POTENTIAL UNCONVENTIONAL GAS PLAYS IN THE MATURE BASIN OF THE CZECH REPUBLIC

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Abstract

The presence of unconventional resources has been proven in deeper parts of mature oil and gas provinces and coal basins of the world. In this context, it is worth to focus also on the prospects of unconventional gas production from within hydrocarbon provinces of the Moravian part of the Vienna basin. The estimation of hydrocarbon generation potential of Jurasic marls from the Mikulov Formation of the Czech part of the Vienna Basin was performed based on the Rock Eval pyrolysis.

Key words: Unconventional Resources, TOC, Palynofacies, Rock Eval, Exploration

1 INTRODUCTION

Over the past decade, gas from different types of unconventional reservoirs or simply natural thermogenic gas which can be produced from low-permeable organic-rich formations only by a combination of stimulation techniques including a hydraulic fracturing treatment and horizontal drilling has become an increasingly important source of energy.

The commercially successful production of gas from shale and tight sandstones formations can be a model for the western part of the world. However, now the interest in targeting unconventional gas is progressively sweeping towards Europe where many countries are attempting to cover the gaps between a steadily growing energy demand and limited supply possibilities, also taking into account the ultimate aim to eliminate their dependence on imported fuels.

In the exploration of unconventional gas, Poland is certainly the country which is definitively ahead of the rest of Europe, including Ukraine or the Czech Republic. By the end of 2015, more than 54 of prospecting wells were drilled in Poland, while, for example, in Ukraine only a few of them. Despite its initial interest in shale gas exploration aimed at mitigating the heavy reliance on imported NG, over the past time, the Czech Republic has become skeptical about the development of unconventional resources.

The thermal maturation of organic matter (OM) in a wide spectrum ranging from OM dispersed in sedimentary clastics to OM concentrated in coal seams, has led to the formation of an enormous unconventional gas resource in many localities throughout the world. In many cases, the same stratigraphic units of kerogen-bearing rocks (shales, marls, coals), from which gas was generated and trapped at the deeper levels because of low permeability, served at shallower levels as source rocks for conventional oil and gas. That means that we could expect the presence of unconventional resources in mature oil and gas provinces and coal basins at levels deeper than the current hydrocarbon production takes place.

This paper is focused on prospects of unconventional gas production from within mature hydrocarbon provinces of the Czech Republic (the Moravian part of the Vienna basin).

2 UNCONVENTIONAL GAS FROM THE POINT OF VIEW OF THE CZECH REPUBLIC

2.1 Geologic structure of the Czech part of the Vienna Basin

Almost all conventional hydrocarbon deposits of the Czech Republic are confined to the Moravian part of the highly prolific Vienna basin where the earliest drilling operations started in 1900. The Vienna Basin is definitively one of the most important oil and gas provinces in Europe containing at least 46 fields in its Austrian part (Wessely, 1999) and at least 20 oil-bearing structures and gas-producing horizons in the Czech and Slovak parts.

The basin is associated with a classical thin-skinned pull-apart basin of Miocene age whose sedimentary fill is overlying the Carpathian thrust belt (Wessely, 1999; Decker, 1996). A deep autochthonous basement in this area comprises Precambrian crystalline and Paleozoic-Mesozoic sedimentary units of the North European Platform (Adámek, 2005).

The pre-Miocene basin floor is heterogenic. It consists of allochthonous nappes sheets emplaced onto autochthonous pre-folding sequences resting on the pre-Mesozoic basement. The formation of the Vienna Basin fault system is dated by the onset of subsidence in the Vienna Basin in Miocene, which opened as a transtensional pull-apart between two left-stepping segments of the fault zone (Fig. 1), which was later compressionally inverted in the Pliocene.

