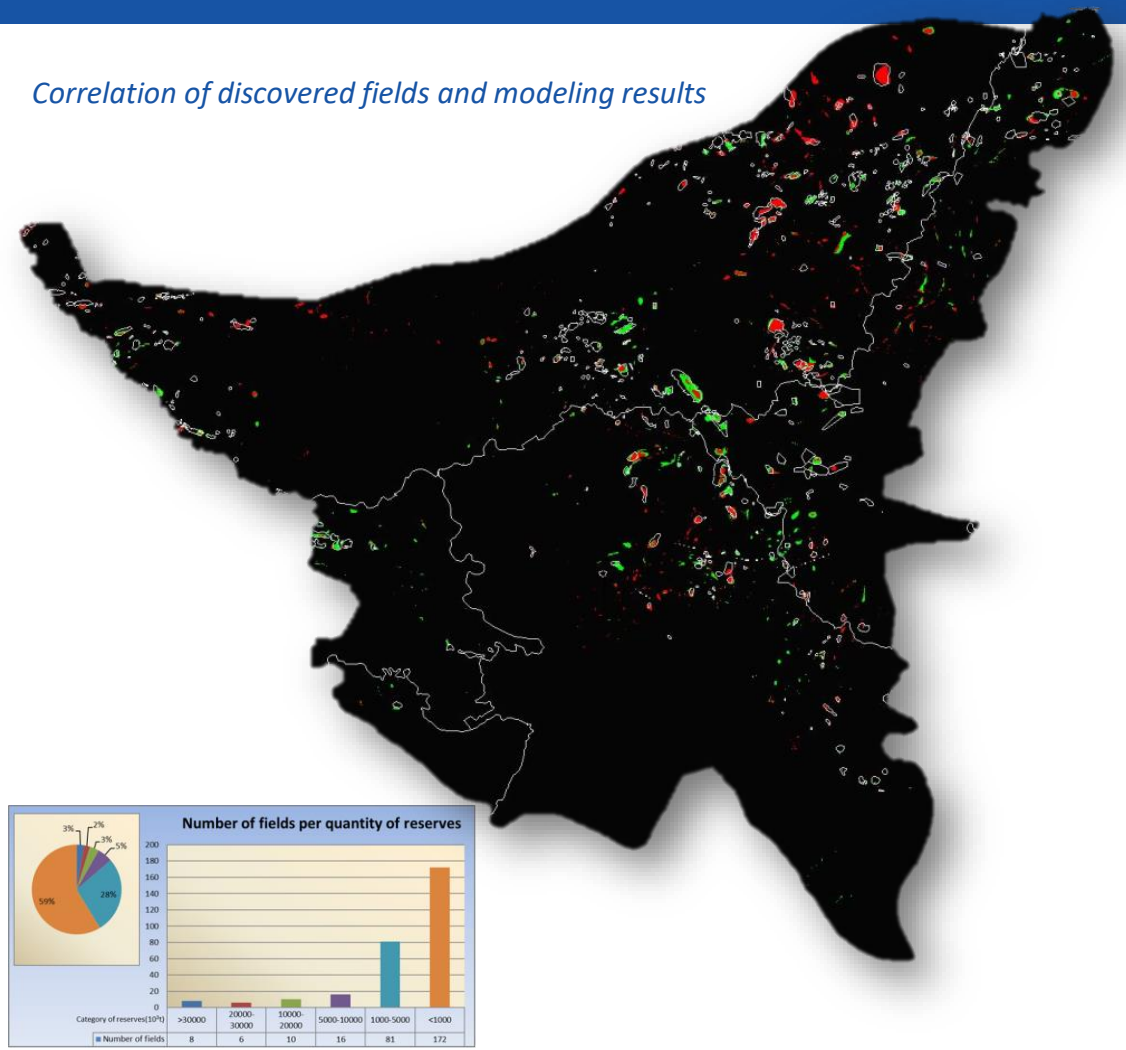
13 – Drava depression

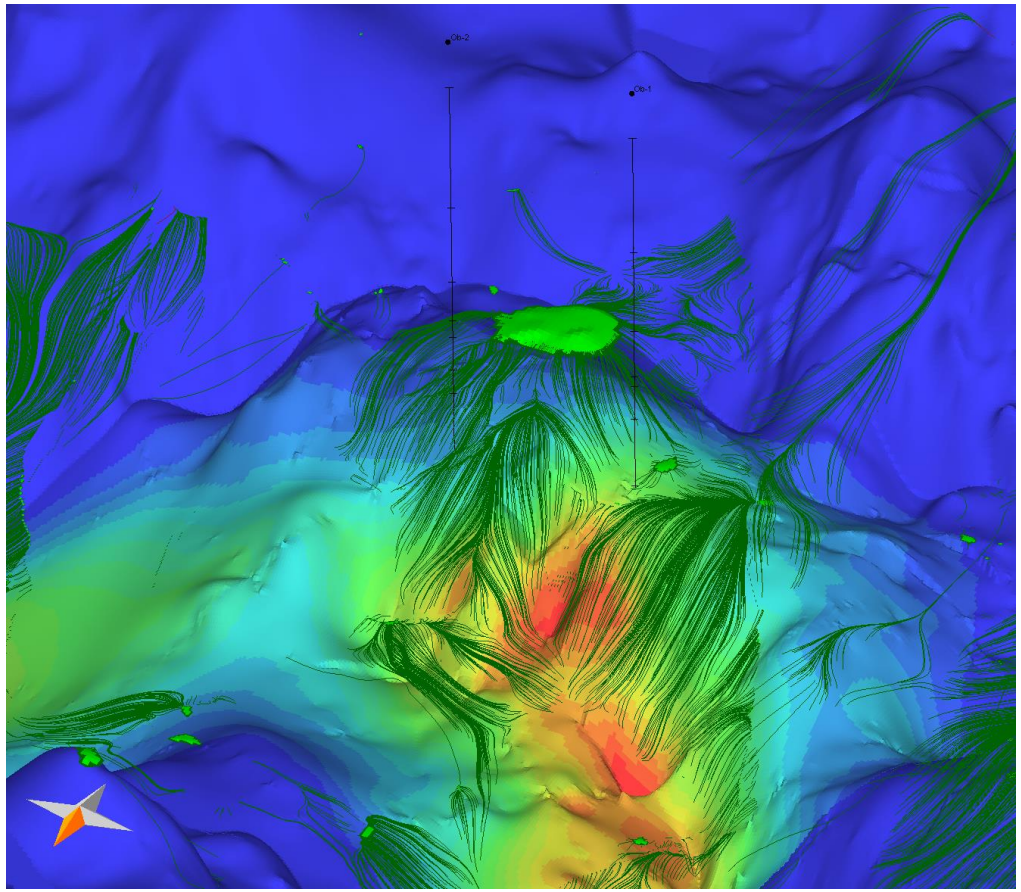
14 – Zala-Somogy depression

3D Petroleum System Model of Southeastern Part of Pannonian basin

3D modeling: Oil & gas fields calibration

Correlation of discovered fields and modeling results





Detail of 3D model with quantities of generated HC, migration routes and potential accumulations

