Potential Hydrocarbon Discoveries in Bjelovar Subdepression, Croatia

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Abstract

This article considers the basic principles of geology with respect to potential discoveries in the Bjelovar subdepression within the Croatian part of the Pannonian Basin petroleum system. It is estimated that potential hydrocarbon discoveries will be on the order of 1,250,000 barrels of recoverable oil. Traps, seals, reservoirs, source rocks, migration, and hydrocarbon preservation were all considered in this analysis of plays that includes Paleozoic basement and Miocene strata.

Regional Geological Setting of Bjelovar Subdepression

The Bjelovar subdepression covers an area of 2900 km^2 and represents the southern part of the Drava depression. The area of Bjelovar is located on the southern margin of the Pannonian Basin System (Figure 1) and is considered a mature petroleum province.

The thickness of Neogene-Quaternary clastics above Mesozoic carbonate basement or Paleozoic igneous/metamorphic basement, reaches a maximum of more than 3500 meters. The highest hydrocarbon potential is represented by lower and mostly middle Miocene coarse-grained clastics, accompanied by fractured and weathered basement rocks in a unique hydrodynamic unit. The lower and middle Miocene reservoirs and traps are relatively shallow and situated at depths between 800 and 1500 m. The main reservoir potential exists in remnants of algal reefs and siliciclastic breccia (Figure 2).

The second reservoir unit is composed of upper Miocene sandstones. These sandstones are characterized by depths of less than 1000 meters but erratic reservoir properties. It is thought that hydrocarbon migration has been along faults and that there probably has been reservoir degradation by meteoric waters (Figure 2).

Source rocks of Ottnangian to Sarmatian age are postulated to be present within two major synclines of the subdepression at depths between 1600 and 2500 meters. These depths were just enough to reach oil window (ΣTTI=15) in the deepest part (Malvic, 1998, 2003). A significant part of the hydrocarbons migrated from the northwestern part of the Drava depression (Figure 1). Within the Drava depression the proven source rocks are represented by mudstones, marls, and siltstones of lower Miocene to Badenian (middle Miocene) age at depths greater than 3000 m (Baric et al., 1998). These sediments reached a high level of thermal maturation and are presently in the gas-condensate window at depths from 3150 to 3800 m.