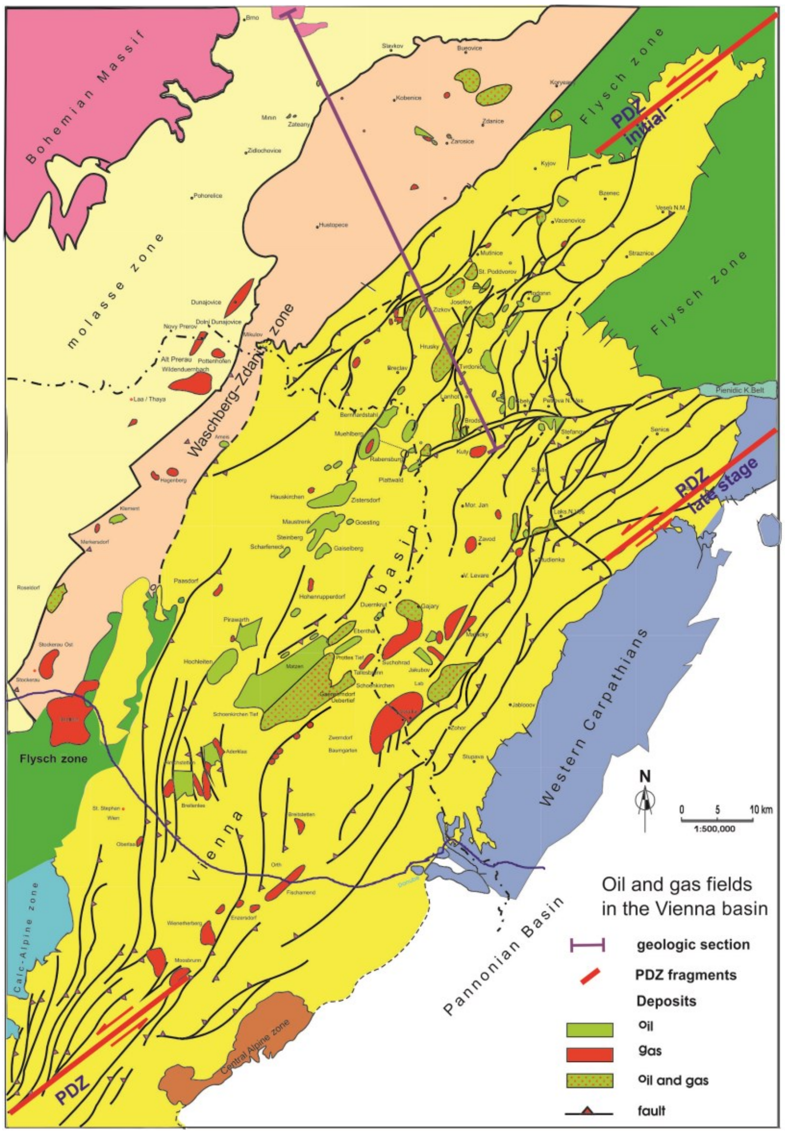

Fig. 1 Oil and gas fields in the Vienna basin (modified after Arzmuller et al., 2006; fragments of principal displacement zone PDZ are from Wu et al., 2009)

In fact, the deposition in the basin and formation of the Central Moravian depression, from our point of view, has been largely controlled by strike-slip reactivations within fragments of the principal displacement zone PDZ (Fig. 1) in the Pre-Miocene basement floor (Wu et al., 2009). The recent active strike-slip faulting is kinematically linked to the reactivation of major Miocene normal faults branching off from the wrench fault in the central part of the Vienna Basin (Hinsch et al., 2005). Current stresses and focal mechanisms from earthquakes along the Vienna Basin mostly indicate a sinistral strike-slip faulting along north-east striking subvertical faults. However, the 3-D interpretation of seismic sections within the Central Moravian Depression and, more specifically, the mapping of paleochannels in the Mid Miocene Badenian sediments did not show significant lateral offsets across such big faults as the Steinberg fault. It can be interpreted either as a prove of absence of strike-slip tectonics, playing a significant role, since the Late Badenian (Prochác et al., 2012; Drusa et al., 2015; Sidorova, 2001; Šofranko et al., 2014), or alternatively as an evidence of a multiple sign-variable sinistral-dextral reactivation of faults with almost zero total displacement.