86% of previously discovered 293 known oil and gas fields in the Pannonian basin were occurred in 3D model (98% in Serbia, because of higher data density).

3D Petroleum System Model of Southeastern Part of Pannonian basin

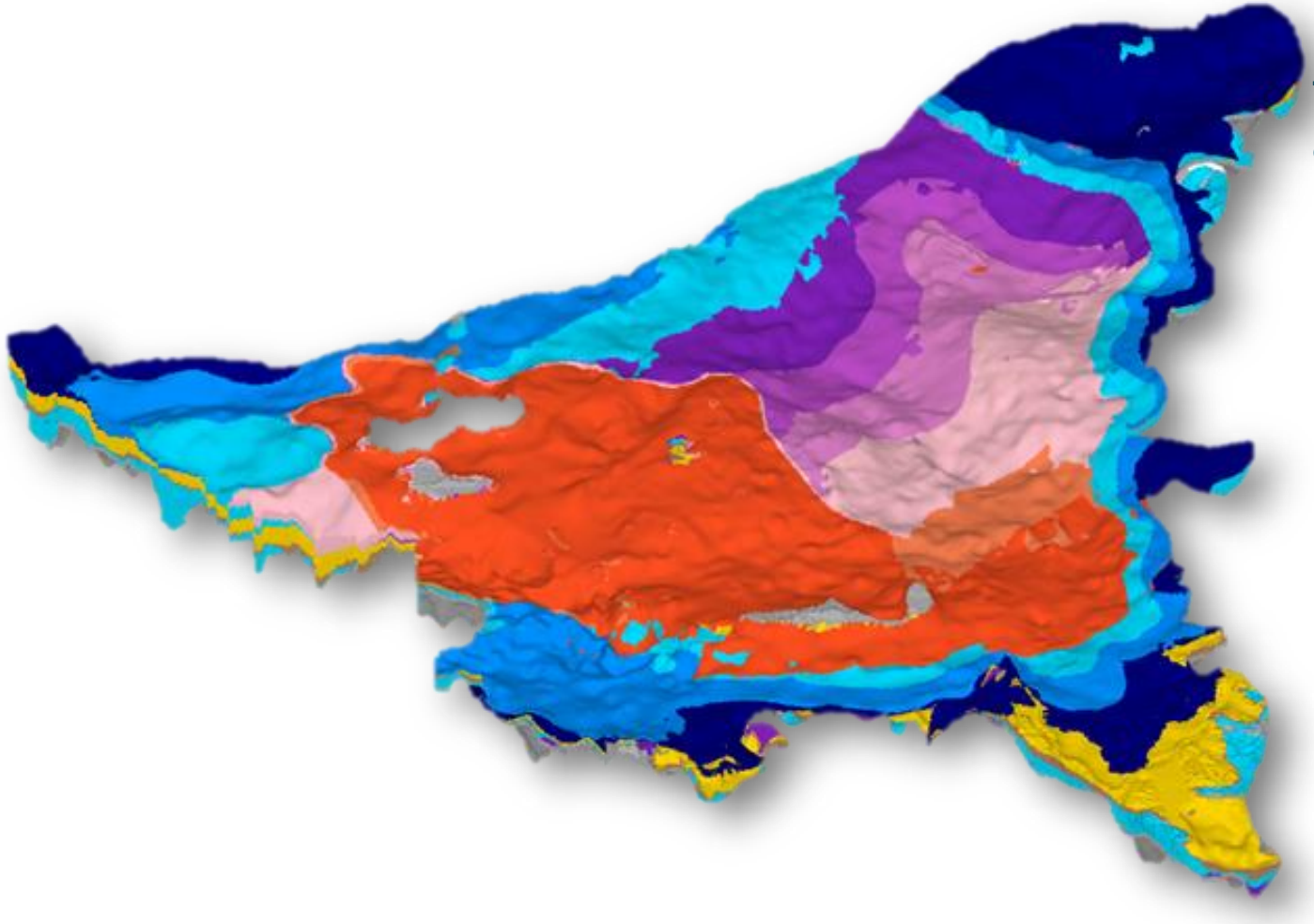
3D modeling: Undiscovered resources unrisking