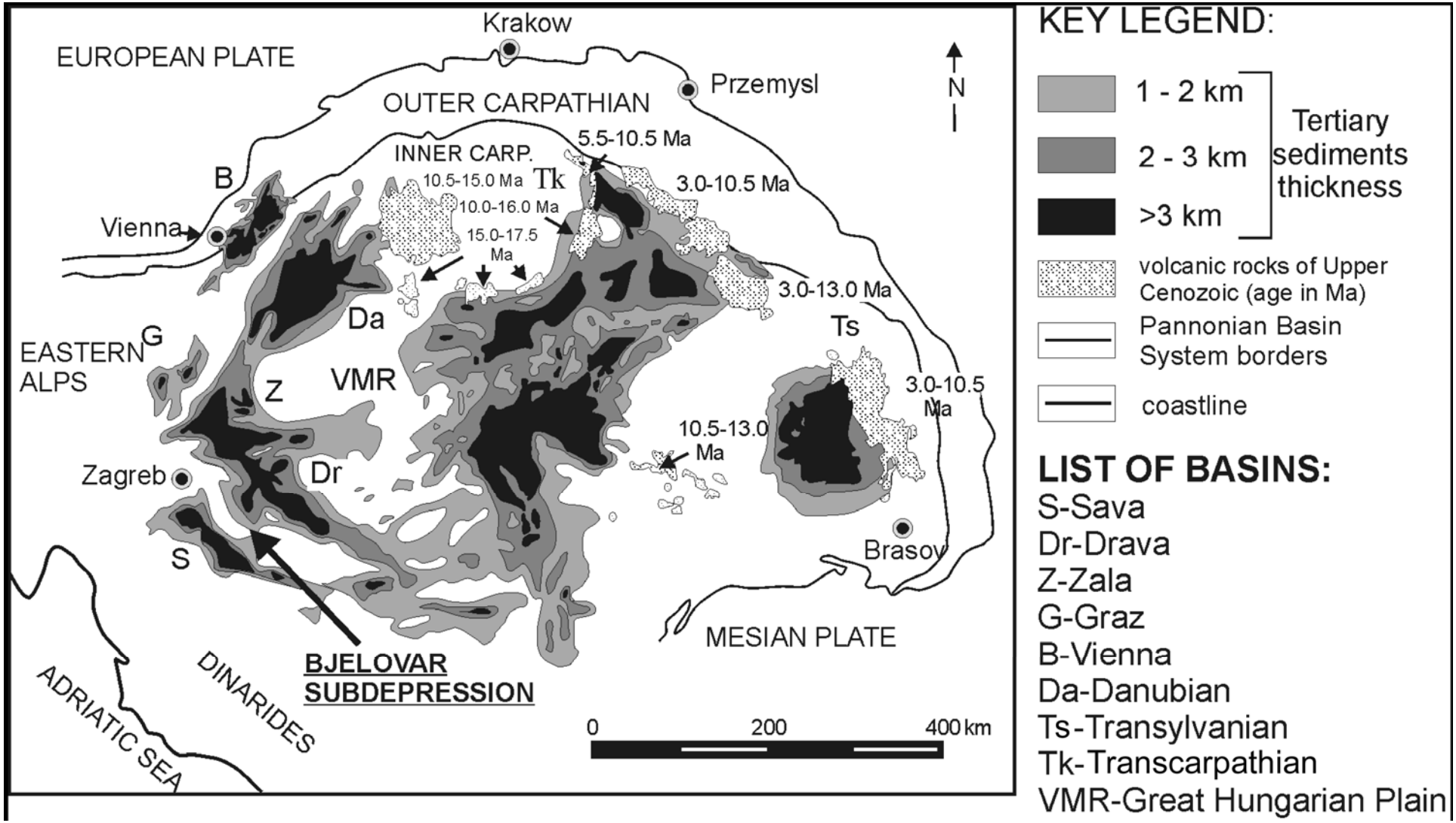

Figure 1. Tectonic setting of the Bjelovar subdepression (modified after Royden, 1988).