The petroleum systems of the Vienna basin Miocene sedimentary cover and the entire Carpathian region in Moravia are mostly associated with the Jurassic source rocks and only partially with the Paleogene source rocks (Picha and Peters, 1998). However, taking into account our special interest in unconventional resource plays (Bujok et al., 2012; Klempa et al., 2013), we focused on the subthrust zone which includes the autochthonous Upper Jurassic Mikulov Formation. It is represented by organic-rich Malmian dark marls which are considered to be qualified as world-class source rocks (Krejčí et al., 1996; Picha and Peters, 1998; Golonka and Picha, 2006). Previous geochemical studies (Ladwein, 1988, Franců et al. 1996, Pícha and Peters 1998; Schulz et al., 2010; Sapinska-Sliwa et al., 2016) demonstrated that the organic matter of the Mikulov marls is composed of kerogens type II/III with total organic carbon (TOC) in a range of 0.2-10 %. According to Krejčí et al. (1996), the reactive part of kerogen in Mikulov marls is of type II, while the abundant inertinite makes the bulk hydrogen index lower.

Oils and gases generated within the formation supplied several oil and gas fields in the Miocene reservoirs mostly laterally via several major faults and fracture zones and, episodically, vertically through locally released domains in the thrust belt during discrete episodes of transtension reactivations of the PDZ. The Mikulov Formation is buried under the flysch units of shaly lithology and these together with the heavily faulted base of the Carpathian thrust belt have served as some kind of regional seal restricting an active vertical migration of gaseous hydrocarbons from deep generation levels (Fig. 2).

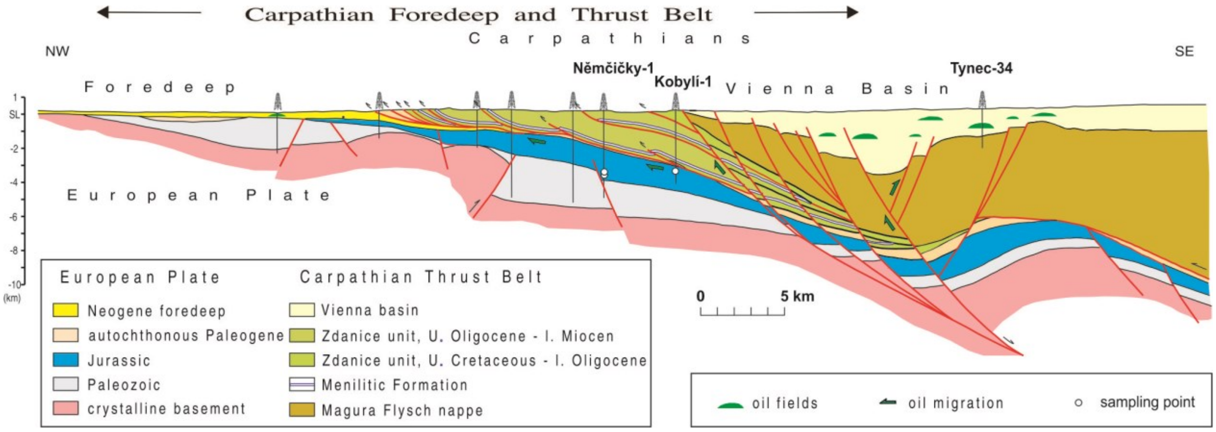

Fig. 2 Regional cross section through the West European plate, the overlying Outer Western Carpathian thrust belt, and the successor Vienna basin (modified after Picha and Peters, 1998)

The biggest accumulations of hydrocarbons in the Czech Republic (e.g. Damborice oil field and Uhrice gas field) have been found at subthrust levels of the Vienna basin within tectonically sealed plays associated with uplifted erosional relics of the Jurassic rocks or adjoining structural highs of the Precambrian basement consisting of highly weathered and fractured granites. All these accumulations were sourced from the Jurassic organic-rich Mikulov Formation. Apparently, the mature section of this 1.5 km thick organic-rich Mikulov Formation is still in an active phase of gas generation (Golonka and Picha, 2006).