Probability of model accuracy	Seismics		Reservoir rocks			Seals	Source rocks				Structural framework			
	3D	2D	Facial diversity	Porosity	Fields	Distribution	Thickness	TOC/HI	Ro	Temperature	Faults	Structural horizons	Grid size	
	km^2/ 1000 km^2	km/ 1000 km^2	Number of lithofacial maps	Number of wells per 1000 km^2	Percentage of confirmed fields	Existence of regional seals	Number of wells per 1000 km^2	Number of wells per 1000 km^2	Number of wells per 1000 km^2	Number of wells per 1000 km^2	Number of faults per 1000 km^2	Number		
1.0	100%	600	10	5	100%	10	10	10	5	5	5	10	50x50	Range of values
0.9	90%	500	9	4	90%	9	9	9	4	4	4	9	100x100	
0.8	80%	400	8	4	80%	8	8	8	4	4	4	8	250x250	
0.7	70%	350	7	4	70%	7	7	7	4	4	4	7	500x500	
0.6	60%	300	6	3	60%	6	6	6	3	3	3	6	1000x1000	
0.5	50%	250	5	2	50%	5	5	5	2	2	2	5	1200x1200	
0.4		200	4	2	40%	4	4	4	2	2	2	4	2000x2000	
0.3		150	3	2	30%	3	3	3	2	2	2	3	3000x3000	
0.2		100	2	2	20%	2	2	2	2	2	2	2	4000x4000	
0.1		50	1	1	10%	1	1	1	1	1	1	1	5000x5000	

All remaining accumulations are risked out based on index of probability of model accuracy, which were defined for each petroleum system, separately. Range of values of probability of model accuracy depending on quantity of the available data, is between **0.46-0.83**.

3D Petroleum System Model of Southeastern Part of Pannonian basin

3D modeling: Results



For all 14 petroleum systems, and for more than 300 defined structures in exploration area were defined

- Generative potential was defined and that includes generated mass of hydrocarbons (separately for oil and gas),
- Distribution and timing of generated masses,
- Amount of remaining (still undiscovered) potential accumulations was obtained
- Also, based on modeling results, COS map is constructed for whole SE part of the Pannonian basin.

3D Petroleum System Model of Southeastern Part of Pannonian basin
Model Usage

Regional 3D petroleum system model of Pannonian basin is now in use as a parent model for 14 high resolution models, used for geothermal potential projects, uncoventional resources estimation, license blocks acquisition projects and risk reduction for the new exploration wells.

High-resolution models were connected to regional model using local grid refinement (LGR) method and there was paid special attention to define lithofacies in the area between wells.

Creation of lithofacies maps was done using seismic facies analysis and lithofacial well log cluster analysis method. Obtained lithologies were modified using calibration data for porosity and permeability derived from well-log data and in that way were made more than 800 lithofacies maps.