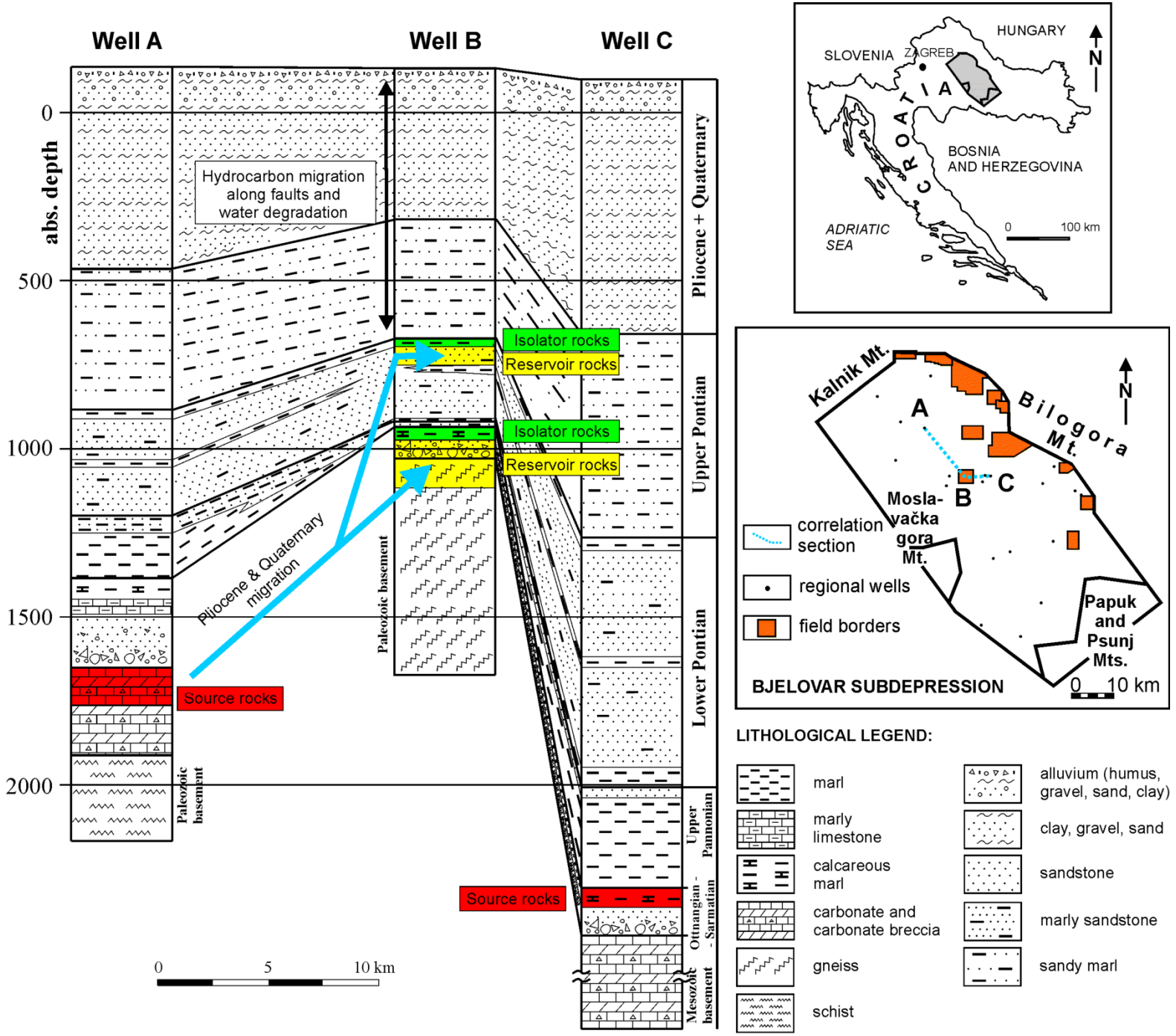

Figure 2. Geological section, including five geological categories, of the central part of the subdepression (modified from Malvic et al., 2005).

Petrophysics, Production, Plays, and Prospects

There are many discovered fields and several potential plays and prospects within the study area. These data provided a reliable geological database for the study. Reservoirs are from upper Miocene (sandstones), middle Miocene (Badenian breccia), and Paleozoic (gabbro and metamorphics) sections. In Miocene sandstones porosity varies between 15 and 25%, while in the breccia this range is between 5 and 15%. The tectonized basement rocks can be characterized by secondary porosity in the range of 1-5%. Horizontal permeabilities vary from 0.05 to 336 millidarcies (mD). Effective thicknesses of reservoirs are between 1 and 15 meters, but in sandstone reservoirs this value mostly depends on fluvial subfacies and thickness of breccia (in part conglomerate) reservoirs in alluvial-fan subfacies. The majority of the fields analyzed are mature. Production started from the late sixties to early eighties. Current daily production is as much as 300 m^3 (1875 barrels) of oil equivalent. The water content varies from 50 to 90%. Total original hydrocarbon in place (OHIP) in the subdepression is estimated at approximately $44x10^6$ m^3 ($275x10^6$ barrels) of oil and $4250x10^6$ m^3 (150 bcf) of gas. One large field includes about 60% of the total estimated reserves.

The majority of traps are structural. The Badenian reservoirs are in anticlines that are very similar geometrically to deeper Paleozoic paleorelief (buried hills). The Pannonian and Pontian (upper Miocene) reservoirs are trapped by faulted anticlines or, rarely, structural noses, and seal rocks are effective regionally. Only locally are deposits of Sarmatian, Pannonian, and Pontian age potentially faulted and providing zones for fluid migration. Shallow seals (above depth of 800 m) could be partially permeable for gas leakage.

The new potential hydrocarbon prospects in the subdepression were analyzed by five independent geological categories: (1) structures (2) reservoirs (3) migration (4) source rocks and (5) preservation of hydrocarbons. Characteristic stratigraphy and lithology of these prospects are represented by a typical geological section across the subdepression (Figure 2). There are several potential plays and prospects in the study area. In general, ‘play’ is defined as an operational unit and ‘prospect’ as an economic unit. Each play can be characterized by several prospects and/or fields having similar geological features and history (Rose, 2001; White, 1992). The term ‘play’ is used as a substitute for stratigraphic interval(s) within which the economic volumes of hydrocarbon reserves had already been discovered in the Bjelovar subdepression. There are two plays: (1) *Paleozoic basement rocks and middle Miocene breccia* and (2) *upper Miocene sandstones* (Figure 2).

In the Neogene sequence a few prospects including mostly structural traps were selected for analysis. Using construction of regional structural maps and palinspastic restorations of the subdepression (Malvic, 1998, 2003), a detailed structural analysis was made. Data analysis showed that a new prospect would be smaller but still interesting from the economic point of view, as it is expected to contain 200,000 m^3 of recoverable oil reserves ($1.26x10^6$ barrels). The USGS (2000) published a similar value of $1x10^6$ barrels as minimal recoverable oil in the potential discoveries of the Zala-Drava-Sava Mesozoic and Neogene petroleum systems. The Bjelovar subdepression is part of the Drava petroleum system (Figure 1).

An appropriate geological database, including the characteristic geological categories and events, was derived from data published in previous regional studies of the Bjelovar subdepression (Malvic, 1998, 2003). These categories were classified into five probability classes (Figure 3).

Each geological category can be evaluated from a different type and quality of data. Seismic data played the main role in structural and stratigraphic interpretation. The second most important information was whether production of hydrocarbons had occurred in the prospect area or in adjacent fields (or analyzed play and adjacent horizons).