2.2 Generation potential of the Mikulov Formation marls

The estimations of the hydrocarbon generation potential of Jurasic marls from the Mikulov Formation of the Czech part of the Vienna basin were performed based on the Rock Eval pyrolysis results (Labus and Bujok, 2013) for 7 core samples from the depth in a range from 3173 m to 4551 m, with the following direct measurements of parameters S1 (the amount of volatilized free hydrocarbons – mg/g of rock), S2 (amount of latent hydrocarbons released from kerogen during gradual heating – mg/g of rock), S3 (amount of CO_2 relieved from organic matter in mg/g of rock), Tmax (temperature – °C, at which maximum release of hydrocarbons occurs at the top of the S2 peak). The initial parameters were normalized to TOC (total organic carbon – g) to give the hydrogen index HI = 100*S2/TOC and oxygen index OI = 100*S3/TOC, both – mg/g of rock.

The derived generation potential S2, hydrogen index HI, and oxygen index OI values were used to qualify the kerogen types more precisely. The analysis of obtained data (Fig. 3) within the plot of Rock-Eval generation potential S2 versus total organic carbon (TOC) and the plot of oxygen index (OI) versus hydrogen index (HI) demonstrates that the studied samples can be determined as a mixture of kerogens of types II (oil-prone organic matter from marine plankton) and III (gas-prone terrestrial organic matter from higher plants).

The measured concentrations of the organic matter of TOC for our dataset are generally considered as good values to serve as effective source rocks (6 samples are showing the range 1.02-1.34 %; average 1.14 %), however, these values are in the range of fair values for shale gas exploration and do not fit with the criteria identified for successful shale gas plays in the USA (more than 2% TOC).

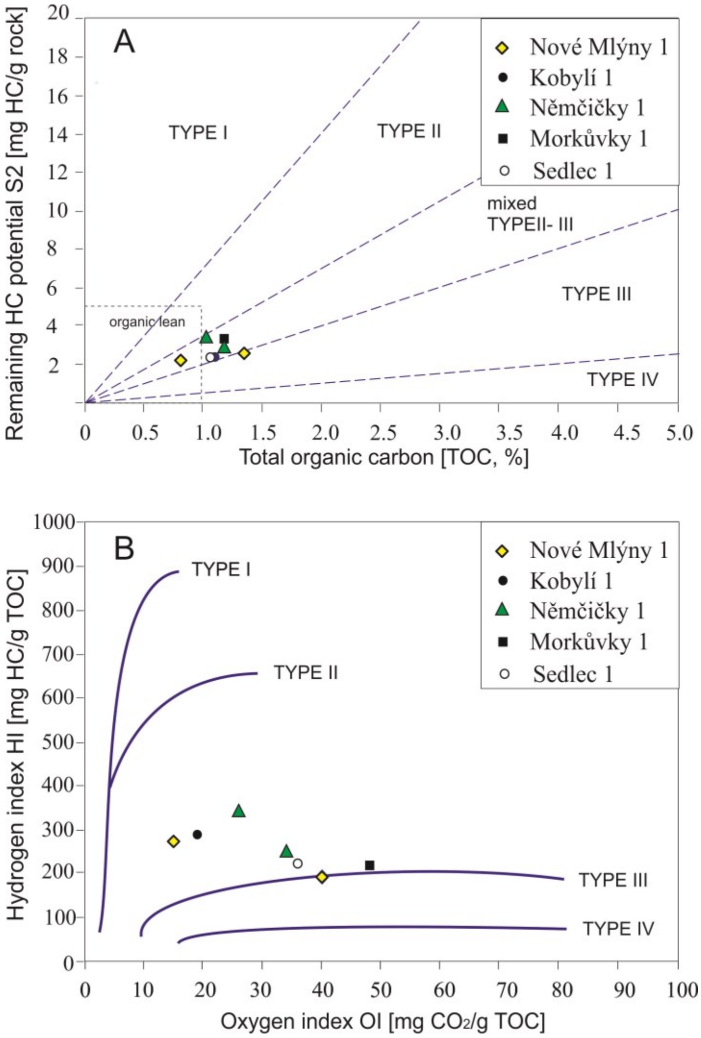

Fig. 3 Plot of Rock-Eval generation potential S2 versus total organic carbon TOC (A) and plot of oxygen index OI versus hydrogen index HI (B). Based on data by Labus and Bujok (unpublished).

The presence of mixed kerogen of II-III types was confirmed also by a palynofacies analysis (Fig. 4, 5) and numerous documentations of remains of the terrestrial organic matter in grains of vitrinite and inertinite (Fig. 6). The presence of inertinite is an important geological record, because it indicates at least oxidation reactions due to atmospheric exposures for the Mikulov Formation during its deposition.

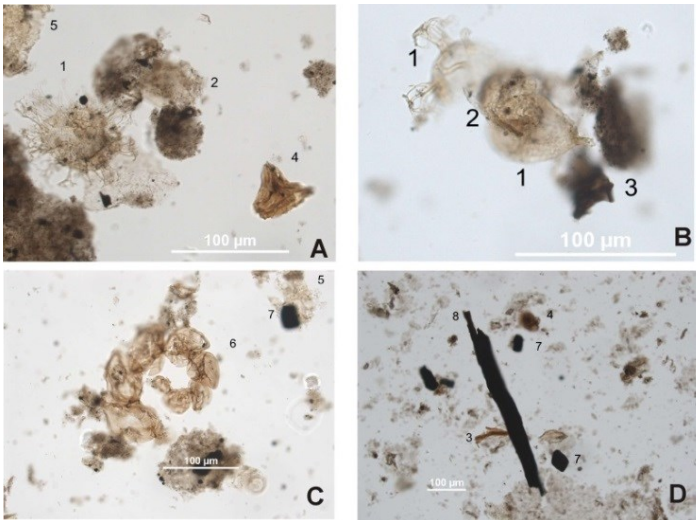

Fig. 4 Palynofacies of samples from wells Sedlec 1, Nové Mlýny 1 and Kobylí 1

A – palynofacies of sample Sedlec; B – palynofacies of sample Nové Mlýny; C, D – palynofacies of sample Kobylí; details: 1 – dinoflagellstae, 2 – algae, 3 – brown particles, 4 – spore, 5 – cuticle, 6 – forameniferal assemblage, 7 – amorphous black particle, 8 – sharp-edged black particle