The geological probability of a new potential discovery in the Bjelovar subdepression was calculated. The play called ‘basement rocks and Miocene breccia’ has a probability value of 28% and the ‘upper Miocene sandstone’ play is characterized by a significantly lower value of 13% (not promising).

TRAP		RESERVOIR		SOURCE ROCKS		MIGRATION		HC PRESERVATION	
Structural		**Reservoir type**		**Source facies**		**HC shows**		**Reservoir pressure**	
Anticline and **buried hill** linked to basement	1.00	**Sandstones** clean and laterally extended; **Basement** granite, gneiss, gabbro; **Dolomites and Algae reefs** (secondary porosity)	1.00	**Kerogen** type **I and/or II**	1.00	**Production** of hydrocarbons	1.00	**Higher** than hydrostatic	1.00
Faulted anticline	0.75	**Sandstone,** rich in silt and clay; **Basement** with secondary porosity, limited extent **Algae reefs**, filled with skeletal debris, mud and marine cements	0.75	**Kerogen** type **III**	0.75	Hydrocarbons **in traces**; **New gas** detected >10 %	0.75	**Approximately** hydrostatic	0.75
Structural nose closed by fault	0.50	**Sandstone** including significant portion of silt/clay particles, limited extent;	0.50	**Favourable palaeo-facies** organic matter sedimentation	0.50	**Oil** determined **in cores** (luminescent analysis, core tests)	0.50	**Lower** than hydrostatic	0.50
Any "positive" faulted structure, margins are not firmly defined	0.25	**Basement rocks**, including low secondary porosity and limited extent	0.25	**Regionally known** source rock facies, but not proven at observed locality	0.25	**Oil** determined **in traces** (lumin. anal., core tests)	0.25		0.25
Undefined structural framework	0.05	Undefined reservoir type	0.05	Undefined source rock type	0.05	Hydrocarbon are not observed	0.05		0.05

Stratigraphic or combined		**Porosity features**		**Maturity**		**Position of trap**		**Formation water**	
Algae reef form	1.00	**Primary** porosity **>15 %**; **Secondary** porosity **>5 %**	1.00	Sediments are in **catagenesis phase** ("oil" or "wet" gas-	1.00	**Trap** is located in proven **migration distance**	1.00	**Still aquifer** of field-waters	1.00
Sandstones, pinched out	0.75	**Primary** porosity **5-15 %**; **Secondary** porosity **1-5 %**	0.75	Sediments are in **metagenesis phase**	0.75	**Trap** is located **between two source rocks** depocentres	0.75	**Active aquifer** of field-waters	0.75
Sediments changed by **diagenesis**	0.50	**Primary** porosity **<10 %**; **Permeability <1x10**(-3)** micrometer**2	0.50	Sediments are in **early catagenesis phase**	0.50	**Short migation pathway** (<=10 km)	0.50	**Infiltrated aquifer** from adjacent formations	0.50
Abrupt changes of petrophysical properties (caly, different facies)	0.25	**Secondary** porosity **<1 %**	0.25	Sediments are in **late diagenesis phase**	0.25	**Long migration pathway** (>10 km)	0.25	**Infiltrated aquifer** from surface	0.25
Undefined stratigraphic framework	0.05	Undefined porosity values	0.05	Undefined maturity level	0.05	Undefined source rocks	0.05		0.05

Quality of cap rock				**Data sources**		**Timing**			
Regional proven cap rock (seals, isolator)	1.00		1.00	Geochemical analysis on **cores and fluids**	1.00	**Trap** is **older than** mature **source** rocks	1.00		1.00
Rocks without reservoir properties	0.75		0.75	Analogy with **closely located geochemical analyses**	0.75	**Trap** is **younger than** mature **source** rocks	0.75		0.75
Rocks permeable for gas (gas leakage)	0.50		0.50	**Thermal modeling** and calculation (e.g. Lopatin, Waples etc.)	0.50	**Relation** between trap and source rocks is **unknown**	0.50		0.50
Permeable rocks with locally **higher silt/clay content**	0.25		0.25	**Thermal modeling** at just a **few locations**	0.25		0.25		0.25
Undefined cap rock	0.05		0.05	Undefined data sources	0.05		0.05		0.05

Figure 3. Geological categories/events classified into five probability classes.

Conclusions

• Based on geological settings of the Bjelovar subdepression, which is considered as a mature petroleum province, it is expected that there are still relatively small, but economically positive, potential discoveries present.
• The ‘basement rocks and Miocene breccia’ play has a better chance for success than the ‘upper Miocene sandstone’ play.

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Authors’ Note

This work is a part of the result of independent investigation on publicly published data, and Malvic’s master (1998) and PhD (2003) theses. Any probability number was not transferred from any official report or company assignments.