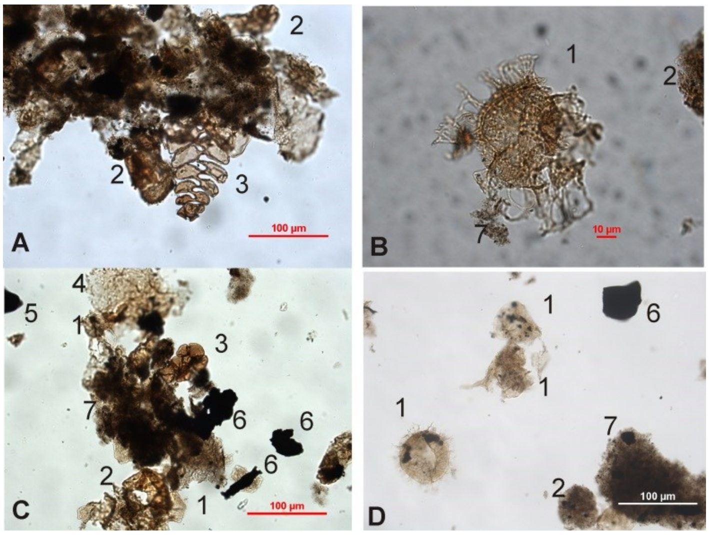

Fig. 5 Palynofacies of samples from wells Němčičky 1, Morkůvky 1

A, B – palynofacies of sample Němčičky; A – algae assemblage and algogenic organic matter , B – cyst of dinoflagellatae; C, D – palynofacies of sample Morkůvky; details: 1 – dinoflagellatae, 2 – algae, 3 – forameniferal assemblage, 4 – cuticle, 5 –spherical black particle, 6 – sharp-edged black particle, 7 – algogenic organic matter

For 6 samples, the vitrinite reflectance Ro have been measured by using an oil-immersion objective of a TIDAS MSP 200 Microscope Photometer in point scan mode.

The hydrogen index (HI) plotted against Tmax for samples (Fig. 6) illustrates that the studied samples are from II/III type kerogen with HI ranging from 193 to 346 mgHC/gTOC and these are already allocated in the oil window.

For the shale gas exploration, it is critically important to obtain estimations of depths of zones for the liquid and gaseous hydrocarbons generation.

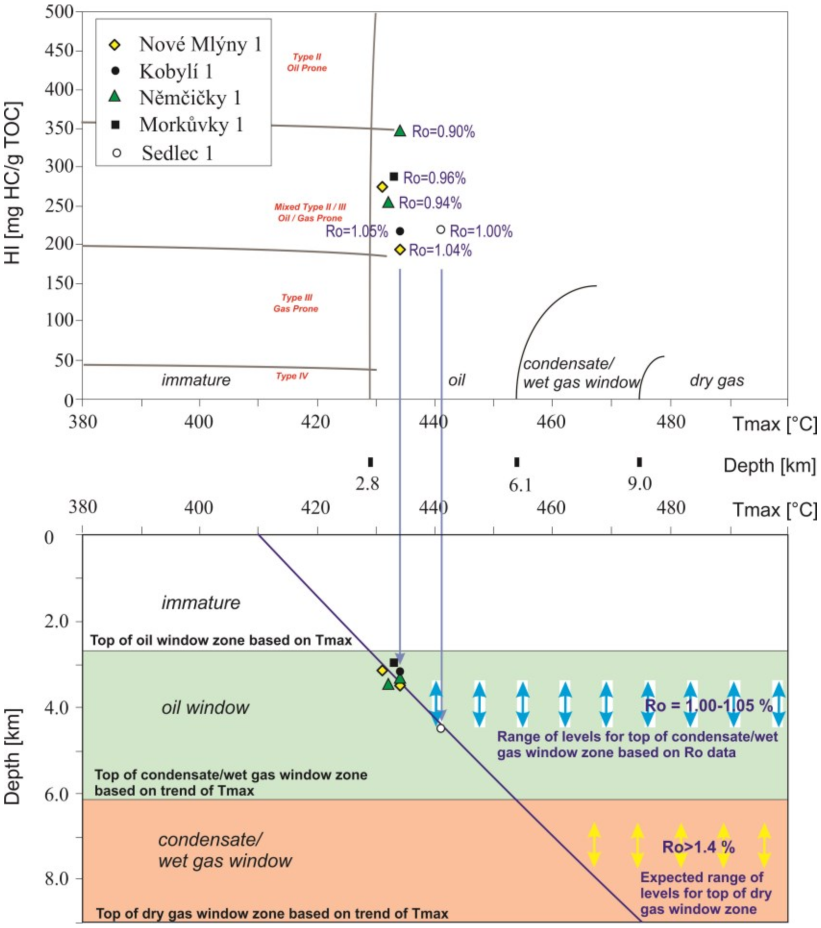

Fig. 6 Plot of hydrogen index HI vs. maturation Rock-Eval parameter Tmax for samples and depth distribution of zones associated with oil, condensate/wet gas, dry gas windows based on Tmax values and trends and alternatively based on measured vitrinite reflectance values. HI and T_{max} data from Labus and Bujok, (2013)

Our attempts to delineate the mature section based on the maturity parameter Tmax suggest that the top of the zone of condensate / wet gases generation zone is allocated at the level of 6.1 km, and the top of the dry gas zone is allocated at a depth of 9.0 km. However, there is a clear misfit between the Ro and Tmax values. In comparison with the maturity based on the measured vitrinite reflectance Ro, our dataset shows anomalously low Tmax values even within the acceptable TOC and S2 parameters. It could be because of impregnating the sampled marls in situ by migrated oil or just resulting from the presence of oil-based mud additives within samples (Peters, Moldowan 1993). Taking into account the level of maturity based on the measured vitrinite reflectance data, we can expect a significant uplift of the top levels of wet gases/ condensate and dry gas zones. The trend of Ro suggests that the condensate / wet gases generation is occurring at a depth of 3.5-4.5 km and we can expect the dry gas generation onset at a depth of approximately 7.0 km.

In the northwest–southeast–trending Dyje–Thaya depression, which was formed during the Jurassic rifting (Picha et al., 2006), a set of subthrust antiformal structures, e.g. Tynec, Holic, and Lednice, have been delineated on seismic data with depths to the tops of these structures in a range from 4000 m (Lednice antiform) to 6000–7000 m (Tynec and Holicantiforms), and these are already in the condensate-gas window. These structures were formed as tilted blocks and horsts during the Jurassic rifting with further reactivation as local restraining bends during the strike-slip faulting.

At such depths, fractured marls of the Mikulov Formation may be overpressured because of sedimentary loading and recent tectonic stresses. One of the reasons to consider this option is the fact that this pelitic-carbonatic unit at the deep levels is tectonically enlarged (Adámek, 2005) by multiple duplications. Such kind of structural thickening related with thrust cleavage duplexes occur in the Marcellus Shale (Pashin, 2009), which is up to now the most successful exploration reservoir for commercial shale gas production. These duplexes are interpreted as manifestations of the progressive transfer of slip from floor to roof through a disturbed zone that serves as a shear boundary between large, more internally passive, thrust sheets (Cook and Thomas, 2010). In case of the Vienna basin, tectonically thickened weak pelitic-carbonatic marls of the Mikulov Formation could serve as the accommodation rock volume for the development of ductile deformations associated with intensive folding and faulting in the overlying competent layers of the allochtonous structural floor. Ductile duplexes and associated thrust-related subhorizontal fracturing related with an abnormal fluid pressure (Hathaway and Gayer, 1996) now are widely recognized as positive signal for targeting productive shale gas reservoirs (Pashin, 2009; Cook and Thomas, 2010).

Fractured intervals with gas kicks in the Mikulov Formations have been observed at great depths (7.5 km scale) in the Austrian part of the Vienna basin (Wessely 1990). We suppose that this fracturing could result from the same mechanism of the formation of compressional duplexes and gives hopes for a good potential of preserving here the subthrust levels of the basin significant unconventional gas resource in deep overpressured compartments.

3 CONCLUSIONS

The presence of unconventional resources has been proven in deeper parts of mature oil and gas provinces and coal basins of the world. In this context, it is worth to focus also on the prospects of unconventional gas production from within hydrocarbon provinces of the Moravian part of the Vienna basin. The estimation of hydrocarbon generation potential of Jurasic marls from the Mikulov Formation of the Czech part of the Vienna basin was performed based on the Rock Eval pyrolysis. The average of the TOC concentration reached 1.14 %, which is a good value for serving as effective source rocks, this, however, does do not fit with the criteria used in the USA for successful shale gas plays.

The maturity level of vitrinite-based reflectance indicates a significant uplift of the top levels of wet gases / condensate and dry gas zones. The trend suggests that condensate / wet gases generation is occurring at a depth of 3.5-4.5 km and a dry gas generation onset could be expected at a depth of approximately 7.0 km.

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